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Mechanical Properties and Assessment of PLA Mixed with Carbon by Using Additive Manufacturing

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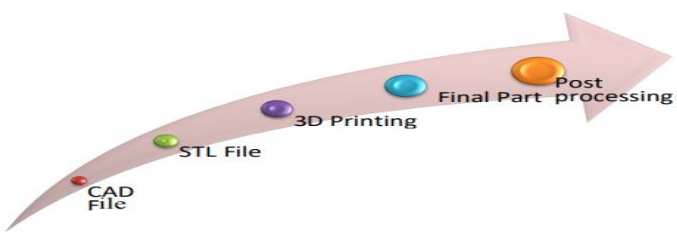
Abstract: Three-dimensional (3D) printing is an additive manufacturing process that creates a physical object from a digital design. The process works by laying down thin layers of material in the form of liquid or powered plastic, metal or cement, and then fusing the layers together. Fused deposition modelling 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 fused deposition modelling printed components, understanding their basic mechanical behaviours is necessary. In this project, the mechanical characteristics, including tensile, hardness and impact properties of samples fabricated by fused deposition modelling with different additives, i.e. wood, ceramic, copper, aluminium and carbon fibres, based polylactic acid composites are comprehensively investigated. The effects of different polylactic composites, build orientations and raster angles on mechanical responses are compared and analysed in detail. In this study, We investigate the mechanical properties such as Tensile strength, Impact strength, and Hardness of three dimensional (3D) Carbon mixed with PLA (polylactic acid) filament. The specimen are made using FDM method. The blend ratio of PLA and the carbon additive is chosen as 8:2 in this Project, which is believed to have the effectively modified mechanical properties compared to the pure PLA. For each printing orientation, two kinds of printing paths are designed with parameter of raster angles , Infill Density , Speed .
Keywords: PLA, PLA mixed CARBON, FDM, Blend Ratio

I. INTRODUCTION

3D printing (3D) is one of the rapid prototyping (RP) techniques of products based on computer-aided 3D modelling. 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. 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. 3D printing has indicated advantages in fabrication of complex structures, multi-material structural elements, and thin-walled structures. Currently, 3D printing technology has been widely used in different fields such as electronic, construction industry.

Flow Chart



II. 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 polymerisation, 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.

III. LITERATURE REVIEW

[1].Dong et al., 2021; Huang et al., 2019; Zhang et al., 2020.,"Material properties and investigate potential applications in various industries" have studied, Carbon mixed with PLA is a composite material that combines the renewable and biodegradable properties of PLA with the mechanical properties of carbon fibers. A study conducted by Dong et al investigated the mechanical properties of carbon/PLA composites using tensile testing. The results showed that the addition of carbon fibers significantly improved the tensile strength and Young's modulus of the composites. Another study by focused on the effect of carbon nanotube (CNT) loading on the mechanical and thermal properties of carbon/PLA composites. The researchers found that the addition of CNTs significantly enhanced the mechanical and thermal properties of the composites, including tensile strength, Young's modulus, and thermal conductivity. In a recent study by the researchers investigated the effect of carbon nanofiber (CNF) loading on the mechanical and electrical properties of carbon/PLA composites. The results showed that the addition of CNFs significantly enhanced the mechanical and electrical properties of the composites, including tensile strength, Young's modulus, and electrical conductivity.

[2].Pramanik et al. 2019.,Wang et al. 2021 "The literature suggests that PLA carbon fiber composites have great potential for a range of applications due to their improved mechanical and thermal properties" have studied, In a study by the researchers investigated the effect of carbon fiber loading on the biodegradability of PLA-based composites. The results showed that the addition of carbon fibers had no significant effect on the biodegradability of the composites, suggesting that they could be suitable for environmentally-friendly applications. A recent study by investigated the effect of carbon fiber loading on the mechanical properties of 3D-printed PLA-based composites. The researchers 5 found that the addition of carbon fibers improved the tensile strength, flexural strength, and impact strength of the composites, with a maximum increase of 58%, 98%, and 118%, respectively.

[3].Salmah et al. 2021., Kim et al. 2020 "PLA carbon fiber composites are a promising material for a range of applications due to their improved mechanical properties and biodegradability" have studied, In a study by the researchers investigated the effect of carbon fiber loading on the mechanical properties of PLA-based composites. The results showed that the addition of carbon fibers significantly improved the tensile strength and stiffness of the composites, with a maximum increase of 47.5% and 36.6%, respectively. Another study by Kim et al. investigated the effect of surface treatment on the adhesion between carbon fibers and PLA matrix. The results showed that surface treatment significantly improved the adhesion strength between the carbon fibers and PLA matrix, resulting in improved mechanical properties of the composites.

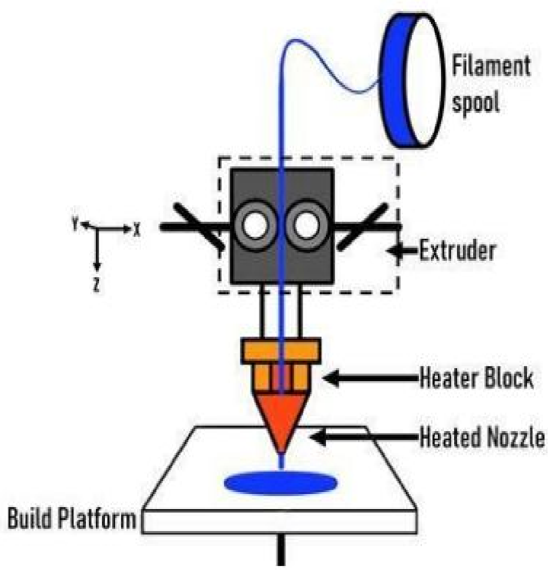
[4].Mohammad Reza Khosravani*, Tamara Reinicke "Farcture Studies Of 3D Printed carbo PLA Composite" have studied, Additive manufacturing (AM) has shown extraordinary growth over the past few years. In this three-dimensional (3D) printing, the final products are made by adding material layer upon-layer. Although mechanical behaviour of 3D-printed Polylactic Acid (PLA) parts have been investigated in several research works, there are a few studies on the mechanical characterization of 3Dprinted PLA-carbon composites. In the present study, fracture behaviour of intact and defected PLA carbon composite specimens were investigated. To this aim, carbon-reinforced PLA material was used to print test coupons. It should be pointed out that the missing extradites were considered as an intentional defect in the defected specimens. In this study, both groups of intact and defected composite specimens were printed with different raster directions. Based on a series of tensile tests, fracture load and stiffness of the examined parts were determined. Moreover, effects of raster orientations on the fracture behaviour of the intact and defected parts were investigated. In this study, the obtained results of tests on intact and defected specimens were compared. This comparison indicated impacts of the defects on the fracture behaviour of additively manufactured composite.

[5].Vigneshwaran, M., Venkatachalam, G, Murugan, R, Karthikeyan, K "Mechanical and thermal properties of polylactic acid/carbon flour composites." have studied, One study found that the tensile strength of carbon PLA composites increased with increasing carbon content, up to a certain point, after which the strength began to decrease. Another study found that the addition of carbon particles to PLA increased the modulus of elasticity and flexural strength, while also decreasing the impact strength of the composite. A third study investigated the effect of different carbon particle sizes on the mechanical properties of carbon PLA composites and found that smaller carbon particles resulted in composites with higher strength and stiffness. Overall, the mechanical properties of carbon PLA composites show promise for a range of applications, particularly in the development of biodegradable and sustainable materials. However, further research is needed to optimize the manufacturing process and to investigate the long-term durability and performance of these materials.

[6].Mishra, S., Misra, M., & Tripathy, S.S "Carbon–plastic composites as promising green-composites for automotive industries." have studied, In addition to improving the mechanical properties of PLA, carbon-PLA composites also have the potential to reduce the environmental impact of traditional polymerbased composites. The use of carbon as a reinforcement reduces the amount of polymer required, and the use of biodegradable PLA as the matrix reduces the amount of non-biodegradable plastic waste. In conclusion, carbon-PLA composites have improved mechanical properties compared to pure PLA, making them a promising material for a variety of applications. The use of renewable and biodegradable materials also makes them an attractive alternative to traditional polymer-based composites.

IV. 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 modelling 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 modelling of the item. Counting on the surface end needed, the ultimate product is dipped in resin as similar in the SL method.



A. 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 behaviour of 3D printed material.

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B. 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 behaviour of a PLA polymer, Re-PLA polymer in the earlier investigation. This chapter the carbon PLA polymer based test parts by using different layer thickness and different printing speeds. The most influencing parameters of mechanical behaviour 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.

C. Materials And Preparation Methods

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

SPECIFICATION AND PROPERTIES OF CARBON PLA POLYMER

Ultimate strength	658 - 3448 Mpa
Stiffness	8/10
Durability	5/10
Maximum Service Temperature	52°C
Coefficient Of Thermal Expansion	30.5 µm/m°C
Density	1.15- 1.25 cm^3
Price	2000 – 3000 per Kg
Printability	9/10
Extruder Temperature	190 – 210°C
Bed Temperature	45 - 60°C

1) 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.

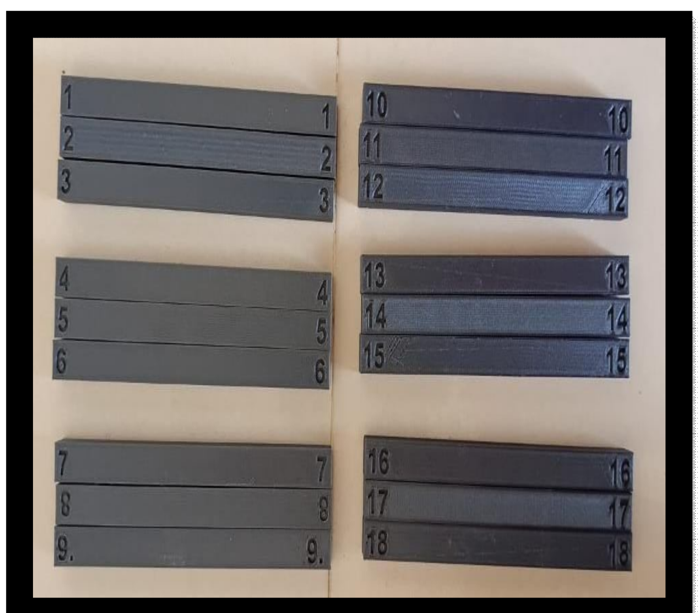
Tensile test parts in accordance with ASTM D638 standards, Charpy impact test parts in accordance with ASTM D256 standards, and Hardness test parts in accordance with same standards of ASTM D256 were used to test the ABS filament. The Flash forge Guide IIS was chosen since it is one of the most suitable and high quality devices for individual usage on the market in terms of price/performance. The accurate alignment of the 3D printer's elements during setup is a crucial requirement for high – quality 3DP Therefore, component prints were completed following minor upgrades and calibration operations to ensure long-term print quality.

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

Respective Production Table for Test Parts

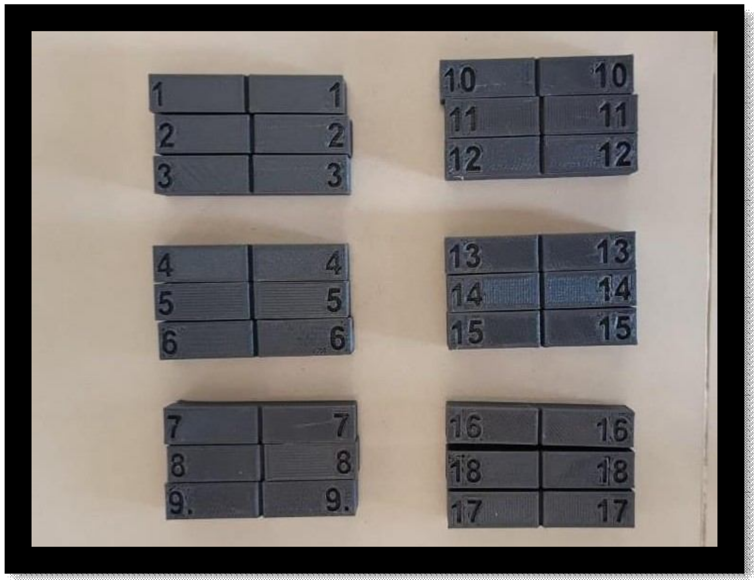
Impact Test Specimen

TENSILE SPECIMEN



HARDNESS SPECIMEN

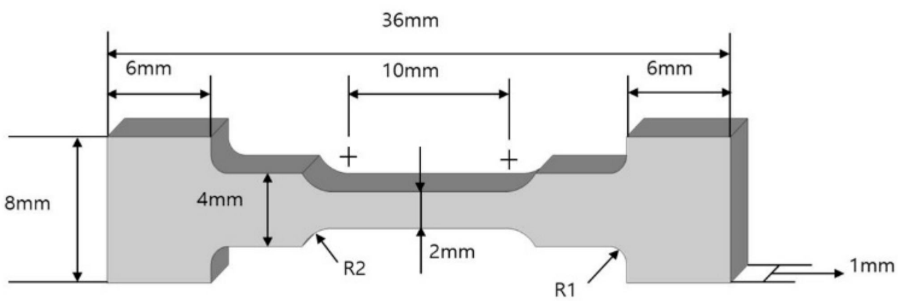
Impact Test Specimen



D. Mechanical Properties Test

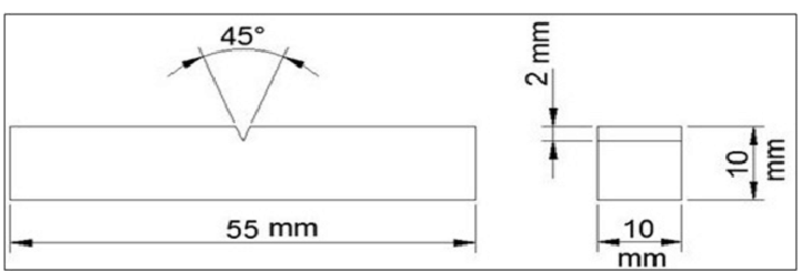
1) Tensile Test

Tensile test specimen as per the ASTM standard (D 638) 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



2) 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



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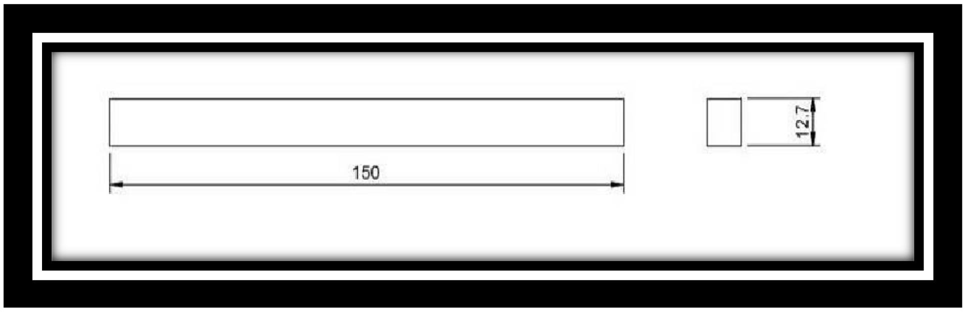
3) Hardness Test

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).



V. RESULTS AND DISCUSSION

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

Tensile strength of the proposed carbon PLA filament for different specimens

S.NO	LAYAR THICKNESS	INFILL DENSITY	TENSILE STRENGTH (Mpa)	AVERAGE VALUE (Mpa)	ELONGATION	AVERAGE VALUE %
1	0.15	20	12.98	14.26	2.04	2.09
2		20	16.46		0.76	
3		20	13.33		3.46	
4	0.15	40	13.74	15.08	3.70	4.06
5		40	17.26		2.84	
6		40	14.24		5.64	
7	0.15	60	16.09	20.33	6.92	5.66
8		60	20.10		1.74	
9		60	24.81		8.32	
10	0.25	20	12.61	13.63	4.70	3.77
11		20	15.48		2.68	
12		20	12.70		3.92	

13	0.25	40	14.84	16.53	3.22	3.15
14		40	19.94		0.28	
15		40	14.81		5.94	
16	0.25	60	14.32	17.94	5.94	4.68
17		60	22.07		1.64	
18		60	17.44		6.46	

IMPACT STRENGTH OF THE PROPOSED CARBON PLA FILAMENT FOR DIFFERENTSPECIMENS

S.N0	LAYAR THICKNESS	INFILL DENSITY (%)	IMPACT ENERGY (J)	IMPACT AVERAGE (J)	IMPACT STRENGTH (J/mm2)
1	0.15	20	120	121.33	11.21
2		20	124		
3		20	126		
4	0.15	40	166	162	14.7
5		40	160		
6		40	160		
7	0.15	60	158	158	14.36
8		60	158		
9		60	158		
10	0.25	20	158	157.33	14.3
11		20	156		
12		20	158		
13		40	152		

14	0.25	40	150	150.66	13.69
15		40	150		
16	0.25	60	148	145.33	13.21
17		60	146		
18		60	142		

Hardness of the proposed carbon PLA filament for different specimens

S.NO	LAYAR THICKNESS (mm)	INFILL DENSITY (%)	HARDNESS TEST	HARDNESS TEST AVERAGE
1	0.15	20	81	82.67
2		20	82	
3		20	85	
4	0.15	40	83	84.23
5		40	85	
6		40	84	
7	0.15	60	79	80.65
8		60	80	
9		60	83	
10	0.25	20	92	89.53
11		20	89	
12		20	86	
13	0.25	40	89	87.34
14		40	87	

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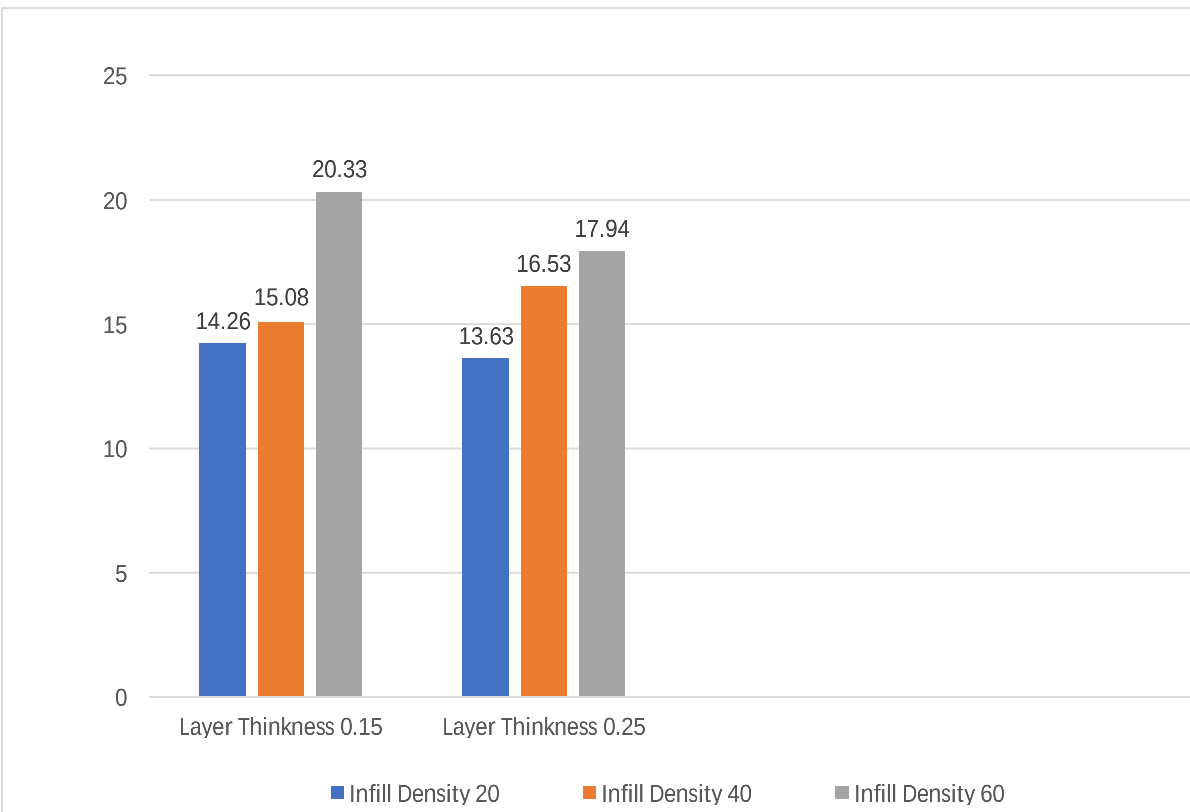
15		40	86	
16	0.25	60	91	91.33
17		60	90	
18		60	93	

A. Tensile Strength

The ultimate tensile strength of a 3D printed material depends on the variations of the filled methods, which shown figure 8.1. The values of the ultimate tensile strength for specimens 1, 2, 3, 4, 5 and 6 shown in table 8.1indicate 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



B. 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 8.2 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

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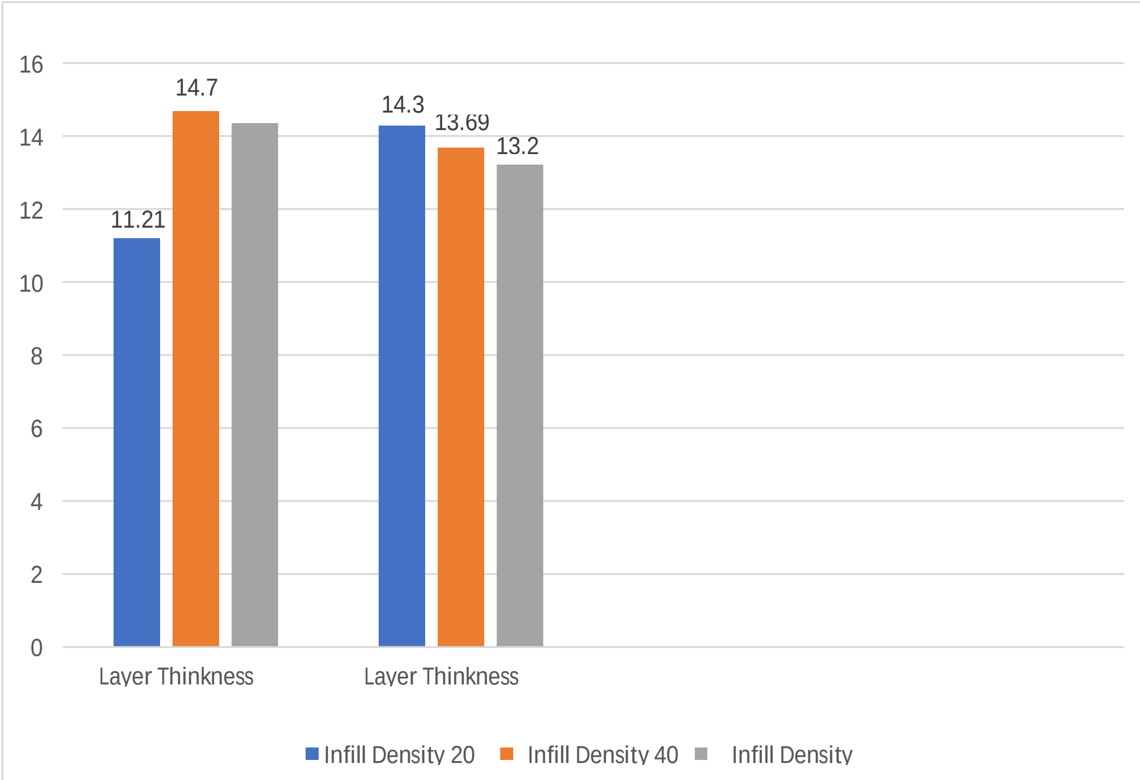
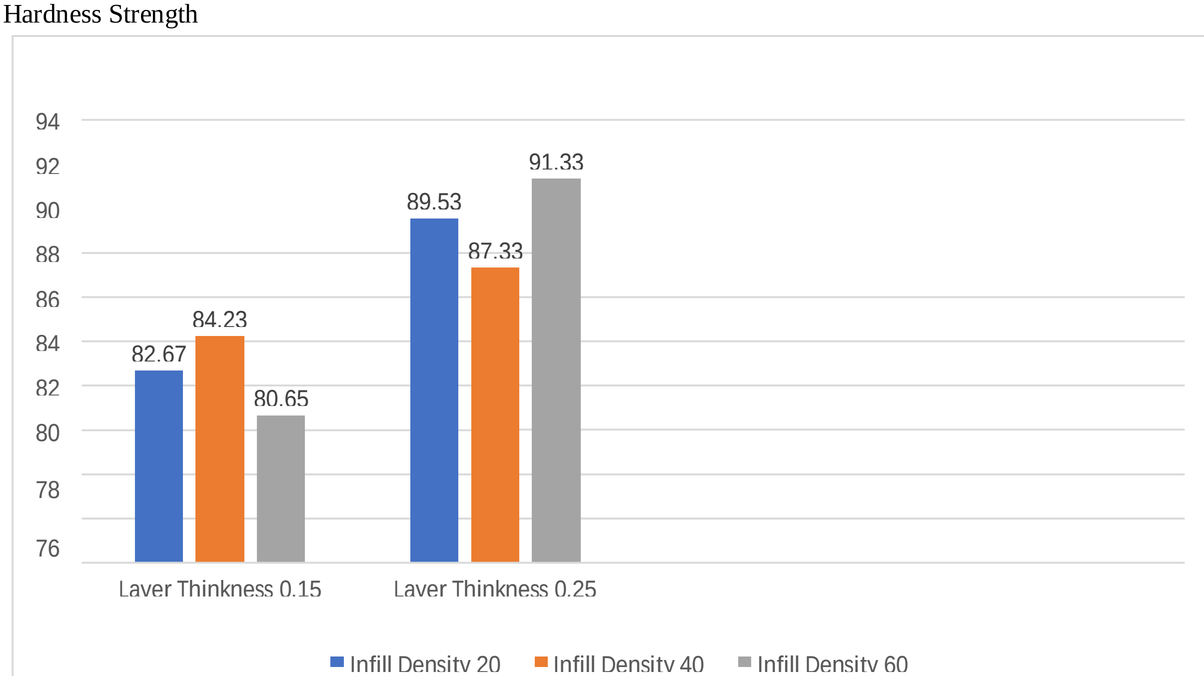


C. Hardness Test

The hardness of a 3D printed material depends on the variations of layer thickness and Infill Density of the printer, which shown in Figure 6.2 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



VI. CONCLUSION

In this study, carbon 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 24.81 MPa is obtained from the layer thickness 0.15 mm and Infill Density 60%.
2) The maximum Impact strength 14.7 J/mm2 is obtained from the layer thickness 0.15 mm and Infill Density 20%.
3) The maximum Hardness 91.33 is obtained from the layer thickness 0.25 mm Infill Density 60%.

In this work, a study was carried out to observe the mechanical properties of the proposed 3D printed material with a change in layer thickness 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 and change in printing speed, also change the width of the specimen other than fly.

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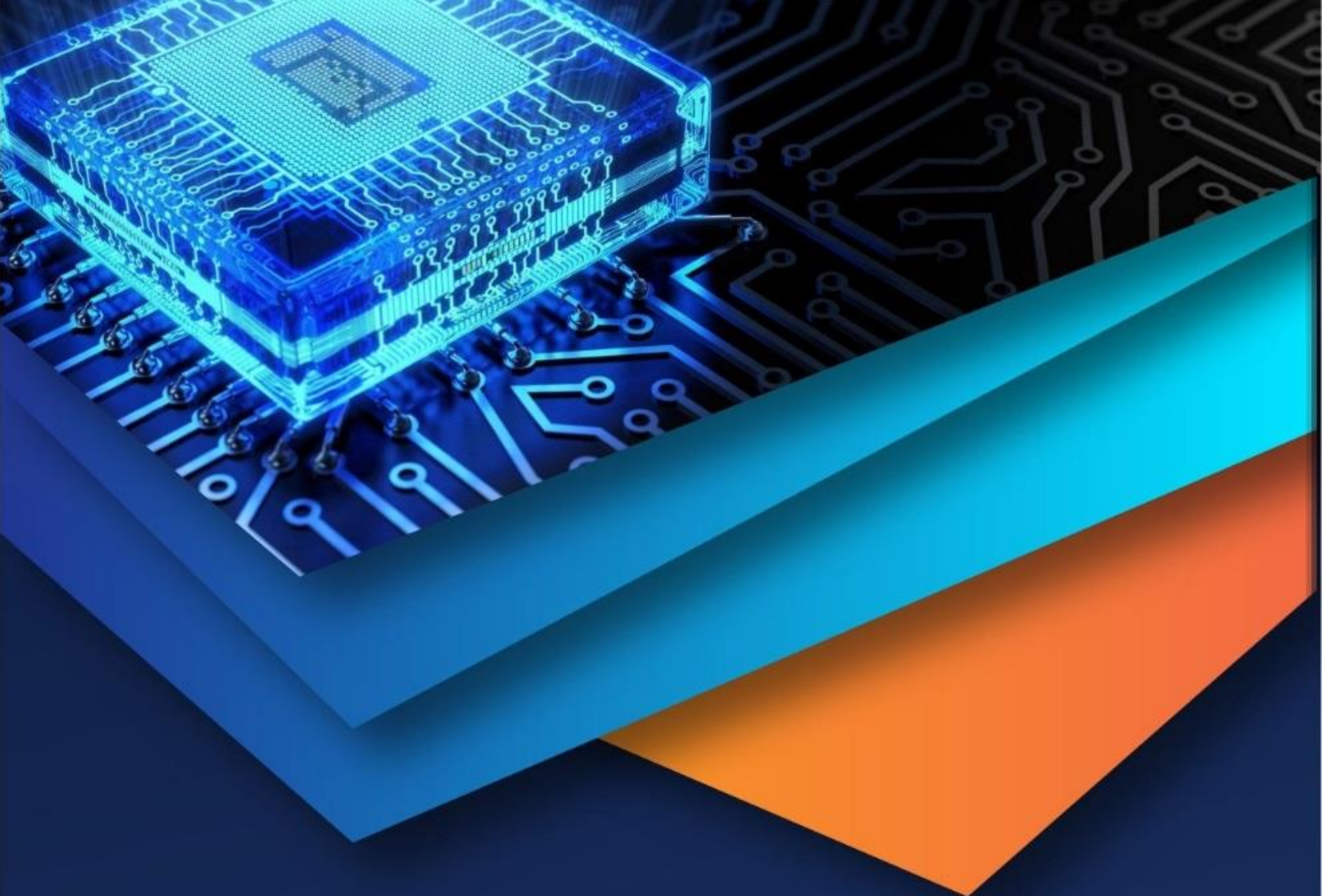

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