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The Effects of Fiber Orientation and Volume Fraction of Fiber on Mechanical Properties of Additively Manufactured Composite Material

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By

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Abstract

Additive manufacturing (AM) also known as 3D printing has tremendous advancements in recent days with a vast number of applications in industrial, automotive, architecture, consumer projects, fashion, toys, food, art, etc. Composite materials are widely used in structures with weight as a critical factor especially in aerospace industry. Recently, additive manufacturing technology, a rapidly growing innovative technology, has gained lot of importance in making composite materials. The properties of composite materials depend upon the properties of constituent's matrix and fiber. There is lot of research on effect of fiber orientation on mechanical properties of composite materials made using conventional manufacturing methods. It will be interesting and relevant to study the relationship between the fiber orientation and fiber volume with mechanical properties of additively manufactured composite materials. This thesis work presents experimental investigation of mechanical behavior like tensile strength and fatigue life with variation in fiber orientation and fiber volume fraction of 3D printed composite materials. The aim is to study the best combination of volume fraction of fiber and fiber orientation that has better fatigue strength for additive manufactured composite materials. Using this study, we can decide the type of orientation and volume percent for desired properties. This study also finds the range of fatigue limits of 3d printed composite materials.

Keywords: additive manufacturing, composite material, 3d printing, fiber glass, MTS, nylon, fatigue testing, tensile testing

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Introduction

As additive manufacturing is enhancing constantly, it has become a powerful tool in creating complex structure and geometries with efficient use of the material in a brief time. Among all other sectors where additive manufacturing technology user-friendly in medical, automotive, and aerospace Industries. The main advantage of this technology is its affordability, low volume production with customized products and diverse applications. Although it has so many advantages, there is still a lot more to improve in the low-quality production, material affordability, equipment accuracy, and reliability.

Composite are two or more materials combined so that other materials enhance the structural properties. for better composite material properties like tensile, fatigue etc., unique type and quantities of the individual material is selected and combined. Composites have more stiffness to weight ratio compared to the traditional materials like metal alloys.

The aim of the study the effect of fiber orientation along with volume fraction on the mechanical properties of additive manufactured composite materials are being studied in detail. Also, the mechanical properties of additive takes composite materials are being compared to that of conventional manufactured.

Therefore, in this research study, we tried to experimentally investigate the mechanical behavior of 3D printed Fiber Glass material by completing tensile and fatigue testing using ASTM standards.

Literature review

Banakar et al. [1] studied the impact of fiber orientation and thickness of laminated polymer composites on tensile properties. The materials used are bi-woven fiber glass that acts like reinforcements and epoxy resin as a matrix material that with transfer the load to the stiff fibers through shear stress. Three different orientation ±30°, ±45°, ±90° and two different thickness 2mm and 3mm are considered. The specimens are made by using a hand lay-up process. Tensile testing of these specimens is tested by using UTM machine They came with some conclusions that specimens with lesser thickness prompt greater ultimate tensile strength regardless of the fiber orientation. In addition to that, the with 90° orientations will withstand higher loads compared to other orientations. Furthermore, Young's modulus and thickness are in inversely proportional. Finally, they concluded that the elongation of the sample is less in the case of 90° and higher in the case of 30°.

Razzak et al. [2] investigated the effects of volume fraction on fatigue strength of unsaturated polyester/glass fiber composites. It studies polymeric composites from unsaturated polyester as a matrix reinforced with glass fiber. Two different volume fractions i.e. ratio of fiber volume to the composite volume is considered 20% and 40%. The samples were tested for reinforced with uniform (woven) epoxy-glass fiber and random (continuous fibers). The study shows both samples with volume fraction 40% has more fatigue strength than the samples with the volume fraction of 20%. The single sheet with required dimensions are made and then it is cut to specimens. The instruments used are Alterbending bending fatigue machine. The study also showed that the samples reinforced with uniform (woven) have fatigue strength more than that for sample reinforced with random (Continuous fibers).

Research done by Kumaresan et al. [3] explored the effects of fiber orientation on mechanical properties of sisal fiber reinforced epoxy composites. samples made from compression molding with orientations of 0°, 90° and 45° are tested for mechanical properties. The material used is Sisal fiber (botanical name Agave sisalana fiber) that was treated with NaOH solution, the matrix material is an Epoxy resin of the grade LY556. The mechanical properties are studied using three different experiments namely tensile testing, bending test or Flexural test and impact test. The mechanical properties like tensile and flexural strength and impact strength are maximum in case of 90° orientation compared to 0° and 45°. They concluded that the 90° orientation will have better mechanical properties in this case. In addition,

Research conducted by Jones et al. [4] revealed the effects on material properties of layer-layer application of pressure for the polymeric parts generated by using additively manufacturing technology. This study compares the properties of commercial thermoplastic elastomers and selective laser sintering (SLS). This concludes that the applying pressure increases the mechanical properties compared to conventional methods. And their future work focusses on perfecting processing conditions to know the processable range materials using additive manufacturing.

From this literature review, these studies made it straightforward for me to understand current and future research in the field of additive manufacturing and composites. I realized that volume fraction and fiber orientation are clearly affecting the mechanical properties of composites. So, the work in this thesis investigates the effects of the orientation of fibers and volume percent on additively manufactured composite materials.

Composite Materials

Composites are generally a combination of two or more material with different properties that yield to a new material with properties different and better compared to the original material. Composite exist in natural and man-made form. Some of the natural composites are wood made with cellulose and lignin. The bone that is made from calcium phosphate, collagen. Granite made up of feldspar, mica, and quartz. Some of the man-made composites include concrete made with sand cement and water, Fiberglass that is a plastic matrix with glass fibers reinforcements. Cement made with ceramics and metal composites. Although some materials seem like composite they are not. For example, plastic that has many fillers they do not change the physical properties. Also metal with impurities does not change physical properties in a noticeable amount.

Uses of composite materials

Now a day's composite has a vast number of applications. Industries like Automotive, aerospace, sports, transportation, infrastructure, healthcare, heavy machinery, consumer goods, agriculture equipment, biomedical industry, computers and much more. In aerospace, the parts need to be lighter, stronger, temperature resistant, and good wear resistant. Some of the components are elevators, rudders, doors, nose, spoilers, stabilizers etc. in aircraft. Pressure tanks, fuel tanks, turbo-motor stators, nose in rockets and missiles. Frames, structural parts, and antennae in satellites. Composites are used to construct Dams, Railway coaches, bridges, ships, boats, trucks, motor cycles, etc.

Classification of composites

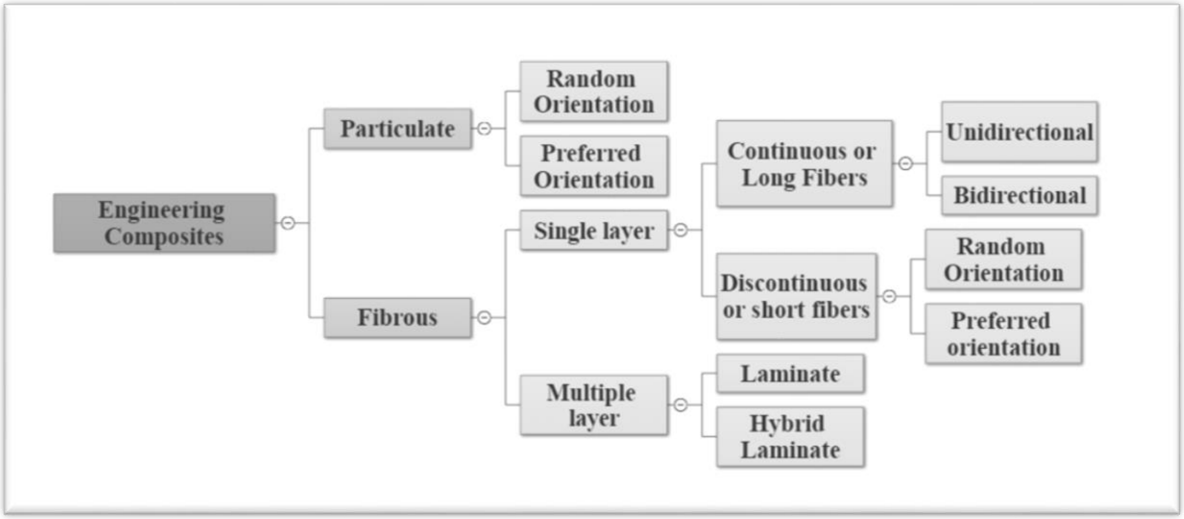

Figure 1Classification of Composites

Composites are classified to two types Particulate composites and Fibrous composites. Particulate composites have one or more material particles in a binding matrix as a reinforcement along with matrix material that binds them. Particles are as small as <0.25 microns. Some examples of particulate composites Include hollow spheres, carbon Nano-tube, platelets, chopped fibers etc. Fibrous composites have one or more material fibers in a binding matrix as a reinforcement along with matrix material that binds them.

Particulates composites are further classified to random orientation and preferred orientation. Random orientation is particles are distributed randomly in all directions, for example, concrete. In concrete all the sand, stone are randomly distributed with no specific arraignment. The preferred orientation of particles is distributed in a specific direction like extruded plastics. Particulate composite does not have good fracture resistance. Particles, in general, add stiffness to the composite. Their hardness is used as an advantage as cutting tools at high speeds as they have better properties a high temperature.

Fibrous material has good thermos-mechanical properties. They are further classified to single layer and multilayer. The single layer has several numbers of layers with all the layers orientation in the same direction. They are again classified to continuous and long fibers, discontinuous and long fibers. Continuous fibers can be either unidirectional or bidirectional reinforcement. Discontinues can be randomly oriented or can be reinforced in preferred directions. Multi-layer has a difference in the orientation of each layer. It can be broken down to laminate i.e. having single material in each layer, hybrid laminate i.e. having two or more materials in the layers.

Advantages of composites

Composites are used widely for engineering applications. Composites can be customized to meet our need with required properties. Some of the properties like strength, weight, electrical conductivity, thermal conductivity, aesthetics, resistance to wear, vibration damping, fatigue and resistance to corrosion, high-impact strength, design flexibility, Part consolidation, nonconductive, durable, and nonmagnetic. Production cost is reduced. Composites also have the stiffness-to-weight ratio.

Disadvantages of composites

Like every coin has two faces, composites have some limitations as well. Composites are brittle than wrought metals. Materials need to be refrigerated and have less shelf life. Special equipment is needed for hot curing process which makes this process expensive. Composites are non-homogenous so their properties vary point to point. Fabrication requires a lot of effort and time taking. Laminate composites are sensitive to high temperatures also to moisture. The performance of the composites varies due to the long-time exposure with composites. Although the product is efficient, the raw materials are expensive.

Alloy vs composites

Although alloy and composites hold two more materials combined to obtain required, there are noticeable differences between them. In alloy, the liquid form of two or more materials Solute and solvent combined to form a solid solution. And in an alloy, they cannot be distinguished or separated. Also, the materials do not keep their original properties after forming an alloy. But in composites, two or more materials can be combined with individual properties. They can be distinguished after combined. After the matrix is added, the reinforcement is not dissolved in the matrix and can be found fibers or particles in the matrix of the composites.

Making of composites

Thermoset composites are fabricated using two methods one is "wet-forming" and another one is "premixes or prepregs". In wet processing, the resin (liquid state) is formed to needed shape and the application of external heat and pressure will cure it. Some of the processes include hand layup, bag molding, filament winding, RTM (resin transfer molding), compression molding, pultrusion.

Hand lay-up

It is one of the oldest methods also called as contact layup process. This method is used for low volume production used in boats, pools, and furniture. This process needs a flat surface to make sheets and mold to generate the final product. Mold can be made with wood, metals, plastic etc. this involved two methods for continuous fiber and one for short fibers. For continuous fiber, the resin is sprayed over the mold using hand brush or spraying tool and fiber is placed layer by layer using layers to remove the trapped air bubbles. This process is done till the part gets required thickness. For short fibers, the fibers are sprayed from the second nozzle of the spray process.

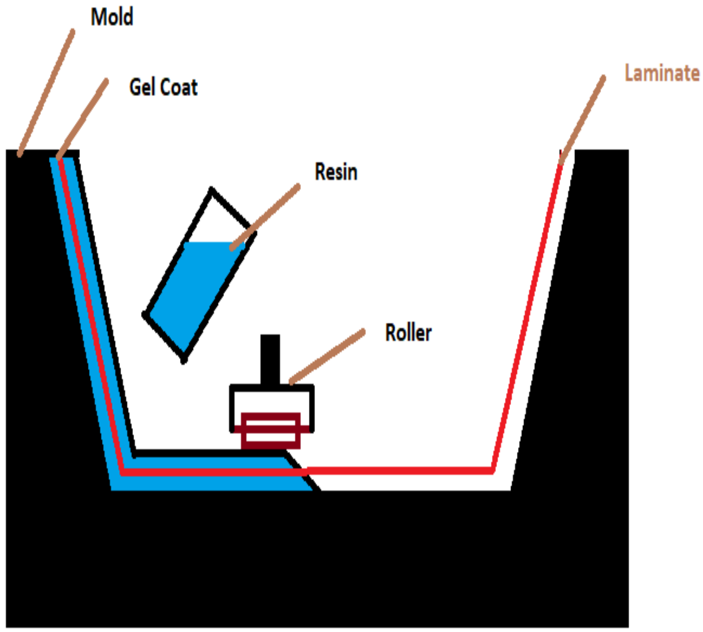

Figure 2 Composite manufacturing using Hand-layout process.

Filament winding

It is open molded process uses a rotating mandrel as a mold. This is mainly used to produce hallow product like cylinders, pipes, pressure vessels and casings. Continuous strands of fibers are mixed with resins and rolled over the mandrel using a computer guided system in a pattern making the part to withstand more loads. After the part of required thickness is obtained it is cured and removed from the mandrel. Filament winding using chopped fibers is called as hoop chop process. This process can control the fiber orientation and tolerances.

Compression molding

Compression molding is used to produce complex at a fast pace of time. The chopped fibers are combined with resin and mixed thoroughly. Layer is then placed in the molding machine that is heated. The molds are closed and pressure, as well as temperature, is applied on the part depending on the size shape and thickness. After the mold is opened and the part can be removed. Labor cost is less and it produces parts with good surface finish.

Pultrusion

This is a closed continuous process with resulting parts have a similar cross-section. This is used to make beams, pipe, tubes, fishing roads etc. these products have good structural properties. Stands of fibers are impregnated with resin then pulled through a steel die so this is called pultrusion. The steel die sets the shape and adjusts the ratio of fiber to the resin. The die is heated to cure the composite resin and later they are cut to specified dimension.

Vacuum bag molding

The mold is put under vacuum this removes the trapped air bubbles and atmospheric pressure is applied on the part compacting it and removing the excess resin. A flexible film of nylon, PVA or polyethylene is placed over the wet layout. After the edges are sealed the vacuum is drawn out of the part. This process can produce parts with the uniform degree. Resin rich problem in traditional methods can be eliminated using this process.

Vacuum infusion process

This closed process is similar to vacuum bag molding but the resin is added after the part is depressurized so there will not be any extra resin deposition over the part. The resin is connected to the mold and as the vacuum draws the air, the resin is pulled to all the perforations in the part. This process will reduce the reduction is the emissions compared to open molding and vacuum bagging.

Resin transfer molding

RTM is an intermediate process of composite production. The mold cavity is arranged with reinforcement and then the mold is closed and clamped. The resin is injected at high pressure and the part is left to cure in the mold. This process takes more time if curing is done at normal temperatures so heating mold are used to increase cycle time and consistency. Any combination of orientation can be achieved by this method. Reinforcement can be positioned in 3D or 2d orientation.

Volume and mass fraction

The volume fraction and mass fraction of composites have a significant influence on mechanical properties of the composites. Mass fraction is easy to obtain in the fabrication process and volume fractions are used for theoretical analysis of composites.

If v_m, v_f and v_c are the volumes of the matrix, fiber, and composite respectively.

where $v_c = v_m + v_f$,

Volume fraction of matrix is defined by $V_m = v_m / v_c$.

Volume fraction of matrix is defined by $V_f = v_f / v_c$.

Also, if m_m, m_f and m_c are the masses of the matrix, fiber, and composite respectively. where $m_c = m_m + m_f$,

Mass fraction of the matrix is defined as $M_m = m_m / m_c$.

Mass fraction of the matrix is defined as $M_f = m_f / m_c$.

Using the value fraction, the overall density of composites can be calculated.

Also, if ρ_m, ρ_f, and ρ_c are the densities of the matrix, fiber, and composite respectively. Now ρ_c can be calculated from

$m_c = m_m + m_f$,

$\rho_c * v_c = \rho_m * v_m + \rho_f * v_f$

$\rho_c = (\rho_m * v_m + \rho_f * v_f) / v_c$

$\rho_c = \rho_m * v_m / v_c + \rho_f * v_f / v_c$

$\rho_c = \rho_m * V_m + \rho_f * V_f$

Longitudinal modulus of unidirectional lamina

Assuming unidirectional composite layers which are uniform and continuous in mechanical properties and geometry. Assuming there is perfect bonding between the fiber and matrix, the strain produced in Fiber (ε_f), Matrix (ε_m) and Composite (ε_c) is same.

i.e., $\varepsilon_f = \varepsilon_m = \varepsilon_c$

If P_c is the total external load applied on the composite this load is shared by matrix (P_m) and fiber(P_f). Assuming the matrix and fiber behaves elastically, equation for stress in fibers and matrix are

Stress in Fiber $\sigma_f = E_f * \varepsilon_f$ (where E_f is Elastic modulus)

Stress in matrix $\sigma_m = E_m * \varepsilon_m$ (where E_m is Elastic modulus)

Now, if A_f and A_m are cross-sectional areas of the fibers and matrix respectively.

$P_f = A_f * \sigma_f = A_f * E_f * \varepsilon_f$ and

$P_m = A_m * \sigma_m = A_m * E_m * \varepsilon_m$

We Know that $P_c = P_f + P_m$

So, we can derive $\sigma_c = (V_f * E_f + V_m * E_m) \cdot \varepsilon$

and differentiating with strain we can derive $E_c = V_f * E_f + V_m * E_m$.

Additive Manufacturing

Additive manufacturing is also called as 3D printing.

Introduction to 3D printers

Additive manufacturing has been improved over the years after the patents of the Stratasys has expired in the year of 2009. Due to this freedom in design, there is a steep rise in the growth in the technology advancements. There are technologies that can also print metals using the electron and laser beam to recreate the component required for the aerospace industry to reduce the weight and increased. Any object that has a digital form i.e. that is designed using in any 3D design software. The 3D printer software produces a 3D model in a format Standard Tessellation Language (STL) can be exported to a printer or through the internet. After that, the design can be sent to the printer directly. In this process, the product is produced through bonding of earlier layered material.

AM process helping to create an experience product outcome rather than a quick improvement. By Using AM process we can create a structure and product before making them in mass production scale. This technology gives a vast number of customization opportunities, with material customization as well as mechanical properties that are like that of the products generated by traditional methods.

AM is a type of technology that can reduce the labor cost as well as the material wastage. Once the product is designed using a design software the only work that needs to do is just to launch the print in most of the cases. It prints samples and structure within no time. I make the easy to deliver the goods with design freedom and with complex structures. It is a low-cost manufacturing process because the operating cost for this machine is low as well the labor required for this machine is far less compared to other technologies. The skill needed to run these machines are far less compared to skill set needed to run for other manufacturing processes.

Working with 3D Printers

Working with the 3D printer is basically very easy to understand. This process starts with the design of a CAD model with required design parameters. Once the part is imported into 3D printer software interface, we need to specify some parameters like temperature, speed, shell thickness, quality of the product. If the product needs high quality, it generally takes more time for making the product. Speed is directly proportional to the quality of the product. Temperature is depended on the material types used for the print. Sometimes there will be two inputs for the printer the supports are built using the second material and it can be washable. That can produce parts with good surface finish. It can print the parts that are assembled products.

After the part is imported to the 3d printing interface with all the settings are set, the software will divide the entire part to layers and create the supports in some cases. Some other changes like scale, drag, and spin are a feature most often used in any type of the 3d printing interface. More setting can be found in the advanced settings.

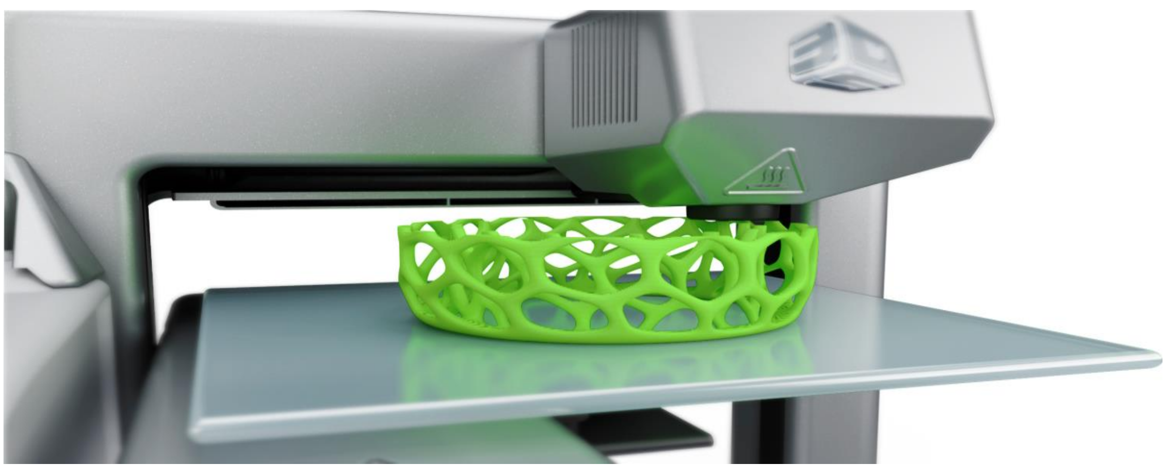

Figure 3Comparison between 2D printing vs. 3D printing

Referred form (http://blog.morphedo.com/2d-printing-vs-3d-printing/)

Typical additive manufacturing schematics looks like fig.2 the print is created on the build platform. Build platform in some cases is heated depending on the printer. Some of the build plates are covered either with a transparent replaceable sheets or glue need to be applied before launching the print. Printers like Stratasys have built plates that are for onetime use. The extrusion head, in this case, has two different materials one is material needed for the part depending on the printer the materials can be ABS, nylon, resin etc., the second nozzle material either second material or supporting material. The part is printed layer by layer, the first layer is printed then next layer of semi melted material is layered over the next one. Once the part is printed the extrusion head will reach its default position.

In some printers, the extrusion head will move in X, Y, and Z direction, in other cases the extruder head will only move X, Y direction, and the build plate is moved in the Z direction.

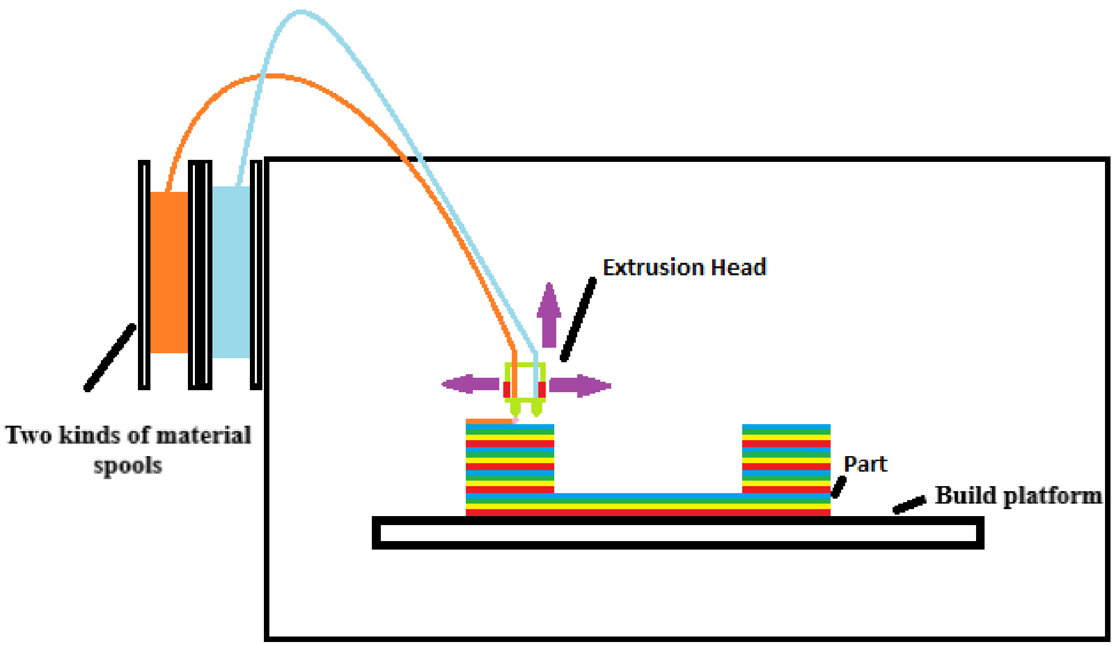

Figure 4Schematic diagram of 3d printer working.

Types of 3d Printing

There are many types of the 3D printer using different types of the technologies. Some of the printers are Stereolithography(SLA), Digital Light Processing(DLP), Fused Deposition

Modeling(FDM) or Fused Filament Fabrication(FFF), Selective Laser Sintering (SLS), Electronic Beam Melting (EBM), Laminated Object Manufacturing (LOM), Robocasting or direct ink writing(DIW), Selective Laser melting (SLM), Selective Heat Sintering (SHS), Direct Metal Laser Sintering (DMLS), Directed Energy Deposition etc.,

Stereolithography (SLA)

It is one of the oldest methods and it is still used in someplace nowadays. Charles Hull patented it in the year 1986. After the required part is converted to STL file from CAD model the stereo lithography apparatus works using liquid plastic converted to solid part using the laser. The laser will start to lay the first layer that is 1/10 of a millimeter and waits till the layer harden. later the print bed lowers by another 1/10 millimeter and the second layer forms by laser. After the part is completed it should be thoroughly cleaned and placed in the ultraviolet oven to remove the supports and to obtain the precise model.

Digital Light Processing(DLP)

Working of DLP is like that of Stereolithography. Larry Hornbeck developed this technology in the year 1987. In this case, the only difference is the source of light. In SLA, the source of light is a laser but in DLP the source is arc lamps. The liquid resin is hardened using the large amounts of light that make the process fast. In DLP instead of the bed, the light source will move in the Z direction to lay the next consecutive layer. The advantage over STL is this process needs very less material that can lead less cost and less waste.

Fused Deposition Modeling (FDM)

Scott Crump, Stratasys Ltd developed and implemented in the year 1980. Maker bot and other companies have adopted a nearly similar technology called as Fused Filament Fabrication (FFF). This is the only technology that can use engineering grade thermoplastic that can, in turn, produce products with excellent chemical, thermal and mechanical properties. This machine prints layer by layer by heating the thermoplastic material to semi molten state. The process is same as SLA but instead of the liquid metal, the solid material spool is converted to the semi molten and then it hardens. The support material is either built with special material that can be dissolved. When the second layer is layered over the first layer after it sticks to the first layer and hardens. This technology is used for new product development, prototyping, and in manufacturing developments. Different kinds of materials can be used like ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic acid) while the water-soluble wax and PPSF(polyphenylsulfone) are used for supporting material.

Selective Laser Sintering (SLS)

This process uses a laser as a power source to make 3D objects. Carl Deckard developed this technology with the help of his professor Joe Beaman in the year 1980's. The difference between the SLA and SLS is it uses powdered material instead of the liquid metal to form 3d objects. At first, the powder is laid flat then the laser will combine the area of the first layer which was sliced by the software and then the next powder layer is laid then laser combines the next layer and finally the finished product is produced. This technology is mostly used industries because the high-power laser used to print which would be expensive. So, this is not generally preferred for a home printer. Also, the powered is so fine that it should be handled carefully for safety. This machine can handle materials like nylon, ceramics, glass, aluminum, steel, and silver.

Selective laser melting (SLM)

This process also uses laser and powder as SLS but it's different from that of SLS. In this process, the powder is melted by a high-powered laser beam and fuses the metallic powder in the pattern of the first layer. It was developed by Fraunhofer institution ILT in 1995. The fine metallic powder is placed over the build plate and 2D first layer of the part is exposed to high power laser that melts the powder on the plate, turns into a solid object. After the first layer is laid then the second layer is after the first layer solidifies. Metals like Stainless-steel, titanium, cobalt chrome, and aluminum. Complex structure with void and channels can be produced using this method. This technology is not widely used for home user's due to the use of lasers.

Electronic Beam Melting (EBM)

This type of technology is used for making metal parts mostly used in medical and aerospace industry. Arcam AB Inc. develops this technology. This technology is like that of the SLM but the difference is the instead of laser EBM uses Electron beam. First layer of powder is heated using the electron beam and after it solidifies the second layer is heated again and so on until the final part is produced. This process is relatively slow compared to SLM and expensive. Materials used in this process are pure titanium, Inconel.

Laminated Object Manufacturing (LOM)

California-based company Helisys Inc. develops this technology. In this type of 3D printing layers of paper, metal or plastic that are adhesive-coated are combined by heat and pressure. the shape is cut with the help of lasers or computer guided knife. After the 3D printed is completed to get the required shape some machining is needed. After the first layer is completed then the platform is moved down and then a new sheet is dragged over the first layer and it is heated and roller and then cut to shape. The process is continued till the part gets its final shape.

Composite Filament Fabrication

Mark forged device mark one uses this technology. This process is using continuous strand of fibers as reinforcement instead of using chopped fibers with a thermoplastic matrix. Structures made from this process has good strength compared to the FFF or FDM. This printer is dual head extrusion, one head is capable of printing CFF and the second one is used to print traditional plastic filaments like PLA and ABS.

Although there are many technologies in 3D printing, every technology uses the same concept of layer by layer printing by splicing the part into 2D shape. They either use the liquid, solid or powder material is used in most of the cases with any other power source to heat the material to heat up the material and combine.

Materials used in additive manufacturing

Technological advancements improved the 3D printing material usage. Now a day's metals can also be easily printed with less waste and less man power that will result in low price products. PLA, ABS, PETG, nylon, TPE, TPU, HIPS, PVA, PET, Metal, lignin, PC polycarbonate, wax, ASA, PP, POM, PMMA, sandstone, nGen, TPC, PORO-lay, Glow in the dark, FPE etc.

Polylactic acid (PLA)

This material is widely used compared to ABS. This is a biodegradable thermoplastic that is derived from natural resources like corn starch or sugar cane. This is widely popular for the reason for this reason and so called green plastic. A widely used in home and classrooms. For this material, the cooling rate is high so there is needed for the heated bed. Due to its rigidity, the printed parts are brittle. Melting range of this materials is 180°C – 230°C. Some of the properties are its durability, flexibility, Brittleness, ideal for small toys, higher prints speeds and thin layers. They are food safe, user friendly and impact resistance.

Acrylonitrile Butadiene Styrene (ABS)

After PLA, the most popular material is ABS. ABS is a thermoplastic type of material and it is cheap, durable, slightly flexible. Lego bricks are made with ABS material. It needed higher temperatures up to 210°C – 250°C which makes the printers fallen a bit. It also needs a heated platform for easy removal of the part from the build plat form. As this not a natural material also it produces some fumes while printing. these fumes might affect people and pets with breathing difficulties. Some properties of ABS include its high durability, solubility in acetone, good strength, and impact resistance. It has some disadvantages need heated bed, no food safe, curling warping and shrinkage.

Nylon (Polyamide)

This material is widely used in industrial applications. It is cost effective, strong, light, and flexible, and wear resistant. Nylon is stronger and durable than PLA and ABS and less brittle. Nylon is used in many applications, like tools, toys, machine parts, containers etc. there is a new development in nylon Taulman nylon that does not emit fumes and is virtually odorless during printing. This nylon also has better tensile strength and layer bonding. Some of the advantages strength, durability, and flexibility. This material can be recycled and few types of nylon can be used for food grade. Disadvantages are its ability to absorb moister make printing difficult. It has some shrinkage after cooling.

Polyethylene Terephthalate, PET (CPE)

It has higher strength and flexibility compared to ABS. PET is easy to print and it has a similar need to that of a PLA substance. PET can be used to make products that need high flexibility and toughness like phone cases and mechanical parts. Some of the benefits high stiffness, and lightweight. This material does not need a heating bed.

Metal PLA / Metal ABS

PLA or ABS materials are blended with metals like brass, steel, copper, and bronze. Although the density of printed part is like PLA or ABS, the parts are different from parts made from pure PLA or ABS products. Some advantages include unique metallic finish, good for statues, jewelry, and artifacts. These materials have high durability and low flexibility. The products made using these materials are not food safe.

Carbon fiber

The material has fine strands of carbon fiber. This will give the material with good rigidity, adhesion, and strength. The nozzles need be of wear resistant because the stand will wear of the nozzle easily so using material is a bit expensive too but nozzle with wear resistance. This material is used to make the mechanical parts, shells, and high durability application. This is not food safe and brittle when flexed.

Fiber glass

Continuous fibers strands are used with matrix material like nylon to give it more strength. This material has a good weight to strength ratio. Fiber glass does not absorb moister and it has good dimensional stability.

Figure 5Fiber glass Spool used in Markforged printer referred from (www.becoming3d.com)

Markforged printer

Mark forged vision is to create real parts within days instead of weeks. Also, able to create complex parts not by limiting to traditional methods. Markforged printers are capable of producing composite parts. These parts are stiffer, stronger, and good impact resistance compared to other 3D printers. This printer uses a browser based software make it easy to store that parts in the cloud and can be accessed from any computer. Also, the status and earlier prints can be continuously checked using the web based software called Eiger (www.eiger.io). The products they develop are The Metal X for 3D print metal parts, The Mark X, The Mark Two, Onyx series.

Mark two printers can create more versatile parts using unique continuous fiber. The printer can be used with carbon fiber, Kevlar, and fiber glass. One of the limitation is that the part should at least have the least length from the point it cuts the fiber till the extruder.

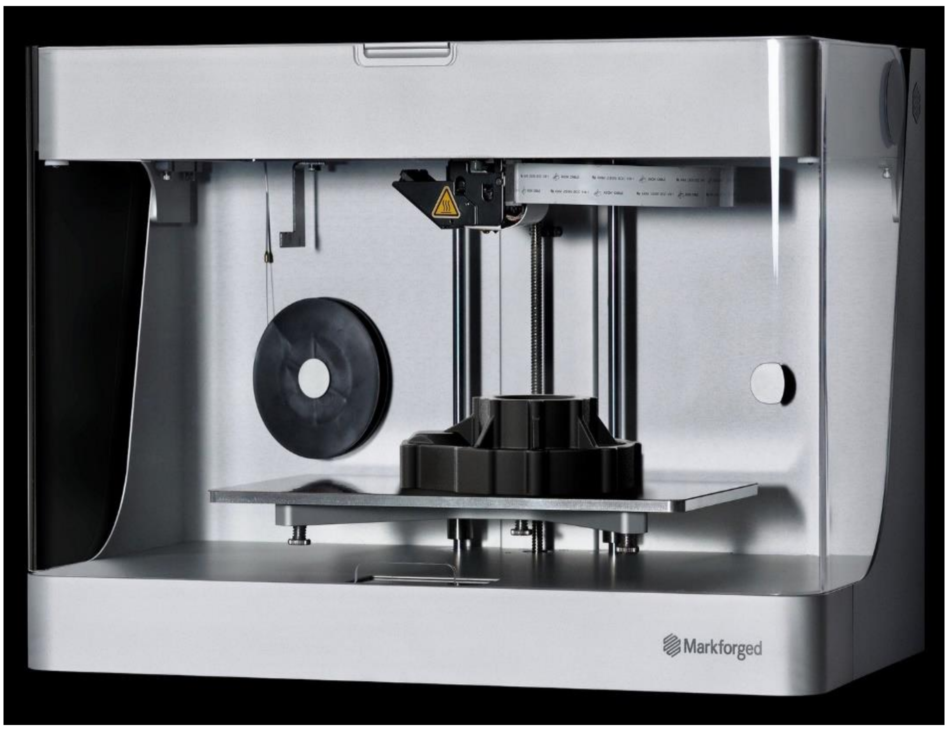

Figure 6Markforged "Mark Two" printer referred from Markforged.com

Average price ranges of filaments used in Markforged Printer according to 2017. Carbon Fiber \$1.55/cm3, Kevlar   \$1.15/cm3, Fiberglass   \$0.67/cm3, and Nylon \$0.22/cm3. Nylon can be substituted with any other cheap filaments like PLA.

Advantages of 3d printing

In this section, we will discuss some of the strategic profitable and technical benefits of the 3d printing in the competitive world.

The speed of the new part production takes less time than traditional methods whatever might be the complexity of the 3D design. This technology will make use to get the model in hours than days or even weeks. It's a single step manufacturing no need of any machining process and obtained with high efficiency. The cost of making the product is very cheap because the printer energy consumption is very less and operational cost for this machine is very low. Material cost for this operation is very less. The labor cost is the biggest advantage because several numbers of printers can be controlled by one person.

This is used to reduce risk in making the design changes. Even a single change in the model can be a major impact. This help to prototype the design in no time and understand the product and can start the process so we can reduce investment in the manufacturing process.

Rapid prototyping. Complexity is not an issue in AM because it splices the 3D part to 2D so that the edges and curves are produced at higher accuracy. And it has the freedom to customize the products. It is used for medical industry to produce the parts and items specifically for a specific purpose. Accessibility of materials and printers has a significant improvement in past 2-3 years. There is a possibility for new materials by mixing with other materials that can be very difficult with traditional methods.

Disadvantages of 3d printing

3D printing is a good tool for making the parts in few hours irrespective of the complexity, but to create large parts with this technology is expensive and not a realistic choice. Although there are advancements for the development in dimensional accuracy the are cases with accuracy disclaimer for items with small tolerances and accuracy. The initial setup cost of the machine is high but the making cost of the product is low. Though there no need of high labor skills there should be enough people to run the machine, like CAD professional. There is lot of post processing needed for the finished product to get the surface finish. Polishing the 3d printed part include complexity as well as involves tedious work.

Fatigue

Fatigue will occur due to repeated cyclic loads that result in fluctuating stress. The load applied to the part may be less that fracture but due to alternating load will break the part over time. On an average 50 to 90% components fail due to fatigue. This makes fatigue testing necessary for product development. Some of the factors affecting the fatigue are stress range, geometry, material, and the environment. Fatigue failure is similar to the behavior of brittle materials even though the materials have ductile properties. This makes fatigue failure sudden and catastrophic. Fatigue failure must be taken in to picture for any structure or part that is subjected to time varying loads. Some of the examples include rotating machinery like pumps, turbines, fans, shafts, pressure vessels like pipes, values, rivets, vehicles, ships, air crafts, bridges etc.

Analysis Considerations

Before designing any part, some question regarding part usage and applications need to be answered. What is the Expected number of cycles till final failure. Does the part be designed for an infinite life time or for a specific time. If the part is designed for an only specified time what will be the inspection intervals. Some input decisions on which the fatigue results depend are Fatigue Analysis Type, Loading Type, Mean Stress Effects, Multi-axial Stress Correction, Fatigue Modification Factor.

Loading types, constant amplitude loading in case of minimum and maximum stress level are constant. In the case of variable amplitude or non-constant amplitude, the stress induced is always varied with time.

Terminology

Minimum stress is σ_{min} and maximum stress is called σ_{max}.

The stress range $\Delta\sigma$ is defined as (σmax - σmin)

The mean stress σm is defined as (σmax + σmin)/2

The stress amplitude or alternating stress $\sigma a = \Delta\sigma/2$

The stress ratio $R = \sigma_{min} / \sigma_{max}$

Fully-reversed loading occurs when an equal and opposite load is applied. This is a case of $\sigma m = 0$ and $R = -1$.

Zero-based loading occurs when a load is applied and removed. This is a case of $\sigma m = \sigma max/2$ and $R = 0$.

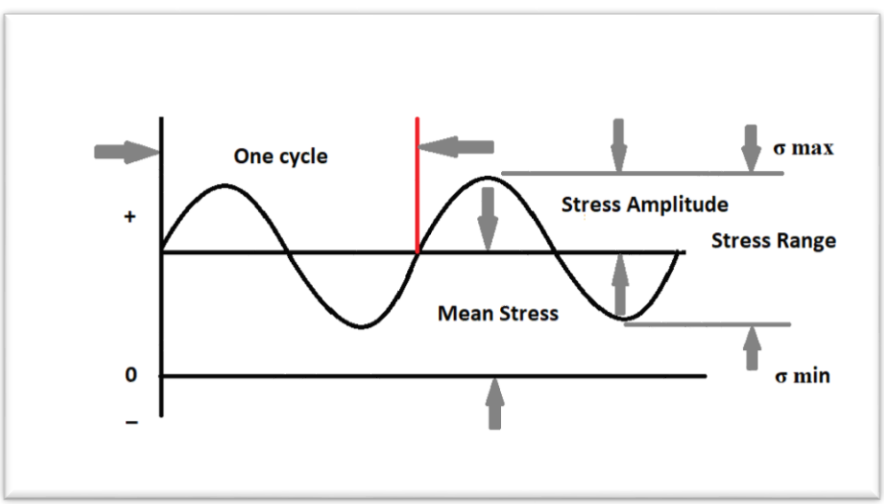

Figure 7 S-N Curve Terminology

Fatigue failure by time-varying loading

Fatigue failure by time-varying loading

High cycle fatigue is with low loads and long life (>10^3 Cycles), this can be commonly analyzed by using stress-life method (S-N curve), this method predicts a number of cycles sustained before failure. The failure criteria for this approach is a fracture.

Low cycle fatigue is with high loads and shorter life (<10^3 Cycles). Fatigue life is analyzed by using strain-life. Failure criteria for this method is initial crack,

Crack propagation is seen in the case of linear elastic or elastoplastic. The failure criteria for this method is crack length and fracture. It involves three stages: crack initiation, crack propagation and crack till critical size.

S-N curve

S-N curve is also called as Wohler curve. It is plotted with stress amplitude on y-axis and number of cycles on the x-axis.

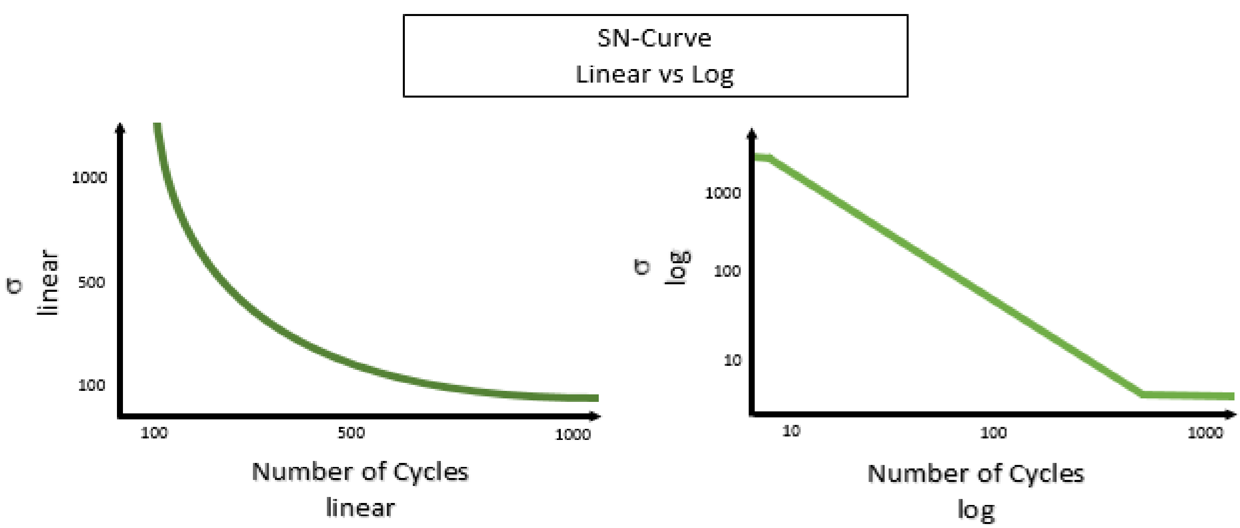

Figure 8 Fatigue life curve referred from siemens PLM community

Endurance limit is the stress level at which the material can survive an infinite number of load cycles. Whereas, Endurance strength limit is the stress level at which the material can survive a specific number of load cycles. The slope of the log vs log curve is called as K-factor which was developed by Wohler. With is related to a number of cycles and stress. Wohler line Life= load $^{-k}$

Using S-N curve and miner rule we can calculate the damage of the structure or part. This formula calculates the damage

$$D=\sum_{i=1}^{j} \frac{n_i}{N_i} \leq 1$$

Where n is a number of cycle for a specific range of amplitude with N as the corresponding number of cycles for failure for that amplitude.

Machine using for fatigue testing

MTS machine is the testing solution for more than 40 years. They worked with fatigue testing professionals to deliver the needs and requirement at high speeds and precision. These machines are able to test for low-cycle, high cycle, and thermomechanical fatigue testing.

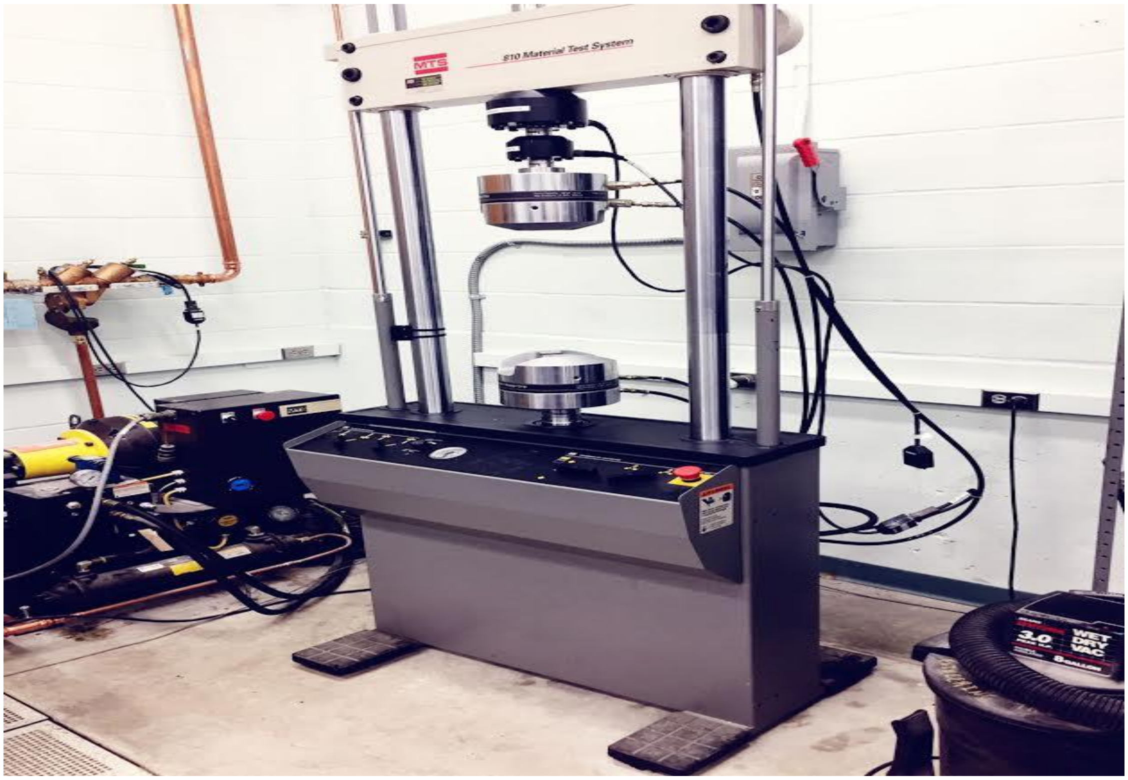

Figure 9 MTS Machine used for testing

Methodology

We have identified the factors affecting the mechanical properties of the 3d printed composite materials and we will identify the key parameters that will mostly affect the mechanical properties. The experimental setup will come to picture. The sample is built in any 3D design software according to ASTM standards. Then the STL file is imported to Eiger software and slicing parameter is set in the software. The part internal view is edited to make alternate layers of fiber and nylon and alter the orientation. The samples are tested using the MTS machine and then the results are analyzed.

Parameters affecting the properties of the 3d Printed composite materials

There are several factors affecting the mechanical properties of the printer component. They can be identified by using cause and effect diagram other Ishikawa diagram or fish bone diagram. The causes are categorized into four parts, Material, slicing parameters, a design parameter, and print parameters.

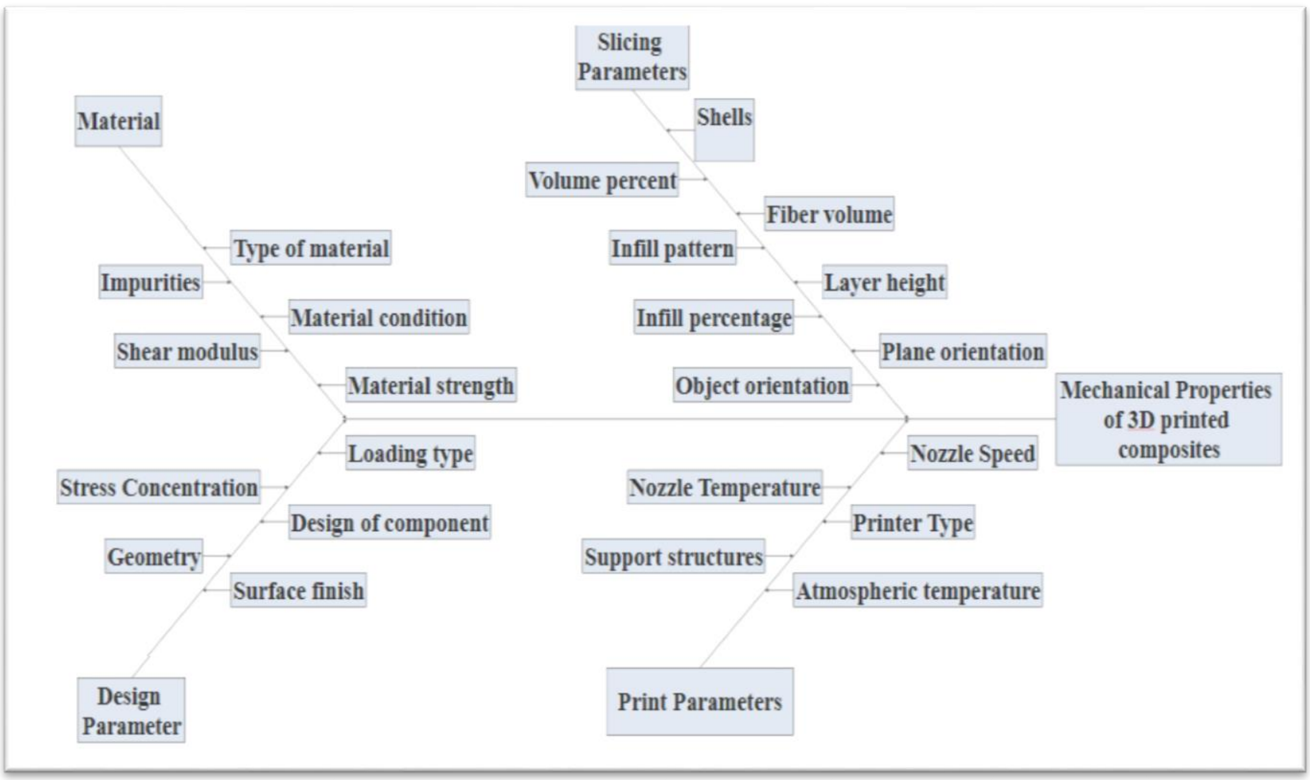

Figure 10 Cause and effect diagram for understanding mechanical properties of AM parts

Although there are many factors affecting the mechanical properties this research is focused on the two key factors fiber volume percent and orientation of the fibers in the composite structure.

Procedure

Composite preparation

Materials used is a composite with matrix material is nylon and reinforcement as fiberglass. The dimensions of the sample ate 250mm X 25 mm X 2.5 mm. The weight ratio of fibers to resin is 25% fibers to 75% resin and 50% fibers to 50% resin. The orientations are 90 deg, 45 deg, and 0 deg. Each sample has four tabs attached at the ends to protect the sample from the pressure applied by the gripers while testing the sample. The tabs are made at the ends of the sample of length with 50 mm X 25 mm x1.5 mm. The parts are Identified by naming id with D as the degree of fiber orientation and F as a number of fibers. So, for example, 0D-6F is a sample with 0 Degree of fiber orientation and has 6 fibers in it.

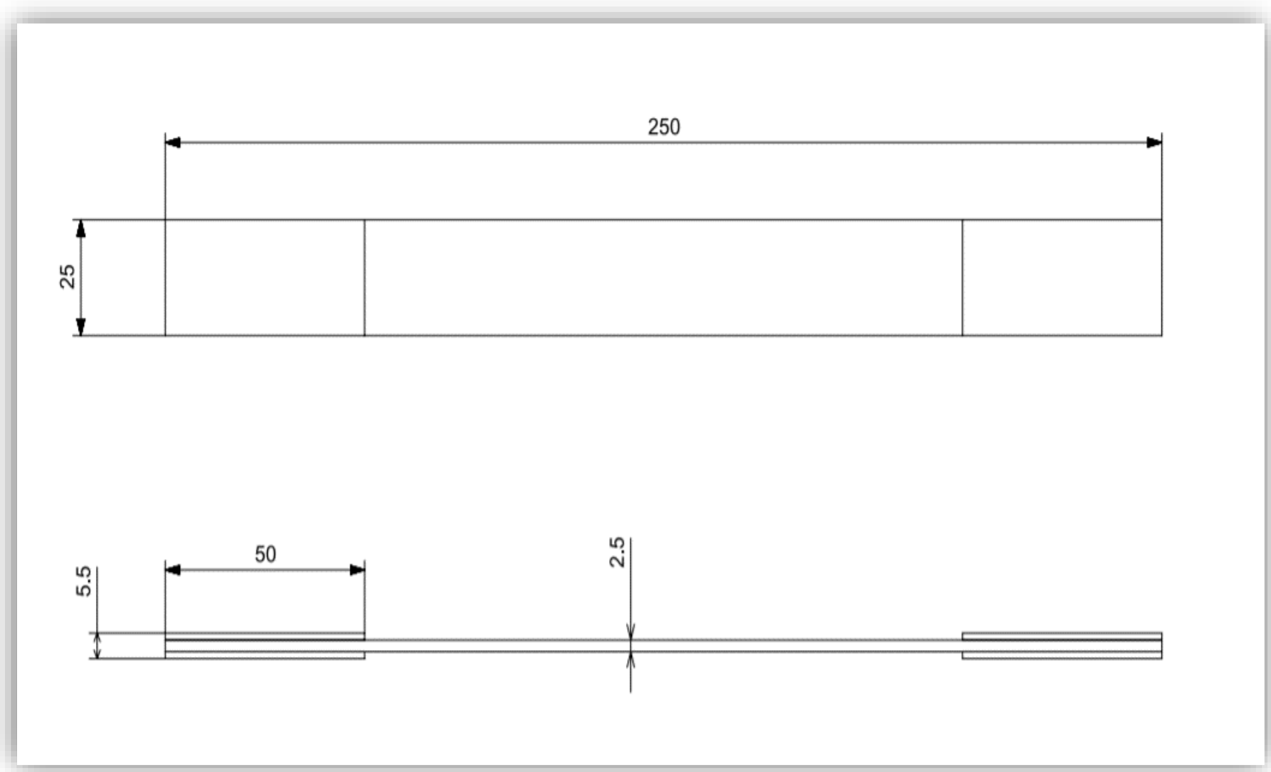

Figure 11 2D View of specimen with tabs attached

Table 1 Samples with different configuration

	Volume percent	Orientation of fiber		
		0 deg	45 deg	90 deg
1	25% fibers to 75% nylon = 6 fibers	OD-6F	45D-6F	90D-6F
2	50% fibers to 50% nylon =12 fibers	0D-12F	45D-12F	90D-12F

Table 2 Total number of samples to print

1	0D-6F-1	45D-6F-1	90D-6F-1	4	0D-6F-4	45D-6F-4	90D-6F-4
	0D-12F-1	45D-12F-1	90D-12F-1		0D-12F-4	45D-12F-4	90D-12F-4
2	0D-6F-2	45D-6F-2	90D-6F-2	5	OD-6F-5	45D-6F-5	90D-6F-5
	0D-12F-2	45D-12F-2	90D-12F-2		0D-12F-5	45D-12F-5	90D-12F-5
3	0D-6F-3	45D-6F-3	90D-6F-3	6	OD-6F-6	45D-6F-6	90D-6F-6
	0D-12F-3	45D-12F-3	90D-12F-3		0D-12F-6	45D-12F-6	90D-12F-6

7	OD-6F-7	45D-6F-7	90D-6F-7
	0D-12F-7	45D-12F-7	90D-12F-7
8	OD-6F-8	45D-6F-8	90D-6F-8
	0D-12F-8	45D-12F-8	90D-12F-8

We have considered 8 samples of each configuration from ASTM standard of D3479 for preliminary and exploratory a minimum for 6 samples are to be tested. For research and development testing of components and structures, a minimum of 12 samples is to be tested. For design, allowable data, and reliability data a minimum of 24 samples are to be tested and these samples are tested for fatigue testing. So, these samples are multiplied by 8 times and the id of the print is added at the end of the sample. The samples are shown above.

Randomizing the prints using excel

Table 3 Randomizing the experiments

Print	Random number	Test specimen ID
1	48	0D-12F-4
	14	0D-12F-3
	22	90D-12F-2
	26	90D-6F-6
2	97	0D-6F-4
	36	90D-12F-3
	34	0D-12F-2

	32	0D-6F-8
3	51	0D-6F-1
	100	90D-12F-3
	96	0D-12F-8
	86	45D-12F-5
4	0	0D-12F-5
	57	0D-6F-5
	38	90D-12F-6
	63	90D-12F-8
5	76	90D-6F-1
	30	90D-12F-1
	4	45D-6F-3
	76	45D-6F-4
6	40	0D-12F-6
	98	45D-6F-8
	43	45D-12F-7
	19	45D-6F-1
7	63	0D-6F-3
	50	45D-6F-7
	43	0D-6F-2

	11	90D-6F-8
8	58	90D-12F-5
	96	45D-12F-6
	11	45D-12F-3
	32	45D-12F-1
9	56	90D-6F-3
	24	45D-6F-6
	77	90D-6F-4
	62	45D-12F-8
10	15	90D-6F-5
	21	45D-6F-2
	99	45D-12F-4
	88	90D-6F-7
11	83	0D-6F-6
	62	0D-12F-1
	86	0D-12F-7
	44	90D-6F-2
12	14	0D-6F-7
	76	90D-6F-7
	3	45D-6F-5
	39	45D-12F-2

Randomizing is very important to make the sample giving the sample equal opportunity for the samples for being selected. This gives better results in any research and generalization of the large group. Although there are many methods to randomizing sample we have used a simple method using excel. The command used is excel Rand () *100 to generate set of 48 random number and then followed by sorting the set by ascending or descending order to create the random data set. There can prints that can be printed at a point of time. So, the randomized samples are separated into Four samples for a print. The random number at present are not in order as the random numbers update every time in the excel. Samples look like as shown above.

Printing the test specimen

Now, the test specimens are randomized the test specimen of required dimension mentioned above is imported in to a Markforged 3d composite printer using Eiger software that is connected to the printer through the internet. The process of splicing take place in the software. The part is placed on the print bed in the best orientation to reduce any supports. The test specimen can be scaled and rotated in the software, the default units for importing will be metric and it can be changed in advanced settings.

Nylon is used as matrix material because it has superior material properties compared to ABS and PLA. Mark forged developed thermos plastic nylon that does not require any post curing also has good adhesion to carbon fiber.

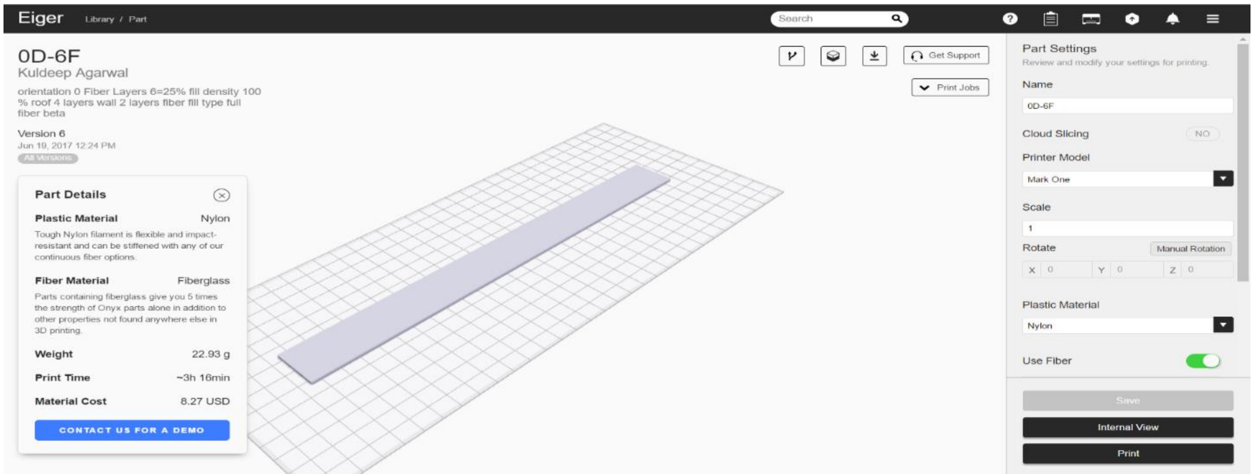

Figure 12 Eiger Software Interface

After login hit Import STL option and add the part to the library. Open the part from the library and interface looks like above. The part can now be oriented and scaled. If you need a part only with nylon or other plastic you can remove the use fiber option. Select the fiber material to fiberglass from drop down (Carbon Fiber, Fiberglass, or Kevlar), a number of layers of fiber, fiber angles. Fiber layers are the number of layers that contain fibers. Once the part is configured hit save to apply changes. On the left side, we can see the part details like print time, material, weight, and approximate part cost. If you start to print the fiber layer will be routed automatically. **Manual fiber routing**

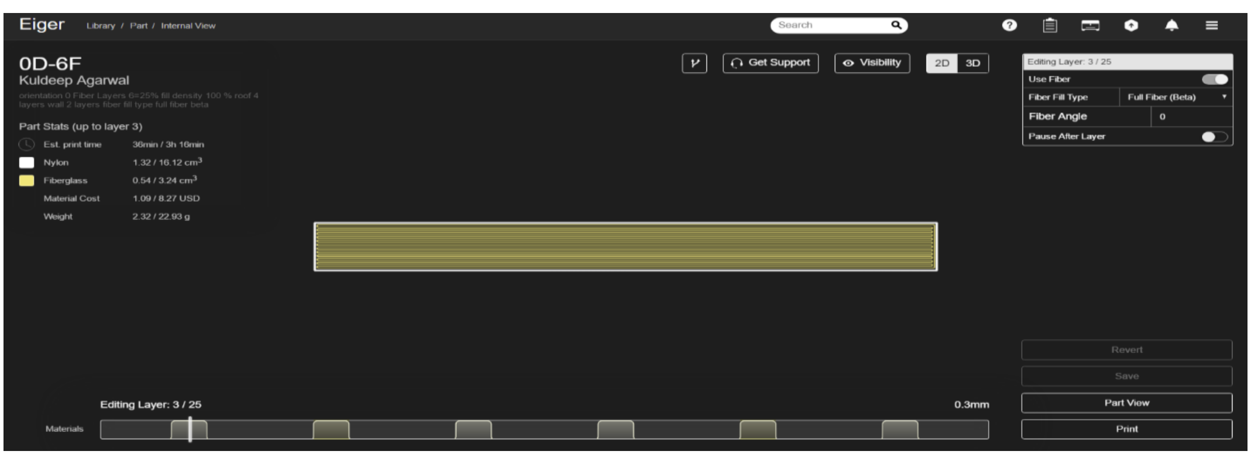

Figure 13 Internal View of Sample in Eiger Software

Although automatic option does create fiber routing. It is a better option to clearly loot and rote the fibers according to loading time for good strength. Eiger software allows editing the part layer by layer. By clicking the internal view, the part shows the fiber sandwich. The internal view shows the 3D view of the part (default view). The 2D view can view layer by layer of the part. If we like to add any additional layer we can edit the layer to the fiber by toggle button on top side right corner. The minimum area size of the layer for the continuous area is 1" square. If the section is having a smaller area than the layer is automatically filled with Plastic.

The fiber orientation and the layers with fiber can be easily seen in the internal view. Below shown picture show the orientation and layers with fiber for 25% and 50% fiber volume percentage. Time taken for print is seen on the top left corner of the internal view. Below show the time taken for printing different sample. The estimated amount of material helps to reload the spool after the specific time. For example, in 45D-12F layer 2 is selected it shows the time is taken to print the sample, the amount of material needed. If the fiber glass spool is only 0.60 cm^3 then the spool can be replaced after 35 min. So that the printer can never run out of material.

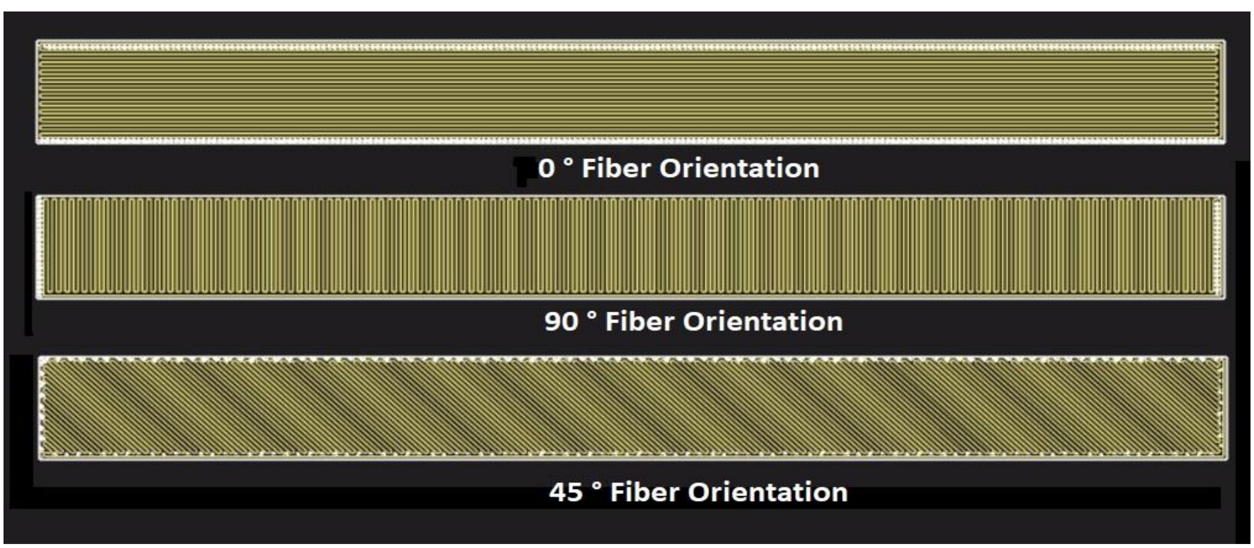

Figure 14 Fiber orientation inside the sample

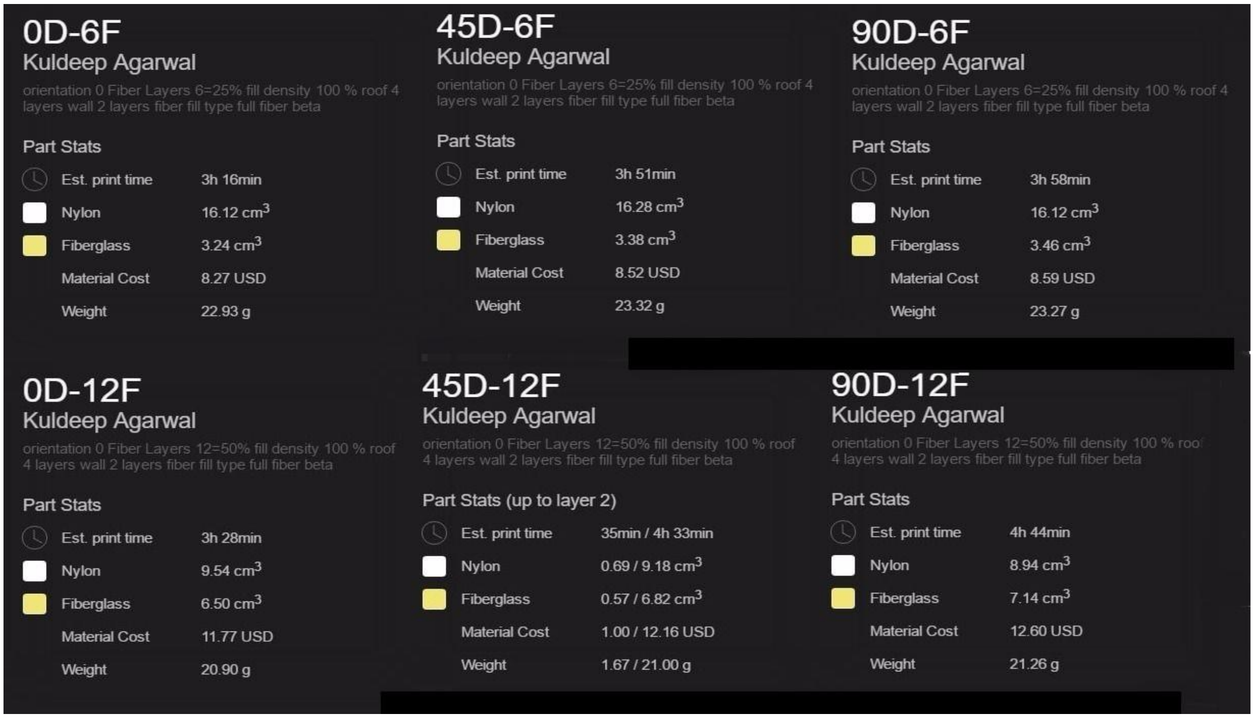

Figure 15 Figure time and material usage of each part

For 6layers or 25% fiber volume out of 25 layers 3,7,11,15,19,23 are fibers, for 12 layers or 50% fiber volume out of 25 layers 2,4,6,8,10,12,14,16,18,20,22,24 are fibers and rest are nylon. After all the changes are configured click save to save the part to the library.

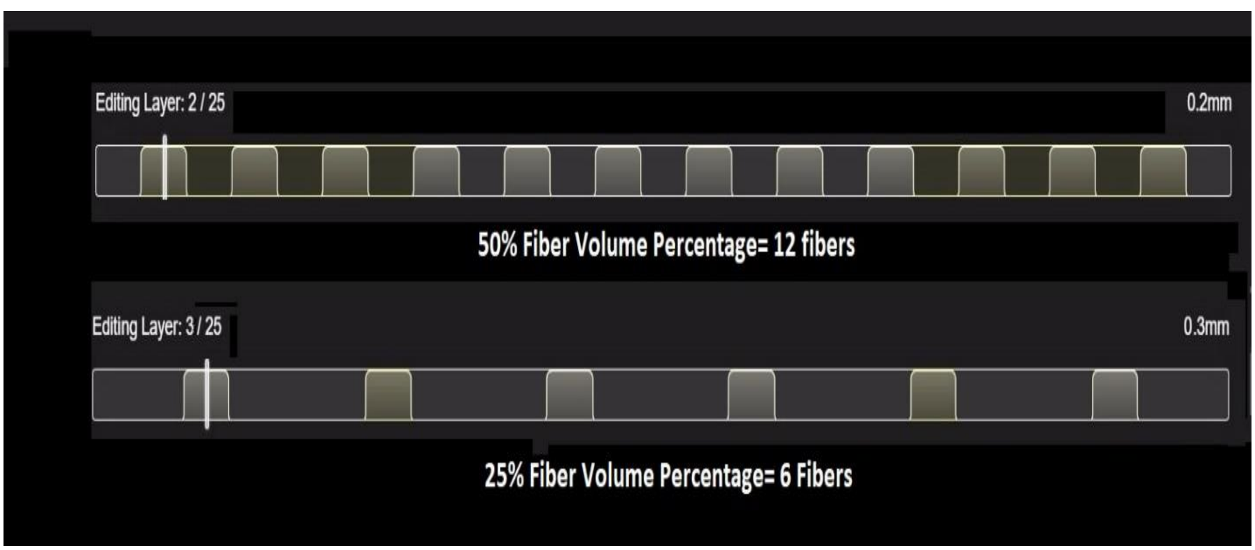

Figure 16 Figure Internal view layers with fibers

Creating Build plate

Once the part is ready and fully configured to print the part click "print". This will navigate to Build page. This page will allow change about how to print. Select the part, click, and drag to the position. Clicking on Add part will allow selecting the part from the library. Part can be removed by clicking on the X next to the part. Once all the configuration is done we printed the parts. The total time taken for the print and the material needed for all the parts in the build area is shown at the top left corner of the page.

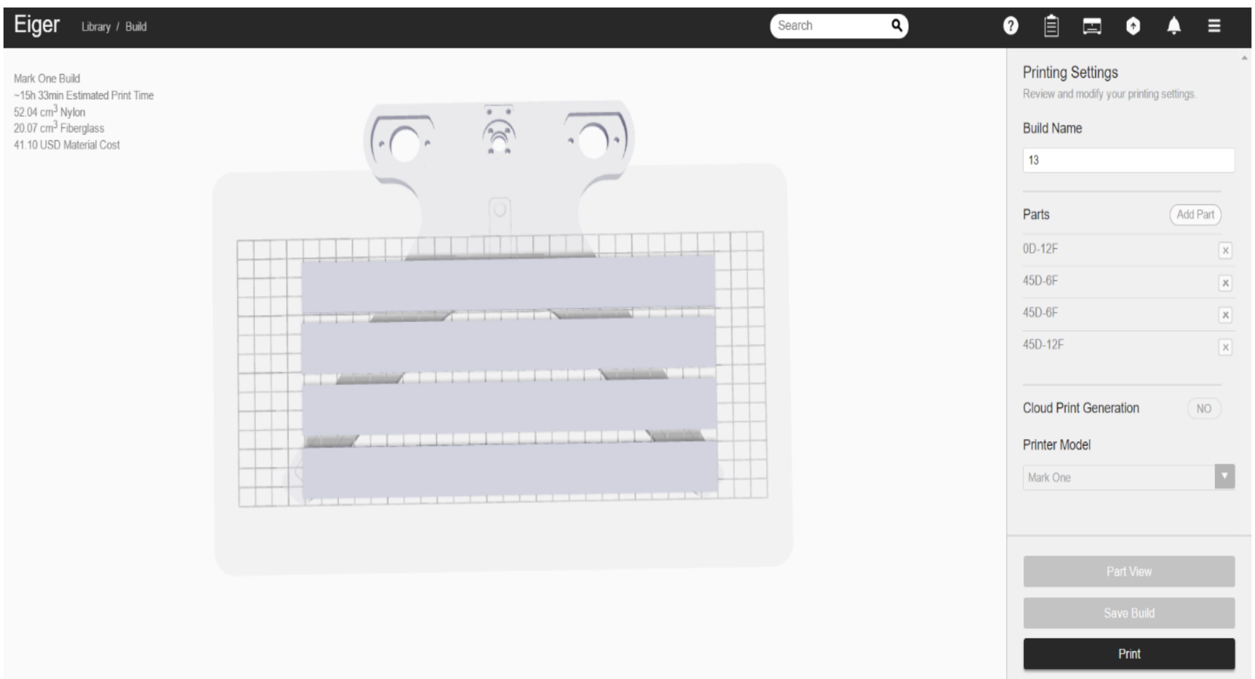

Figure 17 Fig Build page of Eiger software

Tabs are the rectangular strips of composite material printed with dimensions 0.25X5x2.5. these are attached at the end of the test specimen to reduce the compression force by the jaws. The tabs are printed in the same manner.

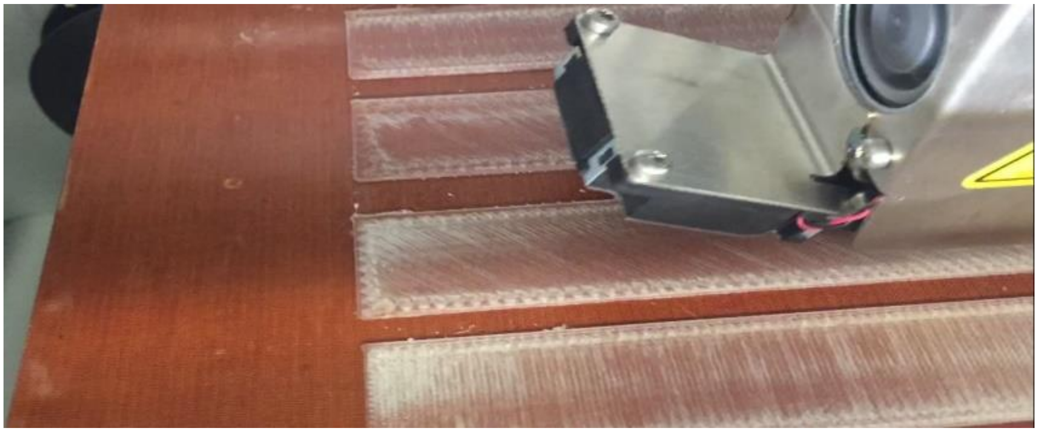

Figure 18 Printing the random samples Using Markforged Printer

Troubleshooting Prints

To get better prints these five steps much be followed every time before launching the print. These are the suggested methods proposed by Markforged.

1. ***Thou shalt level the prints bed, every time***

    This will be the most important factor that determines the success rate of the print quality. Leveling should be done for both fiber extruder and plastic nozzle.

2. ***Thou shalt wash the bed with pure, warm water and dry it with clean, lint free towels***

    This is the second most important step. A clean, dry bed will make the print will give high-quality results.

3. ***Remember the glue stick and use it every print***

    Using a thin glue layer on the print bed will provide good adhering and will act as a release agent for the finished product.

4. ***Thou shalt not let pride get in the way or brim or supports when needed***

    Brim feature can reduce the curling will add support. This will help better for thin parts and support for complicated parts.

5. ***Optimize they design for the z-axis and they shall flourish***

This step looks simple but it often overlooked. The part must be oriented in such a way that the largest or flat face must be near the build plate. This will give best chances of success.

Common Printing Issues

There are many printing issues like Plastic under extrusion, Fiber trails, Dislocation, Plastic Blobs, Fiber offset, Support failed, Plastic stringing, Fiber Residue, Part Adhesion, Plastic Burning, Fiber missing, Warping, or curling. Among these issues, these are common issues faced during the printing.

Plastic burning

Brown or black spots are observed on the part with this issue. This issue only affects the aesthetic look of the part and does not affect the strength of the part. Common causes are poor bed leveling, wet material, dirty nozzles, part warping.

Fiber residue

Fiber residue is due to the irregular level of fiber nozzle and plastic. This residue often presents as small blobs of material outside of a part. Common causes are fiber nozzle too high or print bed too high.

Warping or Curling

It is part peeling of away from the print bed. This happens when plastic cool and contracts and internal stress in plastic pulls towards itself. As internal forces increase the part is pulled from the print bed. Common causes are part geometry, Bed leveling, Printing Environment, plastic material.

Plastic stringing

Stringing is the deposition of plastic material like fiber residue. This occurs when the plastic is heated for long period of time. Also, occurs when a new layer is failed to adhere to the previous layer. Common causes are wet plastic and can be reduced by replacing plastic filament.

Figure 19 Failed print caused damage to print bed

Attaching tabs

After the parts are printed and ready with tabs, then glue is applied to the ends of the sample and tabs are attached to the specimen. pressure is applied on the area to good adhesion. We have used gorilla glue.

Figure 20 Attaching tabs to specimens

Fatigue experimental testing

A modern servo-hydraulic test system does fatigue testing, we used MTS machine. On this modern machine, Multiaxial testing is done by using two or more control systems. After the samples are glued now it's time for testing. In order to apply the cyclic stress at first, the Maximum Stress on the specimen should be identified. So, we have done a tensile test on the part before doing the tensile test on the sample.

After the tensile testing results are known, to start the fatigue testing first the machine tuning should be done. Tuning is very important to know how the system respond to the error between a given test parameters and feedback received. Some more test samples are printed especially for tuning and tuning is done.

Proportional Gain (P Gain)

It increases the effect of the error signal on the servo valve to improve system response. Proportion gain is generally used in any tuning. If P Gain is too high the system will make a lot of sound due to unstable to reach the resulting parameters. If P Gain increase there will decrease in the error and increases the system response. If P Gain is low then the system will never able to reach desired parameters. There is no specific P Gain for this test setup. The P Gain will be initially 2.5 and then slowly increased to 9 till we get the required output. P Gain more than 9 in the case will make the machine unstable. If initial P Gain is above 6 then the system will apply shock loads and specimen breaks at once.

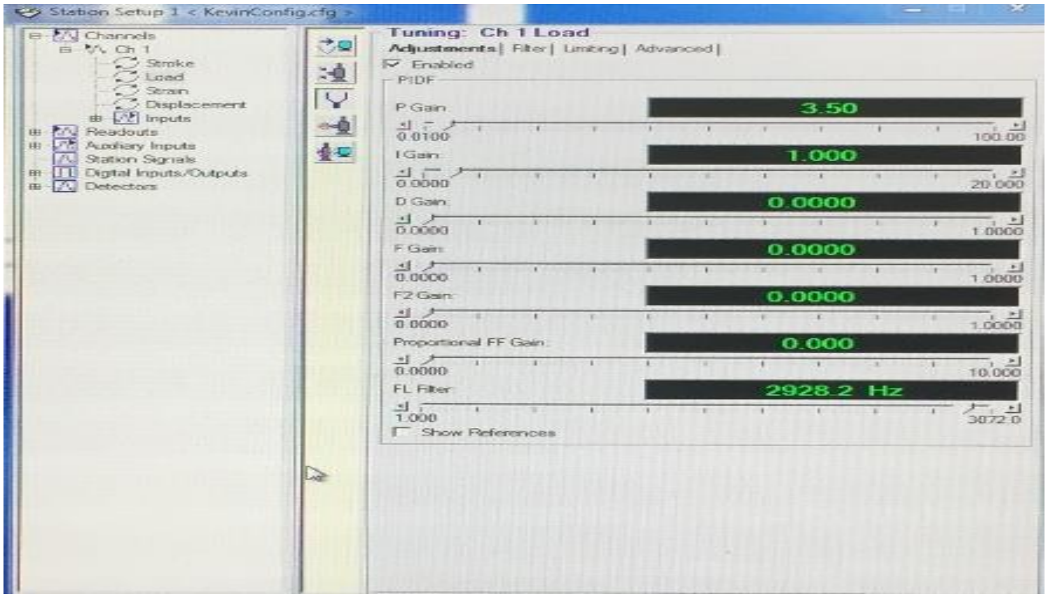

Figure 21 Tuning of MTS machine

The Pressure to hold the specimen is to be around 800 to 1200 psi. if the pressure is lower than 800 psi then the sample will slip while applying the load on the specimen. If the pressure is more than 1200 psi the jaw will crush the sample that results in damage to the specimen, poor results.

Figure 22 Pressure adjustment for grip

For every sample, the inputs required are frequency, absolute end levels i.e. the maximum and minimum values of load. The input loads can be obtained from tensile test results. For every sample, the inputs are decided based on its previous output. For example, for 0D-12F the maximum load is 4.461 kip so we test at 80% of load then goes to 60% and go on decreasing the load percent to find the number of cycles before it breaks. Then comes detect failure it is the displacement change that specifies the specimen had failed. 0deg and 90 deg have lower elongation compared to that of 45 deg so the displacement value must be more in the case of 45deg. The value by default is 0.1 inches I have preferred 1 inches from tensile testing data of the specimens (considered max of all the stroke values). We should also set the parameters that need to be stored. For fatigue testing, we choose the following parameters: load, displacement, time, and a number of cycles.

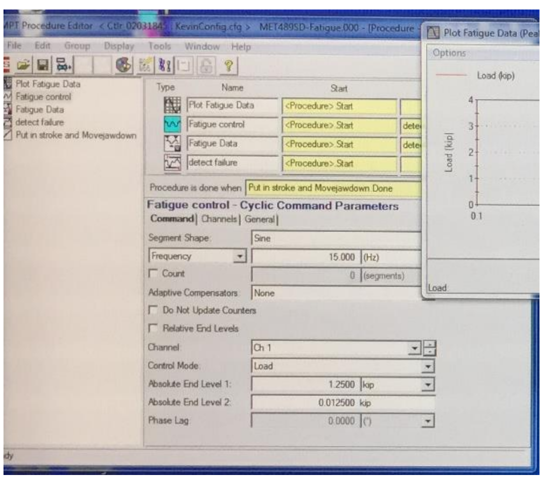

Figure 23 Input parameters for fatigue testing

After the setup is done the load and stroke of the machine must be set. As there will initial load due to the load cell that needs to offset other this load value will be added all the reading. As this load cannot be cleared we must offset but that is not in the in the case of stroke it can be controlled using manual control so, stroke can be brought down to zero.

Now jaws of the machine are adjusted to fit the specimen and place the specimen. Lock the top and bottom jaws of the machine. Make sure that the specimen is vertical and jaws not squeezing the specimen. The Runtime View can be setup with a tabular view of peak and valley of the cyclic loads. Load at that point of time and stoke in the specimen. Once the runtime view is done everything is in its place to run the test. Hit the green play button to start the test. The number of cycles can be monitored at runtime and the ".dat" file is saved with last 2000 values of required stored parameters. The value of 2000 values can be changed in the setup it can also be changed to store every value of the test.

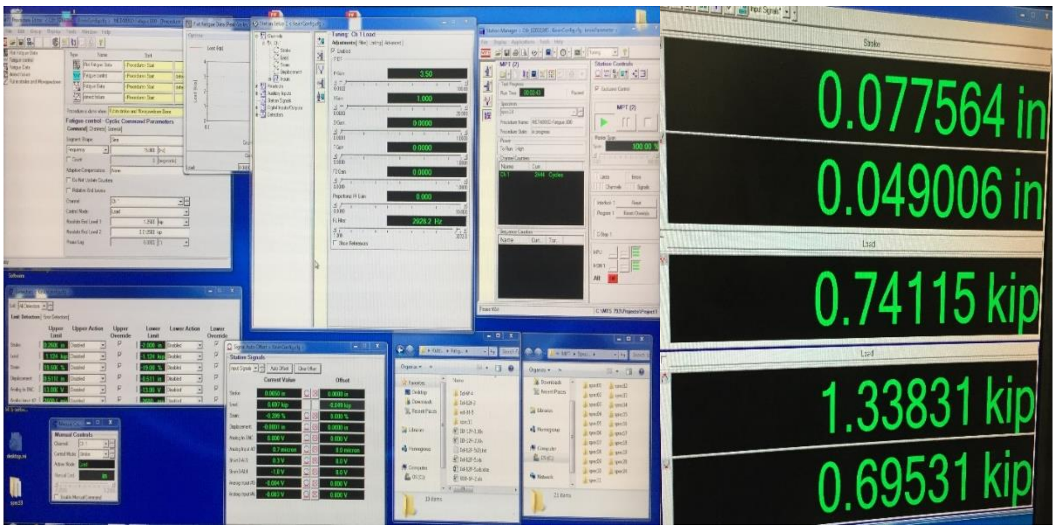

Figure 24 MTS software interface during Fatigue testing

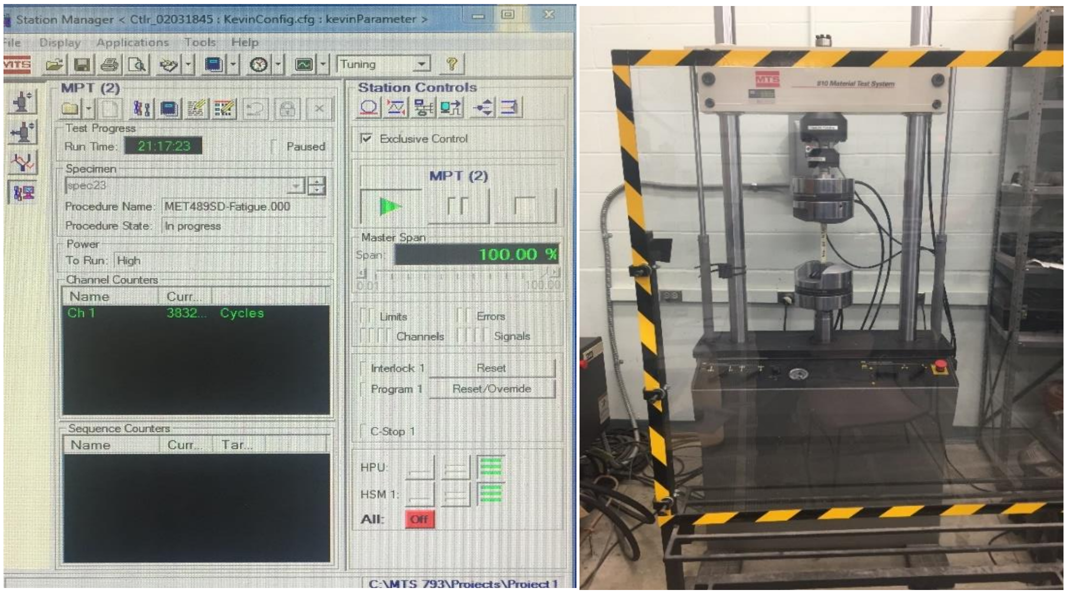

Figure 25 MTS machine running fatigue testing

Results and Discussion

The endurance limit of the material is below which the stress limit under which material will not fail. Or material will only develop the micro cracks after a countable number of failure cycles. The power law drives the fatigue life of the material.

Comparison tables and comments on the test data and results.

0D-6F

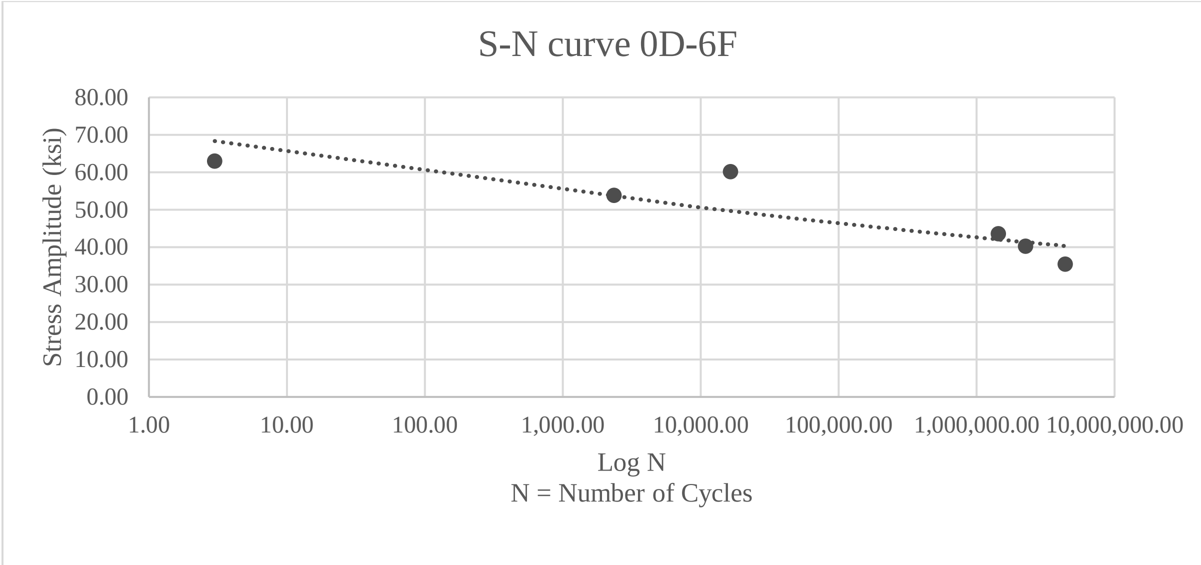

Figure 26 S-N curve for 0D-6F

The material will have the brittle failure in the direction of the fibers. The material shows the endurance limit is more than 35.45 the last loading case since it did not break even after 4*10^7 cycles.

OD-12F

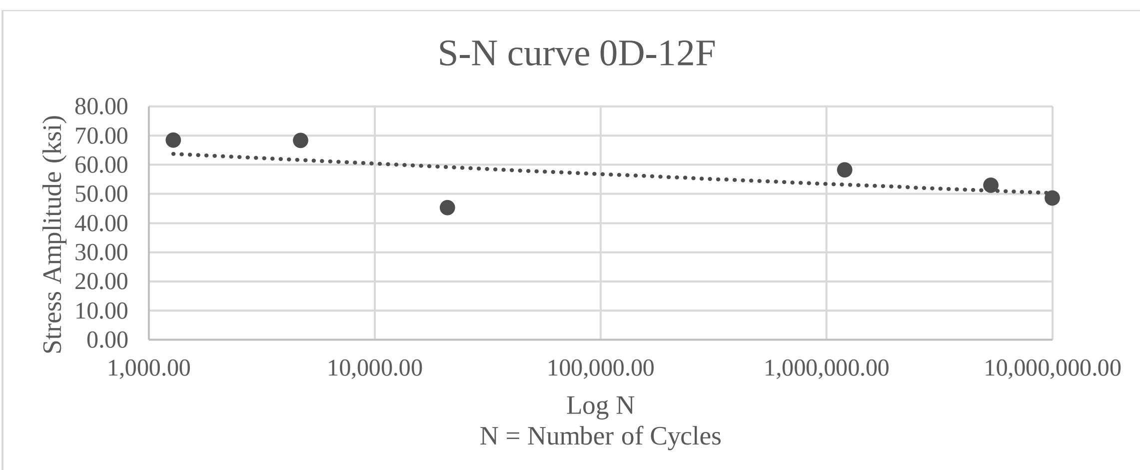

Figure 27 S-N curve for 0D-12F

The material will have the brittle failure in the direction of the fibers. The material shows the endurance limit is more than 48.63 the last loading case since it did not break even after 9*10^7 cycles.

The test results look comprehensive since the increase in the fibers results in the increased fiber volume fraction which will change the properties in macro scale.

The increase in the fiber fraction will increase the fatigue strength of the material. The experiments show the same relation as the fatigue life increased for the 12fiber composite.

45D-6F

As the material is unidirectional, the popular 45 degrees is usually used to specify the shear properties of the material. When the material is loaded in the 45 degrees the Cauchy stress component acts in the direction of the shear in the matrix.

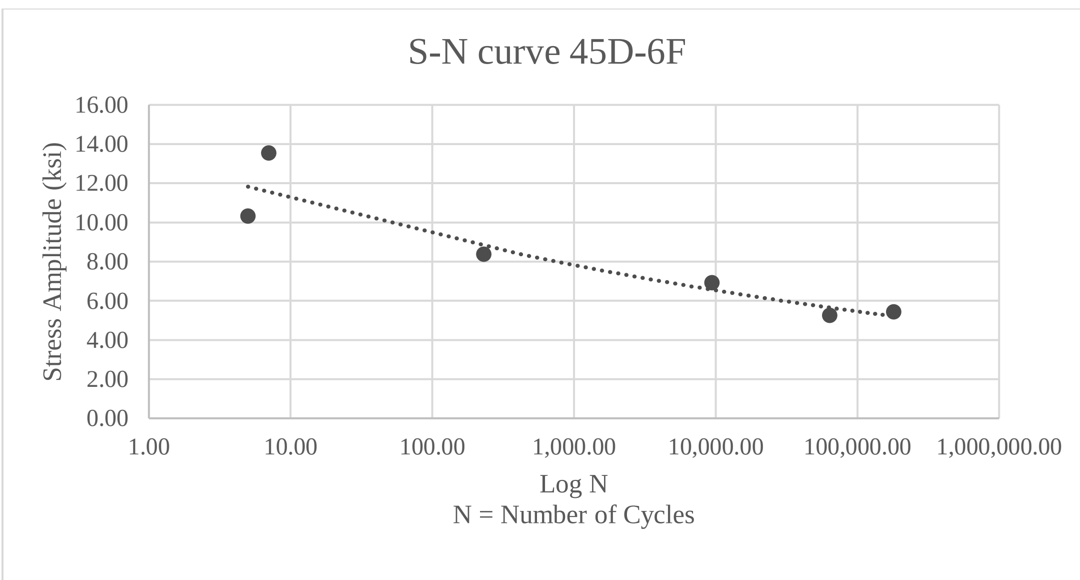

Figure 28 S-N curve for 45D-6F

The material will develop the ductile fracture under the cyclic loading and then break. The material shows the endurance limit is more than 5.25 the last loading case. The material shows the large visco-plastic deformations.

45D-12F

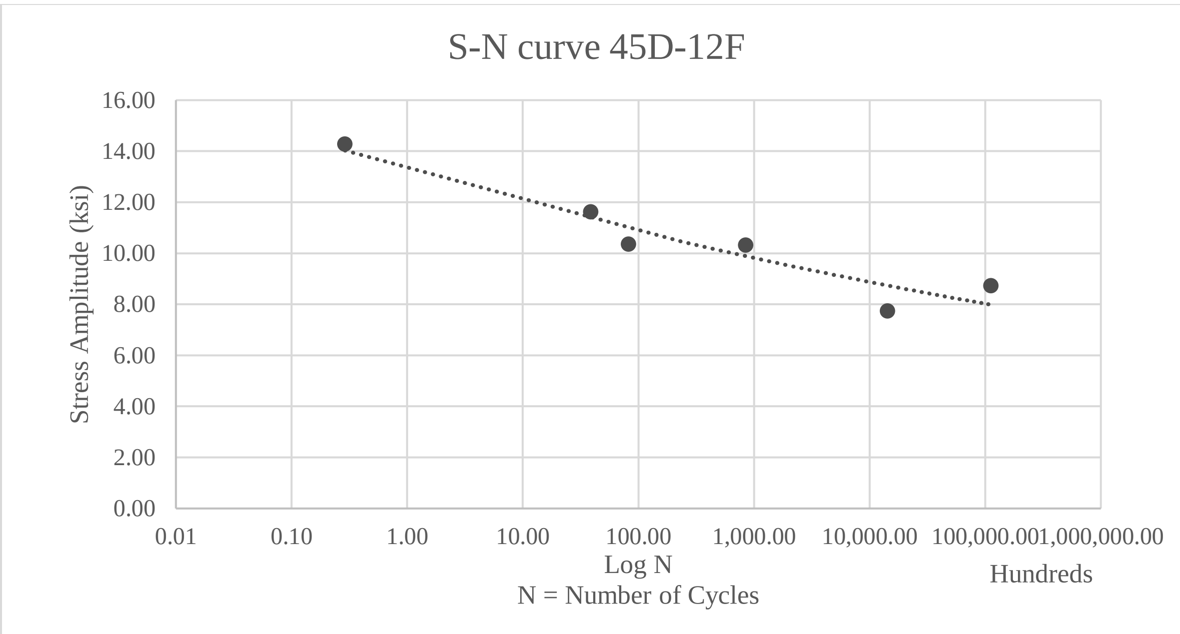

Figure 29 S-N curve for 45D-12F

The material shows the endurance limit is more than 8.73 the last loading case. The material shows the large visco-plastic deformations.

The large stretch in the material at small loads shows that the load is acting on the low strength matrix. The material had progressive damage in the matrix. As the material is having high plastic flow it is very difficult to characterize this kind of material.

90D-6F

This experiment decides the transverse properties of the material which is mostly governed by the property of matrix and the bending strength of the fibers

As the fibers, as very sensitive to the bending, the matrix carries the major part of the load. By the defining parameter will be Young's modulus of the matrix than the rigidity.

Observing the tested specimen, it is determined that failure is in the transverse direction of the matrix.

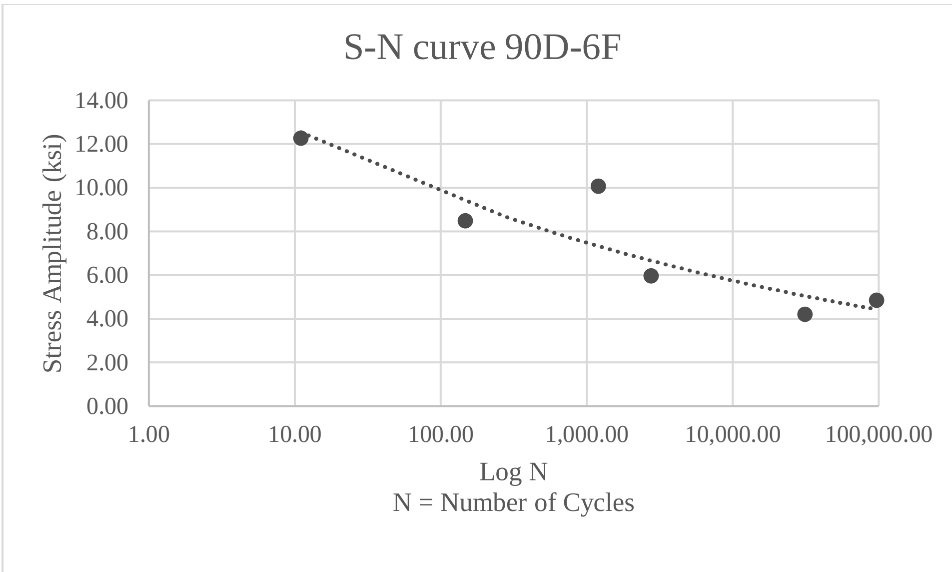

Figure 30 S-N curve for 90D-6F

This experiment determines the transverse properties of the material which is mostly governed by the property of matrix and the bending strength of the fibers. As the fibers as very sensitive to the bending, the major part of the load is carried by the matrix. By the defining parameter will be Young's modulus of the matrix than the rigidity.

Observing the tested specimen, It is determined that failure is in the transverse direction of the matrix. The material will develop the ductile fracture under the cyclic loading and then break. The material shows the endurance limit is less than 4.85 the last loading case. The material shows the large visco-plastic deformations.

90D-12F

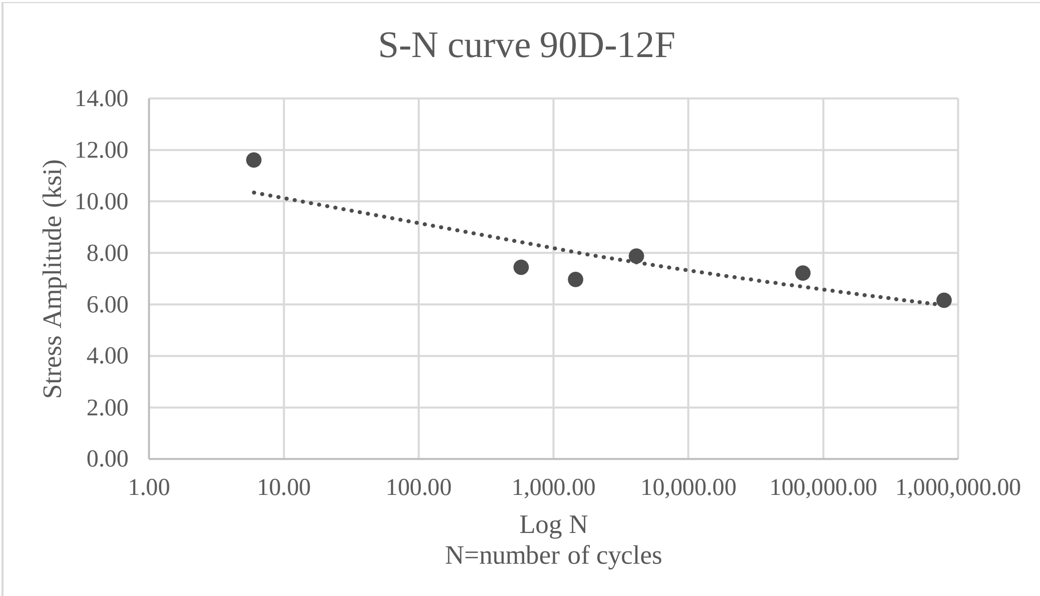

Figure 31 S-N curve for 90D-12F

The material will develop the ductile fracture under the cyclic loading and then break. The material shows the endurance limit is more than 5.25 the last loading case. The material shows the large visco-plastic deformations.

Observing the above data, the following table is formulated.

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Table 4 Overall Fatigue Data comparison.

S. No	Orientation	Endurance limit (ksi)
1	0D-6F	>35.45
2	0D-12F	>48.63
3	45D-6F	<5.25
4	45D-12F	<8.73
5	90D-6F	<4.85
6	90D-12F	<7.22

The material has high strength in the direction of the fiber and least strength in the shear. And elongation before failure is more in case of 45 °compared to 0 ° and 90 °.

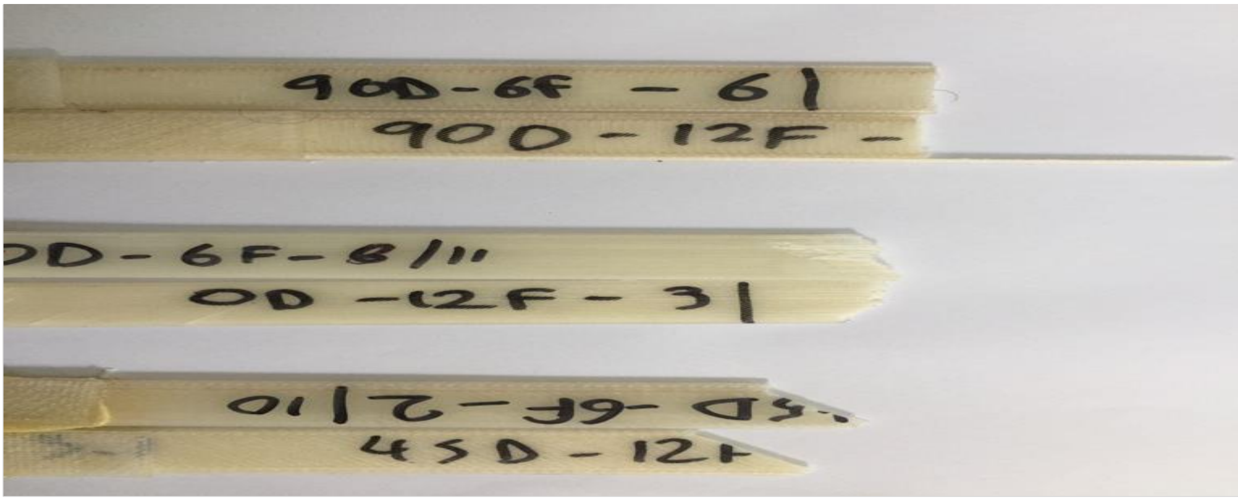

Figure 32 Specimens after the Fatigue testing. 90D on top, 0D in middle, 45 in the bottom

In the case of 90 D and 0 D, fiber orientation the break was at 90 degrees as well but the breakage was in a crisscross pattern in the case of 0 deg. There is a breakage in the direction of 45 degrees in the 45D.

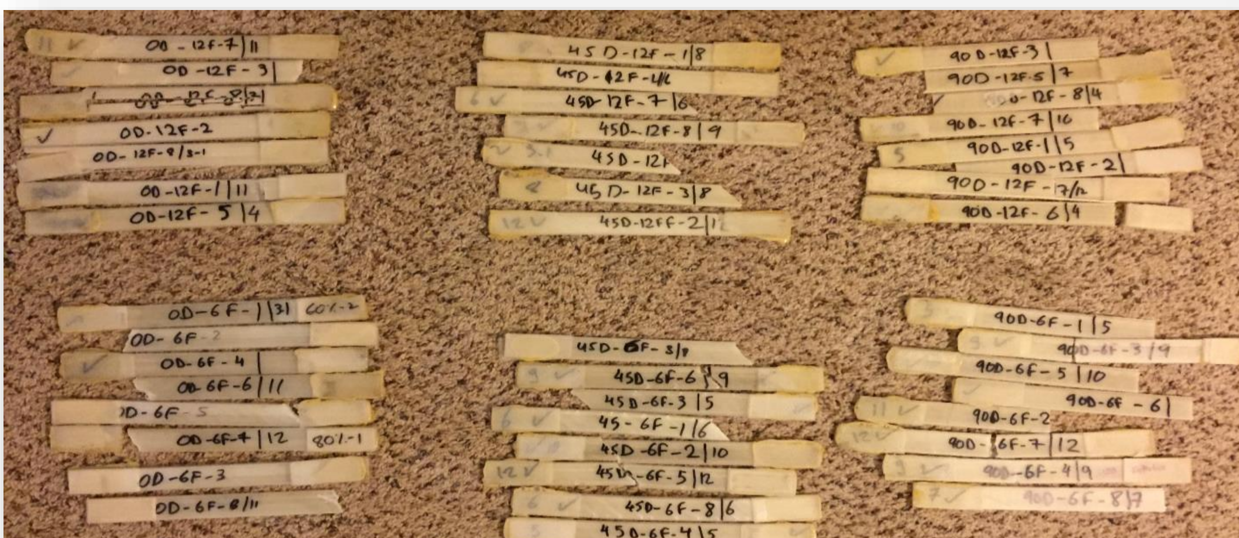

Figure 33 Samples tested for fatigue testing.

Conclusion and Future Scope

Fiber orientation and Volume fraction significantly influence the mechanical properties of the additively manufactured Composite materials as well. The influence of the micro scale defects will influence the fatigue limit in all regards to all the tests in this study. The differences between fatigue limit significantly for pairwise comparison of individual layers. We have found the Endurance limits range in the additively manufactured composite materials for 0 ° followed by 45° and 90°. The volume fraction of the effects the fatigue properties, higher the volume fraction better the fatigue properties of the materials. This is Future work include testing the sample close to the endurance limit to as to find exact point in the SN curve. Test at other orientations. Combining different orientation of 0° ,90°, 45° in side manual routing.

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