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Impact of Honeycomb Polylactide Infill% in FDM Printed PLA/Nylon for Improved Mechanical Properties

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Abstract: ***In conventional manufacturing procedures liable upon the forces acting on the materials may lead to breakage during motion of the part undergoing construct which is inevitable to no change its shape and position. In pretty much every case, materials have anisotropic by its nature and virtue. As additive manufacturing (AM) techniques embedded undergoing processes with improved accuracy of the parts being developed. Since there is far disadvantage of the quality of the AM product, constantly improvements made the process of AM is being escalating than conventional process. The assessment of the product and the complexity of the parts can't be resolved or found before it developing a methodology which impact mechanical properties of the printed parts. An effort has been made in the present work to improve the products mechanical properties by increasing the infill percentage. Study has been carried out as in view of increased infill with elaborated percentages of 15%, 30%, 40% and 50% to enhance the mechanical properties of the parts.***

Keywords: ***Fused Deposition Modeling, Infill, 3D Printing, Mechanical Properties.***

I. INTRODUCTION

The system of assembling objects by consecutively storing layers of material, in light of 3D advanced models, is called Added substance Assembling (AM) or 3D-printing. Fused Deposition Modeling (FDM) innovations alongside the ABS (Acrylonitrile Butadiene Styrene) material are broadly utilized in added substance fabricating. Until today, the mechanical properties of the AM parts can't be resolved nor even approximated before it is produced and tried. In this work a novel methodology is displayed on how the printing components impact the mechanical properties of the printed part so as to acquire how parts can be fabricated (printed) to accomplish improved mechanical properties.

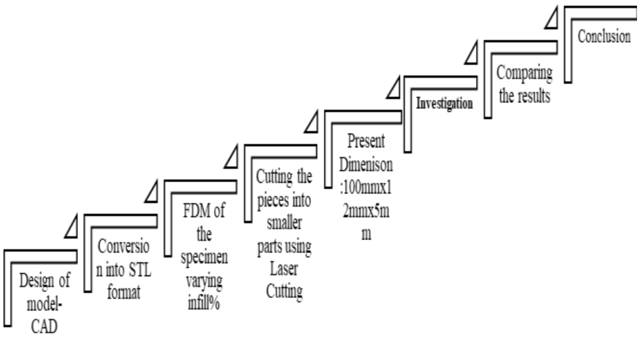

Figure 1 Schematic overview of the methodology

Figure 1 shows the different stages of AM process starting from design of CAD model to the final product. This strategy is followed in this research. Many studies have been carried out on influences of material properties based on different printing techniques. Fused deposition modeling is the process of layer by layer addition to the technique so as to facilitate the treatment of heat for addition forming a solid model. In this process of additive manufacturing technique, there lies an obstacle of quality of the model or part manufactured which is tricky part. Various studies are conducted to determine quality of the product. One being the layer thickness affecting the property of the developed part with time [1], had been investigated. Another by optimizing the sequence of operation carried out in fused deposition modeling which certainly affect the developed model or prototype [2]. Thereby the strength of the product developed is studies varying thickness along with heat treatment analysis. The fractural strain is also considered in few studies individually. Ductility being the major reason for the less quality of the products with less standard mechanical properties, the attempt to increase the mechanical properties has led to advanced futuristic investigations. PLA which is used for the 3-d printing techniques, in which it is aimed to produce the parts having properties mechanically near to bulk PLA are studied. The method of addition infill is carried out in the studies so as to increase the mechanical properties of the materials to be developed.

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Therefore, studies involved in increase in percentage of infill regulate the increase in properties. Various complex models are a developed with high surface obliquity with high infill percentage density in manufacturing of surface moulds.

Hexagonal structural infill along with Hilbert curve is studied with different percentages of 5%, 30% and 60% etc. The time of the printing is considered during extrusion so as to identify the sample with quality are developed. Some results show that the present of voids in the samples varying with infill percentage and density range is observed [5]. This helps in repair of the bones [6] with finite fabrication with elemental study. Various infill patterns were tested along with infill percentages resulted in identifying the improved better mechanical properties [7], this includes ABS which is being extensively useful. Printing time along with firmness and harness is studied so as to study the quality of the part prepared using 3-D printing process [8]. Thereby knowing that the FDM printing technique promises in enabling the improving the texture quality of the materials increasing the percentage of infill [9] though PCA (Principle Component Analysis). The process of 3-D printing technique is economical in making the studied changes [10]. The viscosity of the materials is also studying so as to identify the recovering processing in studying the characteristics [11]. The 3D printing process is keenly observed at different stages of printing process [12], so as the parameters are understood in finding the mechanical properties of the product developed enabling to simplify the development of the part [13]. The increase in the infill resulted in increase in tensile strength [14] and increase in the compressive strength [15] is also observed in products and parts made of PLA [16] developed using FDM.

II. MATERIALS

2.1 Nylon:

Nylon Polyamide is a fantastically solid, tough, and adaptable 3D printing material. Adaptable when slim, yet with very high between layer attachment, nylon loans itself well to things like living pivots and other utilitarian parts. Nylon fibre prints as a splendid characteristic white with a translucent surface, and can retain shading included post process with most normal, corrosive based apparel colours or synthetic material explicit colours. Nylon fibre is amazingly touchy to dampness, so taking drying measures during capacity and promptly preceding printing (utilizing desiccant, vacuum, or raised temperature) is profoundly suggested for best outcomes. Nylon fibres ordinarily require extruder temperatures almost 250 ºC, be that as it may permit printing at temperatures as low as 220 ºC because of their compound synthesis. Numerous printers do exclude a hot end that can securely arrive at 250 ºC, so these lower-temperature renditions can be valuable and possibly spare you from expecting to redesign. One major challenge with Nylon fibres is that they are hygroscopic, which means they promptly ingest dampness from their environment. Nylon printing accumulated with few print quality issues; along these lines, fibre stockpiling turns out to be significant and requires unique consideration.

2.2 Polylactic Acid (PLA):

Polylactic Corrosive or PLA fibre is by a long shot the most prevalent material utilized in FDM 3D printing. It comes in numerous shades and styles, making it perfect for a wide scope of uses. Regardless of whether you're searching for dynamic hues or one of a kind mixes, PLA fibre is a simple to utilize and tastefully satisfying material. It is the default fibre of decision for most expulsion-based 3D printers since it tends to be printed at a low temperature and doesn't require a warmed bed. PLA is an extraordinary first material to use as you are finding out about 3D printing since it is anything but difficult to print, cheap, and makes parts that can be utilized for a wide assortment of uses. It is likewise one of the most earth inviting fibres available today. Gotten from yields, for example, corn and sugarcane, PLA is inexhaustible and in particular biodegradable. As a little something extra, this likewise enables the plastic to radiate a sweet smell during printing. Likewise, since PLA fiber is a biodegradable item, it will in general normally separate in around three to a half year. Other thermoplastic materials can take up to a thousand years to break down, making PLA significantly more ecologically cordial.

Table-1: material properties and processiong conditions:

Properties	Nylon	Pla
Molecular Formula	$(C_{12}h_{22}n_2o_2)_N$	$(C_3h_4o_2)$ N
Melting Point	215ºc	175ºc
Density	1.14 G/Cm^3	1.23 To 1.25 G/Cm^3
Elongation At Break	15-45%	3.8%
Extrusion Temperature	240-250^{0}c	190-220^{0}c
Transparency	Opaque	Translucent

The material properties and the processing conditions are shown in the Table 1, where the melting point of the Nylon is higher than that of PLA, whereas PLA is denser that Nylon.

III. EXPERIMENTATION

3.1 Preparation of CAD Model

The CAD model was prepared in SolidWorks 2013 version. The dimension of the specimen is 100mmx50mmx5mm. First a rectangle was made in the X-Y axis and then it was extruded along the Z axis. After the preparation the model was then converted into. STL format. This format is suitable for 3-D printing process.

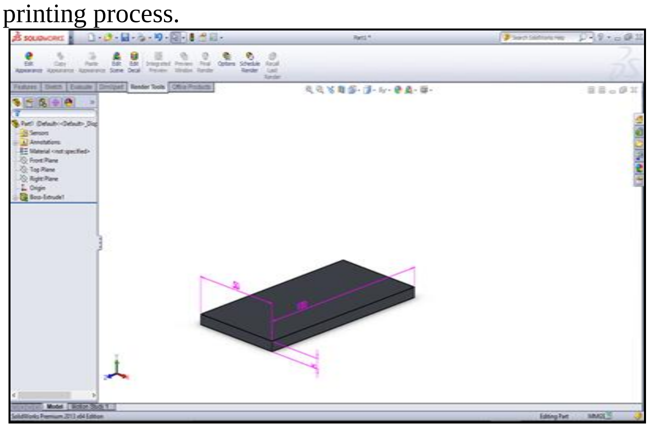

Figure 2 Design of a CAD Model

The CAD model designed is converted to STL file which is a suitable format for 3D printing technology. The stereo lithography file is operated in an FDM so as to construct different parts with increased infill percentage having structural,
Honeycomb polylactide for each specimen. The structs are constructed in a hexagonal shape varying percentage of infill having 15%, 30%, 40% and 50 percent with PLA. The later taken is Nylon, which Is keenly helpful in studying the base for the compositions. The samples are prepared using FDM .The model was then cut into three pieces using the process of laser cutting. This was done to ease the testing process and to observe the anisotropic properties of the material.

3.2 Preparation of 3D Printed Specimen

As obtained the STL file which is created the specimen is prepared accordingly on FDM, *Pramaan 300* that capable of printing volumes extremely of 300mmx300mmx300mm which is a solitary spout printer that can deliver high area prints ranging from 80-800 microns. For the printing procedure, every material has its very own bed temperature and its very own extruder temperature relying upon the material. PLA has a bed temperature of 60-80^{o}C and extruder temperature of 190-230^{o}C. Nylon's bed temperature kept up between 60-80^{o}C and extruder temperature lies between 210-250^{o}C. Certain info settings, for example, layer stature, fill thickness, print speed and so forth are offered legitimately to the printer.

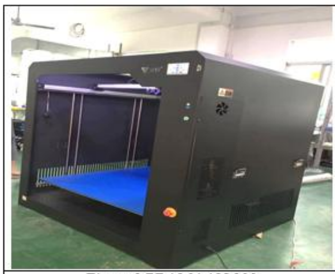

Figure 3 PRAMAAN 300

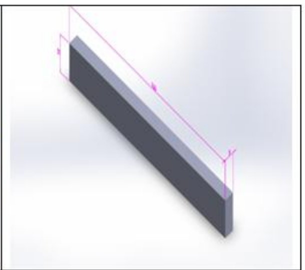

Figure 4 Specimen100mm×12mm×6mm

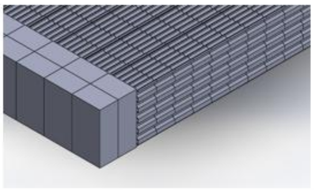

Figure 5 Honeyco polylactide structural

Figure 6 Specimen post testing

The experiment consisted of tensile tests and 3-Point Bending tests to test the specimens using the INSTRON testing machine with different specimen made of different materials to extract and compare the mechanical properties of each. In order to test the various parameters, a predefined set of axes were defined for all test specimens having length, width and thickness oriented relative to a test specimen.

IV. INVESTIGATIONS

4.1 Tensile Test

The tensile tests are conducted on INSTRON 8801 as per ASTM D3039-07 standards test method for tensile properties of composite specimens. This test method determines the in plane tensile properties of PLA with or without Infill particulate filler. The dimension of the sample is 150 mm x 12 mm x 5 mm with a fixed gauge length of 100 mm. Tests are conducted for the samples at normal room temperature (27^{o}C) and quasi-static strain-rate of 10E-4/s. At least three specimens for each composite are tested to get the mean value of the tensile strength. INSTRON 8801 with tensile test setup and the test specimen are as shown in the figure 7 and figure 8.

Figure 7 Tensile test on PLA

Figure 8 Tensile test on Nylon

4.2 3-Point Bending Test

Three-point bending test usually provides values for flexural test, flexural strain, modulus of elasticity in bending and the flexural stress strain reproof the material. The method of testing involves usually a specified text fixture on a universal testing machine. Details of the test preparations, conditioning and conduct affect the test results. The sample is placed on two supporting pins at a certain distance apart, which are as shown in the Figure 7 and Figure 8.

4.3 Flexural Test

For both flexural strength and ILSS, the test is repeated three times for each composite type and the mean value is reported. The flexural strength of the composite specimen is determined using the following equation:

$$Flexural\ strength = \frac{3.P.L}{2.b.t^2} \quad (1)$$

where L is the span length of the sample (mm); P is maximum load (N); b the width of specimen (mm); t the thickness of specimen (mm).
The data recorded during the three-point bend test is used to evaluate the Inter laminar shear strength (ILSS). The ILSS values are calculated as follows:

$$ILSS = \frac{3.P}{4.b.t} \quad (2)$$

V. RESULTS AND DISCUSSION

ASTM standards have been thoroughly followed while testing the specimen for its tensile properties. The present work mainly focuses in increasing the intended properties to the existing varying with sundry improved mechanical properties like stress-strain, Young's modulus, breaking load and ultimate tensile strength following ASTM standards.

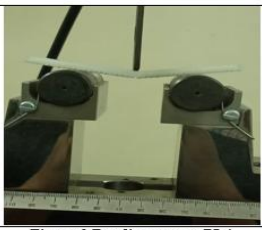

Figure 9 Bending test on PLA

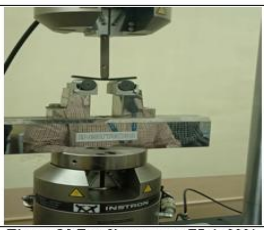

Figure 10 Bending test on PLA-30%

Figure 11 Bending test on PLA-40%

Figure 12 Bending test on Nylon

The experimentation also focuses on strength to weight ratio on different specimens of PLA-15%, PLA-30%, PLA-40% and PLA-50% having infill to Nylon, developed using FDM technique.

TABLE 2: Mechanical observations:

PROPERTIES	PLA	PLA 15%	PLA 30%	PLA 40%	PLA 50%	Nylon
SPECIFIC STRENGTH (MPa/gm)	1.55	3.9042	3.43275	3.6583	4.1438	4.3837
BREAKING LOAD (KN)	0.68	0.872	0.92	1.13	1.17	0.83
YOUNGS'S MODULUS (MPa)	453.769 77	858.769 77	860.722 92	946.032	1128.300 48	741.278 98
FLEXURE STRENGTH (MPa)	29.26	31.58	30.078	36.211	45.88	51.35
TENSILE STRENGTH (MPa)	14.06	16.32	16	19.36	21.74	18.21

From the study and investigation carried out in this present work, the mechanical properties of the PLA with varying infill and Nylon are obtained as shown in the Table 2. The enhanced mechanical properties of PLA-50% Infill is observed to be maximum when compared to PLA without infill and Nylon giving a broad way to the proposed work in identifying the methodology proposed. The observations are elaborately explained for their tensile strength, breaking load, young's modulus, flexure strength, bending moment and tensile strength from figure 13-24.

5.1 Tensile Properties of Nylon and PLA infill percentage:

The observations of stress-strain curves are obtained for the sample of PLA with and without infill and Nylon so as to study the comparable characteristics with percentage of increased infill and nylon as shown from the figure 13-17:
The strain is calculated for the different specimen as formulated:

$$\text{Strain, } \varepsilon = \delta L / L \quad (3)$$

Where, $\varepsilon = strain$;
$\delta L = Change\ in\ original\ Length$;
$L = Original\ length$;

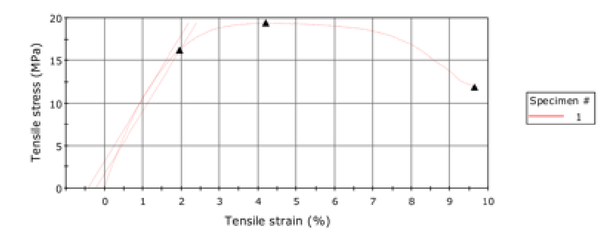

Figure 13 Tensile strength of Nylon

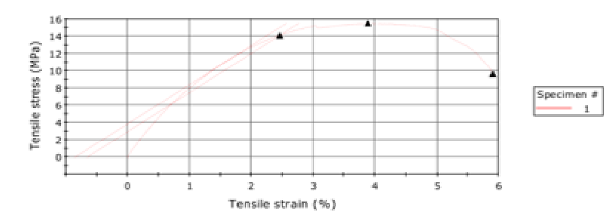

Figure 14 Tensile strength of PLA-15%

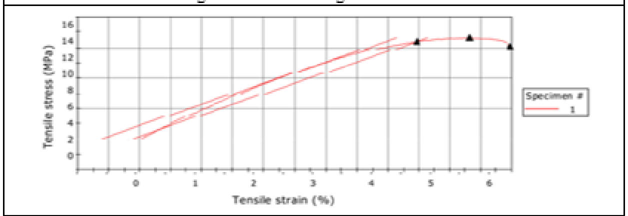

Figure 15 Tensile strength of PLA-30%

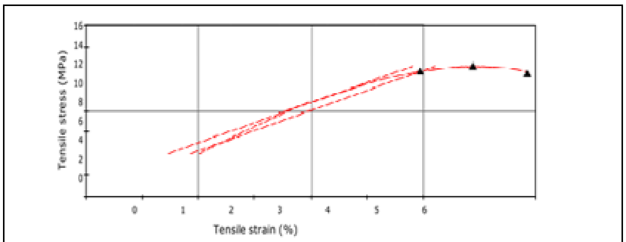

Figure 16 Tensile strength of PLA-40%

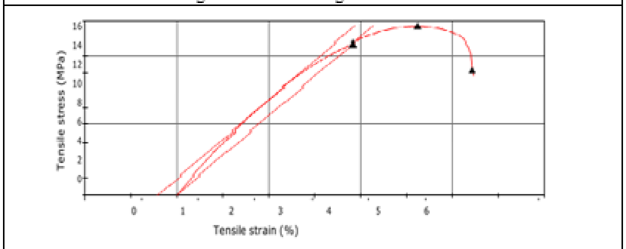

Figure 17 Tensile strength of PLA-50%

(a) Stress-Strain Curve of Nylon

Figure 13: shows that the maximum tensile strength of the Nylon having 18.21 MPa.

(b) Stress-Strain Curve of 15% PLA

From the figure 14, the maximum tensile stress is obtained at 16.32 which shows improved properties than that of PLA without infill having14.06 MPa.

(c) Stress-Strain Curve for PLA-30%

From the figure 15, the maximum tensile strength is obtained at 16MPa which shows reduced properties that PLA with infill and without infill.

(d) Stress-Strain Curve for PLA-40%

From the figure 16, the maximum tensile strength is obtained at 19.36 MPa which shows that increased tensile stress when compared to that of PLA with infill 15% and 30% and PLA without infill.

(e) Stress-Strain Curve for PLA-50%

From the figure 17, the maximum tensile strength is obtained at 21.74 MPa which shows that increase in tensile strength when compared to that of PLA with infill 15%, 30% .40% and PLA without infill therefore gaining strength higher than NYLON.

5.2 Comparative Study of Stress-Strain Curves of PLA With Infill Versus Nylon

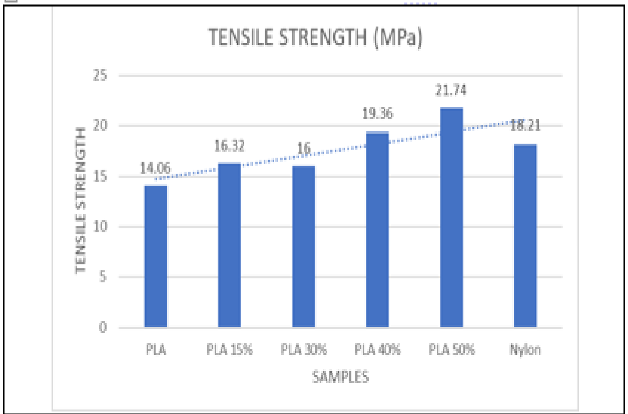

Figure 18 TENSILE STRENGTH OF PLA WITH INFILL Vs NYLON

From the figure 18, its observed by Comparing the tensile strengths of all the materials of PLA with infill 15%, 30%, 40%, 50%, PLA without infill to that of NYLON, PLA-50% showing higher tensile strength of 21.74 MPa results in improved properties than that of NYLON having 18.21 MPa.

(i) Specific strength

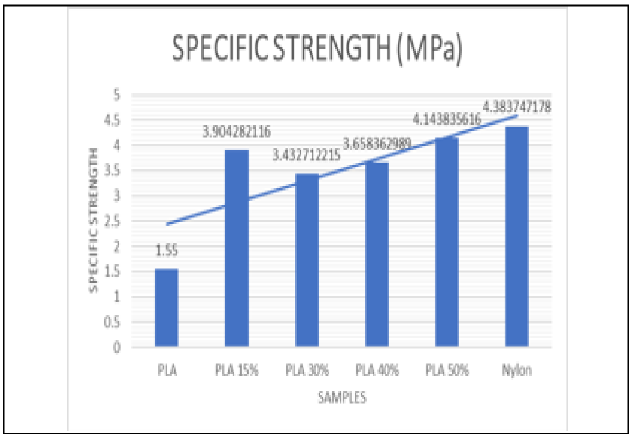

Figure 19 Specific strength Vs PLA with increased Infill% and NYLON

From the graphs which is analysed in the figure 19, observations show that the PLA with 50% infill has got better yield when compared to that of PLA with different infills. Obviously, since its infill percentage is more, the internal structure will be more compact which will result in better Young's modulus. However, when the parameter of specific strength is compared, we can see that PLA with 15% infill and 50% infill are almost comparable. They both have a specific strength of 3.98 MPa/gm and 4.2 MPa/gm respectively.

(i) Young's modulus:

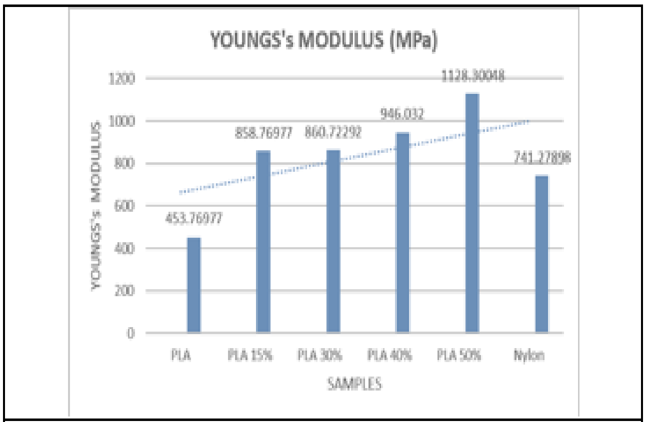

Figure 20 Tensile strength

It is evident from the graph shown in the figure 20; the Young's modulus of Glass PLA is maximum when compared to other materials which were tested. This is because Glass PLA is a composite of Glass fibres reinforced with PLA filament. The reinforcement of glass with PLA has made the PLA strong by almost 1.4 times. Also ease of printing was observed in the case of Glass PLA.

(ii) Breaking load

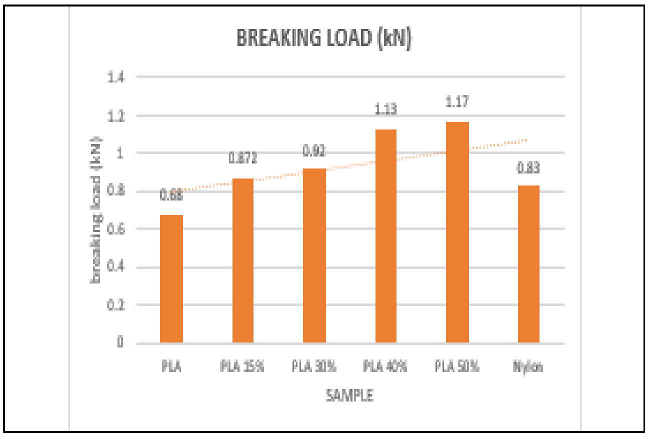

Figure 21 Tensile strength

From the figure 21, the comparative braking load for the sample of PLA with and without infill along with Nylon shows that the maximum breaking load is obtained at 1.17kN for PLA-50% that that of preceding materials and nylon which has a breaking load value at 0.83kN. From the results it is evident that the properties of PLA with increase infill percentage can gain the properties of nylon and higher having economical printing.

(iii) Flexure properties

3-Point Bending Tests or Flexural tests was conducted on the printed specimen. The test was conducted for 18 samples three of each on INSTON Universal Testing Machine and was tested for 3-point bending. Multiple bending tests were carried out to observe the change in the flexural values in the same structure. The materials tested for flexural strength are Nylon, PLA with infill and PLA without infill and results are plotted as shown in the Figure 22 Flexural data of NYLON in Figure 23.

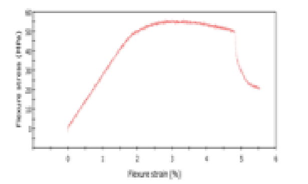

Figure 22 Flexural data of PLA

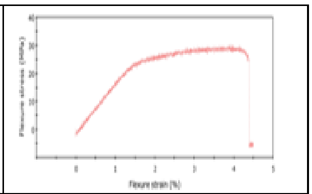

Figure 23 Flexural data of NYLON

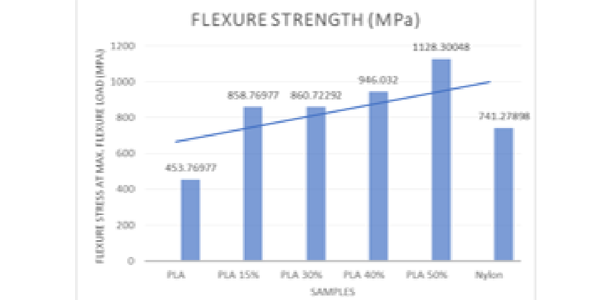

Figure 24 Flexure strength of PLA with-without infill Vs Nylon

By comparing the graphs of all the materials which have been tested for flexural strengths, we can see that within the same material, the values are different even when taken from different sides. It is also observed that the middle portion has lower values than those that of corners. This may be because of the fact that the corners are covered from the three sides whereas the centre portion is only covered from top and bottom. From the Figure 24, the comparative flexural strength is observed among PLA without and with infill comparatively studying the properties of Nylon. It is observed that the PLA-30% having 858.769 MPa and PLA-50% having 1128.300 MPa higher flexure strength than Nylon having 741.278 MPa. The properties of PLA are improved enormously with infill% and the study shows that the flexural property of PLA than that of Nylon is achieved in replacing Nylon of its mechanical properties embedded in PLA with Infill 50%.

VI. CONCLUSION

While contrasting polymers, be it normally fabricated or 3-D printed one's particular quality or quality, weight proportion is one of the most significant variables that must be thought about.

This is on the grounds that when we contrast any composite or polymer and a metal, we can't think about them exclusively based on its quality. So, we have to compare them on specific strength basis, where we can say that for a particular weight, the composite offers more strength. Thereby conclusions show that the properties of the part or product developed effected with difference in build orientation.

Even though nylon is a durable, tougher and chemical resistant plastic which is flexible but lags in strength and stiffness when compared to PLA. PLA process being impurities added during process leads to chemical washed and change is properties.

- The observations show higher specific strength in PLA-50% that with nylon and PLA without infill.
- Flexure properties are found to be anisotropic with same composition having variable results.
- In this case nylon being the better materials with outstanding tensile strength having 4,700 psi -7,000 psi. So as to achieve the improved properties of the PLA which is stronger and stiffer to durable to that of nylon is a considered approach.
- The results show induced nylon properties in PLA with increased infill percentage gaining mechanical properties to that of NYLON.
- From the study it proved that tensile strength of PLA with increase in infill percentage shows increased tensile strength, breaking load and flexure strength along with Young's Modulus.
- Confirming replacement and durability to that of NYLON can be achieved with increased infill percentage in PLA.

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