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MECHANICAL PROPERTIES ASSESMENT OF PLA MIXED WOOD BY USING ADDITIVE MANUFACTURING

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1. ABSTRACT

A real object is produced using the additive manufacturing technique of three-dimensional (3D) printing from a digital design. Thin layers of material, such as liquid or powered plastic, metal, or cement, are first laid down, and then the layers are fused together. Recent years have seen a surge in interest in fused deposition modelling due to its revolutionary impact on the quick production of customized polymer-based composite parts. Understanding these printed components' fundamental mechanical characteristics is crucial to make engineering applications for them easier. In this project, the mechanical properties of samples made by fused deposition modelling with various additives, such as wood, ceramic, copper, aluminum, and carbon fibers based Polylactic acid composites, are thoroughly investigated. These properties include tensile, hardness, and impact properties. A thorough comparison and analysis is done of the impacts of various Polylactic composites, construction orientations, and raster angles on mechanical reactions.

In this work, we examine the mechanical characteristics of 3D-printed Wood mixed PLA filament, including tensile strength, impact strength, and hardness. The FDM process is used to create the specimen. In this project, an 8:2 blend ratio of PLA and the wood addition was chosen since it is thought to have mechanical properties that are successfully adjusted when compared to pure PLA. Types of printing pathways are created with the parameters of raster angles, infill density, and speed for each printing orientation.

1. INTRODUCTION

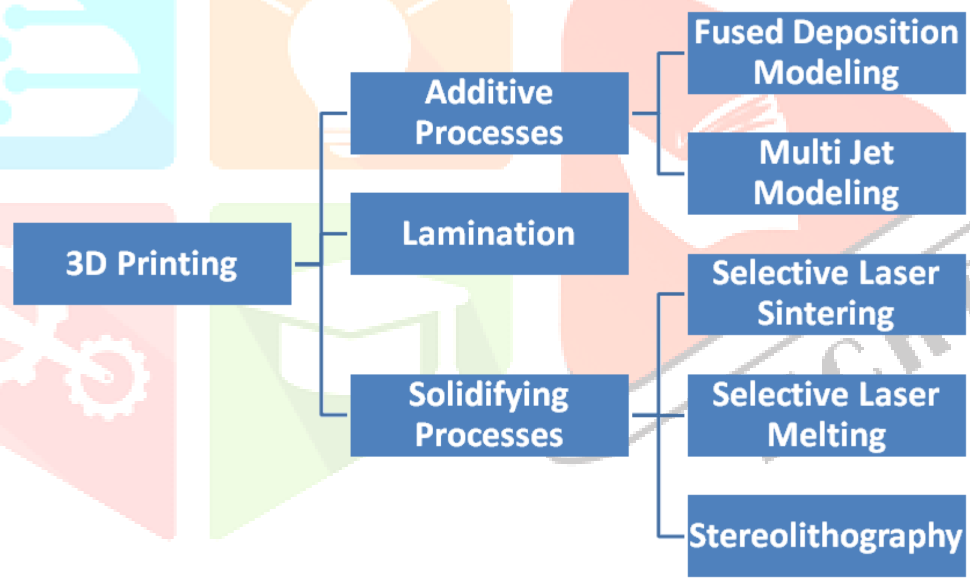
3D printing (3D) is one of the Rapid Prototyping (RP) techniques of products based on computer-aided 3D modeling. It also enables an initial and effective design process for successful and efficient end products. As a result, it comes to the forefront as a driving force in material savings in the production process. It has been suggested that 3DP technology can revolutionize manufacturing practices in many industries. 3DP has gained popularity in recent years as a result of its ability to reduce the amount of time and material used in the manufacturing process. RP, functional part production, and free form production are all production types that benefit from 3DP technology. FDM is the most commercialized 3DP or another name Rapid Prototyping technology currently. The FDM process, works on the premise of adding layer by layer plastic filament material.

Combining Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) technologies, items can be fabricated via Additive Manufacturing (AM) technology without traditional cutting techniques. AM also known as three-dimensional (3D) printing is a manufacturing process for fabrication of parts from a CAD model based on deposition of material layer by layer. For instance, 3D printing has exceedingly reduced fabrication cost and time with flexibility in printing complex geometries Utela et al... Indeed, the use of 3D printing provides the production of any kind of shape from a digital design with a little waste of raw materials Wimpenny et al. 3D printing has indicated advantages in fabrication of complex structures, multi-material structural elements, and thin-walled structures Amirpour et al, Yuan et al. Zhang et al. Currently, 3D printing technology has been widely used in different fields such as electronics Khosravani and Reinicke.

2. CLASSIFICATION OF 3D PRINTING METHODS

In order to satisfy the need for printing intricate models with high resolutions, methods of AM have been developed. Rapid Prototyping has played an important part in the advancement of AM technologies. AM Technologies are based on three main types which are sintering whereby the temperature of the material is raised without being liquefied to compose complex sharp resolution prototypes, melting- where electron beams are used to melt the powders and stereo lithography which uses a method referred to as photo polymerization, which uses an associate ultraviolet laser. This laser is dismissed over a photopolymer resin vat so that torque-resistant ceramic components are ready to encounter utmost temperatures.

As per ASTM (American Society for Testing and Materials), AM have been divided into seven processes which include VAT Photo polymerization, Material Jetting, Binder Jetting, Material Extrusion, Powder Bed Fusion, Sheet Lamination, and Direct Energy Deposition. Some of the main methods have been addressed in depth in the subsequent sections focusing on the work involved in each process, benefits and drawbacks, materials used in different processes, and applications of various 3D printing processes.



3. LITERATURE OF REVIEW

[1].Zhaaobing Liu,Qian Lei,Shuaiqi Xing., "Mechanical characteristics of wood, ceramics, metals and carbon fiber based pla composites fabricated by FDM" have studied Fused deposition modeling (FDM) has gained much attention in recent years, as it revolutionizes the rapid manufacturing of customized polymer-based composite components. To facilitate the engineering applications of these FDM-printed components, understanding their basic mechanical behaviors is necessary. In this paper, the mechanical characteristics, including tensile and flexural properties of samples fabricated by FDM with different additives, i.e. wood, ceramic, copper, aluminum and carbon fiber, based polylactic acid (PLA) composites are comprehensively investigated. The effects of different PLA composites, build orientations and raster angles on mechanical responses are compared and analyzed in detail. It is found that ceramic, copper and aluminum-based PLA composite parts have similar or even increased mechanical properties compared with virgin PLA made parts. In most cases, PLA composite

[2].Russo, P., Gianfreda, L., & Nazzaro, F, "Polylactic acid (PLA) biodegradable polymer: A review of recent developments and future perspectives" have investigated Poly lactic acid (PLA) is a biodegradable and compostable thermoplastic that has received increasing attention in recent years due to its sustainable properties and wide range of applications PLA is derived from renewable resources such as corn starch, sugarcane, and cassava roots, making it a desirable alternative to petroleum-based plastics. PLA has a number of desirable properties that make it a useful material for various applications. For example, it is transparent, rigid, and can be molded into a variety of shapes. Additionally, PLA has good thermal stability, high strength and stiffness, and is resistant to UV radiation. However, its properties can be affected by factors such as temperature, humidity, and moisture, which can cause degradation over time .PLA has a wide range of applications, including packaging, disposable tableware, 3D printing, and biomedical implants. In the packaging industry, PLA is used for producing trays, bottles, cups, and bags. PLA is also widely used in the foodservice industry, particularly for disposable cutlery, plates, and cups. In the medical field, PLA is used for producing surgical sutures, drug delivery systems, and tissue engineering scaffolds.

[3].Li, H., Zhang, Y., & Wang, L. (2020). "Polylactic acid-based composites" have studied, One of the major benefits of PLA is its biodegradability and composability. PLA can be broken down by microorganisms into carbon dioxide and water, and can also be composted into organic matter (Xu et al., 2020). However, there is debate over the environmental impact of PLA. While it is made from renewable resources and can biodegrade, the production of PLA requires a significant amount of energy and resources, and it can also contaminate recycling streams if not properly disposed of. Additionally, the breakdown of PLA may release methane, a potent greenhouse gas. In conclusion, PLA is a versatile and sustainable material with a wide range of applications. Its biodegradability and composability make it an attractive alternative to traditional plastics. However, the environmental impact of PLA is complex and requires careful consideration. Future research should focus on improving the efficiency of PLA production and disposal, and exploring new applications for this promising material.

[4].Scheffer, T. C., & Morrell, J. J., "Wood-based materials and processes for packaging applications" have studied, Wood is a natural, renewable, and versatile material that has been used for thousands of years in various applications. Wood has a unique combination of properties, including high strength-to-weight ratio, good insulation properties, and aesthetic appeal. Additionally, wood is a sustainable material, as it is derived from renewable sources and can be recycled or reused. Wood has a wide range of applications, including construction, furniture, paper, and packaging. In the construction industry, wood is used for structural purposes, such as framing, flooring, and roofing. In the furniture industry, wood is a popular material due to its natural beauty and durability. Wood is also used for producing paper and packaging materials, such as boxes, crates, and pallets.

[5].Rautkari, L., Hill, C. A. S., Curling, S., & Jalaludin, Z., "Wood modification technologies: A review. Construction and Building Materials" have studied, one of the major benefits of wood is its environmental sustainability. Wood is a renewable resource that can be harvested from sustainably managed forests, and it can be recycled or reused at the end of its life cycle. Additionally, wood products can store carbon, which can help to mitigate climate change. However, the environmental impact of wood can vary depending on the specific application and the production process .Wood has some limitations as a material, including susceptibility to moisture and temperature changes, and susceptibility to decay and insect damage. However, these limitations can be addressed through proper processing and treatment, such as drying, impregnation with preservatives, and thermal modification. In conclusion, wood is a versatile and sustainable material with a wide range of applications. Its natural beauty, durability, and environmental sustainability make it a popular choice for construction, furniture, paper, and packaging. However, careful consideration of the environmental impact and proper processing and treatment are necessary to ensure the optimal use of this valuable resource.

[6].Li, L., Xie, Y., Huang, X., Zeng, Q., & Zhou, D., "Recent progress on the properties and modification methods of wood", have investigated In addition to its mechanical properties, wood has a number of other unique characteristics that make it useful for a variety of applications. For example, wood has good thermal insulation properties, which make it an ideal material for windows and doors. Wood is also a good acoustic insulator and is used in flooring and wall panels to reduce noise transmission. Wood has a natural beauty and warmth that make it a popular choice for furniture and decorative items.

[7].Englund, K., Wolcott, M., & McNabb Jr, H. S., "The history and current status of wood plastic composites" have studied, the key advantages of wood-PLA composites is their improved mechanical properties over pure PLA, including increased stiffness, strength, and toughness. This is due to the reinforcement provided by the wood fibers or particles, which also improves the dimensional stability of the several studies have investigated the mechanical properties of wood-PLA composites. For example, Chen et al. (2019) found that adding 30% wood flour to PLA increased its tensile strength and modulus by 60% and 73%, respectively, compared to pure PLA. Similarly, a study by Jia et al. (2020) showed that adding 40% wood flour to PLA increased its tensile strength and modulus by 52% and 62%, respectively, compared to pure PLA.

4. DESCRIPTION OF EQUIPMENT

FUSED DEPOSITION MODELING (FDM)

FDM is a procedure that uses thermoplastic filament that has been parched to its melting point and then thrust out layer upon layer to form a 3D object. FDM technology was introduced by Scott Crump during the early Nineteen Nineties by Stratasys INC, USA introduced this. The 3D printers used for FDM contain a support base that is related to some degree of freedom and it has an arrangement such that it will move in a vertical direction. Aboard with the bottom plate, there's an associate extruder that connects the filament and is liable for heating of the filament up to its freezing point and so extrudes it layer by layer with the assistance of a nozzle to form the required object. The extruder has the supply to maneuver in all three directions (x, y and z). The reason that it's called fused deposition modeling is that the adjacent layers get consolidated to one another whereas deposition is completed by the extruder and therefore the 3D printer is liable for modeling of the item. Counting on the surface end needed, the ultimate product is dipped in resin as similar in the SL method.

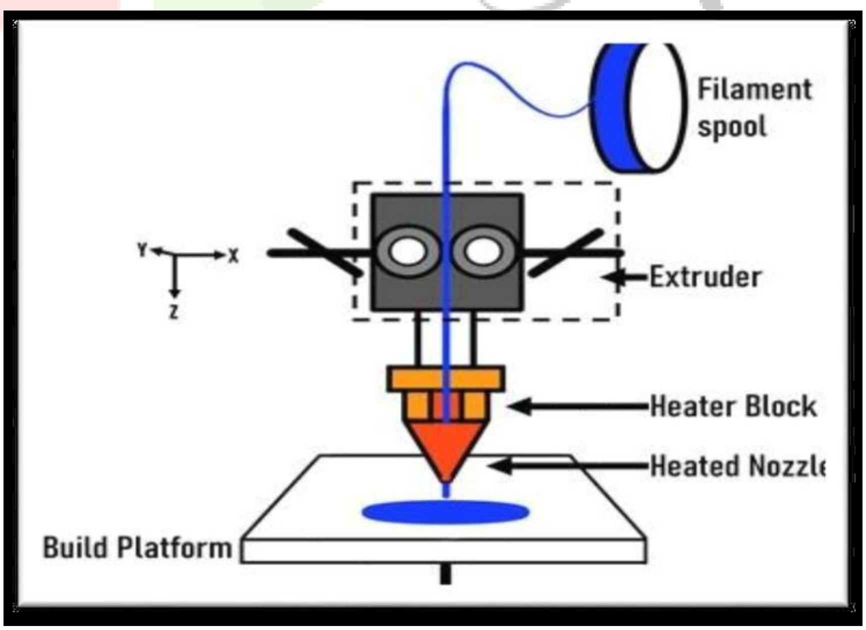


Figure Basic Diagram for FDM Process

FLASHFORGE 3D PRINTER

3D printing refers to transforming three-dimensional models into physical objects that you can hold and touch. It is also called additive manufacturing because the 3D model is created by "adding" layers upon layers of material until the object is fully formed. Fused Filament Fabrication (FFF) is the most common method of 3D printing. It is also the method that the Guider IIS uses. It works by melting plastic material called filament onto a print surface in high temperature. The filament solidifies after it cools down, which happens instantaneously after it is extruded from the nozzle. 3D objects are formed with the filament laying down in multiple layers.

Reference Flash forge 3D Printer

Name	Guider Ⅱ
Number of Extruder	1
Print Technology	Fused Filament Fabrication(FFF)
Screen Size	5.0'' color IPS Touch Screen
Build Volume	280*250*300mm
Layer Resolution	0.05 - 0.4mm
Build Accuracy	±0.2mm
Positioning Accuracy	Z axis 0.0025mm; XY axis 0.011mm
Filament Diameter	1.75mm（±0.07）
Nozzle Diameter	0.4mm
Print Speed	10~200 mm/s
Software	Flash Print Support Simplify 3D
Device Size	490*550*560mm
Net Weight	30Kg
AC Input	Input:100V-240VAC, 47-63Hz Power:500W
Connectivity	USB cable, USB stick, SD card
Camera	Inside the corner between front and right board

5. **Process 3D Printing Involves Three Steps:**

1) Make or download a 3D model

2) Slice and export the 3D model

3) Build the 3D model

1. Make A 3D Model:

Currently, there are three ways to creating a 3D model.

1. Designing From Scratch You can use free CAD (computer-aided design) software such as 3DTADA, AutoCAD, Solid Works, Pro-E, and our own software happy 3D to design your own 3D model.

2. 3D Scanners an alternative method to creating a 3D model is to scan an object. 3D scanners work by digitizing a physical object, collecting its geometric data, and saving it to a file on your PC. There are also apps that can turn a mobile device into a 3D scanner.

3. From the Cloud the most popular way of obtaining a 3D model is to download it from websites that allow users to upload 3D models that they designed.

2. Slice and Export the 3D Model:

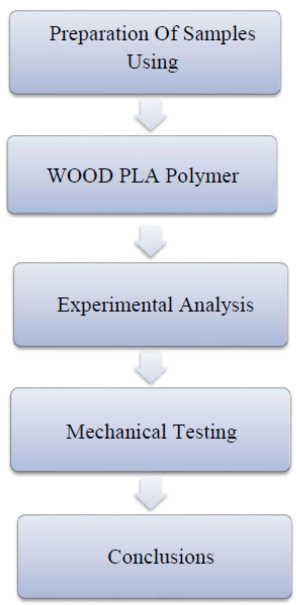
Slice software is the software that prepares 3D models for printing and turns them into instructions for the 3D printers. Flash Print is the slicing software used for the Flash Forge GuiderIIS. Using Flash Print, you can turn STL files into G code files for printing. Then the files can be transferred to your GuiderIIS via USB cable, USB stick, Wi-Fi, SD Card or Ethernet cable.

3. Build the 3D Model:

Once the output file has been transferred to your GuiderIIS, it will start to turn the 3D model into a physical object by laying down layers of filament.

6. METHODOLOGY

This section describes the methodology implement to carry out the proposed research to characterize the mechanical and the properties of 3D printed material using WOOD PLA polymer. It also includes material selection, printing of the parts, experimentation, characterization methods and assessment procedure. The mechanical and thermal behaviors of various filament materials were accounted for in this study. The detailed plan of the investigation is shown in Figure 4.1. Each stage in the scheme of investigation.



7. EXPERIMENTATION, PREPARATION AND CHARACTERIZATION

This chapter describes the general formulation of problem and selection of materials & systems for the present experimentation and characterization. It explains the methods used for the preparation of test sample specimen, experimental setup, experiment matrix and testing procedures of the mechanical behavior of 3D printed material.

NEED FOR THE RESEARCH

Past literature has shown that the PLA & Re-PLA test parts are produced by using layer thickness and occupancy rate. However, limited attempts have been made to study the mechanical behavior of a PLA polymer, Re-PLA polymer in the earlier investigation. This chapter the WOOD PLA polymer based test parts by using different layer thickness, Infill Density, Raster Angle and different printing speeds. The most influencing parameters of mechanical behavior are identified, and the relations about the mechanical properties have been discussed in this chapter. The various characterizations and experimental techniques are discussed in this section.

MATERIALS AND PREPARATION METHODS

Based on the literature survey, the material used for the present research were finalized as WOOD PLA polymer and their properties are given in Tables 5.1 respectively. The WOOD PLA polymer material as in the form of filament has the diameter of 1.75mm, and weight of the material is 1 kg. WOOD PLA material is purchased from Coimbatore,

Ultimate strength	44 - 46 Mpa
Stiffness	8/10
Durability	3/10
Maximum Service Temperature	52℃
Coefficient Of Thermal Expansion	30.5 µm/m℃
Density	1.15- 1.25 cm^3
Price	1500 – 2500 per Kg
Printability	8/10
Extruder Temperature	190 – 210℃
Bed Temperature	45 - 60℃

PREPARATION

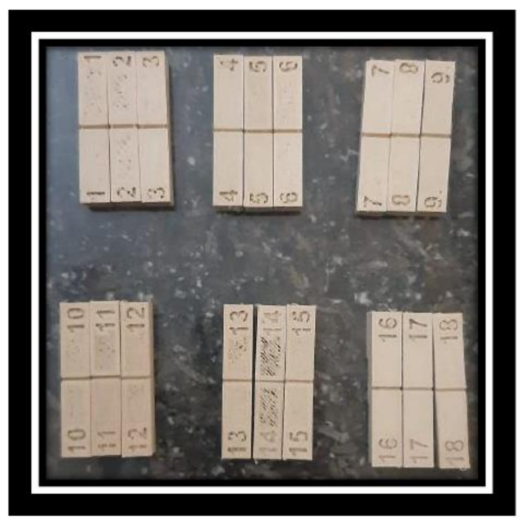
First create the test parts using solid works Computer Aided Design (CAD) program and then it is converted to G-code using the simply 3D slicer program. The important design features, such as dimensions, colour, material type, are included in the files. The slicer program used in the 3D printer is Flash print. Using Flash Print, you can turn .STL files into .G-code files for printing. Then the files can be transferred to your Guider IIS via USB cable, USB stick, Wi-Fi or Ethernet cable.

Tensile test parts in accordance with ASTM D638 standards, Charpy impact test parts in accordance with ASTM D256 standards, and Hardness test parts in accordance with same standards of ASTM E18 were used to test the WOOD PLA filament. Thus properties of follow are

1. Layer Thinness
2. Infill Density
3. Raster Angle
4. Printing Speed

Respective Production Table for Testing Parameter

SPECIMEN NO	LAYAR THICNESS (mm)	INFILL DENSITY (%)	RASTER ANGLE	SPEED (mm/min)
1	0.15	20	0°	60
2		20	45°	70
3		20	90°	80
4	0.15	40	0°	60
5		40	45°	70
6		40	90°	80
7	0.15	60	0°	60
8		60	45°	70
9		60	90°	80
10	0.25	20	0°	60
11		20	45°	70
12		20	90°	80
13	0.25	40	0°	60
14		40	45°	70
15		40	90°	80
16	0.25	60	0°	60
17		60	45°	70
18		60	90°	80



Tensile Specimen

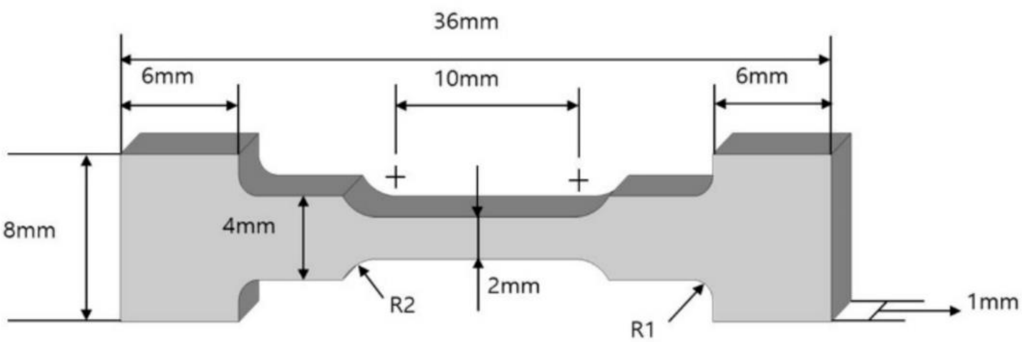
Impact Specimen

Hardness Specimen

8. MECHANICAL PROPERTIES TEST

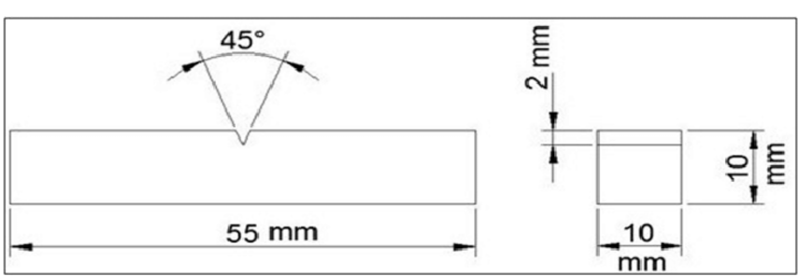
Tensile Test

Tensile test specimen as per the ASTM standard (ASTM D638) were made in dog bone shape and tested in a KMI servo controlled Universal Testing Machine(UTM)(UNITEK 94100-200kN, JAPAN laboratory private Ltd, Chennai) with a crosshead speed of 0.5 mm/min at room temperature. As per the ASTM standard, the filament samples were printed to get the tensile specimens with required dimensions as shown Figure



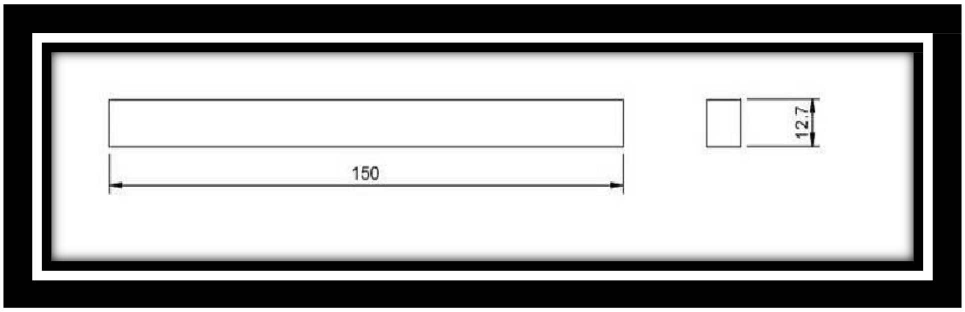
Impact Test

The impact test specimens as per the ASTM standards (D 256) were made in a rectangular V-notch shape and tested in a FIE manual controlled Charpy testing machine (IT 30 STD – 300 J, FIE Pvt Ltd, yadrav) with a crosshead speed of 5.34 mm/s at room temperature. As per the ASTM standard, the filament samples were printed to get the impact specimens with required dimensions shown in Figure



Hardness Test

The Rockwell hardness tester utilizes either a steel ball or a conical diamond known as a brale and indicates hardness by determining the depth of penetration of the indenter under a known load. The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test measures the depth of penetration of an indenter under a large load (major load) compared to the penetration made by a preload (minor load).



9. RESULTS AND DISCUSSION

The values of mechanical properties of the WOOD PLA filament parts obtained through the experimentation are summarized in Table.

S.No	Layer Thickness (mm)	Infill Density (%)	Tensile Strength (Mpa)	Average value (Mpa)	Elongation %	Average Value %
1	0.15	**20**	**20.43**	**12.73**	**8.6**	**4.5**
		20	**9.36**		**2.6**	
		20	**8.41**		**2.3**	
2	0.15	**40**	**9.10**	9.4	**1.8**	2
		40	**12.84**		**2.5**	
		40	**6.26**		**1.7**	
3	0.15	**60**	**10.48**	**16.4**	**4.12**	2.6
		60	**22.69**		**2.4**	
		60	**16.04**		**1.5**	
4	0.25	**20**	**5.14**	**7.6**	**2.4**	**1.6**
		20	**10.95**		**1.5**	
		20	**6.86**		**1.40**	
		40	**7**		**1.56**	
		40	**7.66**		**3.3**	

5	0.25	**40**	**11.35**	8.6	**1.12**	1.9
6	0.25	**60**	**11.29**	10.1	**3.68**	4.4
		60	**9.59**		**3.1**	
		60	**9.49**		**6.62**	

Tensile strength of the proposed WOOD PLA filament for different specimens

S.No	Layer Thickness (mm)	INFILL DENSITY (%)	IMPACT ENERGY (J)	IMPACT AVERAGE (J)	IMPACT STRENTH (J/mm2)
1	0.15	20	100	100	9.09
		20	102		
		20	100		
2	0.15	40	130	133.33	11.93
		40	128		
		40	136		
3	0.15	60	156	157.33	14.3
		60	158		
		60	158		
4	0.25	20	156	157.33	14.3
		20	158		
		20	156		
5	0.25	40	152	152.66	13.87
		40	154		
		40	152		
6	0.25	60	148	144	13.69
		60	142		
		60	142		

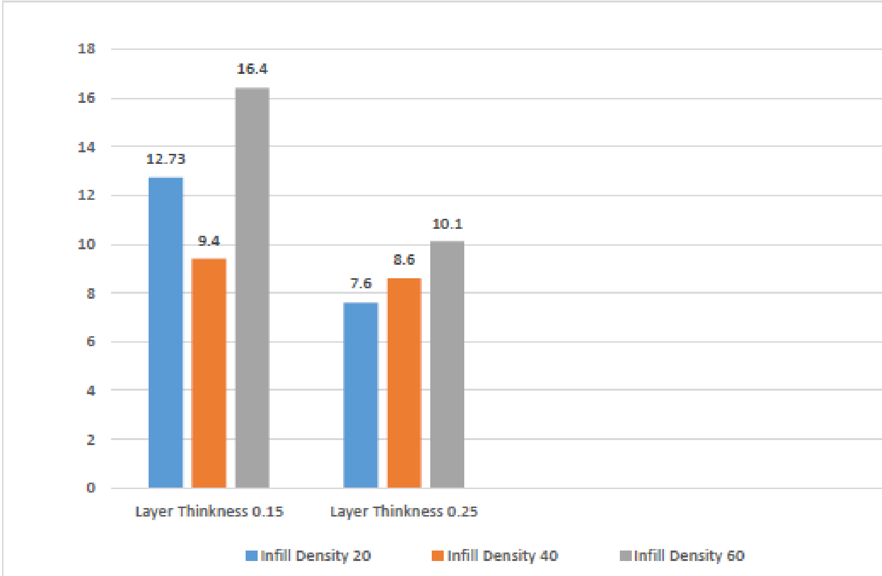
Impact strength of the proposed WOOD PLA filament for specimens

S.No	Layer Thickness (mm)	INFILL DENSITY (%)	HARDNESS TEST	HARDNESS TEST AVERAGE
1	0.15	20	80	**82.86**
		20	81	
		20	87	
2	0.15	40	80	**81.6**
		40	81	
		40	84	
3	0.15	60	81	**82.3**
		60	80	
		60	86	
4	0.25	20	90	**86.3**
		20	86	
		20	83	
5	0.25	40	81	**86**
		40	80	
		40	97	
6	0.25	60	97	**96**
		60	97	
		60	94	

Hardness of the proposed WOOD PLA filament for specimens

TENSILE STRENGTH

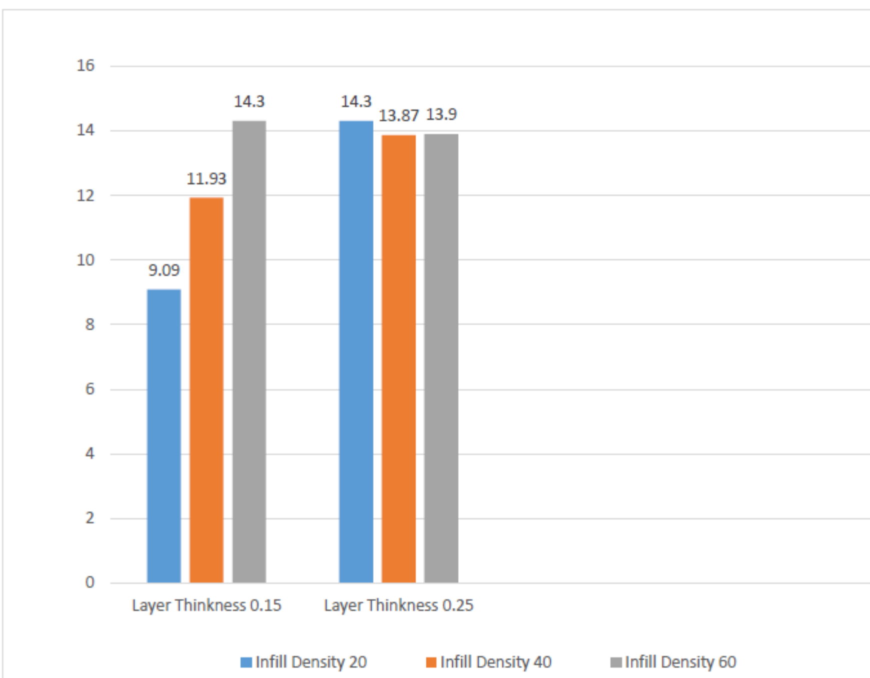
The ultimate tensile strength of a 3D printed material depends on the variations of the filled methods, which shown figure6.1.a. The values of the ultimate tensile strength for specimens 1, 2, 3, 4, 5 and 6 shown in table 3 indicate that there is a remarkable increase in the ultimate tensile strength in specimen 3 and specimen 6 when compared to the starting material. The lowest improvement in strength for specimen 4 may be attribute reason of an insufficient bond between the layer thickness and the Infill Density of the 3D printer to that of the other five specimens.



Graph for Tensile Strength

IMPACT STRENGTH

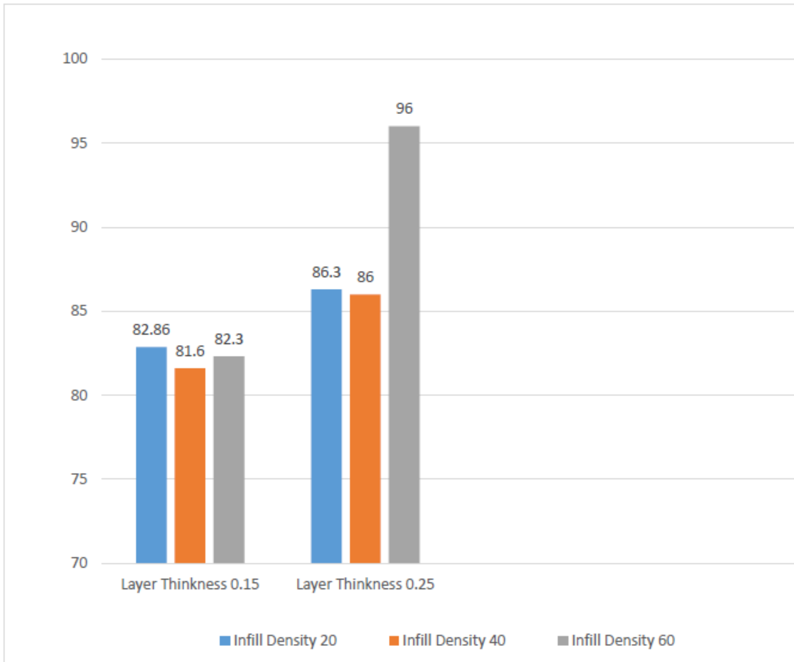
The impact strength of a 3D printed material depends on the variations of the layer thickness and Infill Density, which shown Figure. The values of the impact strength for specimens 1, 2, 3, 4, 5 and 6 shown in table 3 indicate that there is slightly changes occur in the specimens. The specimen 3 and the specimen 4 are have a similar impact strength in the high impact strength and the lowest impact strength is occur at specimen 1.



Graph for Impact Strength

HARDNESS

The hardness of a 3D printed material depends on the variations of layer thickness and Infill Density of the printer, which shown in Figure6.1.d. The values of the hardness for the specimens 1, 2, 3, 4, 5 and 6 shown in table 3 indicate that there is a remarkable increase in the hardness in specimen 2, specimen 3 and specimen 4 when compared to the specimen 1. The hardness decreased in specimen 4 slightly small, but the hardness increased in specimen 4. So, the specimen 6 is the highest hardness of the 3D printed material to given specification of the production.



Graph for Hardness Strength

10. CONCLUSION

In this study, WOOD PLA filaments and FDM from additive manufacturing techniques were used. Test parts of different production parameters; produced using layer thickness, Infill Density, Raster Angle and printing speed. The produced test parts were subjected to tensile, charpy impact and hardness tests. The mechanical properties obtained as a result of the test were examined experimentally and statistically. A part from that, since the properties of the filament cannot be measured in detail, it is not possible to determine the individual contribution of varied factors due to the material properties.

1. The maximum Tensile strength 16.4 Mpa is obtained from the layer thickness 0.15 mm and Infill Density 60%.

2. The maximum Impact strength 14.3 J/mm2 is obtained from the layer thickness 0.15 mm and Infill Density 60%, the layer thickness 0.25 mm and Infill Density 20% in same Impact value.

3. The maximum Hardness 96 is obtained from the layer thickness 0.25 mm and Infill Density 60%.

In this work, a study was carried out to observe the mechanical properties of the proposed 3D printed material with a c change the layer thickness, Infill Density, Raster Angle and printing speed of the materials. The present work may be extended to study the variation of mechanical properties by keeping the change the layer thickness, Infill density, Raster Angle and printing speed, also change the width of the specimen other than fly.

11. REFERENCE

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