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Experimental Investigation on Comparing Mechanical Properties in 3D Printed Polymers by Varying Process Parameter

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Abstract

The Desktop 3D printing is a quickly emergent additive manufacturing process due to its capacity to build complex geometry functional parts. Polymer filaments are used as a raw material for building various functional parts. 3D printing process parameters influence the mechanical properties of a built part. The present study investigate the effect of process parameters like layer thickness and layup speed on the mechanical properties of PLA, Bronze filled PLA and ABS samples manufactured with a low cost 3D printer. Tensile and flexural tests based on ASTM D638 and ASTM D760 standards were performed, respectively to determine the mechanical response of the printed specimens. With respect to the layup speed and layer thickness, it is found PLA has better tensile and flexural properties compared to ABS and Bronze filled PLA.

Keywords: *3D printing, Flexural & Tensile Characterization.*

1.0 Introduction

Rapid prototyping is the most useful method in manufacturing complex geometry [1-4]. The manufacturer can develop complex geometry functional parts using additive manufacturing technology by optimising various process parameters [5]. Fusion deposition modelling (FDM) is the most promising method to manufacture 3D components [6]. FDM involves the fundamental concepts of surface chemistry, thermal and layered manufacturing technology. In FDM raw materials are fed in the form of filament with diameter varying from 1 to 1.75 mm to the nozzle and heated filament is extruded to deposit it in a layer in XY plane [7-10]. In this work acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) & Bronze filled PLA are used as a thermoplastic filament for developing 3D parts.

The various process parameters in FDM are categorized into layer thickness, layup speed and thermal conditions. Evaluation of the process parameters plays a prime role in determining the mechanical properties of 3D specimens. Generally, 3D prototypes are used as a presentation or educational models, functional parts and visual aids in various areas [11-12].

PLA and Bronze filled PLA are the biodegradable, biocompatible and non toxic material used for various medical applications [13-14]. PLA extends a best quality as adhesion on textile materials and also improves the mechanical property for the textile garments [15].

ABS is a thermoplastic material with the natural property of becoming soft while heating and solidifies

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while cooling. The higher strength is found in ABS specimens while inspecting the fracture region manufactured by FDM technology [16]. The tensile strength of ABS specimen fabricated by FDM technique has 11 to 40 MPa [17-21]

In this present study, an attempt has been made to investigate the mechanical characterization of 3D printed specimens as per the ASTM standards by varying process parameters like layer thickness and layup speed.

2.0 Methodology

PLA, ABS and Bronze filled PLA specimens are fabricated in low cost desktop 3D printer using FDM techniques. The tensile and flexural specimens are printed using Type 1 specification using ASTM D638 and ASTM D790 standards represented in Figure 1. The dimension used are represented in Table 1

Total nine parts of each PLA, ABS and Bronze filled PLA are printed on the Kapton Tape build surface. The temperature at the nozzle is maintained at 190ºC for the extrusion of filament and the printer platform is maintained at 60ºC. The printing parameters Layer height, lay-up speed density etc are as shown in Table 2.

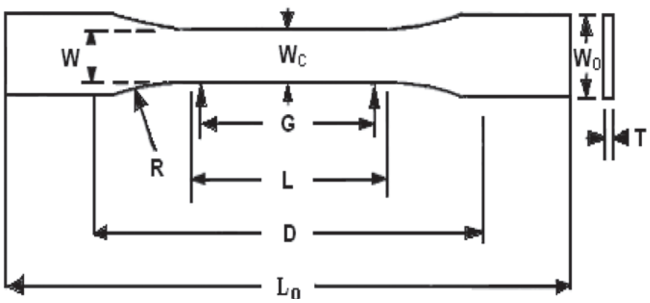

Figure 1: Tensile sample designed in 3D CAD program

Table 1: Specimen specifications

	Geometrical parameter	Dimensions(mm)
1	W-width of a narrow section	13
2	L- length of a narrow section	57
3	WO-width overall, minimum	19
4	LO-length overall, minimum	165
5	G-Gauge length	50
6	D-Distance between grips	115
7	R-Radius of fillet	76

Table 2: Process parameter for 3D printer

Printing Parameter	Particulars
Layer height (mm)	0.4, 0.45 & 0.5
Lay-up speed (mm/Min)	45, 50 & 55
Infill Density, %	100
Infill Pattern	Longitudinal
Nozzle dia (mm)	0.6
PLA density	1.24g/cm3
ABS density	1.04g/cm3
Bronze filled PLA	1.15 g/cm3

2.1 Fabrication of Test specimens

The tensile and flexural samples are modelled using CAD software and sliced using Slice 3r. After slicing the file transformed into .stl format then fed into the 3D printer for fabricating tensile and flexural specimens. Type 1 dimensions are selected for printing the tensile specimens. The 3D specimens printed PLA, ABS and Bronze filled PLA as shown in Figure 2.

Figure 2: Tensile sample made by 3D printing

2.2 Tensile Test

Tensile test is one of the characterization techniques of material to show its strength on loading on uni-axial extension. The tensile test is conducted in the universal testing machine with 10kN load cell. The specimen placed between the Jaws as shown in the Figure 3. The load is applied with crosshead speed of 3 mm per minute. The results obtained represented in the Table 2.

2.3 Flexural Test

A rectangular specimen model is developed in CAD software for flexural testing is shown in Figure 4. The

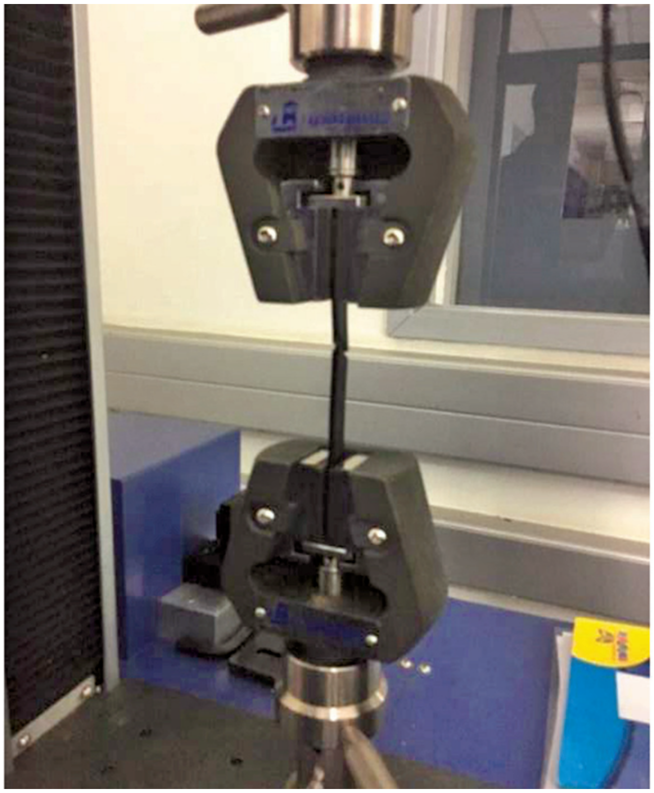

Figure 3: Experimental setup for performing tensile test

specimen is 13.8 centimetres long, 13.5 millimetres wide (b) and 3.5 millimetres tall (h). The specimen is placed on two supports that are 100 cm apart (L), and the actuator is applying a force in the exact middle of the two supports (L/2) and the radii of loading nose is 150mm (R).

Flexural or bending test is characterizes material to with stand the transverse loads. The bending strength is the very much essential for any material to use in day today applications. The flexural test sample is fabricated with different lay up speed and height. The flexural test is performed as per the ASTM D790 standard. The sample specimens of PLA bronze filled PLA & ABS is shown in Figure 5.

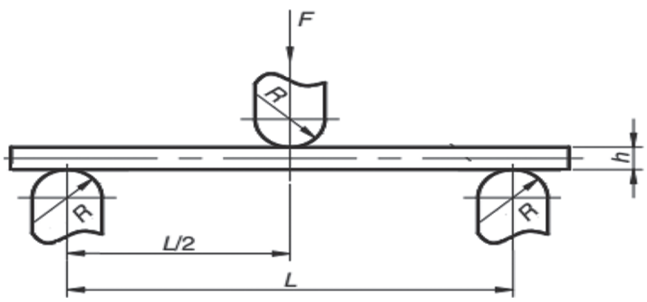

Figure 4: Flexural model is developed in CAD software

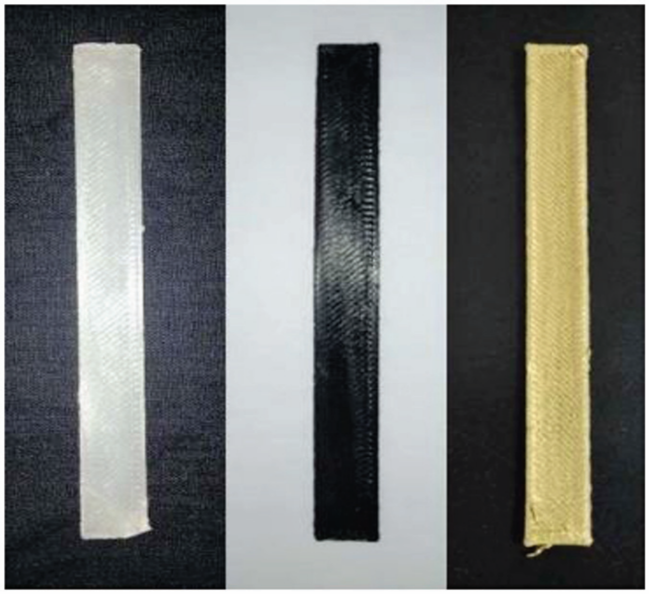

Figure 5: Flexural parts made by 3D printing

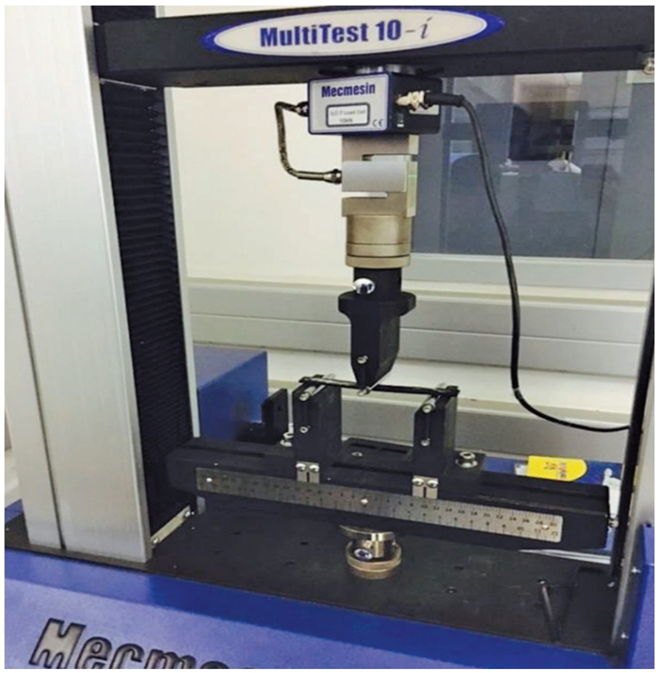

Figure 6: Three-point bending test

The rectangular samples kept in three point bending arrangement as indicated in Figure 6. Flexural strength (σ), and Young's Modulus (E) of the specimen is calculated using load v/s displacement curve. The result of all the specimens is tabulated in the Table 2.

Table 3: Representation of Tensile properties

Sample	Layer height (mm)	Lay-up speed (mm/Min)	PLA		Bronze Filled PLA		ABS	
			Ultimate load (KN)	Ultimate Tensile strength	Ultimate load (KN)	Ultimate Tensile strength	Ultimate load (KN)	Ultimate Tensile strength
1	0.4	45	2.25	41.83	1.11	26.47	1.1	24.81
2	0.4	50	2.2	40.15	1.05	25.49	1.06	23.28
3	0.4	55	2.1	39.67	1.02	22.17	1.09	22.2
4	0.45	45	2.13	40.44	0.97	21.52	1.07	24.49
5	0.45	50	2.29	39.75	0.93	20.3	1.06	20.28
6	0.45	55	2.16	38.94	0.86	19.46	1.05	19.36
7	0.5	45	1.82	35.82	0.83	18.62	0.97	24.37
8	0.5	50	1.78	35.04	0.79	17.4	0.77	17.07
9	0.5	55	1.8	34.14	0.72	16.57	0.76	15.49

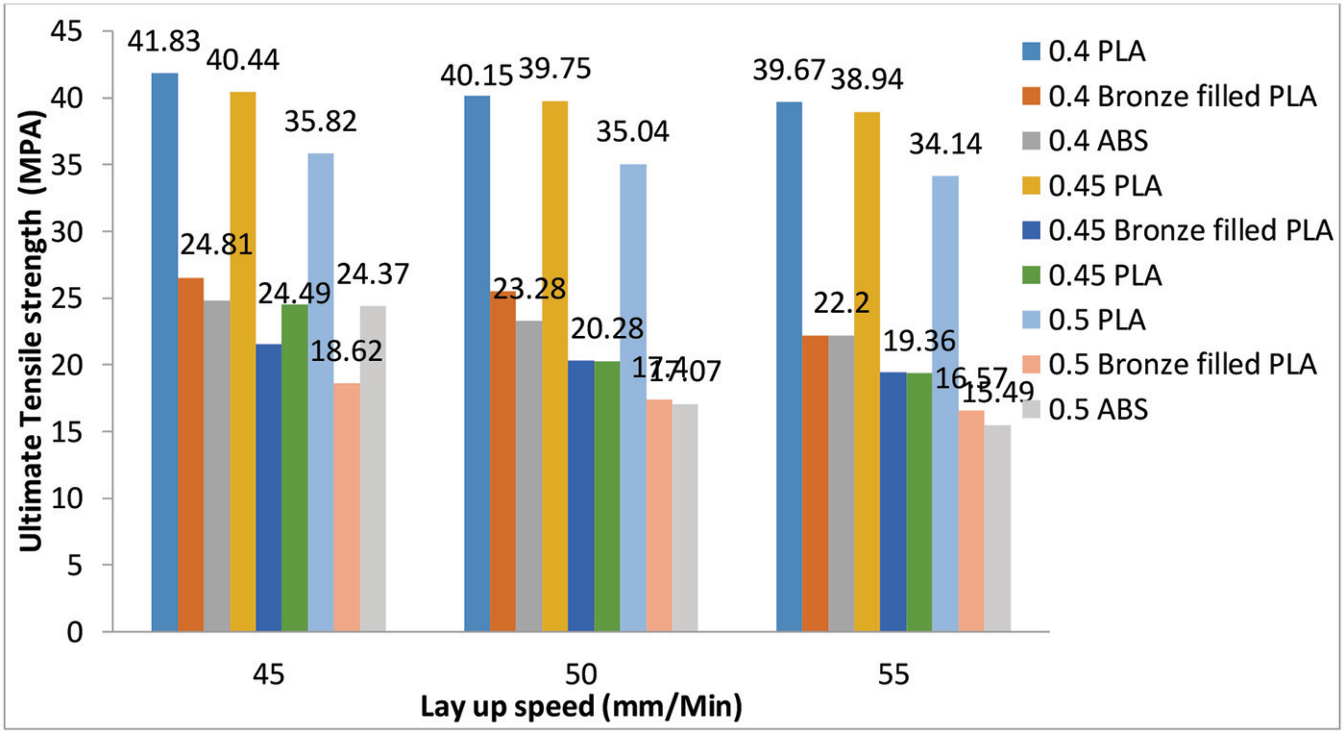

Figure 7: Tensile strength for varying layer height & constant layup speed

3.0 Result and Discussion

3.1. Mechanical properties

The mechanical properties of the 3D printed parts depend on the process parameters like layer height and lay up speed. The results represented in Tables 3 and 4 clearly shown that 3D parts printed with a lower speed and height have good mechanical properties than the other parts printed with higher speed and height because of more curing and settling time.

PLA showed better tensile characteristics than ABS and bronze filled PLA. The detailed comparison of

Table 4: Flexural properties of PLA, ABS and Bronze filled PLA

			PLA		Bronze Filled PLA		ABS	
	Layer height (mm)	Lay up speed (mm/Min)	Young's modulus (Gpa)	Flexural Strength (Mpa)	Young's modulus (Gpa)	Flexural Strength (Mpa)	Flexural modulus (Gpa)	Flexural Strength (Mpa)
1	0.4	45	3.1	78.45	1.91	41.69	2.21	52.51
2	0.4	50	2.79	73.6	1.68	40.98	2.11	51.15
3	0.4	55	2.64	68.23	1.61	40.18	1.92	51.08
4	0.45	45	2.54	64.23	1.46	39.2	1.76	49.97
5	0.45	50	2.27	61.2	1.39	36.13	1.64	49.75
6	0.45	55	2.03	58.1	1.34	34.25	1.56	48.89
7	0.5	45	2.47	54.21	1.2	31.57	1.64	48.22
8	0.5	50	2.11	52.35	1.18	29.12	1.46	47.55
9	0.5	55	1.92	49.45	1.08	28.18	1.26	46.88

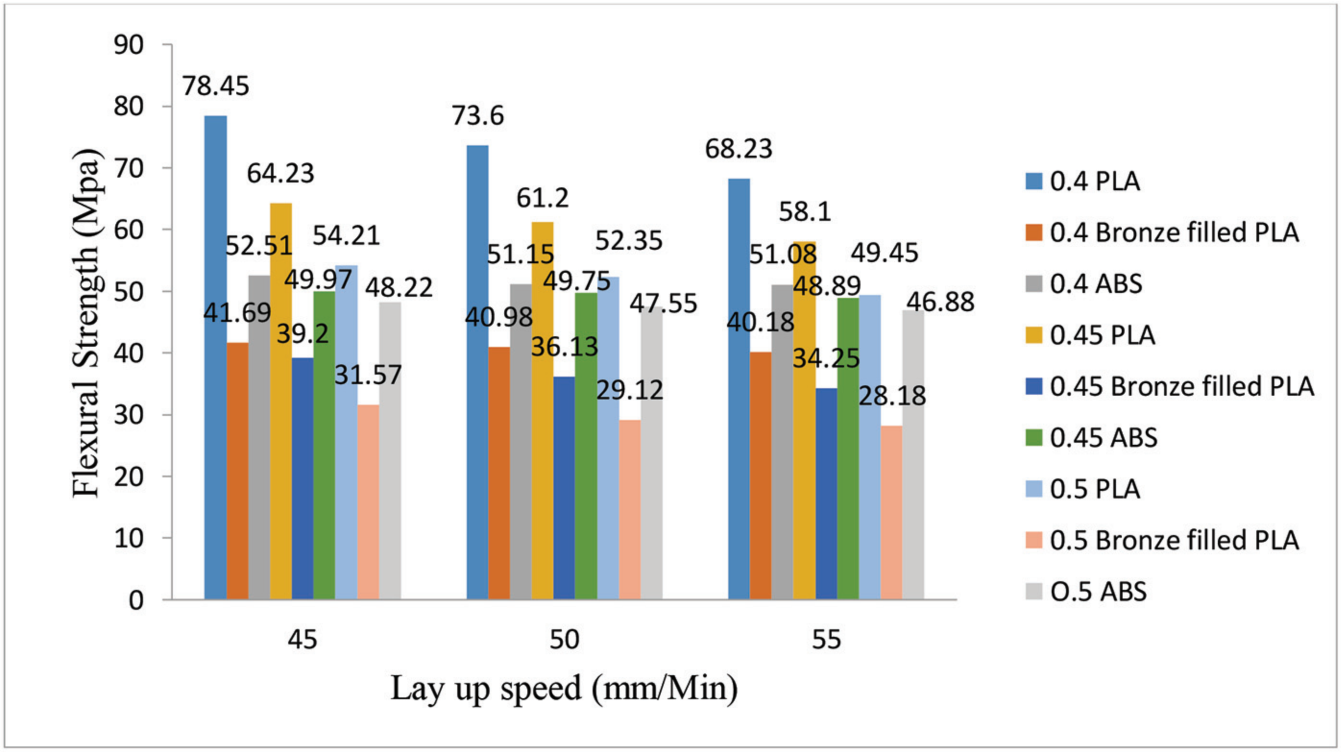

Figure 8: Graph of parts printed with varying speed and height indicating Flexural strength.

tensile strength of specimen fabricated with various layer height and layup speed is shown in the below Figure 7. This may be occurred due to more time for curing, binding and consolidation [22].

3.2. Flexural properties

Flexural test is performed on the custom-made Digital system with a maximum loading force of 20kN. The Table 3 is tabulated with the flexural strength and young's modulus of PLA, ABS and Bronze filled PLA.

Flexural strength of PLA, ABS and Bronze filled PLA parts are represented in Figure 8. The parts printed with Poly Lactic acid showed better tensile characteristics than ABS and bronze filled PLA. The Bronze filled PLA exhibits poor flexural property when compared with PLA and ABS.

4.0 Conclusion

The mechanical properties of the PLA, ABS and Bronze filled PLA made-up by FDM technique are determined through tensile and flexural tests. 3D printed parts with lower layup speed and height exhibit better tensile and flexural strength than the other parts printed with higher speed and height. PLA filament has higher tensile and flexural strength compared to ABS and bronze filled PLA. 3D parts printed with 0.4mm layer height and 45mm/min lay up speed have higher mechanical properties.

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