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Mechanical Properties of 3D Printed PLA Material at different infill density and pattern

The Graduate School of Industry
University of Ulsan

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Abstract

PLA is an organic polymer that lends itself to multiple applications. It is commonly used in fused deposition modeling technology (FDM), which operates by depositing successive layers of material. The material extrusion, in the form of a wire, follows an imposed pattern, which influences the static and dynamic behavior of the final component. In the literature there are many works concerning the mechanical characterization of the PLA but, due to the natural orthotropic of the FDM process and, above all, the ascertained influence of the particular technical system with which the operations are performed, it is necessary to characterize the extruded material through different metrological techniques. To allow the use of this technology for structural elements production, in the present work, quasi-static tests have been carried out to characterize the material and the process considering the three spatial growth directions (x, y, and z). In particular, uniaxial tensile tests were performed for the determination of mechanical strength, modulus of elasticity, and percentage elongation.

The tensile properties of 3D Printing of PLA material and its parameters such as infill density and infill pattern were measured by a tensile test experiment. In general, the results showed that increasing the infill density will increase the tensile properties for both infill patterns. Moreover, the infill patterns affect the tensile properties. Line infill pattern incontestable the best tensile properties compared with the grid pattern. A comprehensive investigation of the result of the infill pattern on the tensile properties is usually recommended for future study.

The main purpose of this thesis is to evaluate the mechanical properties according to the change in infill density by 3D printing using PLA materials and finally find out the applicability of lightweight parts in aerospace or automobiles.

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Chapter 1
Introduction

1.1 Overview

The 3D printing technology is used to print 3d object shapes with the help of a 3D printer and using different materials and different support types of printers to print the 3D object. It has various applications used in various fields. 3D printing is now so much popular because it has been used in the medical field also to manufacture artificial body parts.

1.2 Introduction of 3D Printing

3D Printing technology is an Additive producing process; use to form a 3D object. During this method layers of fabric, and area units are consecutively fashioned beneath a laptop-controlled program to form an object and it illustrates in Fig. 1.1 process of 3D printing.

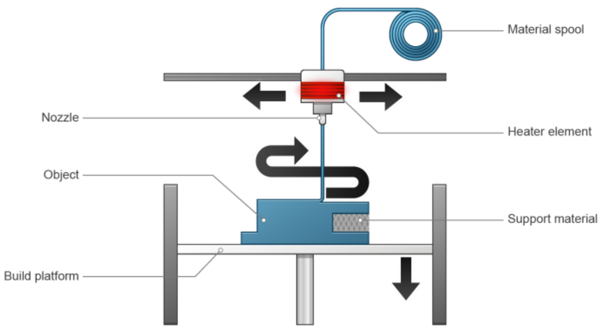


Fig. 1.1: Process of 3D Printing

Introduction [1] the birth of the 3D printer was in 1974, David E. H. Jones set out the thought of 3D-Printing. In 1984, chuck hall of 3D system corporation crammed his patent. The 3Dprinting it's the method of which creating 3D objects from a digital file. During this method, objects are created by printing layers on each other of specific material till the entire object is complete. This can be one every of the most effective methods to form any advanced objects in minimum time while not advanced processes and enormous machines.

1.3 Basic components of 3D-Printer

The print bed is a flat surface shown in Fig. 1.2, wherever the extruder deposits the filament from solid objects. This bed is heated whereas printing however it's depending upon that filament or material we have a tendency to area unit getting to use. Most of the beds' area units are made from Al however currently daily there are conjointly glass print beds obtainable.

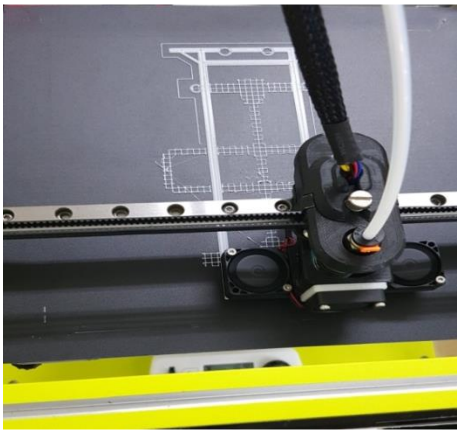


Fig.1.2 Print Bed

1.4 Extruder

The extruder is the half that feeds heated filaments on the bed. This plays important role in printing objects in Fig.1.3. First in extruder filament exerts then it's heated to heating filament starts melting and it starts depositing on the print bed. Necessary a part of the extruder is the Nozzle that is conjointly usually referred to as named as the tip of the extruder. Through the nozzle liquefied filament deposits on the print bed. The dimensions are varying from zero.25 mm to 0.75 mm. The foremost common size of the nozzle is zero.5 mm. The extruder conjointly has 2 types1) direct – Filament is fed on to print bed 2) Bowden- Filament is fed from a precise distance.

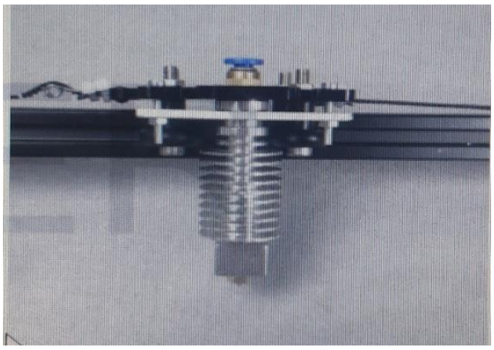


Fig.1.3 Extruder

The filament is material that is inserted into the extruder for creating an object. Usually for 3D printing one.75 mm or 3 mm diameter filament is employed. This material is within the style of wire that feeds to the extruder through a motor. It is most usually PLA and ABS material used for 3D printing. Filaments obtainable in numerous forms of material that we are going to discuss more

1.5 Motherboard or controller board

The circuit card or controller board is the brain of the 3D printer. It directs the motion of elements of the 3D printer. It also helps to read the STL file for printing, moreover, the printing bed and nozzle are also controlled by the mother board on the other hand temperature is also controlled by the controller board as shown in Fig. 1.4 as given below.

Fig.1.4 Mother Board or controller board

1.6 Operation of 3D-printer

The 3D printing process turns a whole object into thousands of tiny little slices, then makes it from the bottom-up, slice by slice. Those tiny layers stick together to form a solid object. Each layer can be very complex, meaning 3D printers can create moving parts like hinges and wheels as part of the same object.

1.6.1 CAD Code

This step contains the drafting of 3D objects that we wish to print in CAD code. However, we tend to not use 3D objects file because it is. These files have two converts into STL file formats. There is a unit of several codes obtainable in the market which might use for drafting and modeling conjointly. A number of these areas' unit fusion360, Solid Works, automotive vehicle CAD, etc. conjointly currently day's 3D scanners also are obtainable for creating computer programmer files.

This program sends to the main board of the printer by mistreatment computers conjointly by the pen drives or memory card.

1.6.2 3D printing operation

This can be the last step of 3D printing. Once the program is given to the printer as per demand material starts to heat in the extruder and filament starts to soften. This melting material is deposited on the print bed as programmed and objects are created by depositing materials layer by layer on each other. The layers' area unit horizontal, cross, zigzag method with one another conjointly in polygon or honeycombs structure as below Fig.1.5 for 3D printing operation.

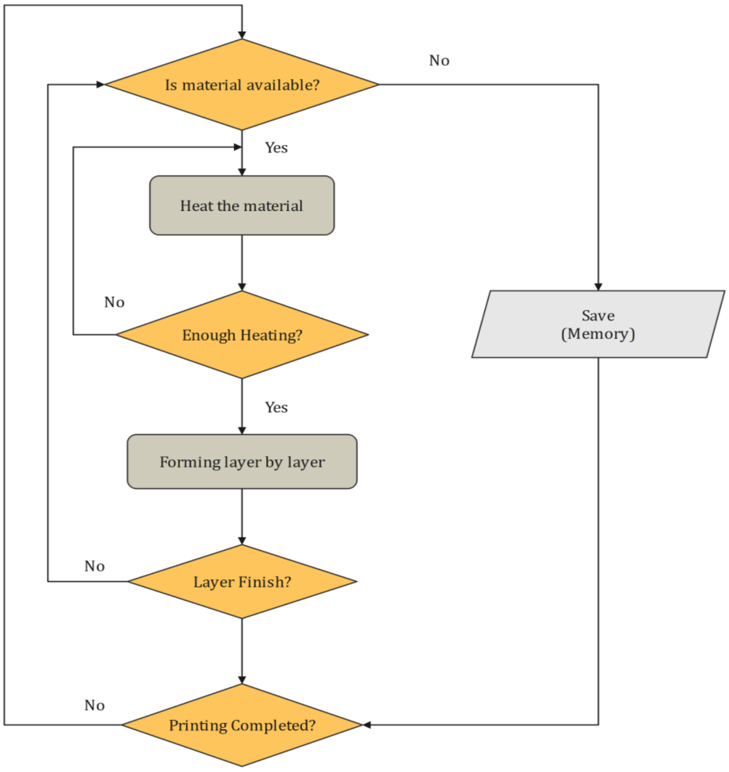


Fig. 1.5 Flow chart of the 3D printing operation

1.6.3 Variety of Material

Materials utilized in 3D-printing technology [2] within the 3D-printing desires prime quality materials for creating prime quality devices. 3D-printers technology is capable of creating prime quality devices by the victimization of the many varieties of materials like metals ceramics and their combination forms.

1.7 Types of Material

The plastic commonest material used for 3D printing [3]. This is often the most numerous material for 3D written toys and social unit products. It has clear and additional colors like inexperienced red or yellow. Plastic is lightweight in weight and additionally high sturdiness its surface smoothness o.k. The kinds of plastic utilized in this method as sometimes made of one in each of the subsequent materials.

1.7.1 Polycystic acid (PLA)

This is an eco-friendly material. PLA is created from sugar cone and corn starch thus perishable. This is often out there in 2 forms soft and laborious. Plastics a made of polycystic acid thus it's utilized in industries laborious polycystic acid a stronger, and thus they are used for creating an ideal product.

1.7.2 Acrylonitrile Butadiene Styrene (ABS)

ABS is the most suitable choice for home-based mostly 3D printers. It's valued for strength and safety. ABS is obtainable in numerous colors. This makes the fabric appropriate for a product like stickers and toys. ABS is additionally accustomed creates jewelry and vases.

1.7.3 Polyvinyl alcohol plastic (PVA)

It is utilized in low-finish home printers. It's low value. This material is used for temporary used things.

1.7.4 Powders

Today’s 3D printers use fine-grained materials to construct objects or products. This powder is liquefied within the printer and distributed in layers unit the well-liked thickness and pattern are created. There are several powders utilized in printers however commonest a 1) polymer (Nylon) Nylon strength and suppleness is extremely thus it's used for change of integrity items and interlocking components in 3D models. 2) Alumina This powder makes the strongest product. This is often primarily used for making industrial models and prototypes.

1.7.5 Metal

The second-hottest material in the business of 3D printing is metal. The properties of this material AR study laborious life and long-lasting life. The properties of metal a smart thus we tend to create complicated shapes of human organs and aerospace components [4]. They are creating additional jewelry for numerous metals used for the product below.

- Unblemished steel-printing out utensil kitchen utensils and alternative things that would ultimately be available in contact with water.
- Bronze -Used for vases and alternative products.
- Gold -Printed for jewelry like rings and jewelry brackets, etc.
- Nickel-Used for written coins
- Aluminum -Used for written skinny metal objects
- Metal -It is the most suitable choice for sturdy solid fixtures

1.8 Objectives of this study

This paper experimented with PLA materials to change the internal filling density, which is the biggest advantage of the 3D printing process. Several tensile specimens were manufactured according to the change in filling density and mechanical properties were evaluated to compare the properties of the conventional PLA materials. Finally, the result of the change in characteristics according to the stacking density is to know the possibility of aerospace or automobile lightweight parts.

Chapter 2
Background

2.1 Overview

The invention of 3D printing started in the year 1971 by Johannes F Gottwald as an ink jet metal material device for printing. Furthermore, it’s improving still now as a 3D printer looks for 3D printing. It has various manufacturing applications in the different sectors on the other hand it has also numerous merits and demerits of 3D printing.

2.2 Background of 3D Printing

In 1971, Johannes F Gottwald proprietary the Liquid Metal Recorder, US3596285A, a never-ending Ink jet metal material device to create a removable metal fabrication on a reusable surface for immediate use or salvaged for printing once more by again melting. This seems to be the primary patent describing 3D printing with fast prototyping and controlled on-demand production of patterns.

The patent states "As used herein the term printing isn't supposed during a restricted sense however includes writing or different symbols, character or pattern formation with AN ink. The term ink as utilized is meant to incorporate not solely dye or pigment-containing materials, however, any flow-able substance or composition fitted to application to the surface for fomenting symbols, characters, or patterns of intelligence by marking. The well-liked ink is of a Hot softened sort.

The very commercially accessible ink compositions that might meet the necessities of the invention don't seem to be glorious at the current time. However, satisfactory printing in line with the invention has been achieved with the semi-conductive metal alloy as ink."

"But in terms of fabric needs for such giant and continuous displays, if consumed at theretofore glorious rates, however, exaggerated in proportion to extend in size, the high price would severely limit any widespread enjoyment of a method or equipment satisfying the preceding objects."

"It is thus a further object of the invention to attenuate use to materials during a method of the indicated category."

"It could be a more object of the invention that materials used in such a method be salvaged for reprocessing."

"According to a different side of the invention, a mixture for writing and also the like contains a carrier for displaying AN intelligence pattern and a meeting for removing the pattern from the carrier

early additive producing instrumentality and materials were developed within the Nineteen Eighties. His analysis results as journal papers were revealed in Gregorian calendar month and November in 1981. However, there was no reaction to the series of his publications. His device wasn't extremely evaluated within the laboratory and his boss failed to show any interest. His analysis budget was simply $545 a year. Feat the patent rights for the XYZ plotter were abandoned, and also the project was terminated.

A Patent U.S.A. 4323756, the technique of Fabricating Articles by ordered Deposition, Raytheon Technologies house granted half dozen Gregorian calendar month 1982 mistreatment tons of or thousands of 'layers' of powdery metal and an optical maser energy supply is early respect to forming "layers" and also the fabrication of articles on a substrate.

AM processes for metal sintering or melting (such as selective optical maser sintering, direct metal optical maser sintering, and selective optical maser melting) sometimes passed their names within the Nineteen Eighties and Nineteen Nineties. At the time, all metalwork was done by processes that area unit is currently known as non-additive (casting, fabrication, stamping, and machining); though lots of automation was applied to those technologies (such as automaton fastening and CNC), the concept of a tool or head moving through a 3D work envelope reworking a mass of stuff into the desired form with a tool path was associated in metalwork solely with processes that removed metal (rather than adding it), like CNC edge, CNC EDM, and lots of others. However, the machine-driven techniques that superimposed metal, which might later be known as additive production, we're getting down challenging that assumption. By the mid-1990s, new techniques for material deposition were developed at Stanford and Carnegie Philanthropist University, together with small casting and sprayed materials kill and support materials had conjointly become a lot of commons, sanctioning new object geometries.

The term 3D printing originally noted a powder bed method using commonplace and custom ink jet print heads developed at Massachusetts Institute of Technology by Emanuel Sachs in 1993 and commercialized by city Technologies, produced by Hone Corporation, and Z Corporation.[citation needed]

The year 1993 conjointly saw the beginning of AN inkjet 3D printer company at first named Sanders paradigm, Ink and later named Solids cape, introducing a high-precision chemical compound jet fabrication system with soluble support structures, (categorized as a "dot-on-dot" technique). In 1995 the Fraunhofer Society developed the selective optical maser melting method. As the numerous additive processes matured, it became clear that before long metal removal would not be the sole formation method done through a tool or head moving through a 3D work envelope, remodeling a mass of stuff into the desired form layer by layer. The 2010s were the primary decade within which metal finish use components like engine brackets [8] and huge nuts [9] would be grownup (either before or rather than machining) in job production instead of obligate being machined from bar stock or plate. It's still the case that casting, fabrication, stamping, and machining areas unit a lot of prevailing than additive producing in formation, however, AM is currently commencing to build important inroads, and with the benefits of style for additive producing, it's clear to engineers that far more is to return.

One place where AM is creating a major inroad is within the aviation trade. With nearly three.8 billion air travelers in 2016, [10] the demand for fuel economy and simply created jet engines has never been higher. For big OEMs (original instrumentality manufacturers) like Pratt and Whitney (PW) and General electrical (GE), this suggests wanting AM as the simplest way to scale back value, scale back the number of unorthodox components, scale back weight within the engines to extend fuel potency and notice new, extremely advanced shapes that may not be possible with the old producing strategies. One example of AM integration with part was in 2016 when the airliner was delivered the primary of GE's LEAP engine. This engine has integrated 3D written fuel nozzles giving them a discount in components from twenty to one, a twenty-fifth weight reduction, and reduced assembly times.[11] A fuel nozzle is that excellent in the road for additive production in a very reaction engine since it permits for an optimized style of the advanced internals, and its coffee stress, non-rotating half. Similarly, in 2015, PW delivered their initial AM components within the Pure Power PW1500G to Bombardier. Protrusive to low stress, non-rotating components, PW elite the mechanical device stators and synch ring brackets [12] to roll out this new producing technology for the primary time. Whereas AM remains enjoying a little role within the total range of components within the reaction engine producing method, the come-on investment will already be seen by the reduction in components, the fast production capabilities, and also the "optimized style in terms of performance and cost"[13]. As the technology matured, many authors had begun to take the position that 3D printing may aid in property development within the developing world [14].

In 2012, Fila larva developed a system for closing the loop [15] with plastic and permits any FDM or FFF 3D printer to be able to print with a wider variety of plastics.

In 2014, Benjamin S. Cook and Manos M. Tentzeris demonstrate the primary multi-material, vertically integrated written physics additive producing platform (VIPRE) that enabled 3D printing of useful physics in operation at up to forty rates [16].

As the value of printers began to drop folks curious about this technology had a lot of access and freedom to form what they needed. The value as of 2014 was still high with the price being over $2,000 nonetheless this still allowed amateur associates entrance into printing outside of production and trade strategies [17]. The term "3D printing" originally mentioned a method that deposits a binder material onto a powder bed with inkjet printer heads layer by layer. A lot of recently, the favored vernacular has started victimization the term to cover a wider form of additive-manufacturing techniques like electron-beam additive production and selective optical device melting. The US and world technical standards use the official term additive producing for this broader sense.

2.3 Introduction of 3D printing

3D Printing, or additive producing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. [18] The term "3D printing" will sit down with a range of processes within which material is deposited, joined or solid beneath laptop management to form a three-dimensional object, [19] with the material being additional along (such as plastics, liquids, or powder grains being amalgamated together), generally layer by layer.

In the Eighties, 3D printing techniques were thought of as appropriate just for the assembly of useful or aesthetic prototypes, and a lot of applicable terms for it at the time was fast prototyping [20]. As of 2019, the exactness, repeatability, and associated material vary of 3D printing have inflated to the purpose that some 3D printing processes area unit thought of viable as an industrial-production technology, whereby the term additive producing is often used synonymously with 3D printing [21]. One of the key benefits of 3D printing is the ability to supply advanced shapes or geometries that may be otherwise not possible to construct by hand, together with hollow components or components with internal truss structures to scale back weight. Amalgamated deposition modeling (FDM), which uses an eternal filament of a thermoplastic material, is the most typical 3D printing in use as of 2020 [22].

3D printing processes area units finally catching up to their full potential, and area units presently getting used in production and medical industries, still as by social group sectors that facilitate 3D printing for business functions. There has been a great deal of hoopla within the last decade once concerning the probabilities we can come through by adopting 3D printing mutually of the most productive technologies.

For an extended time, the problem with 3D printing was that it demanded high entry prices, that don't enable profitable implementation to mass manufacturers compared to plain processes. However, recent market trends noticed have found that this can be finally dynamic. The marketplace for 3D printing has shown a number of the fastest growth at intervals in the producing trade in recent years.

2.4 Manufacturing applications

Three-dimensional printing makes it low-cost to make single things because it is to supply thousands and so undermines economies of scale. It should have as profound a bearing on the planet because of the returning of the mill. Even as no one may have foretold the impact of the external-combustion engine in 1750, the press in 1450, or the electronic transistor in 1950, it's not possible to foresee the semi-permanent impact of 3D printing. However, the technology is returning, and it's possible to disrupt each field it touches.

AM technologies found applications beginning within the Nineteen Eighties in development, knowledge of visual image, speedy prototyping, and specialized production. Their growth into production (job production, production, and distributed manufacturing) has been beneath development for the decades since. Industrial production roles within the formation industries achieved vital scale for the primary time within the early 2010s. Since the beginning of the twenty-first century, there has been an oversized growth in the sales of AM machines, and their value has born considerably in line with Wohler's Associates, a practice, the marketplace for 3D printers and services was priced at $2.2 billion worldwide in a pair of012, up twenty-ninth from 2011. McKinsey predicts that additive production may have an associate degree economic impact of $550 billion annually by 2025. There are a unit several applications for AM technologies, together with design, construction (AEC), industrial style, automotive, aerospace, military, engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewelry, eyewear, education, geographic info systems, food, and plenty of alternative fields.

Additive productions the earliest applications are on the tool room finish of the manufacturing spectrum. As an example, speedy prototyping was one of the earliest additive variants, and its mission was to cut back the interval and value of developing prototypes of recent components and devices, that were earlier solely finished ablative tool room strategies like CNC edge and turning, and exactness grinding, much more correct than 3d printing with accuracy right down to zero.00005" and making higher-quality components quicker, however typically too dearly-won for low accuracy model components. With technological advances in additive producing, however, and also the dissemination of these advances into the business world, additive strategies' area unit moving ever any into the assembly finish of producing in artistic and typically sudden ways in which components that were erstwhile the only real province of ablative strategies will currently in some cases be created a lot of fruitfully via additive ones. Additionally, new developments in Rewrap technology enable the identical device to perform each additive and ablative production by swapping magnetic-mounted tool heads.

2.5 Cloud-based additive manufacturing

Additive production together with cloud computing technologies permits decentralized and geographically freelance distributed production. Cloud-based additive producing refers to a service-oriented networked producing model during which service customers' area units can build components through Infrastructure-as-a-Service (Iaas), Platform-as-a-Service (Pass), Hardware-as-a-Service and Software-as-a-Service (Sass). Distributed producing intrinsically is meted out by some enterprises; there's additionally a service like 3D Hubs that place individuals needing 3D printing to bear with homeowners of printers.

Some firms provide online 3D printing services to each industrial and personal customer, acting from 3D styles uploaded to the corporate website. 3D-printed style area units are either shipped to the client or picked up from the service supplier.

2.6 Mass customization

Miniature face models (from Face Gen) made exploitation Ceramic primarily based material on a Full-color 3D Inkjet Printer in Fig. 2.1.

Companies have created services wherever customers will customize objects exploitation simplified internet-primarily based customization software system, and order the ensuing things as 3D written distinctive objects. This currently permits customers to form custom cases for their mobile phones.

Fig. 2.1: Miniature face models

2.7 Rapid Manufacturing

Advances in RP technology have introduced materials that are acceptable for final manufacture, and that have successively introduced the chance of directly producing finished parts. One advantage of 3D printing for fast production lines within the comparatively cheap production of tiny numbers of elements.

Rapid production may be a new methodology of production and lots of its processes stay unproved. 3D printing is currently coming into the sector of fast production and was known as a "next level" technology by several consultants during a 2009 report. Every of the foremost promising processes appears to be the difference between selective optical maser sintering (SLS), and direct metal optical maser sintering (DM LS) a number of the better-established fast prototyping strategies. As of 2006, however, these techniques were still noticeably in their infancy, with several obstacles to be overcome before RM might be thought of as a practical producing methodology. There are patent lawsuits regarding three-D printing for production.

2.8 Rapid prototyping

Industrial 3D printers have existed since the first Eighties and are used extensively for fast prototyping and analysis functions. These are typically larger machines that use proprietary pulverized metals, casting media (e.g., sand), plastics, paper, or cartridges, and a used for fast prototyping by universities and industrial corporations as shown in Fig.2.2.

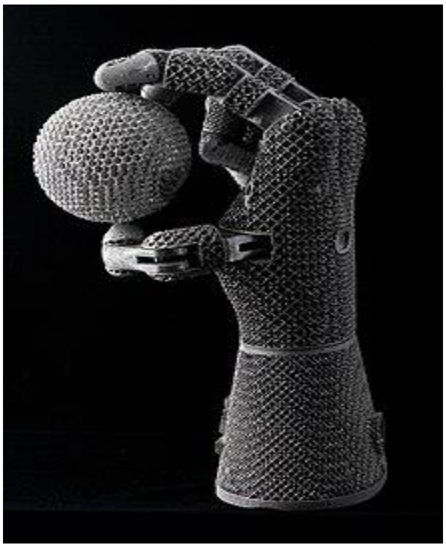


Fig. 2.2 Printed object

2.9Advantage of 3D printing

This production method offers a spread of benefits compared to ancient production strategies. These blessings embrace those associated with style, time, and price, amongst others [23].

2.9.1 Flexible Design

3D printing permits for the planning and printing of a lot of advanced styles than ancient manufacturing processes as shown in Fig. 2.3. A lot of ancient processes have style restrictions that now do not apply with the employment of 3D printing.

Fig. 2.3 Complex design

2.9.1 Rapid Prototyping

3D printing will manufacture components within hours that quicken the prototyping method. This permits every stage to complete quicker. Compared to machining prototypes, 3D printing is cheap and faster at making components because the half is often finished in hours, providing every style modification to be completed at a far a lot of economical rates.

2.9.2 Print on Demand

Print on demand is another advantage because it doesn't want a great deal of area to stock inventory, in contrast to ancient producing processes. This protects area and prices as there's no ought to print in bulk unless needed.

The 3D style files an all keep in an exceedingly virtual library as they're written employing a 3D model as either a CAD or STL file, this suggests they will be settled and written once required. Edits to styles are often created at terribly low prices by written material individual files while not wastage of out of date inventory and investment in tools.

2.9.3 Strong and Lightweight Parts

The main 3D printing material used is plastic, though some metals may be used for 3D printing. However, plastics provide blessings as they're lighter than their metal equivalents as shown in Fig. 2.4. This is often notably necessary in industries like automotive and part wherever light-weighting is a difficulty and may deliver larger fuel potency.

Also, components are often created from tailored materials to produce specific properties like heat resistance, higher strength, or water repellence.

Fig. 2.4Lightweight Parts

2.9.5 Fast Design and Production

Depending on a part’s style and complexity, 3D printing will print objects inside hours that are way quicker than molded or machined components. It's not solely the manufacture of the half that may provide time savings through 3D printing however conjointly the planning method are often terribly fast by making STL or CAD files able to be written.

2.9.6 Minimizing Waste

The production of components solely needs the materials required for the half itself, with very little or no wastage as compared to different strategies that a cut from giant chunks of non-recyclable materials. Not solely will the method save on resources however it conjointly reduces the value of the materials getting used.

2.9.7 Cost-Effective

As a step production method, 3D printing saves time and so prices related to the exploitation of completely different machines for manufacture as illustrated in Fig. 2.4. 3D printers may be established and left to urge on with the task which means that there's no want for operators to be gifted the whole time. As mentioned higher than, this producing method may scale back prices on materials because it solely uses the quantity of fabric needed for the half itself, with very little or no wastage. Whereas 3D printing instrumentality is often the price to shop for, you'll be able to even avoid this value by outsourcing your project to a 3D printing service company.

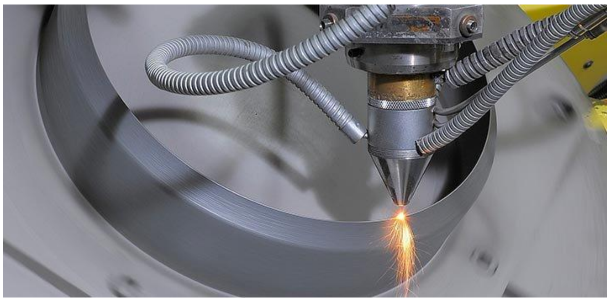


Fig. 2.5Save Time and Cost-Effective Process

2.9.8 Ease of Access

3D printers are getting additional and additional accessible with additional native service suppliers giving outsourcing services for producing work. This protects time and doesn't need dear transport prices compared to additional ancient producing processes made abroad in countries like China.

2.9.9 Environmentally Friendly

As this technology reduces the quantity of fabric wastage used this method is inherently environmentally friendly. However, the environmental edges are extended after you take into account factors like improved fuel potency from the victimization of light-weight 3D written elements.

2.9.10 Advanced Healthcare

3D printing is being employed within the medical sector to assist save lives by printing organs for the physical structure like livers, kidneys, and hearts as shown in Fig. 2.6. Additional advances and uses are being developed within the attention sector providing a number of the most important advances from victimization the technology.

Fig. 2.6 Physical Part Printing Printer

2.10 Drawbacks

Like with virtually the other method there also are drawbacks of 3D printing technology that ought to be thought of before opting to use this method.

2.10.1 Limited Materials

While 3D Printing will produce things in an exceedingly choice of plastics and metals the obtainable choice of raw materials isn't thoroughgoing. Thanks to the fact that not all metals or plastics can be temperature controlled enough to permit 3D printing. Additionally, several of those printable materials cannot be recycled and extremely few are food safe.

2.10.2 Restricted Build Size

3D printers presently have little print chambers that prohibit the scale of elements that will be written. Something larger can get to be written in separate elements and joined along once production. This may increase prices and time for larger elements thanks to the printer's desire to print additional elements before labor is employed to hitch the elements along as shown in Fig. 2.7.

Fig. 2.7Restricted Build Size

2.10.3 Post Processing

Although massive elements need post-processing, as mentioned on top of, most 3D written elements want some type of cleanup up to get rid of support material from the build and to swish the surface to realize the specified end. Post-process ways used embrace water jetting, sanding, a chemical soak and rinse, air or heat drying, and assembly. The quantity of post-process needed depends on factors as well as the scale of the half being made, the supposed application, and also the variety of 3D printing technology used for production. So, whereas 3D printing permits for the quick production of elements, the speed of manufacture will be slowed by post process.

2.10.4 Large Volumes

3D printing may be a static value in contrast to additional standard techniques like injection molding, wherever massive volumes are also adding value effective to provide. whereas the initial investment for 3D printing is also less than different producing ways, once scaled up to provide massive volumes for mass production the value per unit doesn't scale back as it would with injection molding.

2.10.5 Part Structure

With 3D printing (also referred to as Additive Manufacturing) elements are made layer-by-layer. Though these layers adhere along with it conjointly means they will delaminate underneath bound stresses or orientations as shown in Fig. 2.8.

Fig. 2.8 Critical Part Structure

This drawback is additional vital once manufacturing things victimization united deposition modeling (FDM), whereas polyjet and multijet elements conjointly tend to be additional brittle. In bound cases, it should be higher to use injection molding because it creates undiversified elements that may not separate and break.

2.10.6 Reduction in Manufacturing Jobs

Another disadvantage of 3D technology is the potential reduction in human labor since most of the assembly is automatic and done by printers. However, several aggregation countries place confidence in low-ability jobs to stay their economies running, and this technology may place these producing jobs in danger by extirpation the necessity for production abroad.

2.10.7 Design Inaccuracies

Another potential problem with 3D printing is directly related to the type of machine or process used, with some printers having lower tolerances, meaning that final parts may differ from the original design. This can be fixed in post-processing, but it must be considered that this will further increase the time and cost of production.

2.10.8 Copyright Issues

Another potential drawback with 3D printing is directly associated with the sort of machine or method used, with some printers having lower tolerances, which means that final elements might dissent from the initial style as shown in Fig. 2.9. This may be fastened in post-process; however, it should be thought that this can additionally increase the time and price of production.

Fig. 2.9 Duplicate parts

Chapter 3

Mechanical and Physical properties of PLA

3.1 Overview

PLA has mechanical and physical properties at different infill densities and different infill patterns used for printing at different temperature ranges and it also depicted the different values of elastic modulus, tensile strength, and elongation at breaking points respectively different at different temperatures.

3.2 PLA material for Physical and mechanical properties

PLA has become a well-liked material because it is economically made from renewable resources. In 2010, PLA had the second-highest consumption volume of any bioplastic on the planet, though it's still not a trade good chemical compound. Its widespread application has been hindered by varied physical and process shortcomings [24].PLA is the most generally used plastic filament material in 3D printing.

Although the name "poly lactic acid" is widely used, it doesn't fit IUPAC customary language, that is "poly(lactic acid)".The name "poly lactic acid" is probably ambiguous or confusing, as a result, PLA isn't a poly acid (polyelectrolyte), but rather a polyester.

PLA chemical compounds vary from amorphous glassy chemical compounds to semi-crystalline and extremely crystalline polymers with a glass transition of 60–65 °C, a melting temperature of 130-180 °C, and an elastic modulus a pair of.7–16 GPA. Heat-resistant PLA will stand up to temperatures of a hundred and ten °C.[60] the essential mechanical properties of PLA as between those of cinnamon and PET. The melting temperature of PL LA is often augmented by 40–50 °C and its heat deflection temperature is often augmented from more or less sixty °C to up to a hundred ninety °C by physically mixing the chemical compound with PDLA (poly-D-lactide). PDLA and PLLA type an extremely regular stereo complex with augmented crystalline. The temperature stability is maximized once a 1:1 mix is employed, however, even at lower concentrations of 3–10% of PDLA, there's still a considerable improvement. Within the latter case, PDLA acts as a nucleating agent, thereby increasing the crystallization rate [citation needed]. Biodegradation of PDLA is slower than for PLA because of the upper crystalline of PDLA [citation needed]. The flexural modulus of PLA is over cinnamon and PLA has sensible heat stability.

Several technologies like tempering, adding nucleating agents, forming composites with fibers or nanoparticles, chain extending, and introducing cross-link structures are accustomed to enhancing the mechanical properties of PLA polymers. Polylactic acid is often processed like most thermoplastics into fiber (for example, victimization typical softens spinning processes) and film. PLA has similar mechanical properties to PETE chemical compound, however, features a considerably lowermost continuous use temperature.

Race mica PLA and pure PLLA have low glass transition temperatures, creating them undesirable thanks to low strength and temperature. A stereo complex of PDLA and PLLA features a higher glass transition temperature, disposition it a lot of mechanical strength. The high surface energy of PLA ends up in sensible print ability, creating it wide utilized in 3D printing. The strength for 3D written PLA was antecedent determined.

3.3 Physical properties chart for PLA Material

PLA is AN open-chain polyester biopolymer that will be derived from renewable sources, such as corn, potato, molasses, tapioca, cane sugar, and rice. From these renewable sources, lactic acid is essentially created by a fermentation method and used as a compound to synthesize playthrough different chemical process routes, viz. ring gap chemical process (ROP), poly condensation, and different direct ways (e.g. allotropic dehydration and accelerator polymerization.

PLA is offered within the market with totally different molecular weights. ROP affords the assembly of high mass PLA when put next to the polycondensation technique methodology of production. Different firms such as Cargill Copolymer LCC, Shimadzu firm, Mitsui Chemicals, and Musashino Co. also is manufacturePLAtowards numerous industrial applications (e.g. packaging, textiles, pharmaceutical merchandise, and medical specialty devices).

PLA has a minimum of, 3 stereoisomers, namely: poly(L-lactide) (PLLA), Poly(D-lactide) and poly(DL-lactide) (PDLLA), which results from the presence of 2 chiral carbon centers. In In this review, to avoid any confusion, PLA is accustomed describe all PLA-based polymers. The properties of PLA as influenced by many factors, like supply, the component isomers, the process routes, and molecular weights. It's in the main littered with the stereochemistry and thermal history, that additionally influence its crystalline and so, resulting properties. For example, once PLLA content is on top of ninetieth it tends to be extremely crystalline, whereas melting temperature (Tm) and glass transition temperature (Tg) decreased on decreasing PLLA content. Table one presents the most physical properties of PLA-based polymers.

PLA possesses exceptional properties that embrace biocompatibility, ultraviolet light stability, clarity, and luster. PLA has been exploited in numerous fields, like packaging and medical specialty of its biodegradability and biocompatibility. There are, however, some limitations that hinder its success, such as slow crystallization, low glass transition, and crispness.

There has been a great deal of effort to switch PLA to beat these limitations and match the end applications. Many modifications like mixing with different polymers, copolymerizing with purposeful monomers, analysis, and reinforcement with totally different fillers have been explored in appropriate ways. On the opposite hand, the utilization of nanoliters, yielding thus called nanocomposite materials advantage special attention because of the aptitude of those particles to boost mechanical and thermo-mechanical properties further on offer additional functionalities at fairly low contents below as shown in Fig. 3.1.

Polymer	Elastic modulus (GPa)	Tensile strength (MPa)	Elongation-at-break (%)	T_m (°C)	T_g (°C)
PLA	0.35-3.5	21-60	2.5-6	150-162	45-60
PLLA	2.7-4.14	15.5-150	3.0-10	170-200	55-65
PDLLA	1-3.45	27.6-50	2.0-10.0	-	50-60

Fig. 3.1 Physical properties chart for PLA Material

3.4 Mechanical properties chart for PLA Material

The Rap Man is capable of printing 2 differing kinds of plastic materials particularly Poly lactic Acid (PLA) or nitrite hydrocarbon cinnamon (ABS) plastics have different material properties as shown in Table three.

PLA could be thermoplastic polyester that is made from renewable resources, like starch or sugarcane and is quickly perishable in contrast to the organic compound plastics. PLAresins are widely used for medical applications, owing to their biodegrading properties [25].

PLA incorporates a low threshold for top temperatures and is additionally a tricky plastic that's quite brittle, and therefore it cannot be sanded down or ironed out. PLA sometimes extrudes at concerning180ºC and is needed to be cooled by fans while printing. Though the perishable properties and origin of the fabric area unit favorable for rural areas, the mechanical properties, significantly the crispness, build it a not ideal alternative for a lifelike corrective.ABS could be a thermoplastic with a broad variety of desired properties, once considering prostheses. ABS is extremely sturdy and slightly versatile. It is often sanded down, painted, and adheres well once employing an appropriate glue for corrective adhesion. ABS has been successfully used for the application of prostheses in different studies, as a result, the surface roughness is often altered with sandpaper and dissolving agent vapor. The disadvantage of printing with ABS instead of PLA is that ABS incorporates a higher temperature (240 °C), which successively implies that there's a lot of wear and tear on the printer extruder head and that a lot of power is needed to print the half, and also the heat uptime of the extruders longer. For little production sizes, the additional value in energy usage for manufacturing the prostheses is going to be tiny, but any analysis may be done to work out whether for large batches the upper energy needs build ABS associate degree unsuitable alternative of fabrics' shown in blow Fig. 3.2.

Properties	Units	ASTM	Common Material	
			PLA	ABS
Tensile Strength	MPa	D638-03	59	40
Elongation at Break	%	D638-05	7	50
Modulus of Elasticity	MPa	D638-04	3750	2600-3000
Izod Impact Strength	J/m	D256-06	26	34
Density	kg/mm^3		0.00105	0.00125
Cost per kilogram	Rand/kg	-	R 900	R 900
Colour		-	Various	Various

Fig. 3.2 Mechanical properties chart for PLA Material

Chapter 4

Research method

4.1 Overview

The research part used a PLA material for tensile testing through a UTM machine using different simple at different infill densities and different infill patterns to evaluate the value of yield strength, Young modulus, and maximum stress.

4.1.1 Using different infill patterns and different styles for PLA

To use a PLA material to form dock won for tensile testing at totally different infill density and a special infill pattern (60, 75, 80, 95,100) severally density and employing a line and grid each pattern.

4.1.2 Infill density

The infill density defines the number of plastics used within the print. The next infill density implies that there's additional plastic within your print, resulting in a stronger object. Associate in Nursing infill density of around two-hundredths is employed for models with a visible purpose; higher densities are often used for end-use components.

4.1.3 Infill pattern

Infill density is the quantity of filament written within the item, and this directly relates to the strength, weight, and printing length of your print. Different 3D print infill varieties, or infill patterns, will have an effect on the object's final strength while not dynamic the print's weight or filament used.

4.1.4 To use Apparatus

UTM machine used for tensile testing, PLA material dock won etcetera. A universal testing machine additionally called a universal tester, materials take a look acting machine or materials test frame, is employed to check the strength and compressive strength of materials. Associate in a nursing earlier name for a tensile testing machine may be a tensiometer.

4.1.5 Design

With the assistance of fusion 360 to form 3d style exploitation below given drawing, additional over-exploitation of this drawing to form 3d sketch sample at totally different infill density and a special infill pattern each image as shown below in Fig. 4.1, 4.2.

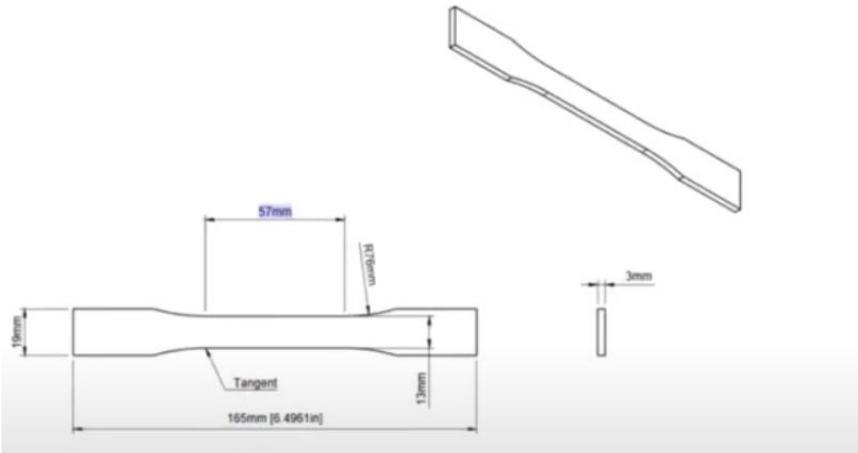


Fig. 4.1ASTM Tensile Specimen drawing

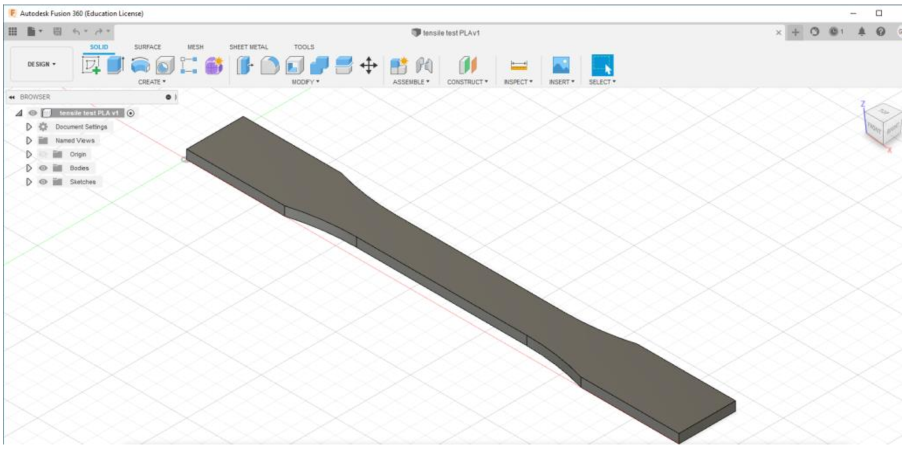


Fig. 4.2 ASTM Tensile specimen 3d modeling in Fusion 360

4.1.6 3D modeling of tensile specimen

After this method making an STL file with facilitating the assistance of Cura software system that helps for slicing the half and setting the temperature or set the worth of infill density and infill pattern then putt into SD card and so putt into FDM Printer, and it takes 2hours quarter-hour for printing the half as the shown sample in Fig. 4.3.

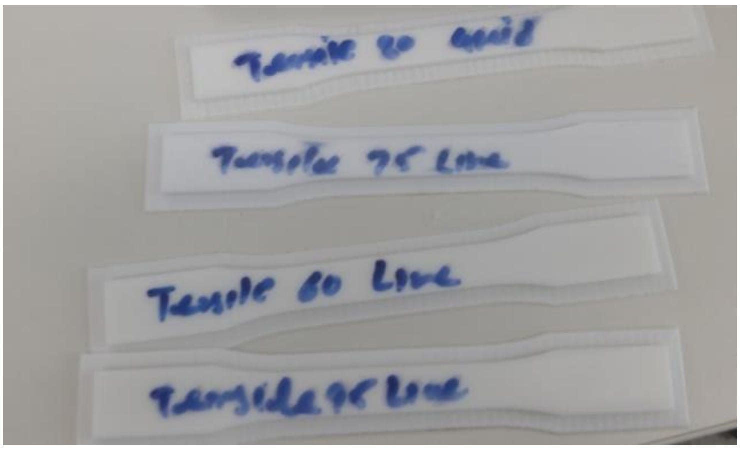


Fig. 4.3 Tensile specimen picture

4.1.7 Final Tensile specimen

Furthermore, these all specimens need post-processing means unwanted material remove then we got it final part of the tensile specimen as shown in Fig. 4.4. The specimen is used in UTM (universal testing machine) to check the capacity of load to bear it according to the properties of PLA material.

Fig. 4.4 Final Tensile specimen

4.1.8 Difference between Grid and Line Pattern

These Patterns setting with the help of Cura Software to select the pattern type grid or line and put the value of infill density also according to the specimen requirements. Cura software also converts the STL File to a G code file because the 3D printer cannot understand the STL file. Moreover, it helps for single-layer slicing because it's important to maintain before printing-on-printing bed thus nozzle makes a layer on the printing bed, not in the air.

Grid and Line pattern setting as shown in Fig. 4.5, 4.6.

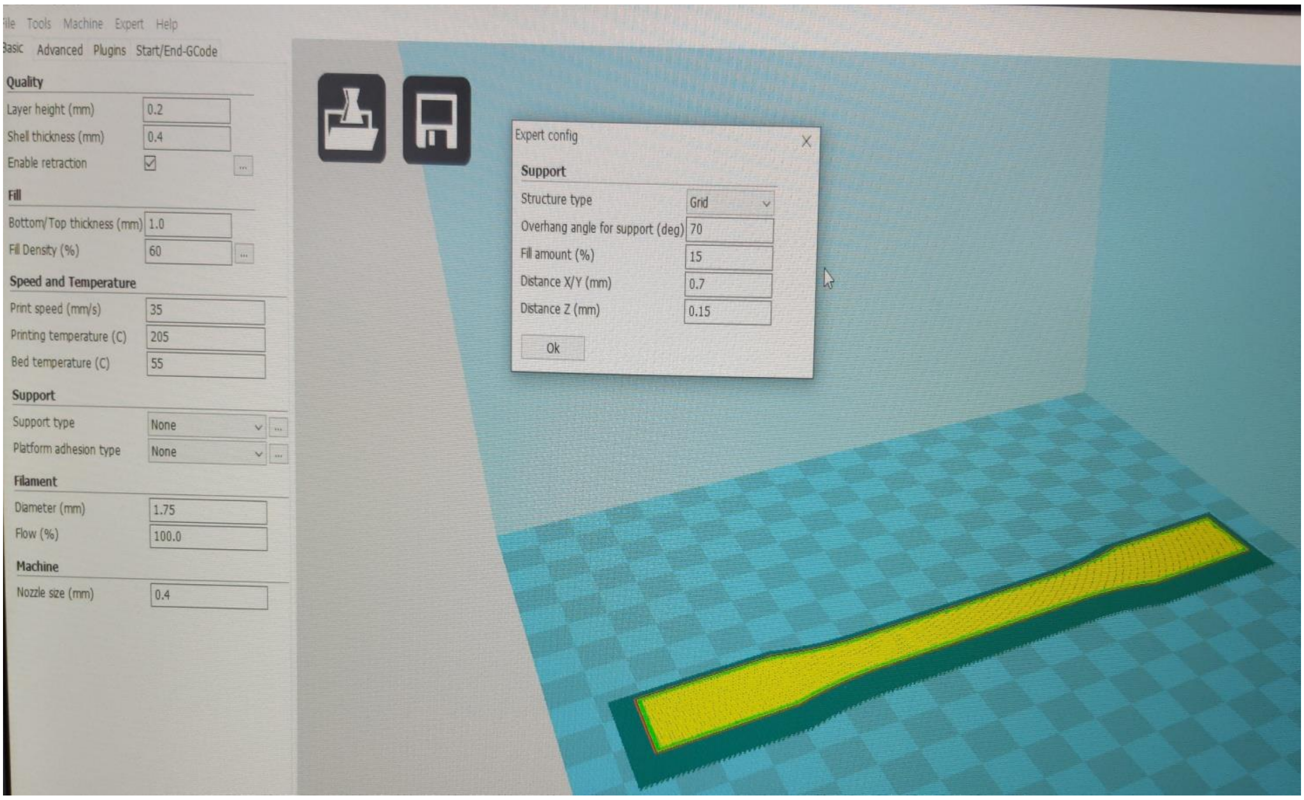


Fig. 4.5 Grid Pattern

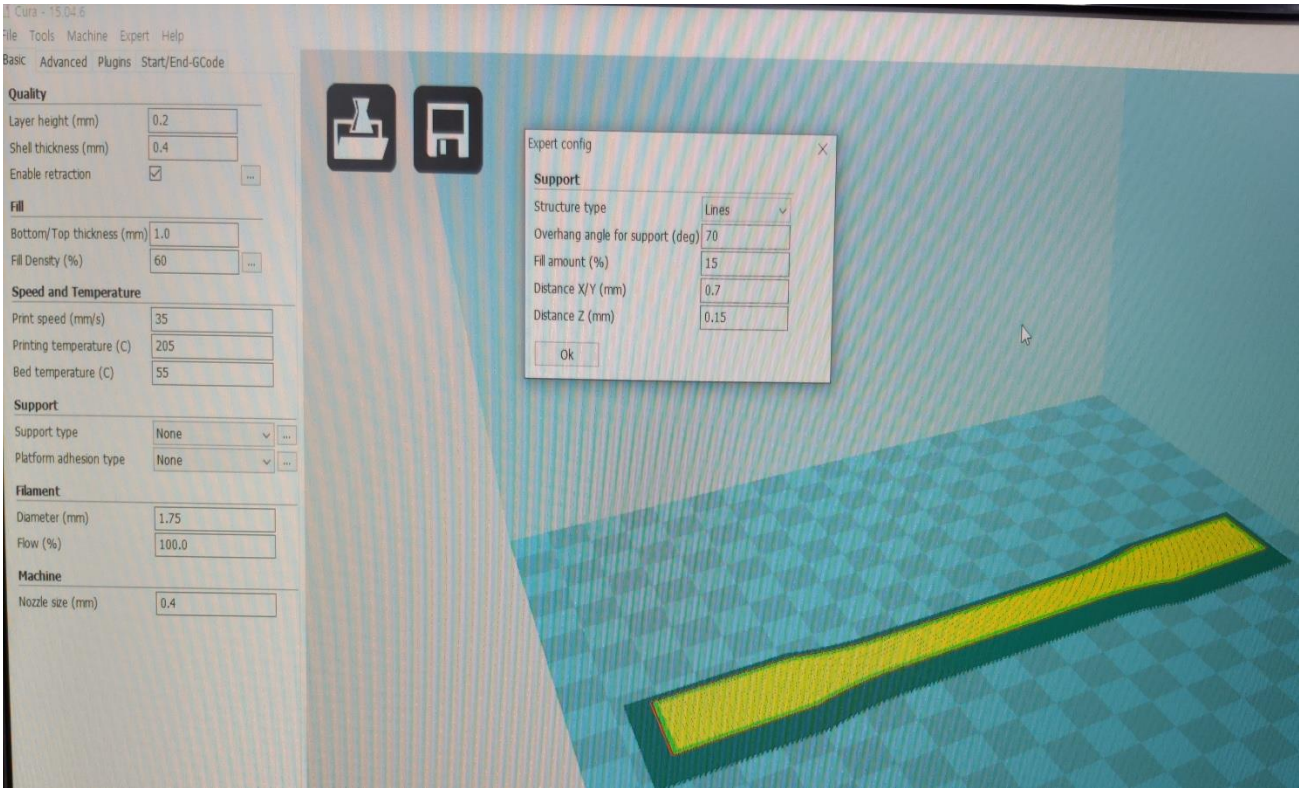


Fig. 4.6 Line Pattern

4.2 Measurements

The next step to mark the gauge length on the specimen it's important before performing the tensile test as shown below in Table 1.

1	Test Type	Tensile Test
2	Control Method	Displacement Control Test
3	Test Speed	1 mm/min;
4	Specimen Shape	Rectangle
5	Thickness [mm]	3
6	Width [mm]	13
7	Gage Length [mm]	51.055
8	Area[mm]	39

Table 4.1Tensile Specimen dimension

4.2.1 Testing through UTM machine

Moreover to hold the specimen into UTM, Machine as given below in Fig 4.7 Universal testing machine.

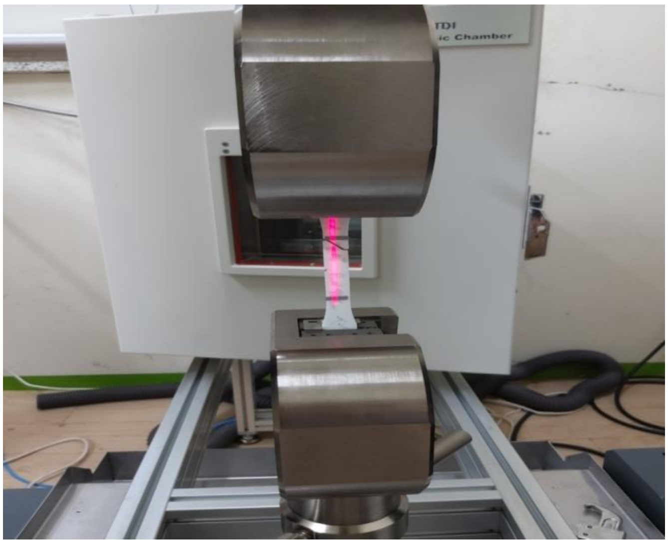


Fig. 4.7 UTM (Universal Testing Machine)

It holds the part gradually increasing the load till the breaking point and before the physical properties of the material have been changed after the fatigue point it has been broken as shown in Fig. 4.8.

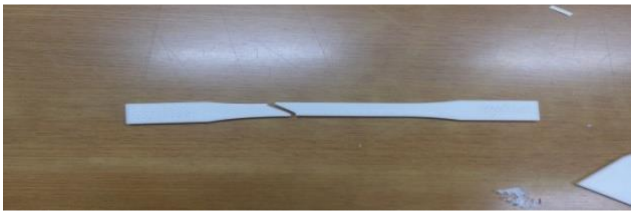


Fig.4.8 Tensile Specimen After Breaking

4.3 Sample description

It makes samples at different infill densities and uses different infill patterns.

- First sample 60% density using line and grid pattern.
- The second sample had 75% density using line and grid patterns.
- The third sample had 80% density using line and grid patterns.
- Fourth sample 100% density using line and grid pattern

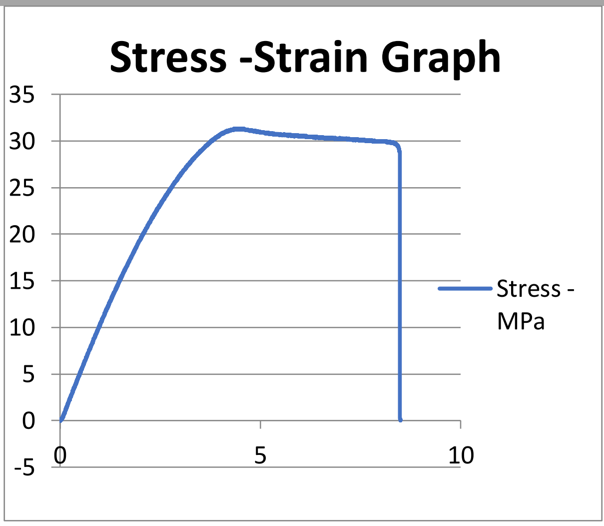
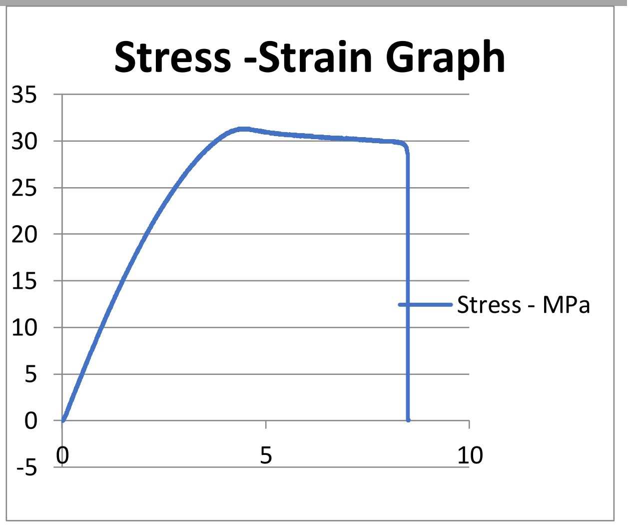
With the help of the above-given sample, we find the value of yield strength, Young modulus, and maximum stress value.

4.3.1 Comparison and combination

Tensile sample data shows the comparison according to density and pattern-wise.

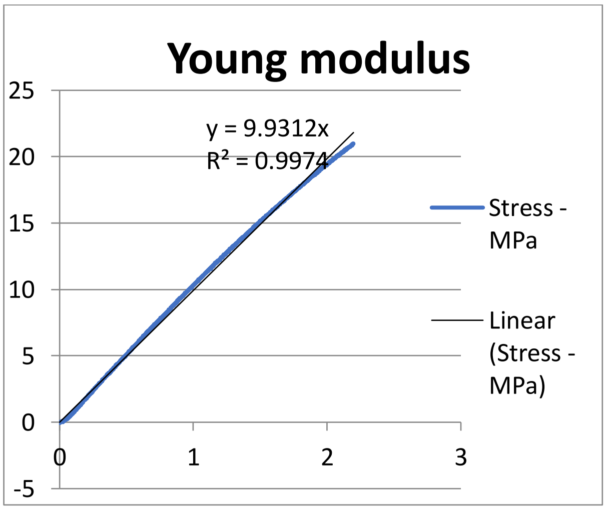
1. Tensile **60%** percent density and using a line, grid pattern means its showing strength difference how much Stress in MPa bear a component before breaking.
2. **60%** grid and line pattern sample graphical stress-strain graph, young modulus, yield strength.

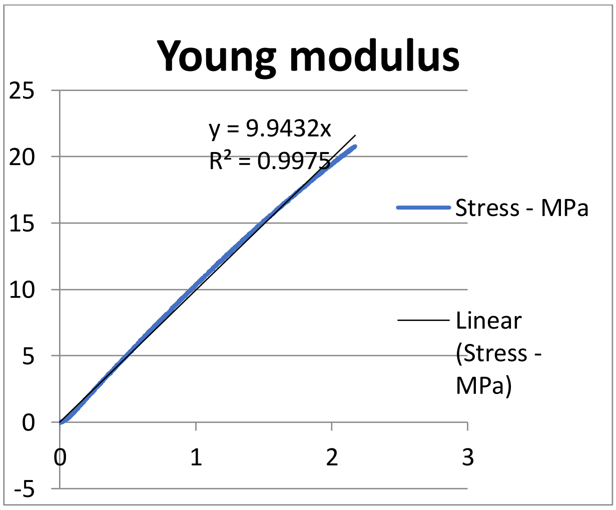
4.3.2 60% Sample graphical data using both patterns

60% Grid	60% Line
	

Graph 4.1 Stress-Strain Graph 60%grid

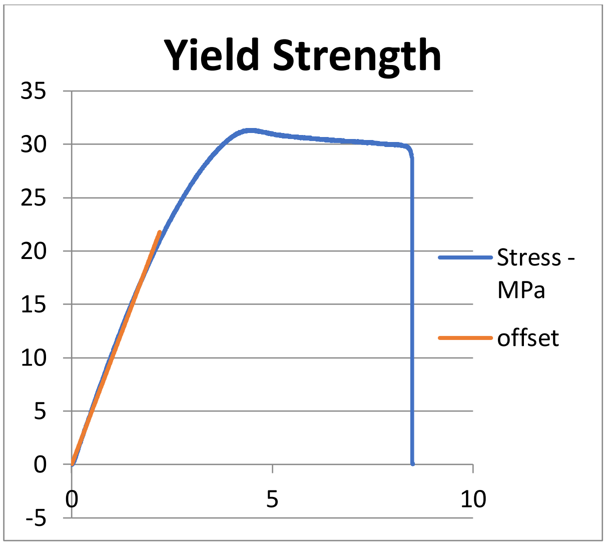
Graph4. 2 Stress-Strain Graph 60% line





Graph 4.3 Young modulus Graph 60%grid

Graph 4.4 Young modulus Graph 60%line



Graph 4.5 Yield Strength 60%grid

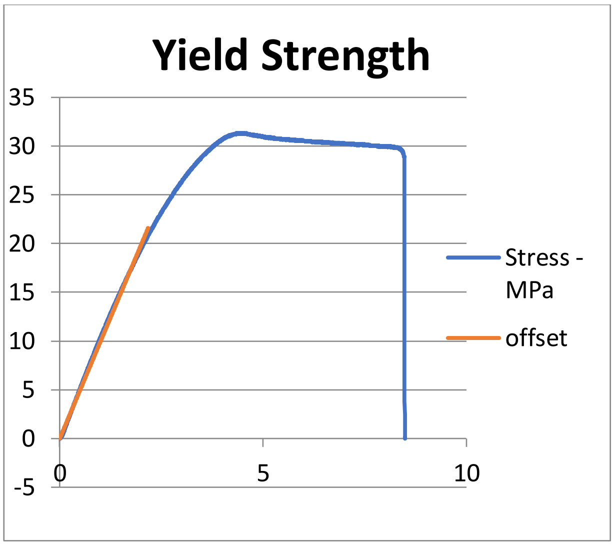
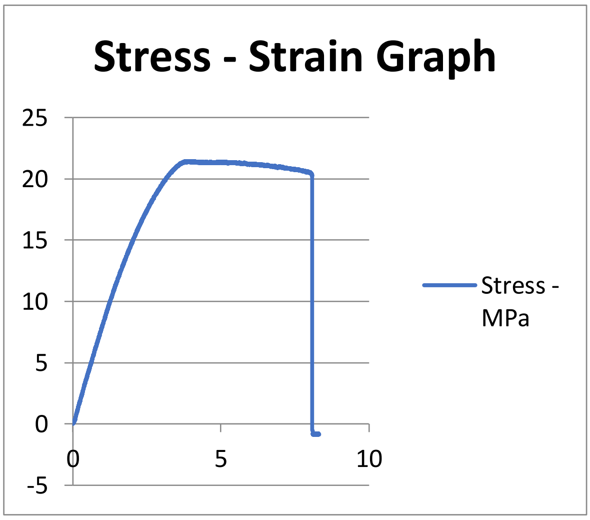


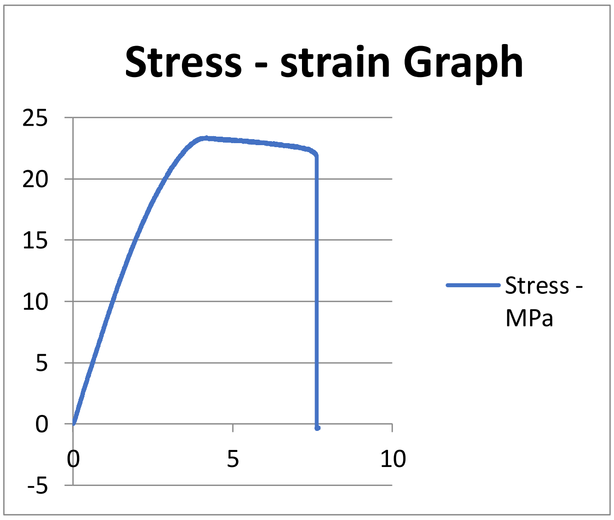
Table. 4.6 Yield Strength 60%line

4.3.3 75% Sample graphical data using both patterns

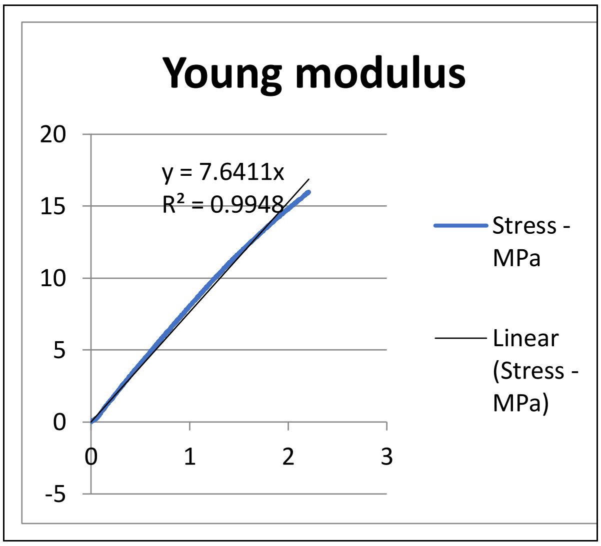
The **75%**of grid and line pattern sample graphical stress-strain graph shows the young modulus or yield strength.



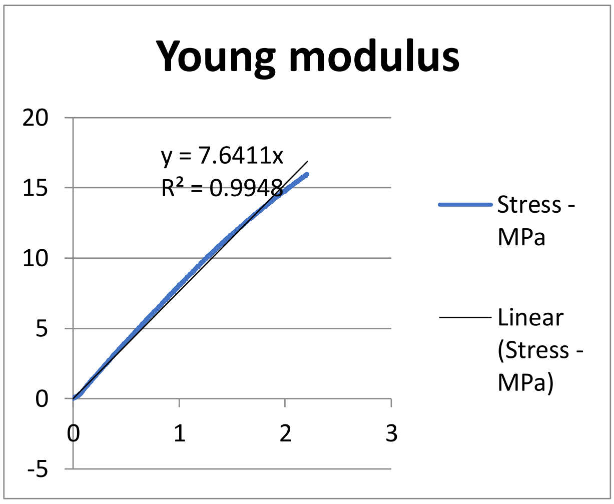
Graph 4.7 Stress-Strain Graph 75%grid



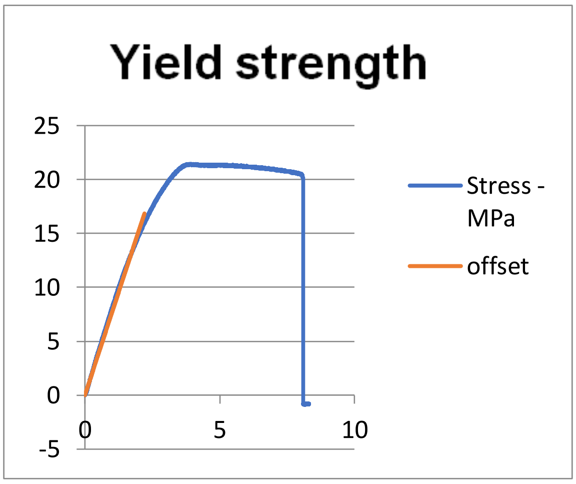
Graph 4.8 Stress-Strain Graph 75%line



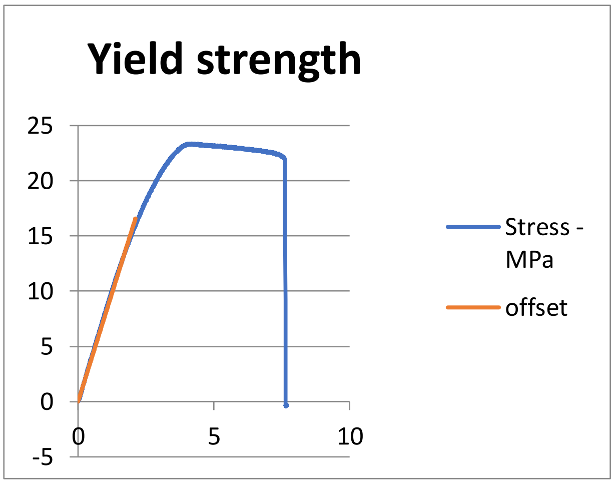
Graph 4.**9**Young modulus 75%grid



Graph 4.10Young modulus 75%line



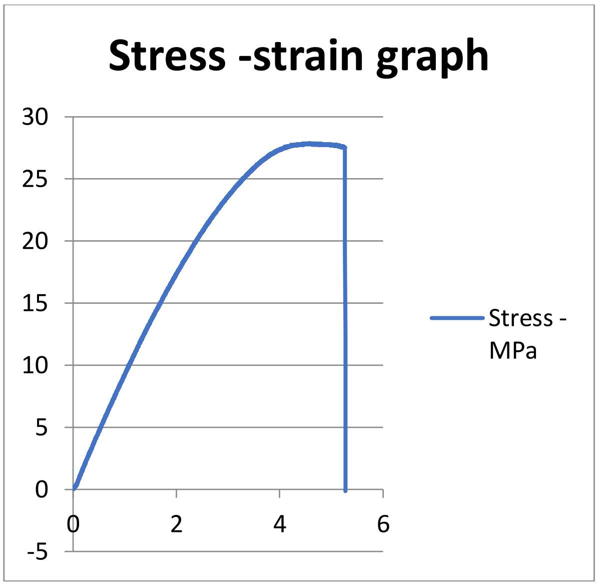
Graph 4.11 Yield Strength 75%grid



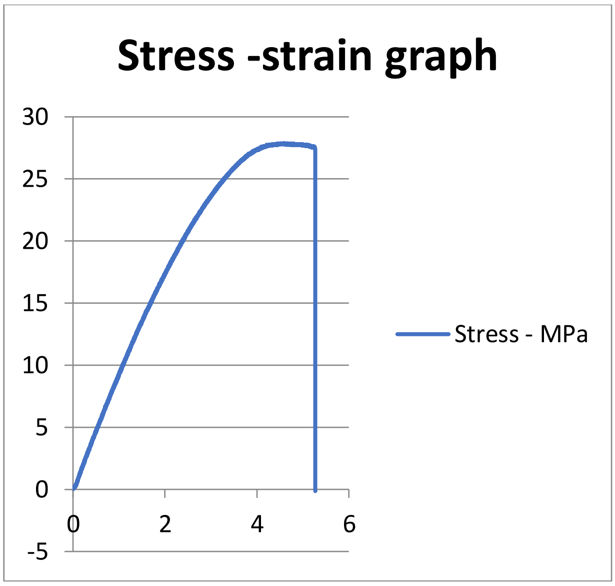
Graph 4.12 Yield StrengthGraph 75%line

4.3.4 80% Sample graphical data using both patterns

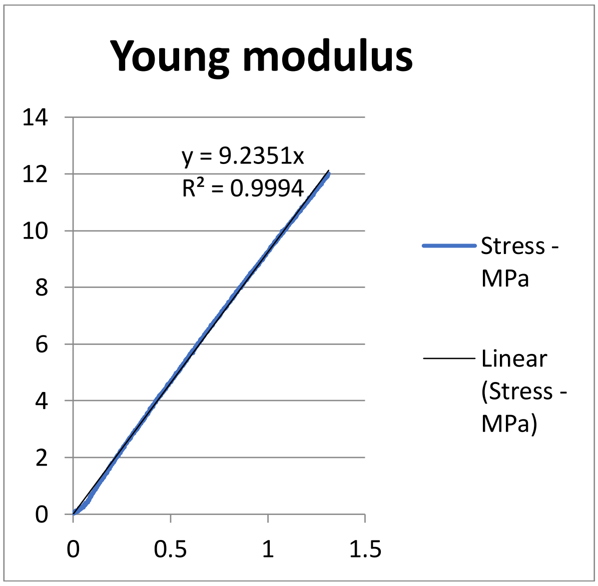
The **80%**of grid and line pattern sample shows the graphical stress-strain graph, young modulus, and yield strength.



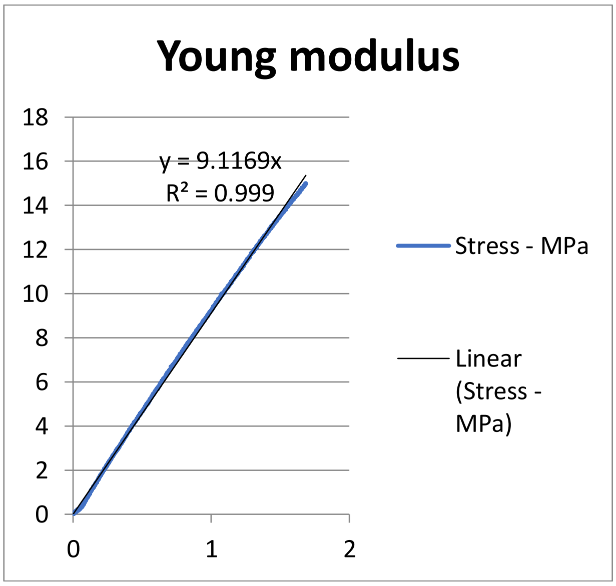
Graph 4.13 Stress-Strain Graph 80%grid



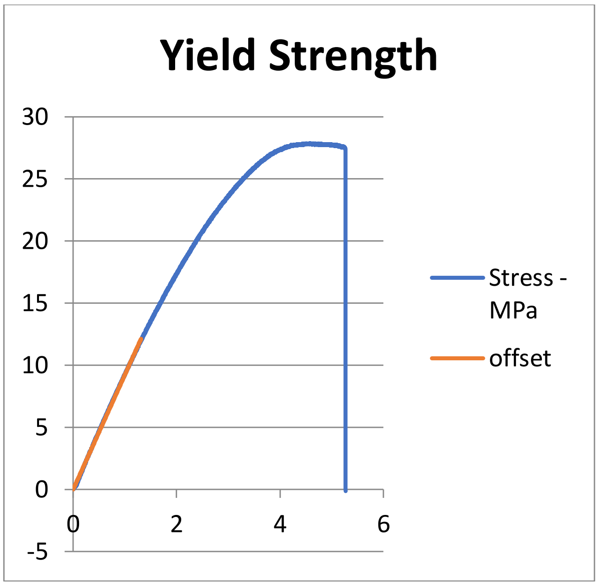
Graph 4.14 Stress-Strain Graph 80%line



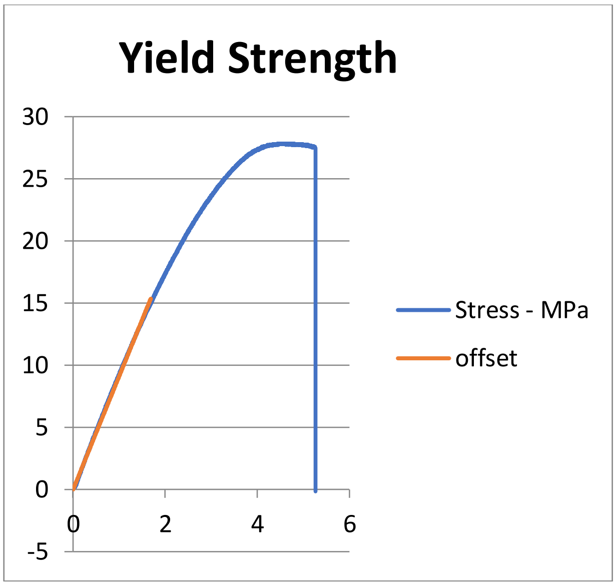
Graph 4.15Young modulus Graph 80%grid



Graph 4.16Young modulus Graph 80%line



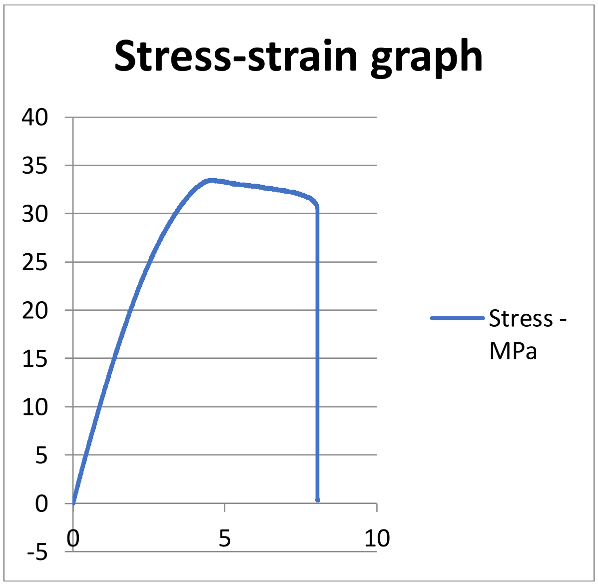
Graph 4.17Stress -Strain Graph 80%grid



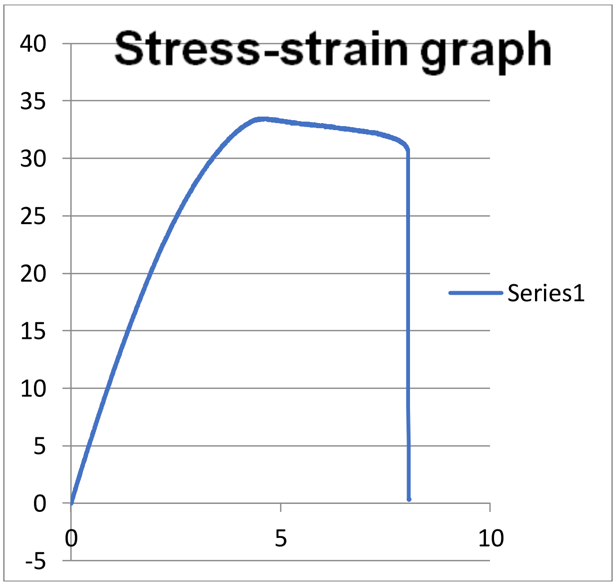
Graph 4.18Stress -Strain Graph 80%grid

4.3.5 95% Sample graphical data using both patterns

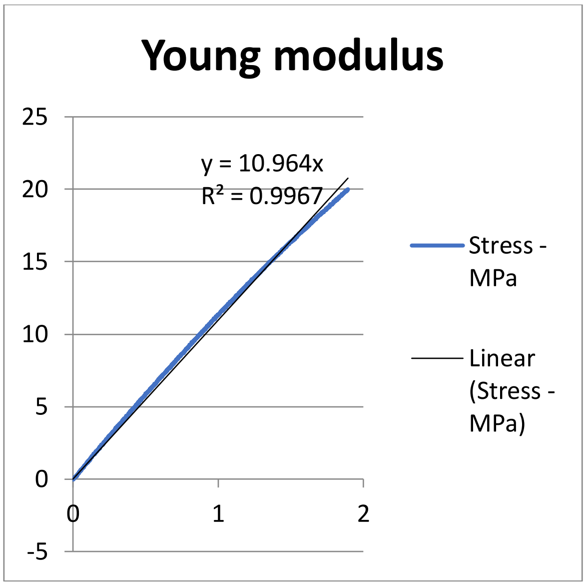
The **95%**of grid and line pattern sample graphical stress-strain graph depicts young modulus, and yield strength.



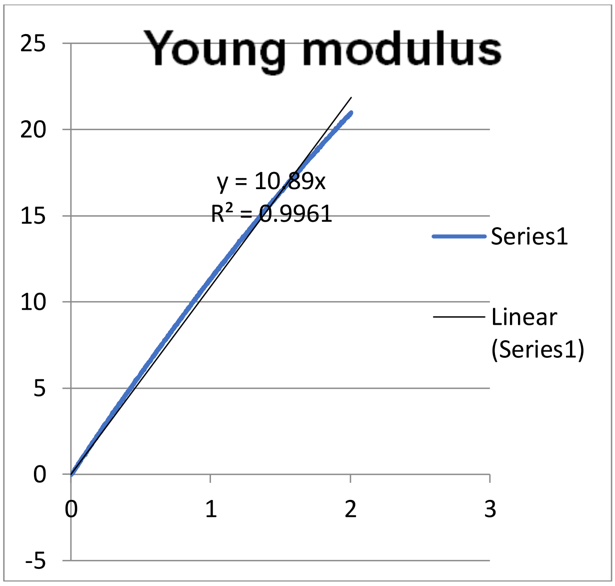
Graph 4.19 Stress-Strain Graph 95%grid



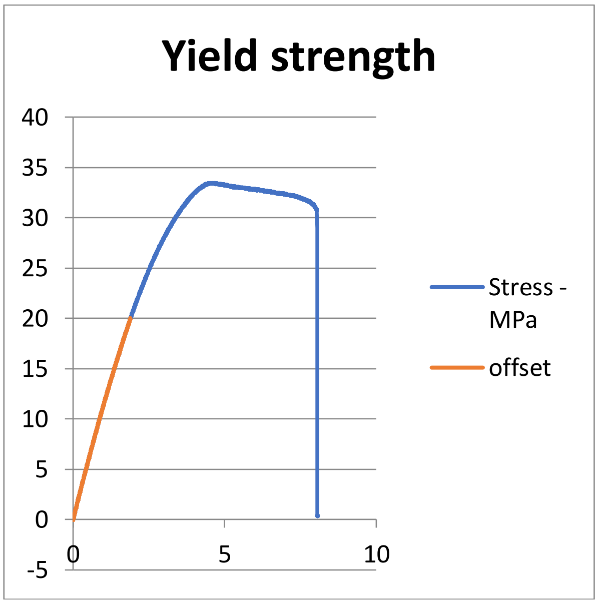
Graph 4.20 Stress-Strain Graph 95%grid



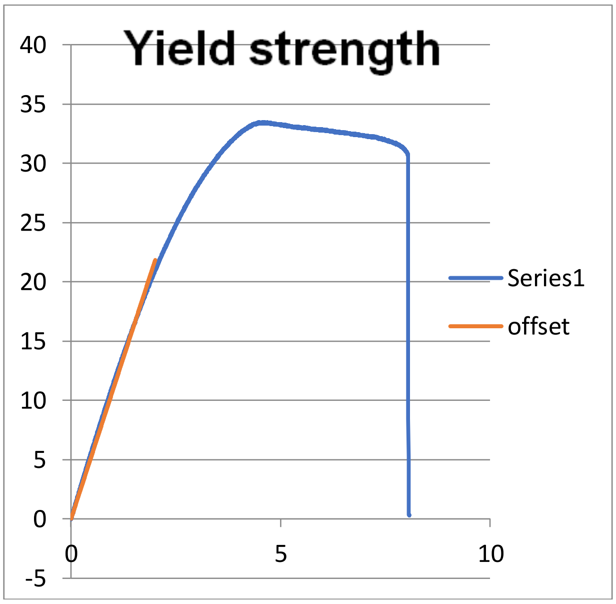
Graph 4.21 Young modulus 95%grid



Graph 4.22 Young modulusGraph 95%grid



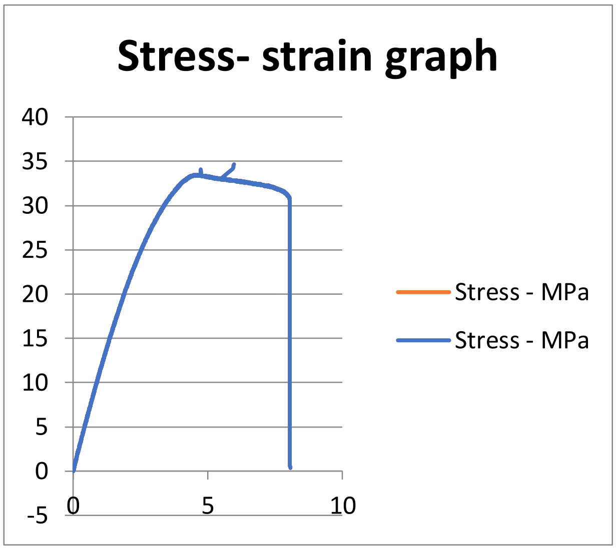
Graph 4.23 Yield Strength Graph 95%grid

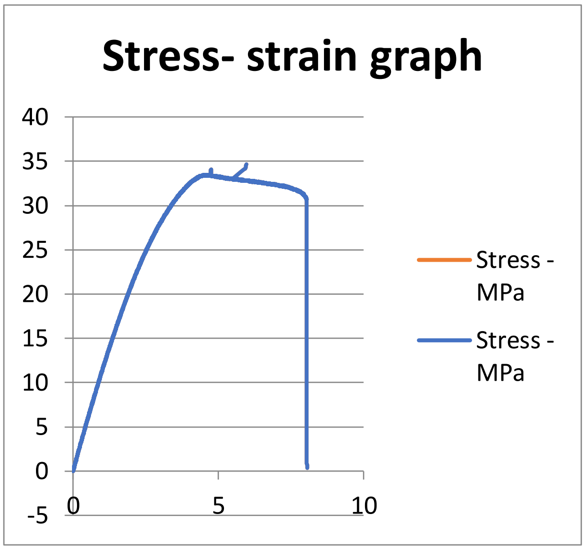


Graph 4.24 Yield Strength Graph 95%grid

4.3.6 100% Sample graphical data using both patterns

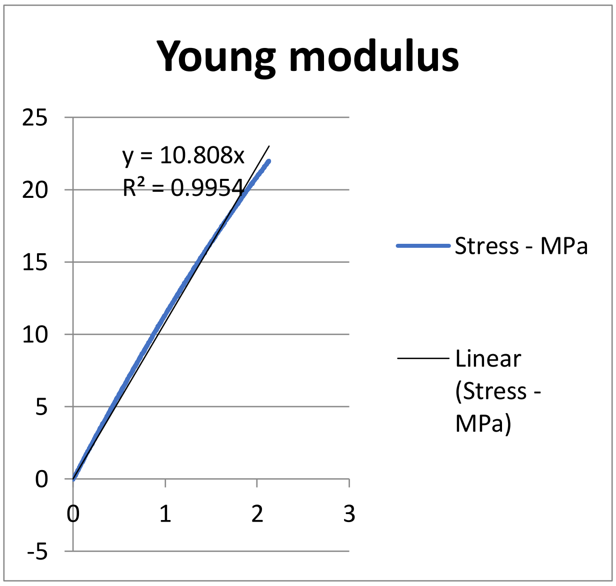
The**100%**of grid and line pattern sample graphical stress-strain graph demonstrate young modulus and yield strength.

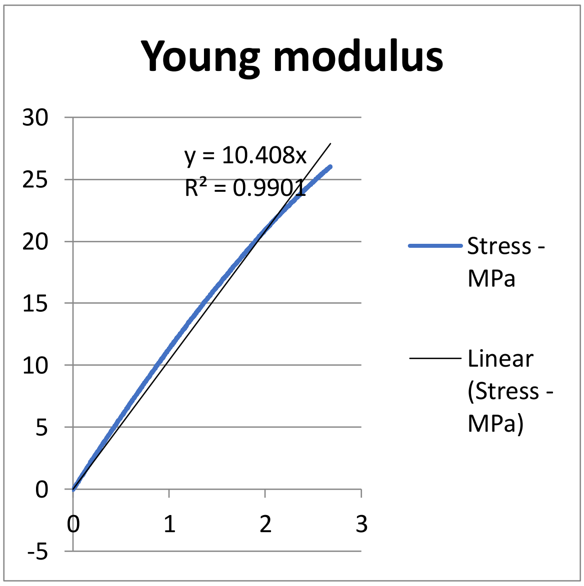




Graph 4.25 Stress-Strain Graph 100%grid

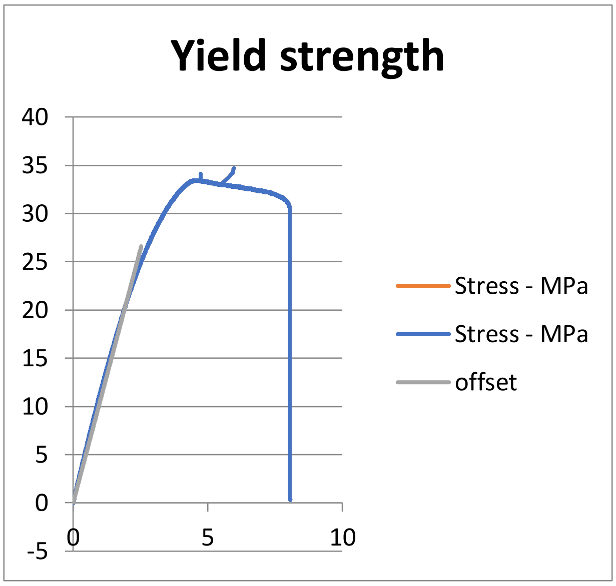
Graph 4.26 Stress-Strain Graph 100%line



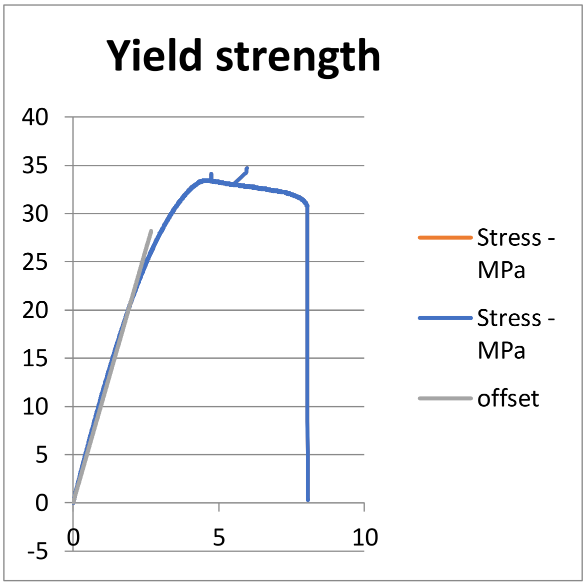


Graph 4.27 Young modulusGraph 100%grid

Graph 4.28 Young modulus Graph 100%line



Graph 4.29 Yield Strength Graph 100%grid



Graph 4.30 Yield Strength Graph 100%line

The above given all graphical illustrations shown in Table. (2- 31) as a Stress-Strain graph, young modulus, Yield Strength of every sample depends on infill density and each elect infill pattern severally (60%, 75%, 80%, 95%, 100%) exploitation line or grid pattern throughout printing.

Firstly, the hour sample shows the distinction between stress-strain graphical information of grid and line pattern, additional over its showing young modulus and yield strength additionally with facilitate of graphical thanks to ascertaining exploitation line linear mechanically to search out the worth of Y it represents the young modulus.

Moreover, 0.002 worth exploitation as an offset to search out the offset worth of stress and strain as a result of with the assistance of this we discover out the yield strength worth. On alternative the opposite hand other samples additionally same thanks to ascertaining the young modulus and yield strength and stress-strain graphical illustration distinction.

4.4 Stress-Strain

Stress and Strain square measure the 2 terms in Physics that describe the forces inflicting the deformation of the objects. Deformation is understood because the modification of the form of Associate in Nursing objects by applications of force. Little forces may cause deformation.

4.4.1 Young modulus

The elastic modulus (or Elastic Modulus) is in essence the stiffness of a fabric. In different words, it's however simply it's bent or stretched. ... The elastic modulus is the slope of the initial section of the curve (i.e., m in y = flux unit + b). Once a fabric reached precise stress, the fabric can begin to deform.

4.4.2 Yield Strength

The point at which the material transforms from elastic to plastic is known as the yield point. The magnitude of the stress at which the transition from elastic to plastic occurs is known as the yield strength. Yield strength is a constant that represents the maximum limit of elastic behavior.

4.5 Tensile Test Results

Tensile Test Results					
Test Speed	**1mm/sec**	sample %& pattern type	Young Modulus	Yield Strength	Maximum stress
Specimen Shape	**Rectangle**	60% Grid	993.1 Mpa	20.76Mpa	22.99Kgf
Thickness [mm]	**3**	60% Line	994.1 Mpa	20.96 Mpa	30 Kgf
Width [mm]	**13**	75% Grid	764.1MPA	15.95 Mpa	21.3Kgf
Gage Length [mm]	**51.055**	75% Line	785.4 Mpa	15.97 Mpa	23.024 Kgf
Area	**39**	80% Grid	911.6 Mpa	12.01 Mpa	27.851 Kgf
		80% Line	923.6 Mpa	15.013Mpa	27.86 Kgf
		95% Grid	108.9 Mpa	20 Mpa	32.99Kgf
		95% Line	109.6 Mpa	21 Mpa	33.42Kgf
		100% Grid	104 Mpa	25.37 Mpa	34.8Kgf
		100% Line	104.5 Mpa	26Mpa	34.1 Kgf

Table 4.2Tensile Test Results

Thus, all samples' results illustrate the increasing value of young modulus, Yield strength, and maximum stress value increase respectively because it directly depends on the value of infill density. If we increase the value of infill density thus young modulus, yield strength and maximum stress value also increase. The line pattern is good because it bears more stress rather than the grid pattern.

Firstly, infill density demonstrates the distinction between each pattern for grid and line as a result of it delineate worth for young modulus 993.1 MPA for grid pattern, on the opposite hand line pattern illustrates the worth of young modulus is 994.1 MPA its means that distinction worth is one MPA for sixty percent sample. is more it's conjointly showed the distinction worth for each pattern for seventy-fifth to 100% samples for young modulus, yield strength, or most stress worth for every sample for line or grid patterns.

For 100% PLA, the material yield strength value was 59 Mpa, but the maximum value was 34 Mpa when tested on 3D tensile specimens. This value is too different. The main reason is that 100% PLA manufactured by polymer process has a 100% polymer structure, but the 3D printed specimen of this study is converted into a wire form with a diameter of 1.75mm, and when the material is heated and melted, it is laminated and has a small porosity gap inside the actual product.

4.6 Five Sample tests for each infill density and infill pattern

Thus, its mean value is calculated ∑as n÷N which represents each sample added and divided by the total number of samples for each infill density and infill pattern.

After conducting five samples I get the mean value is 994.05Mpa for Young Modulus, 20.95 Mpa for Yield Strength, and 29.9 Mpa for Maximum Stress value.

Chapter 5

Conclusion and Future works

5.1 Conclusions

Conclusion: The tensile properties of 3D Printing of PLA material and its parameters such as infill density and infill pattern were measured by a tensile test experiment. In general, the results showed that increasing the infill density will increase the tensile properties for both infill patterns.

Moreover, the infill patterns affect the tensile properties. Line infill pattern incontestable the best tensile properties compared with the grid pattern. A comprehensive investigation of the result of the infill pattern on the tensile properties is usually recommended for future study.

Infill density demonstrates the difference between each pattern for grid and line as a result of its decline for young modulus 993.1 MPA for grid pattern, on the opposite hand line pattern illustrates the worth of young modulus is 994.1 MPA its means that distinction worth is 1MPA for sixty percent sample. It has more conjointly showed the distinction worth for each pattern for seventy-fifth to 100% samples for young modulus, yield strength, or most stress worth for every sample for line or grid patterns distinction.

5.2 Future Works

- Drinkable acid-based open-chain polyesters (PLAs) square measure documented biocompatible bioresorbable polymers that square measure being more and more used as biomaterials for temporary therapeutic applications. Attributable to their sensitivity to water and therefore the formation of degradation by-products that might be simply metabolized by microorganisms, these sorts of polymers conjointly have the potential to switch trade goods polymers in packaging or as mulch films. From an outline of synthesis routes, structural characteristics, and performances, a trial is created to gauge the long run of PLA polymers in so far as industrial development worries.
- The long-run or next-generation cradle-to-pellet PLA production system. This production system is predicted to be introduced in a very few years, reducing the environmental footprint of PLA via the implementation of recent method technology. To guard proprietary interests, additional details cannot be given at this point. As a result of the new technology, cradle-to-Pelle-dextro-glucose, lime, vitriol, steam, and gas intake is going to be reduced, and therefore

the production of co-products has very little worth eliminating. Inexperienced power is predicted to be wont to offer electricity within the Cargill/Nature Works controlled production processes. Within the PLA/NG production system, no RECs square measure purchased to fulfill the electricity needs in non-Cargill/Nature Works facilities.

- It also helps to make a flexible or reliable design because PLA physical and mechanical properties also affect to change the Fracture toughness value for tensile it's also depending on infill density and infill pattern-based to set firstly printed the components, with help of this experiment we know about the physical properties of PLA material using the tensile test on UTM machine.

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