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Effect of layer thickness on flexural properties of PLA (PolyLactid Acid) by 3D printing

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Abstract. This article focuses towards the newer manufacturing technique 3D Printing (3DP). The objective of this work is the mechanical characterization (flexurel properties) of materials produced by 3D printing based on fused filament fabrication with fused deposition modeling (FDM). The materials chosen are a polylactic acid (PLA)**.** This paper described the effect of different layer thickness of PLA by 3D printing on flexural properties.Additive manufacturing, also known as 3D printing, is a common material extrusion process using (bio) polymers PLA. The study begins from manufacture the solid 3D model based on the ASTM standards for flexural properties test of the material using Three-point bending method. Three-point bending test was conducted with Tensilon Universal Testing Machine – AND RTF-2410 with a 100kN load cell, specimen shape and size according to standard size ASTM D 790. The result shown that the layer thickness had an effect on flexural strengths of PLA samples. The maximum flexural strengths from Lt =0.4 to 0.5mm were significantly increase. Moreover, it is worth nothing that ductility decreased as layer thickness increased. According to test result that the maximum flexural strength occurred at 0.5 mm layer thickness with 59.6 MPa and the minimum flexural strength occurred at 0.1 mm layer thickness with 43.6 MPa. The higher layer thickness tended to promote higher strength. The thicker layer is the stronger layer bond in holding the load bending. In this study the thicker layer have tendend to shown a 90-degree delamination fracture and the thinner layer have tendend to shown a 45-degree delamination fracture according to the direction of printing is ± 45°.

1. Introduction

3D printing is one of the main drivers of innovation in smart manufacturing technologies. The first desktop 3D printers were developed by a team led by Professor Adrian Bowyer, at the University of Bath, giving way to the Replicating Rapid Prototype initiative (known as RepRap). The result of this project is an open source design of a self-reproducible 3D printer; all of the results are available online for other users [1]. In this modern manufacturing scenario cost effectiveness and environment friendly design of a production process plays a vital role. 3D Printing (3DP) is technology that can create complex geometry into a solid model. This solid model is made up Fused Deposition Modelling (FDM) method that is a type of rapid prototyping method. In this study, Poly Lactic Acid (PLA) is considered as an alternate to the existing material. PLA is a biodegradable polymer that possesses good strength and biodegradable property which is highly needed in production of newer components through 3D printing (3DP) [2]. The schematic representation of a Fused Filament Fabrication process can be seen in figure 1.

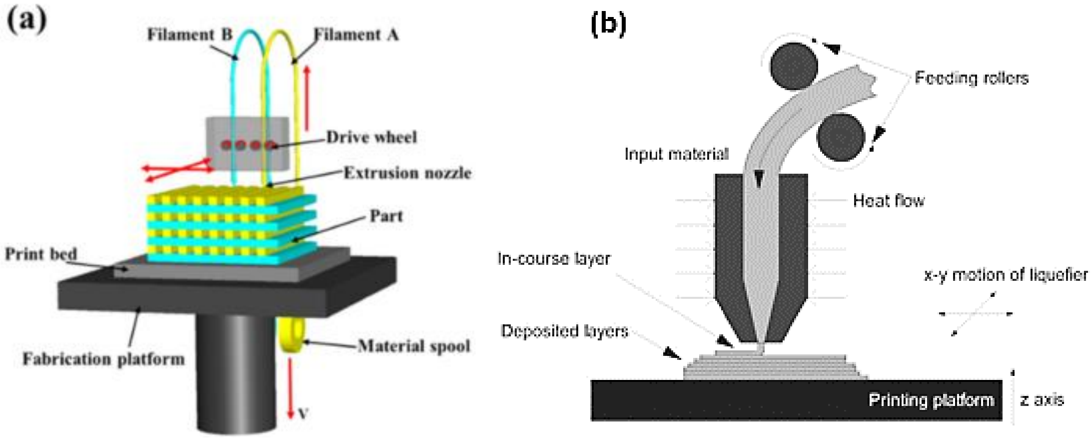

Figure 1. Schematic representation of typical [1]: (a) FDM setup (b) a Fused Filament Fabrication process.

Lembaga Penerbangan dan Antariksa Nasional (LAPAN) was developing unmanned aircraft called Lapan Surveillance UAV (Unmanned Aerial Vehicle – LSU). There were some kind of UAV developing by LAPAN such as LSU-01, LSU-02, LSU-03, and LSU-05. They have some missions such as air picture or mapping of certain region. The main materials used for LSU-02, LSU-03, and LSU-05 are polymer matrix composit using glass or carbon fiber and epoxy or polyester resin. The fiber is synthetic fiber type like glass, carbon, and aramid that widely used in composite because of its high stiffness, strength, and light weight [3]. An alternative materials that can be used in making LSU is PLA or ABS with 3D printing (figure 2), natural fiber and hybrid material. PLA 3D printing have a potential to be used light-weight unmanned aerial vehicle wing structures [4].

Figure 2. 3D printing Filament [5].

Fused deposition modeling (FDM) printers are the most commonly used printers for fabricating polymer composites. Thermoplastics such as PC, ABS and PLA, are commonly used due to their low melting temperature. FDM printers work by controlled extrusion of thermoplastic filaments, as shown in figure 1(a). In FDM, filaments melt into a semi-liquid state at nozzle and are extruded layer by layer onto the build platform where layers are fused together and then solidify into final parts. The quality of printed parts can be controlled by altering printing parameters, such as layer thickness, printing orientation, raster width, raster angle and air gap. The effects of processing parameters have been discussed by Sood *et al.* [6]. The disadvantage of FDM printers is that the usable material is limited to thermoplastic polymers with suitable melt viscosity. The molten viscosity should be high enough to provide structural support and low enough to enable extrusion. Also, complete removal of the support structure used during printing may be difficult. Notwithstanding these drawbacks, FDM printers also offer advantages, including low cost, high speed and simplicity. Another advantage of FDM printing is the potential to allow deposition of diverse materials simultaneously. Multiple extrusion nozzles with

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loading of different materials can be set up in FDM printers, so printed parts can be multi-functional with designed composition [7].

A more controversial parameter is layer thickness (Lt). Rankouhi *et al*. [8] stated that although layer thickness has been studied extensively, it should be further analysed due to the disparity of results. For examples, Sood *et al*. [6] concluded that tensile strength first decreased and then increased as layer thickness increased for Lt ={0.127,0.178,0.254} mm. Tymrak *et al*. [9] stated that the lowest thickness had the highest tensile strength for Lt = {0.2,0.4} mm. However, the authors concluded that PLA specimens showed greater variability between parameters. Lanzotti *et al*. [10] inferred that as the number of shell perimeters increased, the variation of tensile strength with the layer thickness was slightly significant in PLA samples. Ahn et at. [11] deduced a low level of significance of the effect of layer thickness on the final material properties of ABS samples. Finally, Vaezi and Chua [12] reported that for flat oriented samples, a decrease from Lt =0.1mm to Lt =0.087mm increased the tensile strength and decreased flexural strength.

The objectives of this research is to know the influence of layer thickness {0.1, 0.2, 0.3, 0.4, 0.5} mm on flexurel properties of PolyLactid Acid (PLA) 3D printing. three-point bending tests are carried out to determine the flexurel response in terms of strength and stiffness of the printed samples. Finally, conclusions and extensions of this work are outlined.

2. Method

The goal of this study is to analyse the flexurel performance of PLA samples. In this study, the commercial PLA filament with a diameter of 1.75mm was used. Typical values of the main mechanical properties of PLA materials manufactured by FDM technology [8,9] are presented in Table 1. PLA samples were manufactured using a FDM-50-5050 3D printer developed by ZBOT.CC are shown in figure 3 [14]. FDM-50-5050 3D printer is a low cost desktop printer that uses PLA material with a 0.4mm nozzle size. FDM-50-5050 3D printer can be controlled with any open source software. In this study, Cura software [15] was used to generate G-code files and to command and control all the process parameters. There are no standard test methods for flexural properties of parts manufactured using FDM. In this study, the ASTM D790 [16] methods were applied for testing flexural specimens, respectively. The geometry of the 3D printed specimens were modelled using SolidWorks software exported as an STL file and imported to the 3D printing software. The main dimensions of the specimens are shown in figure 4. with deposition line (layer thickness) height (0.1, 0.2, 0.3, 0.4 and 0.5) mm are shown in figure 5.

Figure 3. 3D *printer* ZBOT.CC [14].

Table 1. Typical ranges of mechanical properties for PLA materials fabricated with FDM technology [8][9].

Properties	PLA
Tensile strength (MPa)	15.5–72.2
Tensile modulus (GPa)	2.020–3.550
Elongation at break (%)	0.5–9.2
Flexural strength (MPa)	52–115.1
Flexural modulus (GPa)	2.392–4.93

Each sample set consisted of five specimens for a given group of process parameters, with a total of 25 specimens (flexural specimens). Average strength and stiffness values of the flexural test were taken as the results. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, tests were carried out according to the standards for room temperature. A 100 kN universal electro-mechanical testing machine Tensilon with a 100 kN load cell at a fixed loading rate of 10 mm/min was used 3-point bending tests. The three-point bending tests were performed following the ASTM D790 procedure [16] using a three point bending test fixture are shown in figure 6. The radius of the loading nose and the radii of the support noses of the three-point bending specimen test fixture were 3 mm. For flexural test, a three- point bending configuration was selected with a support span length of 50mm. The flexural modulus of elasticity (E_f) was determined following the previous standard, based on the Classical Beam Theory, supposing that shear effects are negligible. We can define the maximum normal stress σ_f in the three-point bending test as

$$\sigma_f = \frac{3PL}{2wt^2} \quad (1)$$

where P is the fracture force, L is the support span, w is the width of the specimen, t is the thickness of the specimen, and the maximum strain ε of the outer surface at mid-span, which was calculated as follows

$$\varepsilon = \frac{6\delta t}{L^2} \quad (2)$$

where δ is the mid-span deflection. The flexural modulus of elasticity E_f is the ratio of stress to the corresponding strain at a given point on the stress–strain curve. Hence, it can be calculated as

$$E_f = \frac{L^3 m}{w t^3} \tag{3}$$

where m is the slope of the secant of the load-displacement curve.

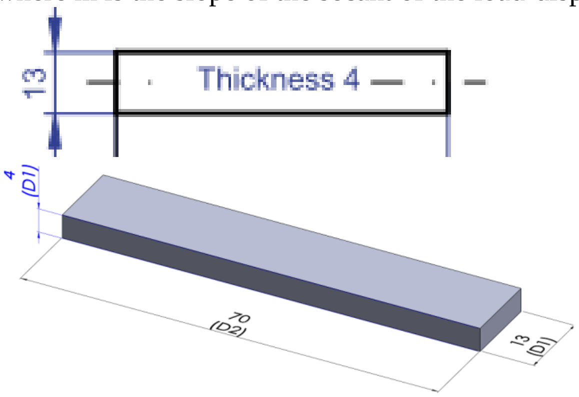

Figure 4. Standard specimens for 3-point bending specimen and dimensions are in mm [16].

In this study, a solid sample was filled with a raster perimeter analyzed, in which the tool path was offset from the perimeter with a distance equivalent to the nozzle size (Fig. 5a). Printing orientation can be seen in figure 5(b) but all samples are made with a raster angle of ± 45°.

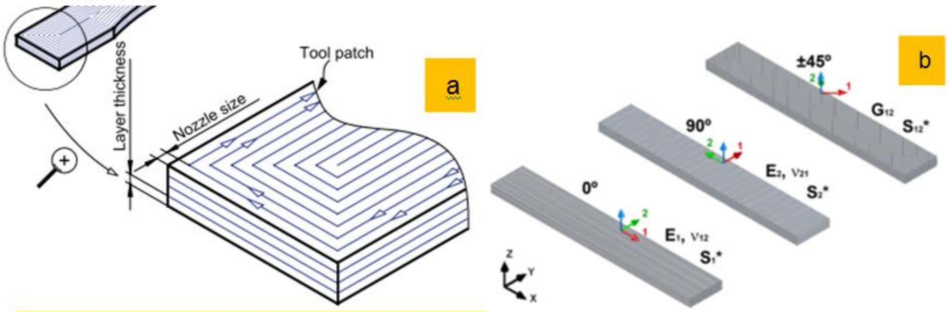

Figure 5. (a) Layer thickness and perimeter raster [17], (b) ilustration of printing orientations [18].

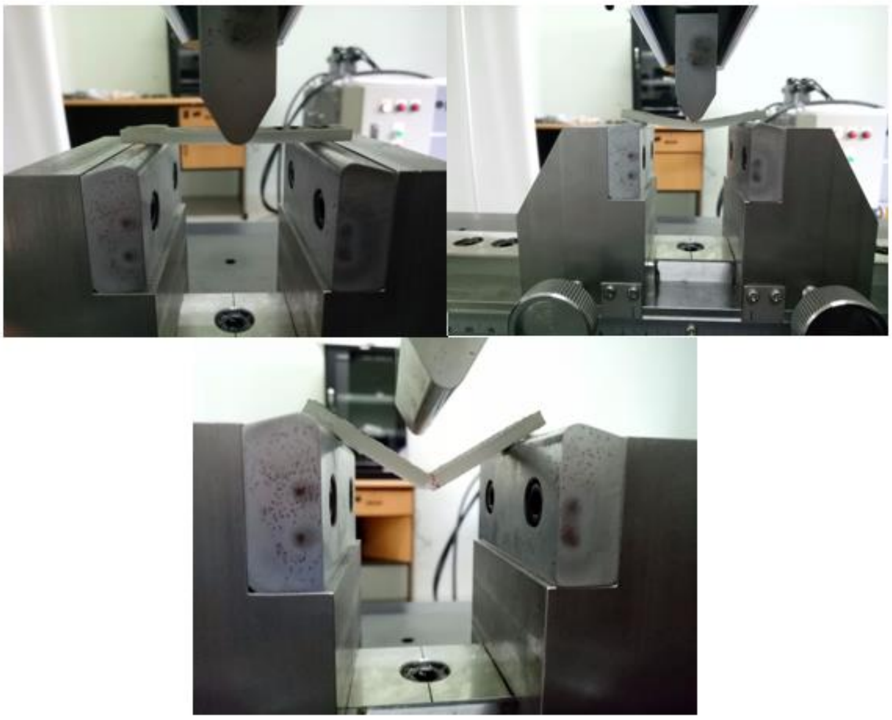

Figure 6. Three-point bending test.

3. Result and discussions

Average and standard deviation of the test results of the maximum load (P), maximum strengths (σ_f) and stiffnesses (E_f) for the printed PLA samples are tabulated for 3-point bending tests in table 2.

Tabel 2. Average 3-point bending test results of the samples and layer thickness parameters ranges. Standard deviation is depicted in brackets.

Layer thickness (mm)	P (N)	σ_f(MPa)	E_f(GPa)
0.1	118.076(9.59)	43.6(3.5)	1.19(0.65)
0.2	119.394(0.46)	44.1(3.2)	1.18(0.46)
0.3	118.744(0.62)	43.8(7.2)	2.13(2.65)
0.4	118.986(0.63)	43.9(6.4)	1.89(2.35)
0.5	161.44	59.	1.5

	6(0.41)	6(2 .8)	4(1. 05)

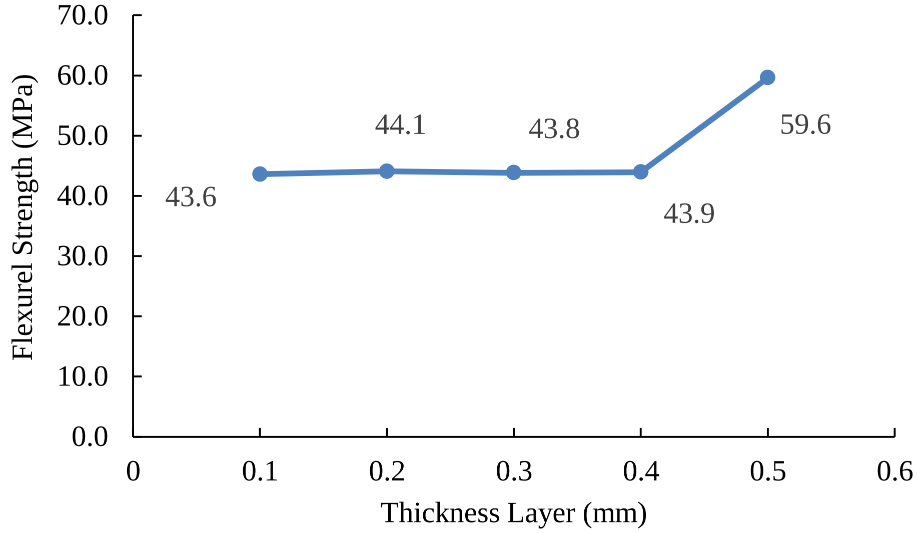

Figure 7. Graphical comparison of average maximum flexural strength (σ_f) for the flexurel specimens as a function of layer thickness.

Figure 7 shows that the increase in layer thickness affects the flexural strength of PLA materials made with 3D printers. At layer thickness {0.1, 0.2, 0.3 and 0.4}mm there is no difference but in the 0.5mm layer thickness there is a significant increase from 43.9MPa to 59.6MPa.

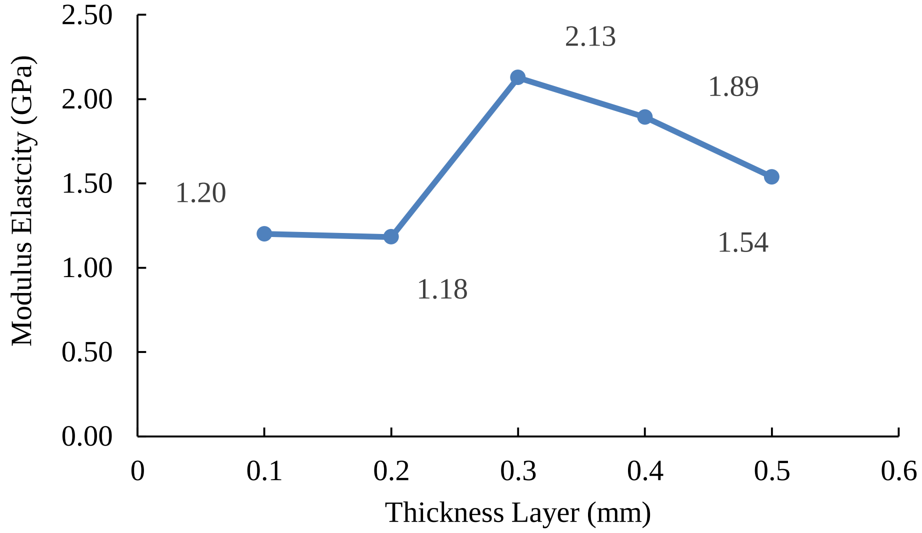

Figure 8. Graphical comparison of average maximum flexural stiffness (E_f) for the flexurel specimens as a function of layer thickness.

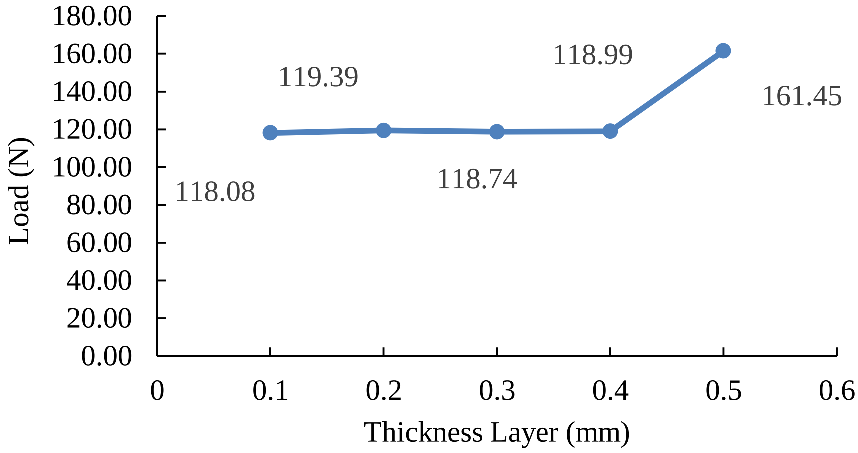

Figure 9. Graphical comparison of average maximum Load (P) for the flexurel specimens as a function of layer thickness.

Layer thickness is directly related to the number of layers needed to print a part and hence to printing time [17]. Figure 7, 8 and 9 shows the average maximum flexural strengths, modulus elasticty and load as a function of layer thickness. Each specimen has the same thickness of 4mm, but the layer thickness of the specimen is different from {0.1, 0.2, 0.3, 0.4 and 0.5}mm to get a thickness of 4mm. The load maximum received by the specimen is different for each specimen so that the value of the flexural strength is also different. The effect of layer thickness on the flexurel properties was different for each sample. In this case, higher layer thickness tended to promote higher strength. These results were in accordance with previous works with PLA [7][10][17]. Vaezi and Chua [12] reported that for flat oriented samples, a decrease from Lt =0.1mm to Lt =0.087mm increased the tensile strength and decreased flexural strength. In general, low layer thickness values resulted in increased in stiffness [9][8] with material ABS and PLA too. But in case, high layer thickness values resulted in increased in stiffness. The elasticity of sample Lt 0.3 has the higher value; it means that this may be due to the difference in printing direction, in case the printing direction of tool path is 45 degree.

Figure 10. Fracture characteristics of PLA samples with diffeerent layer thickness: (a) 0.1mm, (b) 0.2mm, (c) 0.3mm, (d) 0.4mm, (e) 0.5mm.

Figure 10 show the specimen after 3 point bending test, it can be analysed the fracture mode, layer thickness {0.1, 0.2, 0.3}mm have shown a 45-degree delamination fracture but layers thickness {0.4, 0.5}mm have shown a 90-degree fault. It has been explained that the thicker layer is the stronger layer bond in holding the load bending.

4. Conclusions

We have studied the effect of layer thickness on the flexurel properties of PLA samples manufactured with a 3D printer. Different ranges of the process parameters were analysed: layer thickness (Lt ={0.1, 0. 2, 0.3, 0.4, 0.5} mm. Layer thickness had an effect on flexural strengths of PLA samples. The Maximum flexural strengths from Lt =0.4 to 0.5mm has increased sharper than Maximum flexural strengths from Lt = 0.1 to 0.2 mm this result show that tensile strength first decreased and then increased as layer thickness increased and it's complying with previous research Sood *et al.* [6]. In short, the result underscored that in the case of upright orientation, tensile and flexural strengths increased as the layer thickness increased. In addition, in the case of on-edge and flat orientations, the variation of tensile and flexural strengths were of slight significance, except in the case of low layer thickness Lt =0.06 mm [17]. The higher layer thickness tended to promote higher strength. The thicker layer is the stronger layer bond in holding the load bending. In this study the thicker layer have tendend to shown a 90-degree delamination fracture and the thinner layer have tendend to shown a 45-degree delamination fracture according to the direction of printing is ± 45°.

Future works will study the other effect: Build orientation, Feed rate and Tool patch on mechanical properties. Also, will include investigations into other properties of the PLA samples such as tensile and shear strengths including numerical simulations.

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References

[1] R. Jerez-Mesa, J. A. Travieso-Rodriguez, X. Corbella, R. Busqué, and G. Gomez-Gras, "Finite element analysis of the thermal behavior of a RepRap 3D printer liquefier," *Mechatronics*, vol. 36, pp. 119–126, Jun. 2016.

[2] S. A. Raj, E. Muthukumaran, and K. Jayakrishna, "A Case Study of 3D Printed PLA and Its Mechanical Properties," *Mater. Today Proc.*, vol. 5, no. 5, pp. 11219–11226, Jan. 2018.

[3] A. Nugroho, K. Abdurohman, Kusmono, H. Hestiawan, and Jamasri, "Effect of Manufacturing Method to Tensile Properties of Hybrid Composite Reinforced by Natural (Agel Leaf Fiber) and Glass Fibers," *J. Phys. Conf. Ser.*, vol. 1005, no. 1, p. 12004, Apr. 2018.

[4] S. K. Moon, Y. E. Tan, J. Hwang, and Y. J. Yoon, "Application of 3D printing technology for designing light-weight unmanned aerial vehicle wing structures," *Int. J. Precis. Eng. Manuf. - Green Technol.*, vol. 1, no. 3, pp. 223–228, 2014.

[5] "3d-printer24." [Online]. Available: http://3d-printer24.ch/. [Accessed: 16-Jul-2018].

[6] A. K. Sood, R. K. Ohdar, and S. S. Mahapatra, "Parametric appraisal of mechanical property of fused deposition modelling processed parts," *Mater. Des.*, vol. 31, no. 1, pp. 287–295, Jan. 2010.

[7] X. Wang, M. Jiang, Z. Zhou, J. Gou, and D. Hui, "3D printing of polymer matrix composites: A review and prospective," *Compos. Part B Eng.*, vol. 110, pp. 442–458, Feb. 2017.

[8] B. Rankouhi, S. Javadpour, F. Delfanian, and T. Letcher, "Failure Analysis and Mechanical Characterization of 3D Printed ABS With Respect to Layer Thickness and Orientation," *J. Fail. Anal. Prev.*, vol. 16, no. 3, pp. 467–481, Jun. 2016.

[9] B. M. Tymrak, M. Kreiger, and J. M. Pearce, "Mechanical properties of components fabricated

with open-source 3-D printers under realistic environmental conditions," *Mater. Des.*, vol. 58, pp. 242–246, Jun. 2014.

[10] A. Lanzotti, M. Grasso, G. Staiano, and M. Martorelli, "The impact of process parameters on mechanical properties of parts fabricated in PLA with an open-source 3-D printer," *Rapid Prototyp. J.*, vol. 21, no. 5, pp. 604–617, Aug. 2015.

[11] S. Ahn, M. Montero, D. Odell, S. Roundy, and P. K. Wright, "Anisotropic material properties of fused deposition modeling ABS," *Rapid Prototyp. J.*, vol. 8, no. 4, pp. 248–257, Oct. 2002.

[12] M. Vaezi and C. K. Chua, "Effects of layer thickness and binder saturation level parameters on 3D printing process," *Int. J. Adv. Manuf. Technol.*, vol. 53, no. 1–4, pp. 275–284, Mar. 2011.

[13] J. Kotlinski, "Mechanical properties of commercial rapid prototyping materials," *Rapid Prototyp. J.*, vol. 20, no. 6, pp. 499–510, Oct. 2014.

[14] Aniwaa, "ZBOT FDM-50-5050 review - 3D printer." [Online]. Available: https://www.aniwaa.com/product/3d-printers/zbot-fdm-50-5050/. [Accessed: 14-May-2018].

[15] "Ultimaker Cura: Advanced 3D printing software, made accessible." [Online]. Available: https://ultimaker.com/en/products/ultimaker-cura-software. [Accessed: 16-Jul-2018].

[16] ASTM International, "ASTM D 790 - 02 - Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials," vol. 14, pp. 146–154, 2002.

[17] J. M. Chacón, M. A. Caminero, E. García-Plaza, and P. J. Núñez, "Additive manufacturing of PLA structures using fused deposition modelling: Effect of process parameters on mechanical properties and their optimal selection," *Mater. Des.*, vol. 124, pp. 143–157, Jun. 2017.

[18] R. T. L. Ferreira, I. C. Amatte, T. A. Dutra, and D. Bürger, "Experimental characterization and micrography of 3D printed PLA and PLA reinforced with short carbon fibers," *Compos. Part B Eng.*, vol. 124, pp. 88–100, Sep. 2017.