ISSN 1533-9211

DOI 10.17605/OSF.IO/HQY6Z

EXPERIMENTAL ANALYSIS ON MECHANICAL PROPERTIES OF BIO-DEGRADABLE POLYMER (PLA) WITH DIFFERENT BUILD ORIENTATION FABRICATED THROUGH FUSION DEPOSITION MODELING TECHNIQUE

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Abstract:

Due to its numerous benefits over any traditional production processes, additive manufacturing (AM) technology is essential to the current sustainability of Industry 4.0. Common polymers used in procedures requiring thermoplastics, or plastics that are treated by heating to a semi-liquid condition and close to the melting point, include polycarbonate (PC), acrylonitrile butadiene styrene (ABS), poly ether ester ketone (PEEK), polyetherimide (ULTEM), and nylon. These materials have different engineering application in the field of Bio-medical, Automotive, and Aerospace Engineering to cater the requirements of advanced manufacturing technology. There is great demand for the materials which are bio-degradable considering with environmental factors. Polylactic acid (PLA) is one of the bio degradable material finds major applications in Industries. Hence to meet the demand in production of bio-degradable materials, this work attempts to study the analysis on mechanical properties of Polylactic acid (PLA) fabricated through fusion deposition modelling technique with different build orientations. The results have revealed that the test specimens built on x-axis has better tensile and yield properties compared to Y-axis and Z-axis. Impact strength of the material with different orientation does not have significant differences.

Keywords: Additive Manufacturing (AM), Polylactic acid (PLA), Fusion Deposition Modelling.

1. INTRODUCTION

FDM is the additive manufacturing technology that has had the most widespread adoption due to its simplicity, dependability, and reproducibility. The FDM printing process involves the material for the filament being extruded via a heated nozzle while in a semi-solid state. It is then deposited as a thin layer on top of a previously deposited layer or on the build platform according to the slice information [1]. After the deposition of one layer, the nozzle moves away from the layer along the z-axis by the height of one layer thickness. Following this, another layer is deposited, and then another layer is deposited and adhered to the one that came before it. After then, the entire procedure is repeated till the 3D item is finished being constructed. The quality of the parts is substantially impacted by the factors that are present throughout the printing process. These variables include part orientation, raster orientation, layer thickness, infill density, infill pattern, and printing speed. Because the component is built up layer by layer, and because each layer is composed of raster's, the quality of the filament plays a significant role in determining the properties of each layer [2].

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1.1 Build Orientation Parameters

Because it has an effect on both the speed with which and the level of quality to which parts can be 3D printed, component orientation is frequently a key aspect in 3D printing. This is especially true when the additive manufacturing technique known as rapid prototyping is being used. The orientation of the pieces will have a major impact on the overall productivity of the manufacturing process [3-4]. While building the test specimens the following printing parameters were considered as tabulated in Table 1.

Table 1: Build orientation parameters used for 3D Printing

Material	Infill Density	Build Orientation	Print speed (mm/s)
PLA	80	X	180
PLA	80	Y	190
PLA	80	Z	180

Build orientations of (X, Y and Z-axis) is shown in the below Figure 1 a) and Processing parameters of tensile bars is sown in the below Figure 1 b).

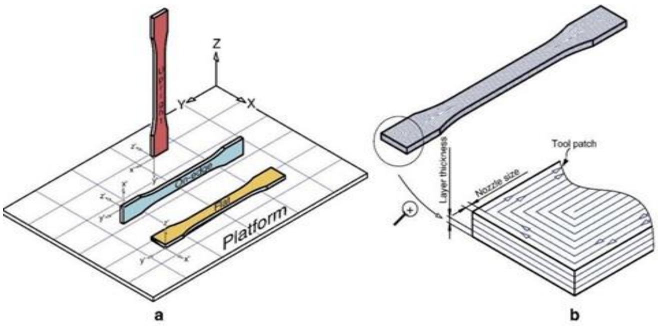

Fig 1: a) Build orientations of (X, Y and Z-axis) b) Processing parameters of tensile bars

2. MATERIALS AND METHODS

2.1 Raw Materials and Processing

For the present research work Polylactic Acid (PLA) filament was procured from M/s Adder Creations, Bangalore in order to study mechanical properties with different build orientation. The filament diameter is 1.75 mm which was used for 3D printer Reality Ender 3 specifications.

3. PREPARATIONS OF TEST SPECIMENS

3.1 Creation OD 3D Models of Specimens

Before conducting the experimental work, the specimens for tests were modelled using CAD software with SolidWorks 2019 version. Once the model is created the next step was to convert the part file to .stl file for converting to slicing model [5-7]. Further stereo lithography file is converted to G-code file in order for input to the 3D printer to fabricate Tensile, Hardness, and Impact and Dimensional accuracy test specimens.

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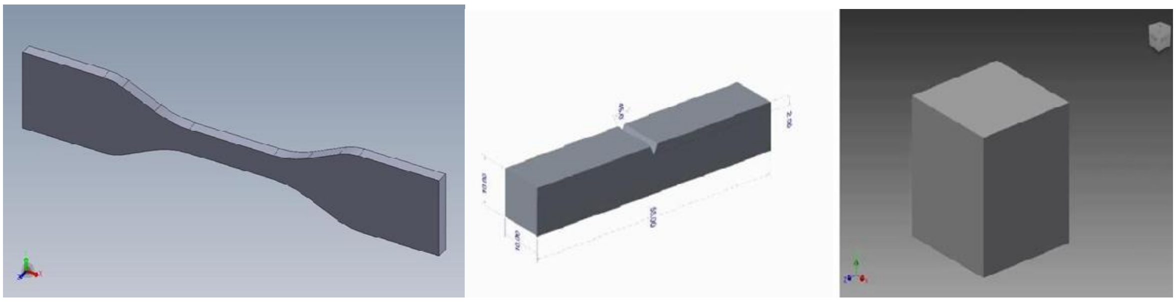
A Tensile specimen model is shown in the below Figure 2 a). A Impact test model is shown in the below Figure 2 b). A Dimension accuracy test model is shown in the below Figure 2 c).



(a) **(b)** **(c)**

Fig 2: a) Tensile specimen model b) Impact test model c) Dimension accuracy test model

3.2 FDM (Fusion Deposition Modeling)

For the creation of 3D parts, from Global 3D laboratories the Praman FDM printers with Prusa i3 technology were employed. A 300mm^3 enclosed chamber was used in the machine [8]. For manufacturing FDM parts, 0.1mm of layer thickness, 240^{0}C of nozzle temperature, printing speed of 0.8m/min, and 45^0 orientations with varying infill densities were selected.

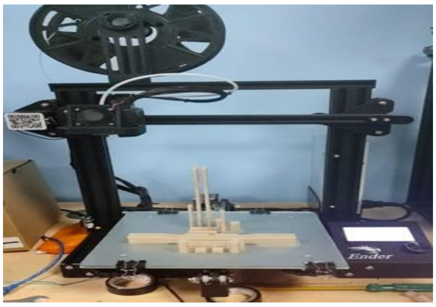


Fig 3: Fabricated test specimens built with different orientation using 3D printer

4. CONDUCTION OF EXPERIMENTAL WORK

4.1 Tensile and Impact Test

A tensile test was conducted in accordance with ASTM 638 at National Analytical Laboratories and Research Centre, Bangalore. Also the impact behaviour was measured in accordance with ASTM D 256 at the same location. Tensile tests were conducted using a FIE machine with a capacity of 0 to 60 tonnes [9-10]. The tensile specimen both before and after the test is depicted in Figure 4 (a) and (b), respectively. The impact specimen both before and after the test is depicted in Figure 4 (c) and (d), respectively.

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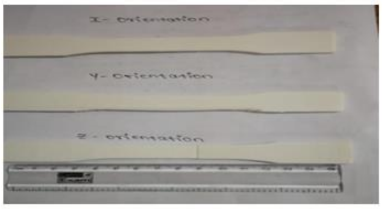
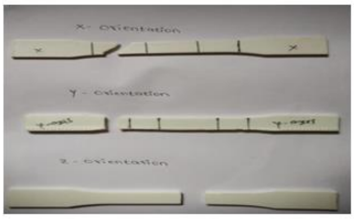
Fig 4: Images shown for a) Tensile specimen before test b) tensile specimen after test c) Impact specimen before test d) Impact specimen after test

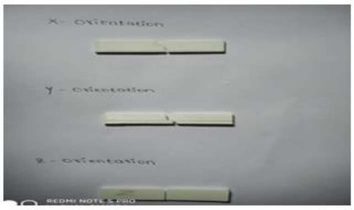


a)



b)

c)

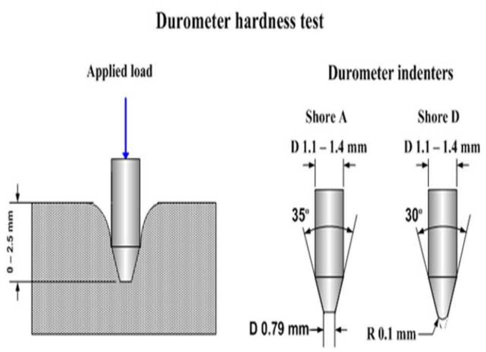


d)

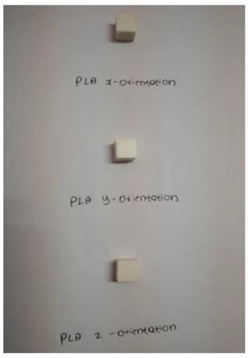
4.2 Hardness Test:

Shore (Durometer) hardness test is used to test hardness of both PLA. The resistance of a material to the penetration of an indenter that is similar to a spring-loaded needle is measured using the Shore hardness scale. The Shore scale is the standard method for determining the hardness of polymers (rubbers and plastics). Shore the testing of soft elastomers (rubbers) and other types of soft polymers requires the use of a scale. The Shore D scale is used to determine the level of hardness of hard elastomers as well as the majority of other polymer materials (thermoplastics, thermosets). The Durometer is the instrument that is used to measure the Shore Hardness [11-12]. Durometer hardness test is shown in below Figure 5 a) and a Hardness test specimen is shown in below Figure 5 b).

Fig 5: Images shown for a) Durometer hardness test b) Hardness test specimen



a)



b)

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ISSN 1533-9211
DOI 10.17605/OSF.IO/HQY6Z

5. RESULTS AND DISCUSSION

The 3D printed specimens were fabricated and were tested with different mechanical properties as one of the important factor was build orientation considering parameters of uniform printing speed and constant infill density.

5.1 Dimensional Accuracy

The dimensional stability a variation between different orientations of PLA is illustrated in Figure 6. Each specimen was averaged based on three trial readings. Specimens with dimensions of 10 x 10 x 20 mm were developed for measuring dimensional stability [13]. The parts fabricated in X build direction had greater dimensional stability in comparison to other orientations. Z direction provided least dimensional stability. PLA volume in Z direction went up to 2006.3mm^3 which was least dimensionally stable sample. Dimensional accuracy has increased as a result. The discrepancy between the desired and actual value is known as the dimension error. The use of optimal process conditions in the FDM method also contributes to the improved dimensional accuracy of reinforced 3D-printed parts [14]. Table 2 illustrates the dimensional precision of PLA in the X, Y, and Z build directions.

Table 2: Dimensional accuracy of PLA, in X, Y and Z build direction

Sl.No.	Build Orientation	Dimension Achieved in mm.
1.	x	Breadth-10, Width-10, Length-20
2.	y	Breadth-9.6,Width-10.26,Length-20.08
3.	z	Breadth-10.67,Width-10.75, Length-20.39

5.2 Ultimate Tensile Strength

The ASTM D638 testing process was utilized so that the ultimate tensile strength of the produced part could be determined. Figure s graph shows that for build orientation in X-direction the tensile strength observed to be comparably higher with maximum strength was 47.48 MPa and least observed was for the specimen build along Z direction. The minimum magnitude of the result was 32.48 MPa.

In comparison to the specimens created using the process of fused deposition modelling, the tensile strength of the conventionally made specimens was significantly higher. The tensile strength increases in proportion to the increase in the filler content expressed as a percentage of the total weight. It had been found that the voids been increased in the beads as the content of filler is increased during a reduction in the voids between the beads [15]. Seyeon et al. a polymer nanocomposites was developed utilizing ABS as the matrix and as the fillers the copper and iron were utilized. 3D-printed specimens with increased fill density had better tensile properties based on tensile strength analysis [16].Similar results were obtained in our study. The Ultimate tensile strength of PLA, in X, Y and Z build direction is shown in the below Figure 6.

ISSN 1533-9211
DOI 10.17605/OSF.IO/HQY6Z

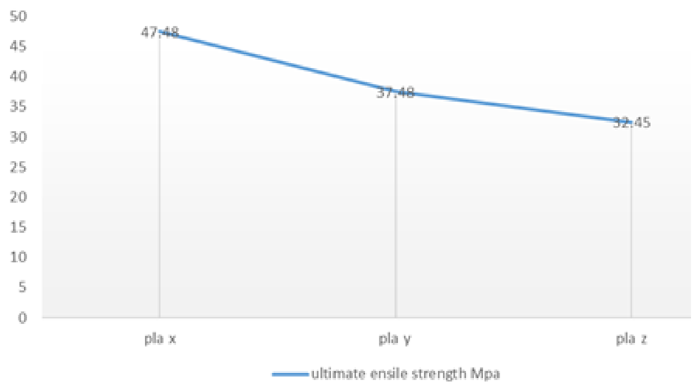

Fig 6: Ultimate tensile strength of PLA, in X, Y and Z build direction

The Graph of yield strength of PLA is shown in the below Figure 7.

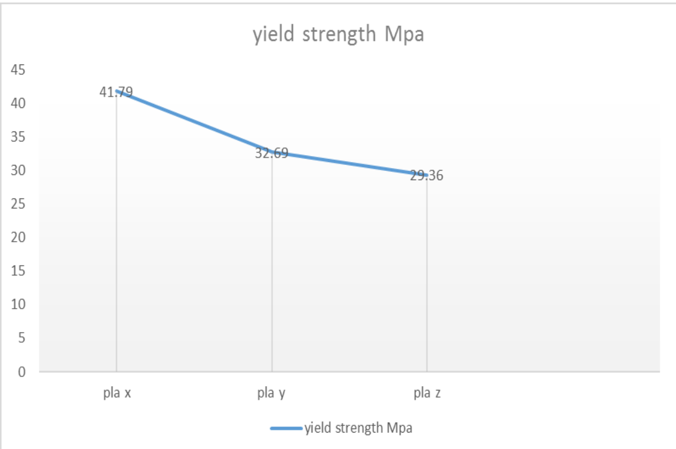

Fig 7: Graph of yield strength of PLA

In contrast, processes that melt and solidify plastics (SLS and FDM) typically result in parts whose strength in the X and Y axes is several times greater than that in the Z axis. This is due to the inter-layer bond strength being lower [17]. If strength is critical for a part's performance, then the part might need to be oriented to ensure the load paths are not in the Z axis.

5.3 Ductility

The ability of a material to be drawn is what's meant when people talk about its ductility, which is a type of mechanical feature. In the field of materials science, "ductility" refers to the degree to which a substance is able to maintain plastic deformation while being subjected to tensile stress without breaking. In the fields of engineering and production, ductility is an essential factor to take into account. [18]. From the graph Figure 8 illustrates that Elongation with desirable property of ductility was observed maximum in build orientation of specimen along X-axis with %elongation of 4.28 and minimum of 0.89 along Z-axis. The printing speed and

ISSN 1533-9211
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layer formation plays very important role in defining variation in the magnitude of % elongation along different orientation of 3D printed part.

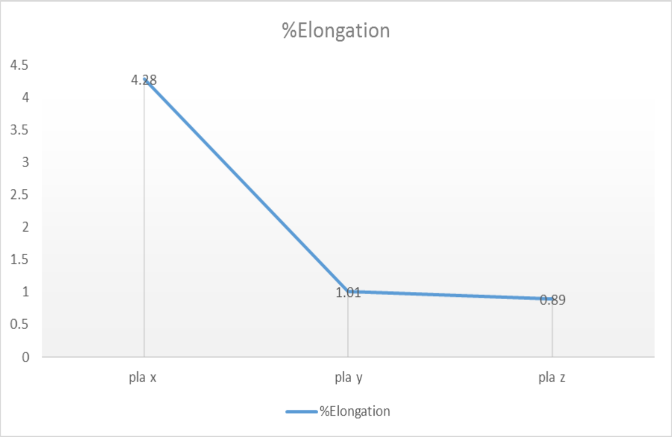

Fig 8: % Elongation under tensile load of PLA with different build orientation

5.4 Impact Strength

Always remember that the Z axis (vertical) of a part created in 3D with an FDM printer will have a lesser strength than the X or Y axes (horizontal). This is due to the fact that the adhesion across layers is almost never higher than the adhesion between lines on the same layer [19]. Pure PLA had an impact strength that was about 0.8 J/mm^2 in both X and Y build direction, the value reduced to 0.6J/mm^2 in Z build direction.

5.5 Hardness Test

Pure PLA fabricated by fusion deposition modelling was tested by conducting shore (Durometer) hardness test. There exist significant differences in observed values of hardness in different orientations. It was increased for the specimen built along Z-axis and minimum for specimen built along x-axis [20-21]. Hardness test for PLA Test specimen results with different orientation is shown in the below Figure 9. It is observed from the graph of hardness test that, Hardness measured by D shore method indicates that z axis printed specimen has found to be harder comparatively with specimen printed along x and y axis [22-24]. The main reason for this is as the material built along z direction appeared to have more elastic stiffness resulting into harder material.

ISSN 1533-9211

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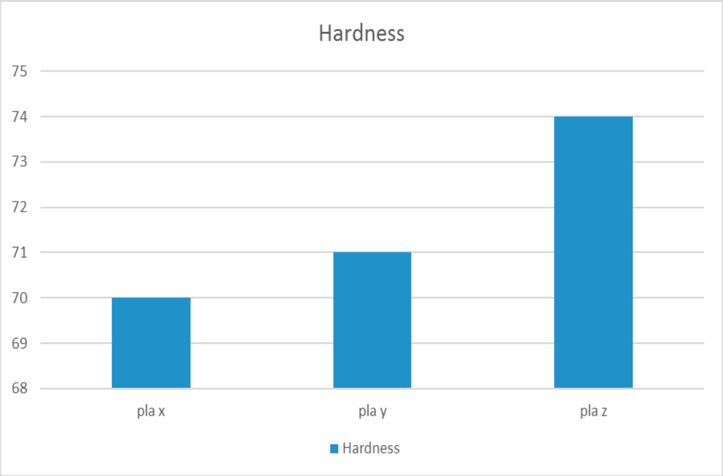
Fig 9: Hardness test for PLA Test specimen results with different orientation



6. CONCLUSION

The experimental study conducted to investigate mechanical properties of Polylactic acid the polymer built in with different orientation created by FFF led to the following conclusion:

- The standard test specimens of PLA are fabricated in different orientations.
- With tensile test, it has been noted that the tensile properties of specimen built along X-axis direction were superior compared other specimen built with different orientation. % of elongation in X-axis is observed to be enhancing better than the other orientation.
- Dimensional accuracy was observed to be desirable along X-axis part orientation and there does not exist discrepancy in actual and desirable dimension of the parts.
- However there is significant difference in value of hardness for specimen built along x-axis found to be minimum and maximum for the part built along z-axis orientation.

Acknowledgements

The authors like to convey their thanking to the SJC College of Engineering, Mysore-570006, Karnataka, India, The VTU, Belgaum-590018, Karnataka, India and APS College of Enginering, Bangalore-560082, Karnataka, India, for the encouragement and support in carrying out the research work.

Declaration of Competing Interests

The authors claim to be unaware of any financial or personal ties that may have affected their study.

Funding

"During the preparation of this work, the authors state that they did not receive any funding, grants, or other support of any kind".

ISSN 1533-9211
DOI 10.17605/OSF.IO/HQY6Z

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