A Project Report on

"STUDY AND DEVELOPMENT OF WASTE SUGARCANE REINFORCED EPOXY BASED COMPOSITE"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
In

Mechanical Engineering

Submitted by

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2020-21

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DECLARATION

We, the students of eight semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, "**STUDY AND DEVELOPMENT OF WASTE SUGARCANE REINFORCED EPOXY BASED COMPOSITES**" has been successfully completed under the supervision of Dr. Ramesh S, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. Ramesh S** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. Ramesh S, Prof. and Head** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to **Dr. Arpitha G R** who gave guidance to do this project work.

At the same time, we express our deepest thanks to **Mr. Vijay Kumar Guna** Research associate, Jyothi Institute of technology for providing lab facilities to successfully finishing the project.

Lastly, we would like to thank our family and friends.

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ABSTRACT

The purpose of this research work is to evaluate and compare the mechanical properties of laminates prepared from different compositions of sugarcane bagasse, alumina and epoxy resin. The mechanical properties that were evaluated are flexural test, hardness test, impact test, water absorption properties and fire resistance test.

The test samples of sugarcane bagasse, alumina and epoxy resin were fabricated by hand lay-up method which is a manual process. Natural fibers have lately become the center of attraction to the scientist and researchers as they are a viable alternative for fiber reinforced composites because of their low cost, non-abrasive and eco-friendly nature. Natural fibers in the near future may play a significant role in developing bio-degradable composite to decide the current ecological and environment problems. This report tells us that natural fibers possesses good mechanical properties and fiber composite can be used in different applications.

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CHAPTER 1

1.1 Introduction

Lately abundant agricultural/industrial waste generated from modern technologies has become a barrier to sustainable development. Due to this government restrictions have forced Industries to priorities agricultural-based material over petroleum-based material to make eco-friendly products. In the process to make green products, natural fiber-reinforced composites were recognized as a potential substitute in various applications due to their availability, cost-effectiveness, non-toxicity, and biodegradability. Moreover, the natural fiber-reinforced composites have displayed remarkable properties such as high strength and stiffness that has made them an excellent alternative to glass or carbon fibers for high strength applications. Various natural fibers have been reported to be used for the fabrication of composites such as Bagasse, Coir, Pineapple, Ramie, Banana, Bamboo, jute, Coconut and Flax. Hybridizing these composites improve the tensile strength and modulus of glass fiber composites.

Composite materials are produced by combining two dissimilar materials into a brand-new material that will be better fitted to a specific application than either of the original materials alone. The most common example of a composite material is the glass fiber reinforced plastic commonly utilized in household goods and in many industrial applications. Composites are made from individual materials remarked as constituent materials. There are two main categories of constituent materials: matrix and reinforcement.

At least one portion of every type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to boost the matrix properties. Epoxy resins are widely used as matrix in many fibers reinforced composites; they are a class of thermoset materials of particular interest to structural engineers as a result of the very fact that they provide a unique balance of chemical and mechanical properties combined with wide processing versatility. Within reinforcing materials, glass fibers are the most frequently employed in structural constructions because of their specific strength properties.

Bagasse is the dry pulpy residue left out after the extraction of sugarcane to develop a natural-fiber composite with appealing mechanical properties, careful choice of materials is necessary. Plant fibers being hydrophilic with polar characteristics of cellulose as the main component, are incompatible with non-polar polymers including polypropylene, polyethylene, etc. Therefore, a third material should be
utilized to improve interface adhesion, i.e., coupling agent. This research also aims to study the effect of fiber loading in tensile properties, flexural properties, impact strength, thermal properties, and water absorption together with hardness and abrasion resistance.

CHAPTER 2

2.1 Literature Survey:

Y.A. El-Shekeil ET. AL.[1] A study of the influence of fiber content on mechanical (i.e. tensile, flexural, impact, hardness and abrasion resistance) and thermal (i.e. TGA) properties of Kenaf bast fiber reinforced thermoplastic polyurethane (TPU) composites. The composite was prepared by method of melt-mixing, followed by compression and molding process. Different fiber loadings were prepared; 20%, 30%, 40%, and 50% weight percent respectively. A 30% fiber loading exhibited the best tensile strength, while modulus increased with increase of fiber content, and strain deteriorated with increase of fiber content. Flexural strength and modulus increased with increase of fiber loading. Increase of fiber loading resulted in decline in impact strength. Hardness increased by addition of 30% fiber content.

Chanthipa Vajrasthira ET. AL.[2] The mechanical and dynamic mechanical properties of thermoplastic polyurethane (TPU) elastomers reinforced with two types of aramid short fibers, m-aramid (Teijin-Conex) and copoly(p-aramid) (Technora), were investigated in this study with respect to the fiber loading. In general, both types of composites exhibited remarkably similar stress–strain behaviors, except that Technora–TPU was stronger than Conex–TPU. This was primarily due to the intrinsic strength of the reinforcing fibers. Both types of fibers reinforced TPU effectively without any surface treatment. Furthermore, the morphologies of cryogenically fractured surfaces of the composites and extracted fibers, investigated with scanning electron microscopy, revealed possible polar–polar interactions between the aramid fibers and TPU matrices. Up to a 10 wt % fiber loading, the modulus of the composites was linearly increased with increasing fiber content.

Muhammad M. Rahman ET. AL. [3] Advanced green composites have been fabricated by using modified liquid crystalline cellulose (M-LCC) fibers and micro-fibrillated cellulose (MFC) modified waxy maize starch (M-WMS) based resin. LCC fibers, as a reinforcement, were modified in terms of tensile properties by a combination of chemical and heat treatment, under a predetermined tension. M-WMS, as a resin, was prepared by two steps. In the first step, an environment-friendly cross-linker, 1,2,3,4-butane tetracarboxylic acid (BTCA), was used to improve the water resistance and tensile properties of the resin. In the second step, 'MFC', as reinforcing agent, was dispersed in the cross-linked resin to obtain substantial improvements in its tensile properties. The results showed that the M-LCC fibers had strength close to 2 GPa and the composites had strength close to 800 Mpa. These advanced green composites could be used in structural applications.

Y.A. El-Shekeil ET. AL. [4] A study on Influence of fiber content on mechanical, morphological, and thermal properties of kenaf fibers reinforced poly (vinyl chloride)/thermoplastic polyurethane poly-blend composites is presented on this paper. Kenaf (Hibiscus Cannabinus) bast fiber reinforced poly (vinyl chloride) (PVC)/thermoplastic polyurethane (TPU) poly-blend was prepared by melt mixing method using Haake Poly drive R600 internal mixer. The composites were prepared with different fiber content: 20%, 30% and 40% (by weight). After mixing, the composite was compressed using compressing moulding machine. Mechanical properties (i.e., tensile properties, flexural properties, impact strength) were studied. Morphological properties of tensile fracture surface were studied using Scanning electron microscope (SEM). Tensile modulus showed an increasing trend with increase in fiber content.

Maria Kuranska ET. AL. [5] An investigation on Porous polyurethane composites with natural fibres is presented on this paper. In the work the methodology and results of the investigations that concern rigid polyurethane foams modified with natural fibres and oil-based polyol are presented. The obtained polyurethane composites had apparent densities about 40 kg/m3. The influence of the rapeseed oil-based polyol, flax and hemp fibres of different length on the cell structure, closed cells content, apparent density, thermal conductivity and compression strength of the rigid polyurethane composites are analysed. It was observed that the application of such renewable components as bio-polyol and natural fibres in the polyurethane formulation allows to increase the content of bio-components and to improve mechanical and heat insulating properties of such porous composites.

Ruijun Gu ET. AL. [6] A feasibility study of polyurethane composite foam with added hardwood pulp is presented on this paper. Polyurethane (PU) composite foams were prepared by pour method with soy-based polyol(soyol). Thermal behaviours as well as foam morphology were investigated. Thermal gravimetric analysis and differential scanning calorimetry results clearly showed the most substantial increase of the glass transition temperature (Tg) and decrease of the decomposition temperature (Td) in the fiber reinforced PU foam. PU composite foam had no influence on compressive strength; however, it had caused slight reduction in tensile strength. PU composite foam displayed a broad distribution of inter-domain spacing associating with morphological changes.

S.M. Sapuan ET. AL. [7] A study on mechanical properties of soil buried kenaf fibre reinforced thermoplastic polyurethane (TPU) composites is presented in this paper. Kenaf bast fibre reinforced TPU composites were prepared via melt-mixing method using Haake Poly drive R600 internal mixer. The composites were subjected to soil burial tests where the purpose of these tests was to study the effect of moisture absorption on the mechanical properties of the composites. Tensile and flexural properties of the composites were determined before and after the soil burial tests for 20, 40, 60 and 80 days. It was also observed that there was no significant change in flexural properties of soil buried kenaf fibre reinforced TPU composite specimens.

Ajay V. Rane ET. AL [8] A research on Thermoplastic polyurethanes. Thermoplastic polyurethanes are classified into polyester and polyether. Polyester polyurethanes are unaffected by oils and chemicals, provide excellent abrasion resistance, offer a good balance of physical properties. Properties of polyurethane composites and nanocomposites depend on the process and the processing condition, proper choice of filler and quantity of filler are also important to obtain desired properties for which a trial and error has to be performed, selection of suitable grade of polyurethane for a specified application must be taken into consideration. Polyurethane composites and nanocomposites have been used in various applications including functional coatings, nanoelectronics, gas-sensing, packaging, biomedical implants, solar cells, seals, etc.

2.2 Objective and scope:

The main objectives of our research project are:

- To produce eco-friendly products by replacing agricultural materials over petroleum-based material.
- As sugarcane is widely cultivated in India its raw material can be used in various application due to is availability
- To develop sugarcane-based composite material by adding alumina particle to enhance the hardness
- To substitute synthetic polymer-based products.
- To make it cost-effective, non-toxicity, and biodegradable composite.
- To analyze the surface morphology of composites by Scanning electron Microscopy
- To analyze the mechanical properties (flexural, tensile, hardness etc.) and water absorption properties for better understanding.
- It can substitute alloys which are mostly used in the making of modern turbines
- To develop a composite that has high thermal and fire resistance which is well suited for the application wind turbine blade.

Chapter-3

METHODOLOGY:

3.1 Materials:

The materials chosen by us are namely, Bagasse (sugarcane waste powder), Aluminum Oxide powder (Alumina), Epoxy (Resin), and Hardener.

- **Bagasse** was bought from sugarcane farms outside Bangalore city where there was plenty of availability. 2kg of bagasse was bought in order to not undergo any kind of shortage and as it was cheap enough to buy.
- **Alumina** was bought from "Vimal Mass Finishing Private Limited", which is a factory situated in Peenya, Bangalore, and is specialized in carrying out metal surface finishing job service. As per requirement, 200 grams of alumina was provided from this factory for free, as it is a very minimal quantity for them and they charge from quantities starting at around 10 kilograms.
- **Epoxy** and **Hardener** were bought from "Yuje Enterprises" which is a supplier of painting equipment and maintenance. It is situated in Sampige road, Malleshwaram, Bangalore. 2 kilograms of Epoxy and 1.5 kilograms of Hardener were bought based on the industry price.

Why Bagasse?

- Sugarcane bagasse is the left-out waste of sugarcane once the sugar content is extracted completely from the cane. It is an agro-industrial residue which is available in high quantities at a very minimal cost, therefore being cost effective. It is fibrous and is of low density ranging wide in the sizes of the particles which also contains high amount of moisture.

- It has high mechanical properties such as, tensile strength, flexion, compression, resilience, etc. This plays a major role in making an ideal fibre-reinforced composite.

Fig: 3.1 Bagasse

Fig: 3.2 Bagasse powder

Why Epoxy Resin?

- As our composite is fibre based, epoxy is a substance that holds a fibre composite firmly in the desired shape. It has high amount of strength, very effective electrical insulation, it has very low shrinkage, it is also cheap and has low toxicity.

Fig: 3.3 Epoxy resin

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Why Alumina?

- Alumina is a very rich ceramic material. It is nothing but aluminium oxide which has high thermal properties, very high compressive strength, high hardness (15 to 19 Gpa), medium kind of thermal conductivity and is mainly used to make our composite as it chemically and physically stable.

Fig: 3.4 Alumina

Why Hardener?

- A hardener is a curing agent which is usually in places where epoxy is used. Its main function is to hold the composite in shape firmly. Without the use of hardener, our desired composite will not attain a solid form.

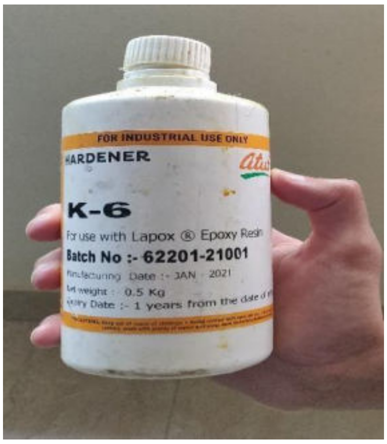

Fig: 3.5 Hardener

3.2 Preparation of composites

- To bring a shape to our composite samples, we made wooden frames of dimensions (210x80mm) and the materials were poured into the wooden frames in respective quantities.

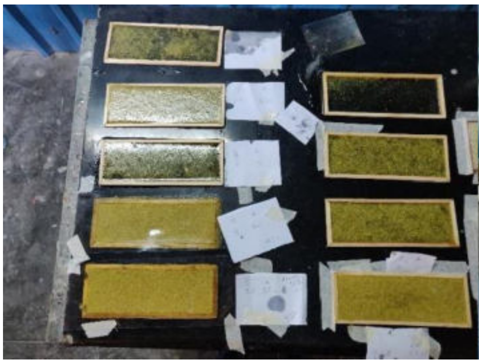


Fig: 3.6 Preparation of composites, Fig: 3.7 Preparation of composites

Fig: 3.8 Preparation of composites

- The quantity of epoxy was a constant for all the 9 samples made i.e., (80% epoxy) and the quantities of bagasse, alumina, and hardener was varied.
- The various proportions of raw materials were used in accurate quantities as we used a gram precision weighing scale.

Fig: 3.9 Preparation of composites

- These 9 samples, after being prepared, were placed on a granite slab with wax coating which would make it easier for us to remove the sample after it was dried up within 2 days of time.

Run	Sugarcane bagasse in wt.%	Alumina in wt.%	Hardener in wt.%	Remarks
1	5	2	13	Sample 1
2	3.5	3.5	13	Sample 2
3	2	2	16	Sample 3
4	5	5	10	Sample 4
5	2	5	13	Sample 5
6	3.5	3.5	13	Sample 2 (R)
7	3.5	3.5	13	Sample 2 (R)
8	3.5	5.62132	10.88	Sample 6
9	3.5	3.5	13	Sample 2 (R)
10	3.5	3.5	13	Sample 2 (R)
11	5.62132	3.5	10.88	Sample 7
12	3.5	3.5	13	Sample 2 (R)
13	3.5	1.37868	15.12	Sample 8
14	1.37868	3.5	15.12	Sample 9

Table 3.1 Details of the loading for composites

3.3 Fabrication of Composites

- Once the samples were dried up, we had to take the composite out of the wooden frame. This was done by *laser cutting* to precisely take the sample out without breakage or cracks.
- After being removed from the frames, the samples were cut into desired dimensions for the various testing to be done.

Fig: 3.10 Fabrication

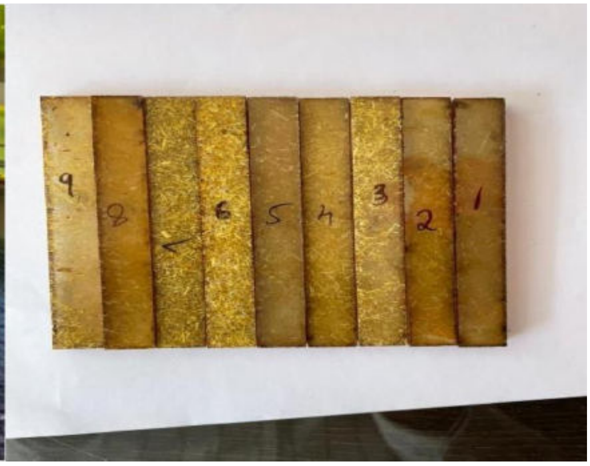

Fig: 3.11 Fabrication

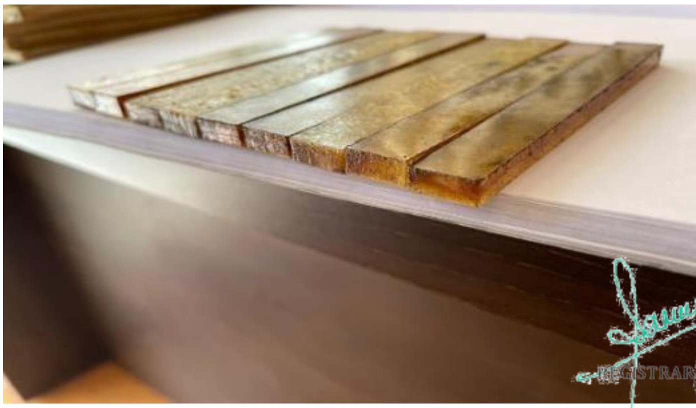

Fig: 3.12 Fabrication

CHAPTER – 4

EXPERIMENTAL SET-UP:

4.1 ASTM STANDARDS:

ASTM International, formerly known as **American Society for Testing and Materials**, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

A group of scientists and engineers, led by Charles Dudley, formed ASTM in 1898 to address the frequent rail breaks affecting the fast-growing railroad industry. The group developed a standard for the steel used to fabricate rails. Originally called the "American Society for Testing Materials" in 1902, it became the "American Society for Testing and Materials" in 1961. In 2001, ASTM officially changed its name to "ASTM International" and added the tagline "Standards Worldwide". Now, ASTM International has offices in Belgium, Canada, China, Peru, and Washington, D.C

Below mentioned are the ASTM standards we used while testing:

- ASTM D 638-14
- ASTM D 790-15
- ASTM D 570
- UL-94
- D 256
- ASTM E-384

4.2 Tensile properties

(Strength and modulus) of the composites were tested on a Universal Tensile Tester equipped with a 1 kN load cell. Test samples (rectangular shaped) were prepared according to ASTM D 638-14 standard with samples having dimensions of 60 mm length and 12 mm wide at the widest section. Crosshead speed of 50 mm/min was used for the tensile tests. At least 20 samples were tested for each condition and the average and standard deviation were tested and recorded for reference.

ASTM D 638-14: This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell or rectangular shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

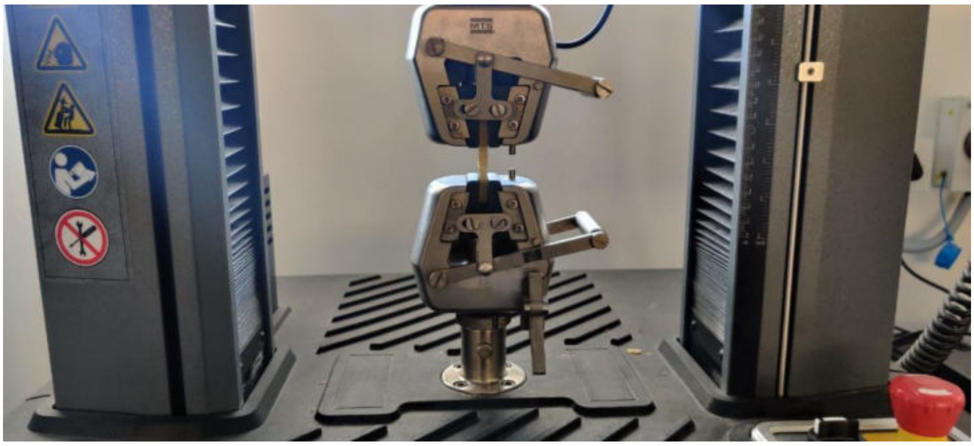

Figure 4.1– Tensile Test Apparatus

4.3 Flexural strength

Flexural strength and modulus were determined according to ASTM D790-15 standard. Samples with length of 60 mm and width of 12 mm were used for the flexural studies. Crosshead speed for flexural tests was set at 10 mm/min. The average and standard deviation values of the samples were recorded.

ASTM D790-15: These test methods are used to determine the flexural properties of unreinforced and reinforced plastics, including high modulus composites and electrical insulating materials utilizing a three-point loading system to apply a load to simply supported beam (specimen). The method is generally applicable to both rigid and semi-rigid materials, but flexural strength cannot be determined for those materials that do not break or that do not fail yield in the outer surface of the test specimen within the 5.0 % strain limit.

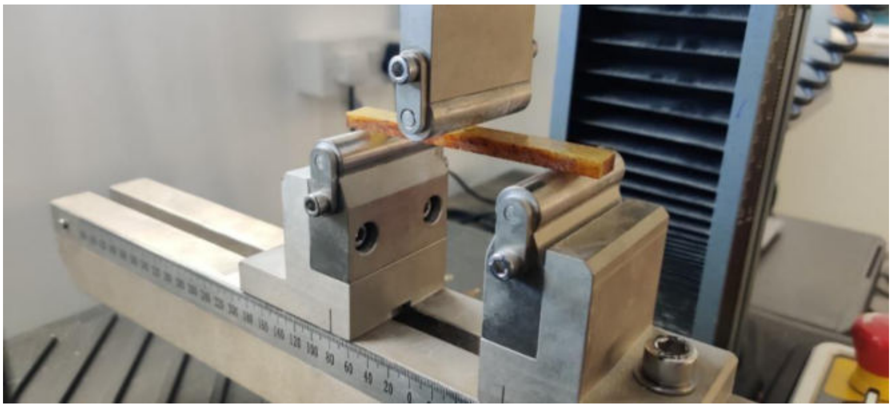

Figure 4.2 – Flexural test apparatus

4.4 Water absorption

Water absorption of the composites were conducted according to ASTM D570 standards. Samples of dimension 76x26 mm was conditioned in an oven for 24h at 110ºC before the tests. After drying, the samples were weighed and then immersed in a container of distilled water for 24h at room temperature. To study the water absorption behavior over the period of 24h, the samples were taken out every 2h until 24h. Once taken out, the samples were wiped with a clean soft tissue and weighed immediately. The percentage water absorption was given based on the weight difference.

ASTM D570: This test method for rate of water absorption has two chief functions: first, as a guide to the proportion of water absorbed by a material and second, as a control test on the uniformity of a product.

Figure 4.3 – Water absorption test setup

4.5 Flammability test

Flammability test for the samples measuring 150 mm x 10mm x 1.6 mm were cut and the flame resistance of the composite was determined as per UL-94 standard test method. The samples were placed vertically above an igniter. The igniter was brought in contact with the specimen for 10 seconds. The time taken for the flame to extinguish was recorded. Further, any dripping of the specimen onto the cotton fibers below the sample was also observed to understand the quality of the sample. The samples were tested for each ratio and the flammability ratings were assigned based on the time to self-extinguish the flame.

- V0: the specimen may not burn with flaming combustion for more than 10 seconds.
- V1: the specimen may not burn with flaming combustion for more than 30 seconds.
- V2: the specimen may not burn with flaming combustion for more than 30 seconds which turns into ashes after few more seconds.

UL-94: UL 94 is used to measure burning rate and characteristics based on standard samples. The purpose of this test is to determine the resistance of plastic materials used for parts in devices and appliances to flame and glow propagation.

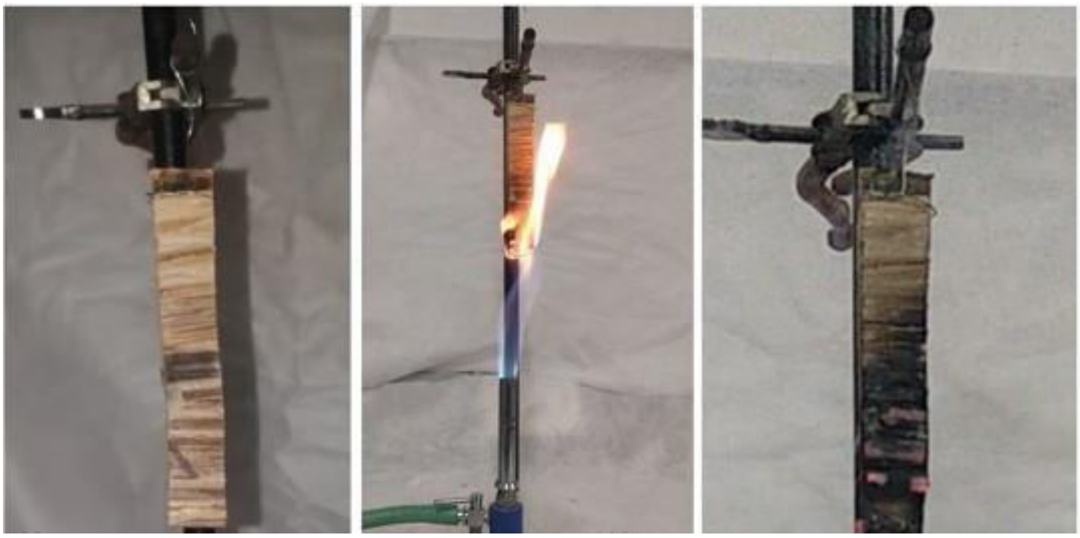

Figure 4.4 Flammability test apparatus

4.6 Impact test

Impact test for the samples measuring 62.5 mm length and 12.5 mm wide were performed as per the ASTM D 256 standard. Various levels of impact strength values were tested on the samples to understand the characteristics of the samples. D 256: Notched Izod Impact is a single point test that measures a materials resistance to impact from a swinging pendulum.

Figure 4.5 Impact test machine

4.7 Hardness test

The Vickers method is based on an optical measurement system. The Micro hardness test procedure, ASTM E-384, specifies a range of light loads using a diamond indenter to make an indentation which is measured and converted to a hardness value.

ASTM E-384: This test method covers determination of the micro indentation hardness of materials.

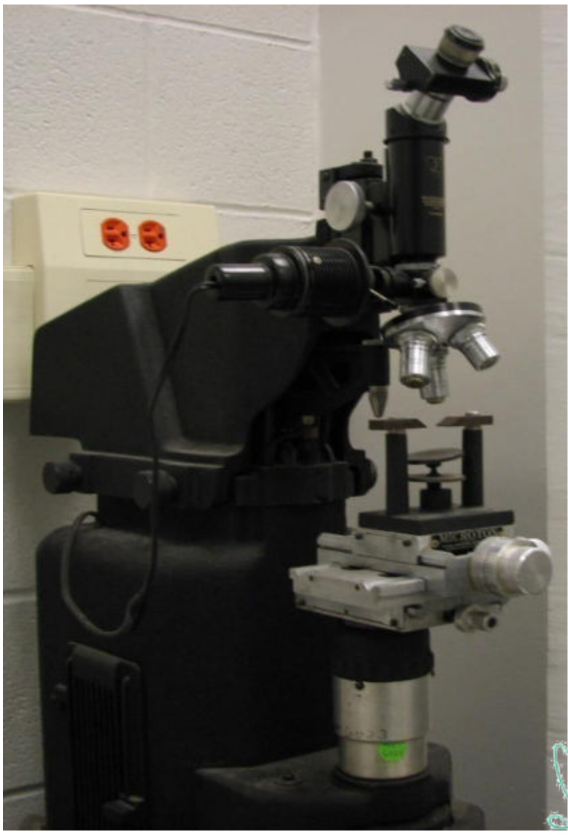

Figure 4.6 Vickers Hardness test

CHAPTER-5

RESULTS AND DISCUSSIONS

5.1 Tensile Test:

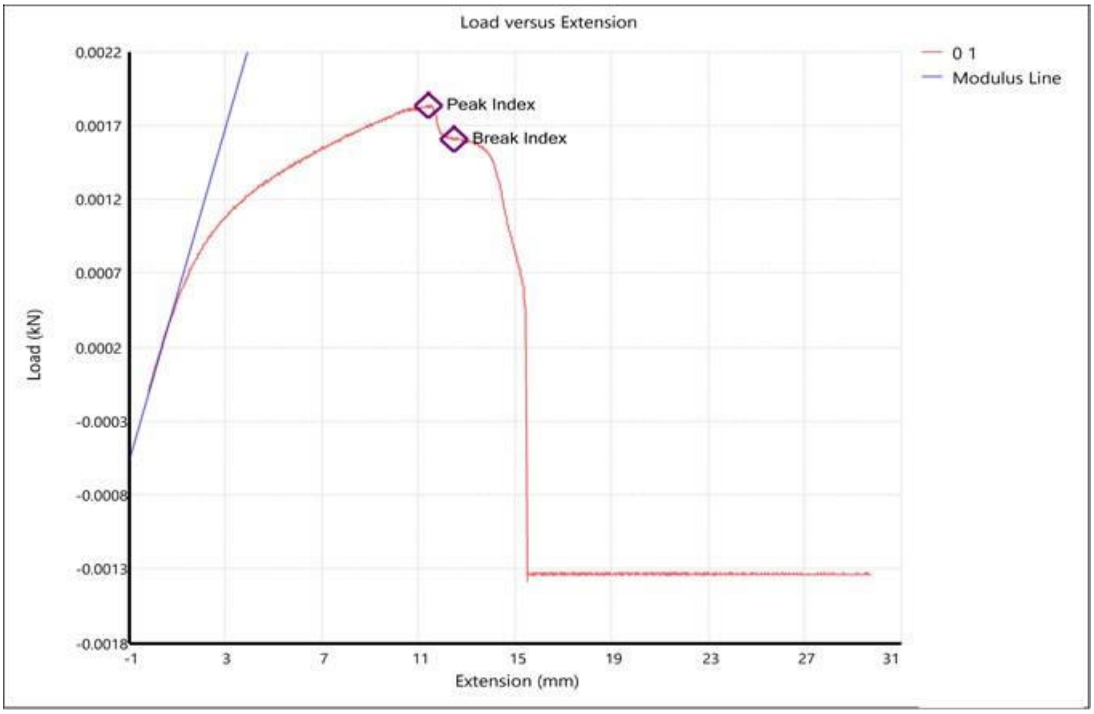

Figure 5.1 MTS EM Tension test and modulus of waste sugarcane reinforced epoxy-based resin

Display Name	Value
Test Run End Reason	**Test Stopped**
Peak Stress	0.3 N/mm^2
Peak Load	1.836N
Strain at Break	21.208
Modulus	6.335
Width	15.000mm
Thickness	0.350

Table 5.1 Tensile test

The 60mm length, 12mm wide sample is now taken to the Universal testing machine with 1kN load cell to find out the tensile strength of the material. During the test, the load applied was ideal with the modulus line till 0.7N and after that, the curve starts deviating from the modulus which indicates the gradual conversion of elastic state to plastic state. For a maximum of 1.836N load, the tensile stress was in a peak of 0.3 N/mm^2 and the material has withstood a strain of 21.2

5.2 Flexural Test Results:

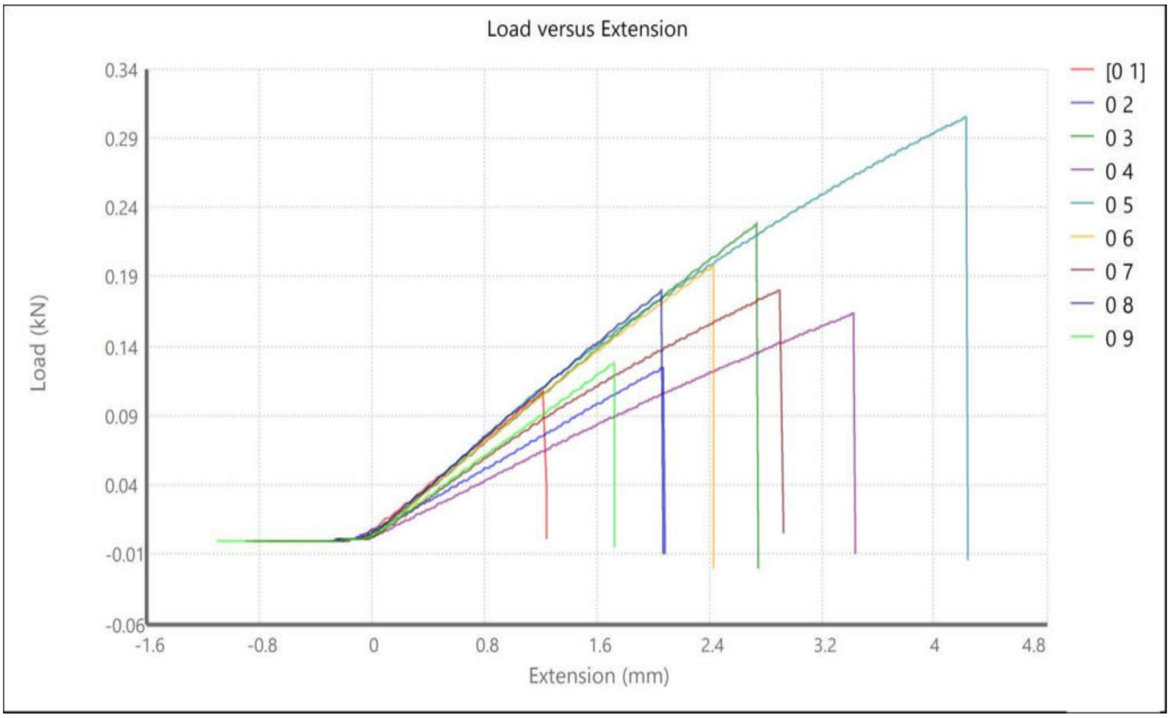

Figure 5.2 Flexural strength graph based on wt/wt ratio

Name	Tagged	Width(mm)	Thickness (mm)	Peak Load (N)	Flexural Strength (N/mm^2)	Stress at Break (N/mm^2)	Strain at Break (%)
01	No	1.100	6.273	107.753	224.0	224.042	1.282
02	No	1.100	6.273	124.749	259.4	259.381	2.173
03	No	1.100	6.273	227.772	473.6	473.586	2.864
04	No	1.100	6.273	163.282	339.5	339.498	3.585
05	No	1.100	6.273	304.908	634.0	633.969	4.421
06	No	1.100	6.273	197.682	411.0	411.024	2.544
07	No	1.100	6.273	180.218	374.7	374.713	3.039
08	No	1.100	6.273	179.114	372.4	372.417	2.155
09	No	1.100	6.273	127.772	265.7	265.666	1.806

Table 5.2 Flexural strength of waste sugarcane reinforced epoxy-based composites

We began the flexural test with nine samples which contains the mixtures of sugarcane bagasse, epoxy resin, hardener, and alumina in different ratios. The reason why we started with the flexural test is, we use 3-point testing method where the material is subjected to loads at three different points and hence as a side effect, the material experiences compression, tensile and bending load as well. Therefore, the strength values that are obtained from the test results are more accurate. Also, it helped us in saving the money and time for conducting the above-mentioned tests individually. At the end of the testing, we observed that as the Alumina ratio increases, the flexural strength increases and as the sugarcane bagasse increases, the flexural strength decreases. Finally, **sample 5** (which has 2% Sugarcane bagasse and 5% Alumina) has withstood **304.9N of load** and showed a **flexural strength of 634 N/mm^2** which is the **highest** of all. So, this sample was used for further testing and observations.

5.3 Water Absorption Test:

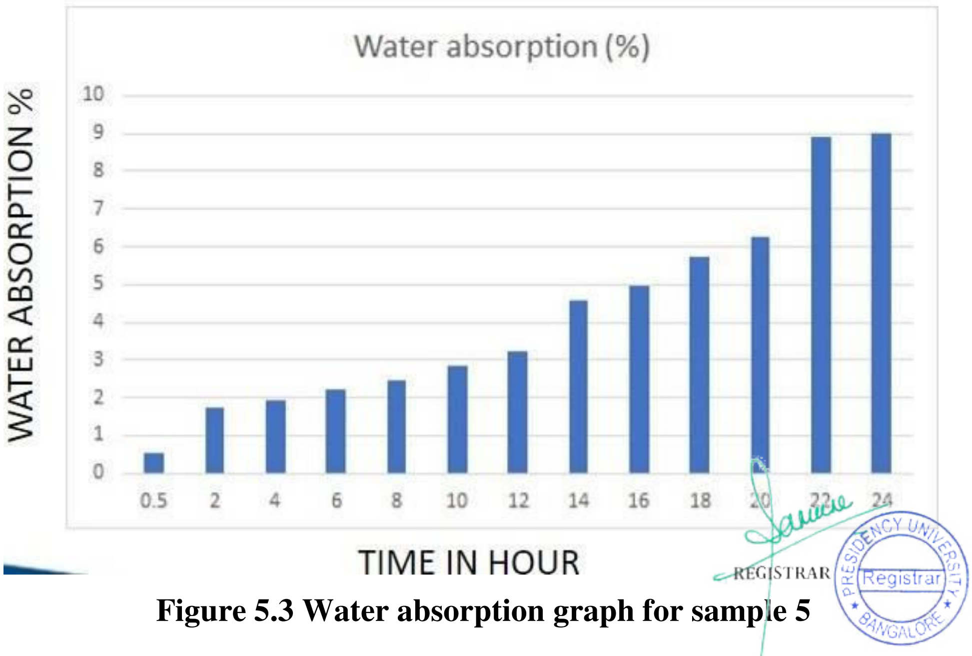

Figure 5.3 Water absorption graph for sample 5

Time(Hr)	0.5	2	4	6	8	10	12	14	16	18	20	22	24
Water absorption(%)	0.54	1.74	1.94	2.21	2.46	2.84	3.24	4.56	4.96	5.74	6.27	8.92	9.01

Table 5.3 Water absorption test

After conditioning the sample in an oven for 24 hours at 110 degrees Celsius, the samples were weighed and immersed in a container of distilled water for 24 hours at room temperature. We absorbed that the sample absorbed 9% of water with respect to its weight after 24 hours. And, during the 24hours, the process of absorption of the water was in a gradual manner.

5.4 Flammability Test:

Sample	Time to Self-Extinguish After Ignition (s)	Observed dripping	UL-94 Rating
5	<30	NO	V-1

Table 5.4 Flammability test

The 150 mm x 10mm x 1.6 mm samples were vertically placed above the igniter for 10 seconds. After two 10-second burning tests are performed on the specimens, the flame is extinguished within 30 seconds, and unable to ignite the cotton wool located 30cm below.

5.5 Impact Test:

Further, the impact strength of sample 5 was calculated by bombarding the sample with a simple pendulum. Various levels of load were used for the testing and the maximum impact strength of the sample was found to be 574.92Mpa.

5.6 Vickers micro hardness Test

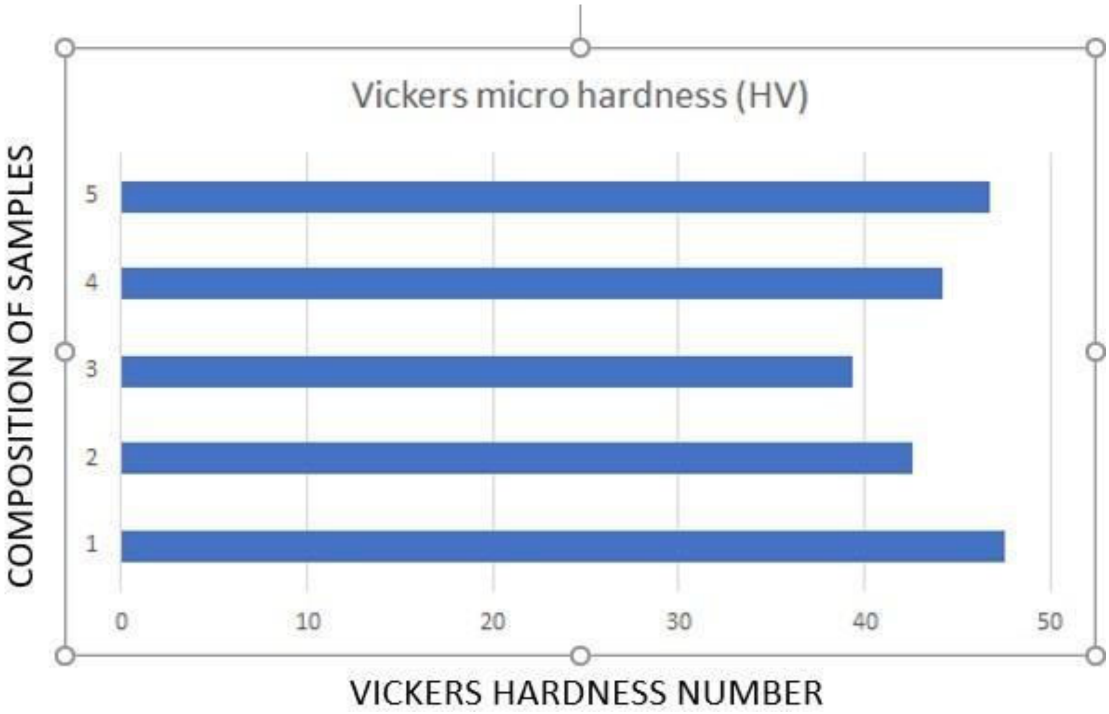

Figure 5.4 Hardness graph for sample 5

Readings	Vickers micro hardness (HV)
1	47.5
2	42.6
3	39.4
4	44.2
5	46.7

Table 5.5 Micro hardness test

After testing the sample with light loads using diamond indenter, we recorded the Vickers hardness number and it is found that, the sample has an average hardness value of 44HV which is almost equal to the hardness of epoxy and copper.

CONCLUSION

Out of the 9 samples that were used for the flexural test, the best sample (sample 5) was selected and used for further testing and from this sample, the following conclusions are drawn.

- ✓ As the amount of alumina increases, the flexural strength of the material keeps increasing and as the amount of bagasse decreases, the flexural strength of the sample keeps increasing until it reaches 2%
- ✓ The maximum flexural strength was observed for a ratio of 2% Sugarcane bagasse, 5% Alumina, 13% hardener and rest 80% epoxy (which is constant for all the samples). Since, the flexural strength of the wind turbines is usually around 100 N/mm^2, our sample is approximately 4.7 times stronger than the glass fiber reinforced polymer.
- ✓ The Tensile test was conducted with a crosshead speed of 50mm/min and from the results, From the flexural, tensile and hardness test, we concluded that the sample can be used to replace fiber glass reinforced composites.
- ✓ We have received V-1 rating in flammability test for all our samples which means that the flame got extinguished within 30 seconds. We also observed an insignificant amount of dripping but it was unable to ignite the cotton wool which was located 30cm below.
- ✓ To get the perfect absorptivity values, we recorded the readings for every 2 hours and found that the sample has absorbed 9% of water after 24 hours. After 20 hours, the water absorption rate has decreased rapidly.

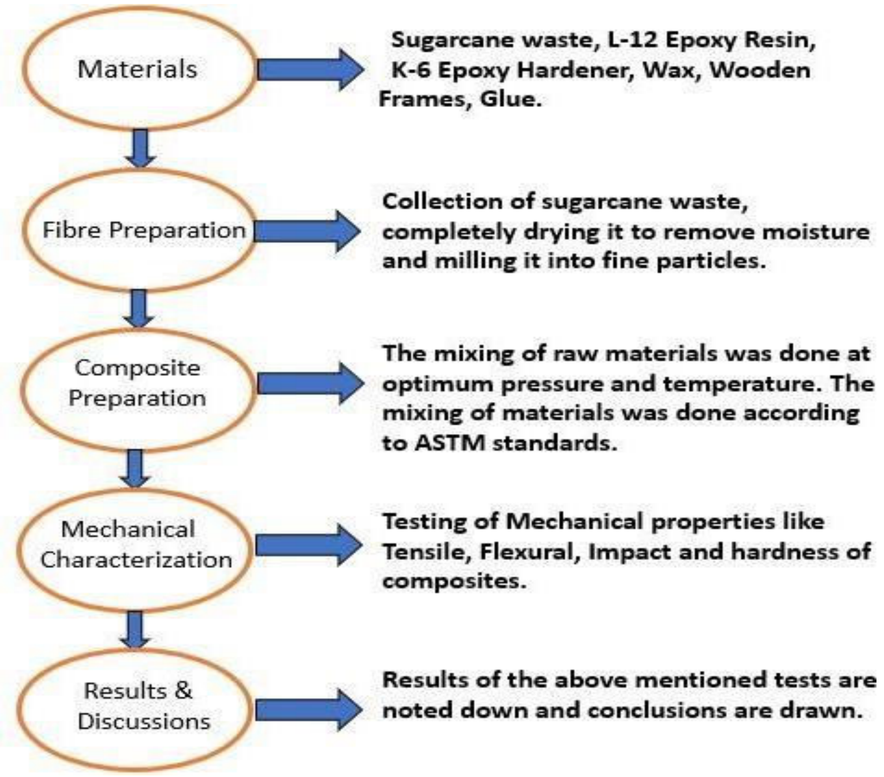

Figure: The overall workflow chart

Recommendation for future work:

Researchers can find out the mechanical properties of this sample by changing the proportion. Also, in future, materials like Kenaf, waste cane, bamboo can be used by the researchers to replace the sugarcane bagasse and analyze the properties

GANTT CHART

	Oct - 20	Nov - 20	Dec - 20	Jan – 21	Feb - 21	Mar – 21	Apr – 21	May – 21	Jun – 21
Literature survey	■	■							
Material Purchasing		■	■						
Fabrication of the samples				■	■				
Testing of the Samples					■				
Characterization						■			
Report Writing							■	■	
Final Submissions								■	■

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A Project Report on

STUDY AND DEVELOPMENT OF WASTE CORNCOB REINFORCED EPOXY BASED COMPOSITES

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project-2
in

Mechanical Engineering

Submitted by

Amogh B Kulkarni	**20171MEC0023**
Harish.D	**20171MEC0071**
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(Private University Estd. in Karnataka State by Act No.41 of 2013)

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2020-2021

Presidency University

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Department of Mechanical Engineering

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CERTIFICATE

Certified that, the project work entitled, **“STUDY AND DEVELOPMENT OF WASTE CORNCOB REINFORCED EPOXY BASED COMPOSITIES”** carried out by Mr.Amogh B Kulkarni (20171MEC0023), Mr.Harish.D (20171MEC0071),Mr.Hemanth.V (20171MEC0073) and Mr.Uday.N (20171MEC0074) bonafide Students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said degree.

Dr. Arpitha G.R
Supervisor

Dr Ramesh S
Professor and Head

Signature with date

End Term Examination examiners

1.**Dr.Uday Ravi**

M.U. Ravi

2.Mr.Sandeep G M

Sandeep

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DECLARATION

We, the students of eigth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, **“STUDY AND DEVELOPMENT OF WASTE CORNCOB REINFORCED EPOXY BASED COMPOSITES**“ has been successfully completed under the supervision of **Dr. Arpitha G.R** , Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021 Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:

Team members:	**ID Numbers**	**Signature of Students**
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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. Arpitha** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. Ramesh S Prof. and Head** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Arpitha** who gave us the opportunity to do this project work.

At the same time, we express our deepest thanks to **Mr.Vijay Kumar Guna** Research associate, Jyothi Institute of technology for providing lab facilities to successfully finishing the project.

Lastly, we would like to thank our family and friends

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ABSTRACT

The purpose of this research work is to evaluate and compare the mechanical properties of laminates prepared of different composition of waste corncob and epoxy. The mechanical properties evaluated are tensile strength, tensile modulus and flexural strength and flexural modulus, the water absorption properties and fire resistance test are also evaluated.

The nine laminates in different proportion of corncob and epoxy are fabricated by hand layup process. Natural fibers have recently become attractive to scientist and researchers as good as alternative for fiber reinforced composites because of their low cost, non-abrasive and eco-friendly nature. Natural fibers may play important role in developing bio-degradable composite to resolve the current ecological and environment problem. This report shows that the natural fiber and also possesses good mechanical properties and then fiber composite can also be used in different application.

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CHAPTER 5.0

Chapter 1

1.1 Introduction

Over the last decades, environmental issues and government restrictions have led industries to replace the petroleum-based material with agricultural-based to make eco-friendly products. In attempt to make green products, natural fibers were employed to reinforce polymers. Natural fibers such as hemp, flax, giant cane, jute, sisal, etc. have some ad-vantages over common inorganic or synthetic fibers, (e.g. glass and carbon fibers). These are less density, less machine wear during processing, no health hazards and high degree of flexibility [8].

Fibre reinforced polymer (FRP) are composites used in almost every type of advanced engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, chemical processing equipment and civil infrastructure such as bridges and buildings. A key factor driving the increased applications of composites over the recent years is the development of new advanced forms of FRP materials. This includes developments in high performance resin systems and new styles of reinforcement, such as glass fiber, carbon fiber, nanoparticles etc [1].

Epoxy resins are widely used as matrix in many fiber reinforced composites; they are a class of thermoset materials of particular interest to structural engineers owing to the fact that they provide a unique balance of chemical and mechanical properties combined with wide processing versatility. Within reinforcing materials, glass fibers are the most frequently used in structural constructions because of their specific strength properties [3].

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix .The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Fiber reinforced polymer materials are composites consisting of high strength fibers (reinforcement) embedded in polymeric matrices. Fibers in these materials are the load-carrying elements and provide strength and rigidity, while the polymer matrices maintain the fibers alignment (position and orientation) and protect them against the environment and possible damage. A pure polymer does not usually have the requisite mechanical strength for application in various fields. The reinforcement by high strength fibers provides the polymer substantially enhanced mechanical properties and makes the fiber reinforced polymer composites (FRPCs) suitable for a large number of diverse applications ranging from aerospace to sports equipment. Natural fiber composites combine plant-derived fibers with a plastic binder. The natural fiber components may be wood, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, banana leaf fibers, bamboo, wheat straw or other fibrous material. The advantages of natural fiber composites include lightweight, less abrasiveness to equipment, renewability, bio degradability, less hazards and reduction in weight and cost. these are less density ,less machine wear during processing [8].

However, these composites have some disadvantages related to the matrix dominated properties which often limit their wide applications. In the industry, the addition of filler materials to a polymer is a common practice. This improves not only stiffness, toughness, hardness, heat distortion temperature, and mold shrinkage, but also reduces the processing cost significantly. In fact, more than 50% of all produced polymers are in no way or another filled with inorganic fillers to achieve the desired properties [4]. Mechanical properties of fiber- reinforced composites are depending on the properties of the constituent materials (type, quantity, fiber distribution and orientation, void content). Beside those proper- ties, the nature of the interfacial bonds and the mechanisms of load transfer at the interphase also play an important role [5]. The present study focuses on fabrication and investigation of corncob reinforced epoxy baesd laminated composites .

Chapter 2

2.1 Literature survey:

K Abdan worked on influence of fiber content on the mechanical and thermal properties of kenaf fiber reinforced thermoplastic polyurethane composites. It can be said that 30% fiber loading is the optimum fiber loading ,because it exhibited the best tensile strength, hardness ,abrasion and impact strength[1].

M . Rahman worked on the advanced green composites using liquid crystalline cellulose fibers and waxy maize starch based resin, By using compression molding The study shows a simple method to improve the tensile properties of composites fabricated using starch-based resin[2] .

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M. Misra woked on Biobased polyurethane and its composite with glass fiber . Using compression moulding .It is observed that with increase of temperature the modulus data drop. Glass fibers reinforce the matrix by allowing greater stress transfer at the matrix-fiber interface, therefore increasing the stiffness of the overall material[5].

Flexural strength and modulus increased with increase of fiber loading. Increase of fiber loading resulted in decline in impact strength. Hardness increased by addition of 30% fiber content. Abrasion resistant decreased with increase of fiber loading. Fiber loading decreased thermal stability of the composites. Tensile modulus showed an increasing trend with increase in fiber content [8].

Failure of composites mainly occurs due to the poor interfacial bonding between fabrics and matrix, fabrics pull out and fracture occurs in fabrics or matrix when loaded is applied. Natural fibers are biodegradable and their productions are associated with lower emission than that in the production of synthetic fiber. Production of natural fiber is labor-intensive and hence NFRPC industry will create new employment and will contribute to the poverty alleviation program in a number of developing countries [10].

NFRPs are economical and new trends in composite materials. Thus it can be concluded that with methodical and constant research there will be a good possibility and better expectations for natural fibre polymer composites in the future[11].

Several factors, influence strength of composites ,such as ,strength of fiber and matrix ,fiber volume fraction and fibers matrix interfacial bonding fibers work as carriers of load in the matrix . good tensile strength depends more on effective and uniform stress distribution[9].

To utilize natural fiber reinforced composite, it is necessary to compromise a balance and strength, stiffness and toughness .This is the first essential step is designing composite materials , lots of work has been done to study the effect of fiber loading on the mechanical properties[5]. Thermal properties are important to understand the behaviour of the raw material and the final product[10].

Effect of fiber content on the thermal properties was studied previously[9]. Hardness And abrasion resistance are also important , hardness property give material high resistance to various kinds of shape change when force is applied[12].

The strength and stiffness of plant fiber depends on the cellulose content and the spiral angle which the bonds of microfibrils in the inner secondary cell wall make with the fiber axis. That is , the structure and properties of natural fibers dependa on the source , age, etc[7].

The structure and properties of the natural fiber itself, experimental conditions such as fiber length , test speedetc, all have some effect on the properties of natural fibers. It has been reported by several authors that modification of fiber improved the mechanical properties of composites[8].

2.2 Objective and scope:

The main objective of our research project is to

- To development of waste corncob based composite by hand lay-up method.
- To develop composites by adding boron nitride particle in different ratios to increase the property of material.
- Develop an eco-friendly, economical sustainable agro-waste composite for commercial applications.
- To analyze the mechanical properties like tensile, flexural, impact, and hardness properties of composites.
- To analyze the surface morphology of composites by scanning electron microscopic.
- Replace Non-biodegradable Acoustic Panels which contains cementations materials like fiber wool, glass wool etc. by an Eco-friendly Composites.
- To effectively make use of Agricultural residues for high value applications.
- To evaluate mechanical properties and water absorption properties of composites.
- These NFRP's materials can be used in transportation, packaging & construction industry so that non-renewable resources can be sustained.
- To find out the factors that constrain this material to come into application or rather prevent it from being used.

Chapter 3

Methodology

3.1 Materials

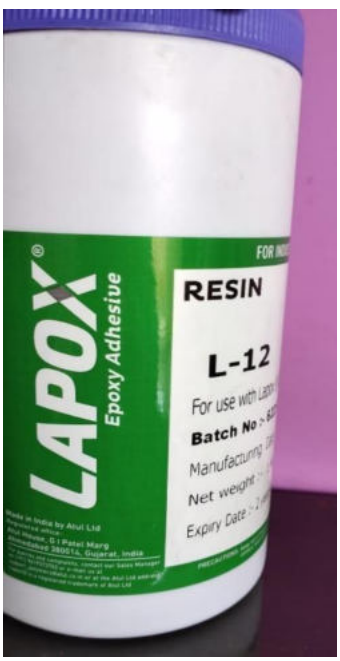
Key boron nitride properties are high thermal conductivity, low thermal expansion, good thermal shock resistance, high electrical resistance, low dielectric constant and loss tangent, microwave transparency, non-toxicity, easily machinability- non-abrasive and lubricious, chemical inertness, non-wetting by most molten metals.

Corn cob were sourced from local agricultural fields near our campus in Bangalore, India. Corn cob botanically known as Zea mays belongs to Poaceae family. A corn cob is a central core of maize. It is the part of ear on which the kernels grow. Clean and dried corn cob shells were first washed with water to remove dirtland and impurities. Corn cob shells are ground in hammer mill and appropriate sieves are used to get required particle size.

Epoxy is the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy is also a common name for a type of strong adhesive used for sticking things together. In the present work Lapox L-12 resin and K-6 hardener were used and this was provided by Yuje Marketing Ltd, Bangalore, India.

Boron nitride

Hardener K-6



Epox Resin L-12

Corncob

Figure 1.1 materials

3.2 Methodology and materials to be used

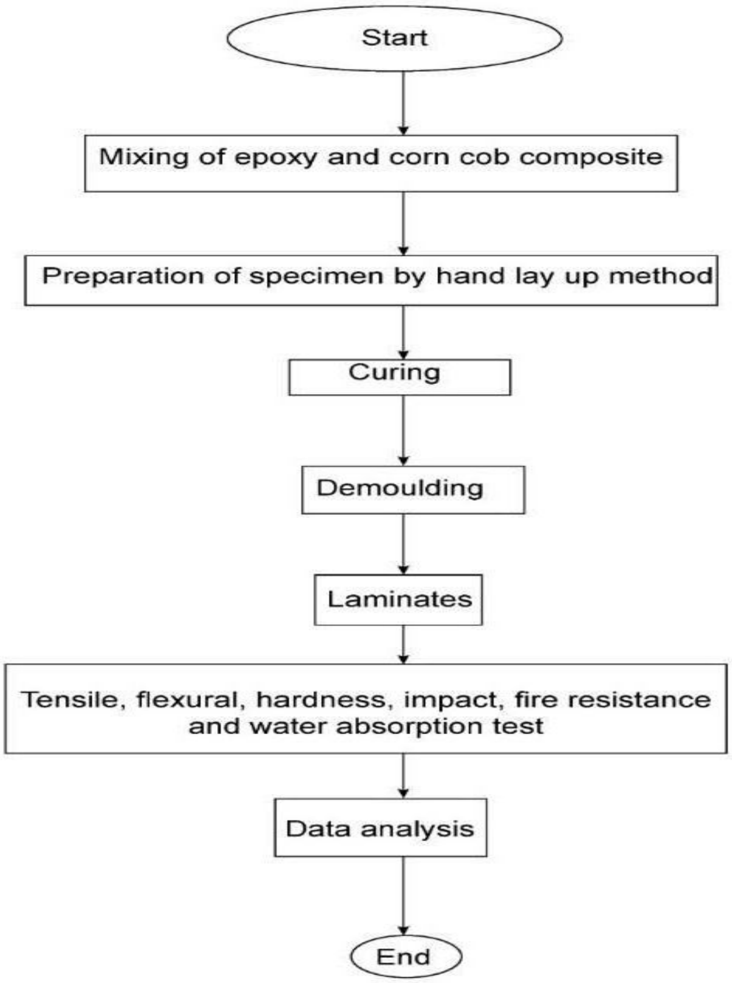


Figure 1.2 flow chart of methodology and material

3.3 Preparation of the composites

The composite laminates was prepared by hand layup process. Corn Cob particles and boron nitride used for the composite preparation. Corn Cob particles are depicted in the table below. Appropriate amounts of corn cob particles and boron nitride along with constant Epoxy resin were taken in a plastic container and stirred thoroughly to get a homogeneous mixture. After adding the hardener, the mixture was again stirred for 10 min and thoroughly mixed mixture was placed in a mold and compressed uniformly. This set up was kept for 52hrs of time and after curing composite board was taken out from the mold. The thickness of the composition is limited to 7mm and the mold size is 210 mm x 110 mm. After curing, the edges of the specimen are neatly cut as per the required dimensions.

Sl.No	Boron Nitride (grams)	Corn cob ratio (grams)
1	3.5	3.5
2	5	2
3	2	2
4	2	2
5	3.5	5.62
6	5.621	3.5
7	3.5	1.37
8	1.37	3.5
9	5	5

Table 3.3 details of the loading for composites

3.4 Design of Composites

Composites were fabricated using the reinforcing materials separately in nine different ratios of reinforcement mentioned in the above table. Based on the mechanical properties of the composites, the ratio of reinforcement was fixed for composites and we have tested flexural test for nine samples and by using optimization technique the highest mechanical properties for composites were obtained in the required ratio 3.5:3.5. For further studies we have done tensile test, impact test,fire resistance test and water absorption test.

Chapter 4

Experimental setup

4.1 Mechanical properties

4.1.1 Tensile test

Tensile properties (strength and modulus) of the composites were tested on a Universal Tensile Tester equipped with a 10 kN load cell. Test samples were prepared according to ASTM D 638 standard with samples having dimensions of 60 mm length and 12 mm wide at the widest section and thickness of 5mm. Crosshead speed of 18 mm/min was used for the tensile tests.

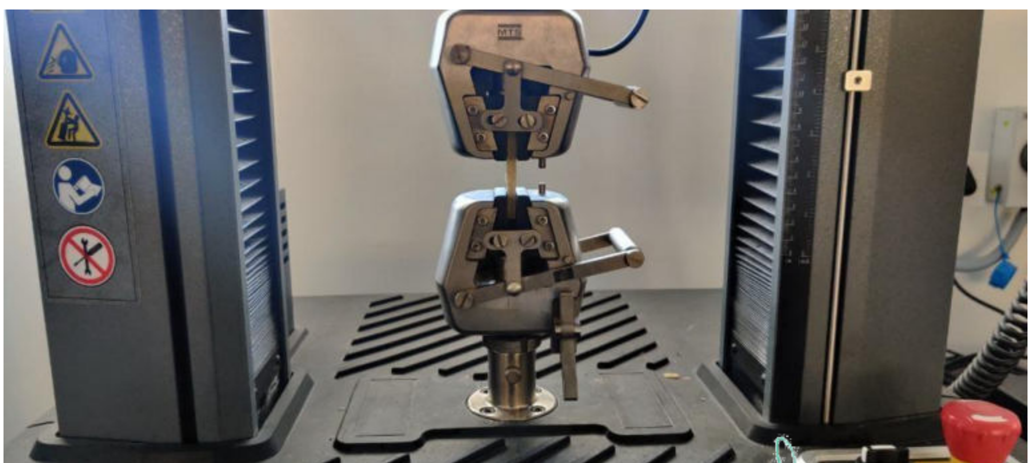


Figure 1.3 Tensile test apparatus

4.1.2 Flexural test

Flexural strength and modulus of the composites were tested in universal testing machine (UTM) equipped with a 10 kN load cell. Samples were prepared according to ASTM D790 standard. Samples with length of 60 mm and width of 12 mm and thickness of 5 mm were used for the flexural studies. Crosshead speed for flexural tests was set at 10 mm/min.

Figure 1.4 Flexural test apparatus

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4.1.3 Vickers Micro Hardness test

Hardness properties of the composites were tested on a Micro Vickers Hardness Testing Machine equipped with a 2kN load cell. Test samples were prepared according to ASTM E384 standard with samples having dimensions of 20mm x 20mm x0.5mm.

4.2 Water absorption

Water absorption of the composites were conducted according to ASTM D570 standards. Samples of dimension 20x20 mm was conditioned in an oven for 24h at 110ºC before the tests. After drying, the samples were weighed and then immersed in a container of distilled water for 24h at room temperature. To study the water absorption behavior over the period of 24h, the samples were taken out every 2h until 24h. Once taken out, the samples were wiped with a clean soft tissue and weighed immediately. The percentage water absorption was given based on the weight difference.

4.3 Flame Resistance Test

Samples measuring 100 mm x 10 mm x 5 mm were cut and the flame resistance of the composite was determined as per UL-94 standard test method. The samples were placed vertically above an igniter. The igniter was brought in contact with the specimen for 10 seconds. The time taken for the flame to extinguish was recorded. Further, any dripping of the specimen onto the cotton fibers below the sample was also observed. The sample were tested and the flammability rating were assigned based on the time to self-extinguish the flame .

- V0: the specimen may not burn with flaming combustion for more than 10 seconds.
- V1: the specimen may not burn with flaming combustion for more than 30 seconds.
- V2: the specimen may not burn with flaming combustion for more than 30 seconds which turns into ashes after few more seconds.

CHAPTER-5

5.1 Results and Discussions

5.1.1 Tensile strength and modulus

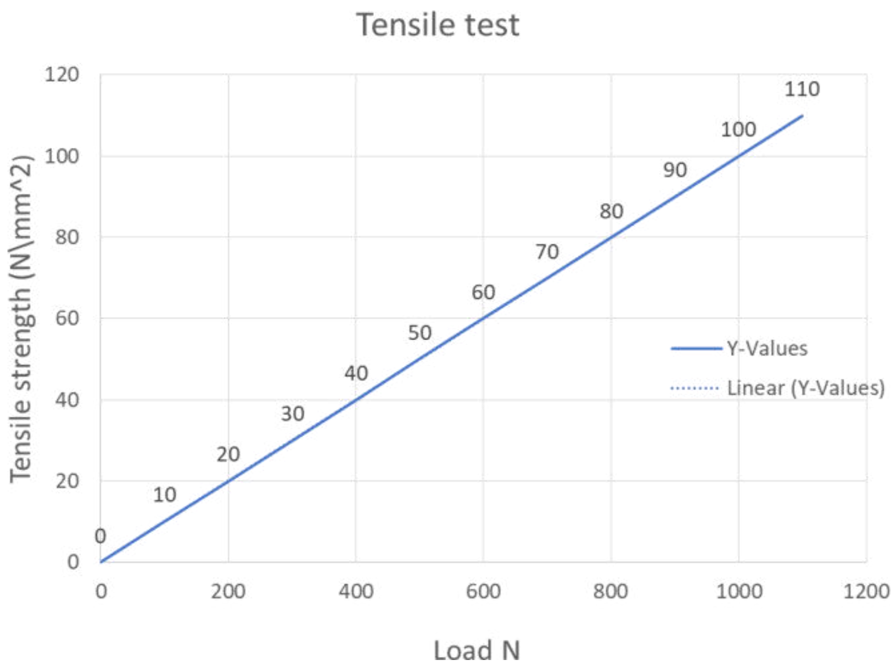

Figure 1.5 Tensile strength and Modulus of composites based on wt/wt ratio

SL.NO	wt/wt ratio (%)	Peak load (N)	Tensile strength (N/mm^2)	Tensile modulus (N/mm^2)
01	3.5/3.5	1079.762	107.1	2329.081

Table 5.1.1 Tensile strength and modulus

Tensile strength of the composites, it was found that the tensile strength and the tensile modulus of the composites were **107.1(N/mm^2)** and **2329.081(N/mm^2).** So, from the above graph the composite prepared **3.5/3.5**

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(3.5% corncob and 3.5% boron nitride) was found to have greater tensile strength and modulus. This blend was used for the further studies as there was optimum blending of the fiber and reinforcement.

5.1.2 Flexural test results

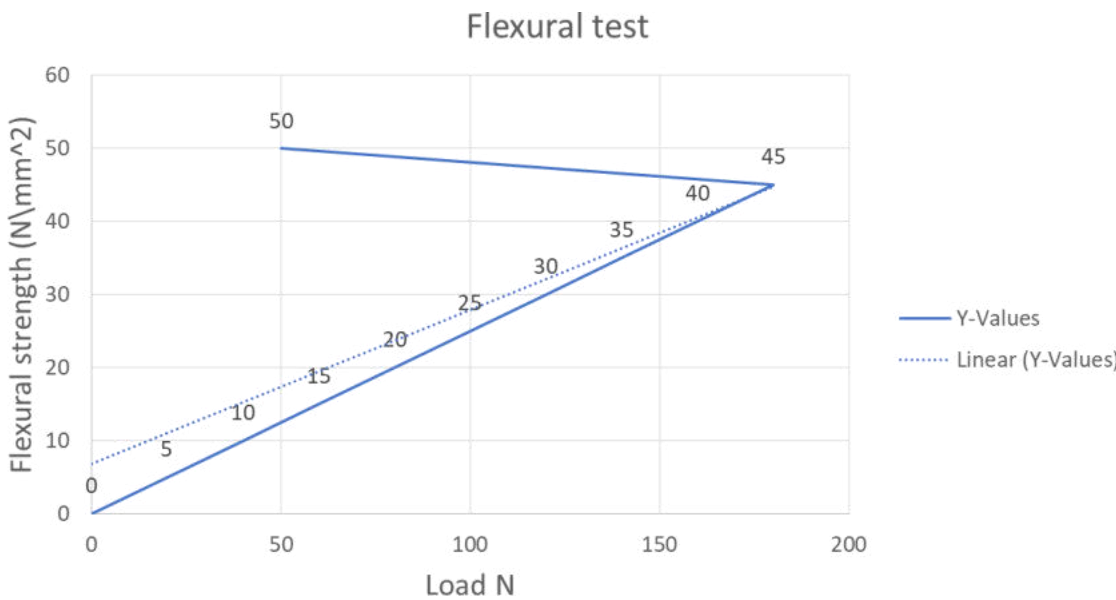

Figure 1.6 Flexural strength and Modulus composites based on wt/wt ratio

SL.NO	wt/wt ratio	Peak load	Flexural strength (N/mm^2)	Flexural modulus (N/mm^2)
01	3.5/3.5	104.382	36.7	2378.546
02	5/2	79.437	25.8	2170.069
03	2/2	137.460	36.0	1933.495
04	2/5	95.638	30.2	2467.708
05	3.5/5.62	91.463	25.9	1764.859
06	5.621/3.5	87.205	15.7	2727.023

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07	3.5/1.37	85.861	19.8	2357.453
08	1.37/3.5	94.327	18.1	4659.051
09	5/5	185.121	20.1	525.121

Table 5.1.2 Flexural strength and modulus

Flexural strength of the composite varied with the different weight ratios of corncob / boron nitride as shown in above table, it was found that the tensile strength and the flexural modulus of the composites were increased with equal amount of corncob and boron nitride(3.5/3.5). When of the (5.621/3.5) was used, the flexural strength and the modulus was found to decrease. So, from the above graph the composite prepared **3.5/3.5** (3.5% corncob and 3.5% boron nitride) was found to have greater flexural strength and modulus i.e., **36.7 N/mm^2** and **2378.546 N/mm^2** respectively. This blend was used for the further studies as there was optimum blending of the fiber and reinforcement.

5.1.3 Vickers Micro Hardness Test

Reading	**Vickers micro hardness (HV)**
01	**35.2**
02	**36.7**
03	**38.1**
04	**37.6**
05	**38.4**

Table 5.1.3 Vickers Micro Hardness test

5.2 Flame resistance test

Sl No.	Time to self-extinguish after ignition (s)	Observed dripping	UL-94 Rating
1	<30	NO	V-1

Table 5.2 Flame resistance test

Flame resistance test was being conducted for the specimens which were prepared. composites the standard referred was UL-94. the samples possessed V-1 rating i.e., the specimens may not burn with flaming combustion for more than 30 seconds after either application of the test flame and the flame will not propagate till the top.

5.3 Water absorption result

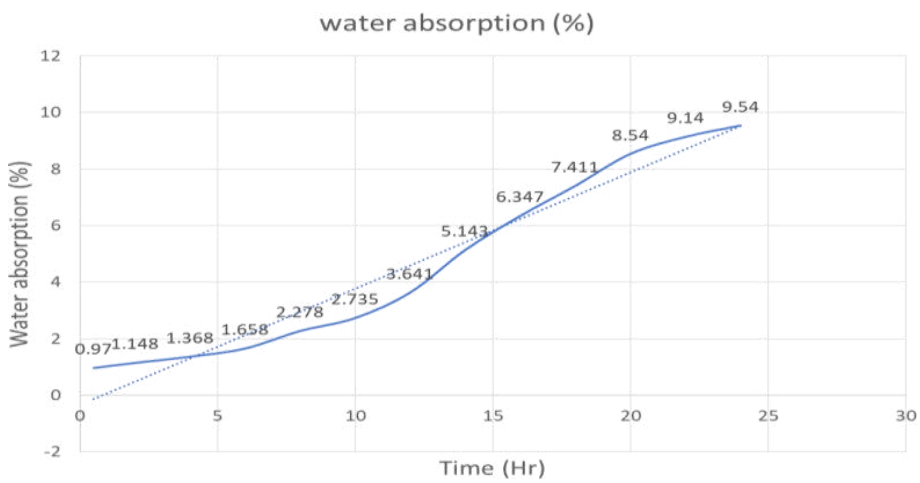

Figure 1.7 water absorption (%) / time (hours)

Time (hr)	Water absorption (%)
0.5	0.97
2	1.148
4	1.368
6	1.658
8	2.278
10	2.735
12	3.641
14	5.143
16	6.347
18	7.411
20	8.54.
22	9.140
24	9.540

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Table 5.3 Water absorption

Amount of water absorbed by the composites after immersion for up to 24h. The samples absorbed water at a gradual pace after 30 min and the sample were taken out every 2h until 24h. the absorption of water starts at 0.97% for 0.5h and start increase at 24h it absorb 9.5%.

5.4 Conclusion:

- Hand lay-up method successfully produce reasonably good mechanics properties of epoxy composites.
- It was found that the flexural strength and the flexural modulus of the composites were increase at equal ratio of corncob and boron nitride. Decrease at different ratios of corncob and boron nitride.
- By using optimization technique other test are done ie, tensile test, Vickers micro hardness test, water absorption test and fire resistance test.
- It was found that the tensile strength and modulus of the composites were increase at equal ratios.
- the samples possessed V-1 rating i.e., the specimens may not burn with flaming combustion for more than 30 seconds after either application of the test flame and the flame will not propagate till the top.
- The highest water absorption was found in 3.5/3.5 ratio at 9.5% at 24h whereas the lowest sorption was found in the 3.5/3.5 ratio at 0.97% at 0.5h. Having low sorption will be ideal for interior and automotive applications.

5.5 Recommendation for future work

In future a researcher can concentrate on other types of naturally available fibers like bamboo, sugarcane etc.

Also they can work on different types of hybrid composites by taking other matrix material like polyester.

Automobile application, household application, toys etc.

Used for interior and exterior design of building.

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Laminates

Figure 1.8 Laminates

DESIGN & ANALYSIS OF HYBIRD COMPOSITE AUTOMOTIVE FRONT BUMPER (FASCIA) FOR LOW SPEED IMPACT

University Project –II Report submitted to the Presidency University, Bengaluru in partial fulfillment of the requirements for award of Degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

Mr. Mahat K Mathew	**ID NO.: 20171MEC0101**
Mr. Manojkumar.T	**ID NO.: 20171MEC0111**
Mr. Vishal.S	**ID NO.: 20171MEC9007**
Mr. Manju Y Badannavar	**ID NO.: 20181LME0024**

Under the Supervision of

Mr. Sreenivas H T

Assistant Professor

GAIN MORE KNOWLEDGE
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PRESIDENCY UNIVERSITY

DEPARTMENT OF MECHANICAL ENGINEERING

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May 2021

PRESIDENCY UNIVERSITY

Bengaluru

Department of Mechanical Engineering

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CERTIFICATE

This is to certify that the University Project- II titled "**DESIGN & ANALYSIS OF HYBIRD COMPOSITE AUTOMOTIVE FRONT BUMPER (FASCIA) FOR LOW SPEED IMPACT**" was carried out by Mr. Mahat K Mathew (20171MEC0101), Mr. Manojkumar. T (20171MEC0111), Mr. Vishal. S (20171MEC9007) and Mr. Manju Yallapa Badannavar (20181LME0024) bonafide students of VIII Semester B.Tech. Mechanical Engineering in School of Engineering, Presidency University. This is in partial fulfillment of the award of the degree ofthe Bachelor of Technology in Mechanical Engineering of Presidency University, Bengaluru, during the academic year 2020-2021.

Mr. Sreenivas H T	**Dr. Ramesh S P**	**Dr. S Ramesh**
Supervisor & Assistant Professor	Associate Professor & Project coordinator	Professor & Head
Department of Mechanical Engineering	Department of Mechanical Engineering	Department of Mechanical Engineering

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DECLARATION

We do hereby declare that the Project Report titled **"DESIGN & ANALYSIS OF HYBIRD COMPOSITE AUTOMOTIVE FRONT BUMPER (FASCIA) FOR LOW SPEED IMPACT"** is a record of the original work done by us under the guidance of **Mr. SREENIVAS H T**, Assistant Professor, Department of Mechanical Engineering, Presidency University, Bengaluru. This report is submitted by us in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Mechanical Engineeringof Presidency University, Bengaluru in the month of December, 2020. The results embodied in this report have not been submitted to any other University or Institute for the award of anydegree or diploma.

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ACKNOWLEDGEMENT

We would like to express our sincere thanks to the supervisor, **Mr. Sreenivas H T** Assistant Professor, Department of Mechanical Engineering for his morale boosting, meticulous guidance, co-operation and supervision throughout this project work.

We would like to owe our heartiest gratitude to **Dr. Ramesh S P**, Associate Professor & Project coordinator, Dept. of Mechanical Engineering for his encouragement during theprogress of this project work.

We would also like to pay our sincere thanks to **Dr. S Ramesh**, Professor & Head, Dept. of Mechanical Engineering, School of Engineering for sharing his valuable experience in completing project work.

We would like to convey our sincere thanks to the Management of our university for providing us required infrastructure within college campus.

We would like to thank both teaching and non-teaching staff members of the Department of Mechanical Engineering for their kind cooperation and all sorts of help to complete this project work successfully.

We would also like to thank all of our juniors, classmates and friends for their valuable suggestions to complete our project work in time.

Last but not the least we would like to thank our parents for always staying beside us and encouraging all the time.

Date: 25th May 2021

Place: Presidency University, Bengaluru

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ABSTRACT

Automotive bumper beam assembly plays very important role in absorbing impact energy and protects passengers from front and rear collisions. A crash-test is a form of destructive testing usually performed in order to ensure safe design standards in crashworthiness and crash compatibility for automobiles or related components. The simulation of vehicle crashes by using computer software's hasbecome an indispensable tool for shortening automobile development time and lowering costs. This paper on the simulated crash test of car frontal fascia. The model used herewas that of a Toyota Avalon 2013 passenger car. The car fasciais designed in CATIA V5 R20 with thickness of 2.15 mm. The designed car fascia was meshed in HYPERMESH-12 with mixed elements of size 4 mm for getting better accuracy and simulated in LS-DYNA.

The results are interpreted by using LS-PREPOST to analyzethe energy absorption characteristics during crash for different materials at a velocity of 30mm/ms which is approximately 108 km/hr for the duration of 15 ms. The project is carried out for three cases and they are different material models, constant velocity for particular selected material model and using same thickness for particular material model. With the help of LS-DYNA codes nonlinear dynamic contact analysis by using different materials can be done effectively and accurately.

CONTENTS

CHAPTER 1: INTRODUCTION

Car accidents are happening every day the majority of drivers believe they should escape such unpleasant conditions. Automobile protection must be improved if we are to achieve our goals. Reduce the number of collisions and casualties. A vehicle one of the most important structures in a passenger car is the bumper beam. The bumper device is intended to discourage or minimize physical harm to a passenger vehicle's front or rear end in a state of collision the hood, trunk, and grill are all protected by the bumper. Protection, as well as the fuel tank, intake, and cooling systems parking lights, headlamps, and other related device the taillights.

A car bumper is a front portion of the vehicle that protects the body from the elements. Fascia is the term for the bumper cover on a vehicle. An automotive bumper is the front or rear portion of the vehicle that is ostensibly designed to withstand an impact without compromising the vehicle's protection. The front and rear fascias of passenger cars are intended to avoid or minimize physical injury to the front and rear ends of the vehicles in the case of a crash. They safeguard the hood, trunk, grill, petrol, exhaust, and cooling systems, as well as protective devices including parking lights, headlamps, and taillights.

In front of the car the fascia and bumper pieces played a significant role. If a collision occurs, it absorbs energy and provides protection to the vehicle. The bumper structure is a structural feature that relates to the crashworthiness or safety of the occupants in the event of a front or rear collision. In the bumper method, researchers are interested in moving away from traditional materials like rubber, aluminium, or steel and into materials like polymeric based composites. In this paper Kevlar, Kenaf composite were used.

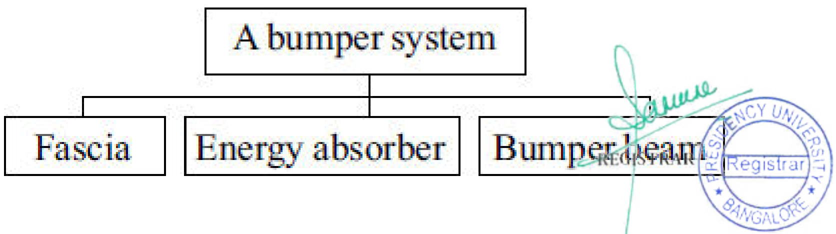


Fig. 1: Automotive bumper system component

When the bumper is struck by a rigid projectile, as in a parking crash or the statutory low-speed impact pendulum test, the bumper fascia alone cannot be strong enough to survive the impact without taking into account the forces acting on it. During the evaluation, four major strategic criteria were investigated.

The automotive bumper system is critical not only in terms of absorbing impact energy but also in terms of style. In recent years, the automobile industry has placed a great deal of emphasis on light weight and adequate protection. As a result, the bumper device with a thermoplastic and energy-absorbing feature is a new industry trend. The most important consideration in bumper device design is the degree of impact energy absorption in a small clearance between the rear face of the bumper and the vehicle's body parts.

Energy absorbers or braces are used in some bumpers, while foam cushioning is used in others. In low-speed crashes, the automotive bumper is intended to avoid or minimize physical harm to the front and rear ends of passenger cars.

The fascia bumper is a crucial part of the guard as well as a styling feature of the bumper, and is an extension of the vehicle's configuration. As a result, using a high-elastic material to maintain the initial form of the bumper fascia during low-speed crashes is critical. Kevlar fibre composites provide designers with more versatility in customizing material properties and structural stiffness, as well as a higher stiffness-to-weight ratio.

Car accidents are happening every day. Most drivers are convinced that they can avoid such troublesome situations. Nevertheless, we must take into account the statistics ten thousand dead and hundreds of thousands to million wounded each year [Hosseinzadeh et al. (2005)]. These numbers call for the necessity to improve the safety of automobiles during accidents. A car bumper is a front part of the car that covers the car's chassis. The cover of the car bumper is called fascia. An automobile bumper isthe front most or rear most part, ostensibly designed to allow the car to sustain an impact without damage to the vehicle'ssafety. Car frontal and rear fascia is designed to prevent or reduce physical damage to the front or rear ends of passenger motor vehicles in collision condition. They protect the hood, trunk, grill, fuel, exhaust and coolingsystem as well as safety related equipment such as parking lights, headlamps and taillights etc [Suddin et al. (2007)].

When the bumper is impacted by a stiff object, such kind may happen in a parking accident or in thelegislative low speed impact pendulum test, then the bumper fascia alone may not be there to withstand the impact without considering the forces acting on it. Thus, there werefour main strategic parameters being studied during the test.Firstly, how the type of material can affect the impactspecifications and what kind of materials can be used as replacement in order to lower part weights. The effect of module of elasticity, yield strength and Poisson’s ratio on impact behavior of bumper beam was under investigation inthis section. Secondly, how the bumpers beam thickness canaffect the impact specifications. Thirdly, how even small changes and modifications can result in easier manufacturing processes and lessening material volume without lowering the impact strength.

A bumper is a car shield made of steel, aluminums,rubber or plastic that is mounted on the front and rear of a passenger car. When a low speed collision occurs, the bumper system absorbs the shock to prevent or reduce damage to the car. Some bumpers use energy absorbers or brackets and others are made with a foam cushioning material. The car bumper is designed to prevent or reduce physical damage to the front and rear ends of passenger motor vehicles in low-speed collisions. Automobile bumpers are not typically designed to be structuralcomponents that would significantly contribute to vehicle crashworthiness or occupant protection during front or rearcollisions [Nitesh Joshi et al. (2016)]. It is not a safety feature intended to prevent or mitigate injury severity to occupants in the passenger cars.

Automotive bumper system plays an important role not only in absorbing impact energy but also in a styling stand point. A great deal of attention with in the automotiveindustry has been focused upon light weight and sufficient safety in recent years. Therefore, the bumper system equipped with thermoplastic and energy absorbing element is a new world trend in the market. The major point for thedesign of bumper system is summarized as a degree of absorption of impact energy in a limited clearance betweenback face of bumper and body parts of the vehicle. While experimental test is rather costly and time consuming, finite element analysis helps engineers to study design concept at an early design stage when prototypes are not available.

In olden days' vehicles are mostly used for transportation. As the years pass on vehicle becomes more essential member of a family. They consider vehicle has an additional assert for them so they are willing to buy an expensive vehicle. Nowadays automobile industries are updating themselves basedon the customer satisfaction. Hence they improved their vehicle standards to become popular in the market. While buying a vehicle customer gives a high priority to safety features bumpers are one oftheir essential safety features in automobile. during impact collision it prevent the damage of front and rear end. A good bumper design will have better aerodynamic property. Different companies makedifferent bumper design to show their uniqueness.

The role of automotive bumpers has changed considerably over the past 70 years. The later performance is achieved by a combination of careful design, material selection to obtain a particular balance of stiffness, strength and energy absorption. Stiffness and Energy absorption are essential criterion. Stiffness is important because vehicle design consideration limits the packaging space for thebumper design to deform under load and Energy absorption is important because bumper must limit the amount of the impact force transmitted to the surrounding rails and vehicle frame. Automotive bumper plays a very important role in absorbing impact energy (original purpose of safety) and styling stand point aesthetic purpose. Now a day, automotive industry concentrates on optimization of weight and safety.

Standards for bumper

As bumper improves the aesthetic look of an automobile and also its design need to satisfy the roads condition. If bumper ground clearance is good it can travel easily in all road condition

India

India is the 10th largest producer of automobile in the world. In the year 2016 our country hasregistered 10 million trucks and 230 million cars. In 1989, the Central Motor Vehicle Rules (CMVR) became effective. Under Rule 126 of the CMVR, each manufacturer must pass the test for their original prototype. All the vehicle to be launched need to satisfy pollution control norms. generally Indian vehicle manufacturer can easily design based on it but foreign vehicle need a slight variation to meet with Indian standard.

Features of best bumper

- Good aerodynamic course
- Light in weight
- Easy to assemble
- Withstand load during impact collision
- Aesthetic design

1.1 OBJECTIVES

By understanding the nature and degree of work completed on hybrid composites with polymer matrix in it, the project aims at,

- ✓ Modelling and simulating the hybrid composite defined using modelling and analysis tool.
- ✓ Obtaining composite with sustainability under low velocity impact conditions.
- ✓ Suggesting the use of composites in real time applications.

1.2 STUDY AREA

1.2.1 Composites

Composites are versatile materials comprising of two or more chemically distinct componentscombined artificially on a macroscopic-scale which have a distinct interface separating them so as to attain characteristics that individual components on themselves can't attain. Constant technological innovations have pushed the physical boundaries of conventional materials, so that there is a need to develop new material solutions to meet application demands. Compositematerials have been chosen as a common replacement for conventional materials in many structural components. Their high specific stiffness-to-mass ratio, in particular, has owned them a spot in the aerospace, automotive, biomedical, military, and renewable energy industries. Composite materials are generally used for light weight at the same time high performance products. They include aerospace components (fuselages, propellers tails, and wings), boat and scull hulls, surfboards, bicycle frames and racing car bodies. Other uses include fishing rods, storage tanks, swimming pool panels, and baseball bats.

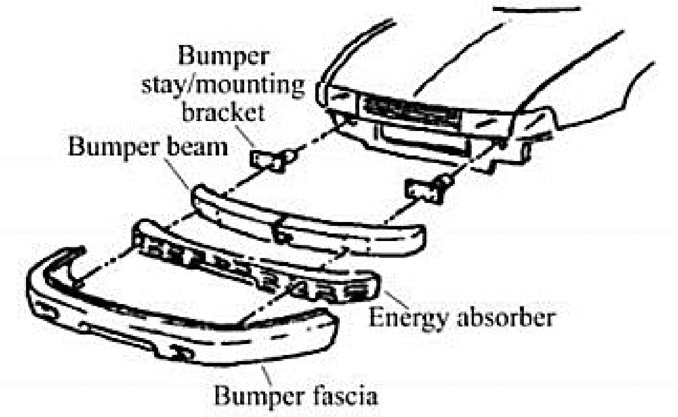


Fig. 2: Components of a Bumper.

Composites are basically a combination of two phases. One constituent is known as the reinforcing phase and the one onto which it is embedded is known as the matrix phase. The function of reinforcing phase is to strengthen and stiffen composite through prevention of matrix deformation by any mechanical restraints. The reinforcing stage materials can be fibers,flakes or particles. The functions of matrix phase are to hold the fiber together, protect the fiberfrom the environment, to uniformly distribute the load through the fibers, propagation of cracks through the fibers etc. The matrix stage materials are generally continuous which are of polymers, metals or ceramics.

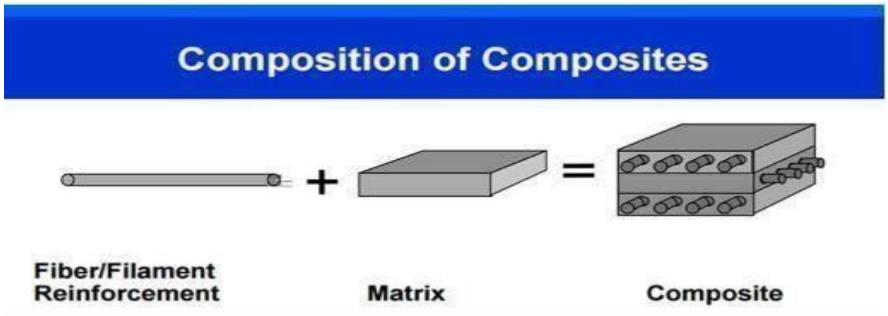


Fig. 3: Composition of composites.

1.2.2 REINFORCEMENT

Based on the geometryof the reinforcement composites are classified into three (**Fig.1.4**). Theyare fiber composites, flake composites, particulate composites.

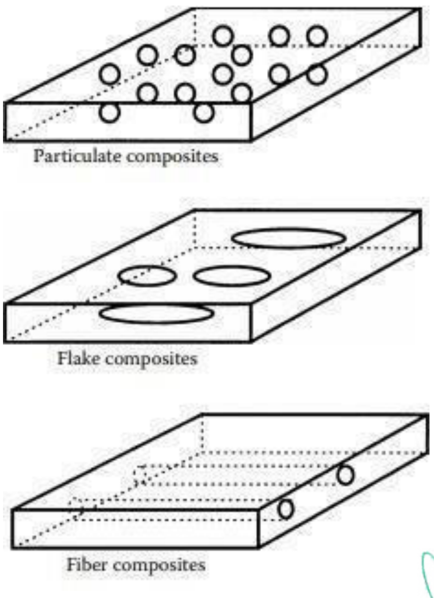


Fig. 4: Classification of reinforcement.

1. Particulate Composites

Particulate composites consist of particles which are immersed in matrices such as alloys and ceramics. They have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. An example is concrete.

2. Flake Composites

Flake composites consist of flat reinforcements of matrices. They provide advantages such as high out-of-plane flexural modulus, higher strength, and low cost. However, flakes cannot be oriented easily and only a limited number of materials are available for use. Examples are glass, mica, aluminum, silver etc.

3. Fiber Composites

Fiber composites consist of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are usually anisotropic. Examples include carbon and aramids. Fibers are mainly classified into two based on their source of origin, namely natural fibers and synthetic fibers.

1.2.3 FIBERS

Natural Fibers

Natural fibers are the substances or hair-like materials directly obtained from natural sourceslike animals, minerals and plants. They can be spun into yarns, filaments, thread or rope and can further be bound, knitted, matted or woven. Examples of natural fibers are jute, sisal, hemp,coconut husk, bamboo, cotton, kenaf etc.

They can be used as components of composite materials, where the orientation of fibers affects the properties of the composites. The advantage of using a natural fiber is reduced tool wear, weight, low density per unit volume, low cost, acceptable specific strength, better thermal and insulating properties, and low energy consumption during processing and also their sustainable renewable and degradable feature in contrast with that of synthetic fiber which critically affects our environment. Natural fibers tend to degrade faster than that of synthetic fibers. Natural fiber can be further classified based on the type of origin as depicted in Fig 5.

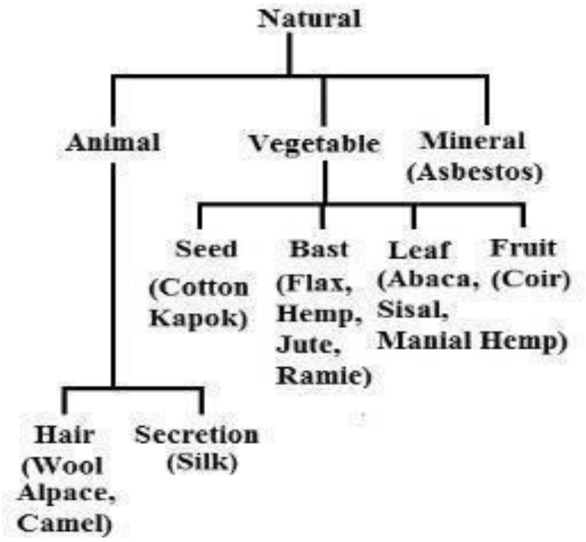


Fig.5: Classification of natural fibers

Properties of Natural Fiber

In contrast to synthetic fibers natural fibers have reduced strength and stiffness. The properties tend to deteriorate over time. Younger fibers tend to exhibit more strength than that of older fibers. Properties of natural fibers also depend on the moisture content in the fiber.

Table 1.1 Tensile wear property of natural fibers.

Material	Fiber	Elastic Modulus (GPa)	Strength (MPa)
Tendon	Collagen	1.50	150
Bone	Collagen	20.0	160
Mud Crab Exoskeleton (wet)	Chitin	0.48	30
Prawn Exoskeleton (wet)	Chitin	0.55	28
Bovine Hoof	Keratin	0.40	16
Wool	Keratin	0.50	200

Advantages of Natural Fibers

- ✓ Renewable resources.
- ✓ Lower production costs.
- ✓ Lower density of composites.

- ✓ Reduced energy consumption during manufacturing.
- ✓ Biodegradability and eco-friendly materials.
- ✓ Lower risk to human health.

Disadvantages of Natural Fibers

- ✓ Inhomogeneous structure of fibers.
- ✓ Dimensional instability as a negative consequence of water absorption.
- ✓ Lower water and thermal resistance.
- ✓ Susceptibility to microbial attacks and rotting.
- ✓ Degradation and aging.
- ✓ Restricted processing temperature (to avoid thermal degradation).

SYNTHETIC FIBERS

Fibers synthesized through chemical processes by humans are known as Synthetic fibers or artificial fibers. Most of the synthetic fibers are generally prepared from petrochemicals where the raw material is mainly petroleum. This process involves combining monomers to make a long chain or polymer and is known as polymerization. Synthetic fibers accounts for about half of all fiber usage, with its applications in almost everyfield of fiber technology. Acrylic, nylon and polyester are the main synthetic fibers which dominates the market with polyester alone accounting for about 60 per cent by volume of synthetic fiber production. Examples include boron fibers, carbon fibers, glass fibers, carbon fibers, Kevlar etc.

There are various processes through which a synthetic fiber can be manufactured, but the typical one is the melt-spinning process. This process involves heating the fiber continuously until it starts to melt, then the fiber should be drawn out of the melt with tweezers as quickly as possible. Then align the molecules in a parallel arrangement so as to bring the fibers closertogether, this allows them to crystallize and orient. Synthetic tend to be more durable than mostof the natural fibers, and will readily pick up different dyes. Besides this, many synthetic fibersoffer user-friendly functions, that are stretching, waterproofing, and stain resistance.

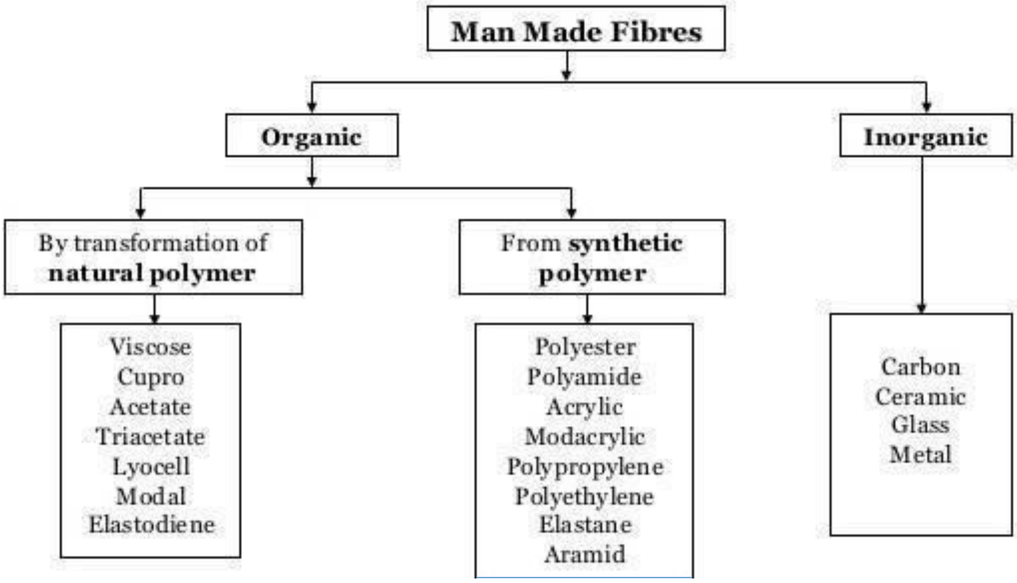


Fig.6: Classification of Synthetic fibers.

Properties of synthetic fiber

Synthetic fibers have got unique characteristics which makes them the most desired fiber among material scientists. The fibers are uniaxial oriented during the melt, dry, or wet spinningprocess, which give the fibers high tenacity and strength. In addition, the properties of synthetic fibers and fabrics can be easily tailored to the application by differing the chemical compositionand the processing conditions. Synthetic fibers are usually more water, stain, heat and chemicalresistant

Table 1.2. Wear property of natural and synthetic fibers.

Fibre	Density (g/cm^3)	Tensile strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
Flax	1.5	345-1500	27.6	2.7-3.2
Hemp	1.47	690	70	1.6
Jute	1.3	393-800	13-26.5	1.16-1.5
Kenaf	1.22-1.44	930	53	1.6
Ramie	1.55	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-700	9.4-22	3-7
Coir	1.15-1.46	131-220	4-6	15
E-glass (synthetic)	2.55	3400	73	2.5
Kevlar (synthetic)	1.44	3000	60	2.5-3.7
Carbon (synthetic)	1.78	3400-4800	230-240	1.4-1.8

Advantages of Synthetic fibers:

- Easy daily maintenance.
- Less expensive.
- Less susceptible to fading in sunlight.
- Lighter in weight.
- Less odor absorption.
- Less moisture absorbent.

Disadvantages of Synthetic fibers:

- More susceptible to heat damage.
- Extremely hazardous to environment.
- Melt relatively easy.
- Not skin-friendly.

1.3 MATRIX MATERIALS

Based on the type of matrix used, composites are classified into:

Polymer Matrix Composites (PMC):

The most advanced composites are polymer matrix composites consisting of a polymerreinforced with thin diameter fibers. Their advantages are low cost, high strength, and simple fabrication methods. Epoxy and polyester are commonly mixed with fiber reinforcement.

Metal Matrix Composites (MMCs):

As the name suggests, have a metal matrix. Metals are usually reinforced to increase ordecrease their properties in order to suit the needs of the application. Their advantages include higher specific strength and modulus, lower coefficients of thermal expansion and strength at high temperatures. Examples of matrices in such composites include aluminium, magnesium, and titanium.

Ceramic Matrix Composites (CMCs):

They have a ceramic matrix such as alumina calcium alumino silicate reinforced by fibers such as carbon or silicon carbide. Advantages of CMCs are high strength, hardness, high service temperature limits, chemical inertness, and low density. However, ceramics by themselves have low fracture toughness. Under tensile or impactloading, they will fail disastrously.

Based on the type of the polymer matrix it can be further divided into Thermoset Polymer and Thermoplastic Polymer.

Thermoset polymers are used as matrix materials which once synthesized into asolid form cannot be reverted back to their original form. The cross links between the adjacent polymer chains results in high melting points and makes them very strong. Examples – Polyester, Polyurethanes, Epoxy

Thermoplastic polymers can be molded, melted and remolded without altering their physical properties. The lack of cross links results in low melting point and less strength. Examples – Polyethylene, Polypropylene and Poly-vinyl chloride.

1.4 TYPES OF BUMPERS

- Steel Bumper
- Carbon Fiber Bumper
- Plastic Bumper

Steel Bumper

It can easily withstand impact load without complete deformation so the stress is induced inside the vehicle. It is tedious to manufacture it is also heavier in weight. Alloying of steel can improve the properties.

Fig. 7: Steel bumper.

Carbon Fiber Bumper

It is highly expensive to manufacture and light in weight .it can easily withstand load compare to other material but it cannot be reformed.

Fig. 8: Carbon bumper.

Plastic Bumper

Nowadays plastics are used to make bumper because they are lighter in weight and easy to manufacture. It is also cost efficient. It can be easily recyclable. It can also easily withstand impact load.

Fig. 9: Plastic reinforced bumper.

ABS Material in Automobile Bumpers.

Early in 1870s bumpers were used as safety features in vehicles and those bumpers were made of steel and aluminum alloys. But those materials were so heavy to be recycled so the industries were searching for a new light weight material which has high strength to withstand the impact load and also capable of being recycled. In 1950s Automobile industries started manufacturing bumpers using polymers and plastics. Later on they discovered a new material called Acrylonitrile Butadiene Styrene (ABS) which has high impact strength to withstand collision in this research we have made both the extreme ends of the wall as fixed support and the bottom two layers of the model is also as displacement support and right and left edge of the model is alsoconsider as displacement support.

Fig. 10: ABS bumper.

1.41 MODELLING

The process of converting 2D drawings, sketches or concepts into live 3D models is known as modeling

Some of the best modelling software's are:

- ✓ AutoCAD
- ✓ Ansys
- ✓ Catia and Solidworks

1.42 ANALYSIS

Composite materials analysis often requires the use of multiple analytical techniques to properly characterize the materials and the interfaces between them which often contribute in important ways to the properties of the materials.

- ✓ Ansys (ACP)
- ✓ Abacus
- ✓ LS-Dyna (Structural Analysis)

1.43 LS-DYNA

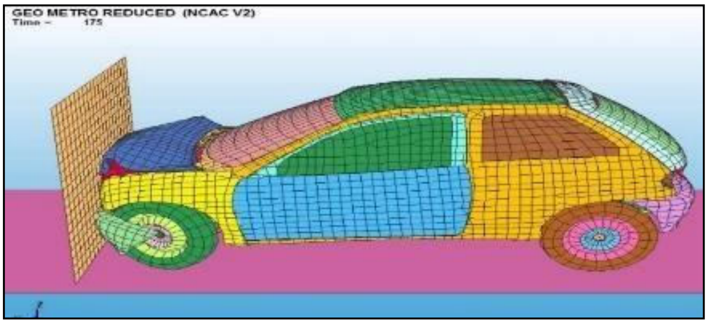


Fig. 11: LS-DYNA Software used for structural analysis.

LS-DYNA is an advanced general-purpose multi physics simulation software package developed by the former Livermore Software Technology Corporation (LSTC), which was acquired by Ansys in 2019. While the package continues to contain more and more possibilities for the calculation of many complex, real world problems, its origins and core-competency lie in highly nonlinear transient dynamic finite element analysis (FEA) using explicit time integration. LS-DYNA is used by automobile, aerospace, construction and civil engineering, military, manufacturing and bioengineering industries.

1.5 LITERATURE SURVEY

Chandramohan D and J. Bharanichandar [1], explored the use of Taguchi method for determining the properties of composites made by, natural fibers like Sisal (Agave sisalana), Banana (Musa sepientum) and Roselle (Hibiscus sabdariffa), Sisal and banana (hybrid), Roselle and banana (hybrid) and Roselle and sisal (hybrid) with bio epoxy resin using moulding method. The disclosure includes the process to make the composite and also the variety of products in automobile accessories. The hybrid composites showed comparatively better performance, the micrographs taken for the fractured sisal, banana, Roselle and hybrid composites. Sisal fibre composites, on tensile loading condition, showed a brittle like failure. Elliptical cracks and their fast propagation is observed. The sisal and Roselle (hybrid) can be used to make the variety of products in automobile accessories.

Neng Sri Suharty et al [2], utilized kenaf as a reinforcement parameter recycled with polypropylene resin, he noticed that there was an increase in tensile strength upto 18%, flexural strength upto 28% and 27% of impact toughness which showed frightful increment in composite properties by reinforcing kenaf.

Suhad D Salman et al [3], found that, use of Kenaf/Kevlar plain weaved hybrid composite, tensile strength was improved and showed ordinary stiffness and non-performance to strain characteristics.

A. Atiqah et al [4], procured kenaf and glass fiber with polyester reinforced composite and processed it by holding volume fraction of 70:30 proportion for treated and untreated fibers. The hybrid composite was experimented for tensile, flexural and izod impact properties which shows 15% treated composite laminate showcased the best results in all the categories. The kenaf fiber alone (30% volume) or higher percentage (22.5% volume) can't avoid the higher impact load leading to fragility and less toughness in the composite.

Noor Haznida Bakar et al [5], contemplated various weight percentage of Kevlar reinforced kenaf/epoxy composites, the measure of impact energy absorbed and the hardness substantially increased when the weight fraction of Kevlar was increased. The outcome displayed 20% weight percentage for Kevlar with Kenaf composites, exhibited maximum energy absorbed which was obtained as 12.76J. It has shown that the incorporation of Kevlar fiber into kenaf composites will improve the impact properties and durability of kenaf composites.

Mohd Nizam Suddin et al [6] studied the different conceptual design and use of polymer composite as a material for bumper fascia. Implementation of polymeric composite material results in reduction of weight, and increases specific stiffness, high specific strength, and high-energy absorption and easy to produce in complex shapes compared to more conventional materials and its manufacturing cost is low.

R.R. Magalhaes et al [7] Studied the use of Numerical technique called Boundary element Method (BEM), this method is used to find out the stress that are developed in a front bumper fascia and also guides Product designers to achieve better component performance in terms of structural requirements.

Chandrakant Rameshchandra Sonawane et al [8] works on slow speed impact tests were conducted in three different positions as per IIHS regulations i.e. central impact, left hand corner impact and right hand corner impact leads to find out the energy absorption by bumper. Finite element analysis (FEA) is used to analyse parameters such as bumper material, shape, thickness, and impact conditions to enhance crashworthiness design in low speed impact.

Sudirja et al [9] assessed on the key materials like carbon fibre Reinforcement vinyl ester with Microsphere (CRVeM) and Mild steel S45C are considered for electric car bumper fascia. Crash simulation were performed to find out the energy absorption ability, deformation and weight of composite material, results were compared between CRVeM and Mild steel S45C.

CHAPTER 2: METHODOLOGY

2.1. MATERIAL SELECTION

From the summary of literature, the best material which gives high damping coefficient will be selected as matrix material. The matrix may be the combination of more than two materials.The natural and synthetic fibers which have good elastic properties will be selected as reinforcement.

Materials Used

In this work natural fiber Kenaf and synthetic fiber Kevlar fiber was used as reinforcement material. Chemicallytreated twill weaved Kenaf (2*2, 2 yarns in warp & weft direction per inch) and Kevlar 49 bi-directional woven fabric ,Unsaturated Polyester used as matrix phase in the development of composite.

KENAF (Natural fiber)

It has many positive things to replace synthetic fiber like glass fiber, Kevlar etc. The use of kenaf fiber gives good wear property tensile strength, comparable to those of synthetic fiber with lower density than traditional materials, light weight and ecofriendly polymer composites.

KEVLAR (Synthetic fiber)

Kevlar is one of the good synthetic fiber with good heat resistant and strong compare with other fiber. Kevlar is used in wide area from bicycle tires, racing sails, bulletproof vests, and many more, because of its tensile strength-to-weight ratio will give stronger than steel.

UNSATURATED POLYESTER RESIN

The polyester resin as a polymer obtained by the polycondensation reaction between polyacids and polyalcohol’s. The development of water is the by-product of this polycondensation process. Specifically, the unsaturated polyester resin, also known by the English acronym UPR, is an easilyprintable liquid polymer which, once cured, keeps the solidshape taken in the mould. The items so realized have exceptional strength and durability characteristics. Unsaturated polyester resins are mostly used in combination with reinforcing materials such as glass fibers.

The main features of the unsaturated polyester resins

- ✓ Poor linear shrinkage.
- ✓ Excellent wet ability of the fibers and charges.
- ✓ Cold cross-linking by addition of hardener.
- ✓ Minimisation of the effect of sagging in vertical stratification.
- ✓ Exceptional lightness.
- ✓ Rigidity.
- ✓ Good electrical insulation.
- ✓ Dimensional stability against temperature changes.
- ✓ A higher strength / weight ratio than steel.
- ✓ Resistance to chemicals.
- ✓ Excellent surface finish.
- ✓ Water repellence.
- ✓ Resistance to wear and high temperatures.

The twill weaved (2*2) Kenaf (natural fiber) fabric was selected for the process to obtain better result compared to other work done on weave pattern of kenaf and plain weaved Kevlar fabric was selected as a synthetic fiber.

2.2 MATERIAL PROPERTIES

The material selection for the fascia has direct effect on the vehicle's impact performance. Hybrid fiber reinforced composite material with stacking sequence is considered as fascia material. The hybrid material used in the current work consists of Twill (2x2) weave Kenaf & plain weave Kevlar as reinforcing material, unsaturated polyester as matrix material. Five different layers of Kenaf & Kevlar stacked together to obtain laminates sequence L1 to L5 for analyzing fascia performance and the influence of these laminates under low impact under different boundary conditions using simulation process. The factors that influence the performance of the fascia is materials used and properties such as density, young's modulus, poisson's ratio etc.

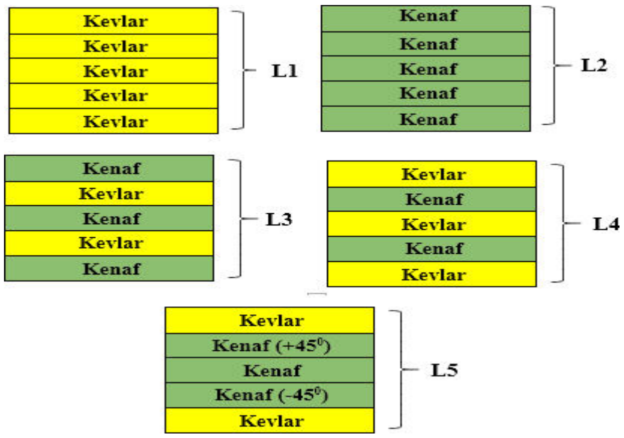


Fig. 11: Stacking Sequence

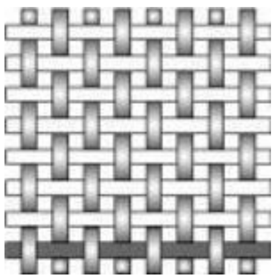
Material properties used in the development of Laminate:

Property	Kevlar 49	Kenaf
Density (g.cm^{-3})	1.44	1.4
Young's Modulus (GPa)	11.7	5.65
Poisson's ratio	0.33	0.31
Elongation (%)	2.8	1.6

2.3 DIFFERENCE BETWEEN PLAIN AND TWILL WEAVE

➢ Plain Weave

Each fiber passes alternately under and over each fiber. The fabric is symmetrical, with good stability and reasonable porosity. However, it is the most difficult of the weaves to drape, and the high level of fiber crimp imparts relatively low wear property compared with the other weave styles.



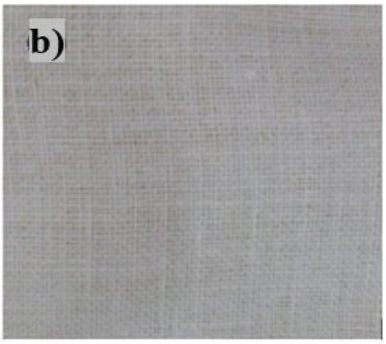
Plain weave Pattern

Plain weave Kevlar fabric

Fig. 12: Kevlar material used in laminate

➢ Twill Weave

One or more fibers alternately weave over and under two or more weft fibers in a regular repeated manner. This produces the visual effect of a straight or broken diagonal 'rib' to the fabric. Superior wet out and drape is seen in the twill weave over the plain weave with only a small reduction in stability. With reduced crimp, the fabric also has a smoother surface and slightly higher wear property.



Twill weave Pattern **Twill weave Kenaf fabric**

Fig. 13: Kenaf material used in laminate

2.4 METHODOLOGY

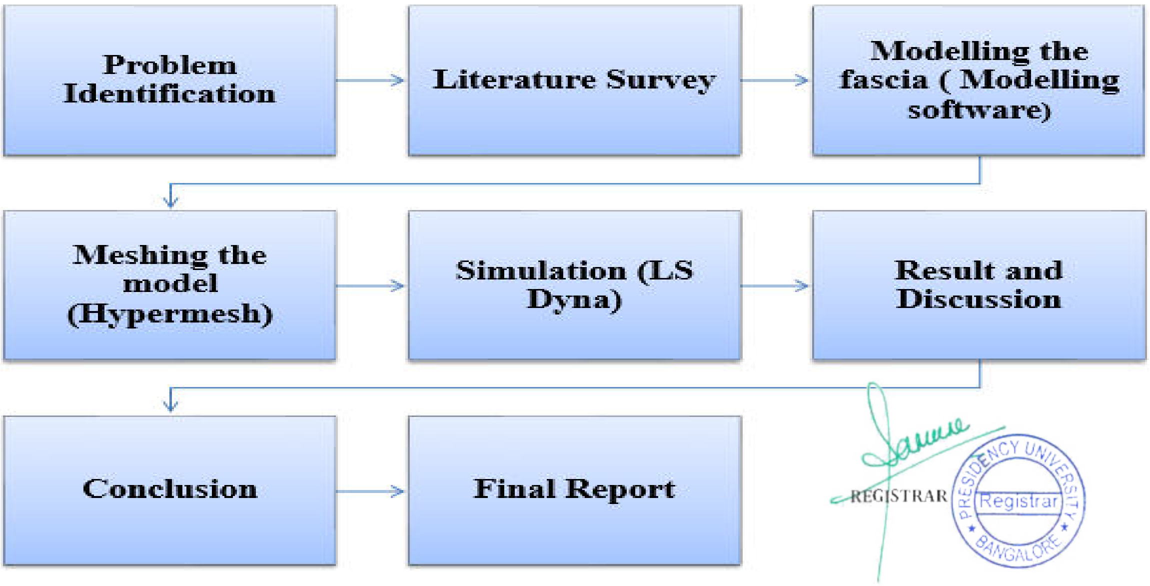


Fig. 14: Block diagram of the entire project

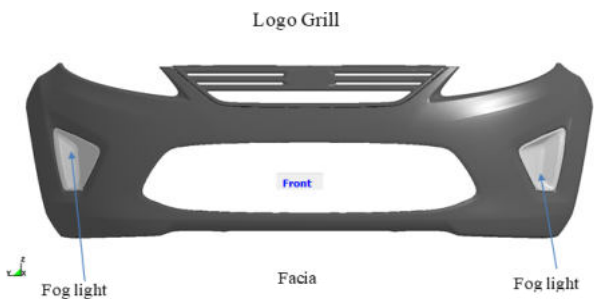
We would analyse the various components of the fascia device as individual sections based on the above work. We will study the whole system as a unit in this project. The concept includes all of the system's components, and we will investigate the impact of the bumper beam and its components by comparing three different materials to the bumper shell, which is made of ABS plastic. The whole structure slammed into a solid wall. The first aspect of the issue is the bumper mechanism, which is a rigid body connected to the device that will create the impact of the bumper. The vehicle's entire mass is located, and the reference point is the vehicle's centre of mass.

Crashworthiness is the study of developing vehicle structures to absorb energy by balanced vehicle deformation while retaining enough room so that residual crash energy can be handled by restraint systems to reduce crash loads transition to the vehicle occupants.

We created a new front car bumper using the CATIA V5 R20 software, finely meshing it with the HYPER MESH software, and then assembling the meshed model. Imported onto the LS-DYNA for analysis through including the data, static analysis, and effect analysis Boundary constraints that correlate.

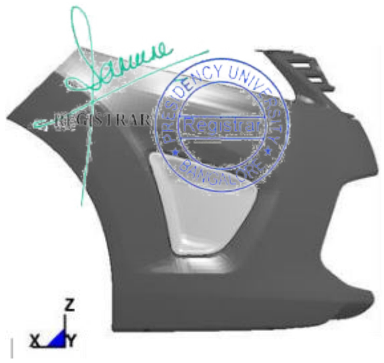
2.5 MODEL DESCRIPTION

CATIA V5 R20 software is used to design the car fascia according to the dimensions. The holes are designed into the fascia to endure the drag forces that occur while the vehicle is moving. The CAD model of fascia seen in Figure.



FASCIA Front view

FASCIA Top view



FASCIA Side view

Fig. 15: 3D Model of the fascia

2.6 FINITE ELEMENT MODEL

Car fascia is taken which is designed in the CATIA V5 R20. The file then exported to Hypermesh software for meshing purpose. To import the file in hypermesh the file should be in .hm format. The meshed file in hypermesh window in shown the Figure. The basic idea behind FEA is to perform measurements at a small number of points and then extrapolate the effects through the whole domain (Surface or volume). Every continuous object has an infinite number of degrees of freedom, so solving the problem in this style is impossible. With the aid of discretization, or meshing, the Finite Element Method reduces degrees of freedom from infinite to finite (nodes and elements).

The imported fascia is not specifically meshed. First, a mid surface is removed since element thickness (specified by the user) is given half in the +Z axis (element top) and half in the -Z axis (element bottom) mathematically (element bottom). As a result, extracting the mid surface and generating nodes and elements on the mid surface is required for proper representation of geometry via 2-d mesh. Fascia has a thickness of 2.15 mm. The element size is kept constant during meshing at 4 mm.

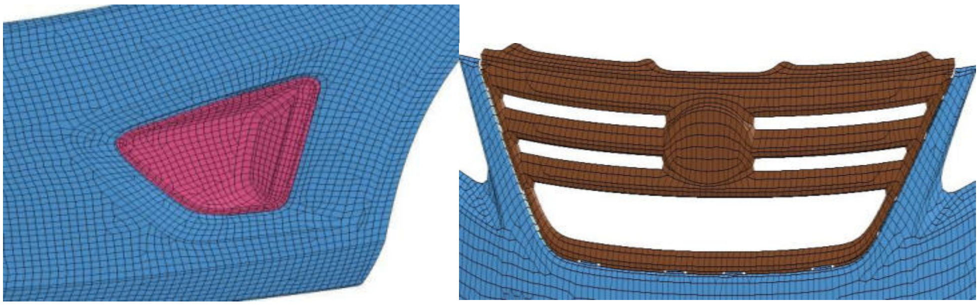


Fig. 16: FASCIA Meshed model

2.7 FINITE ELEMENT ANALYSIS

To simulate the impact experiments and achieve computational results, a finite element model Fascia bumper systems was considered and solved using a transient explicit dynamic analysis. The components that need to be simulated are generated in this section, and properties and boundary conditions are added. Impact model, Fascia, Mass Point, and Rigid Connectors are four components that we produce in our work.

The impact model is made by connecting four nodes that mark the wall's four corners. After constructing the wall, a mass point is established at the car's center of gravity. It was developed because evaluating the whole finite element model of a car takes a long time and is not cost effective. Instead of contemplating the whole car model, a mass point equal to the vehicle's weight is produced. Our research focuses primarily on the frontal fascia of automobiles. Instead of contemplating the whole vehicle model, a mass point equal to the car weight is produced at the car's center of gravity. Without the fascia, the car's mass is determined to be 1623 kg. The car's weight varies depending on the materials used.

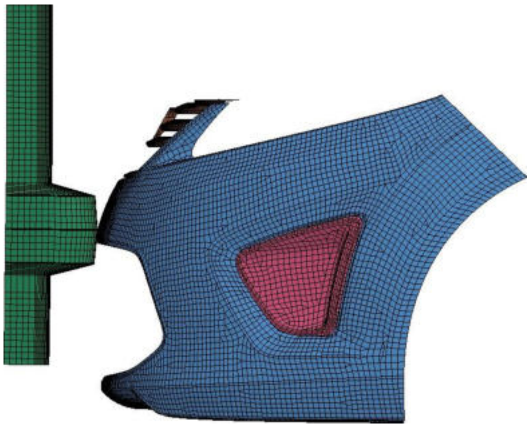


Fig. 17: Finite element model with impactor

CHAPTER 3: RESULTS AND DISCUSSION

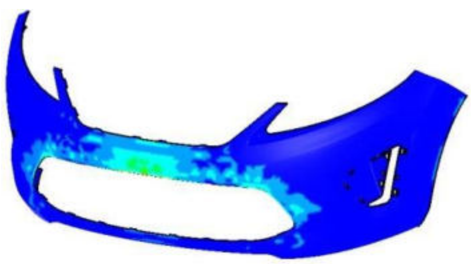
The aim of the approach discussed in this article was to provide a tool for structural robustness in the passenger vehicle production process. Vehicle architecture can achieve stable structural stability and energy absorption by identifying factors that influence vehicle response in car impact before physical prototypes are designed.

Car fascia considered for analyzing the energy absorption characteristics. Since effect events nearly always result in energy loss, linear momentum is preserved while kinetic energy is not conserved. For kinetic energy subtraction, this energy dissipated in the collision can be estimated after and before impact. Because of elastic and plastic deformations in the bumper structure, a part of the system's kinetic energy is converted into strain energy.

Different materials with 5 Different laminates were used in an effort to create a new fascia. However, only a few important findings that demonstrate extraordinary effects are discussed in this article.

L1 Composite:

Conservation of energy, Energy can neither be created nor be destroyed, but it can be converted from one form of energy to other form. Applying the same principle to crash analysis, the amount of kinetic energy lost during impact must be converted to other forms of energy such as internal energy.



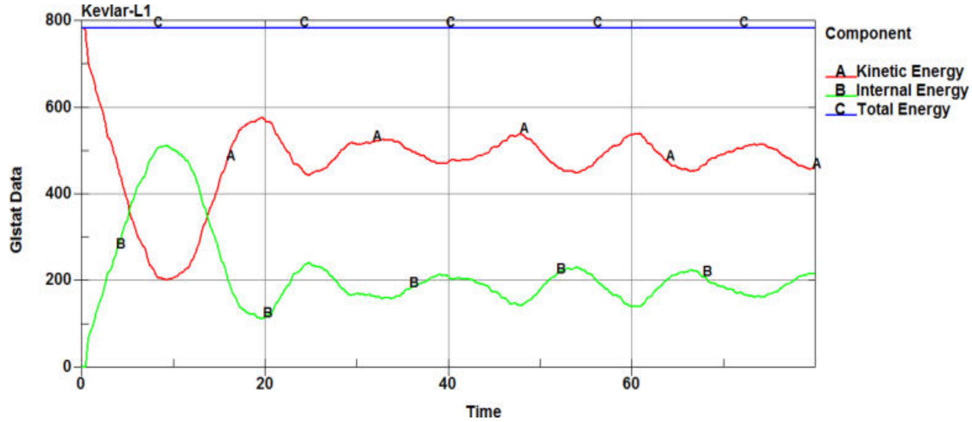
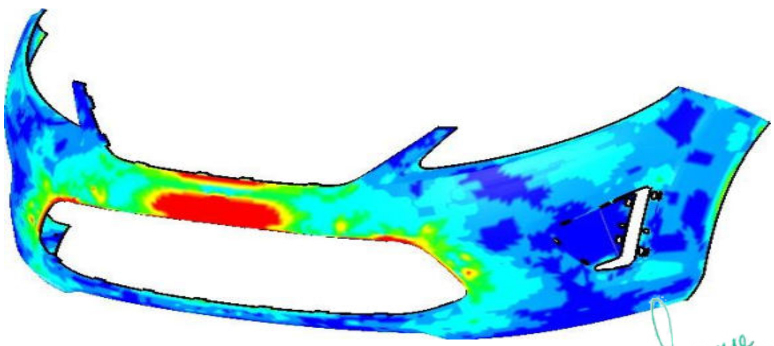
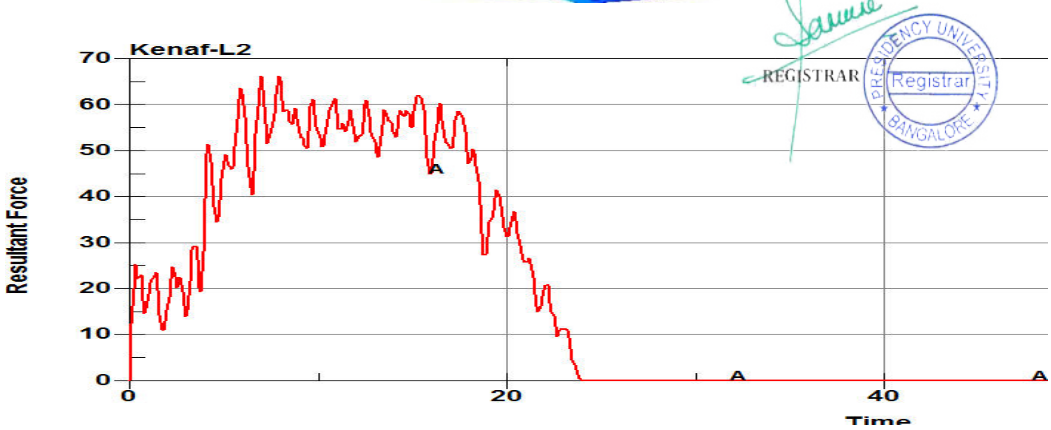


Fig. 18: Laminate L1 crash test results

From Figure 1 it is clear that absorption of internal energy of L1 laminate combination is composed of composite material Kevlar and laminate thickness of L1 is 5mm. Which absorbs the internal energy of (502 J) during frontal collision of bumper facia. The deformation and delamination was measured at the nodes located in the middle of the facia horizontally. Analysis simulation showed that max stress and strain occurred at the center region of the bumper beam as shown in Figure 1. This is because this region will come into contact first and gradually deform. The Maximum force absorbed by Kevlar material is 190 N. Hence the L1 Composite resist maximum impact force and deformation.

L2 Composite:





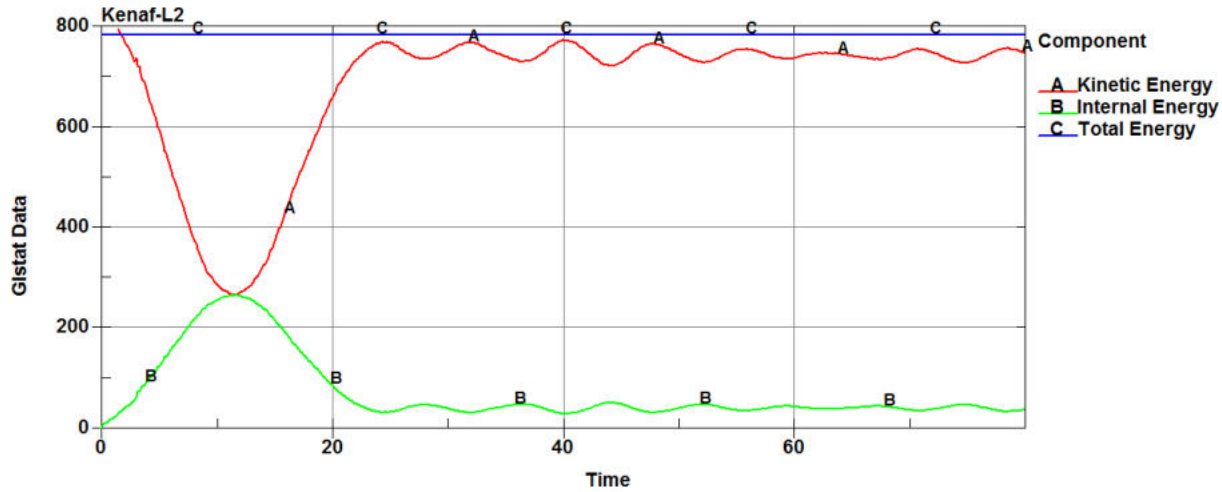
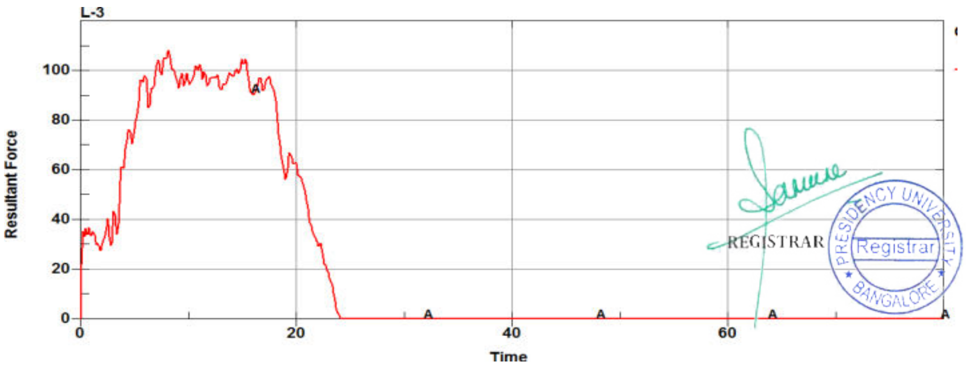


Fig. 19: Laminate L2 crash test results

The L2 Laminates are made up of composite material Kenaf of thickness 5 mm. Figure 2 Clearly shows the energy absorption curve indicates the lowest internal energy of 250.2 J (at t = 10 S) during frontal impact collision test. The maximum deformation and delamination occurs and matrix fibres are behaves differently at center point of contact and also the maximum stress and strain are developed when compared to L1 Composite. The graph also showcases that the maximum deflection increases. The study of bumper forces also shows that the maximum force is around 65 N which is less than L1 Laminate. From above results it can be concluding that the L1 Laminate having more energy absorbing composite and it is more reliable when compare to L2 composite fascia.

L3 Composite:



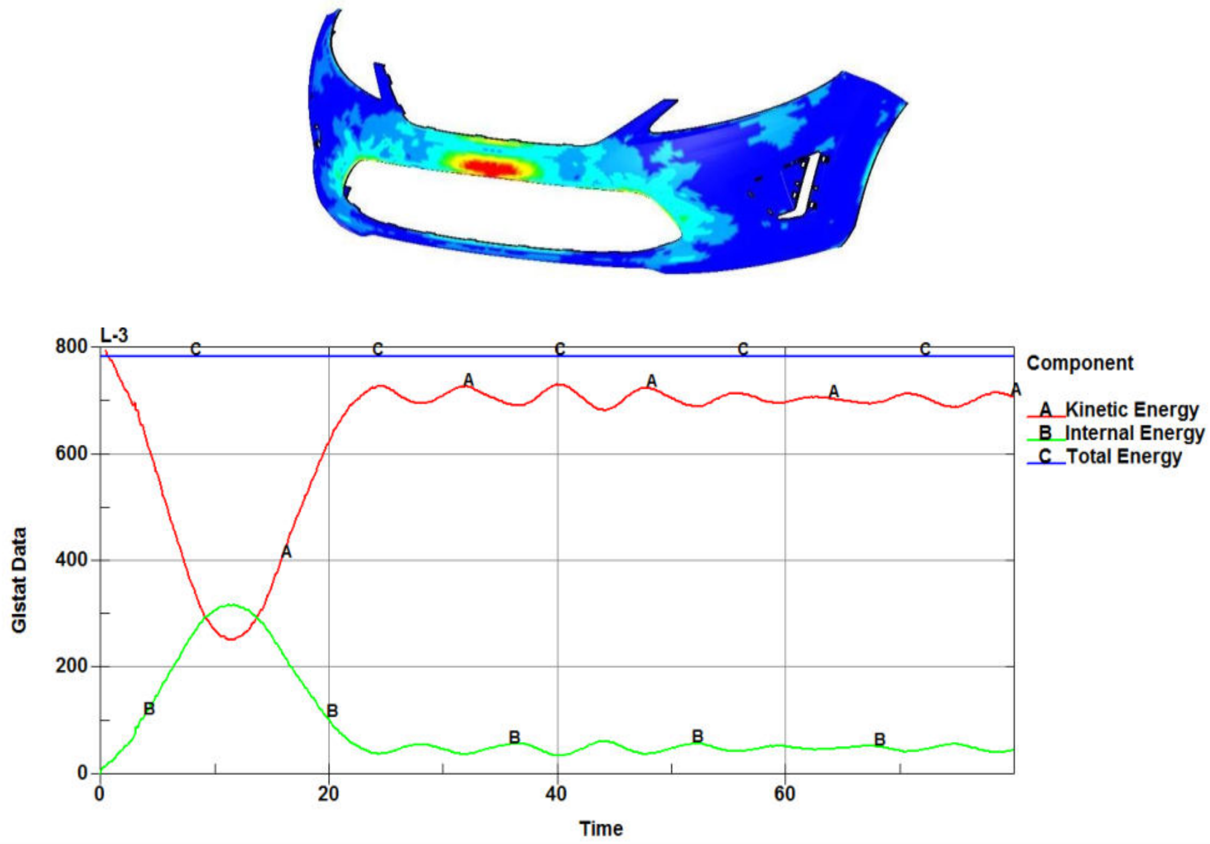
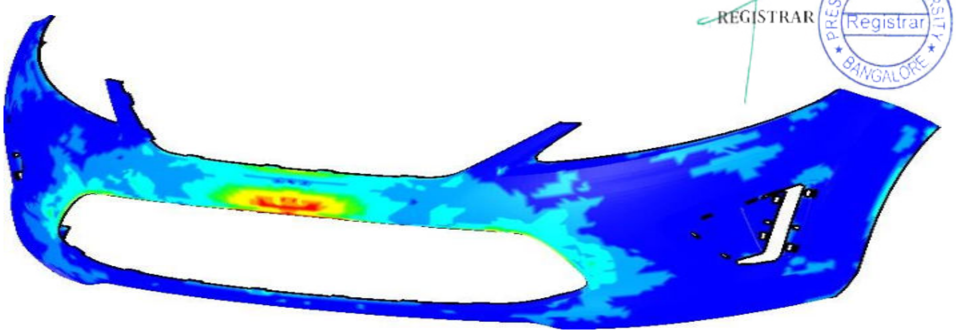


Fig. 20: Laminate L3 crash test results

Figure 3 results are obtained from combination of Kevlar and Kenaf fabrics in this composite, percentage of kenaf fabric composite is more when compared to Kevlar fabrics of laminate thickness 5 mm. The internal energy absorbs around 300J during frontal impact collision. The deformation and delamination values are high and also stresses are more when compared to L1 Laminates. The study of fascia impact force in L3 laminate is 110 N which is less when compared to L1 Laminate. The results which obtained from combination of Kevlar and Kenaf fabrics is better than L2 laminates, i.e. only Kenaf materials.

<u>L4 Composite:</u>



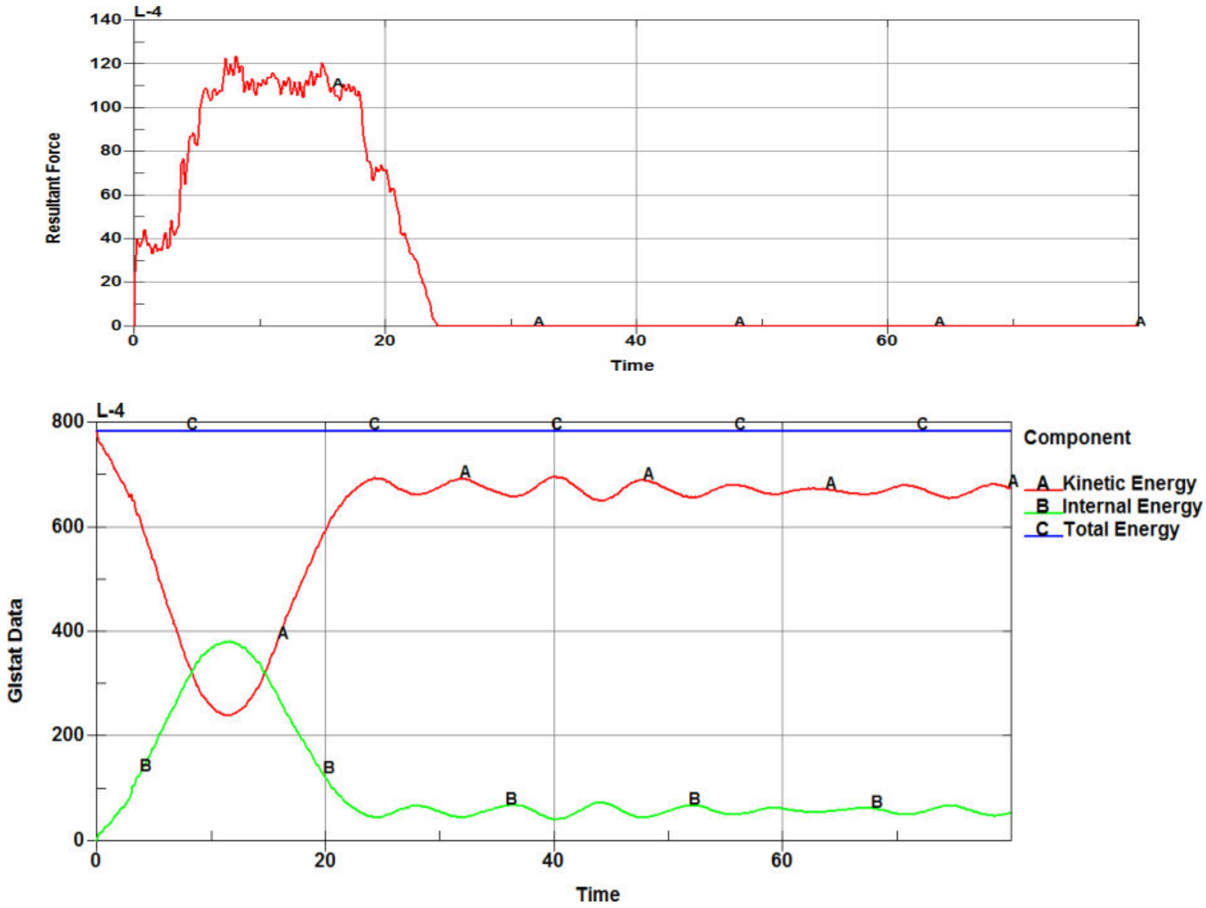


Fig. 21: Laminate L1 crash test results

Laminate L4 represents the composite of Kevlar and Kenaf fabrics. Where Kevlar fabric percentage is more when compared to Kenaf fabric in a combination of L4 Laminate of 5mm thickness. And the results show the internal energy absorbs is of 385.2 J which is having more energy absorbing capacity then L2 and L3 laminates. Thus the deformation and delamination of materials are found to be less when compared to L2 and L3. The study of fascia impact force is 120 N in L4 laminate. Hence proved that Kevlar fabric absorbs more energy when compared to Kenaf fabrics.

L5 Composite

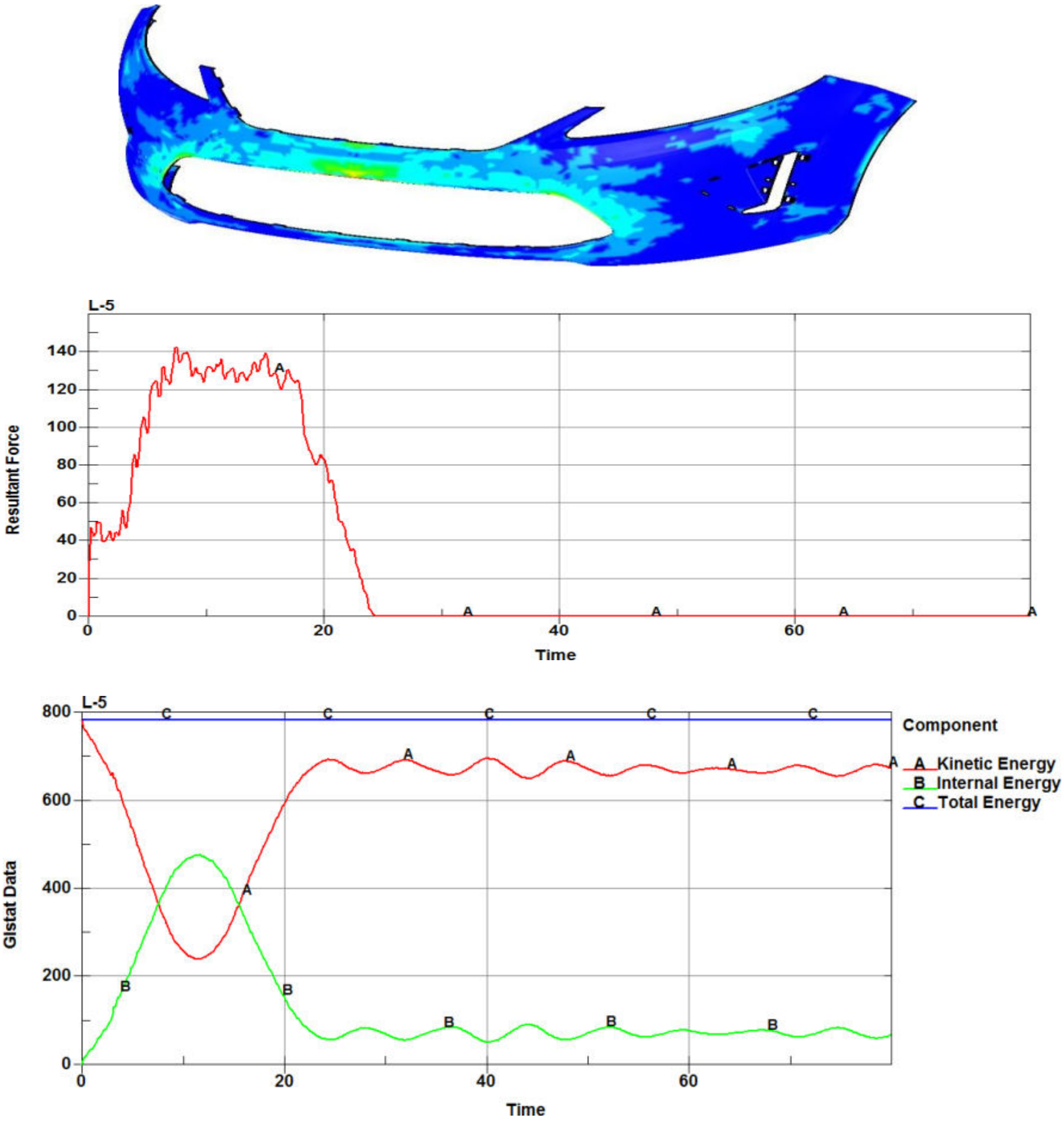


Fig. 22: Laminate L5 crash test results

Figure 5 represents the L5 laminate, composed of Kevlar and Kenaf fabrics, where Kenaf fabric percentage is more of having same thickness as of L1 to L4 composite, but it includes Kenaf orientation of fabrics. The internal energy absorbs 490.2 J, when compared L2, L3 and L4. L5 Shows high energy absorbing capacity and the deformation delamination are very less when compared to above mentioned laminates. L5 study shows sustain more impact forces in hybrid combination. Since in Hybrid combination (Kevlar + Kenaf) is more reliable and sustainable compare to all laminates and impact forces is 140N.

Table 1.3: Results of low speed impact.

Sl.no	Material	Thickness	Impact Energy (J)	Impact Force (N)
1	Laminate 1	5 mm	502	190
2	Laminate 2	5mm	250.2	65
3	Laminate 3	5 mm	300	110
4	Laminate 4	5 mm	385.2	120
5	Laminate 5	5 mm	490.2	140

CHAPTER 4: CONCLUSION

CONCLUSION

In this study, a fascia bumper was investigated for low velocity effect in accordance with industry guidelines. During a collision, the car fascia is the first component to be affected and consumes energy. If the fascia is made of appropriate materials, it retains a significant amount of energy during a collision and protects the occupants. In our work, we used Kevlar and Kenaf composite as fascia materials

The designer should use the formal design approach to help them accomplish their objectives. The importance of conceptual design in construction cannot be overstated. since it is part of the background work layout of the bumper fascia The Methodical The designer should use experimental architecture to in the final design, provide a high-quality design tools for 3-D solid modeling, such as Pro/Engineer has been used a lot in the past The stages of conceptual design and detail design.

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A project Report on

"Wear Studies on Ceramic- Metal Composite Coating"

Submitted in partial fulfilment of the requirement of Bachelor of Technology for the University Project/UP-2

in

Mechanical Engineering

Submitted by

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CERTIFICATE

Certified that, the project work entitled, **“Wear Studies on Ceramic- Metal Composite Coating”** carried out by Mr. Rohith Prajwal (ID 20171MEC0180), Mr. ShivaKumar M R (ID 20171MEC0207), Mr. Srinivas G N (ID 20171MEC0215), MR. Hanumantharaya D (ID 20181LME0037) and Mr. Akash Shetty (ID 20181LME0038), Bonafide students of Presidency University, in partial fulfillment for the award of Bachelor **of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Dr. Sachidananda K B
Supervisor

Dr. S Ramesh S
Prof. and Head

End Term Examination Examiners | **Signature with date**

1.Mr.Basavaraj Devakki

2.Mr.Sandeep G M

DECLARATION

We, the students of eight semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, **"Wear Studies on Ceramic- Metal Composite Coating"** has been successfully completed under the supervision of Dr. Sachidananda K B, Assistant professor, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:

Team members	ID Numbers	Signature of Students
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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, Dr. Sachidananda K B and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank Dr. Ramesh S, Professor and Head Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator Dr. Ramesh S P who gave us the opportunity to do this project work.

At the same time, we express our deepest thanks to Central Manufacturing Technology Institute for giving us our test results despite lockdown being extended.

Lastly, we would like to thank our family and friends.

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ABSTRACT

Plasma sprayed ceramics coatings are widely used for structural components where high wear and corrosion resistance with thermal insulation are required. The coating properties rely upon the material used, plasma processing parameters and the working condition. Parameter interdependencies, correlations and individual impact on coating characteristics controls the plasma spraying process. However, plasma-sprayed coatings built up from the successively immediate solidification of the liquid or partially melted droplets onto target substrate typically present weak interface between splats and irregular reticula of microcracks and pores running through it. In addition, these ceramic coatings are also vulnerable to thermal fatigue and delamination under mechanical load for its intrinsic brittleness. In recent years, numerous studies have been conducted to improve the microstructure and resulting performance of plasma-sprayed ceramic coatings by incorporating metallic second phases into ceramic matrices, plasma-sprayed nanostructured TiO2–Al composite coatings were prepared, and the results obtained from experimental work showed that the Al addition effectively improved the deposition efficiency and mechanical properties of coatings including toughness and wear resistance. Therefore, it is very important to elucidate the wear behaviour of structures with ceramic coatings. Air Plasma spray process is used to deposit Alumina, Aluminium composite coating on a AISI 304 stainless steel substrates under for range of composition.

The phase, microstructure, sliding wear rates, and micro hardness of the Alumina coatings will be investigated. The coating behaviour and quality depends upon inter-particle bonding and coating morphology, the morphology of coatings is investigated by using Scanning Electron Microscopy (SEM). Phase composition of powders and as-sprayed coatings will be investigated by X-ray diffraction (XRD), Measurement of porosity is made using the image analysis technique, Hardness measurement is done using Vickers microhardness tester. Pin-on-disc tribometer is used in order to understand the effect of coating on wear Behaviour, the objective of this study is to investigate the influence of Aluminium (Al) addition on wear behaviour of plasma sprayed Alumina, Al Composite coatings.

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ABBREVIATIONS

XRD	**:**	**X-RAY DIFFRACTION**
SEM	**:**	**SCANNING ELECTRON MICROSCOPE**
COC	**:**	**COMBINATION OF COATING**
Al	**:**	**ALUMINIUM METALIC POWDER**
AL_2O_3	**:**	**ALUMINA (CERAMIC MATERIAL)**
APS	**:**	**ATMOSPHERIC PLASMA SPRAYING**

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Thermal spraying process has been used successfully to produce a range of protective coatings for wear, erosion and heat resistance, as well as restoration of worn parts. Especially, oxide ceramics such as Al_2O_3 ceramic coatings, having superior hardness, chemical stability and refractory character, are commonly utilized to resist wear by friction and solid particle erosion. The porosity and weak interface adversely affect the wear property and the cracks allow corrosive substance in the environment to attach the protective coating. In addition, these ceramic coatings are also vulnerable to thermal fatigue and delamination under mechanical load for its intrinsic brittleness.

1.2 Types of surface coating methods

Mostly special surface treatments are needed for metal surfaces, especially steels' surfaces, in order to have the desired optimum properties. There are various techniques for surface treatment methods but the most common one is surface coating. Steels require further surface coatings for enhanced corrosion resistance, wear-resistance, and surface hardness. The coating methods differ for different applications. Therefore, the classification of coating methods can be very complicated. However, the most common surface coating techniques can be classified as below list

There are different ways by which a Surface Coatings can be performed. Some of them include:

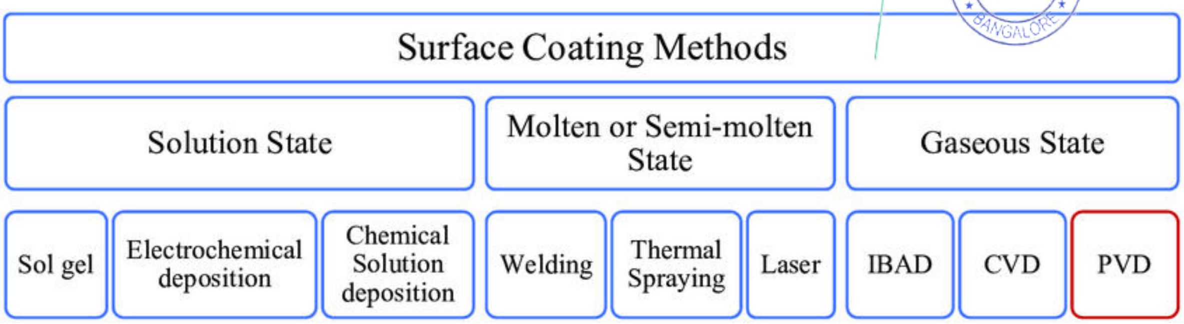

Figure (1) Surface coating methods

1.2.1 TYPES OF THERMAL SPRAY PROCESS

Thermal spraying is an Material processing technique in which the material in a form of finely divided Semi molten or Molten droplets is used to produce coating on the substrate which is kept in front of impinging jet ,in the 1900s, M U. schoop explored that an stream of Metallic particles formed by melting the metal can be used for producing the coating, however ,the thermal spraying technology is elaborated in the early 1970s due to an development of the thermal plasma , the demand has also increased for high wear and temperature resisting materials and coating systems. In 1990s, the thermal spraying has became an standard tool in all sectors for the improvement of surfaces. The material to be coated on the Substrate can be introduced into an heat source in the powder or wire form. Thermal Spraying materials can be Alloys, metallic, polymeric, or ceramic substances. For spraying most commonly used ceramic material are chromia , zirconia, Alumina & alumina/titania , zirconia is used foremost as a thermal transport barrier, and others foremost for the wear resistant coatings. Those materials can be sprayed which will be melted by an heat source employed and is not subject to deterioration during heating.

There are different ways of performing a Thermal Spray. They are:

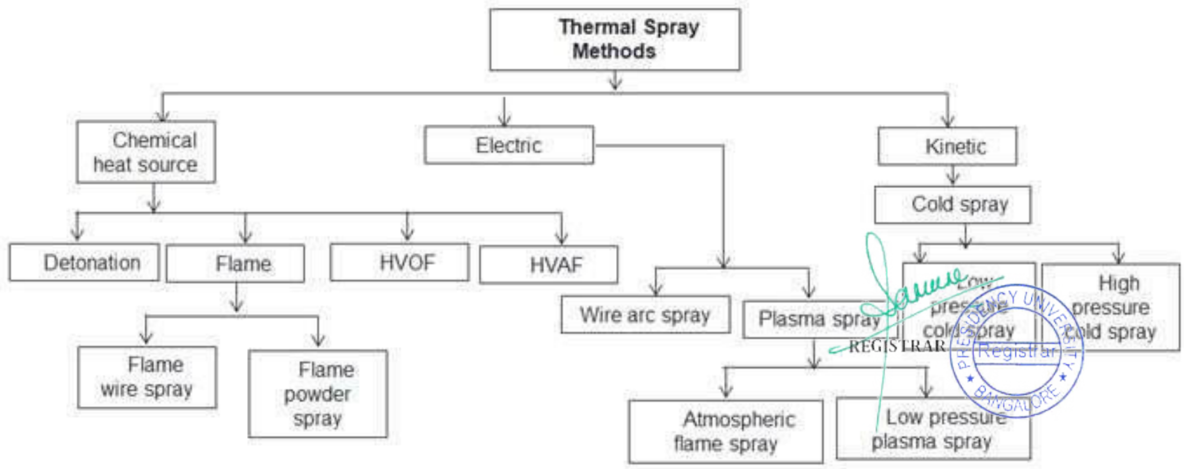

Figure (2) Thermal spray methods

CHAPTER 2

2.1 LITERATURE SURVEY

The surface is most important part of the engineering component, the most component fails because of surface initiated effects. So the surface modification is necessary for the engineering components in order to avoid possible degradation or failure and/or to enhance functional integrity. **N.M. Vaxevanidis** has studied the coating properties in which Alumina is sprayed on the Aluminium and steel substrate using Atmospheric plasma spraying, Spraying is done for the different arc current, Study on the tribological behaviour and the surface integrity of the coatings is done. And the main findings are in case of Aluminium substrate as the arc current increases there is increase in microhardness, the average co-efficient of friction was found uncorrelated with arc current ,average co-efficient of friction was low for the aluminium substrates as compared to steel substrates[1].

Thermal spraying process has been used successfully to produce a range of protective coatings for wear, erosion and heat resistance, as well as restoration of worn parts. Especially, oxide ceramics such as Al_2O_3 ceramic coatings, having superior hardness, chemical stability and refractory character, are commonly utilized to resist wear by friction and solid particle erosion. **Shunyan Tao et al** has studied Microstructure & mechanical properties of Al_2O_3-Al composite coatings deposited by plasma spraying and in this paper the author conducted various tests on Al_2O_3-Al coatings to determine the morphological and mechanical properties. Increases in fracture toughness, strength and wear resistance were effectively improved due to coexistence of metal Al phase and Al_2O_3 ceramic phase[2].

Among the bulk metallic glasses (BMGs) developed in many different alloy systems, Fe-based amorphous alloys have drawn great attention due to their unique physical and chemical properties associated with the amorphous phase and the relatively low cost of iron. Compared with traditional crystalline metallic materials, Fe-based amorphous alloys exhibit high strength, toughness and hardness, and superior corrosion resistance, attributed to their disordered structures as well as the chemical homogeneity. **G.Y.Koga et al** has studied Micrsotructure and wear behaviour of Fe-based amorphous HVOF Coatings produced from commercial precurors and in this paper the author used $Fe_{60}Cr_5Nb_sB_{24}$(at%) coatings of thickness 280µm through HVOF onto API 5L X80 steel substrate and determined wear resistance[3].

Chemical and dimensional stability, mechanical strength, toughness, and Young's modulus similar to that of stainless steel alloys make zirconia an excellent ceramic biomaterial for use as a femoral head [8]. In addition, zirconia has also been used as a second phase to improve the bonding strength and fracture toughness of HA coatings. **Guocheng Wang et al** has studied Microstructure , bioactivity and osteblast behavior of monoclinic zirconia coating with nanostructured surface and in this paper the author prepared monoclinic zirconia coating with a nanostructural surface on Ti–6Al–4V substrate by an atmospheric plasma-spraying technique. to determine the microstructure and composition, mechanical and biological properties and were investigated to explore potential application as a bioactive coating on bone implants[4].

The widely used atmospheric plasma spraying systems commonly contain the plasma generation unit, the powder materials supply unit and other auxiliary units. The plasma generation unit includes the plasma torch, power supply device and water-cooling device. The plasma torch that often uses a type of direct current non-transferred arc plasma torch is one of the crucial parts in the thermal spraying technology. **Sen-Hui Liu et al** has studied Microstructural evolution of alumina coatings by a novel long laminar plasma spraying method and A super long and stable laminar plasma jet was used in the atmospheric plasma spray process in this work. Microstructures evolution and properties of alumina coatings that were obtained using a long spraying distance ranging from 200mm to 350mm in an atmospheric environment were studied in this work[5].

Gas-turbine engines have played a key role in revolutionising the evolution of the transportation, energy and defence sectors over the course of the last few decades by gradually enhancing the thermal barrier coating (TBC) system properties and pushing its operational threshold limits forward. Although these systems are engineered to provide efficient thermal insulation and enhanced mechanical performance in demanding environments, the cyclic exposure to high temperature oxidising atmospheres results in a continuous degradation process that ultimately leads to failure. **Jaao P. Martins et al** has studied Investigation of the bond coat interface topography effect on lifetime, microstructure and mechanical properties of air plasma sprayed thermal barrier coatings and The effect of bond coat/thermal barrier coating (BC/TBC) interface topography on the lifetime of air-plasma sprayed (APS) TBCs was comprehensively investigated in the present work[6].

The thermal conductivity of ZrB2 is lower than that of the TiB2 coating, while the resistance to wear of TiB2 is better than that of the ZrB2 coating. Most importantly, the addition of TiB2 and ZrB2 in the same coating can significantly improve its wear resistance. Hence, the TiB2–ZrB2 ceramic composite coatings were the best choice to improve the quality of the coating blade. However, the pure ceramic is too brittle, so it is necessary to add a ductile metal (NiCr) with a good wettability to form a cermet composite material in order to better meet the use conditions. Furthermore, plasma spraying is especially suitable for ceramic materials with a high melting point because of the higher flame temperature and faster jet speed of the plasma spraying. **Ning Zhang et al** has studied Composition versus wear behavior of air plasma sprayed NiCr-TiBi-ZrB2 composite coating and The performance of the coatings was improved with the increase of the number of ceramic phases, while the hardness and wear resistance of the coating could reach their highest value when the TiB2 and ZrB2 respectively took up 15 wt.% of the total mass of the powder[7].

Wide range of metallic substrates can be protected with NiCrSiBC alloys with using a variety of depositing techniques. Therefore, it is imperative to understanding the relationship between the microstructure and performance of coating, regardless of the deposition technique. Research encompassing NiCrSiBC alloys hardfaced coatings carried out to date have used dissimilar coating/substrate materials combinations, which hinder comparisons on the impact of the microstructure on properties/performance. Considering that microstructure depends on the solidification conditions, a comparative analysis is required to gain a comprehensive understanding of its influence on coating performance. The present work contributes to build the relationships between Colmonoy6® coating microstructure and wear performance. Changes in the solidification conditions were induced by two hardfacing techniques, PTA (Plasma Transferred Arc), HPDL (High Power Diode Laser), allowing to explore the microstructure changes and corresponding abrasive wear performance. **Leandro J. da silva et al** has studied the Effect of microstructure on wear performance of NiCrSiBC coatings and the microstructures of NiCrSiBC coatings were evaluated using EDX, XRD, SEM techniques and hardness measurements. Wear performance was assessed by micro-abrasive wear tests in which normal load, sliding distance and ball sliding speed were varied. Higher hardness coatings with finer microstructure exhibited lower abrasive wear resistance than the coatings with coarser microstructure[8].

Atmospheric plasma spraying (APS) is traditionally the most common spray process for the preparation of ceramic coatings due to their high melting points. These coatings have excellent wear, corrosion and heat resistances. Especially, Al_2O_3 coatings as the representative of oxide ceramic coatings exhibit good mechanical and anti-wear performances. It has been recognized that sintered Al_2O_3 ceramics and thermally sprayed Al_2O_3 coatings possess different phase compositions, even though all commonly used feedstock powders are composed of α-Al_2O_3 (corundum). **Kai Yang et al has** studied Microstructure and mechanical properties of Al_2O_3–Cr_2O_3 composite coatings produced by atmospheric plasma spraying and found Grain refining and solid solution strengthening facilitate the mechanical property enhancement of Al_2O_3–Cr_2O_3 composite coatings[9].

Thermal barrier coatings (TBCs) are widely used in the gas turbine to improve its durability and energy efficiency. Yttria stabilized zirconia (YSZ) ceramic as the top coat material has been employed for decades due to its attractive properties including high fracture toughness, low thermal conductivity and high thermal expansion coefficient. However, the durability and reliability of atmosphere plasma sprayed (APS) YSZ TBCs are restricted for the tendency of fracture and premature spallation due to the formation and growth of thermally grown oxide (TGO) in service. **Ke He et al** has studied Microstructure and mechanical properties of plasma sprayed Al_2O_3-YSZ composite coatings and found Fracture toughness of Al_2O_3-YSZ composite coatings is higher than the YSZ one, and it increases firstly and then decreases with alumina addition varying from 10wt% to 55wt%. The fracture toughness of coatings is related to the amount of heterogeneous specific interface between Al_2O_3 and YSZ splats and the high microcracks density in the composite coatings[10].

Zirconia is an interesting material in fundamental studies as well as application-oriented research on account of its remarkable properties such as good chemical and dimensional stability, high melting point, low thermal conductivity and high wear resistance. It has been widely used in industries as engine components, cutting tools, thermal barrier or wear-resistance coatings and biomedical implants. However, the low thermal conductivity of zirconia much limits its application as tribomaterials. Due to the low thermal conductivity, frictional heating can cause a high contact temperature and therefore thermally induced stress occurs in the frictional layer. In order to improve the wear resistance of zirconia, efforts should focus on the improvements of its thermal conductivity and mechanical properties, e.g. toughness and stiffness. Among the methods for increasing the wear resistance of zirconia, to incorporate a second phase is an effective way. **Bo Liang et al** has studied Friction and wear behavior of ZrO_2–Al_2O_3 composite coatings deposited by air plasma spraying: Correlation with physical and mechanical properties and found Interestingly, the increase in nano-Al_2O_3

fraction (from 15% to 30%) seems to avoid or at least postpone the occurrence of the interfacial fatigue. The tribological behaviors of the two coatings were correlated to their physical and mechanical properties[11].

Oxide ceramics show high strength, hardness and high resistance to wear, as well as good resistance to high temperatures and oxidation. Plasma spraying is developed as a surface coating technique for depositing ceramics due to their high melting point. Cr2O3 and Al2O3 coatings deposited by atmospheric plasma spray (APS) are being used for many applications that require protecting components against wear, corrosion and spallation. **P. Zamani et al** has studied Microstructure, phase composition and mechanical properties of plasma sprayed Al2O3, Cr2O3 and Cr2O3-Al2O3 composite coatings and found Alumina & rich-alumina coatings showed denser microstructure and higher flattening degree of splats as well as lower surface roughness. Bonding strength of individual Cr2O3 and Al2O3 coatings was higher than composite one. Vickers microhardness increased with addition of Cr2O3. Alumina improved spray ability and crack propagation resistant of chromia[12].

Plasma sprayed alumina–titania composite coatings have advantages over pure alumina coatings because titania has a lower melting point and effectively binds alumina grains and reduces their melting point resulting in high density and better performance coatings than pure Al2O3 coatings. Alumina–titania coatings have been applied for the elements in a solar-dynamic space power system require durable, high-emittance surfaces on a number of critical components, such as heat receiver interior surfaces and parasitic load radiator (PLR) element. **M.F. Morks et al** The role of nozzle diameter on the microstructure and abrasion wear resistance of plasma sprayed Al2O3/TiO2 composite coatings Sprayed coatings with a smaller nozzle showed high hardness, low porosity and high abrasion resistance. Moreover, the Al2O3/TiO2 composite coatings sprayed with the Bay State Plasma system showed better mechanical properties than Al2O3/TiO2 coatings sprayed by a SG-series gun[13].

Iron-aluminium (FeAl) intermetallic compounds have been widely studied for their potential applications as high temperature bulk materials, due to their relatively low density and low cost as well as excellent anti-oxidation and anti-corrosion properties compared with Fe-based and Ni-based superalloys. In order to use their excellent properties at elevated temperature in the form of a coating, several thermal spraying processes, such as plasma spraying , high-velocity oxy-fuel (HVOF), wire-arc spraying, and cold spraying have been used to deposit FeAl alloys onto carbon steels and stainless steels. **Bo Song et al** Microstructure and wear resistance of

$FeAl/Al_2O_3$ intermetallic composite coating prepared by atmospheric plasma spraying and found that tribological results show that plasma-sprayed $FeAl/Al_2O_3$ composite coatings have excellent wear resistance under dry sliding wear test conditions due to the combination of the high yield strength of the intermetallic compound FeAl and the high hardness of the Al_2O_3 dispersoids[14].

Zn-Ni alloy coatings have been widely used in a range of industrial applications due to their superior corrosion resistance. These coatings are employed as sacrificial coatings for steel because they preferentially dissolve in corrosive media and result in a surface layer of products with low solubility that slows the corrosion reaction and protects the substrate underneath. **Yang Bai et al** has studied Microstructure and Mechanical Properties of Zn-Ni-Al_2O_3 Composite Coatings and found the presence of Al_2O_3 and Ni increased the wear resistance of the composite coatings, which was higher than that of pure Zn coatings, and the wear mechanism was abrasive and adhesive wear[15].

CHAPTER 3

Objective and Methodology

3.1 Objectives

1. To Coat the Metal-Ceramic composite coating on SS 304 substrate.
2. To study the microstructure and morphology.
3. To study the phase change.
4. To evaluate the effects of addition of Al on the micro hardness of the ceramic coating
5. To evaluate the wear behaviour of the composite coating

3.1 METHODOLOGY

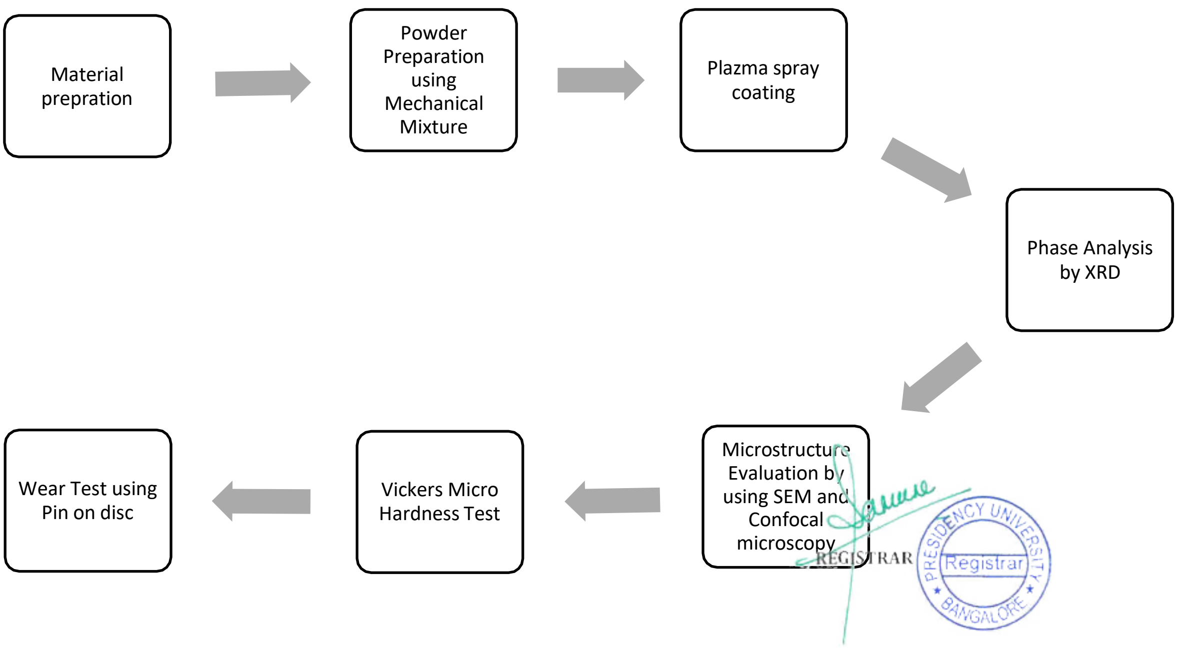

Figure (3) methodology process

For abstract material we chose SS304 stainless steel is a T 300 Series Stainless Steel austenitic. It has a minimum of 18% chromium and 8% nickel, combined with a maximum of 0.08% carbon. It is defined as a Chromium-Nickel austenitic alloy. For coating we choose alumina (al2o3) and aluminium metal powder with a purity of 99.9%.

For coating we choose Plasma spray coatings method plasma spray coating are applied using a high temperature process that involves injecting powdered coating material into a plasma flame. The material is rapidly heated and then accelerated toward the substrate. Once it reaches the surface it begins to cool, forming a hard coating on the substrate. Phase analysis by X-Ray Diffraction, frequently abbreviated as XRD, is a non-destructive test method used to analyze the structure of crystalline materials. XRD analysis, by way of the study of the crystal structure, is used to identify the crystalline phases present in a material and thereby reveal chemical composition information.

Micro struuctural analysis using Scanning Electron Microscopy (SEM) is a test process that scans a sample with an electron beam to produce a magnified image for analysis. The method is also known as SEM analysis and SEM microscopy, and is used very effectively in microanalysis and failure analysis of solid inorganic materials. Electron microscopy is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects.

Micro structural analysis by the confocal microscope uses fluorescence optics. Instead of illuminating the whole sample at once, laser light is focused onto a defined spot at a specific depth within the sample. This leads to the emission of fluorescent light at exactly this point. A pinhole inside the optical pathway cuts off signals that are out of focus, thus allowing only the fluorescence signals from the illuminated spot to enter the light detector.

By scanning the specimen in a raster pattern, images of one single optical plane are created. 3D objects can be visualized by scanning several optical planes and stacking them using a suitable microscopy deconvolution software (z-stack). It is also possible to analyze multicolor immunofluorescence stainings using state-of-the-art confocal microscopes that include several lasers and emission/excitation filters.

Hardness test by Vickers method In the Vickers hardness test, an optical method, the size of indentation (the diagonals) left by the indenter is measured. In contrast, the depth of indentation caused by the indenter is measured in the depth measurement methods.

The wear tests was carried out on a pin-on Disc tribometer under the dry sliding conditions. Before the test the counter body and the specimen are cleaned. The test procedure followed was according to ASTM G99 standard. Rotational speed, wear track diameter and normal load can be varied. The disc is rotating with the help of D.C motor which has speed range of 0-500 rpm with the wear track diameter of 0-160mm. through the pulley string arrangement the load is applied on the pin specimens through dead weights. The system is having maximum load capacity of 500N. in this testing machine the disc is rotated and the pin is kept at perpendicular to the disc.

CHAPTER 4

4.1 MATERIAL SELECTION

We have selected SS304 as our substrate material with a thickness of 2mm. The following are the reason for selecting SS with grade 304:

Corrosion Resistance: - Grade 304 stainless steel is excellent in a wide range of atmospheric environments and many corrosive media. It is subject to pitting and crevice corrosion in warm chloride environments, and to stress corrosion cracking above 60 °C (approximate). Grade 304 is considered to be resistant to potable water up to approximately 200 mg/L chlorides at ambient temperatures, reducing to approximately150 mg/L at 60 °C.

Heat Resistance:- Grade 304 has good oxidation resistance in intermittent service to 870 °C, and in continuous service to 925 °C. Continuous use of 304 in the 425-860 °C range is not recommended if subsequent aqueous corrosion resistance is important. Grade 304L is more resistant to carbide precipitation and can be heated into this temperature range.

Table (1) Typical composition ranges for 304-grade stainless steel

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
304	min. max.	- 0.08	- 2.0	- 0.75	- 0.045	- 0.030	18.0 20.0	-	8.0 10.5	- 0.10
304L	min. max.	- 0.030	- 2.0	- 0.75	- 0.045	- 0.030	18.0 20.0	-	8.0 12.0	- 0.10
304H	min. max.	0.04 0.10	- 2.0	- 0.75	-0.045	- 0.030	18.0 20.0	-	8.0 10.5	-

Table (2) Typical mechanical properties of 304-grade stainless steel

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50 mm) min	Hardness	
				Rockwell B (HR B) max	Brinell (HB) max
304	515	205	40	92	201
304L	485	170	40	92	201
304H	515	205	40	92	201

Table (3) Typical physical properties of 304-grade stainless steel in the annealed condition

Grade	Density (kg/m^3)	Elastic Modulus (GPa)	Mean Coefficient of Thermal Expansion (µm/m/°C)			Thermal Conductivity (W/m.K)		Specific Heat 0-100 °C (J/kg.K)	Electrical Resistivity (nΩ.m)
			0-100 °C	0-315 °C	0-538 °C	at 100 °C	at 500 °C		
304/L/H	8000	193	17.2	17.8	18.4	16.2	21.5	500	720

Plasma Spray Coating is done using Alumina and Aluminium metal powder with a Coating thickness of about 180-200 microns.

Alumina is the most well-known and most commonly used fine ceramic material. It has the same sintered crystal body as sapphire and ruby. It has been used for decades in electrical components for its high electrical insulation and is widely used in mechanical parts for its high strength, and corrosion- and wear-resistance.

Aluminum powder is a light, silvery-white to gray, odourless powder. It is a reactive flammable material. Aluminum powder is a fine granular powder made from Aluminium. The most important property of aluminium powder to undergo a vigorous exothermic reaction when it gets oxidised. Aluminium powder is used as a blasting agent and rocket fuel, as alkyl catalysts in the production of biodegradable detergents.

4.2 PLASMA SPARY COATING

Plasma spraying is one of the thermal spraying processes that utilize a high energy heat source to melt and to accelerate fine particles onto a prepared surface. Upon impact, these molten particles (‘droplets’) cool down and solidify instantly by heat transfer to the underlying substrate and therefore form, by accumulation, a coating consisting of lamellae. The plasma is created by striking an electric arc between the nozzle and the electrode inside the plasma gun. The plasma jet then emerges from the nozzle. Powder particles are injected into this jet where they soften and then strike the surface at high velocity to produce a strongly adherent coating.

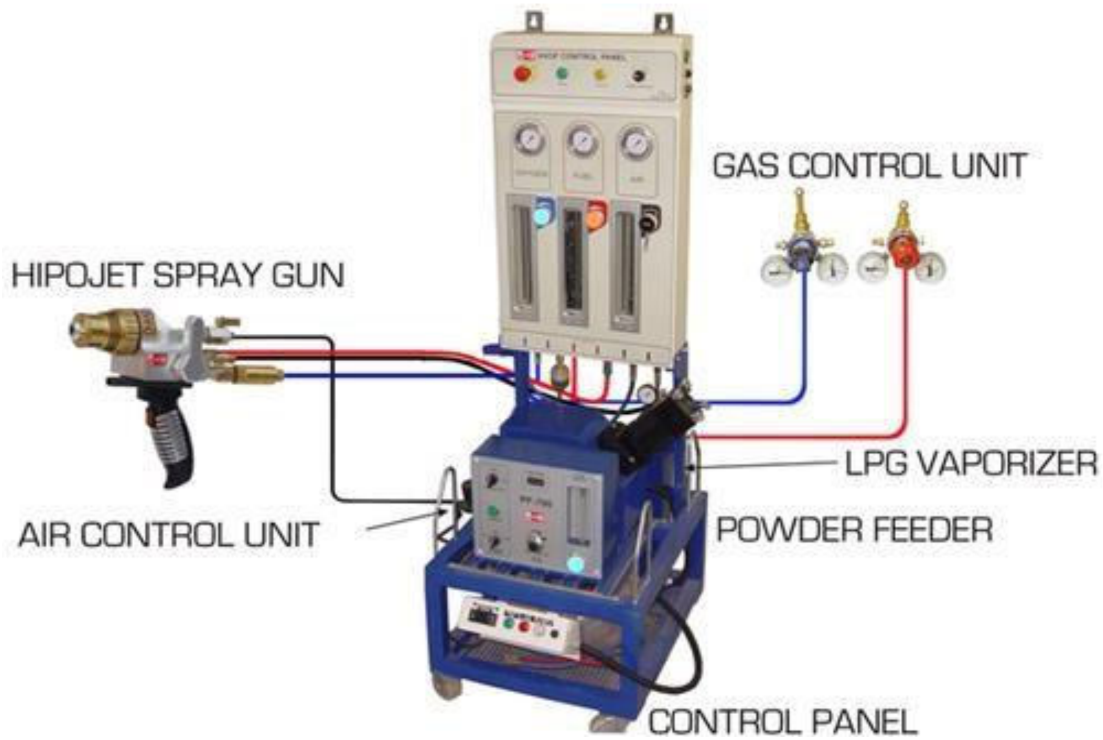

Figure (4) A sample image thermal spray equipment

Figure (5) SS304 without coat pin samples

Figure (6) Coated pin samples with variation of 3%, 6% & 9% of Al

4.3 X-RAY DIFFRACTION

X-Ray Diffraction XRD is a non-destructive test method & a technique used in materials science to determine the crystallographic structure of a material. XRD works by irradiating a material with incident X-rays and then measuring the intensities and scattering angles of the X-rays that leave the material.

XRD Benefits and Applications

1. Identify crystalline phases and orientation
2. Determine structural properties:
   - Lattice parameters
   - Strain
   - Grain size
   - Epitaxy
   - Phase composition
   - Preferred orientation
3. Measure thickness of thin films and multi-layers
4. Determine atomic arrangement

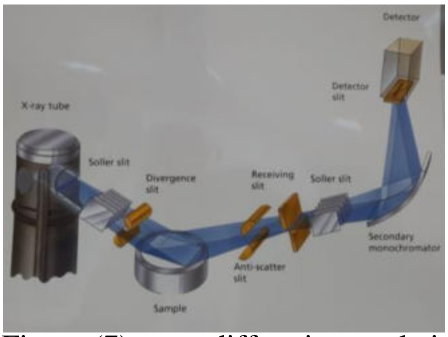

Figure (7) x ray diffraction angle image

Figure (9) XRD testing Machine Image at BMS

Figure (8) powder testing equipment

4.4 CONFOCAL MICROSCOPE

The confocal microscope uses fluorescence optics. Instead of illuminating the whole sample at once, laser light is focused onto a defined spot at a specific depth within the sample. This leads to the emission of fluorescent light at exactly this point. A pinhole inside the optical pathway cuts off signals that are out of focus, thus allowing only the fluorescence signals from the illuminated spot to enter the light detector.

By scanning the specimen in a raster pattern, images of one single optical plane are created. 3D objects can be visualized by scanning several optical planes and stacking them using a suitable microscopy deconvolution software (z-stack). It is also possible to analyze multicolor immunofluorescence stainings using state-of-the-art confocal microscopes that include several lasers and emission/excitation filters.

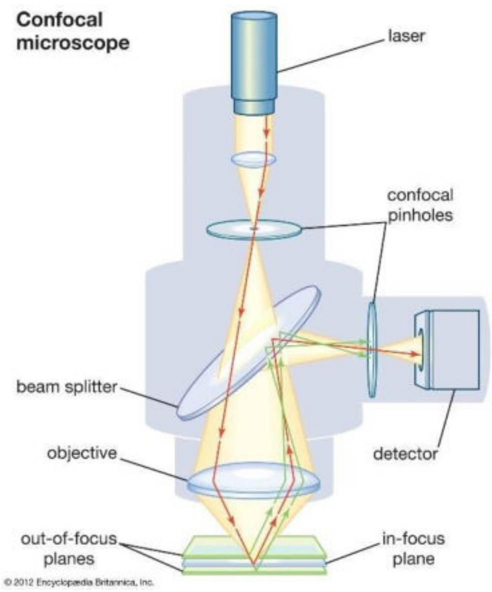

Figure (10) Image of Confocal Microscope

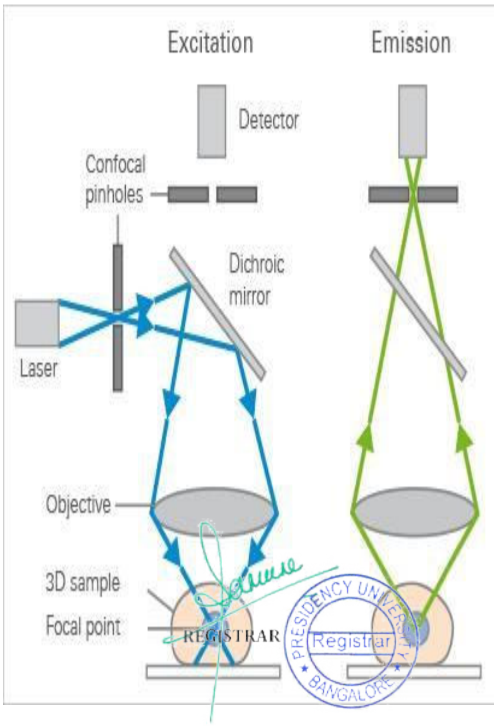

Figure (11) Image of Rays Striking and Reflecting back

4.5 SCANNING ELECTRON MICROSCOPE

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image. In the most common SEM mode, secondary electrons emitted by atoms excited by the electron beam are detected using a secondary electron detector.

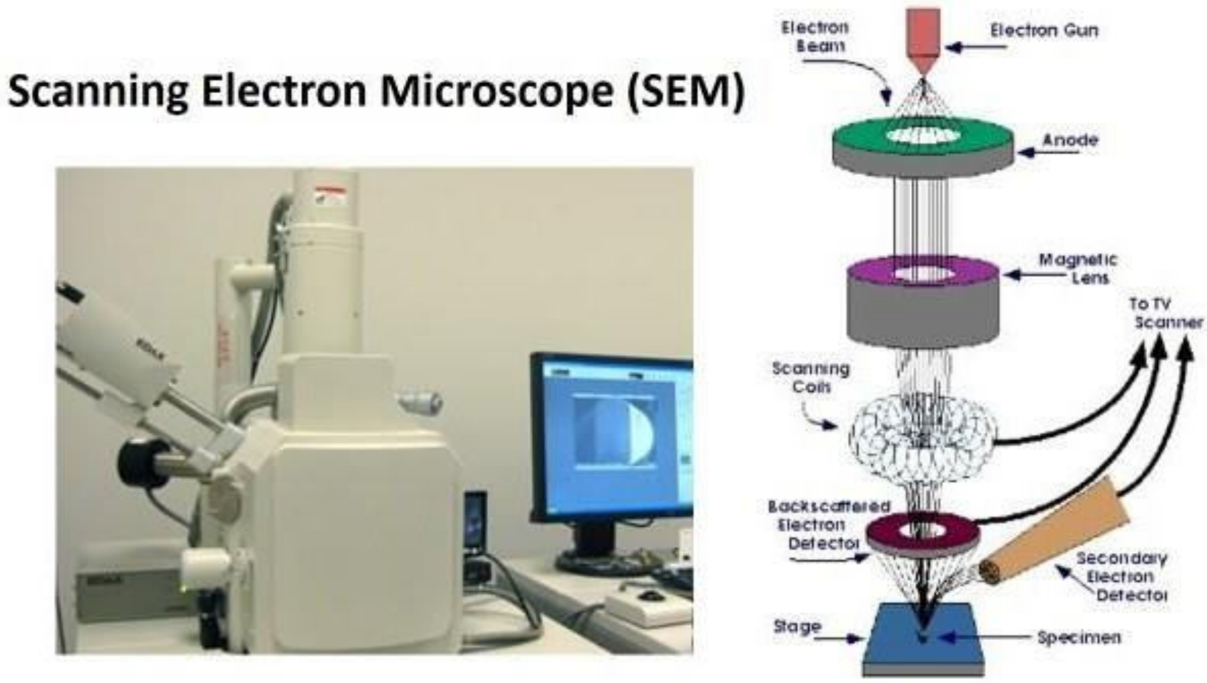

Figure (12) scanning electron microscope testing machine

4.6 MICRO VICKERS HARDNESS

Hardness testing is divided into two ranges:

1. Macrohardness and
2. Microhardness.

Macrohardness covers testing with an applied load over 1 kg or about 10 Newton (N). Microhardness testing, with applied loads under 10 N, is typically used for smaller samples, thin specimens, plated surfaces or thin films.

The Vickers method is based on an optical measurement system. The Microhardness test procedure, ASTM E-384, specifies a range of light loads using a **diamond indenter** to make an indentation which is measured and converted to a hardness value. It is very useful for testing on a wide type of materials, but test samples must be highly polished to enable measuring the size of the impressions. A square base pyramid shaped diamond is used for testing in the Vickers scale. Typically loads are very light, ranging from 10gm to 1kgf, although "Macro" Vickers loads can range up to 30 kg or more.

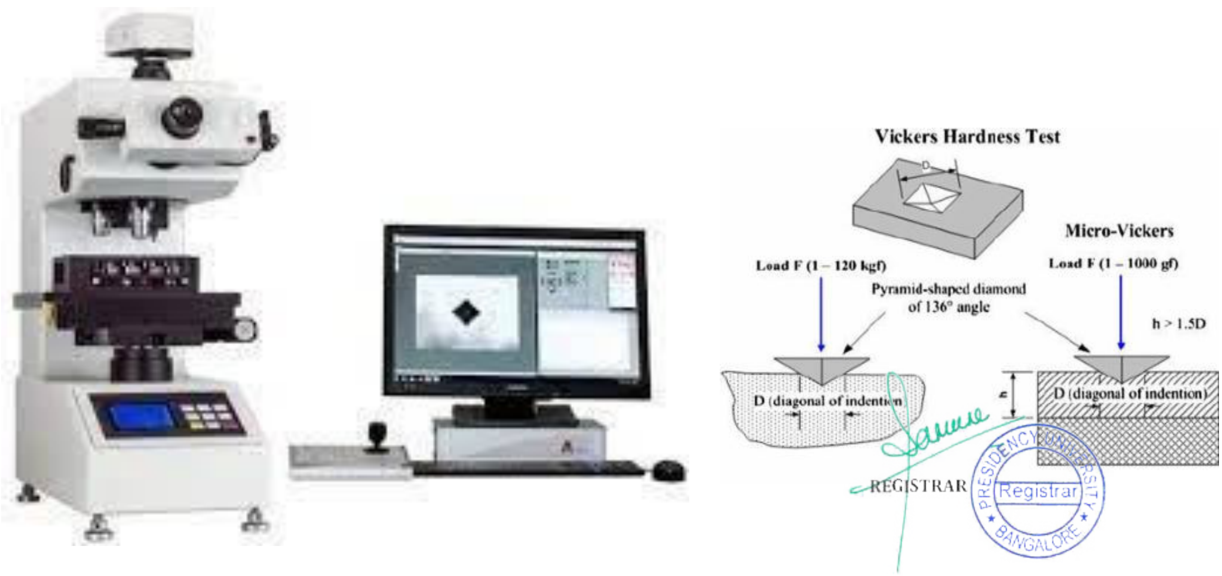

Figure (13) Vickers hardness test machine diamond indentation

4.7 PIN ON DISC WEAR TEST

Wear rate is volume loss per unit distance and its unit is (m3/m). Specific wear rate depends on applied on to cause wear, it is volume loss per unit meter per unit load. Its unit is (m3/Nm). Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM International defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface.

Figure (14) Pin on Disc wear testing machine

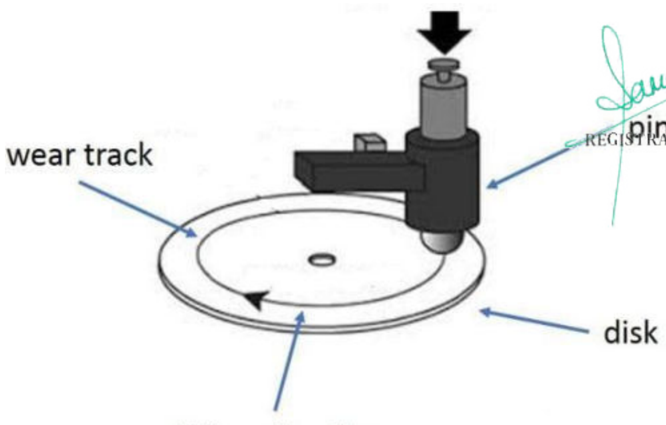

Figure (15) pin on disc process image

CHAPTER 5

Results and Discussion

5.1 RESULTS AND DISCUSSION

5.1.1 X-RAY DIFFRACTION

After conducting the test on the samples and powder the result we got from the XRD test carried on BMS college the results we got defines that the spray coating. The measurement conditions are configuration stage is PW3071, Goniometer is PW3050/60, Sample stage is PW3071, And the raw date is origin by XRDML, start position[°2θ]= 20.0250 and the end position [°2θ]=89.9850and the step size[°2θ]= 0.0300, Divergence slit size [°]0.8709, Specimen Length [mm] 0.3800, Measurement Temperature[°c] 25.00,Diffractometer Type 0000000011174082,Goniometer Radius[mm] 240.00, Dist.Focus-Diverg.Slit [mm] 100.00, The anode material used is copper.

Powder sample with various percentage compositions

Main Graphics, Analyze View:

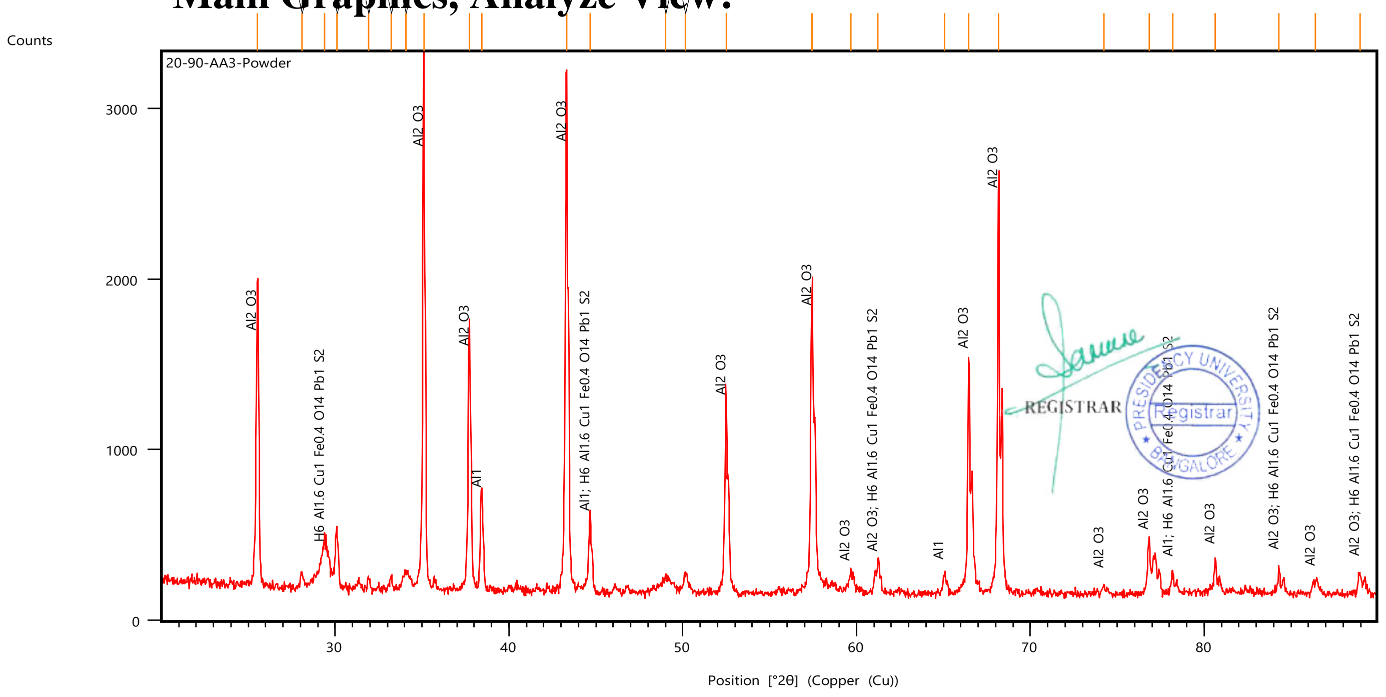

Figure (16) X-Ray diffraction of 3% Al

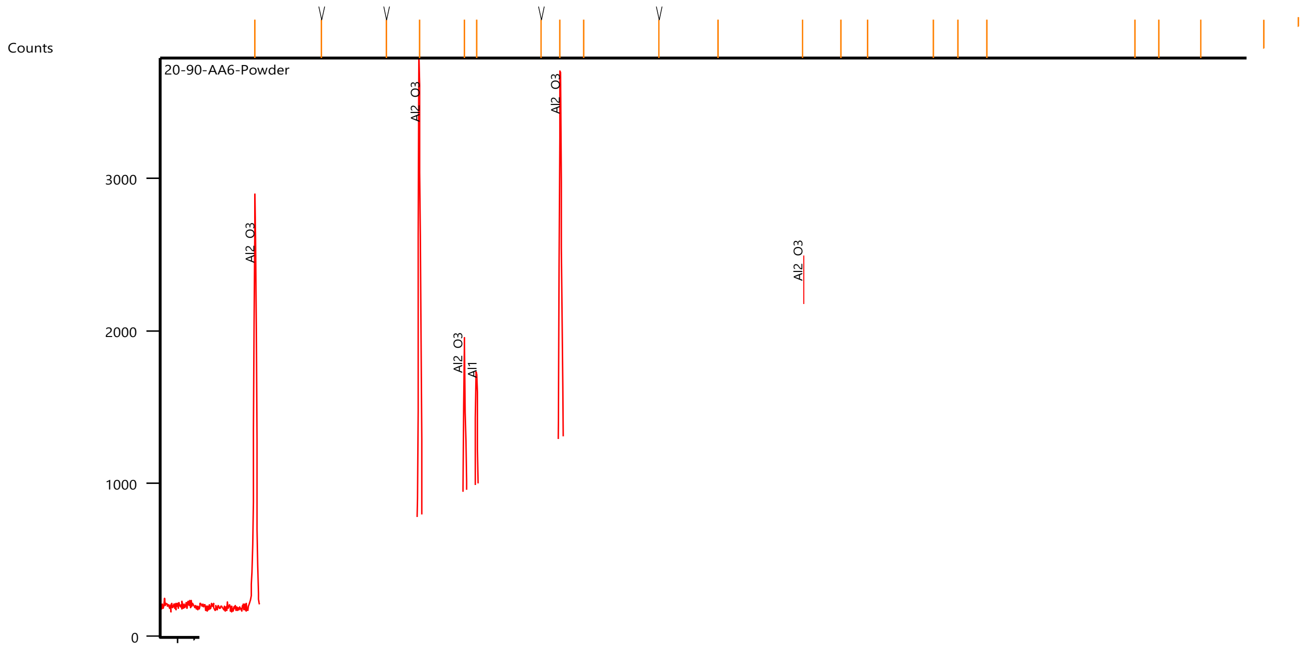

Figure (17) X-Ray diffraction of 6% Al

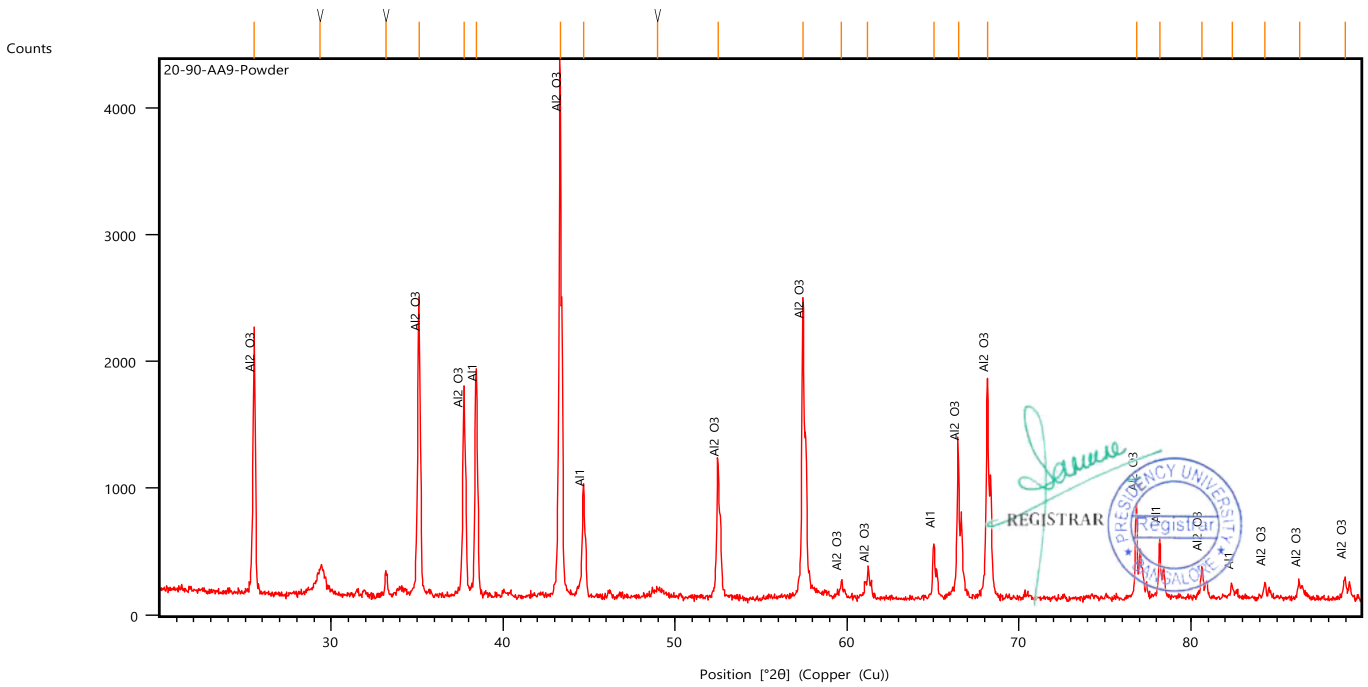

Figure (18) X-Ray diffraction of 9% Al

For 3% Al

XRD analysis of raw powder are

The Crystalline powder is shown with the sharp peaks in the XRD pattern, these crystalline peaks are identified as alpha Aluminium Oxide (Al_2O_3) in case of pure alumina powder and Aluminium (Al) in case of pure Aluminium powder. There are some peaks which are not defined in the graph they are identified as Osarizawaite (H6, Al1.6, Cu1, Fe0.4 O14, Pb1, S2)

The reference codes are : For Aluminium 98-004-4713, for alpha Aluminium Oxide 98-016-0904, for Osarizawait 98-010-0441 respectively.

For 6% Al

XRD analysis of raw powder are

The Crystalline powder is shown with the sharp peaks in the XRD pattern, these crystalline peaks are identified as Corundum (Al_2O_3) in case of pure alumina powder and Aluminium (Al) in case of pure Aluminium powder. There are some peaks which are not defined in the graph they are identified as Creaseyite (H5, Al, Cu2, Fe2 O19, Pb2, Si4)

The reference codes are : For Aluminium 98-060-6000, for Corundum 98-002-4851, for Creaseyite 98-010-0441 respectively.

For 9% Al

XRD analysis of raw powder are

The Crystalline powder is shown with the sharp peaks in the XRD pattern, these crystalline peaks are identified as corundum (Al_2O_3) in case of pure alumina powder and Aluminium (Al) in case of pure Aluminium powder. There are some peaks which are not defined in the graph they are identified as Creaseyite (H5, Al, Cu2, Fe2 O19, Pb2, Si4)

The reference codes are : For Aluminium 98-004-3423, for Corundum 98-002-4851, for Creaseyite 98-010-0441 respectively.

Coated Samples with various percentage of compositions

Main Graphics, Analyze View:

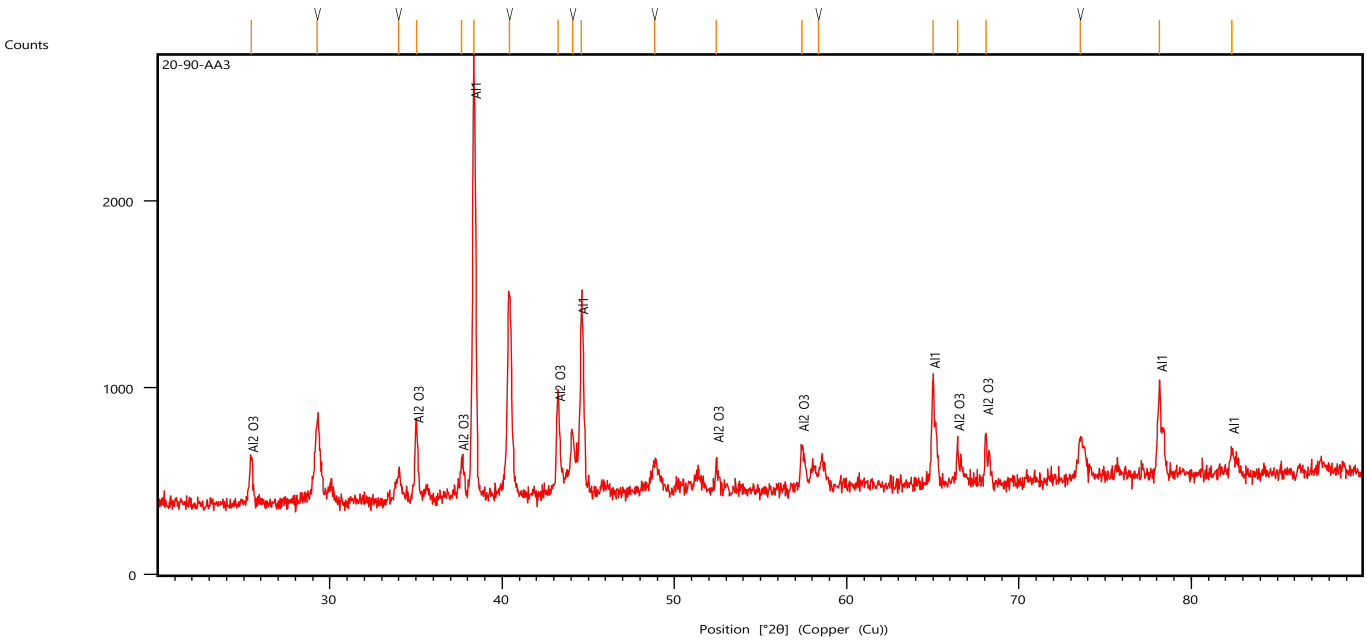

Figure (19) X-Ray diffraction of 3% Al

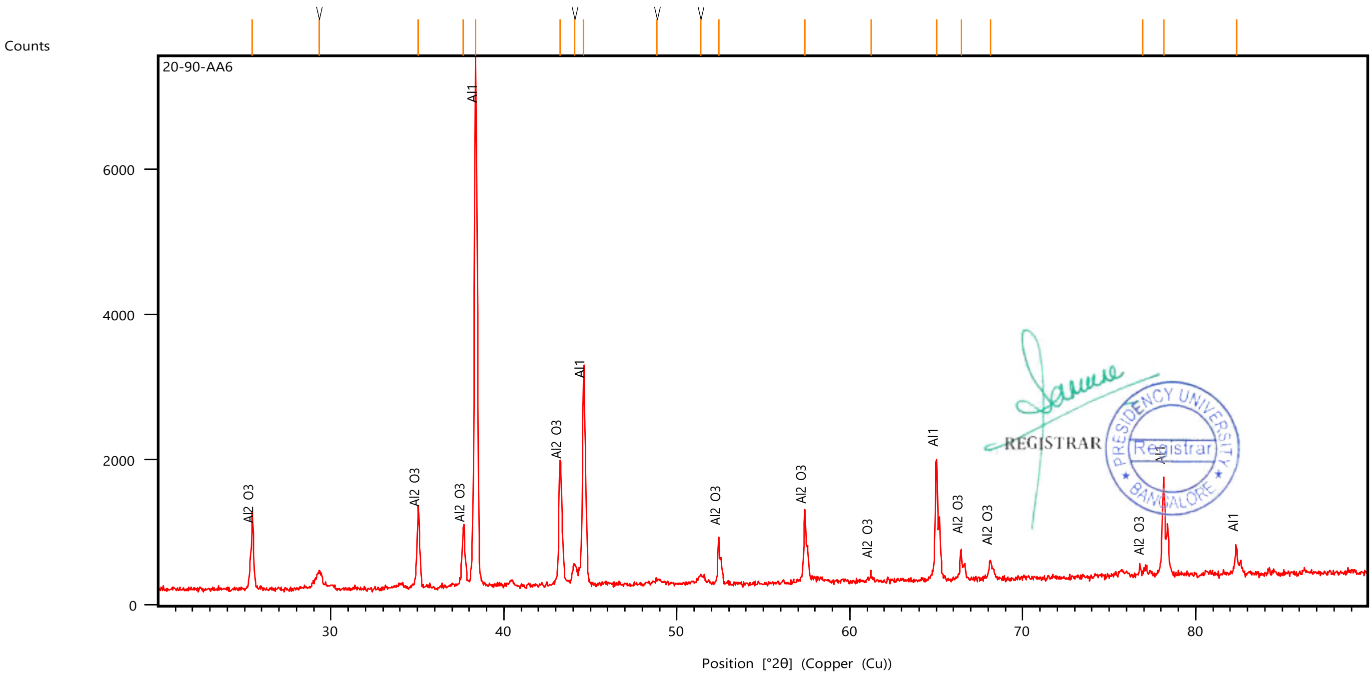

Figure (20) X-Ray diffraction of 6% Al

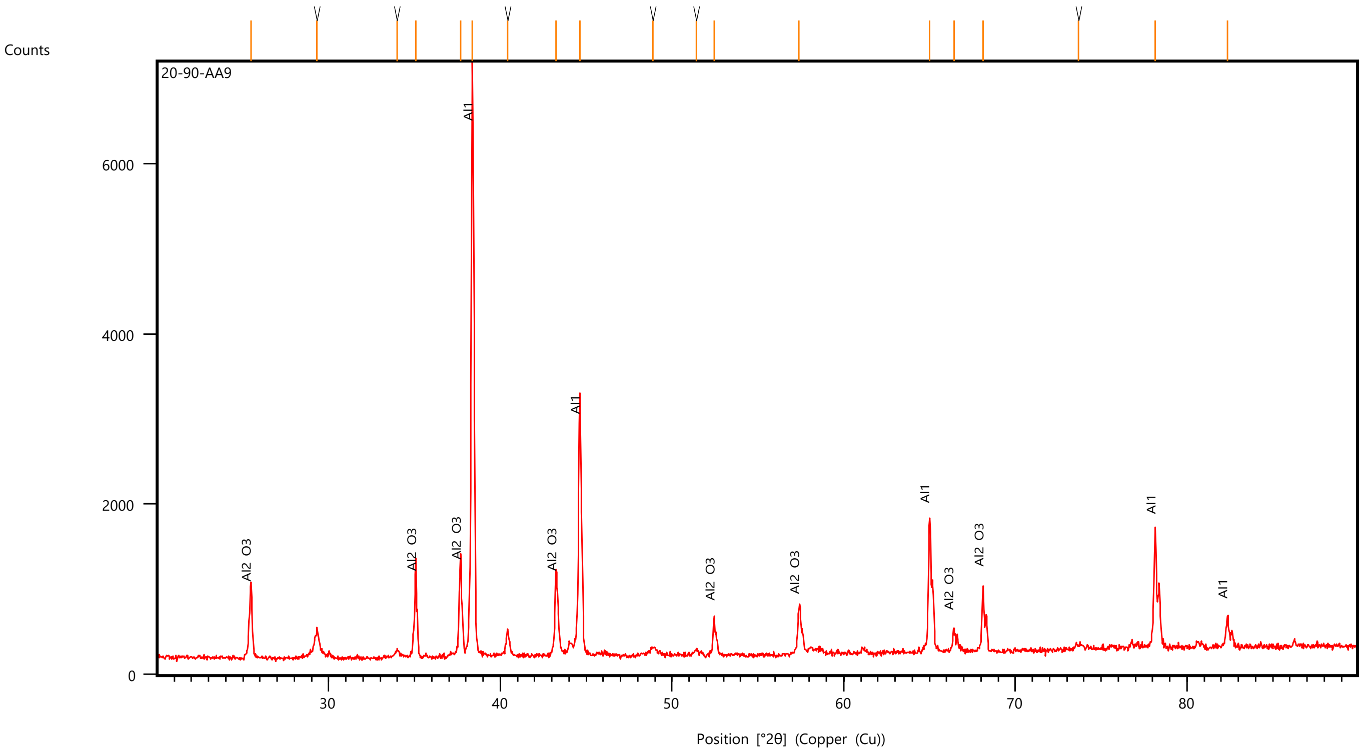

Figure (21) X-Ray diffraction of 9% Al

For 3% Al

XRD analysis of coated samples are

The surface which is coated is shown with the sharp peaks in the XRD pattern, these crystalline peaks are identified as corundum (Al2 O3) in case of pure alumina powder and Aluminium (Al) in case of pure Aluminium powder. There are some peaks which are not defined in the graph they are identified as Creaseyite (H5, Al, Cu2, Fe2 O19, Pb2, Si4)

The reference codes are

For Aluminium 98-024-0129, for corundum 98-016-0605,for Creaseyite 98-029-0256 respectively.

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For 6% Al

XRD analysis of coated samples are

The surface which is coated is shown with the sharp peaks in the XRD pattern, these crystalline peaks are identified as corundum (Al2 O3) in case of pure alumina powder and Aluminium (Al) in case of pure Aluminium powder. There are some peaks which are not defined in the graph they are identified as Iron (Fe)

The reference codes are

For Aluminium 98-005-2255, for Corundum 98-016-0605,for Iron 98-018-5744 respectively.

For 9% Al

XRD analysis of coated samples are

The surface which is coated is shown with the sharp peaks in the XRD pattern, these crystalline peaks are identified as corundum (Al2 O3) in case of pure alumina powder and Aluminium (Al) in case of pure Aluminium powder. There are some peaks which are not defined in the graph they are identified as Creaseyite (H5, Al, Cu2, Fe2 O19, Pb2, Si4)

The reference codes are

For Aluminium 98-024-0129, for Corundum 98-002-4851, for Creaseyite 98-029-0256 respectively.

There are some amount of impurities because the Aluminium metal powder we have used contains 99.9% of Aluminium the 1% consists of mixtures of Copper, Iron, Manganese, Lead, Insoluble HCL in a very small quantities and when its is sprayed in the atmosphere some dust particle gets trapped in it.

Therefore, we can see some small peaks in the graphs

5.1.2 CONFOCAL MICROSCOPE

The test was done at CMTI using a Olympus OLS400 microscope and LEXT software with X Y resolution 120nm and Z resolution 10nm which has an internal magnification of 21X and external magnification of and 20X. The following are the results obtained through confocal microscope test:

Figure (22) Magnification of Laser image in 20X by confocal microscopy

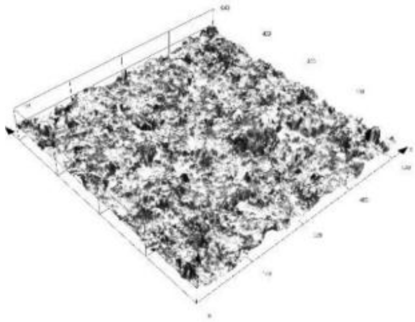
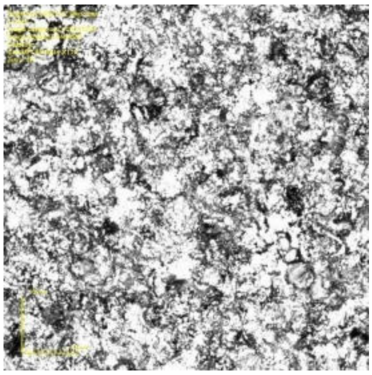
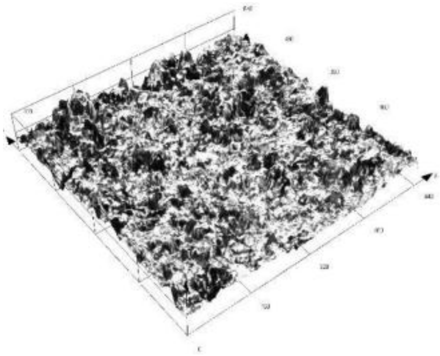
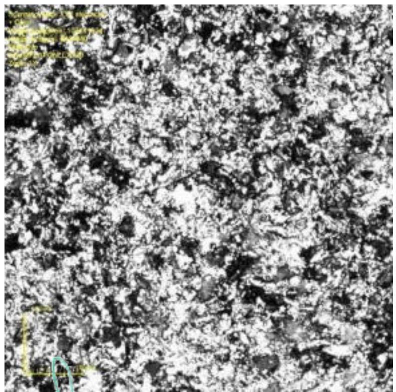
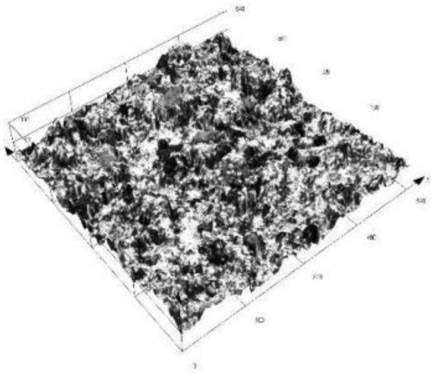
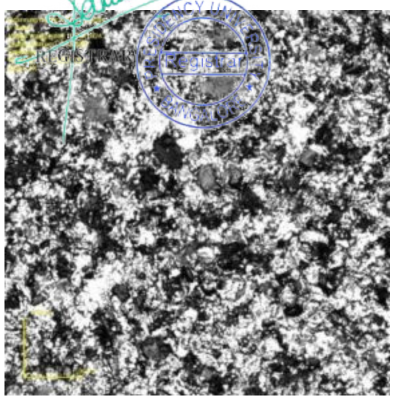
	3D	2D
3% Al (A)		
6% Al (B)		
9% Al (C)		

Figure (23) Magnification of Grey Scale image in 20X by confocal microscopy

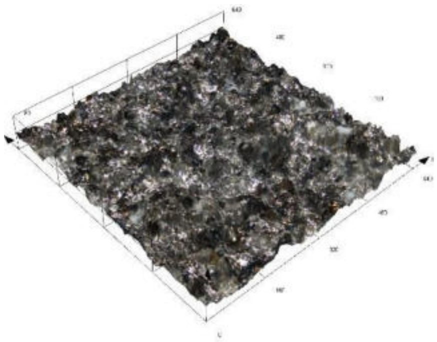
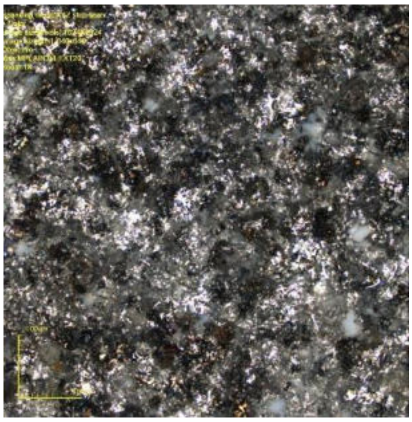
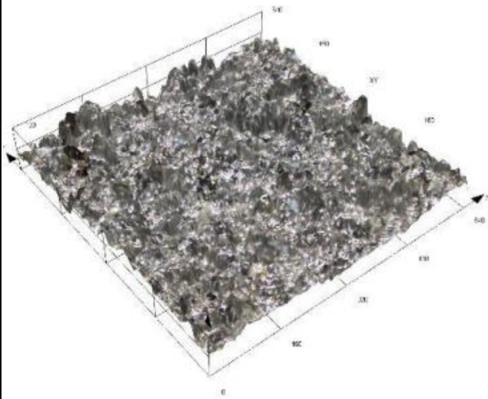
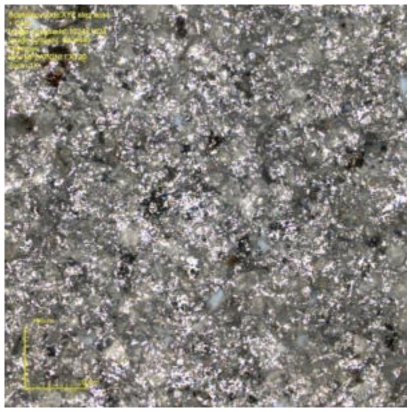
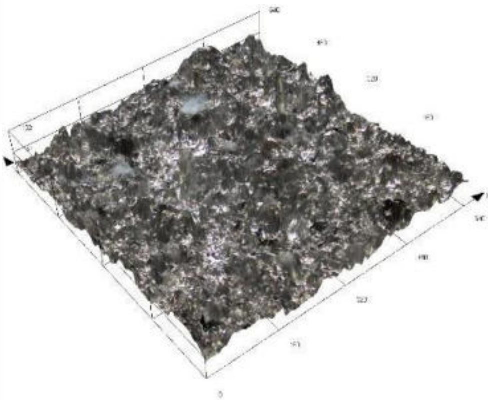
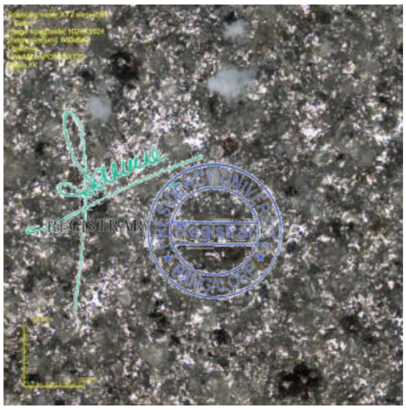
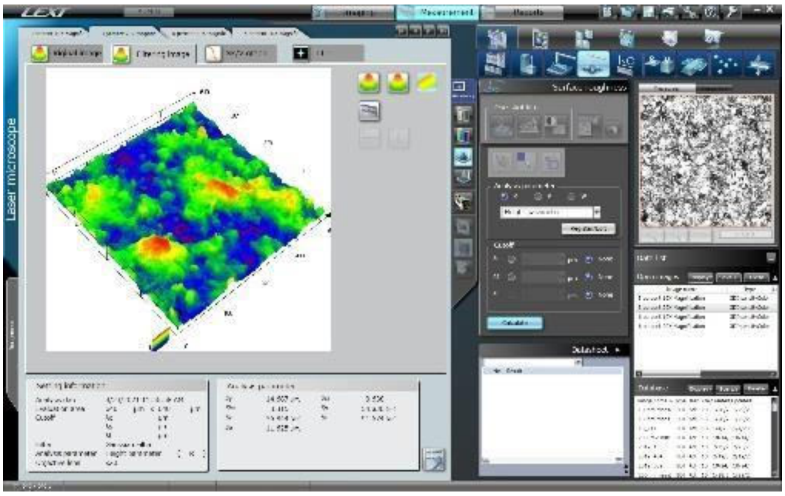
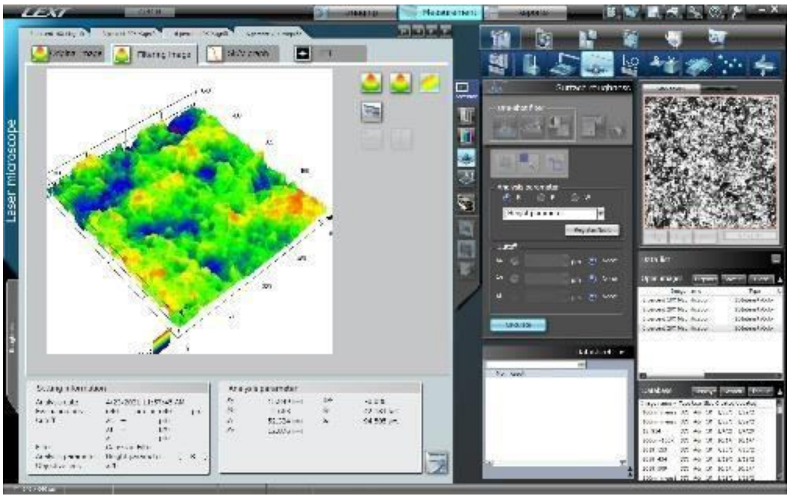
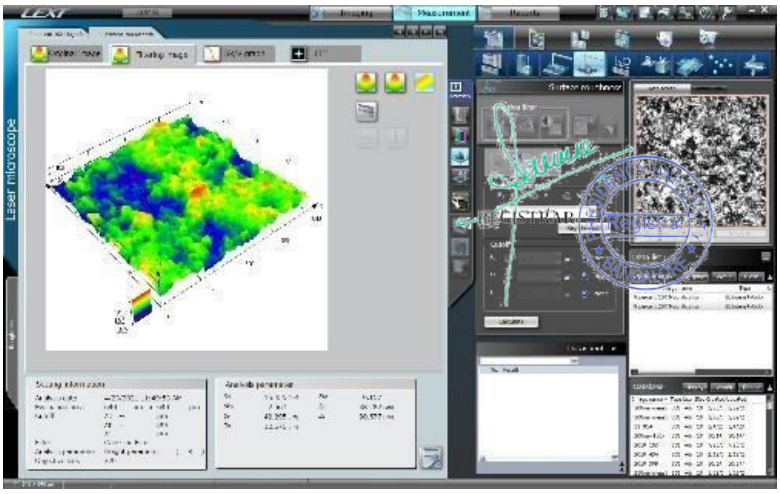
	3D	2D
3% Al (A)		
6% Al (B)		
9% Al (C)		

Figure (24) Magnification of Surface Roughness image in 20X by confocal microscopy

	3D & 2D
3% Al (A)	
6% Al (B)	
9% Al (C)	

The above images show us the bonding of the coating with the substrate material

Gray scale imaging

gray scale means white light scanned image it will be depending on sample color confocal microscope (LSCM) is routinely used to produce digital images of single-, doubleand triple-labeled fluorescent samples. The use of red, green and blue (RGB) color is most informative for displaying the distribution of up to three fluorescent probes labeling a cell, where any colocalization is observed as a different additive color when the images are colorized and merged into a single three-color image

Laser imaging (LCSM)

laser confocal scanning microscopy is an optical imaging technique for increasing optical resolution and contrast of a micrograph by means of using a spatial pinhole to block out-of-focus light in image formation. Capturing multiple two-dimensional images at different depths in a sample enables the reconstruction of three-dimensional structures (a process known as optical sectioning) within an object. This technique is used extensively in the scientific and industrial communities and typical applications are in life sciences,

Surface roughness

Roughness of surfaces is of interest to a wide range of researchers in materials science [1, 2]. A number of methods can be used to measure roughness and the selection of method often depends upon the desired resolution. For instance, roughness on an atomic scale might be best measured by an atomic force microscope while the roughness of a mountain range may be measured by a stereo photography technique. In the range of resolution of optical microscopy, a relatively new technique has become available.

In 3% composition the surface was found with different types of peaks. the higher peaks were found out to be aluminium metal powder and the small peaks were found to be alumina

In 6% composition the surface was found a larger number of high peaks which is basically the deposits of aluminium metal powder and lesser smaller peaks which was identified as alumina

In 9% composition the surface has most number of high peaks i.e., the aluminium deposits and very less number of smaller peaks i.e., the alumina

5.1.3 SCANNING ELECTRON MICROSCOPE

The Test was done at CMTI for various compositions of mixture of Alumina and Aluminium Metal powder using done Carl Zeiss Neon 40 which has a magnification range of 23X to 26,34,240X and can travel 50mm in X and Y direction. Following are the results obtained after performing SEM test.

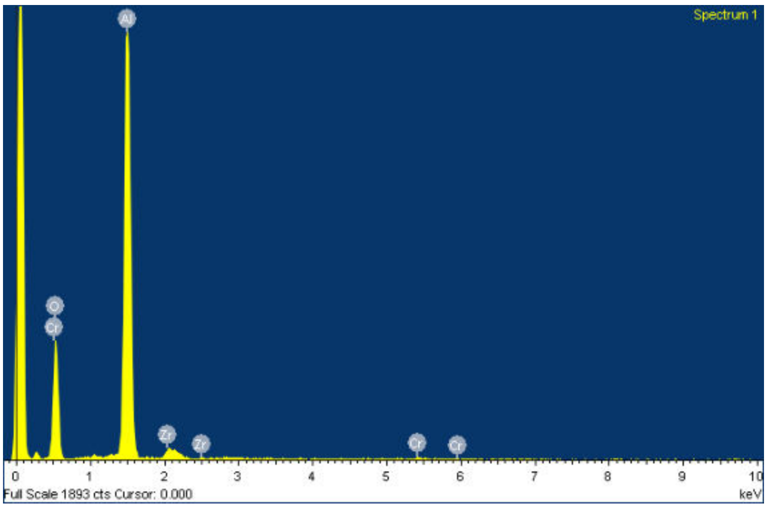
Measurement Composition 3%

In 3% composition we have added 3% of Aluminium Metal powder and the remaining 97% is Alumina Powder. Figure 24 shows how the coating of these powders are bound to the surface, the round shape particles shows the deposition of aluminium metal powder and the particles with irregular shape shows us the traces of alumina powder. Figure 23 shows the different chemical compositions found in the coating which includes traces of aluminium (Al) which is the maximum then followed by oxygen (O) and chromium (Cr) and finally zirconium (Zr) which is the least. During the process the sample was normalised before performing the analysis. For precise results the experiment was conducted with 4 iterations.

Standard: O SiO2, Al Al2O3, Cr Cr, Zr Zr

Table (4) measurement of weight & atoms for 3% Al

Element	Weight%	Atomic%
O K	51.65	65.67
Al K	44.12	33.27
Cr K	0.71	0.28
Zr L	3.52	0.79
Totals	100.00	



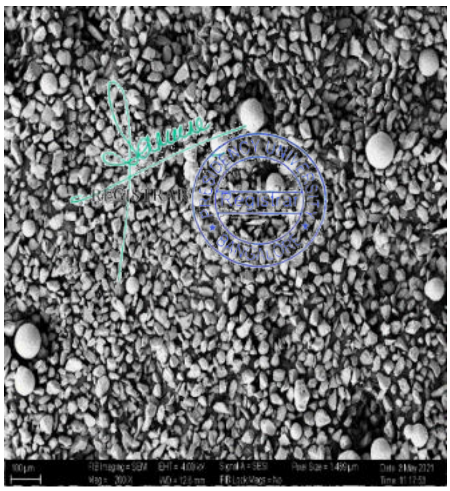


Figure (25) SEM image in magnification 200X representing 3% Al and 97% Al_2O_3

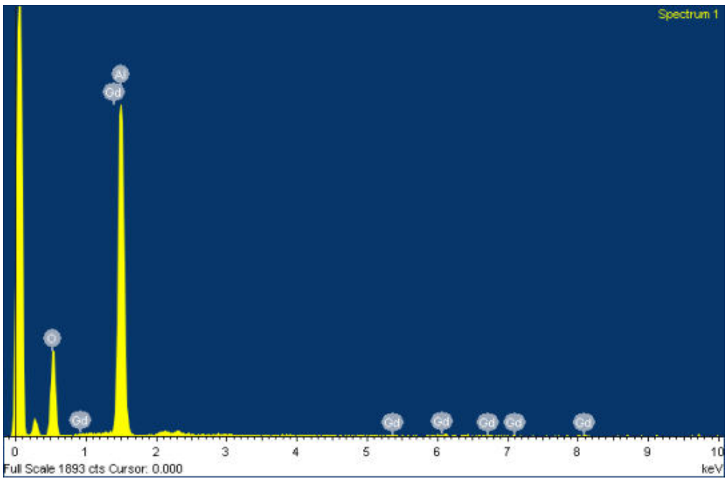
Measurement Composition 6%

In 6% composition we have added 6% of Aluminium Metal powder and the remaining 94% is Alumina Powder. Figure 25 shows how the coating of these powders is bound to the surface, the round shaped particles show the deposition of aluminium metal powder and the particles with irregular shape shows us the traces of alumina powder. Figure 26 shows the different chemical compositions found in the coating which includes traces of aluminium (Al) and gadolinium (Gd) which are the maximum then followed by oxygen (O) which is the least. During the process the sample was normalised before performing the analysis. For precise results the experiment was conducted with 3 iterations.

Standard : O SiO2, Al Al2O3, Gd GdF3

Table (5) measurement of weight & atoms for 6% Al

Element	Weight%	Atomic%
O K	50.27	63.87
Al K	47.59	35.85
Gd L	2.14	0.28
Totals	100.00	



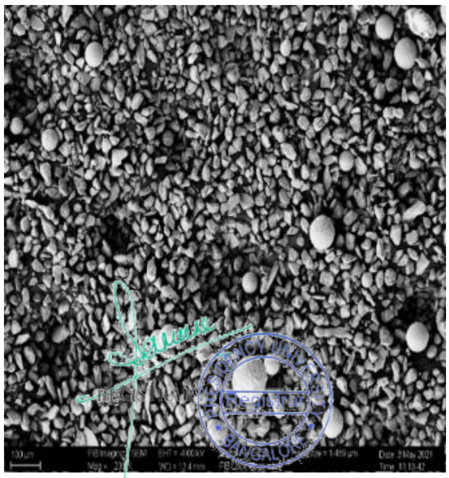


Figure (26) SEM image representing 6% Al and 94% Al_2O_3

Measurement Composition 9%

In 9% composition we have added 9% of Aluminium Metal powder (Al) and the remaining 91% is Alumina Powder (Al_2O_3). Figure 16 shows how the coating of these powders are bound to the surface, the round shape particles show the deposition of aluminium metal powder and the particles with irregular shape shows us the traces of alumina powder. Figure 17 shows the different chemical compositions found in the coating which includes traces of aluminium (Al) which is the maximum then followed by gold (Au) which is basically the sputter coater used to make it conductive as alumina is a very good insulator and since the % composition of alumina is more than the others the insulation property would be more compared to the other i.e.,3% and 6% and finally oxygen (O) which is the least. During the process the sample was normalised before performing the analysis. For precise results the experiment was conducted with 3 iterations.

Standard : O SiO2, Al Al2O3

Table (6) measurement of weight & atoms for 9% Al

Element	Weight%	Atomic%
O K	52.53	65.11
Al K	47.47	34.89
Totals	100.00	

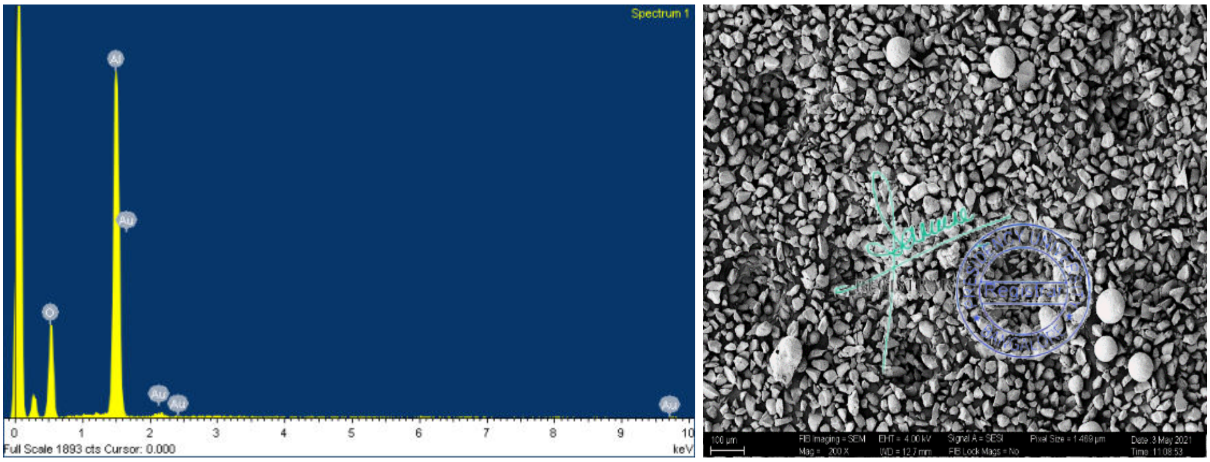


Figure (27) SEM graph representing 6% Al and 94% Al_2O_3

5.1.4 MICRO VICKER HARDNESS TEST

The Test was done at CMTI for samples of coated with mixture of aluminium metallic powder with 3%, 6%, 9% of pure alumina using CLEMEX Dual MMT-X7B Micro hardness tester.

Table (7) Hardness values for Alumina of % Composition 3%, 6%, 9%

SL NO	COMPOSITION	COATING HARDNESS HV
1	97% Alumina and 3% Aluminium metalic powder	426.7
2	94% Alumina and 6% Aluminium metalic powder	462.3
3	91% Alumina and 9% Aluminium metalic powder	400

Following tables are the results got but conducting the test on Micro Vickers hardness test by using diamond indenter.

5.1.5 PIN ON DISC WEAR TEST

The test samples are the cylindrical pins having dimension of 30mm length and 10mm diameter. The pins were weighed before starting the wear test. Weighing is carried out on the electronic weighing balance which has the accuracy up to 0.001g. The track diameter is preset to 90mm. with a specified force of 14.71N the pins were pressed against the disc. The time is preset to the 2min21sec so that a sliding distance of 200m is achieved. test samples were cleaned with the cloth before weighing them so that the worn particles will be removed. before fixing the new specimen the disc has to be cleaned. the test is continued up to 2000m sliding distance with step size of 200m. for every 200m same procedure will be continued. The counter body is made up of EN-31 disc having 100mm diameter and 8mm thickness. The rotating abrasive paper size of 1200 grits is attached to the disc. The abrasive paper will be changed for every 200m sliding distance the wear rate is given by the ratio of Volume loss to the product of Sliding distance and normal applied load. the specific wear rate is given by the following relationship:

$$\text{Specific wear rate } K = \frac{V}{DL}$$

Where,

V- Volume loss= $\frac{m}{\rho}$

m- Mass loss

D- Sliding Distance

ρ- Density of sample

L –Normal load Applied on the specimen

Table (8) Weight of Alumina coat with different % Composition of Al_2O_3 for varying sliding distance

% Composition of Al_2O_3	weight (in g) after sliding distance (in m) of										
	0	200	400	600	800	1000	1200	1400	1600	1800	2000
3%	11.982	11.98	11.978	11.975	11.971	11.965	11.957	11.945	11.931	11.915	11.893
6%	11.963	11.961	11.959	11.956	11.952	11.946	11.939	11.928	11.915	11.899	11.88
9%	12.01	12.008	12.005	12.001	11.996	11.989	11.98	11.967	11.952	11.933	11.91

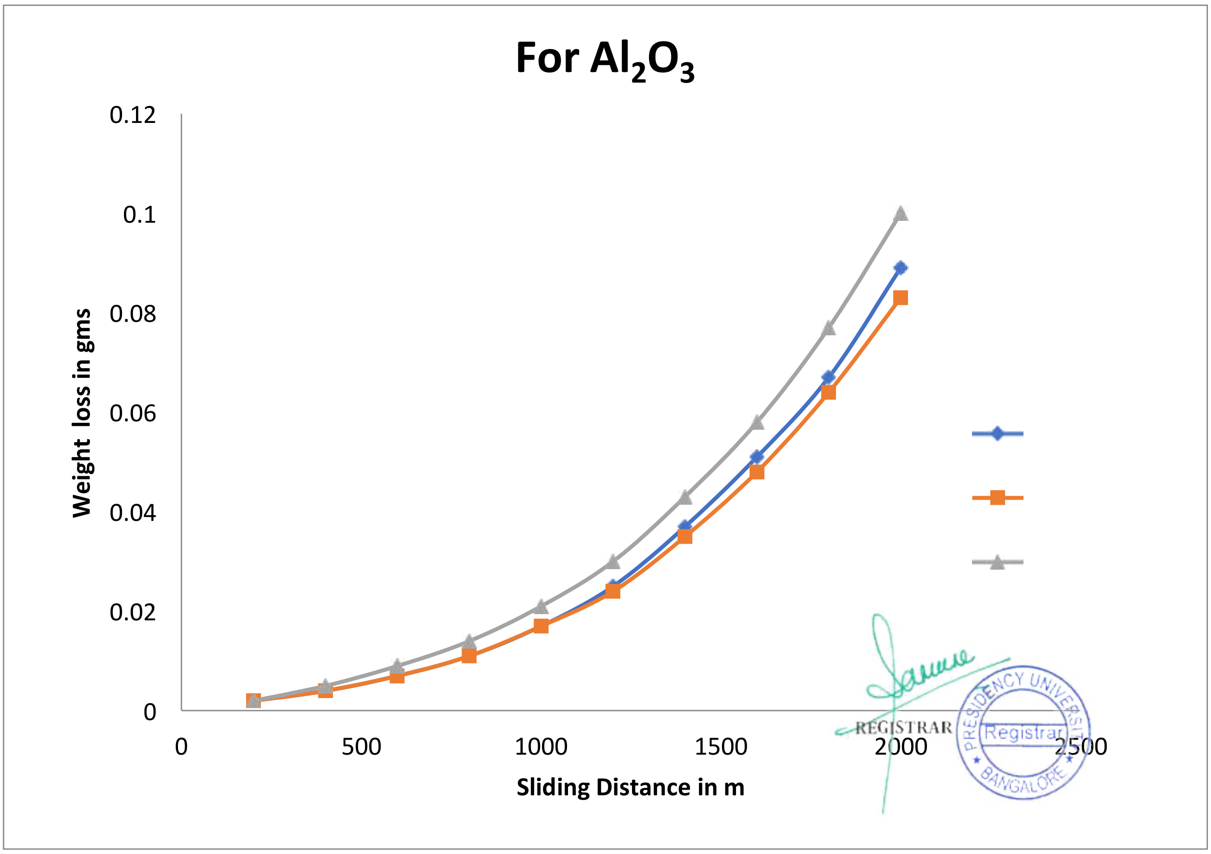


Figure (28) Effect of sliding distance on weight loss for % composition 3%, 6%, 9% and SS uncoated

Table (9) Wear rate of Alumina coat with different for % composition for varying sliding distance

SOD	wear rate in (E-12) after sliding distance of									
	200	400	600	800	1000	1200	1400	1600	1800	2000
70	1.68	1.68	1.96	2.32	2.86	3.51	4.46	5.37	6.28	7.51
90	1.68	1.68	1.96	2.32	2.86	3.37	4.21	5.06	6	7
110	1.68	2.1	2.53	2.95	3.54	4.21	5.18	6.11	7.21	8.43

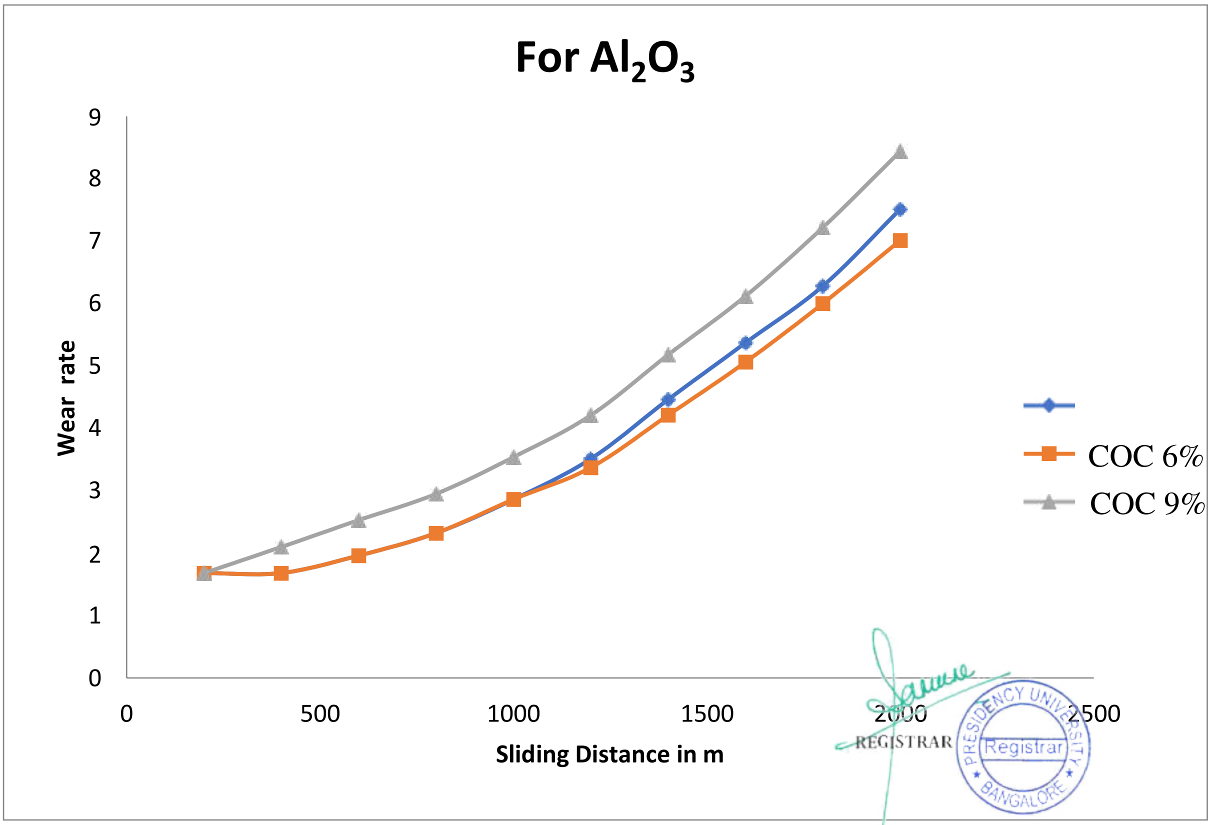


Figure (29) Effect of sliding distance on wear rate for % composition 3%, 6%, 9%

5.2 CONCLUSION

- The Alumina is most widely used Ceramic for corrosion resistance, wear resistance and high temperature resistance, but it fails in its service conditions because of its brittle nature.
- It can be improved by adding secondary phase elements like ceramics or metal powders, this increases fracture toughness and reduces the brittle failure.
- The addition of aluminum powder in alumina in the range of 3% ,6% ,9% showed better wear resistance.
- The micro hardness is found to be decreased because of presence of weak aluminum splats.
- With above observations, it is evident that metal powders can be used for enhancing fracture toughness in ceramic coatings

5.3 FUTURE RECOMMENDATIONS

The following testes are carried on the work piece such as XRD, SEM, Confocal Microscopy and micro hardness test, to know the surface properties, structure and hardness of the material so to know the wear hardness of the material, the test can be conducted to know the wear hardness of the material on the pin on disk wear testing machine.

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FREE VIBRATION, WATER ABSORPTION BEHAVIOUR OF HYBRID FIBER REINFORCED POLYMER COMPOSITES-EFFECT OF STACKING SEQUENCE

University Project – II Report submitted to the Presidency University, Bengaluru in partial fulfillment of the requirements for award of Degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

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MAY 2021

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Bengaluru

Department of Mechanical Engineering

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CERTIFICATE

This is to certify that the University Project – I titled **"FREE VIBRATION, WATER ABSORPTION BEHAVIOUR OF HYBRID FIBER REINFORCED POLYMER COMPOSITES-EFFECT OF STACKING SEQUENCE"** was carried out by Mr. Hithesh Raj P V (20171MEC0076), Mr. Raghav JA (20171MEC0170), Mr. Dhanush V (20171MEC9018), Mr. Dhanush Yadav S (20171MEC9019) and Mr. Shivakumar G (20171MEC9022) bonafide students of VII Semester B.Tech. Mechanical Engineering in School of Engineering, Presidency University. This is in partial fulfillment of the award of the degree of the Bachelor of Technology in Mechanical Engineering of Presidency University, Bengaluru, during the academic year 2020-2021.

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Supervisor & Assistant Professor	Associate Professor & Project coordinator	Professor & Head
Department of Mechanical Engineering	Department of Mechanical Engineering	Department of Mechanical Engineering

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DECLARATION

We do hereby declare that the Project Report titled "**FREE VIBRATION, WATER ABSORPTION BEHAVIOUR OF HYBRID FIBER REINFORCED POLYMER COMPOSITES-EFFECT OF STACKING SEQUENCE"** is a record of the original work done by us under the guidance of **Mr. Sreenivas H T**, Assistant Professor, Department of Mechanical Engineering, Presidency University, Bengaluru. This report is submitted by us in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Mechanical Engineering of Presidency University, Bengaluru in the month of May, 2020. The results embodied in this report have not been submitted to any other University or Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENT

We would like to express our sincere thanks to the supervisor, **Mr. Sreenivas H T** Assistant Professor, Department of Mechanical Engineering for his morale boosting, meticulous guidance, co-operation and supervision throughout this project work.

We would like to owe our heartiest gratitude to **Dr. Ramesh S P**, Associate Professor & Project coordinator, Dept. of Mechanical Engineering for his encouragement during the progress of this project work.

We would also like to pay our sincere thanks to **Dr. S Ramesh**, Professor & Head, Dept. of Mechanical Engineering, School of Engineering for sharing his valuable experience in completing project work.

We would like to convey our sincere thanks to the Management of our university for providingus required infrastructure within college campus.

We would like to thank both teaching and non-teaching staff members of the Department of Mechanical Engineering for their kind cooperation and all sorts of help to complete this projectwork successfully.

We would also like to thank all of our juniors, classmates and friends for their valuable suggestions to complete our project work in time.

Last but not the least we would like to thank our parents for always staying beside us andencouraging all the time.

Date: 25th May 2021

Place: Presidency University, Bengaluru

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ABSTRACT

Increase in demand for environmental friendly engineered structures make the natural fibre reinforced composites as the best option to replace synthetic fiber in polymer composite structures. In this study, the influence of stacking sequence of natural hybrid laminates on free vibration characteristics that are beneficial for structural applications have been focused in which the use of synthetic fibers is varied. To study the effect of stacking sequence efficiently, natural fiber, i.e., Kenaf (Twill weave) and a synthetic fiber, i.e., Kevlar (Plain weave) are preferred. The preferred hybrid composite laminates were prepared by hand layup technique. Five different laminates (L1, L2, L3, L4 and L5) were obtained. The hybrid laminates were tested for free vibration characteristics by means of impact hammer test. The experimental modal frequency values were used for finding the effective elastic constants of hybrid composite laminates. The water absorption behaviour was studied for automobile application and marine application based on the ASTM D570 standard.Based on the results of experimental modal analysis of Kenaf/Kevlar composite beams, the effective stacking sequence for structural application was suggested.

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CHAPTER 1: INTRODUCTION

In modern world, the synthetic fiber-reinforced polymer (FRP) composite is the key material which rapidly replaces the conventional materials in the field of aerospace and automotive industries. Its superior properties along with the added advantage of lightweight character are the key attributes that led to the adoption of FRP. The aspect that concerned most of the material scientists was the non-biodegradable nature of these materials. Besides this aspect, it caused health-risks, it was non-recyclable and non-eco-friendly. A solution to this danger is the hybridization of natural fiber and synthetic fiber. The natural and synthetic fibers are tailored together thus achieving a paradigm shift from FRP to hybrid-reinforced polymer composite system. The linking of natural fibers comes with a lot of benefits but not limited to low density, low cost, availability, renewability, biodegradability and nonabrasive.

Many factors are responsible for the properties of these hybrid composites like the layer configuration, the matrix- fiber bonding, fiber loading, the materials used and so on. Studies on the effects of the mentioned parameters will lead to numerous hybrid composites for various applications. Amongst such researches is a study conducted by Atiqah et al. [11] where a hybrid composite of kenaf/glass-reinforced unsaturated polyester was proposed for structural application.

Studying various research papers, it was proposed to hybridize kenaf and Kevlar with polymer as the matrix. The twill weaving technique was selected for this process.

1.1 OBJECTIVES

- Fabrication of polymer-based hybrid composite reinforced with Natural fiber and Synthetic fiber by using Hand Layup process followed by Autoclave curing method to obtain desired composite.
- To conduct free vibration analysis for the laminates using impact hammer test in cantilever beam and fixed fixed beam.
- To find the damping ratio of laminates and showing which laminate as good result.
- To conduct water absorption test for all the five laminates according to ASTM D 570 STANDARD. To find which laminate as more water absorption capacity.

1.2 STUDY AREA

1.2.1 Composites

Composites are versatile materials comprising of two or more chemically distinct components combined artificially on a macroscopic-scale which have a distinct interface separating them so as to attain characteristics that individual components on themselves can't attain. Constant technological innovations have pushed the physical boundaries of conventional materials, so that there is a need to develop new material solutions to meet application demands. Composite materials have been chosen as a common replacement for conventional materials in many structural components. Their high specific stiffness-to-mass ratio, in particular, has owned them a spot in the aerospace, automotive, biomedical, military, and renewable energy industries. Composite materials are generally used for light weight at the same time high performance products. They include aerospace components (fuselages, propellers tails, and wings), boat and scull hulls, surfboards, bicycle frames and racing car bodies. Other uses include fishing rods, storage tanks, swimming pool panels, and baseball bats.

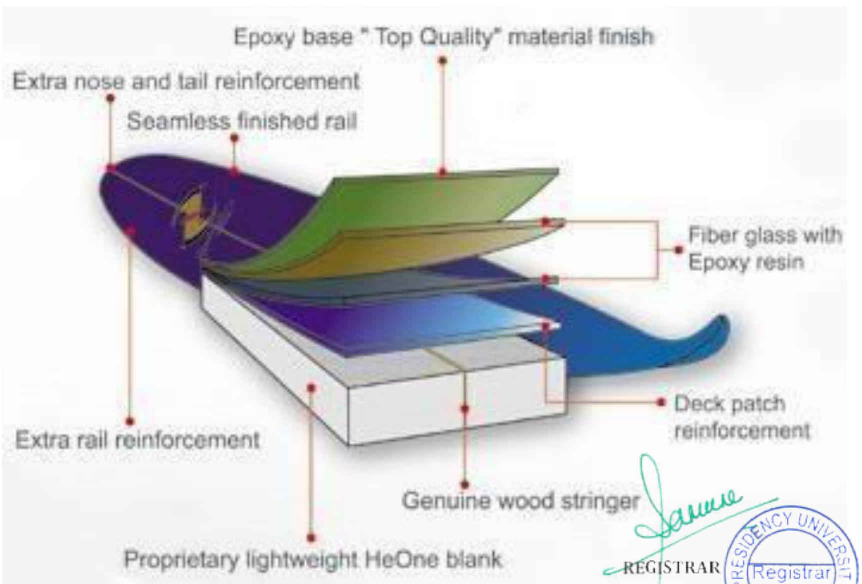

Fig.1.1 Composition of a surfboard.

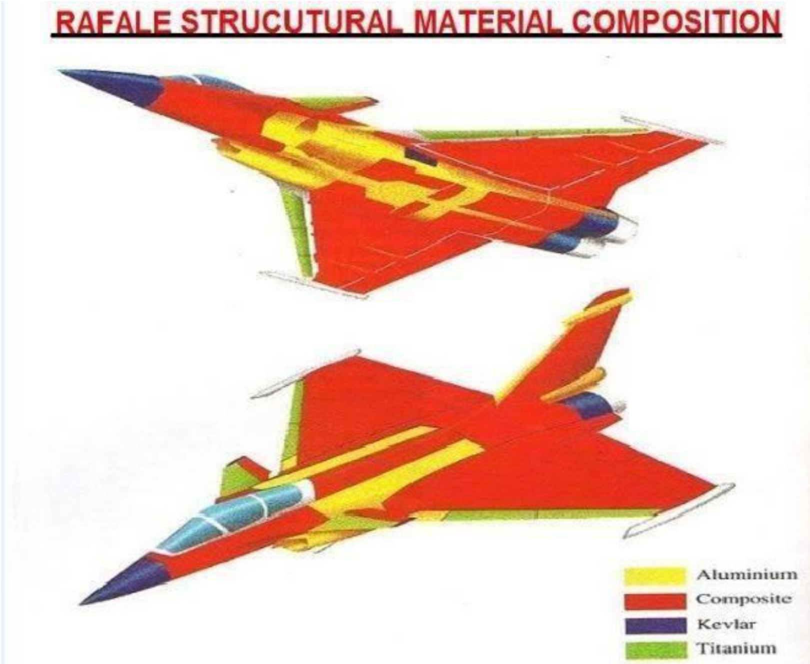

Fig.1.2 Composition of Rafael fighter aircraft.

Composites are basically a combination of two phases (**Fig.1.3**).One constituent is known as the reinforcing phase and the one onto which it is embedded is known as the matrix phase. The function of reinforcing phase is to strengthen and stiffen composite through prevention of matrix deformation by any mechanical restraints. The reinforcing stage materials can be fibers, flakes or particles. The functions of matrix phase are to hold the fiber together, protect the fiber from the environment, to uniformly distribute the load through the fibers, propagation of cracks through the fibers etc. The matrix stage materials are generally continuous which are of polymers, metals or ceramics.

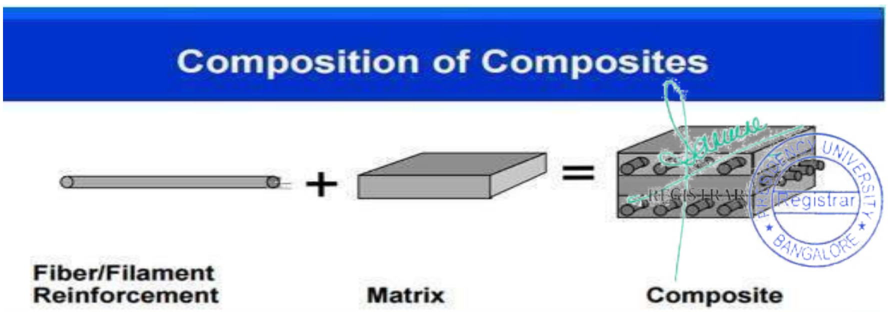

Fig.1.3 Composition of composites.

1.2.2 REINFORCEMENT

Based on the geometry of the reinforcement composites are classified into three (**Fig.1.4**). They are fiber composites, flake composites, particulate composites.

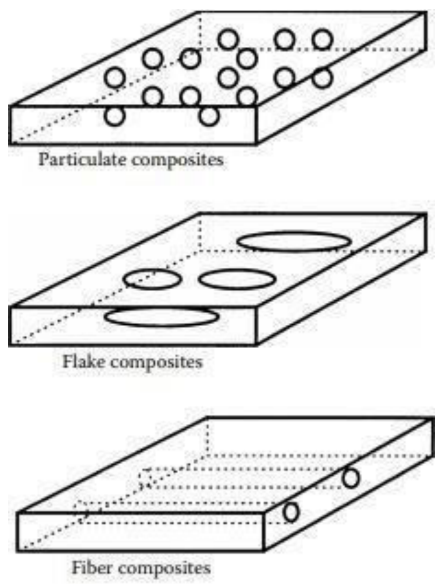

Fig.1.4 Classification of reinforcement.

- ✓ **Particulate Composites**

  Particulate composites consist of particles which are immersed in matrices such as alloys and ceramics. They have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. An example is concrete.

- ✓ **Flake Composites**

  Flake composites consist of flat reinforcements of matrices. They provide advantages such as high out-of-plane flexural modulus, higher strength, and low cost. However, flakes cannot be oriented easily and only a limited number of materials are available for use. Examples are glass, mica, aluminum, silver etc.

- ✓ **Fiber Composites**

  Fiber composites consist of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are usually anisotropic. Examples include carbon and aramids.

Fibers are mainly classified into two based on their source of origin, namely natural fibers and synthetic fibers.

1.2.3 FIBERS

Natural Fibers

Natural fibers are the substances or hair-like materials directly obtained from natural sources like animals, minerals and plants. They can be spun into yarns, filaments, thread or rope and can further be bound, knitted, matted or woven. Examples of natural fibers are jute, sisal, hemp, coconut husk, bamboo, cotton, kenaf etc.

They can be used as components of composite materials, where the orientation of fibers affects the properties of the composites. The advantage of using a natural fiber is reduced tool wear, weight, low density per unit volume, low cost, acceptable specific strength, better thermal and insulating properties, and low energy consumption during processing and also their sustainable renewable and degradable feature in contrast with that of synthetic fiber which critically affects our environment. Natural fibers tend to degrade faster than that of synthetic fibers. Natural fiber can be further classified based on the type of origin as depicted in **Fig 1.5**

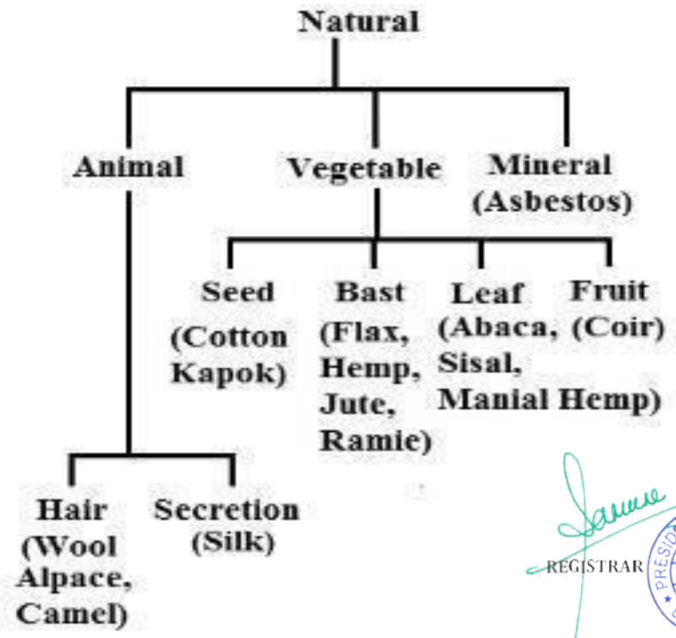

Fig.1.5 Classification of natural fibers

➢ Properties

In contrast to synthetic fibers natural fibers have reduced strength and stiffness. The properties tend to deteriorate over time. Younger fibers tend to exhibit more strength than that of older fibers. Properties of natural fibers also depend on the moisture content in the fiber.

Advantages of Natural Fibers:

- ✓ Renewable resources.
- ✓ Lower production costs.
- ✓ Lower density of composites.
- ✓ Reduced energy consumption during manufacturing.
- ✓ Biodegradability and eco-friendly materials.
- ✓ Lower risk to human health.

Disadvantages of Natural Fibers:

- ✓ Inhomogeneous structure of fibers.
- ✓ Dimensional instability as a negative consequence of water absorption.
- ✓ Lower water and thermal resistance.
- ✓ Susceptibility to microbial attacks and rotting.
- ✓ Degradation and aging.
- ✓ Restricted processing temperature (to avoid thermal degradation).

✓ SYNTHETIC FIBERS

Fibers synthesized through chemical processes by humans are known as Synthetic fibers or artificial fibers. Most of the synthetic fibers are generally prepared from petrochemicals where the raw material is mainly petroleum. This process involves combining monomers to make a long chain or polymer and is known as polymerization.

Synthetic fibers accounts for about half of all fiber usage, with its applicationsin almost every field of fiber technology. Acrylic, nylon and polyester are the main synthetic fibers which dominates the market with polyester alone accounting for about 60 per cent by volume of synthetic fiber production. Examples include boron fibers, carbon fibers, glass fibers, carbon fibers, Kevlar etc.

There are various processes through which a synthetic fiber can be manufactured, but the typical one is the melt-spinning process. This process involves heating the fiber continuously until it starts to melt, then the fiber should be drawn out of the melt with tweezers as quickly as possible. Then align the molecules in a parallel arrangement so as to bring the fibers closer together, this allows them to crystallize and orient. Synthetic tend to be more durable than most of the natural fibers, and will readily pick up different dyes. Besides this, many synthetic fibers offer user-friendly functions, that are stretching, waterproofing, and stain resistance.

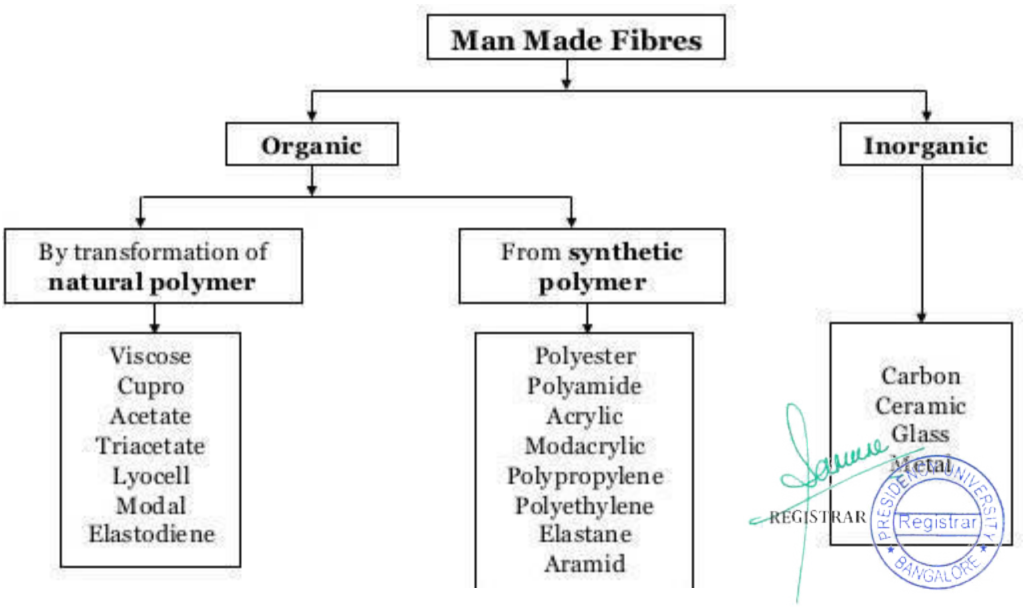

Fig.1.6 Classification of synthetic fibers.

➢ Properties

Synthetic fibers have got unique characteristics which makes them the most desired fiber among material scientists. The fibers are uniaxially oriented during the melt, dry, or wet spinning process, which give the fibers high tenacity and strength. In addition, the properties of synthetic fibers and fabrics can be easily tailored to the application by differing the chemical composition and the processing conditions. Synthetic fibers are usually more water, stain, heat and chemical resistant.

Advantages of synthetic fibers:

- ✓ Easy daily maintenance.
- ✓ Less expensive.
- ✓ Less susceptible to fading in sunlight.
- ✓ Lighter in weight.
- ✓ Less odor absorption.
- ✓ Less moisture absorbent.

Disadvantages of synthetic fibers:

- ✓ More susceptible to heat damage.
- ✓ Extremely hazardous to environment.
- ✓ Melt relatively easy.
- ✓ Not skin-friendly.

1.2.4 MATRIX MATERIALS

Based on the type of matrix used, composites are classified into:

- ✓ **Polymer Matrix Composites (PMC):**

  The most advanced composites are polymer matrix composites consisting of a polymer reinforced with thin diameter fibers. Their advantages are low cost, high strength, and simple fabrication methods. Epoxy and polyester are commonly mixed with fiber reinforcement.

- ✓ **Metal Matrix Composites (MMCs):**

  As the name suggests, have a metal matrix. Metals are usually reinforced to increase or decrease their properties in order to suit the needs of the application. Their advantages include higher specific strength and modulus, lower coefficients of thermal expansion and strength at high temperatures. Examples of matrices in such composites include aluminum, magnesium, and titanium.

- ✓ **Ceramic Matrix Composites (CMCs):**

  They have a ceramic matrix such as alumina calcium alumino silicate reinforced by fibers such as carbon or silicon carbide. Advantages of CMCs are high strength, hardness, high service temperature limits, chemical inertness, and low density. However, ceramics by themselves have low fracture toughness. Under tensile or impact loading, they will fail disastrously.

  Based on the type of the polymer matrix it can be further divided into thermoset polymer and thermoplastic polymer.

- ✓ **Thermoset polymers** are used as matrix materials which once synthesized into a solid form cannot be reverted back to their original form. The cross links between the adjacent polymer chains results in high melting points and makes them very strong. Examples – Polyester, Polyurethanes, Epoxy
- ✓ **Thermoplastic polymers** can be molded, melted and remolded without altering their physical properties. The lack of cross links results in low melting point and less strength. Examples – Polyethylene, Polypropylene and Poly-vinyl chloride

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1.2.5 FABRICATION OF COMPOSITES

There are numerous methods for fabricating a composite component. Some of them were borrowed (injection moulding from plastic industry) but most of them are developed to meet specific design or manufacturing limitations faced by the fiber reinforced polymers. Choosing a particular process for a component will therefore be dependent on the materials, the part design and the application.

✓ WET LAY-UP/HAND LAY-UP PROCESS

This is a skilled manual process which requires very low capital investment and is being widely used for low-volume products, such as boats. The reinforcement (as a woven or chopped strand fabric) is laid into a mould and the matrix (resin) are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics using a roller or brush. Laminates are left to cure under standard atmospheric conditions.

Materials Options

Resins: Any, e.g. epoxy, polyester, vinylester, phenolic.

Fibers: Any, although heavy aramid fabrics can be hard to wet-out by hand.

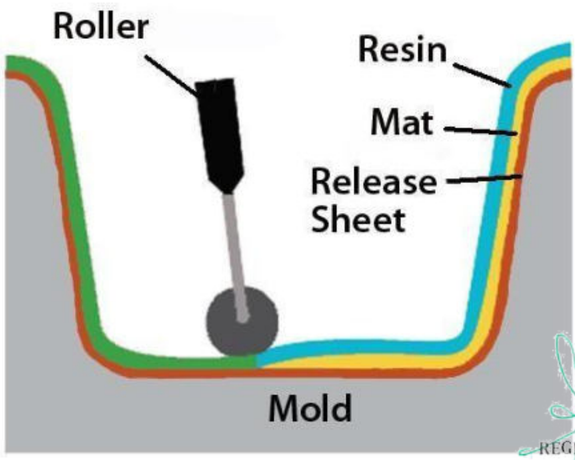

Fig.1.7 Hand lay-up technique.

✓ WET SPRAY-UP PROCESS

Resin is fed through a tube and mixed with catalyst in a hand-held spray gun. The fiber is chopped into the resin stream as it is sprayed onto the mould. This is then left to cure at standard temperature. This is a quick method but leads to a low fiber volume fraction with randomly oriented fibers. Applications include custom parts in low to medium volumes, such as baths, swimming pools, and storage tanks.

Materials Options

Resins: Primarily polyester.

Fibers: Glass roving only.

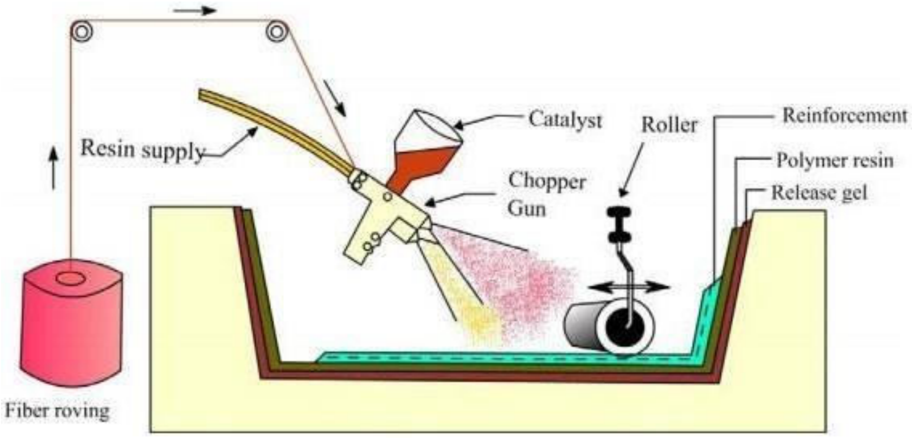

Fig.1.8 Wet spray-up technique.

✓ VACUUM INFUSION PROCESS

Dry fabric plies (layered pieces) are laid up into the mould and covered with a film, or vacuum bag, sealed at the edges. The fabric is compacted under vacuum pressure as resin is drawn through from a reservoir. A flow layer may be needed between the fabric and the bag, especially for less permeable carbon fiber fabrics. This is good for large parts such as boat hulls, wind turbine blades or bridge structures.

Materials Options

Resins: Generally epoxy, polyester and vinylester.

Fibers: Any conventional fabrics. Stitched materials work well in this process since the gaps allow rapid resin transport.

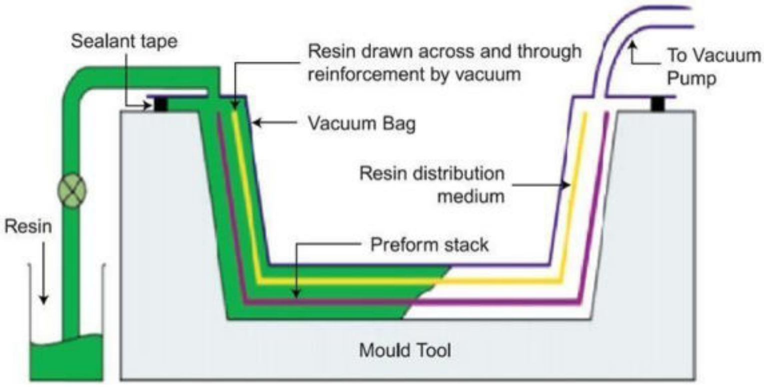

Fig.1.9 Vacuum infusion technique**.**

✓ RESIN TRANSFER MOULDING (RTM) PROCESS

Dry fabric is laid into a two (or more) part mould which is then closed in a heated press. Resin is injected under pressure (e.g. 10 to 20 bar) until the fabric is impregnated and the tool is heated to cure the resin. The flow may be assisted by a vacuum (then referred to as vacuum assisted – VARTM).

Increasing the pressure reduces the cycle time, and the term high pressure RTM (HP-RTM) is used where the pressure is up to 150 bar in the mixing head and from 30 to 120 bar inside the mould, depending on part size and geometry.

Materials Options

Resins: Generally epoxy, polyester, vinylester and phenolic, although high temperature resins such as bismaleimides can be used at elevated process temperatures.

Fibers: Any. Stitched materials work well in this process since the gaps allow rapid resin transport. Some specially developed fabrics can assist with resin flow.

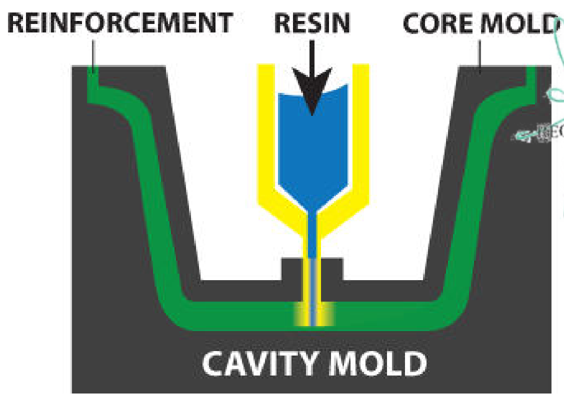

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Fig.1.10 Resin transfer moulding technique.

- ✓ **PREPREG**

  Prepreg fabrics (pre-impregnated with resin) are cut into plies (layered pieces) which are laid up, usually by hand, and smoothed onto the mould tool surface. This is the most popular process for high performance carbon fiber applications in aerospace and motorsport. Some manufacturers are now using automated tape-laying or automated tow placement rather than hand laid prepreg.

Materials Options

Resins: Generally epoxy, polyester, phenolic and high temperature resins such as polyimides, cyanate esters and bismaleimides.

Fibers: Any. Used either direct from a creel or as any type of fabric.

The part can be cured in several ways:

Autoclave: The laid-up part is vacuum bagged and consolidated under vacuum, then cured in an autoclave (pressurized oven) at around 120-180°C and 2-6 bar. Maximizing performance of thermoset composite materials, requires, amongst other things, an increase in the fiber to resin ratio and removal of all air voids. This can be achieved by subjecting the material to elevated pressures and temperatures. To achieve three dimensional, uniform pressures of greater than 1 bar, additional external pressure is required. The most controllable method of achieving this for an infinite variety of different shapes and sizes is by applying a compressed gas into a pressure vessel containing the composite layup. In practice, this is achieved in an autoclave.

Oven: Vacuum bagged parts may be cured in an oven, with just the vacuum pressure applied. Low temperature prepregs are available, formulated to cure at 60-100°C at vacuum pressure. This is good for large parts where a big enough autoclave is not cost-effective.

Hot press: Oven and autoclave processing typically takes several hours. For a shorter cycle time, the prepreg plies may be laid up into matched metal tooling and cured in a press under high pressure, with rapid heat transfer. The part can then be cured and demoulded in just a few minutes, but the tooling is expensive. It may be post-cured in an oven.

Fig.1.11 An Autoclave at the National Composite Centre.

- ✓ **FILAMENT WINDING**

Fiber tows are drawn through a liquid resin bath and wound onto a rotating cylindrical mandrel in a variety of orientations. This is often used to make pipes and tanks. Multi-axis filament winding can be used to create pressure vessels or other shapes by winding the tow around a mandrel with shaped ends. The mandrel may then remain as an inner lining.

Materials Options

Resins: Any, e.g. epoxy, polyester, vinylester, phenolic.

Fibers: Any. The fibers are used straight from a creel and not woven or stitched into a fabric form.

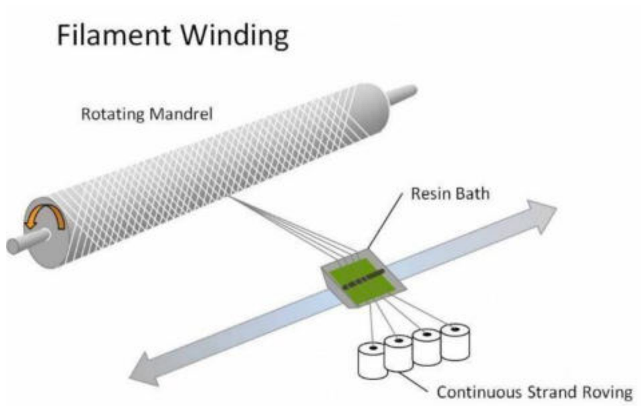

Fig.1.12 Filament winding technique.

- ✓ **PULTRUSION**

Fibers are pulled from a creel through a resin bath and then on through a heated die. The die completes the impregnation of the fiber, controls the resin content and cures the material into its final shape as it passes through the die. This cured profile is then automatically cut to length. Fabrics may also be introduced into the die to provide fiber direction other than at 0°C. Although pultrusion is a continuous process, producing a profile of constant cross-section, a variant known as 'pulforming' allows for some variation to be introduced into the cross-section. The process pulls the materials through the die for impregnation, and then clamps them in a mould for curing.

Materials Options

Resins: Generally epoxy, polyester, vinylester and phenolic.

Fibers: Any.

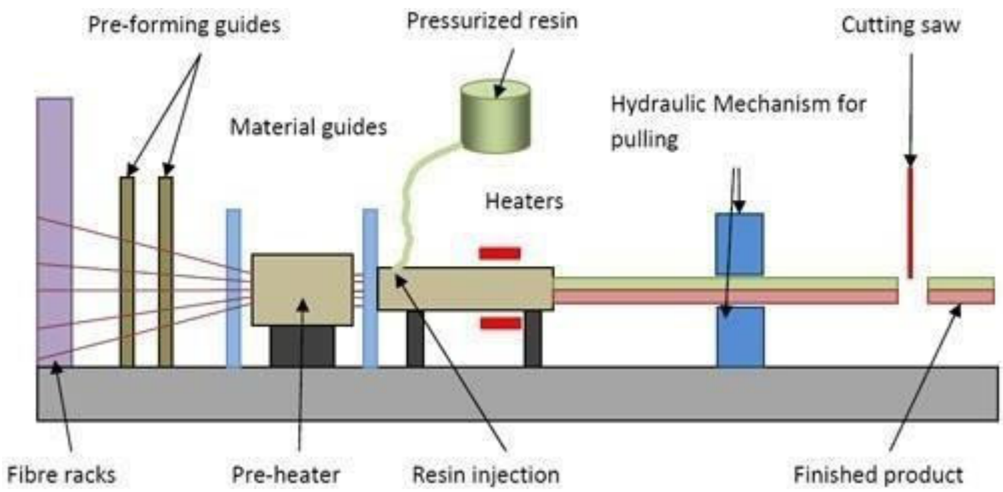

Fig.1.13 Pultrusion technique.

1.3 LITERATURE SURVEY

The following research studies give a brief idea about hybrid composites with polymer matrix composites and their mechanical, damping properties.

Madhu Vani.A et al [1] States that form the past decade, enormous work has been carried out on the characterization of the mechanical and physical properties of natural fiber reinforced polymer matrix composites in the form of short fibers, random distribution and single reinforcement by varying the weight percentage of reinforcement and different chemical treatment of fibers. The alkali treated Sisal/jute natural fibers improved the properties of the fiber. Hybrid Composites were prepared successfully without any voids by hand layup process. From the study, the density of the composites decreases by increasing in the percentage of alkali treatment, the tensile strength and flexural strength of the composites increases by increasing in the percentage of alkali treatment. Bonding between the fiber and the resin improved by the removal of moisture. The natural frequency of the composites were determined using analytical and numerical approach.

J. Alexander et al [2] reported that This work focuses to compare vibration characteristics such as natural frequency and damping coefficient of BFRP composites with GFRP composites at various fiber orientations and end conditions. Due to high damping coefficient of Basalt/epoxy composites and better vibration characteristics. This material can be used in the construction of control surfaces and high lift devices of small aircraft.

Yashwant S Munde et al [3] . Made an attempt to review some of the literature published on vibration damping applied to natural fiber-reinforced composites by experimental and numerical methods; the effects of natural fiber reinforcement on vibrational response of both thermoset and thermoplastic polymer matrix are reviewed. Discussions on the effects of several parameters are made to bring comprehensive knowledge on vibrational response of natural fiber-reinforced composites are done. On the whole, it is concluded that, a strong and thorough exploration of vibration and damping properties of the natural fiber composite is needed now. Development of new engineering/structural materials for automotive and aerospace application may be promoted with those researces.

R. Murugan et al [4] : States The mechanical properties of glass/carbon hybrid laminates, controlled with balanced modulus property, exhibited increased tensile, compressive and flexural modulus than laminates made of glass layered alone. The axial strain variation between the layers of glass and carbon fibre under tensile loading caused the marginal difference in tensile modulus between two types of hybrid laminates considered. During compression study, considerable resistance to axial compressive strain behavior was noticed for hybrid laminate GCCG H1. Due to higher modulus carbon fabric plied as inner core. In hybrid laminates, the arrangement CGGC H2 offered increase in flexural modulus of nearly about 50% increase in value, compared to the other arrangement GCCG H1.

Pushparaj Pingulkar et al [5] In this work, the natural frequencies and mode shapes of a number of cantilever glass fiber reinforced polymer composites (GFRPCs) and carbon fiber reinforced polymer composites (CFRPCs) are numerically obtained .the modal analysis was carried out using finite element software for laminated cantilever composite plates to predict the modal frequencies. Various fiber/matrix combinations were investigated for different fiber volume fractions. The effect of matrix material, hybridization and different laminate stacking sequence was also investigated.

C. Bennet et al [6] Reported that the static mechanical and modal analysis by free vibration response of hybrid natural fiber reinforced polymer composites. The study focused on the effect of the stacking sequence on the composite properties. The trend in mechanical strength followed: untreated<alkali treated<silane treated. Interestingly, regarding vibrational behavior, coconut sheath /Sansevieria cylindrica /coconut sheath offered superior natural frequency in all three conditions. A detailed investigation was done to understand the effect of hybrid and stacking sequence on the untreated and treated Sansevieria cylindrica/coconut sheath polyester composites.

K Mahesh Dutt et al [7] This work considers the Dynamic behavior of Components manufactured from Fiber-reinforced Composite Materials. Towards this, Specimens of Carbon & Kevlar fibers were manufactured using the Hand Lay-up process followed by cutting to the required dimension. Experimental Dynamic Tests were carried out using specimens of different thickness. Experimental and Finite Element Modal analysis of polymer based composites have been considered for different types of fibers with various boundary conditions and the results are compared and found to be in good agreement.

E.C. Botelho et al [8] Non-destructive testing techniques are being used in the characterization of composite materials. Among these, vibration testing is one of the most used tools because it allows the determination of the mechanical properties.the viscoelastic properties such as elastic (E0) and viscous (E00) responses were obtained for aluminum 2024 alloy; carbon fiber/epoxy; glass fiber/epoxy and their hybrids aluminum 2024 alloy/ carbon fiber/epoxy and aluminum 2024 alloy/glass fiber/epoxy composites. The damping behaviors of aluminum 2024 alloy, carbon fiber/epoxy (CF–E), glass fiber/epoxy (GF–E), aluminum 2024 alloy/carbon fiber/epoxy (Hybrid 1) and aluminum 2024 alloy/glass fiber/ epoxy composites (Hybrid 2) were investigated. The dynamic elastic modulus (E0) values from these materials were compared with the theoretical calculated values.

Pankaj Charan Jena et al [9] This research deals with the mechanical behaviour and vibration analysis of short bamboo fibre based polymer composite beam structures. The mechanical properties like tensile strength, tensile modulus is measured. The vibration analysis using analytical method and finite element method are carried out to obtain natural frequencies and mode shapes of SBFRPCB structures. The successful fabrications of a new class of polyester based composites reinforced with short bamboo fibers have been done. The present investigation revealed that 15wt% fiber loading shows superior hardness, tensile strength and impact strength. Whereas, for flexural strength show better in 10wt% of fiber loading. The tensile test and impact test of short bamboo fiber reinforced polyester composite has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties.

M Rajesha et al [10] In this influence of surface pre-treatment with sodium hydroxide and hybridization effect of natural fiber are investigated on flexural test and free vibration behavior. In this work sisal and banana natural fibers are used in short and random orientations to prepare the polymer composites using compression moulding method.

A. Atiqah et al [11], procured kenaf and glass fiber with polyester reinforced composite and processed it by holding volume fraction of 70:30 proportion for treated and untreated fibers. The hybrid composite was experimented for tensile, flexural and izod impact properties which shows 15% treated composite laminate showcased the best results in all the categories. The kenaf fiber alone (30% volume) or higher percentage (22.5% volume) can't avoid the higher impact load leading to fragility and less toughness in the composite.

K. Senthil Kumar et al [12] This work addresses the results of experimental investigation carried out on free vibration characteristics of short sisal fiber (SFPC) and short banana fiber (BFPC) polyester composites. Influence of fiber length and weight percentage on mechanical properties and free vibration characteristics are analyzed. Composite beam specimen is fabricated with random fiber orientations at17 MPa compression using compression molding machine. Natural frequencies and associated modal damping values of the composite laminates were obtained by carrying out the experimental modal analysis. It is found that an increase in fiber content increases the mechanical and damping properties. For SFPC, 3 mm fiber length and 50 wt% fiber content yielded better properties, whereas for BFPC, 4 mm fiber length and 50 wt% fiber content was the best combination. Scanning electron microscopy was performed to study the interfacial mechanism.

R. Murugan, et al [13] In this study we came to know that The influence of stacking sequence on mechanical properties of woven fabric Flax/ Sisal hybrid composite laminates were experimentally evaluated and analyzed. During axial loading condition, the difference in tensile strength among hybrid laminates, H1 and H2, is very negligible. Under the bending load condition, the desired attribute was observed over the control of stacking sequence. The flexural modulus in the arrangement FSSF, designated as H2 was noticeably high. Since the outermost layers with reference to neutral axis held by Flax fabric carrying high intrinsic modulus of elasticity facilitated to increased resistance to deflection in progressive bending load.

Md Zillur Rahman et al [14] This review shows how the composite materials influence the final properties (e.g., stiffness, strength, and damping) of a plant fibre composite. The maximum stiffness and strength can be achieved when long fibres are used, aligned in the loading direction. Bast fibres such as flax fibres are promising fibres because of their superior mechanical properties and high dynamic behaviour, which arise from their chemical compositions and hierarchical microstructure. Plant fibres are not continuous; hence, continuous UD reinforcements in the form of yarns in a fabric ensure the maximum fibre length (or aspect ratios) and high level of alignment. These are also to maximise the stiffness and strength of the composites. Increasing the fibre weight/volume fraction is highly desirable for improving the composite properties. The use of thermoplastic, such as PP, as a matrix material, is also recommended due to its good mechanical properties in addition to the high vibration-damping capability.

The sample fabrication via vacuum bagging is desirable to obtain reasonable stiffness along with high vibration damping. If the use of composite materials is for load-bearing purposes, it is better to produce FFRCs by prepregging (with autoclave consolidation). Fibres are needed to be dried prior to manufacturing the plant fibre composites. There is a potential for flax composites to substitute the conventional materials (e.g., glass fibre composites) in structural applications in terms of stiffness, strength, impact strength, and damping.

Suhad D Salman et al [15], found that, use of Kenaf/Kevlar plain weaved hybrid composite, tensile strength was improved and showed ordinary stiffness and non-performance to strain characteristics.

PEARL CHU et al [16] This study show that many different applications have increased the demandfor materials which can reduce fundamental frequencies and obtain high material damping. At present, composite materials offer the widest choicefor designing lightweight space structures that can be effectively controlled. This study presents analytical/experimental results for natural frequencies of composite beams and plates. Finite element predictions for the fundamental frequency are checked against the experimental modal analysis results for all specimens. Optimum design parameters are sought for composites in terms o f stacking sequence,jiber orientation, aspect ratio and houndary conditions. Effects o(damage on damping and vibration is illustrated with the beam specimens.

Nitesh Talekar et al [17] Tell that tFree vibration analysis of anisotropic laminated composite cantilever beam formulating finite element model in mechanical APDL ANSYS 16.2 were investigated. Various results have been included to represents the effect of the fiber lay-up angle, fiber lay-up sequence, beam geometry, material property, material anisotropy, length-to-thickness ratio and coupling on the different modes and the natural frequencies of bending, transverse and rotational vibration of the generally layered composite cantilever. This model gives reader detail knowledge of proper selection of the lay-up sequence, fiber orientation and length-to-thickness ratio to adjust any mode and natural frequency for particular geometry and material parameters to avoid the resonance. By this model, different modes of vibration can also be altered as per requirements.

Noor Haznida Bakar et al [18], contemplated various weight percentage of Kevlar reinforced Kenaf/epoxy composites, the measure of impact energy absorbed and the hardness substantially increased when the weight fraction of Kevlar was increased. The outcome displayed 20% weight percentage for Kevlar with Kenaf composites, exhibited maximum energy absorbed which was obtained as 12.76J. It has shown that the incorporation of Kevlar fiber into Kenaf composites will improve the impact properties and durability of Kenaf composites.

S. Prabhakaran et al [19] worked on vibration damping properties of flax fiber reinforced composites were characterized and compared with the glass fiber reinforced composites.. The flax fiber reinforced composites have 51.03% higher vibration damping than the glass fiber reinforced composites.

A.M. Mohd Edeeroze et al [20], studied on chemically treated Kenaf fiber, treating it with various percentage of NaOH solution (3%, 6%and 9%) and 6% with water bath, it showed that 9% NaOH solution treatment provided the clear surface to the fiber, but when treated with 6% NaOH solution it gave the best fiber tensile result as compared to other concentration. Thus 9% NaOH solution treatment was very strong and damaged the fibers, thus results in lower tensile strength.

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1.4 SCOPE OF THE THESIS

The general intend of this study is to fabricate a composite material which can be of vital importance in the automotive, aerospace and also in ships, boats and scull hulls. The scope of the project was narrowed to surfboards and automotive industries due to the projected properties and characters the composite can possess through testing.

Based on the literature survey our team had conducted suggests to consider Kenaf as natural fiber, Kevlar as synthetic fiber and unsaturated polyester resin as matrix. For this project we have opted twill weaved kenaf fiber since it is a very light weight material. Kenaf has a very good damping behavior, is very light weight and has good tensile strength. When it comes to synthetic fiber we considered Kevlar because of its excellent thermal stability and it has a high resistance towards puncture, abrasion, wear and tear. Polyester resin can be classified into two groups, namely thermosetting resin and thermoplastic resin. The reason to consider thermosetting resin is because of their thermal stability and high strength. They have less water absorption capacity, good resistance towards oil and other chemical solvents, good electrical properties, and high strength-to-weight ratios.

CHAPTER 2: METHODOLOGY

2.1. MATERIAL SELECTION

From the summary of literature, the best material which gives high damping coefficient will be selected as matrix material. The matrix may be the combination of more than two materials. The natural and synthetic fibers which have good elastic properties will be selected as reinforcement.

Materials Used

Based on the survey, the material to obtain hybrid composite was selected, the reinforcing phase is fiber, they are Kevlar- a Synthetic fiber and Kenaf- a Natural fiber was selected. Similarly, Unsaturated Polyester Resin was selected as a matrix phase. By this combination the composite laminate is fabricated.

2.1.1 KENAF (Natural fiber)

It has many positive things to replace synthetic fiber like glass fiber, Kevlar etc. The use of kenaf fiber gives good wear property tensile strength, comparable to those of synthetic fiber with lower density than traditional materials, light weight and ecofriendly polymer composites.

- **Composition**

Element	Composition (%)
Holocellulose	75.8
Alpha-cellulose	46.1
Hemicellulose	29.7
Lignin	22.1
Pentosan	20.7
Hot water	3.9
Ash	1.6

Table 2.1 Chemical composition of Kenaf fiber

2.1.2 KEVLAR (Synthetic fiber)

Kevlar is one of the good synthetic fiber with good heat resistant and strong compare with other fiber. Kevlar is used in wide area from bicycle tires, racing sails, bulletproof vests, and many more, because of its tensile strength-to-weight ratio will give more stronger than steel.

CHEMICAL STRUCTURE

Kevlar is a type of synthetic fiber; it's also called for aromatic polyamide, in which it gives molecules form long, highly-oriented chains.

Kevlar is made by a condensation reaction of an amine (1, 4-phenylene-diamine) and acid chloride (terephthaloyl chloride).

The Kevlar chains are relatively rigid and tend to form mostly planar sheets, similar to those of silk. This is due to the orientation of the benzene rings. When Kevlar is spinning the chains lock together via H bonds to form a sheet that has a very high tensile strength. The sheets also stack radically, like the spokes on a wheel, allowing additional interactions between the face-to-face aromatic groups on neighboring sheets to help to increase the strength of the overall fiber.

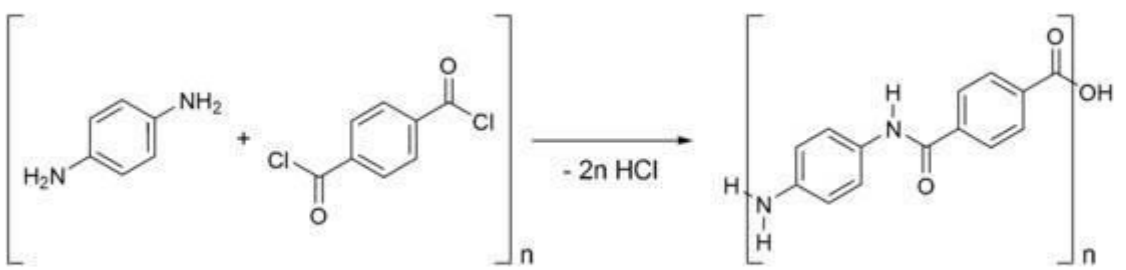

Fig 2.1 Terephthaloyl chloride

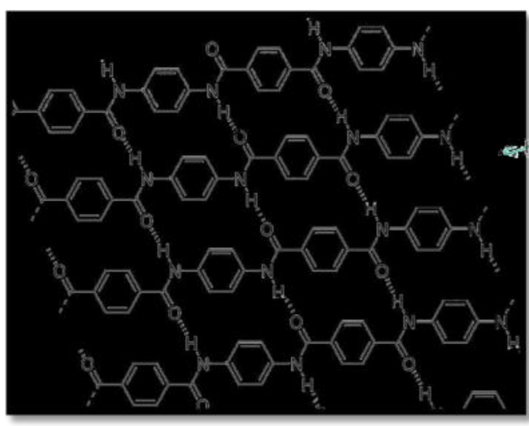

Fig 2.2 Molecular structure of Kevlar (bold represents a monomer unit, dashed lines indicate hydrogen bonds.)

Physical Properties	Metric	English
Density	1.44g/cc	0.0520 lb/ln^3
Water Absorption	3.5%	3.5%
Moisture Absorption at Equilibrium	3.5%	3.5%

Table 2.2 Physical properties

- **Advantages of Kevlar**
  - Strong but relatively light weight.
  - Bear temperature up to 450^0 C (No thermal shrinkage).
  - Kevlar can remain virtually unchanged after exposure to hot water for more than 200 days.
  - Kevlar can be ignited but burning stops when source removed.
  - Low electrical conductivity.
  - High cut resistance.

- **Disadvantages of Kevlar**
  - Very low compressive strength.
  - Quickly absorb moisture.
  - It can be difficult to cut and drill.
  - It suffers some corrosion if exposed to chlorine.

2.2 UNSATURATED POLYESTER RESIN

The polyester resin as a polymer obtained by the polycondensation reaction between polyacids and polyalcohol's. The development of water is the by-product of this polycondensation process. Specifically, the unsaturated polyester resin, also known by the English acronym UPR, is an easily printable liquid polymer which, once cured, keeps the solid shape taken in the mould. The items so realized have exceptional strength and durability characteristics. Unsaturated polyester resins are mostly used in combination with reinforcing materials such as glass fibers.

Fig 2.3 Unsaturated Polyester Resin

➢ The main features of the unsaturated polyester resins

- Poor linear shrinkage.
- Excellent wet ability of the fibers and charges.
- Cold cross-linking by addition of hardener.
- Minimisation of the effect of sagging in vertical stratification.

➢ Solid, after cross-linkage:

- Exceptional lightness.
- Rigidity.
- Good electrical insulation.
- Dimensional stability against temperature changes.
- A higher strength / weight ratio than steel.
- Resistance to chemicals.
- Excellent surface finish.
- Water repellence.
- Resistance to wear and high temperatures
- Good mechanical resistance.

The twill weaved (2*2) Kenaf (natural fiber) fabric was selected for the process to obtain better result compared to other work done on weave pattern of kenaf and plain weaved Kevlarfabric was selected as a synthetic fiber.

2.3 DIFFERENCE BETWEEN PLAIN AND TWILL WEAVE

➢ Plain Weave

Each fiber passes alternately under and over each fiber. The fabric is symmetrical, with good stability and reasonable porosity. However, it is the most difficult of the weaves to drape, and the high level of fiber crimp imparts relatively low wear property compared with the other weave styles.

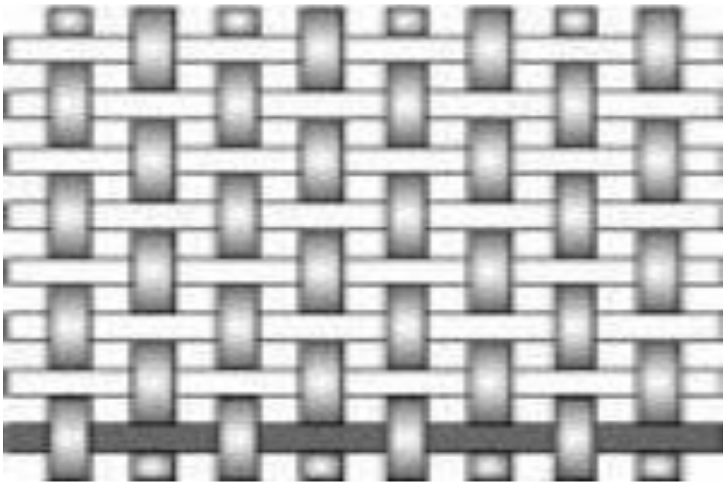

Fig 2.4 Plain weave

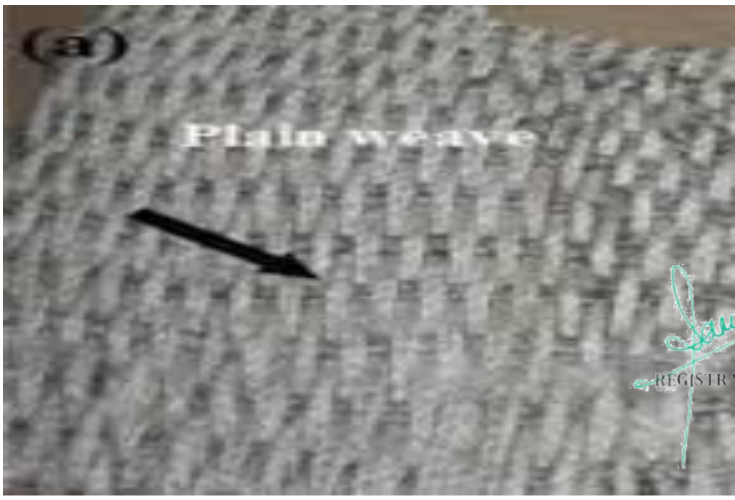

Fig2.5 Plain weave

➢ Twill Weave

One or more fibers alternately weave over and under two or more weft fibers in a regular repeated manner. This produces the visual effect of a straight or broken diagonal 'rib' to the fabric. Superior wet out and drape is seen in the twill weave over the plain weave with only a small reduction in stability. With reduced crimp, the fabric also has a smoother surface.

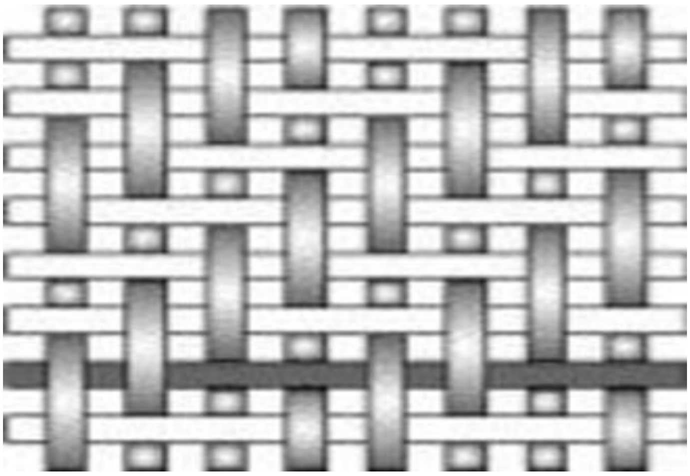

Fig 2.6. Twill weave

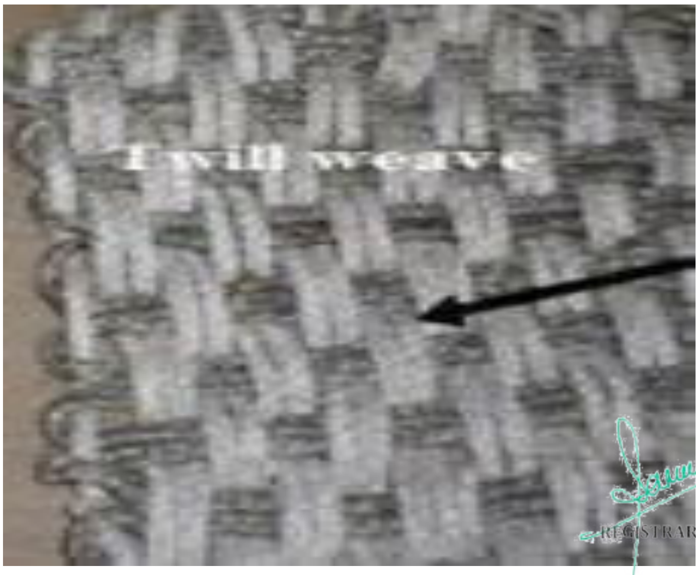

Fig2.7 Twill weave

Except these there are few more weave modes are there like Satin, Basket, Leno, Mock Leno.

Property	Plain	Twill	Satin	Basket	Leno	Mock leno
Good stability	****	***	**	**	*****	***
Good drape	**	****	*****	***	*	**
Low porosity	***	****	*****	**	*	***
Smoothness	**	***	*****	**	*	**
Balance	****	****	**	****	**	****
Symmetrical	*****	***	*	***	*	****
Low crimp	**	***	*****	*	**/*****	**
*****=excellent, ****=Good, ***=acceptable, **=poor, *= very Poor						

Table 2.3 Properties of weaves

2.4 FABRICATION PROCESS

As the materials are finalized, the fabrication method is also selected in order to obtain a sustainable composite laminate, thus hand layup method followed by Autoclave curing process was adopted to the fabrication process.

2.4.1 HAND LAYUP TECHNIQUE

Hand layup method is one of the simplest and oldest methods in the fabrication field. The products are done under by curtail steps.

- The first stage is avoid the sticking of polymer into the surface of mould. By using anti adhesive agent into the mould surface, we can achieve the non-sticky surface mould.
- Then a tin plastic sheet or glass should place on the bottom and top of the mould plate to get a smooth surface of the final product.
- Cut the fabric as per the requirement and place on the surface of the mould. Hear the fabric cut in the dimension of 300x300 mm rectangular shape.
- Apply the resin on the top of fabric and after that sequentially place the fabric up to five layers in different sequence.
- The layers of each fiber is altered, arranged in different sequence and fabricated, hence five composite laminates.
- The hand rollers are used to roll the wet composite to ensure an enhanced interaction between the reinforcement and the matrix, to ensure a uniform resin distribution, avoid the air gaps, and to obtain the required thickness.
- The sequential arrangement of layers is as shown in the Table 7.

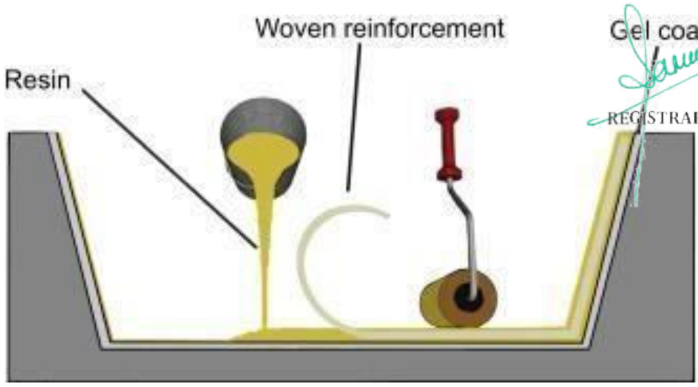

Figure 2.8. Hand layup mould

Laminates	Designations
L1	Kv+Kv+Kv+Kv+Kv (Polyester resin)
L2	Kf+Kf+Kf+Kf+Kf (Polyester resin)
L3	Kf+Kv+Kf+Kv+Kf (Polyester resin)
L4	Kv+Kf+Kv+Kf+Kv (Polyester resin)
L5	Kv+Kf (45^0)+Kf+Kf (-45^0)+Kv (Polyester resin)
*Kv- Kevlar fabrics, *Kf-Kenaf fabrics	

Table 2.4 Sequential arrangement fabric layer by layer for composite laminate

Fig 2.9 Dimensional cutting of fiber

Fig 2.10 First layer of woven fiber

Fig 2.11 Resin application the resin

Fig 2.12 Sequentially spreading by roller.

2.4.2 AUTOCLAVE CURING PROCESSING PROCESS

For maximizing the performance of thermo set composite materials should increase the fiber to resin ratio and avoid the air voids (air bubbles in the final product will affect the quality of the composite material). This can be done by proper pressure and temperature to the material. Here the material to elevate under the pressure of 93 atm and temperature 300^0C. As described in the vacuum bagging section, some pressure can be exerted by applying a vacuum to a sealed bag containing the resin/fiber layup. However, to achieve three dimensional, uniform pressures of greater than 1 bar, additional external pressure is required. The most controllable method of achieving this for an infinite variety of different shapes and sizes is by applying a compressed gas into a pressure vessel containing the composite layup. In practice, this is achieved in an autoclave.

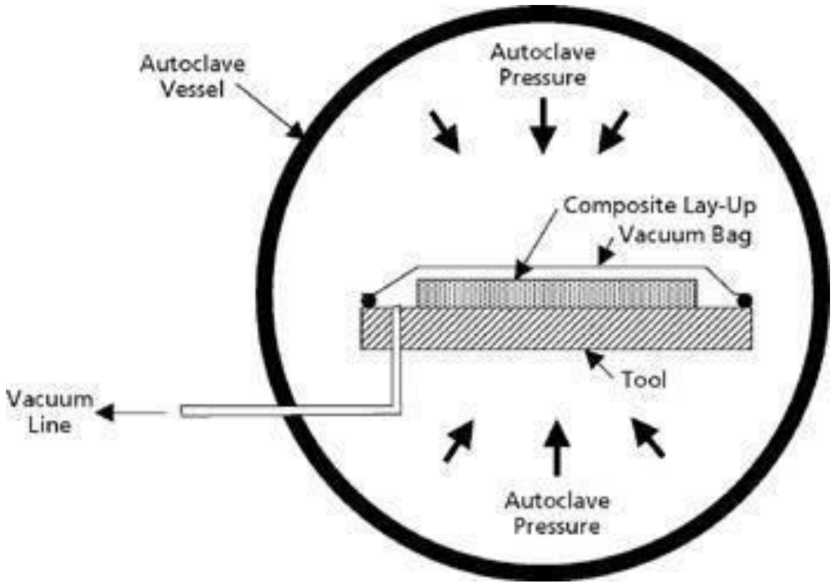

Fig 2.13 Autoclave curing schematic diagram

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WHAT IS VIBRATION

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The word comes from Latin vibrational ("shaking, brandishing"). The oscillations may be periodic, such as the motion of a pendulum—or random, such as the movement of a tire on a gravel road.

Vibration can be desirable: for example, the motion of a tuning fork, the reed in a woodwind instrument or harmonica, a mobile phone, or the cone of a loudspeaker.

In many cases, however, vibration is undesirable, wasting energy and creating unwanted sound. For example, the vibrational motions of engines, electric motors, or any mechanical device in operation are typically unwanted. Such vibrations could be caused by imbalances in the rotating parts, uneven friction, or the meshing of gear teeth. Careful designs usually minimize unwanted vibrations.

The studies of sound and vibration are closely related. Sound, or pressure waves, are generated by vibrating structures (e.g. vocal cords); these pressure waves can also induce the vibration of structures (e.g. ear drum). Hence, attempts to reduce noise are often related to issues of vibration.

WHAT IS VIBRATION ANALYSIS

Vibration Analysis (VA), applied in an industrial or maintenance environment aims to reduce maintenance costs and equipment downtime by detecting equipment faults]VA is a key component of a condition monitoring (CM) program, and is often referred to as predictive maintenance (PdM). Most commonly VA is used to detect faults in rotating equipment (Fans, Motors, Pumps, and Gearboxes etc.) such as Unbalance, Misalignment, rolling element bearing faults and resonance conditions.

VA can use the units of Displacement, Velocity and Acceleration displayed as a time waveform (TWF), but most commonly the spectrum is used, derived from a fast Fourier transform of the TWF. The vibration spectrum provides important frequency information that can pinpoint the faulty component.

The fundamentals of vibration analysis can be understood by studying the simple Mass-spring-damper model. Indeed, even a complex structure such as an automobile body can be modeled as a "summation" of simple mass–spring–damper models. The mass–spring–damper model is an example of a simple harmonic oscillator. The mathematics used to describe its behavior is identical to other simple harmonic oscillators such as the RLC circuit.

2.5 FREE VIBRATION.

The term *free vibration* is used to indicate that there is no external force causing the motion, and that the motion is primarily the result of initial conditions, such as an initial displacement of the mass element of the system from an equilibrium position and/or an initial velocity. The free vibration is said to be *undamped free vibration* if there is no loss of energy throughout the motion of the system. This is the case of the simplest vibratory system, which consists of an inertia element and an elastic member which produces a restoring force which tends to restore the inertia element to its equilibrium position. Dissipation of energy may be caused by friction or if the system contains elements such as dampers which remove energy from the system. Free vibration occurs when there is no external force causing the motion, and the vibration of the system is caused by the initial displacement of the system from the equilibrium position. A plucked guitar string is an example of free vibration. When a force is applied to the string initially and then removed, the vibration that persists on the string is called free vibration. The frequency with which the system vibrates is called natural frequency.

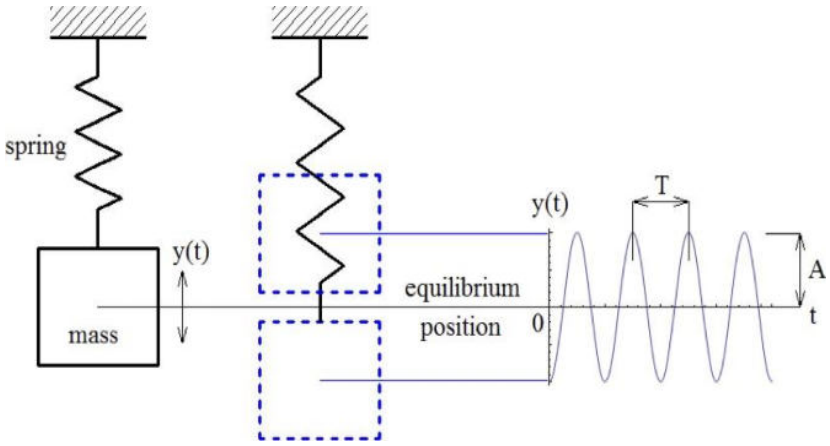
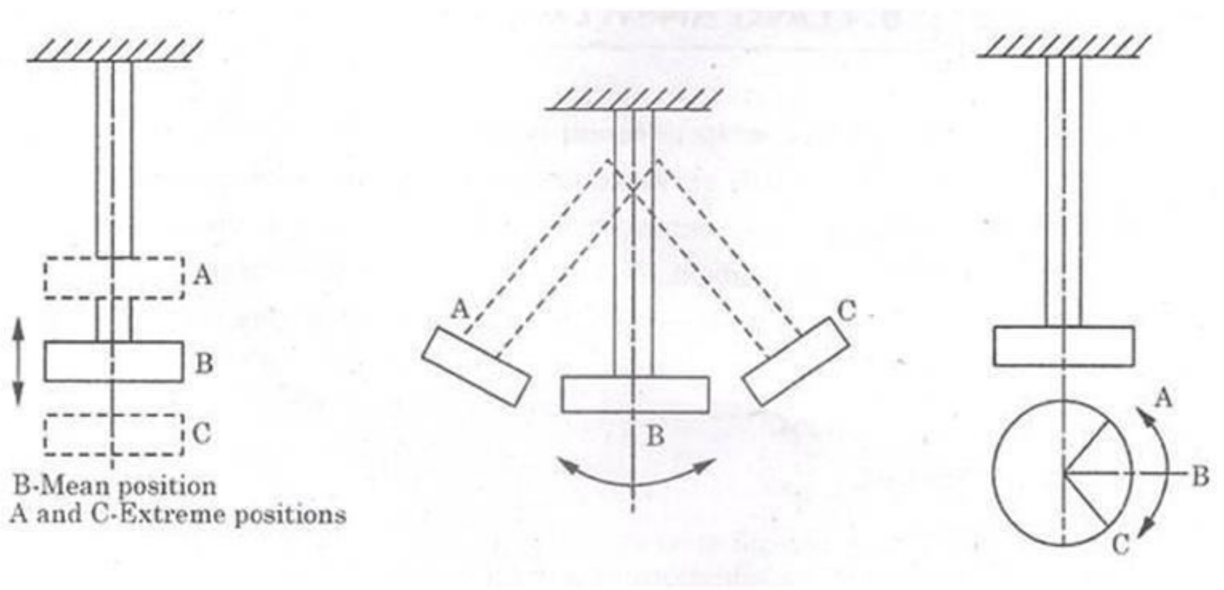


FIG 2.14 Free Vibration Block Diagram

2.5.1 TYPES OF FREE VIBRATION.

- Longitudinal Vibration
- Transverse Vibration
- Torsional Vibration.



LONGITUDINAL VIBRATION TRANSVERSE VUBRATION TORSIONALVIBRATION

FIG 2.15 Types of Vibration

- **Longitudinal Vibration:** In this, the particles of the shaft or disc move parallel to the axis of the shaft as shown in the diagram. In this case, the shaft is elongated and shortened alternately thus executing the tensile and compressive stresses alternately on the shaft.

- **Transverse Vibration:**In this, the particles of the shaft or disc move perpendicular to the axis of the shaft as shown in the diagram.Here the shaft is straight and bent alternatively and hence bending stresses are induced in the shaft.

- **Torsional Vibration:** In this, the particles of the shaft or disc move in a circle about axis of the shaft as shown in the diagram.Here the shaft is twisted and untwisted alternatively and hence torsional shear stress is induced in the shaft.

➢ DAMPED VIBRATION :

When there is a loss of energy during vibration then it is free damped vibration. To start the investigation of the mass–spring–damper assume the damping is negligible and that there is no external force applied to the mass (i.e. free vibration). The force applied to the mass by the spring is proportional to the amount the spring is stretched "x" (assuming the spring is already compressed due to the weight of the mass). The proportionality constant, k, is the stiffness of the spring and has units of force/distance (e.g. lbf/in or N/m). The negative sign indicates that the force is always opposing the motion of the mass attached to it.

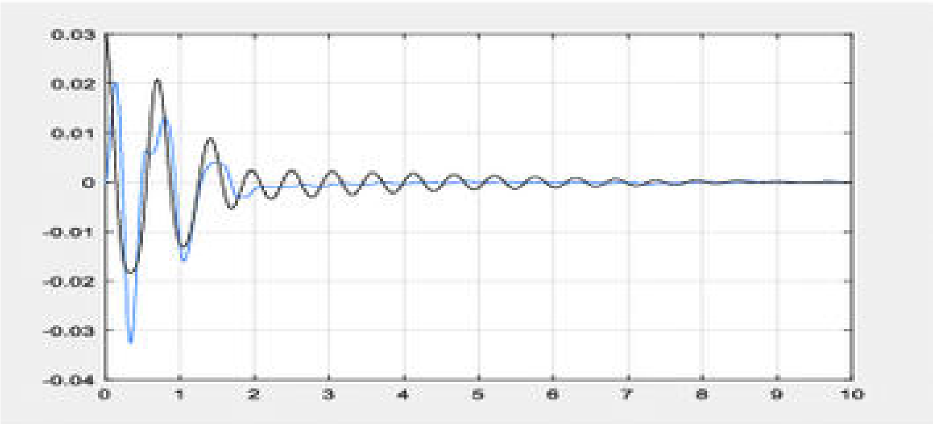


FIG 2.16 DAMPED VIBRATION

➢ UNDAMPED VIBRATION:

If there is no loss of energy throughout the motion of the system, then it is called free undamped vibration. When a “viscous” damper is added to the model this outputs a force that is proportional to the velocity of the mass. The damping is called viscous because it models the effects of a fluid within an object. The proportionality constant c is called the damping coefficient and has units of Force over velocity

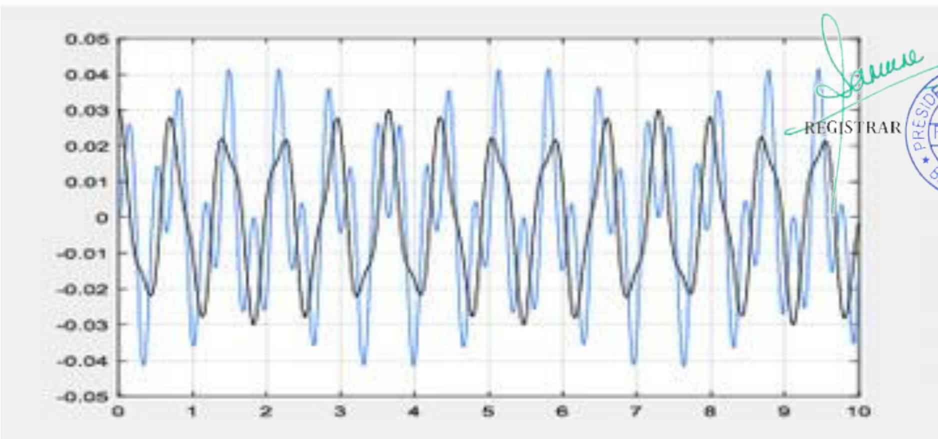


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FIG 2.17 UNDAMPED VIBRATION

2.6 IMPACT HAMMER TEST

This is often also known as Modal Testing. It is a method of testing that allows us to calculate the natural frequencies (modes), modal masses, modal damping ratios and mode shapes of a test structure. This is commonly done using either impact hammer testing or shaker testing. Here we are going to deal only with impact hammer testing.

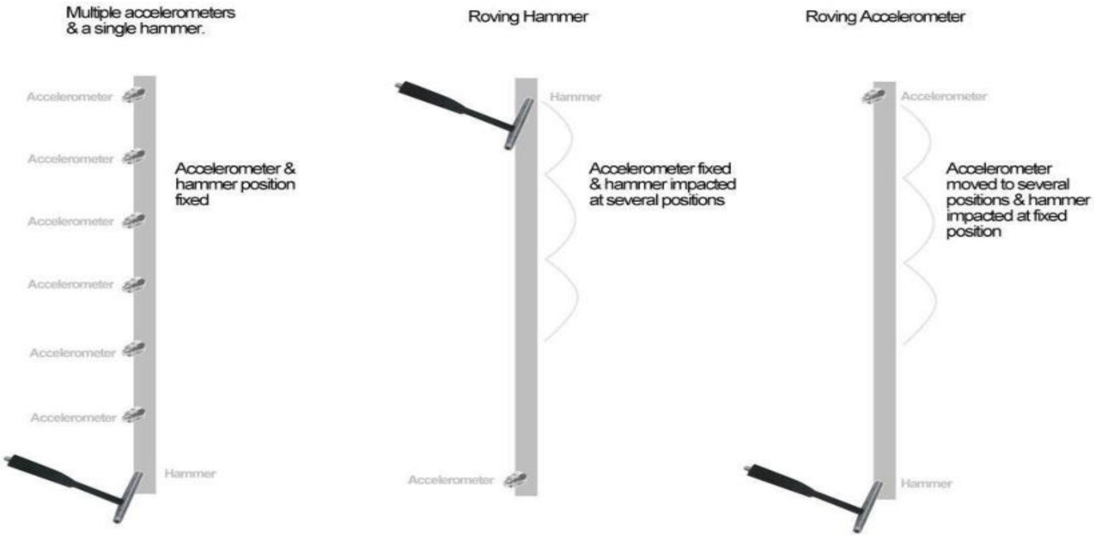
In theory, we would impact the structure under test with a perfect impulse. This would be of infinitely short duration. This would result in a constant amplitude in the frequency domain. Of course, in real life, such an impulse is not possible. Instead, we have a known contact time. The duration of this time is directly linked to the frequency content of the force applied. In hammer impact testing (modal testing) we use a special hammer with a load cell in its tip to measure the force of the impact.

So, to test the structure we need to use the instrumented hammer to generate our impulse and then measure the response. This needs to be done at several points on the structure. There are several ways we can instrument this:

Place accelerometers at many positions on the structure and impact once. This is very time efficient as it requires a single impact and data capture. In reality, we would perform a few impacts in order to perform averaging, but it is still a very quick test. However, this would require a large investment in transducers and an equally large investment in a measurement system with enough channels to simultaneously record all of our responses.

We could fix a single accelerometer to one position and then impact our structure at several locations. This is known as a 'roving hammer' test. This uses the least resources, but takes longer as we have to make several measurements. This is the most common form of hammer impact testing.

Finally, we could impact our structure at a fixed position and move a single accelerometer around several positions. This is known as a 'roving accelerometer' test. While this is still efficient in terms of transducers and measurement system, it is least efficient in terms of time since moving an accelerometer is time consuming. This method is usually used in situations where space considerations make it possible to fix accelerometers, but there is not enough space to use a hammer.



Three different instrumentation configurations for performing a hammer impact test on a simple vertical beam **FIG 2.18**

ACCELEROMETER

An accelerometer is a tool that measures proper acceleration. Proper acceleration is the acceleration (the rate of change of velocity) of a body in its own instantaneous rest frame; this is different from coordinate acceleration, which is acceleration in a fixed coordinate system.

FIG 2.19 ACCELEROMETER

DATA ACQUISITION SYSTEM

Data acquisition is process of sampling signals that measures real world physical condition and converting the resulting samples into digital numeric value that can be manipulated by computer. It abbreviated by the acronyms DAS or DAQ , typically convert analog waveforms into digital values for processing . Its applications are usually controlled by software programs developed using various general purpose programming language such as ASSEMBLY, BASIC, C, C++, FORTRAN, JAVA and many more.

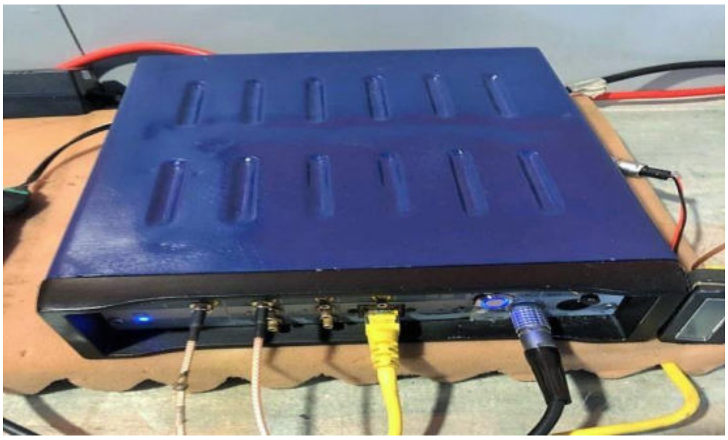


FIG 2.20 DATA ACQUISITION SYSTEM

HAMMER

FIG 2.21 Hammer used in experiment

In hammer impact testing (modal testing) we use a special hammer with a load cell in its tip to measure the force of the impact. So, to test the structure we need to use the instrumented hammer to generate our impulse and then measure the response. This needs to be done at several points on the structure. There are several ways we can instrument this: Place accelerometers at many positions on the structure and impact once.

A modal impact hammer test is broadly classified between two types: roving hammer and roving response. Each method has its own pros and cons.

Implementing the aforementioned methods to perform measurements in one direction (usually out-of-plane) using a single uni-axial accelerometer yields a row of FRF when roving hammer, or a column of FRF when roving sensor. In the case of a FRF column, it is necessary to switch the response and excitation of the DOF of each FRF signal to yield a row of FRF. Curve fitting the row of measured FRFs produces the modal parameters of the test structure.

However, some tests may use more than one accelerometer or measure data in more than one direction. Even though the basics are still the same, care must be taken while performing the experiment to ensure that there is either a complete row or a complete column of the frequency response function. If the resulting FRF signals does not contain this, then the natural frequencies, mode shapes and damping of the structure cannot be obtained.

Roving excitation – response measurement point is fixed (say point 3), and the hammer is roved over the entire structure. The disadvantage of this approach is long test durations. Another downside is that it might be difficult to excite structures with complex geometries. However, this approach does not induce any mass loading effect.

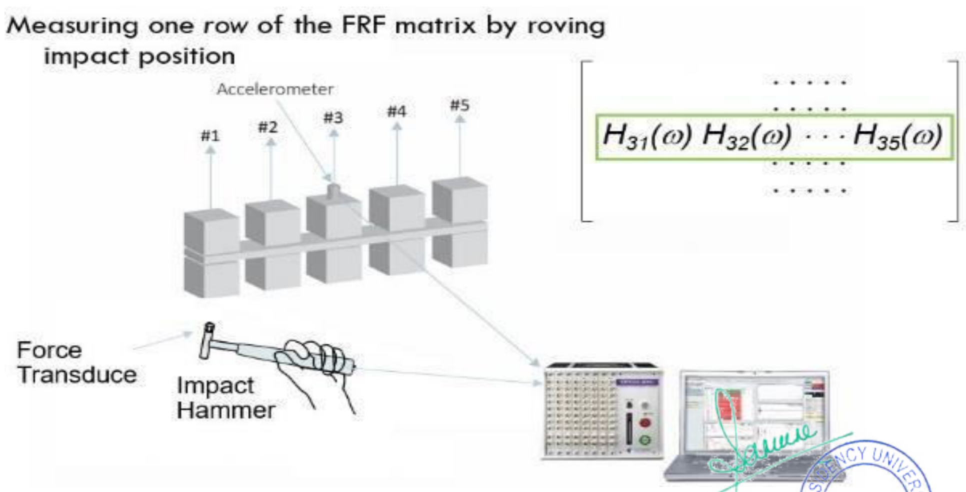


FIG 2.22 Roving excitation test

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Roving response – the excitation point is fixed (say point 1), and the sensor is roved over the structure. This approach helps overcome the problem of achieving perpendicular impacts on intricate structures. Also, if multiple sensors are used then the experimentation times are reduced. However, roving the sensor induces a mass loading effect which affects the accuracy of the results.

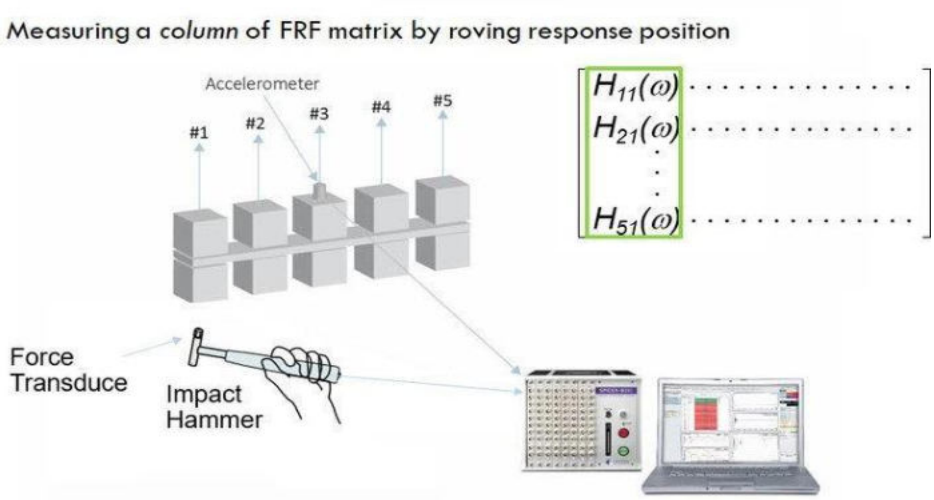


FIG 2.23 Roving response test

APPROPRIATE

- Sensors , to convert physical parameters to electrical signals.
- Signal conditioning circuitry , to convert sensors into form that can be converted to a digital values.
- Analog to digital converters , to convert conditioned sensors signal to digital values.

- **EXEPERIMENTAL SETUP**

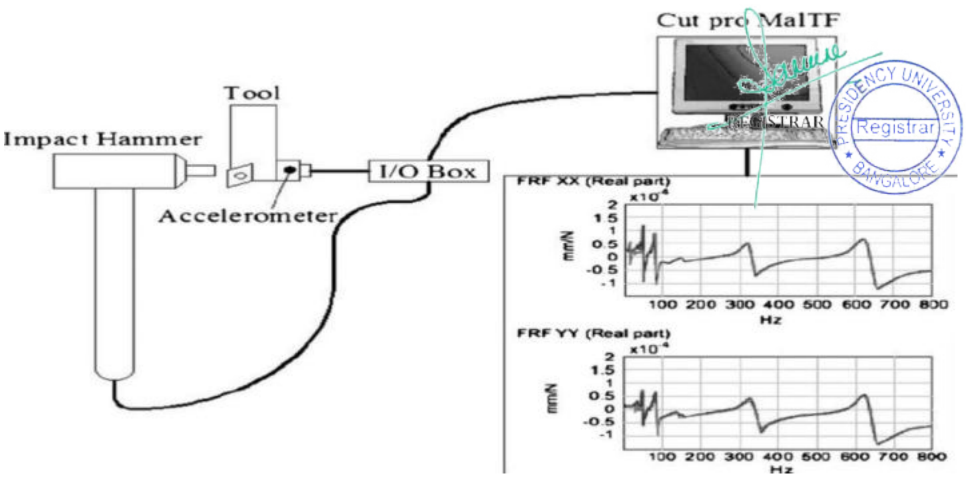


FIG 2.24 EXEPERIMENTAL SETUP

➢ BEAMS

Beams are structural members that have smaller dimensions of cross sections compared to its length (its axis) and are subjected to loads perpendicular to its axis; i.e. they are subjected to transverse loads. The whole beam deforms in the plane containing the axis and the transverse loads. We say that the beam bends. The beams are usually supported at both ends and they are termed differently depending on the support conditions. When one end of a beam is fixed, and the other free, it is called a Cantilever beam, or simply a Cantilever. When both end-supports re simple, the beam is called a Simply Supported Beam. If both ends of a beam are fixed, it is a Fixed-Fixed Beam or simply a Fixed Beam.

➢ Cantilever beam:

A cantilever beam is a rigid structural element that is supported at one end and free at the other. It is a horizontal beam structure whose free end is exposed to vertical loads. When a cantilever is given an impact at some point, it is set into vibration. In general, the cantilever will not vibrate in any one single natural mode with corresponding single natural frequency of vibration. Rather, number of modes will participate in its vibration depending on the point of impact with corresponding natural frequencies as components of the periodic vibration. In an impact test, an accelerator is fitted at some point on the cantilever and the cantilever is hit with an impact hammer giving an impulse to the cantilever. FFT analysis of the signal received from the load cell fitted at the tip of the impact hammer reveals that it contains all frequencies over a range. Similarly, the FFT analysis of the signal will also reveal that it contains all those frequencies but amplitude of vibration corresponding to the natural frequencies will be high. Exactly this phenomenon is used to identify the natural frequencies of the cantilever by impact test. Ratio of signals received from the accelerometer and that of the impact hammer is taken in frequency domain which is called FRF (Frequency Response Function). The accelerometer is fixed at one point on the cantilever and impulse is given at predetermined points with the impulse hammer. Corresponding FRFs are computed using the software of modal analysis. Using techniques of curve fitting, Modal Identification Function is generated that shows peaks at the natural frequencies with the selected range of frequencies. And thus the natural frequencies of the cantilever are found by the impact test.

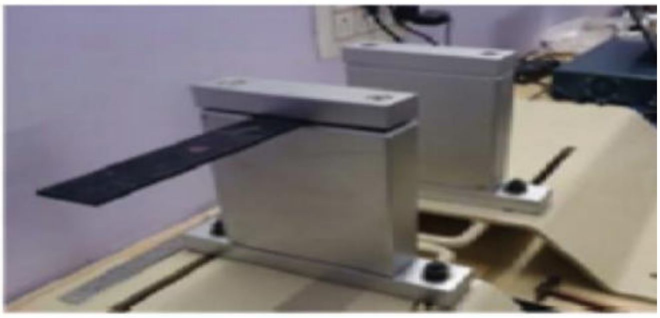


FIG 2.25 CANTILEVER BEAM

.

- **Fixed-Fixed beam:**

  A beam that is supported at both free ends and is restrained against rotation and vertical movement. A beam that is fixed at both ends is called a fixed beam. Fixed beams are not allowed the vertical movement or rotation of the beam. In this beam, no bending moment will produce. Fixed beams are only under the shear force and are generally used in the trusses and like other structures. Both ends of the beam rigidly fixed with supports. A fixed support let the beam to resist vertical, horizontal forces as well as moment. Fixed support is also referred to as rigid support. It resists rotation as well as displacement. So, a simplest structure can take a fixed beam only to support itself.

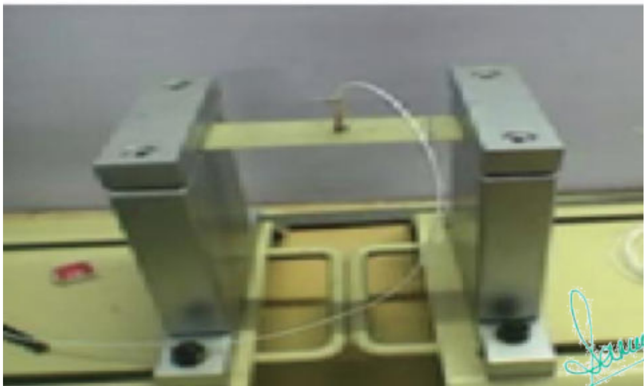


FIG 2.26 FIXED FIXED BEAM

- **Water absorption Test:**

  Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environments

- **ASTM D570 STANDARD**

The purpose of ASTM D570 is to determine the rate of absorption of water by immersing the specimen in water for a specific period of time. More specifically, this test protocol evaluates the percentage increase in weight of the sample following the experiment as a means to characterize this attribute. Furthermore, this standard details many procedures in order to properly address a wide range of materials through the adjustment of the period of immersion and of the temperature of water. As a matter of fact, the reason why there is a variety of methods is due to the fact that each material has a different rate of assimilation of water and it is necessary to alter the test conditions accordingly. Moreover, it is important to assess this attribute, because polymers have a tendency to soak up water and this propensity may lead to an alteration of the properties of the plastic. Indeed, attributes such as: electrical insulation resistance and mechanical strength are tightly associated with the moisture content of that kind of material. Lastly, it is important to keep in mind that the specimen does not necessarily assimilate water in a uniform manner, therefore it is essential to appraise that aspect with this test.

The main factors that are to be considered when running this test are: the time of immersion, the temperature of the water, the thickness of the sample and the type of material.

FIG 2.27 WATER ABSORPTION TEST

SPECIMEN DIMENSION:

- **FREE VIBRATION:** As per machine standard (Senthil Kumar et al.) [11]
  - ✓ **CANTILEVER BEAM**: 200mm x 20mm x Thickness
  - ✓ **FIXED FIXED BEAM:** 200mm x 20mm x Thickness

- **WATER ABSORPTION TEST:** ASTM D570-30mm x 28mm x Thickness

Laminates	Thickness
L1	3 mm
L2	5 mm
L3	4 mm
L4	3.5 mm
L5	4.5 mm

TABLE 2.5 Thickness of laminates

CHAPTER 3: EXPERIMENTATION, RESULTS AND DISCUSSION

3.1 EXPERIMENTATION OF IMPACT HAMMER TEST

3.1.1 CANTILEVER BEAM

The specimen is connected to the bench wise and the other end is suspended freely. The sensor is connected to the at the end of the suspended region which is connected to the Data acquisition system to which the impact hammer is also connected .

The DQS system collects the data from the hammer and the sensor analyses it and interprets it on a computer thus the results are obtained the experiment was conducted on the L1 L2 L3 L4 and L5 laminates

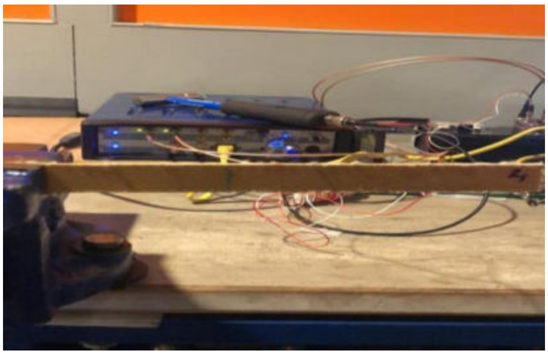


FIG 3.1 LAMINATE 1 OF CANTILEVER BEAM

FIG 3.2 LAMINATE 2 OF CANTILEVER BEAM

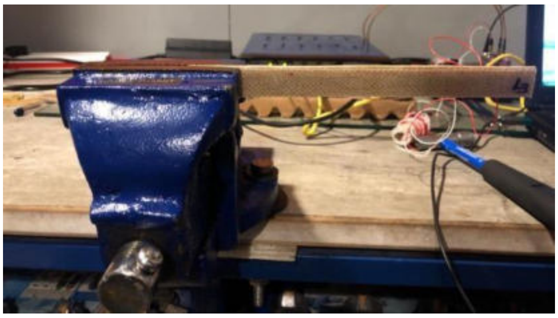


FIG 3.3 LAMINATE 3 OF CANTILEVER BEAM

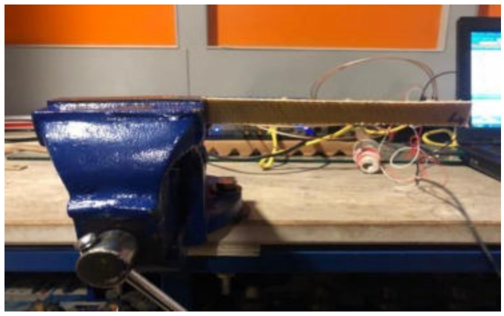


FIG 3.4 LAMINATE 4 OF CANTILEVER BEAM

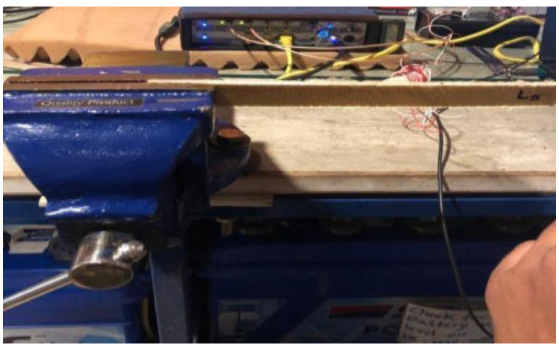


FIG 3.5 LAMINATE 5 OF CANTILEVER BEAM

FIG 3.6 ALL LAMINATE OF CANTILEVER

3.1.2 FIXED FIXED BEAM

The specimen was supported using two bench wise and the sensor was attached to the specimen which was connected to the Data acquisition system along with the impact hammer the experiment was conducted and the singles were received by the DQS system which was analysed and interpreted on the computer thus the results were obtained. The experimentation was conducted on laminates, L1, L2, L3, L4 AND L5.

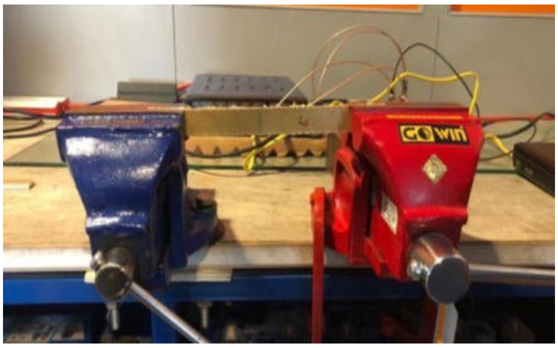


FIG 3.7 LAMINATE 1 OF FIXED-FIXED BEAM

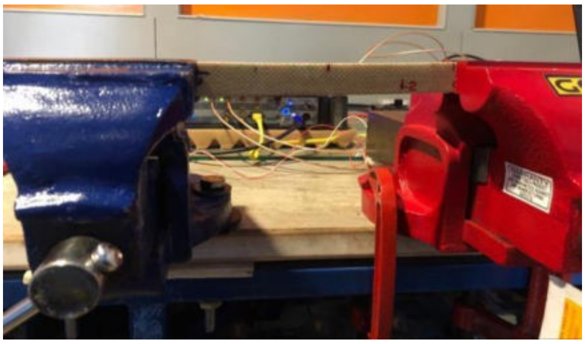


FIG 3.8 LAMINATE 2 OF FIXED-FIXED BEAM

FIG 3.9 LAMINATE 3 OF FIXED-FIXED BEAM

FIG 3.10 LAMINATE 4 OF FIXED-FIXED BEAM

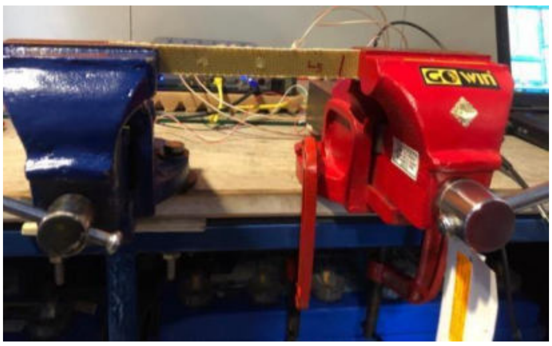


FIG 3.11 LAMINATE 5 OF FIXED-FIXED BEAM

FIG 3.12 ALL LAMINATE OF FIXED-FIXED

3.1.3 WATER ABSORPTION TEST.

We conducted water absorption test by immersing the entire specimens in 3 types of water that are Salt water, normal water and distilled water at room temperature for time durations of 120 days. The sample were taken out and dried with absorbent paper and reweighed. In most studies, the presence of natural fibers commonly increases the water absorption. This test is conducted according to ASTM D570 standard.

FIG 3.13 WATER ABSORPTION TESTING

3.2 RESULTS AND DISCUSSION

DAMPING RATIO

The damping ratio is a parameter, usually denoted by ζ (zeta), that characterizes the frequency response of a second order ordinary differential equation. It is particularly important in the study of control theory . It is also important in the harmonic oscillator. The damping ratio determines the way the system oscillations go to zero. To understand damping ratio. Resonance will occur in any undamped element that obey's Hooke's law when it is vibrated at or close to its natural frequency, and can be unpredictable. Long-term exposure to moderate levels of resonance or instantaneous exposure to excessive resonance will result in premature failure.

$$\frac{d^2x}{dt^2} + 2\zeta\omega_0 \frac{dx}{dt} + \omega_0^2 x = 0$$

Where:

$\omega_0 = \sqrt{\frac{k}{m}}$ the **natural frequency** in radians

$\zeta = \frac{c}{2\sqrt{mk}}$ the **damping ratio**

FIG 3.14 FORMULA FOR CALCULATING THE DAMPING RATIO

Vibration damping is the reduction or avoidance of resonance and can be achieved by any of the following actions:

1) Altering the natural frequency of the sprung system (i.e. to a different frequency)

2) Altering the stiffness of the sprung system

3) Altering the location of the repeated load

4) Reducing the magnitude of the repeated load

5) Reducing the dynamic amplification of the repeated load

- **Damping Ratio (ζ)**

This is the ratio of operational damping to critical damping (ζ = C:Cc)

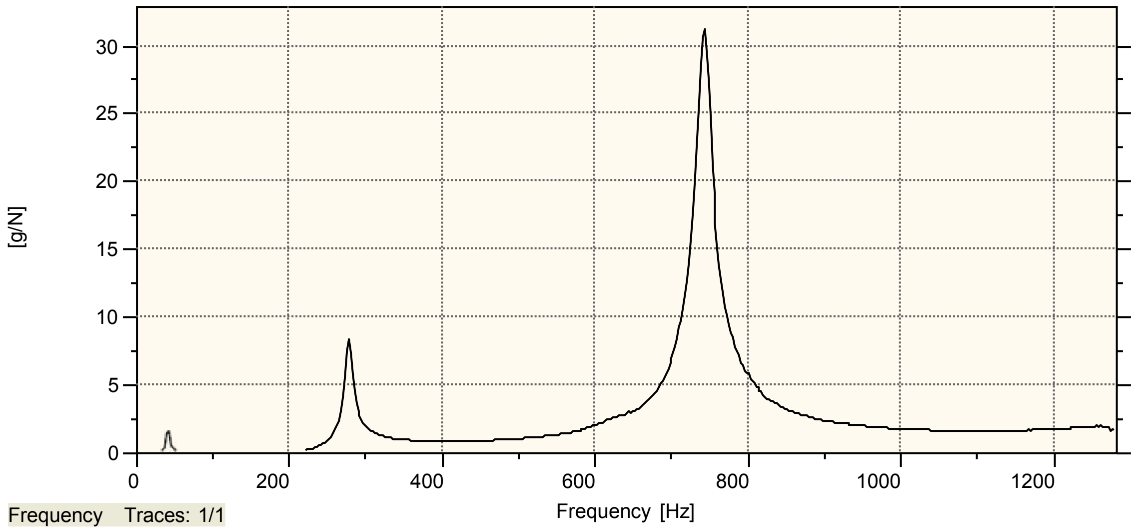
A system that is,

Overdamped ; ζ > 1.0

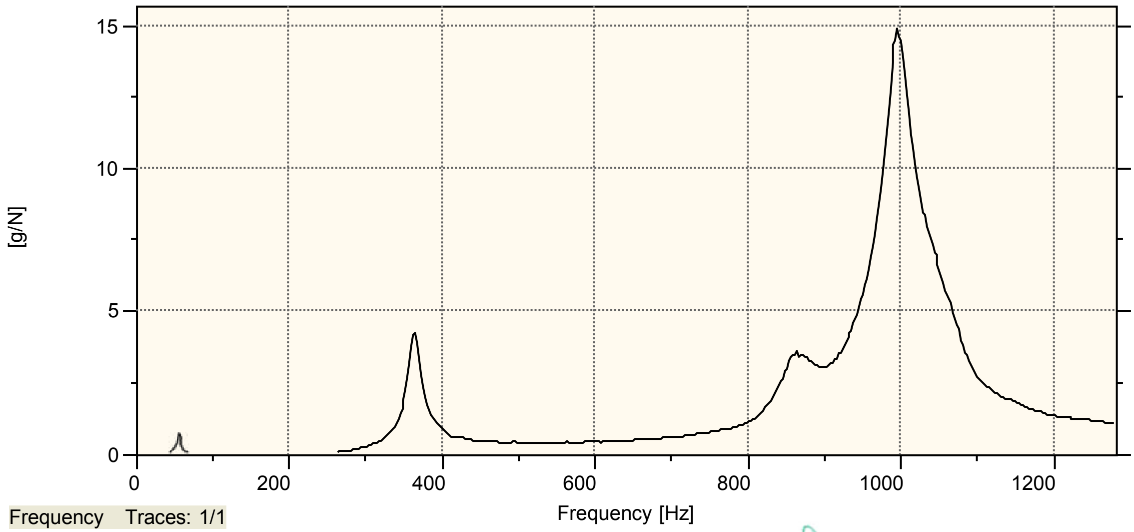
fully damped ; ζ = 1.0

underdamped; ζ < 1.0

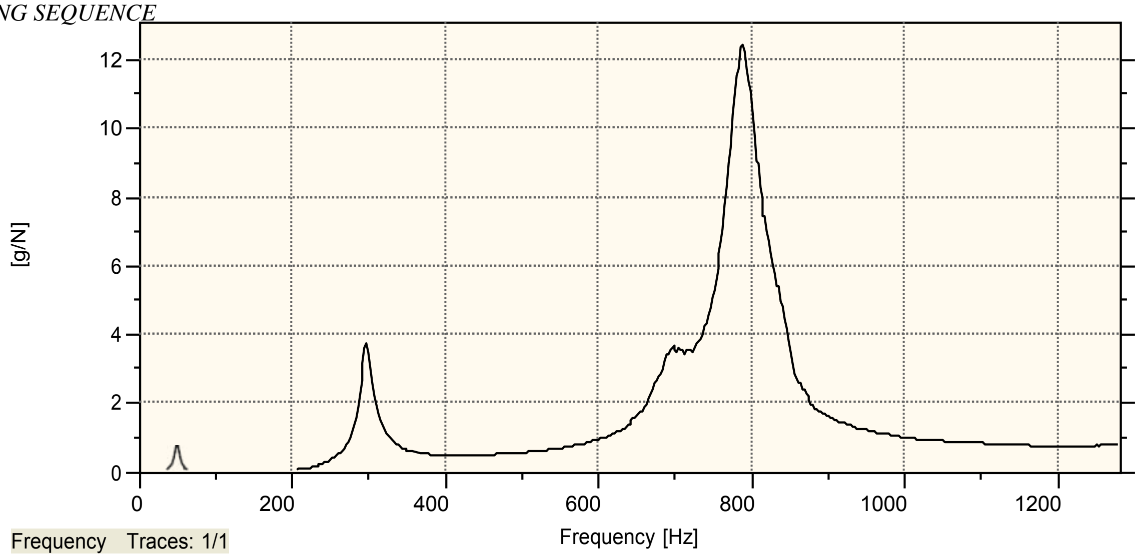
3.2.1 CANTILEVER BEAM



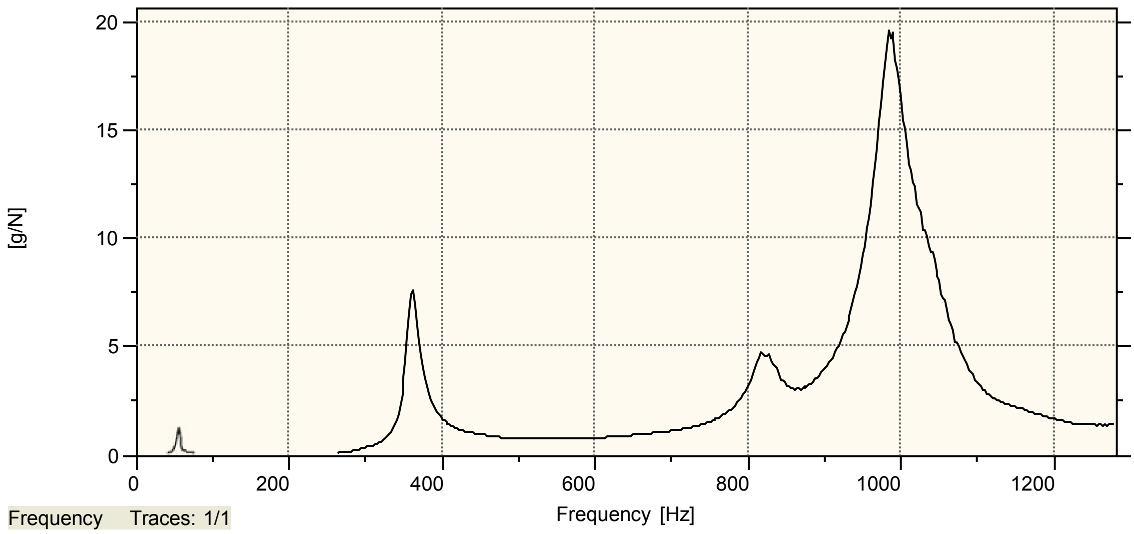
Graph 1: Vibration Acceleration vs Frequency (FRF) data of Cantilever- L1



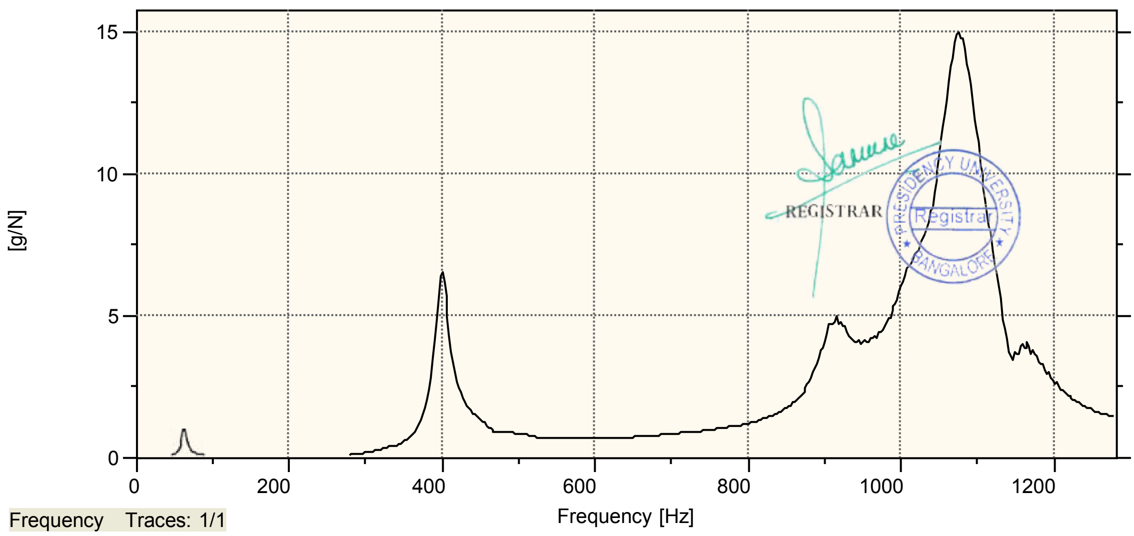
Graph 2: Vibration Acceleration vs Frequency (FRF) data of Cantilever - L2



Graph 3: Vibration Acceleration vs Frequency (FRF) data of Cantilever - L3

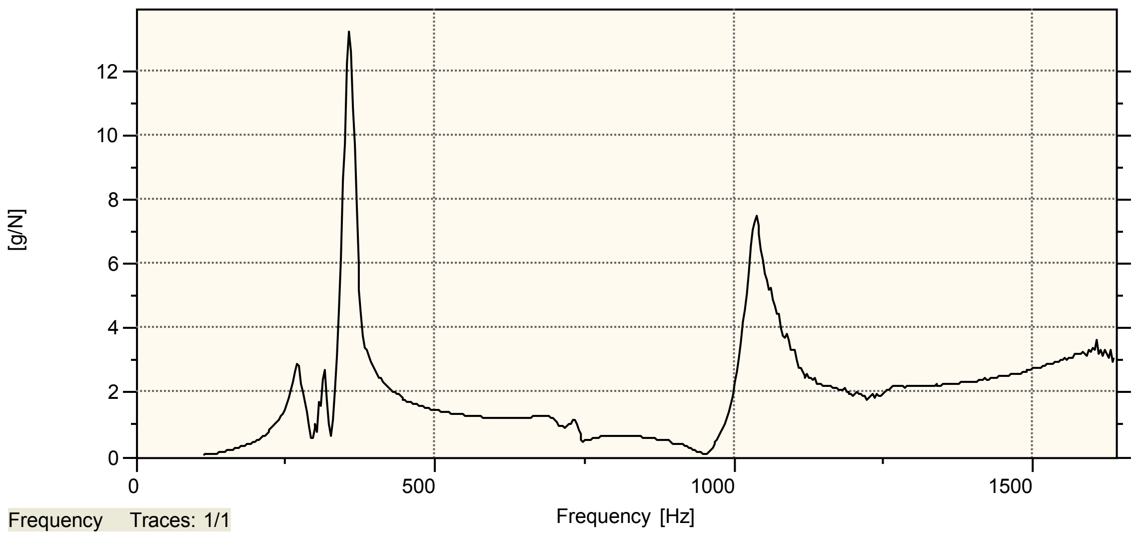


Graph 4: Vibration Acceleration vs Frequency (FRF) data of Cantilever - L4

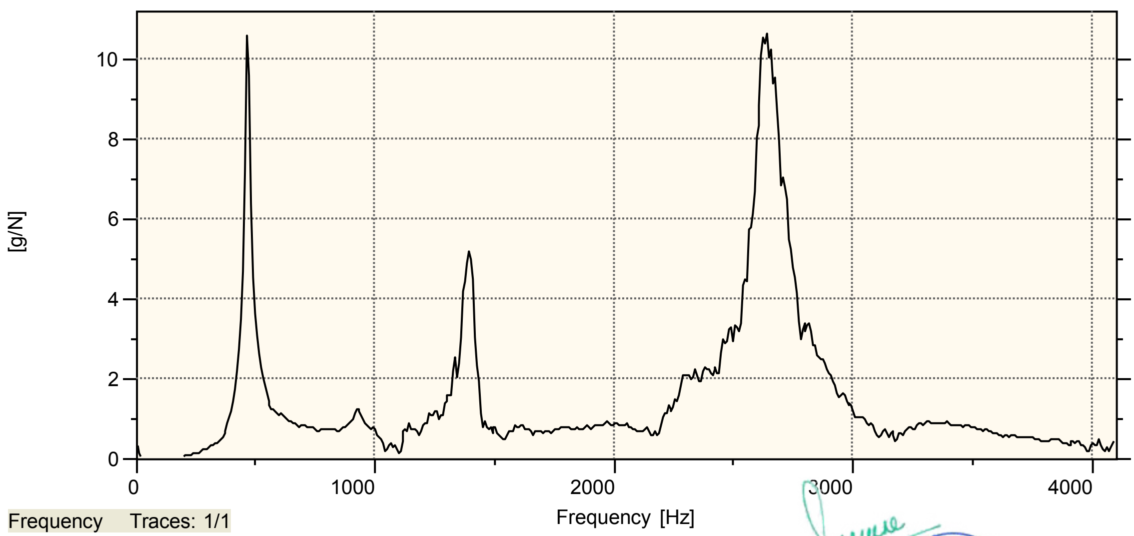


Graph 5: Vibration Acceleration vs Frequency (FRF) data of Cantilever - L5

3.2.2 FIXED FIXED BEAM.



Graph 6: Vibration Acceleration vs Frequency (FRF) data of Fixed-fixed L1



Graph 7: Vibration Acceleration vs Frequency (FRF) data of Fixed-fixed L2

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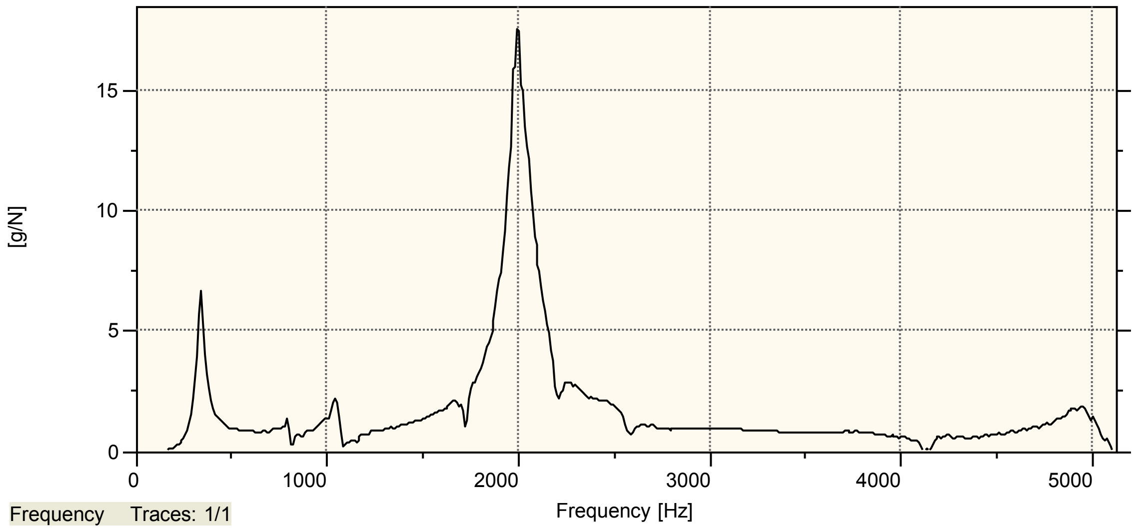
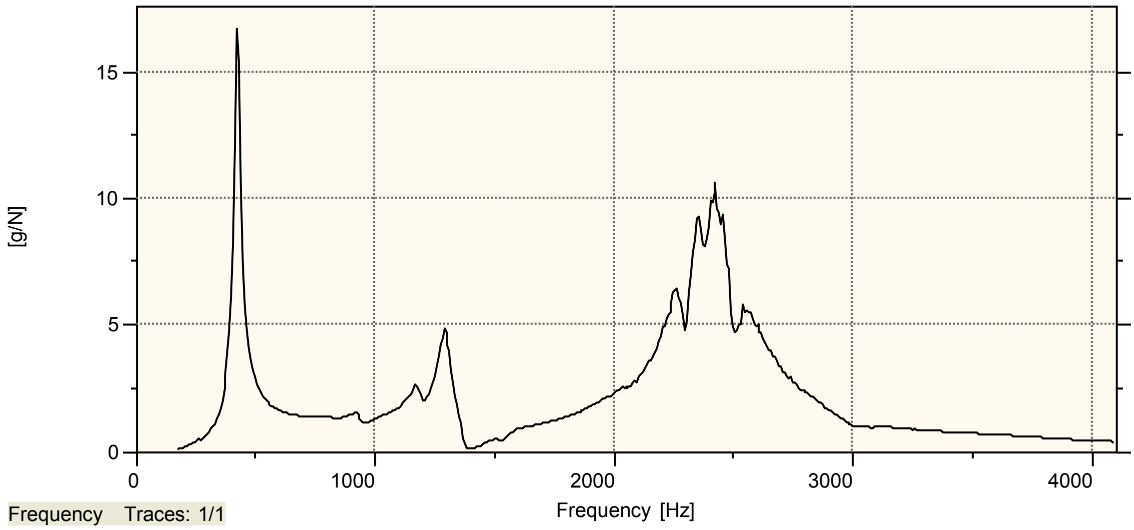
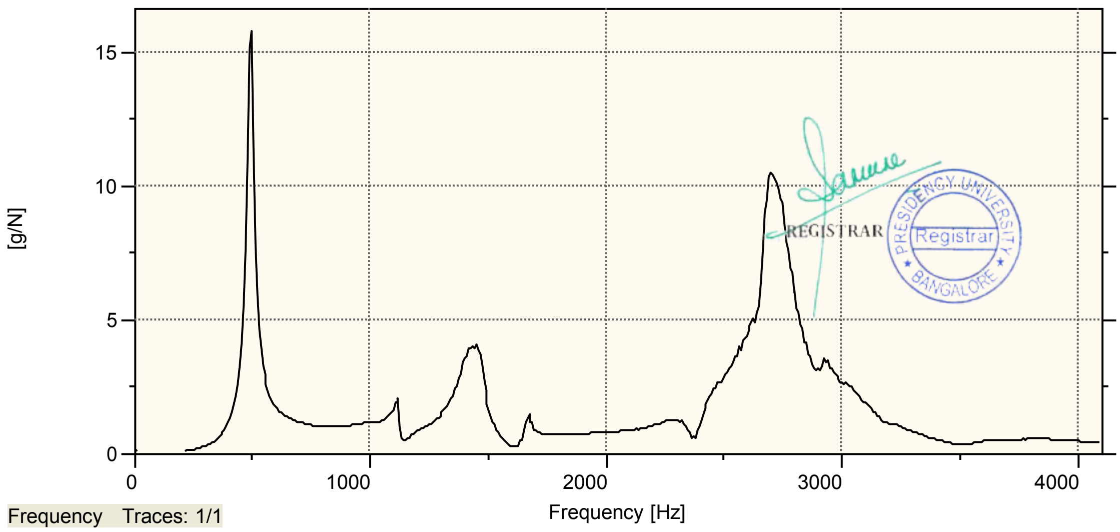


Graph 8: Vibration Acceleration vs Frequency (FRF) data of Fixed-fixed L3



Graph 9: Vibration Acceleration vs Frequency (FRF) data of Fixed-fixed L4



Graph 10: Vibration Acceleration vs Frequency (FRF) data of Fixed-fixed L5

3.2.3 WATER ABSORPTION TEST.

Due to sudden closure of the research lab due to pandemic lockdown announced by the state govt. where water absorption test specimens were kept. The readings cannot be recorded hence the work will be continued after the removal of lockdown.

CHAPTER 4: CONCLUSION

This project mainly focused on fabrication of natural and synthetic fibers i.e. Kenaf and Kevlar fiber reinforced with unsaturated polyester resin implemented for matrix phase using HAND LAYUP method followed by AUTOCLAVE method.

The vibration behavior of all five laminates L1, L2, L3, L4, L5 were evaluated using impact hammer testing in CANTILEVER BEAM and FIXED BEAM for all five laminates.

Graph for Vibration acceleration vs Frequency (FRF-frequency response function) data of cantilever beam and fixed beam is obtained in three modes using LMS TEST EXPRESS. The damping ratio for cantilever beam and fixed beam for all five laminates showed that the laminate L5 showed good damping coefficient. The results also showed that stacking sequence of L5 laminate has influenced the results.

4.1. SCOPE OF FUTURE WORK

The laminates L1, L2, L3, L4 and L5 were proposed for the resistance testing, since due to the pandemic crisis the testing was not carried out and was unsuccessful. In future we will definitely test the specimens for fire resistance, water absorption and obtain results with respect to given parameters and based on the results obtained.

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A Project Report on

"PRODUCTION AND CHARACTERIZATION OF SILICON CARDIBE REINFORCED TITANIUM BASED METAL MATRIX COMPOSITES"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2

in

Mechanical Engineering

Submitted by

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VIJAYKUAMR T MIRASHI	**20181LME0046**
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Under the Supervision of

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(Department of Mechanical Engineering)

Presidency University

(Private University Estd. in Karnataka State by Act No.41 of 2013)

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REACH GREATER HEIGHTS

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Department of Mechanical Engineering

School of Engineering Itgalpura, Rajanukunte, Bengaluru-560064

2020-21

CERTIFICATE

Certified that, the project work entitled, **"PRODUCTION AND CHARACTERIZATION OF SILICON CARDIBE REINFORCED TITANIUM BASED METAL MATRIX COMPOSITES"** carried out by Mr/Miss. Siddharth V Ghadi ID 20181LME0045,Vijaykumar T Mirashi, ID 20181LME0046, Gautham R, ID 20181LME0048, M Nagaraj, ID 20181LME0052, Vinod Reddy, ID 20181LME0053 bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2021-2022. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Satish Babu B

Mr. /Dr Satish Babu B

Supervisor

Dr. Ramesh S

Prof. and Head of Department

Signature with date

End Term Examination

Examiner

1.Mr.Sandeep G M Sandeep

2.Mr.Basavaraj Devakki Baswaraj

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DECLARATION

We, the students of fifth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled,"" has been successfully completed under the supervision of **Dr. Satish Babu B**, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2018-2019. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place : Bengaluru

Date:

Team members	**ID number**	**Signature of the Student**
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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. Satish Babu B** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. Ramesh S,** Prof. and Head**,** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Ramesh. S.P,** who gave us the opportunity to do this project work. We also take this opportunity to thank **Mr. Chikke Gowda,** Lab Instructor, for helping us in getting weight measurements of the samples.

Lastly, we would like to thank our family and friends

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ABSTRACT

Pure aluminium(Al), vanadium(V) and titanium(Ti) powders having 99.7 % purity were purchased. The purchased powders were subjected foe EDS analysis for checking the purity. SiC powder was also purchased in the powder form and subjected to EDS analysis for checking the purity. SiC was used as reinforcement.

A die was prepared for compacting the metal powders. Powders were ball milled (1 hour, 200 rpm) at a predetermined speed for a specific time. The Ti, Al, and V powders were compacted in the die using a hydraulic press for with a specific load to produce Ti-6Al-4V alloy. The metal powders were carefully weighed for attaining the composition related to Ti-6Al-4V alloy and compacted in the die. The compact was removed and sintered at a temperature of 525 degree centigrade for 25 minutes.

SiC reinforcement in varying content was added to the alloy and compacted in the die and sintered in the same way. Microstructural characterization was carried out Scanning Electron Microscopy. The images exhibited uniform distribution of particles. Hardness tests were conducted using Rockwell Hardness Tester to find the hardness of the alloy and the composite. It was found that the hardness of the composite improved with the increasing content of the SiC reinforcement.

INTRODUCTION

1.1 Composite

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from individual components. Within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

The many component materials and different processes that can be used make composites extremely versatile and efficient. They typically result lighter, stronger, more durable solutions compared to traditional materials. Composites contain fillers or nano-material such as Graphene carbon, glass, polymer or natural fibres. The properties and performance of composite are far superior to those of the constituents. Composite consist of one or more discontinuous phase (reinforcement) embedded in a continuous phase (matrix).Most of made of two materials. One is the matrix or brinder. It surrounds and and binds together fibres or fragment of the other material, which is called the reinforcement. Conventional monolithic materials have limitation in achieving good combination of strength, stiffness toughness and density. Dicontinuosly reinforced MMCs were fabricated through a variety of techniques like mechanical alloying, spray deposition, compocasting, rheocasting, powder metallurgy and squeeze casting.

1.1.1 Characteristics of Composites

Composite are multifunctional material system that provides characteristics of not obtainable from any discrete material. The composite properties may the volume fraction sum of properties of the constituent the nature of constituent material .

- The shape of the discontinuous phase the size and size distribution and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix.
- These consist of at least two different species with a well defined interface
- These have at least one property not possessed by the individual constituents.
- Their properties are influenced by the volume percentage of ingredients.

1.1.2 Performance of Composite

1. Properties of matrix and reinforcement,
2. Size and distribution of constituents,
3. Shape of constituents,
4. Nature of interface between constituents.

The resinous binders (polymer matrices) are selected on the basis of adhesive strength, fatigue resistance, heat resistance, chemical and moisture resistance etc. Use of non-reinforced polymer as structure material is limited by low level of their mechanical properties such as tensile strength of one of the strongest polymer-epoxy resin is 2000 psi (140MP). The resinous binders (polymer matrices) are selected on the basis of adhesive strength, fatigue resistance, heat resistance, chemical and moisture resistance etc. The resin must 7 have mechanical strength commensurate with that of the reinforcement.

1.2 Powder metallurgy

Powder metallurgy can be defined as a science of metal powders and using them to manufacture useful materials and objects. Powder metallurgy is the process of mixing elemental or powder alloys, the compact mixture in a die, and then heating or sintering the shapes in an controlled atmosphere using furnace. Most metallurgical powder parts weighs less then 2.25kg, parts weighing 15.89kg can be fabricated in conventional metallurgical powder. Many of the metallurgical powder, such as bushing and bearing are very simple intricate shapes and this is the sophisticated metallurgical powder.

The first consideration in metallurgical powder used for manufacturing processes there are several different measures and initiatives are used to quantify the properties of powder. Powder can be pure alloys or pure elements a powder might be a mixture of different kinds of powders. This can have various types of oxidation, results example oxygen present in the atmosphere

1.2.1 History and capabilities

The history of powder metallurgy and the art of metal and ceramic sintering are intimately related to each other. Sintering involves the production of a hard solid metal or ceramic piece from a starting powder. The ancient Incas made jewelry and other artifacts from precious metal powders, though mass manufacturing of PM products did not begin until the mid or late 19th century. In these early manufacturing operations, iron was extracted by hand from metal sponge following reduction and was then reintroduced as a powder for final melting or sintering.

A much wider range of products can be obtained from powder processes than from direct alloying of fused materials. In melting operations the "phase rule" applies to all pure and combined elements and strictly dictates the distribution of liquid and solid phases which can exist for specific compositions. In addition, whole body melting of starting materials is required for alloying, thus imposing unwelcome chemical, thermal, and containment constraints on manufacturing. Unfortunately, the handling of aluminium/iron powders poses major problems. Other substances that are especially reactive with atmospheric oxygen, such as titanium, are sinterable in special atmospheres or with temporary coatings.

In powder metallurgy or ceramics it is possible to fabricate components which otherwise would decompose or disintegrate. All considerations of solid-liquid phase changes can be ignored, so powder processes are more flexible than casting, extrusion, or forging techniques. Controllable characteristics of products prepared using various powder technologies include mechanical, magnetic, and other unconventional properties of such materials as porous solids, aggregates, and intermetallic compounds. Competitive characteristics of manufacturing processing (e.g. tool wear, complexity, or vendor options) also may be closely controlled.

1.2.2 Powder production techniques

Any fusible material can be atomized. Several techniques have been developed which permit large production rates of powdered particles, often with considerable control over the size ranges of the final grain population. Powders may be prepared by crushing, grinding, chemical reactions, or electrolytic deposition. The most commonly used powders are copper-base and iron-base materials.

Powders of the elements titanium, vanadium, thorium, niobium, tantalum, calcium, and uranium have been produced by high-temperature reduction of the corresponding nitrides and carbides. Iron, nickel, uranium, and beryllium submicrometre powders are obtained by reducing metallic oxalates and formats. Exceedingly fine particles also have been prepared by directing a stream of molten metal through a high-temperature plasma jet or flame, atomizing the material. Various chemical and flame associated powdering processes are adopted in part to prevent serious degradation of particle surfaces by atmospheric oxygen.

In tonnage terms, the production of iron powders for PM structural part production dwarfs the production of all of the non-ferrous metal powders combined. Virtually all iron powders are produced by one of two processes: the sponge iron process or water atomization.

Sponge iron process

The longest established of these processes is the sponge iron process, the leading example of a family of processes involving solid state reduction of an oxide. In the process, selected magnetite (Fe_3O_4) ore is mixed with coke and lime and placed in a silicon carbide retort. The filled retort is then heated in a kiln, where the reduction process leaves an iron "cake" and a slag. In subsequent steps, the retort is emptied, the reduced iron sponge is separated from the slag and is crushed and annealed.

The resultant powder is highly irregular in particle shape, therefore ensuring good "green strength" so that die-pressed compacts can be readily handled prior to sintering, and each particle contains internal pores (hence the term "sponge") so that the good green strength is available at low compacted density levels.

Sponge iron provides the feedstock for all iron-based self-lubricating bearings, and still accounts for around 30% of iron powder usage in PM structural parts.

Atomization

Atomization is accomplished by forcing a molten metal stream through an orifice at moderate pressures. A gas is introduced into the metal stream just before it leaves the nozzle, serving to create turbulence as the entrained gas expands (due to heating) and exits into a large collection volume exterior to the orifice. The collection volume is filled with gas to promote further turbulence of the molten metal jet. Air and powder streams are segregated using gravity or cyclonic separation. Most atomized powders are annealed, which helps reduce the oxide and carbon content. The water atomized particles are smaller, cleaner, and nonporous and have a greater breadth of size, which allows better compacting. The particles produced through this method are normally of spherical or pear shape. Usually, they also carry a layer of oxide over them.

There are three types of atomization:

- Liquid atomization
- Gas atomization
- Centrifugal atomization

Simple atomization techniques are available in which liquid metal is forced through an orifice at a sufficiently high velocity to ensure turbulent flow. The usual performance index used is the Reynolds number R = fvd/n, where f = fluid density, v = velocity of the exit stream, d = diameter of the opening, and n = absolute viscosity. At low R the liquid jet oscillates, but at higher velocities the stream becomes turbulent and breaks into droplets. Pumping energy is applied to droplet formation with very low efficiency (on the order of 1%) and control over the size distribution of the metal particles produced is rather poor. Other techniques such as nozzle vibration, nozzle asymmetry, multiple impinging streams, or molten-metal injection into ambient gas are all available to increase atomization efficiency, produce finer grains, and to narrow the particle size distribution. Unfortunately, it is difficult to eject metals through orifices smaller than a few millimeters in diameter, which in practice limits the minimum size of powder grains to approximately 10 µm. Atomization also produces a wide spectrum of particle sizes, necessitating downstream classification by screening and remelting a significant fraction of the grain boundary.

Centrifugal disintegration

Centrifugal disintegration of molten particles offers one way around these problems. Extensive experience is available with iron, steel, and aluminium. Metal to be powdered is formed into a rod which is introduced into a chamber through a rapidly rotating spindle. Opposite the spindle tip is an electrode from which an arc is established which heats the metal rod. As the tip material fuses, the rapid rod rotation throws off tiny melt droplets which solidify before hitting the chamber walls. A circulating gas sweeps particles from the chamber. Similar techniques could be employed in space or on the Moon. The chamber wall could be rotated to force new powders into remote collection vessels, and the electrode could be replaced by a solar mirror focused at the end of the rod.

An alternative approach capable of producing a very narrow distribution of grain sizes but with low throughput consists of a rapidly spinning bowl heated to well above the melting point of the material to be powdered. Liquid metal, introduced onto the surface of the basin near the center at flow rates adjusted to permit a thin metal film to skim evenly up the walls and over the edge, breaks into droplets, each approximately the thickness of the film.

Other techniques

Another powder-production technique involves a thin jet of liquid metal intersected by high-speed streams of atomized water which break the jet into drops and cool the powder before it reaches the bottom of the bin. In subsequent operations the powder is dried. This is called water atomization. The advantage of water atomization is that metal solidifies faster than by gas atomization since the heat capacity of water is some magnitudes higher than gases. Since the solidification rate is inversely proportional to the particle size, smaller particles can be made using water atomization. The smaller the particles, the more homogeneous the micro structure will be. Notice that particles will have a more irregular shape and the particle size distribution will be wider. In addition, some surface contamination can occur by oxidation skin formation. Powder can be reduced by some kind of pre-consolidation treatment, such as annealing used for the manufacture of ceramic tools.

1.2.3 Powder compaction

Powder compaction is the process of compacting metal powder in a die through the application of high pressures. Typically the tools are held in the vertical orientation with the punch tool forming the bottom of the cavity. The powder is then compacted into a shape and then ejected from the die cavity. In a number of these applications the parts may require very little additional work for their intended use; making for very cost efficient manufacturing.

The density of the compacted powder increases with the amount of pressure applied. Typical pressures range from 80 psi to 1000 psi (0.5 MPa to 7 MPa), pressures from 1000 psi to 1,000,000 psi have been obtained. Pressure of 10 t/in² to 50 t/in² (150 MPa to 700 MPa) are commonly used for metal powder compaction. To attain the same compression ratio across a component with more than one level or height, it is necessary to work with multiple lower punches. A cylindrical workpiece is made by single-level tooling. A more complex shape can be made by the common multiple-level tooling.

Production rates of 15 to 30 parts per minute are common.

There are four major classes of tool styles: single-action compaction, used for thin, flat components; opposed double-action with two punch motions, which accommodates thicker components; double-action with floating die; and double action withdrawal die. Double action classes give much better density distribution than single action. Tooling must be designed so that it will withstand the extreme pressure without deforming or bending. Tools must be made from materials that are polished and wear-resistant.

Better workpiece materials can be obtained by repressing and re-sintering.

Figure: 1.1 Die pressing

Die pressing

The dominant technology for the forming of products from powder materials, in terms of both tonnage quantities and numbers of parts produced, is die pressing. There are mechanical, servo-electrical and hydraulic presses available in the market, whereby the biggest powder throughput is processed by hydraulic presses. This forming technology involves a production cycle comprising:

- Filling a die cavity with a known volume of the powder feedstock, delivered from a fill shoe.
- Compaction of the powder within the die with punches to form the compact. Generally, compaction pressure is applied through punches from both ends of the toolset in order to reduce the level of density gradient within the compact.
- Ejection of the compact from the die, using the lower punch(es) withdrawal from the die.

- Removal of the compact from the upper face of the die using the fill shoe in the fill stage of the next cycle, or an automation system or robot.

This cycle offers a readily automated and high production rate process.

Design considerations

Probably the most basic consideration is being able to remove the part from the die after it is pressed, along with avoiding sharp corners in the design. Keeping the maximum surface area below 20 square inches (0.013 m^2) and the height-to-diameter ratio below 7-to-1 is recommended. Along with having walls thicker than 0.08 inches (2.0 mm) and keeping the adjacent wall thickness ratios below 2.5-to-1.

One of the major advantages of this process is its ability to produce complex geometries. Parts with undercuts and threads require a secondary machining operation. Typical part sizes range from 0.1 square inches (0.65 cm^2) to 20 square inches (130 cm^2). in area and from 0.1 to 4 inches (0.25 to 10.16 cm) in length. However, it is possible to produce parts that are less than 0.1 square inches (0.65 cm^2) and larger than 25 square inches (160 cm^2). in area and from a fraction of an inch (2.54 cm) to approximately 8 inches (20 cm) in length.

Isostatic pressing

In some pressing operations, such as hot isostatic pressing (HIP) compact formation and sintering occur simultaneously. This procedure, together with explosion-driven compressive techniques is used extensively in the production of high-temperature and high-strength parts such as turbine disks for jet engines. In most applications of powder metallurgy the compact is hot-pressed, heated to a temperature above which the materials cannot remain work-hardened. Hot pressing lowers the pressures required to reduce porosity and speeds welding and grain deformation processes. It also permits better dimensional control of the product, lessens sensitivity to physical characteristics of starting materials, and allows powder to be compressed to higher densities than with cold pressing, resulting in higher strength. Negative aspects of hot pressing include shorter die life, slower throughput because of powder heating, and the frequent necessity for protective atmospheres during forming and cooling stages.

1.2.4 Sintering

After compaction, powdered materials are heated in a controlled atmosphere in a process known as sintering. During this process, the surfaces of the particles are bonded and desirable properties are achieved.

Sintering of powder metals is a process in which particles under pressure chemically bond to themselves in order to form a coherent shape when exposed to a high temperature. The temperature in which the particles are sintered is most commonly below the melting point of the main component in the powder If the temperature is above the melting point of a component in the powder metal part, the liquid of the melted particles fills the pores. This type of sintering is known as liquid-state sintering. A major challenge with sintering in general is knowing the effect of the process on the dimensions of the compact particles. This is especially difficult for tooling purposes in which specific dimensions may be needed. It is most common for the sintered part to shrink and become denser, but it can also expand or experience no net change.

The main driving force for solid state sintering is an excess of surface free energy. The process of solid-state sintering is complex and dependent on the material and furnace (temperature and gas) conditions. There are six main stages that sintering processes can be grouped in which may overlap with one another:

- initial bonding among particles.
- neck growth.
- pore channel closure.
- pore rounding.
- densification or pore shrinkage.
- pore coarsening. The main mechanisms present in these stages. are evaporation, condensation, grain boundaries, volume diffusion, and plastic deformation.

Most sintering furnaces contain three zones with three different properties that help to carry out the six steps above. The first zone, commonly coined the burn-off or purge stage, is designed to combust air, burn any contaminants such as lubricant or binders, and slowly raise the temperature of the compact materials. If the temperature of the compact parts is raised too quickly, the air in the pores will be at a very high internal pressure which could lead to expansion or fracture of the part. The second zone, known as the high-temperature stage, is used to produce solid-state diffusion and particle bonding. The material is seeking to lower its surface energy and does so by moving toward the points of contact between particles. The contact points become larger and eventually a solid mass with small pores is created. The third zone, also called the cooling period, is used to cool down the parts while still in a controlled atmosphere. This is an important zone as it prevents oxidation from immediate contact with the air or a phenomenon known as rapid cooling. All of the three stages must be carried out in a controlled atmosphere containing no oxygen. Hydrogen, nitrogen, dissociated ammonia, and cracked hydrocarbons are common gases pumped into the furnace zones providing a reducing atmosphere, preventing oxide formation.

During this process, a number of characteristics are increased including the strength, ductility, toughness, and electrical and thermal conductivity of the material. If different elemental powders are compact and sintered, the material would form into alloys and intermetallic phases.

As the pore sizes decrease, the density of the material will increase. As stated above, this shrinkage is a huge problem in making parts or tooling in which particular dimensions are required. The shrinkage of test materials is monitored and used to manipulate the furnace conditions or to oversize the compact materials in order to achieve the desired dimensions. Although, sintering does not deplete the compact part of porosity. In general, powder metal parts contain five to twenty-five percent porosity after sintering.

To allow efficient stacking of product in the furnace during sintering and prevent parts sticking together, many manufacturers separate ware using ceramic powder separator sheets. These sheets are available in various materials such as alumina, zirconia, and magnesia. They are also available in fine, medium, and coarse particle sizes. By matching the material and particle size to the wares being sintered, surface damage and contamination can be reduced, while maximizing furnace loading per batch.

One recently developed technique for high-speed sintering involves passing high electric current through a powder to preferentially heat the asperities. Most of the energy serves to melt that portion of the compact where migration is desirable for densification; comparatively little energy is absorbed by the bulk materials and forming machinery. Naturally, this technique is not applicable to electrically insulating powders.

Sintering methods

1. Solid state Sintering’s

- Neck formation at contact points between particles-diffusion.
- Neck growth –skeleton of solid particles is formed.

- Pore size reduced –shrinkage =-fully sintered part.

2. liquid phase sintering

- One particles is having low M.P. than –surface tension.
- Neck formation by liquid phase material transport-particle rearrangement at liquid phase.
- Solution and precipitation state-small particles dissolve from contact.
- Final sintered product is obatained.

Sintering Environment

- Prevent undesirable reactions.
- Reduction of surface oxides.
- Composition control.
- Managing the impurity levels.
- Ex- pure hydrogen, ammonia, inert gases, vacuum, nitrogen based mixtures with carburizing agents.

1.3 Titanium metal powder

Titanium is a chemical element with the symbol Ti and atomic number 22. Its atomic weight is 47.867 measured in Daltons. It is a lustrous transition metal with a silver color, low density, and high strength. Titanium is resistant to corrosion in sea water, aqua regia, and chlorine.

Titanium was discovered in Cornwall, Great Britain, by William Gregor in 1791 and was named by Martin Heinrich Klaproth after the Titans of Greek mythology. The element occurs within a number of mineral deposits, principally rutile and ilmenite, which are widely distributed in the Earth's crust and lithosphere; it is found in almost all living things, as well as bodies of water, rocks, and soils. The metal is extracted from its principal mineral ores by the Kroll and Hunter processes.

Titanium can be alloyed with iron, aluminium, vanadium, and molybdenum, among other elements, to produce strong, lightweight alloys for aerospace (jet engines, missiles, and spacecraft), military, industrial processes (chemicals and petrochemicals, desalination plants, pulp, and paper), automotive, agriculture (farming), medical prostheses, orthopedic implants, dental and endodontic instruments and files, dental implants, sporting goods, jewelry, mobile phones, and other applications.

The two most useful properties of the metal are corrosion resistance and strength-to-density ratio, the highest of any metallic element. In its unalloyed condition, titanium is as strong as some steels, but less dense. There are two allotropic forms[11] and five naturally occurring isotopes of this element, ^{46}Ti through ^{50}Ti, with ^{48}Ti being the most abundant (73.8%).

Figure: 1.2 Titanium metal powder

1.3.1 Characteristics

Physical properties

As a metal, titanium is recognized for its high strength-to-weight ratio. It is a strong metal with low density that is quite ductile (especially in an oxygen-free environment),[6] lustrous, and metallic-white in color. The relatively high melting point (more than 1,650 °C or 3,000 °F) makes it useful as a refractory metal. It is paramagnetic and has fairly low electrical and thermal conductivity compared to other metals.[6] Titanium is superconducting when cooled below its critical temperature of 0.49 K.

Commercially pure (99.2% pure) grades of titanium have ultimate tensile strength of about 434 MPa (63,000 psi), equal to that of common, low-grade steel alloys, but are less dense. Titanium is 60% denser than aluminium, but more than twice as strong as the most commonly used 6061-T6 aluminium alloy. Certain titanium alloys (e.g., Beta C) achieve tensile strengths of over 1,400 MPa (200,000 psi). However, titanium loses strength when heated above 430 °C (806 °F).

Titanium is not as hard as some grades of heat-treated steel; it is non-magnetic and a poor conductor of heat and electricity. Machining requires precautions, because the material can gall unless sharp tools and proper cooling methods are used. Like steel structures, those made from titanium have a fatigue limit that guarantees longevity in some applications.

The metal is a dimorphic allotrope of an hexagonal α form that changes into a body-centered cubic (lattice) β form at 882 °C (1,620 °F). The specific heat of the α form increases dramatically as it is heated to this transition temperature but then falls and remains fairly constant for the β form regardless of temperature.

Chemical properties

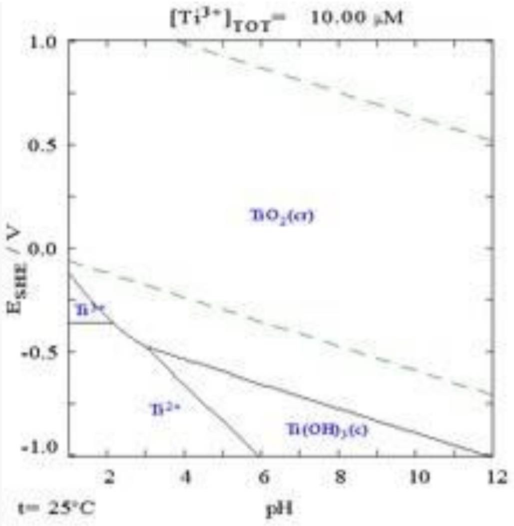

Figure: 1.3 The Pourbaix diagram

Like aluminium and magnesium, titanium metal and its alloys oxidize immediately upon exposure to air. Titanium readily reacts with oxygen at 1,200 °C (2,190 °F) in air, and at 610 °C (1,130 °F) in pure oxygen, forming titanium dioxide. It is, however, slow to react with water and air at ambient temperatures because it forms a passive oxide coating that protects the bulk metal from further oxidation. When it first forms, this protective layer is only 1–2 nm thick but continues to grow slowly; reaching a thickness of 25 nm in four years.

Atmospheric passivation gives titanium excellent resistance to corrosion, almost equivalent to platinum. Titanium is capable of withstanding attack by dilute sulfuric and hydrochloric acids, chloride solutions, and most organic acids. However, titanium is corroded by concentrated acids. As indicated by its negative redox potential, titanium is thermodynamically a very reactive metal that burns in normal atmosphere at lower temperatures than the melting point. Melting is possible only in an inert atmosphere or in a vacuum. At 550 °C (1,022 °F), it combines with chlorine. It also reacts with the other halogens and absorbs hydrogen.

Titanium is one of the few elements that burns in pure nitrogen gas, reacting at 800 °C (1,470 °F) to form titanium nitride, which causes embrittlement. Because of its high reactivity with oxygen, nitrogen, and some other gases, titanium filaments are applied in titanium sublimation pumps as scavengers for these gases. Such pumps inexpensively and reliably produce extremely low pressures in ultra-high vacuum systems.

1.3.2 Applications

- Pigments, additives, and coatings
- Aerospace and marine
- Industrial
- Consumer and architectural
- Jewelry
- Medical
- Nuclear waste storage

1.4 Silicon carbide

Silicon carbide (SiC), also known as carborundum is a semiconductor containing silicon and carbon . Synthetic SiC powder has been mass-produced since 1893 for use as an abrasive. Silicon carbide was discovered by Pennsylvanian Edward Acheson in 1891. It is one of the most important industrial ceramic materials. Plays a key role in the industrial revolut ion and is still widely used as an abrasive and steel additive and structural ceramic Bonding in Silicon Carbide – SiC Silicon carbide crystallizes in a close packed structure covalently bonded to each other. The atoms are arranged so that two primary coordination tetrahedral where four carbon and four silicon atoms are bonded to a central Si and C atoms are formed. These tetrahedra are linked together through their corners and stacked to form polar structures.

The tetrahedral units are linked together through their corners and stacked to form polar structures called Polytypes.

SiC	Silicon Carbide
Density	3.21 g/cm³
Molecular Weight/ Molar Mass	40.11 g/mo
Melting Point	2,730 °C
Compound Formula	SiC

Figure: 1.4 Silicon Carbide

1.4.1 Natural occurrence

Naturally occurring moissanite is found in only minute quantities in certain types of meteorite and in corundum deposits and kimberlite. Virtually all the silicon carbide sold in the world, including moissanite jewels, is synthetic. Natural moissanite was first found in 1893 as a small component of the Canyon Diablo meteorite in Arizona by Dr. Ferdinand

Henri Moissan, after whom the material was named in 1905. Moissan's discovery of naturally occurring SiC was initially disputed because his sample may have been contaminated by silicon carbide saw blades that were already on the market at that time.

While rare on Earth, silicon carbide is remarkably common in space. It is a common form of stardust found around carbon-rich stars, and examples of this stardust have been found in pristine condition in primitive (unaltered) meteorites. The silicon carbide found in space and in meteorites is almost exclusively the beta-polymorph. Analysis of SiC grains found in the Murchison meteorite, a carbonaceous chondrite meteorite, has revealed anomalous isotopic ratios of carbon and silicon, indicating that these grains originated outside the solar system.

1.4.2 Production

Because natural moissanite is extremely scarce, most silicon carbide is synthetic. Silicon carbide is used as an abrasive, as well as a semiconductor and diamond simulant of gem quality. The simplest process to manufacture silicon carbide is to combine silica sand and carbon in an Acheson graphite electric resistance furnace at a high temperature, between 1,600 °C (2,910 °F) and 2,500 °C (4,530 °F). Fine SiO_2 particles in plant material (e.g. rice husks) can be converted to SiC by heating in the excess carbon from the organic material.[16] The silica fume, which is a byproduct of producing silicon metal and ferrosilicon alloys, can also be converted to SiC by heating with graphite at 1,500 °C (2,730 °F).

The material formed in the Acheson furnace varies in purity, according to its distance from the graphite resistor heat source. Colorless, pale yellow and green crystals have the highest purity and are found closest to the resistor. The color changes to blue and black at greater distance from the resistor, and these darker crystals are less pure. Nitrogen and aluminium are common impurities, and they affect the electrical conductivity of SiC. Pure silicon carbide can be made by the Lely process, in which SiC powder is sublimed into high-temperature species of silicon, carbon, silicon dicarbide (SiC_2), and disilicon carbide (Si_2C) in an argon gas ambient at 2500 °C and redeposited into flake-like single crystals, sized up to 2 × 2 cm, at a slightly colder substrate. This process yields high-quality single crystals, mostly of 6H-SiC phase (because of high growth temperature).

1.4.3 Structure and properties

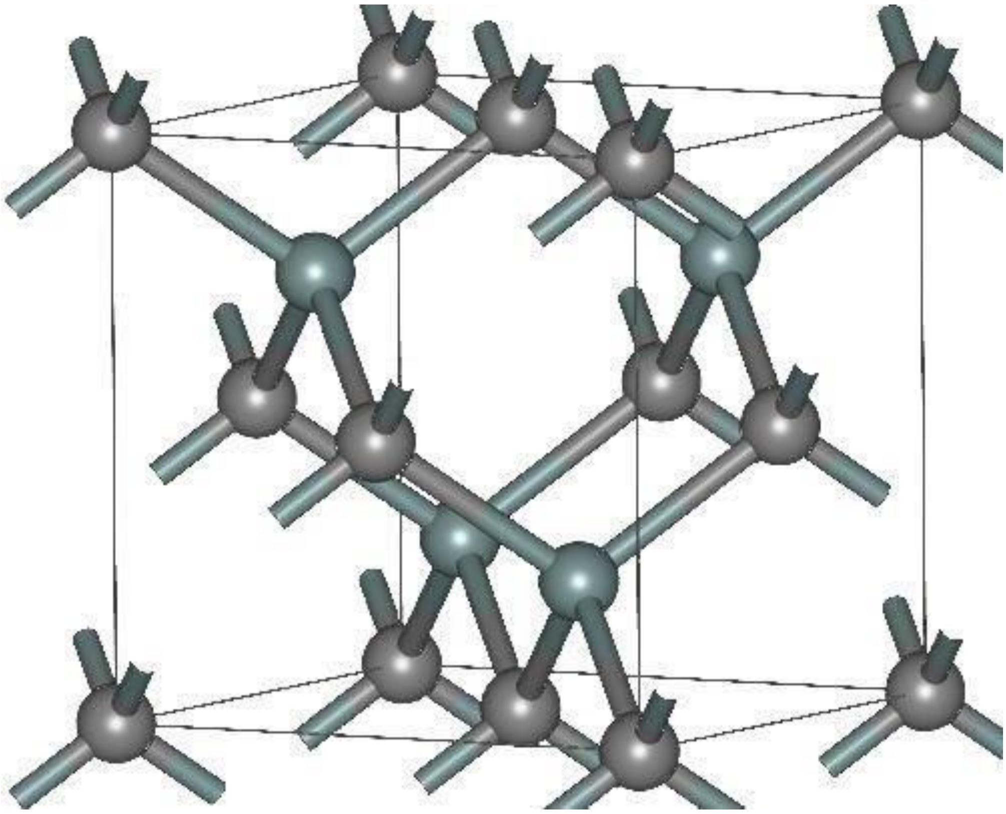

Figure : 1.5 Structure of silicon carbide

Silicon carbide exists in about 250 crystalline forms. Through the inert atmosphere pyrolysis of preceramic polymers, silicon carbide in a glassy amorphous form is also produced. The polymorphism of SiC is characterized by a large family of similar crystalline structures called polytypes. They are variations of the same chemical compound that are identical in two dimensions and differ in the third. Thus, they can be viewed as layers stacked in a certain sequence.

Alpha silicon carbide (α-SiC) is the most commonly encountered polymorph, and is formed at temperatures greater than 1700 °C and has a hexagonal crystal structure (similar to Wurtzite). The beta modification (β-SiC), with a zinc blende crystal structure (similar to diamond), is formed at temperatures below 1700 °C. Until recently, the beta form has had relatively few commercial uses, although there is now increasing interest in its use as a support for heterogeneous catalysts, owing to its higher surface area compared to the alpha form. Pure SiC is colorless. The brown to black color of the industrial product results from iron impurities. he rainbow-like luster of the crystals is due to the thin-film interference of a passivation layer of silicon dioxide that forms on the surface.

The high sublimation temperature of SiC (approximately 2700 °C) makes it useful for bearings and furnace parts. Silicon carbide does not melt at any known temperature. It is also highly inert chemically. There is currently much interest in its use as a semiconductor material in electronics, where its high thermal conductivity, high electric field breakdown strength and high maximum current density make it more promising than silicon for high-powered devices. SiC also has a very low coefficient of thermal expansion (4.0×10^{-6}/K) and experiences no phase transitions that would cause discontinuities in thermal expansion.

1.4.4 Applications

- Abrasive and cutting tools
- Structural material
- Automobile parts
- Electric systems
- Electronic circuit elements
- Astronomy
- Thin filament pyrometry
- Heating elements
- Nuclear fuel particles and cladding
- Jewelry
- Steel production
- Catalyst support
- Carborundum printmaking
- Graphene production
- Quantum physics
- Fishing rod guides

1.5 Vanadium metal powder

Vanadium is a chemical element with the symbol **V** and atomic number 23. It is a hard, silvery-grey, malleable transition metal. The elemental metal is rarely found in nature, but once isolated artificially, the formation of an oxide layer (passivation) somewhat stabilizes the free metal against further oxidation.

Andrés Manuel del Río discovered compounds of vanadium in 1801 in Mexico by analyzing a new lead-bearing mineral he called "brown lead". Though he initially presumed its qualities were due to the presence of a new element, he was later erroneously convinced by French chemist Hippolyte Victor Collet-Descotils that the element was just chromium. Then in 1830, Nils Gabriel Sefström generated chlorides of vanadium, thus proving there was a new element, and named it "vanadium" after the Scandinavian goddess of beauty and fertility, Vanadís (Freyja). The name was based on the wide range of colors found in vanadium compounds. Del Rio's lead mineral was ultimately named vanadinite for its vanadium content. In 1867 Henry Enfield Roscoe obtained the pure element.

Figure: 1.6 Vanadium metal powder

1.5.1 Occurrence

The cosmic abundance of vanadium in the universe is 0.0001%, making the element nearly as common as copper or zinc. Vanadium is detected spectroscopically in light from the Sun and sometimes in the light from other stars.

Vanadium is the 20th most abundant element in the earth's crust; metallic vanadium is rare in nature (known as native vanadium), but vanadium compounds occur naturally in about 65 different minerals.

At the beginning of the 20th century a large deposit of vanadium ore was discovered, the Minas Ragra vanadium mine near Junín, Cerro de Pasco, Peru. For several years this patrónite (VS_4)[38] deposit was an economically significant source for vanadium ore. In 1920 roughly two thirds of the worldwide production was supplied by the mine in Peru.[39] With the production of uranium in the 1910s and 1920s from carnotite ($K_2(UO_2)_2(VO_4)_2\cdot 3H_2O$) vanadium became available as a side product of uranium production. Vanadinite ($Pb_5(VO_4)_3Cl$) and other vanadium bearing minerals are only mined in exceptional cases. With the rising demand, much of the world's vanadium production is now sourced from vanadium-bearing magnetite found in ultramafic gabbro bodies. If this titanomagnetite is used to produce iron, most of the vanadium goes to the slag, and is extracted from it.

Vanadium is mined mostly in South Africa, north-western China, and eastern Russia. In 2013 these three countries mined more than 97% of the 79,000 tonnes of produced vanadium.

Vanadium is also present in bauxite and in deposits of crude oil, coal, oil shale, and tar sands. In crude oil, concentrations up to 1200 ppm have been reported. When such oil products are burned, traces of vanadium may cause corrosion in engines and boilers. An estimated 110,000 tonnes of vanadium per year are released into the atmosphere by burning fossil fuels. Black shales are also a potential source of vanadium. During WW II some vanadium was extracted from alum shales in the south of Sweden.

1.5.2 Characteristics

Vanadium is a medium-hard, ductile, steel-blue metal. It is electrically conductive and thermally insulating. Some sources describe vanadium as "soft", perhaps because it is ductile, malleable, and not brittle.[13][14] Vanadium is harder than most metals and steels (see Hardness's of the elements (data page) and iron). It has good resistance to corrosion and it is stable against alkalis and sulfuric and hydrochloric acids.[15] It is oxidized in air at about 933 K (660 °C, 1220 °F), although an oxide passivation layer forms even at room temperature.

Isotopes

Naturally occurring vanadium is composed of one stable isotope, ^{51}V, and one radioactive isotope, ^{50}V. The latter has a half-life of 1.5×10^{17} years and a natural abundance of 0.25%. ^{51}V has a nuclear spin of 7⁄2, which is useful for NMR spectroscopy.[16] Twenty-four artificial radioisotopes have been characterized, ranging in mass number from 40 to 65. The most stable of these isotopes are ^{49}V with a half-life of 330 days, and ^{48}V with a half-life of 16.0 days. The remaining radioactive isotopes have half-lives shorter than an hour, most below 10 seconds. At least four isotopes have metastable excited states.[17] Electron capture is the main decay mode for isotopes lighter than ^{51}V. For the heavier ones, the most common mode is beta decay. The electron capture reactions lead to the formation of element 22 (titanium) isotopes, while beta decay leads to element 24 (chromium) isotopes.

1.5.3 Production

Vanadium metal is obtained by a multistep process that begins with roasting crushed ore with NaCl or Na_2CO_3 at about 850 °C to give sodium metavanadate ($NaVO_3$). An aqueous extract of this solid is acidified to produce "red cake", a polyvanadate salt, which is reduced with calcium metal. As an alternative for small-scale production, vanadium pentoxide is reduced with hydrogen or magnesium. Many other methods are also used, in all of which vanadium is produced as a byproduct of other processes.[46] Purification of vanadium is possible by the crystal bar process developed by Anton Eduard van Arkel and Jan Hendrik de Boer in 1925. It involves the formation of the metal iodide, in this example vanadium(III) iodide, and the subsequent decomposition to yield pure metal.

$$2\ V + 3\ I_2 \rightleftharpoons 2\ VI_3$$

Most vanadium is used as a steel alloy called ferrovanadium. Ferrovanadium is produced directly by reducing a mixture of vanadium oxide, iron oxides and iron in an electric furnace.

1.5.4 Applications

- Alloys
- Catalysts
- Glass coatings and ceramics
- Vanadium foil is also used to bond titanium to steel.

- Due to its low fission neutron cross section vanadium is also used in nuclear

- As a mordent in the printing and dyeing of fabrics
- In the manufacture of aniline black.

1.6 Aluminium metal powder

Aluminium powder is powdered aluminium.

This was originally produced by mechanical means using a stamp mill to create flakes. Subsequently, a process of spraying molten aluminium to create a powder of droplets was developed by E. J. Hall in the 1920s. The resulting powder might then be processed further in a ball mill to flatten it into flakes for use as a coating or pigment.

Aluminium powder, if breathed in, is not particularly harmful and will only cause minor irritation. The melting point of aluminium powder is 660 °C.

Figure: 1.7 Aluminium metal powder

1.6 Application

- autoclave aerated concrete
- cosmetic colourant
- fingerprint powder
- metallic paint
- pyrotechnics (including the M-80 firecracker)
- refractory
- rocket and missile fuel such as the solid rocket boosters of the Space Shuttle
- Depending on the usage, the powder is either coated or uncoated.

LITERATURE SURVEY

Fei Cao et al.[1] Studied the Ti alloy powders are typically made by a variety of highly advanced atomizing techniques, all of which consist of first making metal alloy, melting the material, and then atomizing the molten metal by different techniques. Atomised alloy powders in general have significantly higher costs than HDH powder.

Fang, Sun, and Para more et al.[2] Studied HSPT is a multi-step pressureless sintering process, in which Ti hybrid or partially hydrogenated Ti powder is blended with master-alloy or elemental powders and sintered under a dynamically controlled hydrogen atmosphere. After sintering, residual hydrogen is removed by annealing under vacuum or inert gas. HSPT takes advantages of the phase transformations in the (Ti-alloy)-H systems to simultaneously refine the microstructure during the thermal cycle. A detailed description of the HSPT processing steps as well as an improved (Ti-6Al-4V)-H phase diagram and description of underlying mechanism for microstructure refinement are available in the literature.

Flumerfelt et al.[3] Cally involves either commercial air atomization (CAA) or commercial inert gas atomization (CIGA). In either case, the direction of molten metal atomization is either horizontal or vertical. The selection of atomizing position depends on the desired production rate of powder and the powder size distribution. Williams [2] comments on three different atomization positions. The vertically upward design. F, which uses an aspirating mechanism of the aluminum melt to induce upward liquid metal flow, produces a wide particle size distribution at high production rates. The vertically downward position. Fi and, relies on the liquid metal head pressure for downward fluid flow, has better control over the powder size distribution, but slower production rates than the vertically upward design. The horizontal system can use either the aspirating design or metal head pressure to induce flow of the molten metal. The horizontal set-up produces medium to coarse powder size distributions. The remainder of this document will concentrate on vertical gas atomization designs, both capable of the fme powder production that is the focus of this study.

Deepak Singla et al. [4] Studied effectively created the Al 7075- fly fiery debris composites by utilizing mix casting course of action with legitimate conveyance of cinder particles all over the example. Moreover, he included the Mg to make strides the wettability of fiery debris molecule by diminishing its surface pressure. He calculated the durability of the composites by utilizing izod and charpy tests. As the sum of fiery debris increments the sturdiness esteem continuously expanded up to a few level. Hardness and ductile quality of the composites moreover appeared the same comes about as like of sturdiness as the fortification was expanded. The thickness of the composites diminished with expanding cinder substance.

Madhuri Deshpande et al. [5] successfully fabricated Pitch based carbon fiber reinforced Al matrix composites Powder Metallurgy (PM) route. Volume % of carbon fibre are (5-50)% uncoated (UnCf) and coated milled pitch based carbon fibers (NiCf) and AA7075 as matrix with different volume contents of carbon fibers. Uncoated and Ni coated carbon fibers were mixed with AA7075 Aluminium alloy powder and subsequently hot pressed and they studied on densification and hardness. A greatest of 11% decreases in thickness is watched for 50vol% Cf composite compared to as cast Al7075. It is observed that the composites developed with uncoated carbon fibre exhibit lower values of hardness as compared with Pure Al7075 hot pressed specimen. Whereas the Ni coated carbon fibre composites show the increase in hardness up to 20Vol% and then it decreases. It is seen from the microstructures that carbon fibres are homogenously distributed in the aluminium matrix for all compositions.

Ravikumar B M, et al. [6] He effectively manufactured Al 7075 TiB composites by fluid metallurgy course utilizing Al 7075 as lattice fabric and 10% and 3%B combinations as the fortifications. He confirmed the presence of TiB and B by Xray diffraction test. By Grain size test he indicated the heterogeneous nucleation in composite mixture. He also stated that hardness of the composite was increased in matrix alloy. He expressed that in his future work he will carry out warm treatment may be carried out to think about the mechanical properties and characteristics of the lattice and fortification and TiB is strengthen in numerous extents to the aluminium lattice to upgrade the mechanical properties. In his future work he will use different casting methods to prepare the composites. From the above journal paper I concluded that they have calculated mechanical properties of metal matrix materials. The amount of Tib increases with increase the hardness of matrix materials.

Daniel Jebin et al.[7] Examined the wear behaviour of the Al 6063 combination composites fortified with alumina of diverse compositions, which are casted by stir casting method keeping a constant load of 2kg and varying the velocities and he concluded that with increase in percentage of alumina wear rate decreases. In his research he concluded that Al 6063 alloy reinforced with 8% alumina is showing higher wear resistance for all velocities tested than the 0% alumina and 4% alumina. oxide, aluminum and/or alumina powders were subjected to optical metallography and X-ray investigation to study their microstructure and phase composition depending on the laser processing parameters. It was demonstrated that fast laser sintering in air yields ceramics with thick structure and a uniform distribution of the balancing out stages. They used ceramic–matrix composites which may be utilized as thermal and electrical protectors and wear resistant covering in solid oxide energy units, pots, heating components, medical instruments. By applying finely scattered Y_2O_3 powder inclusions, the type of the ceramic structure altogether changed. The surface macro- and microstructure examined by optical metallography was relatively dense, smooth and uniform, but contained pores and cracks. The optimal processing parameters were successfully determined for monolayer and layer-by-layer laser sintering within a narrow process parameter window (laser power, scan velocity, beam diameter and hatch distance) in order to minimize shrinkage and eliminate cracking and delaminating.

Prashant S D et al. [8] In this paper they have done that the hardness test, think about of microstructure and mechanical properties such as pliable quality, and surrender quality % prolongation as well as % reduction by using aluminium metal matrix alloy. Then comparison between al 7075 and al 6061 and evaluate the mechanical properties. The result of % elongation as well as % reduction at fracture are performed by experimentally and compared with these result theoretically by using COSMOS works analysis tool. Comparison between al 6061 and al 7075 the almost al 7075 has a more tensile and yield strength of the other alloy.

Ajit kumar senapati,et al. [9] Their work was on the study of the aluminium alloy 6061 and reinforcement as fly ash (10 and 15%wt). They have considered almost the mechanical behaviour of unreinforced combination and metal network composites. They compared the metal lattice composite arranged with 15% of fly ash debris show wat better mechanical property to unreinforced amalgam as well as MM

Włodarczyk Fligier et al. [10] In this he used two methods to produce composites one by powder metallurgy technique and another by pressure infiltration method. Both aluminium matrix composites are reinforced by ceramic particles. He concluded that pressure infiltration method gives good surface quality and powder metallurgy method helps in manufacturing small elements and pressure infiltration method consumes more energy than the powder metallurgy technique.

Sijo M T et al. [11] Silicon carbide metal matrix composites are used in various fields like aerospace, aircrafts, underwater, automobile, substrate in electronics, golf clubs, turbine blades, brake pads etc. Several fabrication techniques are available for the production of aluminium silicon carbide metal matrix composites (Al-SiC MMC). Among the various methods, stir casting route is simple, less expensive, and used for mass production. The main limitations of stir cast Al-SiC MMC are improper distribution of SiC reinforcement in matrix and less wettablity of SiC reinforcement particle with molten Al. Literature survey indicate that various properties of stir cast Al-SiC MMC depends upon fabrication method, volume fraction, shape, size of particles and distribution and properties of constituents. Since metal matrix composites (MMC) lack structural simplicity its analytical modeling is complex. Further, the involvement of several parameters which affect composite properties, makes the experiments difficult. This review paper contemplates the need of simulation or numerical methods for the prediction of mechanical characteristics of Al-SiC MMC.

Sly Bengtsson et al. [12] Vanadium can exist in four different oxidation states, i.e., 2, 3,4 and 5. Its tendency to form various oxoanions is a property which it has in common with molybdenum, tungsten, arsenic and phosphorous. In nature it is known to exist as vanadates of varying composition as well as in organically complexed forms. Metallic vanadium of any degree of purity was not produced until the 1920's. It has a high melting point, 1890°C, and is used to produce steel alloys for making rust-resistant springs and high-speed tools. Information on the total world production of vanadium is inadequate. Vanadium is also of importance (as the pentoxide) as a catalyst in several chemical processes and is used in ceramics and in dyes and paints.

Germund Tyler et al.[13] In most invertebrates studied so far, vanadium concentrations of 0.5-2 ppm dry weight seem to be the rule (6). Many insects are very low in vanadium - in the honey bee a mean of 0.16 ppm dry weight is reported. The body concentration in vertebrates is also very low, often only 0.1-0.2 ppm dry weight or sometimes even less (6). In mammals (including man), considerable differences have been measured between various organs but any distinct accumulation pattern of general validity is difficult to ascertain. Maxima may be recorded in the liver, kidney, lung or spleen (47, 56). High vanadium concentrations, a mean of 3.2 ppm dry weight, have been recorded in the lungs of coal miners and workers in vanadium industry (64). The total body burden of human adults is reported to be 17-43 mg, which corresponds to an approximate mean of 0.4 ppm wet weight (56, 57). The mean daily intake is 1.1-1.2 mg; according to other studies 0.4-0.6mg (55, 56). An excretion rate of 0.2-0.3 mg/day has been reported.

Li zeng et al. [14] Among these methods, precipitation offers low cost and simple operation, however, high purities (> 99%) of products of molybdenum and vanadium cannot be achieved. The loading capacities of activated carbon for molybdenum and vanadium are relatively low, resulting in no industrial application of this technology in the separation of molybdenum and vanadium. Ion exchange offers a useful means for almost complete separation of molybdenum and vanadium and for production of their high purity products, although the scale of application of ion exchange in industry is limited. Solvent extraction is highly selective for separation and recovery of molybdenum and vanadium, and is the most promising method recommended for future research and development.

Ravichandran M et al. [**15]** Carried out the research work by fabricating aluminium metal matrix composites through liquid powder metallurgy route. The aluminium matrix composite containing TiO2 reinforcement particle was produced to study the mechanical properties such as tensile strength and hardness. The characterization studies are also carried out to evident the phase presence in the composite and the results are discussed for the reinforcement addition with the mechanical properties. Results show that, the addition of 5 weight percentage of TiO2to the pure aluminium improves the mechanical properties.

Anand Kumar et al. [16] Research work carried out by Addition of reinforcement such as TiC, SiC, Al2O3, TiO2, TiN, etc. to Aluminium matrix for enhancing the mechanical properties has been a well–established fact. In-situ method of reinforcement of the Aluminium matrix with ceramic phase like Titanium Carbide (TiC) is well preferred over the Ex–situ method. In the present investigation, Al-Cu alloy (series of 2014 Aluminium alloy) was used as matrix and reinforced with TiC using In-situ process. The Metal Matrix Composite (MMC) material, Al-.5%Cu/10%TiC developed exhibits higher yield strength, ultimate strength and hardness. as compared to Al-4.5%Cu alloy. Percentage increase in yield and ultimate tensile strengths were reported to be about 15% and 24% respectively whereas Vickers hardness increased by about 35%. The higher values in hardness indicated that the TiC particles contributed to the increase of hardness of matrix.

Pradeep R et al. **[17]** Observed the study of mechanical properties of Al- Red Mud and Silicon Carbide Metal Matrix Composite (MMC) of Aluminium alloy of grade 7075 with addition of varying weight percentage composition such as SiC8%+Al7075, SiC6%+Red mud2%+ Al7075, SiC4%+Red mud 4%+Al7075, SiC2%+Red mud 6%+Al7075, Red mud 8%+Al7075ed mud and Silicon Carbide particles by stir casting technique. The experimental result reveals that the combination of a matrix material with reinforcement such as SiC and Red mud particles, improves mechanical properties like tensile strength, compressive strength, hardness and yield strength.

H. Izadi et al. [18] Investigated through FSP and has observed improvement in the micro hardness of Al–SiC composites produced by traditional powder metallurgy and sintering methods. The material flow in the stir zone during FSP was successful in uniformly distributing the SiC particles. However, when samples with 16% SiC (by volume) were processed, there were residual pores and lack of consolidation. An increase in hardness of all samples was observed after friction stir processing which was attributed to the improvement in particle distribution and elimination of porosity.

OBJECTIVE AND SCOPE OF STUDY OF PRESENT WORK

- To prepare Ti-6Al-4V alloy using powder metallurgy technique
- To prepare composite reinforced with SiC using the matrix of Ti-6Al-4V alloy
- To evaluate microstructural characterization of the composite using SEM/EDS
- To evaluate the hardness of the Ti-6Al-4V/SiC composite

METHODOLOGY

4.1 Ball milling

Weighed the components Titanium (Ti)+Vanadium (V)+ Aluminium (Al)+ Silicon carbide (SiC) according to the requirement and then followed it for other samples varying the composition of silicon carbide (SiC). Ball milling was carried out for all the four samples for 1 hour at RPM 200 using planetary ball milling machine. 5mm balls were used for milling.

Number of balls used were 25% of samples weight * 100.

Following are the images captured during ball milling

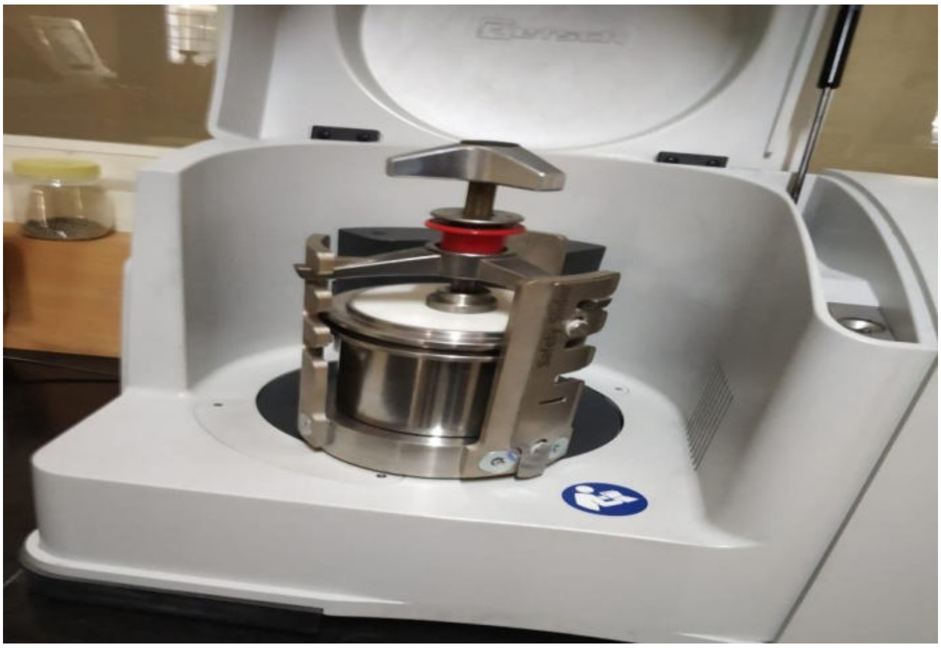

Figure: 4.1 Planetary ball milling machine

Composition

Sample 1: Ti 90%+Al 6%+V 4%

Sample 2: Ti 90%+Al 6%+V 4%+SiC 1.5%

Sample 3: Ti 90%+Al 6%+V 4%+SiC 3%

Sample 4: Ti 90%+Al 6%+V 4%+SiC 4.5%

Metal powder sizes (99.7% pure)

Aluminium metal powder and vanadium size is 63 microns.

Silicon carbide size is 100 mesh course grain.

Titanium metal powder size selected is 75 microns.

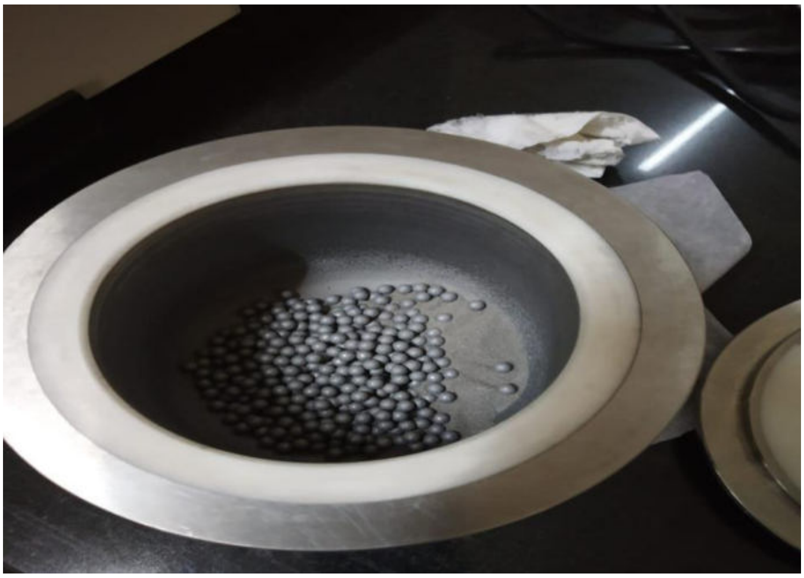

Figure: 4.2 Composition and 5mm balls placed in jar

4.2 Compacting

All the samples were compressed using the EN32 steel die and compression testing machine.

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Figure: 4.3 Compression testing machine

Die is placed in the machine and gradually load was applied (90KN).

Figure: 4.4 Die and plunger (EN32 steel die)

4.3 Sintering

Sintering was carried out for all the samples using muffle furnace. Specimen were heated at temperature 525º C for period of 25 to 30 min and allowed it for cooling for 30 min after cooling specimen were removed from the furnace

Figure: 4.5 Muffle furnace

Figure: 4.6 Placing specimens in furnace

Figure: 4.7 Specimen after sintering

4.4 Disc polishing

Size of the sample were reduced to 10*10 and carried out for disc polishing all the samples were polished up to 20 min. Kroll's reagent and aluminium paste was used as solution while polishing.

Figure: 4.8 Disc polishing machine

Figure: 4.9 Polishing the specimens

4.5 Microstructural characterization

The specimen for micro structural characterization was prepared by cutting a size of about 10mm*10mm from the bottom of casting using a hack-saw. It was then polished using rough and smooth files. The surface was then made even with emery sheets, followed by working on a disc polishing machine containing velvet cloth. A Kellers reagent was used to reveal the grain boundaries. The specimen was finally washed with distilled water. An optical metallurgical metal microscope (Nikon Epiphot 200) was used to capture the micrographs.

4.6 SEM and EDX

Specimen was prepared according requirement of SEM and EDX analyzing. Before carrying out for analyzing testing surface was gold spluttered and carried out for testing.

Figure: 4.10 Gold spluttering

Figure: 4.11 Specimen placed in SEM and EDX testing machine

4.7 Hardness testing

Specimen were carried out for hardness testing using Rockwell hardness testing machine, diamond indenter was used and 60 kgf load was applied.

Figure: 4.12 Hardness testing process (Rockwell hardness)

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RESULTS AND DISCUSSIONS

5.1 SEM analysis

Sample 1 without SiC

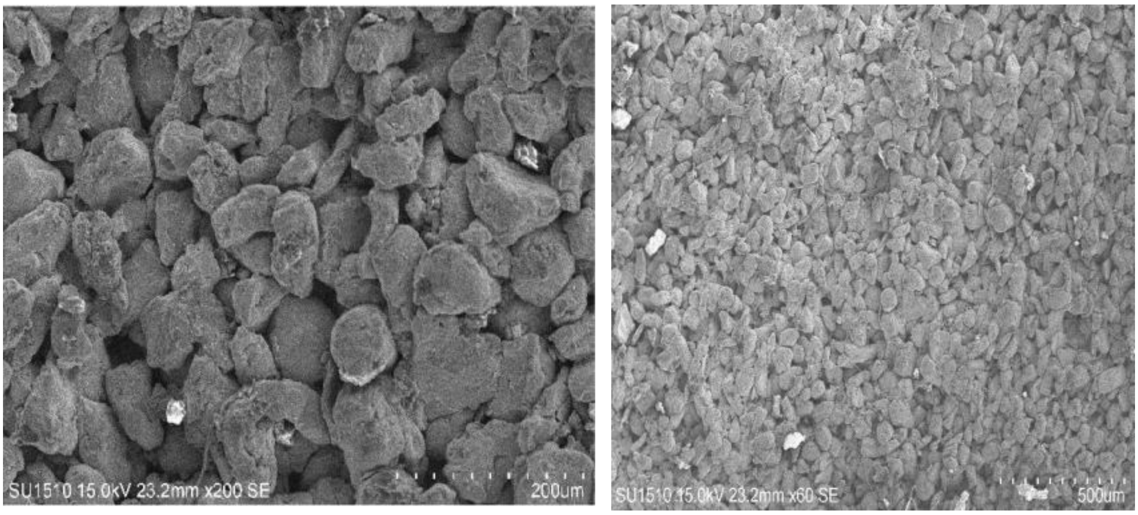

Figure: 5.1 Ti 90%+Al 6%+V 4%

Sample 2 with SiC 1.5%

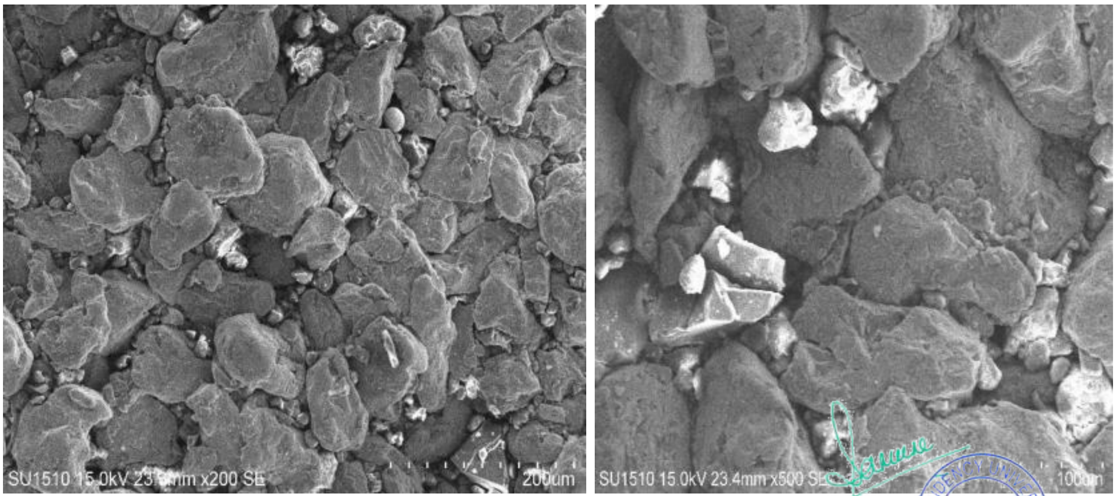

Figure: 5.2 Ti 90%+Al 6%+V 4%+SiC 1.5%

Sample 3 with SiC 3%

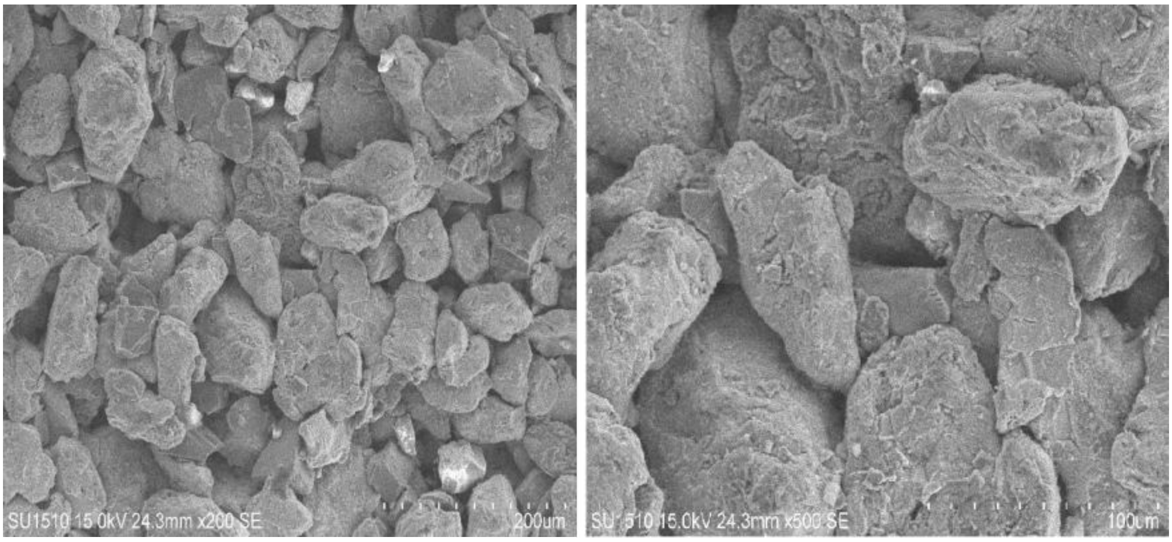

Figure: 5.3 Ti 90%+Al 6%+V 4%+SiC 3%

Sample 4 with SiC 4.5%

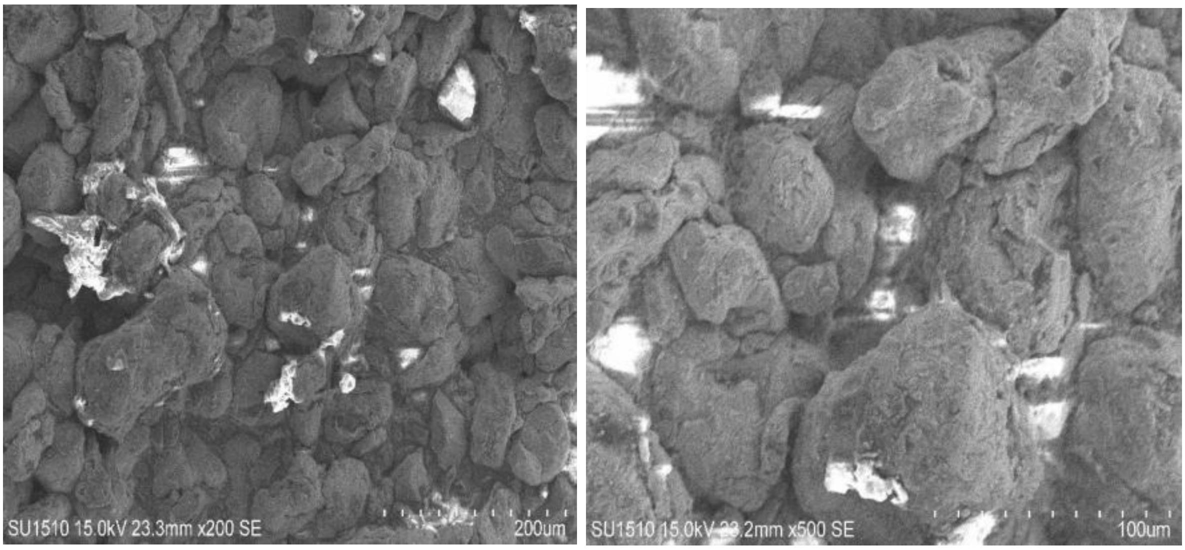

Figure: 5.4 Ti 90%+Al 6%+V 4%+SiC 4.5%

5.2 EDX analysis

Sample 1

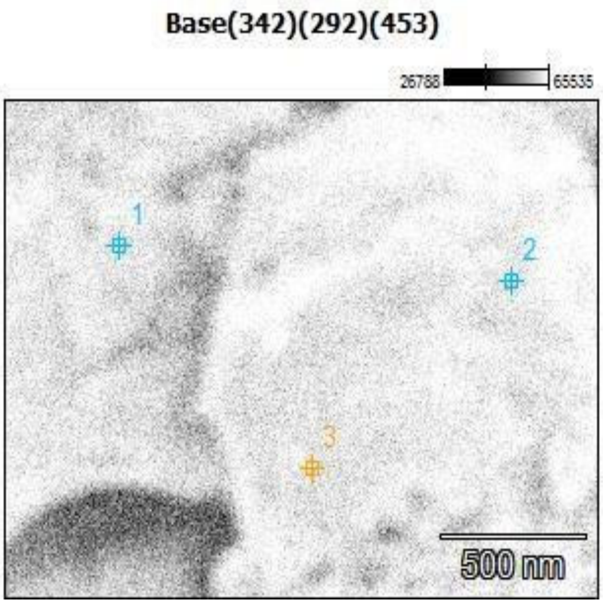

Image Name:	Base(342)(292)(453)
Image Resolution:	512 by 384
Image Pixel Size:	0.00 µm
Acc. Voltage:	15.0 kV
Magnification:	2000

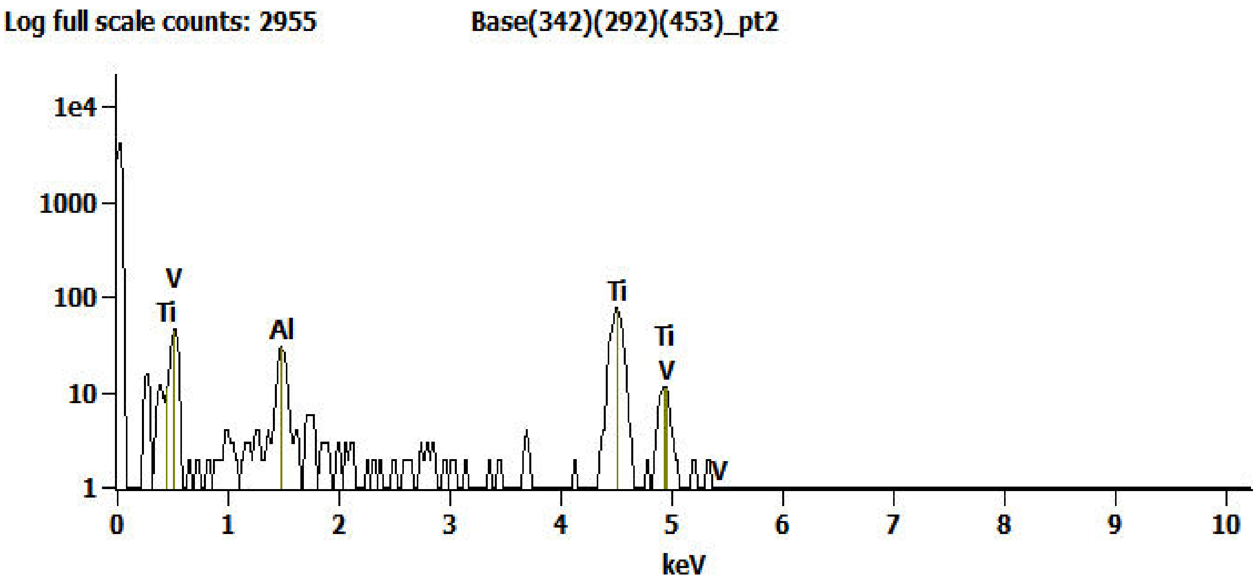

Figure: 5.5 Ti 90%+Al 6%+V 4%

Weight %

	O-K	Al-K	Ti-K	V-K
Base(342)(292)(453)_pt1		3.53	94.94	1.53
Base(342)(292)(453)_pt2		7.92	89.43	2.65
Base(342)(292)(453)_pt3	0	9.67	82.86	0.25

Weight % Error (+/- 1 Sigma)

	O-K	Al-K	Ti-K	V-K
Base(342)(292)(453)_pt1		±0.32	±3.40	±1.53
Base(342)(292)(453)_pt2		±0.69	±3.73	±1.64
Base(342)(292)(453)_pt3	0	±0.42	±2.51	±1.19

Atom %

	O-K	Al-K	Ti-K	V-K
Base(342)(292)(453)_pt1		6.10	92.50	1.40
Base(342)(292)(453)_pt2		13.27	84.38	2.35
Base(342)(292)(453)_pt3	0	14.09	67.99	0.20

Atom % Error (+/- 1 Sigma)

	O-K	Al-K	Ti-K	V-K
Base(342)(292)(453)_pt1		±0.55	±3.31	±1.40
Base(342)(292)(453)_pt2		±1.16	±3.52	±1.46
Base(342)(292)(453)_pt3	0	±0.61	±2.06	±0.92

Compound %

	O	Al	Ti	V
Base(342)(292)(453)_pt1		3.53	94.94	1.53
Base(342)(292)(453)_pt2		7.92	89.43	2.65
Base(342)(292)(453)_pt3	0	9.67	82.86	0.25

Sample 2

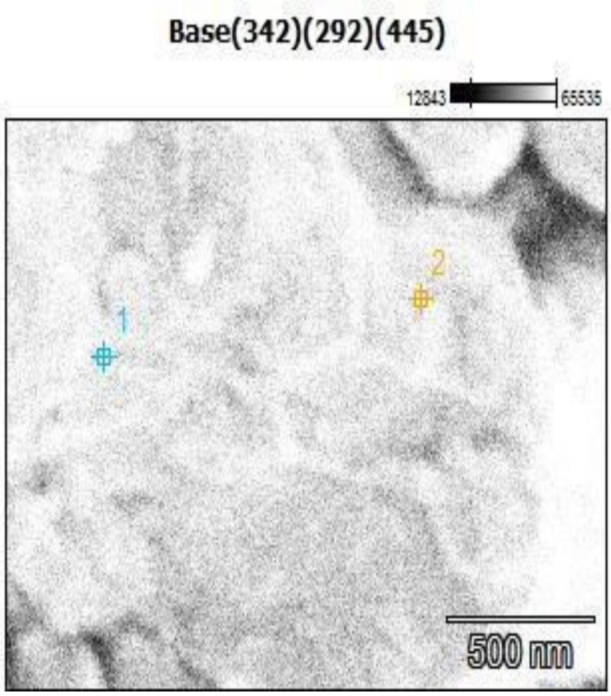

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Image Pixel Size:	0.00 µm
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Magnification:	2000

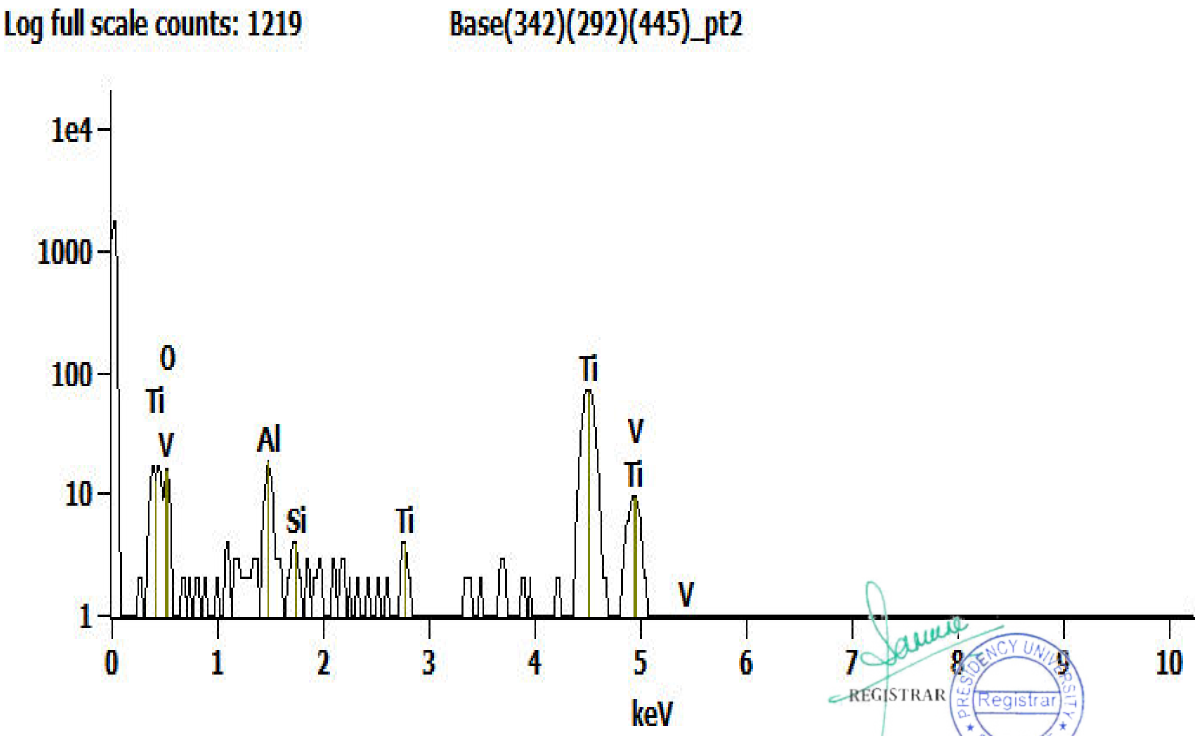

Figure: 5.6 Ti 90%+Al 6%+V 4%+SiC 1.5%

Weight %

	O-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(445)_pt1		0.45	0.51	94.66	4.38
Base(342)(292)(445)_pt2	0	3.28	0.44	91.40	0.78

Weight % Error (+/- 1 Sigma)

	O-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(445)_pt1		±0.25	±0.20	±4.49	±1.69
Base(342)(292)(445)_pt2	0	±0.49	±0.25	±3.59	±1.45

Atom %

	O-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(445)_pt1		0.79	0.86	94.24	4.10
Base(342)(292)(445)_pt2	0	5.25	0.68	82.35	0.66

Atom % Error (+/- 1 Sigma)

	O-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(445)_pt1		±0.44	±0.34	±4.47	±1.58
Base(342)(292)(445)_pt2	±0	±0.79	±0.39	±3.23	±1.22

Compound %

	O	Al	Si	Ti	V
Base(342)(292)(445)_pt1		0.45	0.51	94.66	4.38
Base(342)(292)(445)_pt2	0	3.28	0.44	91.40	0.78

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Sample 3

Base(342)(292)(449)

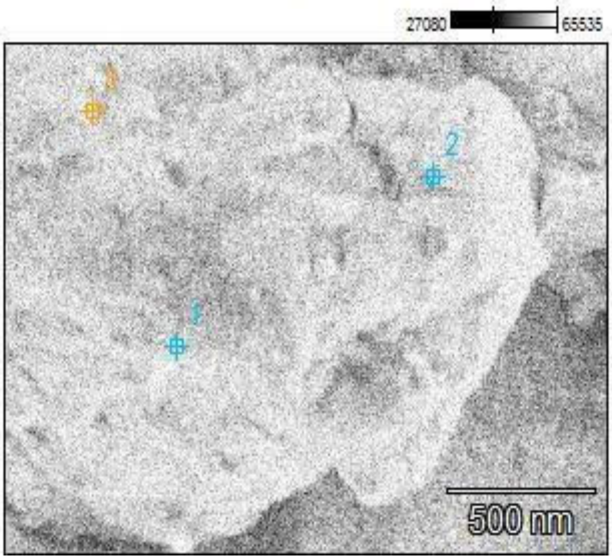

Image Name:	Base(342)(292)(449)
Image Resolution:	512 by 384
Image Pixel Size:	0.00 µm
Acc. Voltage:	15.0 kV
Magnification:	2000

Log full scale counts: 1193 Base(342)(292)(449)_pt3

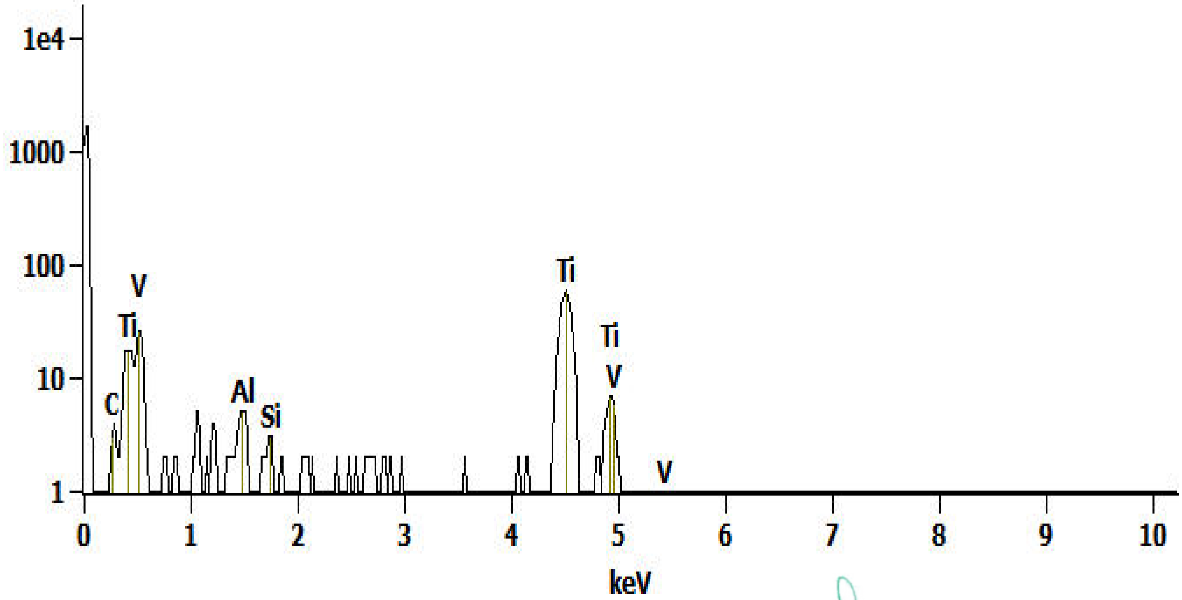

Figure: 5.7 Ti 90%+Al 6%+V 4%+SiC 3%

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Weight %

	C-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(449)_pt1		63.80	6.29	21.00	8.91
Base(342)(292)(449)_pt2	2.23	6.41	0.09	88.50	2.77
Base(342)(292)(449)_pt3	0.51	1.70	0.70	97.09	0.00

Weight % Error (+/- 1 Sigma)

	C-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(449)_pt1		±3.43	±1.50	±4.90	±3.56
Base(342)(292)(449)_pt2	±0.59	±0.66	±0.46	±5.63	±2.26
Base(342)(292)(449)_pt3	±0.23	±0.35	±0.30	±4.48	±0.00

Atom %

	C-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(449)_pt1		73.85	7.00	13.69	5.46
Base(342)(292)(449)_pt2	7.97	10.21	0.14	79.34	2.33
Base(342)(292)(449)_pt3	1.97	2.93	1.15	93.95	0.00

Atom % Error (+/- 1 Sigma)

	C-K	Al-K	Si-K	Ti-K	V-K
Base(342)(292)(449)_pt1		±3.97	±1.67	±3.20	±2.18
Base(342)(292)(449)_pt2	±2.13	±1.04	±0.70	±5.05	±1.91
Base(342)(292)(449)_pt3	±0.90	±0.60	±0.49	±4.34	±0.00

Compound %

	C	Al	Si	Ti	V
Base(342)(292)(449)_pt1		63.80	6.29	21.00	8.91
Base(342)(292)(449)_pt2	2.23	6.41	0.09	88.50	2.77
Base(342)(292)(449)_pt3	0.51	1.70	0.70	97.09	0.00

Sample 4

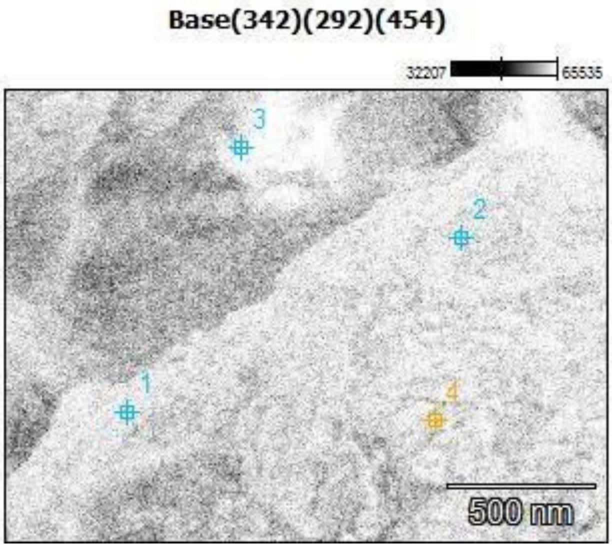

Image Name:	Base(342)(292)(454)
Image Resolution:	512 by 384
Image Pixel Size:	0.00 µm
Acc. Voltage:	15.0 kV
Magnification:	2000

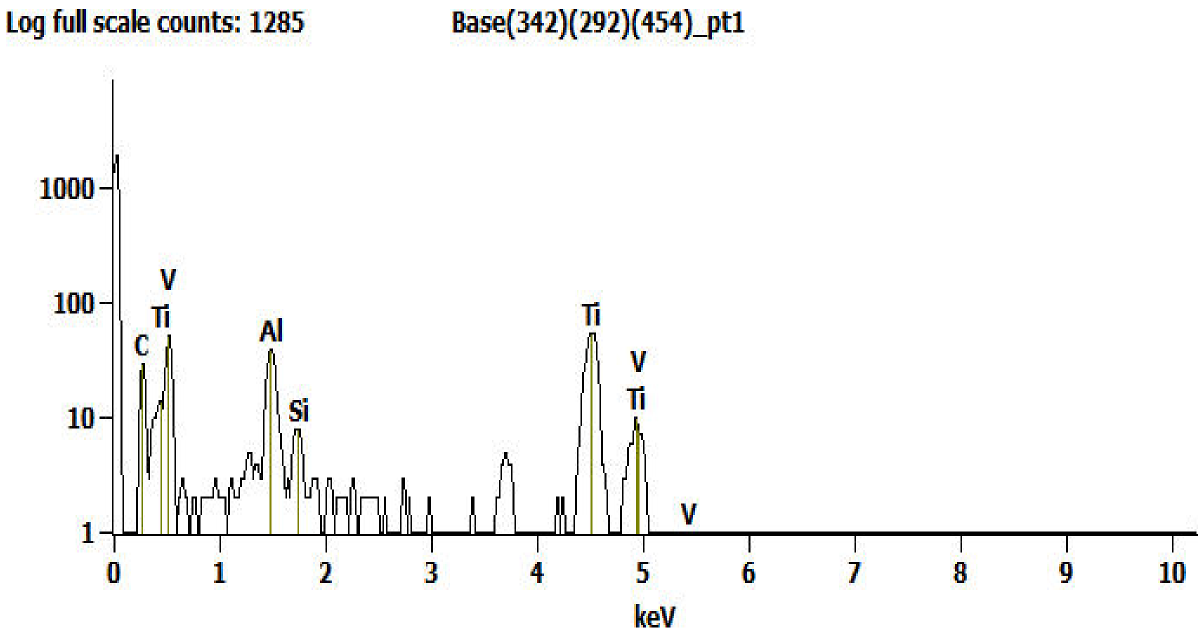

Figure: 5.8 Ti 90%+Al 6%+V 4%+SiC 4.5%

Weight %

	C-K	*O-K*	*Al-K*	*Si-K*	*Ti-K*	*V-K*
Base(342)(292)(454)_pt1	0		11.03	1.90	78.07	2.34
Base(342)(292)(454)_pt2	0		23.25	4.36	67.06	0.69
Base(342)(292)(454)_pt3		0	64.60			
Base(342)(292)(454)_pt4	0.97		23.02	0.99	74.65	0.37

Weight % Error (+/- 1 Sigma)

	C-K	*O-K*	*Al-K*	*Si-K*	*Ti-K*	*V-K*
Base(342)(292)(454)_pt1	±0		±0.83	±0.38	±2.88	±1.69
Base(342)(292)(454)_pt2	±0		±0.89	±0.44	±2.33	±1.18
Base(342)(292)(454)_pt3		±0	±1.28			
Base(342)(292)(454)_pt4	±0.23		±0.86	±0.30	±2.61	±1.50

Atom %

	C-K	*O-K*	*Al-K*	*Si-K*	*Ti-K*	*V-K*
Base(342)(292)(454)_pt1	0		15.10	2.49	60.21	1.70
Base(342)(292)(454)_pt2	0		30.58	5.51	49.70	0.48
Base(342)(292)(454)_pt3		0	51.98			
Base(342)(292)(454)_pt4	3.18		33.66	1.39	61.49	0.29

Atom % Error (+/- 1 Sigma)

	C-K	*O-K*	*Al-K*	*Si-K*	*Ti-K*	*V-K*
Base(342)(292)(454)_pt1	±0		±1.13	±0.50	±2.22	±1.23
Base(342)(292)(454)_pt2	±0		±1.17	±0.56	±1.73	±0.83
Base(342)(292)(454)_pt3		±0	±1.03			
Base(342)(292)(454)_pt4	±0.76		±1.26	±0.42	±2.15	±1.16

Compound %

	C	*O*	*Al*	*Si*	*Ti*	*V*
Base(342)(292)(454)_pt1	0		11.03	1.90	78.07	2.34
Base(342)(292)(454)_pt2	0		23.25	4.36	67.06	0.69
Base(342)(292)(454)_pt3		0	64.60			
Base(342)(292)(454)_pt4	0.97		23.02	0.99	74.65	0.37

The SEM micrographs reveal the uniform distribution of the particles throughout the matrix. This justifies that the ball milling was effectively carried out for mixing the powders. EDS analysis confirms the presence of all the metal powders used. Hence, the composite was successfully prepared using powder metallurgy technique.

5.3 Hardness test

Hardness test was done for all four specimens using Rockwell hardness testing machine under a load of 60 kgf.

Sample	**Hardness Value**
90 %Ti + 6% Al 6%+ 4 %V	39
90 %Ti + 6% Al 6%+ 4 %V+ 1.5% SiC	44
90 %Ti + 6% Al 6%+ 4 %V+ 3% SiC	47
90 %Ti + 6% Al 6%+ 4 %V+ 4.5% SiC	49

It is noted that with the addition of SiC, the harness has improved. SiC which is a relatively harder material is a ceramic reinforcement that is able to take up the load during the indentation. Hence, we observe an improvement in hardness with the increase in reinforcement content.

CONCLUSION

- Ti-6Al-4V alloy was successfully prepared through powder metallurgy process.
- The composite with varying reinforcement content of SiC was prepared with the powders of Titanium, Aluminium and Vanadium as matrix.
- Microstructural studies reveal the uniform distribution of the reinforcements throughout the matrix.
- Hardness tests reveal improvements in hardness in the reinforced composite compared to the base material.

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A Project Report on

"REMOTE CONTROL AND MONITORING OF FUSED FILAMENT FABRICATION 3D PRINTER"

Submitted in partial fulfillment of the requirement of Bachelor of Technology
for the University Project/PP-2

in

Mechanical Engineering

Submitted by 1 June, 2021

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Under the Supervision of

PRIYANKA S UMARJI

Presidency University

(Private University Estd. in Karnataka State by Act No.41 of 2013)

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

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Department of Mechanical Engineering

School of Engineering,

Itgalpura, Rajanukunte, Bengaluru - 560064

2020-21

CERTIFICATE

Certified that the project work entitled "**REMOTE CONTROL AND MONITORING OF FUSED FILAMENT FABRICATION 3D PRINTER**" in partial fulfillment for the award of bachelor of technology in mechanical engineering of the school of engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for university project have been in corporate in the thesis report deposited in the departmental library. the thesis report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

PRIYANKA UMARJI	**Dr. M. Udaya Ravi**
Supervisor	Prof. and Head
End Term Examination	**Signature with date**

Examiners

1.Dr.Arpitha G R

2.Dr.Satish Babu B

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DECLARATION

We, the students 8th semester of department of mechanical engineering, school of engineering, Presidency university. Bengaluru. declare that the work entitled "**REMOTE CONTROL AND MONITORING OF FUSED FILAMENT AND FABRICATION 3D PRINTER**" has been successfully completed under the supervisor of "**PRIYANKA UMARJI**" department of Mechanical engineering, School of engineering, Presidency university Bengaluru. This dissertation work is submitted to presidency university in partial fulfillment of the requirements for the award of university project in mechanical engineering during the academic year 2020-21 further the matter embodied in the thesis report as not been submitted previously by anybody for the award of in a degree or diploma to any university.

Place:- Bengaluru
Date :- 01/06/2021

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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **PRIYANKA UMARJI** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. RAMESH, Prof. and Head** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Ramesh SP** who gave us the opportunity to do this project work.

At the same time, we express our deepest thanks to ………………………………………

Lastly, we would like to thank our family and friends

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ABSTRACT

Most of the current desktop 3D printers are built based on open source designs from online communities. The largest group of open source 3D printer is the self replicating rapid prototype 3D printers. A prototype 3D printer needs to connect the computer are a microprocessor to feed G code had provide interface for users to control the 3D printer however local computer is a relatively expensive solution comparing to the cost of a prototype 3D printer, while the microprocessor as much less computing capability comparing to a normal computer and cannot handle computing intensive jobs like slicing 3d objects or generating G codes. An alternate solution is to use the internet of things (IOT)application to control and monitor 3D printers, IOT is the network of physical devices, vehicles, buildings and other items allowing objects to be sensed and control remotely across existing network. IOT and 3D printing or two important new technologies which progressively impact of a lot of areas of the industries and also our everyday life. students need to be introduced to these technologies and get ready for the future career opportunities.

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CHAPTER 1

INTRODUCTION

1.1 DEFINITION OF 3D PRINTING

The internet of things (IoT) and 3D printing are two new technologies, which progressively impact a lot of areas of the industries and also our everyday life. IoT is the network of physical devices, vehicles, buildings and other items embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. Another important new technology that draws a lot of attention from both industry and academia is 3D printing. Most of the current desktop 3D printers are built based on open-source designs from online communities. However, the local computer is a relatively expensive solution comparing to the cost of the 3D printer; while the microprocessor has much less computing capability which cannot handle compute-intensive jobs like slicing 3D objects or generating G Code.

What is 3D Printing?

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive process.

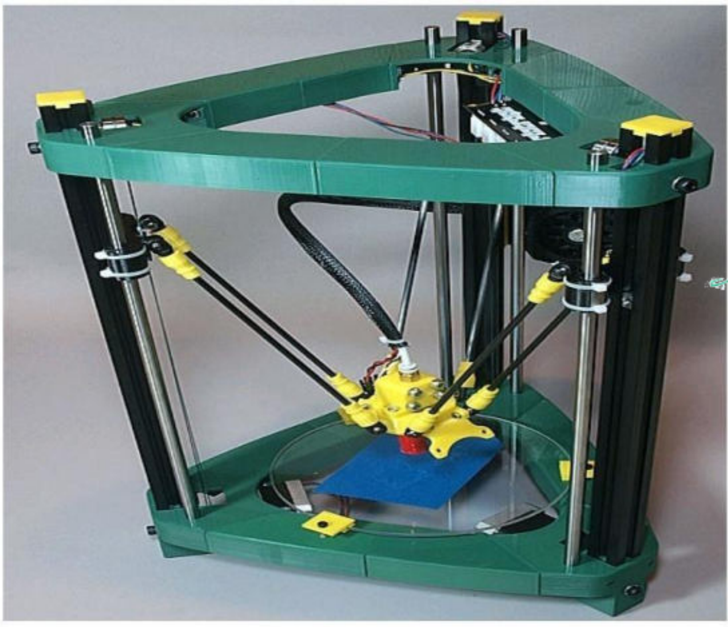

Fig 1.1

1.2 FUEL DEPOSITION MODELLING (FDM)

FDM 3D printing is a method of additive manufacture where layers of materials are fused together in a pattern to create an object. these layers are fused together, building up throughout the print and eventually they will form the finished part.

Principle of FDM

FDM works on an additive principle by laying down materials in layers. a plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off.

How does FDM 3D printer work?

The FDM printer heats solid plastic filament, and melts and extrudes it from a nozzle layer upon layer on to a build tray to form the 3D object. Each layer can be 0.1mm to 0.5mm thick based on the desired resolution.

Disadvantages of FDM.

- A large number of modulators and filters are required
- The communication channel must have a very large band width
- The frequency division multi flexing suffers from the problem of cross talk
- All the frequency division multi flexing channels get affected due to wild band fading

Raw Materials for FDM

Commercially a few of the popular choices of raw material include nylon Acrylonitrile Butadiene styrene (ABS) and its variations polycarbonates, polylactic acid, Polystyrene and thermoplastic urethane

1.3 REMOTE CONTROL AND MONITORING

Remote monitoring and control system are design to control large or complex facilities such as factories, power plants, network operation centers, airports and spacecrafts with some degree of automation. M and C systems may receive data from sensors user inputs preprogrammed procedures.

How does remote monitoring work?

Remote monitoring devices tap digital technology to send communication between patients and provides. Patients monitor themselves to collect data about there health at various points throughout the day then electronically transmit secure data and messages to there techniques.

Thermoplastics like PLA (Polylactide) or ABS (Acrylonitrile butadiene styrene) are the most popularly used materials in 3D printing. ABS is also used to make Legos. Apart from these, 3D printers also use other materials such as rubber, plasticine, modelling clay, porcelain and even some metal clay. Different 3D printers use different materials. These materials differ in terms of strength and temperature properties. It is also possible to get different colors of filaments for 3D printers. This helps in getting variety out of your printer. Based on the information sent from the PC, the nozzle of the printer moves back and forth on the printing surface and shapes the design layer-by-layer, from bottom to the top. Remember that depending on the complexity of the design, a printer can take hours before presenting the final product.

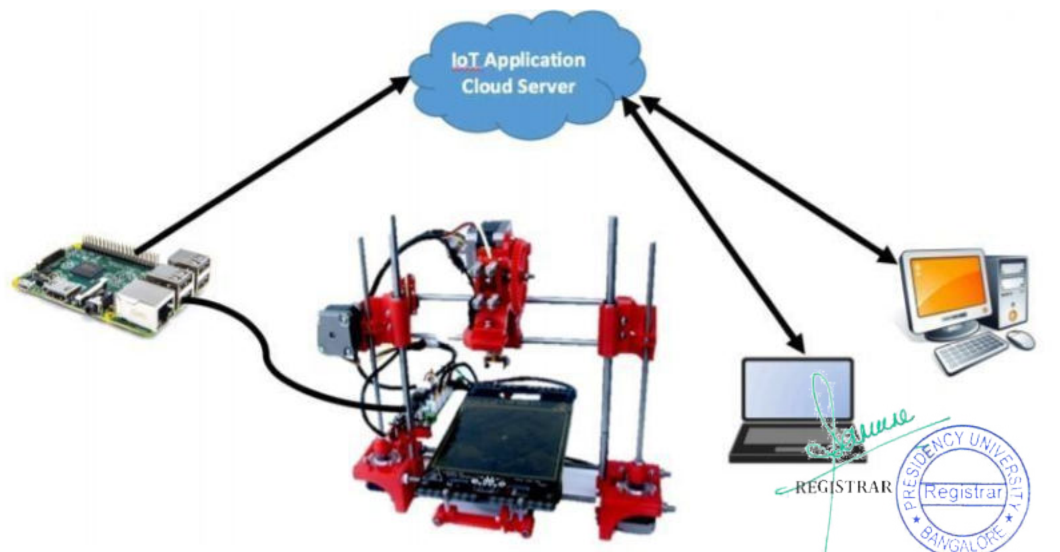

Figure 1 3D Printer with IoT Remote Monitoring Application Layout

CHAPTER 2

LITERATURE

2.1

2.1.1 A filament supply system capable of remote monitoring and automatic humidity control for 3D printer.

A edge computer system for 3d printers that can monitor and control the relative humidity inside the filament supply, here we study changes in the stress strain curve for a 3d printer object owing to the humidity sensitive characteristics of the polylactic acid (PLA) filament, the filament supply is equipped with a relative humidity and temperature sensors and a photo interrupter in order to obtain data.

First we analyzed the effects of humidity on PLA which is one of the most commonly used materials for 3d printing based on the stress-strain curve obtain by tensile testing, as a result of the tensile test they found that what exposed to high humidity.

Published year 2020

Author : Youngchanoh , Heonwoo Lee

2.1.2 Influence of printing parameters on the stability of deposited beads in fused filament fabrication of poly(lactic) acid

This work aims to optimize the printing conditions of the FFF process based on reliable properties, such as printing parameters and physical properties of polymers. The selected polymer is poly(lactic) acid (PLA), which is a biodegradable thermoplastic polyester derived from corn starch and is one of the most common polymers in the FFF process. Firstly, the maximum inlet velocity of the filament in the liquefier was empirically determined according to process parameters, such as feed rate, nozzle diameter and dimensions of the deposited segment.

The maximum inlet velocity of the filament in the liquefier was empirically determined according to the printing parameters, such as the nozzle diameter, feed rate and dimensions of the deposited segment. Then, the rheological behaviour of the PLA, such as the velocity field, shear rate and viscosity distribution in the nozzle, was determined via analytical study and numerical simulation. The shear rate reached its maximum value near the internal wall at a high inlet velocity and small nozzle diameters. Increasing the inlet velocity and decreasing the nozzle diameter increased the shear rate and decreased the viscosity of the PLA.

Published On 2015

Author: France Chabert, Aurthur Cantrel

2.1.3 Monitoring 3D Printer Performance using Internet of Things (IOT) Application

Most of the current desktop 3D printers are built based on open-source designs from online communities. The largest group of open-source 3D printers is the Self-Replicating Rapid Prototype (RepRap) 3D printers. A RepRap 3D printer needs to connect to a computer or a microprocessor to feed G Code and provide interface for users to control the 3D printer. However, local computer is a relatively expensive solution comparing to the cost of a RepRap 3D printer; while the microprocessor has much less computing capability comparing to a normal computer, and cannot handle computing-intensive jobs like slicing 3D objects or generating G Code.

This is an undergoing project, so more data will be collected to support a strong claim of conclusions. However, current results have already clearly show that , It is possible to use an IoT application to remote monitor the performance of a RepRap 3D printer. A group of undergraduate students with different academic backgrounds are able to work collaboratively to solve a multidisciplinary engineering problem with proper trainings and supports from mentors.

Published On : 2014

Author : Dr. Paul Yearling P E , Dr . Shuningli

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2.2

2.2.1 Advances for 3D printing: Remote control system and multi-material solutions

Three-dimensional printing is an emerging manufacturing technology for many applications such as rapid proto- typing, biomedical engineering and industrial designs. This paper aims to provide the implantation of a low-cost and extensible system in order to real-time monitor and modify 3D printing parameters. It is formed by a web- based platform and hardware components to manage and capture the printing process. In addition, we raise an overview about material properties in order to generate multi-material prototypes of bone tissue.

3D printing industry has experimented a fast growing around multiple professional areas. Fused Deposition Modelling (FMD) technology allows the use of a wide variety of thermoplastic materials with the possibility of combining between them. In this paper, we have approached two 3D printing challenges: remote control system to monitor and modify in real-time the printing process and the study of material properties in order to generate multi-material solutions. 3D printing can also be used in medical applications such as bone tissue engineering.

Published On : 2017

Author : Guan M.Jurado , Adraian Luque

2.2.2 Factors effecting real-time optical monitoring of fused filament 3D printing

This study analyzes a low-cost reliable real-time optical monitoring platform for fused filament fabrication-based open source 3D printing. An algorithm for reconstructing 3D images from overlapping 2D intensity measurements with relaxed camera positioning requirements is compared with a single-camera solution for single-side 3D printing monitoring.

This paper described a low-cost reliable real-time monitoring platform for FFF-based 3D printing based on a single- and two-camera system for a single side. The results showed that both of the algorithms with a single- and double-camera system were effective at detecting a clogged nozzle, loss of filament, or an incomplete project for a wide range of 3D object geometries and filament colors. The error calculation was determined from the difference in shape between STL Image and Camera Image, or the different sizes between STL Image and the 3D reconstruction.

Published On : 2016

Author : Michael Roggeman

2.2.3 3D printing metals like thermoplastics: Fused filament fabrication of metallic glasses

Whereas 3D printing of thermoplastics is highly advanced and can readily create complex geometries, 3D printing of metals is still challenging and limited. The origin of this asymmetry in technological maturity is the continuous softening of thermoplastics with temperature into a readily formable state, which is absent in conventional metals. Unlike conventional metals, bulk metallic glasses (BMGs) demonstrate a supercooled liquid region and continuous softening upon heating, analogous to thermoplastics.

The ability to carry out this process in air is of practical importance as it avoids costly and typically complicated inert or vacuum conditions. The low TPF processing temperatures during printing and the absence of a first-order phase transition of the BMG during solidification after extrusion results in little shrinkage, at least one order of magnitude less than the shrinkage of liquid-based additive manufacturing processes for conventional metals.

Published On : 2015

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OBJECTIVE

→ Is to remotely monitor and control a FDM 3D printer. → It is possible to use an IOT Application to remote monitor the performance of 3D Printer.

→The overall objective of this project is to design and develop an IoT application to remote monitor the performance of a 3D printer including the printing progress and the temperatures of the heated bed and hot end.

→ Other potential projects include adding supports to mobile devices for the IoT application and remote-control multiple 3D printers.

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Chapter 3

Methodology

There are four major research tasks involved in the project. Task 1 is to upgrade the current 3D printer; Task 2 is to connect the 3D printer to the Raspberry Pi 3 microprocessor; Task 3 is to design and develop the IoT application with ThingWorx composer; and Task 4 is to test the entire 3D printer system.

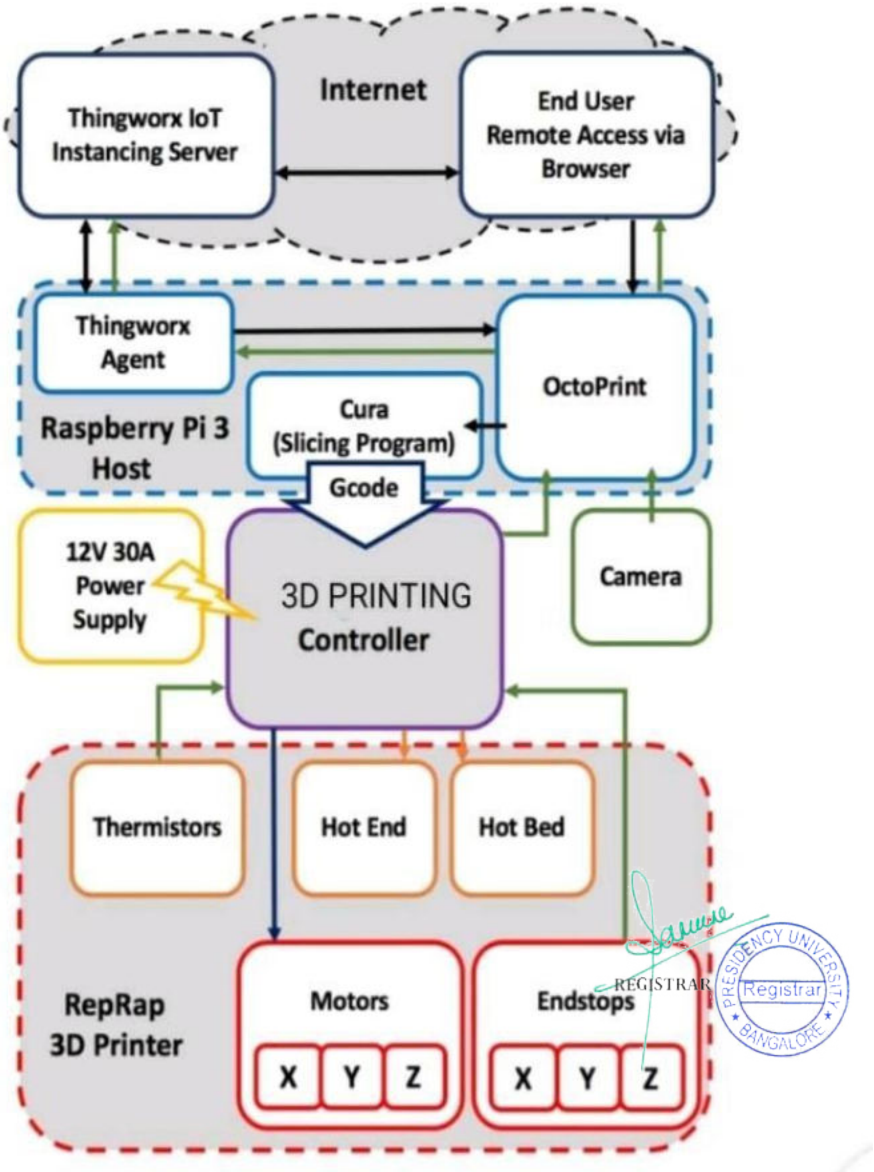


Fig 1.3 System block diagram

Task 1: 3D printer refining and upgrading

The following upgrades are completed to make sure the 3D printer can be connected to the IoT platform, and also to improve the robustness of the 3D print.

- Replace both the Arduino Mega and RAMPS 1.4 board with an Arduino RAMBO 1.2G;
- Replace the old thermistors in the heated bed and hot end;
- Replace the cold end assembly;
- Adjust the 3D printer housing in order to add new components (Webcam and LCD monitor)

Task 2: Connect the 3D printer to Raspberry Pi 3B

The 3D printer is connected to a Raspberry Pi 3B microprocessor through an Arduino RAMBO 1.2G board. Raspberry Pi is a credit card-sized single-board computer which can provide basic computing functionalities. It can be used to interact with different hardware (i.e. drive a motor) and software (i.e. web applications). Raspberry Pi 3B is used in this project due to its better connectivity. It has Wi-Fi and Bluetooth embedded. The operating system is Raspbian Jessie.

Task 3: Design and develop the IoT application

The IoT application is developed using Thingworx Composer 7. The Composer is an integrated development environment (IDE) for the creation of ThingWorx applications. Both the data modeling and user interface development aspects of application development are performed using the Composer.

CHAPTER 4

TESTING AND PERFORMANCE EXPERIMENTAL PROCEDURE

RASPBERRY PI

The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python.

An SD card inserted into the slot on the board acts as the hard drive for the Raspberry Pi. It is powered by USB and the video output can be hooked up to a traditional RCA TV set, a more modern monitor, or even a TV using the HDMI port.

Raspberry Pi is a credit card-sized single-board computer which can provide basic computing functionalities. It can be used to interact with different hardware (i.e. drive a motor) and software (i.e. web applications). Raspberry Pi 3B is used in this project due to its better connectivity. It has Wi-Fi and Bluetooth embedded. The operating system is Raspbian Jessie.

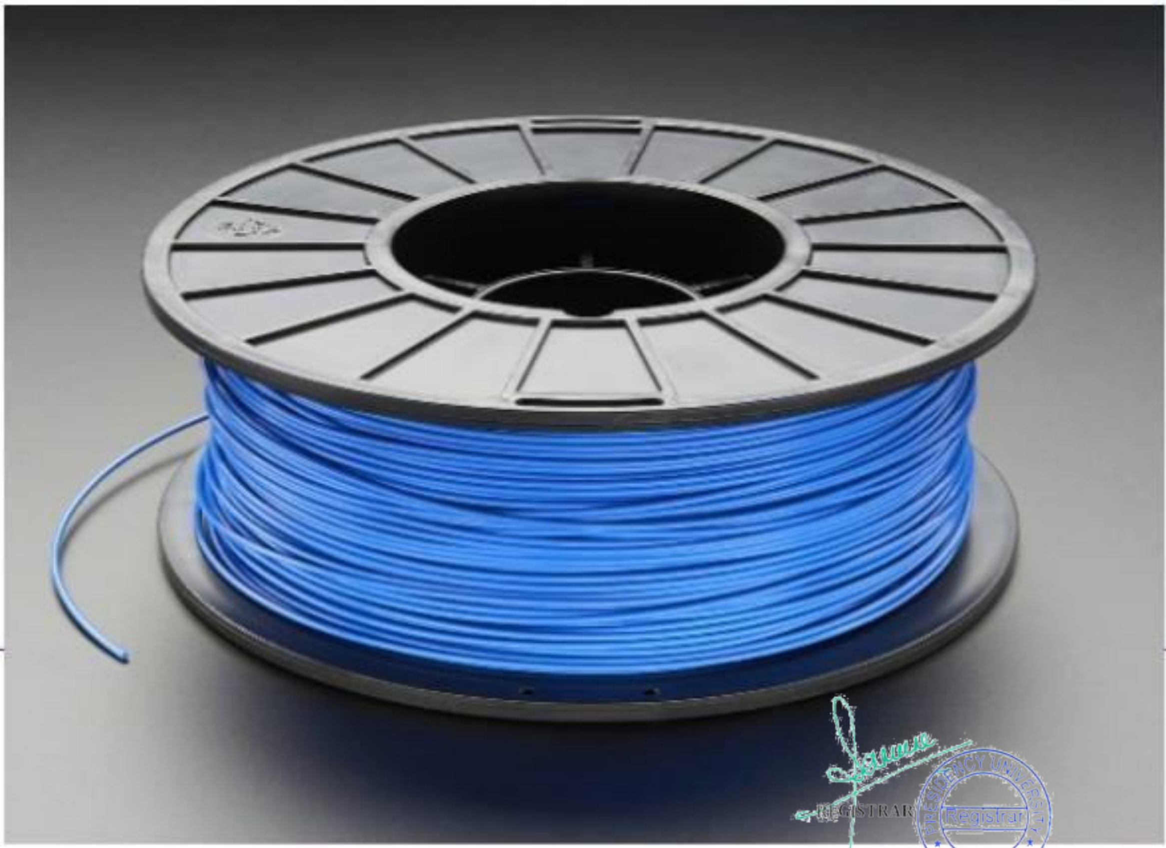
FIG 4.1

PLA

PLA, also known as polylactic acid or polylactide, is a thermoplastic made from renewable resources such as corn starch, tapioca roots or sugar cane, unlike other industrial materials made primarily from petroleum.

PLA is a user-friendly thermoplastic with a higher strength and stiffness than both ABS and nylon. With a low melting temperature and minimal warping, PLA is one of the easiest materials to 3D print successfully. In addition, PLA is brittle, leading to parts with poor durability and impact resistance.

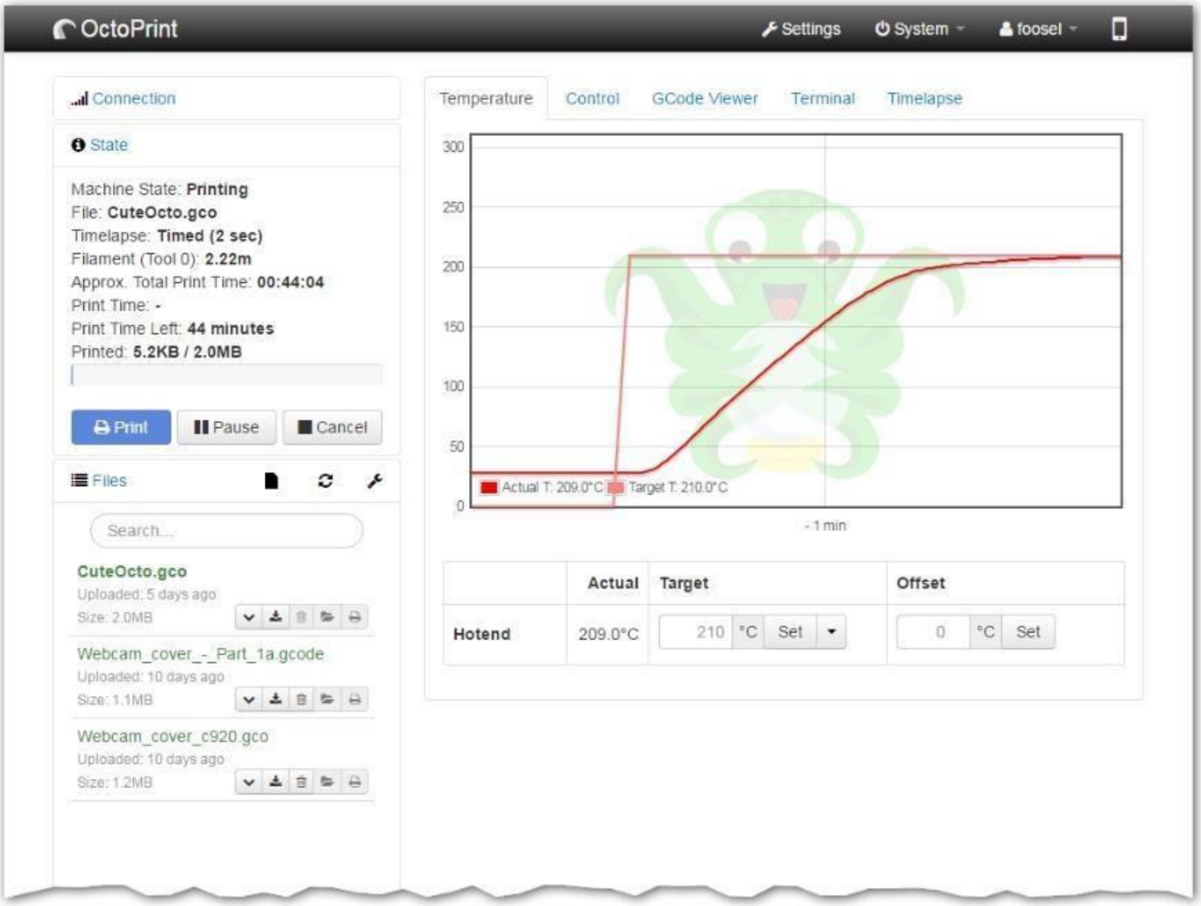
PLA filament has gained wide acceptance within additive manufacturing partly because it is made from renewable products and also because of its mechanical properties. It is often the preferred choice for beginners in 3D printing as it is a very easy material to work with. This material, considered a semi-crystalline polymer, has a melting temperature of 180ºC, lower than ABS filament, which starts melting between 200ºC and 260ºC. This means that when printing with PLA, the use of a heated printing bed is not necessary, and the closed chamber is not a necessity either. The only drawback is that the PLA filament has a higher viscosity which can clog the print head if you are not careful.



OCTOPRINT

Octo Print provides a web interface for controlling 3D printers, allowing the user to start a print job by sending G-code to a 3D printer connected via USB.

Octo Print monitors the status of the print job, as well as the printer itself, including the temperature of the print head (hot end) and the temperature of the bed, if the bed on the printer is heated. It can also show the output of a connected webcam in order to monitor the state of the print, and can visualize the G-code in sync with the print job.



Octo Print can run on a variety of systems, but is commonly run on Raspberry Pi. A distribution called Octo Pi [1] based on the Raspbian OS for Raspberry Pi, provides a pre-configured version of Octo Print along with an mjpeg-streamer support for webcams.

- Create awesome time lapse recordings of your prints.
- Slice your STL files directly within Octo Print.
- Control who can control your printer with the built-in access controls.
- Configure event hooks to react to certain events within Octo.

Evaluate your Octo Print environment

Use a Pi Camera Module with Octo Print

Use a USB camera or webcam with Octo Print

Test and optimize your Octo Print camera setup
Troubleshooting the Octo Print camera feed

1. Evaluate your Octo Print environment
After you've installed Octo Print, consider your priorities when it comes to streaming. Do you want a budget-friendly camera? Do you want to use a camera you already have? Perhaps you just want to stream with high resolution. Whatever your project needs are, identify what they are before investing in a new camera.

2. Use a Pi Camera Module with Octo Print
The official Raspberry Pi camera module works great with Octo Print. The Raspberry Pi camera module is plug-and-play, so you won't have to worry about any special setup configurations. It's a lowprofile option, guaranteed to be compatible with the Raspberry Pi 1, 2, 3, and 4.

This module is designed for the Raspberry Pi and connects using the camera port on the Pi. It's an 8-megapixel camera that can create images with a resolution of 3280 x 2464.

The whole unit is only 25mm x 23mm x 9mm (not including the cable). If you want a small camera with a good image that's easy to mount, you may want to check out the Raspberry Pi Camera Module V2.

3. Use a USB camera or webcam with Octo Print
Octo print will work with many USB cameras, but not all of them. Here's a list of compatible webcams known to work with Octo Print. This makes it easy to set up a camera quickly with a spare webcam or USB camera that you might have lying around the house.

The biggest benefit of using a webcam is better image quality. You will likely spend a little time configuring your webcam to work with the Raspberry Pi, but the results are worth it. Octo Print recommends using mjpg-streamer to set up the webcam. Visit the Octo Print page on Git hub for tips on setting up your camera with Octo Print.

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Test and optimize your Octo Print camera setup
Once you have your camera connected, log into the Octo Print web interface. You can use the IP address of your Raspberry Pi or put http://octopi.local into the address field of a browser window.

Look under the Control tab. This screen allows you to view and make adjustments to your Octo print video stream. Congratulations! Now you're ready to monitor your 3D printing progress remotely.

Troubleshooting the Octo Print camera feed
If you don't see anything, make sure the camera is properly connected. You may want to power everything off and reconnect the camera. If it still doesn't work, make sure the camera is working on other devices.

CURA SOFTWARE

Ultimaker Cura works by slicing the user's model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object.

The open source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats such as STL (stereolithography).

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THINGSWORX

The Thing Worx platform is a complete, end-to-end technology platform designed for the industrial Internet of Things (IoT). It delivers tools and technologies that empower businesses to rapidly develop and deploy powerful applications and augmented reality (AR) experiences.

Thing Worx Analytics enables developers to extract meaning from their IoT data—to learn from past data, understand and predict the future, and make decisions based on data trends. More specifically, it monitors devices to provide: Real-time pattern and anomaly detection on real-time data stream.

Use Ethernet and Wi-Fi boards to connect your edge device to the internet.
Use REST services to communicate with the Thing worx Platform.
Build a circuit diagram in your IoT device.
Work with a Weather IoT device and an App on the Thing worx Platform.

Thing Worx enables you to manage the development lifecycle for your IoT applications in one centralized place. By leveraging the power of the platform, you can quickly connect devices, analyze data, build, and deploy solutions.

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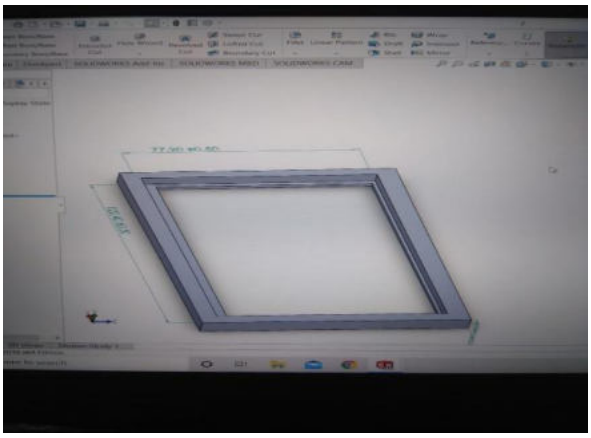
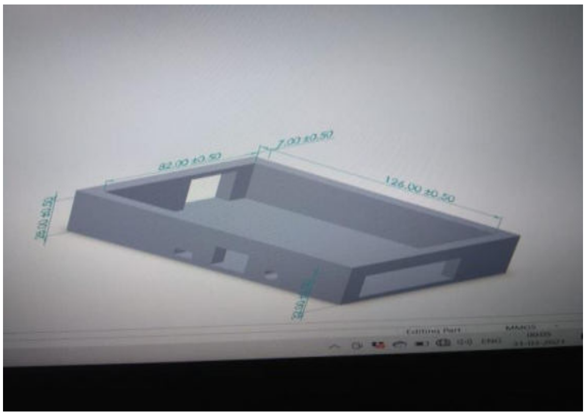
LIST OF FIGURES





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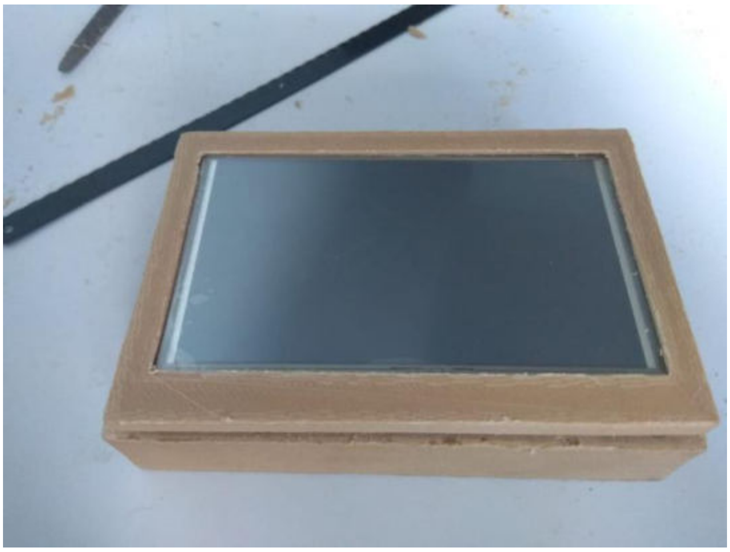

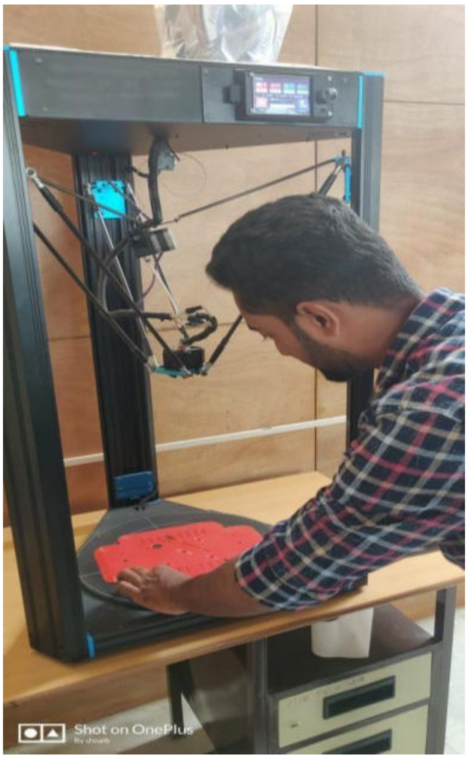
Shot on OnePlus


Shot on OnePlus


Shot on OnePlus

Bill Of Materials

Sl.No	Materials	Amount (in Rs.)
1.	Raspberry pi model 3B	3200
2.	5MP Sony IMX219PQ Pi camera	1900
3.	Pi camera Flex cable	100
4.	16Gb SanDisk Micro Sd card Class 10	600
5.	5 inch Touch display	3100
6.	HDMI connector	200
7.	Type B to type A USB	100
8.	5v power adaptor for pi and screen	800
Total		10000

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CHAPTER 5
RESULTS AND DISCUSSION

RESULTS

Center of the system is the Raspberry Pi
3B with Raspbian Jessie. It is the host of Octo Print which is used to control the 3D printer and collect temperatures of the heated bed and hot end, and the Thing worx client which is for the IoT application. The 3D printer board (RAM Bo 1.2G), the Webcam (Logitech C170), and the LCD monitor (Adafruit TFT Display) are also connected to the microprocessor.

DISCUSSION

This is a multidisciplinary project involving undergraduate students from different engineering backgrounds. Students learn to collaborate with engineers from other disciplines to solve complex multidisciplinary problems. They practice not only their technical knowledge and skills but also improve their communication and project management capability that may be even more important for their future career. The project started with reading the 3D printer documents prepared by the previous team. This task made the whole team aware and better understand the importance of good engineering documentation. They are working on a document that is informative and also easy to read as part of their final deliverables now.
Another benefit for the students is that they have a great opportunity to experience two "big things" (IoT and 3D printing) in current technology world. However, the current project only uses the IoT application to monitor the 3D printer. A futur projects focusing on an application that can be used to remote control the 3D printer is under development. Other potential projects include adding supports to mobile devices for the IoT application and remote control multiple 3D printers. These projects will involve more undergraduate students to research projects.

CONCLUSION

This is an undergoing project, so more data will be collected to support a strong claim of conclusions. However, current results have already clearly show that

1. It is possible to use an IoT application to remote monitor the performance of a 3D printer.
2. A group of undergraduate students with different academic backgrounds are able to work collaboratively to solve a multidisciplinary engineering problem with proper trainings and supports from mentors.

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Private University Estd. in Karnataka State by Act No. 41 of 2013

Itagalpura, Rajanukunte, Yelahanka, Bengaluru-560064

School of Engineering
Department of Mechanical Engineering

University Project-2

Characterization of MR fluid, and dynamic analysis of Quarter Car semi-active suspension

Submitted by

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Under the guidance of,

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Assistant Professor

Department of Mechanical Engineering

School of Engineering

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2020-2021

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Private University Estd. in Karnataka State by Act No. 41 of 2013

Itagalpura, Rajanukunte, Yelahanka, Bengaluru- 560064

School of Engineering

Department of Mechanical Engineering

CERTIFICATE

Certified that, the project work entitled, ***"Characterization of MR fluid, and dynamic analysis of Quarter Car semi-active suspension"***, carried out by Mr. Mohammed Nabeel (20171MEC0129), Mr. Mohammed Tanzeem (20171MEC0134), Mr. N Akash (20171MEC0142), Mr. Kuldeep N (20171MEC0143), and Mr. Sachin B R (20181LMEC0031) are bonafide students of VIII Semester MEC, School of Engineering, Presidency University, Bengaluru, during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Dr Gurubasavaraju T.M
UP-2 Coordinators
Dept. of Mechanical Engg.
Presidency University

Dr S Ramesh
Professor & Head
Dept. of Mechanical Engg
Presidency University

DECLARATION

We, the students of fifth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, " **Characterization of MR fluid, and dynamic analysis of Quarter Car semi-active suspension**" has been successfully completed under the supervision of Dr Gurubasavaraju T.M, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:30th May 2021

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ACKNOWLEDGEMENT

For completing this University Project-2 Report, we have received support and guidance from many people to whom we would like to place on record our deep gratitude. Firstly, we cordially thank **Presidency University** providing platform for such intellectual works and supporting us in all means for our successful completion of the University Project-2. We extend our gratitude to our beloved **Chancellor, Vice-Chancellor, and Registrar** for their support and encouragement in completion of the project.

We express our thanks to **Dr. A.M.Surendra Kumar,** Dean School of Engineering, Presidency University for his advice, encouragement and motivation. We are thankful to **Dr S Ramesh**., Head of the Department, Department of Mechanical Engineering, Presidency University for his moral support and motivation, timely guidance, advice and encouragement provided to us.

We would like to express our sincere gratitude and indebtedness to our coordinators **Dr Gurubasavaraju** T.M, Department of Mechanical Engineering, Presidency University for their valuable guidance.

We are extremely grateful to **Teaching and Non-Teaching staff** of the Department of Mechanical Engineering and also **staff from other Departments** who have extended their valuable help and cooperation

Lastly, we would like to thank our family and friends

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ABSTRACT

Magnetorheological (MR) fluid characteristics especially its operational modes and its application on MR devices such as MR damper, valve, brake, clutch and mount. MR fluids are widely used in the industrial world; however, sometimes their properties fail to meet system requirements. MR fluids are a talk of the day due to their potential applications in various fields. In the present work, six different MR fluids were prepared based on the variation in the percentage of carbonyl iron (CI) particles and carrier liquid.

The dynamic characteristics are evaluated at different input currents. The nonparametric approach is used to model the damper from experimental results. A quarter car semi-active vehicle is considered, and the passive damper is replaced with a magneto-rheological damper using the nonparametric model. Controlling of the system is achieved by adopting the proportional integral derivative controller. The controller parameters are identified by coupling the with an optimization algorithm by considering three optimal criteria. After obtaining the desirable optimal parameters of the controller, the dynamic response of the vehicle subjected to random road excitation is estimated and compared with the vehicle with a passive damper. The results show a reduction in the acceleration and vertical displacement of sprung mass in all classes of the road under optimal parameters conditions, leading to improved performance.

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CHAPTER 1

1.1 Introduction

Vibration suppression is considered a key research field in Mechanical engineering to ensure the safety and comfort of the passengers that use the mechanical structures. To reduce the system vibration, an effective vibration control with isolation is necessary. Vibration control techniques have classically been categorized into two areas, passive and active controls.

1.2 Suspension System (mainly there are three types of suspension system)

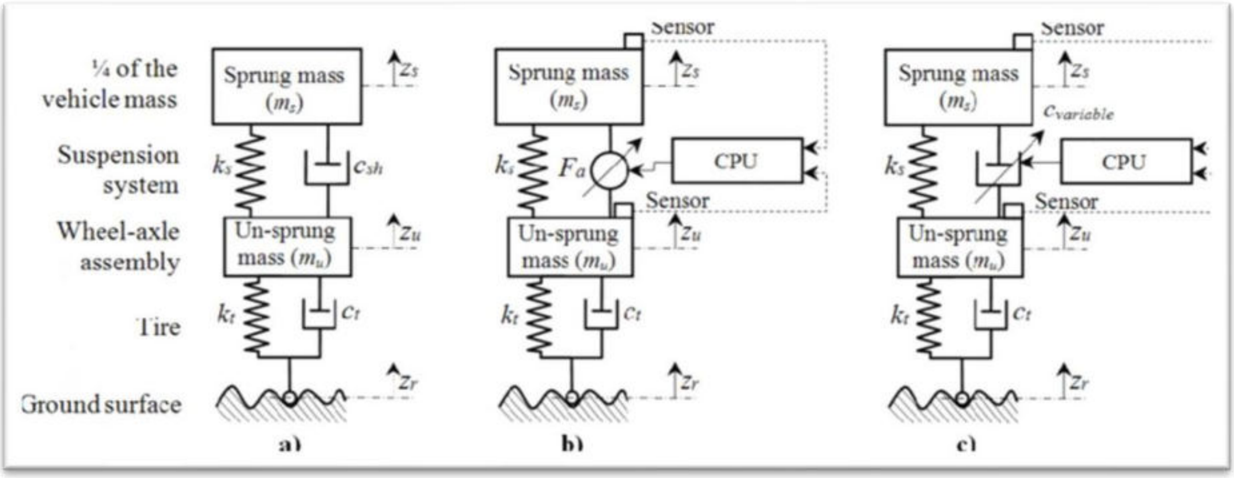

Figure 1.1: Passive, Active, And Semi-active suspension system

Active Suspension: It's a type of automotive suspension that controls the vertical movement of the vehicle relative to the chassis of the vehicle body. It is an onboard system that controls the movement.

Passive Suspension: It uses large springs, where movement is accompanied and guided by the entire road surface. It limits the vehicle's motion according to the unevenness of the road and gives the required comfortable ride.

Semi-Active Suspension: It is a derivative of the active suspension, where it is based on the four-shock absorber continuously adjusting the damping characteristic on a light commercial vehicle.

For a long time, efforts were made to make the suspension system work optimally by optimizing its parameters, but due to the intrinsic limitations of a passive suspension system, improvements were effective only in a certain frequency range. Compared with passive suspensions, active suspensions can improve the performance of the suspension system over a wide range of frequencies. Semi-active suspensions were proposed in the early 1970s, and can be nearly as effective as active suspensions. When the control system fails, the semi-active suspension can still work under passive conditions. Compared with active and passive suspension systems, the semi-active suspension system combines the advantages of both active and passive suspensions because it provides better performance when compared with passive suspensions and is economical, safe and does not require either higher-power actuators or a large power supply as active suspensions do.

1.3 Origin of MR Damper

In early semi-active suspension, many researches on variable orifice dampers had been done. With these damper types, regulation on of the damping force can be achieved by adjusting the orifice area in the oil-filled damper, thus changing the resistance to fluid flow, but adjusting the speed is slow because of mechanical motion limitations. Another class of semi-active suspension uses controllable fluids. Two fluids that are viable contenders for development of controllable dampers are: electrorheological (ER) fluids and magnetorheological (MR) fluids. Although the discovery of both ER and MR fluids dates back to the late 1940's, researchers have primarily concentrated on ER fluids for civil engineering applications. Recently developed MR fluids appear to be an attractive alternative to ER fluids for use in controllable fluid damper.

1.4 MR Damper

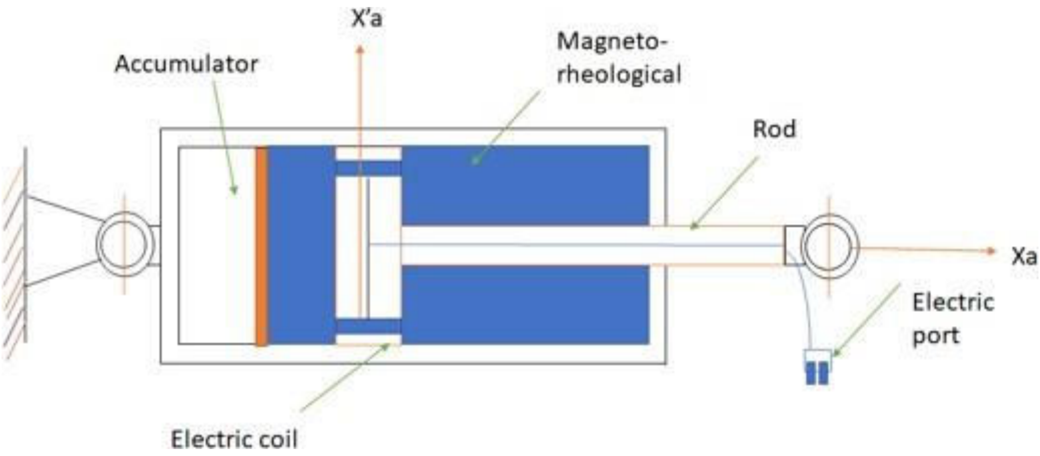

Figure 1. 2: MR Damper

An MR damper consists of a fluid that moves between different chambers via small orifices in the piston, converting "shock" energy into heat However in an MR damper, an electrical circuit is introduced in the piston assembly.

As electrical current is supplied to the damper, a coil inside the piston creates a magnetic field and instantaneously changes the properties of the MR Fluid in the piston.

1.5 What is MR fluid?

Magnetorheological (MR) fluids are a class of smart materials whose yield stress increases considerably in the presence of externally applied magnetic field.

1.6 MR fluid– Working principle

The initial discovery and development of MR fluid can be credited to Jacob Rainbow at the US National Bureau of Standards in the late 1940s.These fluids are suspensions of micron-sized, magnetizable particles in an appropriate carrier liquid. Normally, MR fluids are free flowing liquids having consistency similar to that of motor oil. However, in the presence of an applied magnetic field, the iron particles acquire a dipole moment aligned with the external field which causes particles to form linear chains parallel to the field. This phenomenon can solidify the suspended iron particles and restrict the fluid movement. Consequently, yield strength is developed within the fluid. The degree of change is related to the magnitude of the applied magnetic field, and can occur only in a few milliseconds. A typical MR fluid contains 20-40% by volume of relatively pure, soft iron particles, e.g., carbonyl iron. These particles are suspended in mineral oil, synthetic oil, water or glycol. A variety of proprietary additives similar to those found in commercial lubricant are commonly added to discourage gravitational settling and promote suspension, enhance lubricity, modify viscosity, and inhibit wear. The ultimate strength of an MR fluid depends on the square of the saturation magnetization of the suspended particles. The key to a strong MR fluid is to choose a particle with a large saturation magnetization. Typically, the diameter of the magnetizable particles is 3 to 5 microns. Functional MR fluids may be made with larger particles; however, particle suspension becomes increasingly more difficult as the size increases. Smaller particles that are easier to suspend could be used, but the manufacture of such particles is difficult. Commercial quantities of relatively inexpensive carbonyl iron are generally limited to sizes greater than 1 or 2 microns.

1.7 Technology (how it works)

The magnetic particles, which are typically micrometer or nanometer scale spheres or ellipsoids, are suspended within the carrier oil and distributed randomly in suspension under normal circumstances, as below figure

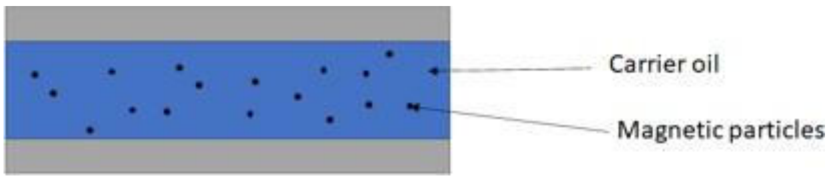

Figure 1. 3: Magnetic particles are at random direction

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When a magnetic field is applied, however, the microscopic particles (usually in the 0.1-10 μm range) align themselves along the lines of magnetic flux see below.

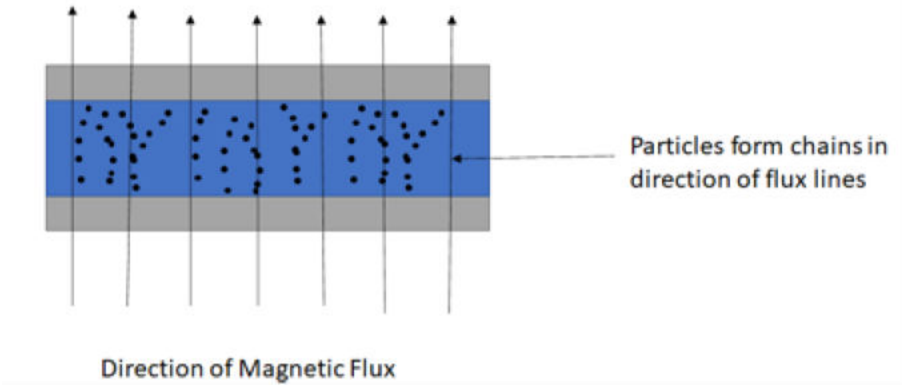

Figure 1.4: Magnetic particles are at aligned

1.8 Application of MR damper

Mono tube

The magneto rheological (MR) damper is one of the most promising new devices for vehicle vibration suppression because it has many advantages such as mechanical simplicity, high dynamic range, low power requirements, large force capacity and robustness. The damper offers a compromise solution for the two conflicting requirements of ride comfort and vehicle handling

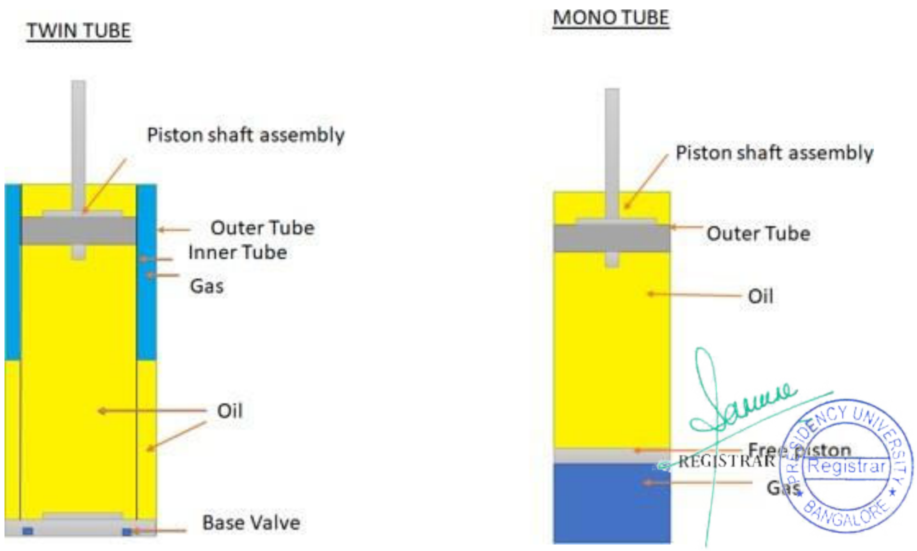

Figure 1.5: Mono Tube

Twin tube

The major **applications of MR Fluids** are in brakes, dampers, journal bearings, **fluid** clutches, pneumatic artificial muscles, aerospace etc. where electrical energy is converted to mechanical energy (Damping Force) in a controlled manner. Within a few milliseconds the **fluid** converts from liquid to semi solid state.

<u>1.9</u> <u>Controller</u> (mainly there are three type of controller)

PID: A **Proportional–integral–derivative** controller is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control.

Skyhook: A **skyhook** control is proposed and applied to the semi-active suspension control strategy design to improve the performance of the vehicle suspension system.

Sliding mode: sliding mode control (SMC) is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal (or more rigorously, a set-valued control signal) that forces the system to "slide" along a cross-section of the system's normal behavior.

CHAPTETR 2

2.1 Literature survey

Viscoelastic properties of MR fluids
In this research paper they investigated the viscoelastic properties of the MR fluid using: (a) strain-amplitude sweep mode and (b) Frequency-sweep mode.

Mechanism of chain formation in nanofluid based MR fluids
In this paper they are trying explain the behaviour of the bi-dispersed colloids in MR fluid and how it is different from the normal MR fluid.

Magnetorheological Fluids: Materials, Characterization, and Devices
This paper from 1996 is investigating and searching for possible ways to produce MR fluids at a feasible price and is also explaining the future possible applications.

An accurate technique for pre-yield characterization of MR fluids
In this paper, they used a sandwich beam structure with an aluminium face layer and MR fluid as the core layer with nearly uniform magnetic field, to explain the technique they chose to explain pre-yield characterisation of MR fluids.

Analytical and experimental free vibration analysis of multi-layer MR-fluid circular plates under varying magnetic flux
This paper is an analytical model of the sandwich annular plate based on classic plate theory. The numerical analysis was performed to study the free vibration responses of the sandwich plate in terms of resonant frequencies and loss factors.

Effects of Polyvinylpyrrolidone and Carbon Nanotubes on Magnetorheological Properties of Iron-Based Magnetorheological Fluids
In this paper, they experiment with iron and glycol-based MR Fluids by adding Carbon Nanotubes and PVP. And they explain the effects and merits of adding them.

An experimental study of MR dampers for seismic protection
In this paper, the performance of the MR fluids is tested by conducting experiments with a three-story structure subjected to one-dimensional ground excitation. And if it is possible to use for seismic protection or not is explained.

A comprehensive analysis of the response time of MR dampers
In this paper is to provide a comprehensive review on the response time of MR dampers. Rapid response time is desired for all real-time control applications.

Experimental Investigation of Using MR Fluids in Automobiles Suspension Systems
In this paper, the MR fluid is necessary or not as a suspension for an automobile and if it is then how it is beneficiary is explained.

Study on an Energy-Harvesting Magnetorheological Damper System in Parallel Configuration for Lightweight Battery-Operated Automobiles

In this paper, they try find that if electric motor is used as an actuator, then can we improve the performance and reduce the amount of the heat produced by converting it to electricity and storing.

Identification of semi-physical and black-box non-linear models: the case of MR-dampers for vehicles control
In this paper they are trying to accurately model the highly non-linear systems of MR-damper. Which are referred to the use of automobile suspensions.

A comparative work on vibration control of a quarter car suspension system with two different magneto-rheological dampers
In this paper they are comparing the comfort of a passenger vehicle whose suspension system is equipped with two different MR dampers: with and without bypass holes in piston.

Vertical dynamic analysis of a quarter car suspension system with MR damper
This paper presents ride comfort and road holding analysis of passive and semi-active suspension system using quarter car model. Semi-active suspension system with MR damper was modelled as non-parametric model.

Passenger seat vibration control of a semi-active quarter car system with hybrid Fuzzy–PID approach
In this paper, semi-active quarter car system with three degrees of freedom is considered for modelling and evaluation of passenger ride comfort.

Modelling and Simulation of Quarter Car Semi Active Suspension System Using LQR Controller
In this paper design of the Linear Quadratic Regulator (LQR) for Quarter car semi active suspension system has been done. In order to improve comfort and ride quality of a vehicle, four parameters are needed to be acknowledged. Those four parameters are sprung mass acceleration, sprung mass displacement, un-sprung displacement and suspension deflection.

Vibration Control of MR-Damped Vehicle Suspension System Using PID Controller Tuned by Particle Swarm Optimization
This paper introduces an investigation into the use of a PSO algorithm to tune the PID controller for a semi-active vehicle suspension system incorporating magnetorheological (MR) damper to improve the ride comfort and vehicle stability.

General Theory of Skyhook Control and its Application to Semi-Active Suspension Control Strategy Design
In this paper the general theory of skyhook is applied to the semi-active suspension control strategy design to improve the performance of the vehicle suspension system. Based on this theory, the mechanical impedance model of the general theory of skyhook suspension is established.

Mixed Sky-Hook and ADD: Approaching the Filtering Limits of a Semi-Active Suspension
In this paper there are two goals: (a) It is to prove that in their specific frequency domains-skyhook (SH) and acceleration driven damping (ADD) they cannot achieve (with same semi-active suspension) better performance. (b) it is to develop a control algorithm which is able to mix the SH and ADD performances.

Adaptive Sliding Mode Fault-Tolerant Control for Semi-Active Suspension Using Magnetorheological Dampers

In this paper, after formulating a full car dynamic model featuring four MR dampers, the fault model of the MR dampers due to the varying working temperature is derived. An adaptive sliding model fault-tolerant control strategy is then proposed after the occurrence of a fault.

Objective and Scope of The Literature Survey:

We all set and gone through many research papers to understand our topic on Characterization of MR fluid, and Dynamic Analysis of Quarter Car Semi-Active Suspension System in a much better way, and which has help us carried out our project much more effectively.

Chapter 3

3.1 Objective/s and expected outcome

Preparation of MR fluid sample.

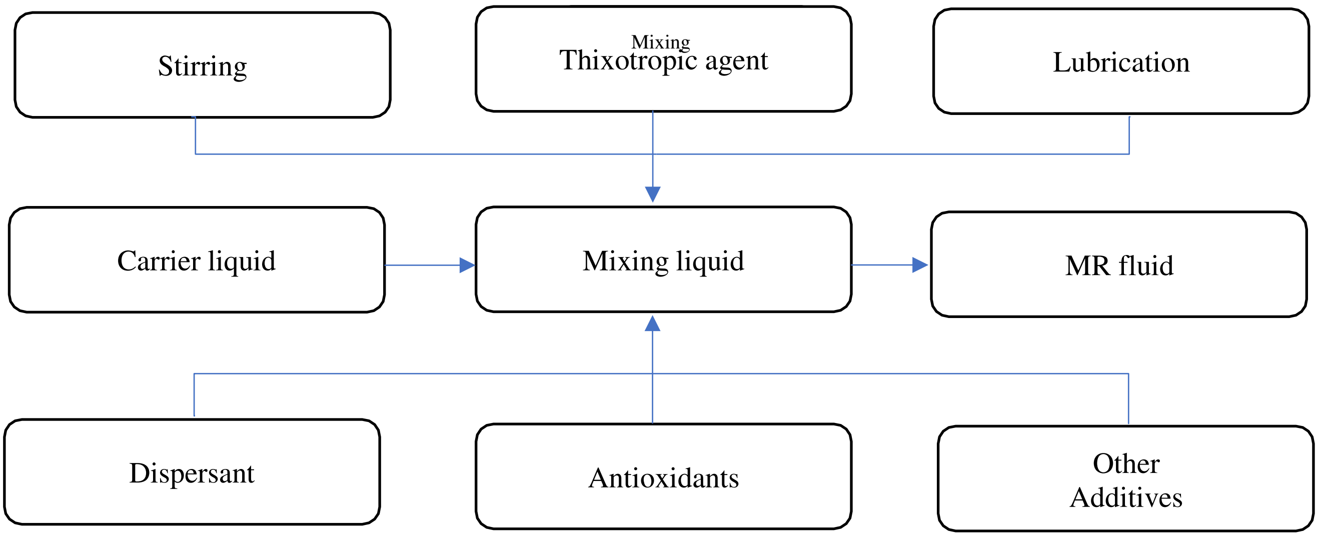

Figure 3.1: Preparation of MR Fluid sample

There are major processes when preparing MR fluids, one is about the preparation of CI particles. The other is regarding the mixing of magnetic particles, carrier liquid, and additives. The detailed process is as shown in Figure. First of all, the CI particles are added into the carrier liquid, and then stirred by the electric mixer for ~2–3 h to make the liquid disperse uniformly. Afterward, every 2 h different kinds of additives including dispersant, lubricant, and anti-sedimentation agent are added quantitatively in sequence, at the same time, make the liquid keep continuous stirring.

Rheological characterisation using Rheometer under different magnetic field.

After preparing MR fluid we are checking behaviors MR fluid by using Rheometer under different magnetic field and characterization of Rheological properties.

Dynamic characterisation of MR damper.

The analysis of the energy dissipated per cycle of vibration is made by a MR damper dynamic characterization on in order to examine the effect of the frequency, the amplitude of the displacement and of the excitation current on the dissipated energy and therefore the equivalent damping coefficient.

Vertical dynamic analysis of semi-active quarter car suspension system.

Here we are going to check the ride comfort and road holding analysis of passive and semi-active suspension system using quarter car model. The simulation of passive and semi-active suspension system was carried out under random road profile for different velocities. Then the result shows that semi-active suspension has significant improvement for a ride comfort and road holding of vehicle than passive suspension system. Experimental studies have been conducted to characterize MR damper and a good match is observed between results with simulation results obtained using non-parametric model

3.2 Methodology and Tools to be used

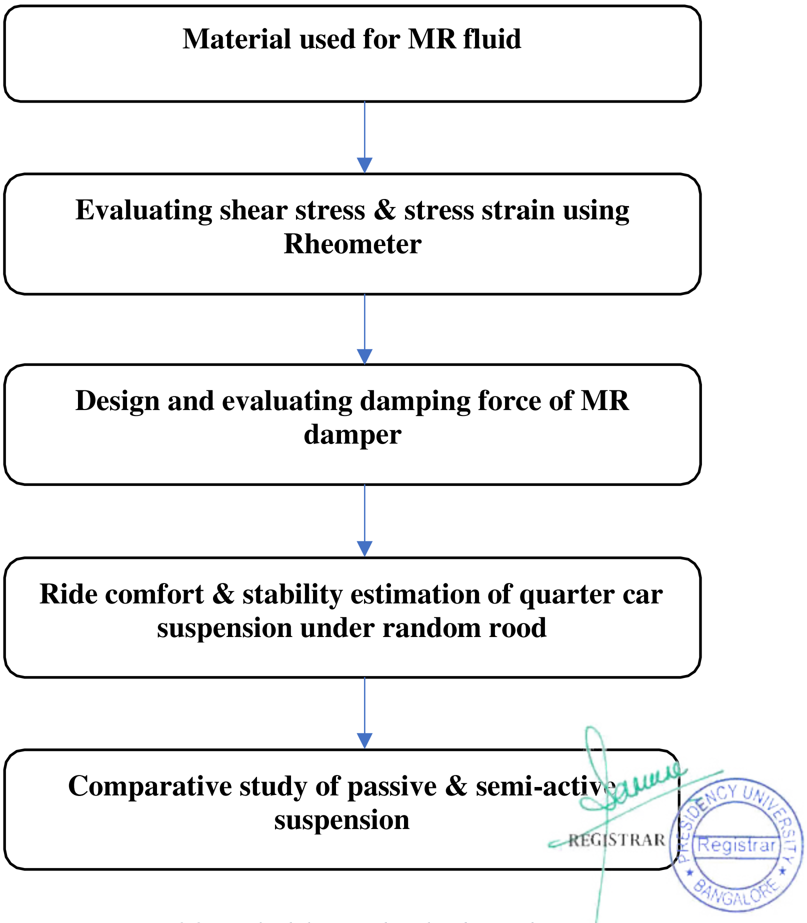

Figure 3.2: Methodology and tool to be used

Detailed about methodology and tools are used, first thing we have to know about the material to be used for the MR fluid. Next, Rheometer is a instrument which help to evaluating shear stress & stress strain. Then design damping force and evaluating damping force of MR damper After evaluating damping force check the Ride comfort & stability estimation of quarter car suspension under random road. At last Comparative study of passive & semi-active suspension.

3.3 Material

Product: **Carbonyl Iron Powder**
Stock No: NS6130-12-000314
CAS: 7439-89-6
Purity: 99.99%
APS: 4µm
Molecular Formula: Fe Molecular
Weight: 55.85g/mol
Form: Powder
Color: Gray
Density: 7.86g/cm3
Melting Point: 1535°C
Boiling Point: 2750°C
Thermal Expansion: 11.8 µm•m-1•K-1
Thermal Conductivity: 0.804 W/cm/K (298.2 K)
Vickers Hardness: 608 MPa
Poisson's Ratio: 0.29
Electrical Resistivity: 9.71 µΩ•cm (20°C)
Electronegativity: 1.8 Paulings
Young's Modulus: 211 GPa
Specific Heat: 0.106 Cal/g/K @ 25°C
Heat of Fusion: 3.56 Cal/gm mol
Solubility: Insoluble in water

Product: **hydraulic Oil**
Grade: EP 46
Brand: JCB
Type: hydraulic oil
Composition: Anti-Wear, complex Agent, inhibitors, Base Oil, and Additives
Density: 0.86 gm per cubic centimeter
Viscosity: 46 mm square per second
Packaging: Barrel
Form: liquid
Property: Mineral Oil-Based
Vapour pressure: less than 0.1 mmHg @25/typical
Solubility in water: Insoluble

Chapter 4
EXPERIMENTAL SET UP/ THEORITICAL/DATAS ANALYSIS/RESULTS AND DISCUSSIONS

4.1 Characterization of MR Fluid

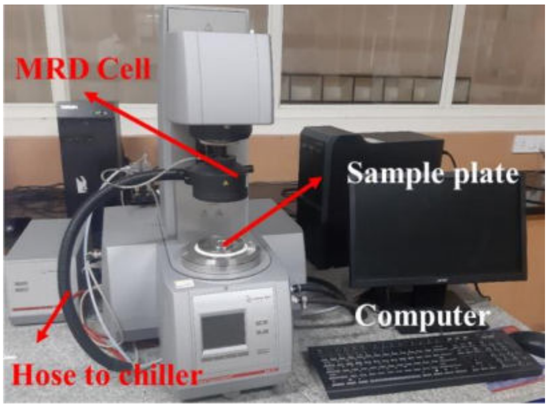

Figure 4.1: Rheological instrument

A Stress- strain curve of a material gives the best relationship between both stress and strains. It is also obtained by applying load to test a coupon and measuring the deformation, from which the stress and strain can be determined these stress and strain curves reveal many of the properties of a material, which results in such as the young ‘s modulus by the yield of strength and ultimate by the tensile strength. The shear stress of MR fluid plays important role achieving variable damping of shear stress is highly depends on the magnetic field included.

It is essential to know the magnitudes of shear stress of MR fluid at different magnetic field. The MR fluid was prepared in the laboratory based on the volume fraction of the ferrous partial carbonyl -iron powder with volume -fraction of 20 was mixed in silicone oil.

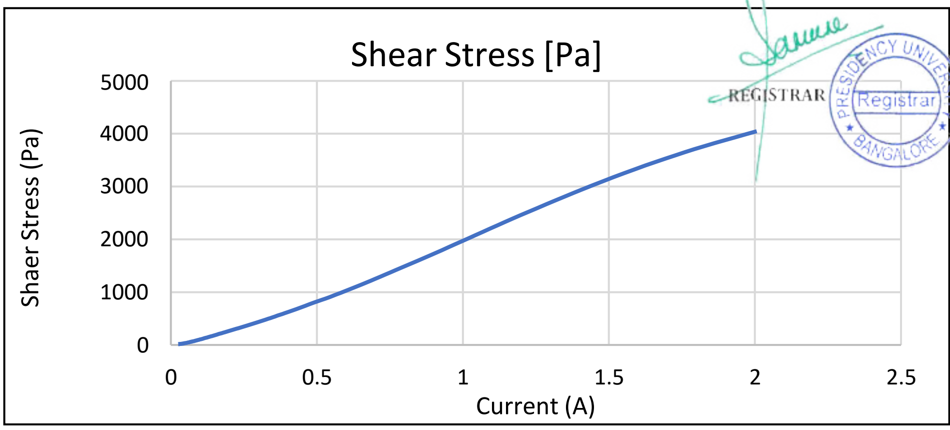

Figure 4.2: a) share stress versus current

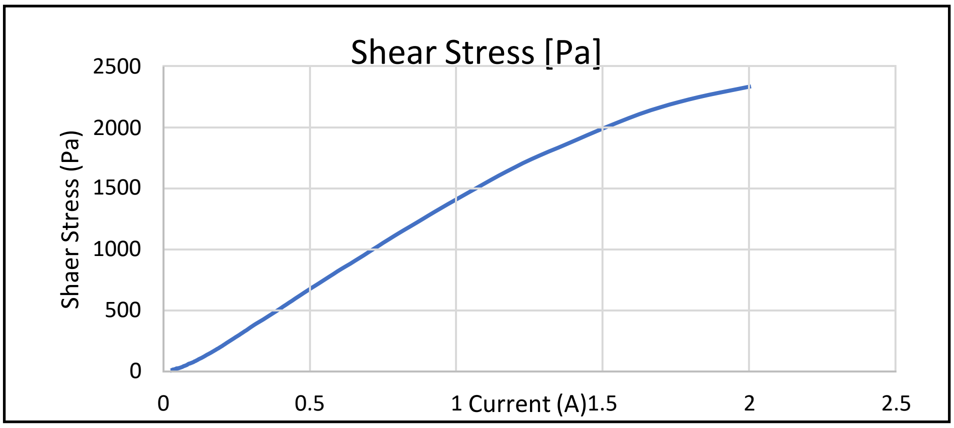

Figure 4.2: b) share stress versus current

Experiment to extract the shear stress of MR fluid is done with constant magnetic flux density. At one state condition that is magnetic flux of 0.333T the shear stress obtained is nearly 5200Pa .and at off -state conditions that is with zero magnetic flux the shear stress is nearly 1000 Pa.

4.2 Calculation of Damping Force

Calculation of damping force usually built-up flow model. From the configuration shown in the figure.

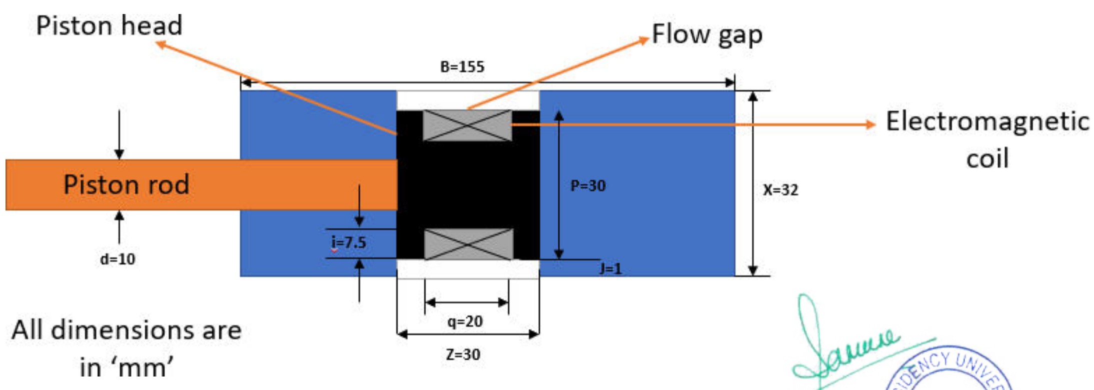

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Figure 4.3: MR damper geometry nomenclature with dimensions of the MR damper

where the valve, which controls the dynamic damping force of the damper, is arranged in the bypass the magnet circuit (including coil and MR fluid) can also be integrated into the piston.

The design procedure of MR damper in this was influenced by the Bingham model, shear force (F_{τ}) and plastic viscous force (F_{η}) can be written as,

$$F_\tau = \left(2.07 + \frac{12Q\vartheta}{12Q\vartheta + 0.4wg^2\tau_y}\right)\frac{\tau_y p A_p}{g} sgn(V)$$

$$F_\vartheta = \left(1 + \frac{wgV}{2Q}\right)\frac{12\vartheta Q L A_p}{wg^3}$$

where, **Q** is the volumetric flow rate,
Ap is the effective cross-section of piston (**Ap** = p (2 –d2) / 4),
d is the diameter of the piston rod,
V is the relative velocity between cylinder and piston,
q is the pole length,
Z is the total length of axial pole (Z = 30 mm),
w is the average circumference of the annular flow path (w= p (p + j)),
p is the diameter of the piston head,
y is the apparent viscosity of MR fluid without a magnetic field,
ty is the yield shear strength of fluid and
j is the height of annular flow path. The geometry nomenclature is shown in figure
The dynamic range (Km) can be written assuming
zero frictional force as (i.e., Ff= 0)

$$K_m = \frac{F_\tau}{F_{uc}} = \frac{F_\tau}{F_\vartheta + F_f} = \frac{F_\tau}{F_\vartheta}$$

Dynamic range and the controllable force are the two important factors considered when designing an MR damper. Based on the application of damper, it is recommended to design with a high dynamic range as well as controllable force.

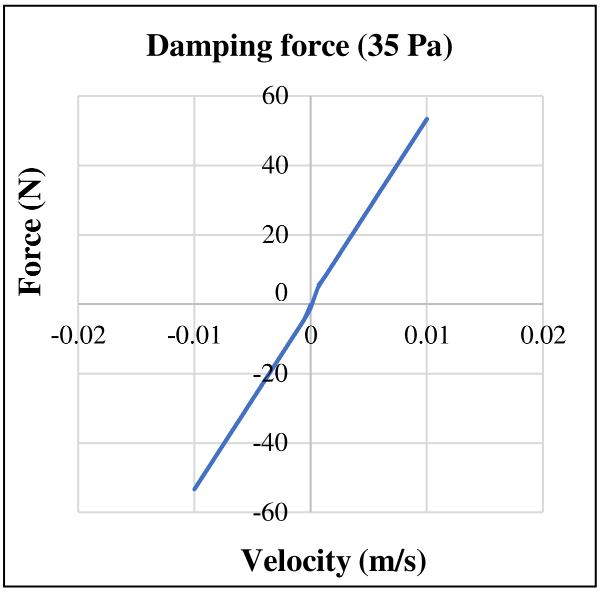


Figure 4.4: a) Resistance force at 35PA versus velocity

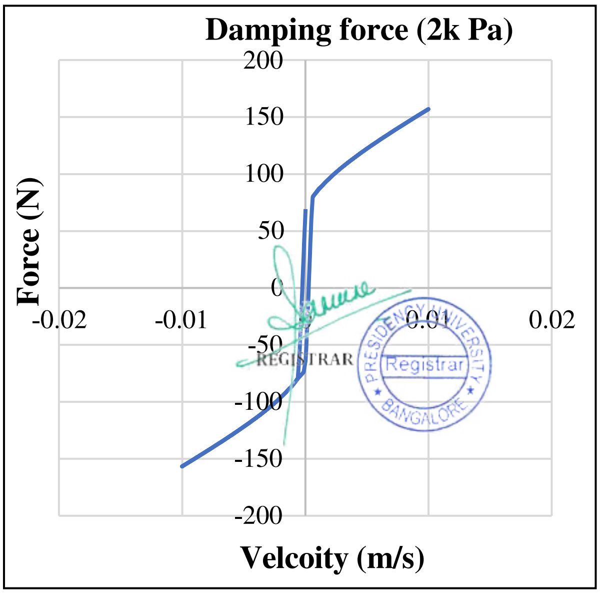
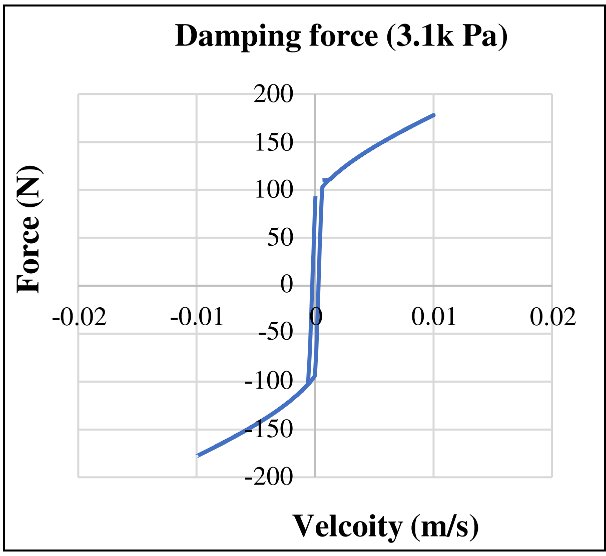


Figure 4.4: b) Resistance force at 2KPA versus velocity



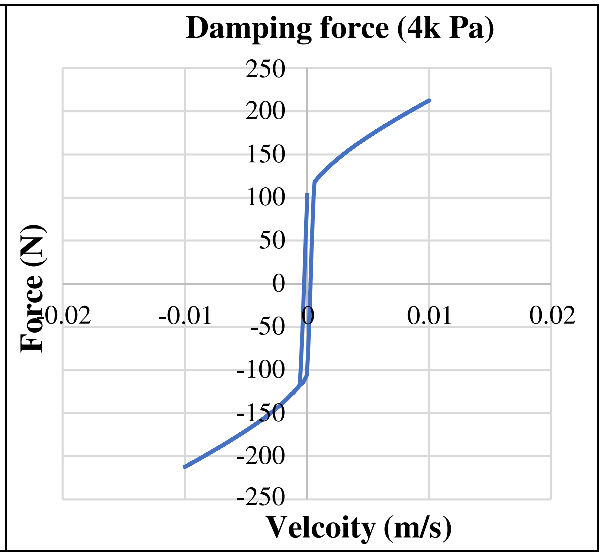


Figure 6.4: c) Resistance force at 3.1KPA versus velocity

Figure 7: d) Resistance force at 4KPA versus velocity

Four set of graphs tell us about Resistance force versus velocity as you can see each graph of slope of rebounded twice/thrice larger than the compression curve in the 4 graphs.
The graph is not quite similar which shows us irregularity in the damping forces experienced by corner of the mass.
So, the first figure shown experienced current at 0 ampere when is current increase the force increases, they are form the experimental data from Rheological instrument.
All these responses indicate that the rise of current has resulted in enhancement in resistance force and designed MR damper has achieved significant improvement in dynamic range.

4.3 Damper model

$$y = 22.102x^3 - 85.814x^2 + 162.1x + 52.188$$

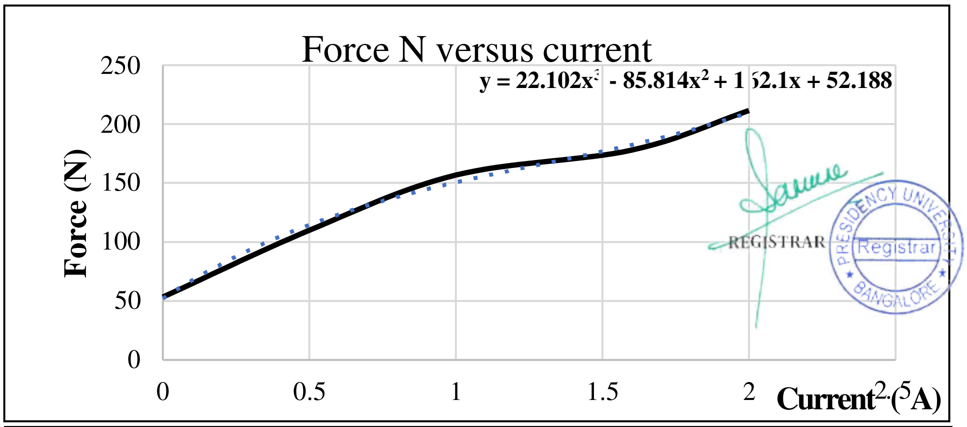


Figure 4.5: Force N versus current

The above equation is found by using Least square method on all of the graphs presented (Least square method is used to predict the behaviour of the dependent variable). When the values are substituted, we will find the Damping Force which will used in the quarter car analysis. And passive and semi-active suspensions will be compared.

4.4 Comparative study of passive & semi-active suspension

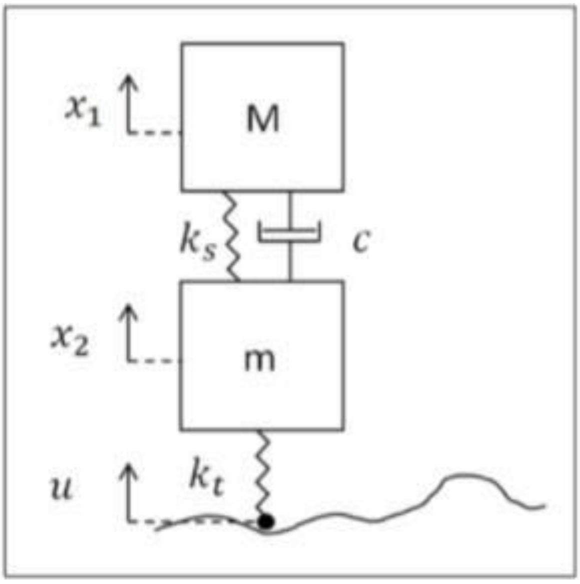


Figure 4.6: A quarter-car model of suspension system

The most frequently used model of a vehicle suspension system is a quarter car model shown on the left. In this model, the tires are modeled with a spring and mass (kt, m); the body of the vehicle is modeled as a mass (M) and the suspension system is modeled with a spring-damper (ks, c). 'u' represents the displacement due to the bumps on the road.

The equations of motion for the two bodies are as follows:

$$M\ddot{x}_1 + c(\dot{x}_1 - \dot{x}_2) + k_s(x_1 - x_2) = 0 \quad (1)$$

$$m\ddot{x}_2 + c(\dot{x}_2 - \dot{x}_1) + k_s(x_2 - x_1) + k_t(x_2 - u) = 0 \quad (2)$$

For the quarter car model given above, determine the transfer functions Gx_1x_2 (s), Gx_2u(s) and Gx_1u (s).

Passive suspension

Road Disturbance	Poor road	256
Road Disturbance	Very Poor road	655
Velocity	RMS acceleration	Road Holding
0	0	0
5	1.049	0.001981
10	1.64	0.0028
15	2.006	0.003425
20	2.311	0.003949
25	2.577	0.004406

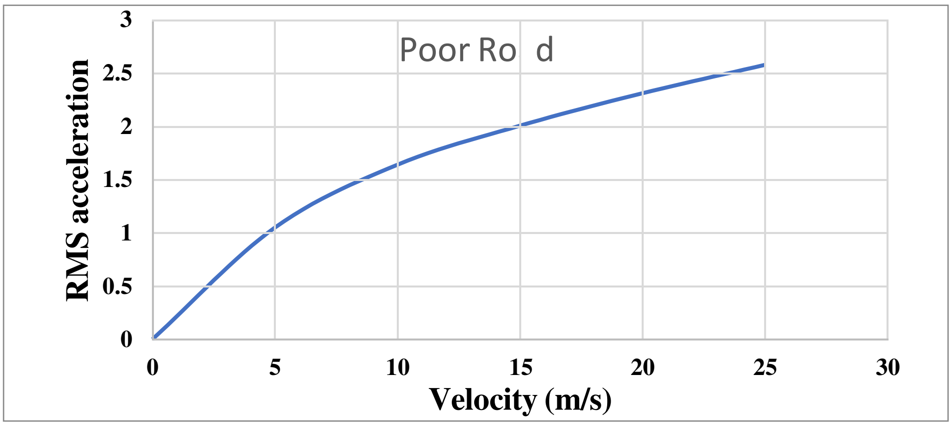


Figure 4.7: a) RMS acceleration versus velocity of poor road

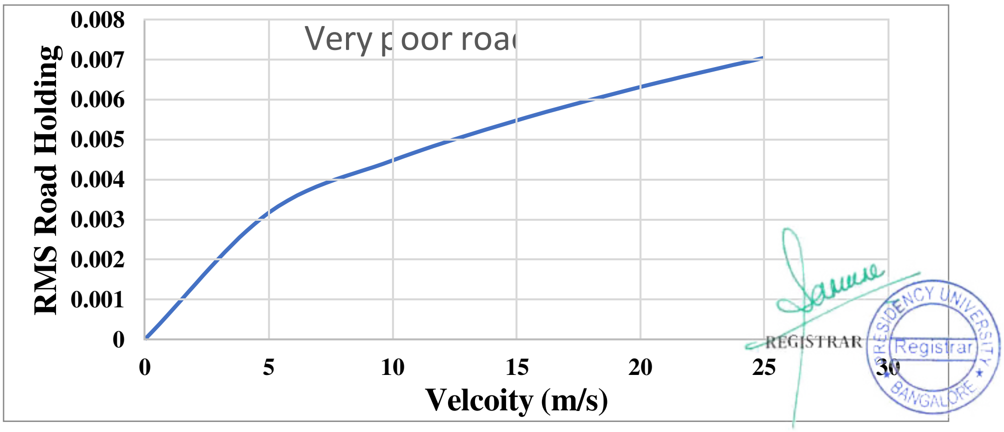


Figure 4.7: b) RMS Road Holding versus velocity of very poor road

Road Disturbance	Poor road	256
Road Disturbance	Very Poor road	655
Velocity	RMS acceleration	Road Holding
0	0	0
5	1.856	0.003168
10	2.623	0.004477
15	3.207	0.005477
20	3.695	0.006314
25	4.12	0.007045

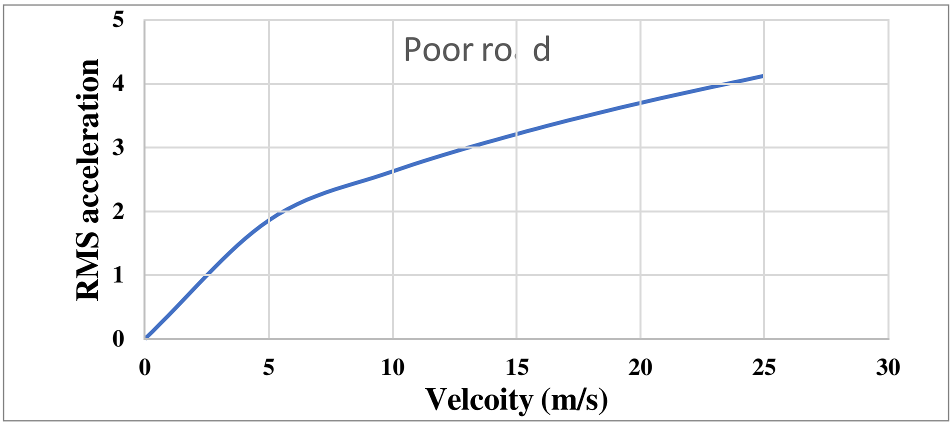


Figure4.7: c) RMS acceleration versus velocity of poor road

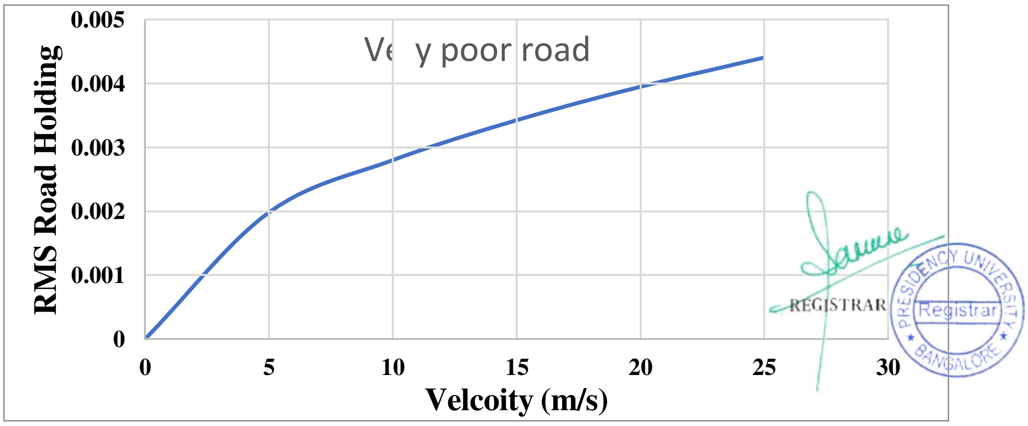


Figure 4.7: d) RMS Road Holding versus velocity of very poor road

Semi-Active Suspension

Road Disturbance	Poor road	256
Road Disturbance	Very Poor road	655
Velocity	RMS acceleration	Road Holding
0	0	0
5	1.646	0.002759
10	2.329	0.003904
15	2.851	0.004781
20	3.288	0.005517
25	3.669	0.00616

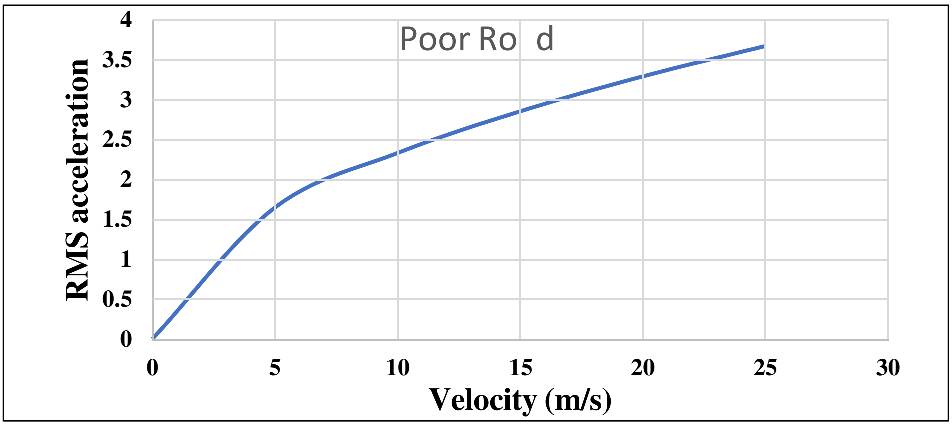


Figure 4.8: a) RMS acceleration versus velocity of poor road

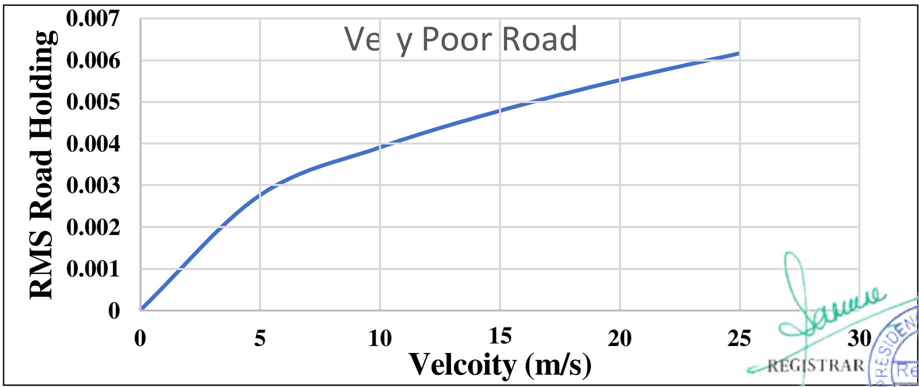


Figure 4.8: b) RMS Road Holding versus velocity of Very poor road

Road Disturbance	**Poor road**	**256**
Road Disturbance	**Very Poor road**	**655**
Velocity	**RMS acceleration**	**Road Holding**
0	0	0
5	2.638	0.004421
10	3.739	0.006266
15	4.586	0.007687
20	5.301	0.008889
25	5.929	0.009949

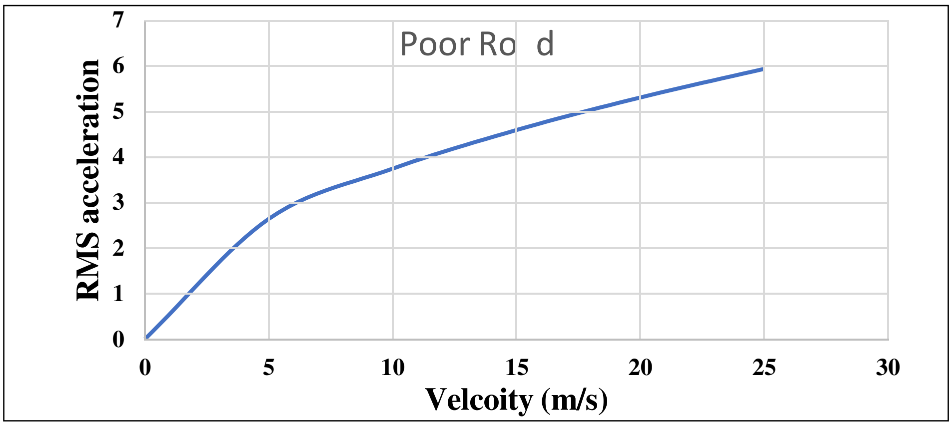


Figure 8.8: c) RMS acceleration versus velocity of very poor road

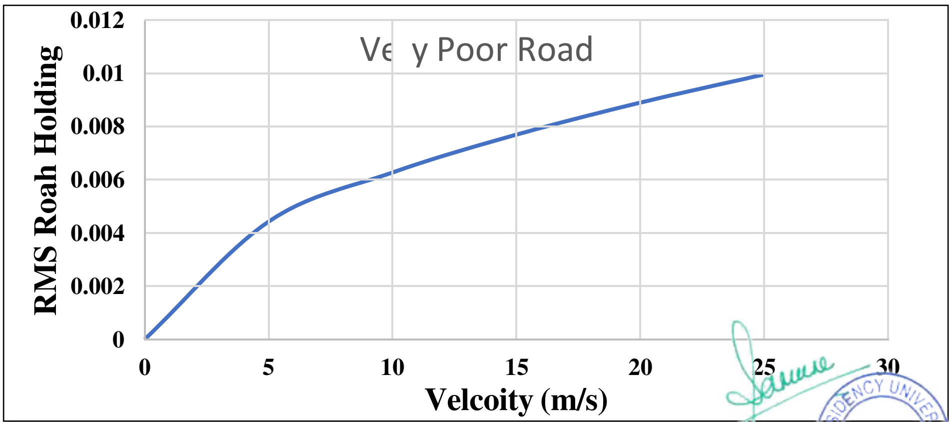


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Figure 4.8: d) RMS acceleration versus velocity of very poor road

The ride comfort of the vehicle is often expressed in terms of RMS acceleration of the sprung mass of the vehicle and the stability of the vehicle is expressed in terms of RMS relative displacement (RMS road holding) of road and wheel. This quantification is according to ISO 2631-1-1997 (Mitra et al., 2016). Hence, evaluations of ride comfort and road-holding ability of the vehicle suspension are performed. The input for the dynamic system is the random road, hence the RMS values are chosen.

The passive and semi-active quarter car ride comfort and road holding were evaluated at different road input conditions. A comparative study of the results has been made to quantify the performance. Figure shows the comparison of RMS acceleration and road holding of the passive and semi-active vehicle at poor road condition.

shows the comparison of response of passive and semi-active vehicle on subjecting to the average road condition. Here, it can also be observed that semi-active suspension system has better performance compared to passive vehicle. The reduction of RMS acceleration in semi-active vehicle is 25.5% and RMS road holding is 29.2%.

The comparison of semi-active suspension and passive suspensions system response to the poor road input conditions have been made in case of the passive the suspension system, the response to the input is reduced in a notable level, while the response to the road disturbance is significantly reduced due to the controller in case of semi-active suspension.

5. Conclusion

- We have done rheological testing, and we have obtained the shear stress for different currents. From that, we have calculated the damping force, later on, used that damping force in quarter car vehicles.
- Model would make significant contribution in improving the reaction time of the overall semi-active suspension system with MR damper.
- A MR damper was formulated by extracting the polynomial expression which represents the dynamic characteristic of the MR damper. This model was used in a quarter car model and its performance in the passive and semi-active suspension was evaluated, and we have achieved a desired result.
- Based on the results obtained in these analyses, it was identified that the parameters served well with the purpose of reducing the acceleration and vertical displacement of sprung mass in all classes of roads to improve the ride comfort and road holding of the vehicle.

6. Recommendations for Future Work

The following are recommendations for future work to help related to Characterization of MR fluid, and dynamic analysis of Quarter Car semi-active suspension:

- Study of the role of Preparation of MR fluid sample.
- Rheological characterization using Rheometer under different magnetic field.
- Evaluation of Dynamic characterization of MR damper.
- The establish a set of tests for assessing vertical dynamic analysis of semi-active quarter car suspension system.

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A Project Report on

"VEHICLE ROUTING PROBLEM IN SPARE PARTS SUPPLY CHAIN IN THE CONTEXT OF AUTONOMOUS ADDITIVE MANUFACTURING VEHICLE"

Submitted in partial fulfillment of the requirement of Bachelor of Technology
for the University Project/PP-1
in
Mechanical Engineering

Submitted by

Abhishek A	**20171MEC0006**
Adithya R	**20171MEC0012**
Akash H	**20171MEC0016**
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Ashok Kumar G	**20171MEC0033**

Under the Supervision of
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Associate Professor

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(Private University Estd. in Karnataka State by Act No.41 of 2013)

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CERTIFICATE

Certified that, the project work entitled, **"Vehicle Routing Problem in Spare parts Supply Chain in the context of Autonomous Additive Manufacturing Vehicle"** carried out by Mr. Abhishek A, ID 20171MEC0006, Mr. Adithya R, ID 20171MEC0012, Mr. Akash H, ID 20171MEC0016, Mr. Arijit Jagadish, ID 20171MEC0028 And Mr. Ashok Kumar G, ID 20171MEC0033 bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Jyoti

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Dr. Jothi Basu
Supervisor

Dr S Ramesh S
Prof. and Head

End Term Examination

Signature with dateExaminers

1.Dr.Arpitha G R

2.Dr.Yuvaraj Nayak

DECLARATION

We, the students of fifth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, " **Vehicle Routing Problem in Spare parts Supply Chain in the context of Autonomous Additive Manufacturing Vehicle**" has been successfully completed under the supervision of Dr. Jothi Basu, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:

Team members:	**ID Numbers**	**Signature of Students**
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Adithya R	**20171MEC0012**	
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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr Jothi Basu** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully. We, take this opportunity to sincerely thank **Dr. Dr S Ramesh S, Prof. and Head** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Ramesh S.P** who gave us the opportunity to do this project work.

Lastly, we would like to thank our family and friends

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ABSTRACT

This study is the integration of the Supply Chain with the Additive manufacturing in adapting the autonomous vehicle technology right from the traditional values to the dynamic values in attaining the various optimization of key parameters. Additive manufacturing (AM), alongside technological developments, has been used in the production of spare parts with positive results for spare parts supply chains. In this study, we investigate spare parts supply chains serving heterogeneous demands from multiple service locations under the mode of make-to-order. Additive Manufacturing (AM) is rapidly gaining interest as a highly innovative manufacturing technology, having many advantages over more conventional manufacturing methods. These advantages include the ability to produce very complex structures that are relatively easily customized to specific user requirements. The fact that AM services become affordable for small companies or even for consumers offers possibilities for decentralized manufacturing, downstream in the supply chain.

We aim to compare different configurations (i.e. centralized and distributed) of spare parts supply chains in terms of their performance and to further propose suggestions to better configure AM-based spare parts supply chains. In order to realize these research objectives, the simulation approach is used as the main research method. Different from the existing perception, our results illustrate that the distributed deployment of AM machines does not always guarantee a quick response, and that centralized configuration is desirable when the demand rate is relatively high due to the pooling effect.AM implementations shows that fully leveraging AM will require innovations at the level of the supply chain, including innovations in business processes, technology and structure, as well as supportive changes in the business environment.

The vehicle routing problem (VRP) with time windows is a generalization of the vehicle routing problem where the service of a customer can begin within the time window defined by the earliest and the latest times when the customer will permit the start of service. In this study, we present the development of a new optimization algorithm for its solution. The results offer a framework to assess the current state and future needs in vehicle routing problem (VRP), AM-related supply chain innovations. Practical ideas are proposed to enhance AM adoption throughout supply chains.

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CHAPTER 1: INTRODUCTION

Additive Manufacturing – A Game Changer in Automotive Spare parts Supply Chain

Supply Chain is nowadays more or less like a frequently encountered term in our day to day life. May it be like, the distribution of consumer goods or distribution of emergency supply like vaccine for Covid -19, the role of Supply Chain is inevitable. After globalization and liberalization, the requirement of Supply Chain related activities increased rapidly and it became the order of the day.

Supply Chain Management

In general, Supply Chain Management is all about managing the flow of goods and services across various stages of the business. Here, the various stages include supplier, manufacturer, distributor, retailer and finally customer. Apart from the physical flow of materials, there will be cash and information flow also across the chain. An example automotive supply chain is shown in figure 1.

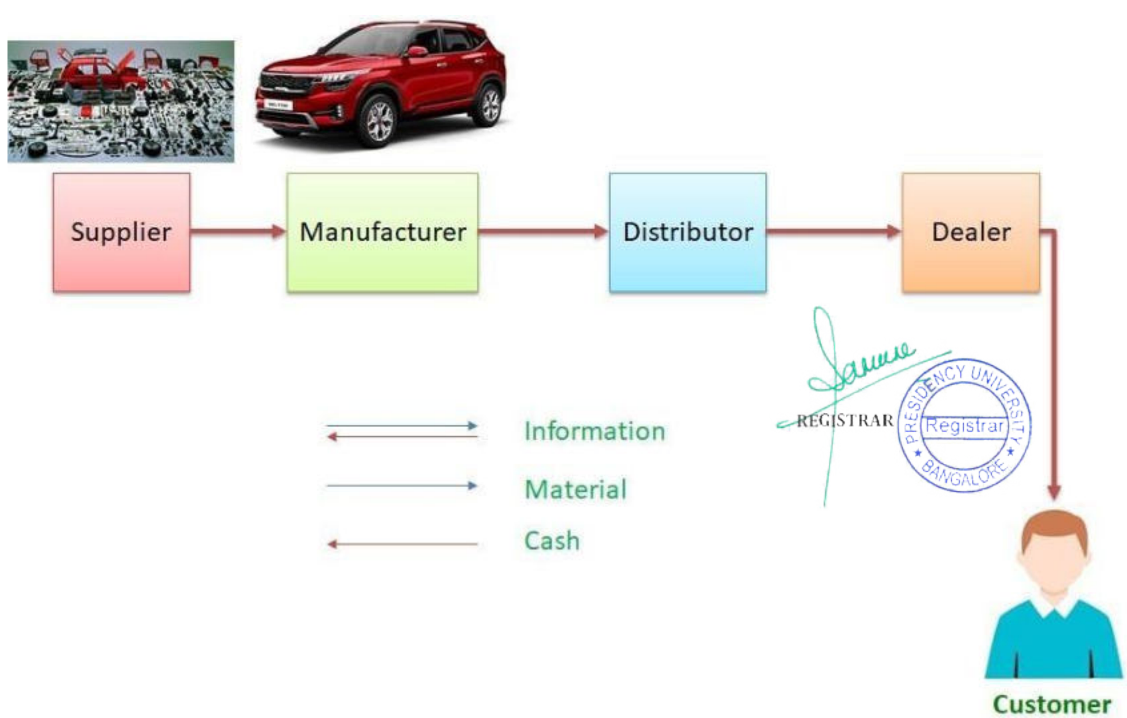

Figure 1.1: Sample automotive supply chain

Automotive Spare parts industry - current scenario

Spare parts of automobiles are generally costly, because of the simple reason that the amount of cost involved in distribution and logistics. From the customer perspective, the availability of spare parts in the nearby service center is very much important and also one of the prominent factors influencing buying decision. Good quality car makers like Fiat India couldn't sustain their presence in Indian market mainly because of poor supply of spare parts. The Indian automotive sector is growing and according to the Statista 2021 report, India's automotive spare parts market is estimated at US$57 Billion.

Figure 1.2: Automotive spare parts for illustration

For a geographically large country like India, distribution and logistics of spares is a challenging task, but it is unavoidable. The main problem here is to match the demand and supply. Because, manufacturing of spare parts happen at one place and produce need to be distributed to all across the service centers. Also, it is literally not possible to keep the stock of all spare parts for all of models of a particular car maker's product line in each and every service center. As you know, each car has tens of thousands of spare parts and it is symbolically represented in the figure 1.2. But, if it is not available, customer may complain. Academician and practitioners keep on trying to optimize the distribution and storage of spares across the market being served, but still the problem persists.

Additive Manufacturing as a Game Changer

Maturity of the Additive Manufacturing (AM) technology looks promising and it is going to be a game changer for the automotive spare parts industry. Researchers across the globe have started working on with the concept of manufacturing and supplying the spares with the help of additive manufacturing enabled truck. Even though, it is at the concept level, still it is promising. As per this idea, it is going to be a radical change from existing push system of manufacturing to pull system for spare parts supply. It means, we are going to manufacture the particular spare parts once we get the order.

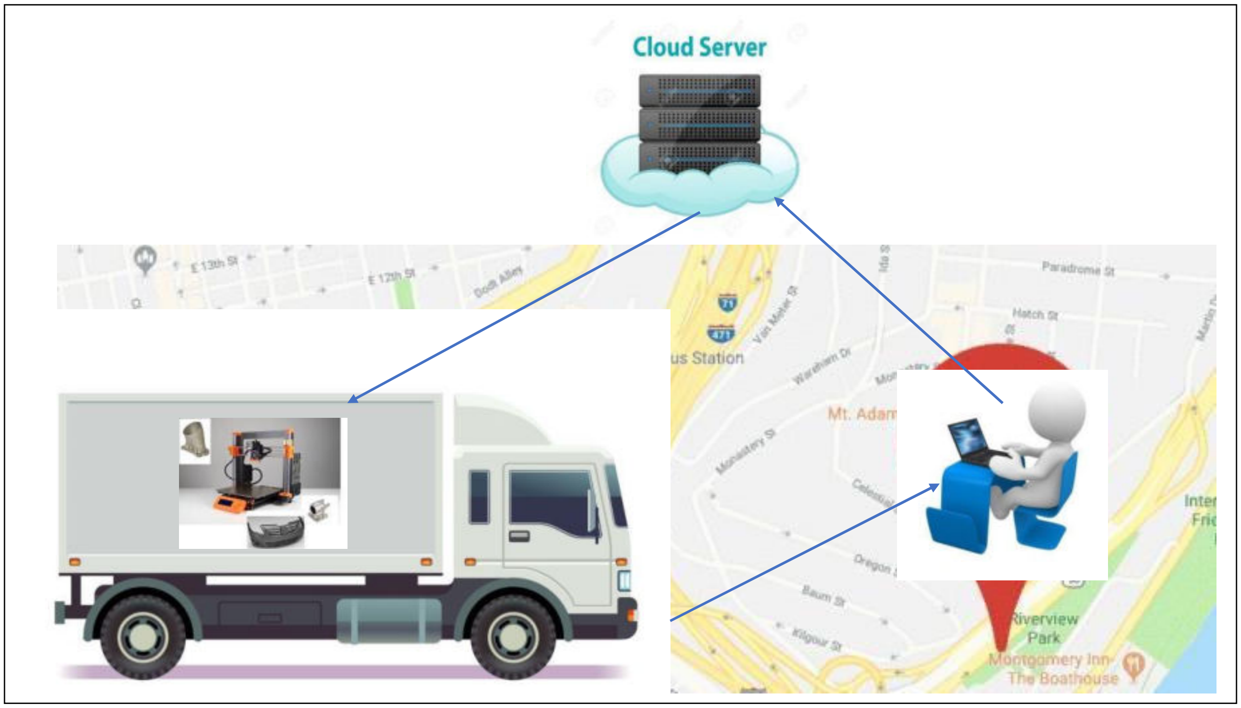

Figure 1.3: Additive Manufacturing enabled Truck (Concept)

Also, it is not going to be manufactured in a central facility like a manufacturing facility of Original Equipment Manufacturer (OEM). Instead, here the manufacturing facility itself distributed close to the market by the way of having AM enabled truck. The concept of the same is shown in the figure 3. First step would be the development of required infrastructure that include a bunch of AM enabled in serving the market, for example, 10 - 20 number of trucks for Bangalore. All trucks need to be connected to GPS and to cloud server. E-Com platform with design part files of the various spare parts that has been stored on the cloud server. Here, the customer will be in a position to order the spare parts through the online platform like any other E-com website. When a customer orders a particular component, the information will go to the cloud server and the server will identify the AM enabled truck close to customer locations in real time. If the truck has the capacity to produce the ordered item, the particular truck is assigned to the corresponding order. By this way, we can eliminate the unnecessary huge distribution/transportation cost as we are manufacturing close to the customer. Also, it eliminates the large spending on inventory cost in the existing model.

Companies develop supply chains so they can reduce their costs and remain competitive in the business landscape. Supply chain management is a crucial process because an optimized supply chain results in lower costs and a faster production cycle.

1.1 The Importance of Supply Chain Management

It is well known that supply chain management is an integral part of most businesses and is essential to company success and customer satisfaction. Well-designed supply chain practices are able to meet customer needs in a more expeditious and timely manner.

Boost Customer Service

- Customers expect the correct product assortment and quantity to be delivered.
- Customers expect products to be available at the right location. (i.e., customer satisfaction diminishes if an auto repair shop does not have the necessary parts in stock and can't fix your car for an extra day or two).
- Right Delivery Time – Customers expect products to be delivered on time (i.e., customer satisfaction diminishes if pizza delivery is two hours late or Christmas presents are delivered on December 26).
- Right After Sale Support – Customers expect products to be serviced quickly. (i.e., customer satisfaction diminishes when a home furnace stops operating in the winter and repairs can't be made for days)

Reduce Operating Costs

- **Decreases Purchasing Cost** – Retailers depend on supply chains to quickly deliver expensive products to avoid holding costly inventories in stores any longer than necessary. For example, electronics stores require fast delivery of 60" flat-panel plasma HDTV's to avoid high inventory costs.

- **Decreases Production Cost** – Manufacturers depend on supply chains to reliably deliver materials to assembly plants to avoid material shortages that would shutdown production. For example, an unexpected parts shipment delay that causes an auto assembly plant shutdown can cost $20,000 per minute and millions of dollars per day in lost wages.

- **Decreases Total Supply Chain Cost** – Manufacturers and retailers depend on supply chain managers to design networks that meet customer service goals at the least total cost. Efficient supply chains enable a firm to be more competitive in the market place. For example, Dell's revolutionary computer supply chain approach involved making each computer based on a specific customer order, then shipping the computer directly to the customer. As a result, Dell was able to avoid having large computer inventories sitting in warehouses and retail stores which saved millions of dollars. Also, Dell avoided carrying computer inventories that could become technologically obsolete as computer technology changed rapidly.

Improve Financial Position

- **Increases Profit Leverage** – Firms value supply chain managers because they help control and reduce supply chain costs. This can result in dramatic increases in firm profits. For instance, U.S. consumers eat 2.7 billion packages of cereal annually, so decreasing U.S. cereal supply chain costs just one cent per cereal box would result in $13 million dollars saved industry-wide as 13 billion boxes of cereal flowed through the improved supply chain over a five year period.
- **Decreases Fixed Assets** – Firms value supply chain managers because they decrease the use of large fixed assets such as plants, warehouses and transportation vehicles in the supply chain. If supply chain experts can redesign the network to properly serve U.S. customers from six warehouses rather than ten, the firm will avoid building four very expensive buildings.
- **Increases Cash Flow** – Firms value supply chain managers because they speed up product flows to customers. For example, if a firm can make and deliver a product to a customer in 10 days rather than 70 days, it can invoice the customer 60 days sooner.

Lesser known, is how supply chain management also plays a critical role in society. SCM knowledge and capabilities can be used to support medical missions, conduct disaster relief operations, and handle other types of emergencies.

Whether dealing with day-to-day product flows or dealing with an unexpected natural disaster, supply chain experts roll up their sleeves and get busy. They diagnose problems, creatively work around disruptions, and figure out how to move essential products to people in need as efficiently as possible.

Improve Quality of Life

- **Foundation for Economic Growth** – Societies with a highly developed supply chain infrastructure (modern interstate highway system, vast railroad network, numerous modern ports and airports) are able to exchange many goods between businesses and consumers quickly and at low cost. As a result, the economy grows. In fact, the one thing that most poor nations have in common is no or a very poorly developed supply chain infrastructure.

- **Improves Standard of Living** – Societies with a highly developed supply chain infrastructure (modern interstate highway system, vast railroad network, numerous modern ports and airports) are able to exchange many goods between businesses and consumers quickly and at low cost. As a result, consumers can afford to buy more products with their income thereby raising the standard of living in the society. For instance, it is estimated that supply chain costs make up 20% of a product's cost in the U.S. but 40% of a product's cost in China. If transport damage is added in, these costs make up 60% of a product's cost in China. The high Chinese supply chain cost is a major impediment to improving the standard of living for Chinese citizens. Consequently, China has embarked on a massive effort to develop its infrastructure.

- **Job Creation** – Supply chain professionals design and operate all of the supply chains in a society and manage transportation, warehousing, inventory management, packaging and logistics information. As a result, there are many jobs in the supply chain field. For example, in the U.S., logistics activities represent 9.9% of all dollars spent on goods and services in 2006. This translates into 10,000,000 U.S. logistics jobs.

1.2 Additive Manufacturing and Its Influence On the Supply Chain

Additive manufacturing is a technological advancement in which computer-aided-design (CAD) software or 3D object scanners are used to create lighter and stronger parts. This technique allows precise objects to be made from a digital design with structures being created out of thousands of minuscule layers. Within

the manufacturing operation, a layering process is applied where the joining of materials required to create the object is completed layer-by-layer – this is opposed to traditional manufacturing where the material is usually carved or shaped.
There are a number of manufacturing techniques which come under the banner of additive manufacturing. The most common is 3D printing but there are other techniques such as VAT photo-polymerization, material jetting, binder jetting, powder bed fusion and direct energy deposition. More techniques are being developed and this highlights that additive manufacturing has an interesting future ahead.

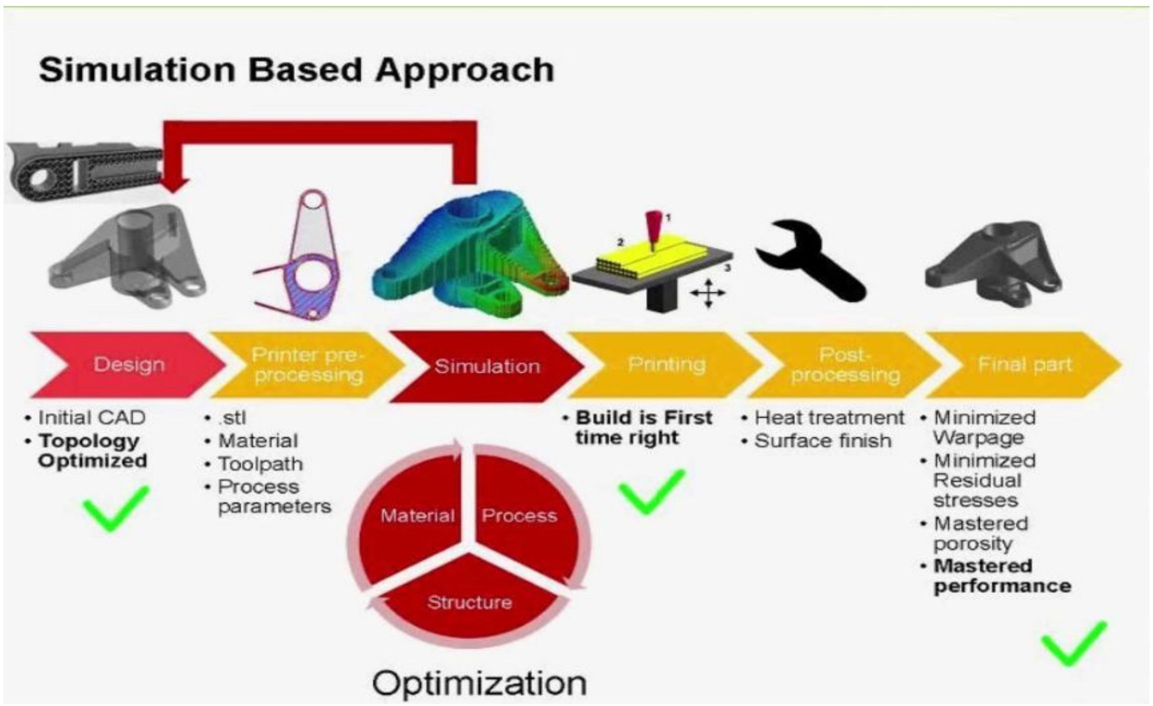

Fig 1.4: Additive manufacturing by simulation approach

There are many benefits to investing and using additive manufacturing. The main **advantage** is that the process is able to produce a greater range of shapes compared to conventional manufacturing where it may not be possible to create an entire part. For example, parts that have a hollow center can't be achieved in one single piece in conventional manufacturing, but it is achievable with additive manufacturing, with the additional benefit that the part will be considered superior because it doesn't have any weak spots.

Another advantage is that the technique is considered much faster. Designs which are done using **CAD** can be changed quickly as opposed to traditional manufacturing methods where engineering meetings would be required to push through changes. Additive manufacturing also has the capability in some instances to produce prototypes overnight, so is also considered to be much more flexible. It is, therefore, no surprise that additive manufacturing will have a big impact on the way that the supply chain functions. These changes are predominantly positive for all parties concerned from the consumer to the manufacturer right through to the brand.

1.2.1 The technique will also continue to push supply chains towards just-in-time, distributed manufacturing and this alone will have the following impacts:

A reduction in manufacturing costs and locational changes
Additive manufacturing techniques such as 3D printers are not required to be housed in huge warehouses that have the capability to run large-scale assembly operations. This means that manufacturing companies can now be located nearer the point of consumption. For example, a company which provides the construction industry with parts could locate close to a construction site that they do business with. This gives them the capability to print/manufacture the spares for their client's heavy machinery as and when required reducing the downtime for their client's high-value assets.

The ability to localize printing and distribution
As we have touched on in the point above, locally-housed printers can be located in a customer's region. Therefore, when a customer orders a part or spare online, it can be printed on a local printer. This also means that local transport can be used which could be more cost-effective.

1.2.2 Provide a consolidation of the supply chain

In additive manufacturing, multiple-part assemblies can now be replaced by single, printed parts which leads to a consolidation in the supply chain. This consolidation occurs because less assembly work is required in the production process to make a finished product. It may also result in more parts being produced by single vendors or single printers, therefore, reducing the need for approved vendor lists.

Require no inventory for spare parts
There are many products such as vehicles and industrial machinery that have long life spans. In the past, these long life-cycles have led to the products being supported by their own inventory stores. However, these inventories require expensive storage and when required, high delivery costs. With

additive manufacturing, the parts can be made on-demand and shipped when required. This, therefore, eliminates the need for an inventory storage.

Reduce times to market

Speed to market is increased with additive manufacturing. This is great news for markets where customer demand varies and the opportunity to market is short because this manufacturing method delivers new products to the market faster.

Push the development of digital ecosystems

By its nature, additive manufacturing is about digital processes and it therefore pushes the development of digital ecosystems. This will, in turn, make the entire manufacturing process more agile and attractive to manufacturers as digital networks connect every aspect of a product's life, leading to a reduction in the time-to-market as well as improved design.

Support low volume and mass customization

Additive manufacturing is the easiest way to ensure low-volume build. This means that some products that would have previously never got off the drawing board can be produced. In the past, a low-volume build won't have been cost-efficient. The manufacturing technique also delivers the potential for mass customization and personalization to scale due to slightly different parts being able to be produced at scale.

We can, therefore, see that additive manufacturing is going to have a huge impact on not only how we manufacture products but also on where the products are manufactured. The manufacturing technique is going to drive through many digital transformational changes within the industry as it gains in momentum. What can be predicted is that the supply chain is going to become more digital, visible, traceable as well as flexible and agile.

It will be important for all manufacturing businesses and their wider counterparts to assess their current manufacturing practices. It will be up to them to embrace the changes that are coming to ensure that they can succeed. It will be vital that they adapt to changes to ensure that their business doesn't get adversely disrupted or affected.

CHAPTER 2 - LITERATURE SURVEY

In this section we provide a literature review on the application of AM in the Vehicle Routing Problem using 3D Printer to manufacture spare parts, as well as various approaches to supply chain cost analysis.

2.1 Choosing and assessing the articles

Using the search terms specified above, peer-reviewed articles were collected in the online databases. The literature search found 250 articles and papers all published before January 2020. Based on an examination of the abstracts, 150 articles were rejected on the grounds that they did not include SC design elements, SC performance outputs, or about vehicle routing problem. The required SC information in the articles was frequently concealed, or in some way unclear, reflecting the complicated problems often observed in organizations. Although all 67 articles were peer reviewed, only a minority of these articles were based on empirical evidence. Nevertheless, the others were kept in the set because their described experience and know-how provides helpful information.

Why choose AM for this scenario?

Additive manufacturing that is layer-based manufacturing technologies is thought to change supply chain operations from global to local. The purpose of this report is to discuss and explain the development of additive manufacturing from a power dependance point of view and how its believed to change the global business landscape. Additive Manufacturing (AM) is rapidly gaining interest as a highly innovative manufacturing technology. The advantages that AM provides include the ability to produce very complex structures that are relatively easily customized to specific user requirements.

The fact that AM services become affordable for small companies or even for consumers offers possibilities for decentralized manufacturing. In addition, AM allows for high degrees of flexibility, both in product design and manufacturing. The ability to work with low setup times and costs and to largely eliminate work in progress inventories while maintaining a high degree of supply chain responsiveness makes AM a promising alternative for low volume, high-value items. People realized several benefits of AM in terms of customization and material saving. With AM technology, a design file can be transformed directly to a product, skipping many traditional production steps. Hence, this new application can affect all logistics and supply chain activities positively. There are various supply chain configurations to supply spare parts in industrial operations. This report aims to explore the promise of a production configuration that combines the benefits of centralized production with the flexibility of local manufacturing without the huge costs related to it.

Design procedure for AM on supply chains

Additive Manufacturing (AM) is one of the most trending production technologies, with a growing number of companies looking forward to implementing it in their processes. Producing through AM not only means that there are no supplier lead times needed to account for, but also enables production closer to the end customer, reducing then the delivery time. This is especially true for companies with a wide range of low and variable demand products.

In the addressed problem, the 3D printers allocation to distribution centers (DC), that will make or customize parts, and the Suppliers- DC-Customers connections for each product need to be defined. The model aims at minimizing the supply chain costs. The recent revolution in the field of manufacturing is 3D printing or Additive Manufacturing (AM). Recently, AM technology is emerging as an eye opener for creating complex geometries with desired material and to improve the designing and modelling of implausible structures. It leads to the disruptive innovations that creates a global impact on the logistics of industries and the supply chain. The main competence of this technology is to fabricate the products closer to the expectations of customers around the world and to customize those products in real time with a given time window.

Examining this study using an optimization model

This study explores the problem of integrated jobs and vehicles scheduling in a two-stage supply chain, where parts are processed on additive manufacturing (AM) machines/ a 3D printer which is located in a cargo that is attached with the truck and then distributed to customers. In this study, we develop an optimization model for the problem with the objective of make span minimization and also the minimization of the time window of the customers. In this regard, this study also contributes to the existing academic literature by investigating the two-stage supply chain scheduling problem with the additive manufacturing technology. A comprehensive experimental study is conducted through random instances, which are generated for small- and large-sized problems by considering real-production data using the anylogistix software.

2.2 Framework for review

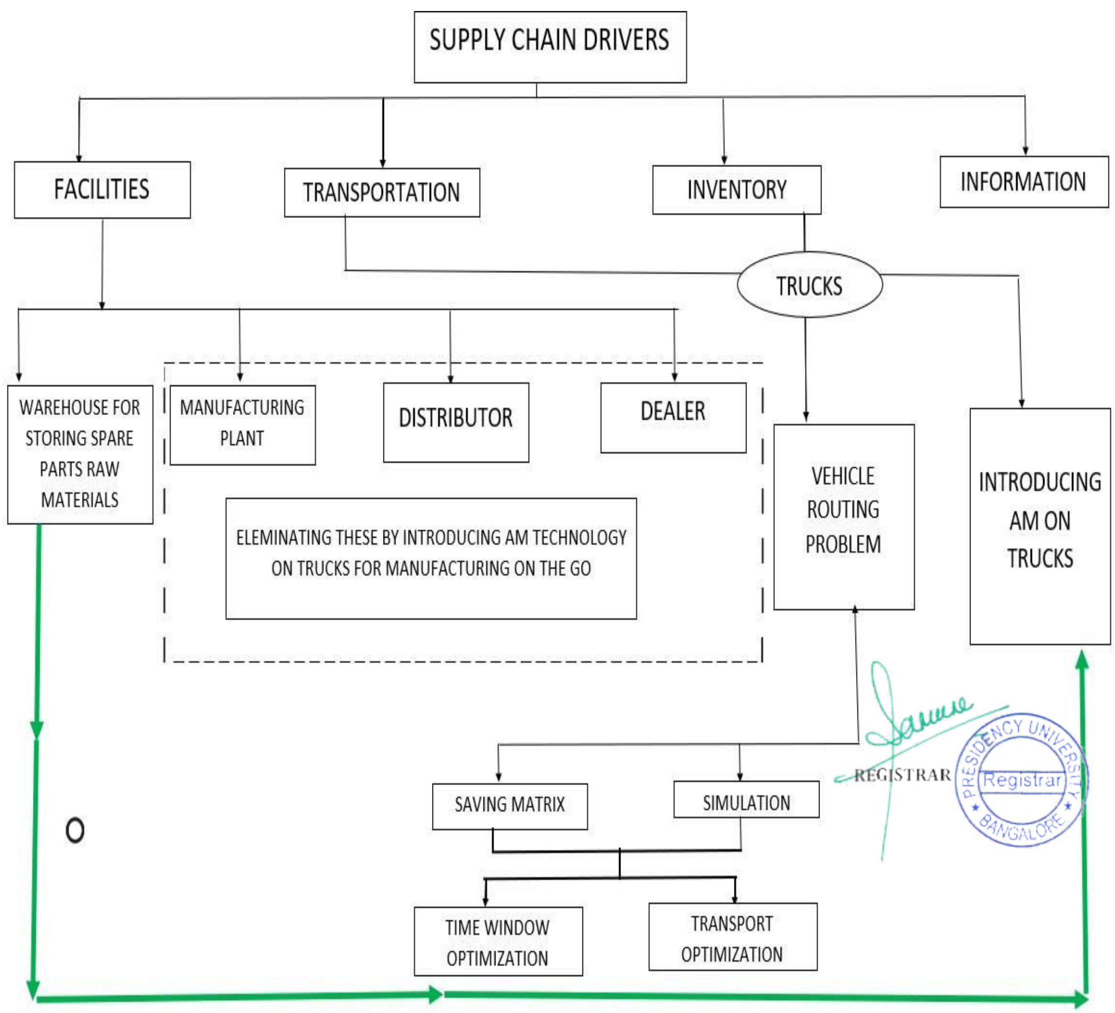

Fig 2.1: Framework for review of supply chain management

This review classifies the peer-reviewed articles right from supply chain management to vehicle routing problem published between 2000 and 2019 based on the framework shown in Figure 2.1. Supply chain drivers are driving the whole world by considering or adapting various techniques to work effectively to reach out to its end customers. Usually having the manufacturing plant, distributor, dealer is a long chain process to reach out to the customers. By eliminating these in the field of supply of spare parts with the adaption additive manufacturing in autonomous vehicle where the manufacturing of the part is on to go while the truck in reaching to its end customer is possible. All we could use is the warehouse to store the spare parts raw materials stock and for truck alt positioning. It's yet a effective way of reaching out customer with no time, the feasibility of the products is amazing for its end customers to enjoy.

This framework with the introduction of Vehicle Routing Problem enables the fastest possible way to reach out its customer. The traditional saving matrix gives the data which analogous to the software used for the VRP hence enabling the best distance optimization along with time optimization. Introduction of Additive Manufacturing on the autonomous vehicle is the disruptive technology that any company can use in the future to stand out in the market, it is also said that a company or organization with the disruptive changes can bring a profit and improve its sales else the company only sustains in the market might never see the improvement later goes bankruptcy.

A customer satisfaction is the ultimate goal of any company, the understandability of customer needs and keeping them satisfied with the service or product they desire is the key. These adaptions in the supply chain management not only provides these but also ensures the trust between the company and the customer, the information is the two-way, customer feedback improves with maximun satisfaction by fulfilling the reach of spare parts within the time window. This framework is the best possibility of the supply chain management in the supply of spare parts, the improvisation of saving matrix with the use of simulation enables the best possibility to meet its end user.

2.3 Gap identified

Most of the fortune 500 companies are successful because of the disruptive changes they made, able to take risk is the key. These are the gaps identified by the companies:

- Lack of communication and delay in reaching the customer on-time.

- Inefficient work by the distributor in reaching the retailer or dealer.
- Not able to adapt proper VRP analysis which is causing delay, hence cancellation of product by customer end.
- Not successful enough to meet the customer time window by lack of prioritizing the customer.
- Unavailability of specific parts required for customer which is not being manufactured.
- No customized parts for the customer.
- No additive manufacturing technology being adapted as it has less wastage of the raw material than traditional methods.
- Lack of proper equipped autonomous vehicles used for transportation with not so good storing techniques adapted inside the vehicle.

OBJECTIVE AND SCOPE

PROBLEM CONSIDERATION

Background of the problem

Global Supply chain is maturing day by with the implementation of new technologies. It include Artificial Intelligence, Internet of Things, Block manufacturing and so on. Additive manufacturing is one of the important technology that will have disruptive effect in SC. Especially in automotive spare parts supply chain. In the current setting, spare parts are generally costly.

Also, some components require some waiting time in the dealer end also. Reason is that the each and every spares for each model of the car at every dealer/service centre end is literally not possible. Since it is associated with lot of money in terms of transportation and storage cost. So, additional cost and waiting time (sometimes) is unavoidable. There is always a concern to get spares for old model vehicles. Additive manufacturing is the easiest way to ensure low-volume build. This means that some products that would have previously never got off the drawing board can be produced. In the past, a low-volume build won't have been cost-efficient. The manufacturing technique also delivers the potential for mass customization and personalization to scale due to slightly different parts being able to be produced at scale.

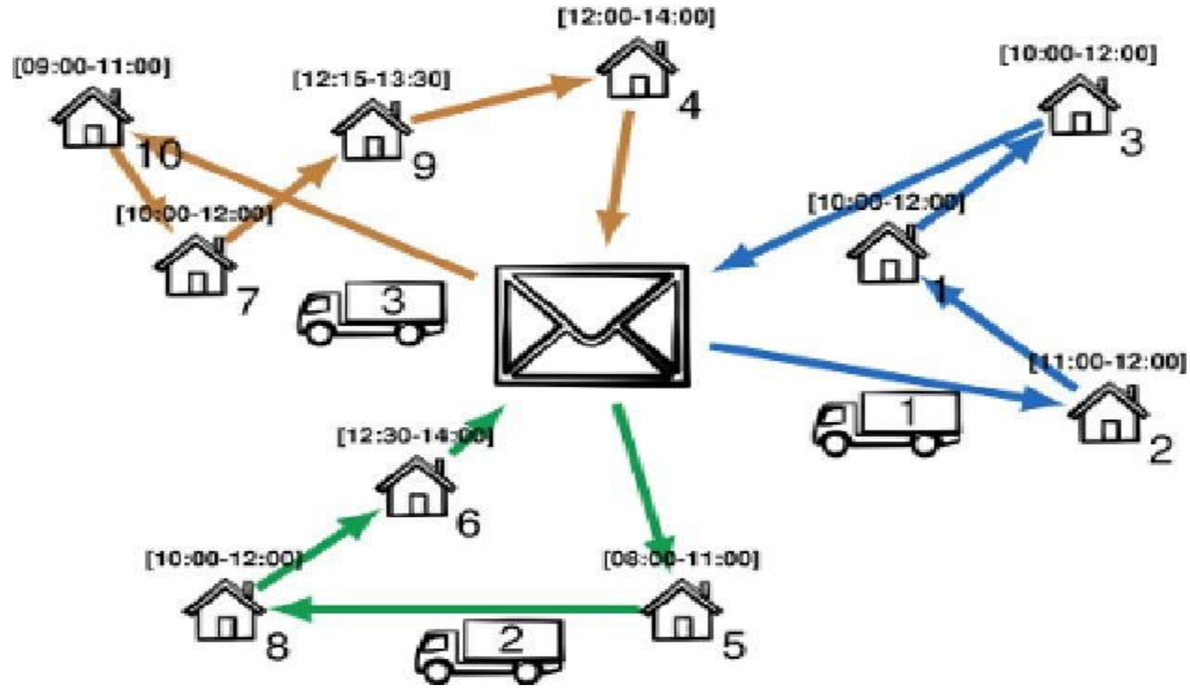

Fig 2.2: Overview of Vehicle Routing Problem with time window

Objective of the problem

In this project work, it is proposed to schedule the routing of the truck which is autonomous and also having 3D printing facility. The following are the objectives of the study:

- To optimize the distance travelled to reach out the customers.
- To meet the time window of the customer.
- To supply customised spare parts for the customer.
- Interfacing with the simulation software.
- With distance optimisation and time optimisation cost optimisation is possible.
- Introducing of Additive manufacturing in the autonomous vehicle enabling the disruptive innovation in the supply chain management.

Assumptions made to solve this problem

- Number of customers are known.
- Items ordered can be manufactured by using 3D printing technique.
- Autonomous Vehicle will have 3D printing machine
- Time window for each customer is also known in advance.

CHAPTER 3 – METHODOLOGY

In this project, it is attempted to solve the problem considered by using the following approaches.

- Saving Matrix method
- Simulation approach using Anylogistix software

3.1 SAVING MATRIX METHOD

Generally, the problem of scheduling and determining delivery routes can have several goals to be achieved such as the goal to minimize shipping costs, minimize the time, or minimize mileage. In the language of a mathematical program, one of these objectives can be a function objective (objective function) and the other becomes a constraint (constraint). For example, the objective function is to minimize shipping costs, but there are time window constraints and maximum mileage constraints per vehicle, in addition to other constraints such as vehicle capacity or other constraints. Saving matrix is a popularmethod used in the calculation to get good's delivery route on good's distribution activity to consumer. It is used for Vehicle Routing problem over many years. Saving Matrix method requires the distance between the Distribution Centre/Warehouse and the customer location.

In saving matrix method, there are several steps that must be done first to get the best route. These several phases are:

1. Identify distance matrix
2. Identify savings Matrix
3. Rank savings
4. Assign customers to vehicles
5. Sequence customers within routes

3.1.1 Saving matrix algorithm

The Saving matrix algorithm enables the step by step procedure resulting the distance optimization of the Vehicle Routing Problem, this algorithm is used in many industries to get optimum results.

STEP 1: Initialize distance data and the number of requests data as a necessary input.

STEP 2: Create a matrix of distances between depot to customers and between customers to the other customers.

STEP 3: Calculate the saving value using the equation S(i, j) = d(Depot,i) +d(Depot, j) −d(i, j) for each customer to find out the value of savings, where d(i, j) is the distance of customer i to customer j.

STEP 4: Sort the customer pairs based on the saving value of distance matrix from the biggest to the smallest saving matrix value.

STEP 5: Determine the first customer which assigned on the tour by selecting the customer combination with the biggest saving value.

STEP 6: Count the number of requests from consumers who have been selected. If the number of requests still meets with the capacity of vehicle, then continue to the step 7. If the number of requests exceeds the capacity of vehicle, proceed to step 8.

STEP 7: Select the next customer who will be assigned based on the last combination of selected customer with the biggest saving value and go back to step 6.

STEP 8: If all of the customers have been assigned, then the Savings Algorithm work process has been completed.

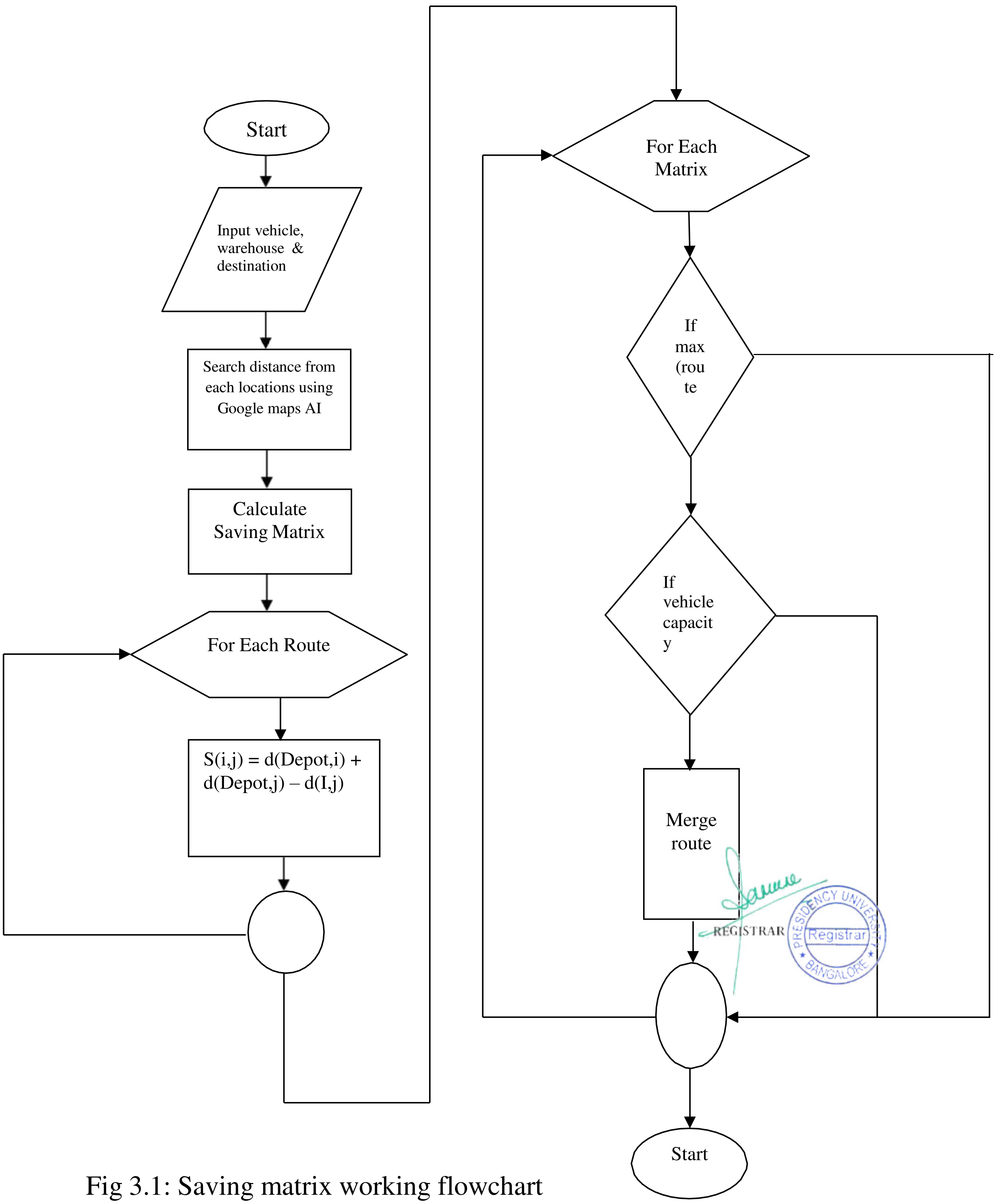

Fig 3.1: Saving matrix working flowchart

3.2 Simulation approach using Anylogistix software

AnyLogistix is a unique tool for supply chain and logistics simulation as well as optimization in regard to management decision-making support. It is an easy-to-understand tool that can be used by management students and professionals without any programming background. It is the only multimethod software for supply chain network design, analysis, and optimization. AnyLogistix combines traditional analytical optimization approaches with innovative simulation AnyLogic technologies.

The Supply Chain system is represented as a set of objects and rules that describe the behavior of objects and their interactions. This helps to visualize the network and provides a higher level of detail. Most Supply Chain optimization tools ONLY use analytical methods. Integration of anyLogistix with other solutions that you use to manage your supply chain, adding powerful multimethod optimization technology to the toolset to improve accuracy and efficiency in decision making.

Fig 3.2: Visualizing the risk-free environment using simulation.

anyLogistix supply chain optimization software allows users to address a broad range of problems:

- Modify/redesign supply chain (close/open/modify sites).
- Manage growth (merger and acquisition case).
- Optimize product flows.
- Measure the influence of a new product/BOM.
- Analyze sourcing and inventory strategies.
- Improve transportation policies.
- Minimize risks across the whole supply chain.

Every supply chain is unique. Capturing every aspect of the network and how components interact.

- **Include any restriction**: Describe restrictions as they are. Do not spend your time trying to “translate” them into formulas.
- **Model any behaviour :** Every supply chain is unique and comes with unique characteristics. Simulation with modeling allows you to capture the singularities at every level of detail.
- **Uncertainty and risk analysis**: Simulation modeling technologies of anyLogistix allow you to capture the random behavior of your network, which means evaluating and reducing risks.
- **Visualization**: The model is not a black box. Having it animated allows you to visually see how the model is working, giving your results credibility. In addition, it allows you to trace and solve problems in the model yourself, without having to call the support team.
- **Change the network design**: Change in the network design, ordering and transportation policies yourself to check what-if scenarios, test sensitivity of your supply chain to environment changes, and more.
- **Ultimate flexibility**: Quickly amend and extend the behavior of supply chain elements in anyLogistix or using AnyLogic Professional to add more details to the model.

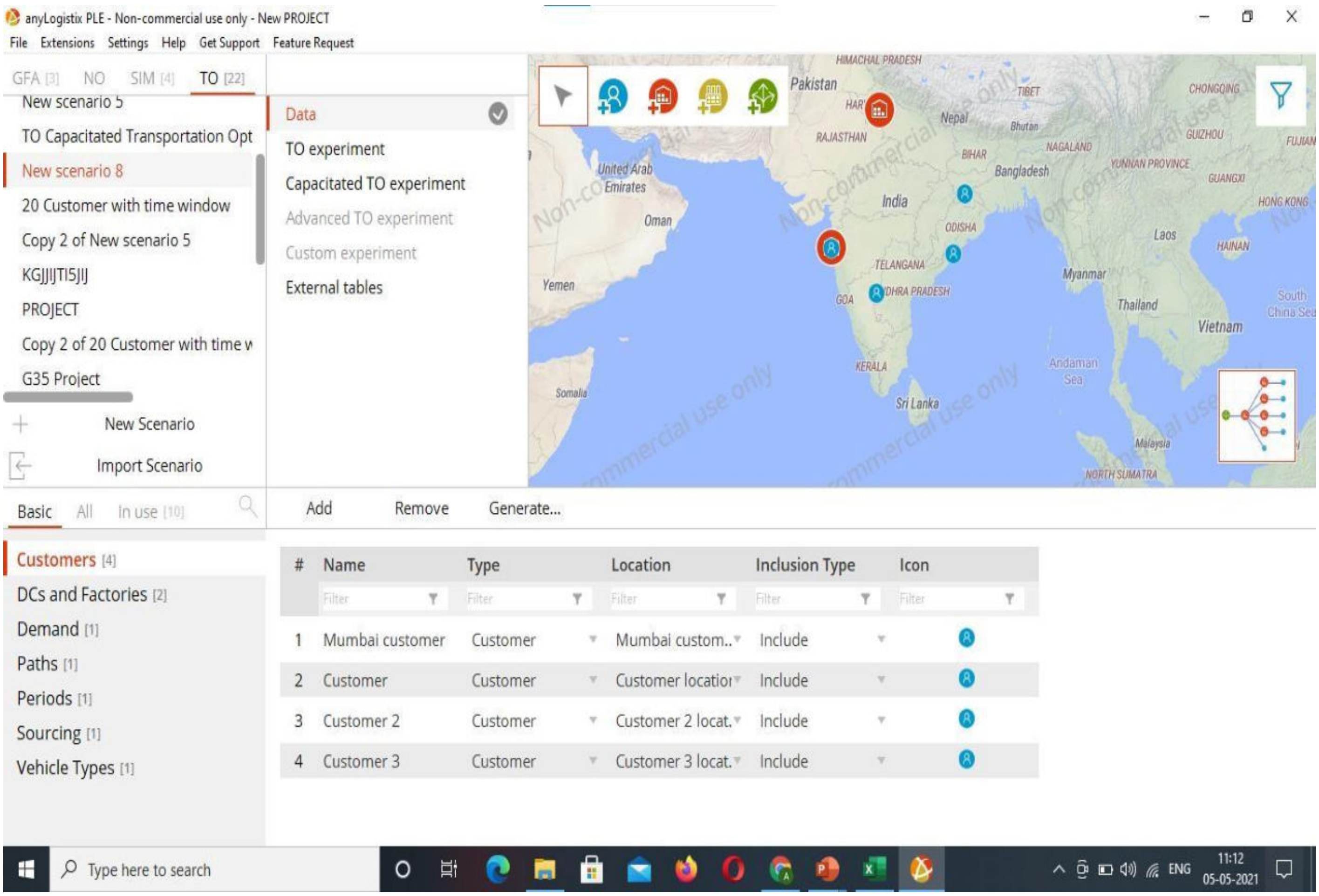

Fig 3.3: anyLogistix software interface

3.2.1 Scenario creation in anyLogistixsimulation software

Figure 3.4 illustrates the Simulation system architecture of the VRP. The scenario generator creates scenarios which specify the problem environment. All master data and simulation parameters are included in a scenario specification. The simulation loads this scenario and performs the simulation run. During a run, certain indicators and key figures can be written to a database. These indicators can be used during or after the simulation run to analyze the performance. During the simulation run, problem instances are created for the simulation that can be optimized. In this case, VRP instances are parameterized by the simulation environment and sent to the optimization component.

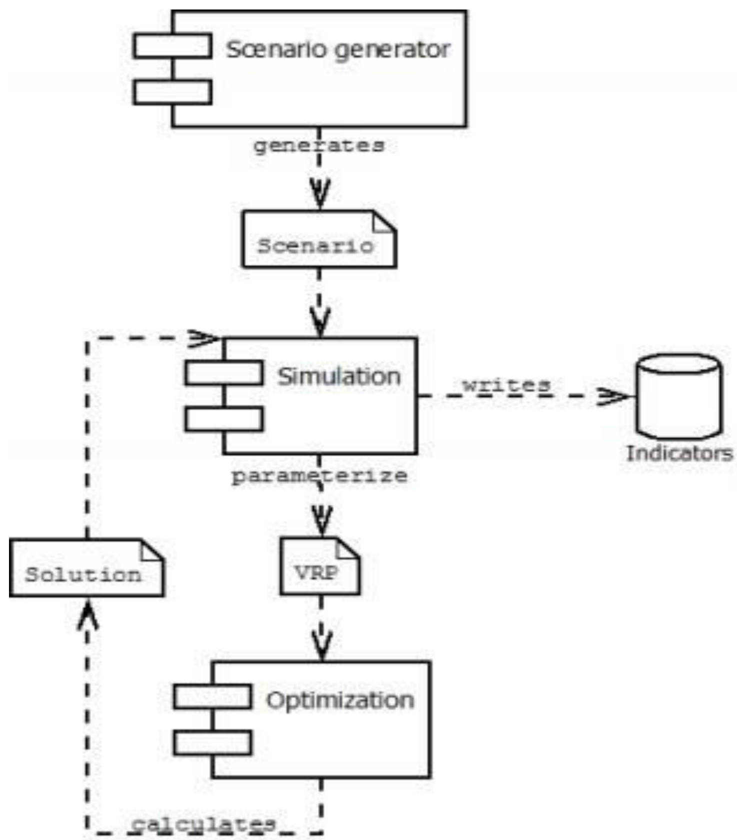

Fig 3.4: Simulation system architecture of the VRP in anyLogistix

The scenario generator creates the problem environment. The master data is integrated into a single scenario file that can be loaded by the simulation component. Additionally, the scenario parameterizes the simulation run. Parameters could for example affect the customer ordering behavior or the delivery strategy. Furthermore, the scenario generator can perform additional tasks like distance matrix generation or data preprocessing.

3.2.1(a) VRP scenario experiment for distance optimization

The input data which consists of many parameters like customers location, Distribution center(DC) location, the demand of the customers, paths from DC to customers, Time period of the movement of the vehicle, product type and product unit valueand vehicle type are specified for further optimizations. The results run under TO experiment give the distance optimization with optimum routing solution. The data is being added similarly for n scenario possibilities for the VRP solution.

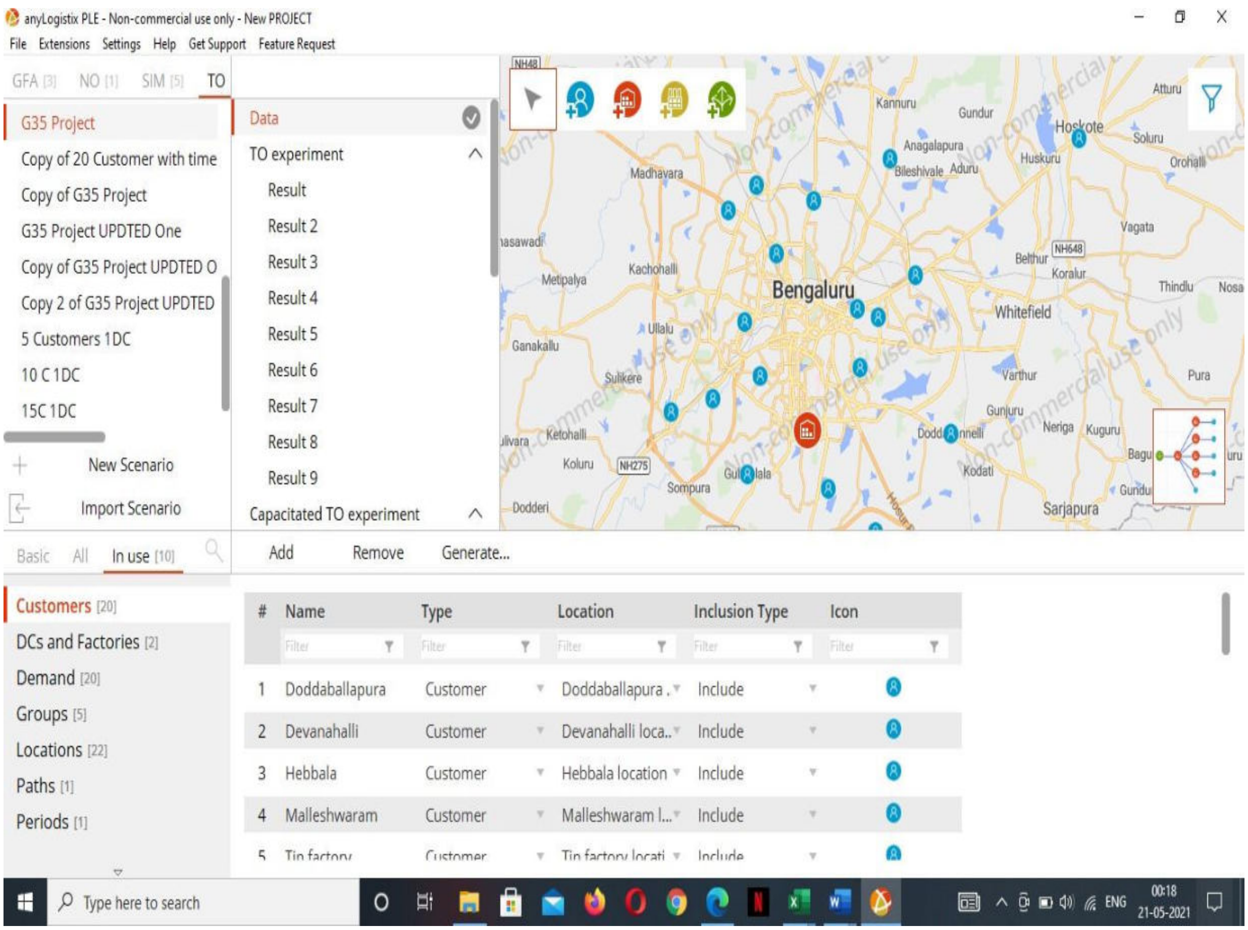

Fig 3.5: anyLogistix software interface for the input data for VRP

For the Transportation Optimization to run we specify the start date and end date that is the working hours of operation for the vehicles these help vehicle to work only under those time window, without over usage of the vehicle. Maximum customers to reach during this period can be initiated as it could possibly work only under this maximum initiated value. Vehicle type is specified in the data initialization it is important to select the right vehicle type to get the experiment right, with similar to the customer limit the travel segment limit, limits the truck to stay only in this constraint. The play symbol is the simulation run icon helps to start the experiment.

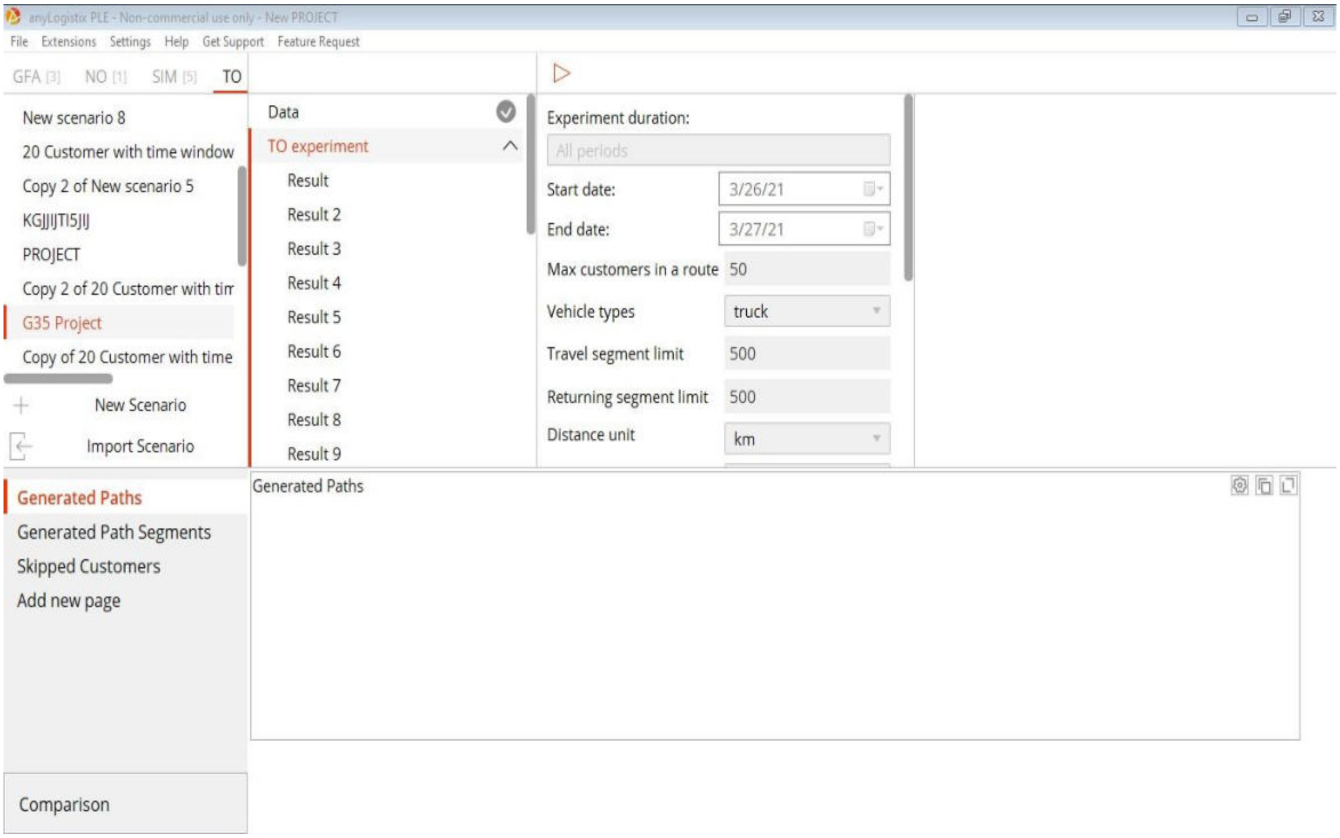

Fig 3.6: TO experiment interface while initiating the run

3.2.2 Vehicle Routing Problem with time window in simulation

Vehicle Routing Problem with time window is encountered very frequently in making decisions about the distribution of goods find a set of closed routes, originating and ending at the depot, that service all customers at minimum cost. Moreover, each route must satisfy capacity and time window constraints. In Vehicle Routing Problem with time window, a set of decision variables is added to the model to specify the times that services begin are the decision variables based on customers. Allowable delivery times of the customers add complexity to the VRP because of the time feasibility check for each customer. In the VRPs with time constraints, the service of a customer, involving pick up or delivery of goods or services, can start within the time window defined by the earliest and the latest times when the customer permits the start of service. In some cases, vehicles are allowed to start service just at the time they arrive to the customer site, so in these types of problems, there are no waiting times for the vehicles at the customer sites. The objective is the minimization of the total distance traveled by all vehicles. Ensure that each customer is visited exactly once and ensures that the number of vehicles leaving the depot should be equal to the number of vehicles arriving at the depot. Constraints are the time window constraints. No vehicle can arrive to a customer after the time window of the customer. It can arrive before but it should wait until the time window. There are two steps of the algorithm:

1. **Route Initialization**: The first route is initialized by selecting the customer farthest from the depot. Other routes are initialized (when necessary) by selecting the customer who has the maximum total Euclidean distance to the previously selected customers and the depot.
2. **Customer time window initialization**: The customer time window is the constraint, this constraint is being satisfied by optimally choosing the routes by the simulation software. It is the same procedure as of VRP of distance optimization, here the constraint differs.

The remarkable advances in information technology have enabled companies to focus on efficiency and timeliness throughout the supply chain. In turn, the VRPTW has increasingly become an invaluable tool in modeling a variety of aspects of supply chain design and operation. Important VRPTW applications include deliveries to supermarkets, bank and postal deliveries, industrial refuse collection, school bus routing, security patrol service, and urban newspaper distribution. Its increased practical visibility has evolved in parallel with the development of broader and deeper research directed at its solution.

3.2.2(a) VRP scenario experiment for distance optimization

The input data which consists of many parameters like customers location, Distribution center(DC) location, the demand of the customers, paths from DC to customers, Time period of the movement of the vehicle, product type and product unit value and vehicle type are specified for further optimizations. The results run under TO experiment give the distance optimization with optimum routing solution. The data is being added similarly for n scenario possibilities for the VRP with time window solution.

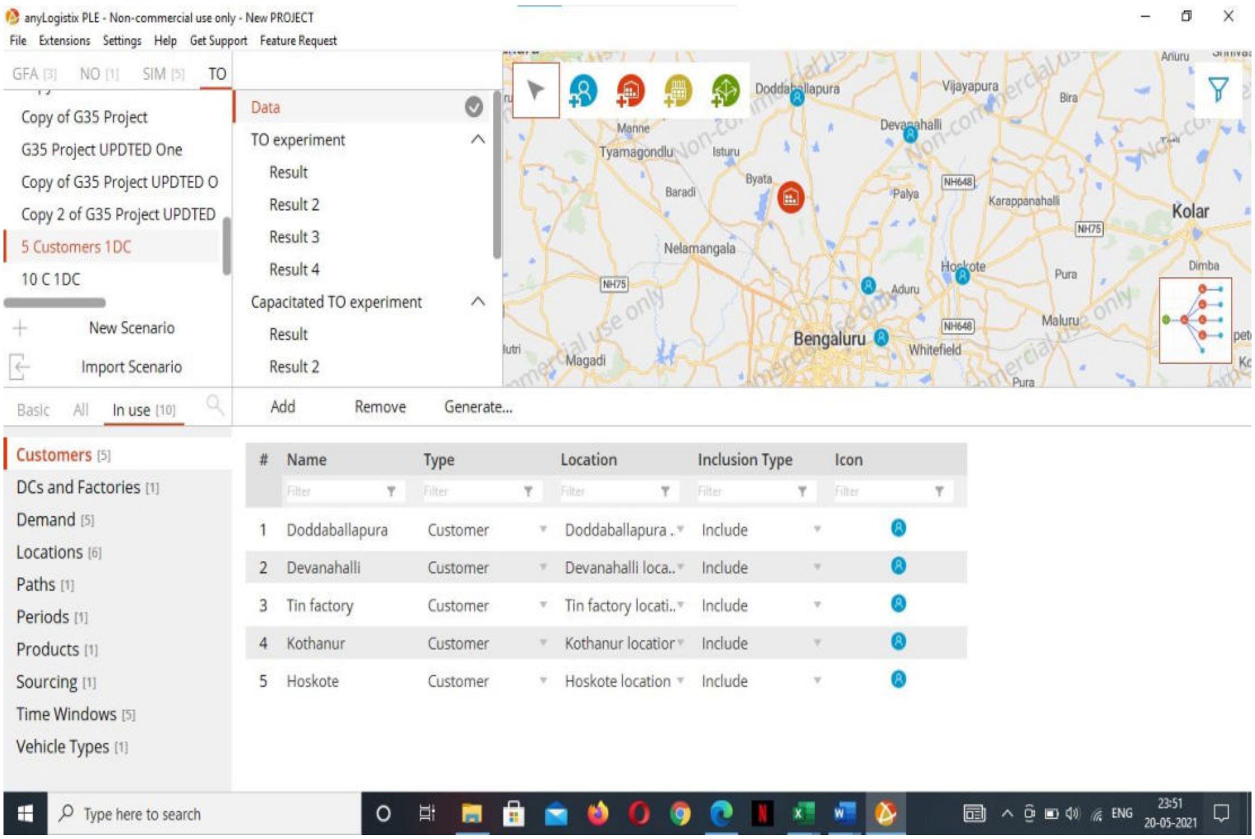

Fig 3.7: anyLogistix software interface for the input data for VRP with time window

For the Capacited Transportation Optimization that is the VRP with time window to run we specify the start period and end period that is the working hours of operation for the vehicles these help vehicle to work only under those time window, without over usage of the vehicle. Maximum customers to reach during this period can be initiated as it could possibly work only under this maximum initiated value. Vehicle type is specified in the data initialization it is important to select the right vehicle type to get the experiment right, with similar to the customer limit the travel segment limit, limits the truck to stay only in this constraint. **Time window** is being selected to ensure the reach of product to the customer accordance to their time of acceptance of the product. The routes are completely different regardless of the distance, the first priority is always the customer's time window. The play symbol is the simulation run icon helps to start the experiment.

CHAPTER 4 - RESULTS AND DISCUSSION

While finding the solutions for the problem we have considered to solve by having a set of 4 case scenarios in each case the problem is equally solved by the traditional way of optimizing using saving matrix and the same case scenario's data is being used for simulation and optimization by adapting anyLogistix supply chain simulation software. Problem size of 5,10,15 & 20 customers with a single operating Distribution center with a single autonomous vehicle with 3D printing are considered for solving using the proposed methodologies.

Case scenarios are classified for both saving matrix method solution and Simulation software method solution:

Case (i): 5 customers operating with 1 Distribution Center and 1 Autonomous vehicle.

loactions	latitude	longitude	co-ordinates
Presidency University (ALT-position)	13.16988461	77.5347662	(13.16988461, 77.5347662)
Doddaballapura	13.293	77.543	(13.293, 77.543)
Devanahalli	13.248	77.713	(13.248, 77.713)
Hebbala	13.03821626	77.59205818	(13.03821626, 77.59205818)
Malleshwaram	13.00267608	77.57012844	(13.00267608, 77.57012844)
Tin factory	12.99745177	77.66980469	(12.99745177, 77.66980469)

Table 4.1: case(i) locations considered

Case (ii): 10 customers operating with 1 Distribution Center and 1 Autonomous vehicle.

loactions	latitude	longitude	co-ordinates
Presidency University (ALT-position)	13.16988	77.53477	(13.16988461, 77.5347662)
Doddaballapura	13.293	77.543	(13.293, 77.543)
Devanahalli	13.248	77.713	(13.248, 77.713)
Hebbala	13.03822	77.59206	(13.03821626, 77.59205818)
Malleshwaram	13.00268	77.57013	(13.00267608, 77.57012844)
Tin factory	12.99745	77.6698	(12.99745177, 77.66980469)
Kothanur	13.06136	77.64937	(13.06135645, 77.64937431)
Hoskote	13.07303	77.79212	(13.07302501, 77.79212415)
Jalahalli	13.05823	77.53891	(13.05823,77.53891)
Vijaynagar	12.97595	77.53487	(12.97595,77.53487)
Peenya	13.0151826	77.50604	(13.0285, 77.5197)

Table 4.2: case(ii) locations considered

Case (iii): 15 customers operating with 1 Distribution Center and 1 Autonomous vehicle.

loactions	latitude	longitude	co-ordinates
Presidency University (ALT-position)	13.16988	77.53477	(13.16988461, 77.5347662)
Doddaballapura	13.293	77.543	(13.293, 77.543)
Devanahalli	13.248	77.713	(13.248, 77.713)
Hebbala	13.03822	77.59206	(13.03821626, 77.59205818)
Malleshwaram	13.00268	77.57013	(13.00267608, 77.57012844)
Tin factory	12.99745	77.6698	(12.99745177, 77.66980469)
Kothanur	13.06136	77.64937	(13.06135645, 77.64937431)
Hoskote	13.07303	77.79212	(13.07302501, 77.79212415)
Jalahalli	13.05823	77.53891	(13.05823,77.53891)
Vijaynagar	12.97595	77.53487	(12.97595,77.53487)
Peenya	13.0151826	77.50604	(13.0285, 77.5197)
J P nagar(DC)	12.939	77.63046	(12.939,77.63046)
Halasuru	12.86012	77.78616	(12.8601194, 77.78615624)
Indiranagar	12.92668	77.54666	(12.92668,77.54666)
Ejipura	12.87231	77.60171	(12.87231,77.60171)
Doddakannelli	12.91511	77.64351	(12.91511,77.64351)
Vittasandra	12.96103	12.96103	(12.9719, 77.5127)

Table 4.3: case(iii) locations considered

Case (iv): 20 customers operating with 1 Distribution Center and 1 Autonomous vehicle.

loactions	latitude	longitude	co-ordinates
Presidency University (ALT-position)	13.16988461	77.5347662	(13.16988461, 77.5347662)
Doddaballapura	13.293	77.543	(13.293, 77.543)
Devanahalli	13.248	77.713	(13.248, 77.713)
Hebbala	13.03821626	77.59205818	(13.03821626, 77.59205818)
Malleshwaram	13.00267608	77.57012844	(13.00267608, 77.57012844)
Tin factory	12.99745177	77.66980469	(12.99745177, 77.66980469)
Kothanur	13.06135645	77.64937431	(13.06135645, 77.64937431)
Hoskote	13.07302501	77.79212415	(13.07302501, 77.79212415)
Jalahalli	13.05823	77.53891	(13.05823,77.53891)
Vijaynagar	12.97595	77.53487	(12.97595,77.53487)
Peenya	13.0151826	77.5060438	(13.0285, 77.5197)
J P nagar(DC)	12.939	77.63046	(12.939,77.63046)
Halasuru	12.8601194	77.78615624	(12.8601194, 77.78615624)
Indiranagar	12.92668	77.54666	(12.92668,77.54666)
Ejipura	12.87231	77.60171	(12.87231,77.60171)
Doddakannelli	12.91511	77.64351	(12.91511,77.64351)
Vittasandra	12.961025	12.961025	(12.9719, 77.5127)
Hulimavu	12.926159	77.605797	(12.9241, 77.6092)
Gubbalala	12.942117	77.575361	(12.9406, 77.5738)
Kengeri	12.97933	77.55366	(12.9982, 77.5530)
Rajarajeshwarinagar	12.939138	77.535477	(12.9526, 77.5293)
Banashankri	12.9766637	77.5712556	(12.9767, 77.5713)

Table 4.4 : case(iv) locations considered

4.1 Saving matrix method of optimization

The random locations in Bangalore are being assigned as customers, the Presidency University being the Distribution Center (DC), the Distance matrix and the savings matrix are being calculated manually by following Saving matrix algorithm and the routes are being sorted according to the proposed methodologies. The time taken to cover all the customer locations and reach the DC is being calculated and the total distance covered by the route is tabulated below.

The optimization of saving matrix is said that it is used by the supply chain management transportation field for over many years experts estimate a overview and work accordingly.

4.1.1 Case scenario(i) in Saving matrix method

Distance matrix for Case(i):

Table 4.5 Distance matrix for case(i)

DISTANCE MATRIX	Doddaballapura	Devanahalli	Tin factory	Kothanur	Hoskote
Presidency University (DC)	18.153	28.833	34.45	24.458	43.85
Doddaballapura	0	22.261	43.379	33.391	50.033
Devanahalli		0	37.847	29.662	28.078
Tin factory			0	9.627	16.211
Kothanur				0	20.686
Hoskote					0

Saving matrix for Case(i):

Table 4.6 Saving matrix for case(i)

SAVING MATRIX	Doddaballapura	Devanahalli	Tin factory	Kothanur	Hoskote
Doddaballapura	0	24.725	9.224	9.22	11.97
Devanahalli		0	25.436	23.629	44.605
Tin factory			0	49.281	62.089
Kothanur				0	47.622
Hoskote					0

Results by Saving matrix for case(i): Table 4.7

No. Of customers	Customers	Distance travelled (km)	Time for covering the distance(min)	Route followed
1	Doddaballapura	152.424	180	0-5-4-3-2-1-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			

4.1.2 Case scenario(ii) in Saving matrix method

Distance matrix for Case(ii):

Table 4.8**:** Distance matrix for case(ii)

DISTANCE MATRIX	Doddaballapura	Devanahalli	Hebbala	Malleshwaram	Tin factory	Kothanur	Hoskote	Jalahalli	Vijaynagar	Peenya
Presidency University (DC)	18.153	28.833	21.84	22.683	34.45	24.458	43.85	18.28	28.312	22.601
Doddaballapura	0	22.261	32.139	36.406	43.379	33.391	50.033	31.997	42.008	35.511
Devanahalli		0	30.265	34.889	37.847	29.662	28.078	33.186	40.98	36.662
Hebbala			0	6.812	14.177	10.114	28.095	6.494	13.274	10.02
Malleshwaram				0	15.546	15.382	30.828	5.541	6.533	5.857
Tin factory					0	9.627	16.211	16.824	19.16	19.159
Kothanur						0	20.686	14.387	20.491	35.511
Hoskote							0	31.652	34.146	36.626
Jalahalli								0	11.846	3.78
Vijaynagar									0	10.466
Peenya										0

Saving matrix for Case(ii):

Table 4.9 Saving matrix for case(ii)

SAVING MATRIX	Doddaballapura	Devanahalli	Hebbala	Malleshwaram	Tin factory	Kothanur	Hoskote	Jalahalli	Vijaynagar	Peenya
Doddaballapura	0	24.725	7.854	4.43	9.224	9.22	11.97	4.436	4.457	5.243
Devanahalli		0	20.408	16.627	25.436	23.629	44.605	13.927	16.165	14.772
Hebbala			0	37.711	42.113	36.184	37.595	33.626	36.878	34.421
Malleshwaram				0	41.587	31.759	35.705	35.422	44.462	39.427
Tin factory					0	49.281	62.089	35.906	43.602	37.892
Kothanur						0	47.622	28.351	32.279	11.548
Hoskote							0	30.478	38.016	29.825
Jalahalli								0	34.746	37.101
Vijaynagar									0	40.447
Peenya										0

Results by Saving matrix for case(ii): Table 4.10

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance(min)	Route followed
1	Doddaballapura	198.752	238.2	0-5-4-6-3-7-10-9-8-2-1-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			

4.1.3 Case scenario(iii) in Saving matrix method

Distance matrix for Case(iii):

Table 4.11: Distance matrix for case(iii)

DISTANCE MATRIX	Doddaballapura	Devanahalli	Hebbala	Malleshwaram	Tin factory	Kothanur	Hoskote	Jalahalli	Vijaynagar	Peenya	Halasuru	Indiranagar	Ejipura	Doddakannelli	Vittasandra
Presidency University (DC)	18.153	28.833	21.84	22.683	34.45	24.458	43.85	18.28	28.312	22.601	32.405	33.405	36	45.667	47.119
Doddaballapura	0	22.261	32.139	36.406	43.379	33.391	50.033	31.997	42.008	35.511	41.335	7.985	44.936	54.596	56.049
Devanahalli		0	30.265	34.889	37.847	29.662	28.078	33.186	40.98	36.662	39.396	40.395	42.996	51.592	53.083
Hebbala			0	6.812	14.177	10.114	28.095	6.494	13.274	10.02	11.318	12.317	14.918	24.579	26.032
Malleshwaram				0	15.546	15.382	30.828	5.541	6.533	5.857	9.266	11.245	12.866	22.23348	23.526
Tin factory					0	9.627	16.211	16.824	19.16	19.159	5.486	6.545	10.116	13.772	23.384
Kothanur						0	20.686	14.387	20.491	35.511	12.287	12.582	16.598	22.722	29.115
Hoskote							0	31.652	34.146	36.626	21.692	21.535	27.519	27.082	38.861
Jalahalli								0	11.846	3.78	13.234	16.205	17.989	27.85	29.102
Vijaynagar									0	10.466	13.054	13.978	12.721	20.78	21.794
Peenya										0	15.007	16.998	18.608	28.0286	29.277
Halasuru											0	2.549	5.483	15.143	18
Indiranagar												0	5.624	14.182	17.038
Ejipura													0	10.735	12.972
Doddakannelli														0	11.589
Vittasandra															0

Saving matrix for Case(iii):

Table 4.12 Saving matrix for case(iii)

SAVING MATRIX	Doddaballapura	Devanahalli	Hebbala	Malleshwaram	Tin factory	Kothanur	Hoskote	Jalahalli	Vijaynagar	Peenya	Halasuru	Indiranagar	Ejipura	Doddakannelli	Vittasandra
Doddaballapura	0	24.725	7.854	4.43	9.224	9.22	11.97	4.436	4.457	5.243	9.223	43.573	9.217	9.224	9.223
Devanahalli		0	20.408	16.627	25.436	23.629	44.605	13.927	16.165	14.772	21.842	21.843	21.837	22.908	22.869
Hebbala			0	37.711	42.113	36.184	37.595	33.626	36.878	34.421	42.927	42.928	42.922	42.928	42.927
Malleshwaram				0	41.587	31.759	35.705	35.422	44.462	39.427	45.822	44.843	45.817	46.11652	46.276
Tin factory					0	49.281	62.089	35.906	43.602	37.892	61.369	61.31	60.334	66.345	58.185
Kothanur						0	47.622	28.351	32.279	11.548	44.576	45.281	43.86	47.403	42.462
Hoskote							0	30.478	38.016	29.825	54.563	55.72	52.331	62.435	52.108
Jalahalli								0	34.746	37.101	37.451	35.48	36.291	36.097	36.297
Vijaynagar									0	40.447	47.663	47.739	51.591	53.199	53.637
Peenya										0	39.999	39.008	39.993	40.2394	40.443
Halasuru											0	63.261	62.922	62.929	61.524
Indiranagar												0	63.781	64.89	63.486
Ejipura													0	70.932	70.147
Doddakannelli														0	81.197
Vittasandra															0

Results by Saving matrix for case(iii): Table 4.13

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance(min)	Route followed
1	Doddaballapura	250.981	300	0-15-13-14-12-11-3-5-4-6-7-10-9-8-2-1-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			
11	Halasuru			
12	Indiranagar			
13	Ejipura			
14	Doddakannelli			
15	Vittasandra			

4.1.4 Case scenario(iv) in Saving matrix method

Distance matrix for Case(iv):

Table 4.14: Distance matrix for case(iv)

DISTANCE MATRIX	Doddaballapura	Devanahalli	Hebbala	Malleshwaram	Tin factory	Kothanur	Hoskote	Jalahalli	Vijaynagar	Peenya	Halasuru	Indiranagar	Ejipura	Doddakannelli	Vittasandra	Hulimavu	Gubbalala	Kengeri	Rajarajeshwarinagar	Banashankri
Presidency University (DC)	18.153	28.833	21.84	22.683	34.45	24.458	43.85	18.28	28.312	22.601	32.405	33.405	36	45.667	47.119	42.752	42.17	36.441	35.385	32.505
Doddaballapura	0	22.261	32.139	36.406	43.379	33.391	50.033	31.997	42.008	35.511	41.335	7.985	44.936	54.596	56.049	51.682	51.709	51.816	48.108	44.704
Devanahalli		0	30.265	34.889	37.847	29.662	28.078	33.186	40.98	36.662	39.396	40.395	42.996	51.592	53.083	49.742	49.61	49.876	45.72	41.83
Hebbala			0	6.812	14.177	10.114	28.095	6.494	13.274	10.02	11.318	12.317	14.918	24.579	26.0[illegible]	21.545	21.904	21.572	18.014	14.124
Malleshwaram				0	15.546	15.382	30.828	5.541	6.533	5.857	9.266	11.245	12.866	22.23[illegible]	23.526	19.159	17.641	16.495	12.938	9.219
Tin factory					0	9.627	16.211	16.824	19.16	19.159	5.486	6.545	10.116	13.772	23.384	21.687	25.43	26.066	22.509	18.299
Kothanur						0	20.686	14.387	20.491	35.511	12.287	12.582	16.598	22.722	29.115	24.631	26.485	28.104	24.547	19.974
Hoskote							0	31.652	34.146	36.626	21.692	21.535	27.519	27.082	38.861	35.557	38.659	41.543	37.581	33.776
Jalahalli								0	11.846	3.78	13.234	16.205	17.989	27.85	29.102	24.284	23.435	17.393	16.65	14.761
Vijaynagar									0	10.466	13.054	13.978	12.721	20.78	21.794	17.637	11.478	10.947	6.623	5.684
Peenya										0	15.007	16.998	18.608	28.0286	29.277	26.749	21.513	16.146	16.659	14

Halasuru											0	2.549	5.483	15.143	18	14.546	17.571	20.201	16.493	12.953
Indiranagar												0	5.624	14.182	17.038	14.99	19.272	22.146	17.33	14.898
Ejipura													0	10.735	12.972	10.923	15.206	19.867	16.159	10.932
Doddakannelli														0	11.589	15.775	20.79144	27.67	24.58	18.694
Vittasandra															0	6.672	17.75	27.346	23.512	18.843
Hulimavu																0	9.444	18.3	16.784	12.785
Gubbalala																	0	9.699	7.985	7.313
Kengeri																		0	5.32	10.03
Rajarajeshwarinagar																			0	5.752
Banashankri																				0

Saving matrix for Case(iii):

Table 4.15: Saving matrix for case(iii)

SAVING MATRIX	Doddaballapura	Devanahalli	Hebbala	Malleshwaram	Tin factory	Kothanur	Hoskote	Jalahalli	Vijaynagar	Peenya	Halasuru	Indiranagar	Ejipura	Doddakannelli	Vittasandra	Hulimavu	Gubbalala	Kengeri	Rajarajeshwarinagar	Banashankri
Doddaballapura	0	24.725	7.854	4.43	9.224	9.22	11.97	4.436	4.457	5.243	9.223	43.573	9.217	9.224	9.223	9.223	8.614	2.778	5.43	5.954
Devanahalli		0	20.408	16.627	25.436	23.629	44.605	13.927	16.165	14.772	21.842	21.843	21.837	22.908	22.869	21.843	21.393	15.398	18.498	19.508
Hebbala			0	37.711	42.113	36.184	37.595	33.626	36.878	34.421	42.927	42.928	42.922	42.928	42.927	43.047	42.106	36.709	39.211	40.221
Malleshwaram				0	41.587	31.759	35.705	35.422	44.462	39.427	45.822	44.843	45.817	46.11652	46.276	46.276	47.212	42.629	45.13	45.969
Tin factory					0	49.281	62.089	35.906	43.602	37.892	61.369	61.31	60.334	66.345	58.185	55.515	51.19	44.825	47.326	48.656
Kothanur						0	47.622	28.351	32.279	11.548	44.576	45.281	43.86	47.403	42.462	42.579	40.143	32.795	35.296	36.989
Hoskote							0	30.478	38.016	29.825	54.563	55.72	52.331	62.435	52.108	51.045	47.361	38.748	41.654	42.579
Jalahalli								0	34.746	37.101	37.451	35.48	36.291	36.097	36.297	36.748	37.015	37.328	37.015	36.024
Vijaynagar									0	40.447	47.663	47.739	51.591	53.199	53.637	53.427	59.004	53.806	57.074	55.133
Peenya										0	39.999	39.008	39.993	40.2394	40.4[illegible]3	38.604	43.258	42.896	41.327	41.106
Halasuru											0	63.261	62.922	62.9[illegible]9	61.524	60.611	57.004	48.645	51.297	51.957
Indiranagar												0	63.781	64.89	63.486	61.167	56.303	47.7	51.46	51.012
Ejipura													0	70.932	70.147	67.829	62.964	52.574	55.226	57.573
Doddakannelli														0	81.197	72.644	67.04556	54.438	56.472	59.478
Vittasandra															0	83.199	71.539	56.214	58.992	60.781
Hulimavu																0	75.478	60.893	61.353	62.472

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Gubbalala																	0	68.912	69.57	67.362
Kengeri																		0	66.506	58.916
Rajarajeshwarinagar																			0	62.138
Banashankri																				0

Results by Saving matrix for case(iv): Table 4.16

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance(min)	Route followed
1	Doddaballapura	247.243	296.4	0-16-15-14-13-12-11-17-20-19-18-10-7-9-8-3-5-4-6-2-1-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			
11	Halasuru			
12	Indiranagar			
13	Ejipura			
14	Doddakannelli			
15	Vittasandra			
16	Hulimavu			
17	Gubbalala			
18	Kengeri			
19	Rajarajeshwarinagar			
20	Banashankri			

4.2 Simulation method of optimization using anyLogistix software

Following the methodologies proposed earlier the simulation for all the four case scenarios are being experimented (run) successfully and the results are being tabulated. The Transportation optimization result (VRP) and Capacitated Transportation optimization (VRP with time window), each show different possible routes with optimum results to the savings matrix method.

4.2.1 Case scenario(i) using anyLogistix software simulation method

4.2.1(a) VRP with distance optimization in anylogistix

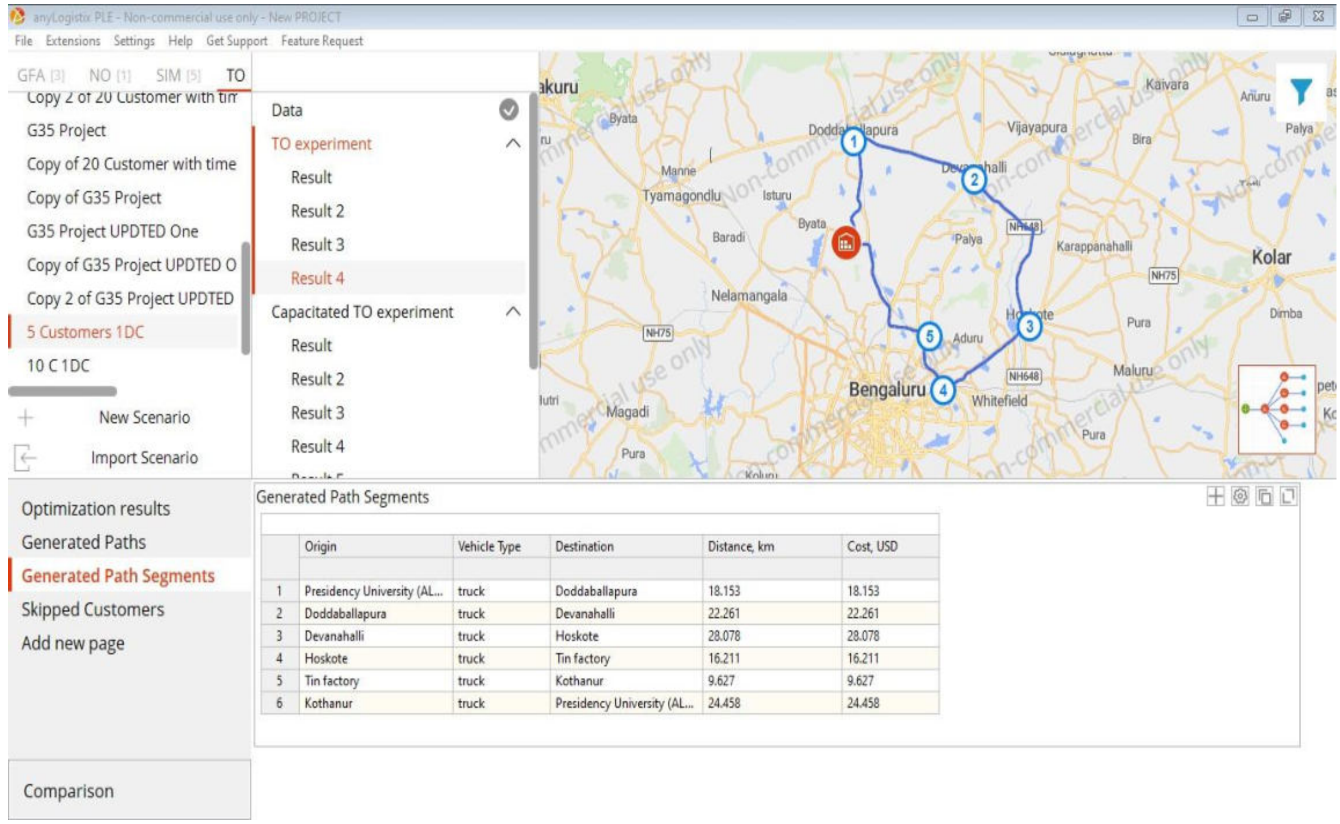

Fig 4.1: Case (i) TO experiment results after simulation run

Results for Case (i) TO experiment: Table 4.17

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura	118.788	142	0-1-2-5-3-4-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			

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4.2.1(b) VRP with Time window optimization in anylogistix

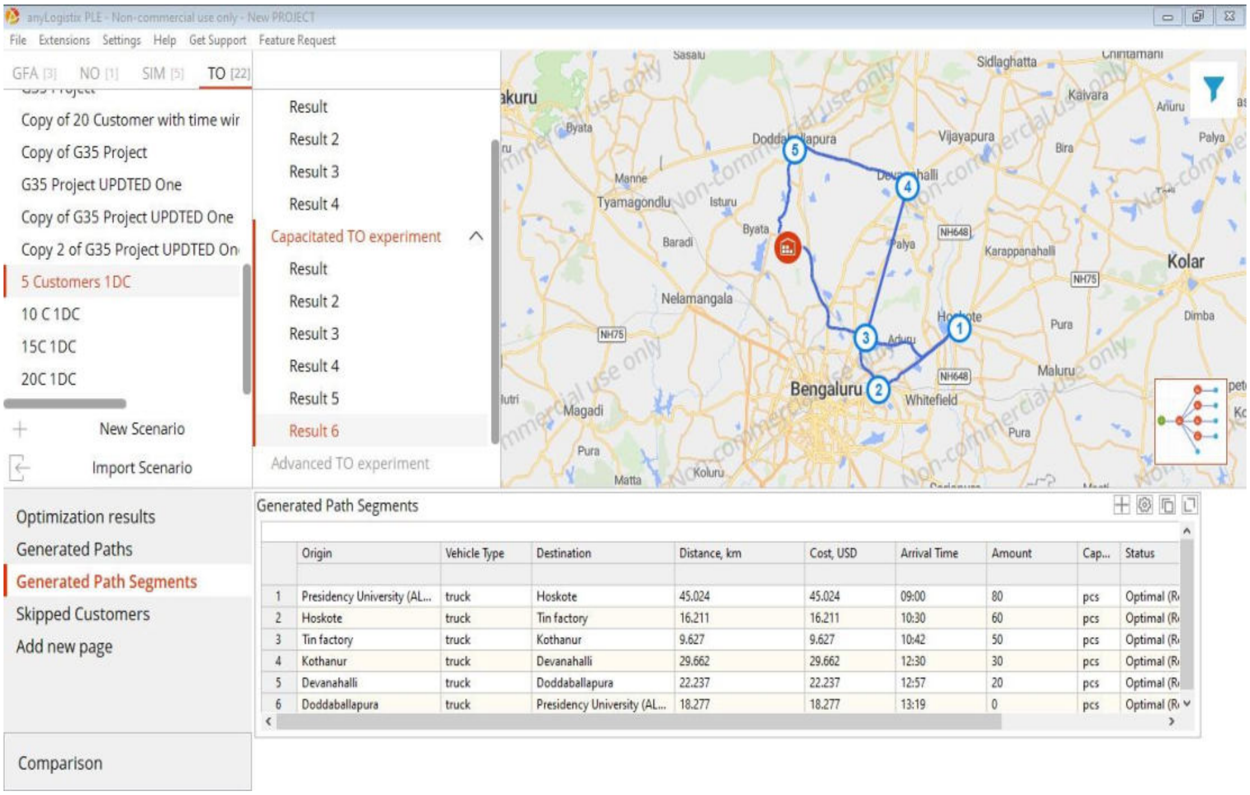

Fig 4.2 : Case (i) Capacitated TO experiment results after simulation run

Results for Case (i) Capacitated TO experiment: Table 4.18

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura			
2	Devanahalli			
3	Tin factory	141.04	169.2	0-5-3-4-2-1-0
4	Kothanur			
5	Hoskote			

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4.2.2 Case scenario(ii) using anyLogistix software simulation method

4.2.2(a) VRP with distance optimization in anylogistix

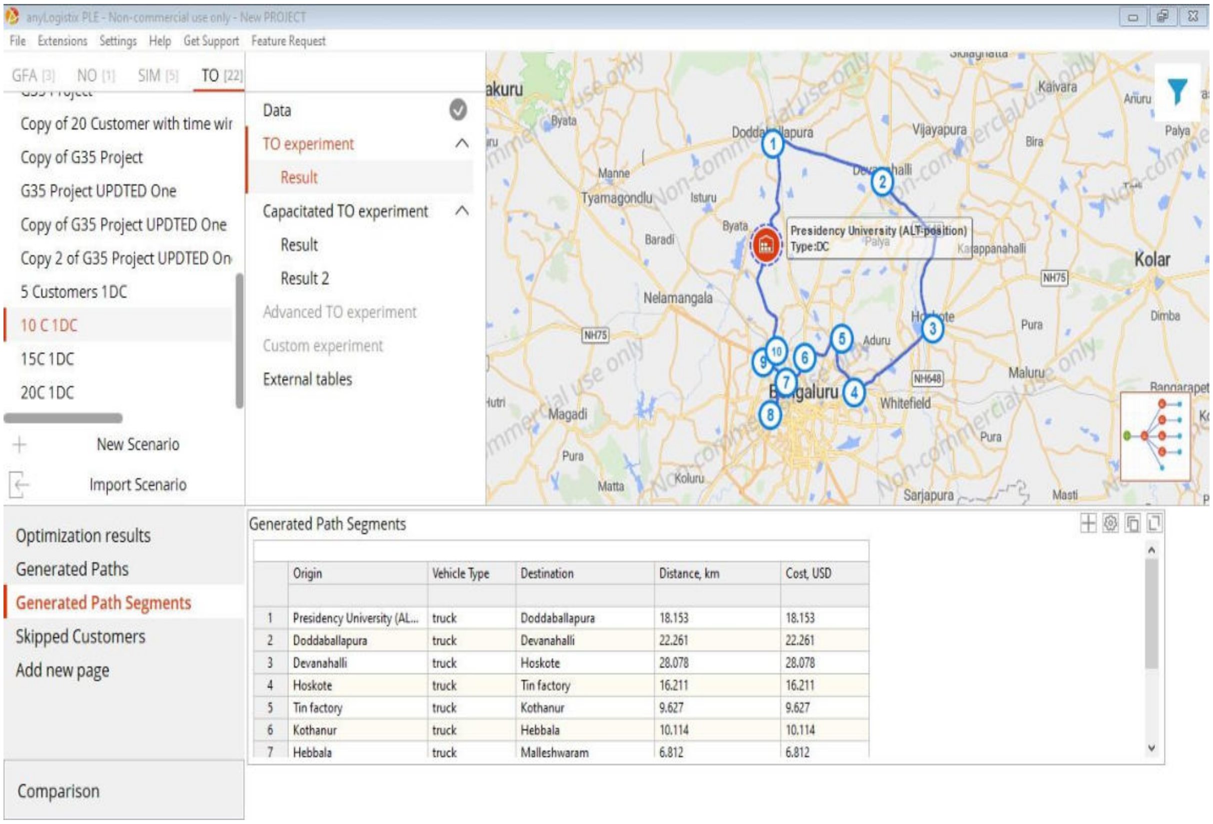

Fig 4.3 : Case (ii) TO experiment results after simulation run

Results for Case (ii) TO experiment: Table 4.19

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura			
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote	150.311	180	0-1-2-5-3-4-6-7-10-9-8-0
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			

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4.2.2(b) VRP with Time window optimization in anylogistix

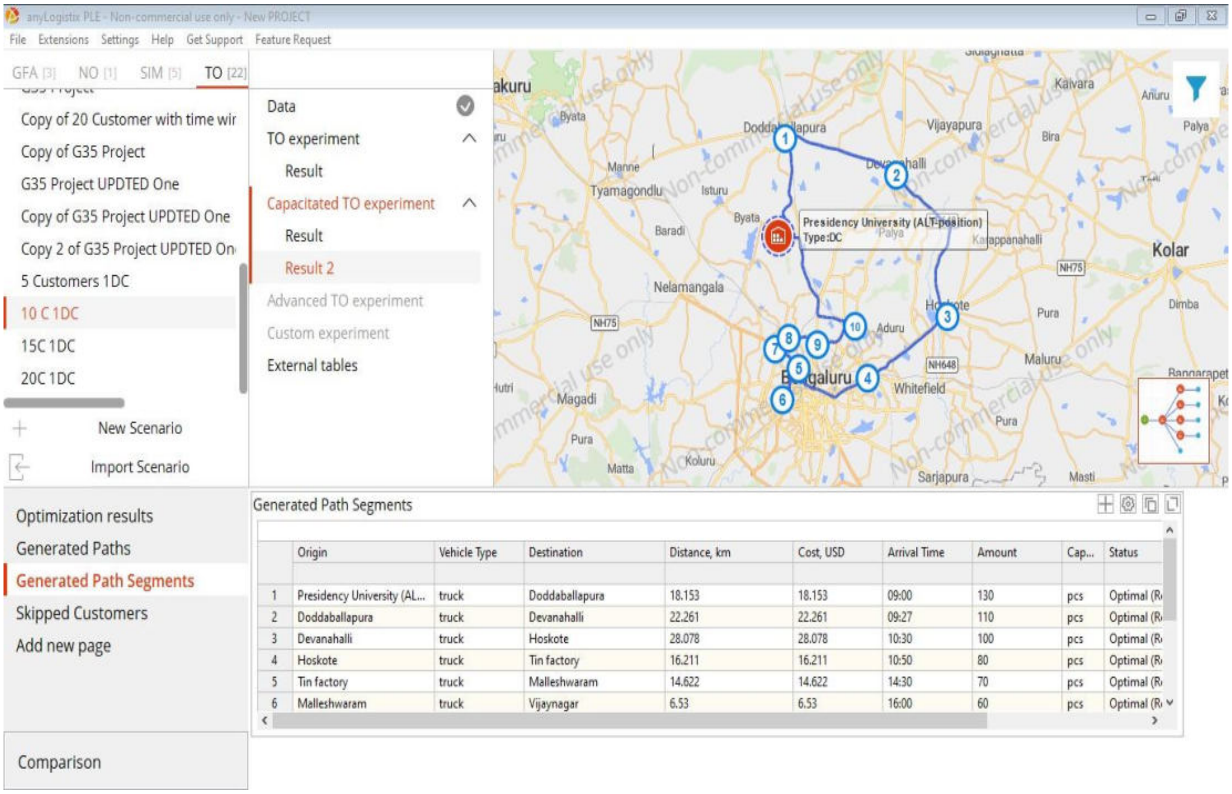

Fig 4.4 : Case (ii) Capacitated TO experiment results after simulation run

Results for Case (ii) Capacitated TO experiment: Table 4.20

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura	160.87	192.6	0-1-2-5-3-7-10-9-8-6-4-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			

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4.2.3 Case scenario(iii) using anyLogistix software simulation method

4.2.3(a) VRP with distance optimization in anylogistix

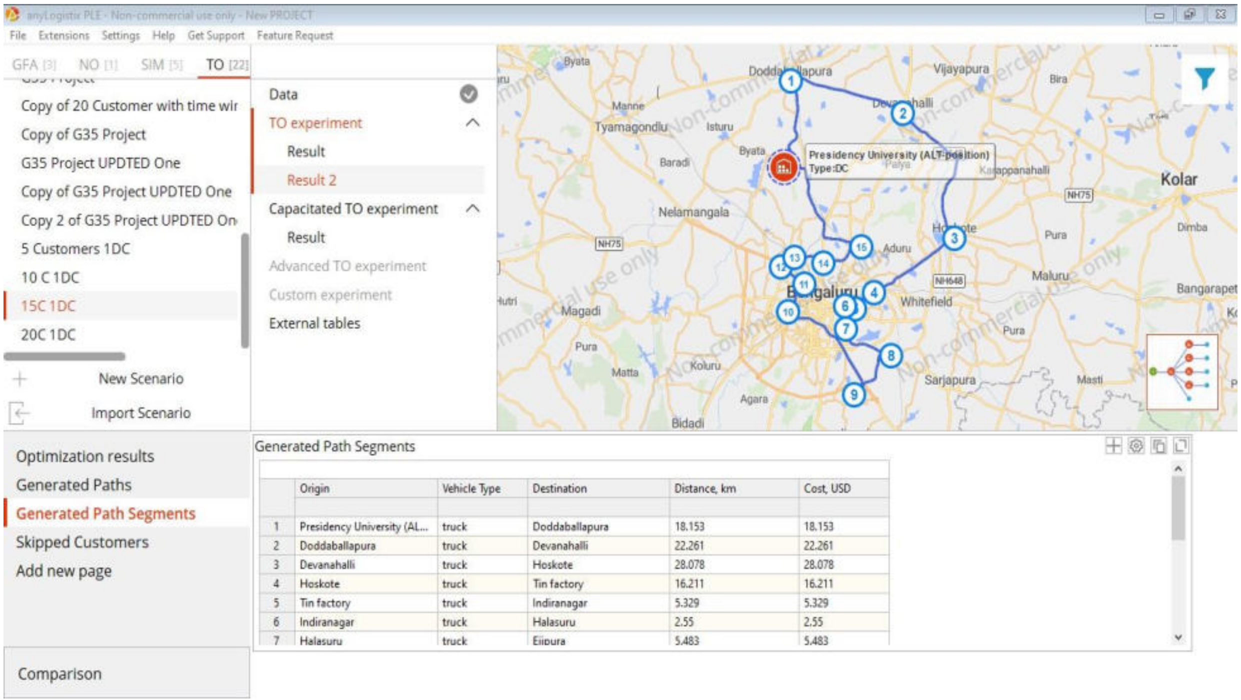

Fig 4.5: Case (iii) TO experiment results after simulation run

Results for Case (iii) TO experiment: Table 4.21

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura	199.188	238.8	0-1-2-5-3-12-11-13-14-15-10-7-9-8-6-4-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			
11	Halasuru			
12	Indiranagar			
13	Ejipura			
14	Doddakannelli			
15	Vittasandra			

4.2.3(b) VRP with Time window optimization in anylogistix

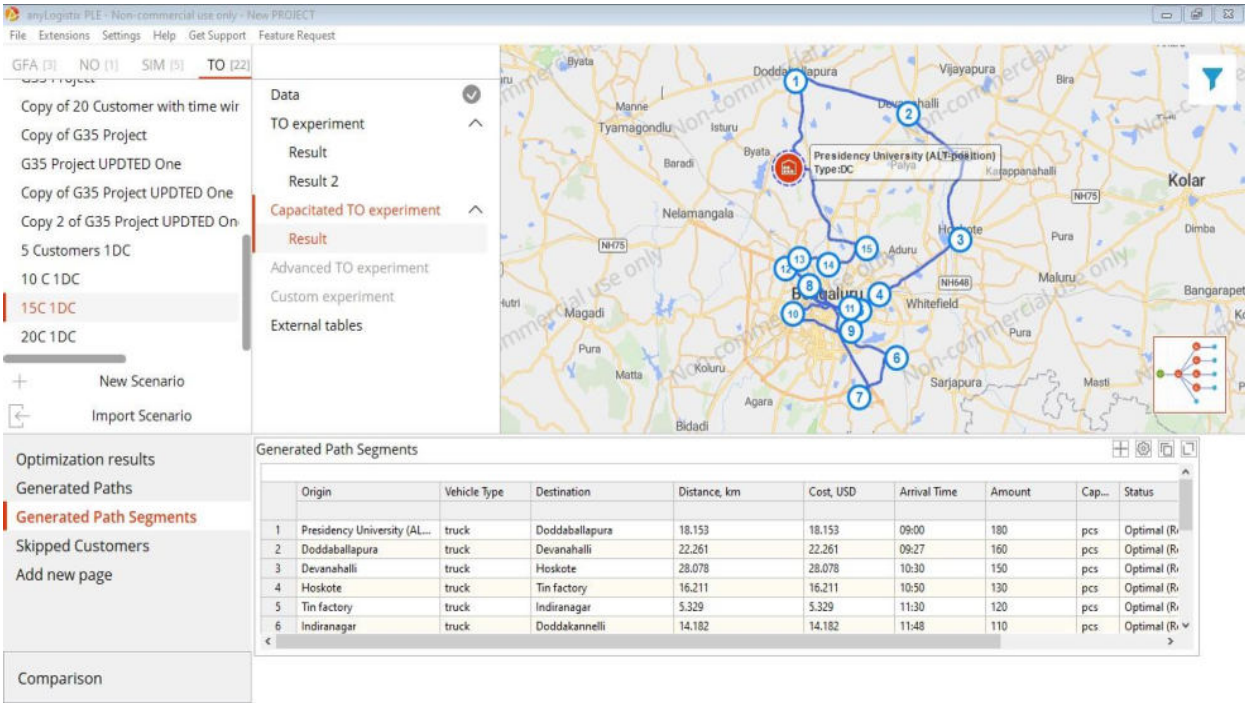

Fig 4.6 : Case (iii) Capacitated TO experiment results after simulation run

Results for Case (iii) Capacitated TO experiment: Table 4.22

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura	236.355	283.2	0-1-2-5-3-12-14-15-7-13-10-11-9-8-6-4-0
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar			
11	Halasuru			
12	Indiranagar			
13	Ejipura			
14	Doddakannelli			
15	Vittasandra			

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4.2.4 Case scenario(iv) using anyLogistix software simulation method

4.2.4(a) VRP with distance optimization in anylogistix

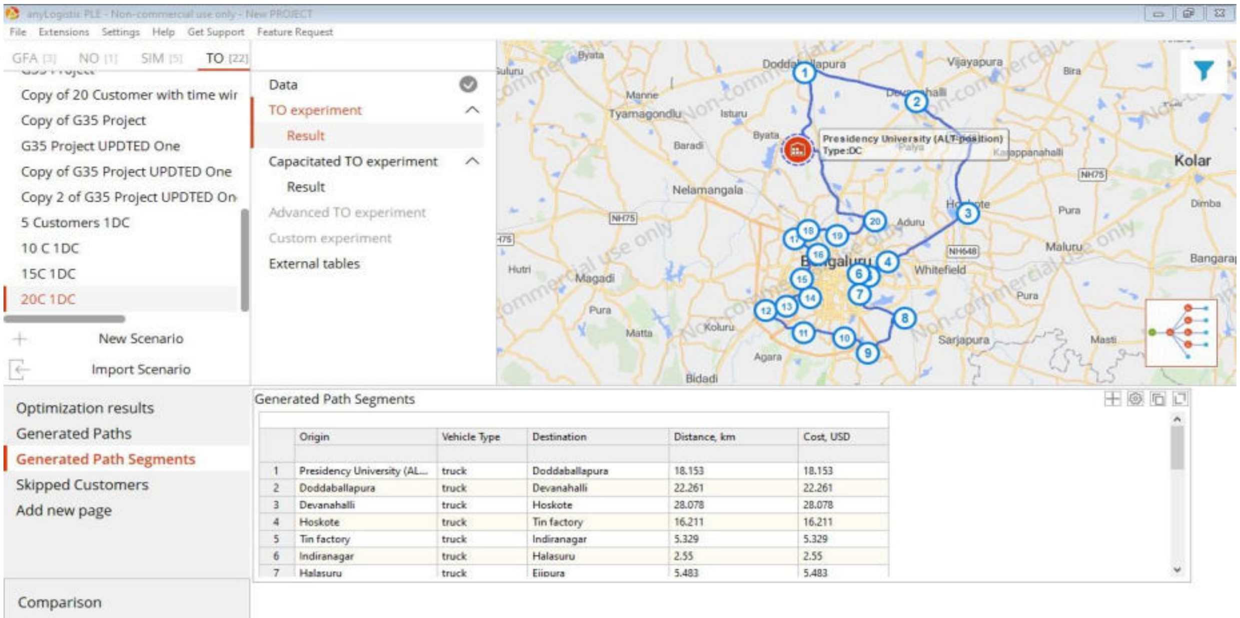

Fig 4.7: Case (iv) TO experiment results after simulation run

Results for Case (iv) TO experiment: Table 4.23

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura			
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar	219.996	263.4	0-1-2-5-3-12-11-13-14-15-16-17-18-19-20-10-7-9-8-6-4-0
11	Halasuru			
12	Indiranagar			
13	Ejipura			
14	Doddakannelli			
15	Vittasandra			
16	Hulimavu			
17	Gubbalala			
18	Kengeri			
19	Rajarajeshwarinagar			
20	Banashankri			

4.2.3(b) VRP with Time window optimization in anylogistix

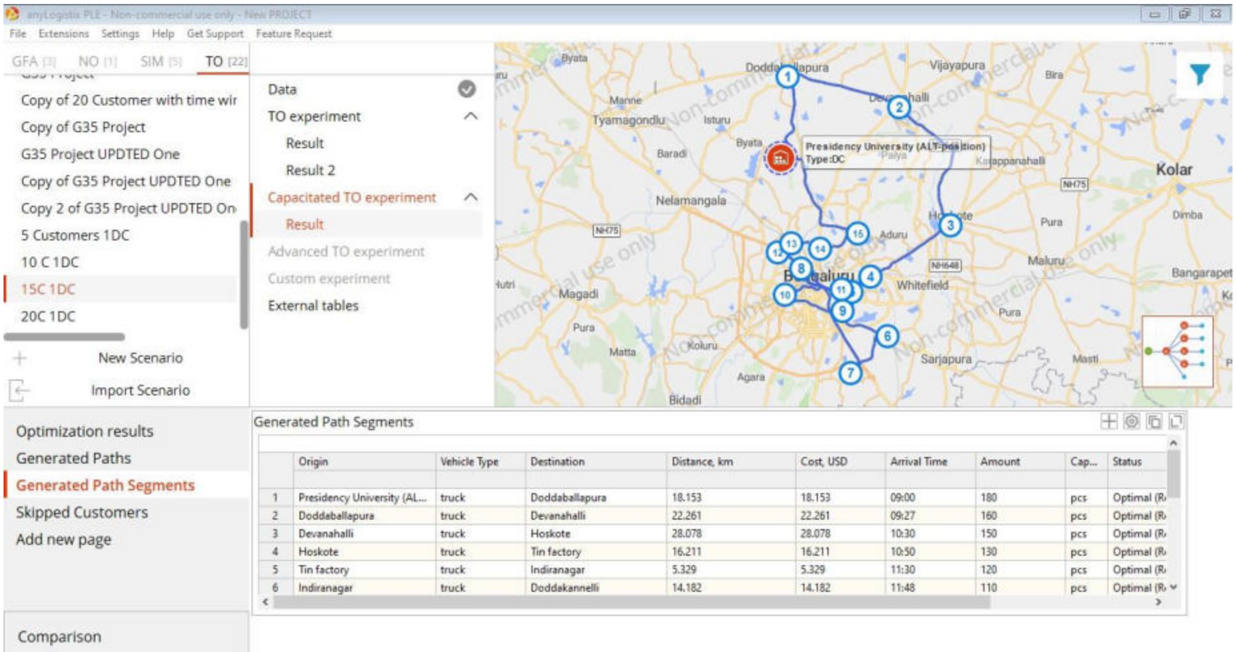

Fig 4.8 : Case (iv) Capacitated TO experiment results after simulation run

Results for Case (iv) Capacitated TO experiment: Table 4.24

No. Of customers	Customers	Distance traveled (km)	Time for covering the distance (min)	Route followed
1	Doddaballapura			
2	Devanahalli			
3	Tin factory			
4	Kothanur			
5	Hoskote			
6	Hebbala			
7	Malleshwaram			
8	Jalahalli			
9	Peenya			
10	Vijaynagar	259.842	311.4	0-1-2-5-3-12-14-15-16-17-18-19-20-7-13-10-11-9-8-6-4-0
11	Halasuru			
12	Indiranagar			
13	Ejipura			
14	Doddakannelli			
15	Vittasandra			
16	Hulimavu			
17	Gubbalala			
18	Kengeri			
19	Rajarajeshwarinagar			
20	Banashankri			

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CHAPTER 5 – CONCLUSION

Managing the spare parts supply chain is always a burden for the automakers to ensure the availability. But it is very important from the customer point of view as they always look for service and spares availability before making purchasing decision. So many car makers failed (Ex: Fiat in India) because of these reasons even though the performance of vehicle is good. In this setting, the introduction of 3D printing technology in the spare parts supply chain would be disruptive. In this work, it is attempted to solve a vehicle routing problem considering additive manufacturing setting. Result obtained are compared for robustness.
Also, it is proposed to expand the problem further by relaxing further assumptions in order to make it close to reality.

AM has already provided a new lease of life to manufacturing industries. The emergence of so many computer science related technologies like Clouds, Big Data, IoT and so on really helpful the companies to change to a better way than now they are currently in. The integration of AM and cloud technologies is one such example of that. Even though, the idea sounds good, there are few challenges that are to be addressed by the researchers as listed below.

- Firstly, cost-effective metal printing using AM technology.
- Challenges in using AM as a prime manufacturing method for wide variety auto components.
- Building network of infrastructure like AM enabled trucks, integration with cloud technology.
- Building the system with minimum human intervention and so on.

By having said that, we can't rule out the potential possibility of implementation of this in near future. Definitely, it will be a game changer like the smartphone technology that changed our lives.

Table 5.1: Results for all the case scenarios

Problem Size	Saving Matrix Method			VRP (AnyLogistix)			VRP with Time window (AnyLogistix)		
	Route	Distance (km)	Time (min)	Route	Distance (km)	Time (min)	Route	Distance (km)	Time (min)
5	0-5-4-3-2-1-0	152.424	182.908	0-1-2-5-3-4-0	118.788	142	0-5-3-4-2-1-0	141.04	169.2
10	0-5-4-6-3-7-10-9-8-2-1-0	198.752	238.2	0-1-2-5-3-4-6-7-10-9-8-0	150.311	150.311	0-1-2-5-3-7-10-9-8-6-4-0	160.87	192.6
15	0-15-13-14-12-11-3-5-4-6-7-10-9-8-2-1-0	250.981	300	0-1-2-5-3-12-11-13-14-15-10-7-9-8-6-4-0	199.188	238.8	0-1-2-5-3-12-14-15-7-13-10-11-9-8-6-4-0	236.355	283.2
20	0-16-15-14-13-12-11-17-20-19-18-10-7-9-8-3-5-4-6-2-1-0	247.243	296.4	0-1-2-5-3-12-11-13-14-15-16-17-18-19-20-10-7-9-8-6-4-0	219.996	263.4	0-1-2-5-3-12-14-15-16-17-18-19-20-7-13-10-11-9-8-6-4-0	237.471	284.965

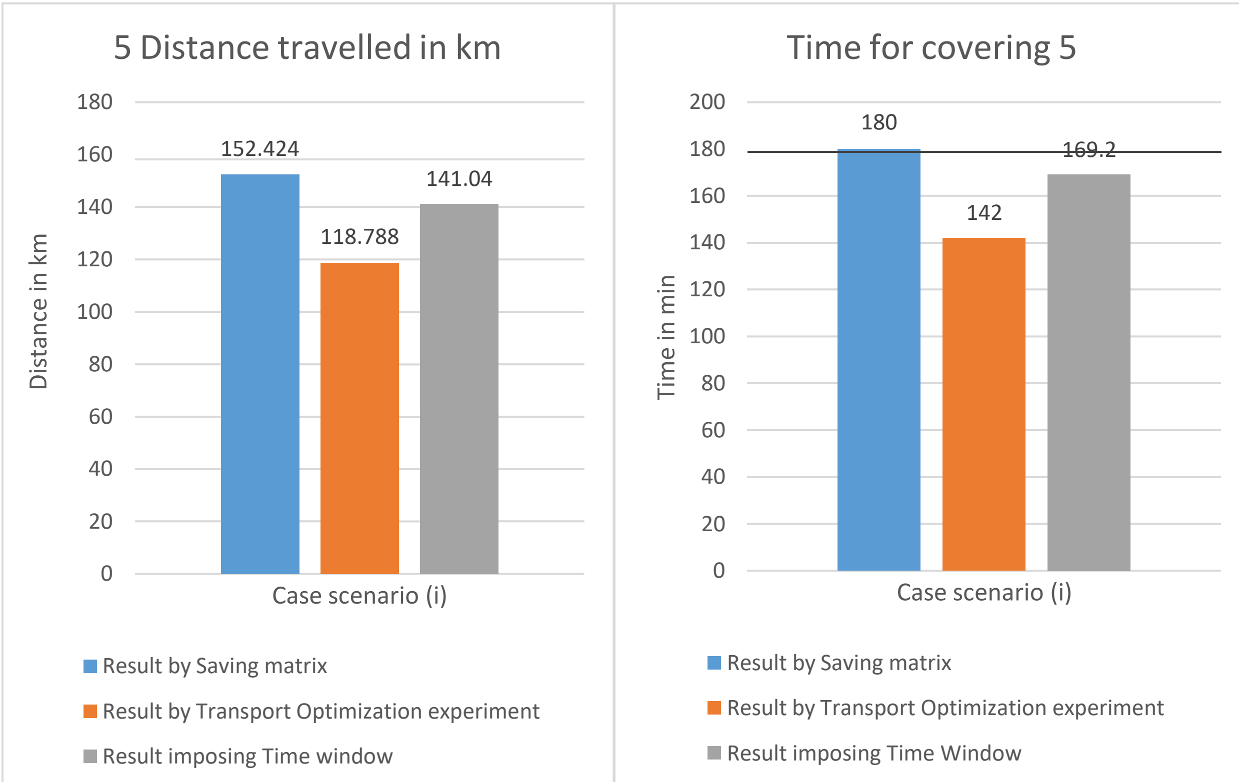

Fig 5.1: Case(i) graphical results

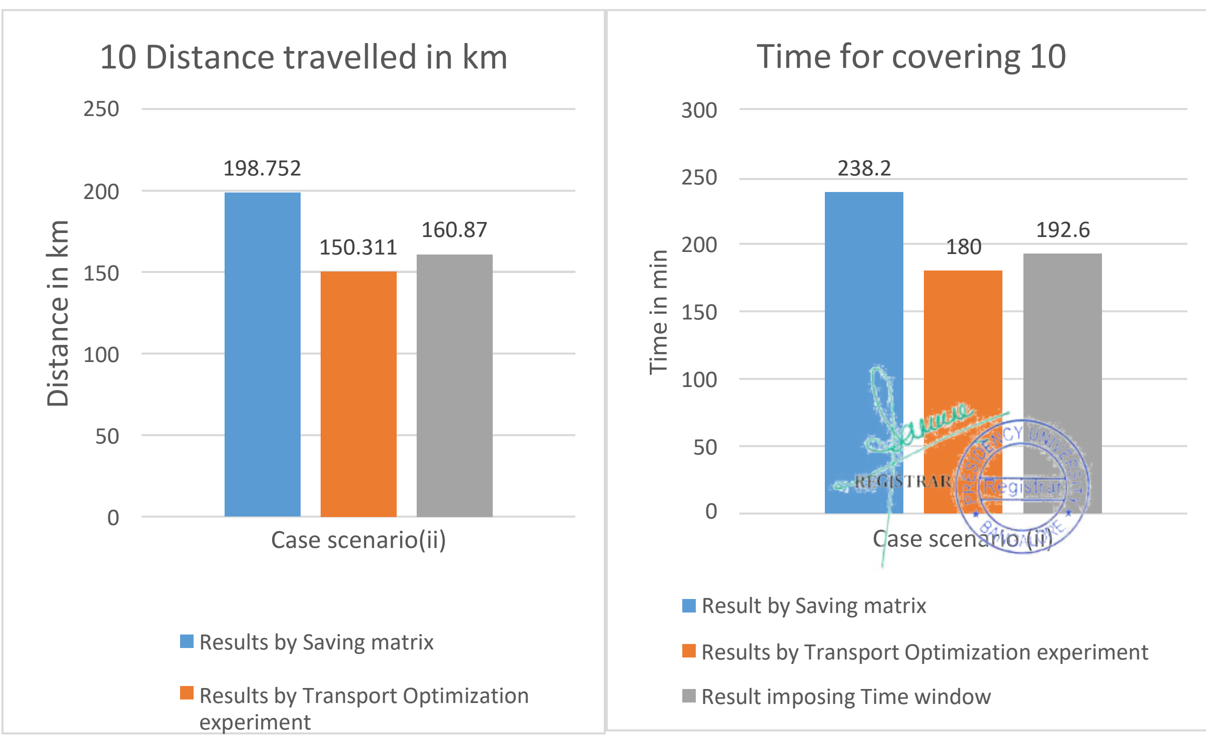

Fig 5.2: Case(ii) graphical results

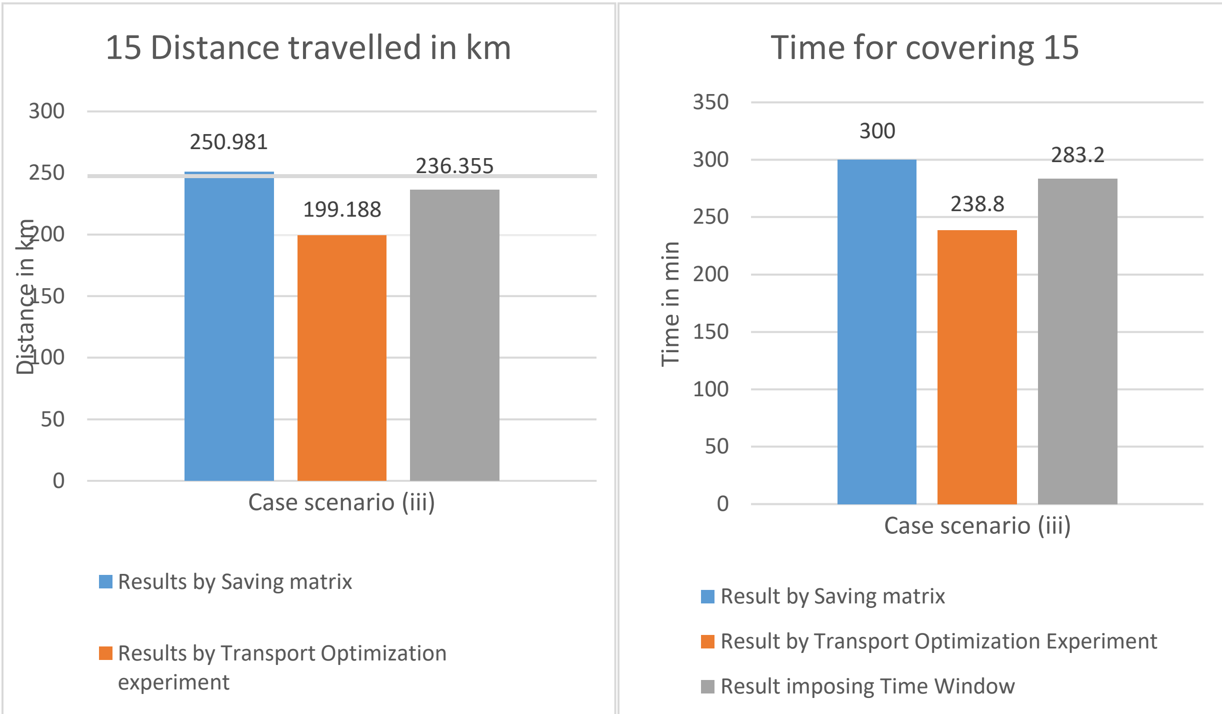

Fig 5.3: Case(iii) graphical results

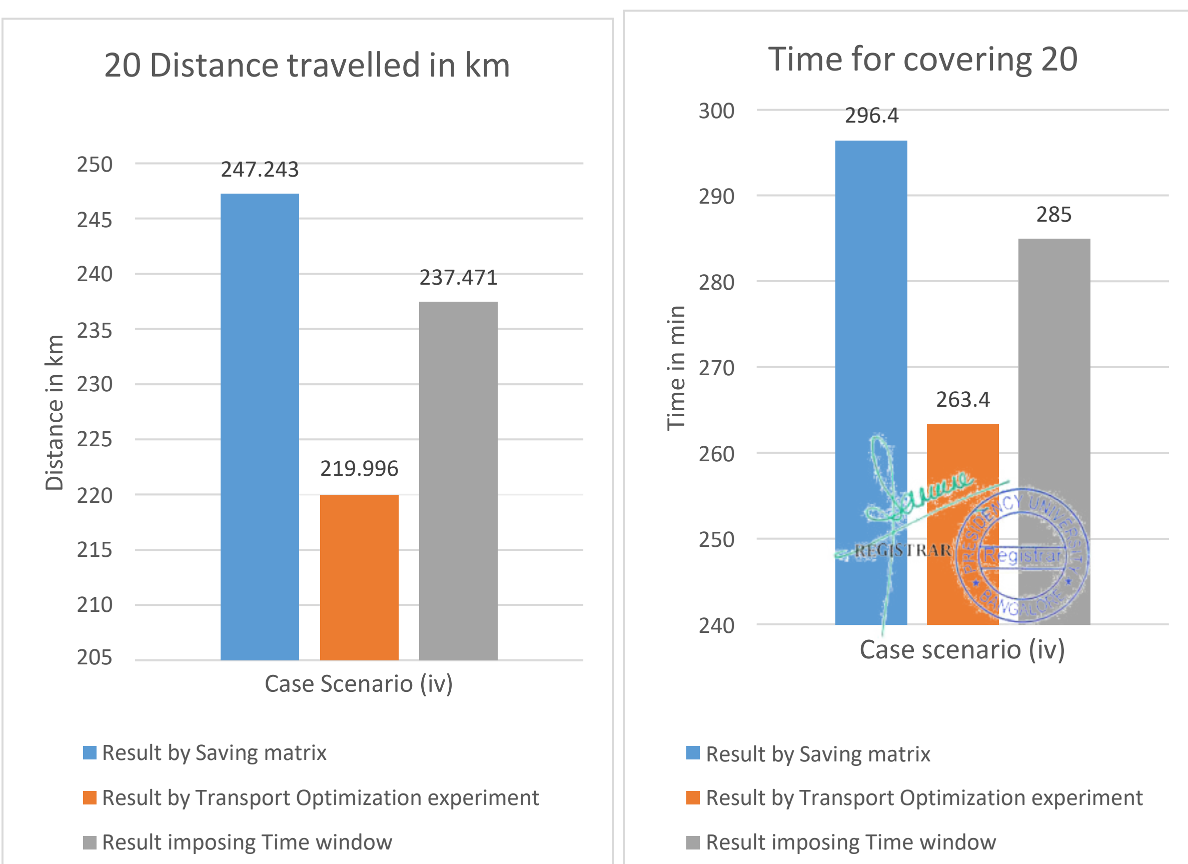

Fig 5.4: Case(iv) graphical results

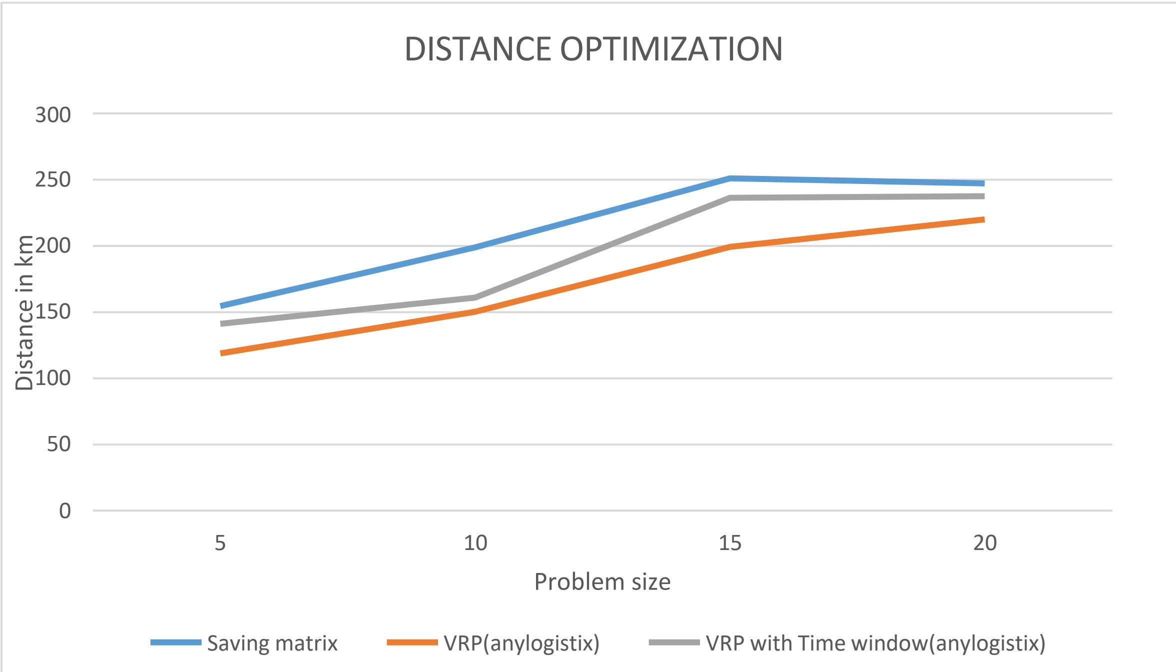

Fig 5.5: Distance optimization in Saving matrix method, VRP and VRP with time window

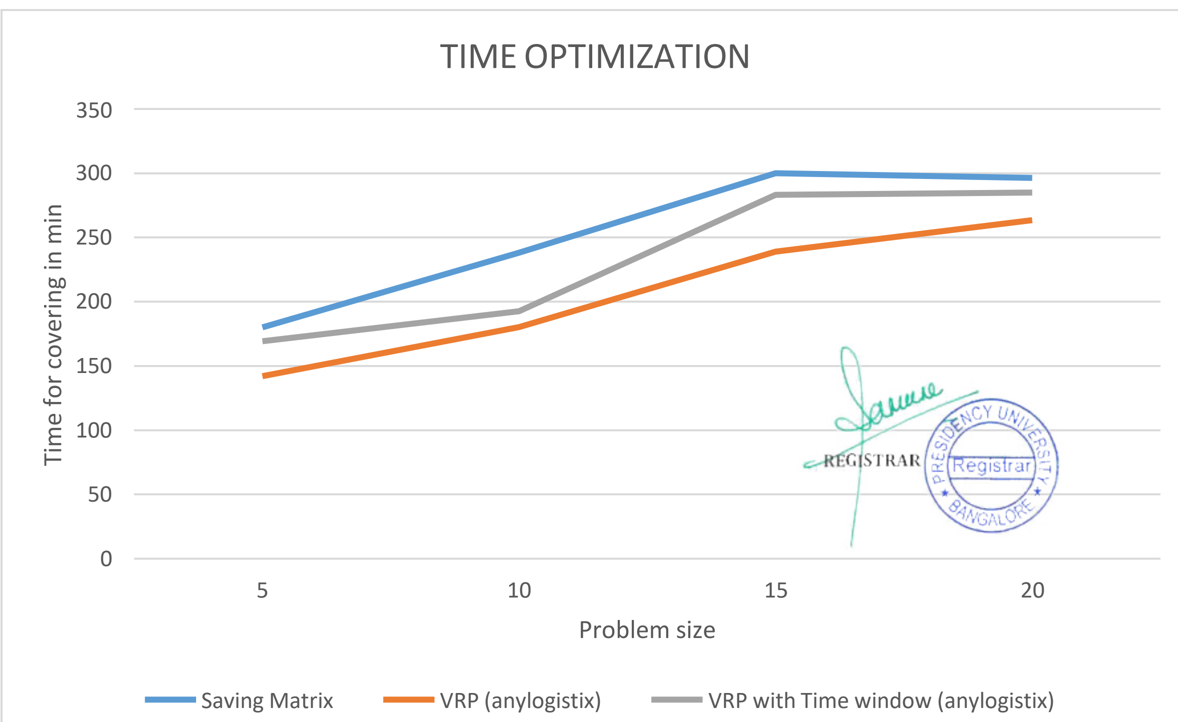

Fig 5.6: Time optimization in Saving matrix method, VRP and VRP with time window

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A Project Reporton

"DEVELOPMENT AND EVALUATION OF MECHANICAL PROPERTIES OF Al 356 ALLOY / ZIRCONIUM DIOXIDE (ZrO_2)"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2

in

Mechanical Engineering

Submitted by

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SACHIN SRINIVASA K R	**20171MEC0185**
SAMEERANA R S	**20171MEC0188**
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Under the Supervision of

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Assistant Professor

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(Private University Estd. in Karnataka State by Act No.41 of 2013)

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2020-21

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School of Engineering

Department of Mechanical Engineering

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CERTIFICATE

Certified that, the project work entitled, **"DEVELOPMENT AND EVALUATION OF MECHANICAL PROPERTIES OF AL 356 ALLOY / ZIRCONIUM DIOXIDE (ZrO_2)"** carried out by Mr Sachin B R, ID 20171MEC0183, Mr Sameerana R S, ID 20171MEC0188, Mr Sachin Srinivasa K R , ID 20171MEC0185 and Mr Sanjeev G Babajiyavar, ID 20171MEC0192,Adarsh K A ,ID 20201LME0033 bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Dr. B. S. Praveen Kumar
Supervisor

Dr Ramesh S
Prof. and Head

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End Term Examination Examiners | **Signature with date**

1.Mr.Sandeep G M

2.Dr.Yuvaraj Nayak

DECLARATION

We, the students of fifth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, **"DEVELOPMENT AND EVALUATION OF MECHANICAL PROPERTIES OF AL 356 ALLOY / ZIRCONIUM DIOXIDE (ZrO_2)"** has been successfully completed under the supervision of Dr. B. S. Praveen Kumar, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:

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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. B. S. Praveen Kumar** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We take this opportunity to sincerely thank **Dr. Ramesh S, Prof. and Head,** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Ramesh S. P.** who gave us the opportunity to do this project work.

Lastly, we would like to thank our family and friends

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1 INTRODCTION

A composite material is composed of at least two materials, which combine to give properties superior to those of the individual constituents. We refer to fiber reinforced polymer (FRP) composites, usually with carbon, glass, aramid, polymer or natural fibers embedded in a polymer matrix. Other matrix materials can be used and composites may also contain fillers or nano-materials such as graphene.

The many component materials and different processes that can be used make composites extremely versatile and efficient. They typically result in lighter, stronger, more durable solutions compared to traditional materials.

1.1 USE OF COMPOSITES

The primary reason composite materials are chosen for components is because of weight saving for its relative stiffness and strength. For example, carbon-fiber reinforced composite can be five times stronger than 1020 grade steel while having only one fifth of the weight. Aluminum (6061 grade) is much nearer in weight to carbon-fiber composite, though still somewhat heavier, but the composite can have twice the modulus and up to seven times the strength

1.1.2 WHEN SHOULD YOU USE COMPOSITES?

As with all engineering materials, composites have particular strengths and weaknesses, which should be considered at the specifying stage. Composites are by no means the right material for every job.

However, a major driving force behind the development of composites has been that the combination of the reinforcement and the matrix can be changed to meet the required final properties of a component. For example, if the final component needs to be fire-resistant, a fire-retardant matrix can be used in the development stage so that it has this property.

I. Weight reduction

- The primary reason composites are chosen is improved specific strength / stiffness (strength / stiffness specific per unit weight).
- This helps to reduce fuel use, or increase acceleration or range in transport.

- It allows for easier, faster installation or faster movement of robot arms and reduces supporting structures or foundations.
- It improves topside stability in vessels and offshore structures and buoyancy for deep sea applications.

II. Durability and maintenance

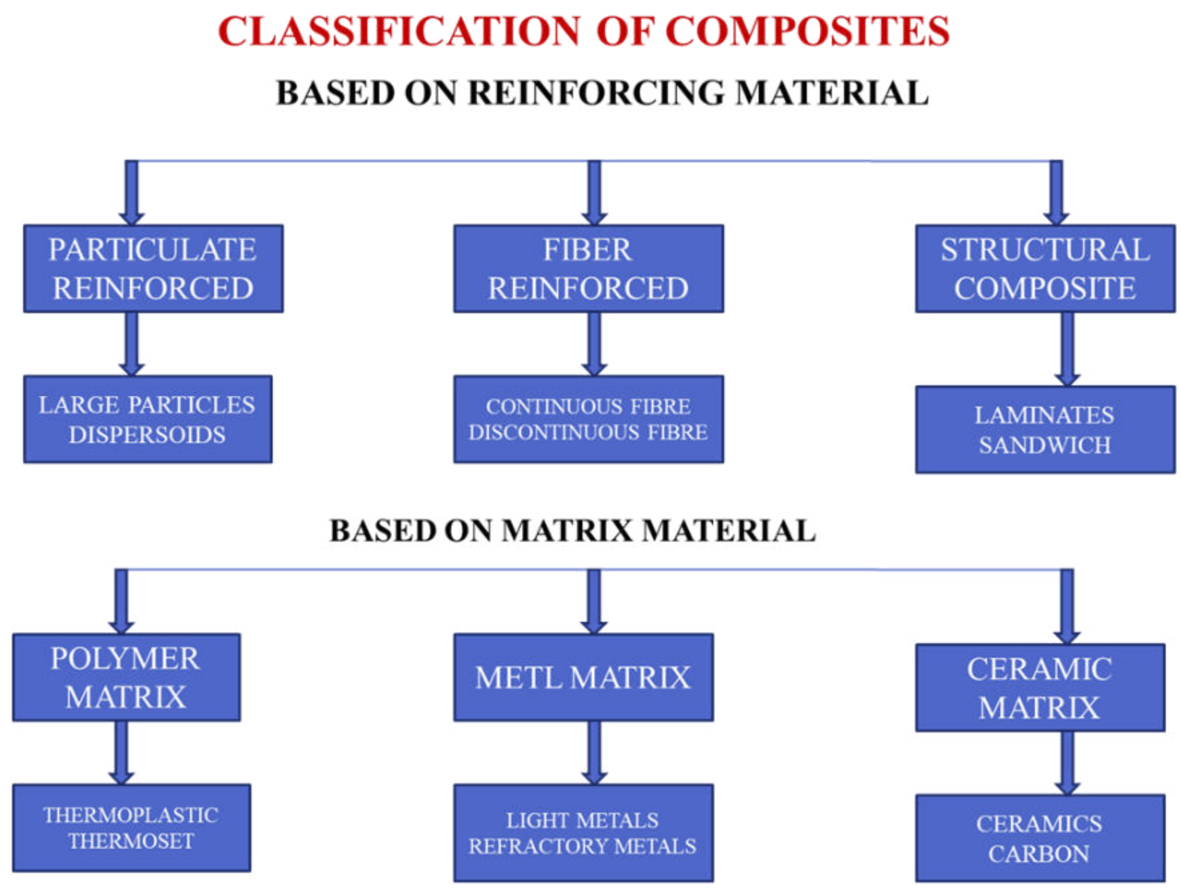
- Composites don't rust, which is crucial, especially in marine and chemical environments. The need for maintenance and painting is reduced or eliminated.
- Composite bearings for marine engines and bridges need no lubrication and don't corrode.
- Combine the excellent fatigue resistance, and composites can increase product lifespan by several times in many applications.

III. Added functionality

- Composites are thermal insulators which is good for fire and blast protection or cryogenic applications.
- Electrical insulation is useful for railway lineside structures and radar transparency. A conductive mesh or coating can be integrated if needed, e.g., to reflect radar or divert lightning.
- Sensors, electronics and cabling can be embedded.

IV. Design freedom

- Composite's design allows for freedom of architectural form.
- Many parts can be consolidated into one, and stiffeners, inserts, etc. can be integrated in-mould.
- Composites can be tailored to suit the application by choosing the constituent materials and embedding extra functionality.



1.2 Types of composite materials

Composite materials are formed by two or more components so that the properties of the final material are better than the properties of the components separately.

This kind of materials consist of:

- Matrix: sets up the part geometrically, gives cohesion to the material, it is usually flexible and not very resistant and transmits efforts from one fiber to another.
- Reinforcement: provides rigidity and resistance.

1.2.1 Types of matrices and reinforcements in composites

Depending on the type of matrix there are:

- Metal matrix composite materials
- Ceramic matrix composite materials
- Organic, polymeric or Reinforced-Plastics matrix composite materials. This group includes composite materials of long fiber reinforcement with a plastic matrix.

Regarding reinforcements, there are different types of them, such as carbon fibers, glass fibers, aramid fibers, natural fibers, etc.

- **Long fiber-reinforced composite materials**

The most used ones because of their lightness and excellent mechanical properties, are composite materials of polymeric matrix with fiber reinforcements. These materials replace others (mainly metallic ones) in those applications in which the mechanical properties-weight relation influences decisively the maintenance costs of the product.

Organic matrices can be thermoplastic, thermosetting or elastomers.

Thermosetting matrices or resins are the most used in high-performance composite materials. These resins result in a solid, insoluble and unmelt able product by a series of chemical reactions known as curing or cross-linking. In contrast, the thermoplastic ones melt when exposed to heat.

MATRICES

THERMOPLASTIC	**THERMOSETTING**	**ELASTOMERS**
Polypropylene (PP)	Unsaturated polyester	Polyurethane (PU)
Polyamide (PA)	(UP)	Silicone (Si)
fibers	Epoxy Resins	
(PEEK)	Vinyl ester resin	
	Phenols	

The main fibers used as reinforcements are:

- Glass fibers
- Carbon fibers
- Boron fibers
- Ceramic fibers
- Metal fibers
- Aramid fibers
- Natural fibers: sisal, hemp, flax, etc.

Regardless of the type of material they are made of, fibers can appear in form of roving, mats, or fabrics.

Another type of products that are incorporated into the composite material fiber-resin is fillers and additives. They are added with the aim of providing particular characteristics to the material or reducing its cost.

The number of added products varies depending on the properties we want to achieve. The general aim is to improve processability and the finished product.

1.2.3 Structural composite materials

Structural composite materials can be classified as follows:

- Sandwich structures: composed by a core and layers. They allow to improve the mechanical properties but without an excessive increase of weight. They also improve thermal and acoustic insulation.

- Monolithic structures: parts with a complex geometry, formed by overlapping fabrics with particular orientations that allow obtaining specific characteristics. This kind of parts is intended to withstand the heaviest structural loads.

1.3 Metal Matrix Composites

According to the classification of composite materials:

Metal Matrix Composite (MMC) is a material consisting of a metallic matrix combined with a ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) dispersed phase.

I. Aluminum Matrix Composites (AMC)
II. Magnesium Matrix Composite
III. Titanium Matrix Composite
IV. Copper Matrix Composites
V. Properties of some Metal Matrix Composites
VI. Aluminum Matrix Composites (AMC)

This is the widest group of Metal Matrix Composites.

Matrices of Aluminum Matrix Composites are usually based on aluminum-silicon (Al-Si) alloys and on the alloys of 2xxx and 6xxx series.

I. Aluminum Matrix Composites (AMC) are reinforced by:

- Alumina (Al_2O_3) or silicon carbide (Sic) particles (particulate Composites) in amounts 15-70 vol%;
- Continuous fibers of alumina, silicon carbide, Graphite (long-fiber reinforced composites);
- Discontinuous fibers of alumina (short-fiber reinforced composites);

Aluminum Matrix Composites are manufactured by the following fabrication methods:

- Powder metallurgy(sintering);
- Stir casting;
- Infiltration.

The following properties are typical for Aluminum Matrix Composites:

- High strength even at elevated temperatures;
- High stiffness (modulus of elasticity);
- Low density;
- High thermal conductivity;
- Excellent abrasion resistance.

Aluminum Matrix Composites (AMC) are used for manufacturing automotive parts (pistons, pushrods, brake components), brake rotors for high-speed trains, bicycles, golf clubs, electronic substrates, cores for high voltage electrical cables.

II. Magnesium Matrix Composite

Magnesium Matrix Composites are reinforced mainly by silicon carbide (Sic) particles (particulate composites)

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The following properties are typical for Magnesium Matrix Composites:

- Low density;
- High stiffness (modulus of elasticity);
- High wear resistance;
- Good strength even at elevated temperatures;
- Good creep resistance.

Magnesium Matrix Composites are used for manufacturing components for racing cars, lightweight automotive brake system, aircraft parts for: gearboxes, transmissions, compressors and engine.

III. Titanium Matrix Composite

Titanium Matrix Composites are reinforced mainly by:

- Continuous monofilament silicon carbide fiber (long-fiber reinforced composites);
- Titanium boride (TiB2) and titanium carbide (Tic) particles (particulate composites).
- Powder metallurgy (sintering)is used for fabrication of Titanium Matrix Composites.

The following properties are typical for Titanium Matrix Composites:

- High strength;
- High stiffness (modulus of elasticity);
- High creep resistance;
- High thermal stability;

Titanium Matrix Composites are used for manufacturing structural components of the F-16 jet’s landing gear, turbine engine components (fan blades, actuator pistons, synchronization rings, connecting links, shafts, discs), automotive engine components, drive train parts, general machine components.

IV. Copper Matrix Composites

Copper Matrix Composites are reinforced by:

- Continuous fibers of carbon (**C**), silicon carbon (SiC), tungsten (W), stainless steel 304 (long-fiber reinforced composites);
- Silicon carbide particles (particulate composites).

Powder metallurgy (sintering) and infiltration technique are used for fabrication Copper Matrix Composites.

The following properties are typical for Copper Matrix Composites:

- Low coefficient of thermal expansion;
- High stiffness (modulus of elasticity);
- Good electrical conductivity;

- High thermal conductivity;
- Good wear resistance.

Copper Matrix Composites are used for manufacturing hybrid modules, electronic relays, electrically conducting springs and other electrical and electronic components

1.4 Structure of composites

Structure of a composite material determines its properties to a significant extent.

Structure factors affecting properties of composites are as follows:

- Bonding strength on the interface between the dispersed phase and matrix;
- Shape of the dispersed phase inclusions (particles, flakes, fibers, laminates);
- Orientation of the dispersed phase inclusions (random or preferred).

1. **Interfacial bonding**

Good bonding (adhesion) between matrix phase and dispersed phase provides transfer of load, applied to the material to the dispersed phase via the interface. Adhesion is necessary for achieving high level of mechanical properties of the composite.
There are three forms of interface between the two phases:

- Direct bonding with no intermediate layer. In this case adhesion (" wetting") is provided by either covalent bonding or van der Waals force.
- Intermediate layer in form of solid solution of the matrix and dispersed phases constituents.
- Intermediate layer (interphase) in form of a third bonding phase (adhesive).

Shape and orientation of dispersed phase
Importance of these structure parameters is confirmed by the fact, that one of the systems of Classification of composites is based on them.

- Particulate Composites
- Fibrous Composites
- Laminate Composites

2. **Particulate Composites**

Particulate Composites consist of a matrix reinforced with a dispersed phase in form of particles.

Effect of the dispersed particles on the composite properties depends on the particle's dimensions.

Very small particles (less than 0.25 micron in diameter) finely distributed in the matrix impede movement of dislocations and deformation of the material. Such strengthening effect is similar to the precipitation hardening. In contrast to the precipitation hardening, which disappears at elevated temperatures when the precipitated particles dissolve in the matrix, dispersed phase of particulate composites (ceramic particles) is usually stable at high temperatures, so the strengthening effect is retained. Many of composite materials are designed to work in high temperature applications.

Large dispersed phase particles have low strengthening effect but they are capable to share load applied to the material, resulting in increase of stiffness and decrease of ductility.

Hard particles dispersed in a softer matrix increase wear and abrasion resistance.

Soft dispersed particles in a harder matrix improve machinability (lead particles in steel or copper matrix) and reduce coefficient of friction (tin in aluminum matrix or lead in copper matrix).

Composites with high electrical conductivity matrices (copper, silver) and with refractory dispersed phase (tungsten, molybdenum) work in high temperature electrical applications.

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When dispersed phase of these materials consists of two-dimensional flat platelets (flakes) which are laid parallel to each other, material exhibits anisotropy (dependence of the properties on the axis or plane along which they were measured). In the case of flakes oriented parallel to a particular plane, material demonstrates equal properties in all directions parallel to the plane and different properties in the direction normal to the plane.

3. Fibrous Composites

Dispersed phase in form of fibers (Fibrous Composites) improves strength, stiffness and Fracture Toughness of the material, impeding crack growth in the directions normal to the fiber.Effect of the strength increase becomes much more significant when the fibers are arranged in a particular direction (preferred orientation) and a stress is applied along the same direction.

The strengthening effect is higher in long-fiber (continuous-fiber) reinforced composites than in short-fiber (discontinuous-fiber) reinforced composites.Short-fiber reinforced composites, consisting of a matrix reinforced with a dispersed phase in form discontinuous fibers (length < 100*diameter), has a limited ability to share load.

Load, applied to a long-fiber reinforced composite, is carried mostly by the dispersed phase - fibers. Matrix in such materials serves only as a binder of the fibers keeping them in a desired shape and protecting them from mechanical or chemical damages.

4. Laminate Composites

Laminate composites consist of layers with different anisotropic orientations or of a matrix reinforced with a dispersed phase in form of sheets.

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite.

Laminate composites provide increased mechanical strength in two directions and only in one direction, perpendicular to the preferred orientations of the fibers or sheet, mechanical properties of the material are low.

Fabrication methods of aluminum metal matrix composites

According to the various methods of adding reinforcement, the fabrication methods of the composite materials can be divided mainly into the solid-state method, the liquid state method and some other special new manufacturing methods, among them the liquid method includes casting methods and the infiltration method. MMCs are convenient and economically viable for liquid state manufacturing, which is very desirable to many industries. The different methods of infiltration and casting.

1.5 NEED FOR DEVELOPING METAL MATRIX COMPOSITE MATERIALS

Over the last thirty years MMC composite materials have been the dominant emerging material.

- The present-day trend is to go in for
- Light weight parts are needed for automobile and aerospace engineering.
- Increasing fuel price has led to a renewed urgency of weight reduction
- Aesthetic appearance, high temperature application
- High resistance to wear
- Tailoring the strength properties for engineering applications.
- Metal-matrix composites have been emerged as potential alternatives to conventional alloys in high-strength and stiffness applications

All these factors have propelled modern designers/researchers to develop newer metal matrix composite materials.

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2. Literature Survey

2.1 Introduction

A MMC can be described as a material which is made up of a continuous metallic phase (the matrix) into which a second phase (or phases) has been artificially introduced. At first, strength properties of light combinations were enhanced by the reinforcement of strands, majorly earthenware(ceramics) production. The microstructures of long fiber are proportionate to those in polymer framework composites. Early MMCs had their application kept to military and aviation applications; their broad use was obstructed because of their high creation costs and constrained generation techniques.The attributes of MMC's are excellent compared to base alloys.A portion of the vital properties of particle fortified MMC's are contrasted with the base alloys [31-33].

Particulate strengthened metal matrix composites are as of now being utilized as auxiliary segments as a part of numerous aviation and car applications on account of their minimal effort and isotropic nature [34].The expanding interest for PMMCs is because of one of a kind mechanical properties accomplished in the metal when ceramic particulates are utilized as reinforcement stages. PMMCs consolidate the pliability and durability of the metal matrix with the high quality and solidness of the fired reinforcement to accomplish properties unattainable in either of the commencing materials.PMMCs frequently have high quality to weight proportions, a vital thought in weight delicate applications.Other particular properties of PMMCs can incorporate great warm strength and amazing wear resistance.

For a long period of time, aluminum alloys were some of the most widely used materials as the matrix in MMCs, both in research and development and in industrial applications due to its low density. In addition, they are inexpensive if contrasted and other low density amalgams, (for example, Mg or Ti).Aluminum composites are exceptionally understood compounds because of their high use in a few commercial ventures, from car and flight to relaxation [35].

Their great conduct, from various perspectives (quality, malleability, erosion), is extremely surely understood and can be changed keeping in mind the end goal to fulfill distinctive applications. Aluminum combinations, particularly prescribed for MMCs, are the age solidifying of Al compounds (Al-Cu-Mg and Al-Zn-Mg-Cu)[36].As of late, in this gathering the age solidifying Al-Li amalgams have been incorporated. Li amalgam to the Al diminishes the density similarly that it expands the Young's modulus, and this is particularly fascinating for the airplane business [37].

Aluminum composites are generally utilized as a part of aviation and auto businesses because of their low thickness and great mechanical properties, better erosion resistance and wear, low warm coefficient of extension when contrasted with ordinary metals and amalgams. Of all the AMCs, molecule fortified AMCs constitutes biggest amount of composites created and used on volume and weight premise. PAMCs are created by lasting mold mix throwing/melt penetration/splashing/in situ preparing procedures at mechanical level. Silicon Carbide (ZrO2), Alumina (Al_2O_3) and Titanium Carbide (TiC) are utilized as reinforcements, which enhances the UTS [38, 39].

Aluminum metal matrix composites (Al MMCs) are being considered as cutting edge materials for its light weight, high quality, high particular modulus, magnificent wear resistance furthermore, Low coefficient of thermal expansion (α) compared to the conventional materials. Zircon particles were transferred into melt by using blending throwing (Stir casting) .The fluid metal is blended with graphite stirrer at 630 rpm to ensure proper mixing.The melt was super heated over its fluid temperature of 500^0 C, then transferred into a die for getting the castings [40, 41].

The presence of Zircon particles in Al alloys, improves the abrasion resistance properties of the MMC.The particulates have a favorable effect on mechanical properties such as hardness, wear resistance and compressive strength. Al356 reveals increase in hardness and decrease of ductility with increasing silicon carbide particles. The ceramic particulate (ZrO2) resists impact, thermal shock, chemical attack and has high melting point [42-44].

2.2 Metal Matrix Composites Fabrication Methods

A number of composite fabrication techniques have been developed that can be placed into four broad categories. These are:

(i) Liquid metallurgy technique (Stir Casting)

(ii) Powder metallurgical techniques,

(iii) Diffusion bonding of filaments and foils, and

(iv) Vapour phase infiltration.

Stir casting is a method of composite preparation via liquid state in which dispersed phase of ZrO2and Al_2O_3 particles were mixed with molten Al6063 alloy by means of mechanical stirring inside a graphite crucible kept inside electric arc furnace. Liquid composite material is cast by pouring the fluid metal into the mould.The base alloy was superheated over its liquefying temperature and then brought down bit by bit until the compound achieved semisolid state. Zircon was immediately transferred into melt [45, 46].

Higher rate of zircon in the composites causes molecule agglomeration, thus stir casting is a superior choice.The term stir casting is the procedure of mixing the liquid metal thoroughly with prompt emptying of the melt into the molds, then cooled and permitted to solidify. In blend throwing, the particles are regularly tends to shape agglomerates, which can be just broken up by lively mixing at high temperature [47].

From a mechanical point of view of property execution relationship, the interface between the base alloy and the fortifying stage is of essential significance. Handling of MMCs now and then permits customizing of the interface between the base alloy and the particles keeping in mind the end goal to meet particular property-execution prerequisites.The expense of creating cast MMCs has descended quickly, particularly with the utilization of minimal effort particulate reinforcement like graphite, alumina and silicon carbide [48, 50].

Ostensible composition of the composite utilized as a part of this study is Al-4.5 wt% Cu strengthened with zircon sand particles with a normal size of 65 micron. The Al-4.5%Cu/ZrO2 4 composite and unreinforced lattice combination were created by stir casting strategy in an instigation furnace followed by hardening of the melt in a metal mold.A degassing treatment in hydrogen could enhance the properties of composites. The preheated zircon sand at 450^0 C was included using a spatula at the rate of 20-30 g/min into the Al-4.5 wt% Cu melt. After accession of zircon sand the melt was poured in a metal form and hardened [51,52].

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2.3 Selection of Matrix Material

Aluminum matrix composites have numerous features, for example, high quality even at raised temperatures, high solidness, low thickness, high wear resistance, high firmness, high warm conductivity and brilliant wear resistance [53, 54].

Aluminum and its compounds utilizing as a part of the numerous motor and numerous applications because of low weight and great mechanical properties and dimensional stability. With the expansion of reinforcements, the properties of the composite can be enhanced and acquired what we needed for some applications with lower weight and enhance the proficiency of the framework. In his exploration, Aluminum and silicon carbide (ZrO2) and cenosphere particulates are utilized to create half breed composite for motor applications by blend throwing course. The obliged material properties for motor applications are more noteworthy quality, light weight, controlled warm development, high warm conductivity and great wear resistance. The mechanical properties like extreme rigidity, compressive quality, density and hardness of the mixture metal matrix composites are tested. From the obtained results thickness of hybrid composite reductions with extension wt% of backing to the base alloy.

An Al-Si-ZrO2 combination shows favored result compared to Al-Si and Al-Si-ZrO2. The best rigidity result has been gained at 15% weight rate of cenosphere and 3% weight rate of Silicon Carbide. The exploratory results unmistakably demonstrate that pressure quality and hardness of composites expanded by expanding the weight portion of reinforcements such ZrO2 and Cenosphere due to light weight Aluminium metal matrix composites are finding increased applications in many areas [55-57].

Among a few series of aluminum composites, A356 is a standout amongst the most broadly utilized combinations for its fabulous properties.BaZrO2ally A356 is an alloy of Aluminium, Magnesium and Silicon, which is highly resistant to corrosion and exhibit moderate strength. The Al356 amalgam is one of the normally utilized age-hardenable cast combination for different applications.The composite can be cast in permanent or sand mould and has incredible castability, great consumption resistance, great wear resistance and weight snugness and better machining and welding attributes.It is an excellent matrix material which finds its application in automobile, aerospace and many other broader areas due to excellent wear resistance and higher hardness. [58, 59].

All Aluminum and its compounds is by a wide margin the overwhelming base alloy system for metal matrix composites.It is when acceptable minimal cost material, which exhibits a low liquefying point, encouraging manufacture. With its low density (2.7 g/cm 3) and the way that it can be worked into any structure by plastic twisting, and cast by all foundry forms, its overwhelming position for use in Metal Matrix Composites (MMCs) is promptly clarified. Interestingly, a more critical view at the literature demonstrates that there has not been a vast push to create amalgams particularly intended for use as composite matricies rather MMCs have to a great extent made utilization of business compounds that were not initially intended for this reason [60, 61].

2.4 Selection of Reinforcement Material

Material Zircon s and comprises of for the most part Zirconium Di-oxide ($ZrO2$) and some hafnium notwithstanding some uncommon earth components, titanium minerals, and monazite. The Zircon sand is utilized for facing up on foundry molds to expand the resistance against metal infiltration.

Zircon sand was observed to be a promising applicant as reinforcement material for aluminum, zinc, and lead composites Zircon s and has high hardness and high modulus and high corrosive erosion resistance and fantastic warm steadiness likewise high temperature resistance. Zircon reinforced composite showed high resistance to wear in comparison to the alumina reinforced composite [62, 63].

The dispersion of the brittle Zirconium Di-oxide form in the pliable base alloy prompted increase in quality and hardness values. These outcomes had demonstrated that, increases of $ZrO2_4$ particles to Al-4.5 % Cu grid compound enhanced properties. From the result of the investigation in this research work it could be concluded that addition of $ZrO2$ particles using Al-4.5%Cu alloy increased both the strength and hardness and an overall reduction in toughness and density. Accession of 5% Zircon into aluminum, 65.9% and 52% increment in the hardness and rigidity have been seen [64, 65].

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Zircon was observed to be a promising material because of its high hardness, high modulus of versatility and great warm soundness. Superb warm soundness is vital since manufacture processes experience gigantic changes in temperature and expansive volumetric changes because of phase change can bring about debonding at the interfaces [66].

Al 12% silicon alloy was reinforced with different percentages of Zircon in particulate form and was tested for heat transfer under different solidification rates. The results demonstrate that the reinforcement influences warmth transfer in composites [67].

2.5 Mechanical and Wear Properties

The Tensile strength of Zircon particles and TiB_2 reinforced Al-A356.1 alloy matrix composites that the mechanical properties and microstructure behavior of composites have improved compared to monolithic alloy Microstructures of the composites in as-cast conditions show uniform appropriation particles and uncover better holding on account of zircon fortified composite contrast with TiB_2, however expanding the measure of reinforcement shows better conditions on account of TiB_2 strengthened composite. It is found out that TiB_2 strengthened composites have a superior wetting condition contrast with zircon fortified composites [68].

The accession of ZrO2particles utilizing Al 2124 compound expanded both the quality and hardness with a general diminishment in durability. The yielding and UTS improved with increment in % ZrO2 expansion up to 15% ZrO2 expansion then diminished to 25% ZrO2 expansion.The highest strength observed at the15% ZrO2 addition was attributed to a more uniform distribution of the reinforcement while above 15% ZrO2 segregation of the particles along the grain boundary grew high, resulting to a decrease in the bonding strength along the grain boundary. The impact imperativeness and rate extending lessened with extension in the rate of ZrO2.The hardness of the MMC's grows straightly with the volume division of ZrO2 particulates in the mix system due to the growing amalgam. Zircon (ZrO2), conversely, is a hard ceramic material, the hardness of which is somewhere around 7 and 8 Mohr's [69-71].

When aluminum was reinforced from to 1- 6% of Zircon particulates, it was observed that UTS of the composite reached a peak value at 5% by weight of Zircon content .Study on Al 12% silicon alloy reinforcement zircon made particulate composites shows marked variation in the mechanical properties, with increase in contents of particulates.9% zircon has exhibited excellent mechanical properties.wear attributes of alumina and zircon sand strengthened MMCs reported that reduction in size of particles provides resistance to wear. Moreover, the zircon fortified composite indicated high imperviousness to wear in contrast with the alumina strengthened composite [72-74].Al composite provides higher wear resistance than base amalgams in all tribo-conditions.

If there should be an occurrence of high stress rough wear, the change is noted to be more at low load and better grating size.At higher loads, the composite shows essentially same wear rate to that of base alloy. Wear rate increments with increment in load.Further, frictional heating and coefficient of friction are noted to be considerably less in composite as compared to that in the alloy [75].

2.6 Microstructure Characterization

A study on the Structure and Mechanical Properties of an Aluminium A356 Alloy base composite With Al_2O_3 particle additions and concluded that the compo casting process led to a transformation of a dendritic to a non dendritic structure of the base alloyA decent scattering of strengthener particles in the base amalgam is accomplished. Distortion characteristic was clarified as far as SEM perceptions of the cracked surfaces of elastic and fatigue samples and the worn out surfaces.Plastic disfigurement was distinguished as the primary wear component working on the worn surfaces of the composites that is researched [76-78].The SEM analysis showed that there are three toughening mechanisms in the composite of Al356/Al_2O_3 like crack bridging, crack deflection and crack branching. High cooling has brought about the arrangement of diminished dendrites and along these lines the particles have been consistently dispersed.A better microstructure dependably compares to higher impact quality [79-81].

2.7 Summary of Literature Survey

The literature survey is carried out to have an insight in to research work done in the domain area of the present work undertaken and to establish the gap in the literature related to Al356 alloy/ ZrO_2 particulate composite.
The literature survey has been carried out for over a period of thirty years, following are the high lights of the literature survey.

- ❖ Among several series of aluminium alloys, A356 is one of the most extensively used alloys for its excellent properties. Basically, A356 is an alloy of Aluminium, Magnesium and Silicon, which is highly resistant to corrosion and exhibit moderate strength [1].
- ❖ Al356 reveals increase in hardness and decrease of ductility with increasing silicon carbide particles [2].

- Zircon particles can be uniformly dispersed in Al-4.5 wt.% Cu alloy by stir casting route and abrasive wear resistance of the composites increases with increasing amount of particle and decreasing particle size [3].
- In the study on Properties of Al6063 MMC Reinforced with Zircon Sand and Alumina. The results reveals that the hybrid reinforced composites have the property improvement better than Zircon sand and Alumina particles alone reinforced composites [4].
- In the comparative study on Hardness and Tensile Strength of Zircon Particles and TiB_2 Reinforced Al-A356 Alloy Matrix Composites that the mechanical properties and microstructure behaviour of composites have improved compared to monolithic alloy. Microstructures of the composites show uniform distribution particles and reveal better bonding in the case of zircon reinforced composite compare to TiB_2, but increasing the amount of reinforcement shows better conditions in the case of TiB_2 reinforced composite [5].
- Higher percentage of zircondioxide in the composites causes particle agglomeration, hence stir casting is a better option. In stir casting the particles are often tends to form agglomerates, which can be only dissolved by vigorous stirring at high temperature [6].
- wear resistance of the composites increases with increase in reinforcement of zircon sand. The wear rates of both the alloy and composite increased with increase in applied load [7].
- Zircon particles of different size and amount have been incorporated in Al- 4.5 wt.% Cu alloy by stir casting route. The matrix of the composites has cellular structure, where the size of the cell depends on zircon particle size and its amount in the composite. The abrasive wear resistance of the composite improves with the increase in amount or decrease in size of zircon particles [8].
- The addition of ZrO_2 particles using Al 2124 alloy increased both the strength and hardness with an overall reduction in toughness. The impact energy and percentage elongation decreased with increase in the percentage of ZrO_2.
- The hardness of the MMC’s increases more or less linearly with the volume fraction of Sic particulates in the alloy matrix due to the increasing ceramic phase of the matrix alloy. Zircon dioxide (ZrO_2), in contrast, is a very hard ceramic material, the hardness of which is between 7 and 8 Mohr’s [9]

3. SCOPE OF THE RESEARCH WORK AND OBJECTIVES

3.1 Scope of the Present Investigation

The remarkable blend of properties and qualities of aluminum and expanding investigation in methods of handling and application frames the premise for expanding utilization of Al in more current fields and has carried it into rivalry with other designing materials. Critical among its preferences are its daintiness consolidated with high quality to weight proportion, imperviousness to erosion, weathering and other substance assaults, high electrical and warm conductivity, great reflectivity to light and great surface ability of being done in mixed bag of hues and compositions.

There are numerous explanations behind Al to be utilized as a part of commercial enterprises, vehicles businesses, residential commercial ventures, and so on. inspite of the fact that the properties of these combinations still miss the mark regarding the standard important to empower them to perform the troublesome errand for which they were planned. The Al composites have a wide mixture of great properties, for example, a great imperviousness to consumption, low thickness, generally high quality, delicacy consolidated with high quality to weight proportion, high electrical and warm conductivity. Al mixes have been being utilized as a part of business undertakings for quite a while. They can be a successful matrix to MMCs with particulate scatterings. Another territory of productive exploration exists wherein a careful examination can be made in regards to the likelihood of utilizing Zirconium di-oxide (ZrO_2) as dispersoid with Al compound as base metal to get a viable composite material. It is imperative to note that, not much work has been carried out on ZrO_2 as reinforcement.

Keeping in mind the end goal to make an aggressive quality-cost proportion in MMCs for Automotive applications it is very important to accomplish high strength, which relies upon making the micro mechanical properties obviously high. On the other hand, if the selected reinforcement Zirconium di-oxide is capable of providing some strengthening due to its excellent mechanical properties when compared with the matrix alloy and an adequate level of interfacial bonding, the tensile strength of the MMCs will be influenced by load transfer from soft matrix to the rigid ceramic particulate reinforcement.

The present work focuses on the preparation and property evaluation of a newly developed metal matrix composite with Al356 alloy as the matrix material and Zirconium di-oxide as the additive reinforcement. ZrO2 has been utilized seldom as a strengthening material. From the literature overview we have comprehended that by the expansion of artistic particulate support to Al compounds, tensile, compression strength hardness, wear and they were bettered.

In the present investigation, Al356-Zirconium dioxide composites were prepared and studied:

1. The Composites were developed by using electrical furnace for different weight percentage of reinforcement (ZrO2) viz 2,4, 6 and8 wt. %.
2. To assess the composite materials and additionally the base ally aluminum combination Al356, to ascertain the different Mechanical properties like the hardness, UTS and Compression strength.
3. A good knowledge of the various characteristics like Hardness, Ultimate Tensile Strength, impact, Wear and Fracture Toughness characteristics makes us aware of the several problems encountered in actual service conditions and explore the various possibilities of using the composite material in automobile applications. The expressions used, characteristics graphs, elaborate information about test conditions, testing machines and sources are shown in report.
4. Microstructure was studied by utilizing optical microscope to know the impact of ZrO_2 addition to base alloy.
5. SEM was used to examine the fractured specimens for understanding interfacial bonding between the base alloy and reinforcement.
6. Wear load and sliding distance effect on mild wear transition in dry sliding of Al356-ZrO_2 particulate composites. Pin-on-disc apparatus was used to assess wear rate.

3.2 OBJECTIVE

The Tensile and Compression strength were correlated experimentally and by FEA. The following are the Research objectives of the work:

- Development of Al356/ ZrO_2 Composite Castings
- Cryotreatment of developed composites
- Characterizations of
    1. Microstructure Analysis
    2. Mechanical Properties:
        a. Tensile strength
        b. Compression strength
        c. Hardness and

4. Composite Preparation

4.1 FABRICATION OF COMPOSITES

- Al356 alloy is chosen as the matrix

- ZrO_2 was chosen as reinforcement for producing the castings of Composites

Fig 1. Aluminium Al356 ingots

Fig 2 .ZrO_2

4.2 ALUMINIUM A356

Overview

A356 aluminium casting alloy is a 7% Si, 0.3% Mg alloy with 0.2 Fe (max) and 0.10 Zn (max). A356 aluminium casting alloy has very good casting and machining characteristics. A356 aluminium casting alloy is used for aircraft parts, pump housings, impellers, high velocity blowers and structural castings where high strength is required. A356 aluminium casting alloy can also be used as a substitute for aluminium alloy 6061. It is typically used in the heat-treated condition of T5 and T6 hardness properties.

A356 aluminium casting alloy has good castability, this makes it a logical choice for intricate and complex castings where lightweight, pressure tightness and excellent mechanical properties are needed.

1. Chemical composition

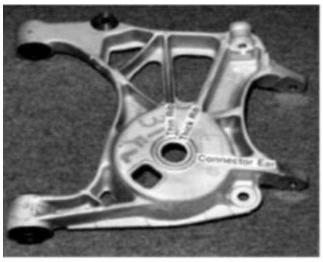
Alloy	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Pb	Al
Al356	7.5	0.2	0.25	0.35	0.45	0.1	0.35	0.2	0.1	remaining

2. PROPERTIES OF A356 & ZrO_2

PROPERTIES	Al356	ZrO2
Density (Kg/m^3)	2.685	3.9
Ultimate Tensile Strength (MPa)	230	290
Thermal Conductivity (W/m-K)	155	3.5
Melting Temperature (^{O}C)	615	1650
Co-efficient of Thermal Expansion (µm/m-K)	21.5×10^{-6}	7.2×10^{-6}
Hardness(BHN)	75	186

3. Application

- ❖ A356 based metal matrix composites utilized widely in aircraft engines, air frames and landing wheels.
- ❖ A356 alloys are usually used for aircraft applications due to their improved corrosion and creep resistance.
- ❖ High specific strength and rigidity coupled with ease of fabrication are important for missile and space applications.
- ❖ Automobile industries are the latest beneficiary of A356 alloy, currently exploring its maximum usage.
- ❖ Typical uses, aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water-cooled cylinder blocks.
- ❖ Other applications, where excellent castability and good weldability, pressure tightness, and good resistance to corrosion are required, aircraft structures and engine controls, nuclear energy installations, and other applications where high-strength permanent mould or investment castings are required.



Upper & Lower Suspension Control Arms

Automotive Wheels

Rear knuckles

Automotive Transmission Cases

Truck Chassis Parts

4.3 ZIRCONIUM DI-OXIDE (ZrO_2)

4.3.1 OVERVIEW

Zirconium dioxide, also known as zirconia and zirconium oxide, is a crystalline metal oxide that has found its way into the ceramics industry. It is characterized by its high thermal resistivity, mechanical resistance, and abrasive properties.

- Properties of Zirconia

Zirconia's exceptional strength, toughness, biocompatibility, high fatigue and wear resistance render it optimal for dental applications. Zirconium (Zr), in particular, is in fact one of the two most commonly used metals in dental implants, alongside titanium, as they both show very good physical and chemical properties and they allow the growth of osteoblasts, the cells that actually form bones. Here's a list of zirconia's most prominent physical and chemical properties. Notice how these properties are high enough to allow zirconia to be an effective material for many applications, especially for refractory and dentistry purposes.

1. **High mechanical resistance**

Zirconium dioxide is highly resistant to cracking (including further development of cracks) and mechanical stress. Other outstanding mechanical properties of zirconia are shown in the table below:

PROPERTIES OF ZIRCONIUM DI-OXIDE	
Mechanical properties	**Values for ZrO_2**
Elastic modulus	100 – 250 GPa at 20ºC
Flexural strength	180 – 1000 MPa at 20ºC
Tensile strength	330 MPa at 20ºC
Fracture toughness	10 MPa·√m at 20 °C
Hardness, Vickers	1220
Hardness, Mohs	8 – 8.5

2. Application Of Zirconium Di-Oxide

Zirconia's high mechanical properties, chemical inertness, high-temperature stability, corrosion resistance, and high quality have put this ceramic steel on the radar in many industries and application areas. Many products of today, ranging from refractory to medical products, pigments, electronics, coatings, and ceramics, have been based on zirconia due to its superior characteristics and advantages as compared to other materials. Some of the typical applications of zirconia include dies for hot metal extrusion, oxygen sensors, membranes in fuel cells, deep well valve seats, and marine pump seals. Here is a list of some of zirconia's most common applications areas and uses.

- Ceramics

The mechanical strength and resistance of zirconium dioxide makes it a suitable component for ceramic manufacturing. This includes ceramic knives, which are noticeably tougher than steel-edged cutlery due to the high hardness factor of zirconia.

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- Refractory purposes

Due to its high thermal resistance, zirconium dioxide is used as a component in crucibles, furnaces, and other high-heat environments. In addition, zirconium dioxide boosts the fireproof properties of ceramics. Refractory bricks and armour plates are examples of zirconia-based refractory applications. Furthermore, when added to melted quartz, zirconia can be used to produce siloxide glass, a harder and more stress resistant glass than quartz opaque glass Zirconia can also be added to aluminium oxide to be used in components for steel casting process.

- Thermal barrier coating (TBC)

Zirconium dioxide is applied as a coating for jet engine components which are exposed to high temperatures. This is made possible through the compound's low thermal conductivity and high heat resistance. Studies have confirmed the effectiveness of zirconium dioxide for TBC applications, as long as the material is applied properly and uniformly.

- Scratch resistant and abrasive material

With its elevated mechanical stability and abrasion resistance, zirconia is being used as an abrasive material. It is also useful as a protective layer for mechanical parts, due to the compound's resistance to scratches and mechanical stress.

- Oxygen-rich systems

While other materials may experience oxidation and compromise its integrity, zirconium dioxide is stable in the presence of oxygen. In fact, it is being used in fuel cell membranes and oxygen sensing mechanisms even at elevated temperatures.

4.4 METHODOLOGY

STEPS INVOLVED TO DEVELOP CASTINGS Of Al356 –ZrO_2COMPOSITES

- ❖ The matrix alloy Al356 is heated in the electric resistance furnace to a temperature of 720^0C.
- ❖ Scum powder is added to the molten metal in order to promote slag formation and slag formed is subsequently removed from the melt.
- ❖ Degasification is carried out by adding Hexachloroethane tablets to the melt and the temperature is kept at 730^0C.
- ❖ Stirrer is engaged and made to rotate at a speed of 300 rpm to create a vortex in the liquid metal.
- ❖ Preheated (400^0C) Reinforcement material ZrO_2 was added to molten metal .
- ❖ After 15 min of stirring, the molten metal is poured to the pre-heated metal mould (350^0C)and left for solidification.
- ❖ Composites are developed for four different weight percentage of reinforcement (ZrO2) viz 2, 4, 6 and 8wt %.

4.5 Composites preparation

The microstructure of any material relies upon the intricate capacity of the casting procedure which involves various processing parameters such as speed of stirrer, processing temperature, pouring speed, mould temperature, reinforcement feed rate.

Along these lines of development of composites is considered as most difficult and troublesome work. Hence stir casting method is used to make Al356-$ZrO2_4$ MMC'S.

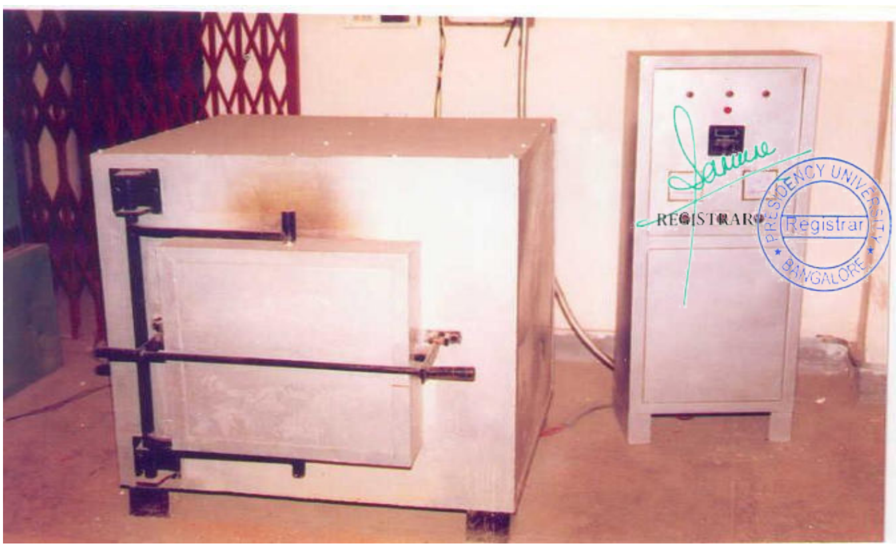
4.5.1 Composite Preparation Furnace

The fabrication was done in a three-stage resistance sort 12 KW limit furnace as shown in Fig.4.1.The maximum temperature of the furnace is 1200^0 C with a precision of 10^0 C fitted with seven segmented light emitting diode read out and partially integrated differential digital temperature controller.It is fitted with an alumina melting pot at its inside and it can be angled by 90^0 on its orientation axis empowering pouring of the melt.

Fig 4.1: Electrical Resistance Furnace for Melting Al356

4.5.2 Preheating of Reinforcement

Muffle furnace shown in Fig. 4.2 was used to preheat the $ZrO2_4$ particulate (44 microns) to a maximum temperature of 400°C and the time period for preheating is about 1 hour. The preheating of the reinforcement is vital with a specific end goal to decrease the temperature slope and to enhance wetting between the liquid metal and the particulate support.



1.1 Fig 4.2 Preheating furnace

4.5.3 Melting of the Base Alloy

The liquefying temperature of Al356 composite is 550-620^{0}C. A known amount of the Al356 ingots were cured in 10% NaOH arrangement at room temperature for ten minutes. Surface taints were taken off by pickling. The filth framed was cleared by submerging the ingots for few seconds in a blend of one section Nitric acid and one section water, and then washed in methanol. Pickled ingots were dried and placed into the crucible for melting purpose.Melt was super warmed to a temperature of 720^0 C.Temperatures were recorded using thermocouple.

Fig 4.3: Hot Molten Metal in Furnace

Fig 4.4: Adding Scum Powder

Fig 4.5: Slag Formation

Fig 4.6: Slag Removal

Fig 4.7: Formation of Vortex

Fig 4.8: Mixing Reinforcement Material and stirring

Fig 4.9: Pre heating the mould box

Fig 4.10 pouring the molten metal into mould

Fig 4.10: Castings obtained from mould

4.5.4 Casting of Composite

The Molten metal was heated to red hot condition and was continuously stirred using a graphite impeller to create a vortex. Vortex was created in the molten metal due to high speed of the stirrer, the speed was around 500rpm.The graphite rod was immersed to a depth of approximately one third the height of the molten metal from the bottom of the crucibleThe pre-heated reinforcement particles were introduced into melt.

The wetting of the particles and the matrix was ensured by constant stirring which was carried out for more than 20 minutes to avoid agglomeration [107]. The scum powder was used as slag removing agent and degassing tablet HexaChloroethene [108] was added to completely remove any gases in the molten metal and continued reheating to a super heated temperature (730°C), then it was poured into the pre heated metal mould to reduce the porosity and enhance the mechanical properties [109], and finally the castings were obtained as shown in Fig. 4.10.

Precautionary Measures and Confinements

- The maximum temperature was maintained around 720^0C, above which it gets supersaturated and aluminum fumes start emanating from the molten metal beyond 750^0 C.
- Due to density differences lot of care was taken in blending the reinforcement with the matrix with continuous stirring and then pouring the melt into the moulds.

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Composites greater than 10 wt % reinforcement could not be prepared due to rejection of the melt at the mixing stage

4.5.6 Cryogenic treatment OF METAL MATRIX COMPOSITE ($Al356-ZrO_2$)

Cryogenic treatment is the ultra-low temperature of about – 196°C, processing of AlZrO2 to enhance their desired metallurgical and mechanical properties. Ultra-cold temperatures are achieved using computer controls, a well-insulated treatment chamber and liquid nitrogen (LN_2). This process is completely eco- friendly and actually help reduce waste.

The entire process takes between 10 to 40 hours, depending on the weight and type of material being treated. The process is not just a surface treatment but it affects the entire mass of the tool or component being treated, making it stronger throughout. The hardness of the material treated is unaffected, while its strength is increased.

Other benefits of this process include:

- Reduced maintenance, repairs and replacement of tools and components
- Reduced vibrations
- Rapid and uniform heat dissipation
- Improved conductivity

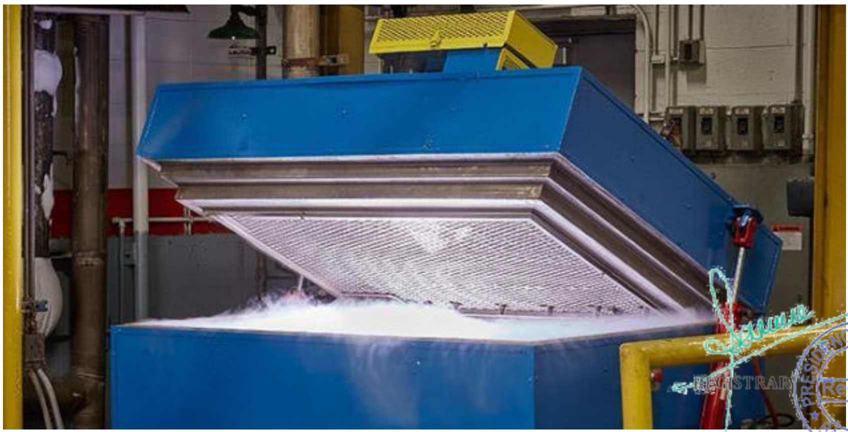


Fig.4.5.6 Cryogenic furnace

Fig . 4.5.6 Specimens Ready for testing after Cryogenic Treatment

Fig1 Cryogenation for 10 hrs

Fig 2 Cryogenation for 30 hrs

Fig 3 . Cryogenation for 40 hrs

5. Experimental Studies

5.1 Objectives

The objective of the present work is to evaluate the mechanical properties, microstructure studies XRD and fracture toughness of ZrO_2 reinforced Al 356 metal matrix composite. Fractured specimens were subjected to SEM examination, furthermore wear test was carried to comprehend wear rate.

5.2 Specimen Preparation for Microstructure Studies

Specimens for microscopic study were developed as per ASTM E3 norms. Sample were initially grinded & polished and then etched.

5.2.1 Grinding and Polishing

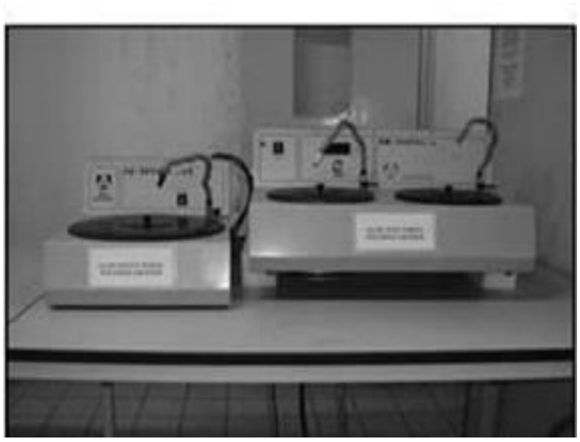


Fig 5.1 Polishing Machine

ZrO2 grit paper(100-1200 grit size) was used to polish the specimens.The samples were held close by and rubbed easily against the ZrO2 papers, practicing adequate consideration to maintain a strategic distance from any profound scratches, because Al is very soft. Fine polishing was performed using MgO_2 glue, followed by diamond glue (1µm thin) using polishing machine shown in Fig 5.1. Billiard cloth was used to cover platform. During fine polishing with magnesium oxide paste, hands as well as the specimens were washed with water in between to prevent carryover of coarser grit from previous steps. Alcohol was employed to clean specimens & they were dried in air.

5.2.2 Etching

A solution of 200 grams of Chromic acid (CrH_2O_4) & 15 grams of Sodium Sulphate (Na_2SO_4) & 1 liter of H_2O was utilized as etchant. To avoid staining after etching, specimens were washed with plenty of H_2O for 5 seconds & dried in air.

5.2.3 Optical microscopy

Fig 5.2 Optical Microscope (Nikon)

Fig 5.3 Specimens prepared for Microstructure studies

Optical micrographs were taken using the Nikon Microscope LV150 with Clemex Image Analyzer (reflection type), fitted with a camera Fig 5.2. Specimens for microstruture studies were cut from castings to a size of approximately 10 mm diameter and 15 mm height Fig 5.3. They were polished on a series of silicon carbide emery papers from 150 grade to 600 grade and finally on sylvet cloth using fine alumina powder as abrasive A computer integrated metallurgical microscope was used for microstruture studies of the specimens. Metallurgical microscope was employed to take micrographs. The magnification used was from 50X to 500X.

5.3 Specimen Preparation for Mechanical Characterization

Specimens of the required dimensions were machined from the prepared castings and usually the middle portion of the castings was selected for this purpose. All specimens were polished for smooth surface finish with different grits of ZrO2 carbide papers except those required for microscopic examination, which required further polishing. Attributes of specimens prepared for different testings are given below:

SL. No	Type of test	Specimen dimension
1.	Tensile test	Diameter 12.5mmand gauge length 65mm
2.	Compression properties	20 mm diameter and 20 mm length
3.	Wear tests	10mm diameter and 25 mm length
4.	XRD studies & SEM (EDS)analysis	5mm x 5mm x 1mm

5.3.1 Tensile Test

Mechanical tests were carried out as per ASTM norms. UTM was used carry out tensile test shown Fig 5.4 (ASTM E8-13a). Tensile specimen's Fig 5.5 of diameter 12.5mm and gauge length 65mm were prepared from castings.

Fig 5.6 Universal Testing Machine

Fig 5.7 Tensile Test Specimens

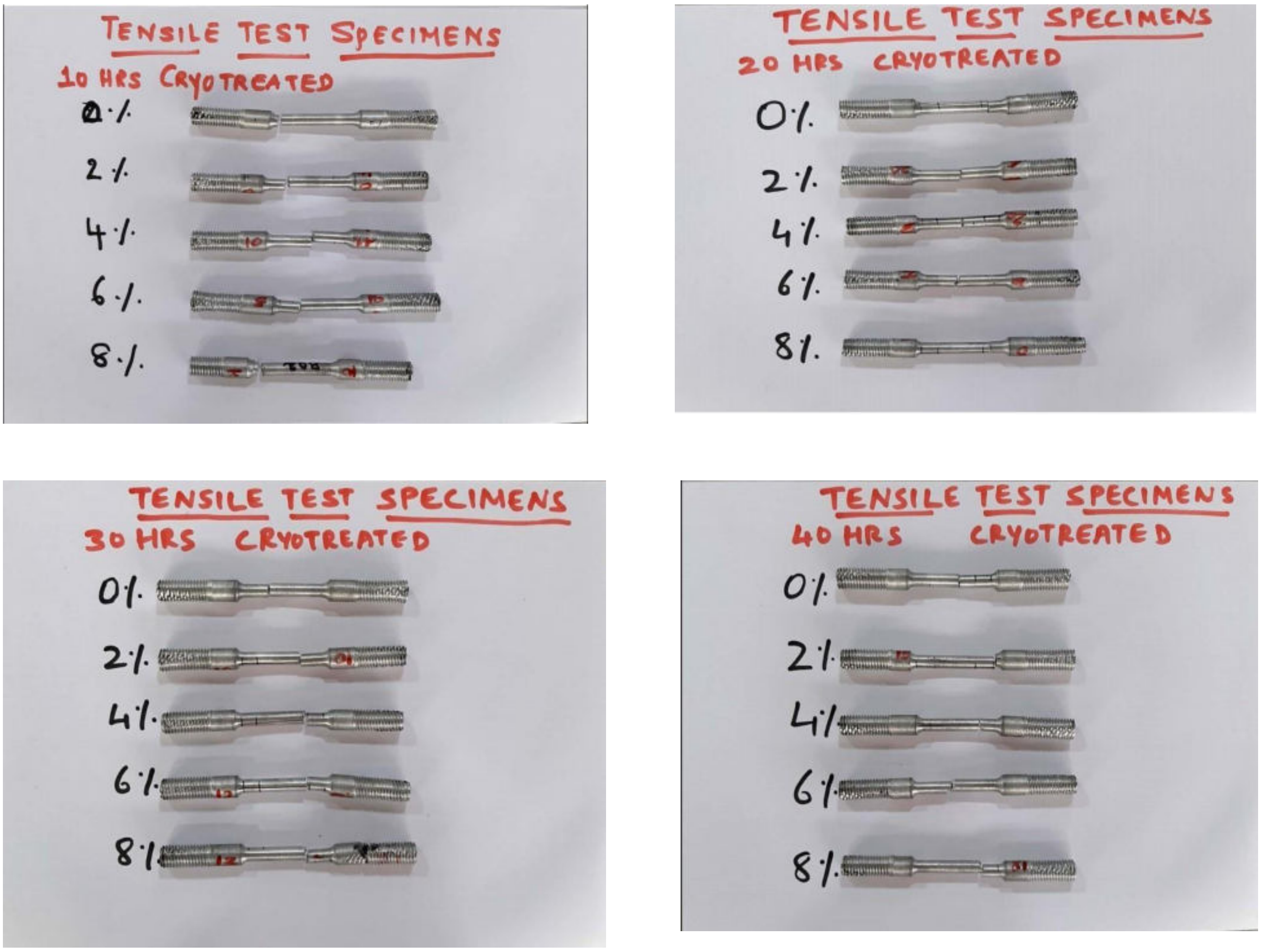


Fig .5.3.1 Tensile test specimens for 10,20,30,40 hours of cryogenation

5.3.2 Compression Test

The compression tests were conducted on specimens Fig 5.6 of 20 mm diameter and 20 mm length machined from the cast composites. Loads were imposed tardily & matching strains were assessed till failure of the specimen happened.

Fig 5.8 Compression Test Specimens

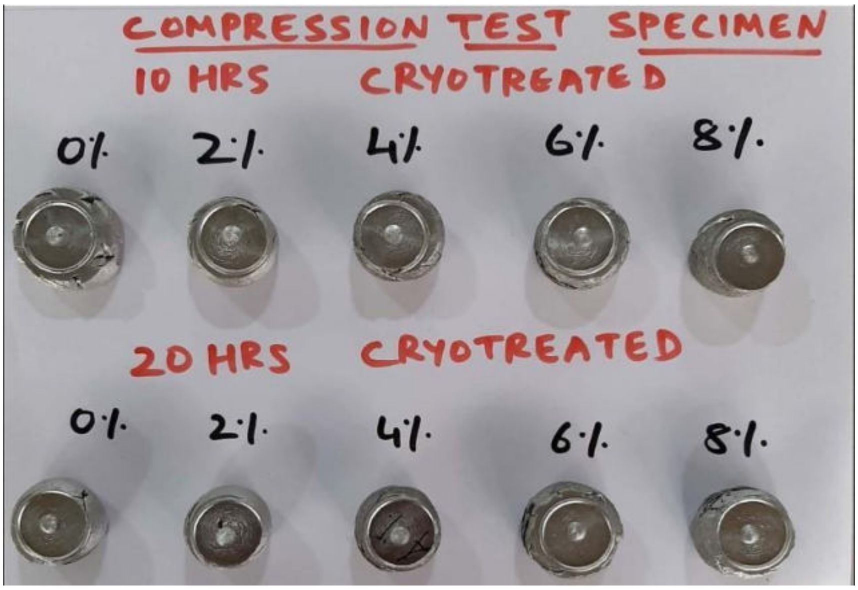


Fig 5.8 Compression Test Specimens

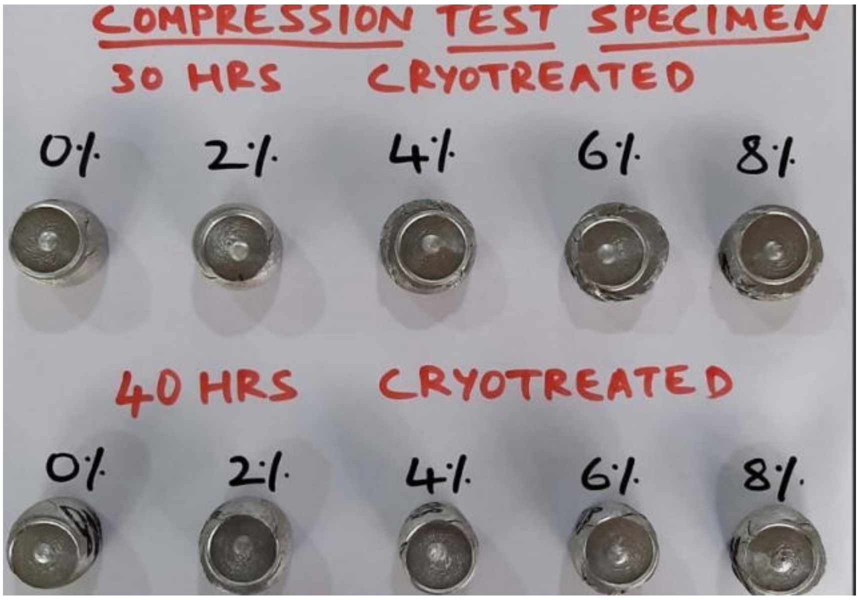
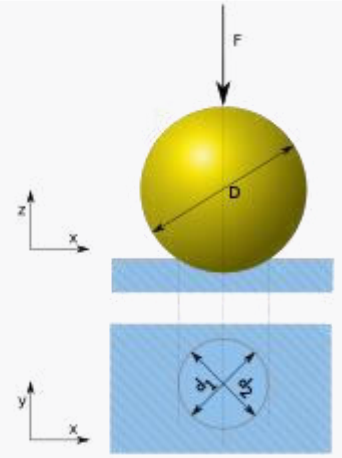


Fig 5.8 Compression Test Specimens

5.4 BRINELL HARDNESS TESTING

5.4.1 BRINELL SCALE



Force diagram

FIG.5.4.1 BRINELL INDENTATION

The **Brinell scale** characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in materials science.

Proposed by Swedish engineer Johan August Brinell in 1900, it was the first widely used and standardised hardness test in engineering and metallurgy. The large size of indentation and possible damage to test-piece limits its usefulness. However it also had the useful feature that the hardness value divided by two gave the approximate UTS in ksi for steels. This feature contributed to its early adoption over competing hardness tests.

The typical test uses a 10 mm (0.39 in) diameter steel ball as an indenter with a 3,000 kgf (29.42 kN; 6,614 lbf) force. For softer materials, a smaller force is used; for harder materials, a tungsten carbide ball is substituted for the steel ball. The indentation is measured and hardness calculated as:

$$\mathrm{BHN} = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

where:

BHN = Brinell Hardness Number (kgf/mm^2)

P **= applied load in kilogram-force (kgf)**

D **= diameter of indenter (mm)**

d **= diameter of indentation (mm)**

Fig 5.9 Brinell Hardness Testing Machine

Brinell hardness is sometimes quoted in megapascals; the Brinell hardness number is multiplied by the acceleration due to gravity, 9.80665 m/s^2, to convert it to megapascals.

The BHN can be converted into the **ultimate tensile strength (UTS),** although the relationship is dependent on the material, and therefore determined empirically. The relationship is based on Meyer's index (n) from Meyer's law. If Meyer's index is less than 2.2 then the ratio of UTS to BHN is 0.36. If Meyer's index is greater than 2.2, then the ratio increases.

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BHN is designated by the most commonly used test standards (ASTM E10-14 and ISO 6506–1:2005) as *HBW* (*H* from hardness, *B* from brinell and *W* from the material of the indenter, tungsten (wolfram) carbide).

In former standards HB or HBS were used to refer to measurements made with steel indenters.

HBW is calculated in both standards using the SI units as where:

F = **applied load (Newtons)**

D = **diameter of indenter (mm)**

d = **diameter of indentation (mm)**

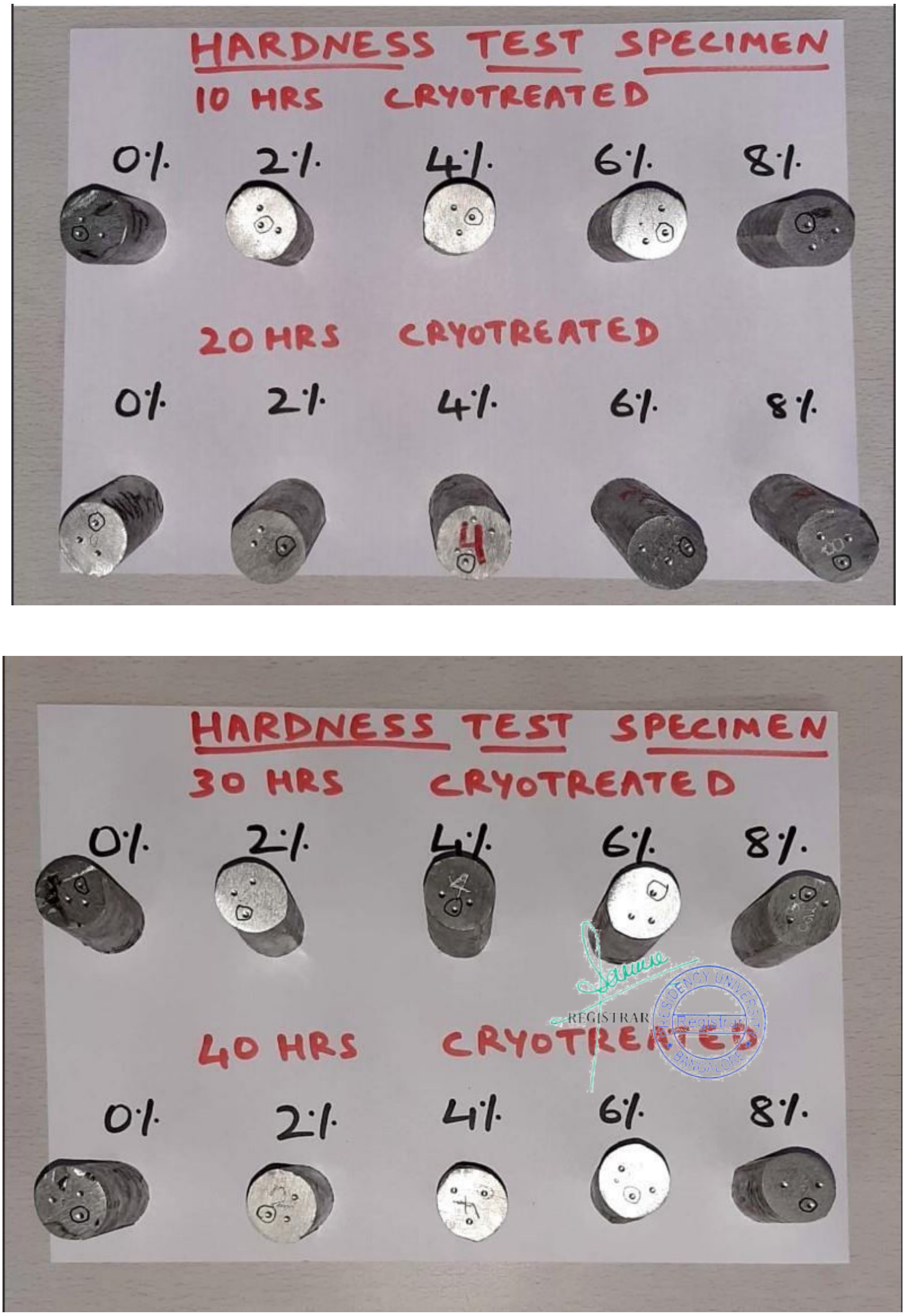

Fig 5.8 Hardness Test Specimens

5.5 SCANNING ELECTRON MICROSCOPE

5.5.1 Scanning Electron Microscopy (SEM)

FIG.5.5.1A TYPICAL SCANNING ELECTRON MICROSCOPE INSTRUMENT

A typical SEM instrument, showing the electron column, sample chamber, EDS detector, electronics console, and visual display monitors.

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties.

Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using EDS), crystalline structure, and crystal orientations (using EBSD). The design and function of the SEM is very similar to the EPMA and considerable overlap in capabilities exists between the two instruments.

5.5.2 Fundamental Principles of Scanning Electron Microscopy (SEM)

Accelerated electrons in an SEM carry significant amounts of kinetic energy, and this energy is dissipated as a variety of signals produced by electron-sample interactions when the incident electrons are decelerated in the solid sample. These signals include secondary electrons (that produce SEM images), back scattered electrons (BSE), diffracted backscattered electrons (EBSD that are used to determine crystal structures and orientations of minerals), photons (characteristic X-rays that are used for elemental analysis and continuum X-rays), visible light (cathodoluminescence--CL), and heat. Secondary electrons and backscattered electrons are commonly used for imaging samples: secondary electrons are most valuable for showing morphology and topography on samples and backscattered electrons are most valuable for illustrating contrasts in composition in multiphase samples (i.e. for rapid phase discrimination). X-ray generation is produced by inelastic collisions of the incident electrons with electrons in discrete ortitals (shells) of atoms in the sample. As the excited electrons return to lower energy states, they yield X-rays that are of a fixed wavelength (that is related to the difference in energy levels of electrons in different shells for a given element). Thus, characteristic X-rays are produced for each element in a mineral that is "excited" by the electron beam. SEM analysis is considered to be "non-destructive"; that is, x-rays generated by electron interactions do not lead to volume loss of the sample, so it is possible to analyze the same materials repeatedly.

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5.5.3 Scanning Electron Microscopy (SEM) Instrumentation

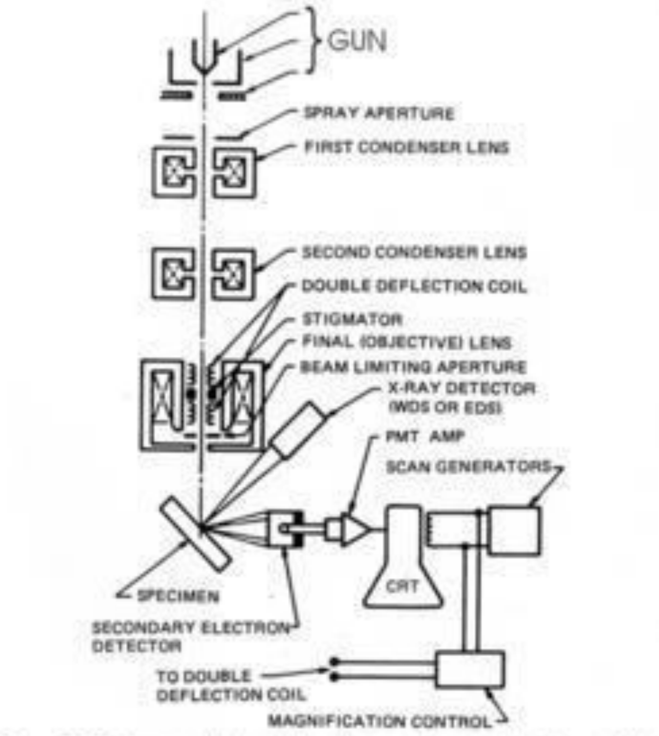


Figure 1.11. Schematic drawing of the electron and x-ray optics of a combined SEM–EPMA.

FIG.5.5.3SCHEMATIC DIAGRAM OF A TYPICAL SCANNING ELECTRON MICROSCOPE INSTRUMENT

5.5.4 Essential components of all SEMs include the following:

- **Electron Source ("Gun")**
- **Electron Lenses**
- **Sample Stage**
- **Detectors for all signals of interest**
- **Display / Data output devices**
- **Infrastructure Requirements**:
  - Power Supply
  - Vacuum System
  - Cooling system
  - Vibration-free floor

- Room free of ambient magnetic and electric fields

SEMs always have at least one detector (usually a secondary electron detector), and most have additional detectors. The specific capabilities of a particular instrument are critically dependent on which detectors it accommodates.

5.5.5 APPLICATIONS

The SEM is routinely used to generate high-resolution images of shapes of objects (SEI) and to show spatial variations in chemical compositions:

1. acquiring elemental maps or spot chemical analyses using EDS,
2. Discrimination of phases based on mean atomic number (commonly related to relative density) using BSE, and
3. Compositional maps based on differences in trace element "activitors" (typically transition metal and Rare Earth elements) using CL.

The SEM is also widely used to identify phases based on qualitative chemical analysis and/or crystalline structure. Precise measurement of very small features and objects down to 50 nm in size is also accomplished using the SEM. Back scattered electron images (BSE) can be used for rapid discrimination of phases in multiphase samples. SEMs equipped with diffracted backscattered electron detectors (EBSD) can be used to examine microfabric and crystallographic orientation in many materials.

5.6 Strengths and Limitations of Scanning Electron Microscopy

1. Strengths

There is arguably no other instrument with the breadth of applications in the study of solid materials that compares with the SEM. The SEM is critical in all fields that require characterization of solid materials. While this contribution is most concerned with geological applications, it is important to note that these applications are a very small subset of the scientific and industrial applications that exist for this instrumentation. Most SEM's are comparatively easy to operate, with user-friendly "intuitive" interfaces. Many applications require minimal sample preparation. For many applications, data acquisition is rapid (less than 5 minutes/image for SEI, BSE, spot EDS analyses.) Modern SEMs generate data in digital formats, which are highly portable.

2. Limitations

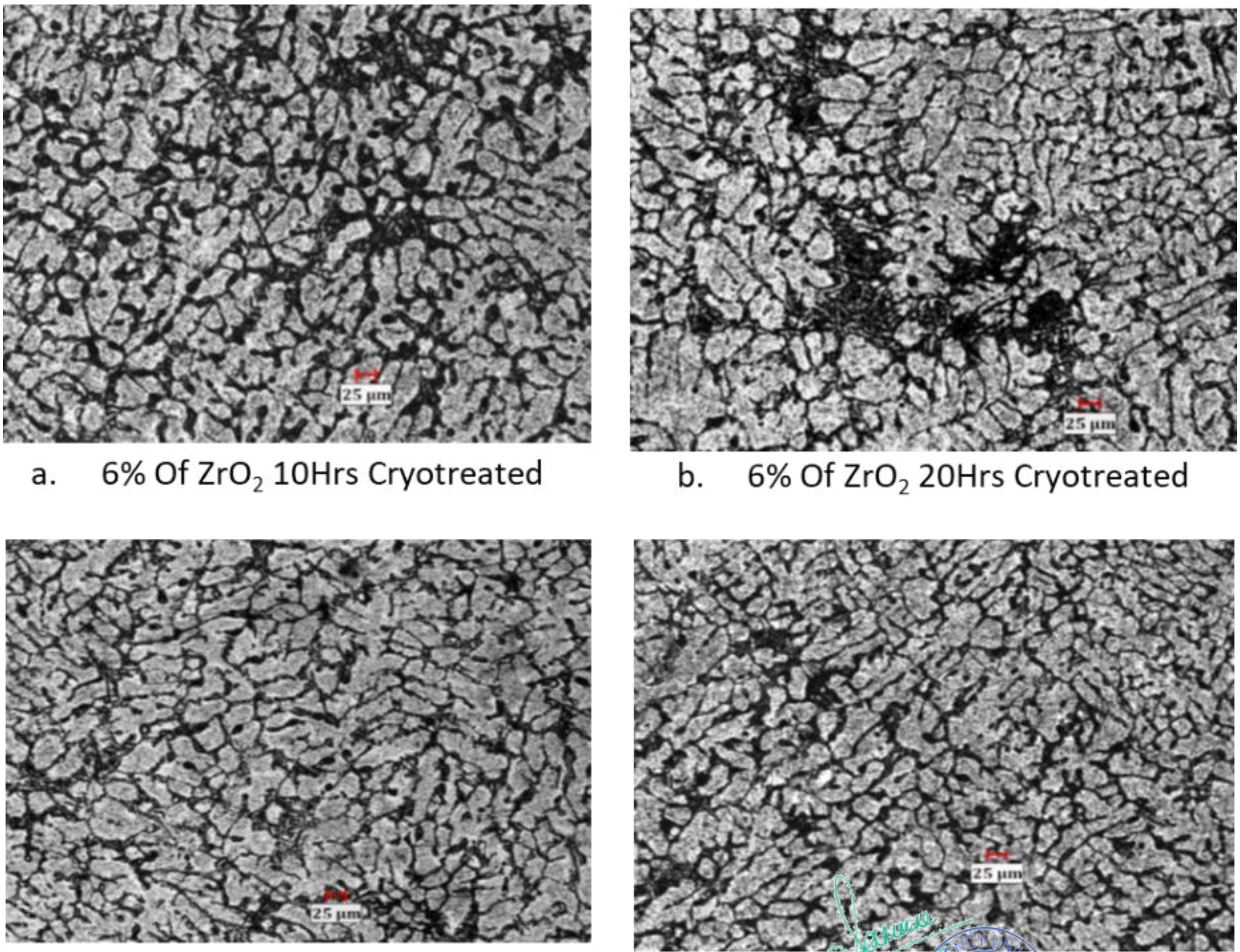
Samples must be solid and they must fit into the microscope chamber. Maximum size in horizontal dimensions is usually on the order of 10 cm, vertical dimensions are generally much more limited and rarely exceed 40 mm. For most instruments samples must be stable in a vacuum on the order of 10^{-5} - 10^{-6} torr. Samples likely to outgas at low pressures (rocks saturated with hydrocarbons, "wet" samples such as coal, organic materials or swelling clays, and samples likely to decrepitate at low pressure) are unsuitable for examination in conventional SEM's. However, "low vacuum" and "environmental" SEMs also exist, and many of these types of samples can be successfully examined in these specialized instruments. EDS detectors on SEM's cannot detect very light elements (H, He, and Li), and many instruments cannot detect elements with atomic numbers less than 11 (Na). Most SEMs use a solid state x-ray detector (EDS), and while these detectors are very fast and easy to utilize, they have relatively poor energy resolution and sensitivity to elements present in low abundances when compared to wavelength dispersive x-ray detectors (WDS) on most electron probe micro analyzers (EPMA). An electrically conductive coating must be applied to electrically insulating samples for study in conventional SEM's, unless the instrument is capable of operation in a low vacuum mode.

6. Results and Discussions

6.1 Microstructure of Al 356-ZrO_2Composites

6.1.1 Optical Micrographs

The micrographs of the specimens were analyzed by using Nikon Microscope LV150 with Clemex Image Analyzer with various magnifications (50X, 100X, 200X, 500X).



a. 6% Of ZrO_2 10Hrs Cryotreated
b. 6% Of ZrO_2 20Hrs Cryotreated
c. 6% Of ZrO_2 30Hrs Cryotreated
d. 6% Of ZrO_2 40Hrs Cryotreated

Fig 6.1(a-e) Micrographs of different % of Reinforcement

Fig.8.1 (a-e) shows the micrographs of the composite materials with varying wt % of reinforcement (2,4,6 and 8). Fig (a) comprises of fine eutectic silicon scattered in the inter dendritic area and fine precipitates of alloying components in the matrix of aluminum solid solution.Fig(c) to Fig (d) Depicts consistent dispersion of ceramic particles with better wettability for Al356-ZrO_2 MMC. Also, there is aggregation of particles in composites, Improper stirring might have lead bunch formation of reinforcement particles.

Length of dendrite structure appeared in Fig (a), decreases in Figs (b-d), which may due to reinforcement particles.Zirconium Di-Oxide particulates act like obstacle to development of dendritic structure.Eutectic silicon provinces across particles to a great extentaffirmed in micrographs. Eutectic silicon dispersion is more elegant and structure changed from needle shaped to spherical around the particles. Porosity is not dominant but cluster and segregation of particles are observed with higher reinforcements.

The microstructure for 6% reinforcement with Cryotreated for varying hours are shown ,30hrs of cryotreatment indicated uniform distribution of reinforcement particulates and due to which enhanced mechanical properties are seen.

6.2 Mechanical Properties

6.2.1.Tensile Test

The tensile specimens were prepared according to ASTM E8-82 standards and were subjected to homogeneous, uniaxial tensile stresses in a universal testing machine. The test values are tabulated in table

Experimental Results of Tensile Test

Sl no	TENSILE STRENGTH (N/mm²) FOR 0% ZrO2	TENSILE STRENGTH (N/mm²) FOR 2% ZrO2	TENSILE STRENGTH (N/mm²) FOR 4% ZrO2	TENSILE STRENGTH (N/mm²) FOR 6% ZrO2	TENSILE STRENGTH (N/mm²) FOR 8% ZrO2	HOURS
1	171.3	166	121.5	110.8	158	10
2	167.937	162.3	127.8	108.5	136	20
3	144.7	163.2	134.5	132.5	132.9	30
4	141	129.2	146.2	116	138.1	40

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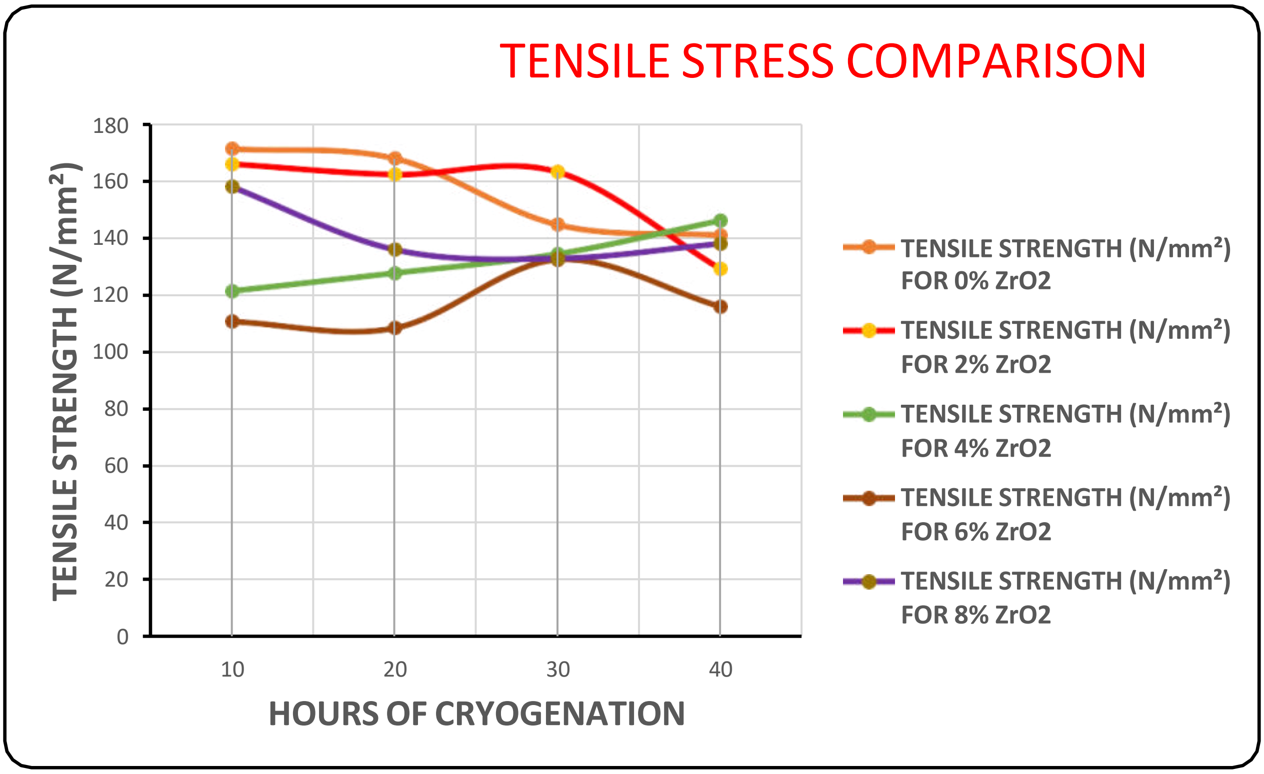

6.2.2 Compression Test

The compression specimens were prepared according to ASTM E9 describes the compression testing of metals such as steel or metal alloys. This test method determines important mechanical properties such as the yield strength, the yield point, Young's Modulus, the stress-strain curve, and the compressive strength

<u>Experimental Results of Compression Test</u>

Sl no	COMPRESSION TEST (N/mm²) 0% OF ZrO2	COMPRESSION TEST (N/mm²) 2% OF ZrO2	COMPRESSION TEST (N/mm²) 4% OF ZrO2	COMPRESSION TEST (N/mm²) 6% OF ZrO2	COMPRESSION TEST (N/mm²) 8% OF ZrO2	HOURS
1	541.507	515.662	540.172	543.674	541.079	10
2	482.304	474.091	501.593	516.647	533.042	20
3	501.911	504.84	526.931	618.461	523.429	30
4	498.346	475.11	448.117	450.918	479.184	40

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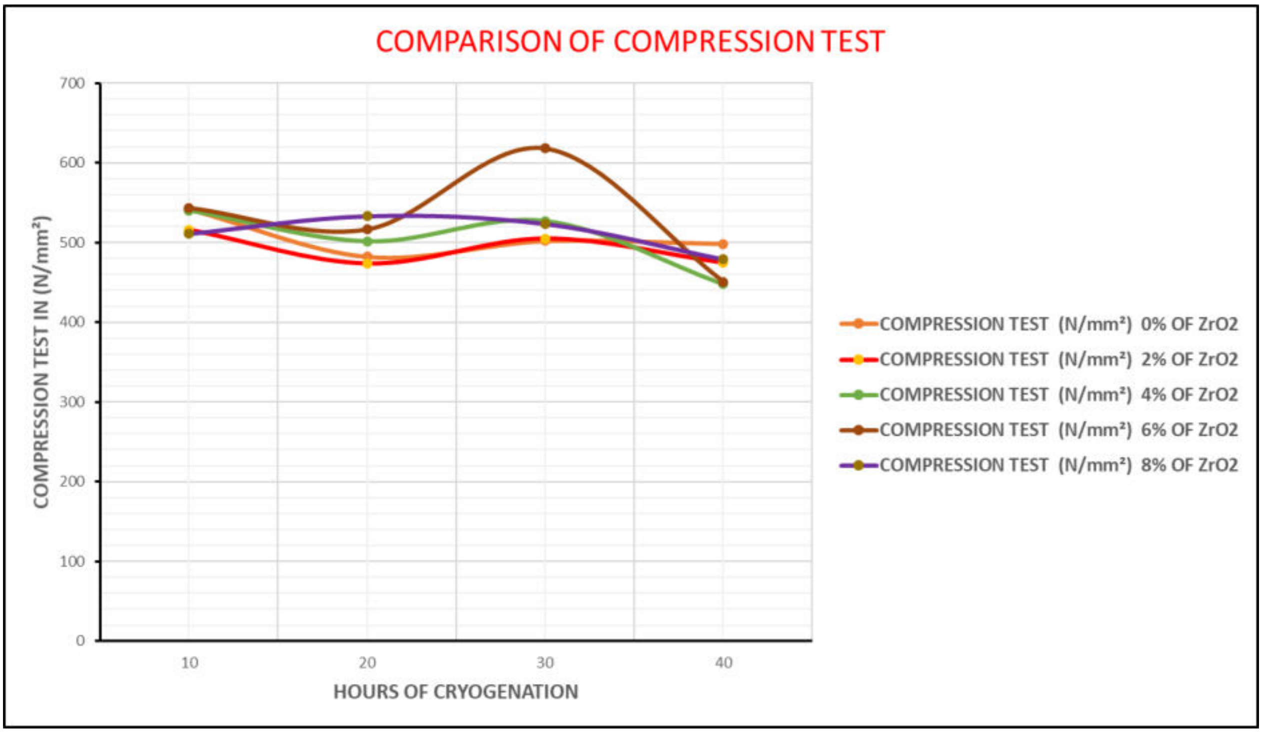


- There is an appreciable amount of increase in compression strength with increase reinforcement and hours of cryogenation.
- The ascast specimens exhibited a compression strength of 501.9 Mpa and specimen with 6 wt% and 30 hours of cryotreatment exhibited a highest compression strength of 618.46 Mpa.

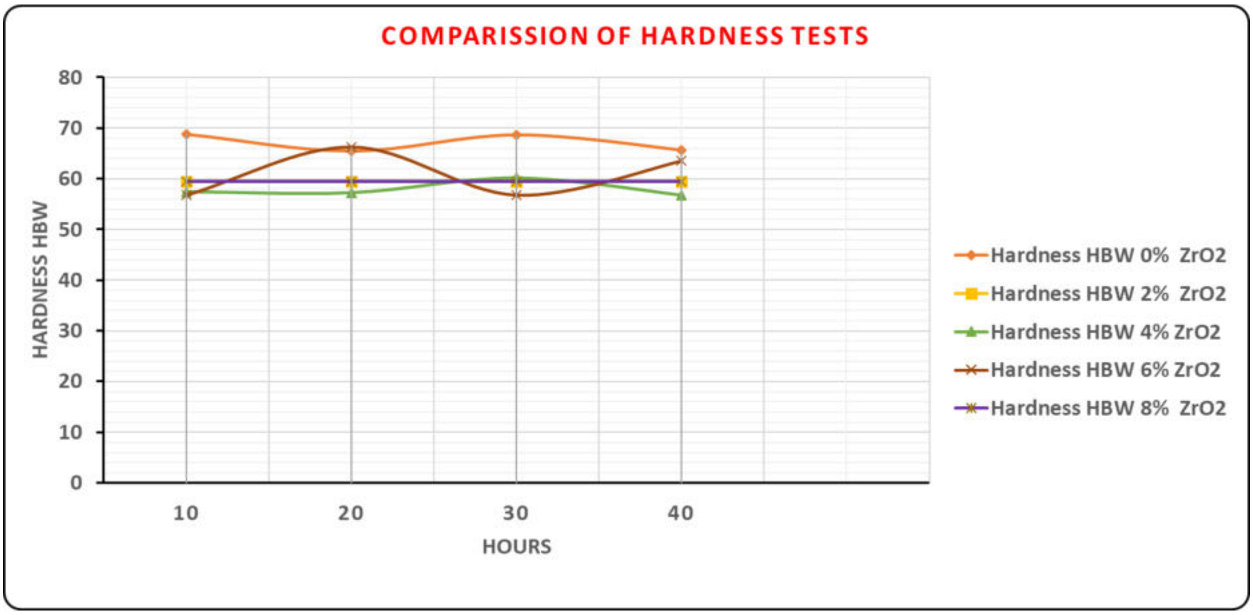
This increase in strength can be attributed to uniform distribution of reinforcement particles and grain refinement due to cryogenation

6.2.3. Hardness Test

The Brinell Test is an indentation hardness test consisting of two steps. Step one, the indenter is brought in contact with the tests specimen perpendicular to the surface and the specified test force is applied. The test force held for the specified time and then withdrawn. Step two, The diameter of the indentation is measured in at lest two directions perpendicular to each other. The Brinell hardness value is computed from the mean of the diameter measurements by the use of a mathematical formula designed for this purpose, or more frequently from a chart based on the formula

Experimental Results of Hardness Test

Sl no	Hardness HBW 0% ZrO2	Hardness HBW 2% ZrO2	Hardness HBW 4% ZrO2	Hardness HBW 6% ZrO2	Hardness HBW 8% ZrO2	HOURS
1	68.7	59.4	57.4	56.7	59.4	10
2	65.4	59.4	57.2	66.3	59.4	20
3	68.6	59.4	60.2	56.7	59.4	30
4	65.6	59.4	56.7	63.5	59.4	40



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- There is an appreciable amount of increase in Hardness with increase reinforcement and hours of cryogenation.
- The ascast specimens exhibited a harndess of 68 and specimen with 6 wt% and 30 hours of cryotreatment exhibited a highest compression strength of 63 Mpa.
- This decrease in hardness can be due to cluster formations.

6.3 Fracture Analysis using Scanning Electron Microscope

SEM studies have been carried out for fractured surfaces of Impact test specimen's using Hitachi SU-1500 with various magnifications 100X-20000X.

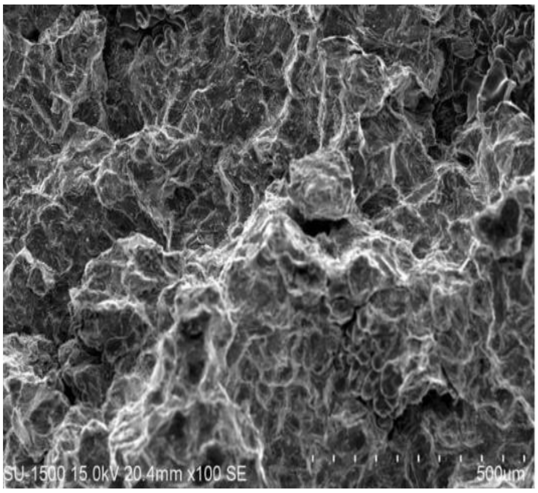

Fig (a) 0% Reinforcement 100X

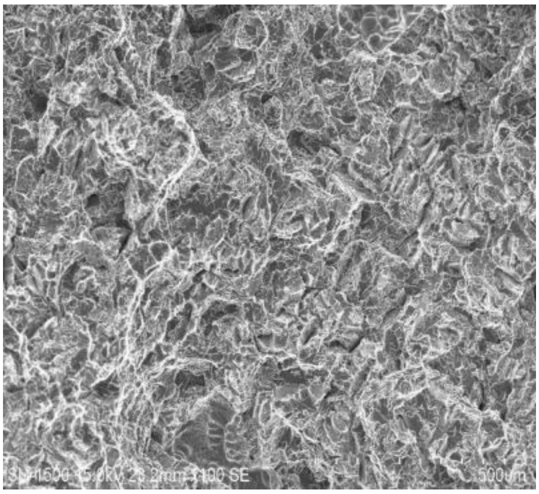

Fig (b) 2% Reinforcement 100X

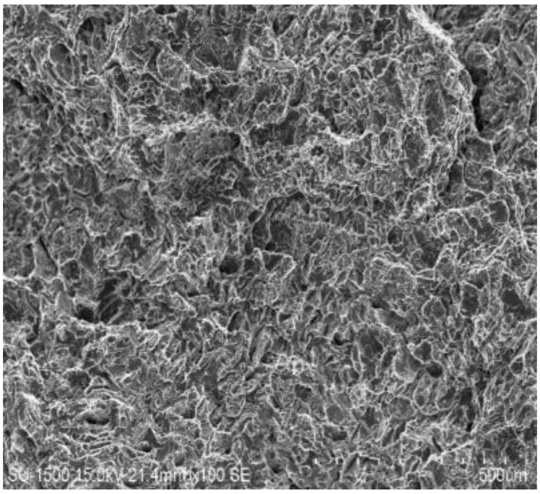

Fig (c) 4% Reinforcement 100X

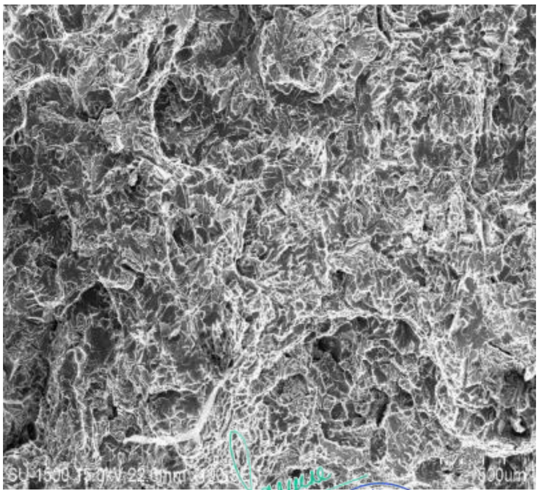

Fig (d) 6% Reinforcement 100X

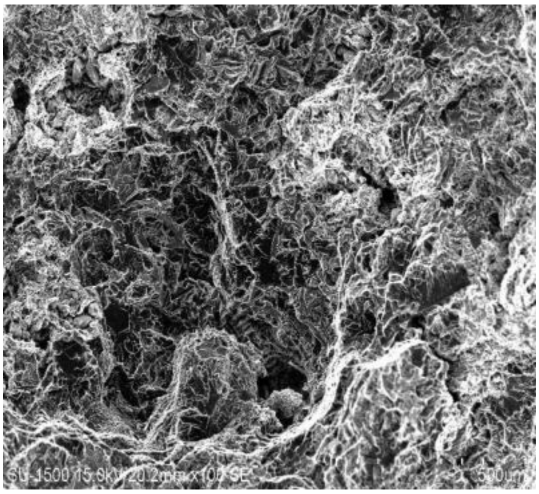

Fig (e) 8% Reinforcement 100X

Fig 6.3(a-e) SEM Images for Al356 base alloy and Composites

Fig (a, b) shows a group of dimples, small crater like structures indicating ductile fracture mode Fig (c, d) shows primary dimples arose from the reinforcement whereas micro-voids of smaller size formed from matrix finer precipitates. Particle-matrix interface debonding along these lines went about as a particular mechanism of crack nucleation. Particle breaking towards development of voids because of special decohesion of support particles from base alloy at interface areas. Large craters like structures have been observed, due to presence of higher quantity of hard and ceramic reinforcement particles, leading brittle fracture.

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7. Conclusions and scope for future work

7.1 Conclusions

This research work has highlights of the current research involving Mechanical, and Wear properties of Al356-ZrO_2 MMCs, which were fabricated by cryogenic technique.

The properties of Al alloy MMCs depend on the different variables like dispersion of reinforcement in the base alloy, dispersion of defects, presence of brittle phases in the base alloy, plastic disfigurement of the base alloy and quality at the interphase in an exceptionally complex way.Thus there is solid requirement for the successful depiction of the attributes of the composites and to extend the information pool.The composite castings with Al356 as base material and ZrO_2 reinforcement with varying particles of 44μm mesh size (2% to 8%) were successfully prepared by using stir casting technique. The microstructure examines disclosed that there was uniform mix of reinforcement particulates upto 8 % beyond which accumulation of particles is seen.

The conclusion can be drawn from the investigation carried in the present work that the increase in percentage of ZrO2 reinforcements in Al356 increases the tensile strength, compressive strength, hardness and fracture strength.ZrO_2 particulates obtained from naturally available rock represents an attractive dispersoid to provide low cost MMCs. Additions of reinforcement observably increased disruption denseness owing to changes in CTE.The enhancement in mechanical properties namely hardness, UTS, and compression strength of the composites can be all around ascribed to the prominent disruption density.

It has been found that the Impact quality diminished with increment in % of reinforcement particles. In fracture studies of developed composites, the fracture was ductile with dimple surface showing particles de-bonding, and particle cracking is due to trans granular fracture of the ZrO_2 reinforcement.

The ascast specimens exhibited a hardness of 63 and specimen with 6 wt% and 30 hours of cryotreatment has a hardness of 68. The composite with 6% ZrO_2 reinforcement shows the highest improvement in the tensile strength. The % elongation of the composite decreased with the increase in ZrO_2 content except in 2% this is mainly due to ZrO_2 is a ductile material.

7.2 Scope for Future work

- In the present research work MMC's were developed with only ZrO2 as reinforcement, hybrid composites can be developed using different combinations of reinforcements.
- Other casting techniques can be used to develop the composite
- Other alloys can be used as base material
- The Mechanical ,wear properties can be evaluated for heat treated and cryo treated MMC's
- There is a need to improve the damage tolerant properties particularly fracture toughness and ductility in MMCs.
- Fatigue test can be carried out
- In future investigation some more experiments can be conducted on the Al356 - ZrO_2 composites and a comparative study with other MMCs.
- Abrasive and Slurry erosive wear test can be carried out.
- Composite can be developed with higher percentage of ZrO_2 reinforcement.
- Corrosive resistive properties of this composite can be found out.
- Fatigue and Impact tests can be carried out.
- Thermal and electrical properties of this composites can be carried out.

Further work can be done to produce high quality and low cost reinforcements from industrial wastes and by-products.

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A Project Report on

"SHEET METAL FABRICATION"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2

In

Mechanical Engineering

Submitted by

Kushal H M	**20171MEC0094**
Manoj Gowda S	**20171MEC0109**
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Under the Supervision of

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2020-21

Presidency University

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Department of Mechanical Engineering

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REACH GREATER HEIGHTS

CERTIFICATE

Certified that, the project work entitled,**"SHEET METAL FABRICATION"** carried out by **Mr.Kushal H M(20171MEC0094),Mr.Manoj Gowda S (20171MEC0109),Mr.Mokshith Tirumala N S(20171MEC0138),Mr.Jayanth B(20181LME0019),Mr.Karthik M S(20181LME0023)**, bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021.It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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Dr. Ashish Srivastava	**Dr. Ramesh S**
Supervisor	Prof. and Head

End Term Examination
Examiners

Signature with date(30/05/2021)

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2. **Devendra Dandotiya**
3. **Narender Singh**
4. **Satish Babu Bopanna**
5. **Ajay Kumar Mishra**

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DECLARATION

We, the students of eigth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, "**SHEET METAL FABRICATION**" has been successfully completed under the supervision of Dr. Ashish Srivastava Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date: 30/05/2021

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3. Mokshith Tirumala N S	20171MEC0138	
4. Jayanth B	20181LME0019	
5. Karthik M S	20181LME0023	

ACKNOWLEDGEMENT

Before initializing the industrial report, we want to accomplish a vital task.First of all, we would like to thank **Presidency University, Mechanical Department** to arrange such a beneficial industrial training for us. For our under graduate career, this is the second industrial training. It was really a fruitful campaign for us.

And I would also like to thank the crew of **Unique Punch Systems Private Limited**.(Bangalore). The management members of the company and workers are really co-operative. They gave us each and every information that was needed and taught us the useful fundamentals. I would like to thank the **Director of the Company (Mr. RangaLakshmish V)** to permit us to get involved in the daily routine of their production. As without their support this training won't be such a productive one.

On behalf of this whole session,we would also thank **Mrs. Seema (HR)**and **Mr. Lakshmi Reddy (Production Dept.)** for their support.Finally I want to express that there is never one man crew, team work is always necessary.

Team members:	**ID Numbers**	**Signature of students**
1. Kushal H M	20171MEC0094	
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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. Ashish Srivastava** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. S Ramesh .Prof. and Head** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Ashish Srivastava** who gave us the opportunity to do this project work.

Lastly, we would like to thank our family and friends.

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ABBREVIATIONS

M.S.–Mild Steel

S.S.–Stainless Steel

C.N.C-Computer Numerical Control

T.I.G–Tungsten Inert Gas M.I.G–

Metal Inert Gas

ABSTRACT

The knowledge of Sheet Metal Fabrication is very useful in our day-to-day life and one needs to know at least the basics of the same. The content of this report includes an over view about the whole manufacturing fundamentals and the processes to be followed in this category in order to obtain the required final product.

The report contains the description of various processes to be followed and their analysis for their better understanding. The various processes included in the report are the Shearing, Punching (CNC & LASER), Bending, Welding, Grinding and Powder Coating Processes.The operation study, machine study,and material information are clearly mentioned out there.

Customer satisfaction is based on service initiation, service quality and staff behaviour. Customers should be treated as a King when he is entering the service centres and should be happy with the respect he gets. This project is to comprehend the various methods to lead customer satisfaction and improve the quality. Each of these categories is dealt with the service centre behaviour scores and implementations to improve to develop the name. If these suggestions are followed accordingly, there would be drastic changes in servicing and staff behaviour with customers.

At the end of the report, there is also a portion of future scope, in which some drawbacks and improvements needed, can be acknowledged. In last words, this report is all about the industrial aspect related to sheet metal fabrication.

REGISTRAR

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BANGALORE

<u>CHAPTER 1.0</u>

CHAPTER 1.1

Introduction of Company

A. Name: Unique Punch Systems Private Limited

B. Address:#485/7, 14th Cross, IV Phase, Peenya Industrial Area, Bengaluru - 560 058

C. Products: Defense Sector,Kiosks,Energy& Power Industry, Medical Equipment, Solar Power, Petroleum Industry, Electronics Industry, Tele –communication Industry etc.

D. Process sequence:

The industry follows a fixed sequence in order to complete a job.There are some corresponding steps, as given below:

- Shearing process
- Punching (CNC or Laser cutting)
- Bending process
- Welding process
- Grinding process
- Finishing (Powder coating,Spray painting etc.)
- Packing and Dispatch.

RESPONSIBILITY AND AUTHORITY

CEO

A) Reports to the Board of Directors

B) Responsible for:

- Overall management of the company
- Laying down quality policy and objectives
- Carrying our management reviews
- Approval of product & process, Design & quality.
- Ensuring the compliance to the quality management system of the company
- Review and approval of quality management system documents
- Finance management
- Approval for purchase of raw materials, consumables and spares
- Review and authorizing all agreement / contract (customer / suppliers)
- Overall responsibility for new products and projects
- Defining responsibility and authority of functions who are expected to take the independent decision
- Providing resources as identified including training
- Appointment of management representative
- Review the performance of the quality management system in line with ISO 9001 / 2000 STD requirement
- Review of orders received from customers
- Review of nonconforming products as a member of review meeting
- Approval of corrective actions taken against customer complaints and purchased products including productions operations

- Coordination and spear heading the continuous improvement activities of the organization
- Receive and record customer complaints in the register
- Maintaining the data related to delivery schedule adherence to customers
- Outsourcing Operations (Productions) as required
- Identification of training needs of functions reporting to him
- Has the authority to stop production

TECHNICAL MANAGER

A) Reports to Chief Executive Officer

B) Responsible for:

- Overall activities of the day to day production operations
- Planning and review of production against plan
- Process design and development
- Identification of training needs of functions reporting to him
- Preparation of work instruction for production activities
- Initiation of corrective action with regard to in process / final stages of production
- Maintaining customer satisfaction and taking suitable corrective action
- Implementing the corrective actions for the customer complaints in coordination with CEO
- New Product Development
- Initiating the corrective action against the customer complaint in coordination with CEO
- Proposal of corrective action and verification of effectiveness of
- corrective actions
- Monitoring customer satisfaction and taking suitable corrective actions
- Ensure safe working practice
- Drawing control in related to distribution and revision and over all maintenance
- Control of customer supplied products / documents
- Has the authority to stop production, to correct the quality problems.

PURCHASE STORE IN CHARGE

A) Reports to CEO

B) Responsible for:

- Preparation of purchase order / Arranging for purchase of Raw Materials, spares and consumables
- Supplier evaluation and maintenance of approved suppliers list follow up with suppliers
- Maintenance of record in relation to purchase of products
- Maintenance of minimum stock level
- Maintenance of FIFCO system for Self Life Item
- Stock register and material identification
- Preservation of materials identification
- Preservation of materials stores

MARKETING IN CHARGE

A) Reports to CEO

B) Responsible for:

- To material Inward and Inspection
- Receipts of enquires / Orders from the customers and enter in the register
- Receives and record customer complaints in the register
- Maintaining records related to customer related processes
- Tracking of customer satisfaction and on time deliveries

SUPERVISOR-PRODUCTION

A) Reports to technical manager

B) Responsible for:

- Production , quality as per planning
- Man, Materials, Methods, Machineries Management
- Monitoring House Keeping
- Ensure safe working practice
- Maintenance of records related to production & quality
- Identification of training needs of functions reporting to him
- Has the authority to stop production, to correct the quality problems

MANAGEMENT REPRESENTATIVE

A) Reports to CEO

B) Responsible for:

- Planning, establishing and implementing quality Management system in consultation with CEO
- Organizing internal quality audits
- Organizing management Reviews meeting and taking follow up actions
- Initiate preventive actions with regard to repeated system non conformities
- Liaison with certifying agencies and arranging for external audits
- Ensuring internal communication in regard to effectiveness of quality management system

REGISTRAR

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CLIENTS

- Rittal
- Schneider Electric
- Wipro
- Precision
- Eureka Forbes
- True Air System

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PRODUCTS

1. Health Care

- HV Tank
- Thin Aluminum Welded Part
- MS Chassis
- Hospital Equipment's
- Thick Aluminum Machined Part

2. Electrical/Aerospace Application

- Terminal Rails
- Perforated Sheet Meta
- Controller Cabinets
- Sheet Metal Frame Structure
- Tube Frame Structure

3. Passenger Lift

- AC Duct
- Elevator Platform Assembly

4. Electrical Assemblies

- Fully Powder Coated Aluminum Component With Screen Printing
- Raw Galvanized Sheet With Screen Printing

5. Defense

6. Wind Energy

7. Kiosk

8. Telecom Products

INSPECTION PROCESS

QUALITY CONTROL

Process input	Mode of output	Process Measures
1.Qualityplan/Work Instruction 2.Drawings/Specifications 3.Incoming Raw material specification 4. Measuring devices 5. Inspection skill 6. In formations/feedback from the customer with regard to quality of the product. 7. Inspection status	1.Inspection report 2.Non conformance report 3.Corrective action report 4.Test certificate	1. Number of customer complaints Related to quality of the product 2. Customer rejection percentage

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INCOMING STAGE:

A. On action on receipt of raw materials from suppliers/processed products from the service providers are inspected as per incoming/process/product wise quality
B. The raw materials/production operations are accepted based on the test certificates/inspection reports wherever required as applicable received from the suppliers/service providers.
C. The quality supplied and accepted criteria is ensured against P.O/job order as applicable and the same is updated in the material inward inspection report/service provider's register
D. The consumable are checked for the quality and specification (Visual through labels or stickers etc.) as per purchase order/purchase orders register and accepted. The result are updated in MIIR The non-conformance identified during this inspection, are handled as in continual improvement process

IN PROCESS AND FINAL STAGE

A. In process and final inspection are carried out as per the process and final inspection quality plan. The inspection results are recorded in inspection reports.
B. Final inspection/Testing are done on the finished 100% Qty of the product as per the final inspection quality plan
C. Final inspection/Testing results are recorded in the Final /stage inspection report.
D. If result are not meeting accepted criteria/tolerance during in process /final stage ,then non-conforming product control process is implemented as per the process module-continual improvement process
E. Inspection status is identified on the components through tag/board/respective location/paint mark identification.
F. Inspection skill is measured through skill matrix and necessary action is taken as per the process module.
G. Proper instrument with valid calibrated are selected for the inspection. Instrument are selected such that its least count is 10% of the size under measurement.

SUPERVISOR-QUALITY CONTROL

A) Reports to technical manager

B) Responsible for:

- Overall quality control and assurance
- Maintenance of records related to incoming materials, in process materials and final stage productions inspection reports including dimensional inspection
- Calibration of inspection and testing equipment / instruments
- Identification of training needs of functions reporting to him
- Has the authority to stop production, to correct the quality problems

ACCOUNTS

A) Reports to CEO

B) Responsible for:

- Overall responsible for accounts related activities includes sales tax, excrise& banking
- Maintaining commercial records and invoice
- Coordinating with auditors for carrying out annual audit

RESPONSIBLITIES OF OTHER PERSONNELS

Concerned sections in charges define and communicate the responsibilities of personnel working in their respective areas.

REGISTRAR PRESIDENCY UNIVERSITY Registrar BANGALORE

QUALITY ASSURANCE

The management of UNIQUE PUNCH SYSTEMS PRIVATE LIMITED is fully committed to the development and implementation of modern quality management system and continually improving its effectiveness. Towards these requirements, the company has oriented all its systems and procedures inline international quality management standards and practices

The quality manual of UNIQUE PUNCH SYSTEMS PRIVATE LIMITED is issued on 31.08.20, which incorporates company's quality policy and the basic procedures.

The company has decided to obtain ISO 9001/2000 certificate to fulfill the requirements of its discerning customers, who are constantly upgrading their own requirements and making increasing demands on their supply chain to enable better competitiveness.

The quality management system is oriented to achieve, maintain and improve overall organization performance, capability and also to identify and meet the needs and expectations of the company's customers, employees, suppliers and owners.

The quality management system procedures in the quality manual are supplemented with further supporting work instructions, check sheet and together they form a comprehensive documented quality management system, designed to result in better customer satisfaction, a basic requirements of the company's quality policy

The Chief Executive Officer/MD, Technical Manager/section in charge is committed to the development and implementation of the quality management system and continually improves its effectiveness by

A) Communicating within the organization, the importance of meeting the customer as well as statutory and regulatory requirements

B) Establishing the quality policy

C) Ensuring that quality objectives are established

D) Conducting management reviews

E) Ensuring the availability of resource

The Chief Executive Officer is authorized to approve the quality management system procedures incorporated in this manual and subsequent amendment to them

The Management representative is authorized to approve other work instructions, check sheet and formats o the quality management system to maintain uniformity within the company.

It is mandatory on the part of all employees of UNIQUE PUNCH SYSTEMS PRIVATE LIMITED, to faithfully implement the quality management system and work towards continuous improvement based on regular analysis of current performance data and keeping in view the increasing expectations of the customers.

Chapter 2.0

Chapter 2.1

Literature survey

Objective of Literature Survey: It is the detailed study of each process that comes under the sequential production. It is much needed to understand the manufacturing thoroughly.

FABRICATION

Fabrication, when used as an industrial term, applies to the building of machines, structures and other equipment, by cutting, shaping and assembling components made from raw materials. Small businesses that specialize in metal are called fab shop.

Fabrication comprises or overlaps with various metalworking specialties:

- Fabrication shops and machine shops have overlapping capabilities, but fabrication shops generally concentrate on the metal preparation aspects (such as sawing tubing to length or bending sheet metal or plate), welding, and assembly, whereas machine shops are more concerned with the machining of parts on machine tools. Firms that encompass both are also common.
- Blacksmithing has always involved fabrication, although it was not always called by that name.
- The products produced by welders, which are often referred to as weldments, are an example of fabrication.
- Boilermakers originally specialized in boilers, leading to their trade's name, but the term as used today has a broader meaning.
- Similarly, millwrights originally specialized in setting up grain mills and saw mills, but today they may be called upon for a broad range of fabrication work.

Ironworkers, also known as steel erectors, also engage in fabrication. Often the fabrications for structural work begin as prefabricated segments in a fab shop, then are moved to the site by truck, rail, or barge, and finally are installed by erectors

METAL FABRICATION

- Metal fabrication is a value added process that involves the construction of machines and structures from various raw materials. A fab shop will bid on a job, usually based on the engineering drawings, and if awarded the contract will build the product.
- Fabrication shops are employed by contractors, OEM's and VAR's. Typical projects include; loose parts, structural frames for buildings and heavy equipment, and hand railings and stairs for buildings.

Various processes are as follows:

➢ SHEARINGPROCESS:

Shearing is a cutting force applied perpendicular to material causing the material to yield and break. Shearing is a process for cutting sheet metal to size out of a larger stock such as roll stock. Shears are used as the preliminary step in preparing stock for stamping processes, or smaller blanks for CNC presses.

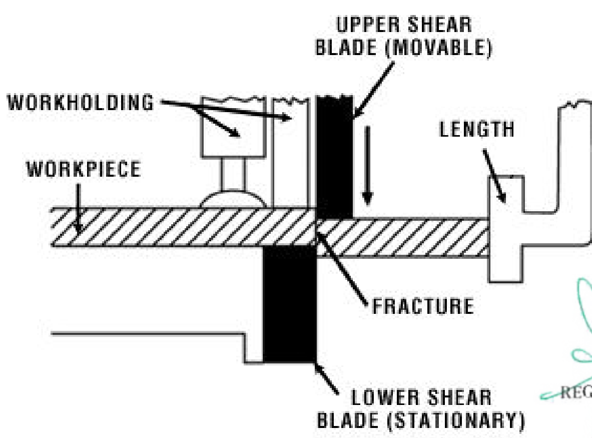


Fig. 2.1 SHEARING PROCESS

Material thickness ranges from0.125mm to 6.35mm (0.005to0.250in).The dimensional tolerance ranges from ±0.125mm to ±1.5mm (±0.005 to ±0.060in).

The shearing process produces a shear edge burr, which can be minimized to less than 10% of the material thickness. The burr is a function of clearance between the punch and the die(which is nominally designed to be the material thickness),and the sharpness of the punch and the die.

The illustration shown provides a two-dimensional look at a typical metal shearing process. Note how the upper shear blade fractures the metal work piece held in place by the work holding devices. The sheared piece drops away. Typically, the upper shear blade is mounted at an angle to the lower blade that is normally mounted horizontally. The shearing process performs only fundamental straight-line cutting but any geometrical shape with a straight line cut can usually be produced on a shear.

Metal shearing can be performed on sheet, strip, bar, plate, and even angle stock. Bar and angle materials can only be cut to length. However, many shapes can be produced by shearing sheet and plate.

Fig: 2.2 Picture of shearing machine

This is a modern shearing machine that can be used to cut the sheets with a smoother operation and high accuracy. The shearing tool imparts the force hydraulically and the operating pedal works pneumatically. The gauge size can be set with a program to cut bars of specific size from a larger sheet. There are supporting anvils for longer sheets. The shearing tool is mounted a bit inclined to x-axis, as to produce trimming effect and to avoid bending of sheet due to single stroke.

Generally this is used to get a blank sheet out of raw materials. It is also used to cut the scrap material and take out the productive portions.

The shearing process characteristics include:

- Its ability to make straight-line cuts on flat sheet stock.
- Metal placement between upper and lower shear blades.
- Its trademark production of burred and slightly deformed metal edges.
- Its ability to cut relatively small lengths of material at any time since the shearing blades can be mounted at an angle to reduce the necessary shearing force required.

➢ **PUNCHINGPROCESS:**

Punching is a metal fabricating process that removes a scrap slug from the metal work piece each time a punch enters the punching die. This process leaves a hole in the metal work piece.

Images explains about entering the values to control panel of punching machine

➢ **CNC Punching and Blanking:**

Punching is the process of forming metal components using a punch. The punch is usually the upper member of the complete die assembly and is mounted on the slide or in a die set for alignment (except in the inverted die).

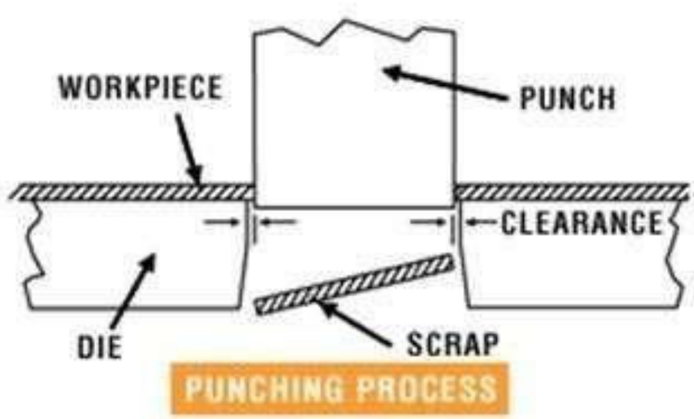


Fig. 2.3

The punching process forces a steel punch, made of hardened steel, into and through a workpiece. The punch diameter determines the size of the hole created in the workpiece.

The illustration that follows provides at work dimension all took at typical punching process.Note how the workpiece remains and the punched part falls out as scrap as the punch enters the die. The scrap drop through the die and is normally collected for recycling.

Image shows the CNC Turret machine in punching process

The Computer Numerical Control (CNC) fabrication process offers flexible manufacturing runs without high capital expenditure dies and stamping presses. High volumes are not required to justify the use of this equipment.

Tooling is mounted on a turret which can be as little as 10 sets to as much as100 sets. This turret is mounted on the upper part of the press, which can range in capacity from 10tonsto100 tons in capacity.

The turret travels on lead screws, which travel in the X and Y direction and are computer controlled. Alternatively, the workpiece can travel on the lead screws, and move relative to the fixed turret. The tooling is located over the sheet metal, the punch is activated, and performs the operation, and the turret is indexed to the next location of the workpiece. After the first stage of tooling is deployed over the entire workpiece, the second stage is rotated into place and the whole process is repeated. This entire process is repeated until all the tooling positions of the turret are deployed.

The illustration that follows shows a few common punches and die configurations and the workpieces that would be formed by this combination. Multiple punches can be used together to produce a complete part with just one stroke of the press.

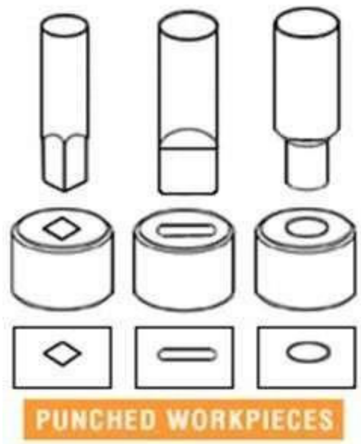


Fig. 2.5

Different shapes of punched workpieces

There are 20 different tool and die holders on which various tools with their specific dies can be mounted. There are certain dies for thin and thick sheets, depending upon sheet thickness. Mainly there are three stations, B, C and D depending on the tool and die size.

Blanking is a metal fabricating process, during which a metal workpiece is removed from the primary metal strip or sheet when it is punched. The material that is removed is the new metal workpiece or blank.

The blanking process forces a metal punch into a die that shears the part from the larger primary metal strip or sheet. A die cut edge normally has four at tributes. These include:

- burnish
- burr
- fracture
- roll-over

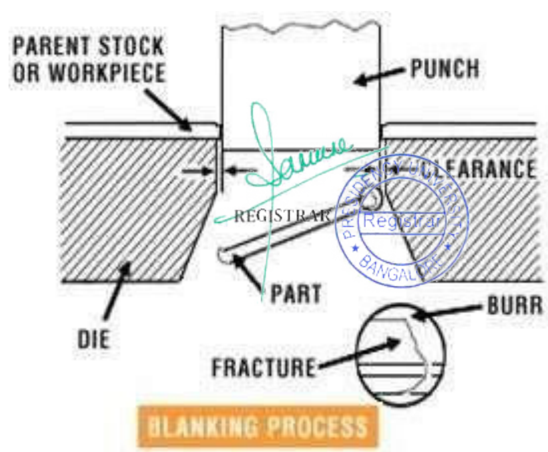


Fig. 2.6

The illustration that follows provides a two-dimensional look at a typical blanking process. Note how the primary metal workpiece remains and the punched part falls out as scrap as the punch enters the die. The scrap drops through the die and is normally collected for recycling.

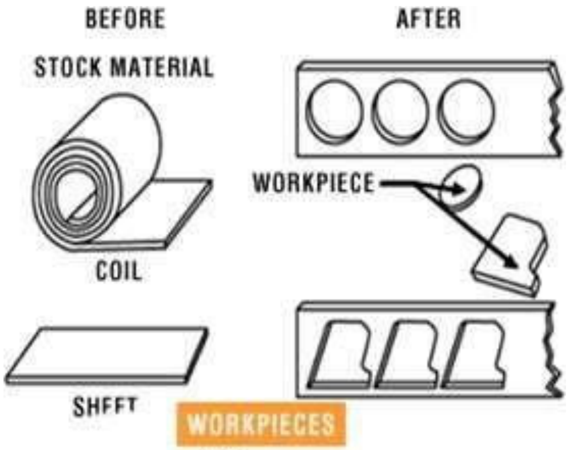
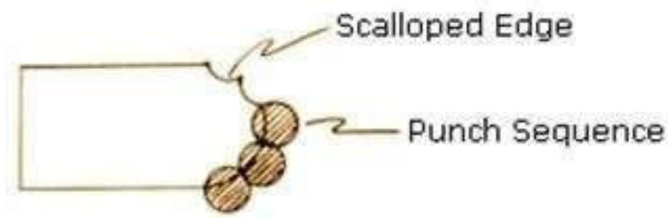


Fig. 2.7



Nibbling with a Cylindrical Punch
Fig. 2.8

Like many other metal fabricating processes, especially stamping, the waste can be minimized if the tools are designed tones parts as closely together as possible.

The illustration that follows shows the workpieces that could be created through the blanking process using either sheet or roll as the parent material.

Quite often, curves and other difficult features are produced by punching out small sections at a time. This process is called nibbling. This leads to triangular shaped features. These triangular shaped features give the edge a scalloped look. This scalloping can be pronounced if the nibbling pitch is coarse. The amount of scalloping that can be accepted is a function of tooling and product cost. Clamp marks are cosmetic in nature, and if objectionable, can be so positioned to cut them away in subsequent processing.

The limitations for CNC turret: Maximum limit for various materials: Aluminum-5mm, Mildsteel-3mm, Copper- 4mmand Brass-3mm.

Continuous cooling is required for proper and safe operation. An oil tank is also used to provide oil for extensive lubrication that is necessary to avoid wear of job and tool. Mostly all jobs can be done on CNC for punching purpose, but there are some limitations of it, due to which there arises the need of Laser CNC machine.

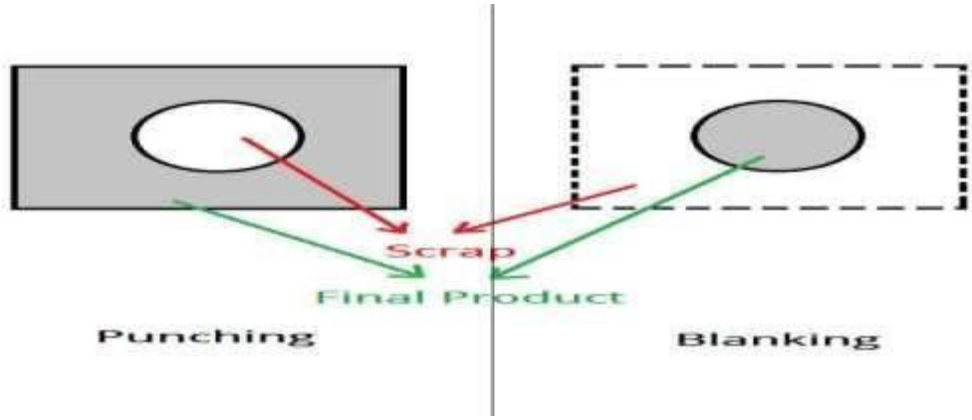


Fig 2.9:Difference between Punching and Blanking

Images shows the different types of punch and dies of punching machine

➢ Laser Cutting:

Laser cutting machines can accurately produce complex exterior contours.The laser beam is typically 0.2 mm (0.008 in) diameter at the cutting surfacewithapowerof1000 to2000 watts.

LasercuttingcanbecomplementarytotheCNC/Turretprocess.TheCNC/Turretprocesscanproduceinternalfeaturessuchasholesreadilywhereas the laser cutting process can produce external complex featureseasily.

Images shows checking the values in control panel

Laser cutting takes direct in put in the form of electronic data from a CAD drawing to produce flat form parts of great complexity. With 3-axis control, the laser cutting process can profile parts after they have been formed on the CNC/Turret process. Lasers work best on materials such as carbon steel or stainless steels. Metals such as aluminum and copper alloys are more difficult to cut due to their ability to reflect the light as well as absorb and conduct heat. This requires lasers that are more powerful.

Lasers cut by melting the material in the beam path. Materials that are heat treatable will get case hardened at the cut edges. This may be beneficial if the hardened edges are functionally desirable in the finished parts. However, if further machining operations such as threading are required, then hardening is a problem.

A hole cut with a laser has an entry diameter larger than the exit diameter. Creating a slightly tapered hole.

The minimum radius for slot corners is 0.75 mm (0.030 in). Unlike blanking, piercing, and forming, the normal design rules regarding minimum wall thicknesses, minimum hole size (as a percent of stock thickness) do not apply. The minimum hole sizes are related to stock thickness and can be as low as 20% of the stock thickness, with a minimum of 0.25 mm (0.010 in)up to 1.9 mm (0.075 in). Contrast this with normal piercing operations with the recommended hole size 1.2 times the stock thickness.

Burrs are quite small compared to blanking and shearing. They can be almost eliminated when 3D lasers are used and further, eliminate the need for secondary deburring operations.

Image shows waiting for the program to sync with the machine

As in blanking and piercing, considerable economies can be obtained by nesting parts, and cutting along common lines. In addition, secondary deburring operations can be reduced or eliminated.

The limits associated with laser cutting–Maximum sheet thickness preferred: Aluminum-1mm, Mildsteel-8mm, Stainless Steels-6mm.

The laser first penetrates the job at specific point, then moves to the boundary of loop and forms the cut as per design. The laser moves in X and Y direction to get desired job. This motion is called as interpolation.

There is a cooling water system comprising of two heat exchangers that maintains the temperature of internal portion of machine where much heat is generated during laser emission.

The main characteristic of Laser cutting is that no finishing operation is required on the job as directly finished job is obtained.

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➢ **BENDINGPROCESS:**

Bending is a process by which metal can be deformed by plastically deforming the material and changing its shape. The material is stressed beyond the yield strength but below the ultimate tensile strength. The surface area of the material does not change much. Bending usually refers to deformation about one axis.

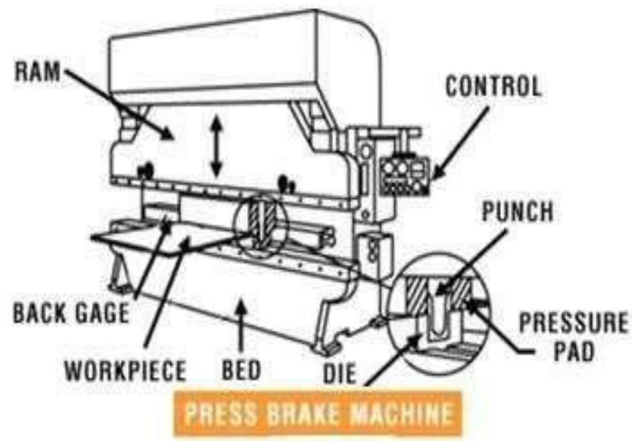

Fig. 2.10

Parts of Bending machine

Bending is a flexible process by which many different shapes can be produced. Standard die sets are used to produce a wide variety of shapes.

The material is placed on the die, and positioned in place with stops and/or gauges. It is held in place with hold-downs. The upper part of the press, the ram with the appropriately shaped punch descends and forms the V-shaped bend.

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Images shows working on bending machine with scrap pieces

Bending is done using Press Brakes. Press Brakes normally have a capacity of 20 to 200 tons to accommodate modate stock from 1m to 4.5m (3feetto15feet). Larger and smaller presses are used for specialized applications. Programmable back gauges, and multiple die sets available currently can make fora very economical process.

The minimum flange width should be at least 4 times the stock thickness plus the bending radius. Violating this rule could cause distortions in the part or damage to tooling or operator due to slippage.

Fig. 2.11

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The machine has a stationary bed or anvil and a slide (ram or hammer)which has a controlled reciprocating motion toward and away from the bed surface and at right angle to it. The slide is guided in the frame of the machine to give a definite path of motion.

A form of open-frame single-action press that is comparatively wide between the housings, with a bed designed for holding long, narrow forming edges or dies. Used for bending and forming strip, plate, and sheet (into boxes, panels, roof decks, and so on).

Dies used in presses for bending sheet metal or wire parts into various shapes. The work is done by the punch pushing the stock into cavities or depressions of similar shape in the die or by auxiliary attachments operated by the descending punch. Various types of machinery equipped with two or more rolls to form curved sheet and sections.

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➢ WELDINGPROCESS:

Welding is the process of permanently joining two or more metal parts, by melting both materials. The molten materials quickly cool, and the two metals are permanently bonded.

Mainly used welding types are Argon (TIG) welding and MIG welding.

Image shoes the welding process

- **TIG welding:**

TIG welding is a slower process than MIG, but it produces a more precise weld and can be used at lower amperages for thinner metal and can even beused on exotic metals. TIG welding is a commonly used high quality weldingprocess.TIG welding has become a popular choice of welding processes when high quality, precision welding is required. The TIG welding process requires more time to learn than MIG.

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Characteristics:

- Uses a non-consumable tungsten electrode during the welding process,
- Uses a number of shielding gases including helium(He) and argon(Ar),
- Is easily applied to thin materials,
- Produces very high-quality, superior welds,
- Welds can be made with or without filler metal,
- Provides precise control of welding variables (i.e, .heat),
- Welding yield slow distortion,
- Leaves no slag or splatter.

In TIG welding ,an arc is formed between an on-consumable tungsten electrode and the metal being welded. Gas is fed through the torch to shield the electrode and molten weld pool. If filler wire is used, it is added to the weld pool separately.

The illustration that follows provides a schematic showing how the TIG welding process works.

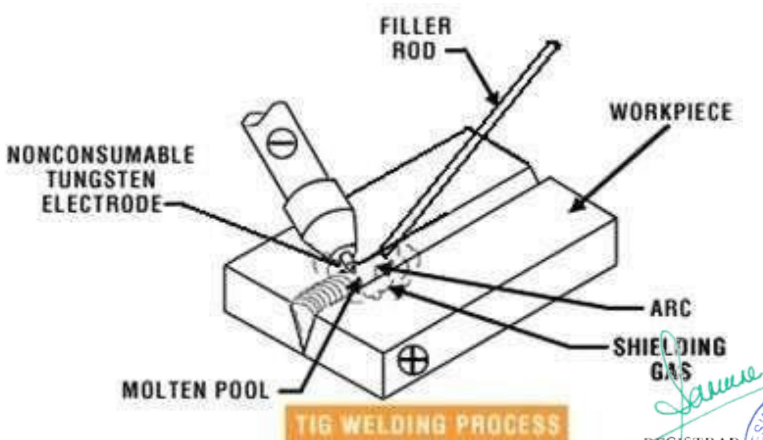

Fig. 2.13

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The following illustration shows the TIG-welded joints:

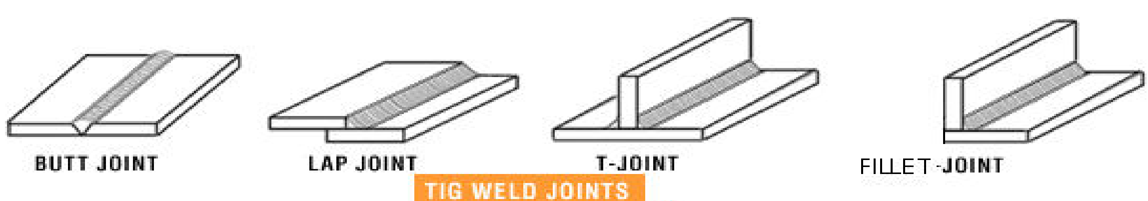

Fig. 2.14

- **MIG welding:**

The "Metal" in Gas Metal Arc Welding refers to the wire that is used to start the arc. It is shielded by inert gas and the feeding wire also acts as the filler rod. MIG is fairly easy to learn and use as it is a semi-automatic welding process.

Welding gun

GMAW torch nozzle cut away image

:(**1**)Torch handle,

(2) Molded phenolic dielectric (shown in white) and threaded metal nut insert (yellow),

(3) Shielding gas diffuser,

(4) Contact tip,

(5) Nozzle output face

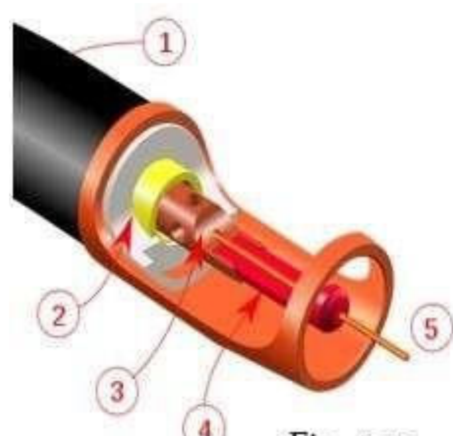

Fig. 2.15

Characteristics:

- Uses a consumable wire electrode during the welding process that is fed from as pool,
- Provides a uniform weld bead,
- Produces a slag-free weld bead,
- Uses a shielding gas,usually–argon,argon-1 to 5%oxygen, argon-3 to 25 % CO_2 and a combination argon/helium gas,
- Is considered a semi-automatic welding process,
- Allows welding in all positions,
- Requires less operator skill than TIG welding,
- Allows long welds to be made without starts or stops,
- Needs little clean up.

The illustration that follows provides a look at a typical MIG welding process showing an arc that is formed between the wire electrode and the workpiece. During the MIG welding process, the electrode melts within the arc and becomes deposited as filler material.

The shielding gas that is used prevents atmospheric contamination.

From atmospheric contamination and protects the weld during solidification. The shielding gas also assists with stabilizing the arc which provides a smooth transfer of metal from the weld wire to the molten weld pool.

Versatility is the major benefit of the MIG welding Process. It is capable of joining most types of metals and it can be performed in most positions, even though flat horizontal is the optimum.

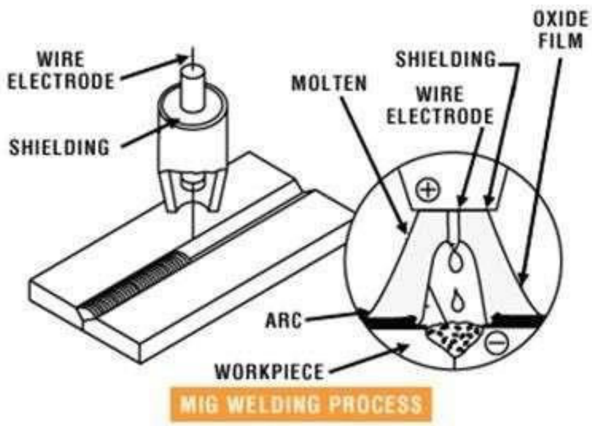

Fig. 2.16

The most common welds are illustrated below. They include the:

- Lap joint
- Butt joint
- T-joint and
- Edge joint

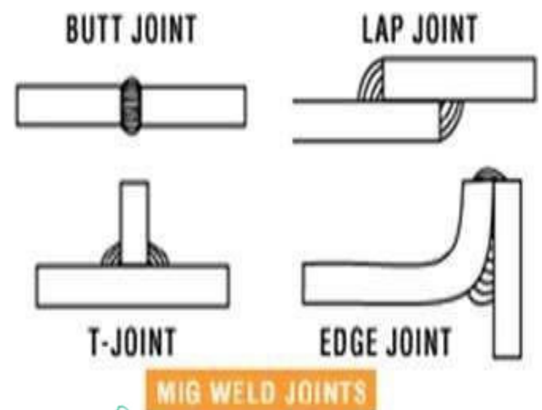

Fig. 2.17

MIG is used to weld many materials, and different gases are used to form the arc depending on the materials to be welded together. An argon CO_2 blend is normally used to weld mild steel, aluminum, titanium, and alloy metals. Helium is used to weld mild steel and titanium in high speed process and also copper and stainless steel. Carbon dioxide is most often used to weld carbon and low alloy steels. Magnesium and cast iron are other metals commonly welded used the MIG process.

➢ GRINDING PROCESS:

Grinding is a finishing process used to improve surface finish, abrade hard materials, and tighten the tolerance on flat and cylindrical surfaces by removing a small amount of material. In grinding, an abrasive material rubs against the metal part and removes tiny pieces of material. The abrasive material is typically on the surface of a wheel or belt and abrades material ina way similar to sanding. On a microscopic scale, the chip formation in grinding is the same as that found in other machining processes. The abrassive action of grinding generates excessive heat so that flooding of the cutting area with fluid is necessary.

Machine tool uses a rotating abrasive grinding wheel to change the shape or dimensions of a hard, usually metallic, workpiece. Grinding is the most accurate of all the basic machining processes. All grinding machines use a wheelmade from one of the manufactured abrasives, silicon carbide or aluminum oxide.To grind a cylindrical form,the work piece Rotates as it is fed against the grinding wheel. To grind an internal surface, a small wheel moves inside the hollow of the workpiece, which is gripped in a rotating chuck. On a surface grinder, the workpiece is held in place on atable that moves under the rotating abrasive wheel.


Fig. 2.18

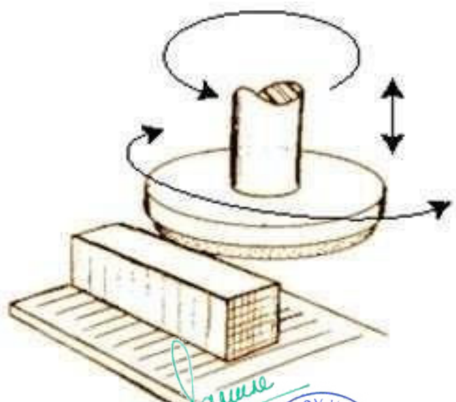
Fig. 2.19

Images of grinding wheel

➤ POWDER COATING PROCESS:

Powder coating is a dry finishing process, using finely ground particles of pigment and resin that are generally electro statically charged and sprayed onto electrically grounded parts. The charged powder particles adhere to the parts and are held there until melted and fused into a smooth coating in acuring oven. Before coating, the parts to be coated are first pretreated similarly to conventional liquid coated parts. The pretreatment process is normally conducted in series with the coating and curing operations.

There is essentially two common ways of applying powder coating: by electrostatic spray and by fluidized bed powder coating. There are several other processes that have been developed, but they are far less used. These Include flame spraying, spraying with a plasma gun, airless hot spray, and coating by electrophoretic deposition.

Electro static spray powder coating uses a powder-air mixture from a small fluidized bed in a powder feedhopper. In some cases, the feed hoppers vibrate to help prevent clogging or clumping of powders prior to entry into the transport Lines. The powder is supplied by a hose to the spray gun, which has a charged electrode in the nozzle fed by a high voltage dc power.

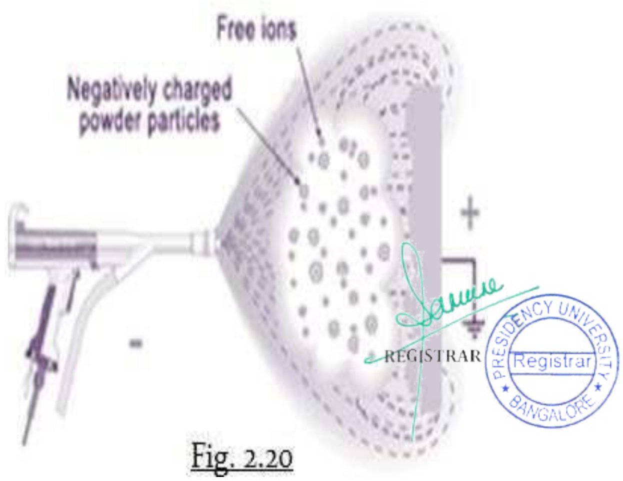

Fig. 2.20

Electro static powder spray guns direct the flow of powder; control the deposition rate; control the pattern size, shape, and density of the spray; and charge the powder being sprayed .The spray guns can be manual (hand-held)or automatic, fixed or reciprocating, and mounted on one or both sides of a conveyorized spray booth. Electrostatic spray powder coating operations use collectors to reclaimover-spray. This reclaimed powder is then reused, adding significantly to the powder coating's high transfer efficiency.

The film thickness is dependent on the powder chemistry, preheat temperature, and welltime. The different surface finishes obtained by powder coating include mattfinish, texture finish, glossy finish,etc.

Finally, the last step is the packing and dispatch of the completed job which is done in a manner depending on the type and shape of the job made, its delicacy,etc.

Image shows powder coating of aluminium extrusion

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Process management procedure activity

1. The schedule/orders from the customers are received by the CEO. After consolidating the schedule, CEO reviews the availability of the capacity along with technical manager/concerned section in charge received from the customers marketing in charge raises the work order to production in charge

2. Based on the work order received from marketing, production plan is arrived by the production in charge in the work order rear side itself.

3. Based on the weekly plan, the raw material/consumables planning is carried out by the CEO interacting with the production in charge and the material requisition is raised to stores about procurement. Stores in charge after verifying the stock raised the intent to purchase in charge for procurement

4. If any additional schedules are received from the customers CEO along with technical manager section in charges in consultation with CEO amend the monthly/Weekly planning. The raw material/consumable planning are also reviewed for additional and if necessary, requirements are informed to purchase in-charge

5. In case of no-availability of the required from the capacity CEO decide about the action to be carried out, including the action of the service providers.

6. CEO instructs the production departments highlighting technical and quality requirements.

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7. The production is carried out under controlled condition based on the customer drawings/requirements. The work instructions/process flow charts/activity charts, quality plan-product wise as applicable, are available in the work spot skill to carry out production process are identified through skill matrix once in a year and the appropriate records are maintained by the section in charges.

8. Production details are recorded in daily production logbook maintained by the concerned section in charges.

9. The in process inspection is carried out as per the quality plan-product wise it is section in charge's responsibility to ensure that operators follow the work instructions. It is ensured that inspection/testing is carried out all stages as per work instructions/quality plan-product wise.

10. Process parameters and product characteristics are monitored as per work instruction or as per customer requirement/quality plan-product wise.

11. In case of any out sourcing productions operations is required it is done through the service providers. The performance of service providers is evaluated and monitored by rating once in 6 months by CEO/Q.A in charges

12. The products after completion of all processes are offered for pre-delivery/final inspection as per the quality plan-products wise are available at work spot.

13. Based on work order/production plan whenever products are already for dispatch, they are dispatched either in loose condition or packed as per customer requirements and the relevant documents are sent along with products. Test certificates and inspection reports are verified by quality control before dispatch.

14. Section in charge in consultation with CEO, decides the corrective action to be taken, in case of any problems related to production and dispatch.

Maintance of Machinery

Preventive maintenance of machinery is carried out as per the preventive maintenance plan and the result/observations while checking are recorded in the preventive maintenance record Preventive parameter are reviewed at least once in 3 months during the MRM meeting. On the basis of repeated break down occurred and the plan is revised if necessary. Problems/break down and the corrective action taken is recorded in the machine history card

WORK ENVIRONMENT

The following factors are managed to achieve conformity of product

1. Proper Housekeeping
2. Identification of products
3. Proper illumination
4. Proper Air Circulation
5. Proper safety equipment is available.

Feedback received from internal audit, Management review and customers are reviewed to improve the process performance

OBJECTIVE OF THE STUDY

- To study about metal sheet fabrication
- To explore the organization structure of the company
- To understand different departments in the organization and their functioning.

2.1 OBJECTIVE

To learn about the concepts involved in sheet metal fabrication and to get an exposure in working Environment.

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2.2 SCOPE

I have learnt many new mechanical processes which is related to sheet metal fabrication process. I understood how a company functions and various management principle employed in governing an Establishment.

METHODOLOGY 3.0

Primary data

- Direct interview with the managers, other employees and workers.
- By observing the departmental works.

Secondary data

- From office records
- From internet and text books

Limitation of the study

- The time period of this study is very short
- The local language of labours made some communication barrier

Chapter 4.0

Experimental setup

Our whole training session was divided in two Departments, half of which in Design Department and the other half in Production Department.

- **Design**

The ordered jobs to be made are received by the industry in the form of their drawings on paper or Adobe files. These drawings are firstly studied by the Design Department regarding the type of the material required by the ordering company, the possibility of the job to be made well with that type of material, the amount of material required in accomplishing the task, the type operations to be performed on respective machines, etc.

The industry follows the following fixed sequence for the completion of the task regarding the design part:

- Detailed study of the drawing
- Development of the drawing
- Part List
- DXF file is made for RADAN software used for punching purpose
- Tooling operations to be performed
- Notepad file is made for RADAN software

A brief description of the above steps are given below, which may please be noted:

In the first step, the drawing of the required job is studied taking in consideration, mainly the possibility of the job to be completed as per order.

For example, if the thickness of the sheet as per order is very small and the processes to be carried out on it are complex, then to produce such a job is very difficult or one can regret the order if the sufficient facilities are not available in the industry.

Then the drawing is developed by unfolding it so that the quantity of the material or the size of the sheet can be known. An allowance is also considered in the development so as to get the exact size as required on order. The following are the allowances to be considered for the respective sheet thicknesses:

Sheet Thickness	Allowance
3.0	2.5
2.5	2.0
2.0	1.6
1.6	1.3
1.2	1.1
1.0	≤ 1.0

Table3.1

A list of individual components or parts comprising the final job is made which is known as part-list. In this list, the dimensions of the parts and the operations to be performed on a particular machine is listed out.Afterwards a drawing is made in Auto CAD in the dxf format showing all the dimensions of the complete job and the components comprising it along with all the bending lines. Then a dxf file is made in which only the profile of the completed job and the components is shown which is used for the RADAN software for the purpose of punching operations.

Afterwards a notepad file is made which is read by the CNC machine for carrying out the operations to be performed on the job and takes the job towards completion.

♦ Production

The designs dept. feed the input to the prod. dept. It provides the finalized drawing and the part list. This part list is then used to get the results for optimise use of available raw material with the help of a software, Plus 2D. It give the effective productivity on the basis of raw material and parts. Minimum criteria followed here is 92% overall.

According to mentioned sequence, the first stop is shearing. The operator is given a drawing or just the figure of final dimensional of sheet that is required of raw material for job work. The worker prepare the specific blank sheet for further processing.

We saw the operation of the shearing machine and its observed the precautions to be taken. Also studied the mechanism of the mechanism just by observing as we were not authorized to operate it. But the presence of mind made it easier to grasp the process funda and the style of the operator.

The sheet is then either fabricated under CNC turret or Laser machine under various circumstances. For CNC work, the CNC operator is given a notepad file via network. He manipulate various parameters and sets the tool and die combinations as per mentioned in the file. Then as the computer is connected to CNC, the CNC reads the required job file and the operator initiates the process of punching in CNC. The accomplished job requires grinding and finishing.

The CNC machine was the most fascinating machine to observe, the operator told us about the program manipulating and its relation to the tool sequence in turret of CNC. We saw the mounting of die and punch combinations for punching purpose. There is a neutral indicating point at which job is to be fixed, in order to get the perfect output.

For Laser process, the operator is provided with a .dxf file that he used to generate a program file for Laser input with a floppy disk. The job is then fixed on the table at neutral point according to axes. The operator initiates the machine work and Laser automatically arrange the sequence of various Cuttings in job. The finishing of job is not required because of good quality cutting and deburred edges.

The job then moves to the bending shop. Here the operator understands the job and its diagram to carry on the required process. The symbols like BUP and BDN shows about the direction of bend to be applied on job. The operator sets the feed into CNC bending machine (Press Brake), and arrange the suitable punch and die for the required job. The job is then set onto the bolster against the gauge that maintains the dimension of a portion of sheet to be bend. The final job is then proceeded for further operations.

We acknowledged the importance of press brake. It was interesting to watch the operation of the bending machine as around 100 tons of force is appliedto make the sheet at right angle or some specific angle.

The job is taken to the welding area. The job and its edges are properly leaned to avoid any inclusions at the time of welding. The job is then kept on an anvil or support frame to weld. The bend edges are then welded by MIG or Argon welding. The job is then left idle toget cooler.

The job is further proceeded for grinding process. Here the edges and the weld portioned is grinded with the help of grinder with abrasive wheel there move the burr off the edges. Also the weld foul appearance is improved a lot by this grinding processes.

The job is then moved on for final coating. Generally the powder coating is done to give it durable outer membrane. This process increase the corrosion resistance and the life of the material. Mostly the various types of finish in powder coating are done on customer demands.

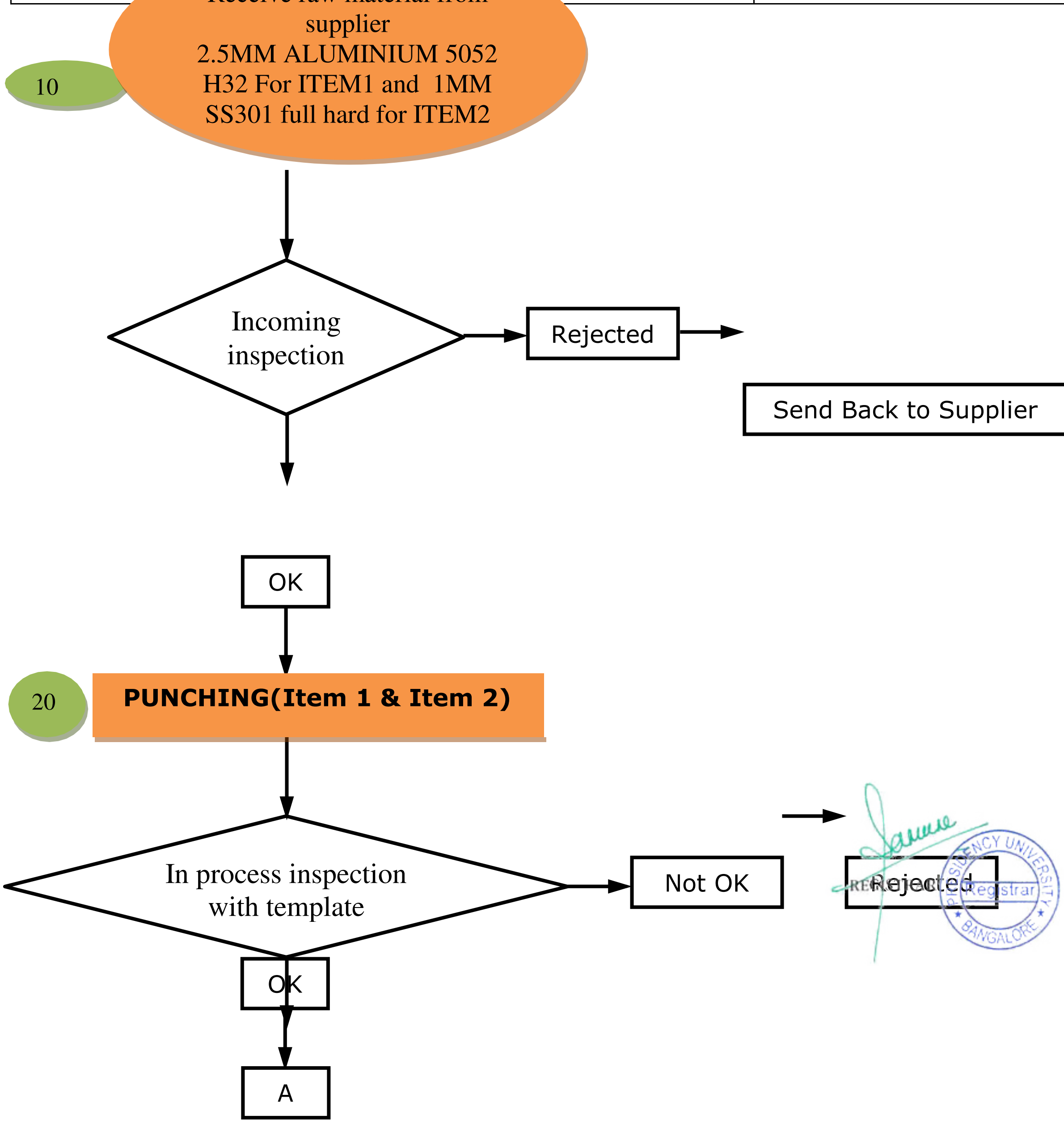
It was great to watch the whole process of fabrication for a sheet material up to ready enclosure or panel (Job). The fixed sequence of observing helped us to understand the pros and cons of various process.

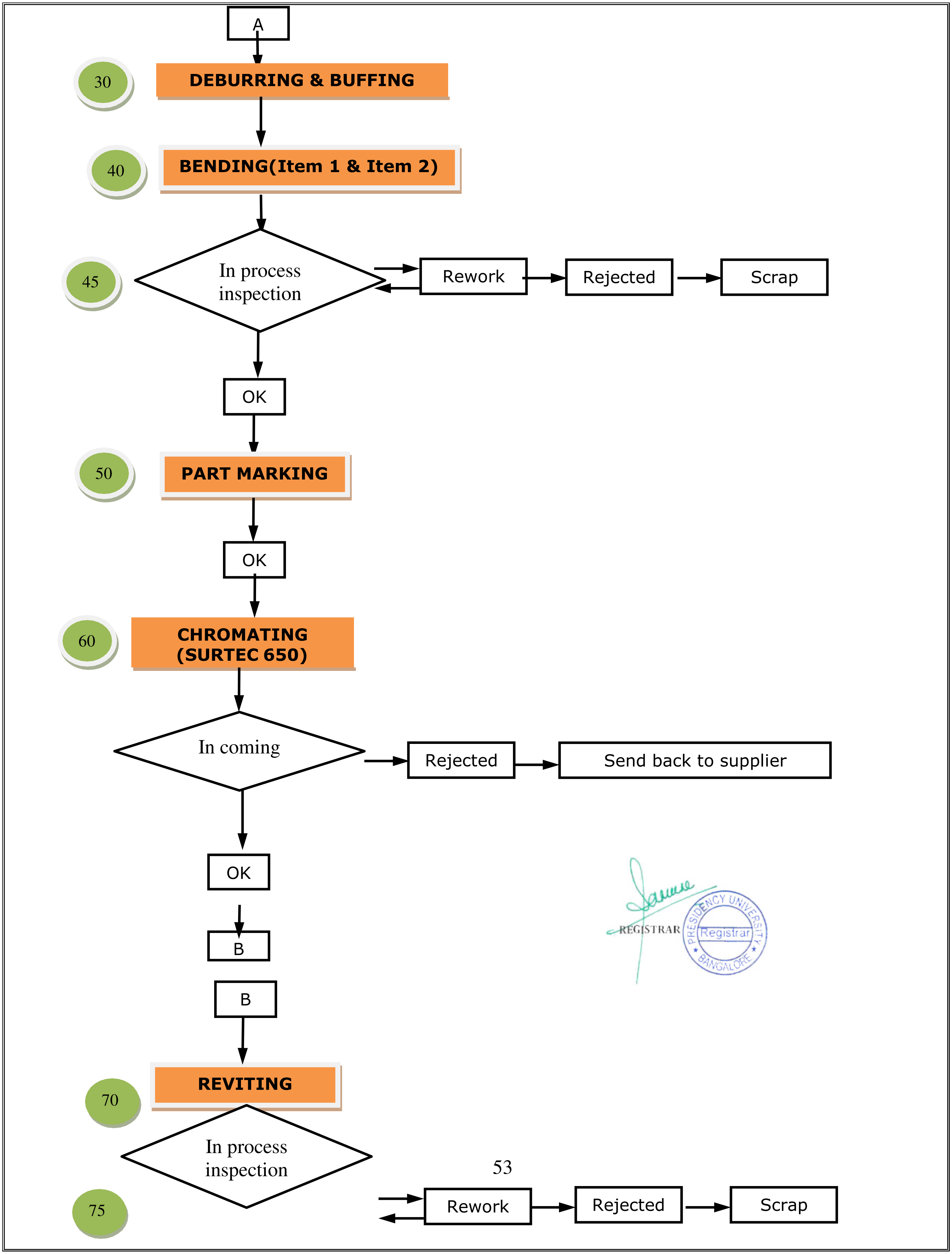
UNIQUE PUNCH SYSTEMS PVT. LTD.

Manufacturing Process Flow Chart

Doc no;PFD/ GE BEL/TONIX/01
Rev#: 00
Last Updated on:10/11/2018

Customer Name	Part No/Dwg no. Rev no	Description
GE	5498 R4	BRACKET HT AND DC FILTER SIDE




A
30
DEBURRING & BUFFING
40
BENDING(Item 1 & Item 2)
45
In process inspection
Rework
Rejected
Scrap
OK
50
PART MARKING
OK
60
CHROMATING (SURTEC 650)
In coming
Rejected
Send back to supplier
OK
B
B
70
REVITING
75
In process inspection
Rework
Rejected
Scrap
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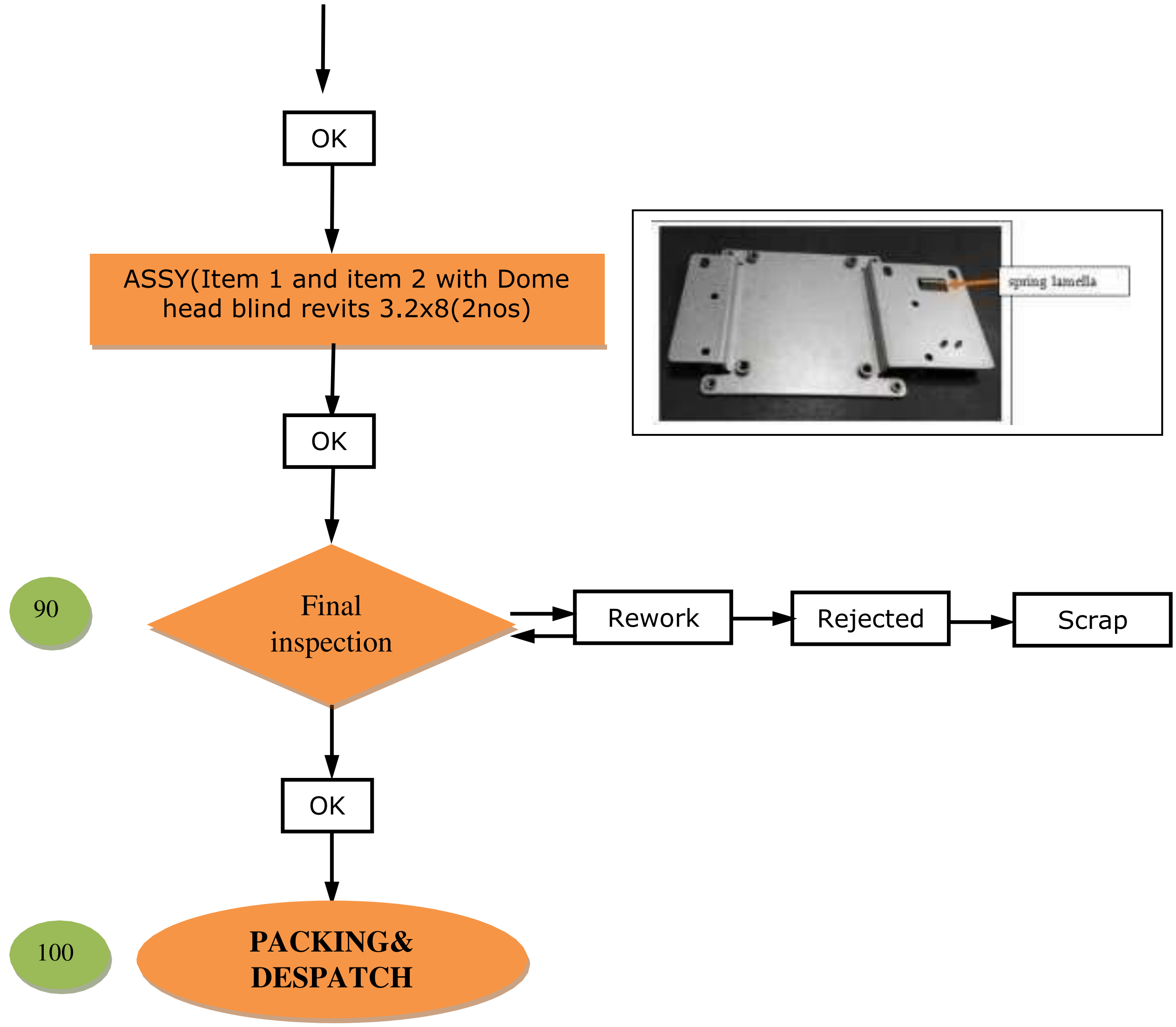

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Chapter 5.0

Results 5.1

Results

- Company focuses on modernization & up gradation
- They have a effective team work
- The company have structured organization
- Absenteeism of the company comparatively large.
- There is a heavy competition from other companies
- Increase in the price of the raw materials is one of the main thread
- They have a full team of experts
- After each operation quality check is done on the work pieces.

Conclusion 5.2

We conclude from this training that the various processes as applied are dependent on various parameters. A good co-ordination is the key to get best efficiency and high productivity.

- Each and every process depends on factors such as the method used to carry out the process, the type of the material used (whether Aluminum, Mild Steel, Brass,etc.) and the thickness of the material(orsheet).
- At the process of development of surfaces, the allowances are to be increased as per the thickness of metal.
- The bending force on the job increases with broadness and thickness of job but decreases with the length of die opening.

In the technical aspect all facilities for fabrications are also available at the premises we conclude that nothing can be understood thoroughly without practical knowledge and practice. We observed almost each process related to sheet metal fabrication that we had just studied in books. It was really a fruitful training for us to enhance our knowledge and confidence level.

On the whole ,this internship was a useful experience. We had gained new knowledge ,skills and met new people and learnt a lot from them. We achieved a lot of my learning goals .We got sight into professional practises currently happening in the industry. We got hands on experience with most of the machines here related to my studies back in college we learnt more about manufacturing ,assembly and finishing of products.

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Furthermore we gained experience that is of lot of importance that education is objective and that we have to be aware of the industrial aspect of the topics we study. This internship project was not one sided, but it was a way of sharing knowledge ,ideas and opinions.

The internship was also good to find out the what our strengths and weaknesses were and this helped us identify and develop that. we can confidently assert that the knowledge we gained through this internship is sufficient to contribute towards my future endeavours. At last this internship has given us new insights and motivation to pursue a career in core mechanical.

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PHOTOGRAPHS

Outlook of the company:Unique punch systems

A Project Report on

“Analysis on Cutting Process in a CO2 Laser Cutting Machine ”

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project in

Mechanical Engineering

Submitted by

Amar Raj R	**20171MEC0019**
Amarnath Gowda C	**20171MEC0020**
Chandan K R	**20171MEC0045**
Vignesh R	**20171MEC0233**

Under the Supervision of

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(Private University Estd. in Karnataka State by Act No.41 of 2013)

Department of Mechanical Engineering

School of Engineering

Itgalpura, Rajanukunte, Bengaluru - 560064

May -2021

Presidency University

School of Engineering

Department of Mechanical Engineering

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

CERTIFICATE

Certified that, the project work entitled, **"Analysis on Cutting Process in a CO2 Laser Cutting Machine"** carried out by **Mr. Amar Raj R** bearing Id No. **20171MEC0019**, **Mr. Amarnath Gowda C** bearing Id No. **20171MEC0020**, **Mr. Chandan K R** bearing Id No. **20171MEC0045**, **Mr. Vignesh R** bearing Id No. **20171MEC0233**, Bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in **Mechanical Engineering** of the **School of Engineering** during the year 2021. The Project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Dr. Ramesh S P
PP-II (In charge),
Associate Professor,
Dept. of Mechanical Eng..
Presidency University

Dr. Madhusudhan M
Guide,
Assistant Professor,
Dept. of Mechanical Eng.
Presidency University

DECLARATION

We, the students of eighth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, " **Analysis on Cutting Process in a CO2 Laser Cutting Machine**" has been successfully completed under the supervision of Dr. Madhusudhan M, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021.

Place: Bengaluru

Date:

Team members:	**ID Numbers**	**Signature of Students**
1. Amar Raj R	20171MEC0019	
2. Amarnath Gowda C	20171MEC0020	
3. Chandan K R	20171MEC0045	
4. Vignesh R	20171MEC0233	

ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. Ramesh S P** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. Ramesh S** Head Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Madhusudhan M** who gave us the opportunity to do this project work.

At the same time, we express our deepest thanks to o the management and staff of Goodwill Industries for giving us the opportunity to work on this project.

Lastly, we would like to thank our family and friends

Students Names	**ID Numbers**	**Signatures**
1. Amar Raj R	20171MEC0019	
2. Amarnath Gowda C	20171MEC0020	Amarnath
3. Chandan K R	20171MEC0045	CKR
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DIAGRAMS

ABSTRACT

LASER(Light Amplification by Stimulated Emission of Radiation) cutting is one of the best technology developed for the cutting, drilling, micro machining, welding, sintering and heat treatment. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated. A typical commercial laser for cutting materials involved a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. All cutting parameters have significant influence on quality work. The aim of this study is to relate the CO2 laser cutting parameters such as laser power and cutting power. The laser beam is typically 0.2mm in diameter with a power of 500～5000W. Depending on the application selection of different gases are used in conjunction with cutting. Increasing the frequency and the cutting speed, decrease the kerf width and the roughness of cut surface, while increasing the power and gas pressure increases the kerf width and roughness. This permits very tight tolerance control, and concentrates the heat to a smaller area, or heat affected zone (HAZ) and as a result, there is the least part distortion of any other heat related cutting technology. The relation between the input parameters and the response were investigated. The performance of laser cutting process mainly depends on laser parameter. Laser has been an important tool in the modern industries. Due to its unique properties such as high power density, coherency and directionality laser has a wide variety of application.

Keywords:-Laser cutting, Surface roughness, Process parameter, Heat affected zone, kerf width, CO2 , Heat affected zone.

1.1 INTRODUCTION

Fig.1

CO2 Laser machine has been used in industry for many applications such as laser cutting, laser engraver and laser marking. Laser cutting process is one of the famous applications of laser machine in industry. Laser beam usually used to cut small and precise products for assembly parts. The finished product of laser cutting process does not need any further finishing process. However, poor quality of cut has been rise as critical issues in industry due to the improper setting of cutting parameters. The main operating parameters associated with laser used machining are: laser power, spot diameter of the laser beam, cutting speed, feed rate and depth of cut. The cut quality traits like Edge Surface Roughness (Ra) and Surface Hardness are considered as output parameters. Improper selection of cutting parameters cause high manufacturing costs, low product quality and high waste. By proper control of the cutting parameters, good quality cuts are possible at high cutting rates.

Therefore, it is important to investigate the impact of cutting **parameters** on quality of cut.

Few advantages of Co2 Laser cutting over other cutting methods are:

High cutting speed: For example, the speed of 2kw laser power in cutting carbon steel with 8mm thickness is 1.6m/min while in cutting stainless steel with 2mm thickness is 3.5/m/min with tiny thermal influence are and tiny deformation.

Clean,safe and non-pollution

High Quality Cutting: Co2 cutting features thin kerf. The two sides of kerf are parallel, and the kerf is vertical to the surface. The cutting precision can reach to ±0.05mm. The cutting surface is clean and nice, with roughness of tens of microns. The cut components can even come into use directly without further machining. After laser cutting, the heat effected area is very small and material near to kerf has not been affected, making little deformation, high cutting precision and perfect geometrical shape.

Non-Contact Cutting: This means there will be no tool wear problem. When processing different shapes, there is no need to change tools, the only way is to alter the output parameter of laser. The whole laser cutting process features low noise, little vibration and little pollution.

1.2 WORKING PRINCIPLE

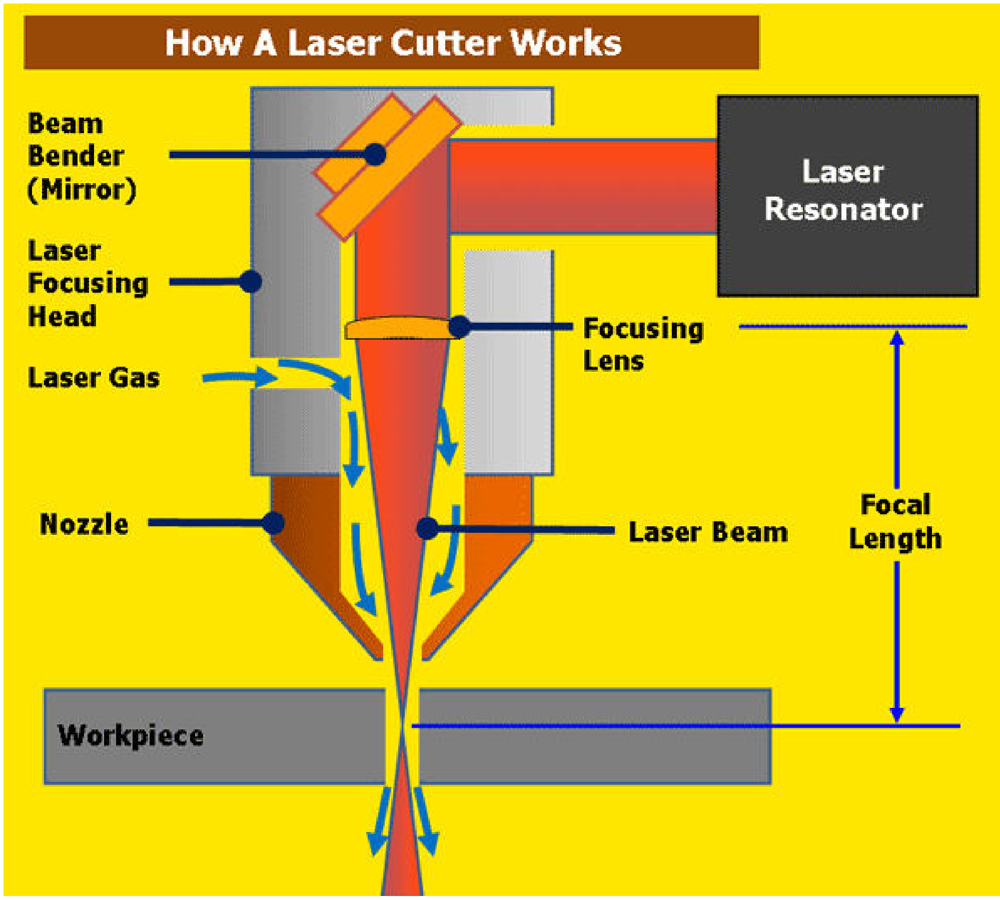


Fig 2

The laser beam is a column of very high intensity light, of a single wavelength, or color. In the case of a typical CO2 laser, that wavelength is in the Infra-Red part of the light spectrum, so it is invisible to the human eye. The beam is only about 0.2mm in diameter as it travels from the laser resonator, which creates the beam, through the machine's beam path. It may be bounced in different directions by a number of mirrors, or "beam benders", before it is finally focused onto the plate. The focused laser beam goes through the bore of a nozzle right before it hits the plate. Also flowing through that nozzle bore is a compressed gas, such as Oxygen or Nitrogen.

Focusing the laser beam can be done by a special lens, or by a curved mirror, and this takes place in the laser cutting head. The beam has to be precisely focused so that the shape of the focus spot and the density of the energy in that spot are perfectly round and consistent, and centered in the nozzle. By focusing the large beam down to a single pinpoint, the heat density at that spot is extreme. Think about using a magnifying glass to focus the sun's rays onto a leaf, and how that can start a fire. Now think about focusing 6 KWatts of energy into a single spot, and you can imagine how hot that spot will get.

The high power density results in rapid heating, melting and partial or complete vaporizing of the material. When cutting mild steel, the heat of the laser beam is enough to start a typical "oxy-fuel" burning process, and the laser cutting gas will be pure oxygen, just like an oxy-fuel torch. When cutting stainless steel or aluminum, the laser beam simply melts the material, and high pressure nitrogen is used to blow the molten metal out of the kerf.

On a CNC laser cutter, the laser cutting head is moved over the metal plate in the shape of the desired part, thus cutting the part out of the plate. A capacitive height control system maintains a very accurate distance between the end of the nozzle and the plate that is being cut. This distance is important, because it determines where the focal point is relative to the surface of the plate. Cut quality can be affected by raising or lowering the focal point from just above the surface of the plate, at the surface, or just below the surface.

1.3 PROCESS PARAMETERS

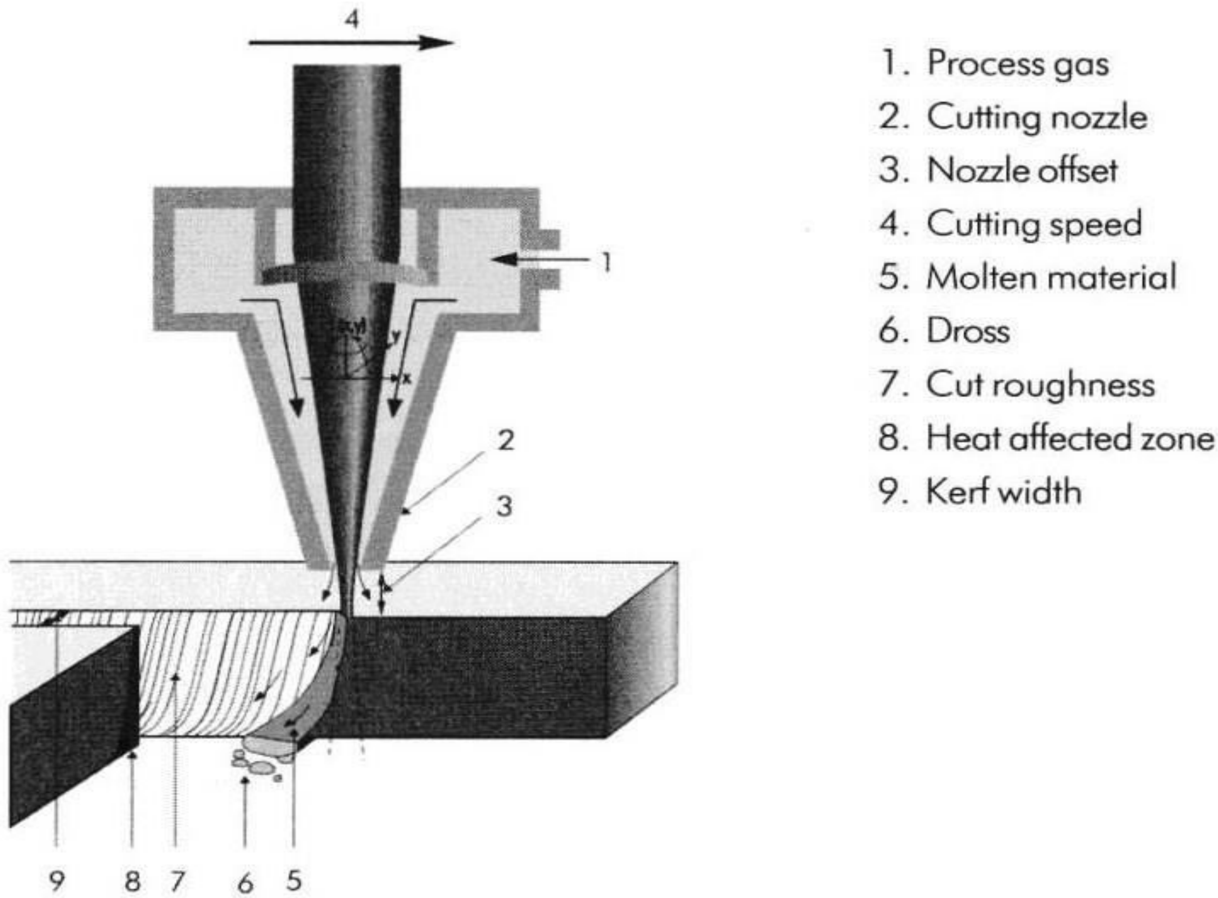
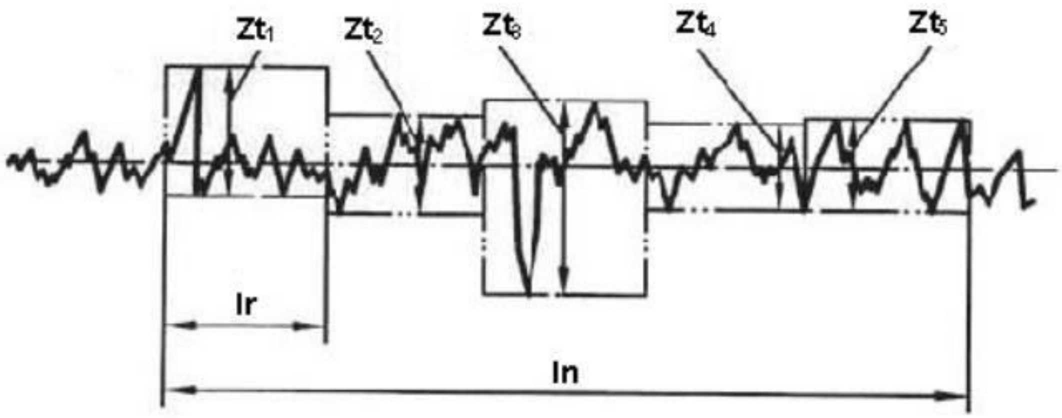


Fig 3:Laser cut surface characteristics

The process parameters include those characteristics of the laser cutting process that can be altered in order to improve the quality of the cutting process and achieve the required cutting results. However, some process parameters are normally not altered by the operator. The various parameters are listed which affects the cutting process.

1.3.1 Surface roughness



Where

Zt_1 to Zt_5	represent single profile elements;
ln	is the evaluation length;
lr	is the single sampling length

Fig 4

Surface roughness is the unevenness or irregularity of the surface profile and is measured as the mean height of the profile, Rz, or as an integral of the absolute value of the roughness profile, Ra. The mean height of the profile, Rz, is used in quality classification. The length of measurement is 15mm, which is divided into five partial measuring lengths. The distance between the highest peak and the lowest trough is determined for each partial measuring length and Rz, measured in micrometers, is the average of the five distances. The figure above is an illustration of single profile elements of five bordering single measured distances from which the average roughness of the profile can be obtained.

1.3.2 Kerf width

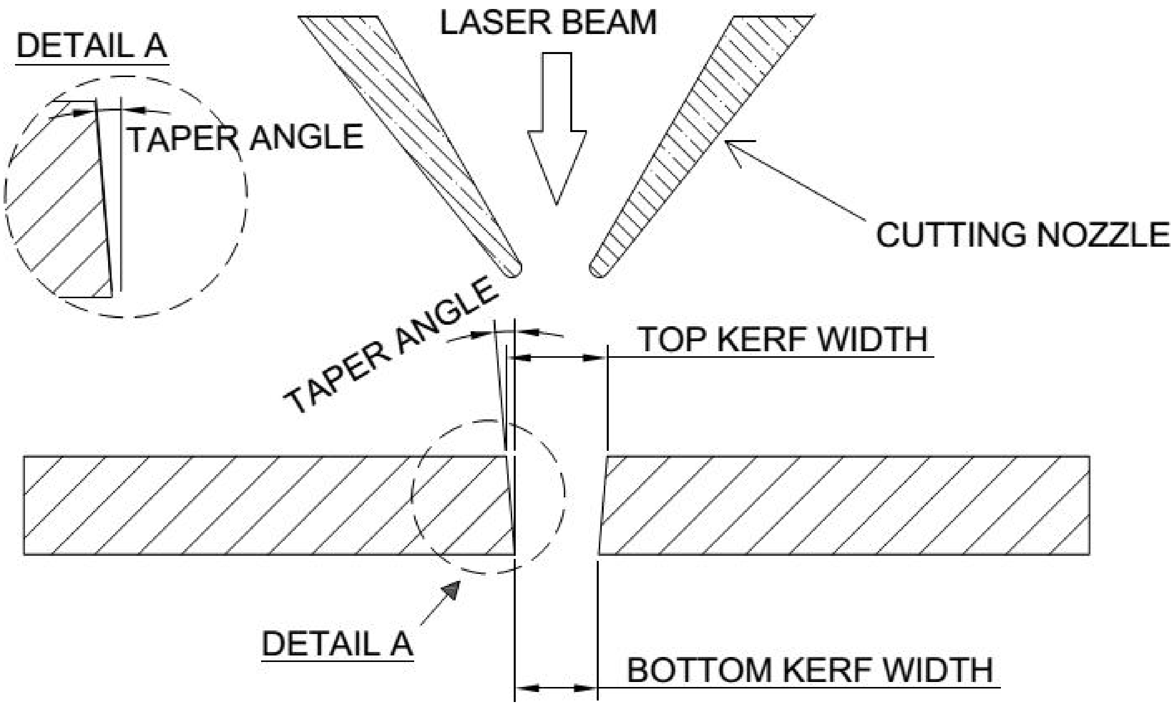


Fig 5

The kerf width refers to the width of the slot that is formed during through thickness cutting and is normally narrower at the bottom surface of the workpiece than at the top surface. The kerf width represents the amount of material removed during the cutting process, which is essentially wasted material; therefore, a smaller kerf width is always desirable especially when small details are to be cut. The width of the cut kerf corresponds to the circular beam waist size which is determined mainly by the laser beam quality and focusing optics. The power at the focused spot, cutting speed and the assist gas jet also have influence on the size of the cut kerf.

1.3.3 Heat Affected zone (HAZ) width

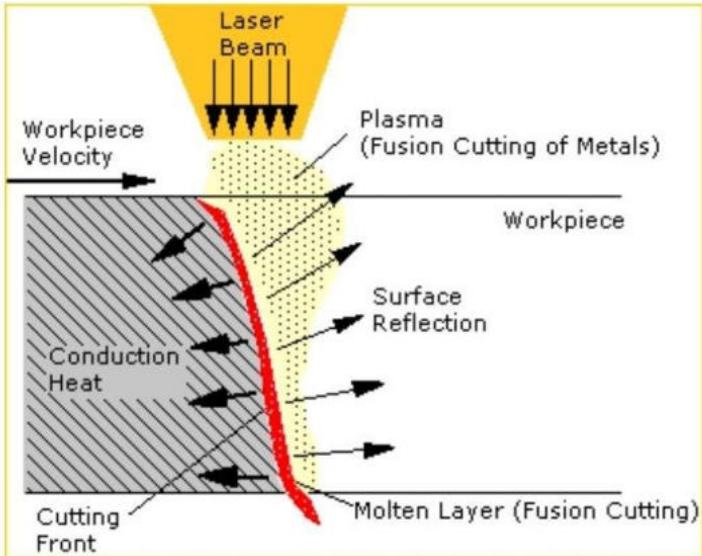


fig 6

The thermal heat of laser cutting produces a heat affected zone (HAZ) next to the cut edge. The heat affected zone is the part of the material whose metallurgical structure is affected by heat but is not melted. Microstructural variation in the heat-affected-zone is one of the characteristics that determine the quality of the laser cut. The HAZ width increases as the energy input per unit length and cut thickness increase. HAZ width is important when cuts are to be made near heat-sensitive components. The figure the several 57 physical mechanisms including conduction, phase change, plasma formation, surface absorption and molten-layer flow, which affect the efficiency of laser cutting. The formation of the heat-affected zone (HAZ) during cutting of austenitic stainless steel is considered to be negligible because the material is not hardenable by heat treatment. However, the heat conduction into the workpiece influences bulk phenomena such as grain refinement, carbide formation and other sulfide and phosphide impurities that might exist due to the alloying elements resulting into the formation of a detectable HAZ.

1.3.4 Cutting speed

The energy balance for the laser cutting process is such that the energy supplied to the cutting zone is divided into two parts namely; energy used in generating a cut and the energy losses from the cut zone. It is shown that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken. Therefore, the energy lost from the cut zone decreases with increasing cutting speed resulting into an increase in the efficiency of the cutting process. A reduction in cutting speed when cutting thicker materials leads to an increase in the wasted energy and the process becomes less efficient. The levels of conductive loss, which is the most substantial thermal loss from the cut zone for most metals, rise rapidly with increasing material thickness coupled with the reduction in cutting speed. The cutting speed must be balanced with the gas flow rate and the power. As cutting speed increases, striations on the cut edge become more prominent, dross is more likely to remain on the underside and penetration is lost. When oxygen is applied in mild steel cutting, too low cutting speed results in excessive burning of the cut edge, which degrades the edge quality and increases the width of the heat affected zone (HAZ). In general, the cutting speed for a material is inversely proportional to its thickness. The speed must be reduced when cutting sharp corners with a corresponding reduction in beam power to avoid burning.

1.3.5 Power and intensity

Laser power is the total energy emitted in the form of laser light per second while the intensity of the laser beam is the power divided by the area over which the power is concentrated. High beam intensity, obtained by focusing the laser beam to a small spot, is desirable for cutting applications because it causes rapid heating of the kerf leaving little time for the heat to dissipate to the surrounding which results into high cutting speeds and excellent cut quality. Additionally, reflectivity of most metals is high at low beam intensities but much lower at high intensities and cutting of thicker materials requires higher intensities. The optimum incident power is established during procedure development because excessive power results in a wide kerf width, a thicker recast later and an increase in dross while insufficient power cannot initiate cutting. High power beams can be achieved both in pulsed and continuous modes; however, high power lasers do not automatically deliver high intensity beams. Therefore, the focusability of the laser beam is an important factor to be considered.

1.3.6 Process gas and gas pressure

The process gas has five principle functions during laser cutting. An inert gas such as nitrogen expels molten material without allowing drops to solidify on the underside (dross) while an active gas such as oxygen participates in an exothermic reaction with the material. The gas also acts to suppress the formation of plasma when cutting thick sections with high beam intensities and focusing optics are protected from spatter by the gas flow. The cut edge is cooled by the gas flow thus restricting the width of the HAZ. Oxygen is normally used for cutting of mild steel and low-alloyed steels. Use of oxygen causes an exothermic reaction, which contributes to the cutting energy resulting into high cutting speeds and the ability to cut thick sections up to 12mm. However, oxygen cutting leads to oxidized cut edges and requires careful control of process parameters to minimize dross adherence and edge roughness. The oxygen pressure is reduced as plate thickness is increased to avoid burning effects and the nozzle diameter is increased. High gas purity is important – mild steel of 1mm thickness can be cut up to 30% more quickly using 99.9% or 99.99% purity oxygen in comparison with the standard oxygen purity of 99.7%. The cutting speeds and 39 maximum material thickness cut are relatively higher for the oxygen assisted cutting than for high pressure nitrogen cutting.

1.3.7 Nozzle diameter and standoff distance

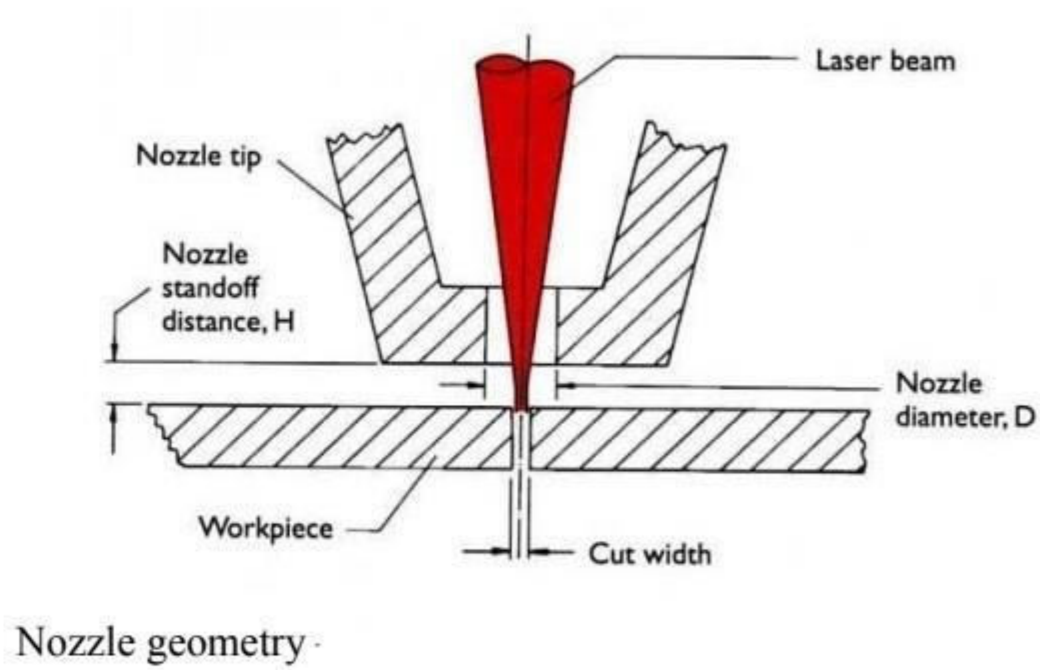


Fig 7

The nozzle delivers the cutting gas to the cutting front ensuring that the gas is coaxial with the laser beam and stabilizes the pressure on the workpiece surface to minimize turbulence in the melt pool. The nozzle design, particularly the design of the orifice, determines the shape of the cutting gas jet and hence the quality of the cut. The diameter of the nozzle, which ranges from 0.8 mm and 3 mm, is selected according to the material and plate thickness. Due to the small size of the focused laser beam, the cut kerf created during laser cutting is often smaller than the diameter of the nozzle. Consequently, only a portion of the gas jet formed by the nozzle penetrates the kerf, which necessitates the use of a high 40 gas pressure. Off-axis nozzles have also been used in mirror focusing applications but the cutting pressure is limited to 200Kpa. The stand-off distance is the distance between the nozzle and the workpiece. This distance influences the flow patterns in the gas, which have a direct bearing on the cutting performance and cut quality. Large variations in pressure can occur if the stand-off distance is greater than about 1mm. A stand-off distance smaller than the nozzle diameter is recommended because larger standoff distances result in turbulence and large pressure changes in the gap between the nozzle and workpiece. With a short standoff distance, the kerf acts as a nozzle and the nozzle geometry is not so critical. The previous figure shows the nozzle geometry definitions.

2. NUMERICAL ANALYSIS

Equations02 for determining surface roughness parameters: the standard roughness Rz and the mean arithmetic profile deviation Ra are obtained , based to experimental results, in the form: where: PL(kW) – the laser power, s(mm) – the sheet thickness, v(m/min) – the cutting speed.

$$R_z = 12.528 \cdot \frac{s^{0.542}}{P_L^{0.528} \cdot v^{0.322}}$$

$$R_a = 2.018 \cdot \frac{s^{0.670}}{P_L^{0.451} \cdot v^{0.330}}$$

2.1 OBSERVATION TABLE

Sl. No	**Laser Power (KW)**	**Cutting Speed (m/min)**	**Material Thickness (mm)**	**Gas Pressure (bar)**	**Rz (μm)**	**Ra (mm)**
1	1.4	1.4	12	13	61.78	8.21
2	1.8	2	12	13	48.23	6.51
3	2	4.4	12	13	35.39	4.78
4	2.4	3	12	13	36.36	5

2.2 RESULTS AND DISCUSSION

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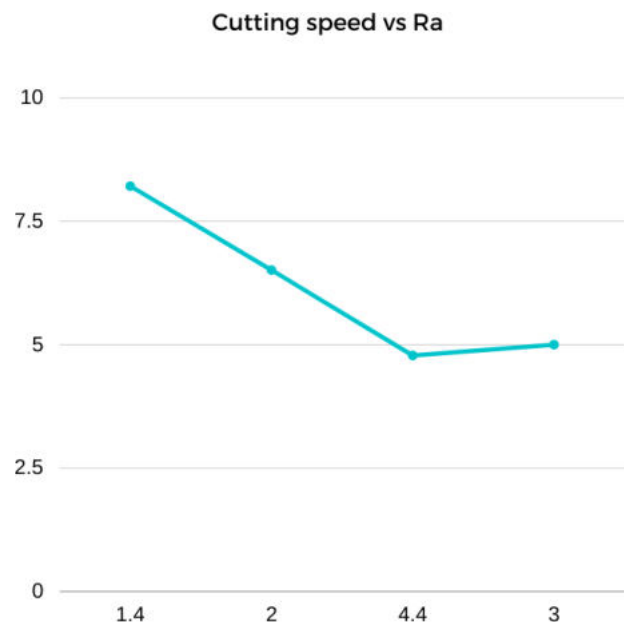

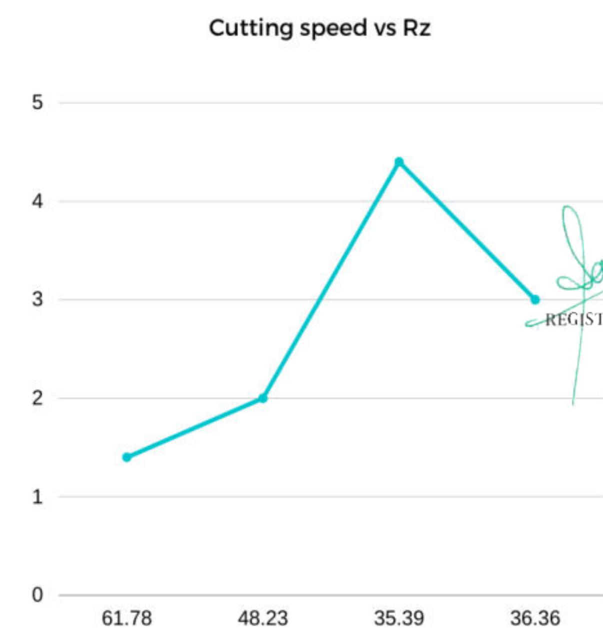

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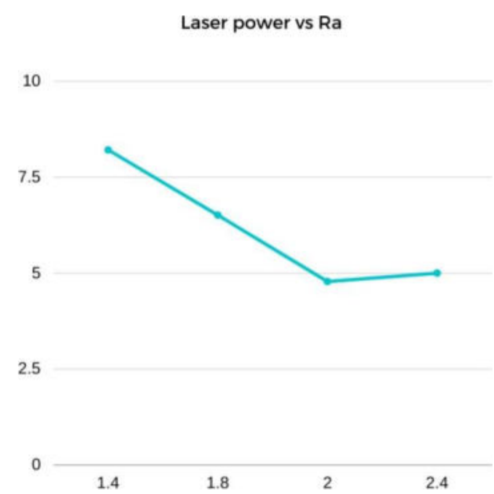
Laser power vs Ra
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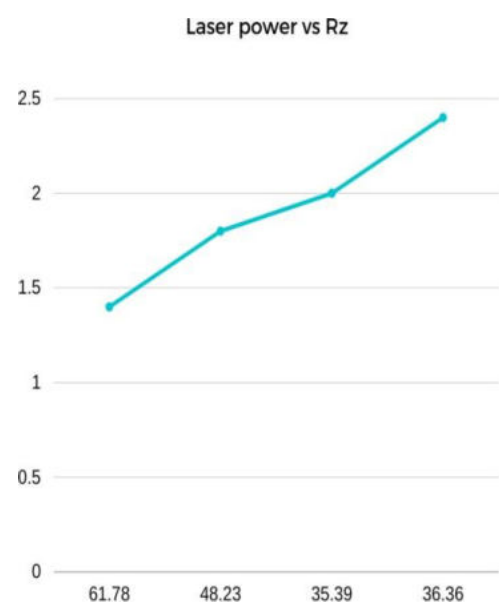
Laser power vs Rz
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1.5
1
0.5
0
61.78
48.23
35.39
36.36


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This experiment have been performed on the CO2 laser cutting machine with the CNC control. The technical characteristics of the CO2 Laser are radiation wavelength 10.6 µm.The optimal laser power is 1200 to 2600 W.The focusing system lens is of 28 mm in diameter and of focal distance is 125 mm.The nozzle con opening is 1.6 mm.The material used for experiment is Mild Steel. The work process is carried out by the oxygen process of 98% in purity. Working conditions are the assisting gas is O2 with pressure of 13 bar, laser power(PL) is 1.4 to 2.4 KW, Laser spot is on top of the plate surface. From the graphs, we can find that the surface roughness changes with cutting speed and laser power. 1.4 KW to 2.4 KW of Laser power by cutting with CO2 laser cutting machine.

3. LITERATURE SURVEY

- In 2012 Snežana Radonjić and Pavel Kovač has defined process parameter of laser machine Experimental research carried out during laser processing of AISI 314 resulted in an optimal cut . The optimal cut is obtained using the following processing parameters: feed rate 1250 mm/min, laser power 4400 W, focal point 16 mm, gas pressure 17 bars and nozzle distance 7 mm.
- Yusof et al. (2008) have found that at all cutting speeds, the kerf width increases by increasing the laser powers while sideline length and percentage over length decreases by increasing laser power. Increasing the cutting speed in pulsed mode led to rough surface and incomplete cutting while in CW mode, increasing the cutting speed with equivalent increase in power, led to better quality and smoother cut surface upto 8 m/min cutting speed. The SR also increases by increasing the peak power, gas pressure, pulse frequency and duty cycle. The surface roughness of the cut specimen can also be changed by changing spot over lap and pulse width.
- In 2008, Avanish Dubey In laser beam cutting (LBC) process, It has been found that the kerf width during LBC is not uniform along the length of cut and the unevenness is more in case of pulsed mode of LBC[8,14]. In this paper, two kerf qualities such as kerf deviation and kerf width have been optimized simultaneously using Taguchi quality loss function during pulsed Nd: YAG laser beam cutting of aluminium alloy sheet (0.9 mm-thick) which

is very difficult to cut material by LBC process. A considerable improvement in kerf quality has been achieved.

- In 2006 Miroslav and Predrag has worked on surface roughness by laser cut. Quality is very important. Observation of the cut surface can reveal two zones: the upper one in the area of the laser beam entrance side and the lower one, in the area of the laser beam exit side. The former is a finely worked surface with proper grooves whose mutual distance is 0.1...0.2 mm while the latter has a rougher surface characterized by the deposits of both molten metal and slag. Standard roughness Rz increases along with the sheet thickness, but decreases with increase of laser power. By cutting with laser power of 800 W standard roughness R is 10 µm for sheet thickness of 1 mm, 20 µm for 3 mm, and 25 µm for 6 mm. Correlation which connected the standard roughness (ten point height of irregularities) and mean arithmetic profile deviation, the linear and exponential relationships can be used.

4. CONCLUSION

According to the literature review, it has been found that most of the experimental studies on laser cutting are based on the one parameter at a time approach (OPAT). Most of the researchers have investigated the effects of different process parameters on different quality characteristics in laser cutting. The parameters studied in this work are kerf width, surface roughness, nozzle alignment, nozzle diameter standoff distance, focal distance, gas pressure and cutting speed. Consequently, all the parameters are analyzed to get the best result in laser cutting process. Certain parameters are needed to be adjusted to receive a best result for the laser cut on the work piece and enhance the quality of the laser cut. Laser cutting process is capable of cutting complex profiles in most of the materials with a high degree of precision and accuracy and the performance of laser cutting process depends on the input process parameters like laser power, cutting speed, assist gas pressure and stand-off distance on the important performance characteristics like surface roughness and kerf width. The parameters such as laser power, cutting speed, stand-off distance have major impact on surface roughness and kerf width. Whereas, the effect of assist gas pressure over surface roughness and kerf width is less significant. Laser cutting process is capable of cutting complex profiles in most of the materials with a high degree of precision and accuracy. The performance of laser cutting process depends on the input process parameters like laser power, cutting speed, assist gas pressure etc and also on the important performance characteristics like surface roughness, HAZ and kerf width.

We can conclude that with the changes in the power the roughness of the material decreases, while the gas pressure also has great effect on the surface roughness but with the high speed the roughness increases any may leads to the increase wider kerf width. For different material different gases are used this parameter has a wider impact on the material roughness and surface finishing. Mainly the CO2 , O2 and N2 are mainly used for the cutting process but with the use oxygen gas the surface may sometimes the material gets cracked and leads to failure of workpiece. Gas pressure has a major effect on all the quality parameters, i.e., HAZ width, kerf width and roughness.

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A Project Report on

"ERGONOMICS IN TABLE DESIGN"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2 in

Mechanical Engineering

Submitted by

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SHUBHADEEP PATRA-	20171MEC0217
STANZIN TSANLEX-	20171MEC0216
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(Private University Estd. in Karnataka State by Act No.41 of 2013)

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School of Engineering

Department of Mechanical Engineering

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CERTIFICATE (20)

Certified that, the project work entitled, **"ERGONOMICS IN TABLE DESIGN"** Bonafide students of Presidency University, in partial fulfillment for the award of Bachelor **of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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Dr. Ramesh S	**Dr. Ramesh S**
Supervisor	Professor and Head
End Term Examination Examiners	**Signature and dates**

DECLARATION

We, the students of eight semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, "ERGONOMICS IN TABLE DESIGN" has been successfully completed under the supervision of Dr. Ramesh S, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:

Team members:	**ID Numbers**	**Signature of Students**
SYED ABIS RIZVI-	**20171MEC0221**	
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ACKNOWLEDGEMENT (20)

We express our sincere gratitude to our supervisor, **Dr/Mr. ……** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. ....Prof. and Head** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. ………** who gave us the opportunity to do this project work.

At the same time, we expressour deepest thanks to ....

Lastly, we would like to thank our family and friends

Students Names ID Numbers Signatures

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2.SUBHADEEP PATRA	**20171MEC0217**
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4.SUDESHNA KASHYAP	**20171MEC0218**

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The success and outcome of this project required a lot of guidance and assistance from many people and we are extremely privileged to have got this all along the completion of our project. All that we have done is only due to such supervision and assistance and we would not forget to thank them.

We respect and thank Dr. M. Udaya Ravi, Prof. and Head of Department of Mechanical Engineering, for providing us an opportunity to do the project work and giving us all support and guidance, which made us complete the project duly. we are extremely thankful to him for providing us with support and guidance, although he had busy schedule managing the academic affairs.

We owe our deep gratitude to our project guide **Mr. MAHESHA K. Sir** who took keen interest on our project work and guided us all along, till the completion of our project work by providing all the necessary information for developing a good system.

we are thankful to and fortunate enough to get constant encouragement, support and guidance from all Teaching staffs of Mechanical Department which helped us in successfully completing our project work. Also, we would like to extend our sincere esteems to all staff in laboratory and workshops for their timely support.

ABSTRACT..

Background: Organization today face multiple challenges to maintain the health and performance of employees while attempting to integrate new technologies and support a widening range of work style. The paradigm shift in the lifestyle of office employees from active to sedentary style can be hours/day in a static working posture. This has impacted greatly the health of the employees. The study was undertaken to provide an insight to the various health-related problems of the office employees due to the workplace design and environmental conditions in the modern offices.

Methodology: 80 desk workers from various corporate office in the city of Mumbai were interviewed. A structural questionnaire for interview purpose was developed to elicit data pertaining to the work environment, workplace furniture, office equipment, and musculoskeletal disorders. The respondents were office workers who were professionals, managers and administrative workers.

Result: The results revealed that 80% of the respondents suffering from lower back pain (68.5%) followed by neck pain (64.2%), upper back pain (45.7%) and shoulder pain (44.2%) Respectively. 81.3% of desk workers did not get any type of ergonomics training on usage of office furniture's and computer related accessories. About 40% and above felt chair and table to be comfortable; but storage and printer placement was not satisfactory. 31.5% of the respondents reported the environment to be noisy and disturbing; leading to mental fatigue.

Conclusion: Sustained prolonged static posture, awkward posture, chair design, placement of keyboard and mouse and non-availability of footrest were stated as the most common causes for the musculoskeletal issues. Majority of the employees reported internal physical environment to be good; but they suffered from lack of concentration and stress respectively.

Key words: Workplace design, desk workers, MSD, furniture, environment.

CHAPTER 1.0

1.1 INTRODUCTION

The word ergonomics is derived from Greek Word 'ergon' and 'nomos'. These Greek words in combination literally mean 'law of work'. Thus ergonomics is concerned with creating laws to suit various works. The effects of health and safety on productivity cannot be properly discussed without touching on the concept of ergonomics.

The major field of application of ergonomics is the attainment of optimal working conditions or the working environment. This is possible by the most suitable use of worker's physical characteristics and physiological and psychological capabilities.

An office is a room where professional duties and administrative work is carried out in the organisation building. The details of the work depend on the type of business, but it will usually include using computers, communicating with others by telephone, e-mail, or fax, keeping records and files, etc., in a soft and hard format. Features of an office such as people, building space, equipment, furniture and the environment must fit together well for workers to feel healthy and comfortable and be able to work efficiently and productively.

Atleast, 50% of the world"s population currently works in some form of office.

Office work is rapidly changing as new developments in computer technology come along, which can make our jobs easier, but which also can present new problems for both management and employers. Office employees often spend more than 40 hours per week at their computer workstations; therefore, the office environment plays a significant role in the daily life a large number of people. Office furniture and office environment are major physical conditions that should gain more attention. Workstation designs significantly affect working posture, which in turn, contributes to physical symptoms.

In extensive survey in US it was found that almost one out of every five employees rated their workplace environment from, „fair to poor"; 90% admitted of work being adversely affected by the quality of their workplace environment and 89% blamed their working environment for their job dissatisfaction respectively. In the workplace, ergonomics is the science of designing or redesigning the workplace to fit the work and improve safety, comfort and productivity. Awkward and prolonged static postures contribute to musculoskeletal discomforts among office desk workers is the known fact.

Although we know discomfort due to long periods of intense office work can be mediated by regular postural change; but research suggests that knowledge about the importance of postural change is not enough. The combination of ergonomic furniture and experimental software applications designed to prompt shifts from seated positions to standing positions, help to produce the most dramatic reduction in discomfort. With proper setup, monitor arms help organizations meet ergonomic requirements for safety and reduce risk of injury to employees. Recent studies show that a safe working environment requires more than just ergonomically designed furniture, suggesting that training and behavioural cues may be required to address the ergonomic challenges of today"s office worker.Tremendous usage of computers in most offices of emerging economies have however, not seen accompanying applications of ergonomics in the design of computer workstation despite the numerous benefits.

Injuries and discomforts therefore have higher propensity to occur since most offices formally designed for paper-based work now accommodate computer workstations, without corresponding redesigning. The need to use computers increases as computer technology advances and software and computer packages are being developed.

As a result, occupational health and safety problems are continuously increasing. This, obviously, can lead to reduced performance and dissatisfaction.[10]In addition to these, individuals who use computers for a prolonged period may also experience eye and vision problems, which are caused due to improper viewing distance, poor lighting, glare on the monitor screen, etc. [11]Indoor air quality is another important factor; not only for workers‟ comfort but also for their health. Poor ventilation, uncontrolled temperature, too high or low humidity are some of the factors that can cause poor indoor air quality. Exposure to these hazards causes immediate symptoms such as headaches, fatigue, concentration problems, and irritation of eyes, nose and throat. Some of the environment related hazards that are usually presented in offices are poor lighting and noise pollution.

Nowadays, some modern offices may lack natural lighting, while some others may face too much noise.[11] A survey was conducted to find the relationship between indoor environment, dissatisfied employees and their productivity. The results revealed that the productivity of the work is affected because the people were unhappy with temperature, air quality, light and noise levels in the office.[12]Stress can help people complete their tasks more efficiently and accomplish goals; but excessive work-related stress can have health effects like anxiety, irritability, depression, sleeping problems, eating disorders, fatigue, inability to concentrate and loss of interest in work that may contribute to low productivity. Stress can be caused by poor work organization, over or under work, lack of support from the employer and colleagues, lack of respect and many other factors. Work styles are becoming more complex, evolving to encompass a wider variety of interactions within a greater diversity of workspace types.

All of these factors elevate ergonomic hazards to office workers now and in the future.[1]Previous studies have reported of physical, psychological and organizational problems that office workers face, including problems like incorrect workstation set-up, poor lighting, poor layout of furniture, electrical hazards, etc. Therefore, the present study was carried out with the aim to find out the risk associated with the workplace design, indoor office environment; MSD‟s problems and other health-related problems among the office workers. required data. This questionnaire consisted of 10 questions in total which focus on the musculoskeletal problems faced by the employees, absenteeism due to health problems, probable causes of the health problems, work environment parameters, workstation comfort, work equipments and training imparted for the use of office furniture. The data was collected through administration of physical questionnaires, telephonic interviews method and Google forms. An insight about the research was explicated to them prior to the commencement of the data collection process.

Consent was taken from all the respondents before starting the data collection process.

Statistical Analysis Statistical analysis was performed using standard descriptive statistical tests with the help of MS Office Word Excel Spreadsheet. Mean and percentages were computed for the tables.

CHAPTETR 2

2.1 LITERATURE SURVEY

ERGONOMIC STANDARDS

The second scientific approach regards the application of ergonomic standards as support tools for the ergonomic effective design. Among the ergonomic standards, the following have to be regarded as the most widely used: the NISOH 81 and the NIOSH 91 equations for lifting tasks (NIOSH stands for National Institute for Occupational Safety and Health); the OWAS analysis for analyzing working postures (OWAS stands for Ovako Working Analysis System); the RULA method for estimating the risks of work-related upper limb disorders (RULA stands for Rapid Upper Limb Assessment); In the sequel research works are introduced according to the ergonomic standard used. The section consists of 5 subsections. Three subsections for presenting the research works concerning the most widely used ergonomic standards (one subsection for each ergonomic standard). The forth subsection is then reported for introducing the less used ergonomic standards: the OCRA methods for analyzing worker's exposure to tasks featuring various upper-limb injury risk factors (OCRA stands for Occupational Repetitive Action); the Garg analysis for assessing the energy expenditure for performing an operation; the Burandt-Schultetus analysis for lifting tasks involving a large number of muscles. In conclusion, the last subsection proposes the research works based on the integration of several ergonomic standards. Before getting into the details of each subsection, a brief description of the ergonomic standard under consideration is provided.

3.1. NIOSH 81 and NIOSH 91 method

NIOSH 81 and NIOSH 91 evaluate the ergonomic risk levels affecting the lifting tasks. The NIOSH 81 method calculates the action limit (AL) and the maximum permissible limit (MPL). AL is the weight value which is permissible for 75% of all female and 99% of all male workers. MPL is the weight value which is permissible for only 1% of all female and 25% of all male workers.

The NIOSH 91 analysis, additionally to the NIOSH 81, includes the recommended weight limit (RWL) and the lifting index (LI). The RWL is the load that nearly all healthy workers can perform over a substantial period of time for a specific set of task conditions. The LI is calculated as ratio between the real object weight and theRecommended Weight Limit. Further information about the cited ergonomic standards can be found in Niosh Technical Report (1981) and Waters et al. (1994). Let us present the research works aiming at achieving the workplace ergonomic effective design by means of NIOSH analysis. Grant et al. (1995) analyze musculoskeletal trauma among preschool workers in the United States by means of NIOSH methods. The authors evaluate the possible causes of back and lower extremity pain among 22 workers at a Montessori day care facility. Finally they present recommendations for modifying the workplace and changing the organization and methods of work as well. Grant et al. (1997) evaluate the magnitude of lifting hazards in the shipping department of a wooden cabinet manufacturing company.

The representative lifts are analyzed using the Revised National Institute for Occupational Safety and Health (NIOSH) Lifting Equation. The results suggest that work in shipping department imposes a high level of physical demand, which may increase the risk of work related back pain and other musculoskeletal injury. In this regards the authors provide recommendations for reducing physical workload through automation, introduction of mechanical assists, changes in work organization and more frequent job rotation. Mital and Ramakrishnan (1999) analyze a complex manual materials handling task, which involved lifting, turning, carrying, and pushing activities, by using both the old and revised NIOSH lifting guidelines (Niosh Technical Report 1981; Waters et al., 1993) as well as the guidelines provided by Mital et al. (1993, 1997). Hermans et al. (1999) evaluate the effect of using a mechanical device on physical load during the end assembly of cars.

According to the NIOSH equation, 8 out of 10 of the tasks should only be performed by trained workers and preferably with tools. Chung and Kee (2000) analyze lifting tasks using the 1991 revised NIOSH lifting equations for a fire brick manufacturing company with a high prevalence of low back injuries. The results suggest that the tasks should be redesigned ergonomically to eliminate the risk factors that may cause low back injuries. The authors propose a tasks redesign based on making horizontal locations closer to a worker or reducing the symmetric angles. Temple and Adams (2000) use the NIOSH analysis in order to establish ergonomic acceptable limits for an industrial lifting station. Through the analysis of several factors the authors define a cumulative lifting index and use such index for detecting ergonomic problems during lifting tasks. They successively modify the lifting station for reducing ergonomic risks and preventing lower back related injuries. Lin and Chan (2007) carry out an ergonomic workstation re-design for reducing musculoskeletal risk factors and musculoskeletal symptoms among female's workers of a semiconductor fabrication room. By means of walkthrough observations of the working environment, discussing with company's managers and using NIOSH analysis, the authors identify the most prevalent and urgent ergonomic issues to be resolved and modify the layout of the workplace for reducing ergonomic hazards.

3.2. OWAS Analysis

The OWAS analysis carries out a qualitative analysis of the worker's movements during a working process. The analysis calculates the stress associated to each body posture and classifies them in one of the following four stress categories:

- Category 1: the stress level is optimum, no corrective interventions are required;
- Category 2: the stress level is almost acceptable, corrective interventions are necessary in the near future;
- Category 3: the stress level is high, corrective interventions are required as soon as possible;
- Category 4; the stress level is very high, corrective interventions must be carried out immediately.

Further information about the cited ergonomic standard can be found in Kharu et al. (1981). During the last years several research works have adopted the OWAS analysis for evaluating the workers body postures. Carrasco et al. (1995) describe an ergonomic evaluation of three different designs of checkouts workstation, which require the operators to stand when they scan the products, pack them into plastic bugs and transfer the packed bags to the customer. Musculoskeletal load and exertion associated with the different checkouts are measured using the OWAS analysis. The results of the evaluation form the basis of recommendations for an improved workstation design.

Nevala-Puranen et al. (1996) analyze physical workload and strain when milking in a parlor. OWAS analysis is accomplished for evaluating the postural load. The authors assert that the information of this study can be utilized in the development of the working environment of milking. Scott and Lambe (1996) implement the OWAS in a poultry industry. The authors apply the ergonomic analysis highlighting wrong postures and providing the guidelines for an improved workstation design. Van Wendel de Joode et al. (1997) conduct a workplace survey in order to quantify the physical load in a population of male workers in two ships maintainace companies. The Ovako Working Postire Analizyng System is used for measuring the postural load.

The results reveal that awkward postures of the back occurr in 38% of the work time and the stress on the neck/shoulder region due to one or both arms above shoulder level is present in 25% of the work time. White and Kirby (2003) use the OWAS analysis for evaluationg health-care workers in the methods used to fold and unfold selected manual wheelchairs. The authors conclude that many of the methodsused include bent and twisted back postures that are known to be associated with a high risk of injury. Perkiö-Makelä and Hentilä (2005) estimate the physical workload and strain of dairy farming in loose housing barns. The feeding and removing manure and spreading of bedding are analyzed by means of OWAS analysis. On the basis of the analysis results, the authors provide some recommendations for the building of new loose-housing barns (for example, providing enough space for automated feeding and cleaning systems).

3.3. RULA method

RULA is a postural targeting method for estimating the risks of work-related upper limb disorders. A RULA assessment gives a quick and systematic assessment of the postural risks to a worker. The analysis can be conducted before and after an intervention to demonstrate that the intervention has worked to lower the risk of injury. The RULA action levels give you the urgency about the need to change how a person is working as a function of the degree of injury risk.

- Action level 1: it means the person is working in the best posture with no risk of injury from their work posture;

- Action level 2: it means that the person is working in a posture that could present some risk of injury from their work posture, so this should be investigated and corrected;

- Action level 3: it means that the person is working in a poor posture with a risk of injury from their work posture, and the reasons for this need to be investigated and changed in the near future to prevent an injury;

- Action level 4: it means that the person is working in the worst posture with an immediate risk of injury from their work posture, and the reasons for this need to be investigated and changed immediately to prevent an injury.

A full description of the RULA method is contained in McAtamney and Corlett (1993). In the last decades, several authors have used the RULA method as support tool for achieving the workplace ergonomic effective design.

Gonzáles et al. (2003) evaluate the relationship between the ergonomic design of workplaces and achieved product quality levels. In particular, a metalworking firm with ISO-9002 certification was selected, and its quality results were analyzed with respect to reprocessed and rejected parts after varying the initial work method on the basis of the results of an ergonomic evaluation by means of RULA. It was concluded that a reduction in ergonomic problems implies better quality records.

Massaccesi et al. (2003) investigate work related disorders in truck drivers using the RULA method. A sample of 77 drivers, of rubbish-collection vehicles who sit in a standard posture and of roadwashing vehicles, who drive with the neck and trunk flexed, bent and twisted, is studied. After the analysis, the authors conclude that ergonomic interventions aiming at modifying the truck's workstation are recommended for preventing musculo-skeletal disorders.

Choobineh et al. (2004) propose ergonomic intervention in carpet mending operations. Seventy-two menders are questioned regarding musculoskeletal disorders. Based on the problems found, a new workstation is developed and eight menders are asked to work in the new workstation. They are observed and evaluated with the RULA technique and their opinion on the improvement is asked working on four Frequently seen tasks. The new workstation improves working posture noticeably.

Shuval and Donchin (2005) propose an application of the RULA method in the HI-TECH industry. Results of the RULA underline the need for implementing an intervention program focusing on arm/wrist posture.

3.4. Others ergonomic standards

Here the OCRA method, the Garg and Burandt Schultetus analysis are briefly described.

3.4.1. OCRA methods

The Occupational Repetitive Action methods (OCRA) analyze worker's exposure to tasks featuring various upper limb injury risk factors (repetitiveness, force, awkward postures and movements, lack of recovery periods). The OCRA methods are the OCRA index and the OCRA checklist. The OCRA index can be predictive of the risk of upper extremity work related musculoskeletal disorders in exposed populations. It is generally used for the (re)design or in depth analysis of workstations and tasks (Columbine et al. 1998, 2002).

The OCRA checklist, based on the OCRA index, is simpler to apply and is generally recommended for the initial screening of workstations featuring repetitive tasks (Occhipinti et al. 2000; Columbine et al. 2002).

The OCRA method is based on a consensus document of the International Ergonomics Association (IEA) technical committee on musculoskeletal disorders (Columbine et al. 2001).
Further information regarding OCRA methods can be found in Occhipinti and Columbine (1996).

3.4.2. Burandt Schulte Tus analysis

The Burandt-Schulte Tus analysis allows evaluating the load limits for a specific working posture (keeping into consideration the weight of the grasped objects). The BurandtSchultetus analysis is usually applied to lifting activities in which a large number of muscle groups are involved. The main result is the maximum weight (Permissible Limit, PL) that the worker can lift. The Permissible Limit can be evaluated by using equation

(1):

PL = G *C * AJ * RF (1)

• G is a coefficient for the worker's gender;

• C is a coefficient for the worker's health condition; • AJ is a coefficient for worker's age and type of job;

• RF is the reference force.

Note that the AJ (Age and Job factor) depends on the effort type (i.e. static or dynamic), the worker's age, the shift time (i.e. 8 hours) and the effort frequency. The RF takes into consideration the torso weight movement, the hands use (i.e. one or two hands), the number of persons performing the operation (i.e. one or two persons), the effect of secondary jobs and the maximum force. In turns, the torso weight movement depends on the lower and upper grasp height and motion frequency; the maximum force depends on body size class (anthropometric measure), upper grasp height and distance of grasp from the body.

The maximum permissible force is then compared to the current actual force (AF) being exerted. Three different cases can be distinguished:

- Case 1: the maximum permissible force does not exceed the actual force then an ergonomic intervention is required;
- Case 2: the maximum permissible force is equal to the actual force, then a corrective intervention is necessary in the near future;
- Case 3: the actual force is lower than the maximum permissible force, then no ergonomic intervention is required.

Further information can be found in Schulte Tus (1980).

3.4.3. Garg analysis

The Garg analysis calculates the total amount of energy spent during the manual operations. The analysis splits up a specified operation into smaller steps calculating for each of them the Energy Expenditure (EE); the sum of these separate steps represents the total Energy Expenditure for the activity. As input parameters, such analysis requires information concerning load weight and body weight as well as gender of the working person. Further information can be found in Garg (1976).

3.5. Ergonomic standards integration

In order to achieve relevant ergonomic improvements some authors propose an effective ergonomic design based on the integration of different ergonomic standards.

Wright and Haslam (1999) investigate manual handling risks within a soft drinks distribution centre using the OWAS postural analysis and the NIOSH equations. The authors compare two working methods involving pallets and cages. The analysis detects significant manual handling risks and reports musculoskeletal disorders.

Jones et al. (2005) present an examination of three common pub occupations (bartending, waitressing and cooking). Risk of musculoskeletal injury is evaluated for the three occupations analysed by means of RULA method and NIOSH Lifting Equation. Finally recommendations for reducing the risks are provided.

Jones and Kumar (2007) quantify physical exposure information collected from 15 sawfilers in four sawmill facilities by means of the RULA, REBA, ACGIH TLV, Strain Index and

OCRA procedures based on multiple posture and exertion variable definitions. Russell et al. (2007) compare the results of different ergonomic standards (NIOSH, ACGIH TLV, Snook, 3DSSPP and WA L&I) for evaluating ergonomic risks in lifting operations. Each ergonomic standard is applied to a uniform task (lifting and lowering two different types of cases) with the aim of choosing the best work methods by appropriately interpreting the results of the ergonomic analysis.

CHAPTER 3.0

3.1 METHODOLOGY

The design process chosen for this project is a user-cantered design. This kind of process is focus on the user needs and requirements. It is developed as follows:

3.1 Problem definition

3.1.1 CATWOE:

"CATWOE" is a mnemonic of a creativity method which aim is to define the goal of the problem. It was designed by Check land and Scholes, Soft Systems Methodology in Action in 1990. CATWOE describes the human activity and its processes performed by customers and actors, controlled by owners and occurs within an environment. This method is applied to the system that contains the problem. It consists in defining the following terms:

C: customers of the system. Those people who benefit or suffer from the process of the system.

A: actors. Those people who are going to carry out the main activities for what the system was defined.

T: transformation process. What the system does to give something useful for the actor in the end.

W: world view. Context in which the system is going to be placed.

O: owners. Those people who control the system and can do whatever they want with it when they wish.

E: environmental constraints. Ethical limits, financial constraints, regulations,

limitations… [10]

3.1.2 Gantt Chart:

A Gantt chart is a tool used to plan the schedule of the project. It includes the start and the end and all the dependencies between the tasks that are going to be done during the project.

The duration of each task can be visualized in bars, their length dependson their duration. It allows to easily see the different activities, when they begin or end, how long they last. [11]

3.2 Product design specifications (PDS):

The product specifications it's a very important tool while developing the product. It is used to enumerate all the requirements that must be met in the product that has to be designed, in order to define it, and complete the first brief. [12] There are different kinds of specifications:

• Technical specifications: characteristics of the product.

• Requirements of the product considering the customer

needs o Ergonomic requirements (size, weight…) o

Functions o Things related to use

• Material requirements o Aesthetics o Environment of the

product (interaction and conditions) o Safety of the

product o Life of the product* o Standards and

requirements o Maintenance of the product* o Recycling

and expected disposal* o Manufacturing process

requirements and limitations* o Packaging requirements*

• Methodological specifications*: characteristics of the process.

o Quantity of products o

Launching date of the product

o Manufacturing time o Time

in stock

3.3 Stakeholder analysis:

This analysis is used in order to identify who the different stakeholders of the product are, their interest and requirements in order to know what to focus on for our design.

[13] The techniques used are:

3.3.1 Mood boards:

This technique is based in a collage consisting of images and text related to a defined theme. It helps to get an overall idea of the topic this product is going to be based on.

[14]

3.3.2 Ability analysis:

In order to know what the children can or cannot do, it is necessary to analyze their abilities so that their limitations when using something can be taken into account.

3.3.3 Requirements:

This analysis is based on the requirements of the users regarding the product. It is used to know more of our stakeholder's needs, which are the most important features for them or how they use the product. [15] o Material requirements o Aesthetics o Environment of the product (interaction and conditions) o Safety of the product o Life of the product* o Standards and requirements o Maintenance of the product* o Recycling and expected disposal* o Manufacturing process requirements and limitations* o Packaging requirements*

• Methodological specifications*: characteristics of the process.

o Quantity of products o Launching date of the product

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3.4 Evaluation of the existing adjustable table:

This analysis provides information of the usability of the table, how the users interact with it and how are they features. It can be used to improve the new table taking into account the problems that the user has with it or the things that can be changed in order to improve the product.

3.5 Task analysis:

This analysis helps to understand better the relation between the product, the task and the user. How the task is going to be developed by the user concerning the product and how to make it easier. [16]

3.6 Analysis of the product environment:

The analysis of the product environment helps to understand the space in which the product is going to be used and placed, so that the design can be adapted to it following its requirements. [17] **3.7 Market analysis:**

3.7.1 Company:

It is important to know which products are part of the company's catalogue in order to follow the same aesthetics and design a similar product.

3.7.2 Competitors: Knowing the competitors in the field where the product is going to be launched is important to understand the market. This analysis helps to know what competitors have and what would be our competence when placing our product in the market and also trends and development of the rest of the companies in order to get an overview of it. [18] Taking into account all this information the new product would be successful in this market. **3.8 Ergonomic analysis:**

In order to have the best design for the product is important to take into account some characteristics of the user and the way he interacts with it. Ergonomics is based in the study of interactions between the product and the user. Ergonomics works together with anthropometrics in order to apply to the products measurements based on the study of the human body and its movements. [19]

The final design is based on anthropometric charts of children on the age range of 7-16 as it is the age range of the users of this new desk.

3.9 Related standards:

Standards are the different norms established that regulate the design of this kind of products and are necessary to take into account while designing. These standards stem from institutes that create them and stablish them in the place they belong to.

Since the table is for a Swedish company, the standards come from the "Swedish standards institute" [20]

3.10 Idea generation:

3.10.1 Brainstorming:

It's a creative method for generating ideas and solutions. This technique is performed by a group of people in which each of the members has to create their own spontaneous ideas based on a problem in order to find a solution for it. The aim of this technique is to come up with as many thoughts and ideas as possible. Some of this ideas are used after as a creative solution for the problem and others can be used in order to develop more ideas. Brainstorming sessions are very helpful since it they are hold by a group, avoiding criticizing which provides a free and open environment where lots of ideas grow. [21]

3.10.2 Sketching:

Making easy drawings in order to understand the ideas that have emerged before. It is an easy method to visualize ideas and give them a shape. [22]

3.10.3 3D modelling:

3D Modelling the process of emerging with representations of a three-dimensional surface of an object. Although they are in 3D, they can be shown as a 2D image through rendering (view in 3.10.4). This kind of representations usually follow the sketching process and they help to visualize the product with computer. It's used to develop the concepts and represent ideas.

Models can be created manually or automatically with a 3D modelling software. [23]The software that is going to be used is called Inventor and it belongs to Autodesk.

Inventor is a 3D CAD software that allows to create mechanical design, documentation, and product simulation tools in a professional-grade. It is similar to other CAD programs such as SolidWorks, Pro-ENGINER, CATIA and Solid EDGE. It provides tools to create different pieces and assemblies. The basics of this program are pieces, built by 2D sketches that can be drawn in a plane and extruded afterwards. This modelling system is very intuitive since it is quite easy to control all the dimensions and parameters of the piece. It provides modelling flexibility, each designer can decide the way he wants to design, with its parametric parameters. It can work with any kind of files from other 3D CAD programs maintaining the same settings. [24]

3.10.4 Rendering:

It's the process of generating a digital image from a 2D or 3D model in a realistic way.In order to get this image, it is necessary to use computer programs based on 3D computer graphics. [25]

There are a lot of different rendering programs but the one that is going to be used is called VRED. This program belongs to Autodesk.

3.11 Idea selection:

3.11.1 Concept evaluation:

Concept evaluation is a method that helps to choose the correct concept in order to develop it in the following steps. It provides the correct information to make the decision.

Each of the concepts are evaluated according to how much value they bring to users and providers. Each of the concepts are given different scores in their user-value and provider value. This scores are plotted in a diagram, translated into coordinates. This provides a basis to compare them and gives an idea about which concept to develop and which could be combined.

- The first step of this method is to create a criterion in order to evaluate the user and provider value.
- Then, it is necessary to create a solution evaluation matrix with different columns in which user-value and provider-value are listed.
- The third step is to choose a scale to score each solution and score each of them to finally record a total of scores for each criterion.
- The forth step is to plot the solutions in a diagram.
- The last step would be to analyse the solutions. This diagram is divided in two parts divided by a diagonal line. This line creates two different triangles. The higher triangle contains the concepts that better designed and would have better acceptance in the market. This is because the solutions in the high user-value and high provided value triangular are high-priority. [26]

3.12 Idea implementation:

3.12.1 Prototyping:

This method is based on producing a mock-up of the product in order to have a physical model. It helps to receive feedback and evaluate it. Prototypes can be produced with many different kinds of materials and techniques.

The main purpose of this method is to have an idea and be able to receive feedback from the users and also to give the designer some clues about it and possible advantages and disadvantages of the product. With all this information, the user is able to optimize it and find new ideas. [27]

CHAPTER 4.0

4.1 EXPERIMENTAL SET UP

The ergonomically designed smart workstation is installed and set up. Table shows the experimental conditions. The smart assembly workstation was designed and developed considering ergonomics in all aspects of design and layout with full adjustability. The size of the tabletop (work surface) was calculated based on the mean reach of the user population with an allowance. Operators could adjust the tabletop to their most preferred work heights. The table could be used for sit, stand, and sit-stand assembly workstations. Figures show the isometric view and the schematic layout of the ergonomically designed smart table in workstation, respectively. An improved work method following the assembly of parts sequence was developed for the task performance on this workstation. Table below is used to display the observed data from the conducted experimental.

Design

- Table slab has been designed so as that it supports the resting of the hands on the table.
- This feature was implemented by adding curves at the front of the table as well as at the resting points on the top of the table.
- For better viewing experience, an in-built monitor stand is available.
- This monitor stand can be tucked in the provided slot when no in use.
- The height adjusting feature is purely mechanical and can be used in different scenarios.
- A multi-purpose hub is provided in front of the table which consists, three USB 3.0 ports, two USB C-type port, headphone and, microphone jack for easy access.
- To the right of the hub a small deck is provided to house the external harddrive or SSD's while they are in use.
- Cables and wires can make the table extremely messy and can cause serious irritation and in some cases anxiety, if not taken care of.
- In the presented design, cable management is taken care by a dedicated column available below the slab of the table.
- Provided column has slits and holes, which have been created minding all the possible sets of cable and wires.

- Wheels are very essential for a comfortable locomotion of the around the space, and hence they are available in the presented design**.**

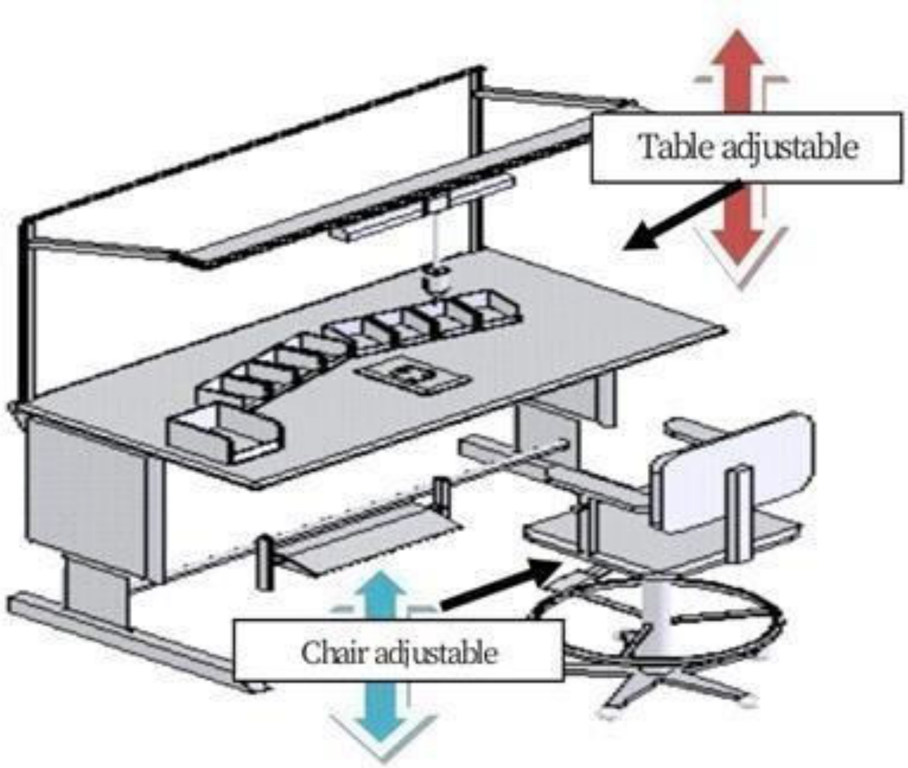
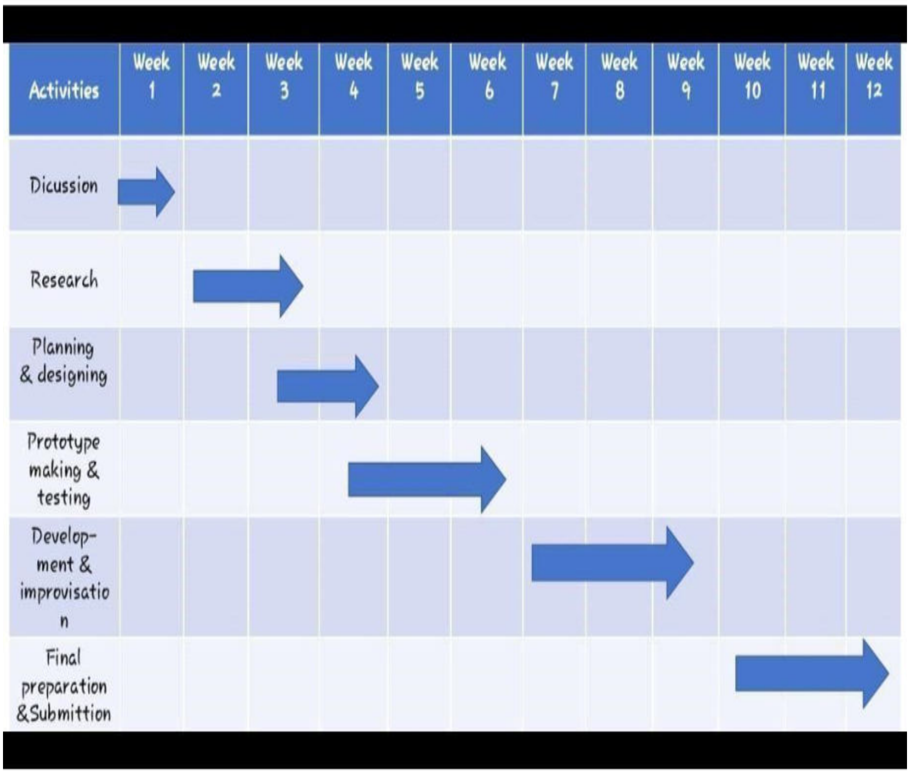


Figure 1: Isometric view of the workstation [21]

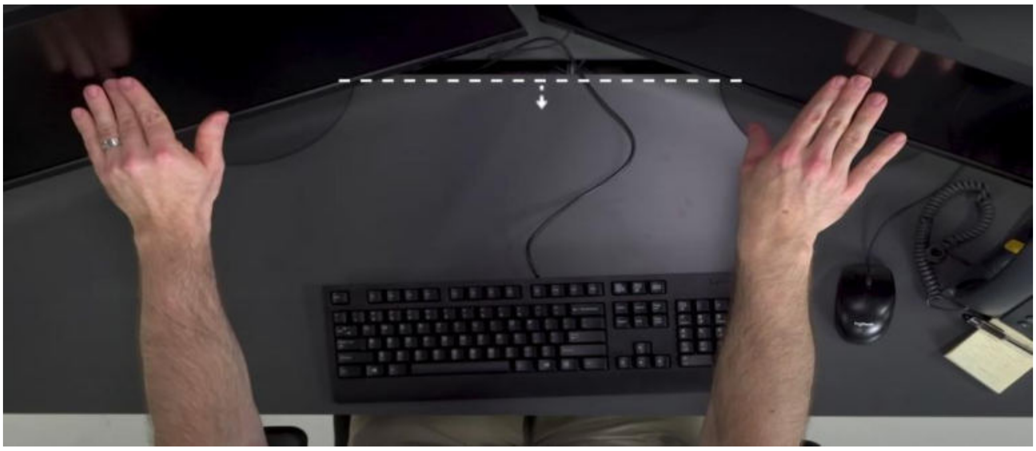


Efficient Setup

- Adjust the monitor height and keep it close enough.

- Adjust your chair height or table height.

- Two monitors should be adjacent with you being in the middle.



- The keyboard should be where your hands end up.

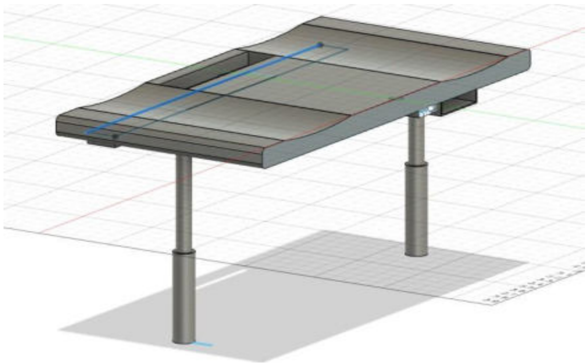
- Accessories like telephone or decors should be on the non-writing side of the desk

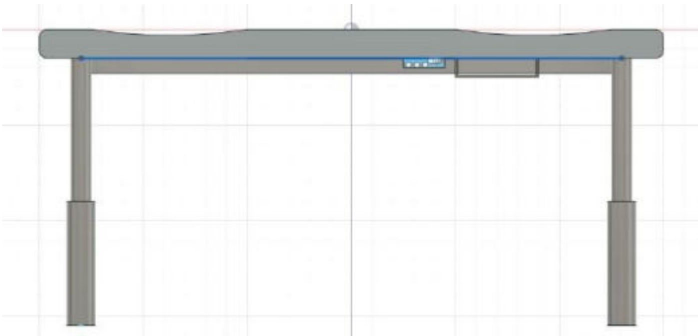
- The use of a mouse pad and wrist rest can enhance the workflow.

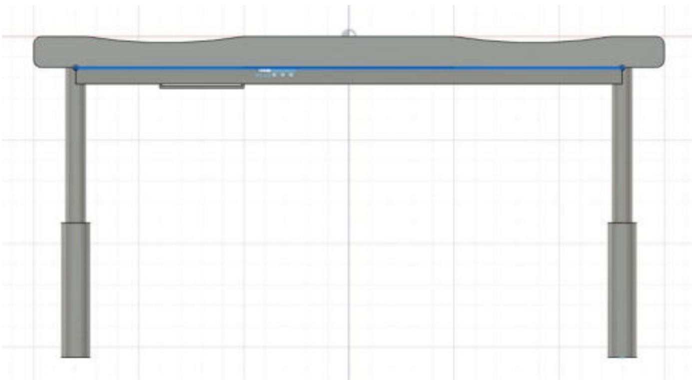
CHAPTER 5.0

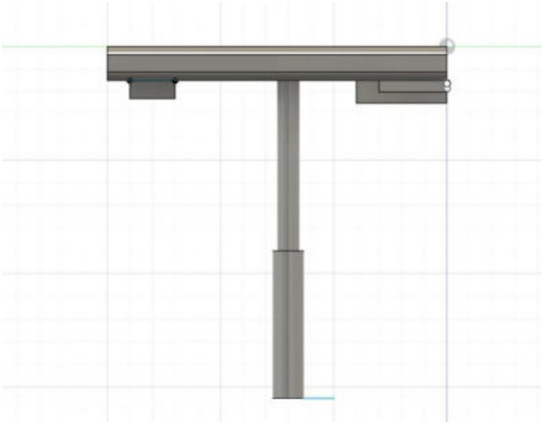
- **RESULTS AND DISCUSSIONS**

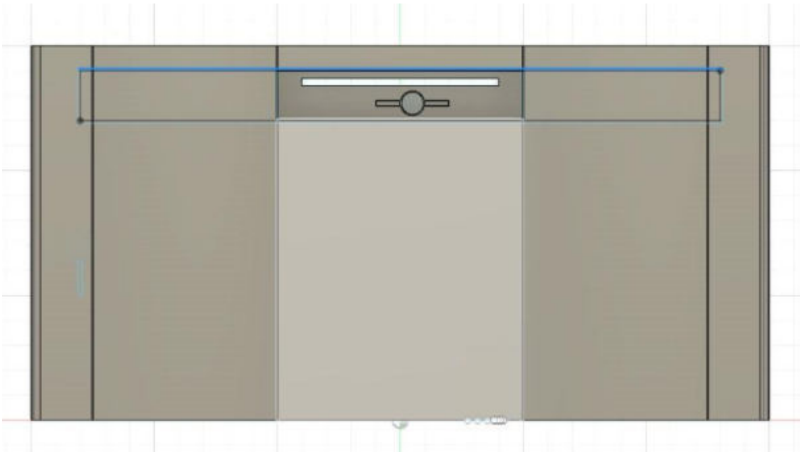
Before preparing the 3-d model of the table, a dummy prototype of the table was made in order to record the affect regular use and common physical weight on the table. For the prototype, a thin plywood sheet of about 5mm was taken and was placed on hollow steel pipes pipe base which as connected with the help of plastic elbow and three-way joints.











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Due to day-to-day usage of the table, the points where the hands were rested. Were significantly curved due to the weight of the hands. The front or the upper chest area of the body was enforced by the straight front of the table. As the base of table was made out of hollow and relatively weak material, the table was not sturdy and was wobbling due to the movement of the body. Cornered and un-finished edges of the table was the means of. physical hurt, very often Height adjustability was not available, and the relocation of the table to different places often resulted in the breakdown of the table. Prototype was extremely messy because of the lack of cable management and due to exterior wood finish, it was very difficult to clean the table. The weak structure and the material of the prototype restricted it to be used at in-door conditions only.

Improvisations

- The slab of the table was improvised by adding curvature at the front and on the top of the table for better hand placement and to reduce enforcement at the front of the table.

- Cable management slab was added below the slab of the table for better cable management.

- Just above the cable management column, a lid-covered slot was made to store the monitor stand when not in use.

- A multi-purpose hub has been provided for easy access and a deck is provided to store any of the in-use external devices.

- A group of three wheels were provided at the base of the table for easy locomotion of the table around the space.

- A beam was added in the middle of the table connected to both of it's base legs to provide an overall sturdy and stable design.

The height adjusting mechanism was a very tough choice. While considering the mechanism, all the relevant thoughts were taken into perspective. The mechanism had to be inexpensive, hustle-free to use, independent of the out-door and in-door scenario, and easily maintainable. Hence the rack and pinion design were implemented, which was checking all the boxes. Once the mechanism reaches to the desired height, it can be held there by the usage of padding with small slits the entire table can be dis-assembled and re-assembled in the matter few screws.

- **CONCLUSIONS**

Ergonomics is the adaptation of working conditions to humans. The emphasis for long periods in time was on the macro ergonomic factors such as poor lighting conditions, dirt, noise, smoke and dust or ensuring the safety of workmen through personal protective equipment(or PPE's).

In addition, the focus was on aspects causing physical exertions such as working in a standing position or under awkward postures or lifting and carrying heavy loads with increased frequency of repetitions and for prolonged periods of time. In the age of digitization and automation with the increased use of digital systems, the focus has to shift towards the study of the cognitive aspects. Maybe the most significant developments in modern ergonomics have been in the field of human-computer interaction, brought on by the explosion of computer usage in the workplace and for that matter in all spheres of human activities.

Nearly every aspect of modern life now includes some level of focus on ergonomically designed systems. Automobile interiors, kitchen appliances, office chairs and desks, and other frequently used devices are being designed ergonomically. The goal is maximizing efficiency at the workplace as well as ensuring increased levels of human comfort and safety. Ergonomics continues to make its contribution towards making life easy in all spheres of human activity under various working conditions.

As a trend when the technology-cost curve becomes steeper every day, more and more innovations will happen through disruptive technologies such as Artificial Intelligence (AI), Augmented Reality &Virtual Reality (AR & VR), Collaborative work system sand the like. These disruptions will be realized at lower costs and will revolutionize the industrial ecosystem. Many researchers feel that the Industry 4.0 age is still at a nascent stage and the industries are still in the transition state of adopting the new systems. The scope for the industries to adopt the new systems by actively considering the human factors and ergonomics aspects will be a compulsive feature in the future to stay relevant to the time while ensuring the profitability of the enterprises.

The following conclusions were drawn from this experimental study:

1. Operators' performance with regard to productivity with the ergonomically smart assembly workstation condition is studied and investigated.

2. The fully adjustable ergonomically designed smart assembly workstation was preferred by the operators and they adjusted and organized the workstation to their comfort.

3. Workstations for assembly tasks should be designed so that any operator can adjust to his/her comfort to relieve stress and improve performance. The ergonomically designed smart assembly workstation is a solution to ergonomic and productivity problems in the workplace.

4. Creating a regression model representing operator performance (productivity) was built based on the experimental work. The main contribution of this work is how to measure the production rate of manual assembly lines based on design ergonomically assembly workstation.

5.3 RECOMMENDATIONS FOR FUTURE WORK

APPENDIX (if any)

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FIGURE)

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"DESIGN AND FABRICATION OF DIFFUSION BONDING UNIT"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the

University Project 1 in **Mechanical Engineering**

Submitted by

Imad Pasha	**20171MEC9009**
D J Chakravarthi	**20171MEC9008**
Mohammad Junaid	**20171MEC0128**
Mohammed Zameer Hussain M	**20171MEC0135**

Under the Supervision of

Mr. ARAVINDA T

(ASSISTANT PROFESSOR)

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

Presidency University

(Private University Estd. in Karnataka State by Act No.41 of 2013)

Department of Mechanical Engineering

School of Engineering,

Itgalpura, Rajanakunte, Bengaluru - 560064 2018-19

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CERTIFICATE

Certified that, the project work entitled, **"DESIGN AND FABRICATION OF DIFFUSION BONDING UNIT"** carried out by Mr. Mohammad Junaid (20171MEC0128), Mr. D.J.Chakravarthi (20171MEC9008), Mr. Mohammed Zameer Hussain M (20171MEC0135) and Mr.Imad Pasha (20171MEC9009). Who are bonafide students of 5th semester B.Tech. Mechanical Engineering In Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2019-2020.

Mr. Aravinda T — Supervisor

Dr. M. Udaya Ravi — Prof. and Head

End Term Examination **Signature with date**

Examiners

1. Mr. Sandeep G M
2. Mr. Basavaraj Devaki

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DECLARATION

We, the students of fifth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, " **DESIGN AND FABRICATION OF DIFFUSION BONDING UNIT**" has been successfully completed under the supervision of Mr. Aravinda T, Department of Mechanical Engineering, School of Engineering, Presidency University, and Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2018-2019. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date:

Team members:	**ID Numbers**	**Signature of Students**
1. Imad Pasha	20171MEC9009	
2. D J Chakravarthi	20171MEC9008	
3 Mohammad Junaid	20171MEC0128	
4 Mohammed Zameer Hussain M	20171MEC0135	

ACKNOWLEDGEMENT

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We express our sincere gratitude to our supervisor, **Mr. Aravinda T** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. M. Udaya Ravi, Prof.** and Head Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Mr. Ramesh SP** who gave us the opportunity to do this project work. We would also like to thank Mr. Chikke Gowda our lab instructor who helped us in preparing the samples.

Lastly, we would like to thank our family and friends

Team members:	**ID Numbers**	**Signature of Students**
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ABSTRACT

Diffusion bonding or diffusion welding is a solid-state welding technique used in metalworking, capable of joining similar and dissimilar metals. It operates on the principle of solid-state diffusion, wherein the atoms of two solid, metallic surfaces intersperse themselves over time. This is typically accomplished at an elevated temperature, approximately 50-70% of the absolute melting temperature of the materials. Diffusion bonding is usually implemented by applying high pressure, in conjunction with necessarily high

temperature, to the materials to be welded; the technique is most commonly used to weld "sandwiches" of alternating layers of thin metal foil, and metal wires or filaments. Currently, the diffusion bonding method is widely used in the joining of high-strength and refractory metals within the aerospace and nuclear industries

When joining two materials of similar crystalline structure, diffusion bonding is performed by clamping the two pieces to be welded with their surfaces abutting each other. Prior to welding, these surfaces must be machined to as smooth a finish as economically viable and kept as free from chemical contaminants or other detritus as possible. Any intervening material between the two metallic surfaces may prevent adequate diffusion of material. Specific tooling is made for each welding application to mate the welder to the work pieces. Once clamped, pressure and heat are applied to the components, usually for many hours.

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Diffusion Bonding 1.0 Introduction

Welding processes can be classified into two main categories:

- Liquid-phase welding, *e.g.* all fusion welding processes such as conventional arc welding, laser welding and electron beam welding.

- Solid-state welding, *e.g.* forge welding, friction stir welding, explosive welding and solid-sate diffusion bonding.

In the former case, bonds are established by the formation and solidification of a liquid phase at the interface while, in the latter case, the applied pressure has a key role in bringing together the surfaces to be joined within interatomic distances.

Although precise details are not known about the actual methods used by early blacksmiths and craftsmen, it is evident that solid-state welding has been used for more than a thousand years [1]. For instance, the famous ancient Japanese and Damascus swords were made by hot forming a piece of high carbon iron into thin strips. Each strip was then folded in two halves lengthwise which were themselves again welded to each other by hammering at high temperatures. This process was repeated tens of times in order to improve the strength and toughness of the swords.

Diffusion bonding, as a subdivision of both solid-state welding and liquid-phase welding, is a joining process wherein the principal mechanism is inter diffusion of atoms across the interface. Diffusion bonding of most metals is conducted in vacuum or in an inert atmosphere (normally dry nitrogen, argon or helium) in order to reduce detrimental oxidation of the faying surfaces. Bonding of a few metals which have oxide films that are thermodynamically unstable at the bonding temperature (*e.g.* silver) may be achieved in air.

Solid-state Diffusion Bonding

Solid-state diffusion bonding is a process by which two nominally flat interfaces can be joined at an elevated temperature (about 50%-90% of the absolute melting point of the parent material) using an applied pressure for a time ranging from a few minutes to a few hours. The International Institute of Welding (IIW) has adopted a modified definition of solid-state diffusion bonding, proposed by Kazakov.

Diffusion bonding of materials in the solid state is a process for making a monolithic joint through the formation of bonds at atomic level, as a result of closure of the mating surfaces due to the local plastic deformation at elevated temperature which aids inter diffusion at the surface layers of the materials being joined

The ever increasing demand for high performance materials has spurred research into the development of advanced alloys and composites. Transport industries, particularly aerospace and more recently car manufacturers have been interested particularly in materials with high strength-to-weight ratios as these can provide significant performance benefits. Since the development of the first heat-treatable aluminium alloy in the early years of this century, aluminium alloys have been of interest because of their reasonably high strength-to-weight ratio, formability, corrosion resistance and long-term durability. The first aluminium aeroplane was manufactured in 1920 and since then, despite significant advances in nonmetallic composites and titanium-based materials, aluminium alloys are still the sought after as an important materials for aero structures as observed by Staley et al. (1997).Aluminium metal matrix composites (Al-MMCs) possess better mechanical properties compared to un-reinforced aluminium alloys (especially their high stiffness, strength and wear resistance). With the recent development of low cost manufacturing processes, Al-MMCs with silicon carbide or alumina particle as reinforcement (i.e.

discontinuously reinforced aluminium, DRA) are now available commercially. The use of Al/SiC composites has reduced the production costs and improved the performance of aircraft components [2,3].However, despite substantial improvements in the range and properties of such advanced aluminiumbased materials, the lack of a reliable and economic joining method has limited their full potential.Due to the high temperatures inherent in fusion welding processes, the use of these methods for joining some of the advanced aluminium-based materials (e.g. Al-Li alloys and Al/SiC MMCs) proved unsuccessful. Unfortunately, the results of more than three decades of research on diffusion bonding aluminium-based materials have not been able to satisfy design engineers that, it is a reliable and commercial method for joining these materials. Also, in most of the cases either the bond strengths are well below the strength of the parent material, or the bonding process is associated with intolerable plastic deformation which is required to achieve reasonable bond strengths. Some of the approaches tried rely on sophisticated prebonding processes and equipment have restricted considerably the application of the method.

Key words: Composites, SiC, Al_2O_3, Fe_2O_3,

1.1. Diffusion Bonding

Diffusion bonding is a method of joining metals similar to welding, but relies only on the surfaces diffusing into one another as similar to 'welding'. This process is aided by high pressure and/or temperature. Diffusion bonding has found several applications, one of which is welding materials which need to be kept out of the atmosphere, hence in a vacuum. Advantages of this process over traditional joining include the small amount of bonding material needed and the fact that it is a very 'clean' process; it does not generate any particulate matter.

Diffusion bonding is a solid-state joining process capable of joining a wide range of metal and ceramic combinations to produce both small and large components. The process is dependent on a number of parameters such as, time, applied pressure, bonding temperature and method of heat application. Other examples of solid-state joining include cold pressure welding, friction welding, magnetically impelled arc butt (MIAB) welding and explosive welding.

Diffusion bonding itself can be categorised into a number of variants, dependent on the form of pressurisation, the use of interlayers and the formation of a transient liquid phase. Each finds specific application for the range of materials and geometries that need to be joined.

1.2. Process mechanism

In its simplest form, diffusion bonding involves holding pre-machined components under load at an elevated temperature usually in a protective atmosphere or vacuum. The load applied is generally below that which would cause macro deformation of the parent materials with temperatures loading of 0.50.8Tm (where Tm = melting point in K) are employed. Duration of temperature loading can range from 1 to 60+ minutes, but it depends on the materials being bonded, the joint properties required and the bonding parameters. Although the majority of bonding operations are performed in vacuum or an inert gas atmosphere, certain bonds can be produced in normal condition.

The surface cleanliness play an major role in the process to form a bond, it is necessary that, clean and flat surfaces to come into atomic contact, with micro asperities and surface layer contaminants being removed from the surface during bonding. Various models have been developed to provide an understanding of the mechanisms involved in forming a bond. First they consider that the applied load causes plastic deformation of surface asperities reducing "interfacial voids". Bond development then continues by diffusion controlled mechanisms including grain boundary diffusion and power law creep.

The mechanism of diffusion bonding can be underlined in the following sequence.

- Initial 'point' contact, showing residual oxide contaminant layer;
- Yielding and creep, leading to reduced voids and thinner contaminant layer;
- Final yielding and creep, some voids remain with very thin contaminant layer;
- Continued vacancy diffusion, eliminates oxide layer, leaving few small voids; □ Bonding is complete;

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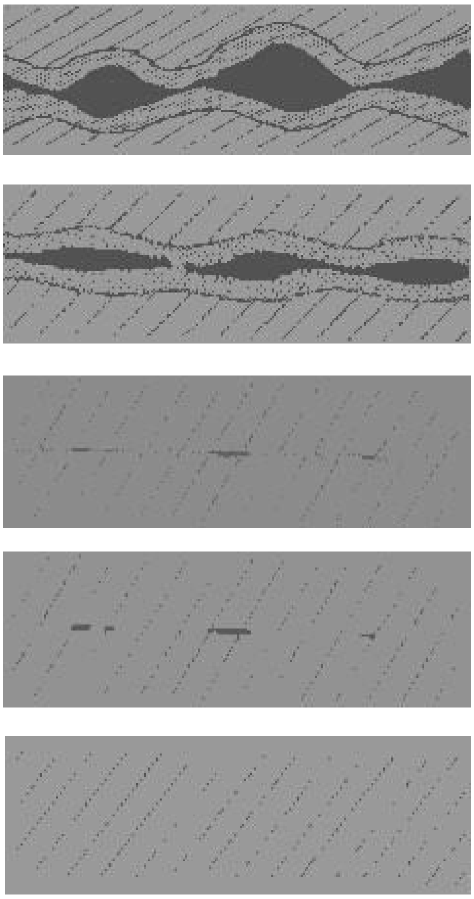


Achieving high integrity joints with minimal detrimental effects on the parent material in the bond region and also the possibility of joining dissimilar materials are the most promising features of diffusion bonding. Accordingly, interest in diffusion bonding has been growing in the last few years. The combination of diffusion bonding and superplastic forming for producing complex structures (e.g. honeycomb structures) has also played a part in increasing the use of this process as a commercial joining method. The most significant property of these Al-MMCs is their high elastic modulus. Elastic modulus is the limiting criterion in the design of components that fail by some sort of elastic instability,

e.g. buckling, and it does not normally change significantly by alloying or hardening processes High stiffness, strength and also wear resistance are the main advantages of these composites. However, inspite of favorable potential vast applications for aluminium-based laminated Composites; very few attempts have been made to develop a reliable joining process. Thus, the lack of a reliable and economical joining technique has restricted the application of these materials and more investigation is required.

1.3 Properties of Material

The chemical analysis of base metals and Hematite ore will be conducted using a X-Ray spectrometer. The mechanical properties of various base metal will be tested and reported in the following sections.

1.3.1 Al 2024

X-Ray Spectrographic (XRS) examination was performed on the as-received materials Al 2024. The aluminum alloy 2024 has a density of 2.78g/cm3, electrical conductivity of 30% IACS, Young's Modulus of 73 GPA across all tempers, and begins to melt at 5000 C.

The base metal roughly includes 4.3 to 4.5% copper, 05 to 0.6 manganese, 1.3 to 1.5 magnesium and less than half percentage of silicon, zinc, nickel, chromium, lead and bismuth. The chemical compositions of Al 2024 and Hematite ore are presented in the Table 1.1. The mechanical properties of the base metals are shown in Table 1.2.

Table 1.1 Chemical compositions of the base metals and Hematite ore in weight percentage.

Material	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Others**	**Balance**
Al 2024	0.5	0.5	4.3-4.9	0.3-0.9	1.2-1.8	0.10	0.25	0.15	0.05	Remaining

Material	**$Fe_2 0_3$**	**FeO**	**SiO_2**	**Al_2O_3**	**MnO**	**TiO_2**	**ZnO**	**CuO**	**MgO**
Hematite ore	92.6	0.44	2.28	1.35	0.01	0.07	<0.01	<0.01	0.11

Table: 1.1

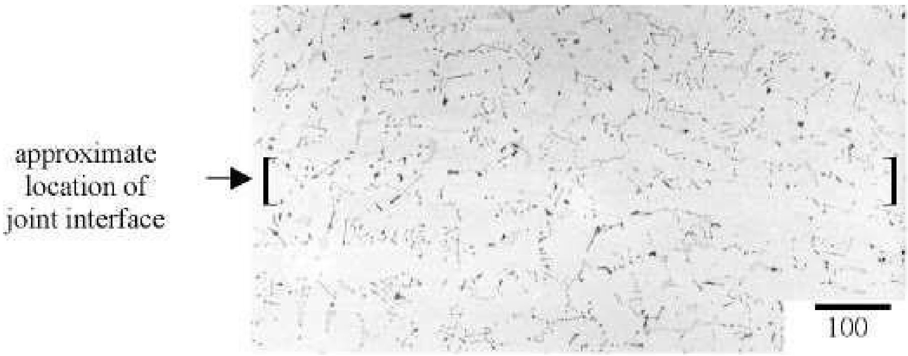
Table 1.2 Mechanical properties of the base metals.

Material	**Yield Strength MPa**	**Ultimate Tensile strength MPa**	**Minimum Elongation %**
Al 2024	97	140-210	10-30

Table:1.2

1.4 Advantages of solid-state diffusion bonding:

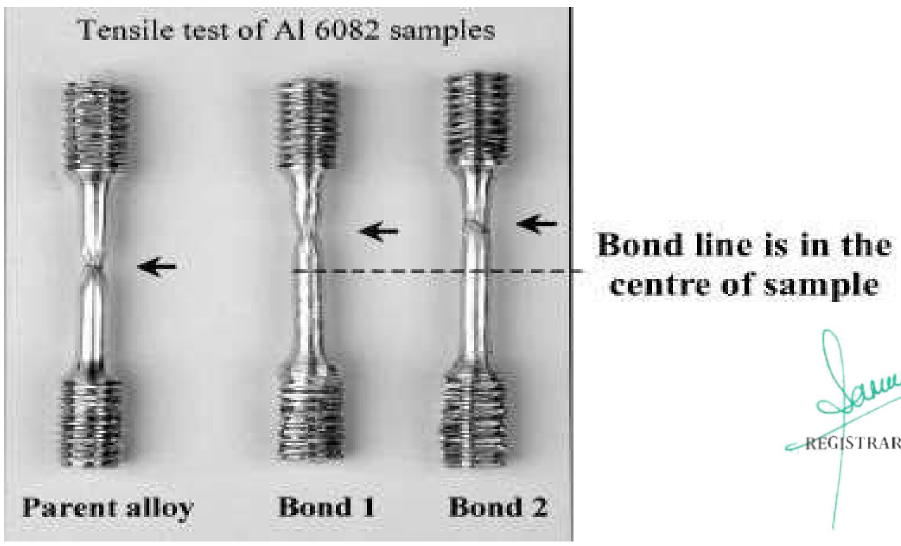
1. The process has the ability to produce high quality joints so that neither metallurgical discontinuities nor porosity exist across the interface.



(FIG 01)

Optical micrograph of the diffusion bond in a cobalt-base superalloy, free from flaws, voids and loss of alloying elements.

3. With properly controlled process variables, the joint would have strength and ductility equivalent to those of the parent material. Failure of the diffusion bonded aluminium samples (bonds 1 and 2), subjected to tensile force, occurred in the parent alloy (shown by arrows) and away from the bond line.



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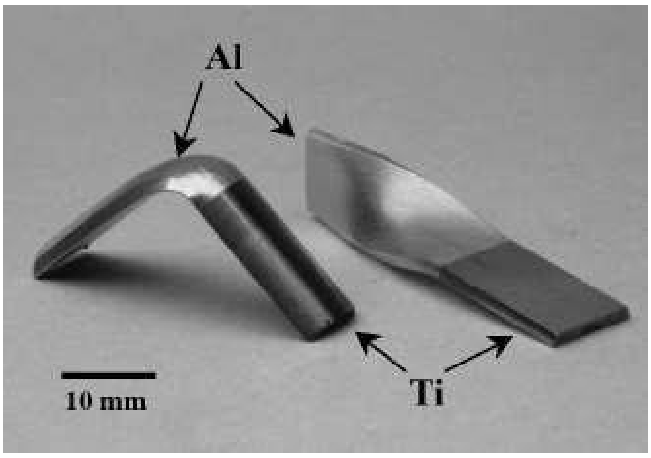


5. Joining of dissimilar materials with different thermo-physical characteristics, which is not possible by other processes, may be achieved by diffusion bonding. Metals, alloys, ceramics and powder metallurgy products have been joined by diffusion bonding. The picture shows dissimilar bonds in Al-6082 and Ti-6Al-4V tested by bending and torsion tests. No preferential failure at the joint interfaces occurred.

6. High precision components with intricate shapes or cross sections can be manufactured without subsequent machining. This means that good dimensional tolerances for the products can be attained. (FIG 04)

Representative high-precision components which fabricated from aluminium (left) and stainless steel (right) using diffusion bonding.

7. Apart from the initial investment, the consumable costs of diffusion bonding are relatively low as no expensive solder, electrodes, or flux are required (although the capital costs and the costs associated with heating for relatively long times may be high).

8. Diffusion bonding is free from ultraviolet radiation and gas emission so there is no direct detrimental effect on the environment, and health and safety standards are maintained.

1.5 Limitations of diffusion bonding

1. Great care is required in the surface preparation stage. Excessive oxidation or contamination of the faying surfaces would decrease the joint strength drastically. Diffusion bonding of materials with stable oxide layers is very difficult. Production of thoroughly flat surfaces and also precise fittingup of the mating parts takes a longer time than with conventional welding processes.
2. The initial investment is fairly high and production of large components is limited by the size of the bonding equipment used.
3. The suitability of this process for mass production is questionable, particularly because of the long bonding times involved.

Variants of solid-state diffusion bonding are also referred to by the following terms:

diffusion welding hot press bonding solid-state
bonding pressure bonding auto-vacuum welding
pressure joining isostatic bonding
thermocompression welding

1.6 Problems with solid-state diffusion bonding

The aim in diffusion bonding is to bring the surfaces of the two pieces being joined sufficiently close that inter diffusion can result in bond formation. There are two major obstacles that need to be overcome in order to achieve satisfactory diffusion bonds.

- Even highly polished surfaces come into contact only at their asperities and hence the ratio of contacting area to faying area is very low.
- In most metals, the presence of oxide layers at the faying surfaces will affect the ease of diffusion bonding. For some metals and alloys, their oxide films either dissolve in the bulk of the metal or decompose at the bonding temperature (e.g. those of many steels, copper, titanium, tantalum,

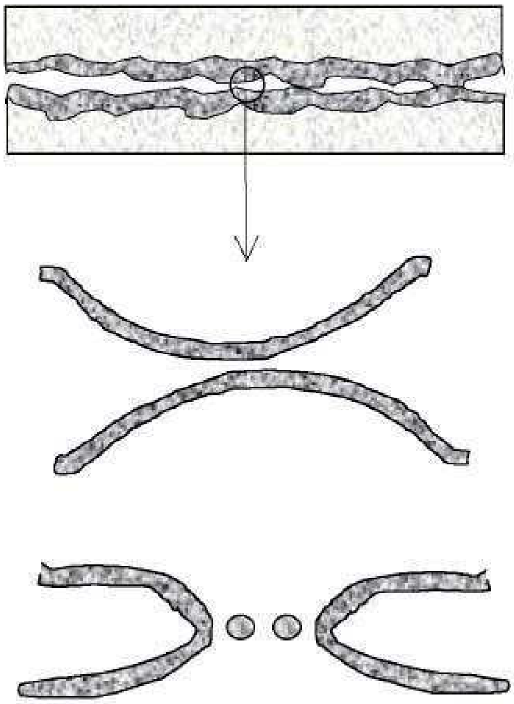
columbium and zirconium), and so metal-to-metal contact can be readily established at the interface. The joining of these materials is relatively straightforward and is not included in this review. However, if the oxide film is chemically stable, as for aluminium-based alloys, then achieving a metallic bond can be difficult.

In practice, because of inevitable surface roughness and also the presence of oxide layers on most faying surfaces, it is neither feasible to bring together the surfaces of two pieces within interatomic distances nor to establish complete metal-to-metal contact by simply putting two pieces together. See Ref. [4] for various aspects of the effects of surface oxides on interface morphology and bond strength, and a summary of the existing approaches used to overcome the oxide problem.

1.7 Mechanism of solid-state diffusion bonding

The mechanism of solid-state diffusion bonding can be classified into two main stages [4]. At the microscopic level, diffusion bonding occurs in three simplified stages:

- Before the surfaces completely contact, asperities (very small surface defects) on the two surfaces contact and plastically deform. As these asperities deform, they interlink, forming interfaces between the two surfaces.
- Elevated temperature and pressure causes accelerated creep in the materials; grain boundaries and raw material migrate and gaps between the two surfaces are reduced to isolated pores.
- Material begins to diffuse across the boundary of the abutting surfaces, blending this material boundary and creating a bond.



(FIG 05)

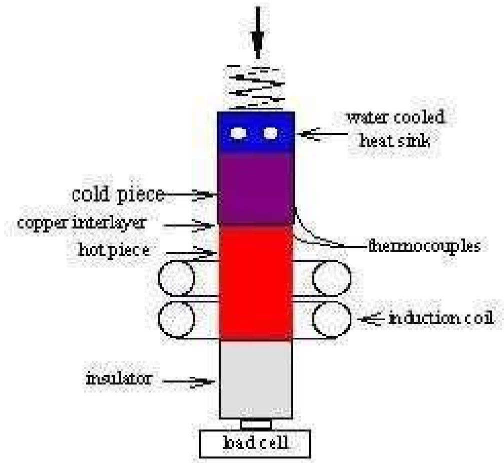
During the first stage, the asperities on each of the faying surfaces deform plastically as the pressure is applied. These asperities arise from the grinding or polishing marks that have been produced in the surface finishing stage. The microplastic deformation proceeds until the localised effective stress at the contact area becomes less than the yield strength of the material at the bonding temperature. In fact, initial contact occurs between the oxide layers that cover the faying surfaces. As the deformation of asperities proceeds, more metal-to-metal contact is established because of local disruption of the relatively brittle oxide films which generally fracture readily. At the end of the first stage, the bonded area is less than 10% and a large volume of voids and oxide remains between localised bonded regions.

In the second stage of bonding, thermally activated mechanisms (creep and diffusion) lead to void shrinkage and this increases further the bonded areas.

1.8 Diffusion bonding makes waves

The joining of aluminium and aluminium base alloys to themselves and to other metals has long created problems because of the tenacious layer of surface oxide which is always present. The difficulties become more acute when melting of the components to be joined is not an option. Shirzadi and Wallach have recently developed a technique for diffusion bonding such materials.

Some advanced materials cannot be welded by conventional techniques because the high temperatures involved would destroy their properties. For such materials, diffusion bonding is an attractive solution because it is a solid state joining technique, which is normally carried out at a temperature much lower than the melting point of the material.



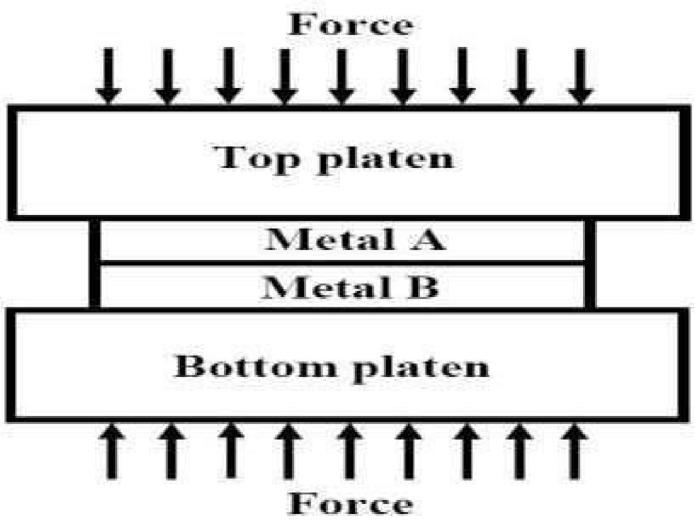
Equipment used for temperature gradient diffusion bonding

(FIG 06)

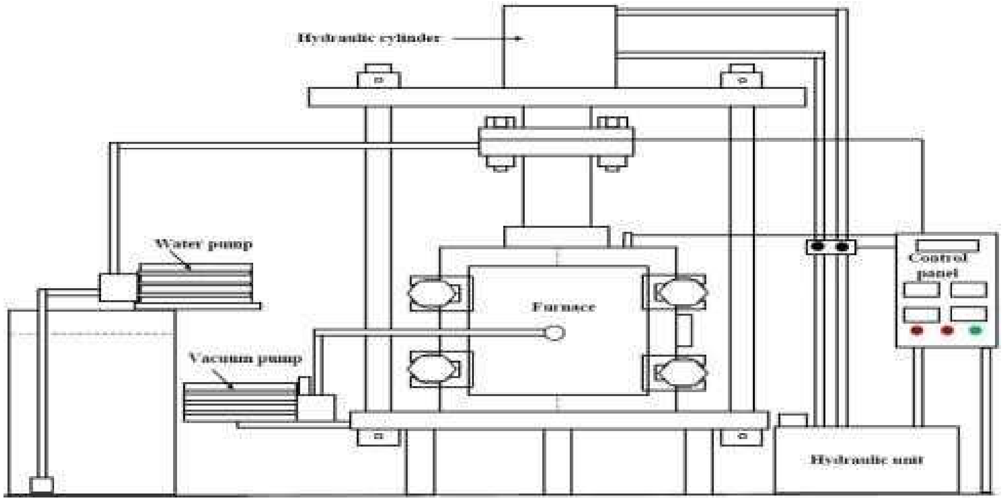
For joining aluminium alloys, insertion of a thin copper or zinc interlayer, allows a low melting point eutectic phase to be formed at a temperature about 100°C lower than the melting point. Even with this technique, the bond strengths produced are lower than the parent metal because of the planar bond interface which contains oxides and included particles. The new technique is based on imposing a temperature gradient across the surfaces to be joined to produce a non-planar (sinusoidal) interface which effectively increases the bonding area or metal to metal interface. This is an exciting development, as it is possible to change the shape of the interface from being planar to cellular, and up to fully dendritic depending on the temperature gradient imposed.Shear test results on aluminium-based composites and alloys show shear strengths up to parent metal values. It is anticipated that this technique can be used for joining dissimilar metal combinations, metal matrix composites and possibly nickel based materials.

The schematic diagram of the joining process is illustrated in Figure 7.

The equipment used for DB process consists of a hydraulic press to apply pressure with a builtin vacuum furnace to maintain vacuum environment and inert gas purging facility as shown in Figure 8. The highly polished surfaces of the specimens are made to rest one over the other and the assembly is kept between the platens as shown in the Figure 8.. Pressure is applied prior to bonding to deform the surface asperities plastically to obtain a smooth flat surface.



(FIG 07) Schematic diagram of the DB Process.



(FIG 08)The general schematic diagram showing the diffusion bonding equipment.

1.9 TYPES OF DIFFUSION BONDING PROCESSES

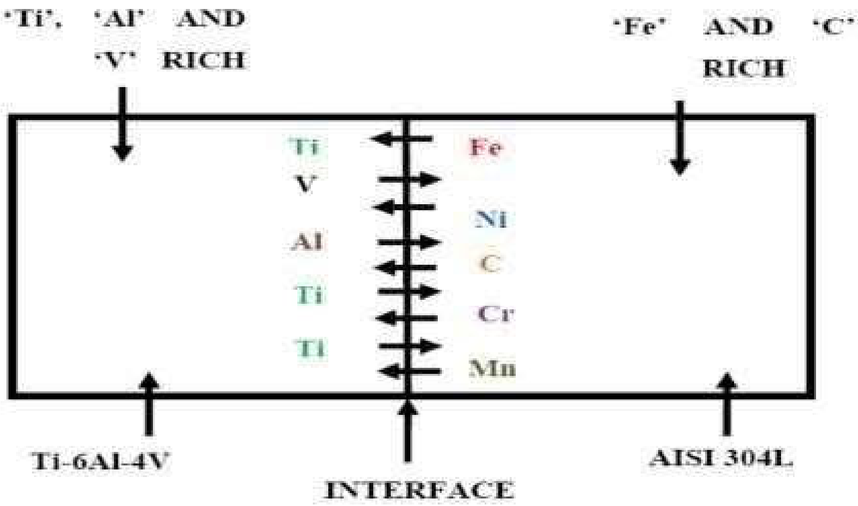
DB process is classified according to type of interlayer used in the joining process as detailed below.

- Direct diffusion bonding (without interlayer)
- Diffusion bonding with interlayer
- Diffusion bonding with fusible interlayer

Further the above processes can be carried out either in vacuum or inert environmental conditions.

1.9.1 Direct Diffusion Bonding

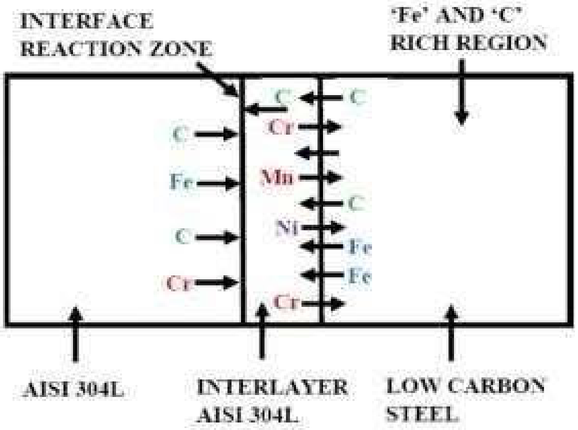
In direct diffusion bonding, joining is achieved with the application of interlayer between the two base metal surfaces. The diffusion of atoms takes place from one base metal to another as a result of thermal energy supplied during bonding process and by applying pressure for a specified time. The exchange of atoms during the process is illustrated in Figure 9.



(FIG 09)A model illustrating the exchange of atoms

1.9.2 Diffusion Bonding with Interlayer

In this case, a suitable interlayer is placed between the base metals and the process is carried out without melting of interlayer. The presence of an interlayer increases surface contact and increases chances of sound bond formation. A model depicting the exchange of atoms with interlayer is illustrated in Figure 10.



(FIG 10)A model showing the exchange of atoms with interlayer.

Kundu et al (2005) performed solid-state diffusion bonding of pure titanium to 304 stainless steel with copper interlayer. Several interlayer materials were used by different researchers for achieving diffusion bonding of dissimilar material combinations considering the physical and mechanical properties of base and interlayer materials. The desired properties of interlayer material are low coefficient of thermal expansion, lower hardness than the base metals and poor tendency to form intermetallic compounds. Further, the intermetallic compounds formed at the interface should possess lower hardness, ductility and strength to achieve sound joints.

1.10 Diffusion Bonding with Fusible Interlayer

In this type of bonding, the interlayer is melted and the joining is achieved. This type of interlayer can be used to join both similar and dissimilar metals. Additionally, fusible interlayer serves to activate the mating surfaces. During the bonding process a fusible interlayer is melted, most of the molten metal is expelled from the joint by the applied load that removes oxides from the interface. Arafin et al (2007) performed transient liquid phase bonding of INCONEL 718 and INCONEL 625 with boron rich-nickel base alloy as fusible interlayer. The liquid phase promotes the detachment, dispersal and dissolution of oxide films.

1.11 EFFECT OF BONDING PARAMETERS

In most of the diffusion-bonded joints, the solid solution formation is limited because the solubility limits of various elements present in the base metals and interlayer. Because of the limited solubility existing between two different elements the formation of intermetallic compounds are inevitable because of higher bonding temperature and time. Therefore, estimating an optimum parameter for bonding is important to obtain sound joint possessing good mechanical properties.

Diffusion Bonding Parameters

The various parameters listed below are having influence on the preparation of quality joints possessing desirable properties.

- Temperature
- Pressure
- Bonding time
- Surface finish and flatness
- Composition of the base metals

Temperature

Temperature has influence over the diffusion of atoms between base metal and interlayer materials. The high temperature maintained during diffusion bonding, changes the structure of allotropic metals. The lattice parameter ‘a’ varies as the crystal lattice changes from one form to another.This phenomenon increases interstitial voids and octahedral voids to enable diffusion to occur easily. The carbon atoms occupy interstitial void position because of limited solid solution formation (0.02%C) with iron at room temperature. At elevated temperature, in γ-iron, the solubility of carbon is 2.1% for FCC that is much higher in comparison with BCC. Avner (2006) explained the metallurgical changes taking place in steels and in titanium alloys at higher temperatures. At room temperature, titanium possesses CPH structure that transforms to BCC at and above 890 °C. The diffusivity of various elements increases, because of this transformation. In addition, the energy level of the atoms are raised which enables the atoms to jump into vacant site and interstitial void position.

Pressure

The pressure is also an important parameter to obtain sound joint. Adequate pressure is essential to maintain good contact between the contact surfaces. If the pressure is too low, poor contact may result in lack of diffusion and formation of voids and discontinuity at the interface. Very high pressure increases plastic deformation (macroscopic deformation) of the contact surfaces as it retards diffusion. Application of very high pressure imparts deleterious effects like barreling, crack formation along the grain boundaries and hot cracking at the periphery of the diffusionbonded samples.

Bonding Time

The bonding time has greater influence on better bond formation, joint strength, interface morphology and materials to be joined (ferrous and non-ferrous). The thickness of the reaction zone adjacent to the interface on both sides of the base metals is directly proportional to the bonding time. If the bonding time is too small, lack of diffusion and a thin weak interface is formed that reduces the bond strength. On the other hand, increased bonding time, increases the width of the reaction zone and more strength when the intermetallic compounds formed are less. Very high bonding time increases the width of the reaction zone to a higher level and the interface will consist of more hard and brittle compounds resulting in poor bond strength.

Surface Finish and Flatness

The surface finish and flatness are also important parameters that have an effect on joints. Higher degree of surface finish is required to obtain diffusion-bonded joints having good strength. In general, the surface must be cleaned to remove grease, oil and oxides from the polished surface before performing bonding process.

Composition of the Base Metals

In the metal matrix, the exchange of atoms from one region to another is influenced by the concentration gradient existing between the base metals. This increases the driving force of atoms for diffusion. Because of diffusion, the base metal composition varies as the diffused elements enrich the solute less base metals adjacent to the interface.

Environment

Various researchers attempted DB of metals in the controlled environment. The diffusion bonding is carried out in a vacuum environment or in a non-vacuum environment. Dissimilar metals are bonded in vacuum environment to prevent oxidation and absorption of interstitial elements during bonding process. DB of different grades of stainless steel to steel is also possible inside a furnace without vacuum. In addition, a low-pressure environment after purging with inert gases could be used effectively to obtain joints that are free from oxides and other deleterious elements.

2.0 Literature survey:

2.1 Theoretical aspects of solid-state diffusion bonding

The aim, of diffusion bonding, is to bring the surfaces of the two pieces being brought sufficiently close that inter diffusion can result in bond formation. In practice, due to inevitable surface roughness greater than an atomic scale, it is not possible to bring the surfaces of two pieces within interatomic distances by simple contact. Even highly polished surfaces come into contact only at their asperities and the ratio of contacting area to faying area is very low. Thus the mechanism of solid-state diffusion bonding can be considered as integration two main stages.

In the initial stage, the asperities on each of the faying surfaces deform plastically as the pressure is applied. These asperities arise from the grinding or polishing marks that have been produced in the surface. The microplastic deformation proceeds until the localised effective stress at the contact area becomes less than the yield strength of the material at the bonding temperature. In fact, initial contact occurs between the oxide layers that cover the faying surfaces. As the deformation of asperities proceeds, more metal-tometal contact is established due to local disruption of the relatively brittle oxide films which generally fractures. At the end of the initial stage, the bonded area will be less than 10% and a large volume of voids and oxide still remains between localised bonded regions.

In the second stage of bonding, thermally activated mechanisms lead to void shrinkage which further enhances the bonded area.

There are several hypotheses to explain how a bond is formed in the solid state, Kazakov (1985) . The "Film Hypothesis" emphasises the effect of surface film characteristics on the joining process. According to this hypothesis, the observed differences in weldability of various metals are attributed to the different properties of their surface films and all metals are assumed to bond if thoroughly cleaned surfaces are brought together within the range of interatomic forces. Another theory, the "Recrystallisation Hypothesis", suggests that the strain hardening of the faying surfaces during plastic deformation causes atoms to move from one

side to the other of the interface at high temperature. Subsequently, new grains grow at the interface and the bond is established. The "Electron Hypothesis" is based on the formation of a stable electron configuration as a result of metallic bond formation. In the "Dislocation Hypothesis", exposure of dislocations to the free surface, as a result of plastic deformation, breaks up the oxide film and produces steps on an atomic scale which enhance the seizure of the joining parts. Finally, the "Diffusion Hypothesis", the most commonly accepted hypothesis, considers the contribution of interatomic diffusion during bond formation. The difference in the energy level of surface atoms and of bulk atoms is the basis for this hypothesis.

The attempts at modelling diffusion bonding have two main aims. The first is to optimise the process variables e.g. surface finish, bonding temperature, pressure and time so that the proper bonding conditions for a particular material can be identified. Secondly, a model attempts to obtain a reasonable and profound understanding of the mechanisms involved and their relative contributions not only for different bonding conditions but also for different materials being joined.

2.2 Solid-state diffusion bonding of aluminum alloys

Oxide layers on the faying surfaces may hinder the ease of solid-state diffusion bonding in certain materials. Some oxide films either dissolve in the bulk of the metal or decompose at the bonding temperature (e.g. those of many steels, copper, titanium, tantalum and zirconium), and hence metaltometal contact can be readily established at the interface. Derby (1990) has depicted some of the possible chemical reactions which are likely to occur at the interface between a pure metal and simple oxides.

On the other hand, if the oxide film is chemically stable, as for aluminium-based materials, then achieving a metallic bond can be difficult. The presence of a tenacious and chemically stable surface layer of aluminium oxide is the main obstacle in most welding processes for aluminium based materials. Different approaches have been developed to overcome the oxide problem associated with the diffusion bonding of such materials.

<u>Imposing macroscopic plastic deformation</u>

solid-state diffusion bonding, a brittle and continuous oxide layer can be broken up by imposing substantial plastic deformation. Metal-to-metal contact is thus promoted due to local disruption of the oxide film on both faying surfaces. Early works on deformation bonding

(pressure bonding) of aluminium alloys by Cline (1966) and by Urena et al. (1995) have showed that about 40% deformation is required to produce bonds with reasonable strengths [6,7]. Cline also studied the effects of joint design and surface condition on the strengths of Al-6061 bonds, in which grooves with different depths were machined on the faying surfaces to provide a low initial contact area with high local pressure. The highest tensile bond strength, of 110 MPa, was obtained with a 1.5 mm groove depth and 50% deformation.

Enhancing microplastic deformation of the surface asperities

An alternative approach to overcoming the oxide problem in solid-state diffusion bonding is to use a fairly rough surface finish, which may lead to higher bond strengths compared to polished surfaces. Rougher the surface, more plastic deformation on the asperities, leading to more oxide fracture occurs, consequently enhancing metal-to-metal bonding. Ricks et al. (1990) studied the effect of surface roughness on the shear strength of Al-8090 bonds. Despite a considerable scatter in results, it was concluded that higher bond strengths were achieved when a rougher surface preparation was adopted. This is probably due to the higher deformation of the surface asperities on a rough surface which leads to more rupture of the surface oxide, in comparison with a smooth surface [8]. These results are consistent with those reported by Tensi&Wittmann (1990) in which the influence of surface preparation on the bond strength of Al-7475 bonds was investigated .

Enjo et al. (1978) used electrical resistance measurements of Al-Al bonds to show that faying surfaces treated by coarse emery paper produced more metallic bonds than smooth faying surfaces [10]. The effect of the shape of asperities (asperity angle) on the interfacial contact process has been modelled by Takahashi & Tanimoto (1995a), where in the effect of surface oxide layer was not considered. The model was reasonably justified by conducting some experiments on oxygen-free copper, (Takahashi & Tanimoto (1995b) .

In contrast, Harvey et al. (1985) showed that polishing the silver cladding on Al-7010 improved the bond strength, compared with the bonds made using as-clad samples. The specimens were argon ion sputter cleaned before the deposition of the silver layer, therefore there was no aluminium oxide between the cladding and the base metal as observed by Harvey
et al. (1986) [12,13]. This inconsistency regarding the effect of surface roughness on bond strength, is probably due to the different properties of the surface layers of silver and aluminium. The surfaces of silver coated samples are virtually oxide free, so improving the surface finish increases the metal-tometal contact at the interface. In contrast, in the case of uncoated aluminium faying surfaces, bond strengths improve by the generation of oxide-free surfaces as a result of the local deformation of the asperities. Low temperature solid-state bonding of copper, using different surface preparations, was investigated by Nicholas et al. (1990). There was a significant reduction in the bond strength as the surface roughness

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increased, which is consistent with the above conclusion regarding the effect of surface roughness on the bonding behaviour of materials without oxide layers.

Use of interlayers and the effect of alloying elements

Barta (1964) examined a variety of interlayers (silver, gold, nickel, aluminium, tin, zinc, iron, copper and magnesium) for low temperature diffusion bonding of Al-7075. The interlayers were in the form of electroplated, vacuum deposited, plasma sprayed, loose foils and clad Al-7072. Bonding was carried out under a very high pressure of 165 MPa in the temperature range 150-230°C. The use of most interlayers resulted in either very poor bonds or no bonding. The highest bond strength achieved, using a clad aluminium sample, was 76 MPa; improving to 110 MPa after post bond heat treatment . However, low temperature diffusion bonding may be of benefit for high precision joining where mechanical properties are not a crucial factor. Bienvenu & Koutny (1990) manufactured a small component for a detector, using a silver coating to sandwich a thin foil of an Al-Mg alloy (8 µm) between two thicker templates (50 µm) of the same material at 400°C .

Maddrell & Wallach (1990) studied the effects of active alloying elements such as magnesium and lithium on the morphology of the surface Al_2O_3 layer, when bonding aluminium-based alloys .

According to this research, these active elements decompose and break up the aluminium oxide layer at the interface. A good correlation between bond strength and the extent of broken oxide was observed, leading to the conclusion that the greater the concentration of these elements, the greater the disruption of the oxide layer and, consequently, higher bond strengths. Kotani et al. (1996a&b) found that increasing the bonding temperature changed the amorphous oxide layer gradually into crystalline particles. The temperature at which the amorphous oxide layer was annihilated could be decreased by additions of magnesium to the alloy matrix.Ricks et al. (1989) investigated the effect of some alloying elements on the bond strengths of Al-8090, using aluminium alloy interlayers containing gallium, lithium and magnesium with thicknesses of about 100 µm. The use of Al-Mg interlayers improved the bond shear strength by up to 50% in comparison with bonds made using pure aluminium interlayers, i.e. from 100 to 150 MPa [20]. Church et al. (1996) conducted tensile tests on miniature Al-Li 8090 bonds. A scanning Auger microprobe was used to analyse the elemental composition of the fractured surfaces. Despite the presence of oxygen in all samples, bonds with high strengths contained lithium and aluminium whereas lithium was not detected on the fracture surfaces of the poor bonds. It was concluded that lithium possibly reacted with aluminium oxide to form a thermodynamically more stable oxide, therefore the bond strength was increased due to the disruption of the initial oxide layer [21]. Dunford & Partridge (1990, 1991 & 1992) and Gilmore et al. (1991) concluded that the lithium in Al8090 modified the aluminium oxide into discontinuous and less stable Li-Al spinels during the bonding process [22,23,24,25,26,27]. TEM examination of the interface proved the absence of the continuous oxide layer in Al-8090 bonds. However, according to Maddrell & Wallach (1990), the native oxide layer was not substantially disrupted and the bond line remained decorated by semi-continuous layer of oxide which reduced the bond strength [28]. Based on TEM observation, Urena et al. (1996a) proposed that interface oxide particles may not be the main cause responsible for pinning down the interface, but that Al_3Zr, which was detected along the grain boundaries in the parent material (Al-8090) as well as at the bond interface, suppresses the migration of the interface [29].All the results, mentioned above are consistent with Maddrell et al.'s (1989) results showing that the presence of some alloying elements, such as Mg and Li can improve bond strength. Similar results had been reported earlier by Dray (1985) . Non-conventional bonding and testing methods

Enjo & Ikeuchi (1984) carried out the diffusion bonding of Al-2017 in the temperature range above the solidus line but below the liquidus line, where solid and liquid phases coexist (i.e. 580°C)[32]. In spite of the formation of a liquid phase, this method was referred to as solid-state diffusion bonding. It should be mentioned that, in contrast to transient liquid phase, solidification in this method occurs as a result of cooling, as in brazing. It was assumed that the formation of the liquid phase could aid the disruption of the oxide layer and provide intimate contact at the interface. Preferential melting at the bond interface and the grain boundaries was directly observed at the bonding temperature. The volume fraction of the liquid phase proved a crucial factor. The maximum shear strength (270 MPa) was achieved when the volume fraction of the liquid phase was 2~3%. The tensile strength of the joint was increased to 400 MPa by a post bond heat treatment. However, when the volume of the liquid phase exceeded 3%, grain boundary cracking occurred and the bond line was associated with a large amount of porosity. No explanation was given for the fact that, despite the formation of the liquid phase at the grain boundaries, the base material could still withstand a bonding pressure of 1 MPa. Because of the high temperature used, the detrimental effects of melting on the microstructure and shape of the base material are expected to be substantial. In practical terms, the process does not seem viable as a minor miscarriage during the bonding process would destroy the part which is heated up to its solidus temperature.

Yokota et al. (1997) developed a new method based on a combination of solid-state diffusion bonding and friction welding to join Al-6061 and Al-6060/SiC MMC. In this method, a torsional force was exerted while an axial force was acting on the parts to be joined. One of the parts had a conical end in order to exclude the worn oxide film from the interface. The specimens were heated using a high frequency induction system and the axial load applied, while the torsional force was used to rotate the upper part at a constant speed of 6 rpm. The maximum tensile strength of the bonds, made applying 90 MPa axial pressure at 250°C, was 200 MPa. An important advantage of this method over diffusion bonding and friction welding is claimed to be the low bonding temperature (250-350°C) and short bonding time (~5 minutes), which reduces the plastic deformation during the bonding process. However, in contrast to diffusion bonding, the method is only applicable to parts with certain shapes (preferably with round cross section) which should be machined to provide conical ends. Also, unlike friction welding which is carried out in air, the new method requires a vacuum .

Dunford & Partridge (1987, 1990, 1991 & 1992) have reported the highest bond strengths for Al-8090, i.e. 181 to 202 MPa for lap shear tests with an overlap of 2 mm. However, the shear strength decreased drastically (~50%) for overlaps of about 4 mm [34] . Tensi et al. (1989) also carried out lap shear tests on Al-7475 with a very short overlap length of 1.5 mm; a maximum shear strength of 410 MPa was reported [35]. However, the reliability and practicality of the methods which are evaluated under extreme testing conditions (e.g. shear test on the joint with an overlap of less than 2 mm) are doubtful.

Cailler et al. (1991) used high speed dynamic loading equipment to study the bond strength, failure elongation and failure energy of Al-2017 diffusion bonds. The projectile speed was 30 m/s and the time duration for transmitting the load was less than 114 µs. The tensile strengths of the joints in the asbonded condition reached 290 MPa, in comparison with 300 and 460 MPa which were the tensile strengths of the parent material in the as-bonded and in the fully aged-hardened condition, respectively. The failure elongation of the bonded samples was about one third of the parent material with the same thermal cycle. Debbouz & Navai (1997) adopted a similar approach to study the effect of bonding conditions on the mechanical properties of Al-2017 bonds. In both cases, it is not mentioned why the bonds were not post bond treated to achieve a fully hardened condition rather than heat treating the parent material. If that had been done, the comparison between the mechanical properties of the bonds and the parent material would be more conclusive.

X-P Zhang L.Ye,Y-W,& Mia (1999)The principle difficulty when joining magnesium (Mg)-aluminium (Al) lies in the existence of formation of oxide films and brittle intermetallic in the bond region. However, diffusion bonding can be used to join these alloys without much difficulty. Temperature, pressure, and holding time are the three main variables which govern the integrity of a diffusion bond. This paper focuses on the effect of these parameters on diffusion layer thickness, hardness and strength of AZ31B magnesium-AA2024 aluminium dissimilar joints. The experiments were conducted based on three factors, five-level, and central composite rotatable design with full replications technique. Empirical relationships were developed to predict diffusion layer thickness,hardness and strength using response surface methodology. From this investigation, it is found that bonding temperature has predominant effect on bond characteristics.

Jihua HUANGy, Yueling DONG, Jiangang ZHANG, Yun WAN and Guoan ZHOU (2005) Mixed Al-Si and Al-Cu powders were investigated as insert layers to reactive diffusion bond SiCp/6063 metal matrix composite (MMC). The results show that SiCp/6063 MMC joints bonded by the insert layers of the mixed Al-Si and Al-Cu powders have a dense joining layer of high quality. The mass transfer between the bonded materials and insert layers during bonding leads to the hypoeutectic microstructure of the joining layers bonded by both the mixed Al-Si and Al-Cu powders with eutectic composition. At fixed bonding time (temperature), the shear strength of the joints by both insert layers of the mixed Al-Si and Al-Cu powders increases with increasing the bonding temperature (time), but get maxima at bonding temperature 600±C (time 90 min).

M. Muratoglu , O. Yilmaz, M. Aksoy (2006) Joining characteristic of SiC particulate reinforced aluminum metal matrix composites (MMCs) with pure aluminum were investigated by diffusion bonding process. The joining quality of the Al/SiCp MMCs was studied to determine the influences of SiCp particulates with homogenization and age hardening on bonding properties. The experimental results indicate that the application of aging before and after diffusion bonding decreases SiC particulate accumulation, and increases other elemental concentration at interface. Especially, the application of aging treatment before the diffusion bonding of Al/SiCp MMCs to pure Al, increased Cu% concentration at interface which treats as the insert alloy.

G Mahendra, S Babu & V Balasubramanian (2009) The principle difficulty when joining magnesium (Mg)-aluminium (Al) lies in the existence of formation of oxide films and brittle intermetallic in the bond region. However, diffusion bonding can be used to join these alloys without much difficulty. Temperature, pressure, and holding time are the three main variables which govern the integrity of a diffusion bond. The paper focuses on the effect of these parameters on diffusion layer thickness, hardness and strength of AZ31B magnesium-AA2024 aluminium dissimilar joints. The experiments were conducted based on three factors, five-level, and central composite rotatable design with full replications technique. Empirical relationships were developed to predict diffusion layer thickness, hardness and strength using response surface methodology. From this investigation, it is found that bonding temperature has predominant effect on bond characteristics.

2.3. Objectives of the work

The aim of the project work is to design and fabricate the diffusion bonding unit in the presidency university campus. The facility of the diffusion bonding can be utilized to develop similar or dissimilar metal joint.From the literature survey, it is observed that work has been carried on diffusion bonding of Aluminum alloys with different reinforcements (SiC,TiC, etc) with different interlayers (copper, lithium, Niobium Alumina etc) . The researchers have performed DB (diffusion bonding) of various material combinations as a viable process by considering material properties such as physical, mechanical, high temperature and corrosion resistant properties. The present work aims at processing of AluminiumHematite composite material. Aluminum alloy Al-2024 selected as base metals to bond with Hematite ore as reinforcement. Hematite is naturally available iron ore which is harder than aluminium and has unique feature that it is corrosion resistance and being used as primary coating to structural works. It is likely improve their corrosion resistance and mechanical properties of the diffusion bonded composite. In addition, during DB processes, control of process parameters like temperature, bonding pressure and bonding time was essential along with protective environment throughout the process to achieve sound bonding.

The optimization of process parameters will be one of the most important areas of study for this work. Therefore, experiments will be conducted at various range of thermal loading (temperature), bonding pressure (mechanical loading) and time to obtain diffusion-bonded samples there by optimizing the process parameters. These samples will be characterized for the metallurgical changes, taken place during diffusion bonding. Analytical tools will be used for measuring the reaction products at the joint region and evaluation of mechanical properties.

3.0 Work Methodology

The DB experiments for an Al 2024 with Hematite ore as reinforcement will be conducted. The procedure that will be adopted during DB of metals and characterization of the joints is presented on a flow chart in the Figure 3.1. The elemental concentrations of base metals will be examined after bonding in order to study diffusivity of various elements and formation of intermetallic compounds. The analytical methods like SEM, EDAX and XRD will be carried out to estimate the level of diffusion and phase identification. The mechanical properties of the joints will be assessed using specially designed fixtures. The diffusion coefficient values, pre-exponential constants and activation energy will be calculated for various elements. The optimum parameters will be estimated for material combinations.

The facility required to obtain an effective diffusion bonding will be developed indigenously which is likely to beneficial in economic aspects of the processing.

4.0 Experimental Set Up

4.1 Diffusion bonding unit set up was developed in-house developed in Presidency University.

The diffusion bonding unit consist of following items

S. No	Item	Quantity	Specification
1	Die	2	Tool Steel 90 x 90 x 30
2	Heating element	6	Φ 14 x 70
3	Thermocouple	2	Contact Type
4	Temperature control Unit	1	Temperature Range 0-600^{0}C

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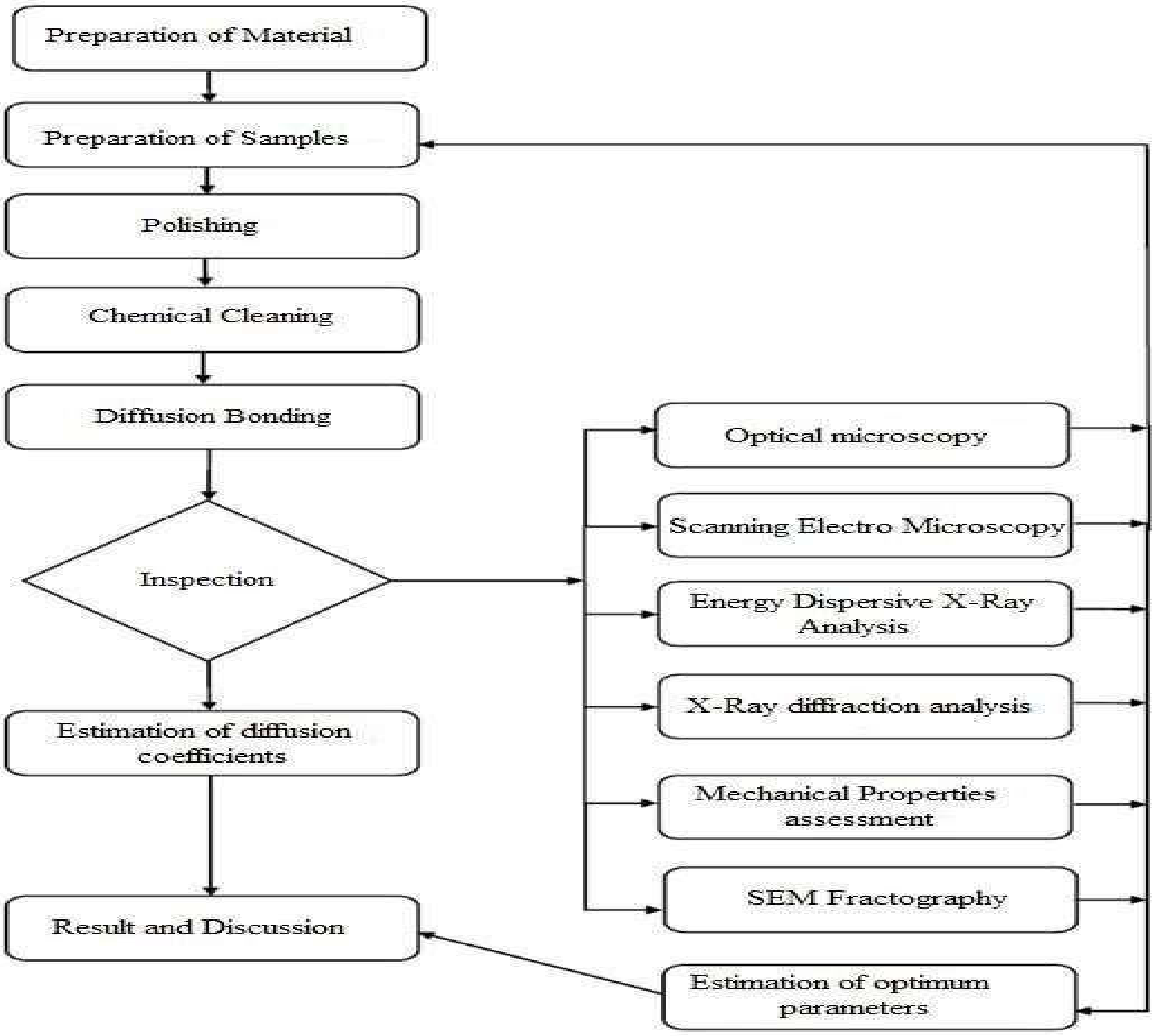

FIG 3.1

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(FIG 11) Diffusion bonding Set up in Presidencu University

The fig.11 shows the the arrangement of diffusion bonding unit for conducting the tests on metal specimens.The size of the specimen was choosen as 50 x 50 x 2 thick sheet of Al 2024 and reinforcement as Hematite ore of 40 μ with various fraction volume.The sample were prepared by changing mainly 3 process paramentes temperature,pressure and time.

4.2 Design Calculation of die for diffusion bonding:

Maximum load calculation (Pmax)

Yield strength of tool steel=311 N/mm2 (Data Hand Book)

Factor of safety =2 (assumed)

Area=90-3(3.14/4 x 162) =111.28 mm2

Yield stress=Pmax/A

311/2= Pmax/111.28

Pmax=155.5 MPa

4.3 Analysis of die using ANSYS software:

Ansys allows you to solve your most complex structural engineering projects and make superior design decisions more quickly. Finite element analysis (FEA) software from ANSYS provides engineers the ability to automate and customize simulations and even parameterize them for many design scenarios. You can easily connect ansys structural Mechanics software to other physics tools for even better realism, predicting performance and behavior of even the most complex projects. Engineers throughout the industry optimize product designs with FEA software from ansys.

STEPS INVOLVED IN FEA ANALYSIS

STEP 1: Preliminary Tests

a. Mathematical modeling
b. Geometry modeling

Step 2: Discritization

Step 3: Selection of displacement model as formation of element displacement function Step 4: derivation of elemental stiffness matrix

Step 5: derivation of global stiffness matrix

Step 6: applying boundary condition

Step 7: obtaining the stress and strain.

Images from Ansys

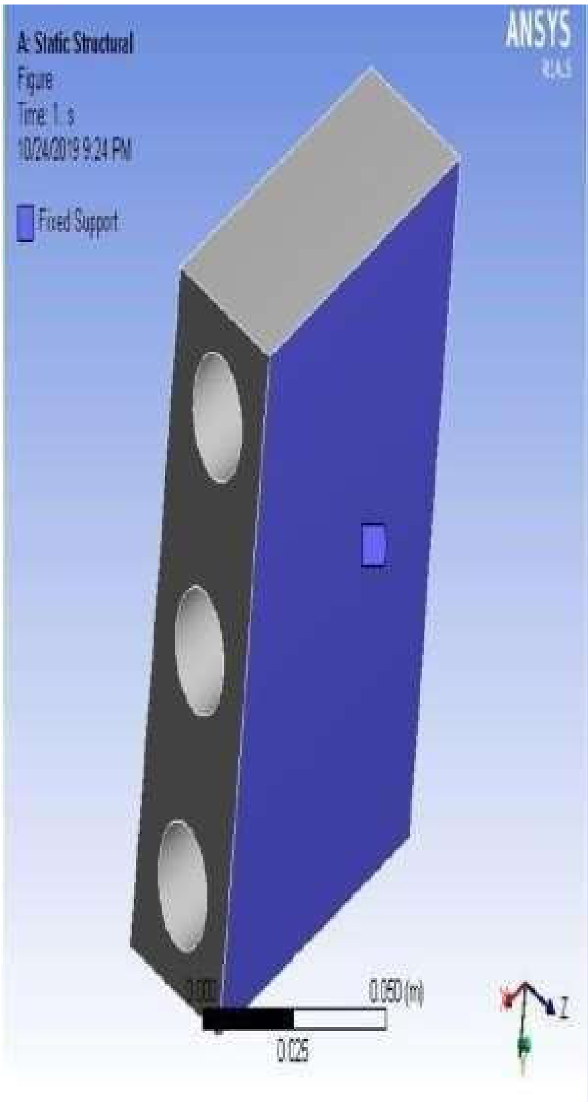


Fig 12.1

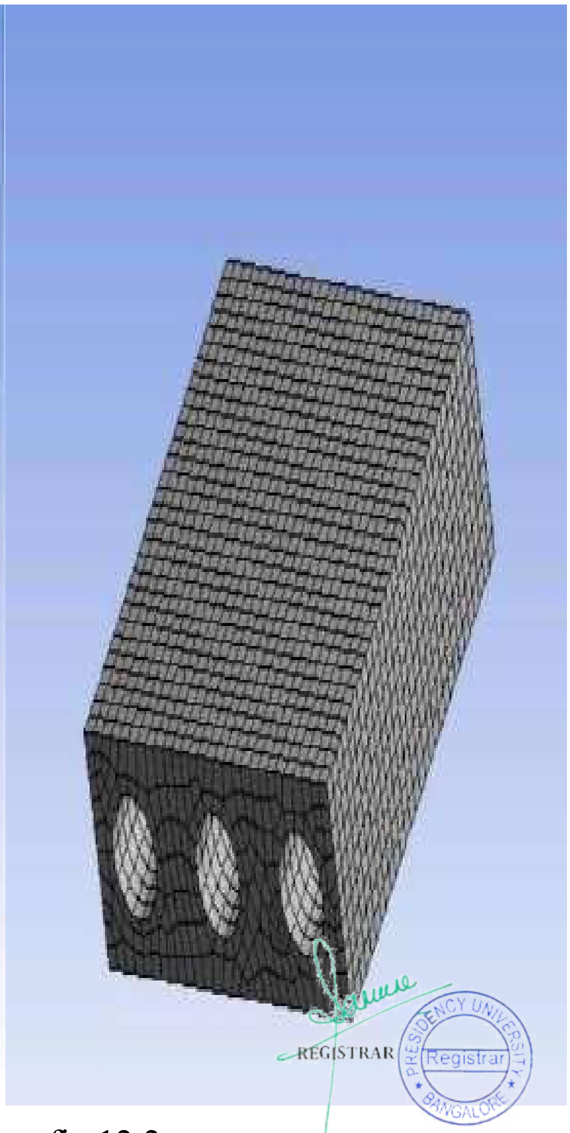
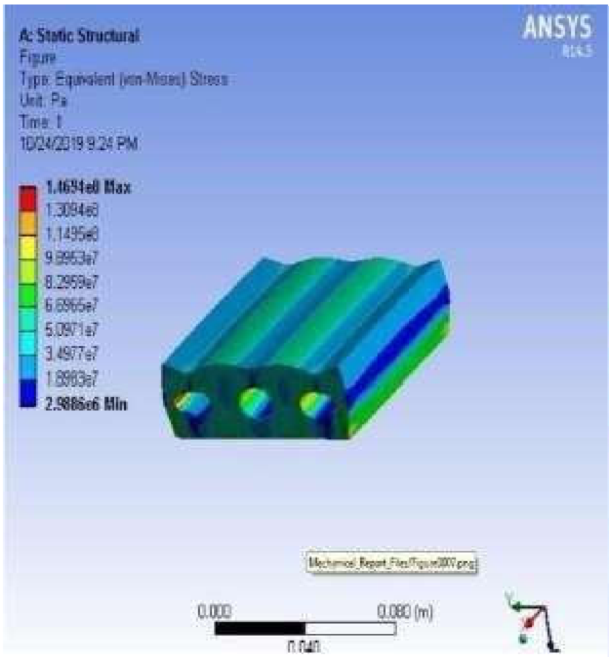


fig 12.2



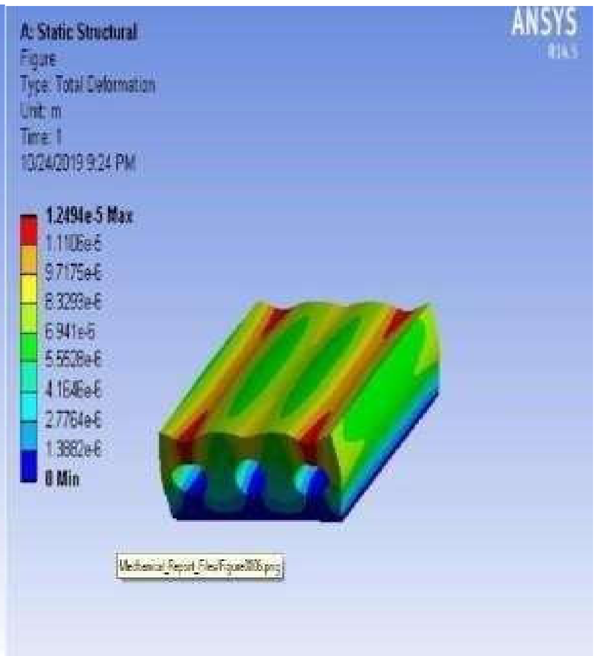


Fig 12.3 fig 12.4

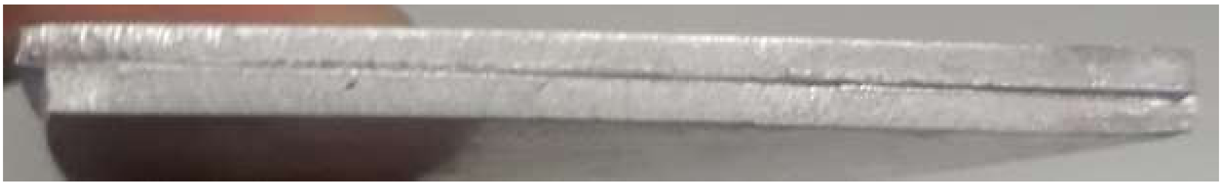
4.4 Cost Analysis:

SL NO	EQUIPMENT	PRICE
1	Control unit	18000
2	Die	3000
3	thermocouple	600
4	Heating coils	3000
	TOTAL	**24600**

5.1 RESULTS AND DISCUSSIONS:

Design and Fabrication of diffusion bonding unit are completed with the trials. Sample are prepared with Al 2024 with 2mm thickness sheet as base metal and hematite ore as reinforcement. While preparing samples we have considered mainly 3 process parameters temperature, pressure, and time.The picture of the samples prepared are shown below in Fig. 13,14 & 15

Sample1: 2mm Thick Al Sheet 2024,Temp: 320, Time: 50 Min, Load 50 KN



Sample1: 2mm Thick Al Sheet 2024,Temp: 400, Time: 30 Min, Load 70 KN

(FIG 13)

(FIG 14)

(FIG 15) shown clear diffusion of Al2024 sheet of 2mm thick.
A Diffusion bonding setup is made by using SS Heating coils, Tool steel die, temperature control panel and thermocouple.

FEA Analysis for the die is been done by using an Ansys software. The total deformation, yield and fracture point of the die has been analyzed and the maximum load of the die is also calculated.

By using diffusion bonding setup Aluminum 2024 sheets of 2 mm are been joined by using this diffusion bonding process. The pictures of the diffusion bonded samples are shown below.

4 samples with varying temperature and pressure are made:

SL NO	**METAL**	**TEMP**	**TIME**	**Load**
1	AL 2024	400^0 C	30 MIN	100 kN
2	AL 2024	400^0 C	30 MIN	100 kN
3	AL 2024	400^0 C	30 MIN	100 kN
4	AL 2024	320^0 C	50 MIN	50 kN

5.2 CONCLUSIONS:

The following conclusion is arrived for the diffusion bonding samples with AL 2024 and Hematite ore.

- The diffusion-bonded samples processed at 320 °C exhibited low bonding strength at low temperature, the bond strength was lower due to the lack of diffusion and poor contact between the surfaces.
- The diffusion-bonded samples processed at 400 °C exhibited good bonding strength at high temperature, the bond strength was higher due to the higher load and good contact between the surfaces.

5.3 RECOMMENDATIONS FOR FUTURE WORK

- Optimization of process parameters such as thermal load (temperature), mechanical load(pressure) and holding time
- Optimize the thickness of the Aluminum sheet
- Prepare specimen with various volume fractions of Hematite ore in between the sheets.

- Study the effect of phase changes using X ray diffraction analysis ➢ Study the effect of mechanical properties,SEM,

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A Project Report on

“Wear Characteristics of AZ-31 Reinforced with Carbon Nanotubes using PM Technique”

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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2020-21

CERTIFICATE

Certified that, the project work entitled, **"Wear Characteristics of AZ-31 Reinforced with Carbon Nanotubes using PM Technique"** carried out by, bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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A Project Report on

"DEVELOPMENT AND EVALUATION OF MECHANICAL PROPERTIES OF HEAT TREATED Al 356 ALLOY / ZIRCONIUM DIOXIDE (ZrO2)"

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A Project Report on

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A Project Report on

"SEVERE PLASTIC DEFORMATION ON Al 7075"

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DECLARATION

We, the students of eight semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled,

"**SEVERE PLASTIC DEFORMATION ON Al 7075**" has been successfully completed under the supervision of **Dr. Satish Babu B**, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfillment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2020-2021. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru

Date: 08/01/20

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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisor, **Dr. Satish Babu B** and all staff of **PRESIDENCY UNIVERSITY** for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We, take this opportunity to sincerely thank **Dr. M. Udaya Ravi,** Prof. and Head**,** Department of Mechanical Engineering for encouraging us to do this work. We would like to express our special thanks to the University Project Coordinator **Dr. Ramesh. S.P,** who gave us the opportunity to do this project work. We also take this opportunity to thank **Mr. Chikke Gowda,** Lab Instructor, for helping us in getting weight measurements of the samples.

Lastly, we would like to thank our family and friends

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ABSTRACT

Aluminium Matrix Composites (AMCs) have been of prime importance for specific applications in space structures, turbine engine components and aircraft skins. In order to enhance the properties of materials like wear resistance, specific stiffness, high elastic modulus, specific strength, excellent corrosion resistance, Metal Matrix Composites (MMCs) have been incorporated with reinforcements .MMCs apply to a specific type of material incorporated with rigid ceramic reinforcements in an alloy matrix or a ductile metal. Some of the reinforcements incude BN, SiO_2, ZrB_2, B_4C, SiC, TiO_2, Si_3N_4, and fly ash. MMCs thus provide a combined effect of metallic properties of matrix materials like toughness in addition to the reinforcement properties like high strength. Due to the low cost of fabrication and isotropic properties, particulate reinforced MMCs have been found to be of prime importance. Owing to the excellent properties of Aluminium alloys, like low density, they are extensively used in aerospace industries. Amongst the other alloys, Al 6061 is used widely in construction field mainly due to its high corrosion resistance and strength.

The present work involves fabrication of graphene and ZrO_2 particle reinforced Al 6061 metal matrix composite. The composite is manufactured using liquid metallurgy technique through stir casting method. Microstructural characterization is carried out using metallurgical microscope and confirms the presence of graphene and zirconium particles. A uniform distribution of reinforcement is observed throughout the matrix. Tensile tests are carried out to study the effect of reinforcement in the matrix and the results are reported.

1. INTRODUCTION

1.1 COMPOSITE

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from individual components. Within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

The many component materials and different processes that can be used make composites extremely versatile and efficient. They typically result lighter, stronger, more durable solutions compared to traditional materials . Composites contain fillers or nano-material such as Graphene carbon, glass, polymer or natural fibres. The properties and performance of composite are far superior to those of the constituents. Composite consist of one or more discontinuous phase (reinforcement) embedded in a continuous phase (matrix).Most of made of two materials. One is the matrix or brinder. It surrounds and and binds together fibres or fragment of the other material, which is called the reinforcement. Conventional monolithic materials have limitation in achieving good combination of strength, stiffness toughness and density. To overcome these composite material are most promising materials. Now days particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary component.

Dicontinuosly reinforced MMCs were fabricated through a variety of techniques like mechanical alloying, spray deposition, compocasting, rheocasting, powder metallurgy and squeeze casting.
The liquid metallurgy route is found to be economical in processing ZrO_2 reinforced Al metal matrix composites providing uniform distribution of the particulates. The tensile strength of the composite increased with increasing content of reinforcement in the Al 6061 alloy. Graphene is used as a reinforcement in Al6061 alloys, since it has tensile property of 130 GPaand Young’s modulus of 1 TPa. Various researchers have worked on different methods to include graphene homogeneously in Aluminium matrix. When grahene flakes were used as reinforcements, an increase in strength is observed, since the contact between matrix and reinforcement would be wide

The mechanical properties of Aluminium based composites were based on the type of reinforcements, the method of adding reinforcement in to the matrix and the size of reinforcement. A lot of researchers worked on adding particulate reinforcements like TiC, WC and AlB_2 using liquid metallurgy techniques

The present work is aimed at processing Al 6061 reinforced with graphene and ZrO_2 particles and its microstructural characterization and finding out yield strength of the composite.

1.1.2 Characteristics of Composites

Composite are multifunctional material system that provides characteristics of not obtainable from any discrete material. The composite properties may the volume fraction sum of properties of the constituent the nature of constituent material .

- The shape of the discontinuous phase the size and size distribution and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix.
- These consist of at least two different species with a well defined interface
- These have at least one property not possessed by the individual constituents.
- Their properties are influenced by the volume percentage of ingredients.

1.1.3 Performance of Composite

1. Properties of matrix and reinforcement,
2. Size and distribution of constituents,
3. Shape of constituents,
4. Nature of interface between constituents.

1.2 Classification of Composites

Composite materials are classified

1. Matrix material,
2. Filler material.

1.2.1 Matrix Material

1 Metal matrix composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. Generally, there are two phase e.g. a fibrous or particulate phase in a metallic matrix.. MMCs are used for Space Shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications. The biggest disadvantages of MMCs are their high costs of fabrication, which has placed limitations on their actual applications MMC's. There are also advantages in some of the physical attributes of MMCs such as no significant moisture absorption properties, non-inflammability, low electrical and thermal conductivities and resistance to most radiations.

Common types of material matrix composites.

- Aluminium matrix composite
- Magnesium matrix composite
- Titanium matrix composite
- Copper matrix composite.

Aluminium is the most popular matrix for metal matrix composite (MMC's).This have been widely used since the 1920 and are used in sporting goods, electronic packaging armours and automotive industries.

- Continuous fibres: boron, silicon carbide, alumina, graphite
- Discontinuous fibres: alumina, alumina-silica
- Whiskers: silicon carbide

Particulates: silicon carbide, boron carbide

Aluminium Matrix composites are manufactured by following methods

- Powder metallurgy
- Stir casting
- Squeeze casting

2 Ceramic matrix composite (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and imbedded fibers of other ceramic material (dispersed phase).Ceramic matrix are designed to improve toughness of conventional ceramics, the main advantage which is of brittleness.

Most of the CMCs are reinforced by silicon carbide fibrous due their high strength and stiffness. Monofilament fibres produce stronger interfacial bonding with the matrix material improving its toughness. Ceramic Matrix Composites (CMCs) used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibers, or whiskers such as those made from silicon carbide and boron nitride.

3 Polymer Matrices Composites (PMC)

PMCs are very popular due to their low A very large number of polymeric materials, both thermosetting and thermoplastic, are used as matrix materials for the composites. These are composed of a matrix from thermo set (Unsaturated polyester (UP), Epoxy) or thermoplastic (PVC, Nylon, Polysterene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase). Polymer matrix cast and simple fabrication methods.

The resinous binders (polymer matrices) are selected on the basis of adhesive strength, fatigue resistance, heat resistance, chemical and moisture resistance etc. Use of non-reinforced polymer as structure material is limited by low level of their mechanical properties such as tensile strength of one of the strongest polymer-epoxy resin is 2000 psi (140MP). The resinous binders (polymer matrices) are selected on the basis of adhesive strength, fatigue resistance, heat resistance, chemical and moisture resistance etc. The resin must 7 have mechanical strength commensurate with that of the reinforcement.

1.3 POWDER METALLURGY

Powder metallurgy can be defined as a science of metal powders and using them to manufacture useful materials and objects. Powder metallurgy is the process of mixing elemental or powder alloys, the compact mixture in a die, and then heating or sintering the shapes in an controlled atmosphere using furnace. Most metallurgical powder parts weighs less then 2.25kg, parts weighing 15.89kg can be fabricated in conventional metallurgical powder. Many of the metallurgical powder, such as bushing and bearing are very simple intricate shapes and this is the sophisticated metallurgical powder.

The first consideration in metallurgical powder used for manufacturing processes there are several different measures and initiatives are used to quantify the properties of powder. Powder can be pure alloys or pure elements a powder might be a mixture of different kinds of powders. This can have various types of oxidation, results example oxygen present in the atmosphere

Powder Properties

It is possible to produce components through powder metallurgical processes that have physical properties and that approach those of analogous wrought materials, to achieve this requires repressing and resintering to be carried out, which in turn add to cost of production.

- It will tensile strength approximately 75% of those of produced/machined from wrought stock.
- Due to porosity, the hardness and ductility of the material will be on lower side.

2. LITERATURE SURVEY

2.1 Types of reinforcement

1. Particulate Composites

In this type of composites, 1µm to 200µm size particles are dispersed in the matrix and the volume fraction is generally between .01Vf to .85Vf. discontinuously reinforced Aluminium (DRA) composites are a subclass of metal matrix composites. Particulate Composites consist of a matrix reinforced by a dispersed phase in form of
particles.

1. Composites with random orientation of particles.
2. Composites with preferred orientation of particles

Hard particles dispersed in softer matrix increase wear and abrasion resistance. Soft dispersed particle in hard matrix improves machinability and reduce coefficient of friction. Their combination of properties and fabric ability makes them attractive candidates for many structural components requiring high stiffness, high strength and low weight.

2. Fibrous Composites

Short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers. A fiber is characterized by its length being much greater compared to its cross-sectional dimensions. Long-fiber reinforced composites. Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.

1. Composites with random orientation of fibers.
2. Composites with preferred orientation of fibers.
3. Unidirectional orientation of fibers.
4. Bidirectional orientation of fibers (woven).

3. Laminate Composites

When a fiber reinforced composite consists of several layers with different fiber Orientations, it is called multilayer composite. Laminate composites provide increased mechanical strength in two directions and only in one direction, perpendicular to the preferred orientations of the fibers or sheet, mechanical properties of the material are low. Laminate Composites are composed of layers of materials held together by matrix. Generally, these layers are arranged alternatively for the better bonding between reinforcement and the matrix.

2.2 ALUMINIUM ALLOY 6061

Aluminium alloy 6061 is one of the most b widely used of the 6000 series aluminium alloy. Typical properties of aluminium alloy are.

- strength retention at higher temperatures,
- higher transverse strength,
- better electrical conductivity,
- superior thermal conductivity,
- higher erosion resistance etc

The density of the Al 6061 is 2.7g/cm^3 and the melting point is 727°C

Application of Aluminium alloy

- Manufacture of automotive components
- Construction of yachts
- Scuba tanks
- Fishing reels
- Electrical fitting
- Camera lenses
- Coupling and valves

Fig: 1 Al6061 alloy

2.3 ZIRCONIUM OXIDE

Zirconium is a chemical element with the symbol Zr and the atomic number 40. The name zirconium is taken from the name mineral zircon. It is lustrous, grey white, soft, ductile, malleable metal that is solid at room temperature, though it is hard and brittle at lesser purities. In powder form, zirconium is highly flammable, highly resistance to corrosion by alkalis, acid salt water and other agents.

The melting point of zirconium is 1855˚C and the boiling point is 4371˚C at room temperature zirconium exhibits a hexagonally close packed crystal structure.

Applications of zirconium oxide

- Chemical process
- Petrochemical
- Oil and gas
- Pharmaceutical
- Geothermal
- Sea water
- Water desalination
- Liquefied natural gas

Fig: 2. Zirconium oxide in powder form

2.4. Graphene

Graphene is being such novel material in carbon group which is discovered very recently (during 2010, invented by Andre Geim and Konstantin Nooselov). It is strong hybridized 2D-Nano scale material which is well recognized with the extreme strength. Further it got immense attention due to its excellent physical and mechanical properties such as Elastic modulus (0.5-1 TPa), tensile strength 130 GPa and Thermal conductivity in the field of research. Compared to other form of carbon materials like CNTs and fullerenes, Graphene has been expected to outperform due to its unique properties and have great potential in developing the nanocomposites. A molecular model of single atomic layer Graphene sheet with various other graphitic forms. Initially Graphene preparation is carried out by breaking the graphite down into Graphene by a mechanical cleavage or liquid phase exfoliation method. The other common method is chemical vapor deposition (CVD).It is also used to synthesize Graphene and in recent day's thinner forms of graphite nanoplates (GNPs).

The work is focused on 6xxx series of Al alloys and an attempt is made to develop an innovative processing powder in liquid media through powder metallurgy route, which is carried out to exploit the effect of the Graphene in the Al 6061.Ultrasonic dispersion is carried out to alleviate the agglomeration of Graphene and to achieve the homogeneous dispersion of Graphene in the matrix followed by ball milling. Thus prepared powder mixture are vacuum hot pressed and sintered. The effect Graphene addititon with different weight fraction on hardness and flexural properties are evaluated.

Fig:3. Graphene used as reinforced material

This chapter presents a review of the literature data available on the effect of various reinforcement types, their size and volume fraction, ageing behavior with Al based MMCs. Matrices can be selected from a number of Aluminium alloys and many reinforcement types SiC, B_4C, Al_2O_3 etc. are available in different sizes, morphologies and volume fractions. These reinforcements can be combined with the different matrices, resulting in large composite systems. Furthermore, several different processing routes, such as powder metallurgy, stir casting, squeeze casting, hot extrusion etc. Composite structures have shown universally a savings of at least 20% over metal counterparts and a lower operational and maintenance cost.

Rao *et al* [1] studied the effect of SiC content and sliding speed on the wear behaviour of aluminium alloy and composite was studied using pin-on-disc apparatus against EN32 steel counterface. These tests were conducted at varying SiC particles in 10, 15 and 25 wt.% an sliding speeds of 0.52, 1.72, 3.35, 4.18 and 5.23 m/s for a constant sliding distance of 5000 m. The results revealed that as the SiC content increases the wear rate and temperature decreases, but reverse trend can be observed for coefficient of friction.

[2]Das *et al.* [2] investigated the effect of zircon sand particles with different size and amount incorporated in Al-4.5 wt% Cu alloy by using stir casting process. Coarser particles of size between

90 -135 μm were dispersed in substantial amounts (up to 30 wt %), where as finer particles of size 15-65 μm had limited dispersion, 10 and 20 wt%, respectively. The matrix of the composites had cellular structure; whereas the size of the cell was dependent on zircon particle size and its amount in the composite. Wear test of cast alloy and composites were subjected to abrasive wear under dry conditions at a load of 15 N. The abrasive wear resistance of the composite improved with the increase in amount or decrease in size of zircon particles.

Andersson. C.-H.*et al* [3]. Successfully prepared relatively in expensive high grade SiC whiskers from rise husks, worked with this SiC whiskers found that with many other ceramic materials available, this silicon carbide has a relatively high thermal conductivity and low coefficient of thermal expansion; giving it a relatively variable thermal shock resistance. Generally, the reinforcing and roughening effects of SiC whiskers are better than those of SiC particles. The proper aspect ratio is 30 – 40, as whiskers that are too long are hard to distribute. As reported by a high content of whiskers is preferred in the production of SiC from rice husks. They also reports that thick whiskers are suitable for ceramic matrix composites; whereas thin whiskers are suitable for metal matrix composites

Navinchand *et al.* [4] reported the studies on polyester filled with RHA. Their reports say that both the tensile and impact strength of the resulting composites decreased with increasing filler loading. It is also reported that in addition to being used in rubbers or plastics, RHA can also be used as a filler in rubber/plastic blends.

Rahimian *et al* [5] studied the effect of production parameters on wear resistance of Al– Al_2O_3 composites. Alumina powder with a particle size of 12, 3 and 48 μ and pure aluminum powder The range of sintering temperature and time were 500, 550 and 600ºC and 30, 45, 60 and 90 minutes respectively. It was found that increasing sintering temperature results in increasing density, hardness and wear resistance and homogenization of the microstructure. However at certain sintering temperatures and time, considerable grain growth and reduction of hardness value occurred, leading to the degradation of wear resistance. The results showed that at high alumina content, relative density of the composite increases. After raising the particle size of alumina, relative density initially increases and then drops to lower values. Increasing weight percent of alumina powder leads to higher hardness and consequently improves the wear zhardness and the wear resistance. Finally, a finer grain size was observed, at high amount and low size of the reinforcement particle.with particle size of 30μ were used. The amount of added alumina powder was up to 20%.

Prasad B. K, *et.al* [6], while trying to find out the factors controlling the abrasive wear of Zinc-based alloy silicon carbide particle composite has reports that when silicon carbide is used as an abrasive, the requirement on purity is not high. The purity of silicon carbide from RHs is high enough to match this requirement. They also reports that the silicon carbide can be either directly used as abrasive material or not pressed with composites.

Shishkovsky *et.al* .[7] investigated the Alumina–zirconium ceramics synthesized by specific laser sintering/melting. The porous refractory ceramics synthesized by specific laser sintering/melting from a mixture of zirconium dioxide, aluminum and/or alumina powders were subjected to optical metallography and X-ray investigation to study their microstructure and phase composition depending on the laser processing parameters. It was demonstrated that fast laser sintering in air yields ceramics with thick structure and a uniform distribution of the balancing out stages. They used ceramic–matrix composites which may be utilized as thermal and electrical protectors and wear resistant covering in solid oxide energy units, pots, heating components, medical instruments. By applying finely scattered Y_2O_3 powder inclusions, the type of the ceramic structure altogether changed. The surface macro- and microstructure examined by optical metallography was relatively dense, smooth and uniform, but contained pores and cracks. The optimal processing parameters were successfully determined for monolayer and layer-by-layer laser sintering within a narrow process parameter window (laser power, scan velocity, beam diameter and hatch distance) in order to minimize shrinkage and eliminate cracking and delaminating.

Sajjadi *et al.* [8] performed the research on nano and micro-composites (A356/Al_2O_3) with different weight percent of particles were fabricated by two melt techniques such as stir-casting and compo-casting. Microstructural characterization was investigated by optical (OP) and scanning electron microscopy (SEM). Tensile, hardness and compression tests were carried out in order to identify mechanical properties of the composites. The results of micro structural study revealed uniform distribution, grain refinement and low porosity in micro and nano- composite specimens. The mechanical results showed that the addition of alumina (micro and nano) led to the improvement in yield strength, ultimate tensile strength, compression strength and hardness. It was indicated that type of fabrication process and particle size were the effective factors influencing on the mechanical properties. Decreasing alumina particle size and using compo-casting process obtained the best mechanical properties.

Robinson *et al.* [9] investigated the influence of hot deformation and alloy composition on the exfoliation corrosion, tear toughness and tensile properties susceptibility of Al-2025 with the addition of zirconium. The addition of 0.12% Zr to Al-2025 in ingot, extrusion, forging and fully heat-treated microstructures that do not differ significantly to a standard 2025 alloy composition.At the lower temperature, recovery resulted in a fine equiaxed substructure while at 440 °C partial recrystallisation occurred. However these micro-structural changes only had a small effect on subsequent processing and mechanical properties; the lower extrusion temperature did appear to promote higher tensile properties in samples forged at 400 and 440°C.The forging temperature had a very strong effect on the resulting fully heat treated microstructure. At lower temperatures the retention of strain energy after forging was sufficient to allow almost complete recrystallisation during heat treatment. Forging at 400 °C and 440 °C however resulted in partial recrystallisation after heat treatment and a mixture of fine sub grains mixed with very large elongated recrystallised grains. Partially recrystallised samples performed well due to the lack of exposed end grain and the relatively small volume fraction of sub grain containing material compared to similarly process full scale propellers.Hydraulic pressing of propellers at low temperatures (250–300 °C) offered the best opportunity of producing optimized exfoliation and tensile properties. However this method imposed technological difficulties as the material had a high flow stress and this can result in loss of dimensional control.

Swamy *et al.* [10] proposed that Addition of SiC as reinforcement in Al6061 alloy system improves its hardness, tensile strength and wear resistance. In the present investigation Al6061–SiC composites was fabricated by liquid metallurgy route with percentages of SiC varying from 4 wt% to 10 wt% in steps of 2 wt%. The cast matrix alloy and its composites have been subjected to solutionizing treatment at a temperature of 530°C for 1 h followed by quenching in different media such as air, water and ice. The quenched samples are then subjected to both natural and artificial ageing. Microstructural studies have been carried out to understand the nature of structure. Mechanical properties such as microhardness, tensile strength, and abrasive wear tests have been conducted both on matrix Al6061 and Al6061– SiCp composites before and after heat treatment. However, under identical heat treatment conditions, adopted Al6061–SiCp composites exhibited better microhardness and tensile strength reduced wear loss when compared with Al matrix alloy.

Ramirez *et al.* [11] found that the wear resistance of Al with the addition of zirconia increases. The composites were created by compacting aluminum powder (Almex) at room temperature in an automatic hydraulic press. The cellulose fibres used during the compacting process increased the porosity and allowed a homogeneous distribution of zirconia; also, the quantity of zirconia present was increased in the interior of the aluminum preforms.Wear test was carried out on a pin-on-disc machine rotating at a speed of 360 rpm with a load of 9 N without lubrication for 2 hrs and the weight loss of the piece was measured after every 30 minutes. By measuring the weight loss, it was observed that the composite had significant improvement in wear resistance when compared to pure aluminum.The best wear resistance was observed in the composites of Al-Zirconia. It was found that the decrease in wear was due to the fact that the ceramic material introduced into the pores acted as reinforcement. The best tribological behavior of this composite was achieved when there was a bigger presence and distribution of zirconia in per-forms. The wear coefficient of composite and pure aluminum showed that, by using this new methodology, a composite with improved wear resistance can be obtained.

Umanath *et al.* [12] fabricated an Al6061alloy with mixtures of SiC and Al_2O_3 particles by stir casting method and their wear resistance and Co-efficient of Friction has been investigated as a function of applied load and Volume fraction of the particles. The dry sliding wear properties of the hybrid composites and that of Al6061 unreinforced alloy at room temperature were investigated by using Pin-on-disk wear testing machine at a constant sliding velocity of 2.09 m/s and sliding distance of 1884m over a various loads of 29.43N, 39.24N and 49.05N (3, 4 and 5 kgf) for particle volume fraction ranging from 5-25%. The results showed that, the reinforcement of the metal matrix with SiC and Al_2O_3 particulates up to a volume fraction of 25% reduces the wear rate at room temperature. The results also showed that the wear of the test specimens increase with the increasing load and sliding distance. The coefficient of friction slightly decreases with increasing volume content of reinforcements. Micro hardness of the specimens at the room temperature was also measured before and after the wear tests by Vickers hardness testing machine. The micro hardness of the hybrid composite test specimens increases with increasing volume fraction of particulates reinforcement. The optical micrographs taken for the micro structure analysis of the hybrid composite specimens showed that the SiC and Al_2O_3 particulates are uniformly distributed in the matrix. The wear surfaces were examined by scanning electron microscopy, which showed that the large grooved regions and cavities with ceramic particles were found on the worn surface of the composite alloy. This indicates an abrasive wear mechanism which is essentially a result of hard ceramic particles exposed on the worn surface.

Suresha and Sridhara *et.al* [13] investigated the impact of addition of graphite particulates on the wear resistance in aluminium–silicon carbide–graphite composites. Aluminium composites with varying reinforcements (hybrid AMCs) were discovering increased applications in light of enhanced mechanical and tribological properties and subsequently had better substitutes for single reinforced composites. Few examinations had been accounted for on the tribological conduct of these composites with % reinforcement over 10%. This study aimed to find out the impact of adding graphite (Gr) particulates as a second reinforcement on the tribological behaviour of aluminum grid composites strengthened with silicon carbide (Sic) particulates. Dry sliding wear tests were performed to study the impact of Gr particulates, sliding distance, load and sliding speed on the wear of hybrid composite examples with combined % reinforcement of 2.5%, 5%, 7.5% and 10% with equivalent weight % of Sic and Gr particulates. The wear of hybrid composites indicates that hybrid composites display better wear attributes as compared with composites strengthened with SiC alone.

Zhu *et al.* [14] analyzed the microstructural evolution and high temperature wear characteristics of aluminum matrix composites fabricated by reaction of Al–ZrO_2–B elemental powders were explored. The amount of the Al_3Zr phase in the composites decreased with the increase of the B/ZrO_2 mole ratio. When the B/ZrO_2 mole ratio reached 2, the Al3Zr components almost diminished and the resultant composites consisted of primarily fine α-Al_2O_3 and ZrB_2 particles. At test temperature of 373 K and the applied load of 20 N, the wear rate of the composites increased and arrived at the maximum value before decreasing with the further increase of sliding velocity. However, when the test temperature was reached to 473 K, the wear rate decreased constantly with the increase of sliding velocity. With the increase of B/ZrO_2 molar ratio, both the wear rate and the friction coefficient of the composites decreased, while the subsurface deformation zone increases.

Abdizadeh *et al.* [15] investigated the improvement in physical and mechanical properties of Al/Zircon composites fabricated by powder metallurgy method. Micro-structures of these composites in powder metallurgy conditions showed different size distribution of zircon when present in different proportions in the composite. The green specimens prepared by isostatic pressing of prepared powders with different zircon percentages, were sintered at two temperatures 600^{o} and 650 ^{o}C. These samples were then examined by distinctive physical and mechanical testing strategies to see, which conditions acquired the best properties. The most enhanced pressure quality was achieved with the example including 5% of zircon sintered at 650^{o} C. With increase in zircon content of composites, the hardness of specimens increased to a maximum value of 75 BHN. While further increase in temperature follows the same trend. Also, higher temperatures increased sintering density and relative density up to 92%. Adding more zircon content increased sintering density to 92% but relative density decreased to 86%. Moreover, sintering temperature improved mechanical properties like: Yield stress and Elongation and Compressive strength. In this experiment 650 ^{o}C as the sintering temperature showed better results than 600^{o} C.

Shivanand and Benal *et.al* [16] studied the improvement in abrasive wear rate of as-cast and heat-treated Al (6061) alloy reinforced with 9% by weight of SiC particulate and 0, 1, 3 and 5% by weight of E-glass fiber subjected to different ageing durations. The liquid melt technique route is used to produce the castings. Castings were machined to the ASTM standards and T6 heat- treatment process is carried out. All the specimens were artificially aged to different durations like 1, 3, 5 and 7 h at a temperature of 175 ºC. It was found that the heat-treatment T65h was the one that provided the matrix greater hardness and therefore it was the one, which shows the heat-treated specimens, are the high wear resistance. The wear rate of the Al-based hybrid composites do not depend on type of reinforcement, but wear rate of the hybrid composites decreases with increasing the weight percentage of reinforcing materials. The abrasive wear resistance of Al-based hybrid composites may be controllably altered by thermal ageing. As- cast hybrid composites and 1 h aged hybrid composites provided relatively low resistance. Maximum wear resistance was achieved when the hybrid composites aged at 5 h condition, when the Al alloy contained a large number of coherent precipitates.

R.Kartigeyan *et.al.* [17],has effectively developed Al7075 alloy and short Basalt Fiber composite through liquid metallurgy technique. The increase in short Basalt fiber maximizes the tensile strength ,yield strength and hardness. The composite containing 6% wt of short Basalt Fiber signifies higher hardness value of 19.7 Mpa when compare to base matrix hardness 92Mpa.The 7075/short Basalt fiber reinforced 6 vol % maximizes the ultimate tensile strength by 65.51%. The distribution of reinforcements in metal matrix genuinely uniform.

Aouici H.*et al* [18] took AISI HILL hardened steel (40; 45 and 50 HRC) to be machined with cubic boron nitride tool .RSM & ANOVA were used to investigate the effect of cutting parameters on surface roughness..They investigated that both feed rate and work piece hardness have significance on surface roughness. The best surface roughness was achieved at the Lower feed rate and highest cutting speed.

Baradeswaran and Perumal *et.al* [19] investigated the Wear and mechanical qualities of Al 7075/graphite composites. This work investigates 7075 aluminum alloy–graphite composites for its tribological and mechanical behavior under dry sliding conditions. The conventional fluid casting system was used for the creation of composite material and subjected to T6 heat treatment. The reinforcement constant was picked as 5, 10, 15 and 20 wt. % of graphite to identify its potential for self-lubricating property under dry sliding conditions. Wear tests were performed by pin on disc apparatus. The wear rate decreased with increase in graphite substance and achieved its base at 5 wt. % graphite. The wear loss was decrease with increasing sliding distance. The normal coefficient of friction decreased with increase in graphite substance and was discovered to be least for 5 wt. % graphite. The mechanical properties decreased with increase in graphite content as compared with base alloy. The worn surfaces were examined through SEM.

Hassan and Aigbodion *et.al* [20] studied the microstructure and ageing behavior of Al–Si–Fe/Mg alloys produced through sand-casting route is presented. 4.0–6.0 wt% Mg was added to Al–Si– Fe alloy. Standard mechanical properties test samples were prepared from the sand cast 25 mm diameter by 45 mm rods. Thermal ageing was done for 6 h at 200 °C. The ageing characteristics of these alloys were evaluated using tensile properties, hardness values, impact energy and microstructure as criteria. The thermal aged samples exhibited higher yield strength, tensile strength and hardness values as the weight percent of magnesium increased up to 5 wt% in the Al–Si–Fe/Mg alloys as compared to as-cast samples. The optimum values were obtained at 5 wt. % Mg. Lower percent elongation, reduction in area and impact energy values were obtained for age-hardened Al–Si–Fe/Mg alloy samples as compared to as-cast samples. The increases in hardness values and strength during ageing are attributed to the formation of coherent and uniform precipitation in the metal lattice. It was found that the age-hardened showed acceleration in ageing compared to the as-cast alloy. However, the 5 wt% Mg addition to the alloy showed more acceleration to thermal ageing treatment. These results show that better mechanical properties are achievable by subjecting the as-cast Al–Si–Fe/Mg alloys to thermal ageing treatment.

Yilmaz and Buytoz *et.al* [21] studied the effects of volume fraction, Al_2O_3 particle size and effects of porosity in the composites on the abrasive wear resistance of compo-casting Al alloy MMCs have been studied for different abrasive conditions. It was seen that porosity in the composites is proportional to particle content. In addition, process variables like the stirring speed, and the position and diameter of the stirrer affect of the porosity content in a way similar to that observed for particle content. In addition, the abrasive wear rates of composites decreased more rapidly with increase in Al_2O_3 volume fraction in tests performed over 80 grades SiC abrasive paper than in tests conducted over 220 grade SiC abrasive paper. Furthermore, the wear rates decreased with increase in Al_2O_3 size for the composites containing the same amount of Al_2O_3. Hence, it is deduced that aluminium alloy composites reinforced with larger Al_2O_3 particles are more effective against abrasive wear than those reinforced with smaller Al_2O_3 particles. At the same time the results show that the beneficial effects of hard Al_2O_3 particles on wear resistance far surpassed that of the sintered porosity in the compocasting metal-matrix composites (MMCs). Nevertheless, the fabrication of composites containing soft particles such as graphite favors a reduction in the friction coefficient. For this reason graphite and copper were used in the matrix in different amounts to detect their effect on wear resistance. Finally, it was seen that wear rate of the composites decreased considerably with graphite additions.

2.5 Gap in Literature Review

As per the literature available investigations are done on the individual effect of reinforcement like silicon carbide, magnesium, zirconium, graphite, zirconium oxide and fly ash on aluminium matrix but no significant work is found on the effect of Zirconium Oxide plus Graphene on the Aluminium metal matrix.

3.OBJECTICES AND SCOPE OF THE PRESENT WORK

- To prepare ZrO_2 and graphene reinforced Al 6061 metal matrix composites.
- To carry out micro structural studies on the composite processed.
- To determine mechanical properties (tensile strength) of the processed composite.

4. EXPERIMENTAL DETAILS

4.1. Processing of composites

Metal matrix composite materials can be produced by many different techniques. The focus of the selection of suitable process engineering is the desired kind, quantity and distribution of the reinforcement components (particles and fibers), the matrix alloy and the application.

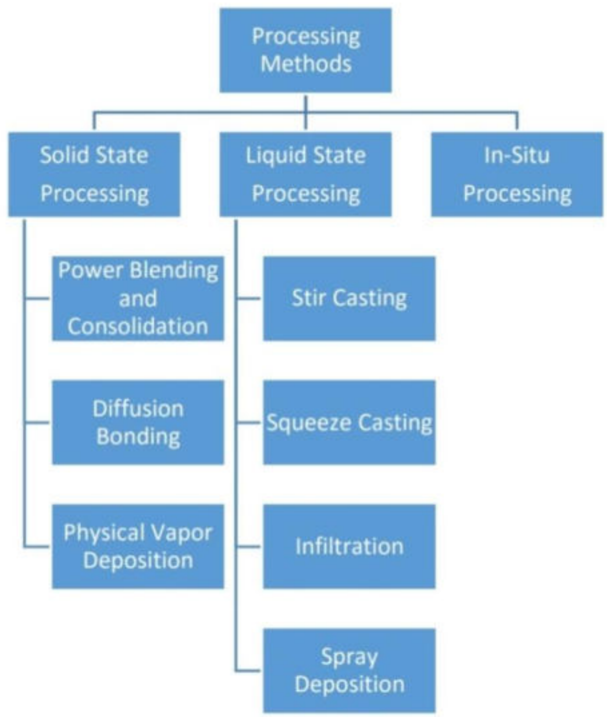

Fig: 4. Methods of processing

Liquid state fabrication of Metal Matrix Composites

Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. The simplest and the most cost effective method of liquid state fabrication is Stir Casting.

4.2. Stir casting

Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means mechanical stirring. Stir Casting is the simplest and the most cost effective method of liquid state fabrication. This involves incorporation of ceramic particulate into liquid Aluminium melt and allowing the matrix to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid Aluminium alloy melt. This process involves stirring of melt, which the melt is stirred continuously, which exposes the melt surface to the atmosphere which tends to continuous oxidation of aluminium melt. As a result of continuous oxidation ,the wet ability of the aluminium reduces and the reinforcement particle remain unmixed. Stir will take uniform distribution of away in the crucible. dropping the degassing enables ,into the crucible will remove gases from the molten materials and also it prevents porosity or micro porosity related problems. However, here gas access into the melt must be absolutely avoided, since this could lead to unwanted porosities or reactions.

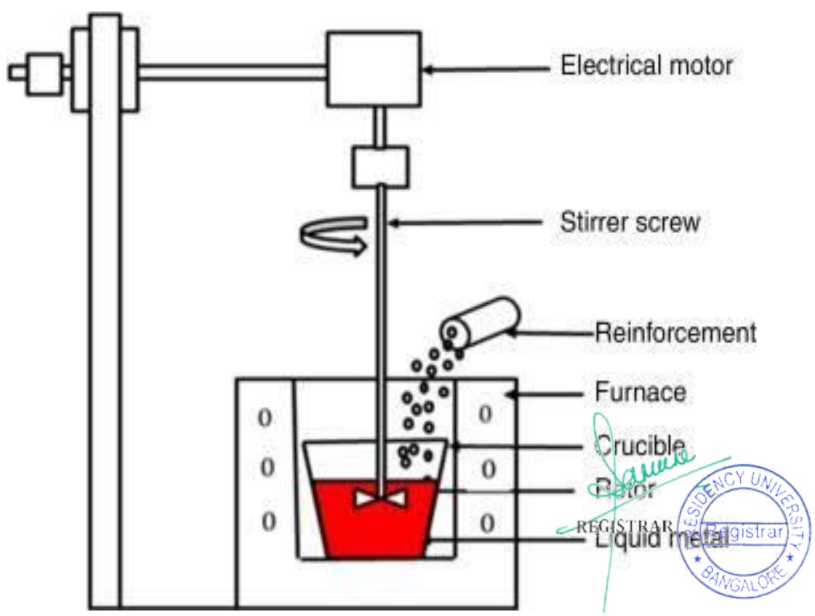

Fig: 5 Stir casting

Distribution of dispersed phase may be improved if the matrix is in semi-solid condition. The method using stirring metal composite materials in semi-solid state is called Rheocasting.

High viscosity of the semisolid matrix material enables better mixing of the dispersed phase.

4.2.1. Stir Casting is characterized by the following features:

• Content of dispersed phase is limited (usually not more than 30 vol. %).

• Distribution of dispersed phase throughout the matrix is not perfectly homogeneous:

1. There are local clouds (clusters) of the dispersed particles (fibers);

2. There may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrix phase.

• The technology is relatively simple and low cost

4.3.Casting of the composite:

Al 6061 alloy is selected as a base matrix and ZrO_2 and graphene particulates are used as reinforcement materials. The alloy is procured in the form of ingots. It is initially cleaned to remove dirt/grease using NaOH solution and then preheated in a muffle furnace to remove moisture. The ingots are then melted at a temperature of 660°C and superheated to a temperature of 800 °C in an electrical resistance furnace, connected to a digital temperature controller. A calculated quantity of ZrO_2 and graphene corresponding to Al6061-1wt.% ZrO_2-1 wt. %graphenecomposite was wrapped in an aluminium foil and added to the melt. The melt was constantly stirred using a stirrer coated with zirconia at regular intervals. Degassing was carried out to remove the dissolved gases during melting process. The reaction time was maintained at 45 min and the melt was finally poured in to permanent die made of special alloy steel. After cooling, the castings were then collected from the die. The composites with Al 6061 alloy-0.2 wt. % graphene-1.5 wt. % ZrO_2 and Al 6061 alloy-0.4 wt. % graphene-2 wt. % ZrO_2 were prepared and taken for characterization.

Fig:6 Shows melting of the Al6061 Alloy

Fig :7 shows adding reinforcement to alloy

Fig:8 Shows pouring of molten composite into die

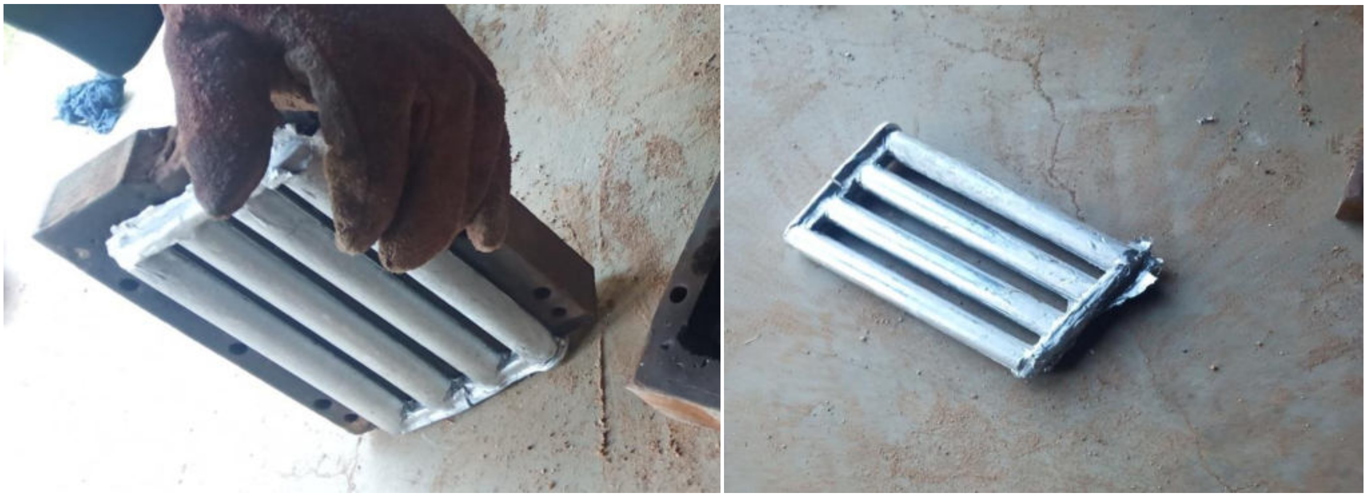

Fig:9 Shows removal of casting from the mold

4.4.Microstructural characterization:

The specimen for micro structural characterization was prepared by cutting a size of about 7mm from the bottom of casting using a hack-saw. It was then polished using rough and smooth files. The surface was then made even with emery sheets, followed by working on a disc polishing machine containing velvet cloth. A solution of Al_2O_3 was used to get a mirror finish while using disc polishing. A Kellers reagent was used to reveal the grain boundaries. The specimen was finally washed with distilled water. An optical metallurgical metal microscope (Nikon Epiphot 200) was used to capture the micrographs.

Tensile strength:

A Universal Testing Machine of 100 tons was used to know the yield strength of the composite. ASTM E8 standard was used to prepare the specimen. Initially, dial gauge and load is set to zero.Slow and gradual loading was applied on the specimen fixed in the jaws of the machine. The change in length of the specimen is noted using the dial gauge. The breaking load is noted down

5. RESULTS AND DISCUSSIONS

5.1.Microstructural characterization

The micrographs of the composite show the uniform distribution of ZrO_2 and graphene particulates throughout the matrix. No porosity was observed suggesting the degassing procedure was The grey spherical shaped particles correspond to the reinforcement particles in the composite as observed from the Figures a to d.

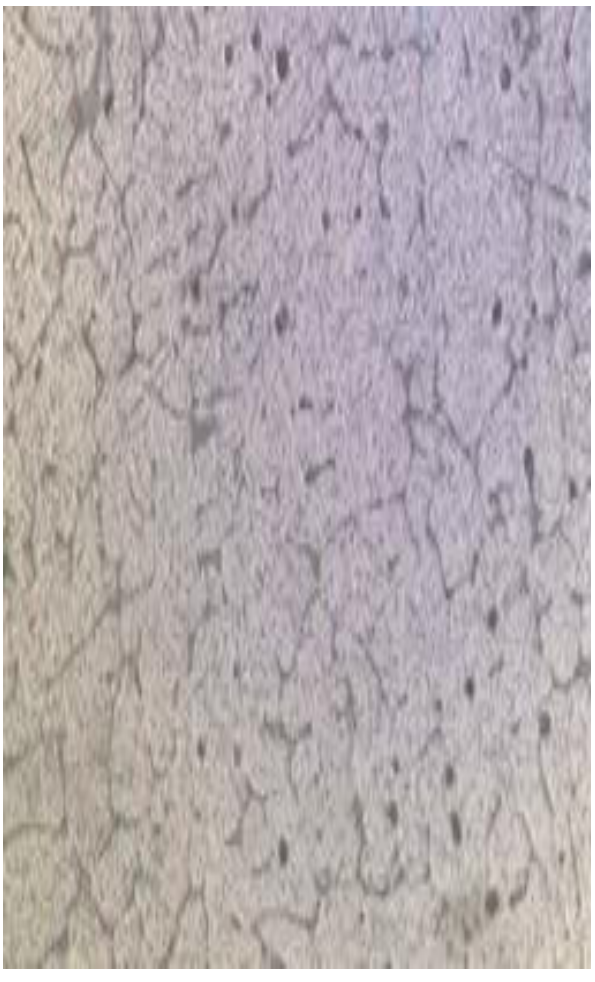	
Fig:10 shows Micrograph of Al 6061 alloy-0.2 wt. % graphene-1.5 wt. % ZrO_2 composite (Specimen 1).	Fig.11 shows Micrograph of Al 6061 alloy-0.4 wt. % graphene-2 wt. % ZrO_2 composite(Specimen 2).

Particle size analysis was done to report the size of the particles using an Image Analyser. An average of 10 measurements was taken at different places on the specimen for each sample. It was found that the maximum and minimum particle size was 4.2 and 4.3 µm respectively. The mean size for 5 such samples was found to be 5.25 µm.

5.2.Tensile strength:

The yield strength of Al6061 all0y (6061-0 temper) was found to be 55. With the addition of the reinforcement, the yield strength increased to 84 and 88 MPa for specimen 1 and 2 respectively. The load at yield point was found to be 9.9KN. Graphene/ZrO_2 acts as an obstruction near the aluminium grain boundaries. The grain growth is thereby controlled due to the reinforcement. Thus the dislocations cannot move freely due to the barriers of the reinforcement. The base matrix goes through transformation toughening with the addition of ZrO_2 reinforcement. A solid holding between matrix and ZrO_2 particles is responsible for the increase in yield strength. This may also be attributed to molecule fortifying by the reinforcements.

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6.CONCLUSIONS

- The composite is successfully prepared in an electrical resistance furnace using the reinforcements of ZrO_2 and graphene.
- Microstructural studies reveal the uniform distribution of the reinforcements throughout the matrix.
- Tensile tests reveal improvements in yield strengths in the reinforced composite compared to the base alloy.

6.1.Recommendations for future work

- To study the wear characteristics of the processed composites using pin on disc machine
- To study the corrosion behaviour of the composites in the acidic and basic media
- To study the effect of heat treatment on the reinforced composites.
- To carry out microstructural studies using XRD, SEM and FTIR.
- To evaluate the mechanical properties using compressive strength, hardness etc..

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www.amces2020.dsce.edu.in

ABSTRACT ACCEPTANCE LETTER

International Conference On
'Advances in Materials, Ceramics & Engineering Sciences'
(AMCES- 2020)
Dayananda Sagar College of Engineering, Bengaluru, India.
17th - 18th January, 2020
Jointly with
ICS - Karnataka Chapter and Department of Nanotechnology, VTU

Dated: 09/12/2019

Paper Title: Synthesis and Characterization of ZrO2 and Graphene particle reinforced Al6061 Metal Matrix Composite

Paper ID : AMCES2020-AB110

Dear S. B. Boppana,

We are very pleased to inform you that your abstract has been accepted for presentation at ***International Conference On 'Advances In Materials, Ceramics & Engineering Sciences' (AMCES- 2020), DSCE***, Bengaluru, India. The schedule of your presentation session will be specified in the AMCES - 2020 conference website https://amces2020.dsce.edu.in/

You can **send full manuscripts on or before 15th January 2020** to the conference email id: **amces2020@dayanandasagar.edu** and follow the manuscript template and author guidelines available on the conference website.

IMPORTANT

Please do register for AMCES - 2020. Your abstract will called for presentation only after registration and confirmation of your payment before **15th December 2019**. The AMCES 2020 abstracts will be published in the Conference souvenir and full paper will be published in **AIP/Materials Today Conference Proceedings (Scopus Indexed)** after Peer Review with publication charges.

REGISTRAR

Thanking you.

Best regards,

Organizing Chair, AMCES-2020

A Project Report on

"Phase Change Materials for Thermal Management of Automobile Cabinet"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

H Girish	20171MEC0066
Mohith	20181LME0012
Darshan P	20171MEC0052
Santhosha N	20181LME0051
Hariharan Mahadev Kalagudi	20171MEC0070

Under the Supervision of
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GAIN MORE KNOWLEDGE
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2020-21

CERTIFICATE

Certified that, the project work entitled, **"Phase Change Materials for Thermal Management of Automobile Cabinet"** carried out by, bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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Supervisor

Dr. M. Udaya Ravi
Prof. and Head of department

End Term Examination Examiners

Signature with date

1. Kunwar Chandra Singh
2. Mr.Basavaraj Devakki

A Project Report on

"THE STUDY OF SPY GLIDER AND ITS APPLICATION"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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NEHAL N	20171MEC0148
NAYAN JONES	20171MEC0146
PALLAVI MEGHANA V S	20171MEC0157
NITHESH SINGH NOEL	20171MEC0151

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2.Mr.Basavaraj Devakki

A Project Report on

"Implementation of Six Sigma in Academia"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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SOHAN CHANDRAKANTH B	20171MEC0212
GABRIEL MAXWELL	20171MEC0060
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Department of Mechanical Engineering

School of Engineering, Itgalpura, Rajanukunte, Bengaluru - 560064
2020-21

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A Project Report on

"Design and Fabrication of Drone by using 3-D printing Technology"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in

Mechanical Engineering

Submitted by

MEESALA GURU RAM SAI	20181LME0002
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Department of Mechanical Engineering

School of Engineering, Itgalpura, Rajanukunte, Bengaluru - 560064

2020-21

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A Project Report on

"Friction stir welding of Nylon-6 polymeric material"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

MOHAMED FARMAN	20181LME0022
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A Project Report on

"Design and fabrication of Robot sanitizer"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
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Submitted by

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A Project Report on

"State of the Art Review on Mechanical Characterization of Areca Fibre Reinforced Polymer Composites."

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in

Mechanical Engineering

Submitted by

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A Project Report on

"DESIGN AND DEVELOPMENT OF 2D PRINTING MACHINE"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

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Signature with date

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2. Dr.Yuvaraj Nayak

A Project Report on

"DESIGN AND FABRICATION OF 360 DEGREE FLEXIBLE DRILLING MACHINE"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

Raghavendra Rohit P	20171MEC0172
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2.Mr.Basavaraj Devakki

A Project Report on

"Risk analysis and assesment in network enviroments"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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2.Dr.Ramachandra C G

A Project Report on

"POWER GENERATION USING SPEED BREAKERS"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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2.Dr.Ramachandra C G

A Project Report on

"Design and fabrication of fruit harvesting robot using rocker bogie"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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Supervisor

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End Term Examination Examiners

Signature with date

1.Dr.Satish Babu B

2.Dr.Yuvaraj Nayak

A Project Report on

"Effect of particle size distribution for variable stirrer speed on mechanical properties and microstructural evaluation of Al-7075/B4C composite"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in

Mechanical Engineering

Submitted by

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Mohammed Ishaq Ahmed	20171MEC0126
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Certified that, the project work entitled, **"Effect of particle size distribution for variable stirrer speed on mechanical properties and microstructural evaluation of Al-7075/B4C composite"** carried out by, bonafide students of Presidency University, in partial fulfillment for the award of **Bachelor of Technology** in Mechanical Engineering of the School of Engineering during the year 2020-2021. It is certified that all corrections/suggestions indicated for University Project have been incorporated in the thesis report deposited in the departmental library. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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A Project Report on

"EDM studies of Ultra fine grained aluminiumalloy Al6082"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

Submitted by

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A Project Report on

"EFFECT OF COOLING RATE ON MICROSTRUCTURE AND PROPERTIES OF A356 ALUMINIUM ALLOY HYBRID COMPOSITE"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
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A Project Report on

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Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
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A Project Report on

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A Project Report on

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A Project Report on

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Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
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A Project Report on

"Study on Variation of Temperature with Time of Bronzeand Copper Alloys for Bearing and Gear Applications"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
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A Project Report on

Structural Analysis of Pulse Tube Cryocooler Expander Assembly

Submitted in partial fulfilment of the requirement of Bachelor of Technology for the University Project in

Mechanical Engineering

Submitted by

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DECLARATION

We, the students of eighth semester of Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru, declare that, the work entitled, **"Structural Analysis of Pulse Tube Cryocooler Expander Assembly"** has been successfully completed under the supervision of Mr. Padmanabhan and Mr Tanneru Sai

Goutam, Engineers, U R Rao Satellite Centre, Indian Space Research Organization, Bengaluru, Dr. Devendra Singh Dandotiya, Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru. This dissertation work is submitted to Presidency University in partial fulfilment of the requirements for the award of University Project in Mechanical Engineering during the academic year 2018-2019. Further, the matter embodied in the thesis report has not been submitted previously by anybody for the award of any degree or diploma to any university.

Place: Bengaluru Date:

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ACKNOWLEDGEMENT

We express our sincere gratitude to our supervisors, Mr. Padmanabhan, Mr. Tanneru Sai Goutam and Mr. Shivanand Kamat, Engineers, U R Rao Satellite Centre, Indian Space Research Organization, Bengaluru, for sharing their support and giving important advice, guidance and arrangement of all facilities to make work easier. We choose this moment to acknowledge their contribution gratefully.

We take this opportunity to sincerely thank Dr. Ramesh S, Prof and Head – Department of Mechanical Engineering for encouraging us to meet the highest peak and prepare this project. We would like to acknowledge our thankfulness and deep sense of gratitude to the University Project Coordinator Dr. Devendra Singh Dandotiya who gave us valuable supervision throughout the project.

We are also obliged to our friends and family for their elevating inspiration and encouraging assistance in the completion of this project.

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ABSTRACT

Pulse tube cryocoolers that operate between 80 and 100 K are widely used in satellites for cooling of infra-red cameras and a variety of electronic devices. ISRO has also been

engaged in the development of pulse tube cryocooler for the same purpose. While the existing model was able to withstand the launch loads in qualification tests, the current work aims to further study the expander assembly of the pulse tube cryocooler, understand the key factors affecting the structure and how altering them can be beneficial.

After some initial literature survey, natural frequency of the simplified model is calculated theoretically. Each part of the existing model is then modelled using the Solidworks software as per dimensions and then assembled. The model is then imported in ANSYS Workbench software, materials are assigned to the parts and meshing is done. The model is then subjected to static structural analysis where the earth gravity is taken into consideration, modal analysis where the natural frequencies and mode shapes are identified, harmonic response analysis and random vibration analysis where the launch loads are applied in all the axes to simulate the shaker used in the actual experiment. In harmonic response analysis, acceleration response results are taken and in random vibration analysis the PSD G acceleration results are taken. These results from the simulation are then compared with the experimental results through parametric studies. Following this, areas for improvement are identified through discussions and possible solutions are suggested.

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CHAPTER 1

1.1 Introduction:

Satellites which orbit several thousand miles above the Earth surface help humans in communication, navigation, environmental monitoring and imaging to study the planetary surfaces. Many electronic systems co-ordinate to accomplish the objective, such as capturing pictures or transferring information. Such systems which are made up of numerous electronic circuits and sensors generate heat and this heat must be extracted and rejected out of the system to protect it from extreme temperatures.

Pulse Tube Cryocooler is a developing technology, which does not have any moving parts at the cold end unlike other cryocoolers, are installed in satellites to extract the heat generated from sensors and circuits and cool them to cryogenic temperatures i.e., temperatures below 120K. Satellites which contains infrared sensors/ detectors sense radiation coming from the Earth. These sensors will have to be cooled and cryogenic temperature range has to be maintained to achieve better Signal to Noise Ratio (SNR) using cryocoolers. Maintenance free cryocoolers for satellites have made pulse tube Cryocoolers an attractive proposition and relatively simple way of reaching cryogenic temperatures.

1.1.1 Main Components of Pulse Tube Cryocooler (PTC)

The main components of a PTR include a compressor, an after cooler, a regenerator, a cold end heat exchanger, a pulse tube, hot end heat exchanger, an orifice valve for Orifice Pulse Tube Cryocooler (OPTC) and an inertance tube for Inertance Tube Pulse Tube Cryocooler (ITPTC) and a reservoir as shown in figure 1.1 below.

Compressor: The compressor is a device which is used to generate high- and low-pressure oscillation in PTR. Hence, gas pressurization and depressurization take place inside a closed volume. Input to the compressor is electric power and it converts the electric power to equivalent mechanical power that causes the piston to reciprocate inside the compressor. Generally, reciprocating compressors are used in Stirling type PTCs and for high frequency moving coil type linear motor driven compressors are preferred.

After Cooler: It is a device which is placed in between compressor and regenerator in the arrangement of PTC. The gas is slightly heated during the compression process in compressor. The main purpose of after cooler is to remove heat from the gas coming from compressor and to supply gas at ambient temperature to the regenerative heat exchanger.

Regenerator: Regenerator is the heart of PTCs. The main function of regenerator is, it absorbs heat from gas during compression stroke and gets heated. Then subsequently release the same heat to cold gas during return stroke and gets cooled. The regenerator is made up of porous matrix. Stainless steel or phosphor bronze wire screens are generally used for constructing porous matrix. Ideally, to get maximum enthalpy flow in pulse tube, regenerator should be ideal i.e., there should be no pressure drop and effectiveness should be close to 100%. But it is very much difficult to maintain effectiveness of such high values at cryogenic temperature. However, in working systems values above 0.99 are necessary to make them practical, stainless steel is used as regenerator packing material as they provide better heat transfer area, high specific heat value, low pressure drops and low thermal conductivity.

Cold end Heat Exchanger (CHX): As compared to the evaporator in a Vapour Compression Refrigeration cycle, there is CHX in case of PTRs. The function of CHX is same as that of evaporator. The system absorbs refrigeration load at CHX. It is placed in between regenerator and pulse tube. Copper wire screens are used to increase the surface area for exchanging heat between CHX and housing wall.

Pulse Tube: Pulse Tube is a hollow cylindrical tube made up of stainless steel. The main objective is to carry heat load from cold end HX to the hot end HX with the help of enthalpy flow. The mechanism behind heat carrying from cold end to hot end of the pulse tube is by maintaining the desired phase between the flow parameters which is provided by the phase shifting mechanism in a OPTC or IPTC. The thickness of the pulse tube wall is kept optimum to promote surface heat pumping, in basic pulse tube cryocoolers (BPTC)

Hot end Heat Exchanger (HHX): HHX is used to remove heat of compression carried by the gas from the cold end in every stroke of cycle. The heat is released to atmosphere. Generally, water cooling or aircooling systems are used to take heat away.

Phase shifter: Orifice valve for OPTC and inertance tube for ITPTC are usually known as phase shifter. These are placed in between the hot end of pulse tube and reservoir. The optimum phase relationship can be achieved by adjusting orifice valve's diameter in OPTC and by adjusting length and diameter of inertance tube in ITPTC. Physically, inertance tube is a long thin tube and orifice valve is a needle valve type.

1.1.2 Working of a Basic Pulse Tube Cryocooler

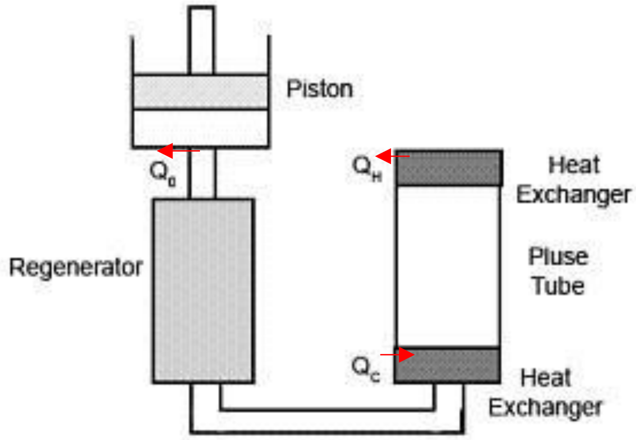

Fig. 1.1: Basic Pulse Tube Cryocooler (Source: Stanford Edu Courses)

The first pulse tube was built in 1963 by Gifford and Longsworth. Its basic components include a pulse tube, a regenerator, a pressure wave generator, and two heat exchangers as shown in Fig. 1. The pulse tube is a simple tube with one open end and one closed end. The closed end is the hot end and is capped with a heat exchanger that cools it to the ambient temperature. The open end is the cold end. It is connected to the regenerator and a cold stage by a second heat exchanger. The regenerator is a periodic flow heat exchanger. It absorbs heat from gas pumped into the pulse tube pre-cooling it, and stores the heat for half a cycle then transfers it back to outgoing cold gas in the second half of the cycle cooling the regenerator. The interior of the regenerator tube is filled with either stacked fine mesh screens or packed spheres to increase its heat capacity. A piston, compressor or similar pressure wave generator is attached to the warm end of the regenerator and provides the pressure oscillations that drive the refrigeration. Helium is used as the working gas due to its monotonic ideal gas properties and low condensation temperature. In systems with a base temperature below 2K the He_3 isotope is used.

The pulse tube works by transporting heat against a temperature gradient in a process called surface heat pumping. Surface heat pumping is expected to occur in many systems subjected to pressure oscillations [1]. The piston compresses the working gas, and every gas particle moves towards the closed end of the pulse tube. At the same time the temperature of the gas particles rises as they undergo adiabatic compression. The pressure experienced by a gas molecule in the pulse tube is determined by when it entered the pulse tube.

All the gas that was initially in the tube will be compressed to the hot end. The extra gas that flows in from the regenerator has a pressure gradient. The pressure is highest closest to the hot end and decreases to zero at the bottom of the pulse tube. Gas at the bottom entered the tube just as equilibrium was established. The pressure gradient directly results in a temperature gradient. At the hot end of the pulse tube the gas conducts its heat to the heat exchanger and the gas temperature falls. The piston then retracts and the gas undergoes adiabatic expansion cooling it even more. As the expanding gas passes from the pulse tube into the regenerator it absorbs heat from the regenerator and the pulse tube walls cooling them. The next cycle starts by compressing the gas back through the pre-cooled regenerator. The gas begins at a lower temperature and it therefore reaches an even lower temperature after finishing its compression expansion cycle. The net result of the cycle is that each element of the gas transports heat against the temperature gradient toward the closed hot end of the pulse tube where it is absorbed by the heat exchanger.

Record low temperatures achieved with this basic pulse tube design are 124K with a single stage and 79K using two stages [2]. Two stages describe two pulse tube coolers in series powered by the same compressor. The hot end of the second pulse tube is thermally anchored to the cold end of the first pulse tube cooler. There is a valve at the cold end of the first regenerator that allows compressed gas to flow into both the second regenerator and the pulse tube of the first cooler.

1.1.3 Classification of Pulse Tube Cryocoolers

- **Stirling type pulse tube cryocoolers** are very attractive for cooling of diverse application because it has it has several inherent advantages such as no moving part in the cold end, low manufacturing cost and long operation life. To develop the Stirling-type pulse tube cryocooler, we need to design a linear compressor to drive the pulse tube cryocooler. A moving magnet type linear motor of dual piston configuration is designed and fabricated, and this compressor could be operated with the electric power of 100 W and the frequency up to 60 Hz.

- **Gifford-McMahon cryocoolers** have found widespread application in many low-temperature systems for example in MRI and cryopumps. The cold head contains a compression and expansion space, a regenerator, and a displacer. Usually, the regenerator and the displacer are combined in one body. The pressure variations in the cold head are obtained by connecting it periodically to the high- and low-pressure sides of a compressor by a rotating valve. Its position is synchronized with the motion of the displacer. During the opening and closing of the valves irreversible processes take place, so GM-coolers have intrinsic losses. This is a clear disadvantage of this type of cooler.

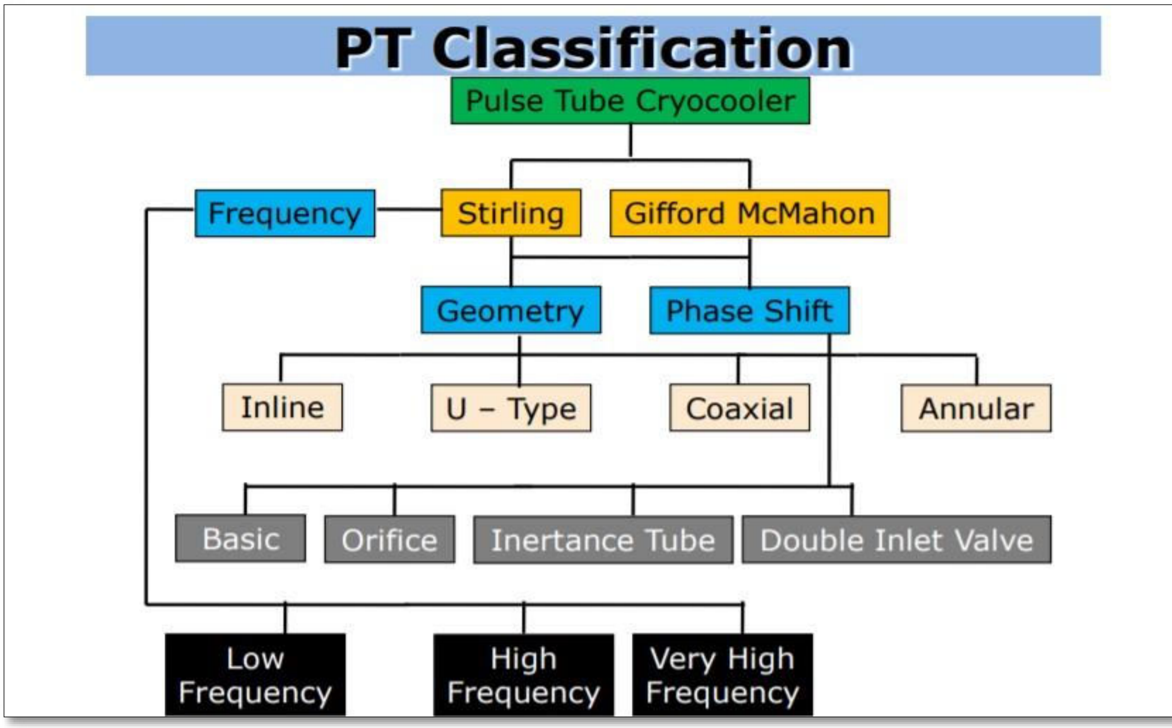

Fig. 1.2: Pulse Tube Cryocooler Classification (Source: NPTEL Cryogenic Engineering)

According to the nature of pressure wave generator:

a. Stirling type PTCs

b. Gifford McMahon (G-M) type PTCs

Stirling Type PTC	G-M Type PTC
Operating frequency is high (40Hz to 120Hz)	Operating frequency is low (1Hz to 5Hz)
Compressor is directly connected to expander without any valve in between.	Compressor is connected to expander with a valve in between (generally rotary or solenoid valves are used).
Dry compressor is used and capacity is low (in few hundred of Watts).	Bulky and oil lubricated compressor is used and capacity is more (in kW).
Coefficient of performance (COP) is high.	COP is low.
Pressure ratio is low.	Pressure ratio is high.

A temperature of 20K can be achieved.	A temperature of 4K can be achieved.

Based on geometry:

i. **Inline:** The gas does not change the direction of flow. Hence, the pressure losses are minimum. This arrangement delivers best performance as compared to others. The cold end is at the center of the system. The system is less compact since it occupies huge space (length wise).

ii. **U- Tube:** The gas flow undergoes a 180-degree change in flow direction. Due to which the system exhibits pressure drop. The cold end is exposed and it is easily accessible. The system is more compact and it occupies less space. The performance is dependent upon the sharpness of the bend.

iii. **Co-axial:** Co-axial arrangement of PTCs is very much compact. The regenerator of these type of PTCs are constructed as a ring shape. This ring shape regenerator surrounds the pulse tube. As there is a physical contact between regenerator and pulse tube, there is a large temperature difference and hence heat transfer between pulse tube and regenerator. The remedy for this difficulty is to provide a thin layer of insulation between pulse tube and regenerator, which increases the overall size of cryocooler.

iv. **Annular:** In this arrangement, the regenerator is placed inside the pulse tube, whereas in case of co-axial PTR pulse tube is placed inside the regenerator. The system exhibits maximum pressure drop due to change in flow direction. The cold end is exposed and it is easily accessible. The system is more compact but there is a possible heat transfer between the PT and regenerator.

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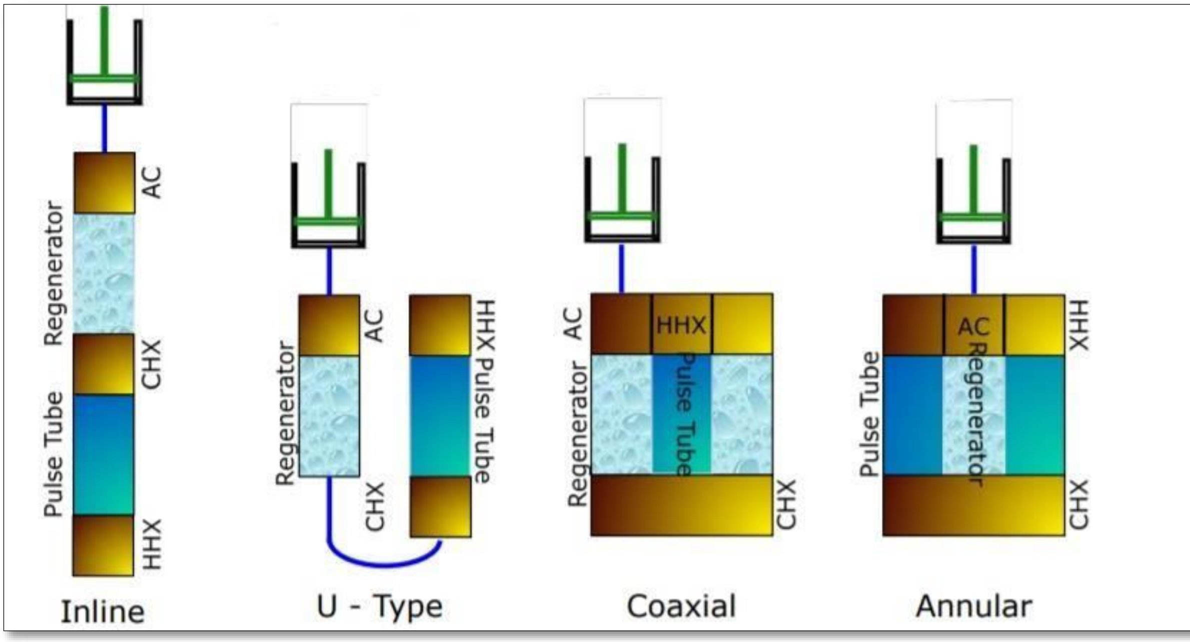

Fig. 1.3: Classification of Cryocoolers Based on Geometry
(Source: NPTEL Cryogenic Engineering)

Based on construction:

1. **Basic Type Pulse Tube Cryocooler:** Its basic components include a pulse tube, a regenerator, a pressure wave generator, and two heat exchangers. The pulse tube is a simple tube with one open end and one closed end. The closed end is the hot end and is capped with a heat exchanger that cools it to the ambient temperature. The open end is the cold end. It is connected to the regenerator and a cold stage by a second heat exchanger. The regenerator is a periodic flow heat exchanger.

2. **Orifice Pulse Tube Cryocooler:** The basic pulse tube Cryocooler and more generally the surface heat pumping technique is clearly of limited use for reaching very cold temperatures, and in 1984 Mikulin improved the design by adding an orifice near the warm end of the pulse tube. An orifice is just a throttle valve or needle valve to regulate flow. Their new design had a base temperature of 105K [3] Radebaugh further improved the design, reaching a low temperature of 60K, by placing the orifice outside the heat exchanger and adding a reservoir closing the orifice [2].

3. **Double Inlet Pulse Tube Cryocooler:** To overcome limitations of the orifice type cryocooler, one more valve is attached in between the hot end of pulse tube to the inlet of regenerator. This arrangement is called Double inlet Pulse Tube Cryocooler (DIPTR) and it enhances the refrigeration power and cooling per unit mass flow rate. Fig 1.7 shows the various components of DIPTR and arrangement of the components of DIPTR. A temperature of 41K can be achieved with the help of DIPTR and also the rate of temperature fall is more as compared to OPTR. The drawback associated with DIPTR is the fluctuation of cold end temperature. This fluctuation of temperature occurs due to the circulating flow of gas through the pulse tube and regenerator, which is known as DC gas flow.

4. **Inertance Tube:** To avoid fluctuation of cold end temperature, a relatively new passive flow element, known as the inertance tube is added in place of orifice valve which utilizes the inertia of the oscillating flow to bring about a shift in the phase between the flow and the pressure [4]. For small pulse

tube cryocoolers where the mass flow in the inertance tube is small the phase shift may be only a few degrees. In order to achieve the optimum phase angle of flow lagging pressure by about 30° at the cold end means that the inertance tube will need to lag the flow at its inlet by about 60° to accommodate the change in phase through the pulse tube. Such a large negative phase for flow in the pulse tube component produces a large magnitude of flow for a given acoustic power flow. However, because the pulse tube is an open tube, large flows there do not contribute to large losses.

5. **Multistage Pulse Tube Cryocooler:** Multistaging of pulse tube cryocooler (PTC) is done to achieve much lower temperature below 30K. Multistaging of PTC is done by simply arranging the PTCs in which the hot end of pulse tube in 2nd stage is connected to room temperature instead of connecting to the cold end of 1^{st} stage. By 3-stage arrangement of PTCs, a temperature of 1.78K can be achieved by taking helium as working fluid.

6. **V-M Type Pulse Tube Cryocooler:** The advantage of V-M type pulse tube Cryocooler is that, it uses thermal compressor instead of mechanical compressor. In case of mechanical compressor, the oscillatory motion of piston causes the pressure oscillation, but in case of thermal compressor pressure oscillation is generated by temperature difference. The main components of V-M type PTC are displacer, expander, work transfer tube, regenerator, pulse tube, heat exchanger. The heat exchangers are immersed in liquid nitrogen bath.

1.1.4 Advantages and Disadvantages

Advantages of Pulse Tube Cryocooler

1) Less moving parts, so no maintenance and fewer losses 2)
Low power consumption
3) Multi staging is possible.
4) Longer life
5) No lubrication required
6) Can be used instead of cryogenic cycles

Disadvantages of Pulse Tube Cryocooler

1) Comparatively lower coefficient of performance (COP) as work recovery is absent.
2) COP depends on the length of the tube

1.1.5 Applications of Pulse Tube Cryocooler

1. Space
   a. Cooling and maintaining temperature of infrared detectors used in satellites.
2. Defense
   a. Infrared sensors used for guidance of missile, surveillance and night vision.
   b. Monitoring the nuclear activity by Gamma-ray sensors.
3. Environmental

a. Infrared sensors used for monitoring of pollution and also for studying atmosphere.

4. Commercial purpose

a. Cryo-pumps used for fabrication of semiconductors.

b. Superconductors used for high-speed communication and electric transmission with minimum losses.

c. Semiconductors used for high-speed computers.

d. Liquefaction of industrial gases like Nitrogen, Helium, Oxygen.

5. Medical science

a. Used for cooling of superconducting magnets for Magnetic Resonance Imaging (MRI).

b. To study heart and brain (SQUID magnetometers).

c. Cryosurgery and cryo-ablation catheters.

6. Transportation

a. Liquefied Nitrogen gas used for vehicles.

b. Superconducting magnets used for Maglev trains.

7. Security

a. Infrared sensors used for rescue and for security purpose in night.

8. Biology and Agriculture

a. For storing specimens, biological cells and tissues.

b. High pressure cooling for preservation of macromolecular crystals.

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CHAPTER 2

2.1 Literature Survey

Two scientists from Syracus University, Gifford and Longsworth introduced a new method to achieve low temperature in 1963, Pulse tube Cryocooler. They published their first research paper in 1964 [5] which described that "temperature gradient is generated in a closed volume by simply pressurizing and depressurizing the gas inside that closed volume from a point on its periphery". The temperature gradient hence generated depends upon operating conditions and the size and geometry of closed volume.

There 1st design comprised of a hollow cylindrical tube with one end closed and the other end open. The closed end was exposed to the atmospheric heat exchanger and the open end is the clod end. Due to the oscillatory motion of the piston, an oscillatory pressure wave is created inside the tube which causes the cooling of open end. This refrigeration system is named as Basic Pulse Tube Cryocooler (BPTR).

Gifford and Longsworth [6] predicted the relation between cooling temperature at cold end and zero heat pumping concerning length ratio, hot end temperature and the ratio of specific heats of gas by using the mechanism of surface heat pumping. They observed that the surface heat pumping occurs due to the abnormal interaction between the fluid displacement and exchange of energy in the surface and fluid. Gifford and Longsworth [7] examined the BPTR between the critical pressure ratios and got the useful refrigeration.

An important improvement in BPTR was done by de Boer [8] by adding a heat exchanger and regenerator at both the ends of pulse tube. He studied the heat flow in regenerator, heat exchangers and pulse tube by using control volume analysis.

Ashwin et al. [9] performed the numerical simulation of high frequency miniature PTRs. They simulated the model by considering different length-to-diameter ratios (L/D ratios) of the pulse tube by using CFD package FLUENT software. For modeling the porous zones, the local thermal non-equilibrium of gas and porous matrix were considered. They examined the dynamic characteristics of gas flow and mechanism of heat transfer in the tube. They found that, considering thermal non-equilibrium of gas and matrix a much lower temperature at cold end side of tube as compared to that of thermal equilibrium conditions. They concluded that for pulse tube diameter 4 mm and L/D ratios between 10 and 20 is beneficial.

Ray Radebaugh [10] in his paper 'Pulse Tube Cryocoolers for Cooling Infrared Sensors' mentions the recent advancements of pulse tube cryocoolers. Efficiencies in the range of 10 to 24% of Carnot at 80 K have been achieved in small pulse tube cryocoolers with input powers of 10 to 100 W. Such efficiencies are much higher than the 2.5 to 6.4% efficiencies required of the cryocoolers for the second-generation thermal imaging systems. With such high efficiencies it should then be possible to make pulse tube refrigerators with coaxial geometries for the pulse tube and regenerator that have small enough diameters and lengths for the cold finger.

The 1.0 W and 1.75 W coolers should be relatively easy to retrofit. The 0.35 W cooler will require careful optimization and experimentation to develop a pulse tube cooler with such a small diameter cold finger.

B. Wang et.al [11], in their paper 'A critical review of liquid helium temperature high frequency pulse tube cryocoolers for space applications' mentions that the insufficient supply and high cost of liquid helium in recent Years have led to the rapid development of liquid helium mechanical cryocoolers and their wide application in the aerospace field. Among the different kinds of mechanical cryocoolers, high Frequency pulse tube cryocoolers operating at liquid helium temperature (LHT-PTC) offering the advantages of long life, high Reliability and compact structure present one of the best candidates for cooling systems of deep space observations. Operating frequency has a significant influence on the performance of LHT-PTCs, and the regenerative materials with high Volumetric heat capacity at temperature below 15K can enhance the performance of LHT-PTCs significantly. Activated charcoals and carbon nano materials with strong adsorption capacity at low temperature and high surface area to volume ratio are very promising high performance regenerative materials.

A.D. Badgujar et.al [12], in their paper 'Theoretical and Experimental Investigation of Flow Straighteners in U-Type Pulse Tube Cryocoolers' mentions that the U-bend, together with the sudden change in cross section area at the cold end of the pulse tube, have an adverse effect on pulse tube cooling due to formation of eddies and undesirable mixing at the cold end of the pulse tube. The theoretical analysis and experimental investigation have demonstrated that flow straighteners are very effective at reducing the formation of eddies in U-type PTCs. There exist an optimum number of flow straighteners; the deviation from which on either side results in degraded performance.

LIU XuMing et.al [13], in their paper 'Attaining the liquid helium temperature with a compact pulse tube cryocooler for space applications' mentions that a multi-bypass coaxial HPTC (High Frequency Pulse Tube Cryocooler) driven by only one non-oil-lubrication compressor has been developed as the precooling system for the Chinese HUBS satellite program. It obtained a no-load temperature of 4.4 K, which set the record for a gas-coupled two-stage HPTC. The prototype provided a cooling power of 87 mW at 8 K, or 5.2 mW at 5 K with an input power of 425 W. It is demonstrated that the HPTC can simultaneously output cooling power at the first stage cold head (around 140 K), the multi-bypass (around 40 K), and the second-stage cold head (below 5 K), which would be appealing for future space applications.

At ISRO, every novel sub-system undergoes an extensive qualification program. The pulse-tube cryocooler in question here has undergone vibration tests in an experimental setup as part of the qualification program.

2.2. Objectives & Scope:

- At ISRO, post proving the technology, in order to be certified for on-board use, all subsystems go through an extensive qualification program, involving a number of tests, the most critical being the vibration tests which simulates the launch loads.
- In the vibration test involving the PTC, maximum stresses are expected in the expander assembly owing to its functional requirements and hence taken up for analysis with particular interest.
- This assembly has to meet two stringent and conflicting requirements viz. one that of thermal and the second that of structural.
- Cold generated by the unit has to be concentrated at the cryotip, else it results in high losses leading to a drop in the coefficient of performance (COP). Hence, a highly resistive path involving extremely thin tubes of minimum cross-section and of low conductive material is chosen for both tubes.
- However, the very thin sections chosen lead to structural issues because in addition to mechanical loads they also need to contain the working fluid at high pressure ensuring its hermeticity and hence a trade-off is necessary between the two to achieve a working/practical unit that meets the requirements.
- This analysis attempts to simulate the tests on ANSYS Workbench to address these issues by arriving at an optimized section meeting both requirements while ensuring the stresses are below the working values and also make recommendations for improving the overall performance of the cryocooler.

CHAPTER 3

3.1 Methodology

The PTC Expander assembly consists of five major parts, namely:

1) Pulse Tube
2) U-Tube Cryotip
3) Regenerator
4) Flange
5) Base

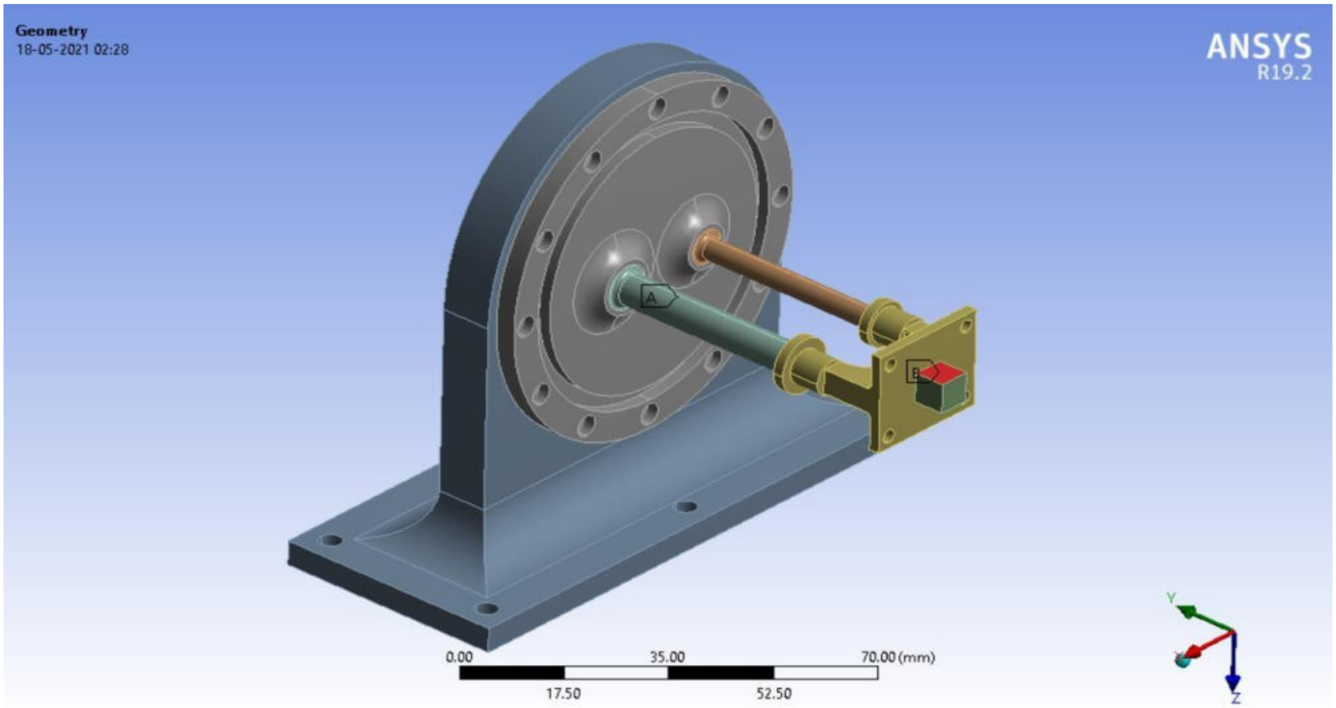

Fig. 3.1: CAD Model of Expander Assembly

Apart from these major parts, small masses have been placed at two locations which correspond to sensors placed on the actual assembly.

The dimensions of the parts of the assembly used at ISRO were shared with us through drawing sheets along with the respective material properties. Solidworks was used for the CAD Modelling of the parts and the assembly. This assembly was then imported in ANSYS Workbench wherein the material properties were defined and each part was assigned its respective material. Subsequently meshing was done and further analysis which included the following was carried out:

- Modal Analysis
- Harmonic Analysis
- Random Vibration Analysis

The results of harmonic and random vibration analysis were then tabulated and analyzed.

3.2 Input Specifications

Input specifications refer to the launch loads that the expander assembly is subjected to. This consists of sine/harmonic vibration and random vibration loads. In both these cases, there is one set of values applicable to the Z – Axis which is normal to the mounting plane and another set of values applicable to the X and Y Axis which are parallel to the mounting plane.

3.2.1 Sine Vibration

Table 3.1: Sine Vibration Loads - Normal to mounting plane

FREQUENCY	**AMPLITUDE**	
(Hz)	Qualification Level	Acceptance Level
5-16	9.7mm	6.5mm

16-50	10g	6.7 g
50-70	8g	5.3g
70-100	6g	4g
Sweep rate	2oct./min	4oct./min

Table 3.2: Sine Vibration Loads - Parallel to mounting plane

FREQUENCY	**AMPLITUDE**	
(Hz)	Qualification Level	Acceptance Level
5-11	10.3mm	6.9mm
11-100	5g	3.3 g
Sweep rate	2oct./min	4oct./min

3.2.2 Random Vibration

Table 3.3: Random Vibration Loads - Normal to mounting plane

FREQUENCY	**PSD**	**(g^2/Hz)**
(Hz)	Qualification Level	Acceptance Level
20-100	+3db/oct.	+3db/oct.
100-700	0.28	0.12
700-2000	-6db/oct.	-6db/oct.
Overall rms	17.5g	11.7g
Duration	120s	60s

Table 3.4: Random Vibration Loads - Parallel to mounting plane

FREQUENCY	**PSD**	**(g^2/Hz)**
(Hz)	Qualification Level	Acceptance Level
20-100	+3db/oct.	+3db/oct.
100-700	0.1	0.04
700-2000	-3db/oct.	-3db/oct.
Overall rms	11.8g	7.9g
Duration	120s	60s

3.3 Geometry

3.3.1 Base Flange

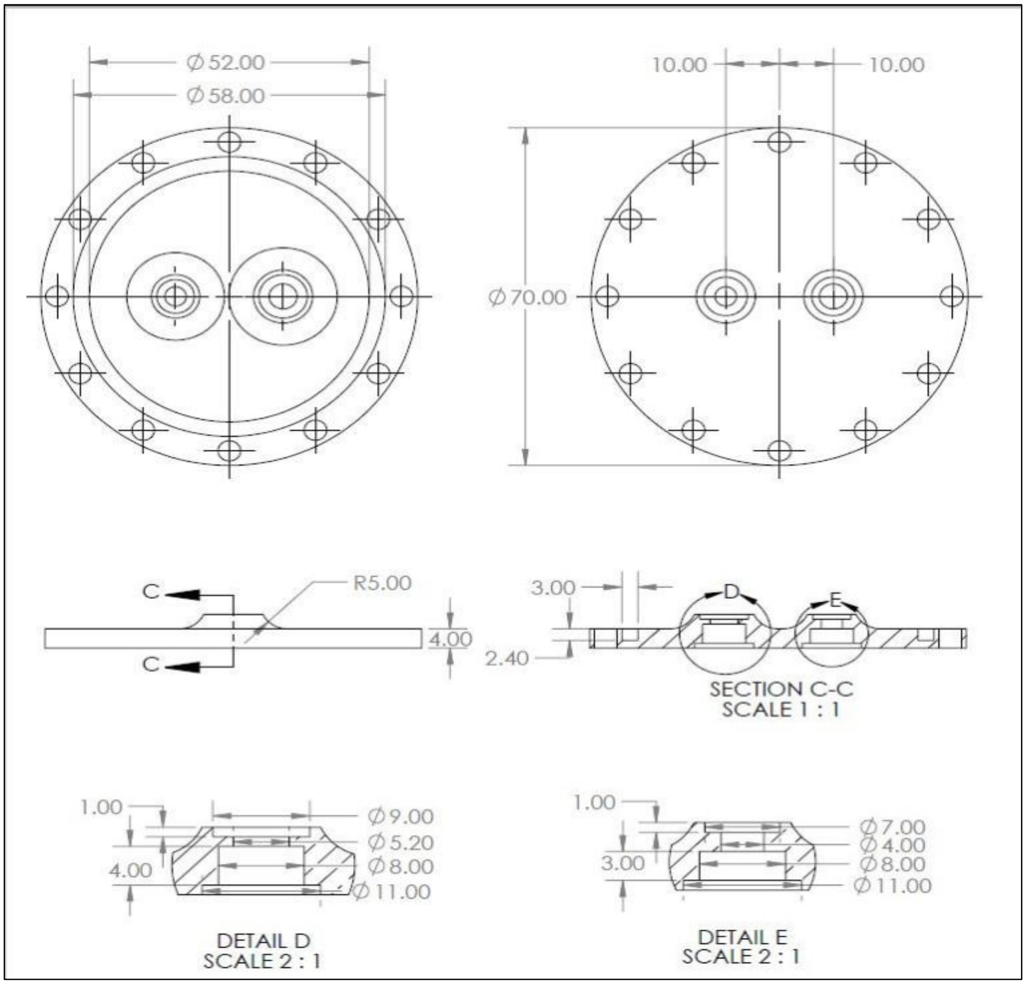

Fig. 3.2: Base Flange Geometry (Source: Solidworks)

Table 3.5: Base Flange Material Properties

Material	Oxygen Free High Conductivity Copper (OFHCCu)
Mass	130.68 grams
Density	9595.51 kg/m^3
Poisson's ratio	0.31
Young's modulus	1.15E+11 Pa
Bulk modulus	1.008E+11 Pa
Shear modulus	4.389E+10 Pa

3.3.2 Base Plate

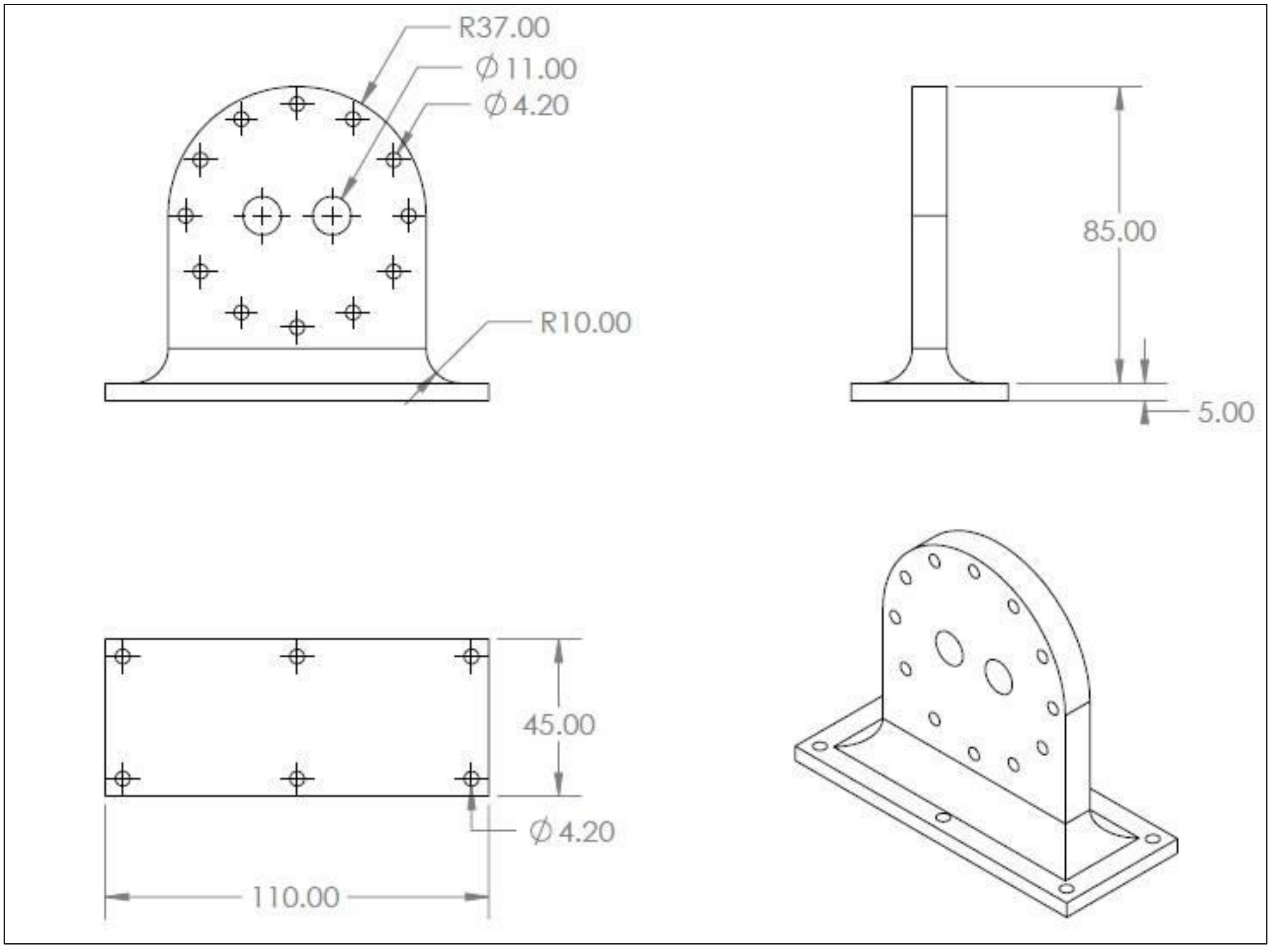

Fig. 3.3: Base Plate Geometry (Source: Solidworks)

Table 3.6: Base Plate Material Properties

Material	Al-6061
Mass	220.01 grams
Density	2689.94 kg/m^3
Poisson's ratio	0.33
Young's modulus	6.89*10^{10} Pa
Bulk modulus	6.75*10^{10}Pa
Shear modulus	2.59*10^{10} Pa

3.3.3 Pulse Tube

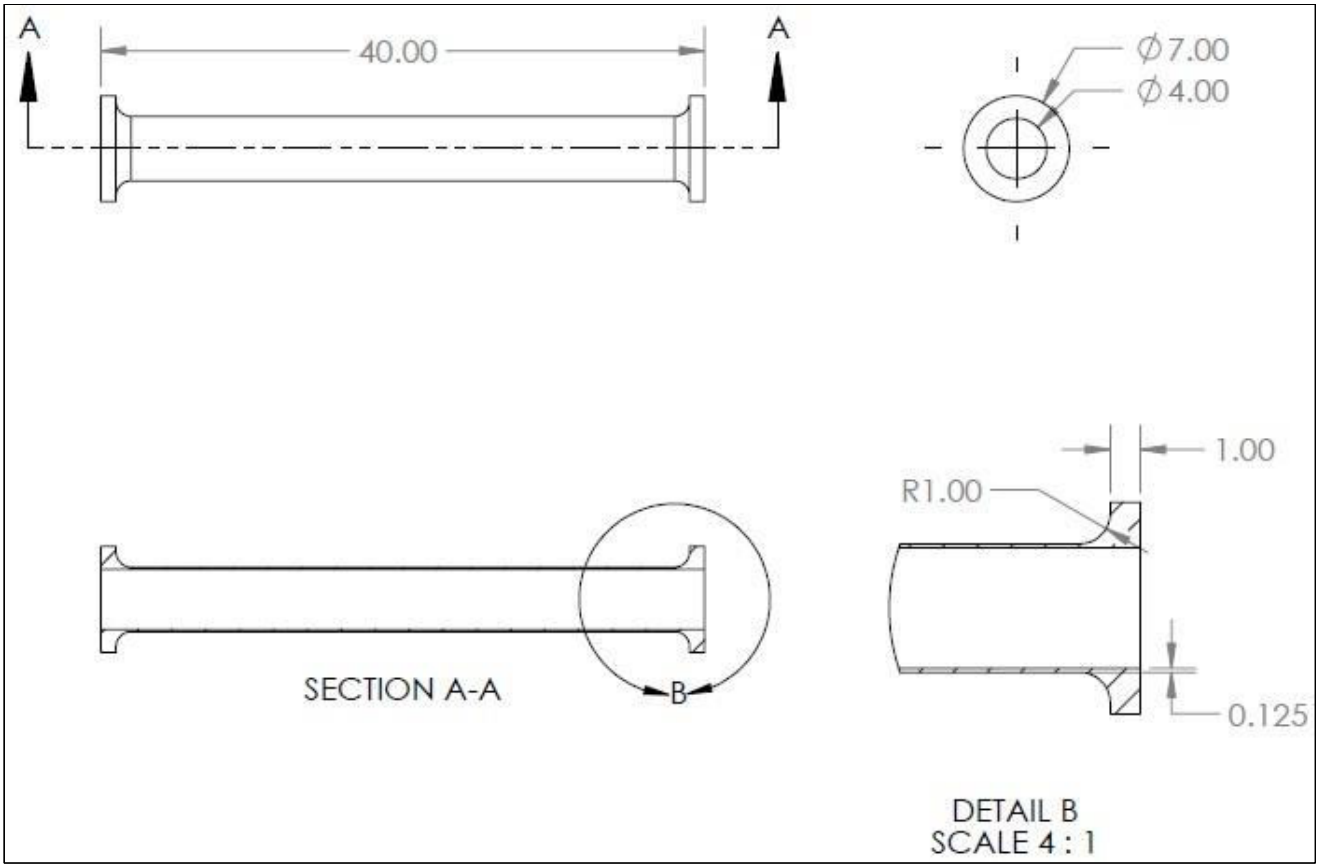

Fig. 3.4: Pulse Tube Geometry (Source: Solidworks)

Table 3.7: Pulse Tube Material Properties

Material	Ti6Al4V
Mass	0.50222 grams
Density	4313.2kg/m^3
Poisson's ratio	0.31
Young's modulus	$1.1*10^{11}$ Pa
Bulk modulus	$9.64*10^{10}$Pa
Shear modulus	$4.19*10^{10}$ Pa

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3.3.4 Regenerator

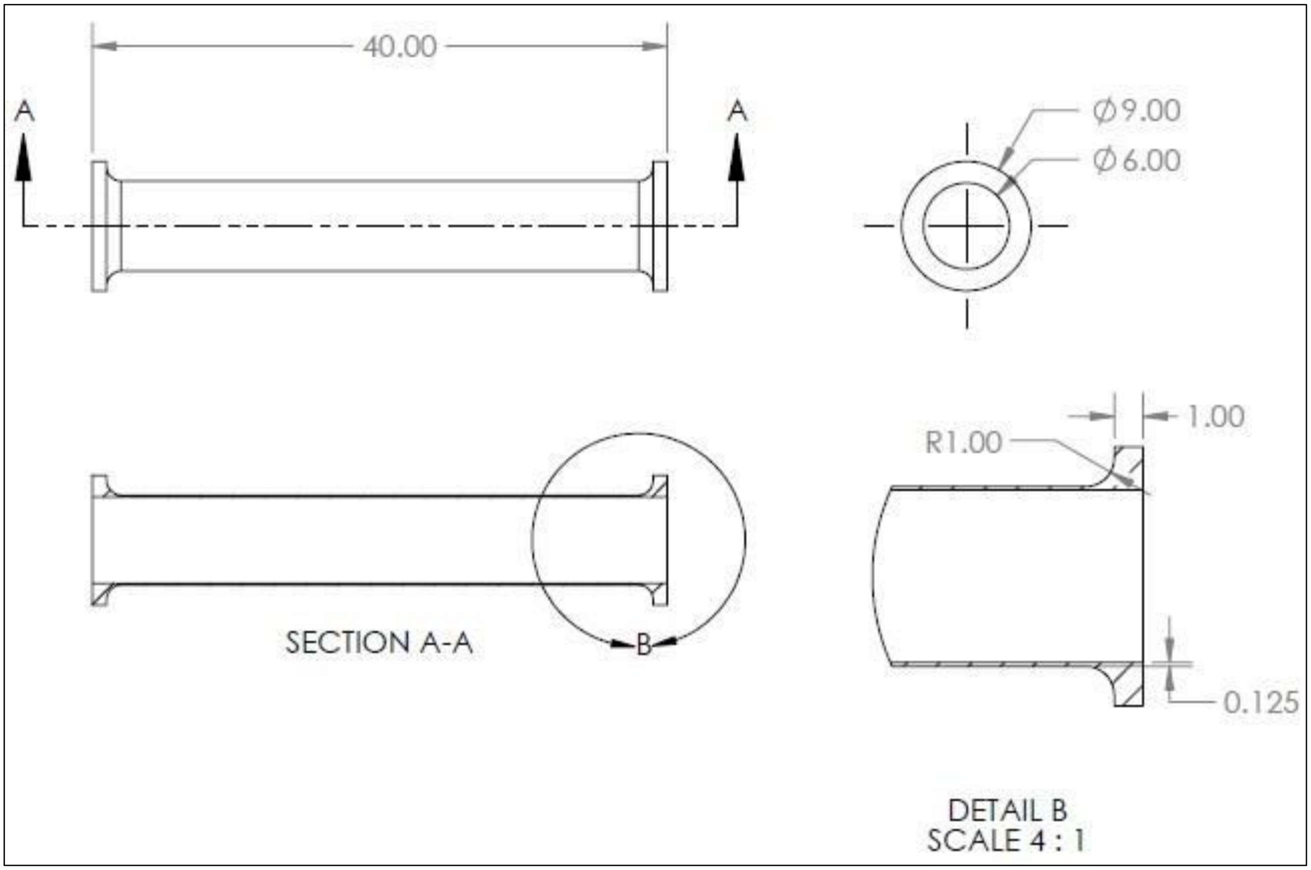

Fig. 3.5: Regenerator Tube Geometry (Source: Solidworks)

Table 3.8: Regenerator Tube Material Properties

Material	Ti6Al4V
Mass	0.71018 grams
Density	4175.73 kg/m
Poisson's ratio	0.31
Young's modulus	$1.1*10^{11}$ Pa
Bulk modulus	$9.64*10^{10}$Pa
Shear modulus	$4.19*10^{10}$ Pa

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3.3.5 U- Tube Cryotip

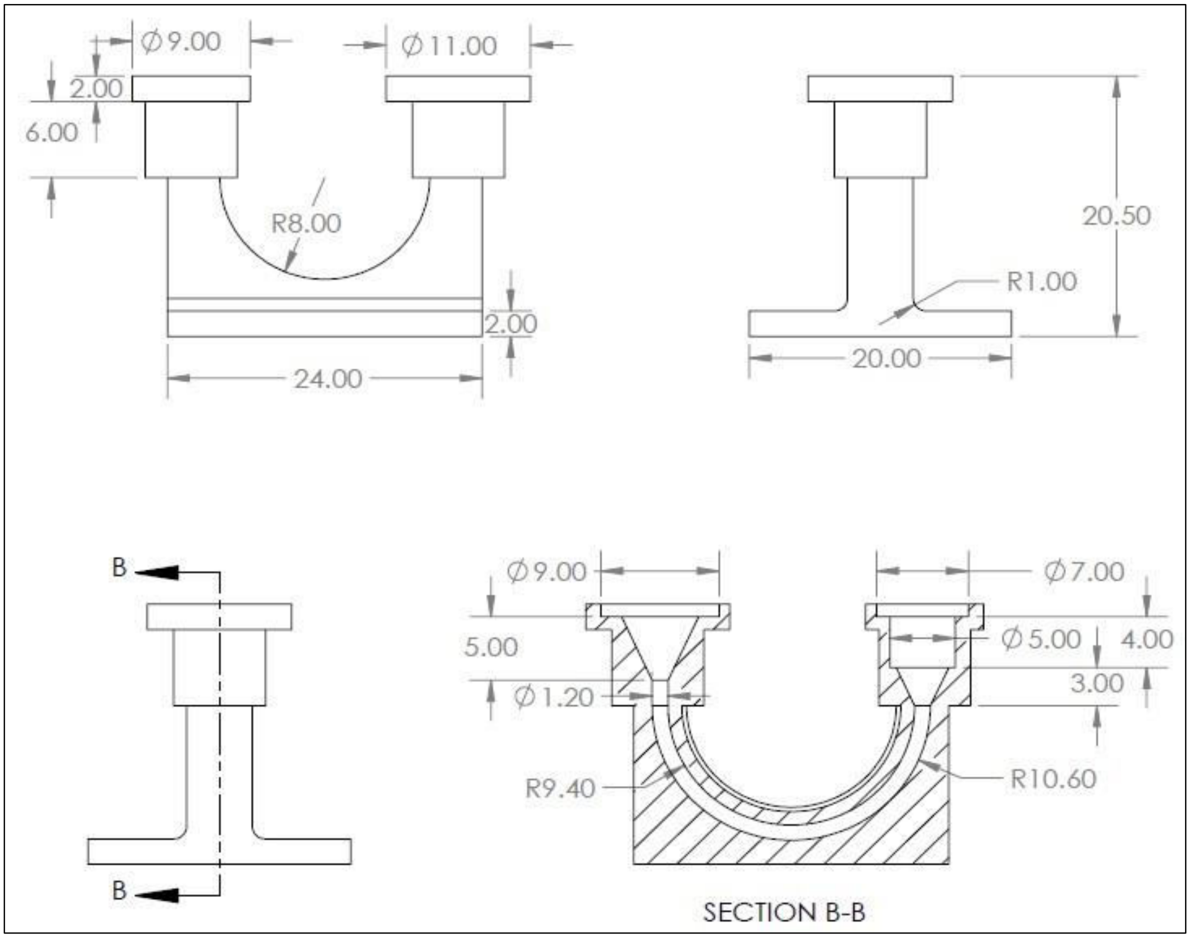

Fig. 3.6: U-Tube Geometry (Source: Solidworks)

Table 3.9: U-Tube Material Properties

Material	Oxygen Free High Conductivity Copper (OFHC-Cu)
Mass	17.462 grams
Density	8167.94 kg/m^3
Poisson's ratio	0.31
Young's modulus	1.15*10^{11} Pa
Bulk modulus	1.008*10^{11}Pa
Shear modulus	4.389*10^{10} Pa

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<u>NOTE:</u> The total mass of the assembly is 383.21 grams. The densities have been adjusted to match the actual measured mass of the sub-assembly in the actual experimental setup.

3.4 Meshing:

Hex-Dominant Mesh

The goal of hex-dominant meshing is to generate meshes where hexahedral elements dominate, both in number and volume. Hexahedra meshes are economic with the number of elements because the same degrees of freedom (or for 8 nodes) for one Hexahedron corresponds to six Tetrahedra. It is obvious that increasing the number of elements will not increase the size of the global finite element matrices but the computations for one hexahedron are generated also for six tetrahedra. [14]

Advantages of selecting hex/ brick mesh:

- Number of elements and nodes generated by brick mesh are of the order of 1/2 to 1/50 in comparison to tetra mesh. Hex mesh reduces solution time and results in ease of handling the model on workstation.
- Analysis types like crash or nonlinear give preference to brick mesh due to number of nodes and mesh flow lines.
- For the same cell amount, the accuracy of solutions in hexahedral meshes is the highest.

Considering these advantages and efficiency in analysis which includes smaller number of elements and comparatively lower computational time which leads to accurate results, hex-dominant meshing method has been used for the analysis.

MultiZone mesh method provides automatic decomposition of geometry into mapped (structured/sweepable) regions and free (unstructured) regions. It automatically generates a pure hexahedral mesh where possible and then fills the more difficult to capture regions with unstructured mesh. The MultiZone mesh method and the Sweep mesh method operate similarly; however, MultiZone has capabilities that make it more suitable for a class of problems for which the Sweep method would not work without extensive geometry decomposition.

Multizone method was used on U-tube and the regenerator tube to produce hex-dominant mesh on the respective parts.

3.4.1 Assembly

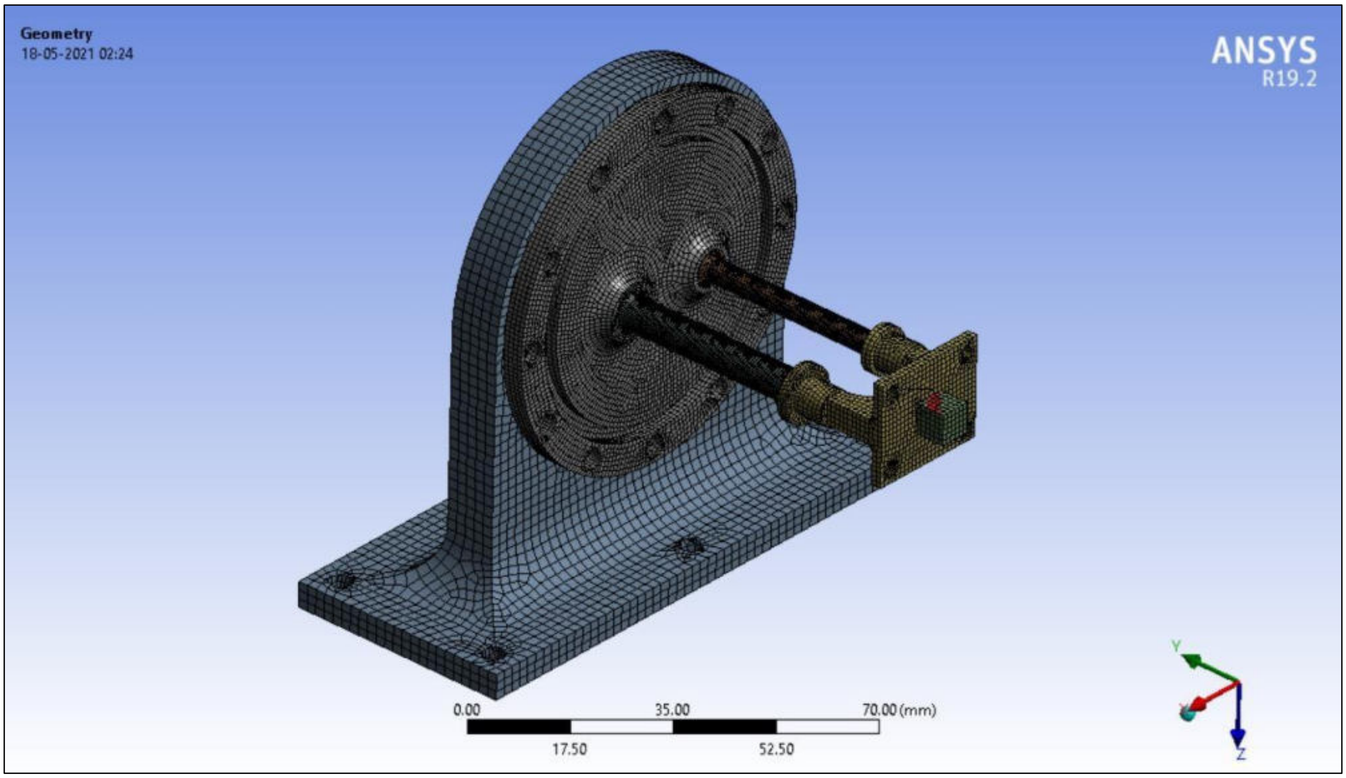

Fig. 3.7: Meshing of Assembly

Table 3.10: Mesh Details of Assembly

Total number of nodes	70421
Total number of elements	74496
Total mass	383.21 grams
Meshing method	Hex-dominant
Element order	Linear
Smoothing	Medium

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3.4.2 Base Flange:

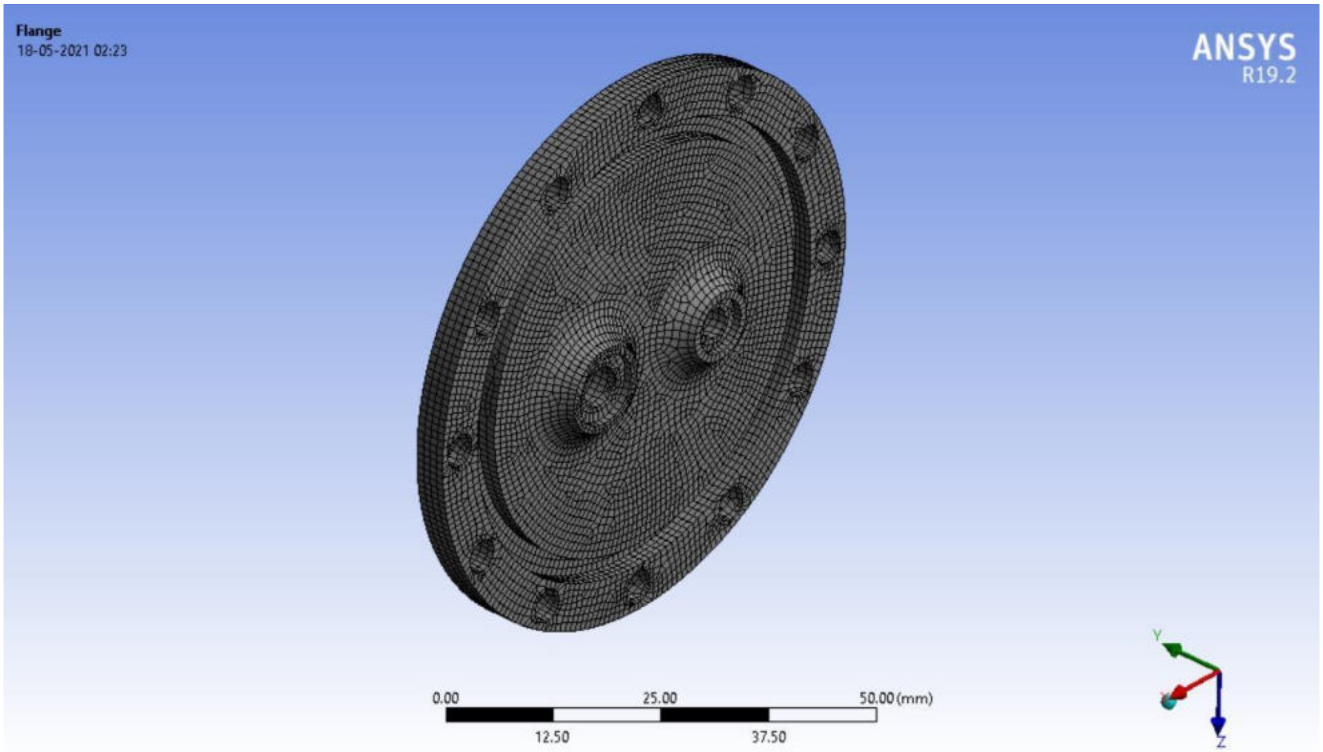

Fig. 3.8: Meshing of Base Flange

Table 3.11: Mesh Details of Base Flange

Number of nodes	28257
Number of elements	33576
Element size	1 mm
Method	Hex dominant
Body sizing	1 mm

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3.4.3 Base Plate:

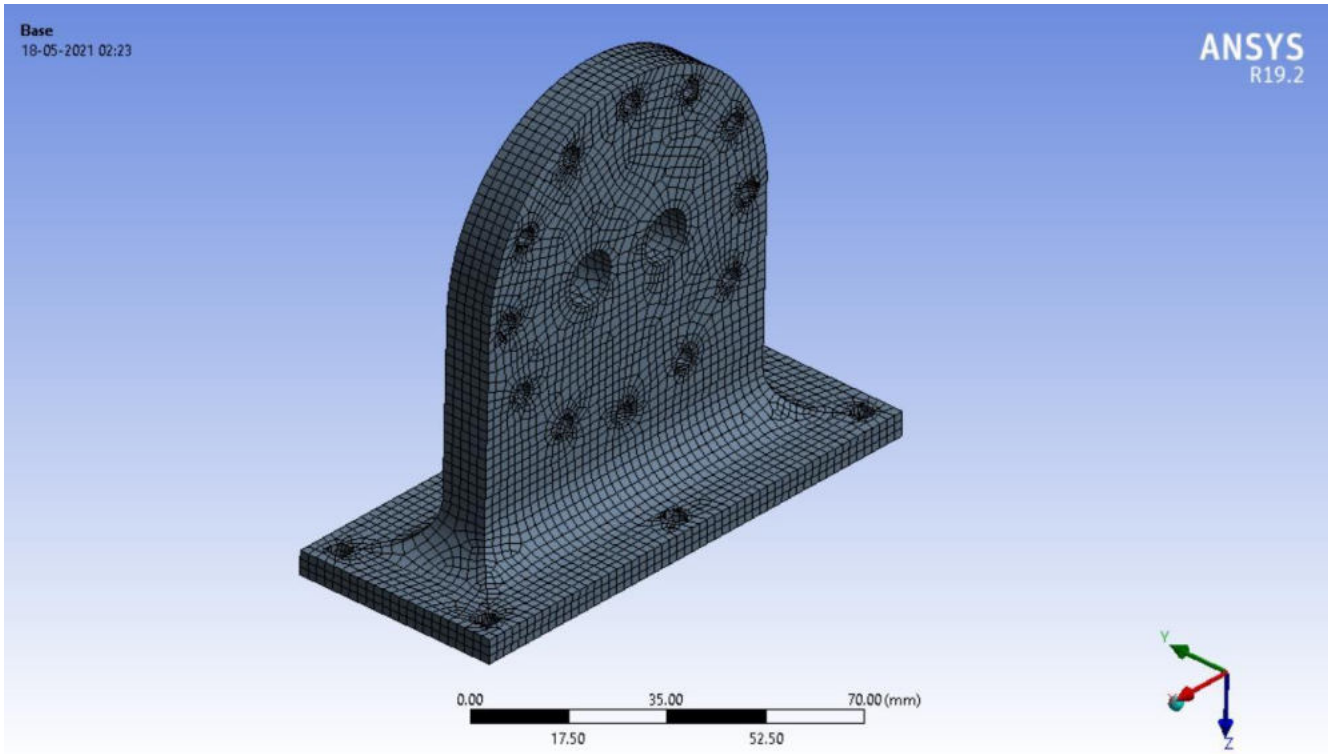

Fig. 3.9: Meshing of Base Plate

Table 3.12: Mesh Details of Base Plate

Number of nodes	19310
Number of elements	22851
Element size	2mm
Method	Hex dominant
Body sizing	2mm

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3.4.4 Pulse Tube:

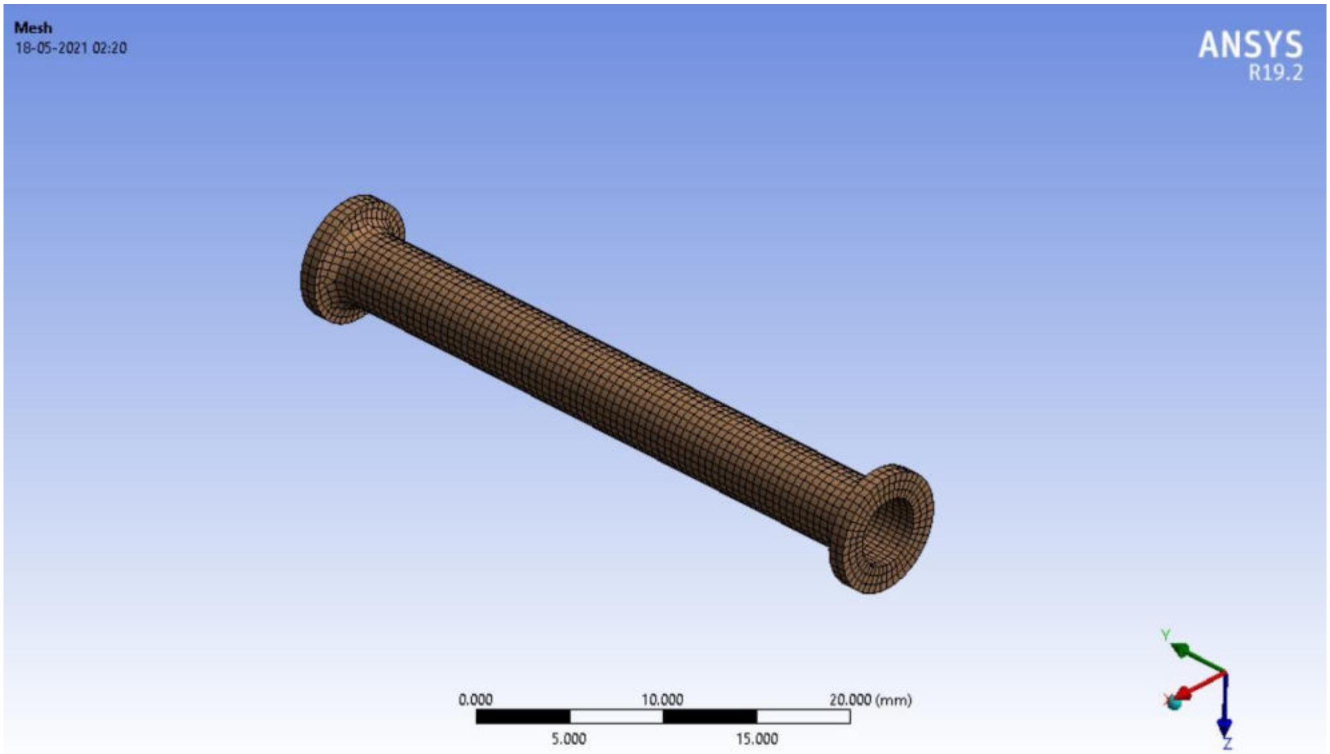

Fig. 3.10: Meshing of Pulse Tube

Table 3.13: Mesh Details of Pulse Tube

Number of nodes	6572
Number of elements	4502
Element size	0.5 mm
Method	Hex dominant
Body sizing	0.5 mm

3.4.5 Regenerator:

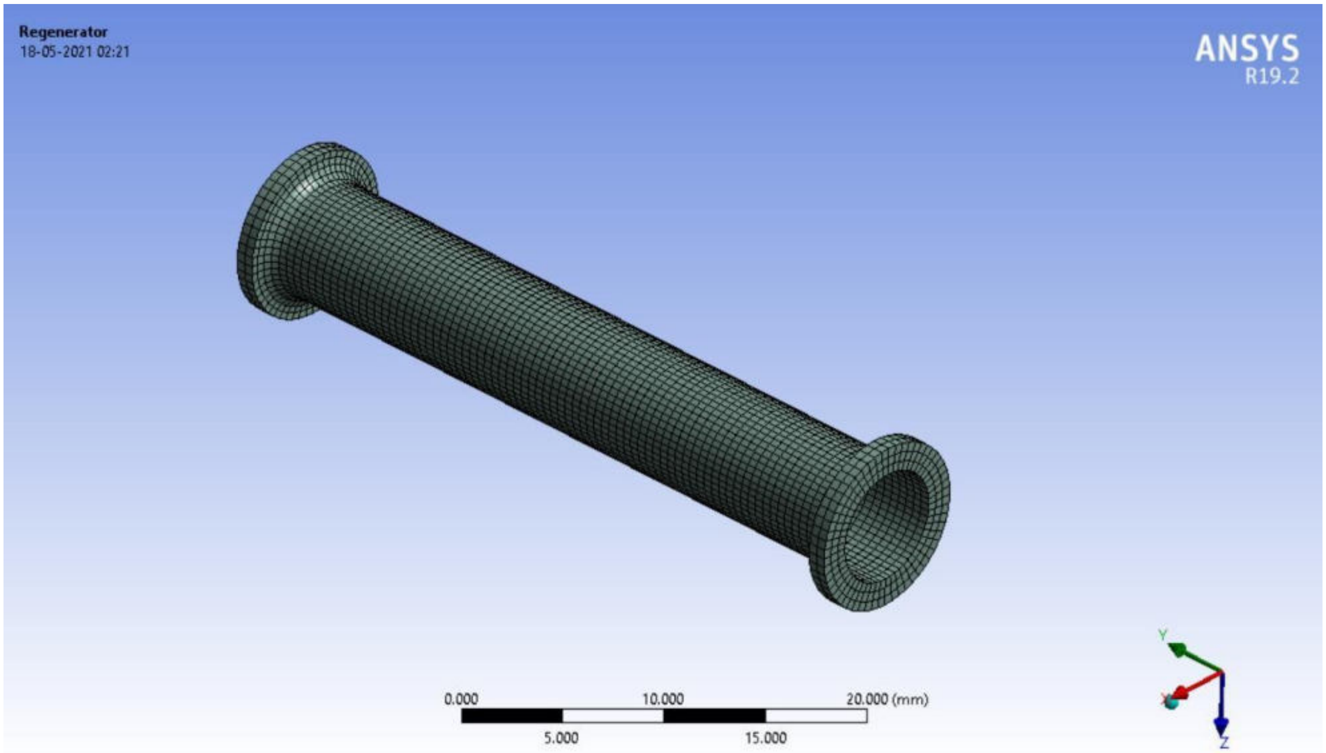

Fig. 3.11: Meshing of Regenerator

Table 3.14: Mesh Details of Regenerator

Number of nodes	9856
Number of elements	5040
Element size	0.5 mm
Method	Hex dominant
Body sizing	0.5 mm

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3.4.6 U- Tube Cryotip

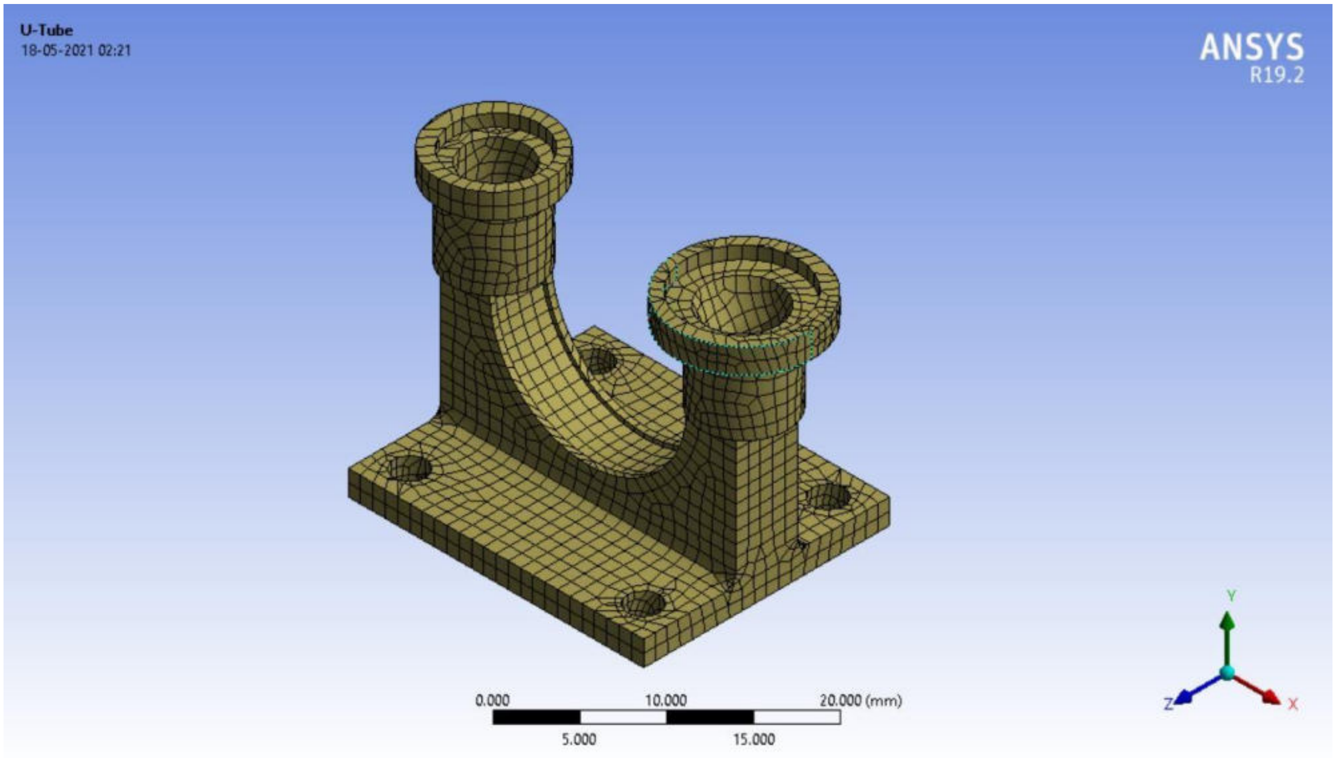

Fig. 3.12: Meshing of U-Tube Cryotip

Table 3.15: Mesh Details of U-Tube Cryotip

Number of nodes	6083
Number of elements	8311
Element size	1 mm
Method	Hex dominant
Body sizing	1 mm

CHAPTER 4

4.1 ANSYS Workbench Simulation

4.1.1 Static Structural Analysis:

In actual test conditions the model is subjected to self-weight due to gravity and pressure of the working fluid (helium gas) inside the pulse tube, regenerator and the U-tube. This pressure however has been neglected as it barely alters the result. As mentioned in boundary conditions, six holes in the base of the expander assembly are taken as fixed supports. Standard earth gravity of 9.8066 m/s^2 has been applied in the +Z direction.

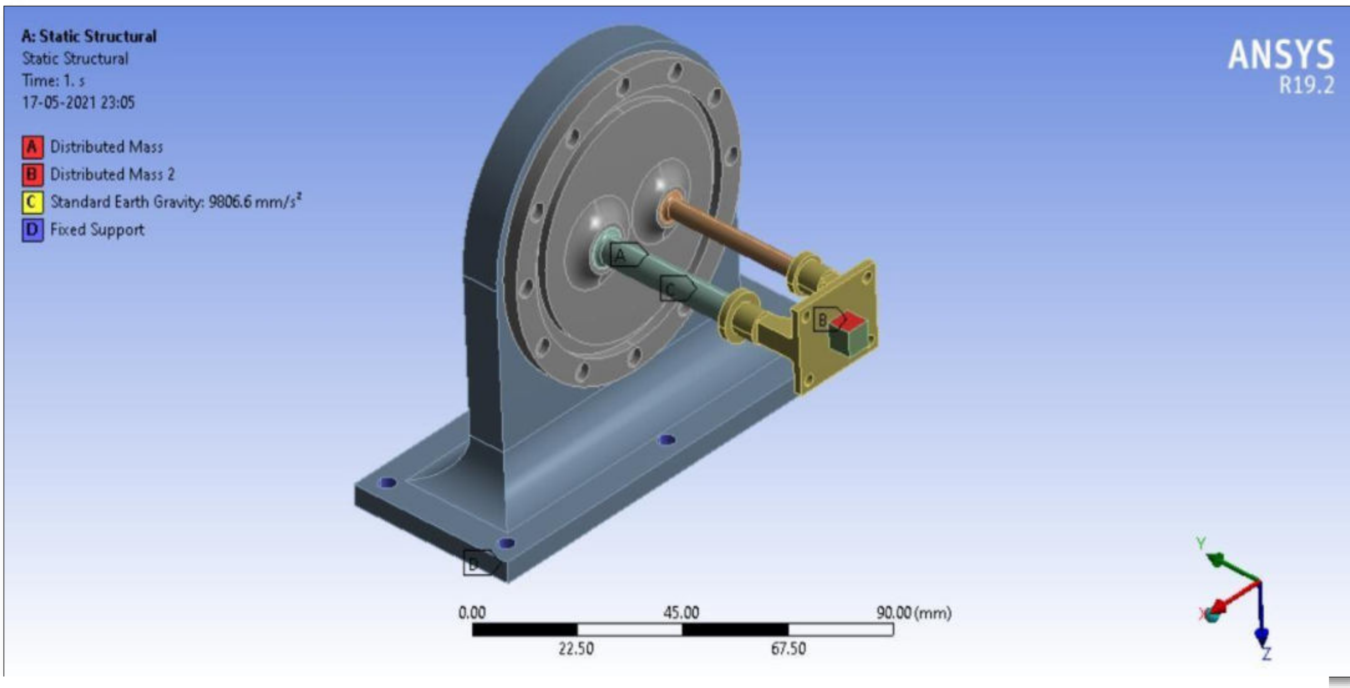

Fig. 4.1: Boundary Conditions & Loading in Static Structural Analysis

4.1.2 Modal Analysis:

Modal analysis is a technique to study the dynamic characteristics of a structure under vibrational excitation. Natural frequencies, mode shapes and mode vectors of a structure can be determined using modal analysis. Modal analysis allows the design to avoid resonant vibrations or to vibrate at a specified frequency and gives engineers an idea of how the design will respond to different types of dynamic loads.

The setup used in static structural analysis is further used in modal analysis to obtain the natural frequencies and modes. Since in random vibration analysis, the frequency range is from 20Hz to 2000Hz, the modal analysis range is to be 1.5 times the upper limit of the random vibration. Hence, frequency range in modal analysis is limited from 0Hz to 3000Hz to obtain modes in the specified frequency range.

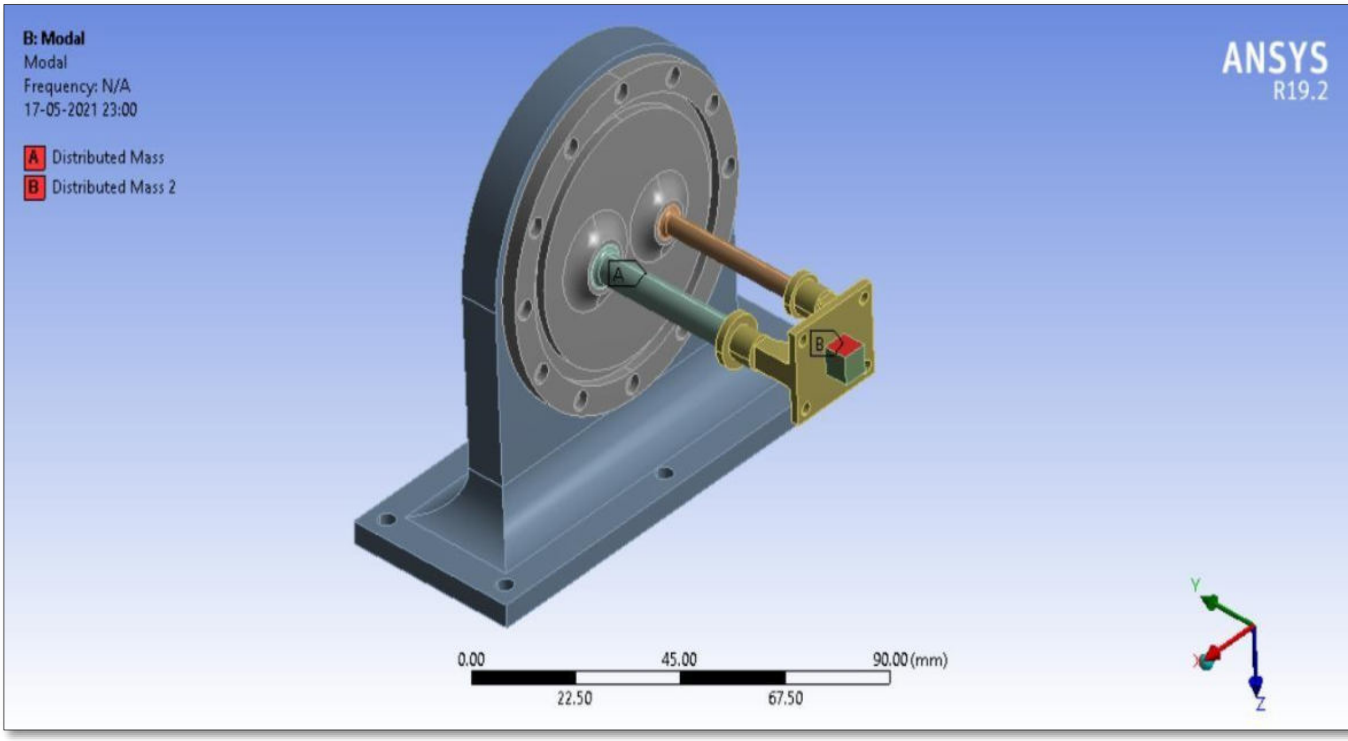

Fig. 4.2: Load Conditions in Modal Analysis

Table 4.1: Load Conditions in Modal Analysis

Maximum modes to find	6
Range Minimum	0 Hz
Range Maximum	3000 Hz

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4.1.3 Harmonic Analysis:

Harmonic analysis on a structure determines the steady-state sinusoidal response varying loads all acting at a specified frequency. Harmonic Response Analysis is a linear dynamic analysis used to determine the response of a system to excitation at specific frequencies. It is also referred to as Frequency Response

Analysis. The prerequisite for a Harmonic Response Analysis is modal analysis, as the input frequencies needed for a harmonic response analysis are the results of a modal analysis. Due to the analysis using results already calculated, harmonic response analysis is a type of restart analysis which uses modal superposition to calculate its results. [15]

The launch load specifications have been included as mentioned in the input specification table which also shows that the frequency is limited from 0Hz to 100Hz.

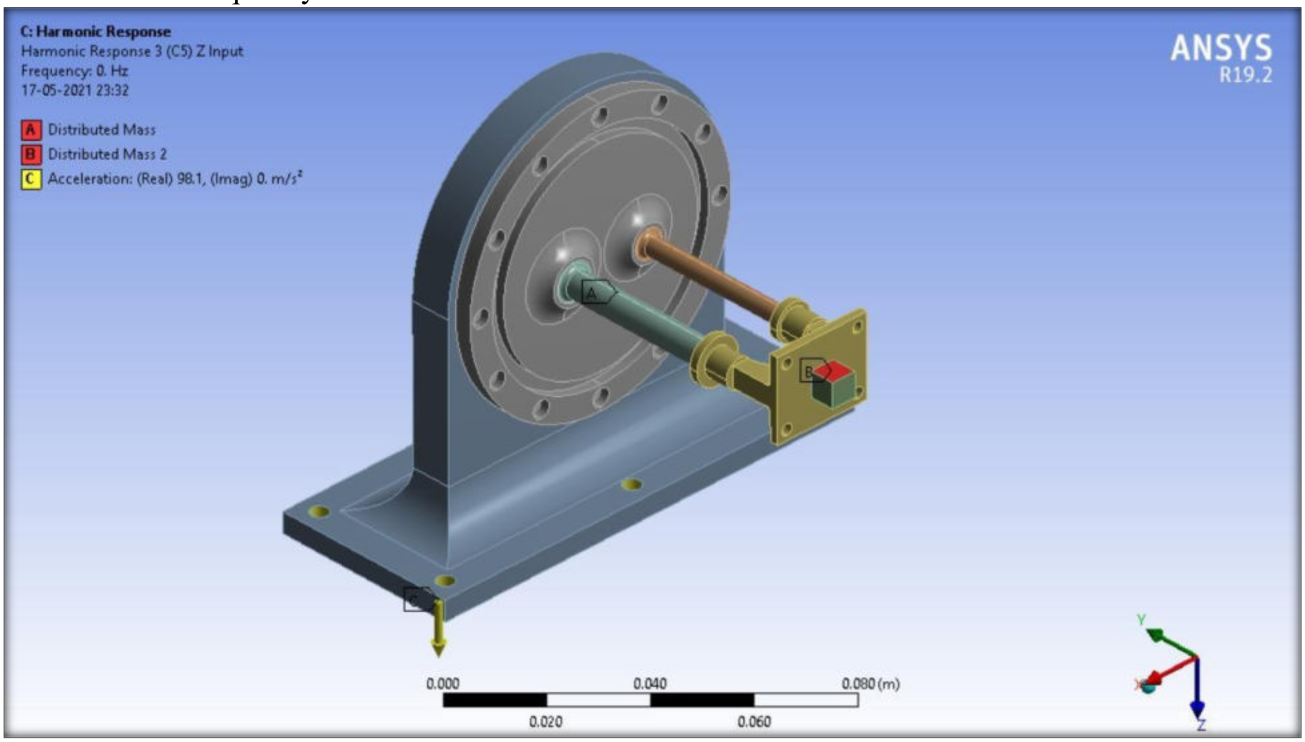

Fig. 4.3: Load Conditions in Harmonic Analysis

Table 4.2: Load Conditions in Harmonic Analysis

Base excitation	Yes
Frequency spacing	Linear
Range minimum	0 Hz
Range Maximum	100 Hz

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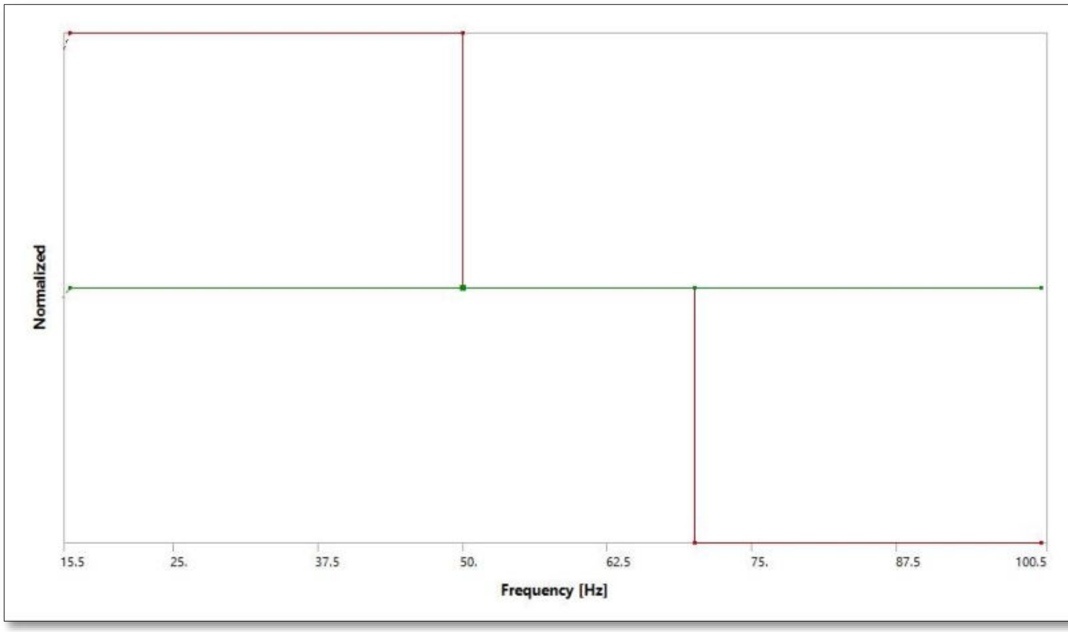
Acceleration

Table 4.3: Input Frequency & Acceleration in Harmonic Analysis

Frequency (Hz)	**Acceleration (m/s^2)**
16	98.1

50	98.1
50.01	78.48
70	78.48
70.01	58.86
100	58.86



Graph 4.1: Load Condition - Frequency v/s Acceleration for Harmonic Analysis

4.1.4 Random Vibration Analysis

Harmonic analysis focuses upon a single frequency at any one time. As the expander assembly experiences launch loads, random vibration comes into picture. A random vibration test excites all the frequencies in a defined spectrum at any given time. One of the main goals or uses of random vibration testing in the industry is to bring a DUT to failure. Random testing is the key testing method to understand how a component fails under various environmental vibrations it may encounter.

The modal analysis results act as a prerequisite for random vibration analysis and the frequency range for PSD G acceleration is 20Hz to 2000Hz as mentioned in the input specification table.

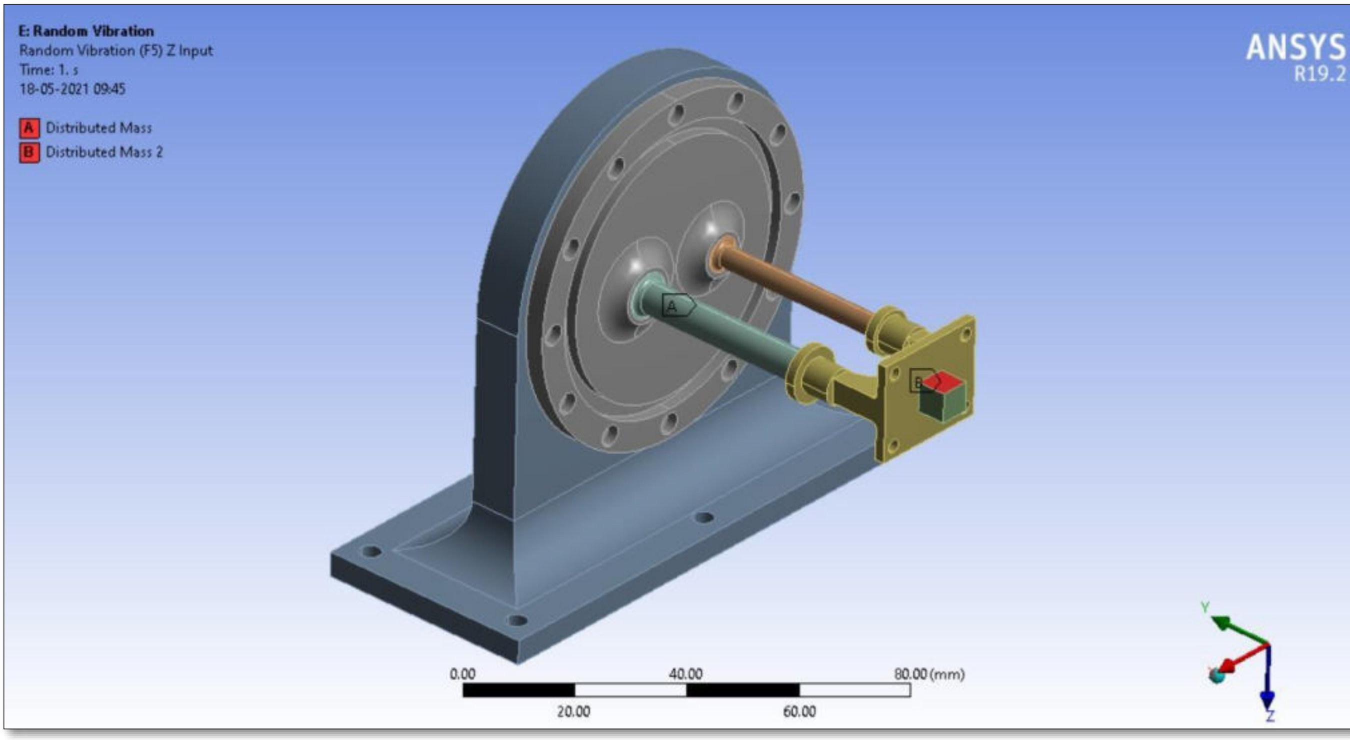
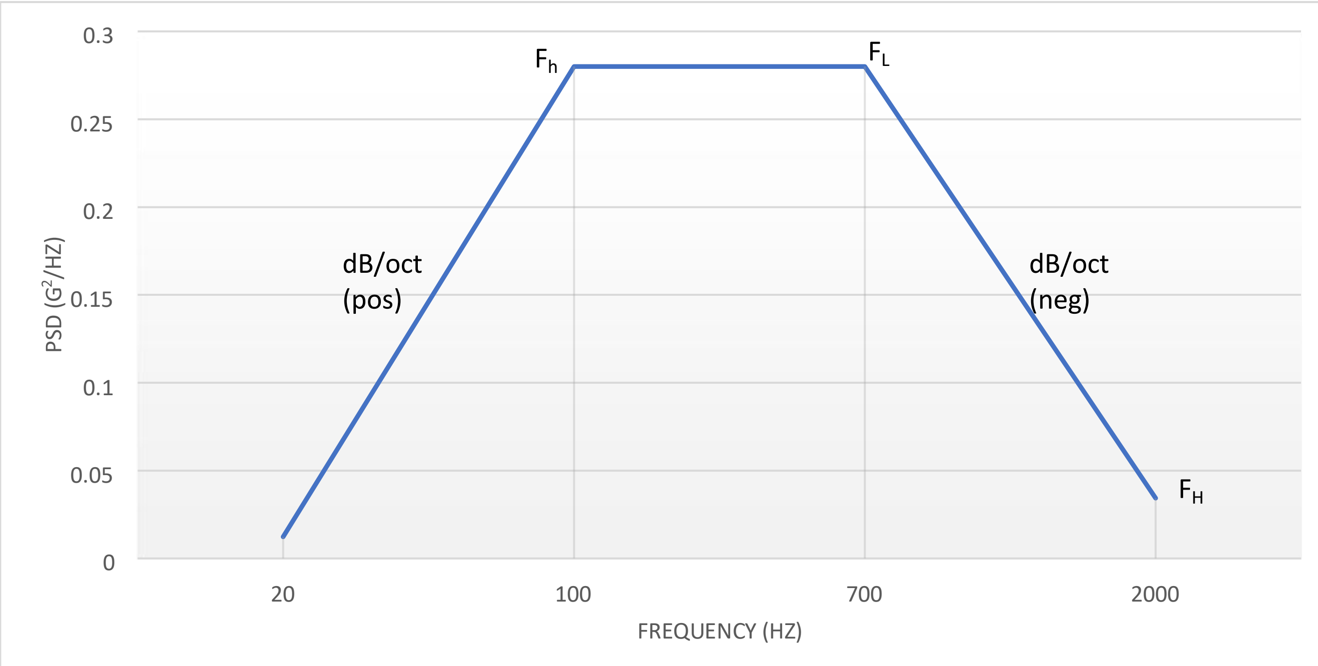


Fig. 4.4: Load Conditions in Random Vibration Analysis

Table 4.4: Damping Ratios

Input Axis	Damping Ratio
X	0.025
Y	0.054
Z	0.0194

<u>NOTE:</u> The model is quite complex and has sections in all the axes which will have different levels of damping. The damping ratios have therefore been fine-tuned to match the experimental setup.



Graph 4.2: PSD v/s Frequency

In order to calculate the G^2/Hz value of the specified range of frequency, the given slope value (dB/oct) is substituted in the formula given below:

$$\frac{ASD_H}{ASD_L} = \left(\frac{F_H}{F_L}\right)^{\frac{m}{10\log(2)}}$$

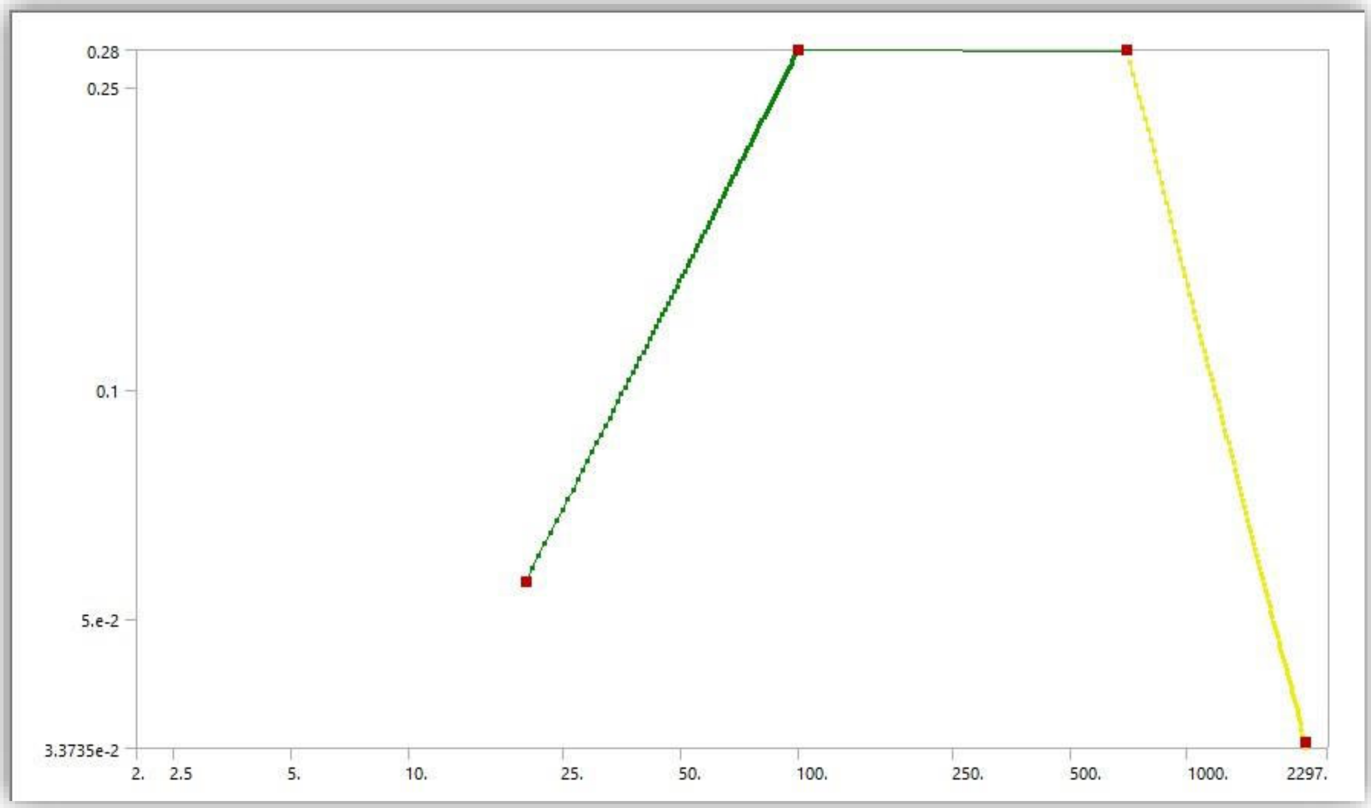
$$\frac{ASD_H}{ASD_L} \approx \left(\frac{F_H}{F_L}\right)^{\frac{m}{3.01}}$$

PSD G Acceleration:

Table 4.5: Input Frequency & Acceleration for Random Vibration Analysis

Frequency (Hz)	Acceleration (G^2/Hz)

20	0.056
100	0.28
700	0.28
2000	0.0343



Graph 4.3: Load condition - Acceleration v/s frequency for Random Vibration Analysis

4.2 Theoretical Natural Frequency

To calculate the natural frequency of the first mode analytically we will consider the two tubes (Pulse tube and Regenerator) as cantilever beams fixed at one end and loaded at the other. The loaded ends are assumed to equally share a load of 28.25 grams which is the weight of the U-Tube cryotip, sensors and the aluminum block which acts as the base for sensor mounting.

We shall first find out the spring constants for both the cantilever beams. As the two beams are in parallel, we will add the stiffness of both and then calculate the natural frequency.

Outer diameter of regenerator = 6.25 mm

Inner diameter of regenerator = 6 mm

Length of regenerator = 40 mm

Young's Modulus of Ti6Al4V, E = 1.1×10^{11} Pa

$$I = \frac{\pi(D^4 - d^4)}{64}$$

$$I = \frac{\pi[(0.00625^4) - (0.006)^4]}{64}$$

$$I = 1.128 \times 10^{-11}\, m^4$$

k_{reg} = 3LEI3 = 3×1.1×10110.×041.3128×10−11

k_{reg} = 58162.5 N/m → (1)

Outer diameter of pulse tube = 4.25 mm

Inner diameter of pulse tube = 4 mm

Length of pulse tube = 40 mm

Young's Modulus of Ti6Al4V, E = 1.1×10^{11} Pa

$$I = \frac{\pi(D^4 - d^4)}{64}$$

$$I = \frac{\pi[(0.00425^4) - (0.004)^4]}{64}$$

$$I = 3.448 \times 10^{-12}\, m^4$$

k_{pt} = 3LEI3 = 3×1.1×10110.×043.3448×10−12

k_{pt} = 17778.75 N/m → (2)

Now, from equations (1) & (2),

$$k_{eq} = k_{reg} + k_{pt}$$

$$k_{eq} = 58162.5 + 17778.75 = 75941.25 \text{ N/m}$$

Let m_a be the mass of the cryotip + sensors + Al block,

$$m_a = 28.25 \text{ grams}$$

In case of the test specimen, the beam mass is distributed over the length. However, by taking one-third of the total mass of beam at the free end (Thompson. 1961)[16], the system can be assumed as discrete system. Hence, taking mass of the two beams as m_b and total mass as 'm', we have,

$$m = m_a + \frac{33}{140} \times (m_b)$$

$$m_b = \text{Mass of Pulse Tube + Mass of Regenerator + Mass of Regenerator Mesh}$$

$$m_b = 0.50222+0.71018+3.050 = 4.2624 \text{ grams}$$

$$m = 28.25 + \frac{33}{140} \times (4.2624)$$

$$m = 29.2547 \text{ grams} = 0.02925 \text{ kg}$$

$$\omega = \sqrt{\frac{k_{eq}}{m}}$$

$$\omega = \sqrt{\frac{75941.25}{0.02925}}$$

$$\omega = 1611.168 \text{ rads/s}$$

$$\omega = 2\pi f$$

$$f = \frac{\omega}{2\pi}$$

$$f = \frac{1611.168}{2\pi}$$

$$f = 256.42 \text{ Hz}$$

CHAPTER 5

5.1 Results and Discussions

5.1.1 Results

5.1.1.1 Static Structural Analysis

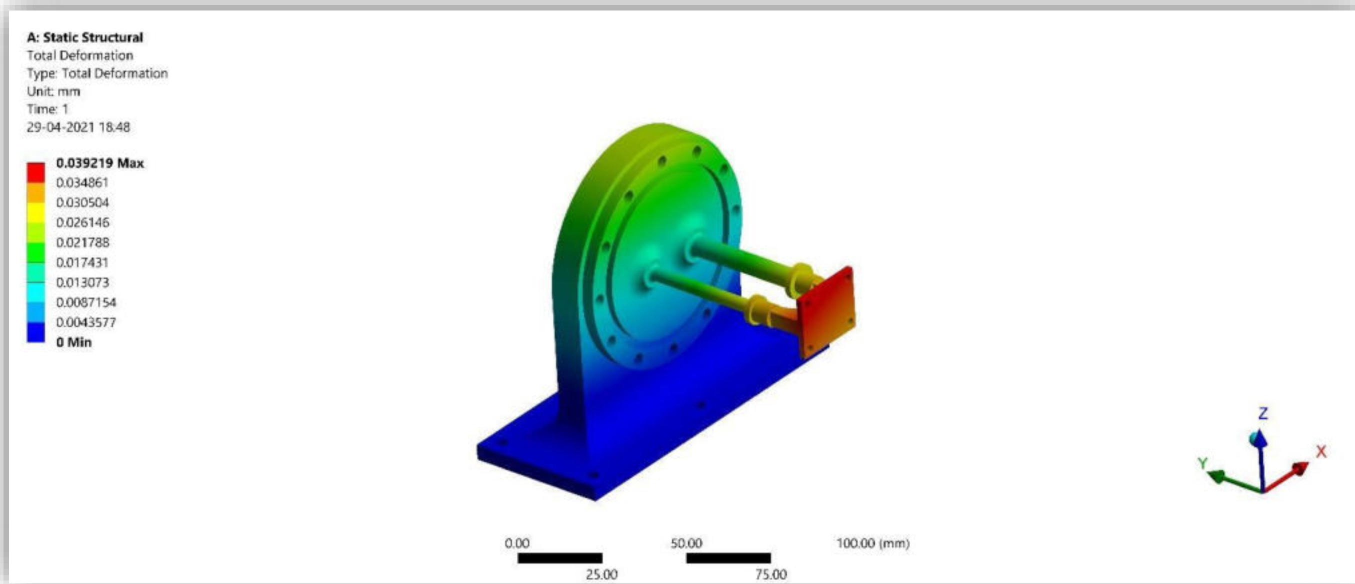


Fig. 5.1: Total Deformation in Static Structural Analysis

5.1.1.2 Modal Analysis

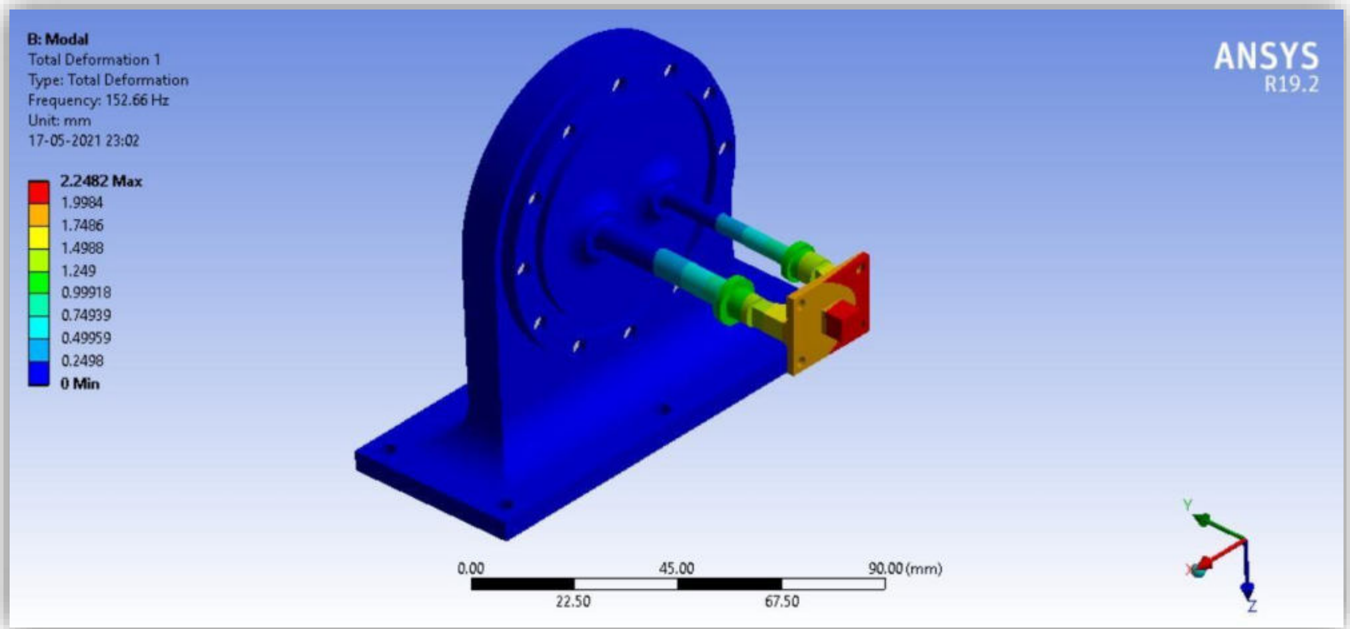


Fig. 5.2: Total Deformation 1 in Modal Analysis

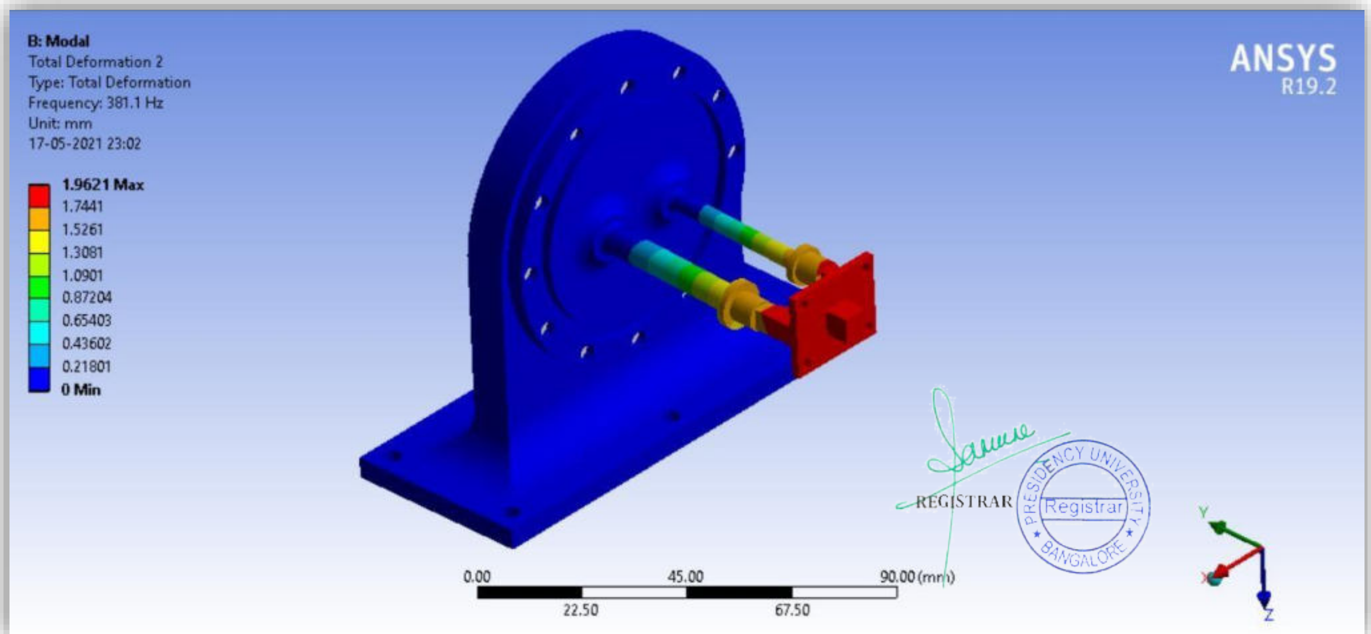


Fig. 5.3: Total Deformation 2 in Modal Analysis

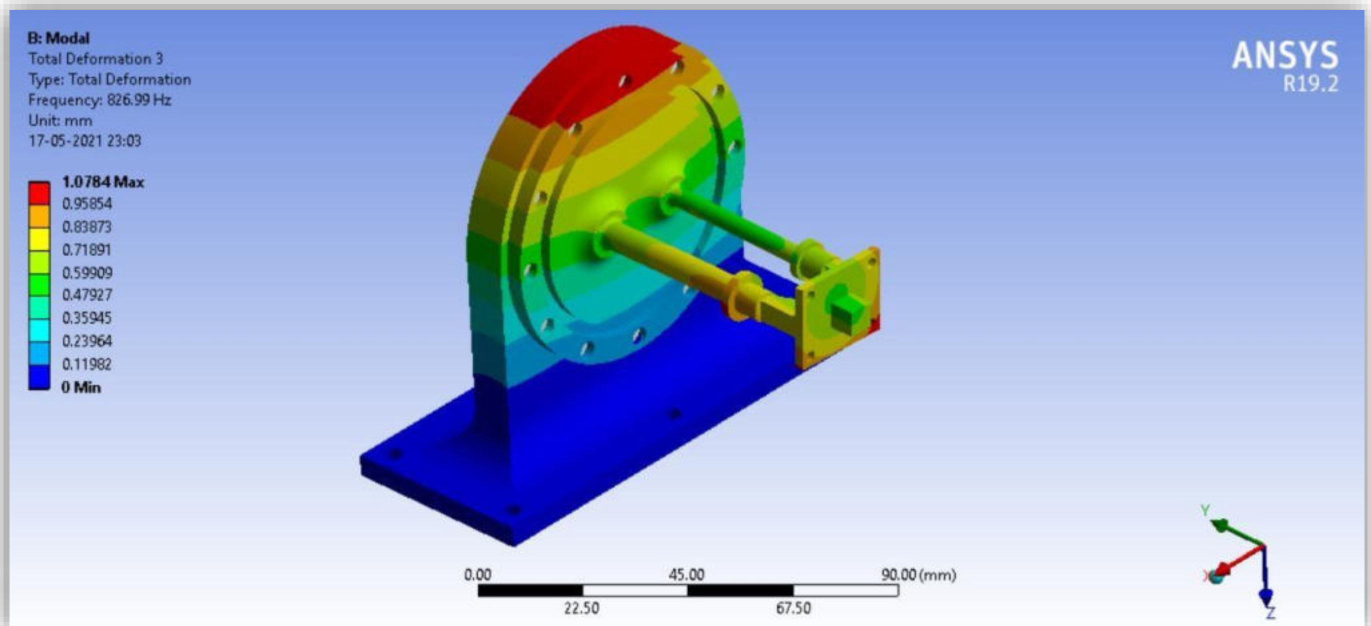


Fig. 5.4: Total Deformation 3 in Modal Analysis

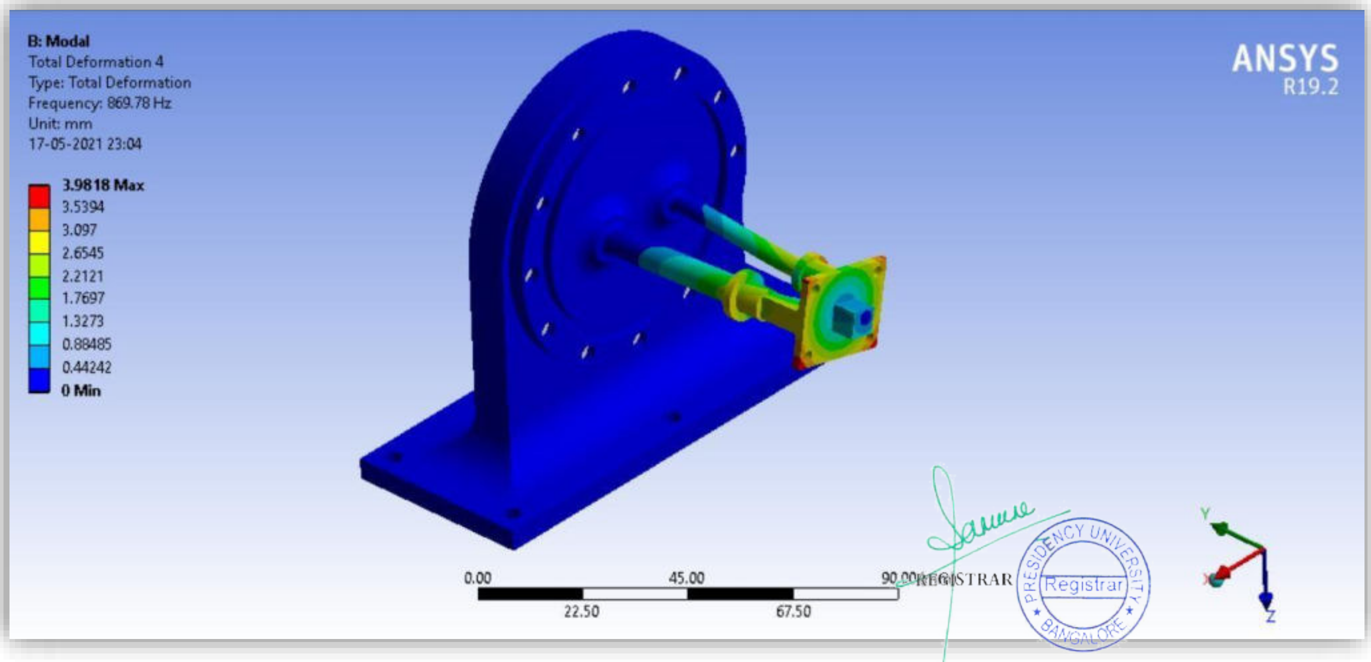


Fig. 5.5: Total Deformation 4 in Modal Analysis

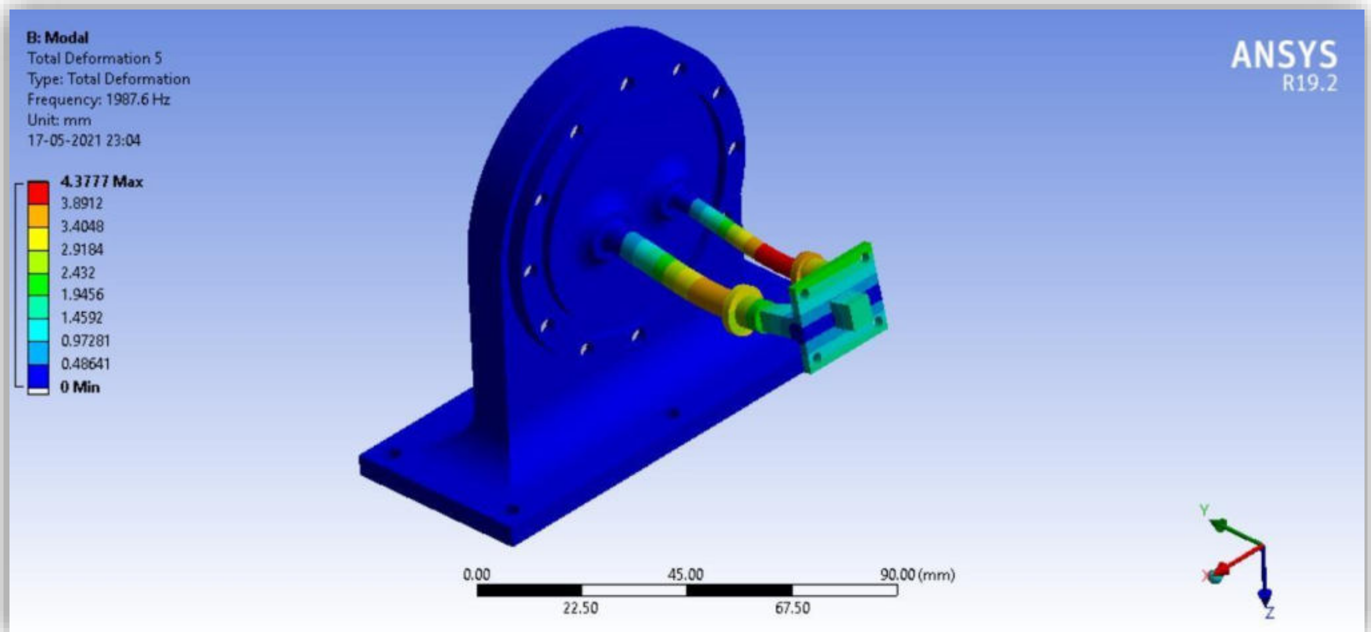


Fig. 5.6: Total Deformation 5 in Modal Analysis

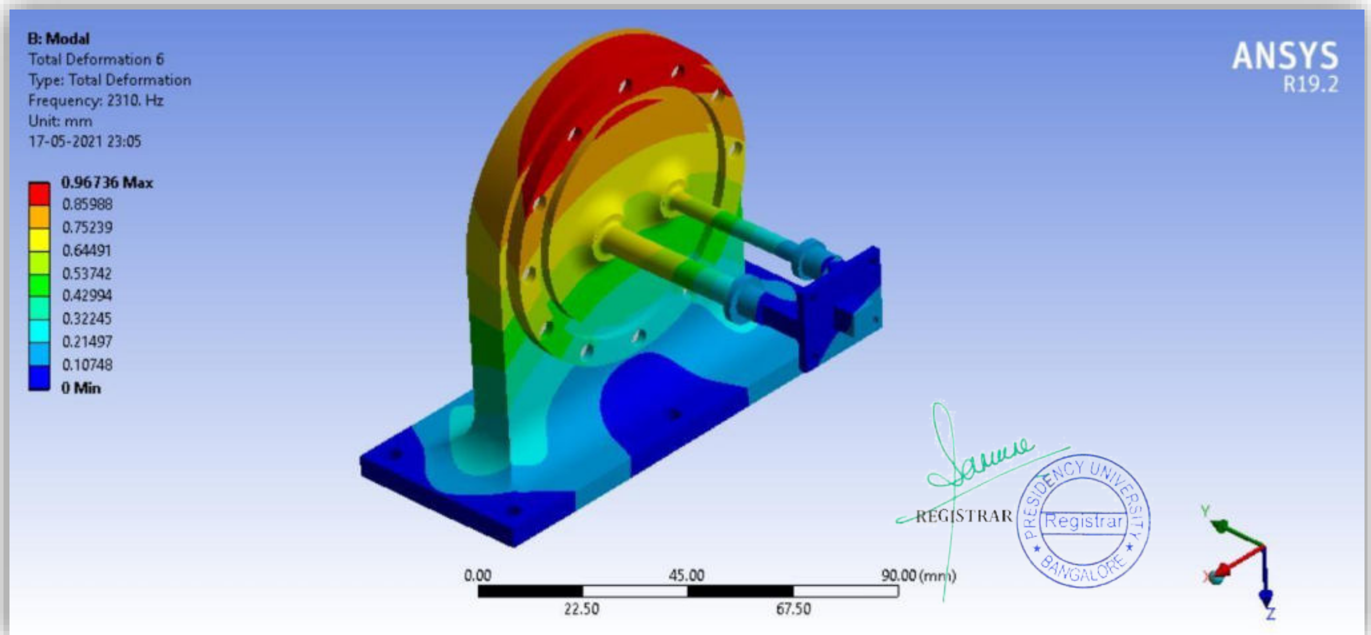


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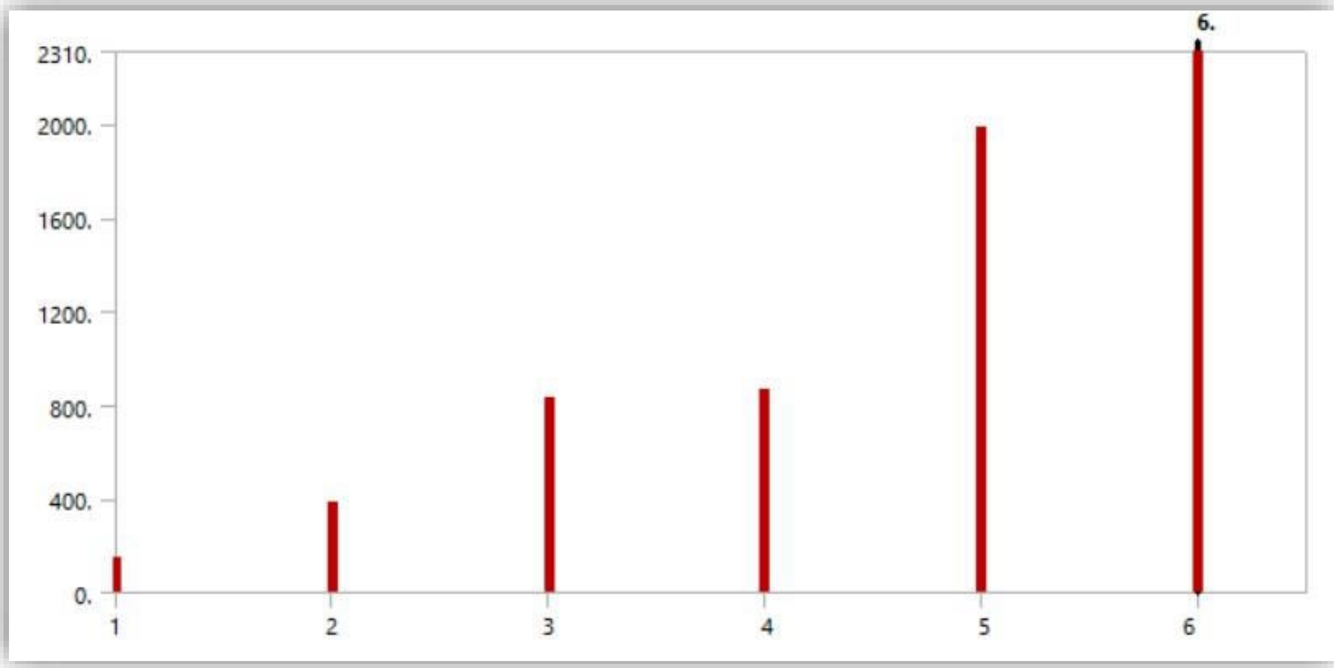
Fig. 5.7: Total Deformation 6 in Modal Analysis



Graph 5.1: Modes v/s Frequency

Table 5.1: Modal Analysis Results

Modes	Frequency (Hz)	Max. Deformation (mm)
1	152.66	2.2482
2	381.1	1.9621
3	826.99	1.0784
4	869.78	3.9818
5	1987.6	4.3777
6	2310	0.96736

5.1.1.3 Harmonic Response Analysis

Input: X – Axis

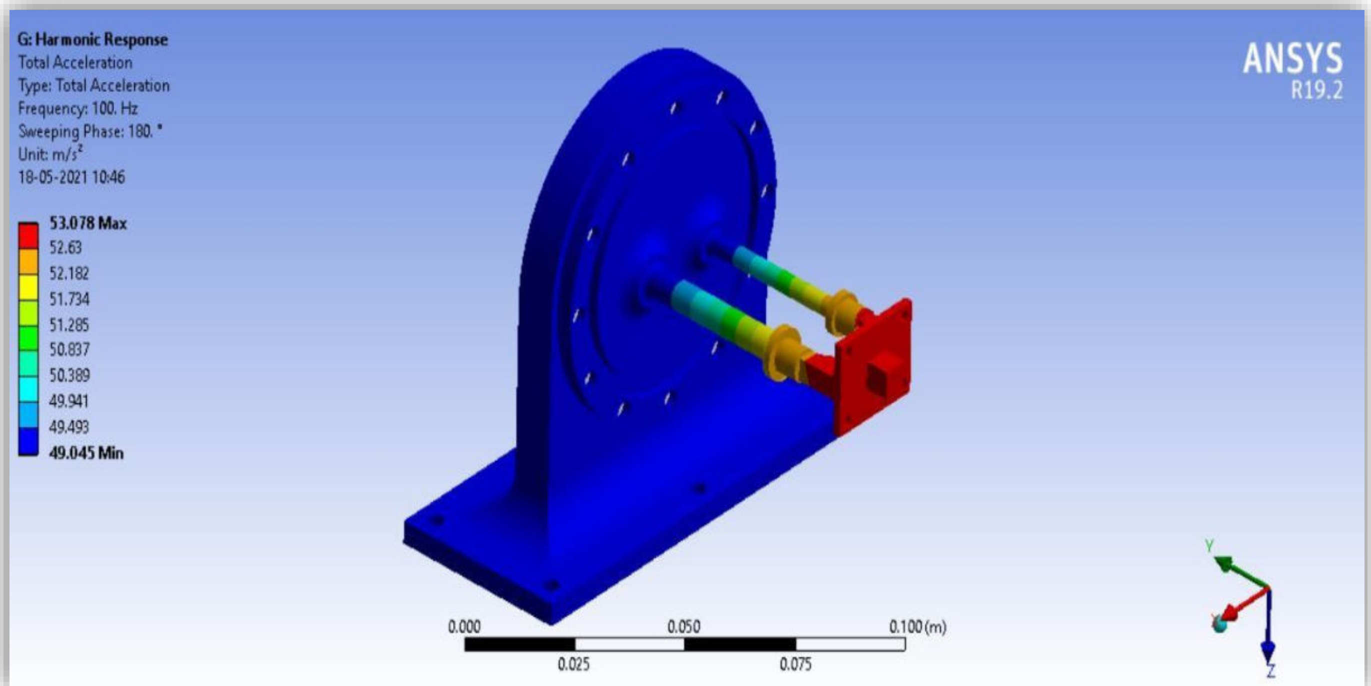
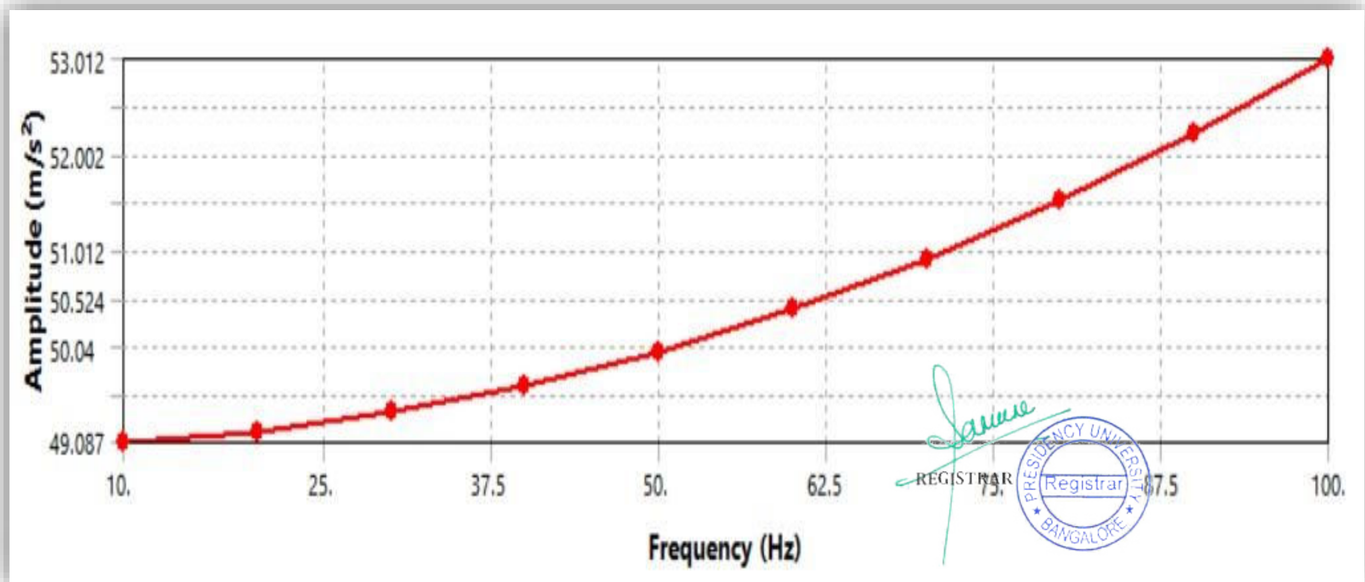
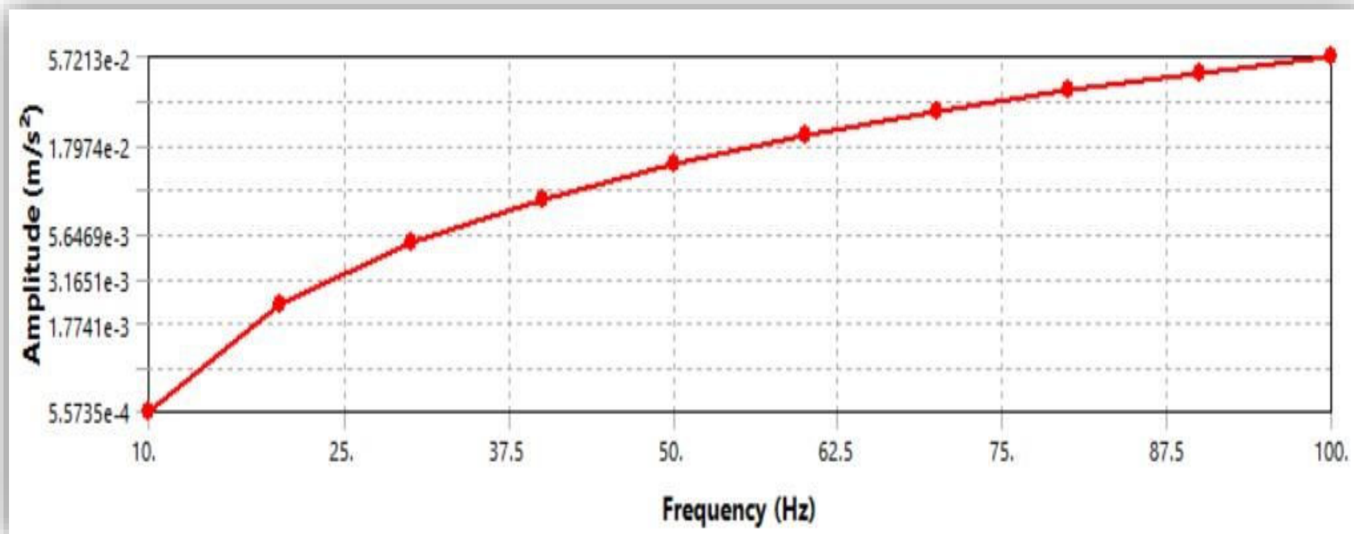


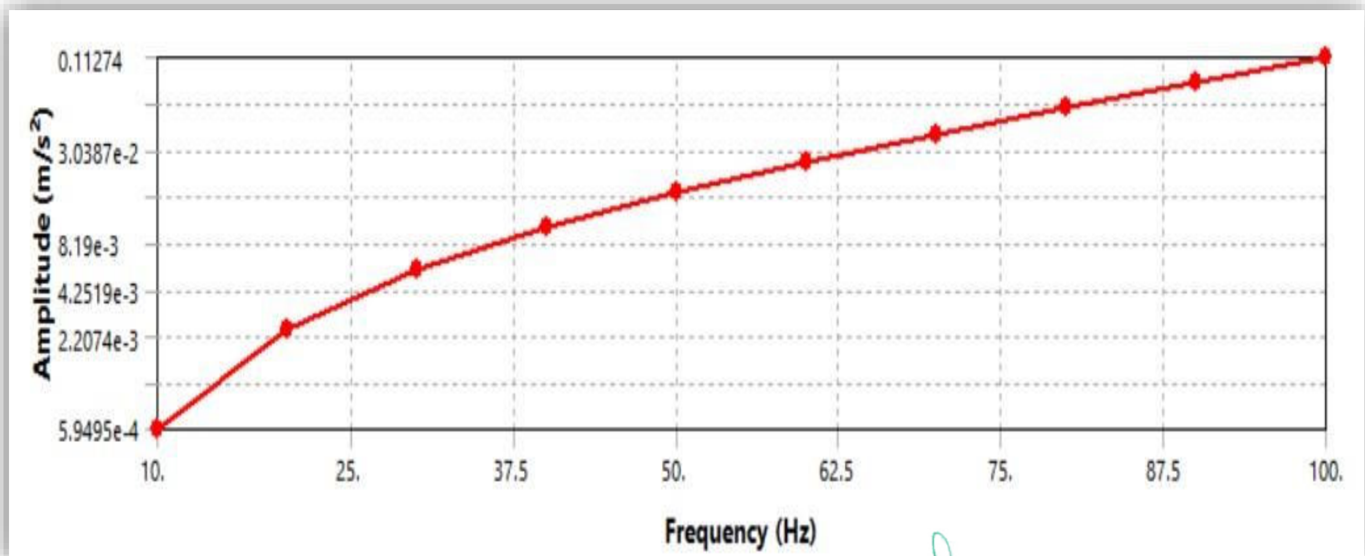
Fig. 5.8: Total Acceleration in Modal Analysis in X - Axis



Graph 5.2: Harmonic Analysis - Amplitude v/s Frequency Graph (Input X – Output X)



Graph 5.3: Harmonic Analysis - Amplitude v/s Frequency Graph (Input X – Output Y)



Graph 5.4: Harmonic Analysis - Amplitude v/s Frequency Graph (Input X – Output Z)

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Input: Y – Axis

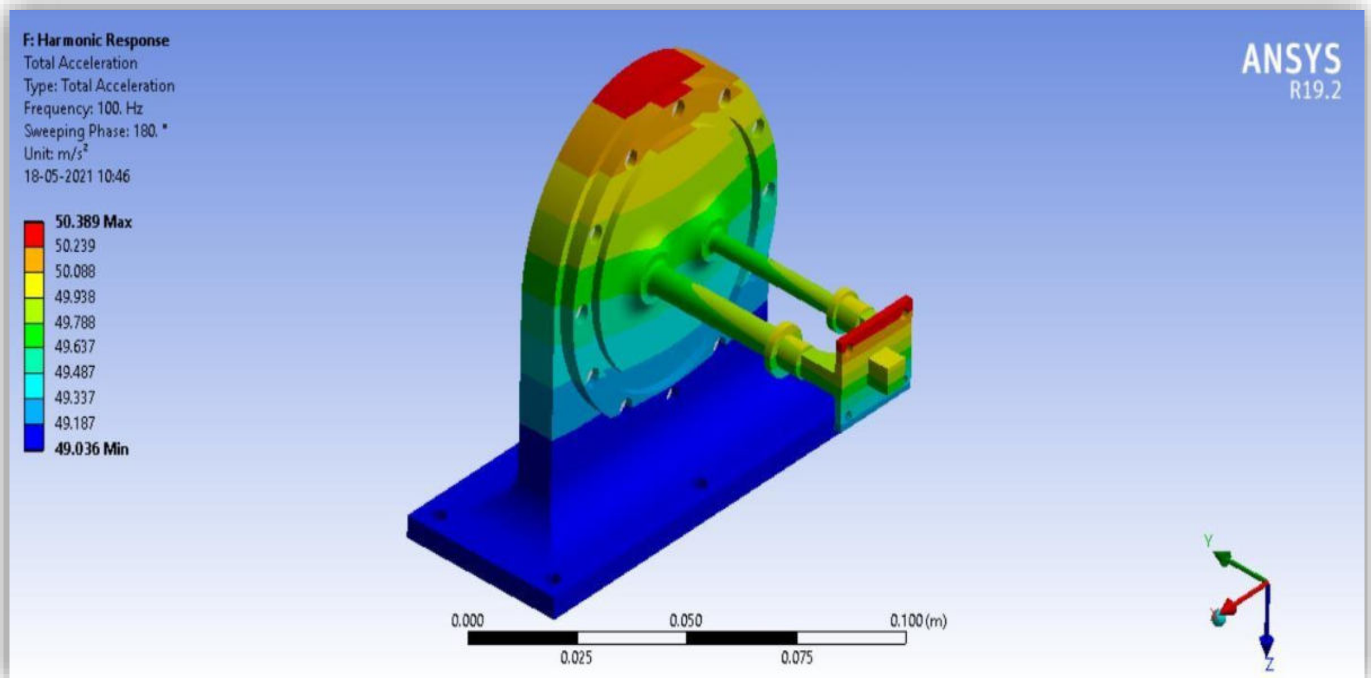
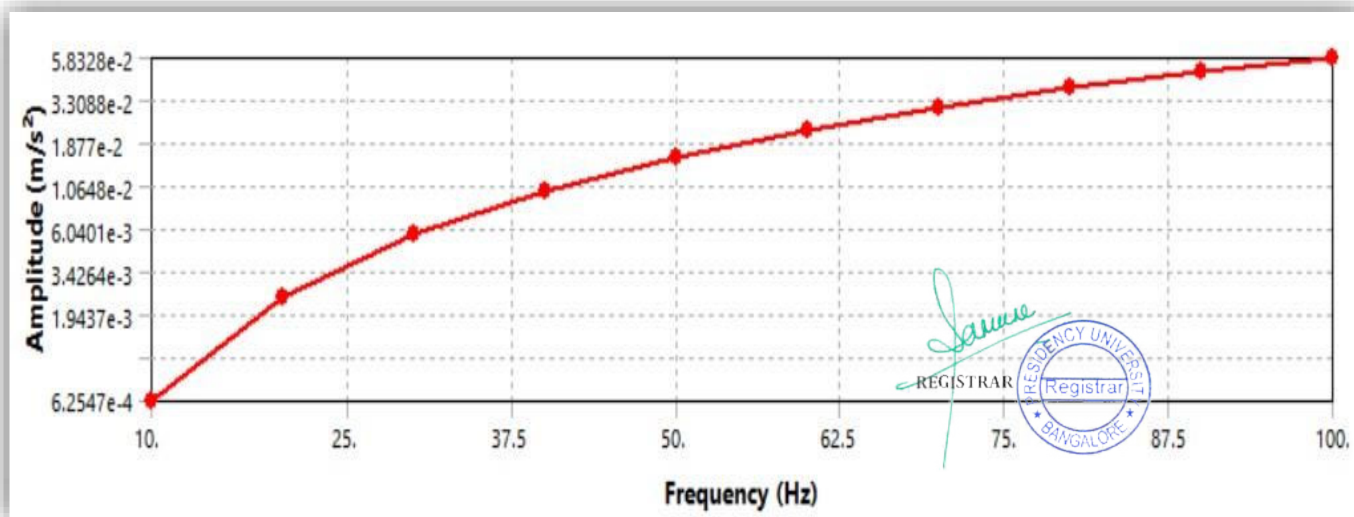
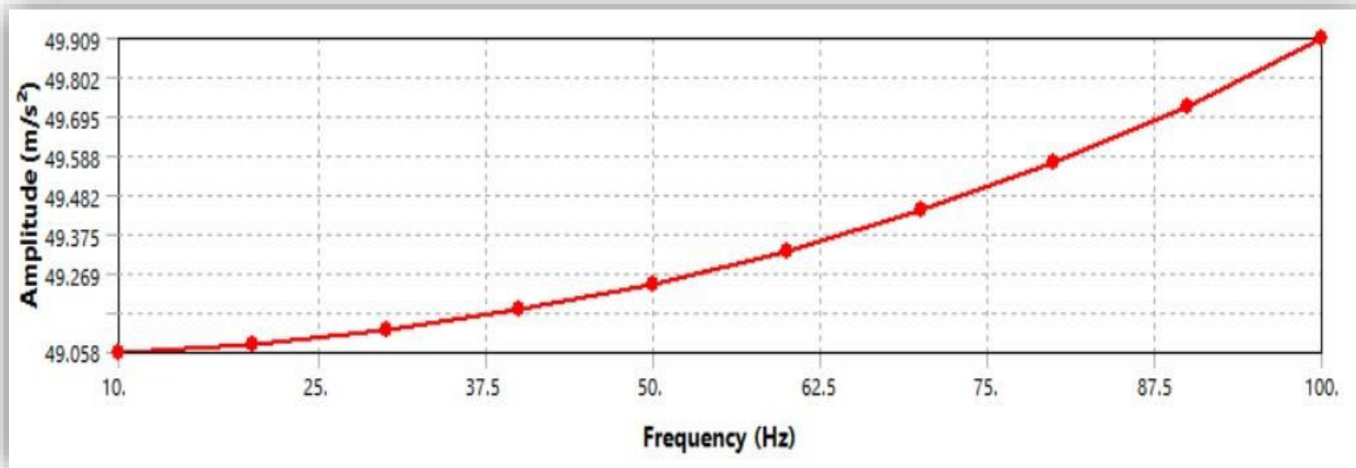


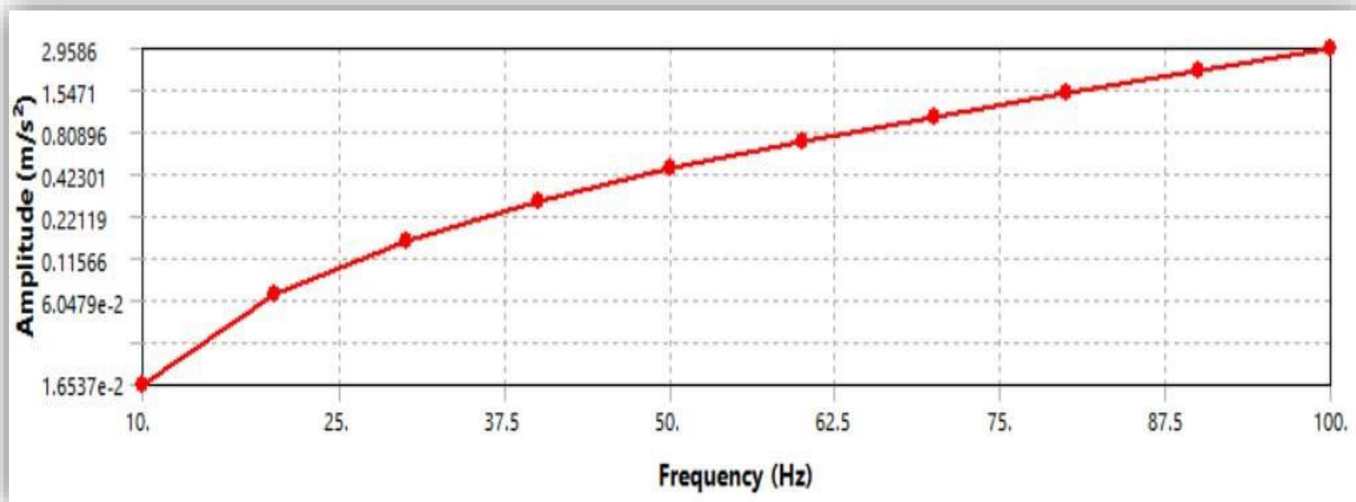
Fig. 5.9: Total Acceleration in Modal Analysis in Y - Axis



Graph 5.5: Harmonic Analysis - Amplitude v/s Frequency Graph (Input Y – Output X)



Graph 5.6: Harmonic Analysis - Amplitude v/s Frequency Graph (Input Y – Output Y)



Graph 5.7: Harmonic Analysis - Amplitude v/s Frequency Graph (Input Y – Output Z)

Input: Z – Axis

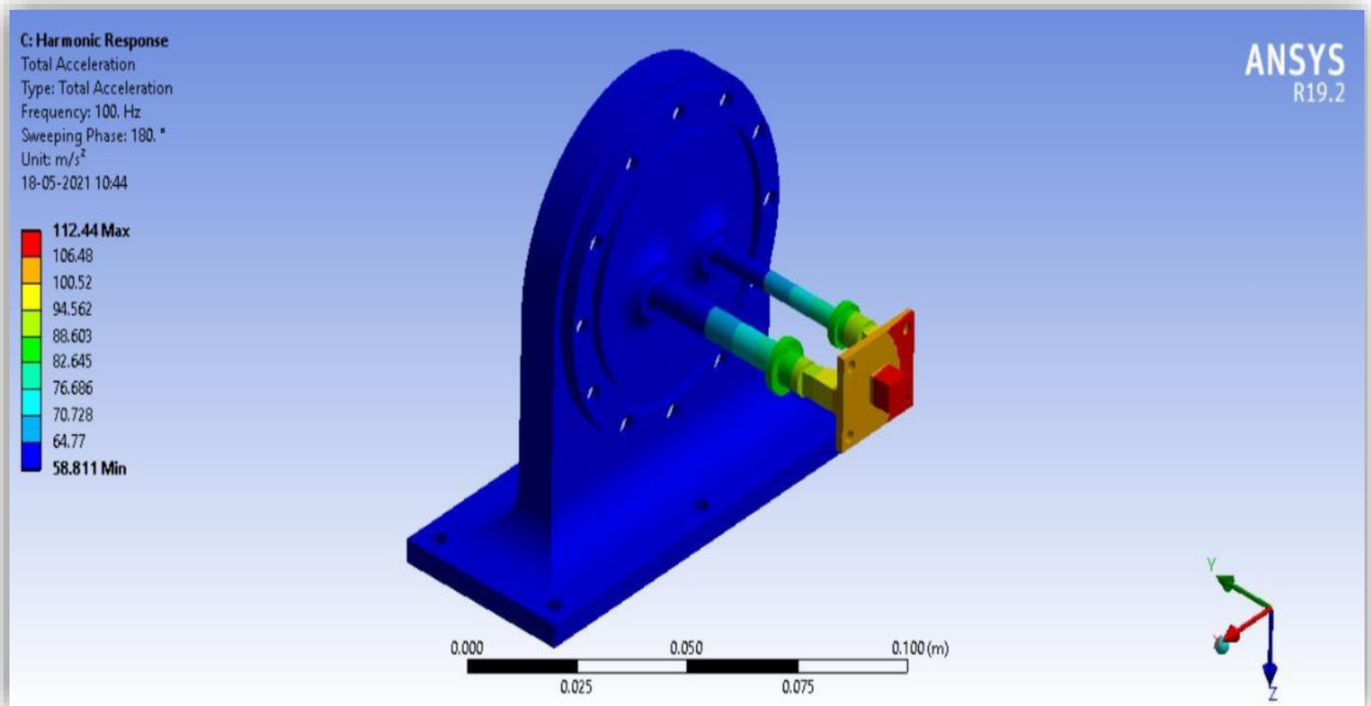
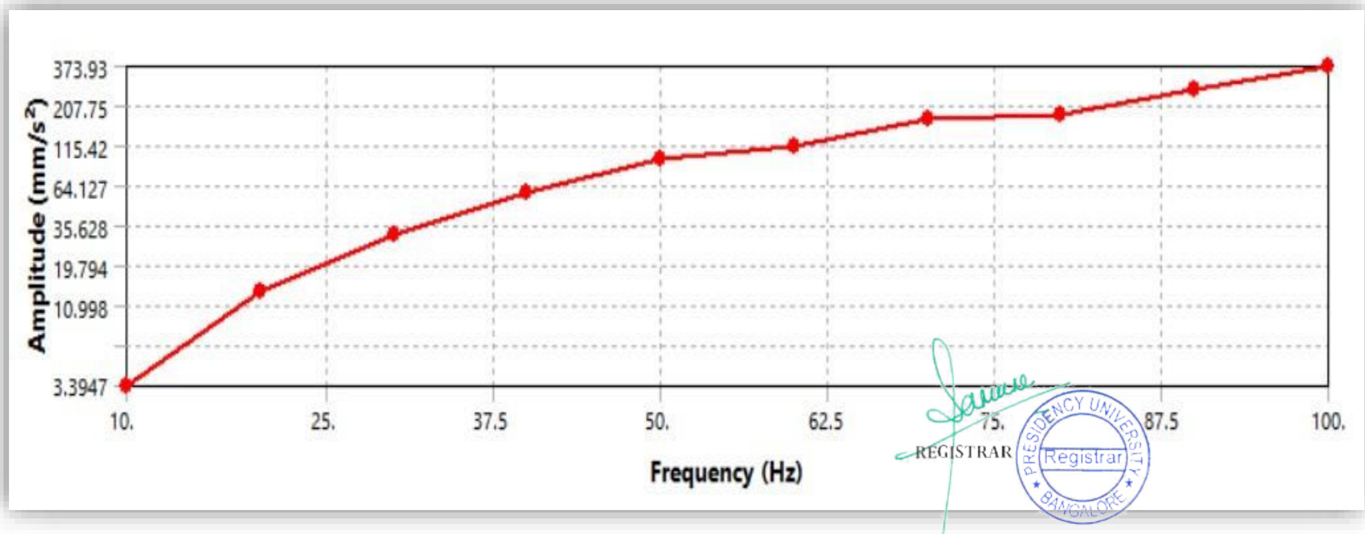
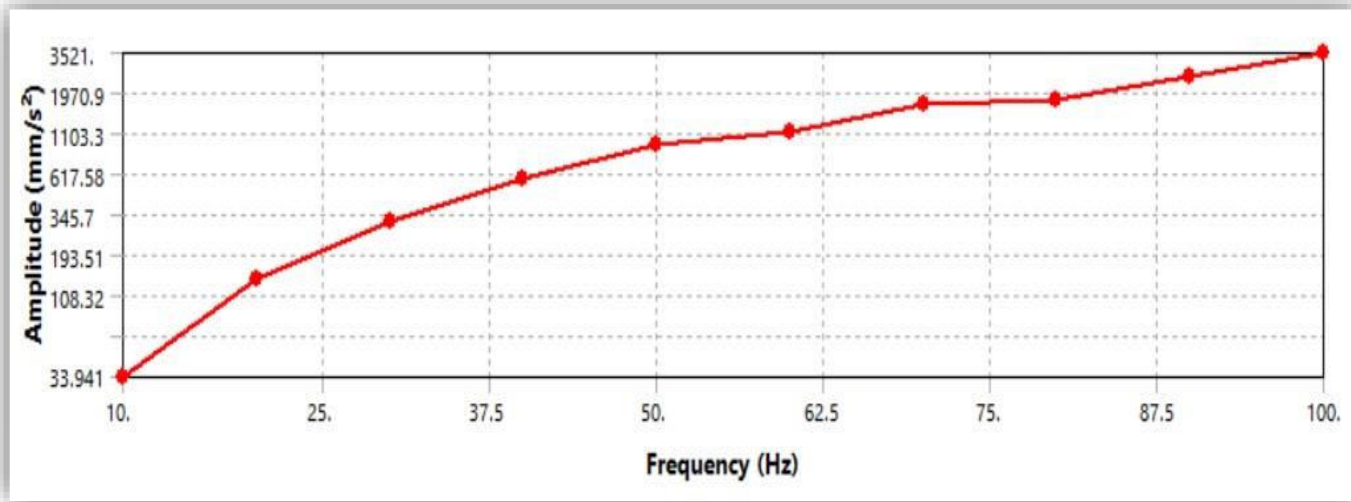


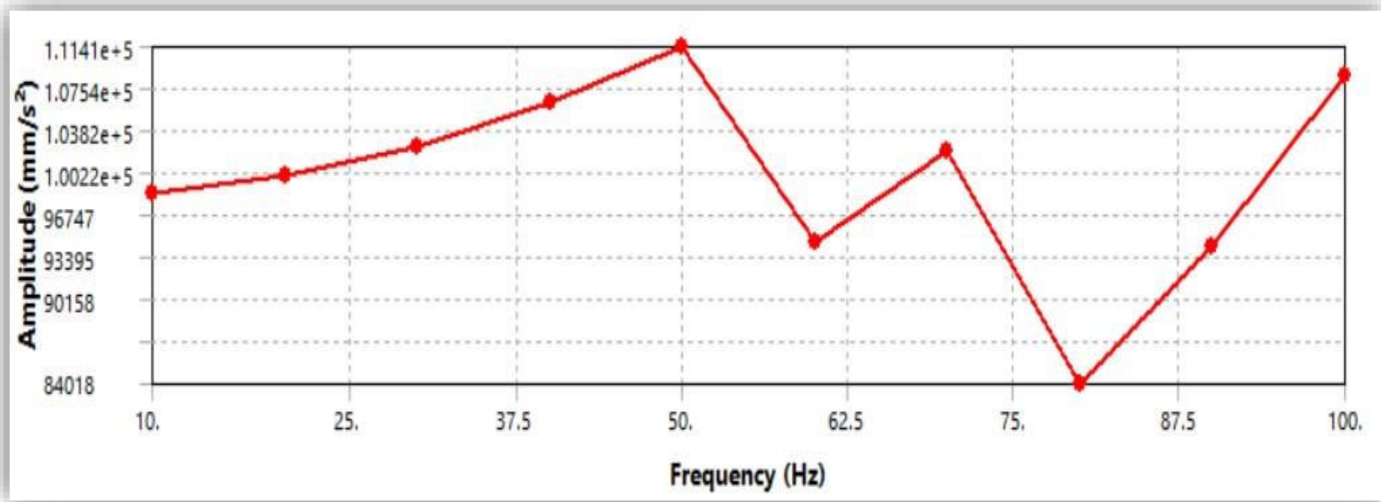
Fig. 5.10: Total Acceleration in Modal Analysis in Z - Axis



Graph 5.8: Harmonic Analysis - Amplitude v/s Frequency Graph (Input Z – Output X)



Graph 5.9: Harmonic Analysis - Amplitude v/s Frequency Graph (Input Z – Output Y)



Graph 5.10: Harmonic Analysis - Amplitude v/s Frequency Graph (Input Z – Output Z)

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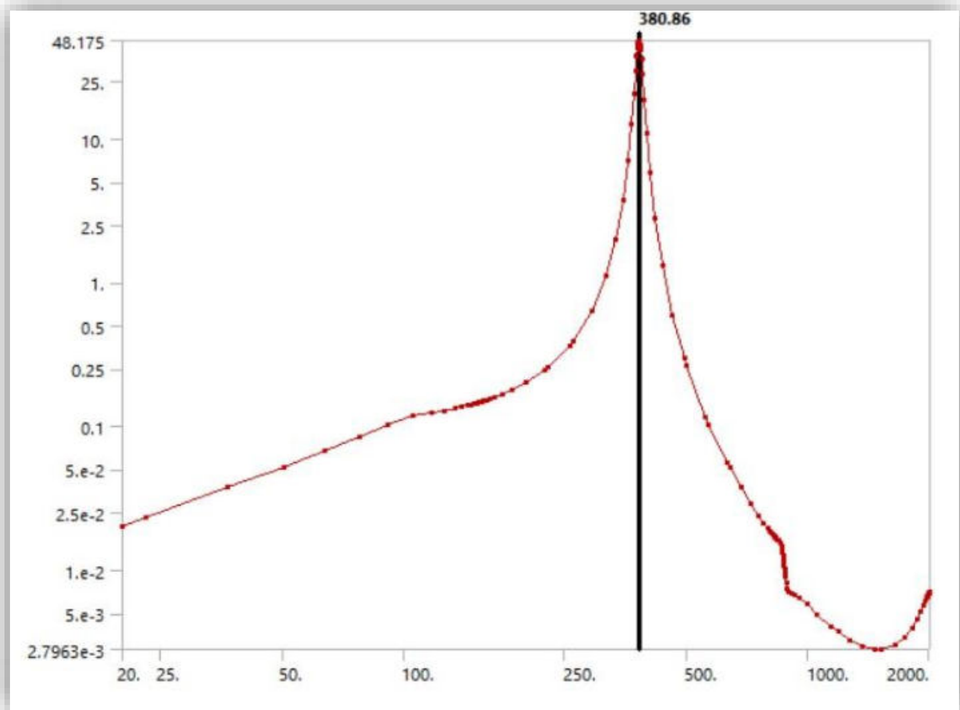
Table 5.2: Harmonic Analysis Simulation Results v/s Test Results

	Simulation Results	Test Results

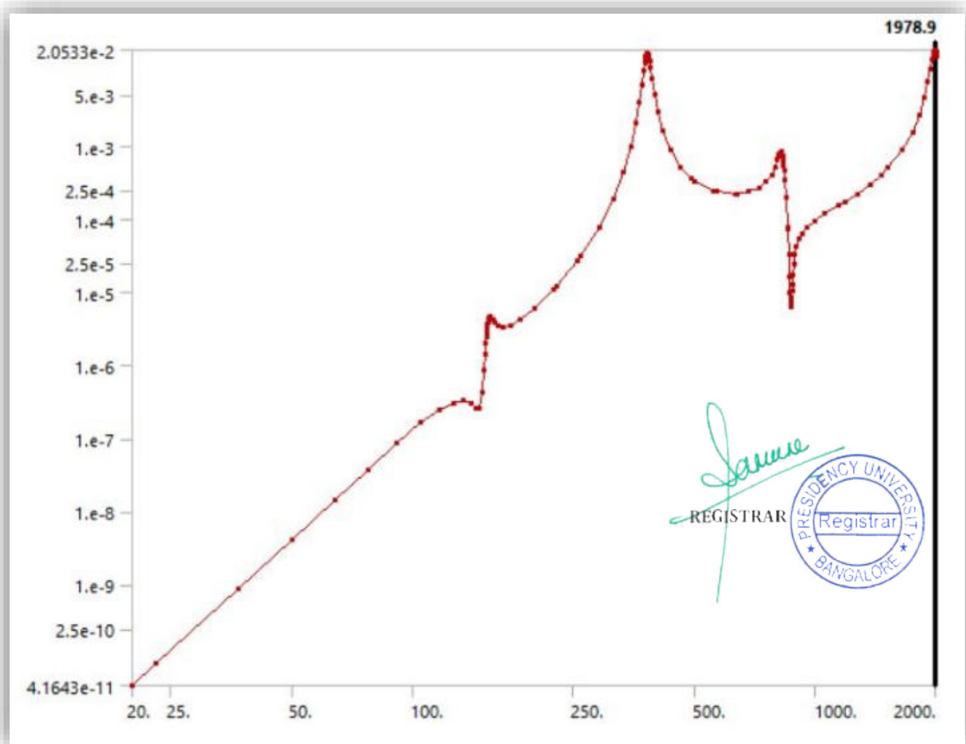
Input/Output	Max. Amplitude (g)	Corresponding Frequency (Hz)	Max. Amplitude (g)	Corresponding Frequency (Hz)
X-X	5.4	100	5	100
X-Y	0.00583	100	-	-
X-Z	0.01149	100	0.3	80
Y-X	0.00594	100	-	-
Y-Y	5.08	100	5	100
Y-Z	0.3	100	1	99
Z-X	0.0381	100	2.5	27
Z-Y	0.3589	100	-	-
Z-Z	11.35	50	11.4	49.8

5.1.1.4 Random Vibration Analysis

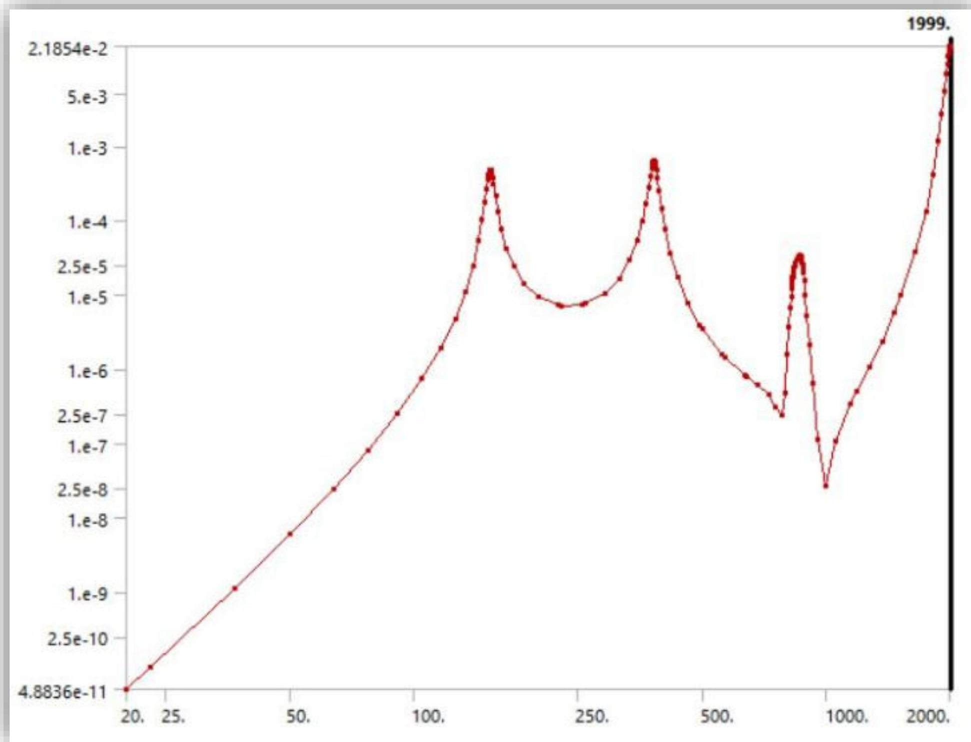
Input: X – Axis



Graph 5.11: Random Vibration Analysis - PSD v/s Frequency (Input X – Output X)



Graph 5.12: Random Vibration Analysis - PSD v/s Frequency (Input X – Output Y)



Graph 5.13: Random Vibration Analysis - PSD v/s Frequency (Input X – Output Z)

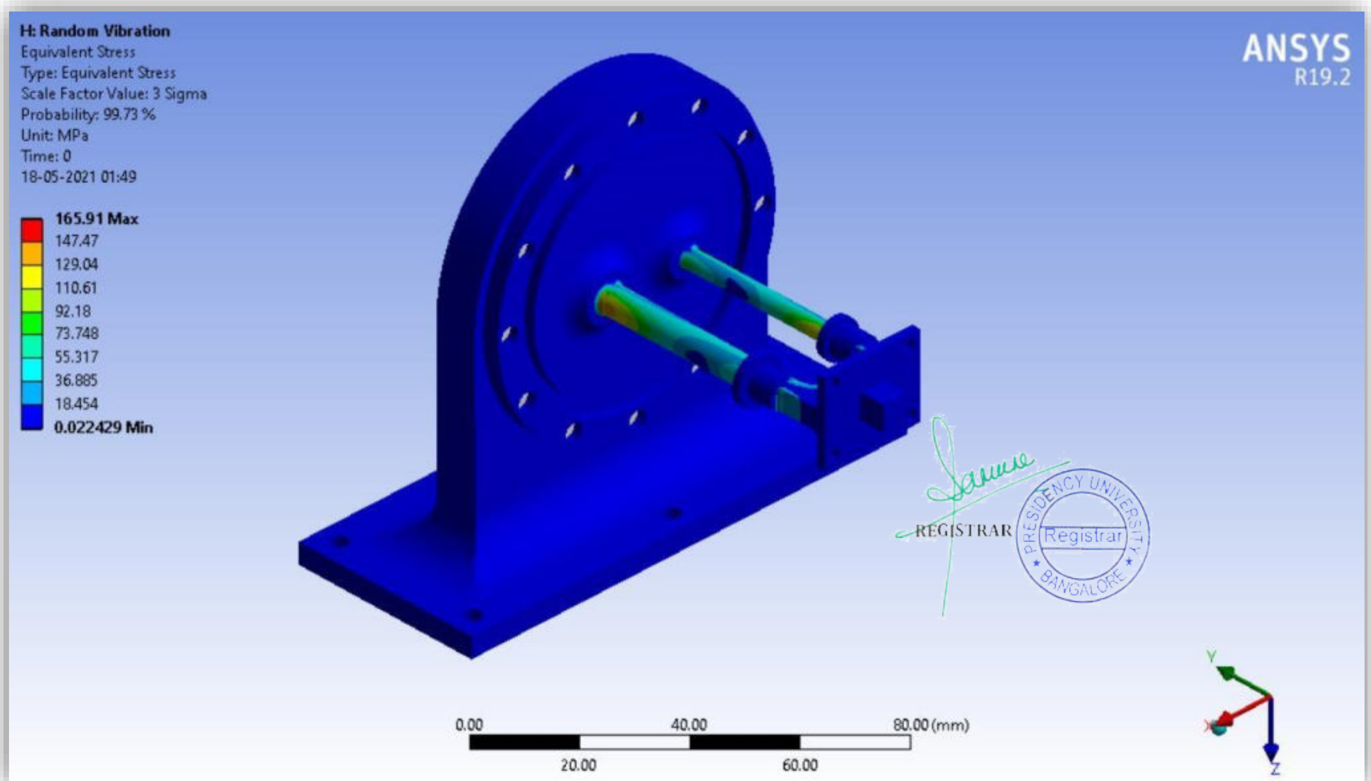
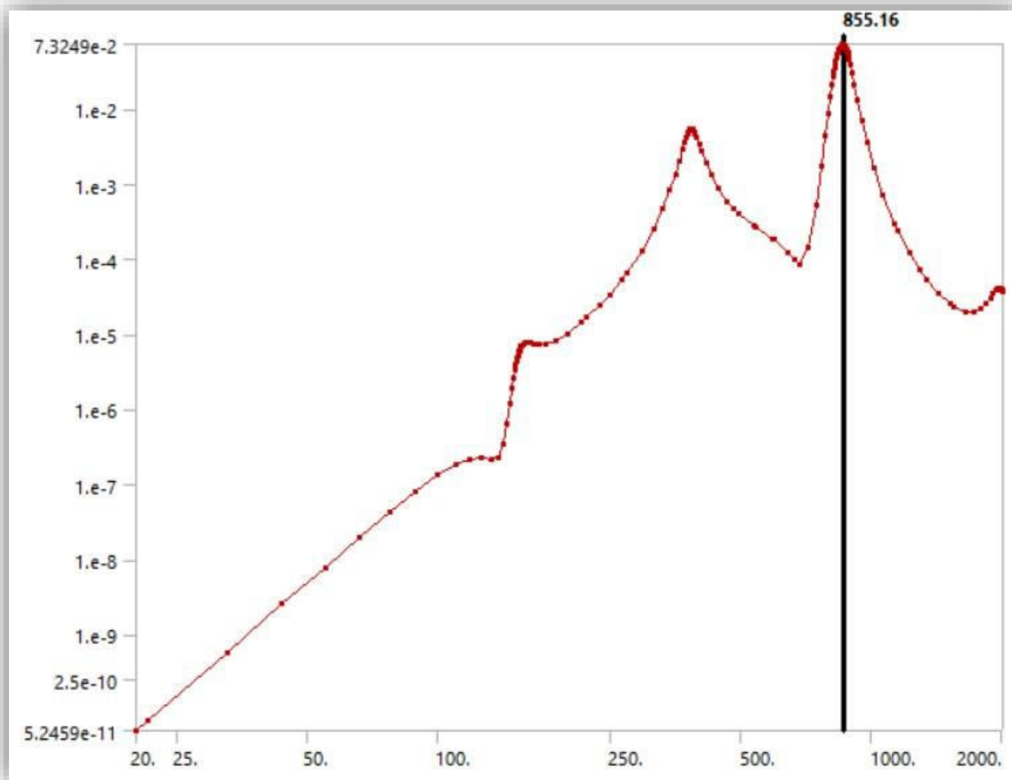
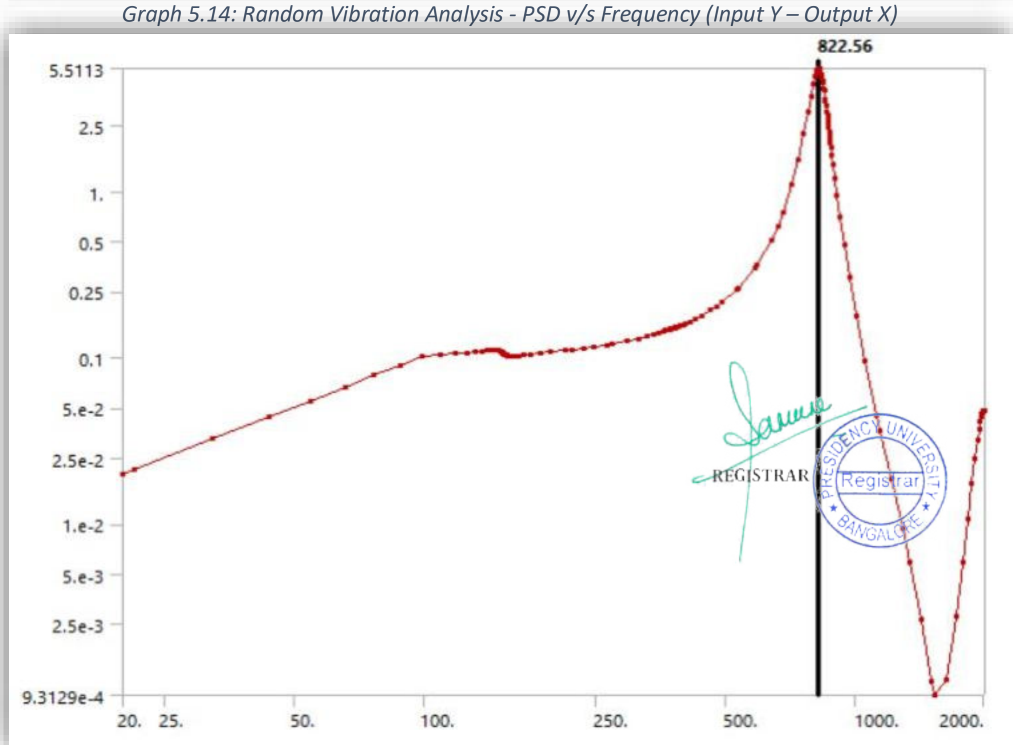


Fig. 5.11: Equivalent Stress in X - Axis

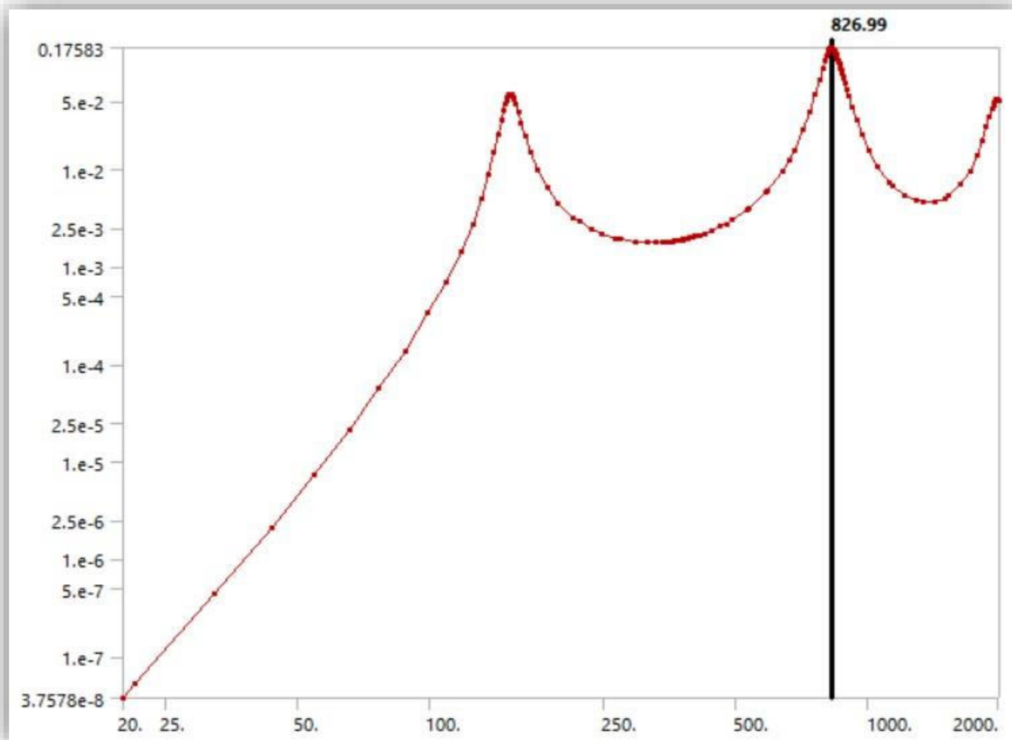
Input: Y – Axis



Graph 5.14: Random Vibration Analysis - PSD v/s Frequency (Input Y – Output X)



Graph 5.15: Random Vibration Analysis - PSD v/s Frequency (Input Y – Output Y)



Graph 5.16: Random Vibration Analysis - PSD v/s Frequency (Input Y – Output Z)

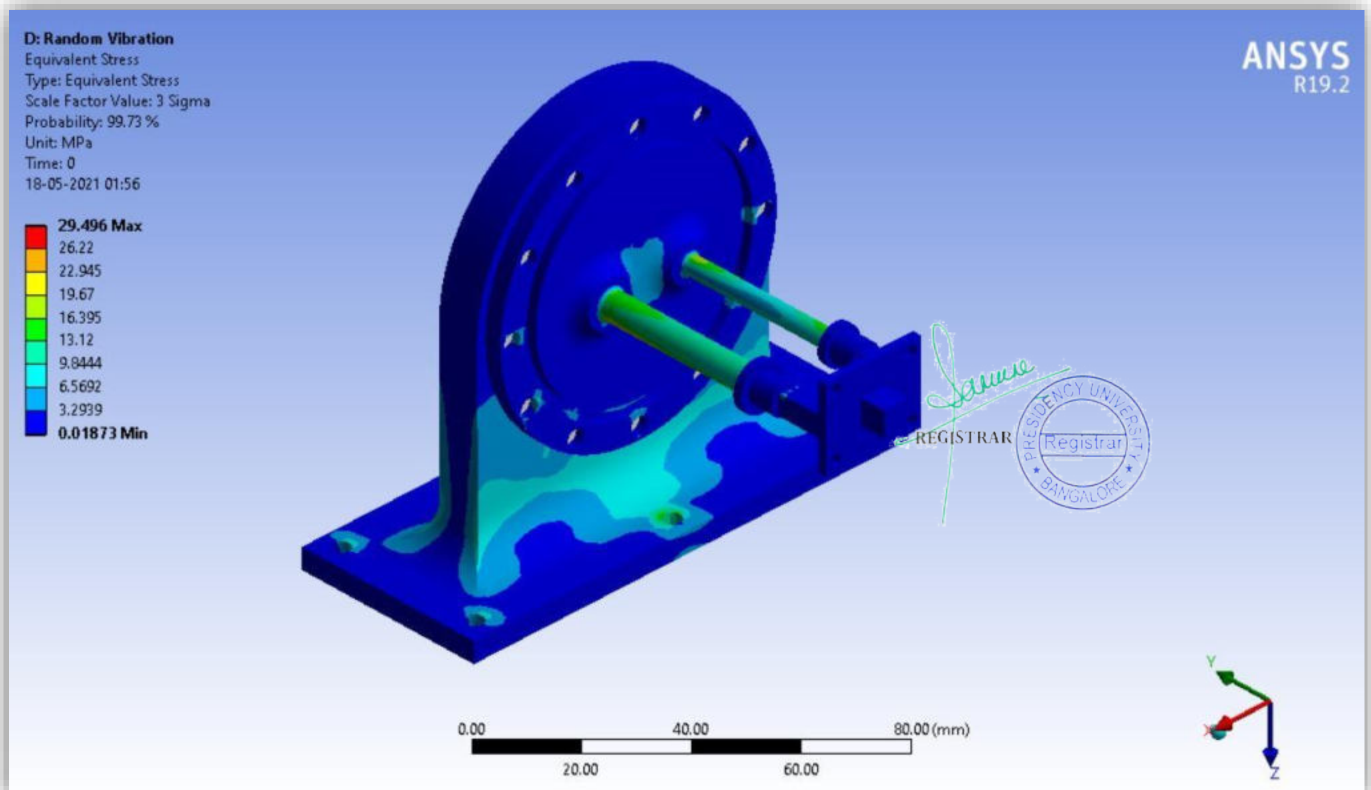
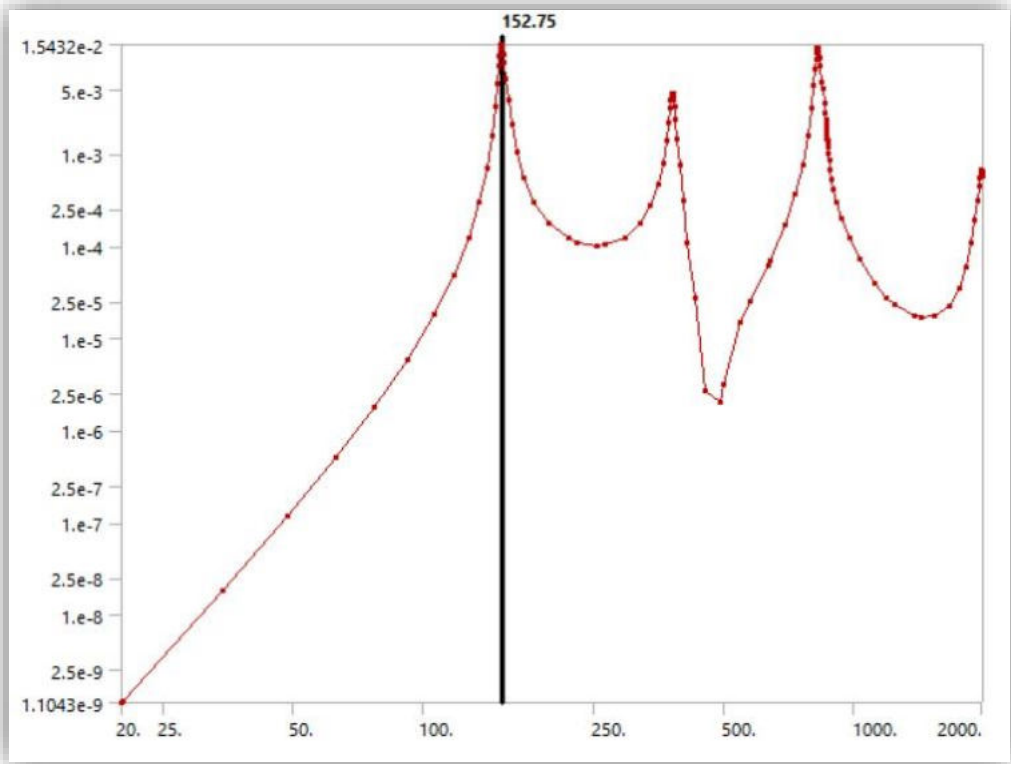
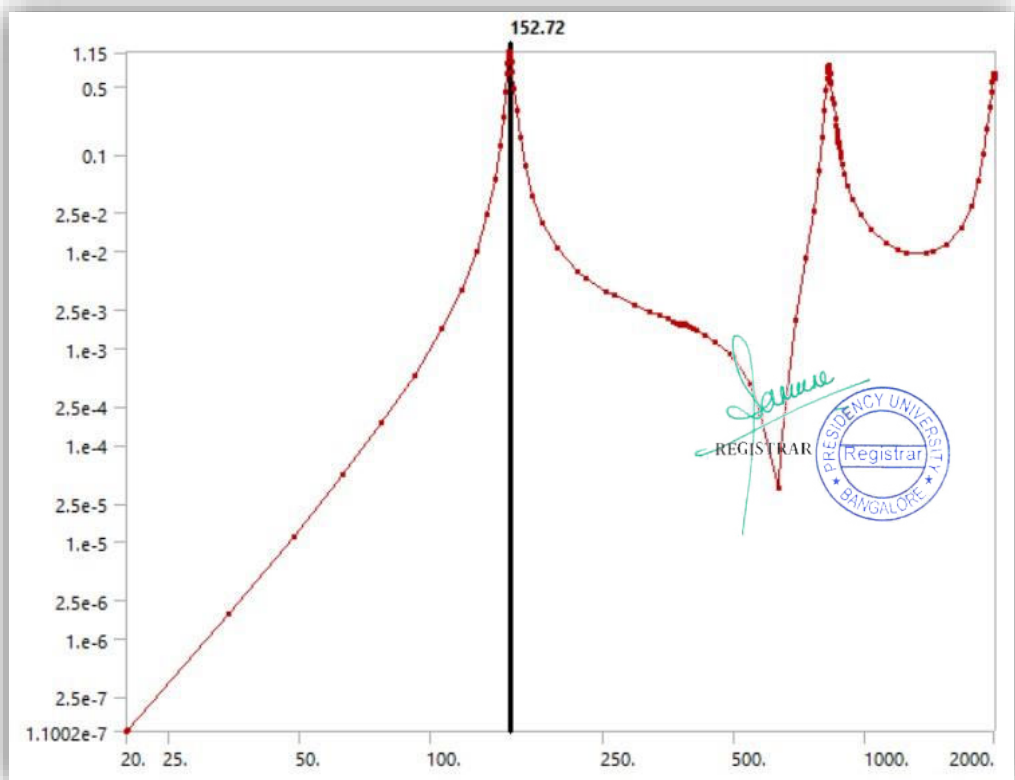


Fig. 5.12: Equivalent Stress in Y - Axis

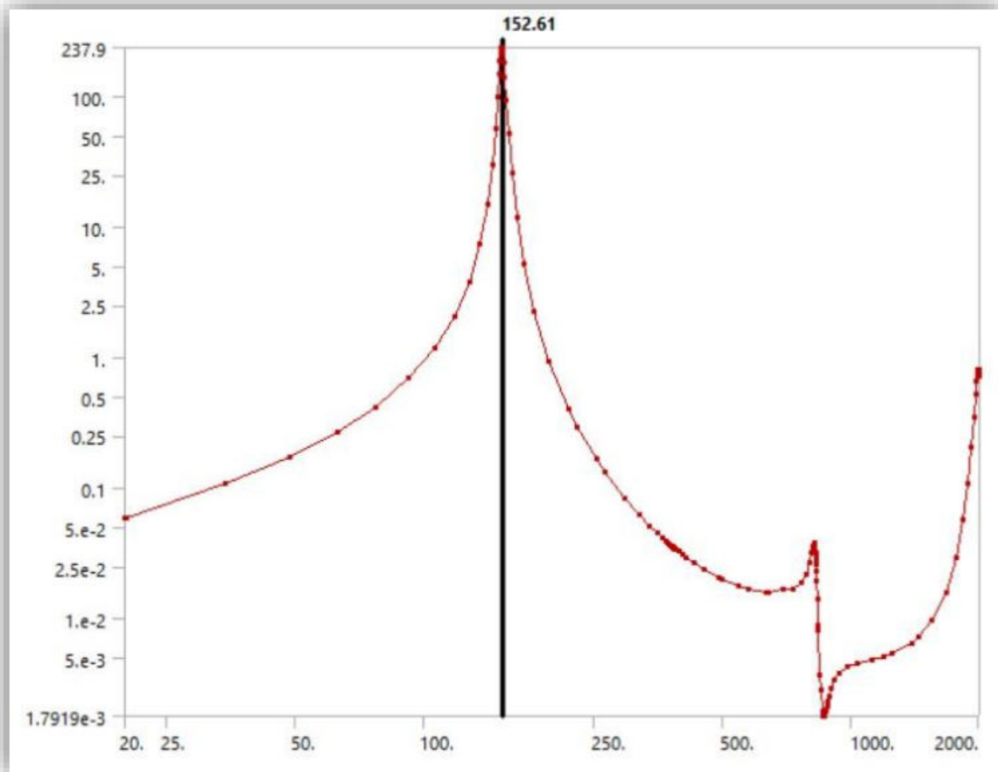
Input: Z – Axis



Graph 5.17: Random Vibration Analysis - PSD v/s Frequency (Input Z – Output X)



Graph 5.18: Random Vibration Analysis - PSD v/s Frequency (Input Z – Output Y)



Graph 5.19: Random Vibration Analysis - PSD v/s Frequency (Input Z – Output Z)

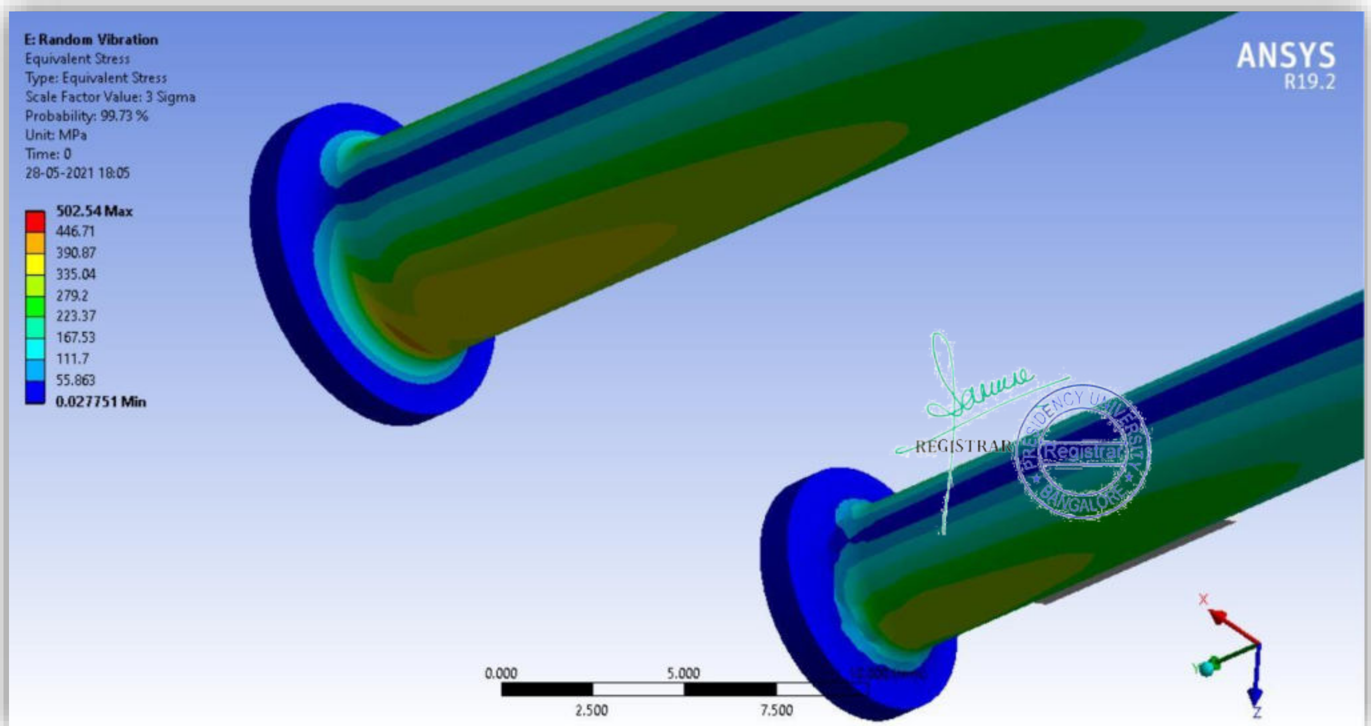


Fig. 5.13: Equivalent Stress in Z - Axis

Table 5.3: Random Vibration Analysis Simulation v/s Test Results

	Simulation Results			Test Results	
Input/Output	Damping Ratio	Frequency (Hz)	PSD G Acceleration (G^2/Hz)	Frequency (Hz)	PSD G Acceleration (G^2/Hz)
X-X	0.025	380.86	48.175	388	46.4
X-Y		1978.9	0.02053	-	-
X-Z		1999	0.02185	1688	1.8
Y-X	0.054	855.16	0.07324	-	-
Y-Y		822.56	5.5113	224	4.1
Y-Z		826.99	0.17583	224	11.5
Z-X	0.0194	152.75	0.01543	1456	7.3
Z-Y		152.72	1.15	-	-
Z-Z		152.61	237.9	152	238.1

5.1.1.5 Margins of Safety in Random Vibration Analysis

The maximum stresses occur on the pulse tube and regenerator which are key elements affecting the thermal performance. All the results above are of a model with pulse tube and regenerator thickness of 125 microns. The margin of safety has been calculated in each axis using the following formula:

$$\text{Margin of Safety (MoS)} = \frac{\text{Yield Strength of Ti6Al4V}}{\text{Maximum Stress}} - 1$$

Yield strength of Ti6Al4V = 1100 MPa

Table 5.4: Margin of Safety (125 Micron Thickness Model)

Axis	Equivalent Stress (Von-Mises)	Margin of Safety
X	165.91	5.63
Y	29.496	36.29
Z	502.54	1.19

The Z – axis is of particular interest as the stresses in this case are significantly higher than that of X and Y. As the equivalent stress is well within half of the yield strength of Ti6Al4V, it was decided to reduce the thickness of the pulse tube and regenerator to 100 microns and then further to 75 microns to study the stresses and respective MoS and determine the best-suit for optimal thermal performance.

Table 5.5: Margin of Safety (100 Micron Thickness Model)

Axis	Equivalent Stress (Von-Mises)	Margin of Safety
X	199.38	4.51

Y	35.195	30.25
Z	521.56	1.109

Table 5.6: Margin of Safety (75 Micron Thickness Model)

Axis	Equivalent Stress (Von-Mises)	Margin of Safety
X	247.02	3.45
Y	36.727	28.95
Z	644.57	0.706

5.1.2 Discussions

- The mass sensitivity at the free-end is extremely high, as even a minor increase or decrease in the value affects the frequency by a significant margin. At first, mass of the sensors at the cryotip was taken as 4 grams and the resultant frequency at mode 1 was 197 Hz. The mass was then doubled to 8 grams and the resultant frequency at mode 1 came down to 171 Hz. At a mass of 10.8 grams, the resultant frequency at mode 1 was 152.66 Hz.
- Overall performance is a feature of structural and thermal performance. The trade-off between structural and thermal performance is clearly shown between the 125, 100 and 75-micron models. Although the thermal performance is guaranteed to improve as the thickness of the tubes is reduced, it comes at the cost of a lower margin of safety due to the increased stresses.
- Although the base excitation is applied to one axis, there is significant response in the other two axes.
- Pressure of the helium gas (30 bar) was taken into account initially, but the results were barely affected. This could not be verified as the implementation of the pressure could have been incorrect.
  • The disparity between the theoretical and simulation values of natural frequency could be owing to the complexity of the model which requires further understanding of the shortcomings of the theoretical calculation to reach a more accurate value.

5.2 Conclusions

- The 125-micron model can be guaranteed to be safe but the same cannot be said about the 100micron and especially the 125-micron model. The 100-micron model shows some promise as the maximum stress occurring is still within half of the yield strength of the material of the tubes (Ti6Al4V – 1100 MPa).

- A thorough and in-depth review of test data is required to further understand the deviations in the frequencies in the simulation of random vibration test in the Y – axis.
- The trade-off between structural and thermal performance needs to be further experimented with in case of the 100-micron and 75-micron models.
- This can be done by using modern 3 – D printing technology to manufacture the thin section tubes which could not be done earlier owing to time constraints as well as lack of technology for the same.

5.3 Recommendations for Future Work

- The 100-micron model, although on the edge structurally, can be worked on by some stiffening at the flange end to reduce the stresses as it can offer significant improvement in thermal performance.
- This can be done by slightly increasing the root radius at the flange end in such a way that the loss in thermal performance is minimal and at the same time stresses are adequately reduced.

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A Project Report on

"TITANIUM FORGING FOR LCA APPLICATION"

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
in
Mechanical Engineering

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A Project Report on

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A Project Report on

“MANUFACTURING AND TESTING OF ALUMINIUM MICRO HYBRID COMPOSITES FOR AEROSPACE APPLICATION””

Submitted in partial fulfillment of the requirement of Bachelor of Technology for the University Project/PP-2
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A Project Report on

“DESIGN AND ANALYSIS OF CLOOS ROBOT WELDING FIXTUREFOR L&T 990HFI TANDEM COMPACTOR”

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A Project Report on

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A Project Report on

"HD 785 DUMP-TRUCK ASSEMBLY LEAD TIME REDUCTION THROUGH KAIZEN"

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A Project Report on

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A Project Report on

"FIXTURE MODELING AND ANALYSIS FOR VMC MACHINING OPERATION"

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A Project Report on

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A Project Report on

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