“Development & Experimental Evaluation of ABS C type Hook Manufacture using FDM technique”

A Thesis submitted to Atmiya University

For the Award of

Master of Technology

In

Mechanical Engineering- CAD/CAM

By

Mr. Niraj P. Makwana

Enrolment No. 200045002

Under supervision of

Mr. Shivang S. Jani

ATMIYA UNIVERSITY RAJKOT

[June 2023]

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Faculty of Engineering & Technology

Department of Mechanical Engineering

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[June 2023]

CERTIFICATE

It is certified that the work contained in the dissertation thesis entitled **" Development & Experimental Evaluation of ABS C type Hook Manufacture Using FDM technique "** submitted by **Mr. Niraj P. Makwana** (**200045002)**, studying at Mechanical Engineering Department, Faculty of Engineering & Technology, for the award of M.Tech (CAD/CAM) is absolutely based on his own work carried out under my supervision and this thesis has not been submitted elsewhere for any degree.

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Development & Experimental Evaluation of ABS C Type Hook Manufacture using FDM Technique

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ABSTRACT

Fused Deposition Modelling (FDM) is an extrusion-based modern technology that is becoming increasingly popular because it allows manufacturers to produce difficult components immediately from computer-aided design (CAD) models. For the industries like automotive, aerospace, and die & mould, etc., it is necessary to investigate the mechanical behaviour of 3D printed parts. FDM printed components' a competitor mechanical characteristics compared to injection moulded ones make functional application difficult. The complexity of process factors makes it difficult to forecast the mechanical behaviour of FDM printed components. Here, the issue at discussion is the mechanical characteristics of 3D- printed components. For modelling, Fusion 360 parametric is utilised, while ANSYS Workbench is used for analysis. The lateral movement of a C Type Hook is calculated conceptually, and for validation, the practical results are compared to those from static structural analysis. The research's main topic of investigation is the effect of varied Infill densities in C Type Hooks. Five levels of infill density (10%, 20%, 30%, 40%, and 100%) honeycomb structure are evaluated mechanically to acquire tensile abilities when utilising ABS material in real-world scenarios. Further work was done to investigate different tensile mode characteristics for an FDM manufactured Infill pattern. Results from both the practical and analytical bases are compared in this work.

Keywords: Fused Deposition Modelling, Mechanical properties, Infill density, Infill structure

CHAPTER 1

INTRODUCTION

1.1 Introduction to Additive Manufacturing (3D printing)

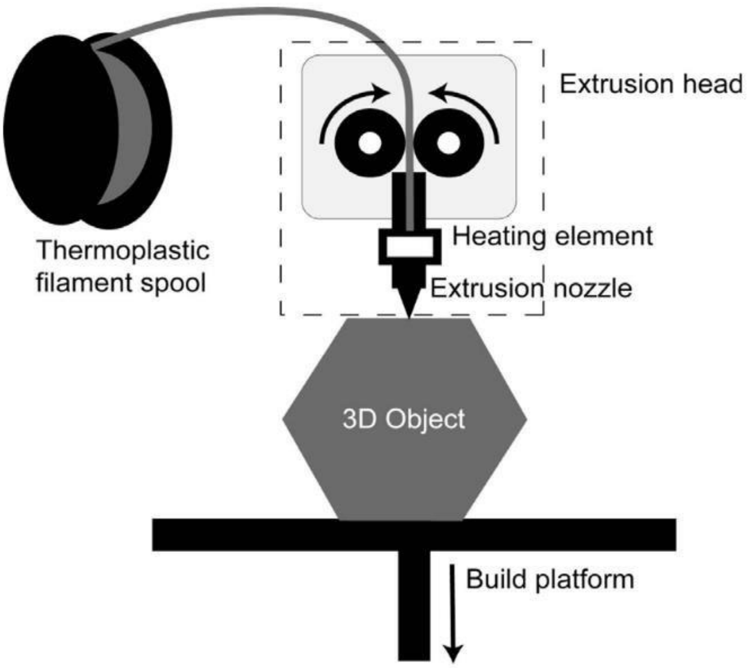


Figure 1.1 Basic Figure of Additive Manufacturing [1]

Making an actual thing out of a three-dimensional model is known as additive manufacturing, sometimes known as 3D printing. Additive manufacturing involves building up a material in several thin layers over time. By adding layers of material, it transforms a computer or CAD image into its actual form. The manufacturing process used by additive manufacturing, often known as 3D printing, is flexible in terms of design. Innovation- promoting 3D printing that reduces prohibitive costs and lead times.

Using a 3D printer, it is possible to build complicated items with precise geometry at no additional expense while also reducing assembly requirements. The production procedure employed as much standard material as possible, potentially reducing the product's environmental effect during its entire life cycle. Different methods utilised in additive manufacturing, often known as 3D printing, treat different materials in different ways. Due to the method's endurance, Fused Deposition Modelling (FDM) is the most user-friendly method. It is also referred to as fused filament fabrication (FFF). The FDM technique involves melting plastic filament that is applied to a build layer by layer using a heated extruder or nozzle in accordance with 3D data sent to the printer. As they are applied, the layers solidify and stick to each others. The FDM techniques are precise and reliable as well.

1.2 Brief history

Rapid Prototyping (RP) technologies, the first 3D printing predecessors, initially emerged into public view in the late 1980s. This is due to the fact that the techniques were first designed as a rapid and more affordable way to produce prototypes for the creation of products inside industries. A fascinating side aspect is that Dr. Kodama submitted the initial patent application for Rapid prototyping technology in Japan in May 1980. However, the whole patent specification was not submitted before the application's one-year deadline, rendering the patent application insufficient. [2]

Charles Hull was given the first 3D printing patent in 1986 for his stereo lithography equipment (SLA). He designed the technology in 1983 and later assisted in founding 3D Systems Corporation, one of the largest and most effective companies in the field of three-dimensional printing today. [2]

The first commercial Rapid Prototyping system from 3D Systems became available in 1987. In the 1980s, there were numerous investigators working on various methods for establishing additive manufacturing, as with every emerging technology. [2]

1.3 Working Principle

The precise same basic idea behind all 3D printing operations: a 3D printer takes a digital model (as input) and transforms it into an actual, three-dimensional item by combining on material. It differs significantly from normative production techniques like injection moulding and CNC machining, which build the required structure from a solid block using a wide range of cutting tools. But utilising 3D printing, items are produced immediately onto the constructed platform without the need for machinery to cut.The procedure begins

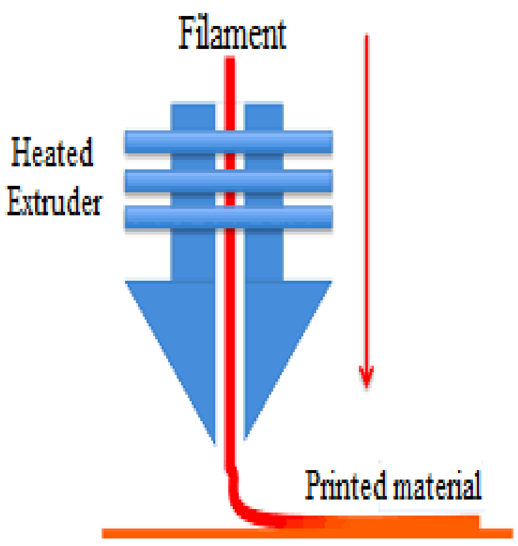


Figure 1.2 Working Principle of 3D printing

with a digital 3D model, which is the object's foundation. The 3D model is divided into thin and two-dimensional layers via the programme (unique to the printer). It then converts them into a set of machine language commands that the printer may use. The printing process can take several hours to print out, dependent on the printer's parameters and the size of the object.

1.4 Types of Additive Manufacturing (3D printing)

1.4.1 Stereo lithography

Among the most prevalent and widely used methods in the industry of additive Manufacturing is stereo lithography, sometimes known as SLA 3D printing. It functions by employing a strong laser to build the required 3D shape by hardening liquid resin that is kept in a reservoir. In a word, this technology uses a low-power laser and photo polymerization to transform photosensitive liquid into 3D solid polymer compounds level by level.

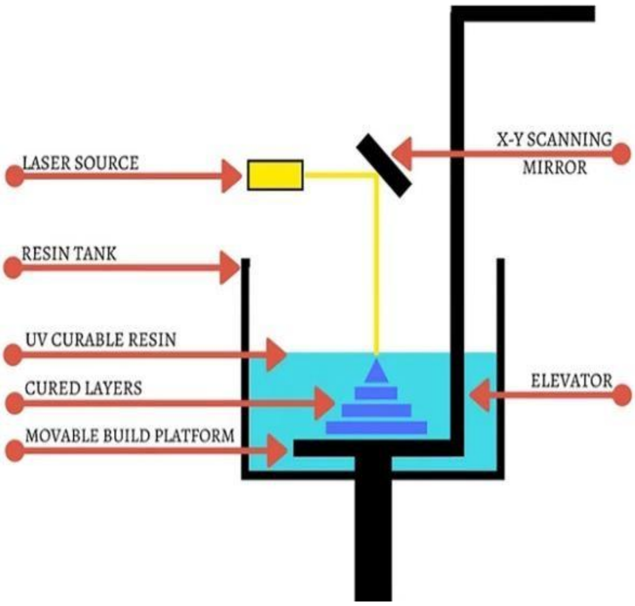


Fig. 1.3 Stereo Lithography [3]

1.4.2 Selective Laser Sintering (SLS)

A powerful light source is used in the Additive Manufacturing (AM) technique referred to as selective laser sintering to fuse small particles of polymer powder into a solid part based on a three-dimensional (3D) model. Researchers and manufacturers have long preferred SLS 3D printing. The method is perfect for a variety of applications, including fast prototyping and small-batch, bridge, or bespoke production because of its low cost per component, high productivity, and well-established materials.

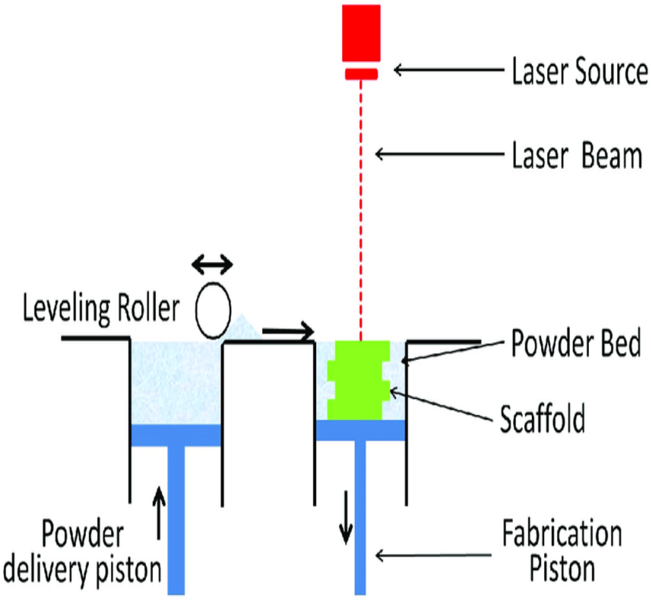


Fig. 1.4 Selective Laser Sintering [4]

1.4.3 Fused Deposition Modeling (FDM)

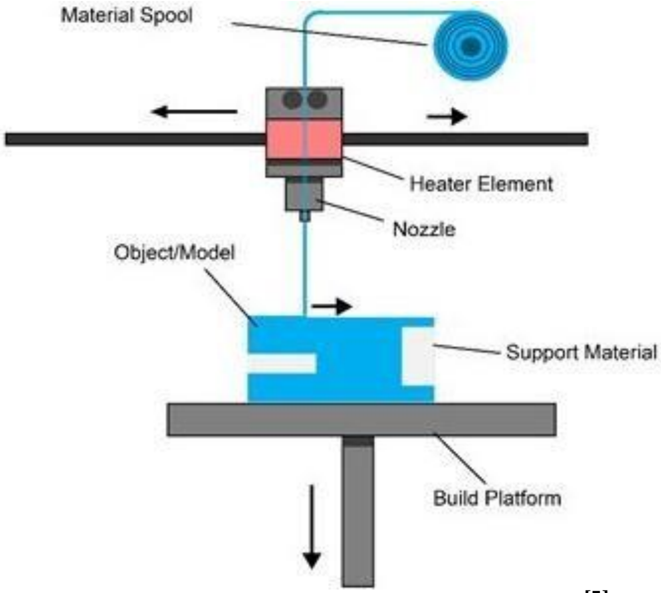


Figure 1.5 Fused Deposition Modeling [5]

Extruding thermoplastic material to produce 3D objects is without a doubt the most well-known and widely-used 3D printing technique. The technique is most frequently referred to as "Fused Deposition Modelling" (FDM) due to its duration.

FDM technology has been utilised as an industrial-grade 3D printing method. The vast number of economical 3D printers that have emerged after 2009, however, mostly utilise a similar technology known as Freeform Fabrication (FFF), although in a more streamlined manner.

3D data given to the printer, the procedure entails melting plastic filament that is transferred to a construction platform using a heated extruder, one layer at a time. As more layers are added, each one grows tougher and is connected to the one before it. Although the assortment keeps expanding, materials are more limited at the market's starting level. The most commonly used substances for entry-level FFF 3D printers are ABS and PLA. For FDM applications, support structures must be present for any applications with overhanging geometry. Use of breakaway support materials is also a possibility because these materials may be eliminated by breaking them off the component.

1.4.4 Digital Light Process (DLP)

A vat polymerization technique is what DLP 3D printing is. DLP uses liquid thermosetting resins to manufacture components rather than the thermoplastics seen in Fused Deposition Modeling. A vat of this liquid resin has been subjected to intense light from a projector during the DLP process, which selectively cures the resin to a build platform layer by layer. A 3D model's whole layer is projected at once using the DLP method, simultaneously healing every spot.

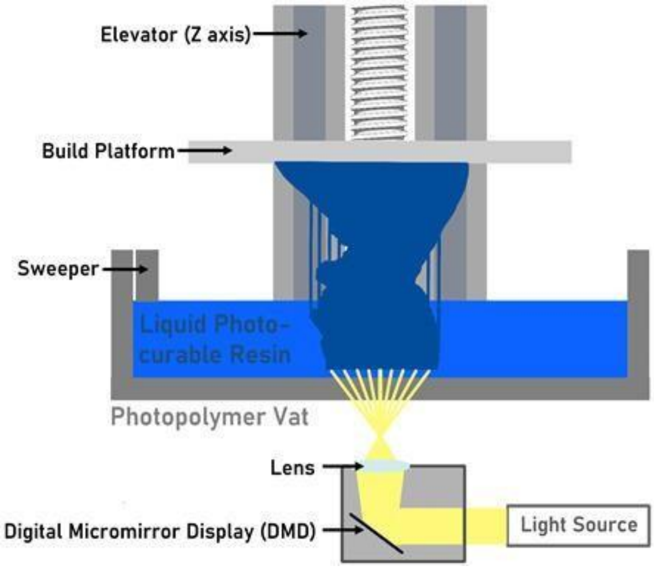


Figure 1.6 Digital Light Process [6]

1.4.5 Multi Jet Fusion (MJF)

Multi Jet Fusion (MJF) powder-bed 3D printing technique, which uses a method equivalent to binder jetting to bind agent and powder. MJF strategically dispenses fusing and finishing materials across a bed of powdered form, and layers are fused together using infrared light, in contrast to step-by-step laser-based powder-bed fusion techniques.

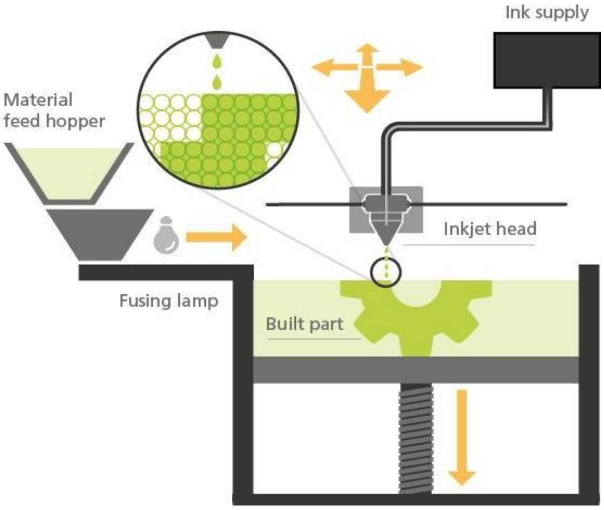


Figure 1.7 Multi Jet Fusion [7]

1.4.6 Direct Metal Laser Sintering (DMLS)

The computer-aided design (CAD) model is digitally split into paper-thin layers as part of the DMLS process, and any required backbone structures are built in to help with the laser sintering procedure. After that, the file is uploaded to one of our DMLS computers. The construction platform is then covered with a thin coating of the chosen material. A powerful laser is used to generate the bottom layer of the bath of sections and any temporary reinforcements that are required for the build while construction gets underway. The lasing procedure is repeated after another vary small coating of metal powder has been wiped across the components by a rubber brush.

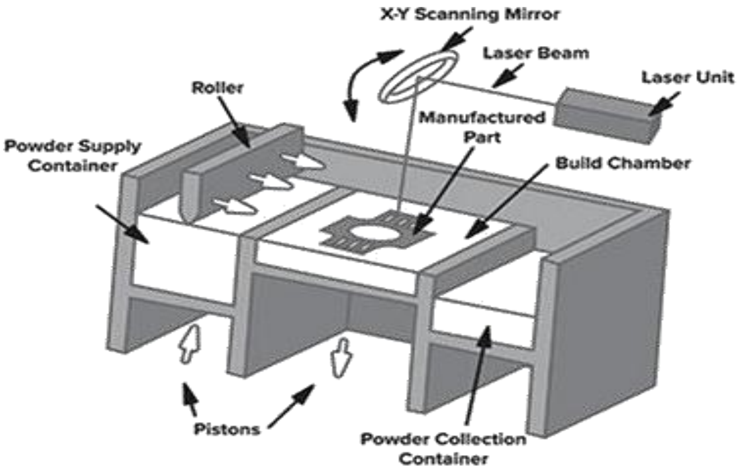


Figure 1.8 Direct Metal Laser Sintering [8]

1.4.7 Electron Beam Melting (EBM)

A revolutionary method employed in the industry is laser beam melting, an additive manufacturing process based on powder beds. We can characterise the flow action and packing behaviours of the granular raw material, which have a big impact on the building parameters, using our powder analytics.

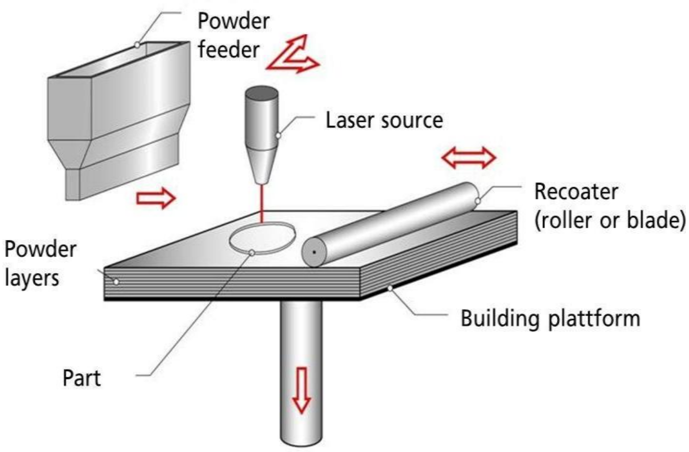


Figure 1.9 Electron Beam Melting [9]

1.4.8 Polyjet

According to the CAD data, the jetting heads move back and forth along the X-axis and back and forth along the Y-axis to deposit a single layer of the build material into the build platform. The software meticulously controls the depth of every single layer. The two ultraviolet (UV) light sources situated on each side of the jetting head continue to cure and harden the liquid photopolymer particles as soon as they are released. The build platform descends in the Z direction to make room for the subsequent layer once a layer of photo polymer has dried. The procedure is continued until the item is finished, at which point the next layer of photopolymers is expelled from theprint heads.

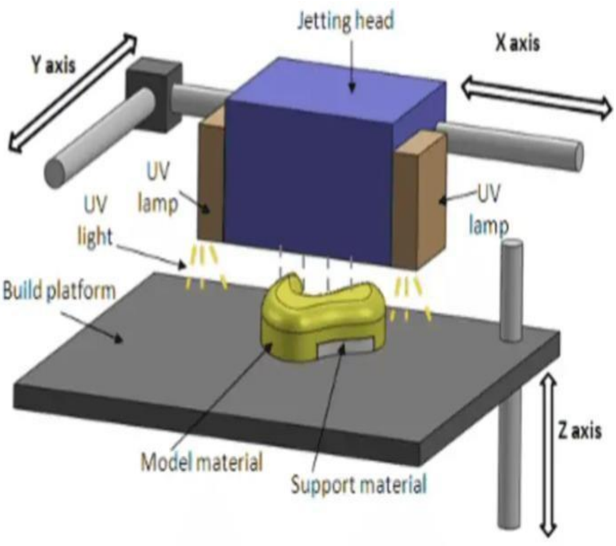


Figure 1.10 Polyjet [10]

1.5 Introduction to Fused Deposition Modeling

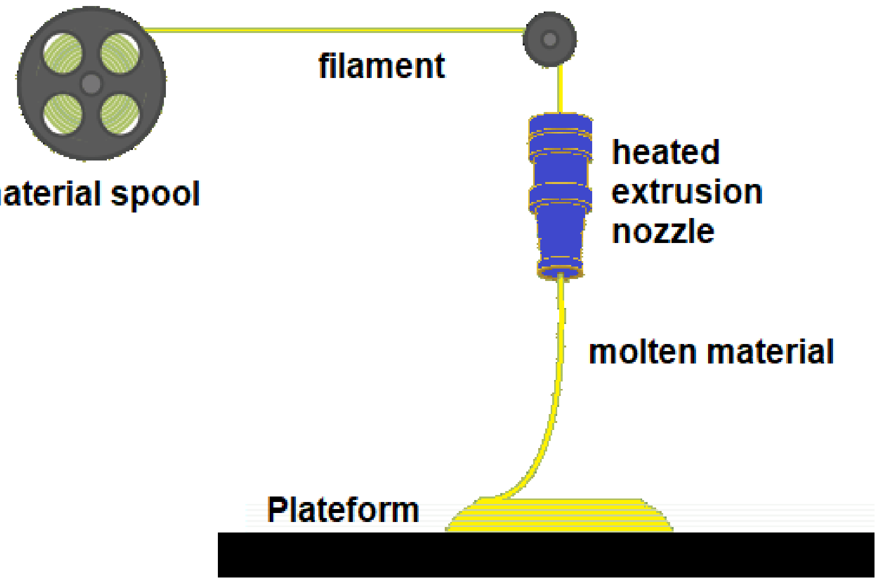


Figure 1.11 Fused Deposition Modeling process

A popular additive manufacturing technique for modelling, prototyping, and production uses is fused deposition modelling. FDM applies layers of material according to an "additive" approach. Unwound from a coil, a plastic filament or metal wire feeds material to an extrusion nozzle that controls the flow. The nozzle is heated to melt the material, and a numerically controlled mechanism that is directly managed by a CAM software programme may move it both horizontally and vertically. The model or component is made by extruding tiny beads of thermoplastic material to create layers that solidify as soon as they leave the nozzle. The extrusion head is commonly moved using stepper or servo motors. fast manufacturing and prototyping are done using FDM, a popular fast prototyping technique. Iterative testing is made easier by quick prototyping, and rapid manufacturing can be a more affordable option for extremely small batches. [11]

1.6 Material Used in FDM

➢ **Polymer** [12]

ABS and PC are examples of common polymers that may be used in 3D printing. A range of waxes and epoxy-based resins can also be utilised, in addition to the usual structural polymers. Many diverse structural and aesthetically pleasing materials may be made by combining various polymer powders. You can use the following polymers:

1. ABS (Acrylonitrile butadiene styrene)
2. PLA (Poly lactic Acid)
3. Nylon
4. Epoxy resin
5. Wax

➢ **Metal** [12]

A variety of metals, including some appropriate for structural and integrated component components, can be employed;

1. Gold and Silver
2. Aluminium
3. Stainless steel
4. Steel
5. Titanium alloy
6. Cobalt chrome alloy

➢ **Ceramic** [12]

Ceramic powders can be printed, including:

1. Silica/glass

1.7 Merits and Demerits

1.7.1 Merits [13]

❖ **Flexible design**

More complicated designs may be created and printed with 3D printing than using conventional manufacturing techniques. Utilising 3D printing has no limitations when it comes to design processes.

❖ **Rapid prototyping**

The prototype process may be accelerated by 3D printing since it produces parts more quickly than conventional manufacturing methods. This makes it possible for each step to finish sooner. In comparison to machining prototypes, 3D printing is less expensive and faster at making parts because the part can be finished more quickly, allowing for each designmodification to be finished at a much faster rate.

❖ **Print on demand**

The 3D design files are kept in a virtual library and may be found and printed whenever necessary since they are produced using a 3D model as a CAD or.STL file. By altering individual files rather than wasting money on out-of-date inventory and buying equipment, redesigns may be accomplished for very little money.

❖ **Strong and light weight parts**

Although some metals can also be used, plastic is the primary material for 3D printing. However, since plastics are lighter than their metal counterparts, they have advantages. This is crucial in sectors like automotive and aircraft where weight reduction is a concern and can result in higher fuel economy.

❖ **Fast design and production**

Compared to moulded or machined components, 3D printing may produce an object in a matter of hours, depending on the part's complexity and design. Through the use of 3D printing, time can be saved not only during the part's production but also during the design phase.STL or CAD files that are ready for printing.

❖ **Minimizing waste**

When compared to other methods, which use large chunks of non-recyclable materials, the production of parts uses only the materials required for the part itself, with little to no waste.

- **Cost effective**

The use of 3D printing reduces manufacturing costs and time spent on various machinery. There is also no requirement for operators to be present at all times when using 3D printers; they may be set up and allowed to complete the task.

- **Environmental friendly**

This procedure is by nature ecologically benign since it decreases the quantity of material waste required. When you take into account things like increased fuel economy from employing lightweight 3D printed parts, the environmental advantages are expanded.

1.7.2 Demerits [13]

- **Limited material**

Although 3D printing can produce objects from a variety of plastics and metals, the range of raw materials is not completely diverse. This is because not all metals or polymers can be heated to a temperature that enables 3D printing.

- **Restricted build size**

The size of components that may be manufactured is currently limited by the tiny print chambers of 3D printers. Anything larger will require printing in many pieces that are assembled after manufacturing. Due to the printer requiring to produce more pieces before manual work is employed to assemble the parts, this might raise prices and production time for larger products.

- **Post process required**

To get the desired finish on 3D printed components, cleaning is necessary to remove support material from the construction and to smooth the surface. Water jetting, sanding, chemical soak and rinse, air or heat drying, assembling, and other post-processing techniques are utilised. The size of the generated object, the intended purpose, and the kind of 3D printing technique employed during manufacturing all affect how much post processing is necessary.

- **Large volume**

Unlike more traditional methods like injection moulding, where producing high volumes may be more cost-effective, 3D printing has a static cost. While 3D printing may have a lower initial investment than other manufacturing processes, once it is scaled up to mass-produce large volumes, the cost per unit does not decline as it would with injection moulding.

- **Reduction in Manufacturing job**

Given that printers handle the majority of the production and automation, 3D technology has the potential to reduce the need for human labour. However, the technology could jeopardize these manufacturing jobs by eliminating the need for production abroad. Many third world countries depend on low skill jobs to maintain their economies.

- **Copyright Issue**

It will be nearly hard to distinguish between fake and counterfeit goods since there is a larger likelihood that they will be produced. This clearly has problems with quality control and copyright.

1.8 Application

- **Education [14]**

More schools are adding 3D printing techniques to their curricula every day. By enablingstudents to make prototypes without the need of costly tooling, 3D printing for education improves students by better preparing them for the future. Students create models they can handle to learn about the uses of 3D printing.
Students investigate design, engineering, and architectural concepts as they learn about various 3D printing applications. To study in the classroom, they can make copies of museum artifacts like fossils and historical artifacts without risking harm to priceless assets. They are able to see topographic maps from a fresh, three-dimensional angle.

- **Prototyping and Manufacturing [14]**

In the manufacturing industry, is best used when a product won't be mass produced sinceit enables the relatively affordable fabrication of a product in much lower amounts or on an individual basis. It improved in rapid prototyping (RP) technology have led to the creation of material and reduced assembly time.

- **Construction** [14]

Extrusion (concrete/cement, wax, foam, and polymers), powder bonding (polymer bond, reactive bond, and sintering), and additive welding are examples of 3D printing applications utilised in the construction industry. The private, commercial, industrial, and public sectors may all benefit from 3D printing in building. These technologies provide benefits such as enabling higher complexity and precision, accelerating construction, paying for less labour, enhancing functional integration, and producing less waste.

- **Art and Jewellery [14]**

By utilising 3D printing materials like PLA, ABS, gold, or platinum, it is also possible to create original, one-of-a-kind jewellery pieces or customised items at a significantly reduced cost utilising 3D printing.

- **Apparel**

Products such as customize shoes, clothes and eye wears are being manufactured.

- **Firearms**

AM has also produced weapons of defence such firearms, rifles, and safety gear. A US military team created a plastic pistol that anyone with a 3D printer could download and make.

1.9 Introduction to ABS material

Acrylonitrile-butadiene-styrene (ABS) moulding and extrusion materials are designated according to ISO 2580-1:2002, which can serve as the foundation for specifications. [15]

Acrylonitrile Butadiene Styrene, sometimes known as ABS plastic, is a thermoplastic that is amorphous, impact-resistant, and opaque.

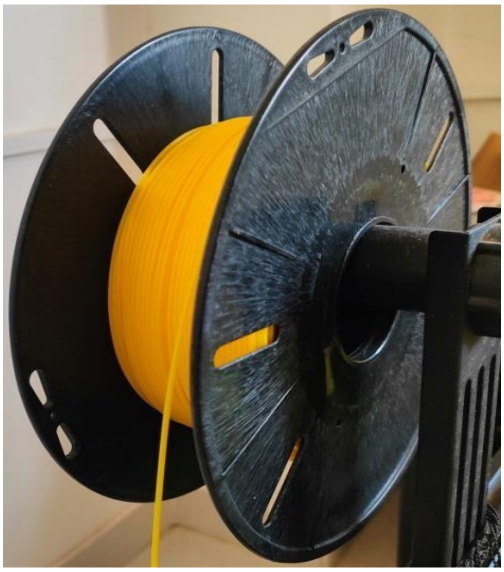


Figure 1.12 ABS material

ABS plastic is thought to have excellent structural strength. This makes it the perfect option for a variety of applications that require a robust, rigid plastic that can withstand impacts from outside forces. It is extensively utilised in applications that need structural stability, such as protective housings, camera housings, rigid packaging, etc.

ABS plastic is a recyclable and biocompatible substance. It lacks a unique plastic identification number. 100% of ABS may be recycled. Recycled ABS may be used with virgin material to create items that are higher quality while being more affordable. [15]

Due to its characteristics, ABS plastic material finds extensive use across a variety of industries and is compatible with a number of manufacturing techniques.

1.10 Properties of ABS material

ABS is a robust and long-lasting polymer. It is a resin that resists chemicals. Polar solvents are quickly affected by it. It offers better impact characteristics and a slightly higher heat distortion temperature. [16]

The processing window for Acrylonitrile butadiene styrene is large. On most types of common equipment, it can be processed. It can be extruded, blow-molded, or injection- molded. Due to its low melting point, it can be processed for 3D printing on an FDM machine. [16]

ABS sits between engineering resins (acrylic, nylon acetal, etc.) and ordinary resins (PVC, polyethylene, polystyrene, etc.). It frequently satisfies the property standards for a fair price and cost-effectiveness. It is the perfect material for a variety of structuralapplications.[16]

1.10.1 Physical properties [16]

- Excellent weld ability, high stiffness, and insulating qualities
- even at low temperatures, good impact resistance
- good resilience to abrasion and strain
- High dimensional stability
- Excellent surface quality and high surface brightness

1.10.2 Mechanical properties

Table No. 1.1 Mechanical properties of ABS material [17]

Sr. No.	Property	Value
1	Density (g/cm^3)	1.05
2	Tensile strength (Mpa)	47
3	Flexural Modulus (Gpa)	2.7
4	Melting Temp. range (°C)	230 – 270
5	Mould Temp. range (°C)	40 - 90

1.10.3 Chemical properties [16]

- Excellent tolerance to weak acids and alkalis

- Moderate aliphatic hydrocarbon resistance
- Poor resistance to alcohols, halogenated hydrocarbons, and aromatic hydrocarbons

1.11 Introduction to Infill structure:

While keeping your 3D printed parts relatively light, infill adds internal rigidity and strength. You can acquire the perfect strength-to-weight ratio for your 3D printing by using the best infill patterns. Your filament material and printing time will be conserved, lowering the overall cost of your prints. [18] A recommended infill percentage for ordinary 3D printing that will see some light usage and need some strength is between 15% and 50%. This rangeof infill density will strengthen the part's structure and offer a modest amount of strength without significantly increasing print time or weight. The cost of 3D printing will be less expensive the lower the infill percentage, as less material will be required.

These types of 3D printing can still carry out their intended function with a lower infill density (0–15%) and the most basic infill patterns, like lines or a grid. These two patterns are easy to print and strong enough in only two dimensions. Lines are less durable than grid, which delivers strength in both directions, although taking less time to print and using less material.

1.11.1 Different types of Infill structure

- **Grid**

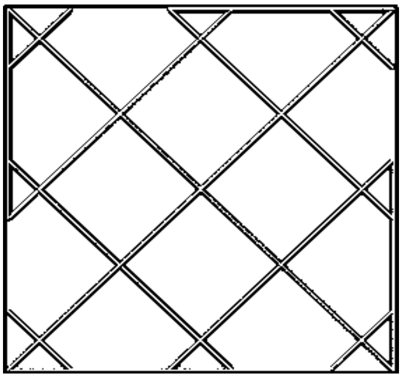


Figure 1.13 Grid Infill structure

The grid infill pattern looks like lines, but each layer has double the amount of space between its lines and is composed of two-dimensional, rather than one-dimensional, lines. Even though it only has two dimensions, this design is very strong. The grid design is produced with a standard quantity of material and in a decent length of time. [18]

- **Triangular**

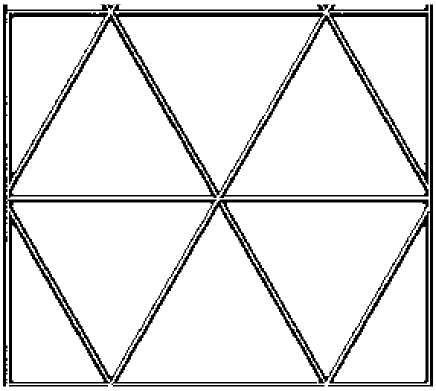


Figure 1.14 Triangular Infill structure

Triangular infill is the strongest infill design because of the strength of triangles. They provide the best support structure and are least likely to warp behind the part's walls. This type of infill prints quite quickly due to the print head's largely linear movement over the component. Due to its robustness and speed when combined, triangular infill is one of the best solutions for infill in 3D printing. [18]

- **Honey comb**

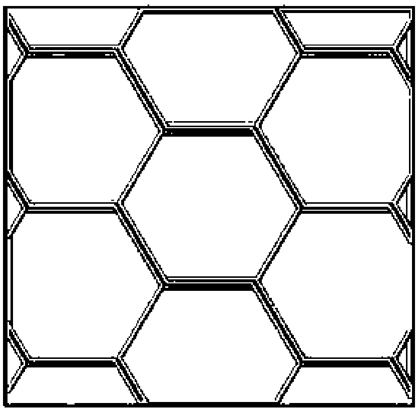


Figure 1.15 Honey comb Infill structure

As the name implies, this design produces an aesthetically appealing honeycomb structure. This infill pattern is appropriate for prints that demand substantial strength but are only fairly speedy and shouldn't consume a lot of material. This fill type has the highest strength-to-weight ratio of all the infill patterns since it is composed of tessellating hexagons. However, of all the infill types, it takes the longest to print because the printhead must frequently change directions. [19]

- **Rectilinear**

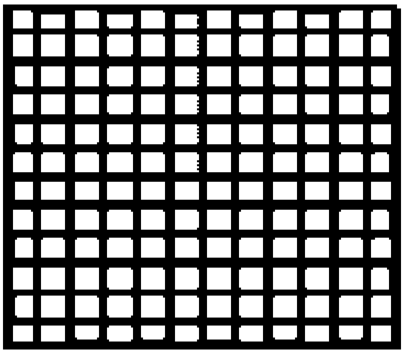


Figure 1.16 Rectilinear Infill structure

The only type of infill that may provide a 100% dense component is rectangular infill, which is made up of a grid of parallel and perpendicular extrusions. Rectangular infill prints swiftly as well due to the linear motion of the printhead. [20]

- **Concentric**

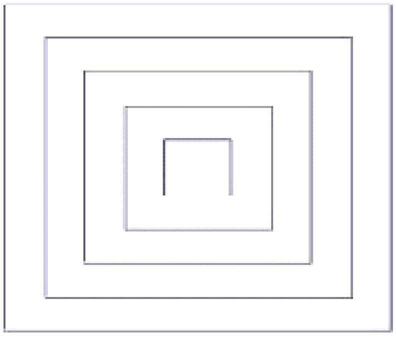


Figure 1.17 Concentric Infill structure

The perimeter shapes of the concentric infill pattern's interior structure are shown by concentric lines. This design prints rapidly, consumes significantly less material than other patterns, and works well for flexible components. [20]

- **Line**

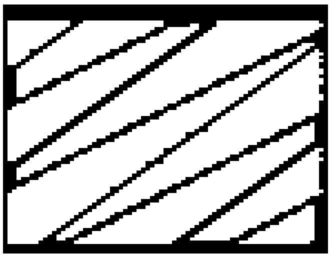


Figure 1.18 Line Infill structure

The lines in the infill pattern are printed in one direction on every other layer. This infill pattern provides strength in only two dimensions and is perfect for quick printing. The lines pattern's sparse use of material and relatively light weight. [20]

1.12 Introduction to Honeycomb structure [18]

The strongest infill pattern for FDM 3D printing is honeycomb. The six sides of the honeycomb construction evenly distribute weight. It results in a solid 3D printed component with excellent strength in all directions. Printing pieces that need to be light but still have a good load-bearing capability is appropriate for honeycomb infill.

Printing pieces that need to be light but still have a good load-bearing capability is appropriate for honeycomb infill. By keeping your 3D printed objects relatively light, infill adds interior stiffness and toughness. You can acquire the perfect strength-to-weight ratio for your 3D printing by using the best infill patterns. Your filament material and printing time will be conserved, lowering the overall cost of your prints.

Figure 1.19 3D printed Honeycomb structure

1.12.1 Different Density in Honeycomb structure

The amount of plastic used internal structure to print the Infill structure. A 3D printed model's internal structure is referred to as infill density. The infill percentage, on the reverse together, controls the density of this structure and can be expressed as a percentage. A 3D model with zero infill will be produced as an empty shell, whereas one with 100% infill will have a substantial interior structure. To put it another way, a greater infill percentage will result in more material being used inside the 3D-printed part. [21]

- **Different densities Infill structure specimen**

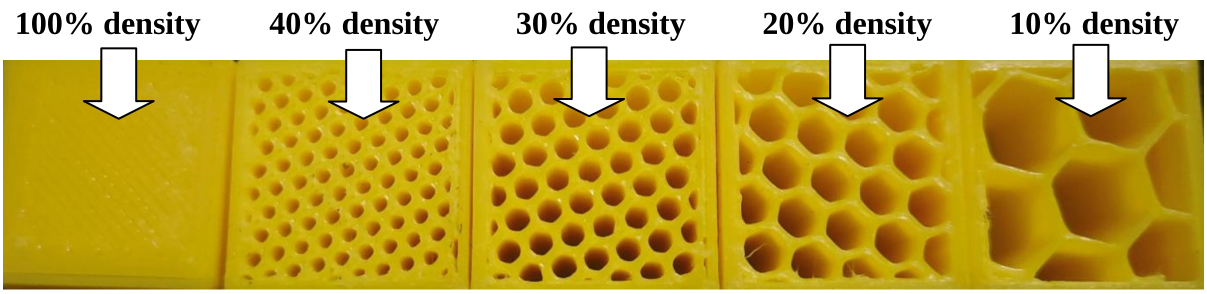


Figure 1.20 Different densities in Honeycomb structure

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

Saquib Rouf et al. [22] investigation found that 3D printing may successfully replace conventional production processes, especially when creating intricate and optimised products. The current study is structured to concentrate on the many 3D printing procedures utilised for the creation of industrial goods, the different process parameters involved in each process, and their impact on the mechanical characteristics of these components, especially fatigue, tensile, bending strength, and so on. There is a section devoted to the multiple uses for these 3D printed goods, particularly in the fields of medicine, aircraft, and automobiles.

Mohammad Reza Khosravani et al. [23] suggested that it was important to look at the mechanical strength of these parts. In this experiment, the polylactic acid (PLA) substance and FDM procedure were used to manufacture the specimen. This study may be used to create open-holed polymer plates for 3D printing that is stronger mechanically and structurally. By applying a tensile force to the manufactured plates, the mechanical strengths of the plates are ascertained. Since the strength of the component is influenced by the ratio of the specimen width to the hole diameter (w/D), we printed samples with various hole diameters.

Gaoyuan Ye et al. [24] had suggested that compression testing should be used to determine which vertically printed X structures with a filling angle perpendicular to the strut length and along the strut length should be used. Investigated were the effects of strut length, diameter, and inclination angle on compressive properties. This study's findings show that the strut slenderness ratio had a significant influence on structural failure modes and that a densification stage only appeared when the slenderness ratio exceeded 0.175. The strength and specific strength of the X structures were most heavily influenced by the strut length and inclination angle.

A.Sabik et.al [25] had suggested that the project include an experimental and numerical analysis of the Polylactic Acid (PLA) samples made through fused filament fabrication (FFF) that fail under tension. In this study, strain and stress distribution are identified by continuously scanning the deformation of the specimens during the tests with the 3D Aramis measuring system utilising the digital image correlation method.

Mohammed Hikmat et.al [26] had demonstrated that in three-dimensional (3D) printing using fused deposition modelling (FDM), the process parameters have a significant influence on the printed object; the parameters must be carefully adjusted to enhance the characteristics of the finished output. In light of this, the current study examined how the build orientation, raster orientation, nozzle diameter, extruder temperature, infill density, shell number, and extrusion speed of Polylactic acid (PLA) filament affected the tensile strength of the final product.

A.K. Haldar et.al [27] had research on unique corrugated trapezoidal and triangular core designs. To determine the effects of core thickness, skins, core height, and the contact area between the core and skins on the mechanical properties of sandwich panels, a number of experimental studies were carried out. The compressive strength and energy-absorbing properties of the sandwich panels tested increase quickly with core thickness.

Qi Feng et.al [28] conducted research on methods for optimising process parameters with machine learning to reduce the impact of warpage. In this study, a framework was built to clearly identify the quasi-optimal process parameters in order to reduce residual stress and minimise the effects of warpage through simulation using the Finite Element Method.

Gurcan Atakok et.al [29] had studied that test parts were examined using the Taguchi methodology to determine the effects of Fused Deposition Modelling (FDM) production parameters on tensile strength, three-point bending strength, and impact strength. The results showed that layer thickness is the most effective factor for increasing tensile strength, three point bending strength, and impact strength, regardless of occupancy rate or filament types. The most effective parameter for enhancing mechanical properties was found to be layer thickness.

Dhinesh S.K et.al [30] had claimed that ABS and PLA are the two materials used in 3D printing the most. to assess the tensile and flexural strength of the material. The tensile characteristics of the sandwich are being improved by the ABS's toughness and might surpass PLA. The power of the alternative layers exceeds that of the individuals. Sandwiching PLA between two ABS layers may increase mechanical properties and ultimately act as a substitute.

C K Basavaraj et.al [31] had looked at the fused deposition modelling (FDM) process parameters are Layer thickness, orientation angle, and shell thickness are some of the process variables that were investigated. Dimensional accuracy, manufacturingability, and maximum tensile strength. Layer thickness is the process variable that has the greatest impact on response characteristics. because thinner layers provide better axial loading capability and bonding strength.

Atefeh Rajabi Kafshgara et.al [32] had examined that Several input design parameters, including infill density; extrusion temperature; raster angle; and layer thickness are taken into consideration as variables in order to investigate the impact of process variables on the tensile properties of 3D printed Polylactic Acid (PLA) material. The Taguchi and ANOVA procedure is used to examine the link between mechanical properties (such as ultimate tensile stress, yield strength, modulus of elasticity, toughness, and elongation at break) and process factors.

Nicolas G. Morales et.al [33] had suggested that this research on the interlayer cooling affects the mechanical properties of Acrylonitrile Butadiene Styrene (ABS) structures that are 3D printed using fusion-based material extrusion. The purpose of one sample is to evaluate the compressive strength of the structural material. Printer features can help to mitigate interlayer cooling's effects.

Yu Zhao et.al [34] had evaluated that the tensile strength and Young's modulus of FDM additive manufacturing PLA material with varied printing orientations and layer thicknesses, two original theoretical models had been constructed. In the study, the impact of layer thickness and printing angle on the tensile strength and Young's modulus of FDM PLA materials was examined.

Philippe Lesage et.al [35] had proposed that study describes the dynamical characterization of mechanical structures manufactured using the Selective Laser Melting (SLM) process at different orientations. A subtractive specimen created from an AlSiMg10 ingot was compared to an AM specimen made in three orientations (Flat, Upright, and Rotate) and angles.

Aboma Wagari Gebisa et.al [36] had looked on process variables affected the tensile properties of FDM components. In this paper evaluated that the impact of process parameters on the material's tensile qualities, high performance ULTEM 9085 polymetric material and a full factorial design of experiment. The inquiry evaluates the following five variables: counter number, counter width, raster angle, and airgap.

M. Ajay Kumar et.al [37] had suggested that because to its better formability, toughness, and strength, carbon fibre reinforced poly lactic acid (PLA), a thermoplastic polymer, is frequently used in structural applications such the manufacturing of frames and tools. By adjusting various machine settings in accordance with the suggestions made by Taguchi for experimental design and optimisation, the study seeks to produce PLA thermoplastics reinforced with carbon fibre that have the desired tensile strength. Infill density and print speed have a substantial impact on the tensile strength of PLA specimens produced by 3D printing.

Kyle Raney et.al [38] had investigated that the ability to produce useful goods with aesthetic appeal. This article's goal is to explain how specimen mesostructure affects the monotonic tensile behaviour of components made using FDM ABS.

Nagamani Bankupalli et.al [39] had proposed that butadiene content and build orientation might affect how ABS components made using fused filament fabrication (FFF) behave in terms of tribology. The ABS material's butadiene concentration and construction orientation have a significant effect on the wear rate and coefficient of friction. As the load is changed while maintaining a constant speed and track radius, the volumetric wear rate rises. As the load increases, the coefficient of friction gradually decreases from higher to lower values.

K.G. Jaya Christiyana et.al [40] had reviewed that the maximum tensile and flexural strength values for the ABS + hydrous magnesium silicate composite to be employed as the study's starting material, are presented. Other samples with a layer thickness and maximum printing speed experienced a slight decrease in strength values. Higher bonding between the prior layer and the layer printed at a low printing speed leads to higher tensile and flexural strength.

Junior Nomani et.al [41] had researched had that the deposition layer thickness affected the mechanical properties of printed ABS material when using fused filament fabrication (FFF). On samples printed with layer thicknesses ranging from 0.2mm to 0.8mm, tensile and compression tests were carried out in accordance with standards. The number of deposited layers increased the interlayer bonding strength, and the extrusion process caused the material to harden during shear.

Mohammad Reza Khosravani et.al [42] had experienced that designing, manufacturing, and characterising sandwich-structured 3Dprinted components that were put through a variety of loadings and environmental conditions. The specimens made of ASA with honeycomb cores demonstrated the highest stability under bending force during thermal ageing. This experiment examined the stability and failure of ABS cores that were 3D printed using FDM in various shapes, including honeycomb and triangles. Compared to the triangular lattice, the hexagonal construction showed larger load bearing capacity.

Antonella Sola et.al [43] had reviewed that the standardisation needs in AM with a focus on mechanical testing. Due to their widespread use, mechanical properties are frequently used to describe tensile qualities. This might be important as polymer additive manufacturing grows in popularity for producing load-bearing structures, lightweight components, and topologically optimal constructs with designs that are not at all similar to a standard rectangle.

Juraj Beniak et.al [44] had provided researched on operational traits that affect additive manufacturing production processes and the quality of components produced using fused deposition modelling (FDM) technology. In terms of analysing the measured strength characteristics of produced components, including quality metrics like roughness and correctness, the study provides the whole experimental assessment of input parameters for digital model pre-processing. In terms of elongation during tensile testing and compressive strength, annealing affects the material properties of produced specimens.

Stefan TABACU et.al [45] had proposed that to produce a selection of lattice, honeycomb, and rectangle-patterned 3D structures. First, a straightforward, one-element model was used to estimate and calibrate the parameters required to define the damage, and then sample traction and compression models are used. The input data for materials using tension and compression curves is more labor-intensive, the results are more precise than those obtained using simple tensile test results.

Rahul Roy et.al [46] had suggested using ABS and PLA thermoplastics to build the samples for exploratory study work in a 3D printer. The material deposition layer thickness, infill angle, infill pattern, and deposition orientation are the important printing factors. Hardness, tensile and torsion strength, among other topics, are possible extensions of the research. The majority of AM materials are sensitive to environmental factors including temperature, humidity, and noise, which might reduce the accuracy of the FDM-produced object.

Daniel Foltut et.al [47] had suggested that the tensile mechanical properties of Acrylonitrile Butadiene Styrene (ABS), a thermoplastic amorphous polymer produced via FDM printing and injection moulding, are examined and material's behaviour switches from brittle to ductile as the temperature rises. Injection-molded ABS samples have a higher tensile strength than FDM-printed ABS samples.

Mahendra N. Vhatkar et.al [48] had hypothesised that the strength of 3-D printed components is discovered to be significantly influenced by the infill density, print quality, and layer thickness. The paper looks at research and advises utilising ANSYS Workbench for the initial design and analysis of the plain component as well as for manufacturing these plain components using different combinations of infill density, layer thickness, and print quality.

M. Manoj Prabhakar et.al [49] had investigated the input parameters such as filament diameter, extruder temperature, feed rate, and raster angle, working material characteristic, nozzle angle, and separation between parallel faces affected output characteristics. FDM has become into the most popular and affordable 3D technique. The practise of emptiness development is seen during coating sediment and FDM extrusion due to heating and heating.

Manav Doshi et.al [50] had suggested that analysis of the printing variables that affect the mechanical properties of FDM components, including tensile strength, stress, and Young's modulus. This article examined the most crucial printing variables that affect mechanical properties, such as layer thickness, infill density and pattern, printing speed, build orientation, and raster angle.

Chamil Abeykoon et.al [51] had suggested the mechanical, thermal, and morphological characteristics of 3D-printed specimens under varying processing conditions, including printing materials, infill pattern, infill density, and infill speed.

Rishi Kumar et.al [52] had researched that 3D printed object use, manufacture, and recycling of commonly used filament materials (PLA, ABS, and PETG) on the environment. By contrasting the environmental effects of various materials and choosing the most ecologically friendly choice, the research aids stakeholders in decision-making.

Carla M. Ferreira et.al [53] had indicated that the high cycle fatigue behaviour of solid cylinder specimens made of acrylic butadiene styrene for fused filament production under both static and cyclic torsional loads. changing the infill pattern from concentric to zigzag and the number of outside walls from one to two to three. The zigzag infill pattern was shown to have superior mechanical properties under torsion stress in monotonic testing compared to the concentric design.

Junior Nomani et.al [54] had investigated how the thickness of the deposition layer affected the mechanical properties of printed ABS material while using fused filament fabrication (FFF). On samples printed with layer thicknesses ranging from 0.2mm to 0.8mm, ASTM standards-compliant tensile and compression tests were performed.

F. Saenz et.al [55] had proposed that the mechanical properties of ABS produced by additive manufacturing at 77 K and related them to 3D printing settings. In that study, the Young's modulus, yield strength, and ultimate strength of ABS manufactured additively are examined at room temperature (RT) and 77 K while varying the 3D printing parameters of layer thickness, raster pattern, and infill.

Leipeng Yang et.al [56] had researched that focuses on optimised the settings to create greater tensile strength and lower surface roughness with shorter build times during the FDM process, as had been recommended based on a central composite design for the tensile specimen creation process. Investigated are the effects of five extrusion factors on three outputs: tensile strength (TS), surface roughness (SR), and build time (BT). These parameters include nozzle diameter, liquefier temperature, extrusion velocity, filling velocity, and layer thickness. The findings show that the approach described in this study is effective for improving mechanical properties, surface quality, and FDM process efficiency.

David E. Fly et.al [57] had proposed that 3D printed plastic parts were composite structures with separate layers of predetermined porosity and density. A 3D printed item with an internal channel has a different internal construction pattern than a part with the same form but no internal channel. That studied looked at how an internal channel and the direction of the structure affected tensile strength. Although the ultimate tensile strength was significantly impacted, the modulus of elasticity was unaffected by the presence of an internal channel.

Harshit K. Dave et.al [58] had suggested that the tensile behaviour of FDM printed objects with multiple layer stacking configurations, multi-infill patterns, and different infill densities for different raster orientations. Two thermoplastic materials, PLA and ABS, are used to print combined patterned pieces that are then mechanically tested to evaluate their tensile qualities. The printing process includes six possible stacking sequences, three various degrees of infill density, and two alternative raster layouts.

Gabriel A. Johnson et.al [59] had summerised that the Samples produced by two commercially available 3D printers underwent tensile testing. The materials looked at included PLA, ABS, PETG, various nylons, Polycarbonate/ABS, and ASA filaments. On samples printed with varying levels of infill, tensile properties were evaluated. At full infill, Nylon had the highest tensile strength while PLA had the lowest. As the infill percentage decreased, the range of tensile strengths for all materials drew closer together, proving that the infill percentage had a significant impact on tensile strength.

2.2 Literature Summary

The following inference may be made from an examination of available material on mathematical analysis of mechanical characteristics verified by experimental data:

- The application of 3D printing to product usage defines the mechanical characteristics of the component parts.
- Analytical approach is useful for product pre-examination data.
- To improve technique by making 3D printed parts lighter and using less expensive materials.
- The application of 3D printing to product usage defines the mechanical characteristics of the pieces.
- Pre-examination data on 3D printed products benefit from analytical methods.
- Optimisation process that reduces the weight and cost of the materials used to make the 3D printed object.
- One of the key mechanical characteristics of a structure is its strength, which is affected by the internal structural density of a 3D-printed object.
- Mechanical characteristics are significantly impacted by residual stresses.
- Using varying layer thicknesses and analysing the compressive and tensile strengths of components leads to less waste and greater material utilisation in their application.

2.3 Research Gap

There is some research gap from available research paper:

- According to our research, ABS is the ideal material for constructing prototypes, production facilities, casings bodies, the automobile sector, and toys.
- In our study, we discovered that the mechanical characteristics, such as tensile strength, compressive strength, and bending strength, are primarily impacted by the infill structure, infill density, layer thickness, and nozzle temperature.
- Grid, rectilinear, and triangle structures are the most typical infill structures. Few honeycomb structures are used in research papers to determine their tensile, compressive, and bending strength.

2.4 Problem Definition

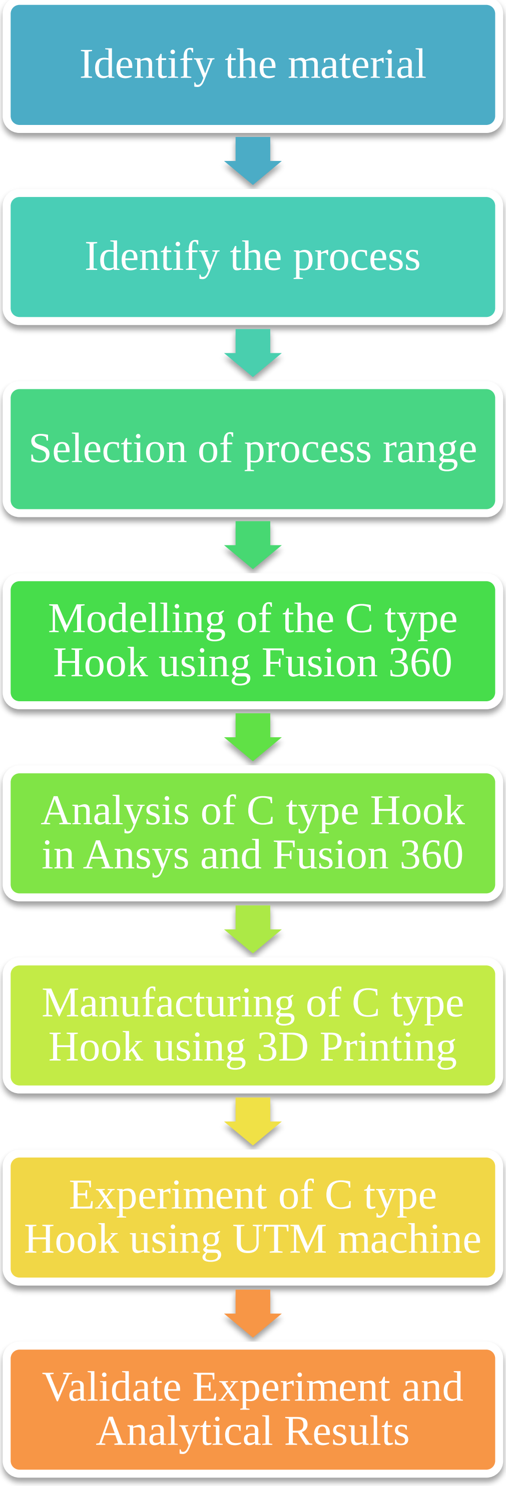
- We conducted an experiment utilising ABS material
- In experiments, the fused deposition modelling approach is employed in additive manufacturing (3D printing)
- To develop a 3D model in CAD software and convert it to a 3D model utilising additive manufacturing
- Filament size and Infill density are parameters dependent on geometry
- Nozzle speed and Nozzle temperature are process-based factors
- Layer thickness is a characteristic depending on structure

2.5 Objectives

- To determine the mechanical characteristics currently present in the 3D-printed components and to identify appropriate features as well as process-related variables
- To identify mechanical components using an organised literature review and 3D CAD model
- To determine the process parameters related to the FDM (Fused Deposition Modelling)
- To selected the 3D printing component using FDM
- To examine honeycomb patterns by varying densities of Selected Component
- Validate the experiment results with software analysis

CHAPTER 3

METHODOLOGY



CHAPTER 4

MODELLING AND ANALYSIS OF C TYPE HOOK

4.1 Introduction to Modelling and Analysis

Modelling are used in design to assess and changes on already-existing design or to develop new design. These models may be used to evaluate design elements and explain them to another. The use of a logical model of a given system to create data and assist decide decisions or make predictions about the system is known as Analysis. [61]

4.2 Introduction to C type Hook

A C type Hook is used to grip and lift loads using a hoist or crane. Lifting hooks may be divided into many categories, such as single hook, double hook, and C type hook. Its great load carrying capacity, simple to assemble, good operating life and tough in construction.

4.2.1 2D sketch of C type Hook

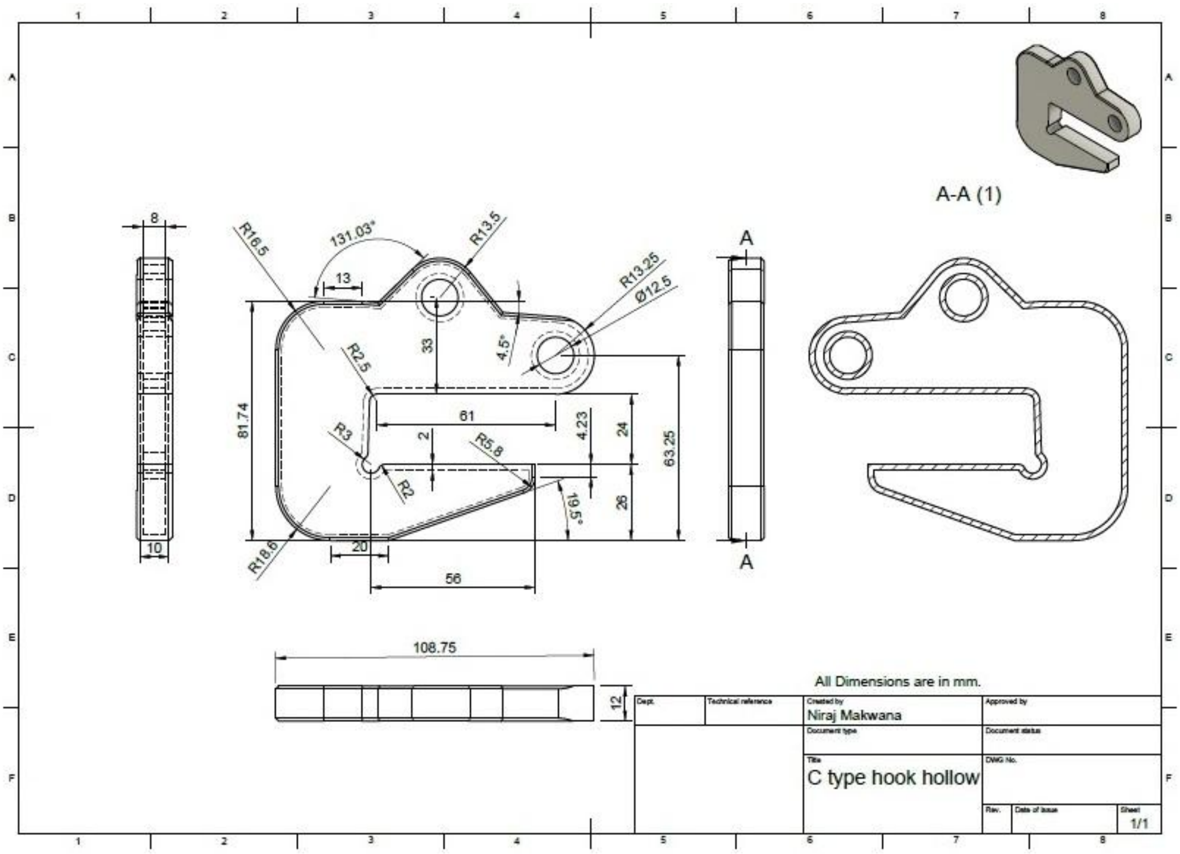


Figure 4.1 2D sketch of C type Hook

4.2.2 Modelling Procedure of C type Hook

- Select front plane and create 2D drawing on it.
- Select extrude feature to create 3D model of 2D drawing.
- To select 3D model face and sketch circle and select extrude cut to create 3D hole.
- Select Chamfer feature to remove sharp edges of 3D model.
- Select the material for the 3D component.
- Save the 3D model.

4.2.3 CAD model of C type Hook

Figure 4.2 CAD model of C type Hook

4.2.4 3D printed model C type Hook

Figure 4.3 3D printed C type Hook model

4.3 Introduction to Saddle Clamp

Saddle clamps, also known as pipe saddles allow for the addition of branch lines to existing piping systems to fixing temporary or permanent installations. Saddle clamp is widely used in applications of automobile, plumbing, piping industries, fittings & electrical.

4.3.1 2D sketch of Saddle clamp part I

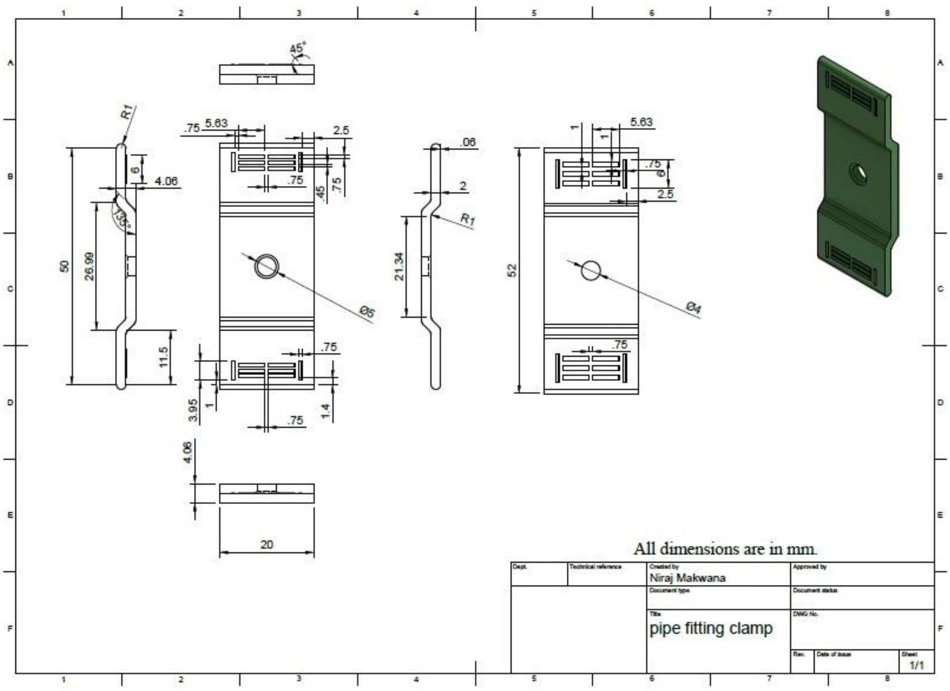


Figure 4.4 2D sketch of Saddle clamp part I

4.3.2 2D sketch of Saddle clamp part II

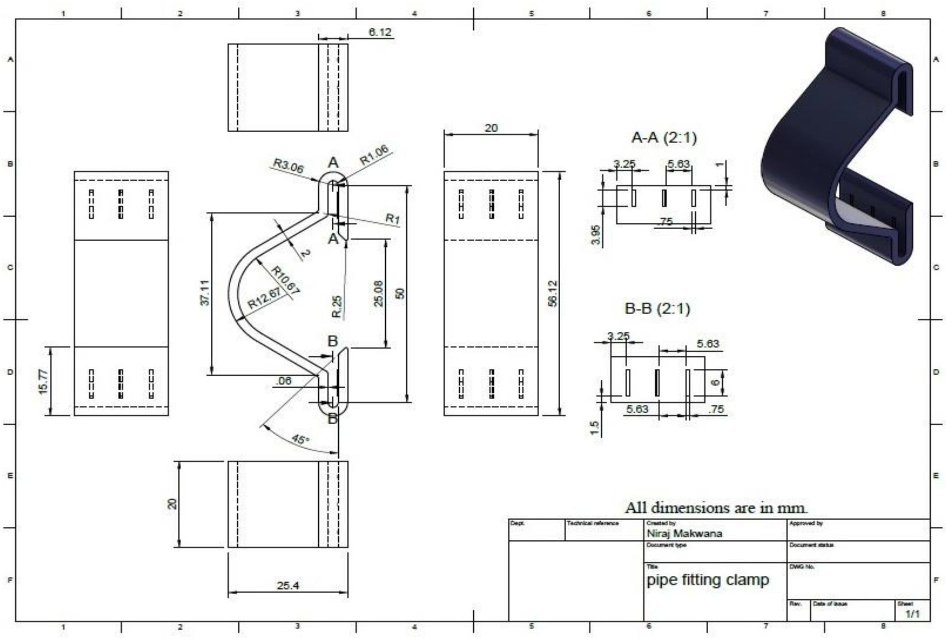


Figure 4.5 2D sketch of Saddle clamp part II

4.3.3 Modelling Procedure of Saddle clamp

- Select front plane and create 2D drawing on it.
- Select extrude feature to create 3D model of 2D drawing.
- To select 3D model face and create 2D Rectangular shape and select extrude command end convert into 3D.
- To select 3D model face and create 2D circle and select extrude cut to create 3D hole.
- Select the material for the 3D component.
- Save the 3D model.
- To open the model and insert the other component of clamp and to select the assembly option.
- To select the 3D CAD model surface and to apply slide option into the model and also apply boundary condition to slide in fixes range.
- To save the Assembly of CAD model.

4.3.4 CAD model of Saddle clamp

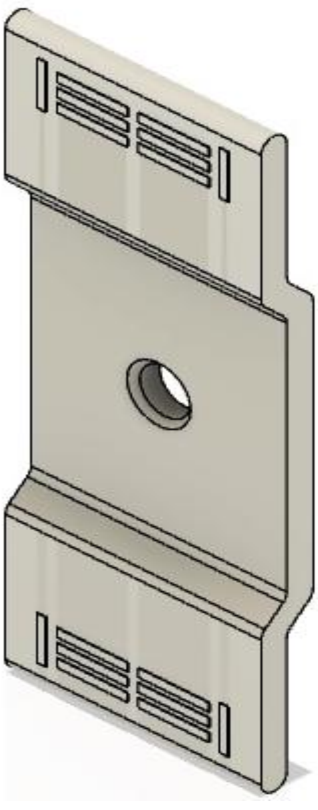


Figure 4.6 CAD model of Saddle clamp part I

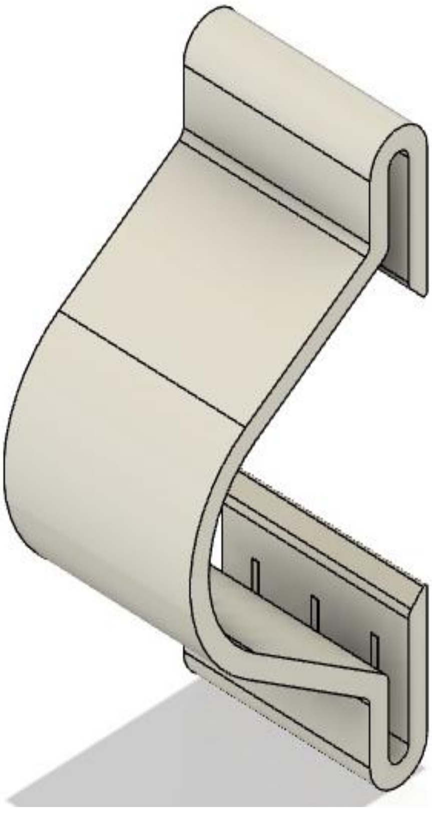


Figure 4.7 CAD model of Saddle clamp part II

4.3.5 Assembly of CAD model Saddle clamp

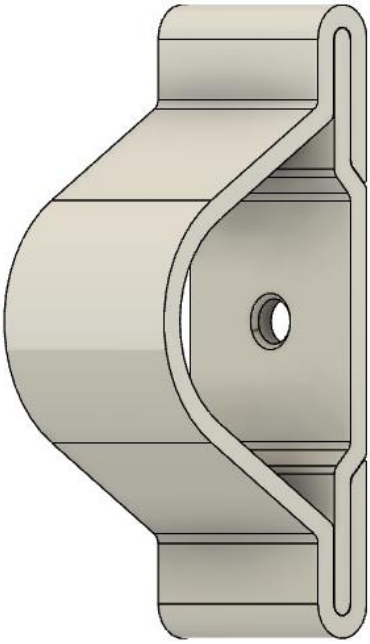


Figure 4.8 Assembly of CAD model Saddle clamp

4.3.6 3D printed model of Saddle clamp

Figure 4.9 3D printed Saddle clamp model

4.4 Introduction to Brake Lever

Brake levers are made from plastic or metal levers installed on your handlebars that, when pushed, engage the cycles or bikes to stop you from moving by drawing a cable.

4.4.1 2D sketch of brake lever

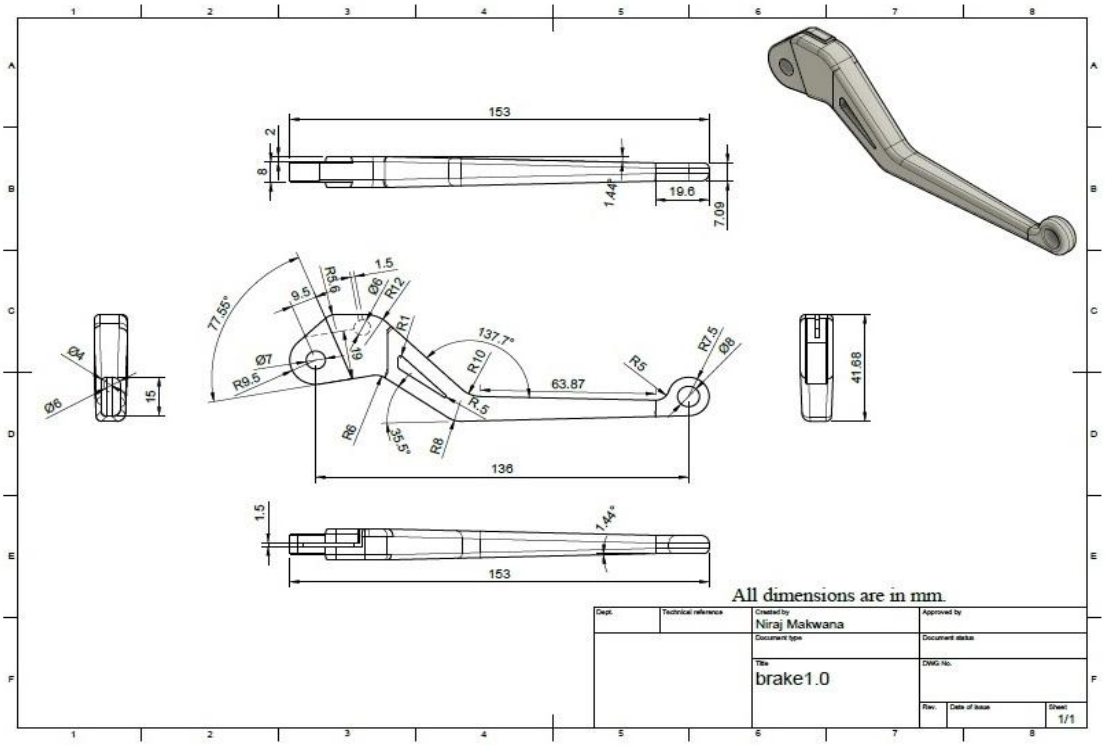


Figure 4.10 2D sketch of brake lever

4.4.2 Modelling procedure of Brake lever

- Select front plane and create 2D drawing on it.
- Select extrude feature to create 3D model of 2D drawing.
- To select top plane and create 2D triangular shape and select extrude cut command and cut 3D model.
- To select 3D model face and create 2D circle and select extrude cut to create 3D hole.
- Select Fillet command and convert sharp edges into smooth edges.
- Select the material for the 3D component.
- Save the 3D model.

4.4.3 CAD model of Brake lever

Figure 4.11 CAD model of Brake lever

4.4.4 3D printed model of Brake lever

Figure 4.12 3D printed brake lever model

4.5 3D printing procedure to manufacture components

- To select the 3D model and then open in slicing software and then convert into .STL file.
- .STL file open into Slicing software and check the material parameters Like Nozzle dia., Layer thickness, infill structure & density, Bed temp. & Nozzle temp., Print Speed of nozzle, etc.
- Convert into G code and save the data in pen drive. To insert the pen drive in 3D printer and click the start button to run the 3D printer.
- After few minutes 3D model is ready to remove on the plate form.
- After removing the model it required finishing process to remove some extra layers.
- Our 3D printed model is ready.

4.6 CAD model with Different Density in 30x30x30mm Specimen

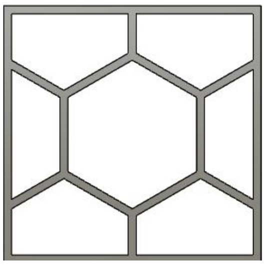


Figure 4.13 10% density in Specimen

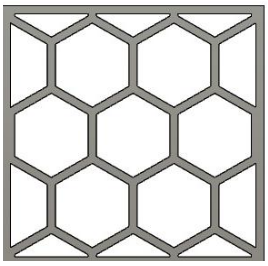


Figure 4.14 20% density in Specimen

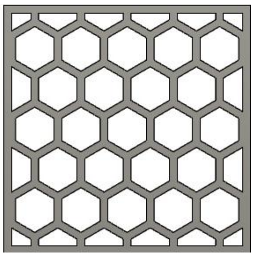


Figure 4.15 30% density Specimen

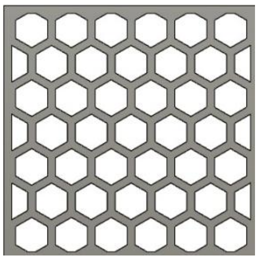


Figure 4.16 40% density in Specimen

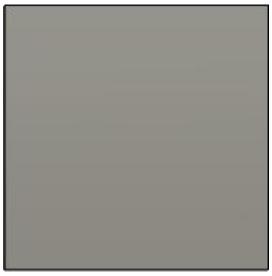


Figure 4.17 100% density in Specimen

- **Dimensions of all Specimen**

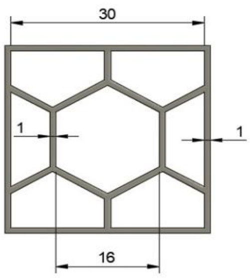


Figure 4.18 10% density Specimen dimension

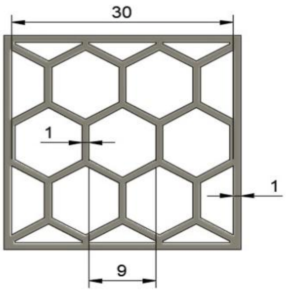


Figure 4.19 20% density in Specimen dimension

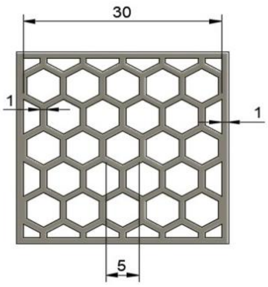


Figure 4.20 30% density Specimen dimension

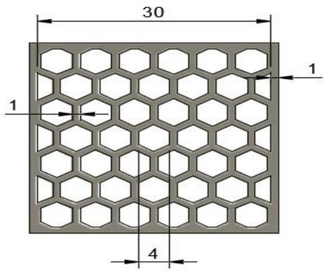


Figure 4.21 40% density in Specimen dimension

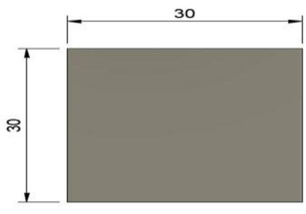


Figure 4.22 100% density in Specimen dimension

4.7 Static Structural Analysis of C type Hook Using FEA

4.7.1 Introduction to FEA

It is numeric tool to get approximate solution of physical system. The object is modeled using discrete building blocks called elements. Each element has exact equations that describe how it responds to a certain load. The "sum" of the response of all elements in the model gives the total response of the design. The elements have finite number of unknowns, hence the name finite elements. FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within.

➢ **Why FEA is needed?**

- To reduce the amount of prototype testing.
- Computer simulation allows multiple “what-if” scenarios to be tested quickly and effectively.
- To simulate designs that are not suitable for prototype testing.
- Cost savings.
- Time savings and reduce time to market.

➢ **Objectives of Static Structural Analysis**

The objectives of static structural analysis are to predict behavior of columns under loading condition and check change in deformation and stress introduced into it.

4.7.2 Methodology Adopted for Static Structural Analysis

a) Build Geometry

Construct the 3D model of object is the first step of static structural analysis. 3D modelling software like Fusion 360 is require to develop 3D model of object.

b) Define Material Properties

Second step is to define some necessary material properties that compose the object being modeled.

c) Generate Mesh

Mesh tool provide various options to mesh the 3D model. The mesh can be 2D or 3D depending upon the requirement. Selected volumes or areas can be meshed using mesh option.

d) Apply Loads

Once the system is fully designed, the next task is to provide constraints, such as boundary conditions, physical loadings.

e) Obtain Solution

This is actually a step, because ANSYS needs to understand within what state (steady state, transient etc.) the problem must be solved.

f) Obtain the Results

After the solution has been obtained, there are many ways to present ANSYS results, which can be choose from many options such as tables, graphs, and contour plots.

4.7.3 Steps for Static Structural Analysis of C type Hook

- **Build Geometry**

A 3D model of cold aggregate feeder unit is developed using Fusion 360 as shown in Fig. 3.13

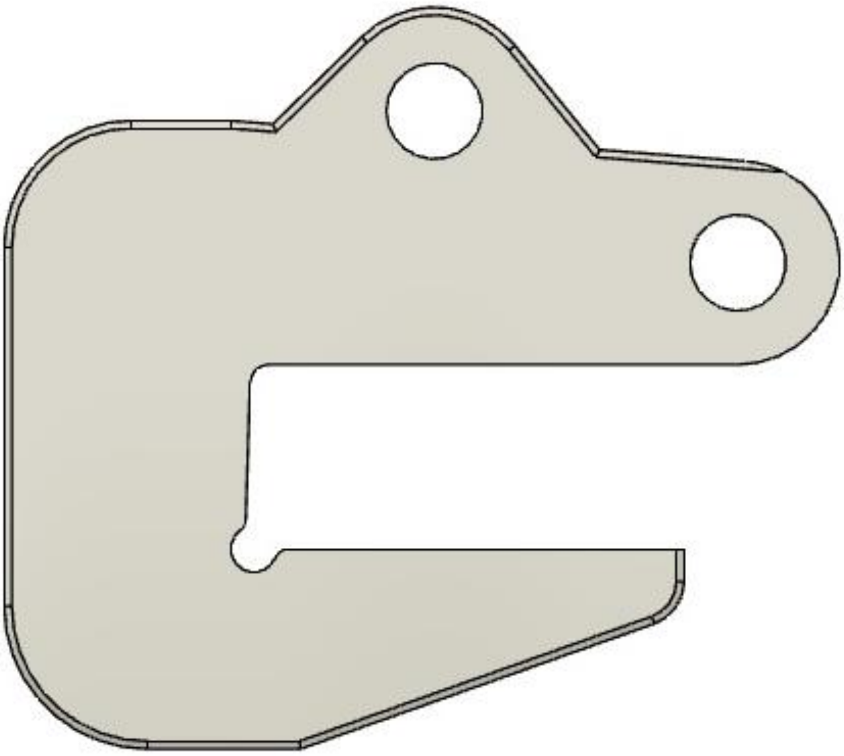


Figure 4.23 C type Hook CAD Geometry

- **Define Material Properties**

For static structural analysis, 3D model created using Fusion 360 is imported in ANSYS Workbench 2023. Then after material of C type Hook and its mechanical properties are defined in ANSYS as given in Table No.3.1

Table No. 4.1 Mechanical properties are available in Ansys workbench

Sr. No.	Properties	Values
1	Material	Acrylonitrile Butadiene Styrene (High-impact, Injection Molding)
2	Density	1030 kg/m3
3	Tensile Ultimate Strength	36.26 mpa
4	Tensile Yield Strength	27.44 mpa

- **Mesh Generation**

Figure 3.14 shows that finite element mesh is adopted in all the analysis. Total number of nodes and elements generated are 5169 and 2653 respectively.

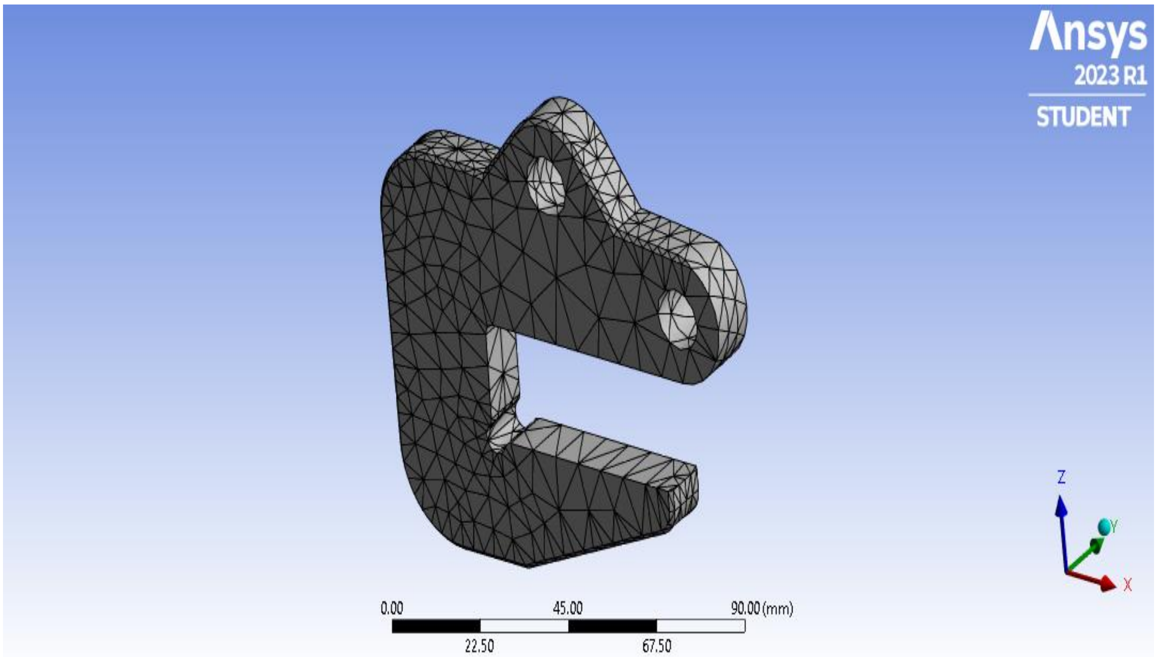


Figure 4.24 Mesh generated Finite Element Model of C type Hook

- **Boundary condition**

Here as shown in Figure 3.15, fixed support is applied at the upper Hole.

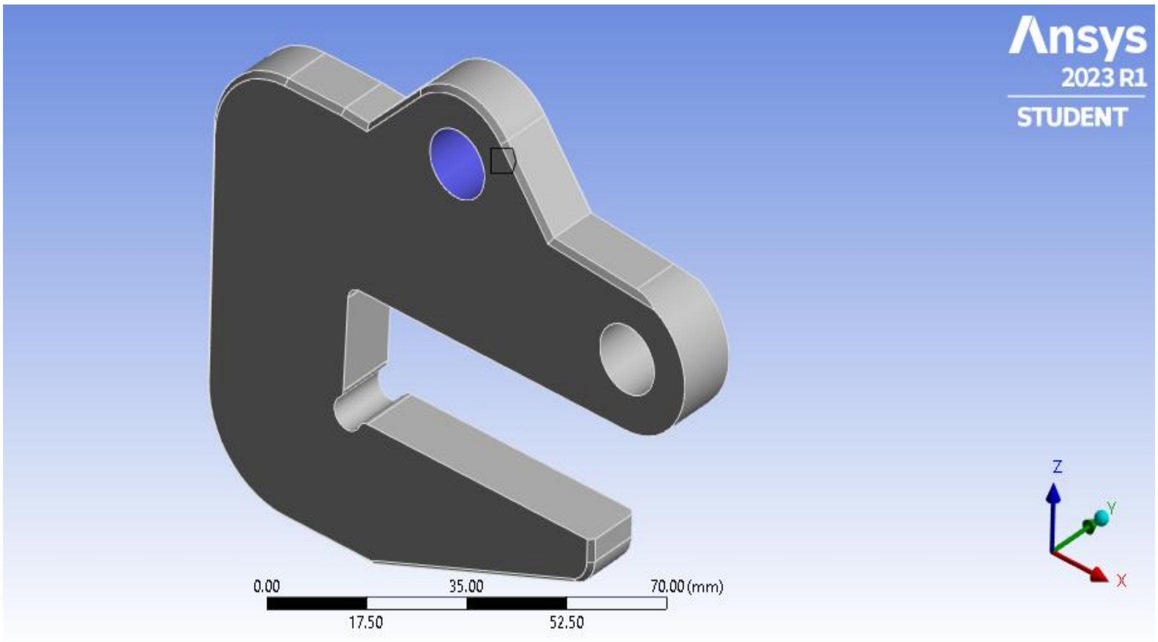


Figure 4.25 C type Hook fixed portion

- **Load applied**

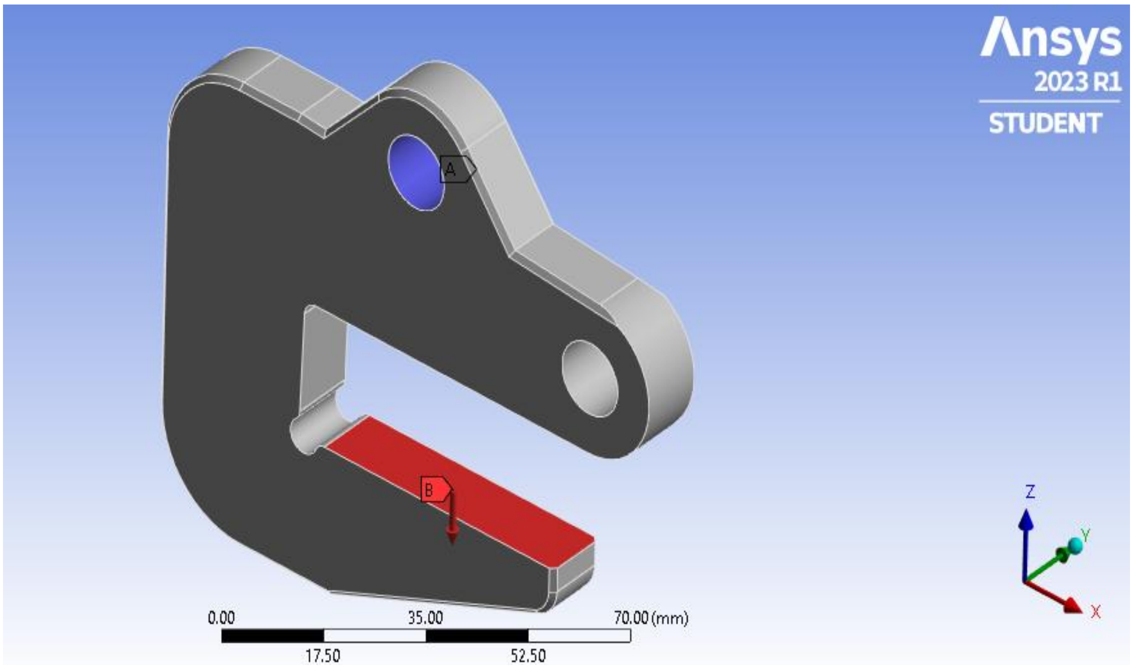


Figure 4.26 Load applied in rectangular area

- **Results**

A. Equivalent (Von-Mises) Stress generated in C type Hook

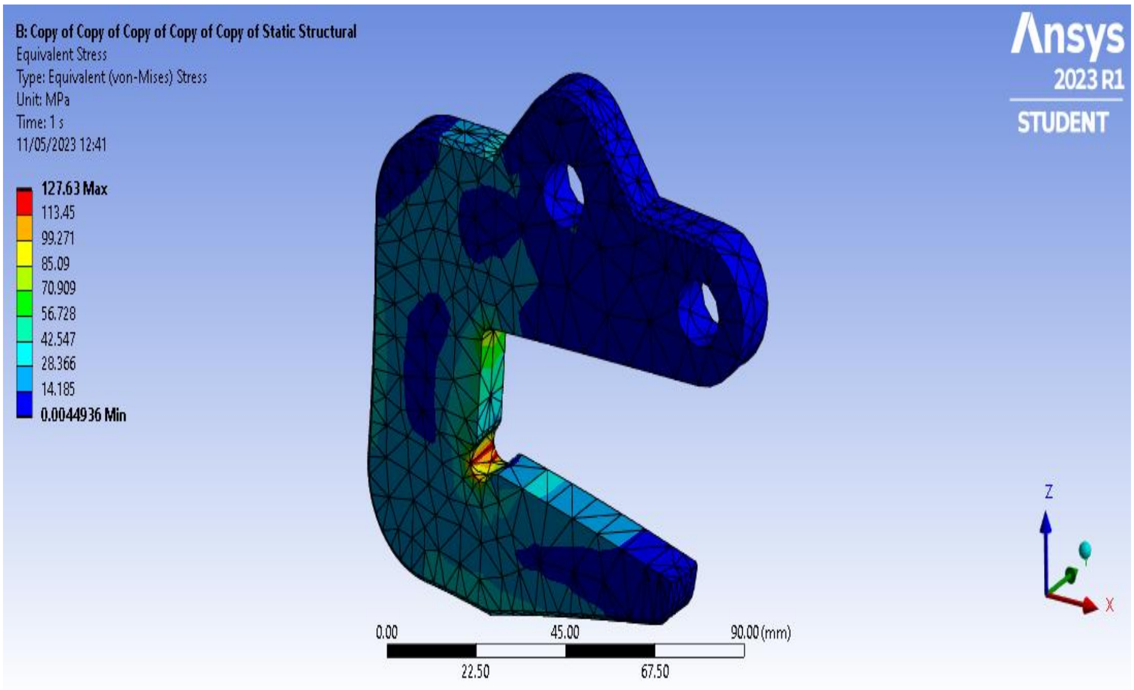


Figure 4.27 An Equivalent (Von-Mises) Stress in C type Hook

B. Total deformation generated in C type Hook

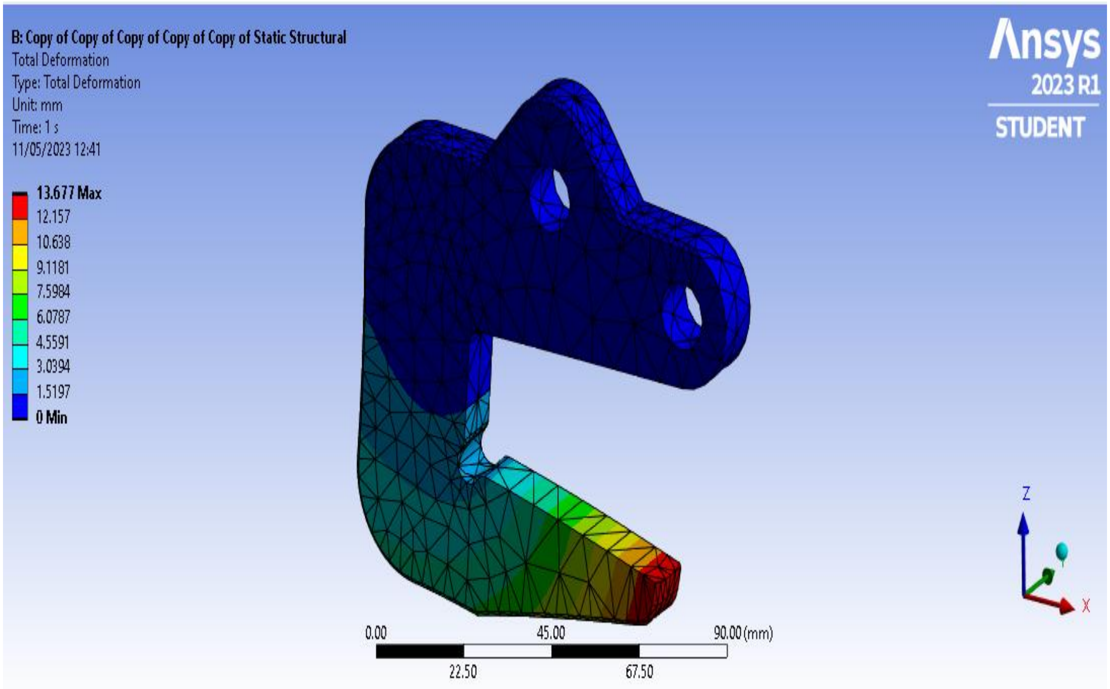


Figure 4.28 Total deformation in C type Hook

C. Factor of safety generated in C type Hook

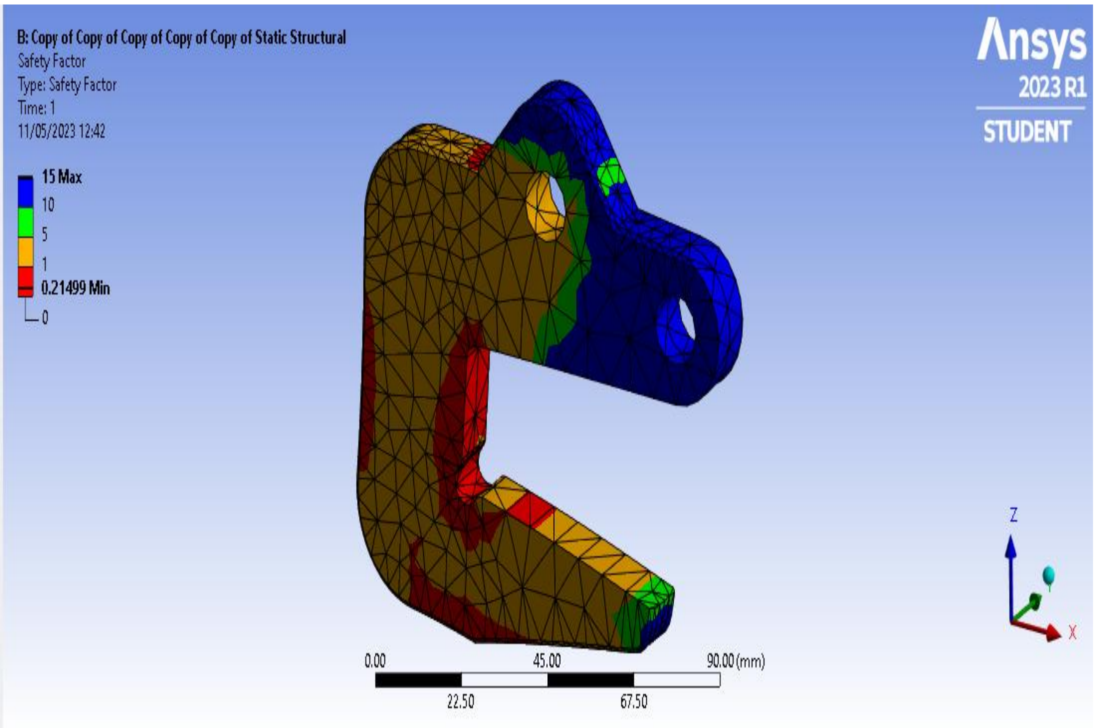


Figure 4.29 Factor of safety in C type Hook

4.8 FEA analysis of 10% density in C type Hook

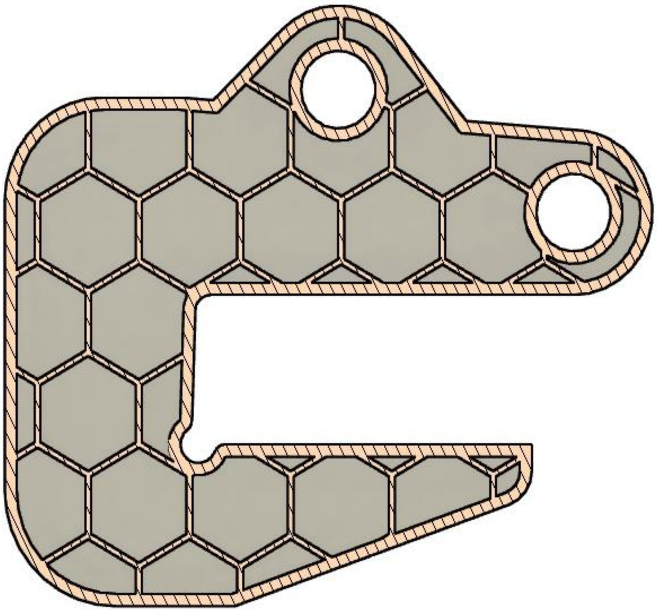


Figure 4.30 10% Infill density in C type Hook

➢ **Min. and Max. values of C type Hook**

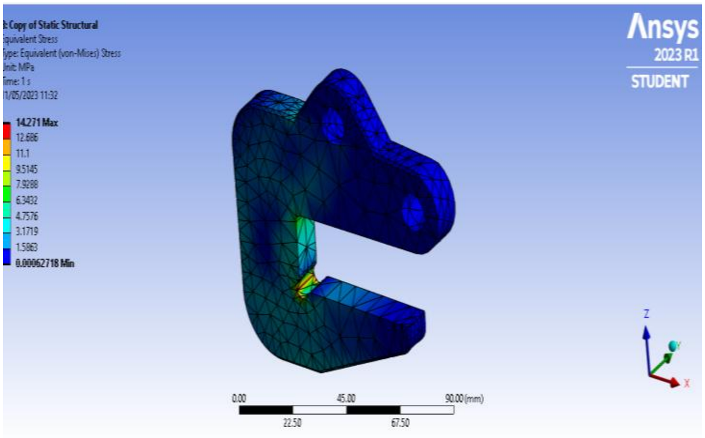


Figure 4.31 Min. Value of Stress in 10% density C type Hook

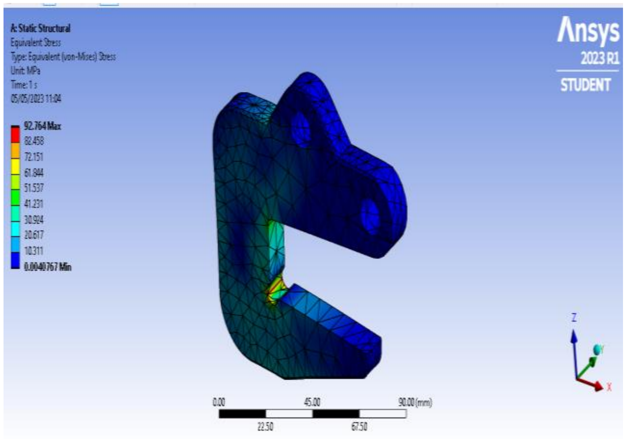


Figure 4.32 Max. Value of Stress in 10% density C type Hook

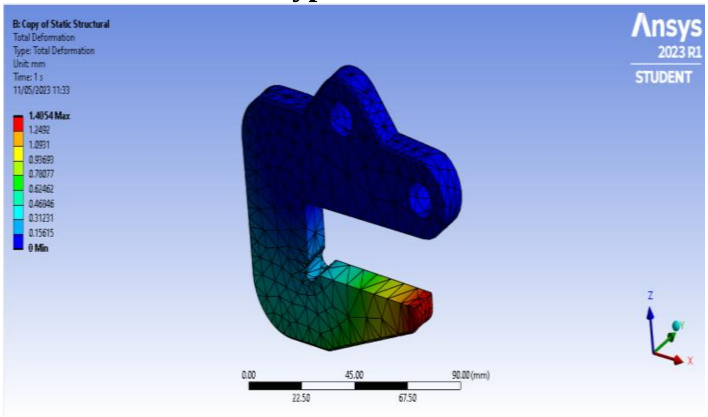


Figure 4.33 Min. Value of Deformation in 10% density C type Hook

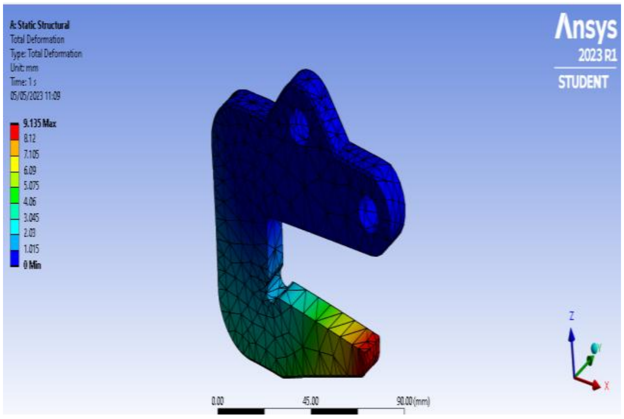


Figure 4.34 Max. Value of Deformation in 10% density C type Hook

4.8.1 Result obtained in Ansys Workbench software

Table No. 4.2 Max. And Min. Values of 10% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)		Stress (mpa)		Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.
1	10	100	650	14.27	92.76	1.40	9.58

4.9 FEA analysis of 20% density in C type Hook

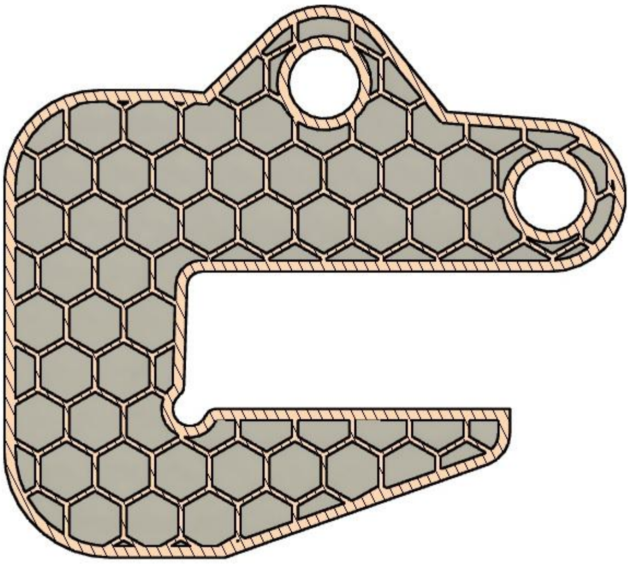


Figure 4.35 20% Infill density in C type Hook

- **Min. and Max. value of C type Hook**

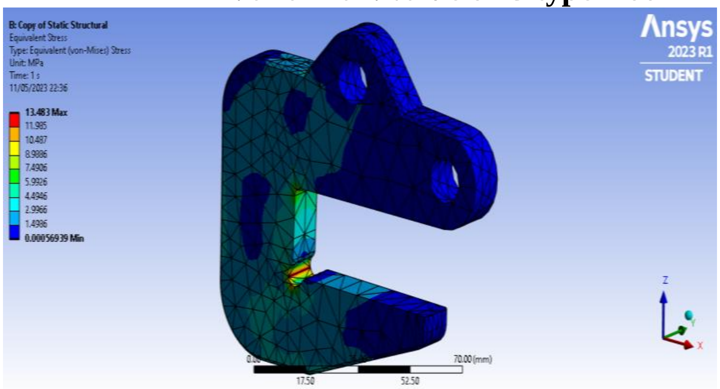


Figure 4.36 Min. Value of Stress in 20% density C type Hook

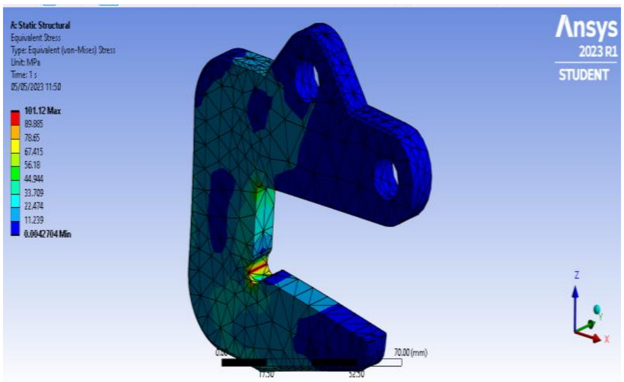


Figure 4.37 Max. Value of Stress in 20% density C type Hook

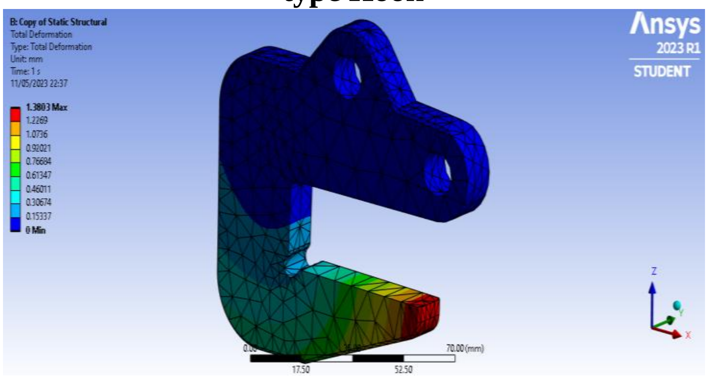


Figure 4.38 Min. Value of Deformation in 20% density C type Hook

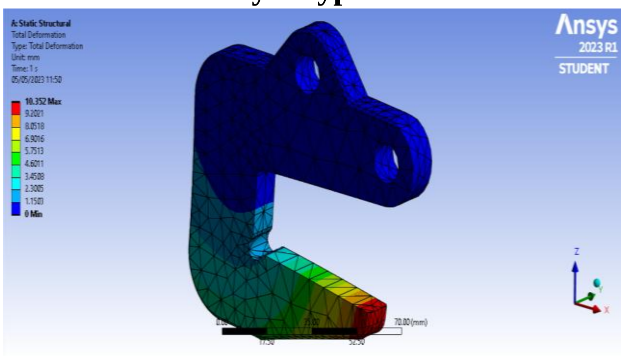


Figure 4.39 Max. Value of Deformation in 20% density C type Hook

4.9.1 Result obtained in Ansys Workbench software

Table No. 4.3 Max. And Min. Values of 20% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)		Stress (mpa)		Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.
1	20	100	750	13.48	101.12	1.38	11.46

4.10 FEA analysis of 30% density in C type Hook

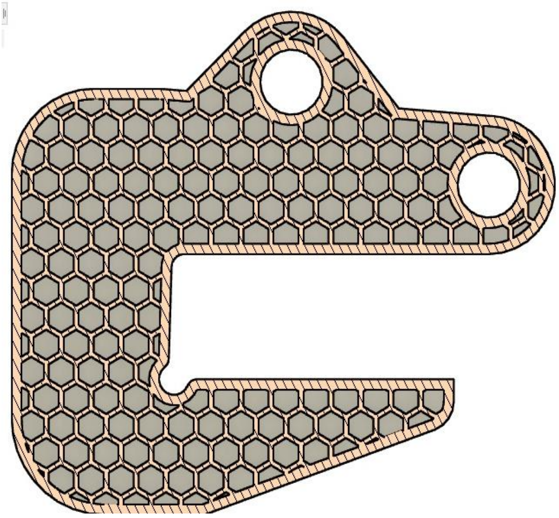


Figure 4.40 30% Infill density in C type Hook

- **Min. and Max. value of C type Hook**

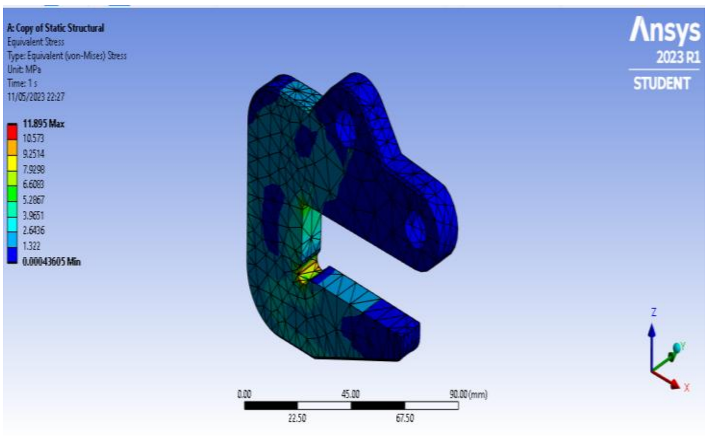


Figure 4.41 Min. Value of Stress in 30% density C type Hook

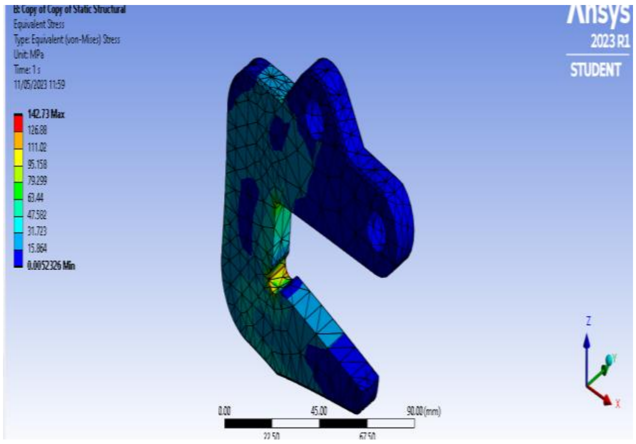


Figure 4.42 Max. Value of Stress in 30% density C type Hook

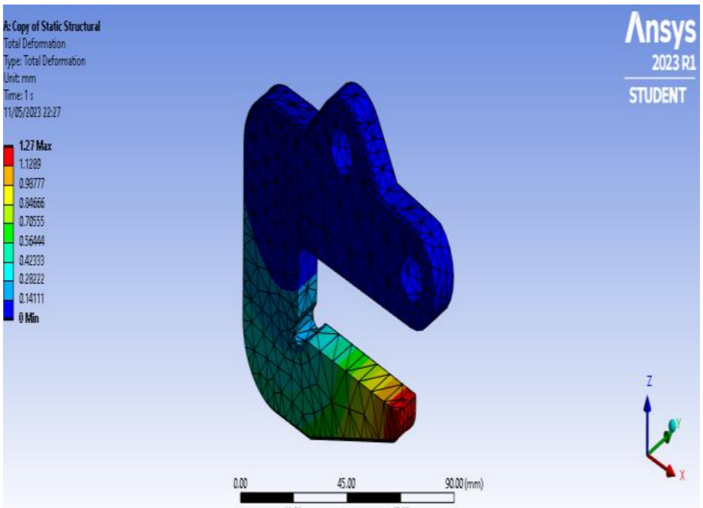


Figure 4.43 Min. Value of Deformation in 30% density C type Hook

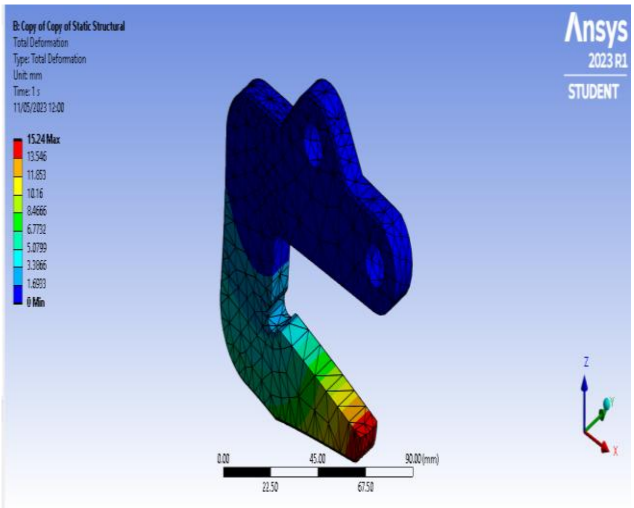


Figure 4.44 Max. Value of Deformation in 30% density C type Hook

4.10.1 Result obtained in Ansys Workbench software

Table No. 4.4 Max. And Min. Values of 30% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)		Stress (mpa)		Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.
1	30	100	1200	11.89	142.73	1.27	15.24

4.11 FEA analysis of 40% density in C type Hook

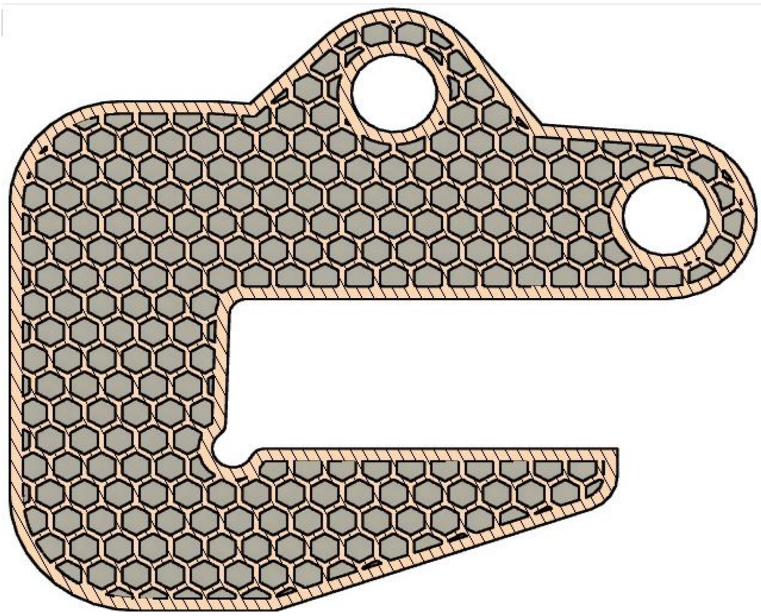


Figure 4.45 40% Infill density in C type Hook

- **Min. and Max. value of C type Hook**

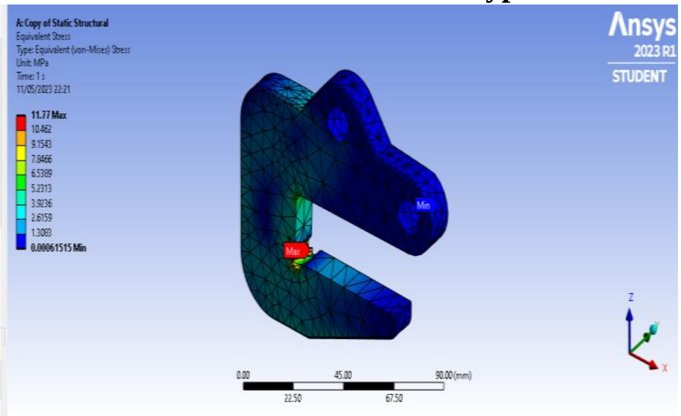


Figure 4.46 Min. Value of Stress in 40% density C type Hook

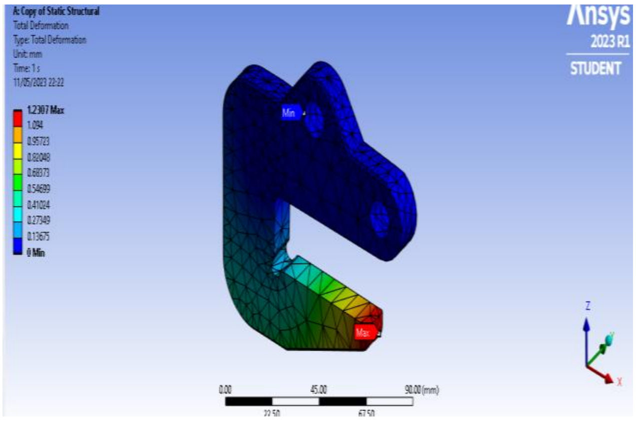


Figure 4.47 Max. Value of Stress in 40% density C type Hook

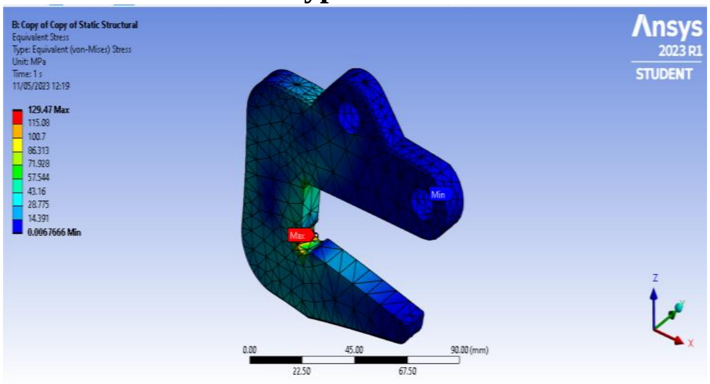


Figure 4.48 Min. Value of Deformation in 40% density C type Hook

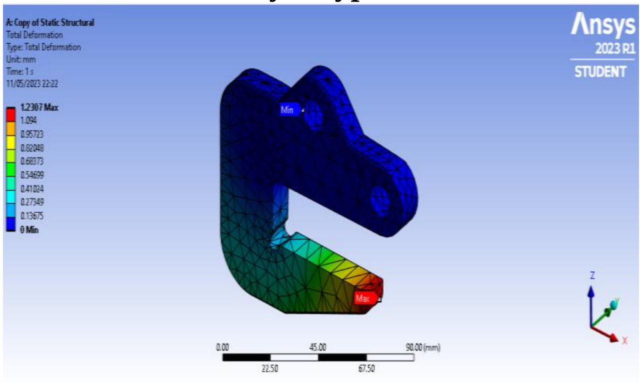


Figure 4.49 Max. Value of Deformation in 40% density C type Hook

4.11.1 Result obtained in Ansys Workbench software

Table No. 4.5 Max. And Min. Values of 40% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)		Stress (mpa)		Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.
1	40	100	1100	11.77	129.47	1.23	13.53

4.12 FEA analysis of 100% density in C type Hook

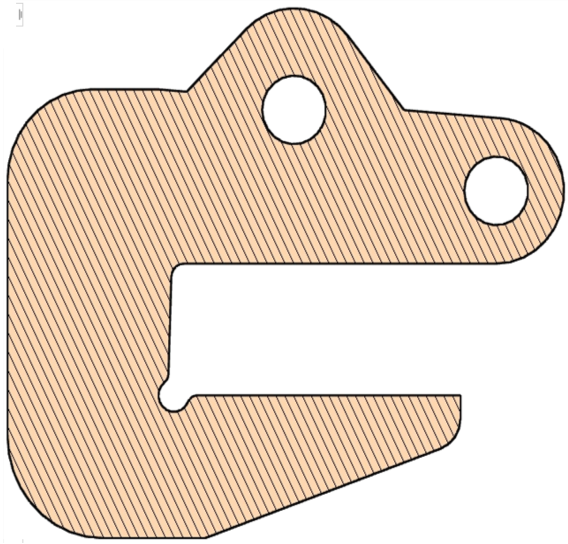


Figure 4.50 100% Infill density in C type Hook

- **Min. and Max. value of C type Hook**

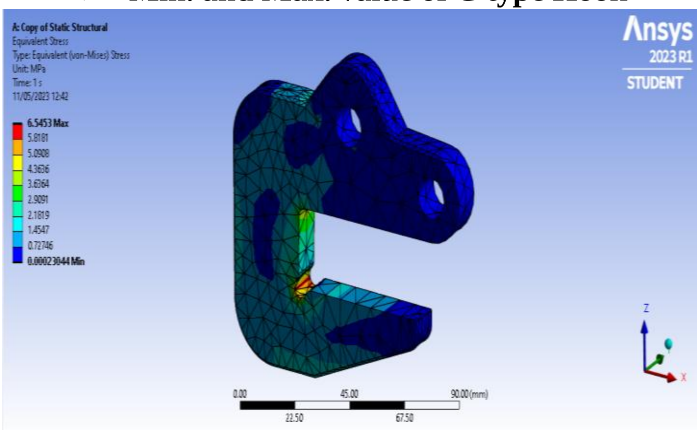


Figure 4.51 Min. Value of Stress in 100% density C type Hook

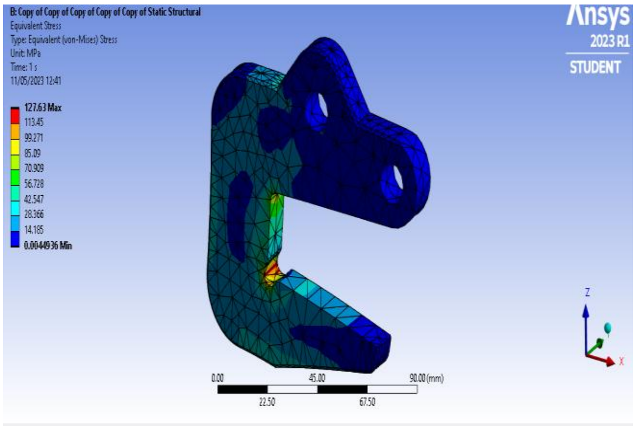


Figure 4.52 Max. Value of Stress in 100% density C type Hook

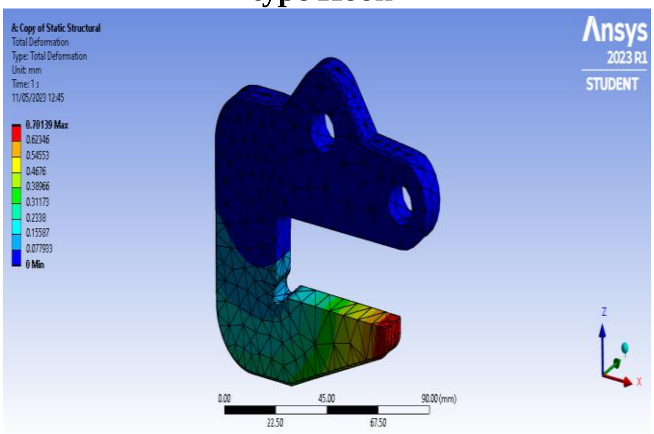


Figure 4.53 Min. Value of Deformation in 100% density C type Hook

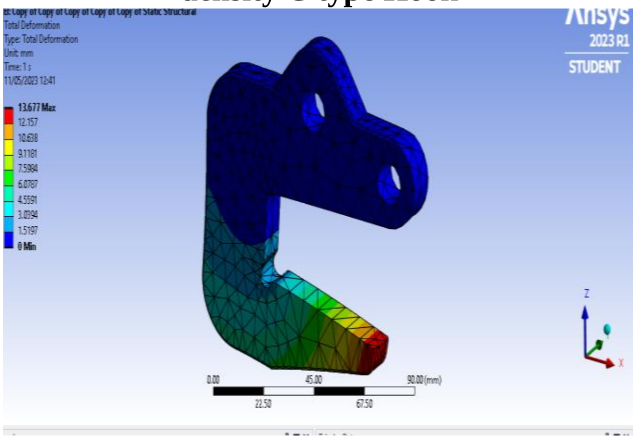


Figure 4.54 Max. Value of Deformation in 100% density C type Hook

4.12.1 Result obtained in Ansys Workbench software

Table No. 4.6 Max. And Min. Values of 100% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)		Stress (mpa)		Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.
1	100	100	1950	6.54	127.63	0.79	10.66

4.13 Validation of results for different density in C type Hook

Comparison of minimum and maximum Values of Analysis results of C type Hook is shown in Table No. 4.7

Table No. 4.7 Comparison between minimum and maximum Values for different densities in C type Hook

Sr. No.	Different Infill Density (%)	Load (N)		Stress (mpa)		Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.
1	10	100	650	14.27	92.76	1.40	9.58
2	20	100	750	13.48	101.12	1.38	11.46
3	**30**	**100**	**1200**	**11.89**	**142.73**	**1.27**	**15.24**
4	40	100	1100	11.77	129.47	1.23	13.53
5	100	100	1950	6.54	127.63	0.79	10.66

CHAPTER 5

MANUFACTURE AND EXPERIMENTAL RESULTS OF C TYPE HOOK

5.1 Specification of 3D Printer

Table No. 5.1 3D printer specification

Sr. No.	Name	Value
1	Build Volume (mm)	220x220x250
2	Nozzle Dia. (mm)	0.6
3	Print Speed (mm/sec)	45
4	Layer thickness (mm)	0.2
5	Bed Temp. (℃)	90

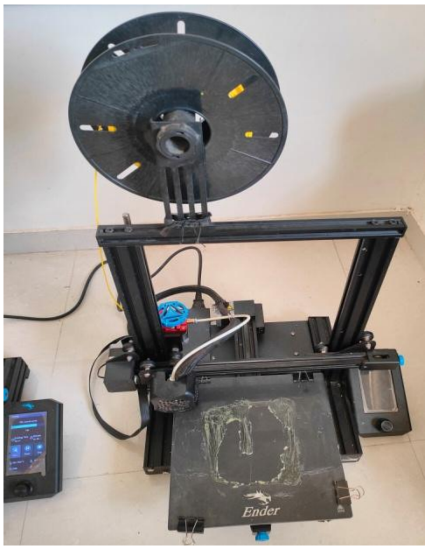
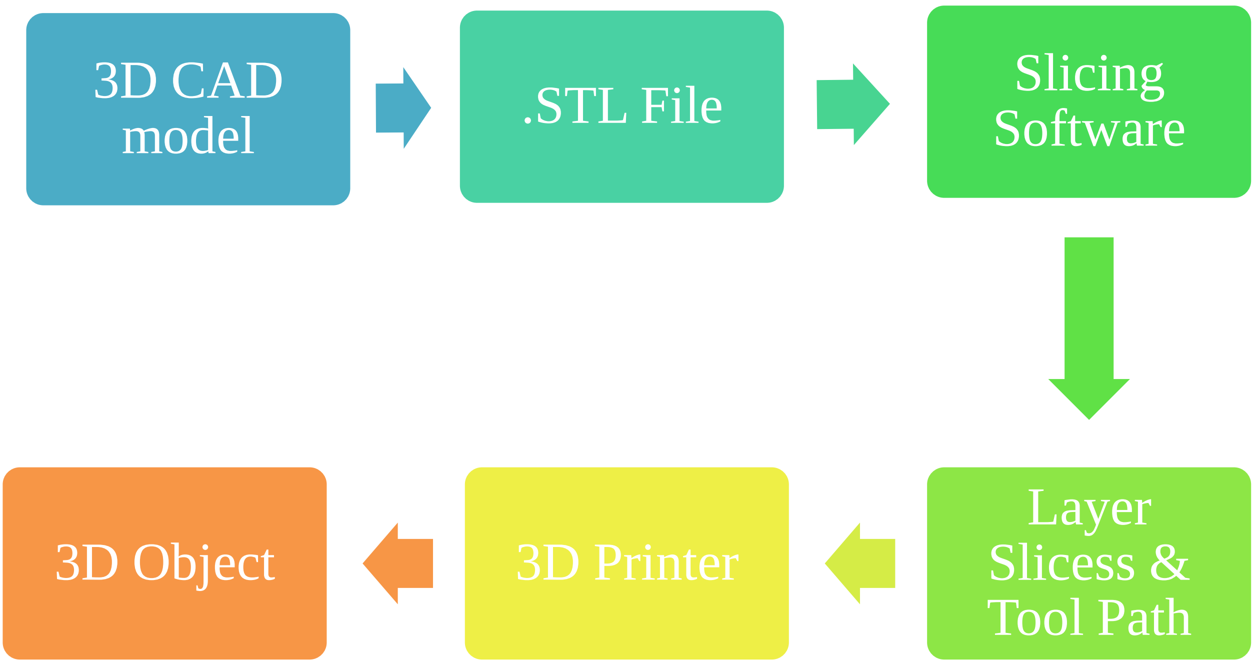


Figure 5.1 3D printer

5.2 Process of manufacture C type Hook using 3D printer



➢ **Steps for manufacture C type Hook**

1. **3D CAD model**

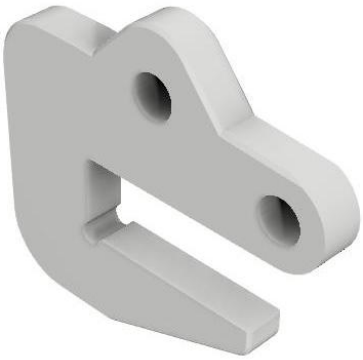


Figure 5.2 CAD model C type Hook

To develop 3D CAD model of C type Hook using Fusion 360 software

2. **.STL file**

Convert the 3D model File into .STL file for open into 3D printer software

3. **Slicing Software**

In the Slicing software to add the parameters like Nozzle Dia. And it's Temp. , Layer thickness, Bed Temp. , Infill density and Structure, Print Speed etc. and it convert into G code

4. **Layer Slice & tool path**

➢ **Manufacture with Different Density in Specimen Using 3D Printer**

After completed the process parameter CAD model divided into 2D slices

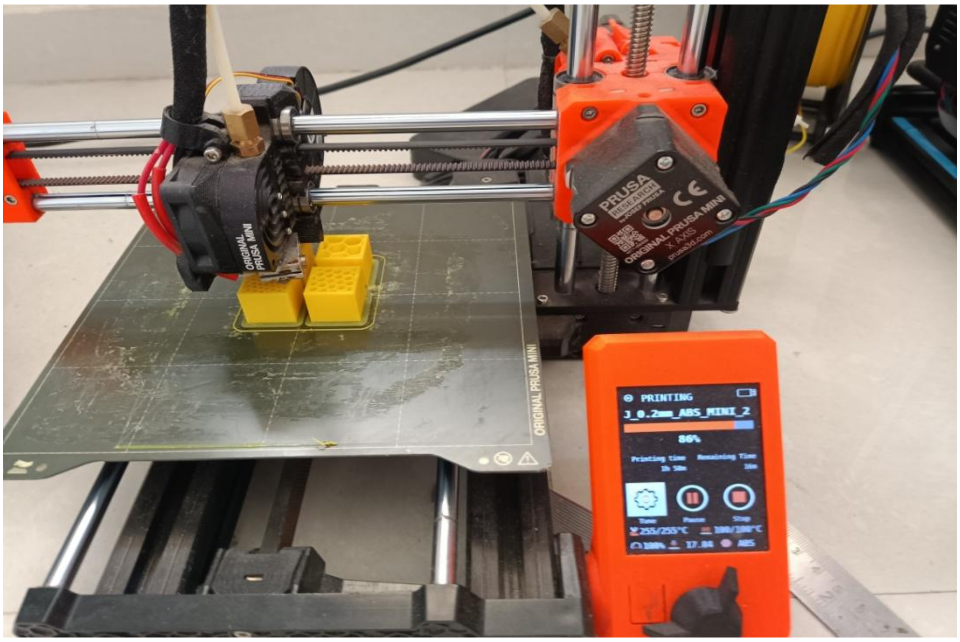


Figure 5.3 Manufacture Specimen

5. 3D printer

3D printer make a layer one by one and convert it into 3D model

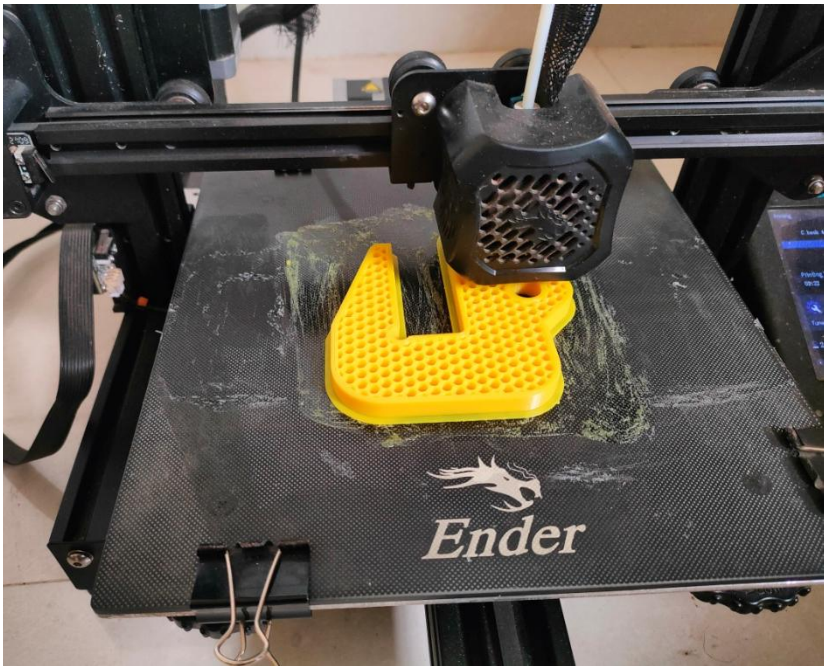


Figure 5.4 Manufacture 30% density in C type Hook

5.3 Post Process after manufacture C type Hook using 3D Printing

- **There are some post processes:**
  - **Remove the C type Hook after manufactured:**

Figure 5.5 Remove C type Hook after manufactured

After completion of C type Hook, Using Sharp knife with a thin, flexible metal blade that will allow you to get in between the plastic and the printer's platform.

- **Rough Cleaning**

Remove the excess layer on the C type Hook using a sharp knife.

Figure 5.6 Remove extra material on the C type Hook

- **Working in small details**

Fill extra material into the C type Hook with the aid of additional material.

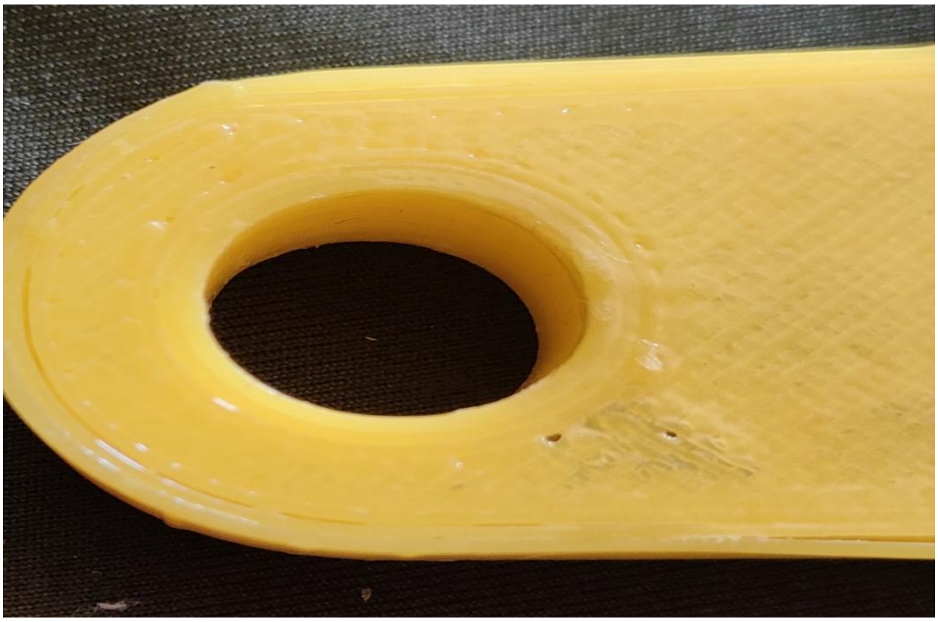


Figure 5.7 Fill extra material in C type Hook

- **Apply Heat Gun**

Figure 5.8 After apply Heat Gun on C type Hook

After removing some additional layer from the C type Hook, using a Heat Gun to smoothen the surface and shine the C type Hook.

5.4 Weight of All C type Hook and specimen

Table No. 5.2 Weight of all C type Hook and specimen

Sr. No.	Infill Density (%)	Weight (g)
C type Hook		
1	10	25.200
2	20	29.120
3	30	33.410
4	40	36.850
5	100	56.380
Specimen		
1	10	2.700
2	20	3.400
3	30	4.000
4	40	4.600
5	100	7.300

5.5 Introduction to Universal Testing Machine (UTM)

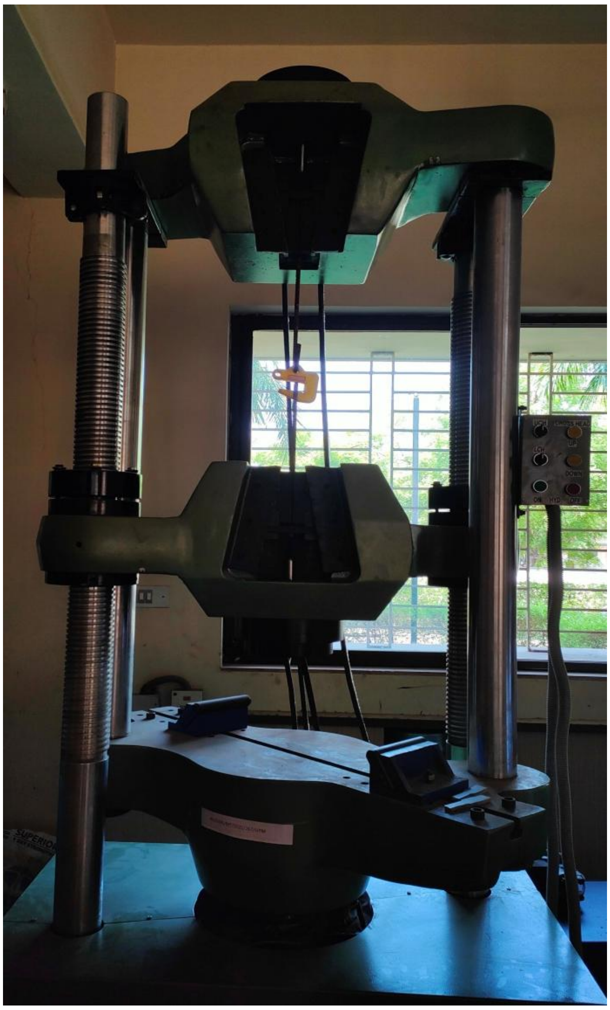


Figure 5.9 Universal Testing Machine

A universal testing machine (UTM), also known as a universal tester, materials testing machine, or materials test frame, is a machine that measures the tensile and compressive strength of materials. The specimen is put between the grips of the machine, and an extensometer, if necessary, can automatically record the change in gauge length during the test. C types Hook are tested in UTM and it gave some interesting data regarding different Infill density. Results are given below with Figure. [61]

- **There are some parts of Universal Testing Machine(UTM):**
  - Upper cross Head
  - Fixing Jaw
  - Movable crosshead
  - Table

- Load Indicator
- Speed Control

5.6 Experimental result for 10% density in C type Hook

Figure 5.10 10% density before Experiment

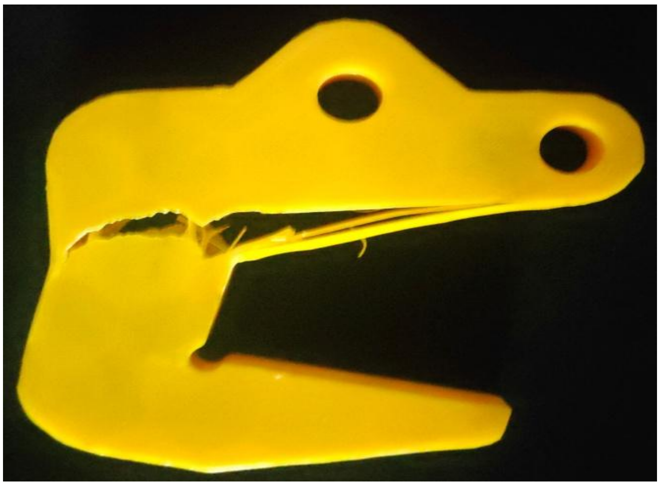


Figure 5.11 10% density after Experiment

Table No. 5.3 Maximum Load, strength and deformation in 10% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)	Strength (mpa)	Deformation (mm)
1	10	650	0.590	10.27

5.7 Experimental result for 20% density in C type Hook

Figure 5.12 20% density before Experiment

Figure 5.13 20% density after Experiment

Table No. 5.4 Maximum Load, strength and deformation in 10% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)	Strength (mpa)	Deformation (mm)
1	20	750	0.681	12.52

5.8 Experimental result for 30% density in C type Hook

Figure 5.14 30% density before Experiment

Figure 5.15 30% density after Experiment

Table No. 5.5 Maximum Load, strength and deformation in 10% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)	Strength (mpa)	Deformation (mm)
1	30	1200	0.935	13.95

5.9 Experimental result for 40% density in C type Hook

Figure 5.16 40% density before Experiment

Figure 5.17 40% density after Experiment

Table No. 5.6 Maximum Load, strength and deformation in 40% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)	Strength (mpa)	Deformation (mm)
1	40	1100	0.857	12.53

5.10 Experimental result for 100% density in C type Hook

Figure 5.18 100% density before Experiment

Figure 5.19 100% density after Experiment

Table No. 5.7 Maximum Load, strength and deformation in 100% density C type Hook

Sr. No.	Infill density of Material (%)	Load (N)	Strength (mpa)	Deformation (mm)
1	100	1950	1.51	11.69

5.11 Comparison of Experiment and Software results for C type Hook

Table No. 5.8 Comparison of Experiment and Software results for C type Hook

Different Infill Pattern (%)	Experimental Result		Software Result		% Variation
	Max. load (N)	Max. Deformation (mm)	Max. load (N)	Max. Deformation (mm)	
10	650	10.27	650	9.58	6.95
20	750	12.52	750	11.46	8.84
30	**1200**	**13.95**	**1200**	**15.24**	**9.24**
40	1100	12.53	1100	13.53	7.98
100	1950	11.69	1950	10.66	9.21

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The evaluation of C type Hook following outcomes:

- Deformation obtained by practical procedure in different density is 10.27, 12.52, 13.95, 12.53 and 11.69 mm, while deflection obtained by software analysis is 9.58, 11.46, 15.24, 13.23 and 10.66 mm
- Five different Infill densities 10, 20, 30, 40 and 100% taken from the major parameters for this research work
- Strength obtained by practical procedure is 0.950, 0.681, 0.935, 0.857, 1.51 mpa while stress obtained by software analysis is 92.76, 101.12, 142.73, 129.47, 127.63 mpa
- Results obtained by Analyze of the Deformation of the C type Hook considerable load of 1200 N and the optimum value of deflection is observed at 30% Infill density
- Overall, this study has provided useful information and some insight in respect of reducing material wastage and to reduce the weight 56.380gram to 33.410gram of the C type Hook

6.2 Future Scope

Based on the research results and analysis presented in this paper, improve the mechanical properties of these 3D printed items. The method may be improved to offer the best tensile, compressive bending, and tribological properties. Different qualities and densities have an impact on how the component behaves. To overcome challenges like the problem of infill density and density, extensive research is needed to get a better knowledge of the process and theories behind these sections. The crucial process variables are nozzle diameter, printing speed, infill pattern, and layer thickness. The characteristics of the construction part and production effectiveness are significantly influenced by a number of process variables.

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APPENDIX A

Review Card

ATMIYA UNIVERSITY
FACULTY OF ENGINEERING TECHNOLOGY
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(Dissertation Review Card)

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❖ **Comments For Internal Review (   )** **(Semester 3)**

Exam Date : 19/12/2022

Sr. No.	Comments given by Internal review panel (Please write specific comments)	Modification done based on Comments
1.	Improve LR	Indepth study of LR was done.
2.	Identify specific component	C-type hook also had been identified
3	Modify/Add objectives	Objectives are modified as per problem definition
4.	Fundamentals need to improve	→ Basic fundamentals related to 3D Printing was studied.
5	Identify process Parameters	• Process parameters has been identified
		(Guide Sign.)

Particulars	Internal Review Panel	
	Expert 1	Expert 2
Name :	M. V. Shekadiya	Hardik Chauhan
Institute :		Atmiya University
Institute Code :		
Mobile No. :	90990 76108	9428310289
Sign :		

Particulars	Internal Guide Details	
	Expert 1	Expert 2
Name :		
Institute :		
Institute Code :		
Mobile No. :		
Sign :		

-2-

Enrollment No. of Student : 2 0 0 0 4 5 0 0 2

❖ **Comments of Dissertation Phase-1 (   )** **(Semester 3)**

Exam Date : 19/12/2022

Title : Experimental Evolution of mechanical Properties of machine elements components using EDM technique.

....
....

1. Appropriateness of title with proposal. (Yes/ No) ____________
2. Whether the selected theme is appropriate according to the title ? (Yes / No) __________
3. Justify rational of proposed research. (Yes/ No) ____________
4. Clarity of objectives. (Yes/ No) ___________

– 3 –

Enrollment No. of Student: 2 0 0 0 4 5 0 0 2

Exam Date : 20 / 12 / 2022

Sr. No.	Comments given by External Examiners (DP-I) : (Please write specific comments)	Modification done based on Comments
1	Review paper is required to publish	Review paper was published
2	Need to change the title as per the problems & objectives	Title was modified as per the problems & objectives.
3	Need to identify specific component	→ C-type hook was been selected.
4	identify the process parameters	→ Process parameters was studied & identified.

(Internal Guide Sign.)

- Approved ☐
- Approved with suggested recommended changes ☑
- Not Approved ☐

Please tick on any on. If approved/approved with suggession then put marks ≥ 50%.

➢ **Details of External Examiners:**

Particulars	Full Name	University / College Name & Code	Mobile No.	Sign.
Expert 1	R. L. Patel	GEC Rajkot	9998910340	
Expert 2				

4

Enrollment No. of Student : 2 0 0 0 4 5 0 0 2

❖ Comments of Mid Sem Review ( ) (Semester 4)

Exam Date : 13 / 4 / 2023

Sr. No.	**Comments given by External Examiners :** i) The appropriateness of the major highlights of work done; State here itself if work can be approved with some additional changes. ii) Main reasons for approving the work. iii) Main reasons if work is not approved.	Modification done based on Comments
1	identify the mechanical properties for analysis	Mechanical Properties Identified.
2	what is output of work	Tesile Strength of diff. Density
3	objectives are not well define	Defined.
4	Need to change title as per objectives	Changed
5	Need to improve presentation	Presentation skill improved.

Internal Guide Sign.

- *Approved* ☐
- *Approved with suggested recommended changes* ☑
- *Not Approved* ☐

Please tick on any on.
If approved/approved with suggession then put marks ≥ 50 %.

➢ ***Details of External Examiners:***

Particulars	*Full Name*	*University / College Name & Code*	*Mobile No.*	*Sign.*
Expert 1	R. L. Patel	GEC Rajkot	9998910340	(signed)
Expert 2				

5

APPENDIX B

Compliance Report

The comments given during dissertation phase-1 in semester-3 and mid semester review in semester - 4 and modification done based on comments are following.

➢ Comments of Dissertation phase- 1 (200045002) (Semester 3)

Sr.No.	Comments Given by External Examiner	Modification done based on Comments
1	Review paper is require to publish	Review paper was published
2	Need to change title as per the problem & objective	Title was modified as per problems & objectives
3	Need to identify specific component	C type Hook has been selected
4	Identify the process parameters	Process parameters was studied & Identified

➢ Comments of Mid Sem. Review (200045002) (Semester 4)

Sr.No.	Comments Given by External Examiner	Modification done based on Comments
1	Identify the mechanical properties for analysis	Mechanical properties Identified
2	What is output of work	Tensile strength of different density
3	Objective are not well	Defined
4	Need to change the title as per objective	Changed
5	Need to improve presentation	Presentation skill is improved

APPENDIX C

Review Paper Publication Certificate


Journals Pub

Certificate of Publication

We acknowledge the manuscript

" Technical review on study of Mechanical properties of component using FDM technique in 3D Printing "

Submitted by

Makwana Niraj Pravinbhai

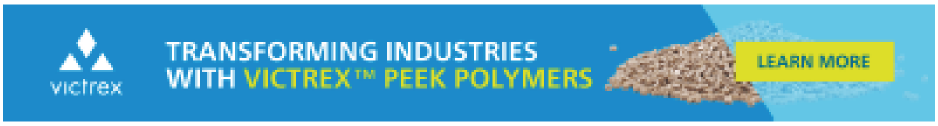
Published in International Journal of Machine Design and Manufacturing

Volume 08 Issue 02 Year 2022

Director's Signature

APPENDIX D

Standards



Overview of materials for Acrylonitrile Butadiene Styrene (ABS), Molded

Categories: Polymer; Thermoplastic; ABS Polymer; Acrylonitrile Butadiene Styrene (ABS), Molded

Material Notes: This property data is a summary of similar materials in the MatWeb database for the category "Acrylonitrile Butadiene Styrene (ABS), Molded". Each property range of values reported is minimum and maximum values of appropriate MatWeb entries. The comments report the average value, and number of data points used to calculate the average. The values are not necessarily typical of any specific grade, especially less common values and those that can be most affected by additives or processing methods.

Vendors: Click here to view all available suppliers for this material.

Please click here if you are a supplier and would like information on how to add your listing to this material.

Printer friendly version Download as PDF Download to Excel (requires Excel and Windows)
Export data to your CAD/FEA program

Add to Folder: My Folder 0/0

Physical Properties	Metric	English	Comments
Density	0.882 - 3.50 g/cc	0.0319 - 0.126 lb/in³	Average value: 1.07 g/cc Grade Count:734
Water Absorption	0.0250 - 2.30 %	0.0250 - 2.30 %	Average value: 0.380 % Grade Count:78
Moisture Absorption at Equilibrium	0.100 - 0.300 %	0.100 - 0.300 %	Average value: 0.233 % Grade Count:25
Water Absorption at Saturation	0.00950 - 1.03 %	0.00950 - 1.03 %	Average value: 0.561 % Grade Count:14
Maximum Moisture Content	0.0100 - 0.150	0.0100 - 0.150	Average value: 0.0459 Grade Count:71
Linear Mold Shrinkage	0.000 - 0.0290 cm/cm	0.000 - 0.0290 in/in	Average value: 0.00532 cm/cm Grade Count:559
Linear Mold Shrinkage, Transverse	0.00200 - 0.00900 cm/cm	0.00200 - 0.00900 in/in	Average value: 0.00522 cm/cm Grade Count:52
Melt Flow	0.0800 - 125 g/10 min	0.0800 - 125 g/10 min	Average value: 16.6 g/10 min Grade Count:766

Mechanical Properties	Metric	English	Comments
Hardness, Rockwell M	53.0 - 82.0	53.0 - 82.0	Average value: 65.0 Grade Count:3
Hardness, Rockwell R	13.0 - 122	13.0 - 122	Average value: 108 Grade Count:406
Hardness, Shore D	79.0 - 103	79.0 - 103	Average value: 87.0 Grade Count:3
Ball Indentation Hardness	70.0 - 120 MPa	10200 - 17400 psi	Average value: 101 MPa Grade Count:68
Tensile Strength, Ultimate	2.60 - 73.1 MPa	377 - 10600 psi	Average value: 40.7 MPa Grade Count:327
	20.0 - 43.0 MPa @Temperature 60.0 - 90.0 °C	2900 - 6240 psi @Temperature 140 - 194 °F	Average value: 31.8 MPa Grade Count:2
Tensile Strength, Yield	2.00 - 77.0 MPa	290 - 11200 psi	Average value: 44.8 MPa Grade C[illegible]2

Elongation at Break	1.40 - 110 %	1.40 - 110 %	Average value: 28.7 % Grade Count:472
Elongation at Yield	1.70 - 40.0 %	1.70 - 40.0 %	Average value: 3.41 % Grade Count:183
Modulus of Elasticity	0.778 - 21.2 GPa	113 - 3080 ksi	Average value: 2.35 GPa Grade Count:352
Flexural Yield Strength	0.379 - 655 MPa	55.0 - 95000 psi	Average value: 70.6 MPa Grade Count:598
Flexural Modulus	0.0241 - 6.89 GPa	3.50 - 1000 ksi	Average value: 2.32 GPa Grade Count:659
	1.50 - 4.00 GPa @Temperature 60.0 - 90.0 °C	218 - 580 ksi @Temperature 140 - 194 °F	Average value: 2.84 GPa Grade Count:2
Poissons Ratio	0.360 - 0.380	0.360 - 0.380	Average value: 0.364 Grade Count:5
Izod Impact, Notched	0.100 - 7.85 J/cm	0.187 - 14.7 ft-lb/in	Average value: 2.40 J/cm Grade Count:479
	0.350 - 3.00 J/cm @Temperature -50.0 - 0.000 °C	0.656 - 5.62 ft-lb/in @Temperature -58.0 - 32.0 °F	Average value: 0.983 J/cm Grade Count:21
	0.290 - 2.35 J/cm @Temperature -40.0 - 0.000 °C	0.543 - 4.40 ft-lb/in @Temperature -40.0 - 32.0 °F	Average value: 0.983 J/cm Grade Count:30
	0.290 - 2.35 J/cm @Thickness 3.17 - 12.7 mm	0.543 - 4.40 ft-lb/in @Thickness 0.125 - 0.500 in	Average value: 0.983 J/cm Grade Count:30
Izod Impact, Unnotched	1.50 J/cm - NB	2.81 ft-lb/in - NB	Average value: 8.81 J/cm Grade Count:26
	0.600 - 6.47239 J/cm @Temperature -30.0 - 0.125 °C	1.12 - 12.1254 ft-lb/in @Temperature -22.0 - 32.2 °F	Average value: 1.24 J/cm Grade Count:4
	0.392266 - 4.8051 J/cm @Temperature -30.0 - -20.0 °C	0.734875 - 9.0019 ft-lb/in @Temperature -22.0 - -4.00 °F	Average value: 1.24 J/cm Grade Count:34
	0.392266 - 4.8051 J/cm @Thickness 3.20 - 6.40 mm	0.734875 - 9.0019 ft-lb/in @Thickness 0.126 - 0.252 in	Average value: 1.24 J/cm Grade Count:34
Izod Impact, Notched (ISO)	1.00 - 45.0 kJ/m²	0.476 - 21.4 ft-lb/in²	Average value: 18.7 kJ/m² Grade Count:182
	6.00 - 22.0 kJ/m² @Temperature -40.0 - -20.0 °C	2.86 - 10.5 ft-lb/in² @Temperature -40.0 - -4.00 °F	Average value: 9.12 kJ/m² Grade Count:61
	6.00 - 9.00 kJ/m² @Temperature -40.0 - -20.0 °C	2.86 - 4.28 ft-lb/in² @Temperature -40.0 - -4.00 °F	Average value: 9.12 kJ/m² Grade Count:2
	6.00 - 9.00 kJ/m² @Thickness 4.00 - 4.00 mm	2.86 - 4.28 ft-lb/in² @Thickness 0.157 - 0.157 in	Average value: 9.12 kJ/m² Grade Count:2
Izod Impact, Unnotched (ISO)	39.2 kJ/m² - NB	18.7 ft-lb/in² - NB	Average value: 79.9 kJ/m² Grade Count:27
	60.0 - 70.0 kJ/m² @Temperature -30.0 - -30.0 °C	28.6 - 33.3 ft-lb/in² @Temperature -22.0 - -22.0 °F	Average value: 68.0 kJ/m² Grade Count:5
	NB - NB @Temperature -20.0 - -20.0 °C	NB - NB @Temperature -4.00 - -4.00 °F	Average value: 68.0 kJ/m² Grade Count:1
	NB - NB @Thickness 4.00 - 4.00 mm	NB - NB @Thickness 0.157 - 0.157 in	Average value: 68.0 kJ/m² Grade Count:1
Charpy Impact Unnotched	1.00 J/cm² - NB	4.76 ft-lb/in² - NB	Average value: 11.3 J/cm² Grade Count:143
	0.300 J/cm² - NB @Temperature -40.0 - -20.0 °C	1.43 ft-lb/in² - NB @Temperature -40.0 - -4.00 °F	Average value: 7.48 J/cm² Grade Count:96
Charpy Impact, Notched	0.100 - 14.0 J/cm²	0.476 - 66.6 ft-lb/in²	Average value: 1.90 J/cm² Grade Count:289
	0.200 - 2.40 J/cm² @Temperature -40.0 - -20.0 °C	0.952 - 11.4 ft-lb/in² @Temperature -40.0 - -4.00 °F	Average value: 0.877 J/cm² Grade Count:103
Gardner Impact	1.80 - 22.6 J	1.33 - 16.7 ft-lb	Average value: 16.7 J Grade Count:6
Dart Drop, Total Energy	2.37 - 46.3 J	1.75 - 34.1 ft-lb	Average value: 28.0 J Grade Count:5
	32.8 - 32.8 J @Temperature -18.0 - -18.0 °C	24.2 - 24.2 ft-lb @Temperature -0.400 - -0.400 °F	Average value: 35.8 J Grade Count:1
	37.3 - 37.3 J @Temperature -18.0 - -18.0 °C	27.5 - 27.5 ft-lb @Temperature -0.400 - -0.400 °F	Average value: 35.8 J Grade Count:1
	37.3 - 37.3 J @Thickness 3.20 - 3.20 mm	27.5 - 27.5 ft-lb @Thickness 0.126 - 0.126 in	Average value: 35.8 J Grade Count:1
Falling Dart Impact	2.82 - 37.6 J	2.08 - 27.7 ft-lb	Average value: 25.3 J Grade Count:9
Instrumented Impact Total Energy	5.40 - 54.0 J	3.98 - 39.8 ft-lb	Average value: 39.6 J Grade [illegible]1

Tensile Creep Modulus, 1 hour	2200 - 2500 MPa	319000 - 363000 psi	Average value: 2370 MPa Grade Count:3
Tensile Creep Modulus, 1000 hours	1250 - 1900 MPa	181000 - 276000 psi	Average value: 1640 MPa Grade Count:4

Electrical Properties	Metric	English	Comments
Electrical Resistivity	1500 - 1.00e+18 ohm-cm	1500 - 1.00e+18 ohm-cm	Average value: 1.88e+16 ohm-cm Grade Count:126
Surface Resistance	1000 - 2.00e+17 ohm	1000 - 2.00e+17 ohm	Average value: 6.94e+15 ohm Grade Count:120
Static Decay	0.250 - 3.00 sec	0.250 - 3.00 sec	Average value: 1.46 sec Grade Count:7
Dielectric Constant	2.70 - 3.50	2.70 - 3.50	Average value: 2.97 Grade Count:53
Dielectric Strength	15.7 - 53.0 kV/mm	400 - 1350 kV/in	Average value: 32.0 kV/mm Grade Count:79
Dissipation Factor	0.00400 - 0.0900	0.00400 - 0.0900	Average value: 0.00944 Grade Count:51
Arc Resistance	0.000 - 180 sec	0.000 - 180 sec	Average value: 78.8 sec Grade Count:28
Comparative Tracking Index	92.0 - 600 V	92.0 - 600 V	Average value: 560 V Grade Count:92
Hot Wire Ignition, HWI	7.00 - 120 sec	7.00 - 120 sec	Average value: 26.9 sec Grade Count:33
High Amp Arc Ignition, HAI	30.0 - 200 arcs	30.0 - 200 arcs	Average value: 123 arcs Grade Count:33
High Voltage Arc-Tracking Rate, HVTR	0.000 - 150 mm/min	0.000 - 5.91 in/min	Average value: 34.4 mm/min Grade Count:31

Thermal Properties	Metric	English	Comments
CTE, linear	7.90 - 139 µm/m-°C	4.39 - 77.2 µin/in-°F	Average value: 84.2 µm/m-°C Grade Count:175
CTE, linear, Transverse to Flow	81.0 - 100 µm/m-°C	45.0 - 55.6 µin/in-°F	Average value: 91.4 µm/m-°C Grade Count:15
Specific Heat Capacity	1.60 - 2.13 J/g-°C	0.382 - 0.509 BTU/lb-°F	Average value: 1.99 J/g-°C Grade Count:7
Thermal Conductivity	0.128 - 0.187 W/m-K	0.888 - 1.30 BTU-in/hr-ft²-°F	Average value: 0.163 W/m-K Grade Count:17
	0.250 - 0.250 W/m-K @Temperature 30.0 - 260 °C	1.74 - 1.74 BTU-in/hr-ft²-°F @Temperature 86.0 - 500 °F	Average value: 0.250 W/m-K Grade Count:1
Maximum Service Temperature, Air	50.0 - 109 °C	122 - 228 °F	Average value: 74.9 °C Grade Count:24
Hot Ball Pressure Test	75.0 - 105 °C	167 - 221 °F	Average value: 88.0 °C Grade Count:27
Deflection Temperature at 0.46 MPa (66 psi)	56.0 - 120 °C	133 - 248 °F	Average value: 95.1 °C Grade Count:237
Deflection Temperature at 1.8 MPa (264 psi)	63.9 - 220 °C	147 - 428 °F	Average value: 89.2 °C Grade Count:665
Vicat Softening Point	45.0 - 135 °C	113 - 275 °F	Average value: 99.4 °C Grade Count:538
Heat Distortion Temperature	76.4 - 87.8 °C	170 - 190 °F	Average value: 84.2 °C Grade Count:6
Glass Transition Temp, Tg	105 - 109 °C	221 - 228 °F	Average value: 107 °C Grade Count:9
UL RTI, Electrical	50.0 - 120 °C	122 - 248 °F	Average value: 73.4 °C Grade Count:94
UL RTI, Mechanical with Impact	50.0 - 105 °C	122 - 221 °F	Average value: 71.1 °C Grade Count:85
UL RTI, Mechanical without Impact	50.0 - 120 °C	122 - 248 °F	Average value: 73.2 °C Grade Count:84

Flammability, UL94	HB - 5VA	HB - 5VA	Grade Count:478
Oxygen Index	19.0 - 30.0 %	19.0 - 30.0 %	Average value: 21.6 % Grade Count:5
Glow Wire Test	600 - 960 °C	1110 - 1760 °F	Average value: 673 °C Grade Count:48

Optical Properties	Metric	English	Comments
Haze	2.00 - 4.00 %	2.00 - 4.00 %	Average value: 2.83 % Grade Count:6
Gloss	30.0 - 98.0 %	30.0 - 98.0 %	Average value: 84.0 % Grade Count:57
Yellow Index	-1.40 - 24.3 %	-1.40 - 24.3 %	Average value: 14.2 % Grade Count:5
Transmission, Visible	0.000 - 90.0 %	0.000 - 90.0 %	Average value: 68.5 % Grade Count:50

Processing Properties	Metric	English	Comments
Processing Temperature	170 - 270 °C	338 - 518 °F	Average value: 213 °C Grade Count:65
Nozzle Temperature	180 - 310 °C	356 - 590 °F	Average value: 238 °C Grade Count:172
Adapter Temperature	200 - 300 °C	392 - 572 °F	Average value: 277 °C Grade Count:31
Die Temperature	200 - 295 °C	392 - 563 °F	Average value: 267 °C Grade Count:31
Melt Temperature	5.00 - 323 °C	41.0 - 613 °F	Average value: 234 °C Grade Count:303
Mold Temperature	10.0 - 120 °C	50.0 - 248 °F	Average value: 62.4 °C Grade Count:342
Injection Velocity	200 - 240 mm/sec	7.87 - 9.45 in/sec	Average value: 232 mm/sec Grade Count:30
Roll Temperature	60.0 - 150 °C	140 - 302 °F	Average value: 127 °C Grade Count:29
Drying Temperature	60.0 - 120 °C	140 - 248 °F	Average value: 84.2 °C Grade Count:346
Moisture Content	0.0100 - 0.300 %	0.0100 - 0.300 %	Average value: 0.0712 % Grade Count:103
Dew Point	-29.0 - -17.8 °C	-20.2 - 0.000 °F	Average value: -19.6 °C Grade Count:6
Injection Pressure	4.14 - 130 MPa	600 - 18900 psi	Average value: 56.6 MPa Grade Count:34
Vent Depth	0.00254 - 0.0510 cm	0.00100 - 0.0201 in	Average value: 0.0123 cm Grade Count:10

Some of the values displayed above may have been converted from their original units and/or rounded in order to display the information in a consistent format. Users requiring more precise data for scientific or engineering calculations can click on the property value to see the original value as well as raw conversions to equivalent units. We advise that you only use the original value or one of its raw conversions in your calculations to minimize rounding error. We also ask that you refer to MatWeb's terms of use regarding this information. Click here to view all the property values for this datasheet as they were originally entered into MatWeb.

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APPENDIX D

Experimental Results

TEST CERTIFICATE

Date : 04-05-2023 , 11:36 AM

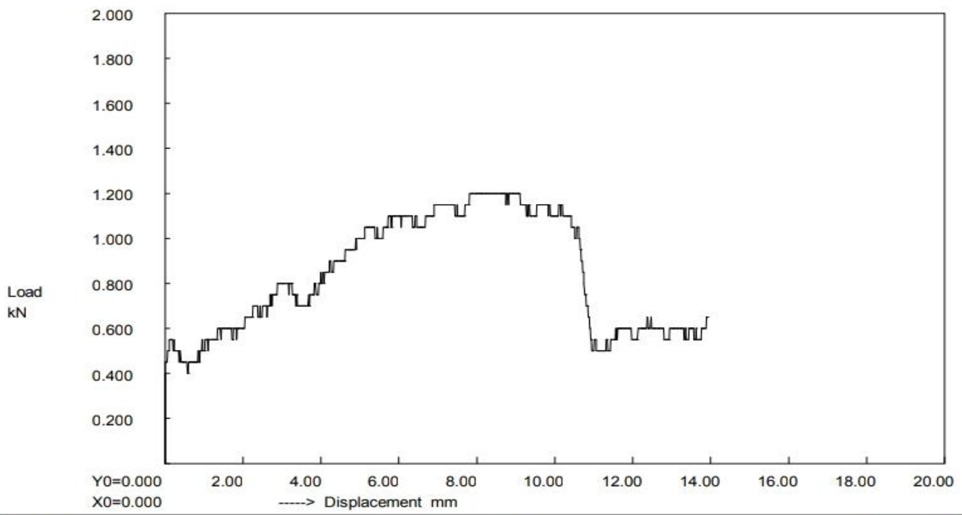
Atmiya
RAJKOT

To / Dept. : Civil
Address : Atmiya Rajkot
sample Identification : ABS PLASTIC
Part description :
Part Number :
Machine : Universal Testing Machine SERVO 1000 kN

Input Data
File Name : NM30 , Record No. : 1
Sample Type : Rectangular Bar   Area : 1,284.000 mm ²
Width : 107 mm   Thickness : 12 mm
Gauge Length : 24 mm   Final Gauge Length: 26 mm
Final Area : 1100 mm ²
Testing with Load Rate : 0.10 kN/min

Results of Tension Test
Maximum Force (Fm) : 1.200 kN   Elongation : 8.333 %
Disp. at Fm : 7.82 mm
Max. Disp. : 13.950 mm
Reduction in Area (Z) : 14.330 %
Tensile strength (Rm) : 0.935 MPa

Graph : Load Vs Displacement



TESTED BY   INSPECTED BY   WITNESSED BY

TEST CERTIFICATE

Date : 04-05-2023 , 11:43 AM

Atmiya

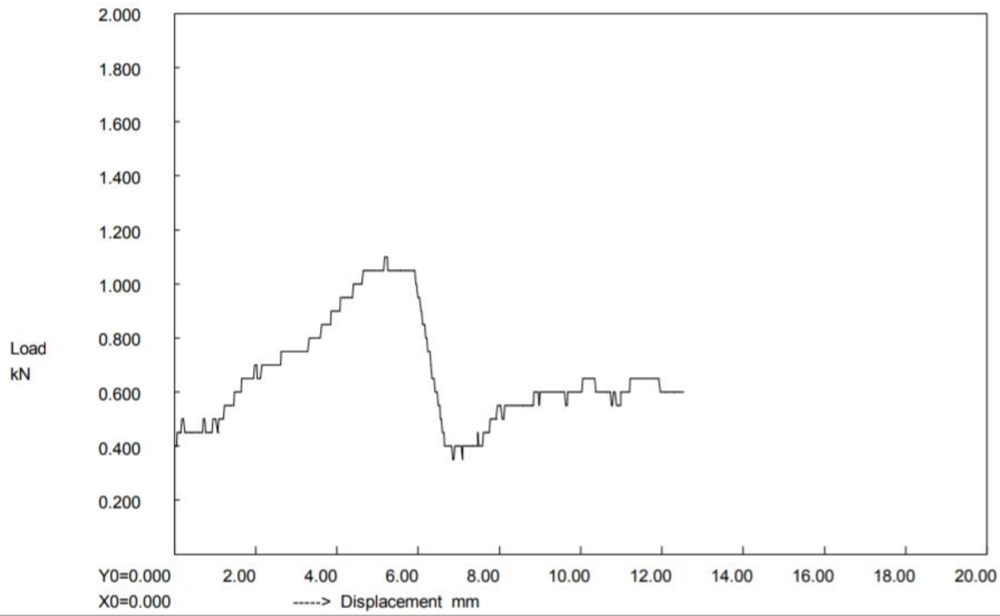
RAJKOT

To / Dept. : Civil
Address : Atmiya Rajkot
sample Identification : ABS PLASTIC
Part description :
Part Number :
Machine : Universal Testing Machine SERVO 1000 kN

Input Data
File Name : NM40 , Record No. : 1
Sample Type : Rectangular Bar   Area : 1,284.000 mm ²
Width : 107 mm   Thickness : 12 mm
Gauge Length : 24 mm   Final Gauge Length: 26 mm
Final Area : 1100 mm ²
Testing with Load Rate : 0.1 kN/min

Results of Tension Test
Maximum Force (Fm) : 1.100 kN   Elongation : 8.333 %
Disp. at Fm : 5.18 mm
Max. Disp. : 12.530 mm
Reduction in Area (Z) : 14.330 %
Tensile strength (Rm) : 0.857 MPa

Graph : Load Vs Displacement



TESTED BY   INSPECTED BY   WITNESSED BY

TEST CERTIFICATE

Date : 04-05-2023 , 11:46 AM

Atmiya
RAJKOT

To / Dept.	: Civil
Address	: Atmiya Rajkot
sample Identification	: ABS PLASTIC
Part description	:
Part Number	:
Machine	: Universal Testing Machine SERVO 1000 kN

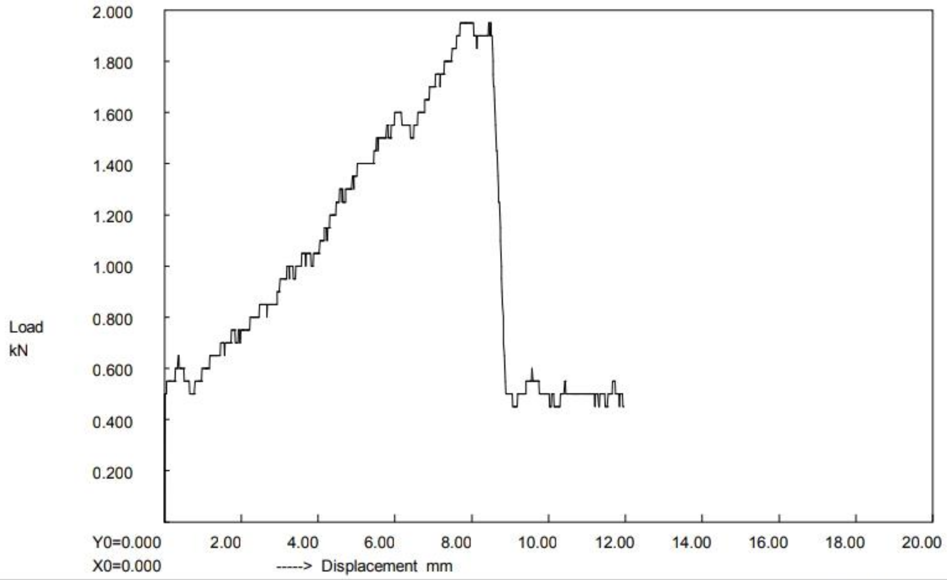
Input Data File Name : NM100 , Record No. : 2
Sample Type : Rectangular Bar Area : 1,284.000 mm ²
Width : 107 mm Thickness : 12 mm
Gauge Length : 24 mm Final Gauge Length: 26 mm
Final Area : 1100 mm ²
Testing with Load Rate : 0.1 kN/min

Results of Tension Test

Maximum Force (Fm)	: 1.950 kN	Elongation	: 8.333 %
Disp. at Fm	: 7.70 mm	Yield Load	: 1.050 kN
Max. Disp.	: 11.960 mm	Yield Strength (Re)	: 0.818 MPa
Reduction in Area (Z)	: 14.330 %	Stress Ratio Re/Rm	: 0.538
Tensile strength (Rm)	: 1.519 MPa		

* Note : Yield Calculated From Graph

Graph : Load Vs Displacement



TESTED BY INSPECTED BY WITNESSED BY

APPENDIX E

Plagiarism Report

Ouriginal by Turnitin

Document Information

Analyzed document	Abstract to Reference.pdf (D168322553)
Submitted	5/25/2023 7:33:00 AM
Submitted by	Dr. Sheetal Tank
Submitter email	librarian@atmiyauni.ac.in
Similarity	6%
Analysis address	librarian.atmiya@analysis.urkund.com

Sources included in the report

SA	**basheer_thesis part 2.pdf** Document basheer_thesis part 2.pdf (D142825798)	1
SA	**Thesis 200120708004.pdf** Document Thesis 200120708004.pdf (D136267688)	2
W	URL: https://3dprintingindustry.com/wp-content/uploads/2014/07/3D-Printing-Guide.pdf Fetched: 5/25/2023 7:34:00 AM	2
W	URL: https://www.thomasnet.com/articles/custom-manufacturing-fabricating/digital-light-processing-d... Fetched: 5/25/2023 7:34:00 AM	1
W	URL: https://xometry.eu/en/polyjet-3d-printing-technology-overview/ Fetched: 5/25/2023 7:34:00 AM	1
W	URL: https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons Fetched: 5/25/2023 7:34:00 AM	7
SA	**Research Proposal (TENGKU DINIE ATIQAH BINTI TENGKU KAMARUL ZAMAN_2020476658).pdf** Document Research Proposal (TENGKU DINIE ATIQAH BINTI TENGKU KAMARUL ZAMAN_2020476658).pdf (D157191735)	5
W	URL: https://www.makerbot.com/stories/design/top-5-3d-printing-applications/ Fetched: 5/25/2023 7:34:00 AM	1
W	URL: https://omnexus.specialchem.com/selection-guide/acrylonitrile-butadiene-styrene-abs-plastic Fetched: 5/25/2023 7:34:00 AM	2
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W	URL: https://clevercreations.org/what-is-strongest-infill-pattern-cura-prusa/ Fetched: 5/25/2023 7:34:00 AM	1
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XIII DEVELOPMENT & EXPERIMENTALLY EVALUATION OF ABS C TYPE HOOK MANUFACTURE USING FDM TECHNIQUE (200045002) Niraj Makwana Atmiya University, Rajkot nirajmakwana1999@gmail.com Abstract Fused Deposition Modelling (FDM) is an extrusion-based modern technology that is becoming increasingly popular because it allows manufacturers to produce difficult components immediately from computer-aided design (CAD) models. For the industries like automotive, aerospace, and die & mould, etc., it is necessary to investigate the mechanical behaviour of 3D printed parts. FDM printed components' a competitor mechanical characteristics compared to injection moulded ones make functional application difficult. The complexity of process factors makes it difficult to forecast the mechanical behaviour of FDM printed components. Here, the issue at discussion is the mechanical characteristics of 3D- printed components. For modelling, Fusion 360 parametric is utilised, while ANSYS Workbench is used for analysis. The lateral movement of a C Type Hook is calculated conceptually, and for validation, the practical results are compared to those from static structural analysis. The research's main topic of investigation is the effect of varied Infill densities in C Type Hooks. Five levels of infill density (10%, 20%, 30%, 40%, and 100%) honeycomb structure are evaluated mechanically to acquire tensile abilities when utilising ABS material in real-world scenarios. Further work was done to investigate different tensile mode characteristics for an FDM manufactured Infill pattern. Results from both the practical and analytical bases are compared in this work. Keyword: Fused Deposition Modelling, Mechanical properties, Infill density, Infill structure

Introduction Page 1 CHAPTER 1 Introduction 1.1 Introduction to Additive Manufacturing (3D printing) Fig. 1.1 Basic Figure of Additive Manufacturing [1] Making an actual thing out of a three-dimensional model is known as additive manufacturing, sometimes known as 3D printing. Additive manufacturing involves building up a material in several thin layers over time. By adding layers of material, it transforms a computer or CAD image into its actual form. The manufacturing process used by additive manufacturing, often known as 3D printing, is flexible in terms of design. Innovation- promoting 3D printing that reduces prohibitive costs and lead times. Using a 3D printer, it is possible to build complicated items with precise geometry at no additional expense while also reducing assembly requirements. The production procedure employed as much standard material as possible, potentially reducing the product's environmental effect during its entire life cycle. Different methods utilised in additive manufacturing, often known as 3D printing, treat different materials in different ways. Due to the method's endurance, Fused Deposition Modelling (FDM) is the most user-friendly

Introduction Page 2 method. It is also referred to as fused filament fabrication (FFF). The FDM technique involves melting plastic filament that is applied to a build layer by layer

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using a heated extruder or nozzle in accordance with 3D data sent to the printer.		

As they are applied, the layers solidify and stick to each others. The FDM techniques are precise and reliable as well. 1.2 Brief History [2] Rapid Prototyping (RP) technologies, the first 3D printing predecessors, initially emerged into public view in the late 1980s. This is due to the fact that the techniques were first designed as a rapid and more affordable way to produce prototypes for the creation of products inside industries. A fascinating side aspect is that Dr. Kodama submitted the initial patent application for Rapid prototyping technology in Japan in May 1980. However, the whole patent specification was not submitted before the application's one-year deadline, rendering the patent application insufficient. Charles Hull was given the first 3D printing patent in 1986 for his stereo lithography equipment (SLA). He designed the technology in 1983 and later assisted in founding 3D Systems Corporation, one of the largest and most effective companies in the field of three- dimensional printing today. The first commercial Rapid Prototyping system from 3D Systems became available in 1987. In the 1980s, there were numerous investigators working on various methods for establishing additive manufacturing, as with every emerging technology. 1.3 Working Principle The precise same basic idea behind all 3D printing operations:

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Journal of the Brazilian Society of Mechanical Sciences and Engineering (2021) 43:23, 2021 59 Gabriel A. Johnson et.al. Evaluation of Infill Effect on Mechanical Properties of Consumer 3D Printing Materials, Advances in Technology Innovation, vol. 3, no. 4, 2018, pp. 179 – 184 60 Modelling and simulation Introduction available online at: https://www.tutorialspoint.com/modelling_and_simulation/modelling_and_simulation_introd uction.htm 61 UTM machine Introduction is available online at: https://en.wikipedia.org/wiki/Universal_testing_machine#cite_note-1

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using a heated extruder or nozzle in accordance with 3D data sent to the printer.

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2/34 **SUBMITTED TEXT** 14 WORDS **100%** **MATCHING TEXT** 14 WORDS

a 3D printer takes a digital model (as input) and transforms it into

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3/34 **SUBMITTED TEXT** 33 WORDS **42%** **MATCHING TEXT** 33 WORDS

an industrial-grade 3D printing method. The vast number of economical 3D printers that have emerged after 2009, however, mostly utilise a similar technology known as Freeform Fabrication (FFF), although in a more

W https://3dprintingindustry.com/wp-content/uploads/2014/07/3D-Printing-Guide.pdf

4/34 **SUBMITTED TEXT** 15 WORDS **70%** **MATCHING TEXT** 15 WORDS

The most commonly used substances for entry-level FFF 3D printers are ABS and PLA.

W https://3dprintingindustry.com/wp-content/uploads/2014/07/3D-Printing-Guide.pdf

5/34 **SUBMITTED TEXT** 15 WORDS **71%** **MATCHING TEXT** 15 WORDS

It then converts them into a set of machine language commands that the printer

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6/34 **SUBMITTED TEXT** 13 WORDS **91%** **MATCHING TEXT** 13 WORDS

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which selectively cures the resin to a build platform layer by layer.	which selectively cures the resin to a build platform in a layer-by-layer

W https://www.thomasnet.com/articles/custom-manufacturing-fabricating/digital-light-processing-dlp- ...

7/34	SUBMITTED TEXT	14 WORDS	86% MATCHING TEXT	14 WORDS
	and forth along the X-axis and back and forth along the Y-axis to		and fro along the X-axis and back and forth along the Y-axis according to	

W https://xometry.eu/en/polyjet-3d-printing-technology-overview/

8/34	SUBMITTED TEXT	47 WORDS	45% MATCHING TEXT	47 WORDS
	for each step to finish sooner. In comparison to machining prototypes, 3D printing is less expensive and faster at making parts because the part can be finished more quickly, allowing for each design modification to be finished at a much faster rate. ? Print on demand		for each stage to complete faster. When compared to machining prototypes, 3D printing is inexpensive and quicker at creating parts as the part can be finished in hours, allowing for each design modification to be completed at a much more efficient rate. 3. Print on Demand	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

9/34	SUBMITTED TEXT	13 WORDS	84% MATCHING TEXT	13 WORDS
	they are produced using a 3D model as a CAD or STL file.		they are printed using a 3D model as either a CAD or STL file,	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

10/34	SUBMITTED TEXT	32 WORDS	96% MATCHING TEXT	32 WORDS
	Through the use of 3D printing, time can be saved not only during the part's production but also during the design phase.STL or CAD files that are ready for printing. ?			

SA Research Proposal (TENGKU DINIE ATIQAH BINTI TENGKU KAMARUL ZAMAN_2020476658).pdf (D157191735)

11/34	SUBMITTED TEXT	23 WORDS	88% MATCHING TEXT	23 WORDS
	of non-recyclable materials, the production of parts uses only the materials required for the part itself, with little to no waste. ?			

SA Research Proposal (TENGKU DINIE ATIQAH BINTI TENGKU KAMARUL ZAMAN_2020476658).pdf (D157191735)

12/34	SUBMITTED TEXT	30 WORDS	60% MATCHING TEXT	30 WORDS
	There is also no requirement for operators to be present at all times when using 3D printers; they may be set up and allowed to complete the task. ?			

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13/34	SUBMITTED TEXT	32 WORDS	48% MATCHING TEXT	32 WORDS
	D printing can produce objects from a variety of plastics and metals, the range of raw materials is not completely diverse. This is because not all metals or polymers can be		D Printing can create items in a selection of plastics and metals the available selection of raw materials is not exhaustive. This is due to the fact that not all metals or plastics can be	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

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14/34	SUBMITTED TEXT	13 WORDS	87%	MATCHING TEXT	13 WORDS
	to remove support material from the construction and to smooth the surface.			to remove support material from the build and to smooth the surface	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

15/34	SUBMITTED TEXT	16 WORDS	62%	MATCHING TEXT	16 WORDS
	Unlike more traditional methods like injection moulding, where producing high volumes may be more cost-effective, 3			unlike more conventional techniques like injection moulding, where large volumes may be more cost effective	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

16/34	SUBMITTED TEXT	18 WORDS	81%	MATCHING TEXT	18 WORDS
	produce large volumes, the cost per unit does not decline as it would with injection moulding. ?			produce large volumes for mass production, the cost per unit does not reduce as it would with injection moulding. 5.	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

17/34	SUBMITTED TEXT	15 WORDS	76%	MATCHING TEXT	15 WORDS
	Many third world countries depend on low skill jobs to maintain their economies. ?			many third world countries rely on low skill jobs to keep their economies	

W https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons

18/34	SUBMITTED TEXT	18 WORDS	93%	MATCHING TEXT	18 WORDS
	Construction [14] Extrusion (concrete/cement, wax, foam, and polymers), powder bonding (polymer bond, reactive bond, and			construction include extrusion (concrete/cement, wax, foam, and polymers), powder bonding (polymer bond, reactive bond, sintering) and	

W https://www.makerbot.com/stories/design/top-5-3d-printing-applications/

19/34	SUBMITTED TEXT	35 WORDS	91%	MATCHING TEXT	35 WORDS
	ABS plastic is thought to have excellent structural strength. This makes it the perfect option for a variety of applications that require a robust, rigid plastic that can withstand impacts from outside forces. It				

SA Research Proposal (TENGKU DINIE ATIQAH BINTI TENGKU KAMARUL ZAMAN_2020476658).pdf (D157191735)

20/34	SUBMITTED TEXT	53 WORDS	30%	MATCHING TEXT	53 WORDS
	it can be processed. It can be extruded, blow-molded, or injection- molded. Due to its low melting point, it can be processed for 3D printing on an FDM machine. [16] ABS sits between engineering resins (acrylic, nylon acetal, etc.) and ordinary resins (PVC, polyethylene, polystyrene, etc.). It frequently satisfies the property			It can be processed on most standard machinery. It can be injection-molded, blow-molded, or extruded. It has a low melting temperature making it suitable for processing by 3D printing on an FDM machine. ABS falls between standard resins (PVC, polyethylene, polystyrene, etc.) and engineering resins (acrylic, nylon acetal, etc.). It often meets the property	

W https://omnexus.specialchem.com/selection-guide/acrylonitrile-butadiene-styrene-abs-plastic

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21/34	SUBMITTED TEXT 57 WORDS	21% MATCHING TEXT 57 WORDS
	cost-effectiveness. It is the perfect material for a variety of structural applications. [16] 1.10.1 Physical properties [16] ? Excellent weld ability, high stiffness, and insulating qualities ? even at low temperatures, good impact resistance ? good resilience to abrasion and strain ? High dimensional stability ? Excellent surface quality and high surface brightness 1.10.2	cost effectiveness. It is an ideal material of choice for various structural applications. This is because of its several physical properties such as: • High rigidity, good weldability, and insulating properties • Good impact resistance, even at low temperatures • Good abrasion and strain resistance • High dimensional stability (Mechanically strong and stable over time) • High surface brightness

W https://omnexus.specialchem.com/selection-guide/acrylonitrile-butadiene-styrene-abs-plastic

22/34	SUBMITTED TEXT 30 WORDS	42% MATCHING TEXT 30 WORDS
	A recommended infill percentage for ordinary 3D printing that will see some light usage and need some strength is between 15% and 50%. This range of infill density will	a higher infill percentage. Standard 3D prints For standard 3D prints, which will undergo light usage and require some strength, an infill percentage between 15% and 50% is suggested. This range of infill density will

W https://www.wevolver.com/article/infill-percentage-for-3d-printing-what-you-need-to-know

23/34	SUBMITTED TEXT 48 WORDS	22% MATCHING TEXT 48 WORDS
	The strongest infill pattern for FDM 3D printing is honeycomb. The six sides of the honeycomb construction evenly distribute weight. It results in a solid 3D printed component with excellent strength in all directions. Printing pieces that need to be light but still have a good load-bearing	

W https://clevercreations.org/what-is-strongest-infill-pattern-cura-prusa/

24/34	SUBMITTED TEXT 14 WORDS	76% MATCHING TEXT 14 WORDS
	A 3D model with zero infill will be produced as an empty shell,	a 3D model with 0% infill will be printed as an empty shell.

W https://www.wevolver.com/article/infill-percentage-for-3d-printing-what-you-need-to-know

25/34	SUBMITTED TEXT 47 WORDS	55% MATCHING TEXT 47 WORDS
	and optimised products. The current study is structured to concentrate on the many 3D printing procedures utilised for the creation of industrial goods, the different process parameters involved in each process, and their impact on the mechanical characteristics of these components, especially fatigue, tensile, bending strength,	and optimized products. The current paper is structured to focus on the various processes of 3D printing used for the development of industrial products, the various process parameters involved in each process and their effect on the mechanical properties of these parts particularly fatigue, tensile, bending strength,

W https://www.researchgate.net/publication/334831854_Effect_of_fused_deposition_modelling_process_p ...

26/34	SUBMITTED TEXT 11 WORDS	100% MATCHING TEXT 11 WORDS
	the ratio of the specimen width to the hole diameter (	the ratio of the specimen width to the hole diameter

W https://www.sciencedirect.com/science/article/pii/S2452321622005340

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27/34	SUBMITTED TEXT	34 WORDS	51%	MATCHING TEXT	34 WORDS
	to enhance the characteristics of the finished output. In light of this, the current study examined how the build orientation, raster orientation, nozzle diameter, extruder temperature, infill density, shell number, and extrusion speed				
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28/34	SUBMITTED TEXT	14 WORDS	76%	MATCHING TEXT	14 WORDS
	ultimate tensile stress, yield strength, modulus of elasticity, toughness, and elongation at break)			Ultimate Tensile Strength, Yield Strength, Modulus of Elasticity and Elongation at Break,	
W	https://www.researchgate.net/publication/338133726_Fused_Deposition_modeling_process_parameters_o ...				

29/34	SUBMITTED TEXT	11 WORDS	100%	MATCHING TEXT	11 WORDS
	on the tensile properties of 3D printed Polylactic Acid (PLA)				
SA	Research Proposal (TENGKU DINIE ATIQAH BINTI TENGKU KAMARUL ZAMAN_2020476658).pdf (D157191735)				

30/34	SUBMITTED TEXT	12 WORDS	100%	MATCHING TEXT	12 WORDS
	the standardisation needs in AM with a focus on mechanical testing.			the standardisation needs in AM with a focus on mechanical testing,	
W	https://www.researchgate.net/publication/349248482_Mechanical_properties_of_thermoplastic_parts_p ...				

31/34	SUBMITTED TEXT	15 WORDS	100%	MATCHING TEXT	15 WORDS
	layer thickness, infill density and pattern, printing speed, build orientation, and raster angle.			layer thickness, infill density and pattern, printing speed, build orientation, and raster angle	
W	https://www.researchgate.net/publication/334831854_Effect_of_fused_deposition_modelling_process_p ...				

32/34	SUBMITTED TEXT	14 WORDS	100%	MATCHING TEXT	14 WORDS
	and strength, carbon fibre reinforced poly lactic acid (PLA), a thermoplastic polymer, is				
SA	Manan_ 200090709001.pdf (D135936190)				

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33/34	SUBMITTED TEXT	31 WORDS	68% MATCHING TEXT	31 WORDS
	A universal testing machine (UTM), also known as a universal tester, materials testing machine, or materials test frame, is a machine that measures the tensile and compressive strength of materials.		A universal testing machine (UTM), also known as a universal tester,[1] materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials.	

W https://en.wikipedia.org/wiki/Universal_testing_machine#cite_note-1

34/34	SUBMITTED TEXT	27 WORDS	65% MATCHING TEXT	27 WORDS
	The specimen is put between the grips of the machine, and an extensometer, if necessary, can automatically record the change in gauge length during the test.		The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test.	

W https://en.wikipedia.org/wiki/Universal_testing_machine#cite_note-1