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3D Printing & Mechanical Characteristion of Polylactic Acid and Bronze Filled Polylactic Acid Components

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Abstract: Rapid prototyping (RP) technologies have emerged as fabrication methods to obtain engineering components within a short span of time. Desktop 3D printing, also referred as Additive Manufacturing (AM) technology is a powerful method of rapid prototyping technique that can fabricate three-dimensional engineering components. Poly Lactic acid (PLA) is a green alternative to petrochemical commodity plastics, used in packaging, agricultural products, disposable materials, textiles, and automotive composites, 3-D printing technology enables fabrication of PLA and bronze filled PLA, which has less tensile and flexural modulus. In order for 3D printed parts to be useful for engineering applications, the mechanical properties of the material will play an important role in the functioning of the components. In the present study, commercial grade PLA & bronze filled PLA has been considered as material for preparation of samples using desktop 3D printer. The samples were tested for their mechanical characteristics like Tensile and flexural strength properties. The test Samples were fabricated using 3D printing with different layer height and with different layer build-up speed. Comparison between the PLA & bronze filled PLA based on the experimental results are discussed and found PLA has superior tensile and flexural property when compared to Bronze filled PLA.
Keywords: 3D printing, PLA, Bronze filled PLA.

1. Introduction

Thermoplastic polymers reinforced with natural fibres are increasingly studied as they provide an interesting range of specific mechanical properties in combination with a controlled environmental footprint [1]. 3D Printing is the process by which a 3D digital design is converted into a component by depositing material using additive processing. As a process, components are made layer-by-layer from a range of materials which are available in; liquid resin, filament and fine powder form. As a result, a range of different metals, plastics and composite materials can be used to make 3D printable objects [2]. Fused deposition modeling (FDM) is one of the popular additive manufacturing technique, after stereo-lithography [5]. It is a process of depositing material layer-by-layer through heated nozzle, whose position is controlled in two axes, on a platform which descends to add third dimension to the part [6]. In FDM printing, usually diverse thermoplastic polymers are used, such as PLA, Acrylonitrile butadiene styrene (ABS), polyamide 6.6 (PA 6.6), polycarbonate, etc. [4]. Additionally, several special filaments exist, combining polymers with different other materials, such as wood, brick dust, or metal particles. These filaments, however, are in the moment only used for printing models, not objects that may be stressed mechanically, since their mechanical properties are known to be reduced in comparison with pure polymer filaments.

In this paper, describes the mechanical properties of two commercially available PLA & bronze filled PLA, fabricated by different printing parameters, and measured in elongation and bending tests. PLA was chosen as the base material due to several reasons: Firstly, it belongs-together with ABS-to the most often used polymers in FDM printing. PLA is of special interest due to its biocompatible, biodegradable, non-toxic, non-immunogenic, and non-inflammatory properties, making the material usable in medical applications [3]. In biomedical applications, degradation is often advantageous, especially due to the lack of toxicological risks [9]. Additionally, PLA offers the best adhesion on textile materials and is thus also suited to add new mechanical properties or design aspects to technical textiles or garments [10]. The latter aspect is of special importance for metal-filled printing polymer, which can be expected to show a reduced mechanical strength, but interesting optical properties, suggesting their use in combination with another material with higher tensile strength.

2. Experimental details

Tensile and Flexural specimens are prepared from desktop 3D printing process (3D photomaker). The printing process is carried out with high resolution in X-Y directions. PLA and Bronze filled PLA filaments are heated to melting temperature and made to flow through nozzle and printed on the print-block. However, the worker can prefer to leave the top surface uncoated. During printing process, the print-block can move along the X-axis and deposits material in to &fro translations. After the completion of printing process, the print block brought down to remove the specimen.

PLA & Bronze filled PLA specimens were manufactured with variable layup speed and layer height. For printing the specimen, 3D models are created in CAD software and it is converted into a stereolithography (STL) files for tensile and flexural test specimen as per ASTM D638 and D790 standard. Total 18 specimens of both PLA & Bronze filled PLA are manufactured for experimental testing. Slice3r software is used for slicing the .STL files into machine readable G- codes.

2.1. Preparation of tensile test specimens:

To evaluate mechanical characterization, nine samples of both PLA & Bronze filled PLA were made with variable layup process parameters. The dog-bone sample shown in Fig 1 is designed using a 3D CAD program confirming to the geometry and dimensions indicated in the ASTM D638 and Type I dimensions are selected which is tabulated in table 1 3D CAD model is converted into a .STL format and this file format that is transferred to Slice 3r software provided to slice the part, design the road tool path. This related command is send to the 3D printing machine. After slicing the parts, the tool path has been chosen first so as to obtain a pseudo-isotropic stacking sequence.

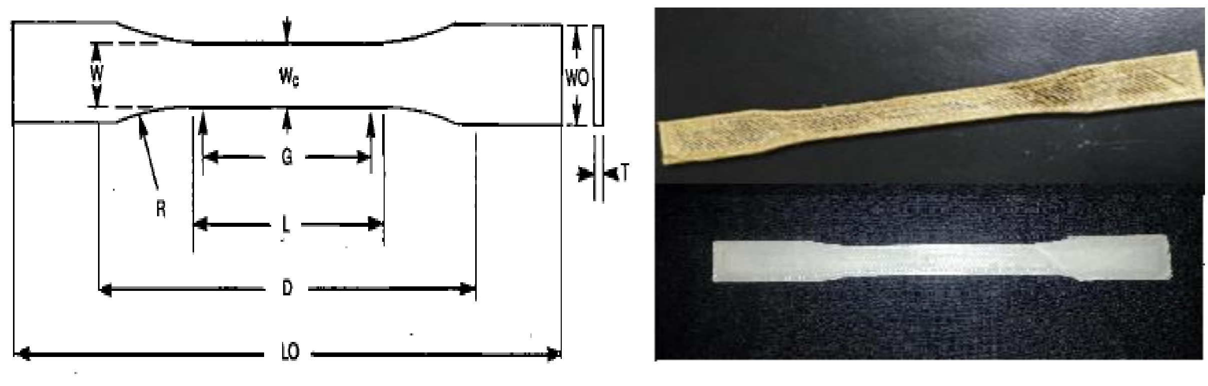

Figure 1 dog-bone sample designed using a standard 3D CAD program.

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Table 1. Specimen specifications

Sl. No.	Particulars	Type I 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

2.2. Experimental procedure for tensile specimen:

Diameter and gauge length of the specimen are measured with the help of vernier-caliper of accuracy 0.02mm to evaluate the tensile strength. Displacement for variable loads is recorded; the stress-strain curves of each tested specimen are generated respectively. Ultimate tensile strength of each specimen is tabulated. Experimental setup for tensile test is shown in the Fig 2.

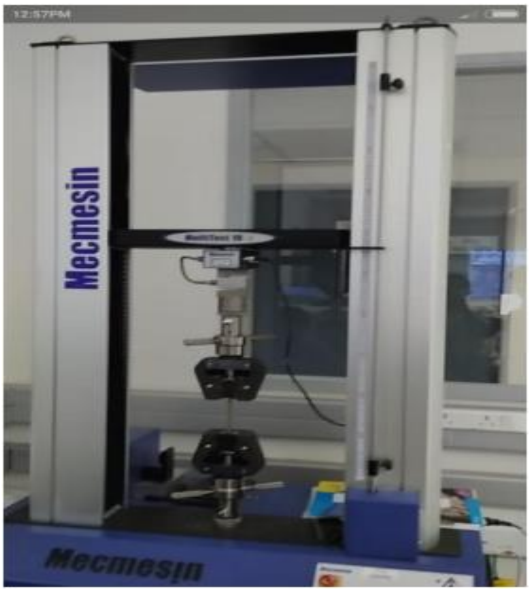

Figure 2 Jaws of the tensile test machine holding the 3D parts.

2.3. Preparation of flexural test samples:

Three-point bending test is carried out to evaluate the flexural properties, nine samples of both PLA & Bronze filled PLA were made with different layup speed and layer height. According to the ASTM D 790 dimensions of Molding Materials (Thermoplastics and Thermosets) are recommended to be L=12.7 by h=3.2 mm tested flat wise on a support span (Minimum radius R = 3.2 mm) as shown in Figure 3 The sample is designed using a standard 3D CAD program and thus it is transferred in a .STL format. This file format can be transferred into Slice 3r which slice the part and finally printed in 3D desktop printer.

2.4. Experimental procedure for flexural specimen:

A rectangular specimen is subjected to a three-point bending test. The dimensions of test specimens were determined using verniercaliper. The specimen is 13.8cm long, 13.5mm wide (b) and 3.5mm tall (h). The specimen is placed on two supports that are 100 cm apart (L) as shown in the Fig 4, and the actuator is applying a force in the exact middle of the two supports (L/2). Computerized load v/s

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displacement curve is plotted to determine the maximum flexural strength (σ), and Young's Modulus (E) of the specimen. Elastic modulus was determined from the slope of the straight-line portion of the stress strain curve.

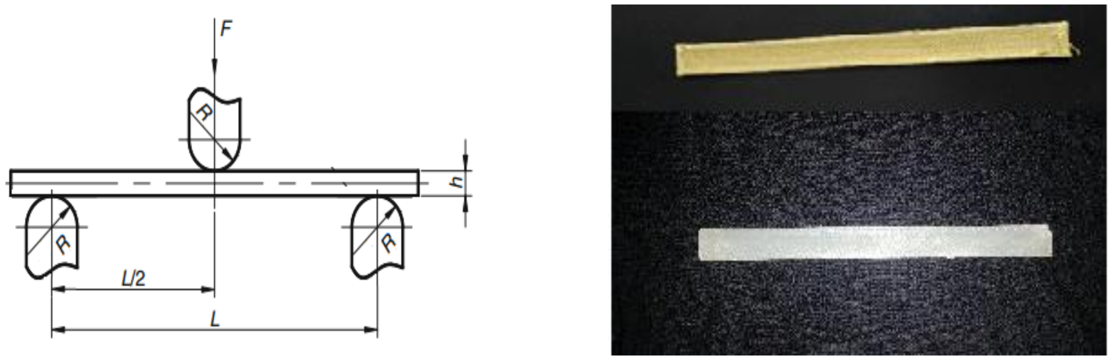

Figure 3 Flexural specimen for bending test.

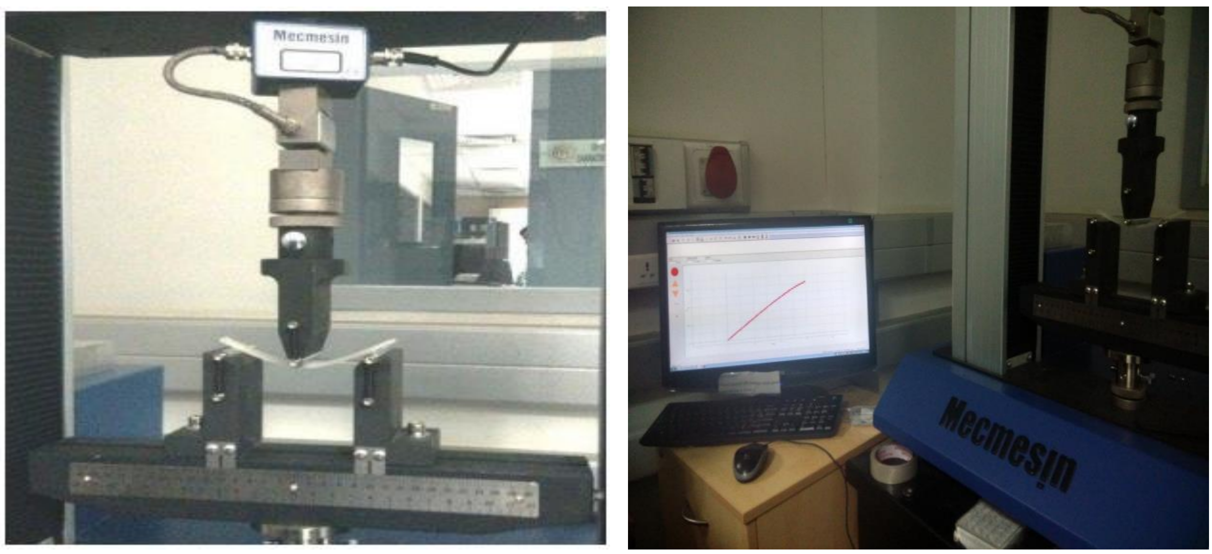

Figure 4 Three-point bending test setup

3. Results and discussion

3.1. Mechanical properties

The superior mechanical properties of PLA & Bronze filled PLA are attributed by less layer height and minimum layup speed. Table 2 represents the tensile strength of PLA & Bronze filled PLA made with various process parameters such as layer height & layup speed. Specimens printed with a 0.4 mm layer height and 45 mm/Min layup speed had the highest tensile strength in both PLA & Bronze filled PLA. Minimal tensile strength is identified when specimens printed with 0.5mm layer height and 55mm/min layup speed.

Comparison of Tensile strength of PLA & Bronze filled PLA categorized by layer height and layup speed is shown in Figure 5. In PLA the tensile strength reaches maximum of 41.83 MPa for the layup speed 45mm/Min at a layer height of 0.40mm and has minimal of 34.14MPa for the layup speed 55mm/Min and layer height 0.5mm. In bronze filled PLA for layup speed 45mm/Min at a layer height of 0.40mm has maximum tensile strength of 26.47 MPa and has minimal of 16.57 MPa for the layup speed 55mm/Min and layer height 0.5mm. It may notice that lower the layup speed and layer height, higher is the tensile strength in both PLA and Bronze filled PLA. In PLA at 0.4mm layer height, increase in tensile strength is by 36.72% for layup speed of 45mm/min, 36.51% for layup speed of 50mm/min and 44.11% for layup speed of 55mm/min when compared with Bronze filled PLA. This may be attributed to increased curing time, consolidation and binding. PLA exhibits highest tensile property when compared with bronze filled PLA. Because bronze filled exhibits lower strain to failure due to irregular powder. The distribution of the bronze particles is quite irregular; such in homogeneities will result in some areas being less strong, containing less polymer material and more bronze than others, becoming the "weak links" in the whole sample [8].

Table 2. Comparison of Tensile strength of PLA & Bronze filled PLA categorized by layer height and layup speed

Sample No	Layer height (mm)	Lay up Speed (mm/Min)	PLA		Bronze Filled PLA	
			Ultimate load (KN)	Ultimate Tensile strength	Ultimate load (KN)	Ultimate Tensile strength
1	0.4	45	2.25	41.83	1.11	26.47
2	0.4	50	2.20	40.15	1.05	25.49
3	0.4	55	2.10	39.67	1.02	22.17
4	0.45	45	2.13	40.44	0.97	21.52
5	0.45	50	2.29	39.75	0.93	20.30
6	0.45	55	2.16	38.94	0.86	19.46
7	0.5	45	1.82	35.82	0.83	18.62
8	0.5	50	1.78	35.04	0.79	17.40
9	0.5	55	1.80	34.14	0.72	16.57

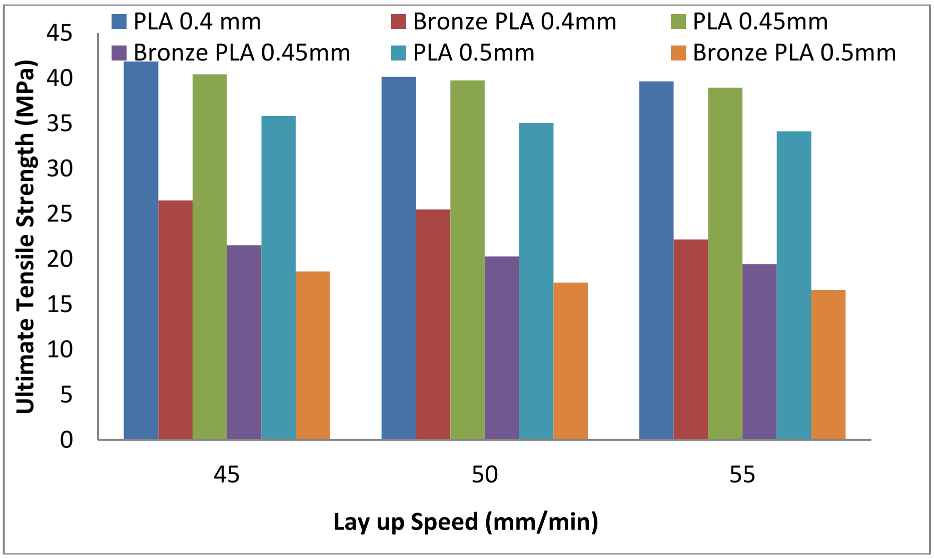

Figure 5 shows tensile strength for varying height and constant speed

For determining the flexural properties custom built Digital Flexural test system was used with a maximum loading force of 20kN. For determining the flexural properties, the test specimen placed over the jaws of the Digital Flexural test system and extended with force F, at cross head speed t=3 mm/min, as defined by ASTM standard.

The young's modulus of the printed specimens calculated using the formula given below.

$$E = \left(\frac{P}{\Delta}\right)\frac{L^3}{4t^3W}$$

The flexural strength of the printed specimens calculated using the equation given below.

$$\alpha = M/Z = \frac{PL*6}{4*Wt^2}$$

The flexural strength and young's modulus are tabulated in the table 3

Table3. Shows the flexural strength and young's modulus of tested specimen

Sl no	Layer height (mm)	Lay up speed (mm/Min)	Young's modulus (Gpa)	Flexural Strength (Mpa)	Young's modulus (Gpa)	Flexural Strength (Mpa)
1	0.4	45	3.10	78.45	1.91	41.69
2	0.4	50	2.79	73.60	1.68	40.98
3	0.4	55	2.64	68.23	1.61	40.18
4	0.45	45	2.54	64.23	1.46	39.20
5	0.45	50	2.27	61.20	1.39	36.13
6	0.45	55	2.03	58.10	1.34	34.25
7	0.5	45	2.47	54.21	1.20	31.57
8	0.5	50	2.11	52.35	1.18	29.12
9	0.5	55	1.92	49.45	1.08	28.18

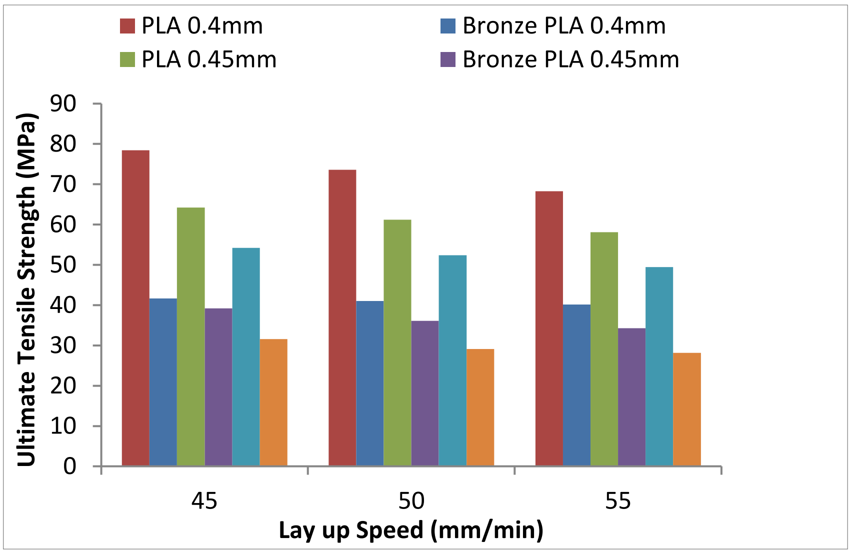

Figure 6 Flexural strength of PLA and Bronze filled PLA for varying speed and height.

Comparison of flexural strength of PLA & Bronze filled PLA categorized by layer height and layup speed is shown in Fig 6. PLA & Bronze filled PLA specimens are printed at variable layup speed 45mm/Min, 50mm/Min & 55mm/Min and at variable layer height 0.40mm, 0.45mm & 0.5mm. In PLA the flexural strength reaches maximum of 78.45 MPa for the layup speed 45mm/Min at a layer height of 0.40mm and has minimal of 49.45MPa for the layup speed 55mm/Min and layer height 0.5mm. In bronze filled PLA for layup speed 45mm/Min at a layer height of 0.40mm has maximum flexural strength of 41.69MPa and has minimal of 28.18 MPa for the layup speed 55mm/Min and layer height 0.5mm. In PLA at 0.4mm layer height, increase in flexural strength is by 46.85% for layup speed of 45mm/min, 44.32% for layup speed of 50mm/min and 41.11% for layup speed of

55mm/min when compared with Bronze filled PLA. Flexural strength has highest value in natural PLA compared with bronze filled PLA. Because bronze filled exhibits lower strain to failure due to irregular powder and higher percentage fill. Other factors which may cause less tensile strength when compared with bronze filled PLA are bonding, distribution & surface finish [7]. As the metal volume percentage increases, the porosity increases, and lower strength is exhibited.

The young's modulus of the printed PLA specimen has higher value when compared to Bronze filled PLA. In PLA the young's modulus reaches maximum of 3.1 GPa for the layup speed 45 mm/Min and layer height 0.4mm and has minimal of 1.92 GPa for the layup speed 55mm/Min and layer height 0.5mm. In Bronze filled PLA young's modulus reaches maximum of 1.9 GPa for the layup speed 45 mm/Min and layer height 0.4mm and has minimal of 1.08 GPa for the layup speed 55mm/Min and layer height 0.5mm.

4. Conclusion

The mechanical properties of PLA components made using desktop 3-D printers were characterized through standard tensile tests and flexural test to determine tensile strength and flexural strength. The results show that the ultimate tensile strength and flexural strength of 3D printed PLA specimens has superior when compared with Bronze filled PLA. For layer height 0.4mm and layup speed 45mm/min ultimate tensile strength is increases by 36.72% and flexural strength is increased by 46.85% in PLA when compare with bronze filled PLA. It is also identified that as the layer height and layup speed increases the tensile strength, flexural strength and young's modulus decreases both in PLA and Bronze filled PLA. From these results it may be concluded that lower the layup speed and layer height higher the tensile strength, flexural strength and young's modulus in both PLA and Bronze filled PLA.

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