STUDY OF FREE VIBRATION AND MECHANICAL BEHAVIOUR OF PRINTABLE CARBON NANO FIBRE COMPOSITE FOR LIGHT WEIGHT STRUCTURES

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report **"STUDY OF FREE VIBRATION AND MECHANICAL BEHAVIOUR OF PRINTABLE CARBON NANO FIBRE COMPOSITE FOR LIGHT WEIGHT STRUCTURES"** is the bonafide work of "**ARUNAGIRI ADHITHIAN R , DAVID ALLEN VAZ L , DHANNUSH S , KIRUBAKAR V K** "who carried out the project work under my/our supervision.

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ABSTRACT

In most of the Automotive Industries light weight structures are incorporated aiming weight reduction which is the major factor in achieving a light weight structure to increase the life and the performance of the component without compromising the quality and the durability of the structures, so the industries are always open to new light weight material which can fulfil all the purposes and which can all might be affordable to make the material more dependable in all aspects. The important aspect is manufacturing process must be simple and accessible. 3D printing or Additive manufacturing is a very well known manufacturing process which helps the manufacturer to produce components that can be easily customized. Even light weight automotive parts can also be manufactured using this technique .So the material must be less in weight and also capable to bear all the stress produced when it undergoes a process. And our project is about to bring up a new composite material which can meet all the aspects of the industrial requirement. Poly Lactic Acid and Acrylonitrile Nitrile Butadiene are most commonly used industrial thermo plastics suitable for 3D printing. Our Aim in this project is to study the characteristics, Physical properties, Mechanical Behaviour and the free vibration of the newly created specimen of carbon fibre with Poly Lactic Acid (PLA) and also with Acrylonitrile Butadiene Styrene (ABS). Once when we are done with the individual findings of the properties of the newly made composite material of carbon fibre with PLA and ABS, we will be able to compare the Laboratory results of the individual findings of both the specimen so that we could infer the most reliable composite material from the findings.

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CHAPTER 1
INTRODUCTION

Carbon fibre is a long thin strand and it is obtained by pyrolysis of an appropriate precursor fibre. The crystal alignment makes the fibre extremely strong for its size. Several thousands of Carbon fibres are used to be formed as a yarn it can be used as it is or woven into fabric. The yarn or fabric is mixed with epoxy to form composite material of any shapes.

1.1 CLASSIFICATION OF CARBON FIBRE

Carbon fibres are classified with respect to the tensile modulus of the fibre. The tensile modulus determines the ability of the fibre to withstand the pulling force without breakage. With respect to the tensile modulus they are classified as

a. Low modulus
b. Standard modulus
c. Intermediate modulus
d. High modulus
e. Ultra high modulus

The strength of ultra-high modulus carbon fibre is five times stronger than steel.

1.2 PREPARATION OF CARBON FIBRE

1.2.1 RAW MATERIAL

Precursor is the raw material used for making carbon fibre. Poly acrylonitrile is used to produces 90% of the carbon fibre rest of the 10% are produced from rayon or petroleum pitch. All of these are organic polymers, characterized by long strings bounded by carbon atoms. The composition of precursor varies from on company to other and considered to be a trade secret. During the manufacturing process of the carbon different types of gases and liquids are used. Some of them are used to react with the fibre to achieve some special effect on it and some of these materials are used to prevent the reaction with the fiber.

1.2.2 MANUFACTURING PROCESS

The manufacturing process of carbon fibre is the combination of both chemical and mechanical part. The precursor is drawn into strands or fibre and heated at very high temperature without allowing the fibre to contact with oxygen. Without oxygen, fibre cannot burn instead the atoms in the fibre vibrates violently until most of the non-carbon atoms are expelled. This process is called carbonization and leaves Fiber strands of interlocked chain of carbon atoms and a few non-carbon atoms remaining.

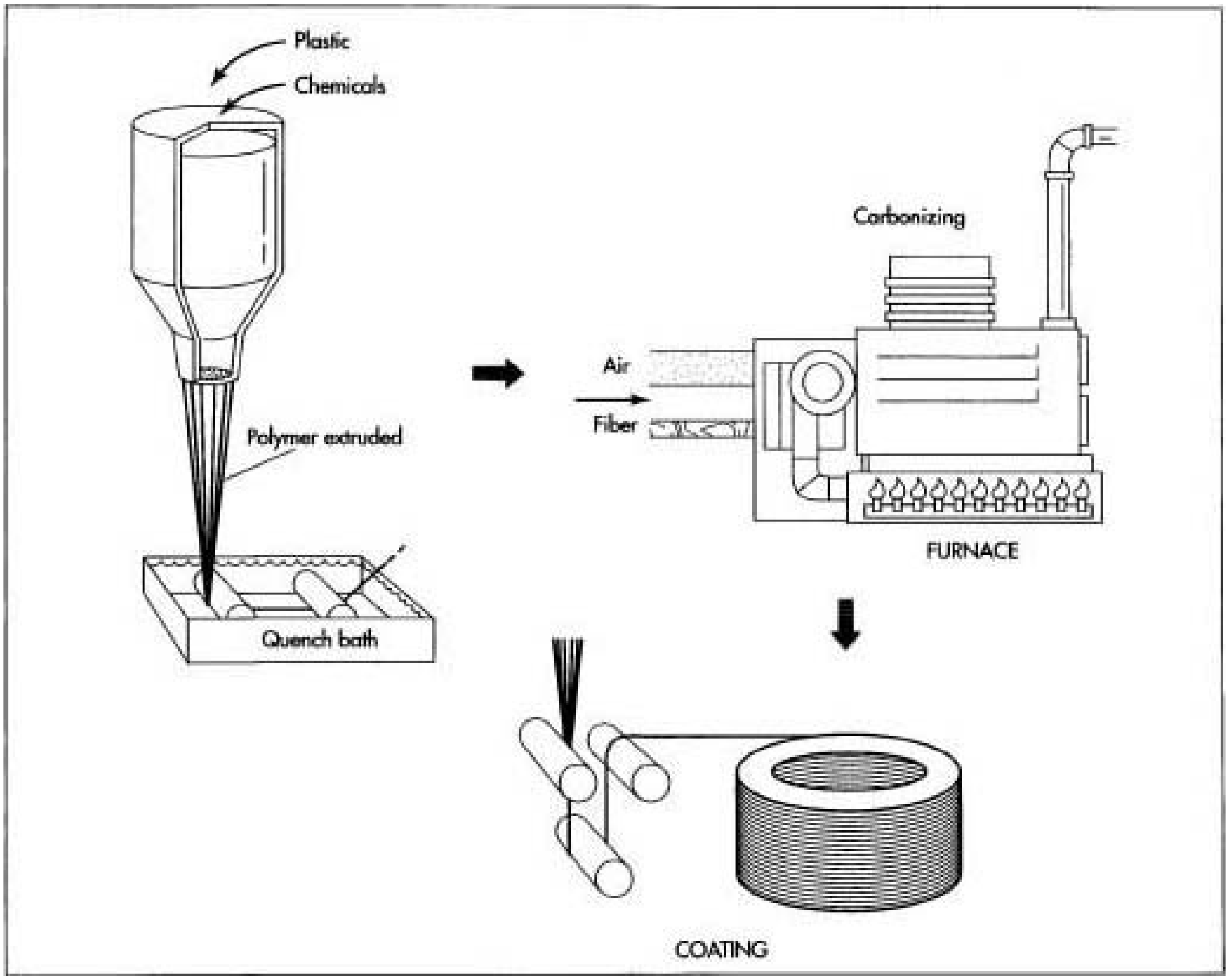

Fig No:1.1 Plastics are drown into long strands of fibres

The steps involved in the process of making carbon fibre are

- Spinning
- Stabilizing
- Carbonizing
- Treating the surface
- Sizing

1.2.2.1 SPINNING

Acrylo nitrile plastic powder is mixed with another plastic, like methyl acrylate or methyl methacrylate, and is reacted with a catalyst in a conventional suspension or solution polymerization process to form a poly acrylonitrile plastic.

The plastic is then spun into fibers using one of several different methods. In some methods, the plastic is mixed with certain chemicals and pumped through tiny jets into a chemical bath or quench chamber where the plastic coagulates and solidifies into fibers. This is similar to the process used to form polyacrylic textile fibers. In other methods, the plastic mixture is heated and pumped through tiny jets into a chamber where the solvents evaporate, leaving a solid fiber. The spinning step is important because the internal atomic structure of the fiber is formed during this process.

The fibers are then washed and stretched to the desired fiber diameter. The stretching helps align the molecules within the fiber and provide the basis for the formation of the tightly bonded carbon crystals after carbonization.

1.2.2.2 STABILIZING

Before the fibers are carbonized, they need to be chemically altered to convert their linear atomic bonding to a more thermally stable ladder bonding. This is accomplished by heating the fibers in air to about 390-590° F (200-300° C) for 30-120 minutes. This causes the fibers to pick up oxygen molecules from the air and rearrange their atomic bonding pattern. The stabilizing chemical reactions are complex and involve several steps, some of which occur simultaneously. They also generate their own heat, which must be controlled to avoid overheating the fibers. Commercially, the stabilization process uses a variety of equipment and techniques. In some processes, the fibers are drawn through a series of heated chambers. In others, the fibers pass over hot rollers and through beds of loose materials held in suspension by a flow of hot air. Some processes use heated air mixed with certain gases that chemically accelerate the stabilization

1.2.2.3 CARBONIZING

Once the fibers are stabilized, they are heated to a temperature of about 1,830-5,500° F (1,000-3,000° C) for several minutes in a furnace filled with a gas mixture that does not contain oxygen. The lack of oxygen prevents the fibers from burning in the very high temperatures. The gas pressure inside the furnace is kept higher than the outside air pressure and the points where the fibers enter and exit the furnace are sealed to keep oxygen from entering. As the fibers are heated, they begin to lose their non-carbon atoms, plus a few carbon atoms, in the form of various gases including water vapor, ammonia, carbon monoxide, carbon dioxide, hydrogen, nitrogen, and others. As the non-carbon atoms are expelled, the remaining carbon atoms form tightly bonded carbon crystals that are aligned more or less parallel to the long axis of the fiber. In some processes, two furnaces operating at two different temperatures are used to better control the rate de heating during carbonization.

1.2.2.4 TREATING OF SURFACE

After carbonizing, the fibers have a surface that does not bond well with the epoxies and other materials used in composite materials. To give the fibers better bonding properties, their surface is slightly oxidized. The addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties. Oxidation can be achieved by immersing the fibers in various gases such as air, carbon dioxide, or ozone; or in various liquids such as sodium hypochlorite or nitric acid. The fibers can also be coated electrolytically by making the fibers the positive terminal in a bath filled with various electrically conductive materials. The surface treatment process must be carefully controlled to avoid forming tiny surface defects, such as pits, which could cause fiber failure.

1.2.2.5 SIZING

After the surface treatment, the fibers are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are chosen to be compatible with the adhesive used to form composite materials. Typical coating materials include epoxy, polyester, nylon, urethane, and others.

The coated fibers are wound onto cylinders called bobbins. The bobbins are loaded into a spinning machine and the fibers are twisted into yarns of various sizes.

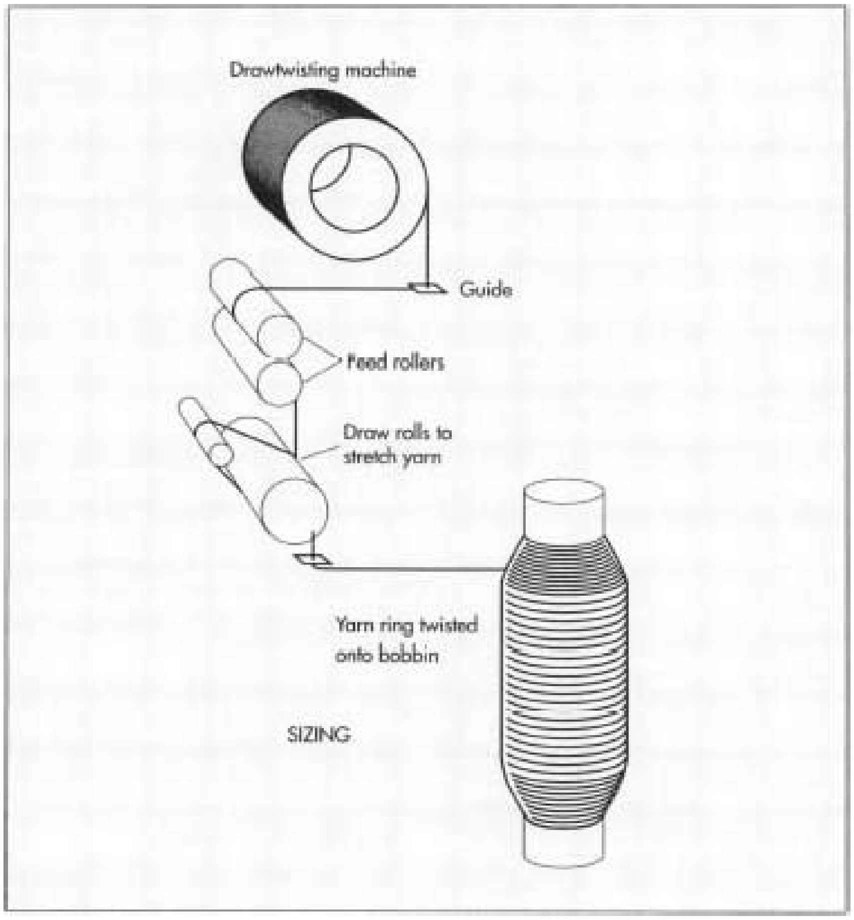

Figure No: 1.2 The fibers are coated to protect them from damage during winding or weaving. The coated fibers are wound onto cylinders called bobbins.

1.3 CARBON FIBRE APPLICATIONS

- Carbon fibres are thin filaments, they are one-tenth the thickness of a human hair,Available in a wide range of useful forms. These fibres are bundled, woven and shaped into tubes and sheets (up to ½-inch thick) for construction purposes, supplied in the form of cloth for moulding, or justconventional thread for filament winding. The automotive industries is ever growing in usage of the carbon fibre-reinforced polymer as a new materials and new manufacturing processes become available.

- The use of composite material to the various parts in aircraft manufacturing started from the year 1970s. In current situation the usage of composite materials in aircraft have reduced the weight of >10% of the total weight. Due to this applications the use of carbon fibre based composite materials will be increased in the near future for the structural body parts of car and commercial transportation. This is enabled by the European legislation centered on CO2 emission and fuel efficiency, By doing this the weight of the vehicle is reduced and the manufacturer can able to produce the vehicle with the preference of the customer and the vehicle is more ecological.
- Not only in automotive purposes they also used in production of tennis rackets, golf-club shafts in order to achieve the weight reduction and to increase the durability and rigidity of the product.
- The presence of radiolucent features in CFRP are used in medical field for X-ray devices and light weight devices in medical field like limb prostheses and wheel chair. The studies of carbon fibre is also done in energy fields for the development of fuel cells and oil drilling, as well as in electronic devices like personal computer and liquid-crystal projectors.
- Carbon fibre also find its place to be used as biomaterials since 1970s. The carbon fibre is used as biomaterials because of its light weight, High strength and flexibility. They has an ability to combine with conventional biomaterials and have various fibre morphologies and high radiolucency

1.4 COMPOSITE MATRIX

The matrix is basically a homogenous and monolithic material in which a fiber system of a composite is embedded. They are generally used in a fibre system provide a medium for binding and holding reinforcement together into solid.

Most commonly used resins for Carbon Fibre are Acrylonitrile Butadiene Styrene, Polyester resin, Vinyl Ester and bio materials like Poly lactic acid . The suitable resin for additive manufacturing of Carbon composites are ABS, PLA and Nylon.

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1.5 Poly Lactic Acid (PLA)

Poly-lactic acid (PLA) is produced from the monomer of lactic acid. PLA can be able to produced by two well known methods

a) Direct poly condensation (DP)
b) Ring opening polymerization (ROP)

Even though DP is the simpler method for producing Poly-lactic acid, ROP method is preferred to produce a low molecular weight brittle form of PLA. The lactic acid for this process is obtained by fermentation of sugar. The lactic acid is then converted to lactide and eventually to PLA. It should be noted that there are two different terms “poly(lactic acid)” and “polylactide,” for the polymer of LA. Both terms are used interchangeably, however, Scientifically there is difference because polylactic acid is produced through the ROP routewhereas PLA is generated using the DP route. Generally speaking, the term “poly(lactic acid)” is widely used to mean the polymer that is produced from LA.

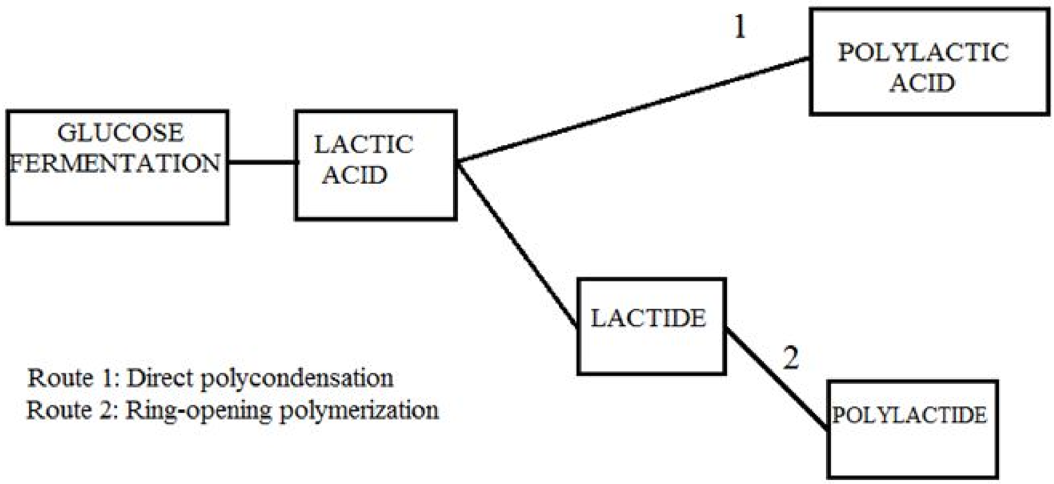

Fig: 1.3 General processes of poly lactic acid production

1.5.1 PRODUCTION OR SYNTHESIS OF PLA

The flow chart given below clearly explains the extraction of PLA from Raw materials. PLA is nothing but a refined form of starch obtained from pentose and hexode of agricultural biomass. Various natural cycles are involved in the synthesis of PLA like recycling of ammonia and recycling of alcohol.

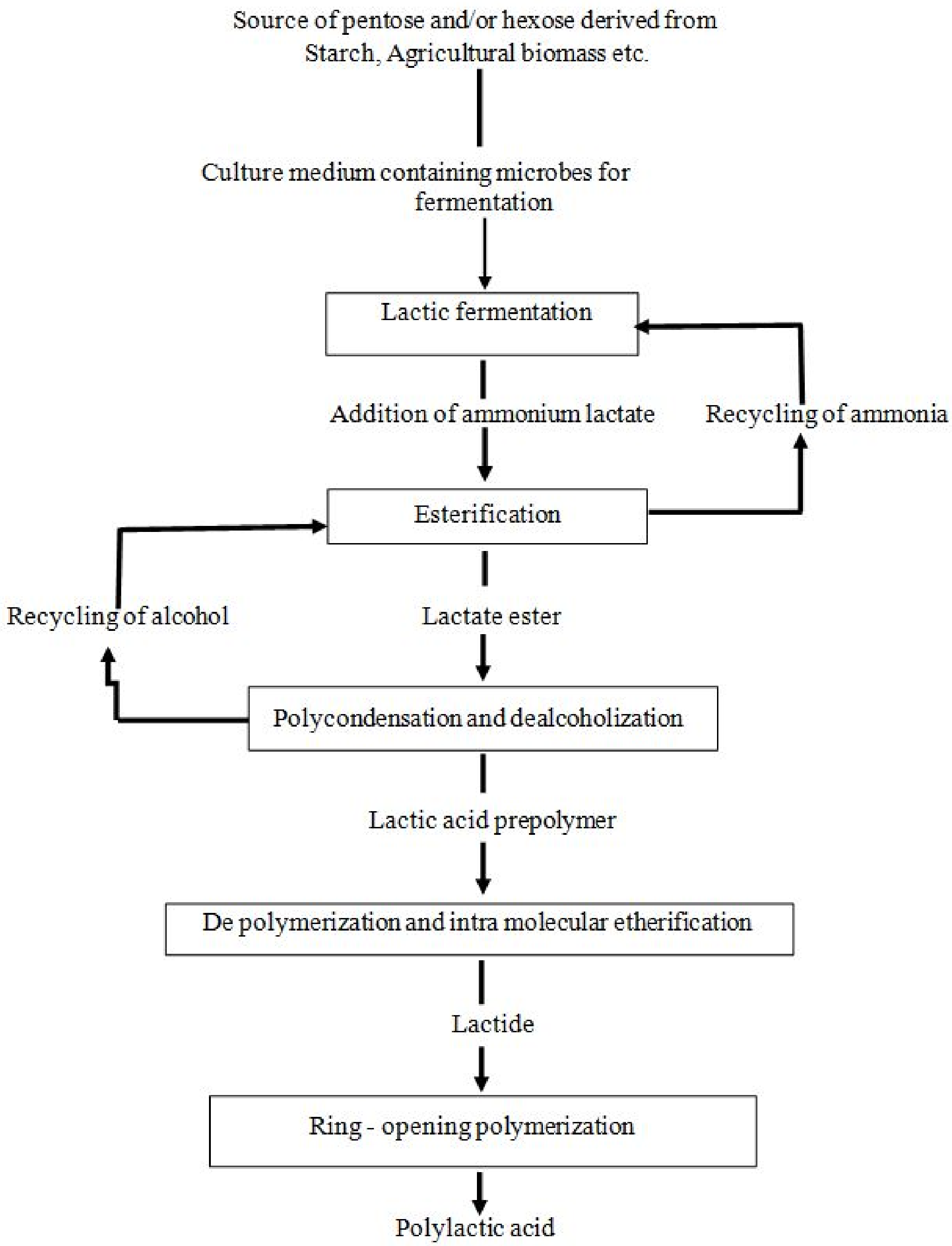

Figure 1.4 Steps to produce PLA from the initial fermentation process

Ohara et al, 2003 [24]

1.6 ACRYLONITRILE BUTADIENE STYRENE

ABS is the third member of a family of high impact composite materials based on a thermoplastic matrix and a particulate rubber phase, being preceded by high impact polystyrene (HIPS) and PVC/nitrile rubber blends.

The best of these materials have an excellent balance of properties, due in part to their two phase nature, and may be considered as engineering plastics. The most significant advantage gained by the incorporation of the rubber is the transformation of a brittle organic gloss into a ductile thermoplastic with high impact strength.

Since the first of these materials in 1949, polystyrene containing emulsion styrene-butadiene rubber (SBR), a large number of combinations of rubbers with thermoplastics have been examined, many of which are commercially successful.

In spite of alternative approaches, ABS is now established as the most important and versatile of these materials although not used in as great a volume as HIPS. This article reviews the processes, structures, range of properties, processing applications and techniques, and major outlets for ABS. Emphasis is placed on composite materials where the matrix consists ofa copolymer of styrene and acrylonitrile with optionally a third monomer, and the rubber phase is a polymer or copolymer containing butadiene.

Three main processes are employed for the manufacture of rubber reinforced thermoplastics in order of increasing importance for ABS these are mechanical blending, bulk copolymerization, and emulsion grafting.

1.7 3D PRINTING OR ADDITIVE MANUFACTURING

The three dimensional printing has been invented to meet the demand for rapid prototyping instead of the old fabrication methods. There are two methods for printing polymer

a. Stereo lithography apparatus

b. Fused deposition modeling

While SLA technologies are suitable for photosensitive resin materials to fabricate highly accurate prototypes requiring high cost facilities. Meanwhile, FDM is the most common 3D printing technique in market. The main reason for using FDM as most common technique due to its low cost of the printing device and suitable for wide range of thermoplastic materials. Thermoplastic polymers such as PLA, acrylonitrile-butadiene-styrene, nylon, polycaprolactone, high-density polyethylene (HDPE), and polypropylene can be printed using the FDM method. The advantage of the FDM printing method is that it does not require fabrication of expensive moldsto produce complex design plastic products, merely requiring programming skills to model the shape and subsequently input it to a suitable interface so that the design can be printed out in a 3D printer. Generally, 3D printing of PLA is of the filament type with a variety of colours available in the market. The PLA filament type can be printed successfully on a wide range of printers, for example, Makerbot Replicator, Ultimakers and Formlabs, Flashforge, Shinning, and Robo (Noorani et al, 2018)[25]. The price of 3D printers suitable for PLA application can be very affordable with the low price. The filament usually used in the diameter of range 3 or 1.75mm, It is important to consider the diameter should be consistent because if the diameter of the filament is larger than the extruder it will tends to jam the printer and stop extruding. In contrast to that if the diameter of the filament is too small, the printer quality such as binding effect of the polymer layer can be weaker and resulting in a poor quality product. Although PLA is considered to be a strong mechanical polymeric material, the strength of the PLA printed object is also highly dependent on the direction of printing, thus the design should also consider the following aspects

1. The direction of force application and avoid being perpendicular to the

printing layer

2. Additional support structure according to the build orientations
3. Outer shell thickness, printing pattern and density, interconnect parts when designing a complex model which can lead to premature brittleness.

In addition, when the extruded molten PLA lands on the platform/bed, the platform/bed needs to hold the printed materials firmly so that the printing process is done smoothly to avoid the printed spot from being pulled out, disturbed, or distorted. In order to hold it firmly, it is recommended the platform for printing of PLA be secured with so called Blue painter's tape (e.g., 3M Scotch Blue Tape) (Horvath et al, 2014)[26].The PLA printed material will stick to the surface with the Blue painter's tape which can be removed easily without damaging the model upon finishing printing. In addition, Blue painter's tape is also used to avoid warpage, especially for semi crystalline PLA which can undergo significant uneven shrinkage when layers and layers of molten PLA are laid continuously. In addition to using Blue painter's tape, the platform can also be heated to have a sticking effect when printing PLA. This is because most of molten polymers are sticky in nature. However, the temperature of the platform is crucial in order to avoid a softening effect or even worse, causing degradation The typical recommendations for the platform temperature of PLA and other materials are listed in table It is also worth noting that PLA filaments need to be properly stored to avoid exposure to moisture and elevated temperature. The reason for this is that the PLA filament can undergo degradation/de polymerization/ chain scissoring when subjected to moisture or heat. The most convenient way to avoid this problem is to keep the PLA filament in a securely sealed condition and stored in a dry cabinet below 10% relative humidity. It is recommended to unseal the PLA filament just before the commencing printing.

Table: 1.5Three dimensional printing parameters for PLA and other polymers

Material	Platform Temperature (°C)	Print Temperature (°C)
PLA	60	210
ABS	100–110	240
Nylon 618	115	240
High-impact polystyrene	90–100	240
Polyethylene terephthalate	80	210–250
Polycarbonate	90–100	270

1.7.1 ADDITIVE MANUFACTURING

Additive manufacturing or 3D printing is the construction of three dimensional model from a CAD model or a digital 3D model. The term 3D printing can refer to a variety of process in which the materials are printed layer by layer and solidified to form a three dimensional object with the help of computer control.

1.7.1.1Steps involved in creating a 3D model.

1. Building up a CAD model of the design
2. Convert the CAD model into stereolithography (STL) file format
3. Divide/slice the STL file into 2D cross -sectional layers
4. Selection of the polymers and parameters
5. Printing the prototype by the molten/extrude polymer in layers
6. and the prototype is ready

Step 1: Building up a CAD model of the design

This involve creating the CAD solid model using software packages, that is

AutoCAD, Pro/Engineer, or Solidworks

Step 2: Convert the CAD model into stereolithography (STL) file format

There are various CAD softwares in the market that can be used to design the model,however all these designs need to be converted into STL format due to STL being selected as the standard in the rapid prototyping industry. STL enables the model to be represented in a triangular planar structure in order to further undergo the ‘slicing’ step

Step 3: Divide/slice the STL file into 2D cross -sectional layers.

The STL file will further undergo a slicing process so that the model will divide into layers. Usually this process involves the preprocessing software as provided by the3D printer manufacturer. The slicing process is to enable adjustment of the layer thickness according to the accuracy demands. For instance, low thickness is expected when producing high-accuracy objects, yet the printing time is longer. Often good preprocessing can also generate the necessary support structure for models involving overhands, internal cavities, and thin-walled sections.

Step 4: Selection of the polymers and parameters

The selection of polymers needs to meet the requirements of the prototype to be produced. Usually, PLA, acrylonitrile-butadiene-styrene copolymer (ABS), nylon, polycarbonate, and poly methyl methacrylate are selected. Each of the polymeric materials has unique characteristics, like melting points and viscosity, which can be varied from one grade to another .

Step 5: Printing the prototype by the molten/extrude polymer in layers

After the SLT file is processed and sliced, it is sent to the printer for execution. The machine will print the object layer by layer until finished.

Step 6: Clean and the prototype is ready .

After completing the printing process, the prototype is removed and proper cleaning is needed to ensure the longevity of the machine. Some parts need to be lubricated and the printer nozzle head needs to be cleaned to avoid blockages resulting from the leftover polymer after printing .

1.7.1.2 TYPES OF 3D PRINTERS

1 .Fused deposition modelling (FDM)

2. Stereo lithography (SLA)

3. Digital Light Processing (DLP)

4. Selective Laser Sintering (SLS)

5. Selective laser melting (SLM)

6. Laminated object manufacturing (LOM)

6. Digital Beam Melting (EBM)

In our project Fused deposition modelling is used due to its low cost manufacturing of the composite and good surface finishing.

1.8 FUSED DEPOSITION MODELLING (FDM)

Fused Deposition Modelling (FDM) is commercialized by Stratasys in Eden Prairie, Minnesota and is one of the most popularly known techniques in additive manufacturing exclusively used for modelling, prototyping and production purposes. In this process, a plastic or wax matter is ejected through a mini nozzle that follows the cross-sectional area of the object (layer by layer). These plastics are extruded as a semi-molten filament. The 3D CAD data is processed and the filament is deposited in layers eventually resulting in construction of the desired object. FDM makes use of two kind of materials to print such as modelling material which is used to construct the prototype and the support material acts as a platform. Material filaments are moved in the X and Y coordinates, resulting in deposition of material before the base moves down in the Z-direction and the corresponding layer begins. All movements are directed by software that provides a track for the nozzle to follow. The consumer breaks the support material away or dissolves it in detergent and water, and the element is ready to use. The materials that are prominently made used in this process are polyamide, polycarbonate, polyethylene, ABS, polypropylene and investment casting wax. This technique is a clean, effective and user-friendly 3D printing process.

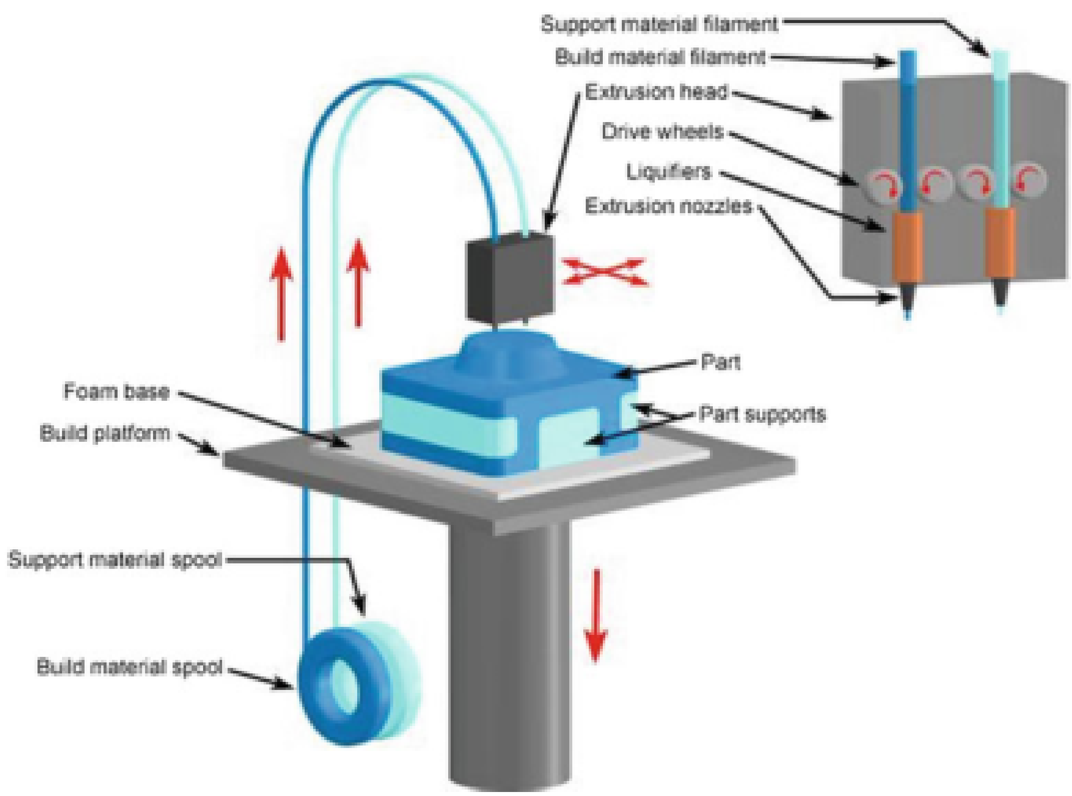

Figure 1.5 Schematic diagram of FDM

1.9 CHAPTER SUMMARY

This chapter deals with the Manufacturing of Carbon fibres with PLA/ABS in the wire based filament suitable for 3D printing and their applications. It is explained in a sequential procedure. The main focus of this study is the process of 3d printing. The Fused Deposition Modelling is the method in which the specimens are printed for this study. These aspects are taken in considerations tomanufacture the specimens for this study.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

The literature review is performed in almost related to this study such as 3D printing , Poly lactic acid, Acrylonitrile Butadiene Styrene, free vibration analysis, Carbon based PLA and Carbon based ABS. The main objective of the literature review is to derive a conclusion from where the properties or the strength previously been recorded. It also paves way to improve the properties of present findings.

2.2 3D PRINTING

DivyaZindani, Kaushik kumar et al, 2019 [1], observed the manufacturing of Fibre reinforced polymers using additive manufacturing techniques gained special attraction among industries. It is deliberately found that usage of proper additive manufacturing techniques enhances the mechanical properties as well as the interlayer bonding of the fibre reinforced materials. Also each additive manufacturing techniques has its unique advantages as well as disadvantages too.

AbomaWagari Gebisiaf et al, 2018 [2] investigated the tensile behaviour of 3d printed specimen under FDM process. This investigation focussed mainly over the parameters like air gap, raster width, raster angle, contour width and contour angle. Among the five parameters raster angle is the one which is much influenced in enhancement of tensile property of ULTEM 9085. The raster angle considered are +45/-45. Therefore FDM process and printing orientation enhances the tensile property of specimen.

S. Valvez,P. Santos et al, 2019 [3] manufactured specimens using FDM process and found that the limitations in printing carbon based composites in a 3d printing in terms of machine specifications. Inspiteof all odds the specimens were printed and found that there is considerable increase in the property compared to hand lay method. They concluded that further study is required to develop to make FDM applicable to industrial use.

S.Garzon-Hernandez et al**,** 2019 [4] Additive manufacturing technologies provide new opportunities for the manufacturing of components with customisable geometries and mechanical properties. In particular, fused deposition modelling (FDM) allows for customisable mechanical properties by controlling the void density and filament orientation. Finally, a parametric study was conducted to illustrate the potential of the proposed model for the optimisation of FDM components. This study points to the layer height and environment temperature as the most relevance manufacturing parameters.

J. Lluch-Cerezo, R.Benavente et al**,2019 [5]** Parts manufactured by Fused Deposition Modelling (FDM) present anisotropic properties, which have influence in tensile test results. In this paper, test samples of Polylactide are manufactured by FDM according to geometries defined in ISO 527 and ASTM

D638. PLA without colour has allowed to visualize concentration stress zones.Mechanical properties of PLA samples are consistent with those reported in the literature. FDM manufacturing process of PLA, compared with another processes as injection moulding plastic, fragile parts, increasing stress concentration effects generated during manufacturing.

V. Durga Prasad Rao et al [6] observed that PLA+ composites or ABS + Composites are most commonly used Thermoplastics for FDM process. They are use to manufacture parts on account of good mechanical properties. It is found through experimental results that Intermolecular bonding between the layers are higher when printed in FDM process. Significant increase in Tensilepropert of Carbon Fibre PLA is observed. Finally they concluded that Carbon fibre PLA is a good thermoplastic of FDM process.

2.3 PLA (POLY LACTIC ACID)

K. Jim Jem,Bowen Tan, et al 2020 [7] The environmental issues of global warming and plastic pollution have contributed to an increase in demand for alternative materials, Bio-based plastics are being developed to replace traditional petroleum-based plastics to reduce carbon emissions (because the bio-based raw materials absorbed CO_2 from atmosphere).In the last two decades, PLA has attracted tremendous attention and interests. The major reasons are probably the concerns on resource sustainability, global warming and environment pollution caused by plastic wastes.Compared to most other bio-degradable and bio-based plastics,PLA is far the most important and promising one for rigid applications.

K. jimJemet al 2020 [8] observed that PLA has gained tremendous response in the field of Bio based plastic materials due to its sustainability. He also stated that among bio degradable and bio based plastics PLA is the promising substance for Rigidapplications. He concluded that if PLA matrix is made to reinforce with proper fibre it will be one of the renowned industrial plastic on the basis of sustainability and tailorability .He also stated that PLA with PG will be the future of plastic industry.

2.4 ABS (ACRYLONITRILE BUTADIENE STYRENE)

Chevrychkina A.A et al 2017[9] studies have been carried out to determine the mechanical properties of additive material made of acrylonitrilebutadiene styrene (ABS) plastic under quasi static and dynamic loads. These days, there is a growing attention for 3D-printing (or Additive Manufacturing) techniques. While these techniques are already applied for years in the mechanical industry. The conducted experimental studies on the measurement of the tensile strength of an additive material made of ABS plastic on a 3D printer in quasi-static and dynamic modes showed that the static strength and the Young's modulus of the printed samples correspond to the values of the raw material. The experiments data showed the possibility of testing small samples to achieve higher strain rates

A.S. de Leon,A. Domínguez-Calvoet al 2019[10] found that many printable materials the ABS and TPU are chosen for this study. The materials are printed into various shapes and tested under various conditions. They concluded that pure ABS has a great intermolecular bonding in terms of printing which means the adhesive property between the layers are enhanced very well. It is used as industrial plastic for tough applications.

2.5 MECHANICAL BEHAVIOUR

M. Somireddy,C.V. Singh et al 2019[11] manufactured the specimens which are 3d printed using Reinforced short Carbon fibers laminates. The two types of specimens where manufactured one with very low layer thickness other with comparatively higher layer thickness .They concluded that in tensile and flexural test the low layer height exhibit better mechanical performance and choice of proper layer height is necessary before 3D printing the specimens.

ZhaobingLiu, Quan lei et al,2019 [12] facilitate the engineering applications of these FDM-printed components, understanding their basic mechanical behaviours is necessary. In this paper, the mechanical properties of PLA and its composites have been evaluated taking the effects of important printing variables, i.e. build orientation and raster angle into consideration. Moreover, PLA composite samples that are FDM-printed in on-edge orientation with +45°/−45° raster angles have the highest mechanical strength in most cases. While, all the samples printed along upright orientation have the weakest mechanical strength and modulus due to weak interlayer bonding. They concluded that the angle of boding between the layer is directly proportional to the Mechanical behaviour.

Tetsuya Yamamoto, KatsumasaUematsu et al [13] found that Mechanical behaviour of Carbon Fibre reinforced with epoxy resins are much more appreciable in 3 point bending flexural test. The main cause of this effect is the interaction between the carbon fiber and matrix where each resin was improved by the adsorbed polymer particles, thereby strengthening the surface adhesion between them Fibre and matrix.

2.5 VIBRATION TESTING

C. Senthamaraikannan, R.Ramesh et al [14] found that the carbon epoxy beam gain more attention in the field of structural engineering mainly Aerospace industries. In this study the impulse response test was conducted where ther box beam performed well with minimum amplitude compared to other beams involved in this study. The box shaped beam has a effective damping behaviour under cantilever condition compared to other cross sectional beam.

Meng-Kao Yeh et al 2014 [15] observed the vibration characteristics including mode shapes and natural frequency of carbon multi-walled nano tube composite material. The Doppler vibration method was used to measure the Resonant frequencies. The young's modulus of the composite material is directly proportional to the resonant frequencies. The slight increase of resonant frequency is observed when the Carbon multi-walled nanotubes is added.

Zeng.Tet al 2019 [16]Acontinuous homogeneous theory is employed to formulate a governing equation for predicting the free vibration of the graded corrugated lattice core sandwich beam. The Rayleigh-Ritz method is adopted to solve the governing equation for various types of boundary conditions**..**The natural frequencies are obtained and the theoretical predictions are validated by the numerical simulations and experimental results. From the experiment relationships between the natural frequencies of the graded corrugated lattice core sandwich beam and geometric parameters, including the graded parameter, face sheet thickness, core height and length of beam, were studied. The results show that the natural frequency of the graded sandwich beam can be adjusted by changing the graded parameter while keeping the quality of the structure unchanged. Increasing the thickness of the facesheet and height of core will increase the natural frequencies of the graded corrugated lattice core sandwich beam.

Sahu .S.K et al 2019 [17] found that Composite beams are increasingly used in aerospace, automobile, and other applications. Crack is the most common defect in structures during its service life. The cracked composite beams are subjected to dynamic loads and the vibration of the cracked beams is of technical significance to the structural integrity of systems. The effects of natural frequencies with respect to the various boundary conditions, crack depth and locations are investigated to support in real applications. The results show that natural frequencies are decreased with cracks when they are located closer to the fixed end of the beams, the maximum reduction in fundamental frequency occurs than cracks are located near the middle and free end. And an the natural frequency increase in fibre orientation.

Wang, Y.-F et al [18] Exponential damping is an improved version of the viscous damping model and better represent energy dissipation character of actual structures. This study aims at verifying the applicability of the exponential damping model for concrete structures and the accuracy of model parameter identification methods. Here the dynamic tests are conducted on a series of reinforced concrete cantilever beams to obtain frequency response functions. The obtained results show that the exponential damping model can better reflect the energy dissipation capacity of concrete components, especially in the high frequency vibration modal. The recently proposed identification method based on FEM updating for the exponential damping system can predict accurately not only natural frequencies but also the FRFs of concrete beams. The research of the exponential damping will increase the accuracy and efficiency of dynamic behaviour analysis of actual concrete structures.

2.6 CARBON ABS

Lopes, B. J., & d' Almeida, J. R. M et al 2019 [19] investigated the Carbon fiber reinforced ABS (Acrylonitrile Butadiene Styrene) was produced via extrusion with varying fiber content and length. In this initial study, the challenges of processing this material were investigated along with the determination of rheological and thermal properties of the final composite. Degradation of the polymeric matrix was detected at temperatures as low as 220°C during processing, below manufacturer's recommended temperatures. Results showed correlation between the presence of process additives and carbon fiber content with composite properties, mainly in thermal stability and actual fiber content whereas rheological properties seemed largely unaffected. All mixtures were also submitted to mechanical testing and SEM (Scanning Electron Microscopy). Mechanical testing showed increases in tensile strength and modulus. Surface analysis showed poor interface between fibers and matrix as well as a random distribution of the reinforcement phase along the composite.

Dawoud, M., Taha, I., &Ebeid, S. J. et al (2018) [20], Carbon Black filled Acrylonitrile Butadiene Styrene (ABS) was used to prepare a polymer composite by Fused Deposition Modelling (FDM) technology. The effect of printing setup on the strain sensing behaviour of the composite was investigated, targeting the fabrication of a functionalized composite that is able to detect stress or strain changes in engineering members. Experimental work revealed that internal stresses can be detected based on monitoring the change in resistance as a response to strain.The printing setup was systematically varied in terms of raster angle and gap width. to yield the most sensitive constellation for conductivity The use of a negative gap between the individual rasters in combination with a raster angle of +/−45° was observed to have a positive influence on intensifying the detected signals, making this constellation most sensible for strain sensing applications.This study proved the potential for monitoring the stress in 3D printed carbon black ABS as a response to strain

2.7 CARBON PLA

K.K.Guduru, G.Srinivasuet al [21] found that Carbon infused Poly lactic Acid offers good tensile strength used in Automobile industries especially. In this research, 15% of carbon infused in PLA and prepared as a filament of 1.75 mm diameter. The tensile strength results of Carbon infused PLA is comparatively higher than normal PLA plastics as the tensile strength of normal PLA is around 45-50 Mpa whereas Carbon infused PLA exhibits 75-80 mpa. A significant improvement is observed in stated properties.

Ajay Kumar, M., Khan, M. S., & Mishra, S. B et al [22] found that Carbon fibre reinforced poly lactic acid (PLA), a thermoplastic polymer is widely used for the various structural applications like manufacturing of frames and tool due to its excellent formability, durability and strength. The carbon fibre reinforced PLA specimens are 3D printed in FDM machine by selecting the process parameters.. The factors chosen for 3D printing of the specimen are infill density, print speed and layer height. The optimum tensile strength is obtained as 21.961 MPa when the process parameters infill density 80%, print speed 80 mm/sec and layer height 100m with the maximum desirability function of 0.77.The Taguchi L9 experimental design technique is employed to plan and execute the experiments on fabrication of carbon fibre reinforced PLA samples using FDM process as per ASTM standards.

Heidari-Rarani, M., Rafiee-Afarani, M., &Zahedi, A. et al [23] stated that AM of fibre reinforced composites is of great interest in various industrial applications. In this study, an innovative extruder is designed and manufactured for fused deposition modelling (FDM) 3D printers in order to produce continuous fibre reinforced thermoplastic (CFRT) composites. The main advantage of this extruder is that it can be mounted on the available FDM 3D printers and consequently there is no need to design a new chassis. In order to assess the quality of products, standard tensile and three-point bending specimens made of pure poly lactic acid (PLA) and carbon fibre reinforced PLA are printed and tested under quasi-static loading. Experimental results show significant improvements of tensile and bending properties of PLA. Morphological analysis is also conducted to study the bonding between the carbon fibre and PLA.

2.8 WORKFLOW METHADOLOGY

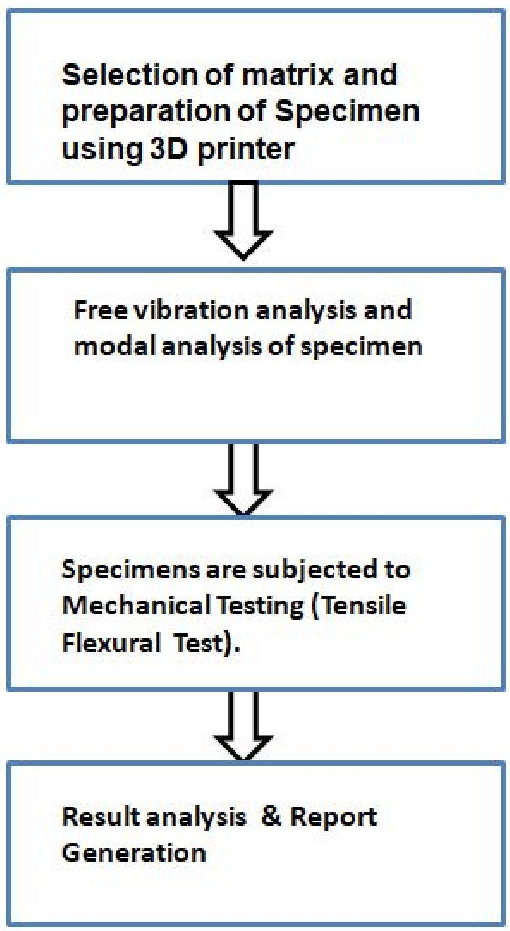

Figure 2.1 Workflow Chart

2.9 SUMMARY

This research includes an overview of the available literatures and existing findings related to this study. In this chapter the aspects like mechanical behaviour vibration analysis as well as the materials use in this study are reviewed elaborately. The proportions and properties analyzed are given in this chapter. These reviews were useful in selecting materials and methods.

CHAPTER 3
MATERIALS AND METHODS

3.1 MATERIALS

The Primary material chosen for this study is Carbon Fibre along with two different Matrices namely Poly Lactic Acid (PLA) and Acrylonitrile Butadiene Styrene. The material used is a combination of matrices and finely chopped Carbon Fibre. It well known as Carbon PLA and Carbon ABS.

3.1.1 CARBON FIBRE

Carbon fibre is selected as the primary fibre for this study as Carbon fibres are micro scale fibres which exhibit remarkable Mechanical, Thermal and Electrical properties. CF'S constitutes a wide range of commercial applications including those in Aerospace, Automobile and Marine industries. The major part in selecting Carbon fibre in this study is it enhances the physical properties of polymer composites. The addition of Carbon fibres in micro level along with polymer composites develops a great interfacial bonding as well as resulting in the increase of varied strength and stiffness properties. Further processing such as additional heat and chemical treatment can result in further fibre structure and surface tailorability, which can lead to improved polymer composite performance when incorporated.

3.1.2 POLY-LACTIC ACID (PLA) WITH CARBON FIBRE

The Carbon PLA are purchased from Robokits India pvt.ltd in the form of wire based filament . The wire based filament is the perfect requirement for Additive manufacturing processes. The basic specifications of the wire filament constitute the thickness in terms of diameter of 1.75 mm. On the other hand certain temperatures corresponding to the particular filament must be known to choose the perfect parameter for Additive manufacturing. The Print temperature of Carbon PLA ranges from 200^{o}– 230^{o}C. Another important temperature parameter to be known is the Print Bed temperature which is important in Carbon based Additive manufacturing but for Carbon PLA print bed temperature is not much necessary. The print Bed temperature ranges from 0^{o}-60^{o}C. In recent years Bio degradable polymers grab attention due to their wide range of applications. Poly lactic acid is the most considerable bio-Polymer. The applicable method to improve the strength of PLA is to combine it with various material in terms of applications. Among various combinations of PLA, Carbon PLA is chosen as the material for study as it has a enhanced Mechanical and Thermal property. The carbon fibre exhibits a great bonding with PLA.

3.1.3 ACRYLONITRILE BUTADIENE STYRENE (ABS) WITH CARBON FIBRE

The Carbon ABS is purchased from Robokits India Pvt.Ltd in the form of wire based filament. The wire based filament is the perfect requirement for Additive manufacturing processes. The basic specifications of the wire filament constitute the thickness in terms of diameter of 1.75 mm. On the other hand certain temperatures corresponding to the particular filament must be known to choose the perfect parameter for Additive manufacturing. The Print temperature of Carbon ABS ranges from 200^{o}– 230^{o}C as like of Carbon ABS. The Bed temperature is the most important for Carbon ABS as the printed material might get stuck over the bed due to adhesiveness. The specified Print bed temperature ranges from 100^{o} – 110^{o} C. The Carbon fibre generally exhibit a greater mechanical property when combined with different Matrix. ABS is a tough matrix has a great adhesive property towards polymers. Among various polymer composites Carbon ABS is one of the well known composite in terms of strength and varied stiffness. In order to achieve a great rigidity and stiffness in 3d printed materials Carbon ABS is utilized. The main purpose of using Carbon filaments is to achieve stiff and sturdy light weight structures.

3.2 MANUFACTURING METHODS

3.2.1 DESIGN OF THE SPECIMEN

The design part of the specimen is purely based on Computer Aided Design which enhances the job of designing much simple. The CAD model is created using Creo parametric 5.0. The dimensions of the manufactured specimens are purely based on American Society of Testing and Materials. This study requires two different types of specimens based on their dimensions. The table 3.1 represents the data of designed specimens.

Table 3.1: Details of the Specimen Designed.

MATERIAL	SPECIMEN-1		SPECIMEN-2	
	DIMENSIONS (mm)	NO.OF SPECIMENS	DIMENSIONS (mm)	NO.OF SPECIMENS
CARBON WITH PLA	250X25X4	3	125X12.5X4	6
CARBON WITH ABS	250X25X4	3	125X12.5X4	6

The CAD model of the specimens with specified dimensions (Table 3.1) is given below in fig 3.1(a) and fig 3.1 (b).

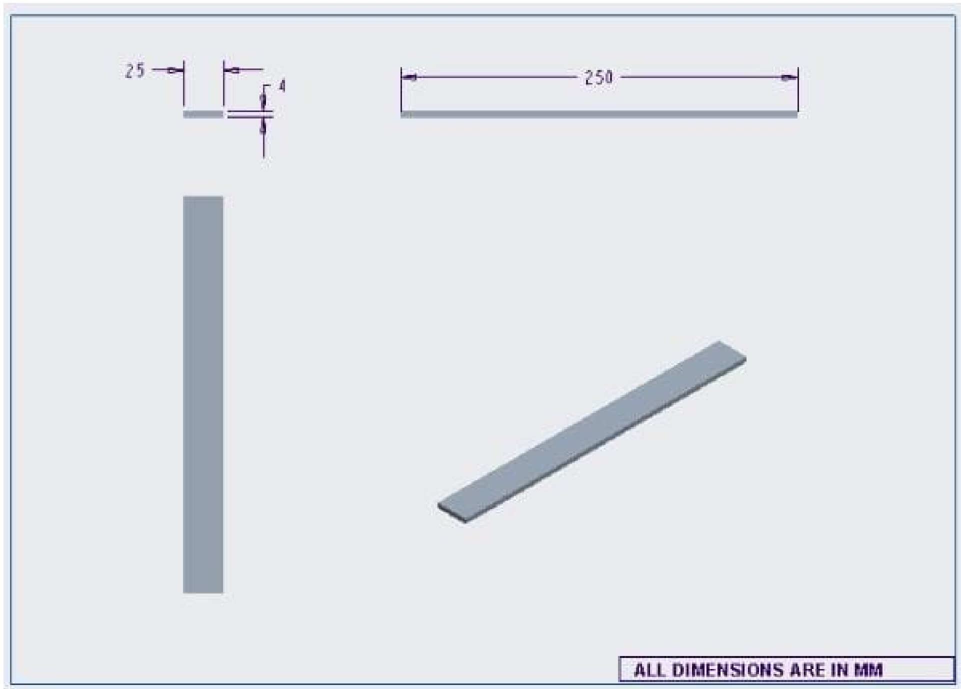

Figure 3.1 (a): Specimen-1 for both Carbon ABS and Carbon PLA

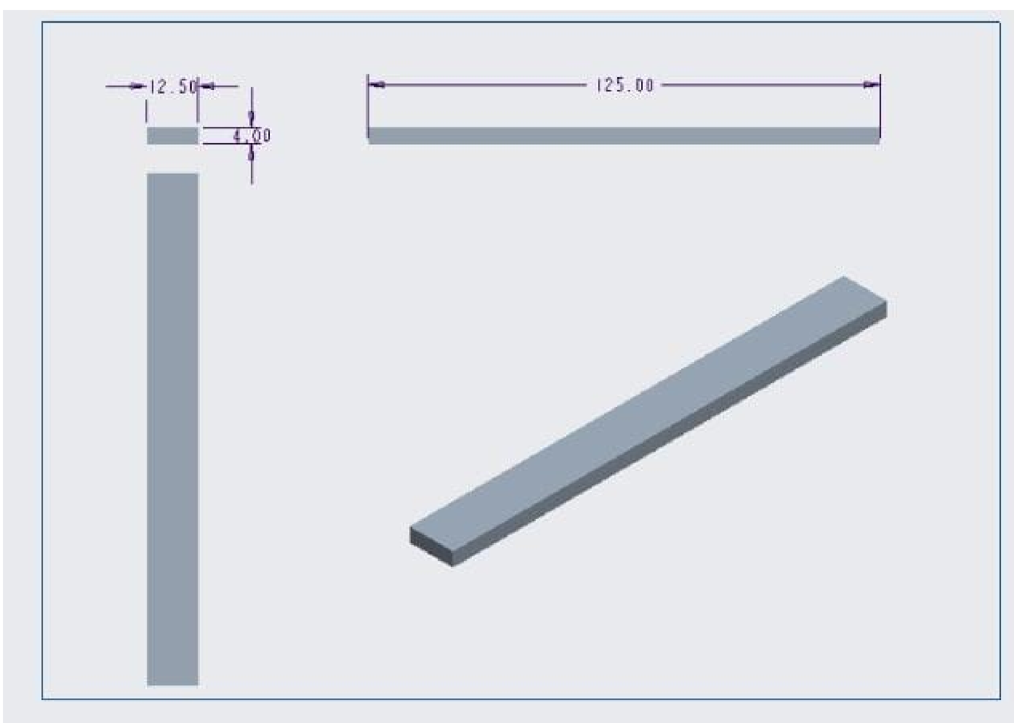

Figure 3.1 (b): Specimen-21 for both Carbon ABS and Carbon PLA

The complete design process of this study is explained in the above provided figures and tables.

3.2.2 ADDITIVE MANUFACTURING OR 3D PRINTING

This study is completely based on modern process of manufacturing called Additive manufacturing or 3Dprinting. Additive manufacturing is achieved in various methods one such effective and cost efficient method is Fusion Deposition Modelling. This process is nothing but the layer by layer addition of molten wire based filament. The molten filament comes through the extruder as per the input design. The process of FDM involves few Pre-Production processes.

3.2.2.1 HARDWARE PRE-PRODUCTION PROCESS

The pre-production process in FDM involves both Hardware process as well as Software processes. In hardware process the 3D printer is customized on the basis of temperature, with respect to the Specimen manufactured. This involves the adjustment of Extruder temperature to print Carbon with PLA and Carbon with ABS. Print bed temperature is also adjusted if the Material chosen demands.

Figure 3.2 (a) Temperature adjustment for Carbon with ABS

The figure 3.2 (b) conveys the print bed temperature as 60° C which is not applicable for Carbon with PLA.

Figure3.2 (b) Temperature adjustment for Carbon with PLA

2.2.2.2 SOFTWARE PRE-PRODUCTION PROCESS

In this process the CAD model is transferred to machine readable codes using software called Simplify3D. This Software is used to determine the Print speed, orientation angle, type of infill and layer thickness. The CAD model is converted into thin horizontal slices and stored as file with a extension .stl and this Stl file is transferred to the Machine. This simplify3D software converts the Design into G-codes and M-codes which are most commonly utilized machine readable language Preview of the whole process can be viewed in the form of animation. In the preview animation the type of infill and printing angle can also be verified. It also evaluates the total time required to manufacture our design The figure 3.3 given below is the preview of the specimen and the alignment of major three axes. Here the X- axis and Y-axis denote breadth and length whereas Z-axis denotes the thickness of the specimens.

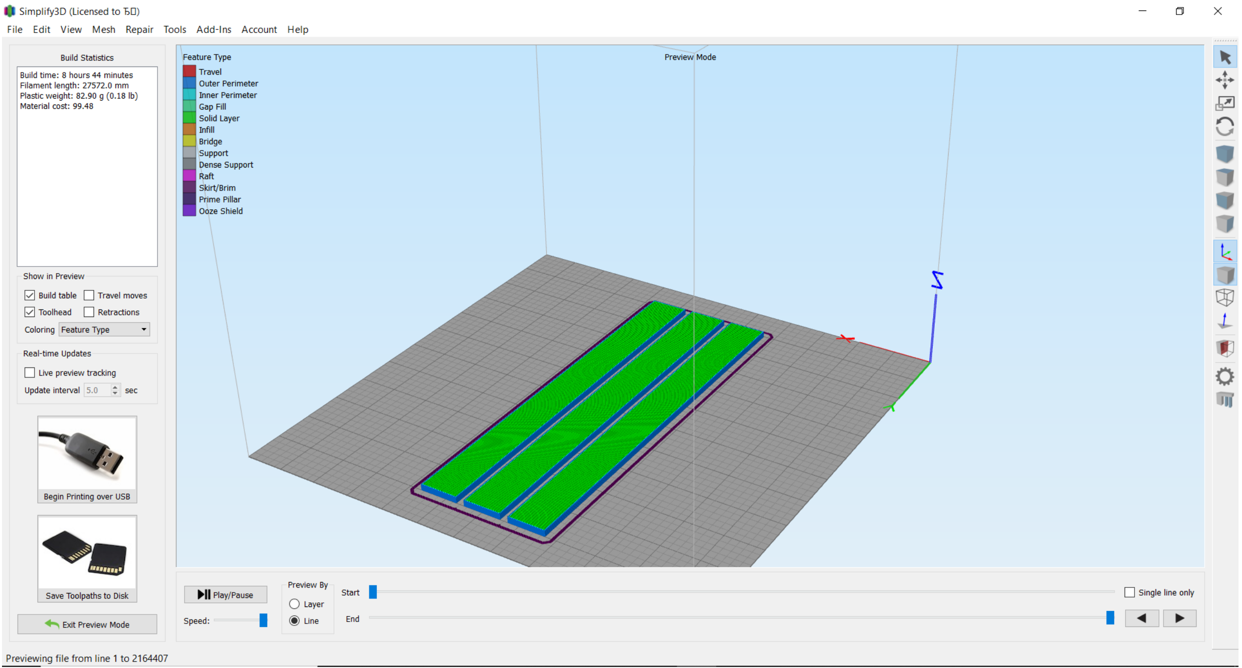

Figure 3.3 Preview of specimen using simplify 3D software

2.2.3 PRINTING OF SPECIMENS

2.2.3.1 MACHINE SPECIFICATION

The specification given table 3.2 belongs to the 3D printer with which the specimens are manufactured for study. The 3D printer used in this study is manufactured by Falcon 3D and the model name is Falcon Zeus. The parameters given below are based on the parameter which is required to print samples for this particular study. For complicated or large design the parameter is changed accordingly. The construction of 3d printer includes major parts like the Extruder nozzle, heat bed, stepper motors as well as the frame

i. Frame is otherwise called the chassis of 3d printer it holds all the components. It is directly responsible for the stability and durability of machine.

ii. Extruder nozzle used in this machine is made of Brass alloy of input diameter of 1.75mm and output diameter of 0.5 mm.

iii. Heat bed is the surface in which the specimens are printed it is a composite material made up of copper and glass. It supports up to 24v of power and maximum temperature is 120 °C.

iv. Stepper motors are responsible for the x y z axis movements and also it is used to pull filament towards extruder.

Table 3.2 Machine specifications

Parameters	**Range**
Bed size (mm)	200x200x200
Printing speed	3600 mm/min
x/y axis movement speed	4000 mm/min
Z axis movement speed	1000 mm/min
Primary layer height	0.1 mm
Printing direction	Inside out
First layer speed	50 mm/min
Nozzle diameter	1.75 mm

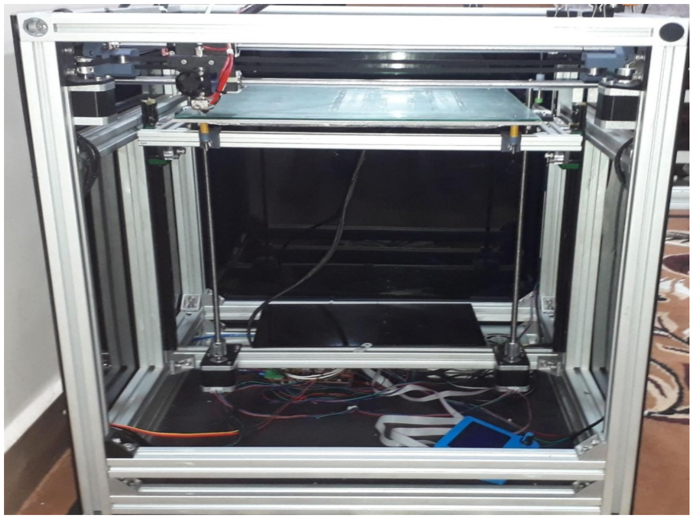

Figure 3.4 Falcon 3D printer

The printing duration is based on the printing speed and size of the print, the time is calculated by the software based on the CAD model given.

3.2.3.2 MANUFACTURING OF SPECIMENS

The raw materials used in this study are loaded into the 3d printer. Software simplify 3D recognizes the machine and the CAD model is given as input. Certain inputs like the layer thickness or Angle of orientation can be adjusted in software .The machine starts to extrude the filament on the surface of the bed as shown in figure 2.4(a)

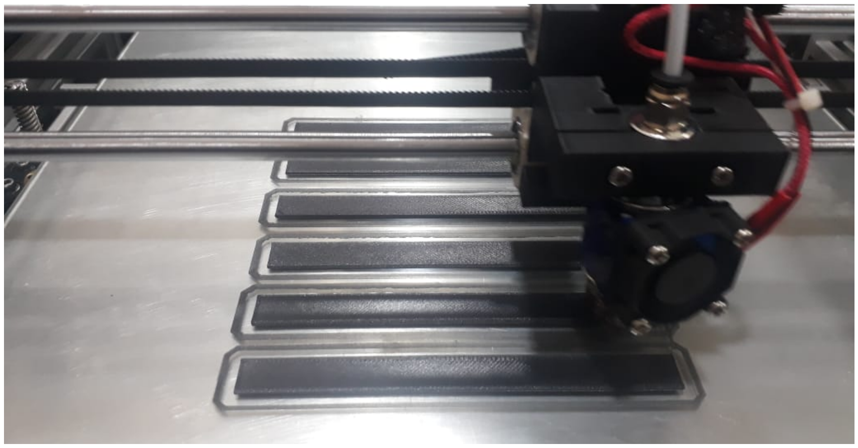

Figure 3.5(a) Specimens are Printed

This study is more focussed on the Printing orientation of the specimens .Both specimens are printed in a Raster angle of $+45^{o}/-45^{o}$,This print orientation is clearly visible in figure 3.4 (b) . The printing orientation can be customized using Simplify 3D software.

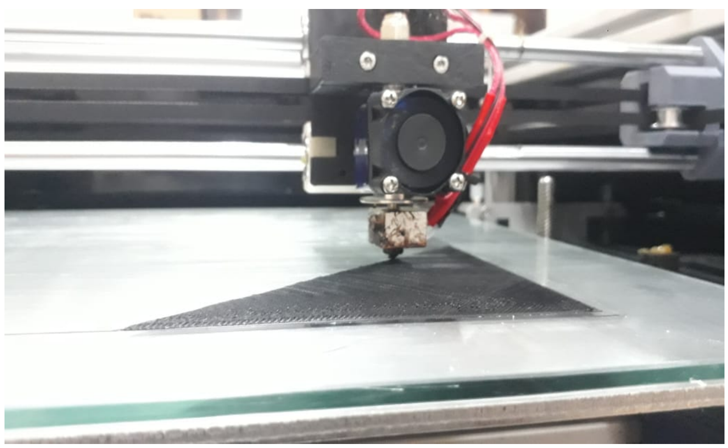

Figure 3.5(b) Orientation angle of specimen

The finished specimens are collected and named for various tests like Mechanical and Free vibration analysis. The specimens are once again cross checked manually for proper measurements as shown in figure

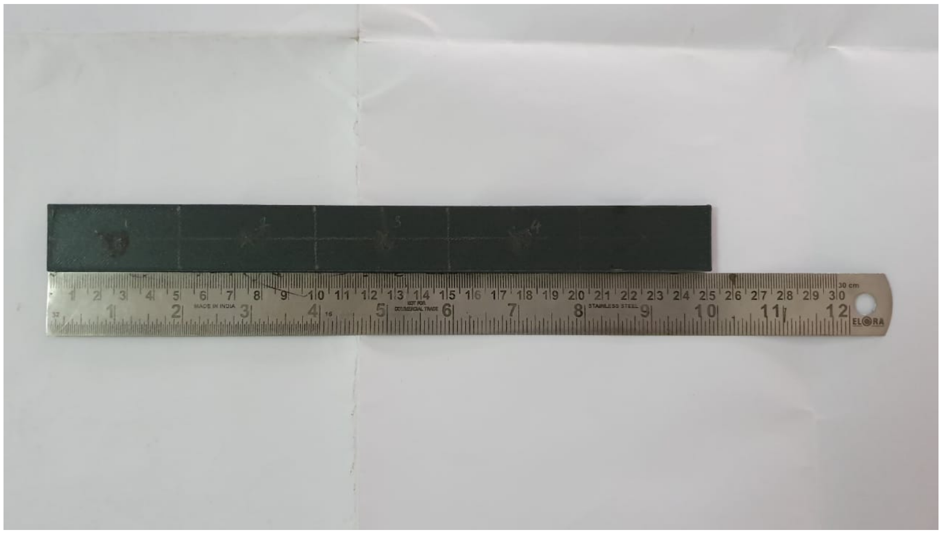

Figure 3.5 (C) Finished specimen

The specimens are sorted out based on different ASTM standards and marked over the specimen to avoid confusion as like in fig 3.4(d) and 3.4(e).

Figure 3.5 (d) finished specimen of Carbon with PLA

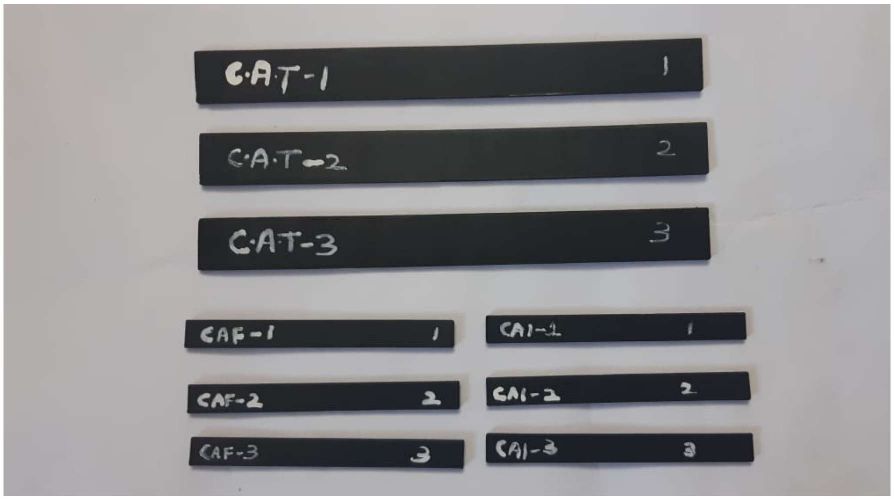

Figure 3.5 (e) Finished specimen of Carbon with ABS

3.3 TESTING METHODS

This study mainly focuses on various testing methods of 3D printed specimens in order to calibrate the material’s Stiffness, Behaviour as well as the damping capacity of each.

3.3.1 MECHANICAL TESTINGS

The printed specimens were subjected to mechanical testing like Flexural and Tensile test. The specimens are manufactured based on certain standards suitable for Mechanical testing called American Society of Testing and Material standard (ASTM). To incorporate materials were subjected to proper standards and correct ASTM numbers were provided as like in the table 3.3 and 3.4. These table consist of tests which were performed , machine used and ASTM number provided.

3.3.1.1 TENSILE TEST

Tensile test was performed to determine the behaviour of the specimen under Tension load. It is destructive testing as the test is carried out until fracture of specimen. The tensile force, elongation and Modulus of Toughness were evaluated by conducting this test. The testing standards are given in the table below.

Table3.3 Tensile testing parameters

TEST	ASTM STANDARD	MACHINE	TEST SPEED	SPECIMEN SIZE (mm)
TENSILE TEST	D3039	TINIUS OLSEN'S (MODEL IT503)	CROSS-HEAD SPEED OF 5mm/min	250x25x4

The ASTM standard D3039 is used as common testing standard to determine the Tensile properties of Composite materials. The specimens were clamped in fixture provided in Tinius Olsen machine and were subjected to axial tensile load until fracture of the specimen as shown in fig 3.5 (a) and 3.5 (b). The results and graphs were recorded in order to evaluate the tensile behaviour. In total totally 3 specimens were tested to achieve more accurate results. The average of three specimens until fracture are recorded and plotted in a Graph as results.

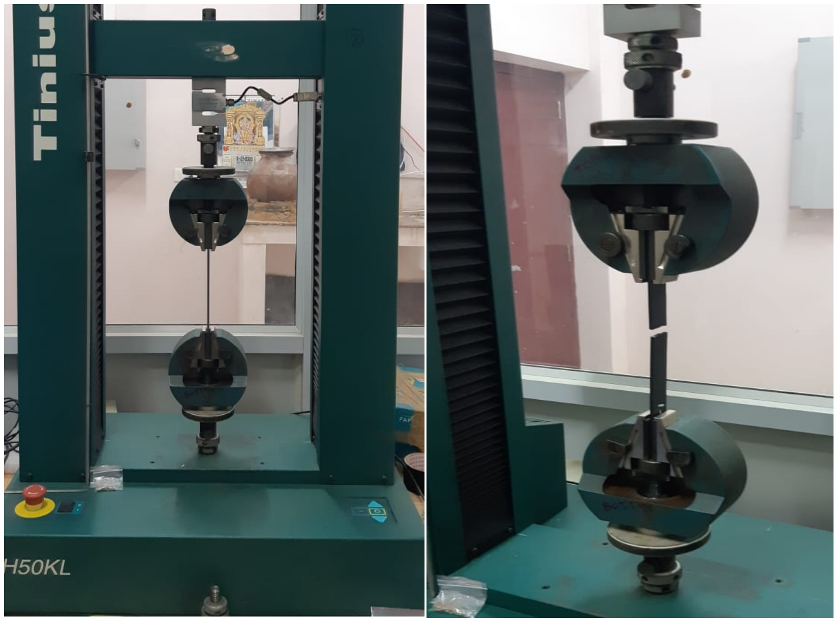

Figure 3.6 (a) Experimental setup before and after fracture

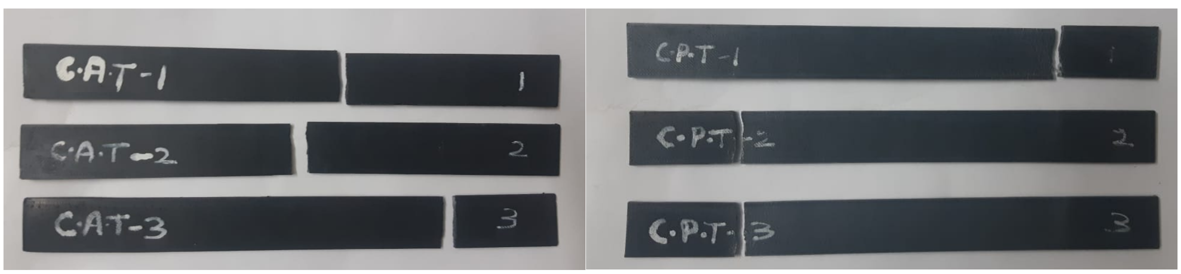

Figure 3.6 (b) Fractured specimens of both Specimens

3.3.1.2 FLEXURAL TEST

Flexural test was performed to determine the flexural strength or the bending stress of the material. Flexural strength is defined as the maximum stress created in the outermost fibre of the specimen. The outermost fibre experiences compression as well as tension on either side. After the evaluation of results modulus of toughness is also calculated. The specimens are manufactured based on American Society of Testing Materials (ASTM) standards. The table given below exhibits the testing machine and testing speed as well as the specimen dimensions.

Table 3.4 Flexural testing parameters

TEST	ASTM STANDARD	MACHINE	TEST SPEED	SPECIMEN SIZE (mm)
FLEXURAL TEST	D790	TINIUS OLSEN’S (MODEL IT503)	CROSS-HEAD SPEED OF 1.2 mm/min	125x12.5x4

The above mentioned ASTM standard D790 is the flexural testing standard for reinforced plastics. The specimens are laid horizontally over two points of contact (lower support span) and then a force is applied to the top of the material through either one or two points of contact (upper loading span) until the specimen fails. The maximum recorded force is the flexural strength of that particular specimen.

The mentioned experimental setup is shown in figure 3.6 (a) and the fractured specimens are shown in figure 3.6 (b). For every material three specimens of similar ASTM standards were manufactured and tested for three iterations with which much close results are derived. The required results are recorded in the form of Graphs and plot points.

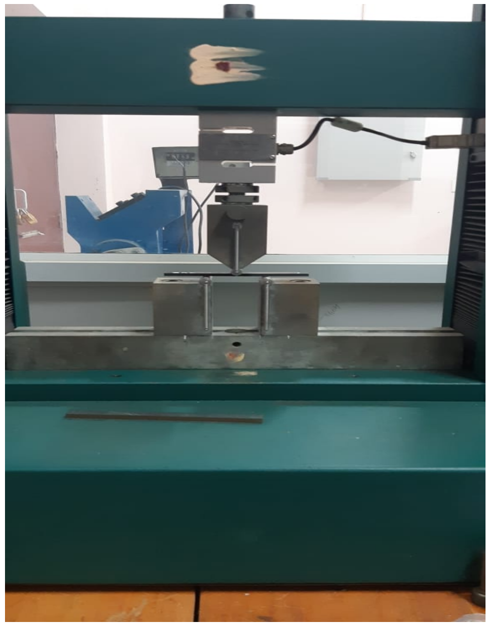

Figure 3.7 (a) Experimental setup of Flexural test

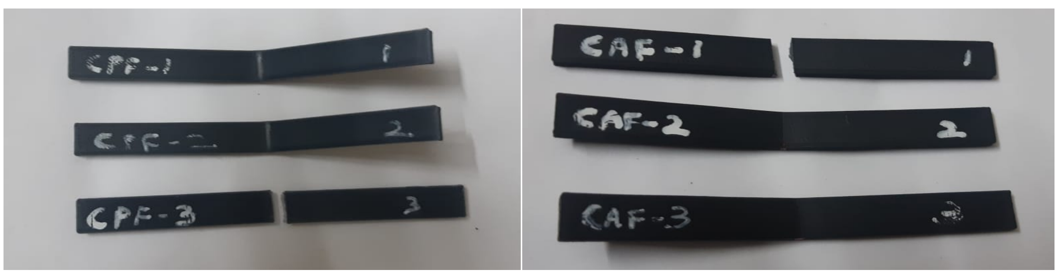

Figure 3.7 (b) Fractured specimen of both the specimens

3.5 CHAPTER SUMMARY

This Chapter mainly focuses on the Material used and Methods incorporated in this study. It covers the material used and the accurate properties of those materials. The method incorporated is also explained in the correct sequential order in which the specimens were manufactured for further testing. It also consists of the Machines used and testing methods with which the Mechanical behaviour is evaluated. Further specimens are subjected to Free vibration analysis for this study.

CHAPTER – 4
FREE VIBRATION ANALYSIS

4.1 INTRODUCTION

In this study of free vibration analysis of 3D printed carbon fibre material in combination with the Acrylonitrile Butadiene Styrene (ABS) and Poly Lactic Acid (PLA) as Carbon ABS and Carbon PLA. In this experiment of free vibration analysis we analyse the natural frequency and the damping properties of the 3D printed Specimen .The Free Vibration Analysis is done to achieve the properties of natural frequency and damping of the newly made specimen to obtain the reframed properties of the composite materials .The naturalfrequency is the rate at which an object vibrates when it is not disturbed by an outside force and the Damping is an influence within or upon an vibrating system that has the effect of reducing, restricting or preventing its vibrations. In physical systems, damping is produced by processes that dissipate the energy stored in the vibration

4.1.1 EXPERIMENTAL SETUP

In the testing of the Composite material for the Free Analysis the component is held in the fixture .The dimension of the component which is to tested are of 250x25x4 mm . The component is held in a 4 screw clamp where 40 mm of the total length is clamped and the remaining 210 mm hangs has a cantilever beam . The Accelerometer is fixed 30 mm before the leading edge of the cantilever beam .The beam is kept fixed at one end and the other end is let to free as Fixed-Free end .The Fixed free end is proposed for the measurement of the natural frequency and the damping properties of the testing specimen. Unlike Forced vibration in Free vibration where the force is applied only once and the vibration is allowed to prolong until the specimen comes to a complete rest this in other words this type of vibration is also known Natural Frequency**.** Free vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely.The below given figures 4.1(a) and 4.2 represents the actual and the schematic diagram of the Experimental testing setup.

Figure 4.1 Specimen arrangement

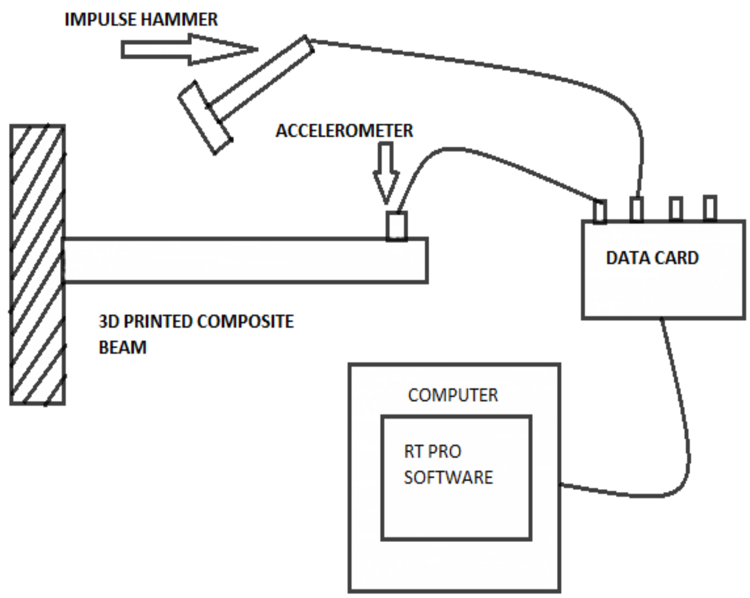

Figure 4.2 Block diagram of free vibration setup

4.1.2 INSTRUMENTS OF TESTING

For the testing of Free vibration we made use of few instruments with which the testing process in carried for the free vibration Analysis .The Testing Instruments for the experiment consists of Impulse Hammer, Accelerometer, Data Card , Computer

4.1.2.1 IMPULSE HAMMER (B&K Type 5800B4)

The impulse hammer is in the shape of the normal house hold hammer , the impulse hammer is used to analyse the force that being applied to the specimen and consolidate the reading .The impulse hammer consists of a piezoelectric force sensor which measures the force applied at the time of hitting at the point of hitting. The impact tip of the impulse hammer consists of various interchangeable impact tips suitable for various testing material . The measured force is then transmitted by means of a coaxial connector for transferring the signals to the data card . The below figure 4.2 (a) and 4.2(b) represents the schematic and the actual diagram of the impulse hammer

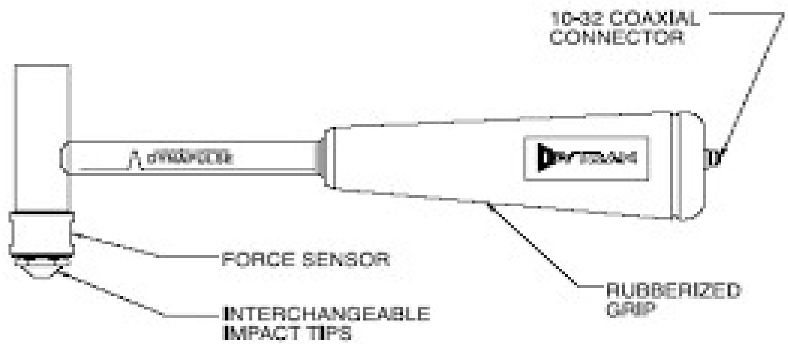

Figure 4.3 (a) Impulse hammer parts

Figure 4.3 (b) Impulse hammer used

4.1.2.2 ACCELEROMETER (B&K Type 3055B2)

The Accelerometer is used to measure the vibration that is produced by hitting the hammer on the Specimen . The Instrument is placed on the specimen and the vibration is sensed .Most of the accelerometers rely on the use of the piezoelectric effect, which occurs when a voltage is generated across certain types of crystals as they are stressed. The acceleration of the structure is transmitted to a seismic mass inside the accelerometer that generates a proportional force on the piezoelectric crystal. This external stress on the crystal then generates a high-impedance, electrical charge proportional to the applied force and, thus, proportional to the acceleration. And then the measured disturbance is then transferred to the data card by means of coaxial connector. The below diagram 4.1.2.2 (a) and 4.1.2.2(b) represents the actual and the schematic diagram of the accelerometer

Figure 4.4(a) Accelerometer

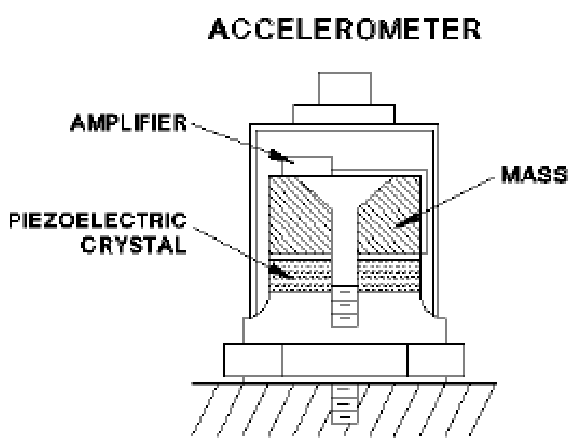

Figure 4.4(b) Accelerometer parts

4.1.2.3 DATA Acquisition CARD (B&K Type Photon+)

The data card is a box type setup which is a part of the testing instruments unlike other instruments which is used to measure the vibration and forces whereas this piece of device is used to collect data from the Impulse hammer and Accelerometer and then converts the analogous values to binary values and inputs the computer with the converted binary values for the analysation of the measured values . The output of the binary values from the Data Acquisition card is then feed as the input to computer to create various graphs corresponding to the values obtained

Figure 4.5 Data card used

4.2.1.3 COMPUTER

The computer here is likely to be the main component in this entire experiment. The entire instruments in the setup is being monitored by the system and the signals from all the instruments is gathered in the system software and the signals are processed and finalised as graphical outputs with various charecteristics

4.2.1 RT PRO SOFTWARE

To analyse the characteristics of the Free Vibration Analysis , we use the RT prosoftware to Analyse and get a clear and detailed view on the reframed properties of the Carbon fibre material . The RT pro software is used to record and analyse data immediately for a complete on site or a field test verification for this purpose we chose RT pro software to analyse the Free Vibration Analysis. At the end of the Analysation of the recorded values , they are represented in the form of various graphs representing various curves

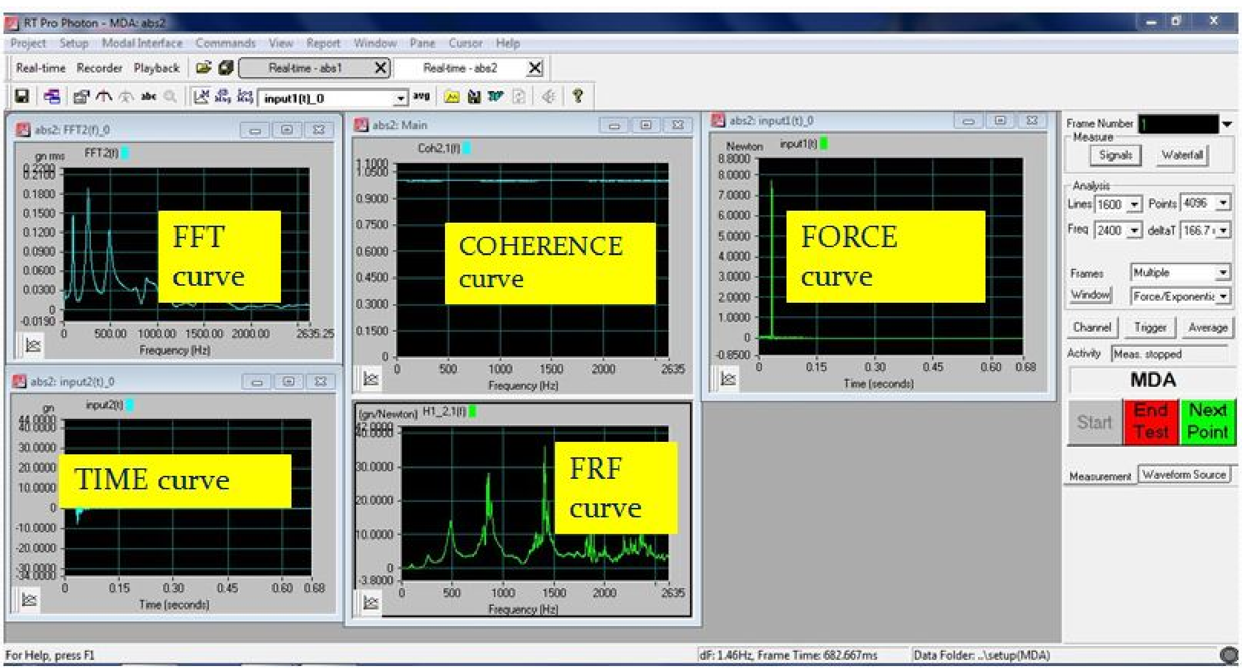

Figure 4.6 RT pro software graphs

4.2.2 FAST FOURIER TRANSFORM CURVE

The FAST FOURIER TRANSFORM CURVE is also known as the input curve The FFT curve is the input curve from which the given as the input to the formation of the other curves .The impulse force obtained from the impulse hammer is the input of the FFT curve . Once the force is obtained the force is converted into Sinusoidal signal waves. These waves are then converted into binary values by means of Data Acquisition card and the output is fed into the computer. The RT pro software then displays the data of the sin waves in FFT curve

4.2.3COHERENCE CURVE

The **coherence** is a statistic that can be used to examine the relation between two signals or more data sets with which the quality of the vibration is being checked. When the three impulse force are given the curves checks for the correlation one wave with the others

4.2.4 FORCE CURVE

The Force Curve depicts the measure of force that is being applied to the specimen by means of the Impulse hammer. When the applied force by the impulse hammer exceeds the required force value the curve indicates that the excessive force is applied to the specimen to the software

4.2.5 TIME CURVE

The Time Curve is used to measure the prolonging period of the Natural frequency and the corresponding successive resonant .This curve is also used to measure the oscillation time of the specimen until the specimen comes to a complete rest

4.2.6 FREQUENCY RESPONSE FUNCTION CURVE

A Frequency Response Function (**FRF**) is a function used to quantify the response of a system to an excitation, normalized by the magnitude of this excitation, in the frequency domain.TheFrequency Response Function curve is the output curve of the vibration process .Accelerance is obtained as an output of the FRF curve

4.3 IMPULSE FREQUENCY RESPONSE TEST

After fixing the specimen on fixture the Free vibration testing were performed for both the Carbon fibre material having the boundary condition of Fixed-free end using the Testing kit . Once the setup is ready the experiment is carried out . A disturbing force is given on the composite beam near the fixed end by means of the impulse hammer **(B&K Type 5800B4)** and the response of the vibration of hitting is being measured by a piezoelectric accelerometer **(B&K Type 3055B2) .** Both the measured values of force from the impulse hammer and the vibration sensed by the piezoelectric accelerometer is sent to the Data Acquisition Card **(B&K Type Photon+)**with FFT analyser converts the analogous values into binary values and transfers the data to the computer which records and stores the data . The other graphical curves of the tested specimen was acquired by the **RT pro Photon+** software which is processed for the first natural frequency , successive resonant sets and its corresponding damping factors. A set of Three trials were performed repeatedly to check and confirm the consistency of the vibration pattern .

4.4 CHAPTER SUMMARY

This chapter deals with the instruments used for free vibration analysis, which includes Impulse hammer, Data card ,Accelerometer , computer and Rt pro software. The explanation of how these instruments contribute in free vibration analysis is mentioned in detail. These observations were clearly recorded after the analysis and tabulated elaborately in Results and Discussion.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 TESTINGS AND ANALYSIS

Mechanical test and modal analysis were performed to determine the following results for both CARBON ABS and CARBON PLA. By comparing the results from the following tests the comparatively superior specimen for light weighted structure can be identified.

Mechanical testing:-

- Modulus of toughness

  It is the amount of strain energy per unit volume that a material can absorb before it breaks.

Modal analysis and vibration testing:-

- Resonant peaks and their respective damping percentage
- Mode shapes

5.2 MECHANICAL TESTING

Tensile and flexural test were conducted on the ASTM standard specimen. Modulus of toughness for flexural and tensile of both the materials was obtained from their respective stress - strain graphs by calculating the area under each curve for different specimen in the stress – strain graph of both tensile and flexural tests.

Tensile test is carried out to determine the plastic tensile properties such as ultimate strength, yield strength and elongation of both specimens under the same condition. The test process involves placing the test specimen in the machine and slowly extending it until it factures. During this process the elongation of the specimen is recorded against the applied force.

In flexural test, when a specimen is placed under flexural loading all three fundamental stresses (compressive, shear and tensile) are present which are used to determine the flexural strength and modulus of the used specimen.

5.2.1 TENSILE TEST

The given figure 5.1 depicts the stress – strain values obtained from the tensile test of Carbon PLA and Carbon ABS. The areas under the curve for both specimen's values are calculated and is depicted in the figure 5.2. From figure 5.2 it is derived that the modulus of toughness in tensile behavior is high for Carbon PLA than Carbon ABS.

From the figure 5.1, though the yield point is more or less at the same value for both the specimens other factors are also determined such as the necking region of Carbon ABS is longer than that of Carbon PLA. It is also interpreted that the value of UTS (Ultimate strength) in Carbon PLA at 33MPa is higher than 24 MPa of Carbon ABS, which in turn depicts that the strain hardening period is higher for Carbon PLA.

Also by analysis the necking region of both the specimen it is shown that Carbon PLA is more brittle in nature during the tensile test. This represents that Carbo ABS has high strain absorption rate when force acts axially on both the specimens. Thus it is seen that when ABS and printable carbon are made into a filament, the bondage of fibers of the specimen increases axial to the specimen.

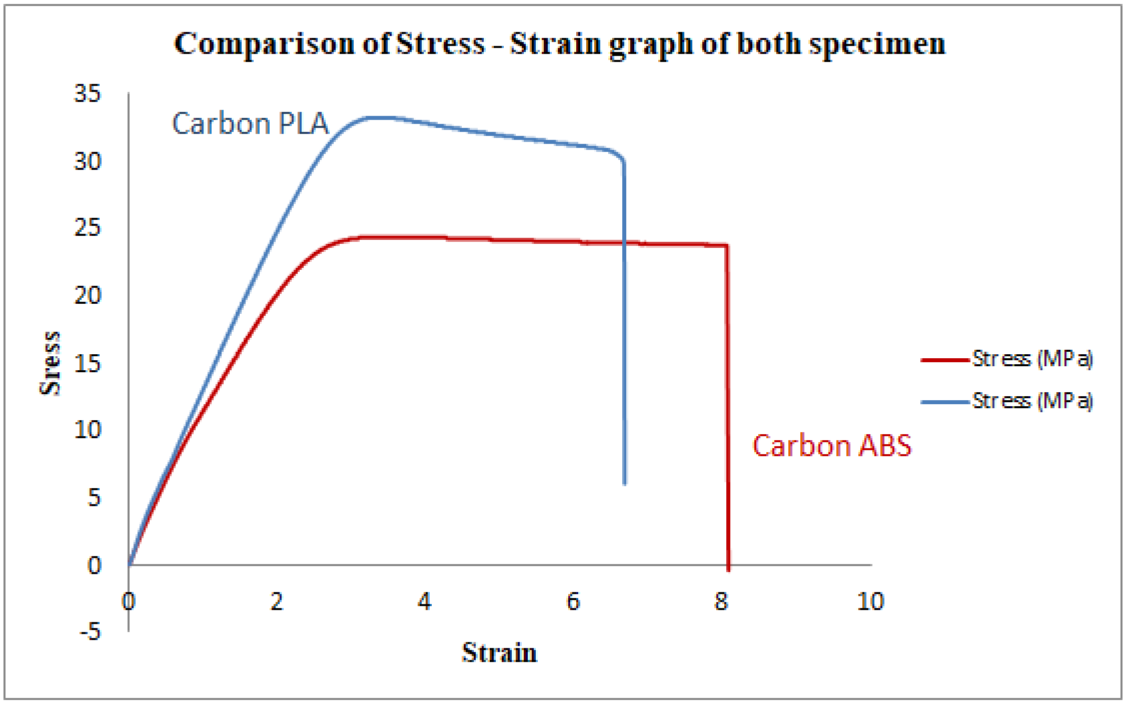

Figure 5.1 Stress - strain graph for tensile test

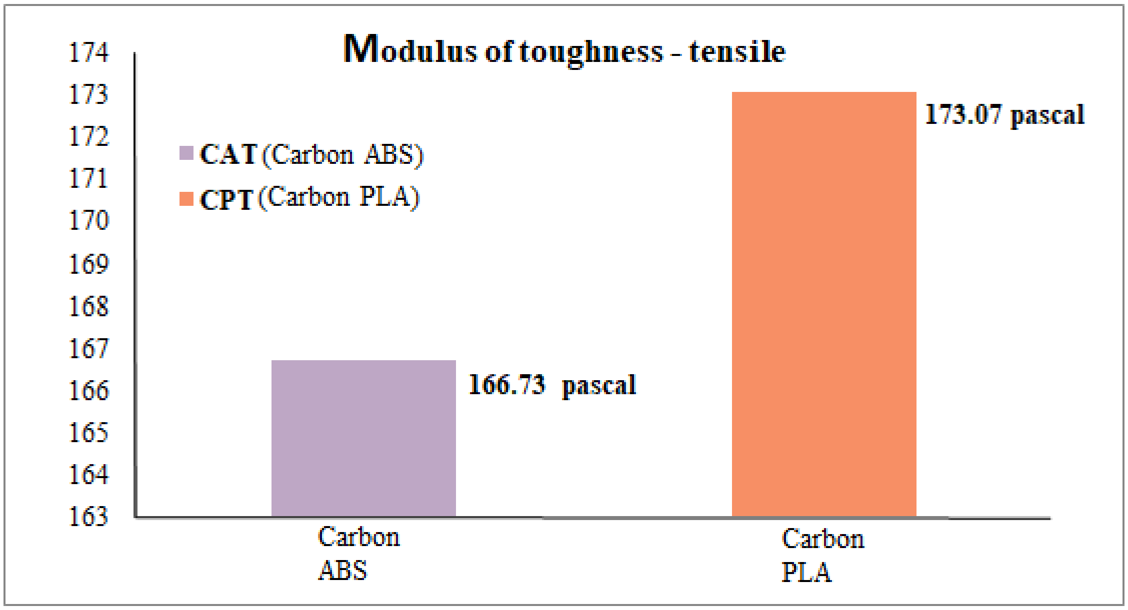

Figure 5.2 Area under the curve of stress – strain graph

5.2.2 FLEXTURAL TEST

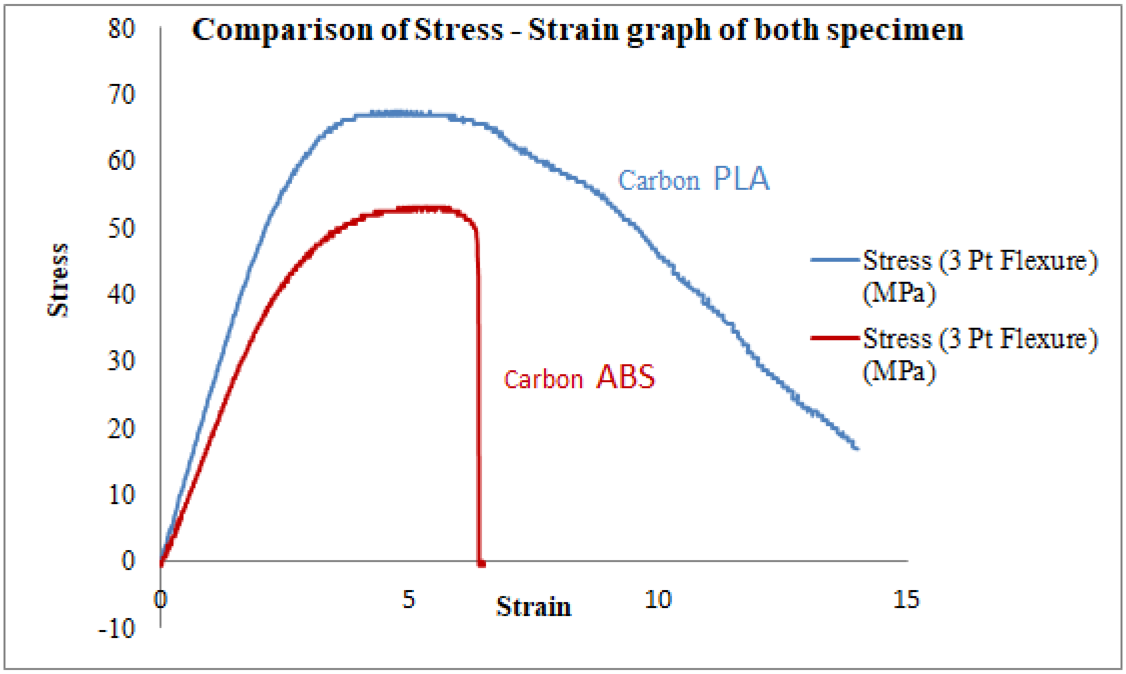

Figure 5.3 Stress – Strain graph for flexural test

From figure 5.3 it is also interpreted that Carbon ABS fractures a 55 MPA showing its brittle characteristic. Since fracture of Carbon PLA specimen did not occur during the 3 point flexural test shows the flexibility and comparatively higher bonding of the fibers present in the specimen.

It also shows that PLA when combined with printable Carbon material, it improvises the flexibility nature of the fibers. That is, it increases the flexibility of the fiber when force acts perpendicular to the axis of the specimen.

5.3 MODAL ANALYSIS AND VIBRATION TESTING

The results obtained from both analyses are used to determine the resonance peaks, damping percentage, mode shapes and the natural frequencies of both the specimens.

5.3.1 VIBRATION TESTING

This analysis results in providing by converting units displacement, velocity, and acceleration in the Time Wave Form (TWF). TWF is derived from the Fast Fourier transform obtained from the measurements. The results further represent the Frequency Response Function (FRF) as shown in figure 5.4, from which the successive resonance peaks is obtained for both of the specimens.

From figure 5.4 it shows the successive resonant peaks of Carbon PLA and ABS. The first peak of Carbon PLA occurs at 118 Hz which is less than the frequency of Carbon ABS of 263 Hz. But at the 2^{nd} and 3^{rd} resonant peaks of Carbon PLA at 524 Hz and 940 Hz respectively are higher than that of 2^{nd} and 3^{rd} resonant peaks of Carbon ABS at 483 Hz and 854 Hz. Thus by analyzing the curve and

the corresponding values in the FRF curves of both specimen represented in figure 5.4, due to reduction in values of frequency of consecutive resonant peaks of Carbon ABS it shows that the damping characteristic is higher for Carbon ABS than Carbon PLA.

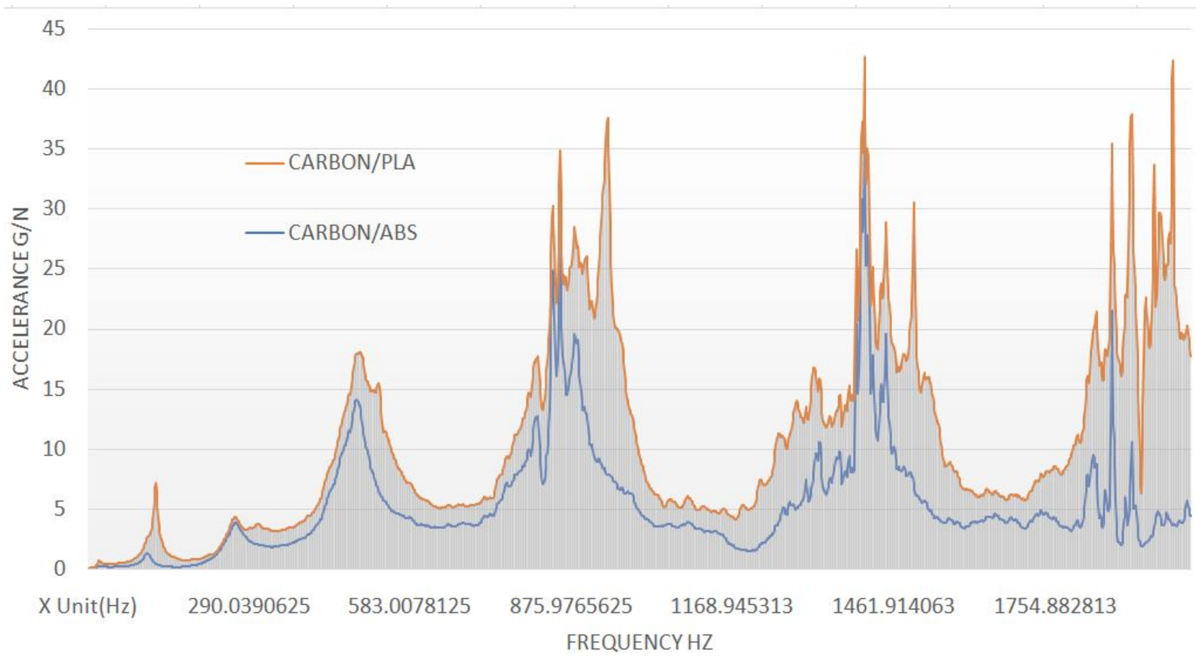

Figure 5.4 FRF curves of both the specimens

Using the frequency response obtained from the free vibration analysis it is further used to determine the damping percentage of both the specimens at their respective resonant peaks. The damping at resonance in a FRF curve is determined using the classical method known as “3dB method“(also called as half power method). In the FRF the damping is proportional to the width of the resonant peak about the peak’s center frequency. By determining 3 dB down from the peak level the associated damping can be identified.

The damping percentage associated with the 1st, 2nd and 3rd peaks of Carbon PLA is found to be 2.77%, 1.87% and 0.8% respectively. Similarly for Carbon ABS it is found to be 5.82%, 4.39% and 0.9% for their respective resonant peaks starting the least.

Table 5.1 Recorded observations of Free vibration analysis

Composite material	Modal parameters	At successive resonant peaks		
		I	II	III
CARBON/PLA	Frequency (Hz)	118	524	940
	Damping %	2.77	1.87	0.8
CARBON/ABS	Frequency (Hz)	263	483	854
	Damping %	5.82	4.39	0.9

By comparing the results from the figure 5.4 and table 5a, it proves that the damping percentage of Carbon ABS is higher than Carbon PLA at successive resonant peaks. This shows the Carbon ABS has higher reduction of amplitude of vibration.

5.3.2 MODAL ANALYSIS:

This analysis is performed to determine the natural mode shapes using values obtained from the cumulative FRF curve and the TWF curve of both the specimens during free vibration. The result shows more than one resonance from which mode shapes at consecutive resonant points that can be determined from the least frequency. Modal analysis uses the overall frequency and time values to determine the various periods known as mode shape at which the structure will naturally resonate. Mode shapes are specific pattern of vibration executed by a mechanical system at a specific frequency.

5.3.2.1 MODAL ANALYSIS OF CARBON ABS

Firstly the resonant frequencies obtained from the vibration testing of Carbon ABS were obtained and given as input to the ME scope for the modelled cantilever specimen based on the ASTM standards as shown in figure 5.5.

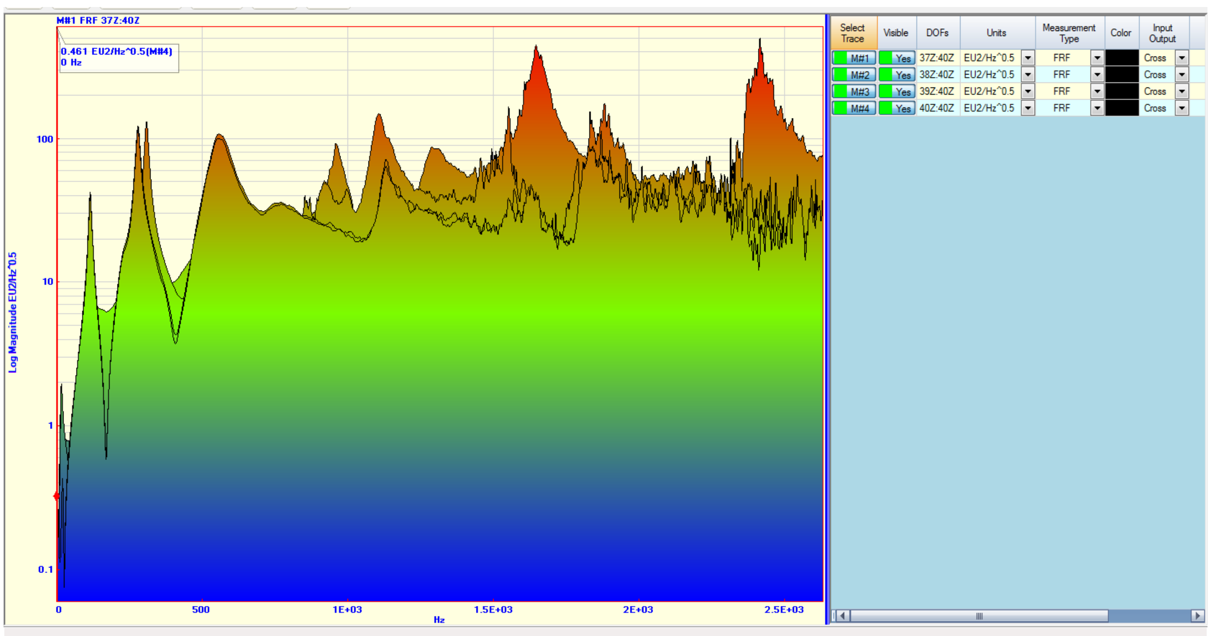

Figure 5.5 Cumulative FRF curve of Carbon ABS specimen

By animating the modeled cantilever beam using the result values from the cumulative FRF curve obtained from the Carbon ABS, the mode shapes at various resonant peaks for cantilever beams are identified in Figure 5.6 which represents the first mode shape at the first resonant frequency.

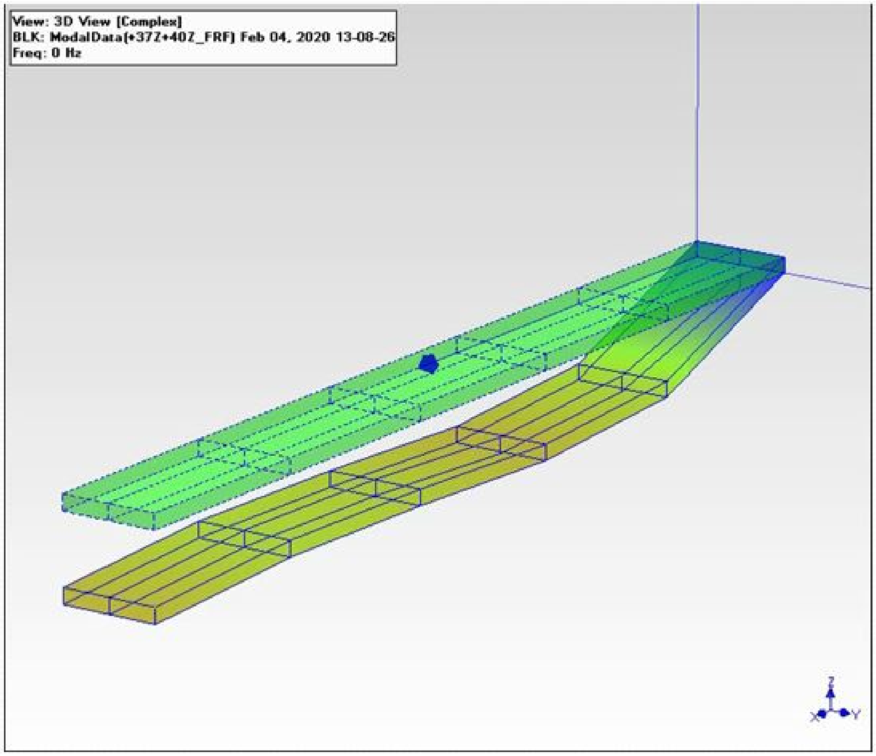

Figure 5.6 First mode shape at the first resonance frequency at 263 Hz

Due to further Resonant frequency the mode shapes occur as in Figure 5.7 represents the second mode shape that occurs at frequency of 483 Hz

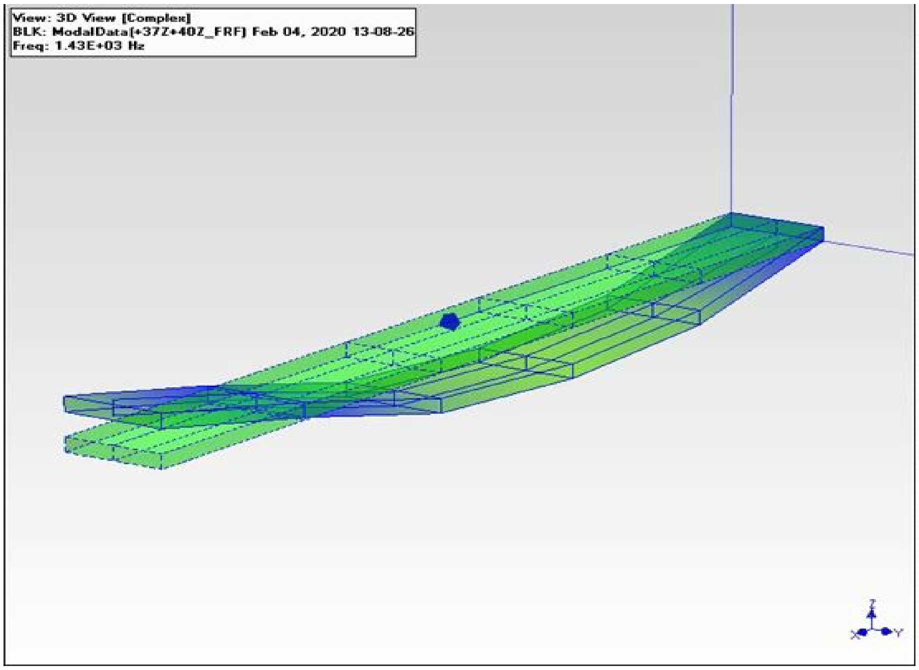

Figure 5.7 Second mode shape at the second resonance frequency at 483 Hz

The first three mode shapes of the cantilever beam are recorded after the three resonant peaks they are negligible. Figure 5.8 depicts the Third mode shape of the resonant peak.

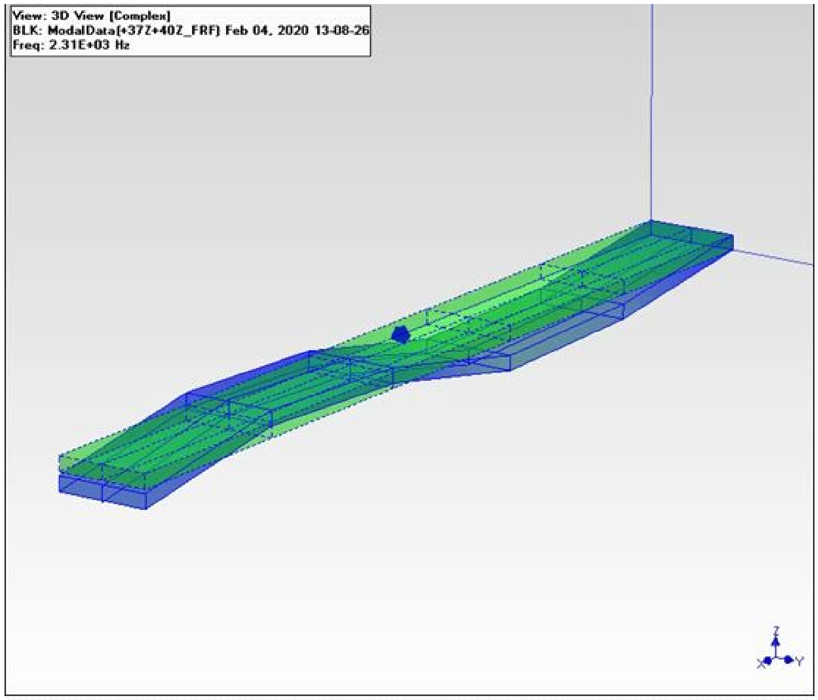

Figure 5.8 Third mode shape

5.4 SUMMARY

The overall observation were recorded based on the various tests which were performed in this study are discussed. The discussions are purely based on the areas in which each specimen are superior in performance and areas which require much more improvements. These observations were helpful in concluding this study.

CHAPTER 6

CONCLUSION

6.1 RESEARCH FINDINGS

This chapter enlightens the Research findings of this study which are been observed.

- The orientation angle contributes much in the improvement of Inter laminar bonding of the 3D printed specimens. The orientation Angle of $+45^0/-45^0$ has increased the Tensile strength of both specimens compared to other specimens of different orientation angle.

- In terms of Tensile property, Carbon with PLA and Carbon with ABS exhibit a better tensile strength compared to normal PLA and ABS. The Fused Deposition Modeling or FDM contributes much in the Adhesive property of Fiber and Matrix.

- Among Carbon ABS and Carbon PLA the Modulus of Toughness is higher for Carbon with Poly Lactic Acid. This is because of the difference in the Energy dissipation until fracture of both specimens. The difference in elastic region conveys that the elasticity of Carbon with PLA is more.

- Flexural strength of the Carbon with PLA is higher than Carbon ABS as the Fracture occurs very earlier. The specimens of Carbon PLA were not fractured in 3 point bending test which shows the flexibility of Carbon with PLA as specific Fracture point could not be identified in Stress strain graph.

- In terms of both Mechanical tests performed Carbon with Poly Lactic Acid has a better performance in Mechanical properties compared to Carbon with ABS.
- The free Vibration Analysis concludes that the Damping percentage of Carbon with Acrylonitrile Butadiene Styrene is comparatively higher than Carbon with Poly lactic Acid. This effect is due to the effective bonding of Carbon fiber with ABS matrix.

6.2 INDUSTRY IMPLEMTATION

- Automobile industries search for materials which have higher Damping percentage; in order to arrest Vibrations in such scenarios Carbon with ABS are suitable and can be implemented.
- Carbon PLA can be implemented in industrial sectors where the Mechanical performance plays the major role and damping is negligible.

6.3 LIMITATIONS

- Mass production is not possible in 3D printing or Additive Manufacturing.
- The Machine Specifications should be modified for each and every materials used.

6.4 FUTURE SCOPE

- Further improvement in Fibre matrix ratio can improve the Mechanical performance in all aspects.
- Further more study or a SEM image is required to analyze the micro level bonding of the fibre and the matrix.

- Mass production using 3D printing attracts more industry based persons to choose this method of Manufacturing.

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