STUDY THE QUASI – EXPERIMENTAL PROPERTIES OF DISSIMILAR LAYER PATTERN IN PLA5NF USING FDM

A PROJECT REPORT

Submitted by

JAGADEESH K	**(211419114114)**
JUDE VALAN K	**(211419114128)**
KABILAN K	**(211419114129)**
KIRUBAKARAN S	**(211419114148)**

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BONAFIDE CERTIFICATE

Certified that this project report **" STUDY THE QUASI – EXPERIMENTAL PROPERTIES OF DISSIMILAR LAYER PATTERN IN PLA5NF USING FDM "** is the bonafide work of **" JAGADEESH K (211419114114) , JUDE VALAN K(211419114128), KABILAN K (211419114129), KIRUBAKARAN S(211419114148)"** who carried out the project work under my supervision.

SIGNATURE	**SIGNATURE**
Dr .L. KARTIKEYAN M.E.,M.B.A., Ph.D.,	**Mr. S THAMIZH SELVAN M.E,**
HEAD OF DEPARTMET	**ASSISTANT PROFESSOR**
Mechanical Engineering	Dept. of Mechanical Engineering
Panimalar Engineering college	Panimalar Engineering college
Chennai – 600 123	Chennai – 600 123

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

Several components were manufactured using traditional machining techniques is antiquity. The amount of wasted materials, labor hours, machining expenses, and machining times is significant when producing multiple complex pieces and also have more possibilities for defect. To reduce the rejection of component due to defect, many industries have created a number of strategies for optimizing the machining process with a zero PPM aim(i.e. no defects in 1 million parts).

One of the strategies is additive manufacturing (rapid prototype 3D printing) is widely used. Several components or parts has been manufacturing by 3D printing using various printing filament. One of the main disadvantages in rapid prototype (3D printing) is limited printing filament (polymer and fiber) and limited composite filament are available.

Therefore, our goal of project is to identify and analyze the new polymer matrix composite filament with mechanical testing. So, we made a new composite polymer matrix filament. Using new polymer composite filament, specimen was manufacture (based on ASTM standard) using 3D printer and study the properties of the new material under mechanical testing.

KEYWORDS : optimizing, zero PPM, new composite polymer matrix filament.

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CHAPTER 1

INTRODUCTION

1 INTRODUCTION TO ADDITIVE MANUFACTURING

3D printing or Additive Manufacturing is the construction of a three-dimensional object from a CAD model or a digital 3D model It can be done in a variety of processes in which material is deposited, joined or solidified under computer control with material being added together (such as plastics, liquids or powder grains being fused), typically layer by layer.

Additive Manufacturing(AM) is different from conventional manufacturing processes such as machining, casting, and forging, where materials are removed from a block or injected into a mould to form the product. For traditional subtractive machining, detailed process planning must be made to determine machining steps to obtain the physical geometries. For example, in computer numerical control (CNC) machining, proper tools must be selected for specific materials, and the tool path must be carefully designed to prevent tool crash. In contrast, AM is a tool-free process and therefore can reduce both wear and machine setup times. AM also provides more flexibility in product design. In general, there are no limits in terms of design since AM is a building-up process with materials added layer by layer. Components that are difficult to fabricate by conventional processing such as parts with hollow features are easy to build by AM. The complexity of components no longer complicates the AM process. Besides, an assembly that consists of several components is now able to be constructed by AM. AM also provides more customized and personalized solutions because the geometry of a component can be easily adjusted.

The earliest 3D printing technologies first became visible in the late 1980's, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more costeffective method for creating prototypes for product development within industry. As an interesting aside, the very first patent application for RP technology was filed by a Hideo Kodama, in Japan, in May 1980. Unfortunately for Hideo Kodama, the full patent specification was subsequently not filed before the one-year deadline after the application, which is particularly disastrous considering that he was a patent lawyer! In real terms, however, the origins of 3D printing can be traced back to 1986, when the first patent was issued for stereolithography apparatus (SLA). This patent belonged to one Charles (Chuck) Hull, who first invented his SLA machine in 1983.

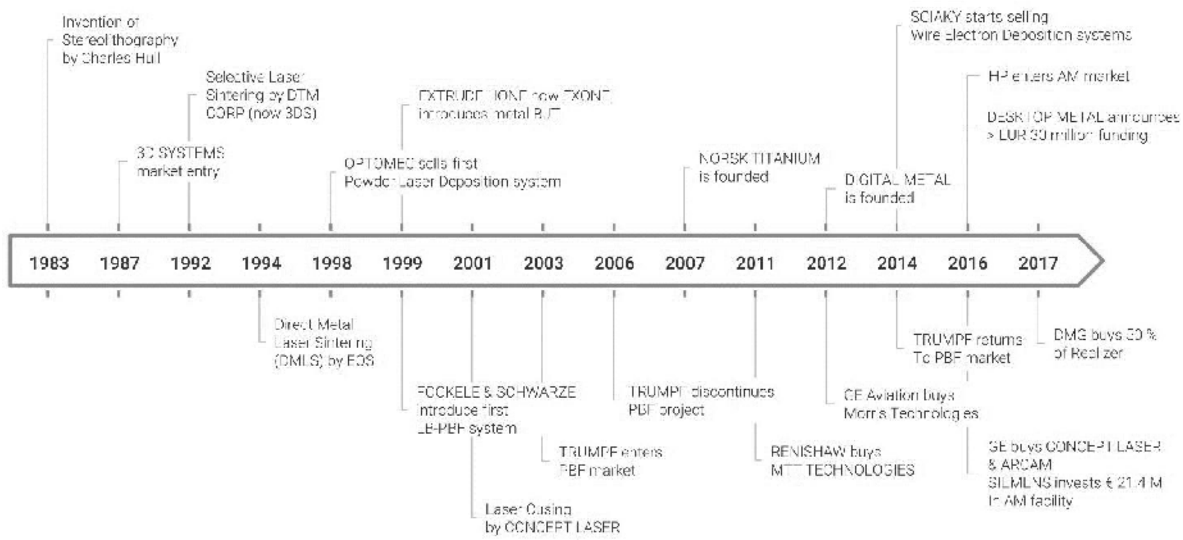

Fig 1.1 History of Additive Manufacturing

3D Systems' first commercial RP system, the SLA-1, was introduced in 1987 and following rigorous testing the first of this system was sold in 1988. As is fairly typical with new technology, while SLA can claim to be the first past the starting post, it was not the only RP technology in development at this time, for, in 1987, Carl Deckard, who was working at the University of Texas, filed a patent in the US for the Selective Laser Sintering (SLS) RP process. This patent was issued in 1989 and SLS was later licensed to DTM Inc, which was later acquired by 3D Systems. 1989 was also the year that Scott Crump, a co-founder of Stratasys Inc. filed a patent for Fused Deposition Modelling (FDM) the proprietary technology that is still held by the company today, but is also the process used by many of the entry-level machines, based on the open-source RepRap model, that are prolific today. The FDM patent was issued to Stratasys in 1992.

By the beginning of 2000, only polymers were used for 3D printing, which are plastics that can be moulded into any shape. From 2000 to 2005, industries considered the RP technologies as a Rapid Manufacturing (RM) tool. Therefore in 2009, the American Society for Testing and Materials (ASTM) and The International Organization for Standardization (ISO) defined Rapid Prototype as Additive Manufacturing that is entirely opposite to the conventional subtractive manufacturing and formative manufacturing methodologies.

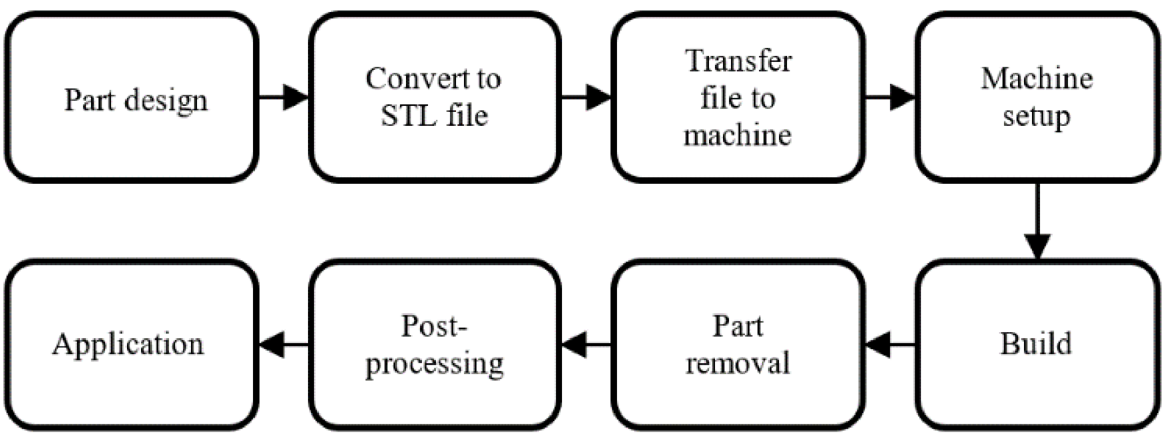

Fig 1.2 Additive Manufacturing process flow

In 3D printing technology, successive layers of materials are laid down one after the under-computer control until the entire designed object is made from the raw material used. 3D designs are created using CAD software like CATIA, PRO E, SOLIDWORKS etc. The design should be then converted into a “stl” file format i.e., Stereo Lithography format, based on which the 3d printer works. The format slices the designed object or part into spatial orientations like X, Y, Z axis and each orientation confirms the machine on how to proceed with the process of manufacturing.

The materials like Thermoplastics(polymers), metals and composites are used in Additive Manufacturing. Thermoplastics are the raw material commonly used globally where PLA and ABS is the prime material used. Other materials like Nylon, Polycarbonate (PC), poly ether ester ketone (PEEK)etc. Polymer materials are usually provided as solid filament, pellets, liquid resin or powders. Metal includes, but are not limited to, steel, aluminium, stainless steel, copper, cobalt, tungsten, titanium, and nickel- based alloys. Precious metals like platinum, gold, palladium, and silver can also be used in 3D printing.

Carbon fibre and composites are cutting-edge materials that offer a fast way of producing an object that is as-strong or stronger than metal. They are most commonly employed in the bicycle and aeronautics industries. Graphene, an allotrope of carbon, is the strongest material ever tested. It has the potential to create totally new technologies, for its efficient heat and electrical conductivity.

1.1 TYPES OF 3D PRINTERS

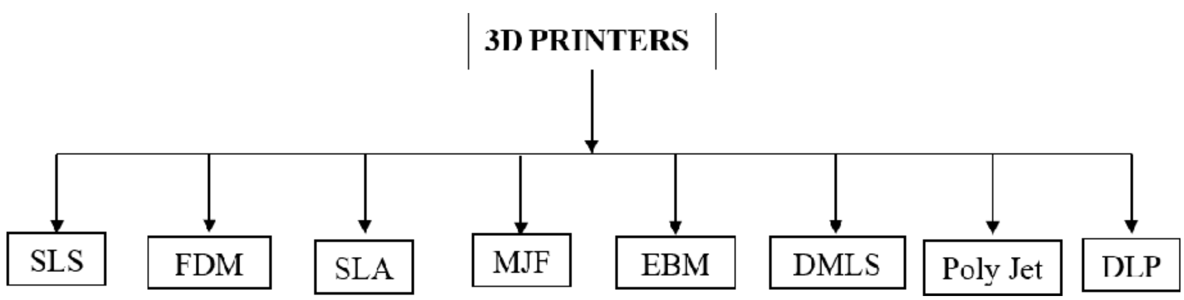

Fig 1.3 Types of 3D Printers

1.1.1 Selective Laser Sintering (SLS)

Selective laser sintering (SLS) is a 3d printing process (additive manufacturing) that uses high-powered lasers to sinter, or bind, finely powdered material together into a solid structure. The SLS apparatus shown in the Fig 1.4 . In this process, a printer lays down an even layer of powder and then precisely sinters that layer, repeating the deposition and sintering process until the part is complete. The shape of the object is created by aiming a laser at the powder bed in specific points in space, guided by a digitally produced CAD (computer-aided design) file.

This process offers a great variety of materials that could be used: plastics, metals, combination of metals, combinations of metals and polymers, and combinations of metals and ceramics.

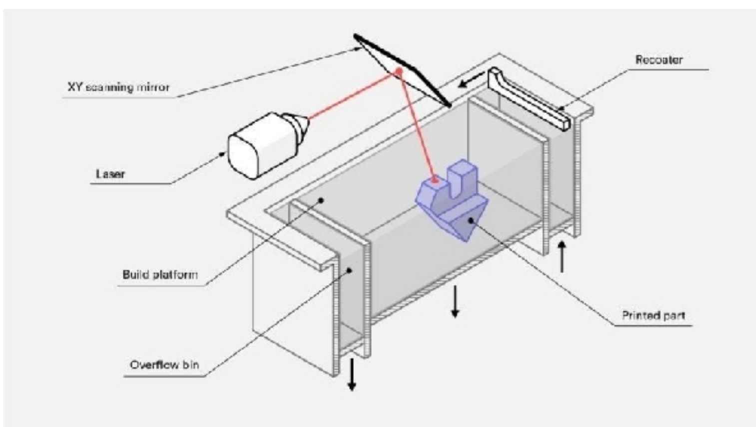

Fig 1.4 Schematic diagram of Selective laser sintering

1.1.2 Fused Deposition Modelling (FDM)

Fused Deposition Modelling (FDM) is a popular 3D printing technology that creates objects by melting and extruding thermoplastic filament layer by layer. The Fig1.5 shows the actual overview of FDM machine It is an additive manufacturing process that builds objects from the bottom up by depositing material in a predetermined pattern. In FDM, a spool of thermoplastic filament is fed into a heated extruder, where it is melted and then extruded through a nozzle onto a build platform. The extruder moves in the X and Y directions while the build platform moves in the Z direction, building up the object layer by layer.

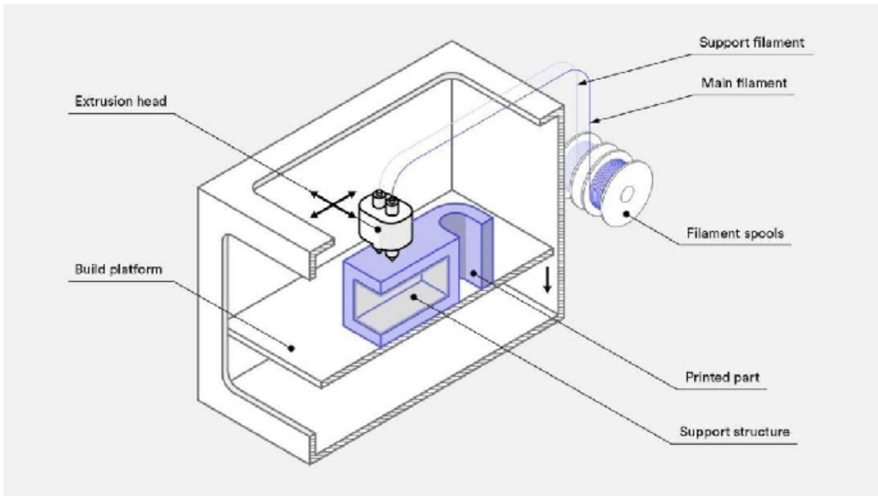

Fig 1.5 Schematic diagram of Fused Deposition Modelling

The process of FDM is often used to create prototypes, models, and even finished products in a variety of industries, including aerospace, automotive, and medical. FDM is popular because it is relatively fast, affordable, and offers a wide range of material options. However, the surface finish of FDM parts may not be as smooth as other 3D printing technologies, and the layer lines may be visible.

1.1.3 Stereolithography (SLA)

Stereolithography belongs to a family of additive manufacturing technologies known as vat photopolymerization, commonly known as resin 3D printing. These machines are all built around the same principle, using a light source a laser or projector to cure liquid resin into hardened plastic. The main physical differentiation lies in the arrangement of the core components, such as the light source, the build platform, and the resin tank. SLA 3D printers use light-reactive thermoset materials called “resin.” When SLA resins are exposed to certain wavelengths of light, short molecular chains join together, polymerizing monomers and oligomers into solidified rigid or flexible geometries.

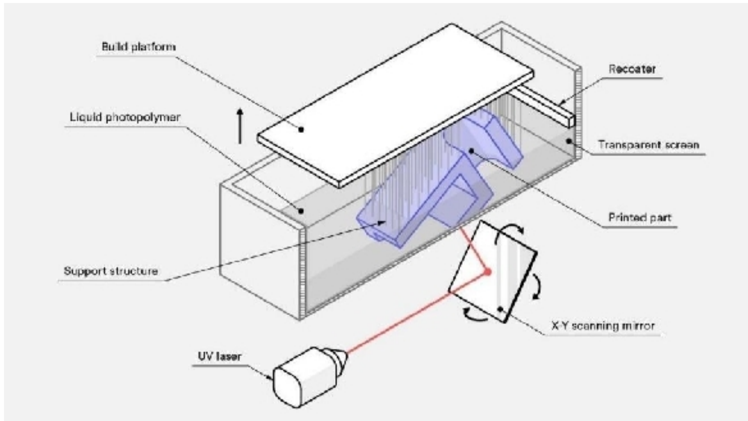

Fig 1.6 Schematic diagram of Stereolithography

1.1.4 Multi Jet Fusion (MJF)

Multi Jet Fusion (MJF) is a 3D printing technology developed by HP that uses a combination of heat and pressure to fuse nylon powder into a solid object layer by layer. It is an additive manufacturing process that builds objects from the bottom up. MJF is known for producing strong and durable objects with high detail and accuracy. It also allows for the production of parts with a range of mechanical properties, such as flexibility and stiffness, by adjusting the printing parameters. No laser is involved. MJF works by depositing fusing and detailing agents in a bed of powder material, then fusing them into a solid layer.

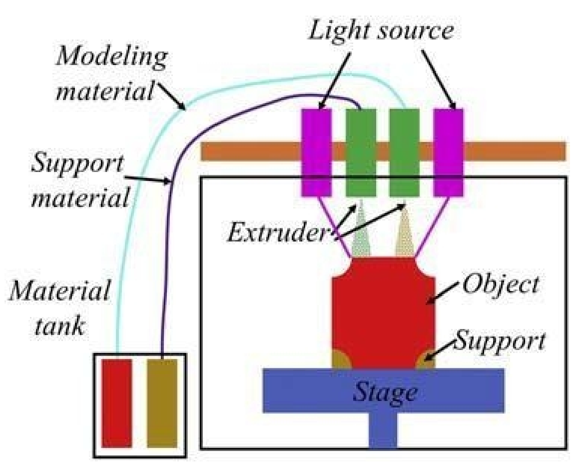

Fig 1.7 Schematic diagram of Multi Jet Fusion

1.1.5 Electron Beam Melting (EBM)

Electron beam melting (EBM), or electron beam powder bed fusion (EB PBF), uses a high-powered electron beam to melt conductive metal powders like copper and titanium together layer by layer. The resulting parts are highly dense and mechanically strong, finding a use in everything from turbine blades to hip implants. EBM is known for producing strong and complex metal parts with high accuracy and detail. It also allows for the production of parts with a range of mechanical properties, such as flexibility and stiffness, by adjusting the printing parameters. EBM is commonly used in industries such as aerospace, automotive, and medical, where high strength and precision are required. However, it can be more expensive than other 3D printing technologies, and the process can take longer due to the need for cooling time between layers.

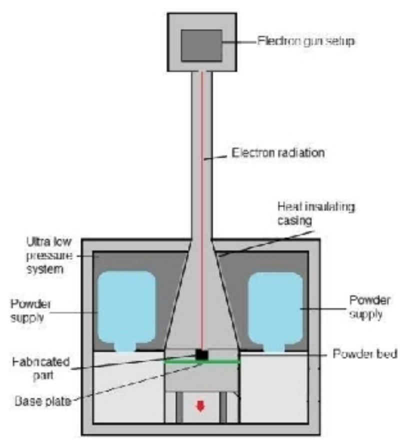

Fig 1.8 Schematic diagram of Electron beam melting

1.1.6. Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering (DMLS) is a 3D printing technology that uses a high-powered laser to melt and fuse metal powder layer by layer into a solid object. It is an additive manufacturing process that builds objects from the bottom up. In DMLS, a layer of metal powder is spread onto a build platform, and a laser fuses the powder in the desired shape, melting it together to form a solid layer. The platform then drops down and a new layer of powder is added on top, and the process repeats until the object is complete. DMLS is known for producing strong and complex metal parts with high accuracy and detail. It also allows for the production of parts with a range of mechanical properties, such as flexibility and stiffness, by adjusting the printing parameters. DMLS is commonly used in industries such as aerospace, automotive, and medical, where high strength and precision are required. Overall, DMLS is a highly effective 3D printing technology for producing high-quality metal parts with complex geometries and a range of mechanical properties.

1.1.7 Poly Jet

In Poly Jet, a layer of liquid photopolymer resin is jetted onto a build platform, and a UV light is used to cure the resin in the shape, creating a solid layer. The platform then moves down, desired and a new layer of resin is added on top, and the process repeats until the object is complete. Poly Jet is known for producing highly detailed and precise objects with smooth surfaces and a wide range of colours and materials. It is also capable of producing multi-material parts with varying properties and textures. Poly Jet is commonly used in industries such as product design, prototyping, and medical, where high detail and accuracy are required. However, it can be more expensive than other 3D printing technologies, and the process can take longer due to the need for cooling time between layers. Overall, Poly Jet is a versatile and effective 3D printing technology for producing high-quality, detailed objects with a wide range of colours and materials. It is particularly well-suited for applications where high accuracy and multi-material capabilities are required.

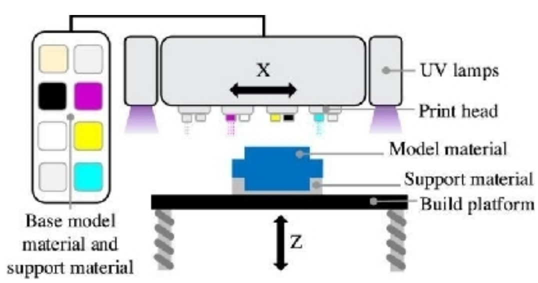

Fig 1.9 Schematic diagram of Poly Jet

1.1.8. Digital Light Process (DLP)

DLP 3D printing is what is known as a vat polymerization technique. Instead of using the thermoplastics found in fused deposition modelling (FDM) , DLP instead implements liquid thermosetting resins to create parts. The DLP process subjects a vat of this liquid resin to high-intensity light from a projector, which selectively cures the resin to a build platform in a layer-by-layer process. The DLP process projects an entire layer of a 3D model all at once, curing each point at the same time. It is found in two main arrangements: DLP can print parts upsides down (known as bottom-up printing) or right- side-up (known as top-down printing). Bottom-up DLP designs are typically used in desktop printers, as they maximize build volume, while top-down models are reserved for larger industrial application.

1.2 TYPES OF 3D PRINTER FILAMENT

The some of types of 3D Printer filaments are listed below:

1. PLA Filament
2. ABS Filament
3. PVA Filament
4. PETG Filament
5. Wood Filament
6. Metal Filament

1.2.1. Poly Lactic Acid (PLA) Filament

PLA stands for polylactic acid. It is the most widely used 3D printer filament type, partially because it is easy to print with. It has a lower printing temperature than some other filaments, including ABS, and it doesn’t easily warp, so it doesn’t require a heating bed. Another benefit of using PLA it is generally considered an odourless filament. PLA is available in a large variety of colours and styles. Many specialty filaments use PLA as the base material, such as those with glow-in-the-dark or conductive properties. PLA is considered more environmentally friendly than most 3D printer filaments, since it is created using renewable resources like corn starch and is biodegradable.

Compared to other types of 3D printer filament, PLA is brittle, so its applications don’t include items that might be bent, twisted, or repeatedly dropped, such as phone cases or tool handles. It also can’t be used for things that must withstand higher temperatures, as PLA tends to deform around temperatures of 60 degrees Celsius or higher. For all other applications, PLA makes for an excellent choice in 3D printer filament. Commonly printed items include models, low-wear toys, prototype parts, and containers.

Application: various surgical implants, including surgically implanted pins, rods, screws, and mesh.

Fig 1.10 Component made by PLA

1.2.2 Acrylonitrile Butadiene Styrene (ABS) Filament

Acrylonitrile butadiene styrene, or ABS, is the second most commonly used 3D printer filament. Products made of ABS have high durability and the ability to withstand high temperatures. Still, it does have a high printing temperature, a tendency to warp during cooling, and intense, potentially hazardous fumes while printing. When printing, a heated bed and in a well-ventilated space or enclosure is required.

ABS is moderately flexible and an excellent general-purpose 3D printer filament, but it is ideal for printing frequently handled or dropped items and parts that must withstand high temperatures. Examples include tool handles, phone cases, high-wear toys, and automotive trim components

Application: It is a great choice for printing plastic automotive parts, moving parts, musical instruments, kitchen appliances, electronic housings, and various toys.

Fig 1.11 Application of ABS

1.3.3 Polyvinyl Alcohol (PVA) Filament

PVA, or Polyvinyl Alcohol, is a soft and biodegradable polymer that is highly sensitive to moisture. When exposed to water, PVA will actually dissolve, which makes it a very useful support structure material for 3D printing. When printing extremely complex shapes or ones with partially enclosed cavities, PVA supports can be used and easily removed by dissolving in warm water. Standard supports may have been difficult to print or remove in these situations. PVA can also be used as a model material if there is a need to make quick prototypes.

PVA (Polyvinyl alcohol) is a good 3D filament that is typical it is a support material when printing with ABS or PLA. Support materials are necessary when printing 3D parts with notable overhangs. Without the support, these parts would be impossible to print or perfect. As a support material, PVA works best with printers that have dual extruders. All popular desktop FDM printers can use PVA with a heated build platform as this prevents warping during the build process.

Application: It used as a thickener in paper adhesives, in personal hygiene products, as a mould-release agent, kid's putty, and freshwater fishing products.

1.3.4. Polyethylene terephthalate glycol (PETG) Filament

PETG is an immensely popular 3D printing filament, widely used for its high strength, relative flexibility, and temperature resistance compared to the ever-popular PLA.PETG is a Glycol Modified version of Polyethylene Terephthalate (PET), which is commonly used to manufacture water bottles. It is a semi-rigid material with good impact resistance, but it has a slightly softer surface which makes it prone to wear. The material also benefits from great thermal characteristics, allowing the plastic to cool efficiently with almost negligible warpage. There are several variations of this material in the market including PETG, PETE, and PETT. The tips in this article will apply to all of these PET- based filaments.

Application: various food containers and other kitchen utensils.

Fig 1.12 Component made by PETG

1.3.5 Wood Filament

It seems strange, but yes, 3D wood filaments are very real. It's a great material for anyone who wants or needs to be more creative with their 3D printed projects. These filaments contain a careful mixture of recycled woods with a special binding polymer. The output model not only looks like real wood, it smells like it too. There's no shortage of impressive examples online that illustrate the amazing finish wood filaments can produce when printed to perfection.

Application: This filament uses for decor, ornate boxes, tables and chairs, figurines, and whatever else catches the imagination.

Fig 1.13 Components made by Wood Filaments

1.3.6 Metal Filament

Metal filaments are offering some very impressive, unique finishes to 3D printed parts. The materials consist of PLA combined with a higher percentage of fine metallic powders. The 3D printed parts look and feel just as they would if they had been made of 100% metals. Popular choices include aluminium, brass, bronze, copper, and stainless steel. Anyone who wants more of a creative effect can work on the end piece.

Application: It is perfect for hardware products, jewellery items, statues, replicas of artifacts and much more.

Fig 1.14 Components made by Metal Filaments

1.4 FIBRE

Fibres are thread-like structures that are long, thin and flexible.

1.4.1. TYPES OF FIBRE

a. **Natural Fibre**

b. **Synthetic Fibre**

1.4.1.1 Natural Fibre

The fibres obtained naturally from both plants and animals are termed as the natural fibres. These fibres are hair-like raw material directly obtainable from different plants and animals.

- Plant fibre
- Animal fibre
- Mineral fibre

a. Plant Fibre: The fibres obtained from the plant sources like – cotton and jute. The materials like Bamboo, coconut fibre, Flax seeds, Cannabis sativa plant species, Vegetable fibre, straw, Nettle, Ramie, wood, grains are different sources of plant fibres.

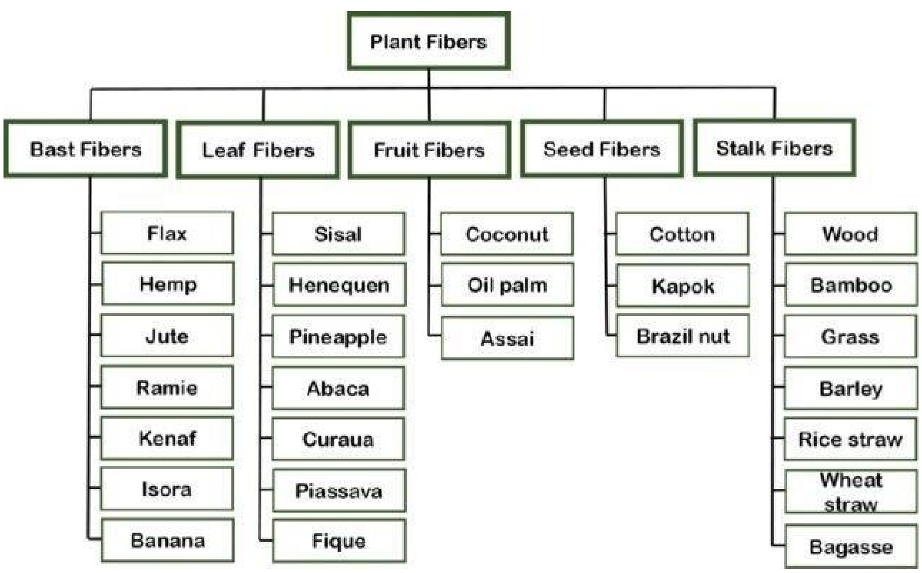

Fig 1.15 Classification of Plant Fibers

b. Animal Fibres: The fibres obtained from the animal sources are wool and silk. The animal fibres consist exclusively of proteins. Sheep, camel, cashmere, mohair goats, rabbits, and yak are the animals that provide us with wool. Silk is obtained from the silkworms.

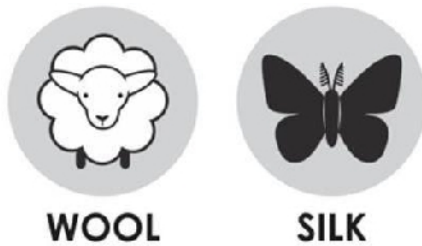

Fig 1.16 Animal fibre

c. Mineral Fibres: The inorganic materials shaped into fibres are known as mineral fibres. For example – Asbestos. These fibres are resistant to fire and acid and are used for industrial applications.

1.4.1.2. Synthetic Fibre

Synthetic fibres are man-made fibres produced from chemical substances. These are made by the process of polymerization. Synthetic fibres can either be completely synthetic or semisynthetic. Fibres that are purely synthetic like nylons, polyesters, acrylics are made from chemicals whereas semisynthetic fibres such as rayons are produced with the utilization of natural polymers as raw material.

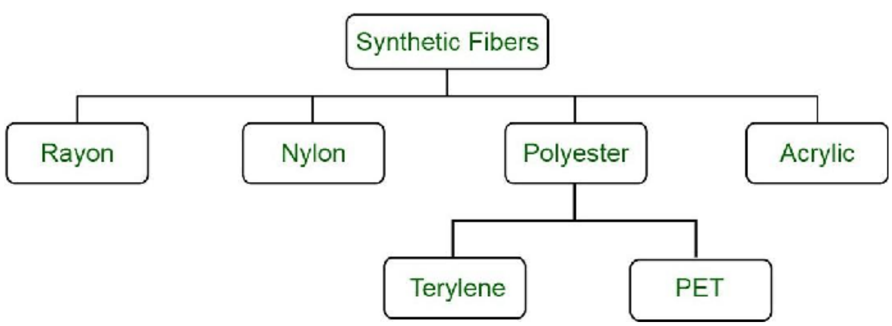

Fig 1.16 Classification of Synthetic Fibers

a. Rayon: Rayan has properties similar to those of silk .It is a man-made fibre and cheaper than silk. It is obtained from wood pulp .It is infused with cotton or wool to prepare bedsheets and carpets respectively. is also known as artificial silk and can be dyed in a wide variety of colours.

b. Nylon: These are strong elastic and light, lustrous and easy to wash fibres made from water, coal, and air initially. The fibre is completely synthetic and stronger than steel wire. It is used to make socks, ropes, toothbrushes, tents, seat belts, curtains, etc. Used to make ropes for rock climbing and parachutes.

c. Polyester: Polyester is made up of many units of an ester .It is suitable for making dress material because it is easy to wash and stays crisp and wrinkle-free. Terylene is a known polyester. PET (Polyethylene terephthalate) is used to make many useful products like bottles, utensils, films, wires.

d. Acrylic: Many sweaters and blankets are not created from natural wool but from a kind of synthetic fibre known as acrylic. The clothes prepared from acrylic are cheaper and more durable. Acrylic is more prevalent than natural wool.

CHAPTER 2

LITERATURE SURVEY

2.1. Farah Syazwani Shahar , Mohamed Thariq Hameed Sultan , Syafiqah Nur Azrie Safri , Mohammad Jawaid , Abd. Rahim Abu Talib , Adi Azriff Basri , Ain Umaira Md Shah January 2022 "**Fatigue and impact properties of 3D printed PLA reinforced with kenaf particles**" to investigate the density, fatigue and impact strength of the printed kenaf/PLA composite for its possible usability for AFO. The filler within the kenaf/PLA composite was varied at 3, 5 and 7 wt. % and extruded to obtain the composite filament, which was used with 3D printer to print out the specimens used for density, impact, and fatigue test. As the amount of fillers increased, the density and impact resistance decreases while fatigue life increases. In conclusion, the results found in the density and fatigue tests show a positive perspective towards its usability for AFO.

2.2. R. Jerez-Mesa , J.A. Travieso-Rodriguez , J. Llumà-Fuentes , G. Gomez- Gras , D. Puig 5 October 2017 **"Fatigue lifespan study of PLA parts obtained by additive manufacturing"** a design of experiments through Taguchi orthogonal arrays is applied to analyse the influence of five factors on fatigue life on PLA specimens. Five fatigue tests are performed for each combination of parameters. Results show that fill density, nozzle diameter and layer height are the most influential factors on fatigue lifespan. Finally, honeycomb proves to be the most beneficial infill pattern with regards to fatigue life**.**

2.3 LaythMohammed, M. N. M. Ansari, Grace Pua, Mohammad Jawaid, and Saiful Islam 30 August 2015 "**A Review on Natural Fiber Reinforced Polymer Composite and Its Applications**" Natural fiber-reinforced polymer composites have better properties such as low density, less expensive, and reduced solidity when compared to synthetic composite products This paper evaluates the characteristics and properties of natural fiber reinforced polymer composites. It stated clearly about mechanical, thermal, energy absorption, moisture absorption properties etc.

2.4. J. Antonio Travieso-Rodriguez, Ramon Jerez-Mesa, Jordi Llumà, Oriol Traver- Ramos, Giovanni Gomez-Gras and Joan Josep Roa Rovira 22 November 2019 analysed a paper in the **“Mechanical Properties of 3D-Printing Polylactic Acid Parts subjected to Bending Stress and Fatigue Testing” .** The orientation of the stacking of the layers is the most influential parameter in the rigidity, in the flexural resistance, and in the maximum deformation. The layer height and the filament width had a great significance in stiffness and flexural strength and no influence on maximum deformation. Printing velocity had a small, but significant effect on rigidity and flexural strength and no influence on maximum deformation. The fill density and infill pattern had no effect on the studied mechanical properties.

2.5 Lauren Safai, Juan Sebastian Cuellar, Gerwin Smit, Amir A. Zadpoor 23 March 2019 reviewed in the paper of **A review of the fatigue behavior of 3D printed polymers** ,review clearly show that, due to the synergism between printing parameters and the properties of the printed material, it is challenging to determine the best combination of variables for fatigue resistance. There is therefore a need for more experimental and computational fatigue studies to understand how the above-mentioned material and printing parameters affect the fatigue behaviour.

2.6. Feiyang He and **Muhammad Khan** 19 July 2021 **Effects of Printing Parameters on the Fatigue Behaviour of 3D-Printed ABS under Dynamic Thermo-Mechanical Loads .**The environmental temperature has the greatest influence on the fatigue performance, followed by the building orientation and nozzle size, whereas the layer thickness does not show a significant influence with a 0.164 *p*-value of ANOVA; A combination of the following parameters provides the longest fatigue life among the tested values: X building orientation, 0.8 mm nozzle size, and 0.15 mm-thick layer; Higher temperature reduces the fatigue life possibly due to more active molecular movement. The mean fatigue life of beams under 70 °C is approximate 32,000 cycles. It is only one third of that under 50 °C. It was found that printing void defects fundamentally affect the fatigue life of the FDM structure. Future work will extend the analytical modelling of the relationship between these printing parameters and the bending fatigue life of the ABS beam.

2.7. Fugen Daver, Kok Peng Marcian Lee, Milan Brandt and Robert Shanks October 2018 analysed a paper in the topic of **"Cork–PLA composite filaments for fused deposition modelling".** Inclusion of cork granules decreased the tensile strength, but improved impact strength. As the cork percentage increased, density of the composites decreased. Hence, the specific modulus and specific tensile strength properties improved as the cork content increased in the composites. Tributyl citrate (TBC), a biodegradable plasticiser, was used to overcome the inherent brittleness of PLA. TBC decreased the modulus, tensile yield strength; however, it increased ductility of the composites. A selected cork composite was used for filament production and it proved to be suitable for fused deposition modelling. 3D printed composites were compared with compression moulded composites. 3D printing resulted in slightly lower elastic modulus and tensile yield strength, but higher elongation at break compared with compression moulded composites.

2.8. **Yubo Tao, Honglei Wang, Zelong Li, Peng Li and Sheldon Q. Shi** 24 March 2017 analysed a paper in the title of "**Development and Application of Wood Flour-Filled Polylactic Acid Composite Filament for 3D**

Printing". The WF/PLA composite filament is suitable to be printed by the FDM process. Adding WF changed the microstructure of the PLA fracture surface, and the interfaces between the WF and PLA were obviously observable. The initial deformation resistance of the composite was enhanced after adding WF, compared to pure PLA. The starting thermal degradation temperature of the composites decreased slightly, and the final thermal decomposition residual ratio of the composites increased. Adding WF of 5 wt % has no effects on the melting temperature of the PLA.

2.9. Eda Hazal Tümer and Husnu Yildirim Erbil 29 March 2021 analysed in the paper of "**Extrusion-Based 3D Printing Applications of PLA Composites: A Review**" The selected additives for a specific application are mixed with the PLA matrix polymer, mostly using the melt extrusion. These are used in tissue engineering, bone repair applications, sensor, and battery industries. Printing orientation and temperature of the interfaces are important to determine the adhesion strength betweenthe deposited layers, which define the total mechanical strength of the object.

2.10. Emmanuel J. Ekoi , Andrew N. Dickson and Denis P. Dowling 2021 analysed a paper on **"Investigating the fatigue and mechanical behaviour of 3D printed woven and nonwoven continuous carbon fibre reinforced polymer (CFRP) composites"** from this study that the superior fatigue strength of the AM fabricated woven carbon fibre composites, indicate their potential for applications requiring high cyclic loads. Applications which can directly exploit this potential include medical devices (for example, prosthesis), contact sports equipment, structures, etc. In order to accomplish this, further investigations are necessary to understand the complexity of failure modes as it relates to AM woven composites. Amongst the planned investigations is the development of virtual testing methods for the fatigue failure of AM woven composites.

2.11. Miroslav Müller, Vladimír Šleger, Viktor Kolář , Monika Hromasová, Dominik Piš and Rajesh Kumar Mishra 23 March 2022 analysed a paper on **"Low-Cycle Fatigue Behavior of 3D-Printed PLA Reinforced with Natural Filler"**. The pure PLA and PLA reinforced with biological filler materials. Both types of samples were unable to pass 1000 test cycles with a load range of 5 to 70%. Under cyclic loading, the viscoelastic behaviour of the tested materials was determined from the results of relative deformation after finishing the 1st cycle and relative deformation after the last cycle. From the results, it was clear that as the cyclic loading value of 30%, 50% and 70% increases, the permanent deformation of the tested materials, i.e., viscoelastic behaviour (creep), also increases. Results of the low-cycle fatigue test for 3D-printed PLA reinforced with pinewood, bamboo and cork fillers showed that the addition of filler at different cyclic loading intensity reduced the relative deformation after the last cycle with respect to PLA without filler. The ratcheting deformation accumulated during cyclic loading under controlled stress has essentially no detrimental effect on the fatigue life of the tested materials.

CHAPTER 3

METHODLOGY

CHAPTER 4

FABRICATION OF SPECIMEN

4.1 PREPARATION OF FILAMENTS

From the above literature survey, we observed that the limited filament is only available for 3D printing. So, we decided to identify the new Composite Filament.

So, we decided to mix Natural Fibre like Flax to primary polymer like PLA. For that first PLA and Flax is converted into powder form and mixed together in certain ratio to make new composite matrix filament.

COMPOSITION : 95 % PLA & 5 % Flax

Fig 4.1 Fabrication on new composite filament

4.2 DESIGN OF SPECIMEN

For preparing the dogbone shape specimen, first the specimen can be drawn in anyone 3D design software like “Pro-E, CATIA, FUSION 360, etc., We drawn the specimen using the Creo software as per the standard (ASTM D638) dimensions as shown in fig 4.3(a) and (b) and file has been saved in respective format.

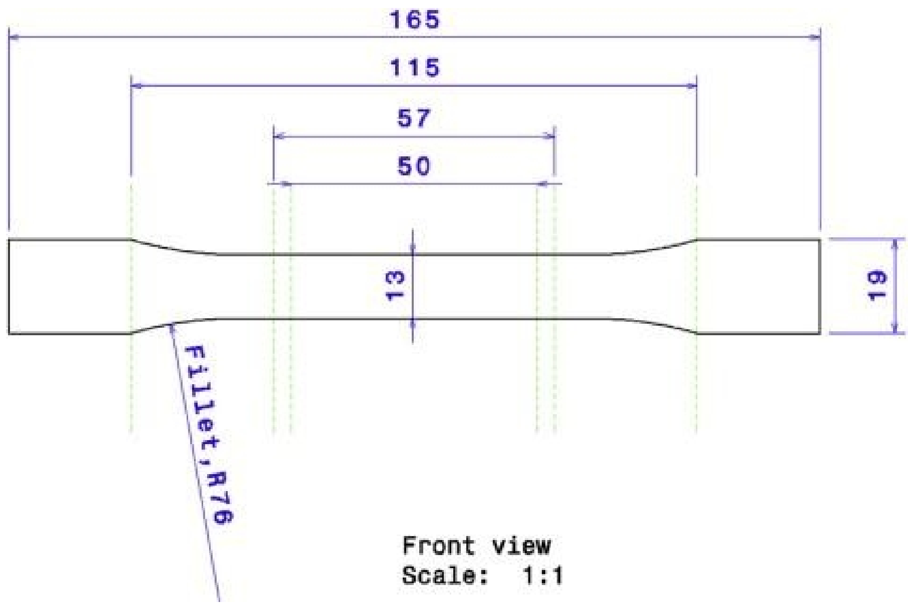

Fig 4.2 ASTM D638 dimension

ASTM D638 specifies methods for testing the tensile strength & fatigue test of plastics and other resin materials and for calculating their mechanical properties, and outlines accuracy requirements for the test frames and accessories used. This test method uses dumbbell-shaped specimens with either a 25 mm or 50 mm gauge length.

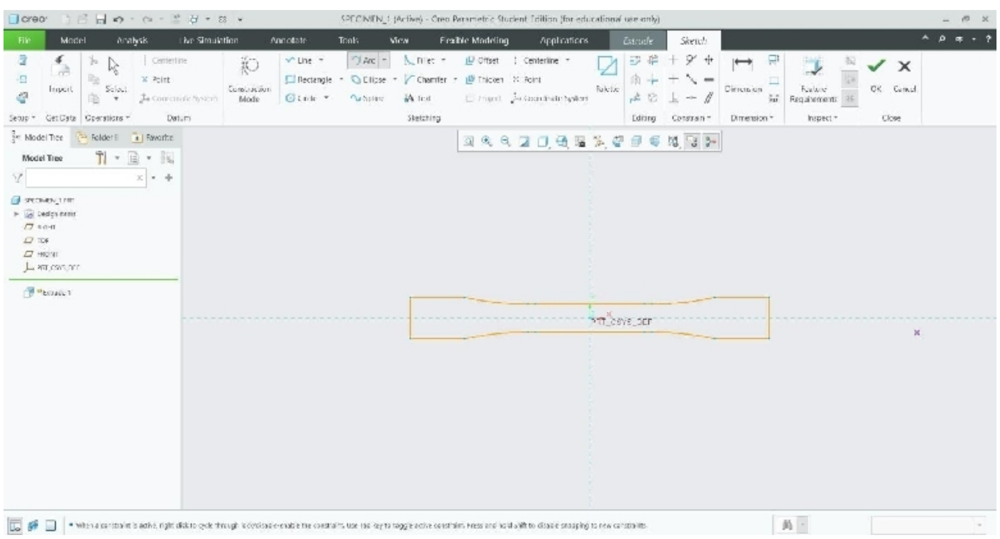

Fig 4.3(a) 2D Design in Creo Software

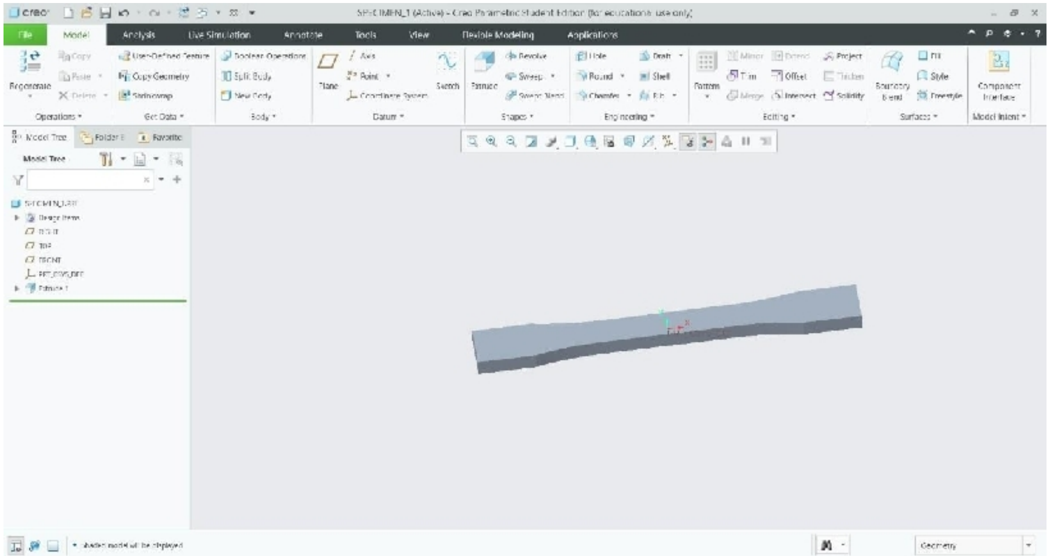

Fig 4.3 (b) Cero Design 2D Design After Extruded.

4.3 SLICING OF SPECIMEN

The diagram can be imported into the “Ultimaker Cura” software where the dimensions of the specimen are to be entered first. Then parameters such as layer thickness, wall height, wall count, top thickness, top layers, bottom thickness, bottom layers are to be encoded as shown in Fig 4.4.

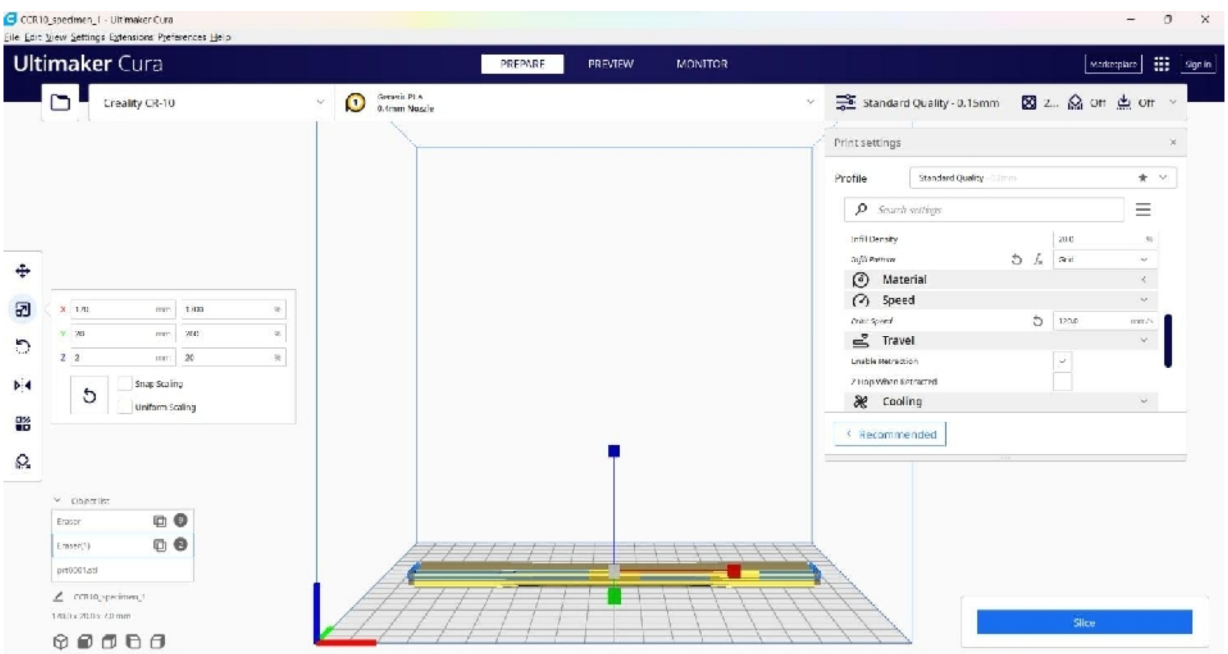

Fig 4.4 selection of parameters for specimen in ultimaker cura

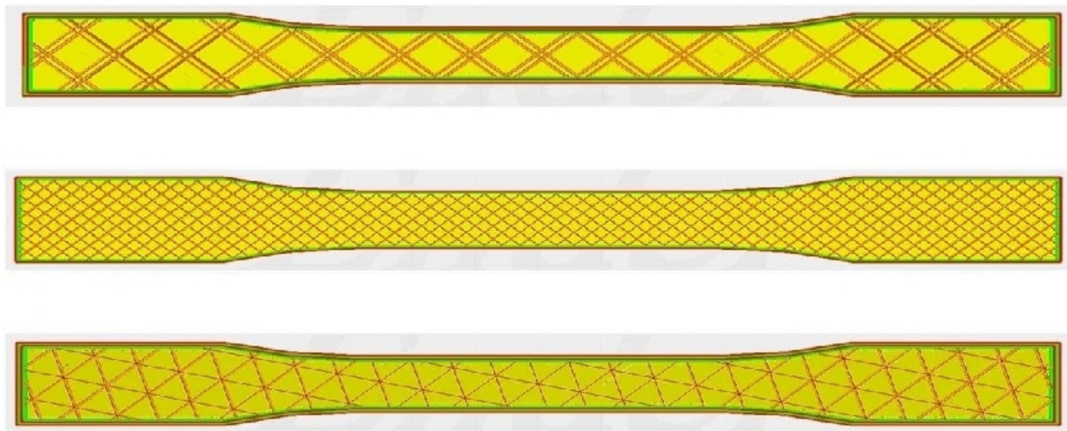

Fig 4.5 Various pattern we used in specimen

Next infill its density in terms of percentage and one of the infill patterns such as cross, tri-hexagon, triangles, lines, grid, cubic and zigzag can be selected. The printing temperature, build plate temperature and printing speed are to be entered and the process is to be sliced whereit shows a figure of the working of process and below it shows the weight of the specimen, length of filament to be used by the printer and time required for printer to print are displayed. These parameters are varied and the product can be produced.

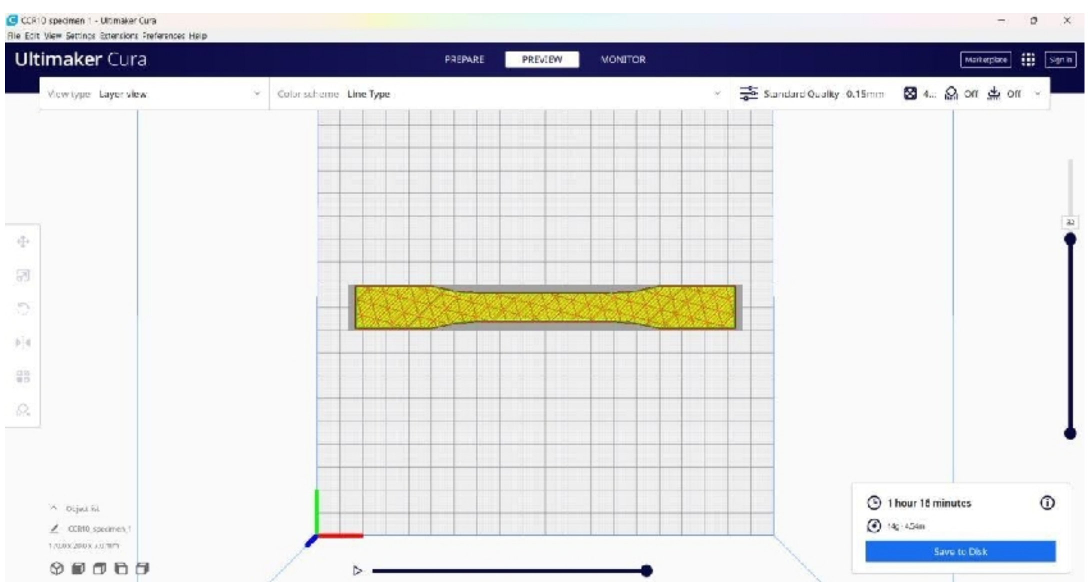

Fig 4.6 specimen 1 is ready for printing.

After sliced some G codes and M codes for Specimen 1

```
;FLAVOR:Marlin
;TIME:7873
;Filament used: 5.94891m
;Layer height: 0.2
;MINX:6.5
;MINY:79.5
;MINZ:0.2
;MAXX:193.5
;MAXY:120.5
;MAXZ:7
;Generated with Cura_SteamEngine 4.13.1 M140 S50
M105 M190 S50
M104 S200 M105
M109 S200
M82 ;absolute extrusion mode
; Ender 3 Custom Start G-code G92 E0 ; Reset Extruder
G28 ; Home all axes
G1 Z2.0 F3000 ; Move Z Axis up little to prevent scratching of Heat
Bed G1 X0.1 Y20 Z0.3 F5000.0 ; Move to start position
G1 X0.1 Y200.0 Z0.3 F1500.0 E15 ; Draw the first line G1 X0.4 Y200.0
Z0.3 F5000.0 ; Move to side a little G1 X0.4 Y20 Z0.3 F1500.0 E30 ;
Draw the second line G92 E0 ; Reset Extruder
G1 Z2.0 F3000 ; Move Z Axis up little to prevent scratching of Heat
Bed G1 X5 Y20 Z0.3 F5000.0 ; Move over to prevent blob squish
G92 E0 G92 E0
G1 F2700 E-5
;LAYER_COUNT:35
;LAYER:0 M107
G0 F6000 X15.403 Y79.713 Z0.2
;TYPE:SKIRT G1 F2700 E0
G1 F1200 X16.33 Y79.572 E0.03119 G1 X17.201 Y79.513 E0.06022
G1 X17.522 Y79.504 E0.0709 G1 X17.83 Y79.5 E0.08115 G1 X49.806
Y79.501 E1.14467 G1 X50.443 Y79.51 E1.16586 G1 X51.38 Y79.563
E1.19708
G1 X52.363 Y79.706 E1.23012 G1 X53.472 Y79.919 E1.26768 G1 X53.706
Y79.967 E1.27562 G1 X56.165 Y80.495 E1.35927 G1 X58.707 Y81.003
E1.44549 G1 X61.184 Y81.426 E1.52907 G1 X63.663 Y81.777 E1.61234 G1
X66.202 Y82.063 E1.69732
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G1 X68.571 Y82.265 E1.7764 G1 X71.172 Y82.415 E1.86306 G1 X73.678 Y82.489 E1.94644 G1 X75.118 Y82.5 E1.99434 G1 X124.883 Y82.5 E3.64953 G1 X127.491 Y82.463 E3.73628 G1 X130.029 Y82.355 E3.82077 G1 X131.462 Y82.263 E3.86853 G1 X133.982 Y82.045 E3.95266 G1 X136.504 Y81.755 E4.0371 G1 X138.961 Y81.403 E4.11965 G1 X141.475 Y80.969 E4.2045 G1 X143.843 Y80.493 E4.28484 G1 X146.799 Y79.86 E4.38538 G1 X147.433 Y79.734 E4.40688 G1 X148.36 Y79.591 E4.43808 G1 X149.346 Y79.525 E4.47095 G1 X150.443 Y79.502 E4.50744 G1 X150.674 Y79.5 E4.51513 G1 X181.951 Y79.501 E5.5554

G1 X182.649 Y79.511 E5.57862 G1 X183.585 Y79.565 E5.6098 G1 X184.513 Y79.697 E5.64098 G1 X185.427 Y79.909 E5.67219 G1 X186.319 Y80.198 E5.70337 G1 X187.184 Y80.561 E5.73457 G1 X188.014 Y80.997 E5.76576 G1 X188.805 Y81.502 E5.79697 G1 X189.549 Y82.073 E5.82816 G1 X190.242 Y82.705 E5.85936 G1 X190.879 Y83.393 E5.89054 G1 X191.454 Y84.134 E5.92174 G1 X191.965 Y84.92 E5.95292 G1 X192.407 Y85.748 E5.98414 G1 X192.776 Y86.61 E6.01533 G1 X193.071 Y87.5 E6.04651 G1 X193.289 Y88.412 E6.0777 G1 X193.429 Y89.34 E6.10891 G1 X193.487 Y90.201 E6.13761 G1 X193.496 Y90.521 E6.14826 G1 X193.5 Y90.83 E6.15854

G1 X193.499 Y108.9 E6.75955 G1 X193.49 Y109.627 E6.78373 G1 X193.439 Y110.564 E6.81494 G1 X193.307 Y111.492 E6.84612 G1 X193.098 Y112.406 E6.8773 G1 X192.811 Y113.299 E6.9085 G1 X192.449 Y114.165 E6.93972 G1 X192.015 Y114.996 E6.9709 G1 X191.511 Y115.787 E7.0021 G1 X190.942 Y116.532 E7.03328 G1 X190.311 Y117.227 E7.0645 G1 X189.624 Y117.865 E7.09568 G1 X188.885 Y118.442 E7.12687

G1 X188.099 Y118.954 E7.15807 G1 X187.273 Y119.397 E7.18924 G1 X186.411 Y119.769 E7.22047 G1 X185.522 Y120.065 E7.25163 G1 X184.61 Y120.285 E7.28283 G1 X183.683 Y120.426 E7.31402 G1 X182.799 Y120.487 E7.34349 G1 X182.478 Y120.496 E7.35417 G1 X182.17 Y120.5 E7.36442

G1 X150.194 Y120.499 E8.42794 G1 X149.557 Y120.49 E8.44913 G1 X148.62 Y120.437 E8.48035 G1 X147.637 Y120.294 E8.51339 G1 X146.528 Y120.081 E8.55095 G1 X146.294 Y120.033 E8.55889 G1 X143.835 Y119.505 E8.64254 G1 X141.293 Y118.997 E8.72876 G1 X138.816 Y118.574 E8.81234 G1 X136.337 Y118.223 E8.89561 G1 X133.798 Y117.937 E8.98059 G1 X131.429 Y117.735 E9.05967 G1 X128.828 Y117.585 E9.14633 G1 X126.322 Y117.511 E9.22971 G1 X124.882 Y117.5 E9.27761 G1 X75.117 Y117.5 E10.9328

G1 X72.509 Y117.537 E11.01955 G1 X69.971 Y117.645 E11.10404 G1 X68.538 Y117.737 E11.1518 G1 X66.018 Y117.955 E11.23593 G1 X63.496 Y118.245 E11.32036 G1 X61.039 Y118.597 E11.40292 G1 X58.525 Y119.031 E11.48777 G1 X56.141 Y119.51 E11.56865 G1 X53.216 Y120.137 E11.66814 G1 X52.574 Y120.265 E11.68992 G1 X51.647 Y120.409 E11.72112 G1 X50.654 Y120.475 E11.75422 G1 X49.557 Y120.498 E11.79071 G1 X49.326 Y120.5 E11.7984

G1 X18.049 Y120.499 E12.83868 G1 X17.351 Y120.489 E12.86189 G1 X16.415 Y120.435 E12.89308 G1 X15.487 Y120.303 E12.92425 G1 X14.573 Y120.091 E12.95546 G1 X13.681 Y119.802 E12.98665 G1 X12.816 Y119.439 E13.01785 G1 X11.986 Y119.003 E13.04903 G1 X11.195 Y118.498 E13.08024 G1 X10.451 Y117.927 E13.11144 G1 X9.758 Y117.295 E13.14263 G1 X8.546 Y115.866 E13.20501 G1 X8.035 Y115.08 E13.23619 G1 X7.593 Y114.252 E13.26741 G1 X7.224 Y113.39 E13.2986

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G0 F9000 X18.649 Y98.411
G1 F1500 X28.587 Y108.349 E1787.10684 G0 F9000 X28.021 Y108.349
G1 F1500 X18.649 Y98.977 E1787.54767 G0 F9000 X18.649 Y99.542
G1 F1500 X27.456 Y108.349 E1787.96192 G0 F9000 X26.89 Y108.349
G1 F1500 X18.649 Y100.108 E1788.34955 G0 F9000 X18.649 Y100.674
G1 F1500 X26.324 Y108.349 E1788.71056 G0 F9000 X25.759 Y108.349
G1 F1500 X18.649 Y101.24 E1789.04497 G0 F9000 X18.649 Y101.805
G1 F1500 X25.193 Y108.349 E1789.35278 G0 F9000 X24.627 Y108.349
G1 F1500 X18.649 Y102.371 E1789.63397 G0 F9000 X18.649 Y102.937
G1 F1500 X24.062 Y108.349 E1789.88855 G0 F9000 X23.496 Y108.349
G1 F1500 X18.649 Y103.502 E1790.11654 G0 F9000 X18.649 Y104.068
G1 F1500 X22.93 Y108.349 E1790.31791 G0 F9000 X22.365 Y108.349
G1 F1500 X18.649 Y104.634 E1790.49267 G0 F9000 X18.649 Y105.199
G1 F1500 X21.799 Y108.349 E1790.64084 G0 F9000 X21.233 Y108.349
G1 F1500 X18.649 Y105.765 E1790.76238 G0 F9000 X18.649 Y106.331
G1 F1500 X20.668 Y108.349 E1790.85733 G0 F9000 X20.102 Y108.349
G1 F1500 X18.649 Y106.896 E1790.92567 G0 F9000 X18.649 Y107.462
G1 F1500 X19.536 Y108.349 E1790.96739 G0 F9000 X18.97 Y108.349
G1 F1500 X18.649 Y108.028 E1790.98249 G0 F9000 X18.3 Y108.028
;TIME_ELAPSED:7873.108214 G1 F2700 E1785.98249
M140 S0 M107
G91 ;Relative positioning G1 E-2 F2700 ;Retract a bit
G1 E-2 Z0.2 F2400 ;Retract and raise Z G1 X5 Y5 F3000 ;Wipe out
G1 Z10 ;Raise Z more
G90 ;Absolute positioning

G1 X0 Y200.0 ;Present print M106 S0 ;Turn-off fan
M104 S0 ;Turn-off hotend
 M140 S0 ;Turn-off bed
```

Fig 4.7 Specimen while printing

CHAPTER 5

TESTING OF SPECIMEN

5.1 FATIGUE TEST

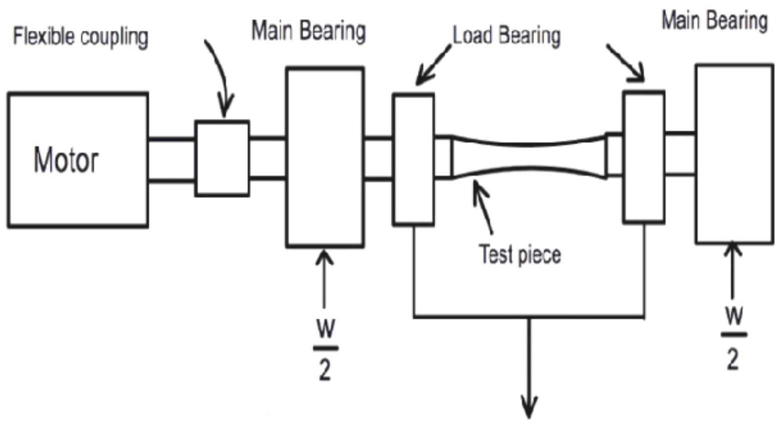


Fig 5.1 Fatigue test apparatus

Fatigue is the failure (by fracture) of structures that are subjected to repeated or cyclic loading i.e., periodic stress-time variation, e.g.,

(a) axial tension-compression,

(b) reversed bending and

(c) torsion or twisting.

Once a fatigue crack has initiated, each loading cycle will grow the crack a small amount, typically producing striations on some parts of the fracture surface. The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, producing rapid propagation and typically complete fracture of the structure.

Usually, the purpose of a fatigue test is to determine the lifespan that may be expected from a material subjected to cyclic loading, however fatigue strength and crack resistance are commonly sought values as well. The fatigue life of a material is the total number of cycles that a material can be subjected to under a single loading scheme. A fatigue test is also used for the determination of the maximum load that a sample can withstand for a specified number of cycles. All of these characteristics are extremely important in any industry where a material is subject to fluctuating instead of constant forces.

To perform a fatigue test a sample is loaded into a fatigue tester or fatigue test machine and loaded using the pre-determined test stress, then unloaded to either zero load or an opposite load. This cycle of loading and unloading is then repeated until the end of the test is reached. The test may be run to a pre-determined number of cycles or until the sample has failed depending on the parameters of the test.

Compact tension coupon (CT). The compact specimen uses the least amount of material for a specimen that is used to measure crack growth. Compact tension specimens typically use pins that are slightly smaller than the holes in the coupon to apply the loads. This method however prevents the accurate application of loads near zero and the coupon is therefore not recommended when negative loads need to be applied.

- *Centre Cracked Tension* panel (CCT). The centre cracked tension or middle tension specimen is made from a flat sheet or bar containing two holes for attaching to grips .
- *Single Edge Notch Tension* coupon (SENT). The single edge coupon is an elongated version of the compact tension coupon.

The following instrumentation is commonly used for monitoring coupon tests:

- Strain gauges are used to monitor the applied loading or stress fields around the crack tip. They may be placed beneath the path of the crack or on the back face of a compact tension coupon.
- An extensometer or displacement gauge can be used to measure the crack tip opening displacement at the mouth of a crack. This value can be used to determine the stress intensity factor which will change with

the length of the crack. Displacement gauges can also be used to measure the compliance of a coupon and the position during the loading cycle when contact between the opposite crack faces occurs in order to measure crack closure.

- Applied test loads are usually monitored on the test machine with a load cell.

Application of fatigue test:

1. Usually the purpose of a fatigue test is to determine the lifespan that may be expected from a material subjected to cyclic loading, however fatigue strength and crack resistance are commonly sought values as well.
2. The fatigue life of a material is the total number of cycles that a material can be subjected to under a single loading scheme.
3. A fatigue test is also used for the determination of the maximum load that a sample can withstand for a specified number of cycles.
4. All of these characteristics are extremely important in any industry where a material is subject to fluctuating instead of constant forces.

5.2 IMPACT TEST

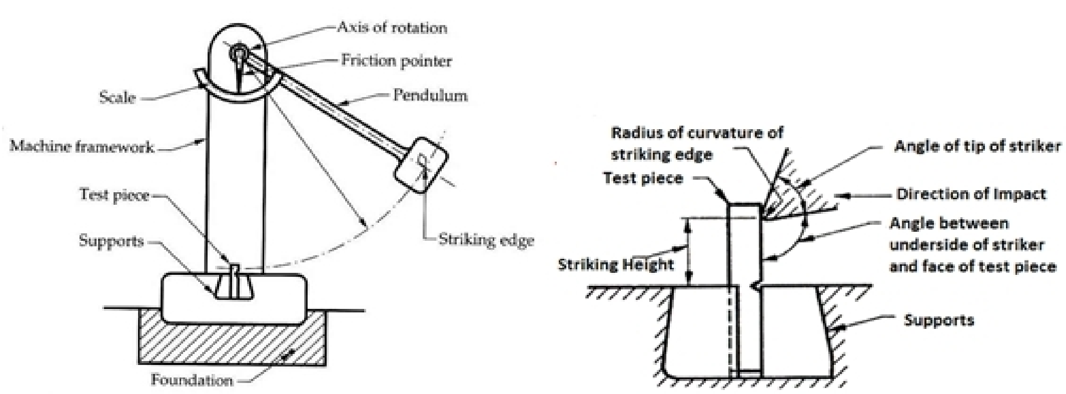


Fig 5.2 Impact test

Impact resistance is a property which is not a unique value for every material as it can differ considerably depending on the HDT of the object. It is therefore interesting to investigate the different behaviour of the material at different temperatures in order to construct a graph and understand the possible temperature ranges of use.The tests are performed by a tool equipped with a calibrated mallet which impacts the specimen with a known amount of energy (proportional to the weight of the mallet and the starting height) when it rotates. The energy dissipated is measured by the angle at which the bat rises after impact; the greater the angle, the less energy is dissipated. In the picture below we can see the test machine in use in Weerg, ready to run the test on a PA12 specimen made in HP MJF.

The following picture shows the two different configurations. In Weerg all tests are performed by the Charpy approach following the regulations, in order to have uniform and comparable data both between the different materials available in our portfolio and materials produced with other technologies. It also gives designers a clearer idea of the possible applications of the processed materials with additive technologies, which are increasingly replacing traditional production technologies. The standard test method for Dynamic Tear testing of metallic materials as defined by ASTM International. Dynamic Tear Testing has a wide range of Research and Development applications. Used to study the effects of metallurgical variables like heat treatment, composition, and processing methods on the dynamic tear fracture resistance of material. Manufacturing processes, such as welding, can be effectively evaluated for their effect on dynamic tear fracture resistance Additional uses for this impact test include evaluating the appropriateness of selecting a material for an application where a baseline correlation between Dynamic Tear energy and actual performance has been developed.

The drop-weight test employs simple beam specimens specially prepared to create a material crack in their tensile surfaces at an early time interval of the test. The test is conducted by subjecting each of a series (generally four to eight) of specimens of a given material to a single impact load at a sequence of selected temperatures to determine the maximum temperature at which a specimen breaks. The impact load is provided by a guided, free-falling weight with an energy of 250 to 1400 ft·lbf (340 to 1900 J) depending on the yield strength of the steel to be tested. The specimens are prevented by a stop from deflecting more than a few tenths of an inch.The on-site Mechanical Engineering laboratory is staffed by specialists and engineers in product evaluation of actual prototype components and subassemblies. From custom design and fabrication of fixtures, to conducting the test, our mechanical engineers have the expertise and resources to assist our various testing departments in delivering data to customers in an efficient and timely manner.

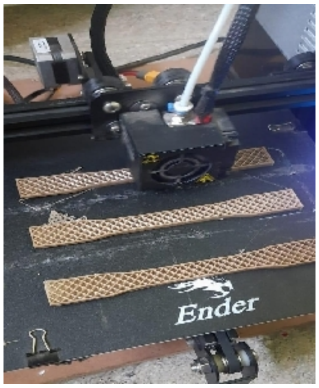
Application of impact test:

1. An impact test is used to observe the mechanics that a material will exhibit when it experiences a shock loading that causes the specimen to immediately deform, fracture or rupture completely.
2. The purpose of an impact test is to determine the ability of the material to absorb energy during a collision.
3. This energy may be used to determine the toughness, impact strength, fracture resistance, impact resistance or fracture resistance of the material depending on the test that was performed and the characteristic that is to be determined.
4. These values are important for the selection of materials that will be used in applications that require the material to undergo very rapid loading processes such as in vehicular collisions.
5. This collision between the weight and specimen generally results in the destruction of the specimen but the transfer of energy between the two is used to determine the fracture mechanics of the material.

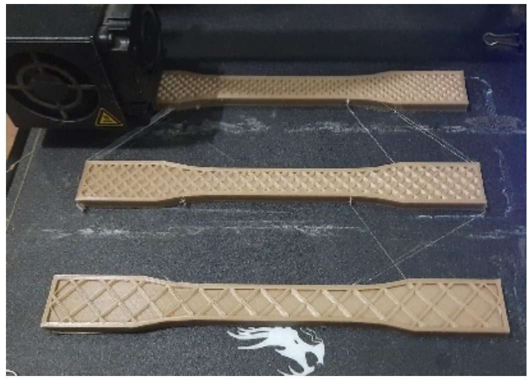
5.3 PRINTING OF SPECIMEN

Here there are n number of components has been prepared according to ASTM standard based on the parameters like layer height, infill and printing speed are varied by using a “Taguchi Method”.

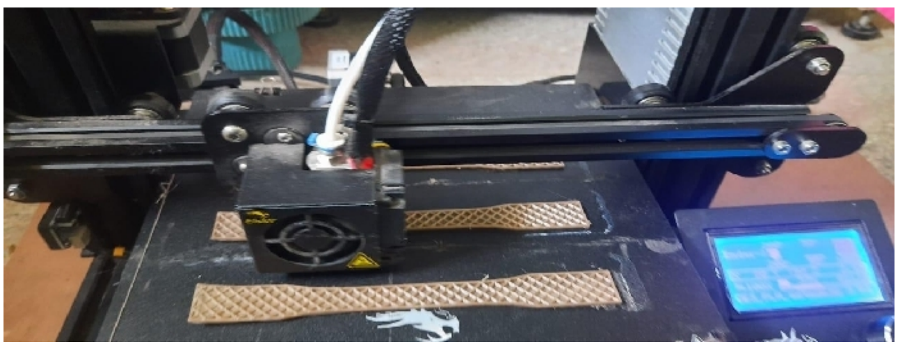
The below figure 4.6 (a), (b), (c) shows how the specimens are made by the 3d printers. Here each specimen is varied by the density percentage of infill and the pattern of the infill.



(a)



(b)



(C)

FIG 5.3 (a), (b), (c) MAKING OF SPECIMEN IN 3D PRINTER

The various input process parameters of infill, speed and layer thickness of specimens is to be tested for tensile properties for gradual applying load is shown in the below table.

Table 5.1: Input Parameters by Taguchi method of quality control.

SL. NO.	TOP INFI(LL %	BOTTOM INFILL	SPEED mm/s	LAYER THICKNESS	MAX LOAD(KN)	MIN LOAD(KN)	FREQUENCY(HZ)	DISPLACEMENT (mm)	
1	15	15	70	0.2	1.420	0.257	5.134	1.822	1.07
2	15	45	50	0.15	0.938	0.113	5.081	1.011	0.681
3	15	30	60	0.1	0.737	0.102	5.12	0.917	0.639
4	45	15	50	0.1	1.207	0.219	5.1360	1.417	0.862
5	30	15	60	0.15	1.092	0.159	5.081	1.183	0.740

CHAPTER – 6

CONCLUSION

We conducted “Fatigue Testing” with 3D specimens as shown in figure 6.1 and 6.2 which we have fabricated, some results have been discussed below of the materials properties.

Fig 6.1 specimen loaded in Fatigue test machine

Fig 6.2 After run the Fatigue test Specimen

The gauge length of the specimen is measured. The width and thickness of the different specimen is measured. The input percentage of applied stress for different specimen are noted. The maximum stress applied is noted down. The maximum load can be applied for different specimen is noted. The stress ratio and frequency is 0.1 and 5Hz for each specimen. The number of cycles for the specimen fails is noted in cycles. The graph between the load (KN) and number of cycles shown in figure 6.3

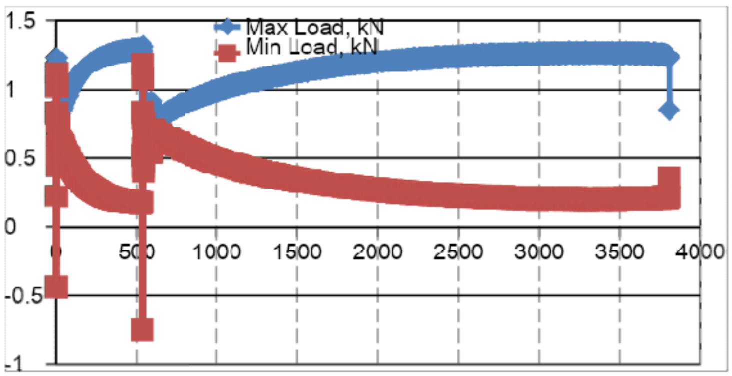


Fig 6.3 load (KN) VS number of cycle

In above graph (Fig 6.3), brown color indicates minimum strain value and blue color indicates maximum stress value. From the graph maximum stress value is 1.25 Mpa and minimum stress value is 0.29 Mpa. The Graph shows that the specimen withstand load upto 3806 cycles.

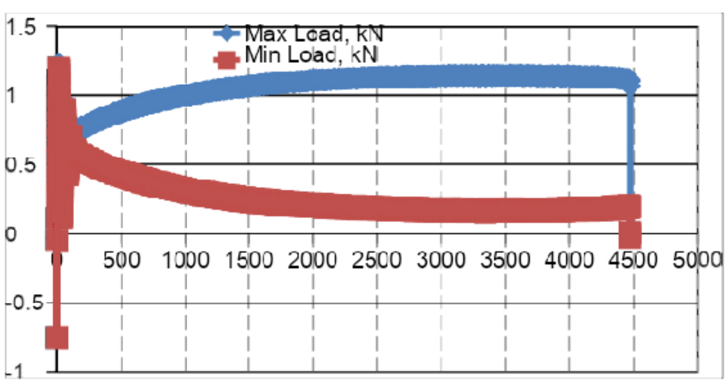


Fig 6.4 load (KN) VS number of cycle

In above graph (Fig 6.4), brown color indicates minimum strain value and blue color indicates maximum stress value. From the graph maximum stress value is 1.15 Mpa and minimum stress value is 0.19 Mpa. The Graph shows that the specimen withstand load upto 4475 cycles.

Fig 6.5 load (KN) VS number of cycle

In above graph (Fig 6.5), brown color indicates minimum strain value and blue color indicates maximum stress value. From the graph maximum stress value is 1.02 Mpa and minimum stress value is 0.4 Mpa. The Graph shows that the specimen withstand load upto 11962 cycles.

Fig 6.6 load (KN) VS number of cycle

In above graph (Fig 6.6), brown color indicates minimum strain value and blue color indicates maximum stress value. From the graph maximum stress value is 0.85 Mpa and minimum stress value is 0.13 Mpa. The Graph shows that the specimen withstand load upto 16383 cycles.

Fig 6.7 load (KN) VS number of cycle

In above graph (Fig 6.7), brown color indicates minimum strain value and blue color indicates maximum stress value. From the graph maximum stress value is 0.69 Mpa and minimum stress value is 0.09Mpa. The Graph shows that the specimen withstand load upto 55083 cycles.

Fig 6.8 Specimen after impact test

This Figure 6.8 shows that the breakage of specimen after impact test. Then the value is used to draw SN ratio curve.

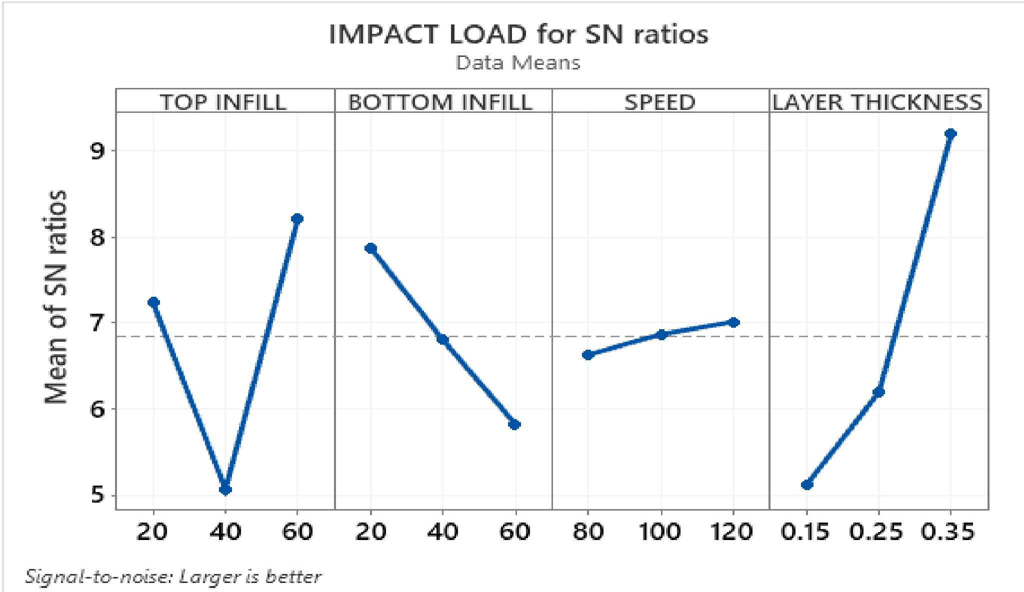


Fig 6.9 SN Ratios for Impact Test

Above Fig 6.9 drawn for signal to noise (SN) ratio curve with varying the parameters like top infill, bottom infill, speed and layer thickness.

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