Journal of Engineering and Technology

ISSN 2180-3811 eISSN 2289-814X https://jet.utem.edu.my/jet/index

A COMPARISON OF THE FLEXURAL PROPERTIES OF PLA AND ABS PRINTED PARTS

M. N. Sudin*[1], N. M. Daud[1] and M. A. Yusuff[1]
[1] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
*corresponding_nizamsudin@utem.edu.my

Article history:
Received Date: 16 August 2022
Revised Date: 23 November 2022
Accepted Date: 20 December 2022

Keywords: Additive Manufacturing, Fused Deposition Modelling, Flexural Properties, ABS,

Abstract— The additive manufacturing (AM) technique produces three-dimensional objects by stacking successive layers of material. Fused deposition modelling, abbreviated FDM for convenience, is an additive manufacturing (AM) technique. Using FDM, objects are created by successively depositing molten filaments of thermoplastic onto the printing surface. This is referred to as slicing. The mechanical properties of FDM-printed parts depend on a number of factors, including the composition of the material, the extrusion temperature, the printing parameters, and the ambient temperature at the time the parts are printed. The objective of this study was to investigate the consistency of mechanical properties of elements

PLA.	produced using FDM additive manufacturing technology. Ten thermoplastic ABS and PLA samples were subjected to flexure testing in order to accomplish this. Utilizing the Instron 5585 Floor Model Testing System, flexure testing was conducted. The ultimate flexural strength, along with the strain and Young modulus, was studied. During flexural tests, the thermoplastic ABS material demonstrated greater consistency in terms of its mechanical properties. The fact that different PLA samples had different flexural strengths showed that their mechanical properties were less repeatable.

I. Introduction

Fused deposition modelling, sometimes known as FDM for short, is now one of the most common methods used in the field of 3D printing. Its prominence can be observed in a variety of industries, including aerospace, automotive, consumer goods, and healthcare, where businesses utilise FDM for prototypes, product development and sampling, and production operations [1]. Specifically, FDM is utilized in the manufacturing of consumer products. Thermoplastic filament is used in the FDM manufacturing process both as a printing medium and as a printing material. Plastic filaments that are only partially solid are extruded onto the printing surface by first pulling the filament into the print head and then melting it. These threads come out of the nozzle in an extruded form. As the threads continue to cool and become more solid, a coating of material will develop as it does so. The creation of a 3D item is accomplished by stacking successive layers one on top of the other in a layered pattern.

A. FDM materials

Over the last 30 years, scientists and engineers have presented a wide range of materials that can be used as FDM filaments, and it is unusual for the end user to have access to information regarding the precise filament composition. The FDM printing process makes use of filaments made of thermoplastic materials such as Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Polycarbonate (PC), Polyether-Ether-Ketone (PEEK), Nylon, and other composites. The following is a brief description of two of the most popular FDM filaments on the market today. 1) PLA is a biodegradable thermoplastic polyester made from naturally renewable materials like maize, sugarcane, wheat, or other carbohydrate-rich sources. It is a recyclable material [2-5]. PLA is currently the most commonly used material in 3D printing. Because of its eco-friendliness, it is well suited for use in food packaging, as well as surgical and medical applications [3,4]. 2) ABS is created by fusing styrene with acrylonitrile in the presence of polybutadiene [6,7]. ABS is an excellent material for components that must withstand cyclic stress and temperature fluctuations [8]. ABS filaments are commonly used in 3D printing to create toys, prototypes, medical procedures models, and home appliances. ABS has proven to be an excellent material for the production of items such as LEGO building blocks due to its strong mechanical properties, which allow it to withstand extended use and wear [9].

B. Influence of FDM parameter settings on mechanical property

In addition to the material itself, the mechanical properties of FDM parts are influenced by the choice of parameters for the FDM process. Infill density, infill pattern, raster angle, raster width, raster gap, layer thickness, build orientation, printing speed, nozzle temperature, ambient temperature, and platform temperature are some of the factors that have been investigated by a great number

ISSN: 2180-3811 Vol. 13 No. 2

of researchers in the course of their studies. They came to the conclusion that a number of these parameters have a significant bearing on the mechanical properties of the FDM parts [4-10].

The tensile strength and flexural strength of FDM parts were investigated by Durgun and Ertan [10] for a variety of build orientations and raster angle configurations. They came to the conclusion that build orientation had a greater impact on surface roughness and mechanical behavior than raster angle, in particular on tensile and flexural strength. Camargo et al. [11] investigated the PLA-graphene parts fabricated with FDM technology in terms of their mechanical properties, including their tensile strength, flexural strength, and impact energy. Both the infill pattern and the layer thickness were changed, but the build orientation was kept at flat, and the honeycomb infill pattern remained the same. They found that increasing the layer thickness led to an increase in the mechanical properties of the material. According to Dawoud et al. [12], with the right choice of FDM parameters, it is possible to achieve mechanical properties comparable to those of injection-moulded parts under both static and dynamic loading conditions. They found that a raster angle of 0/90° produced the highest flexural strength.

Luzanin et al. [13] discovered that the layer thickness had a dominant and statistically significant influence on the flexural force. They found that a low layer thickness exhibited the maximum flexural strength. While, Wu et al. [14] discovered that the optimal flexural strength, of PEEK samples, was attained when the layer thickness was set to 300 m and the raster angle was set to 0º. They tested the flexural strengths of PEEK samples for a variety of layer thicknesses (200, 300, and 400 m) as well as raster angles (0º, 30º, and 45º). In addition, the research carried out by Christiyan et al., [15] demonstrated that the highest flexural strength could be achieved by printing at slow speeds. In the meantime, Abdullah et al. [16] found that the layer thickness and the raster angle had a greater impact on the flexural strength of the test specimen than they did on the tensile strength. Camargo et al. [11] discovered that an increase in the infill density led to an increase in the material's flexural strength.

The findings of the previous study concerning the effect of FDM process parameters show that the tensile and flexural properties of FDM parts that have been subjected to a variation in parameters are inconsistent with one another. Nonetheless, because the value of the parameter is constantly shifting, it is permissible. Utilizing ABS and PLA thermoplastic materials as well as constrained printing parameters, the purpose of this study is to carry out an investigation into the degree to which the mechanical properties of FDM printed samples are consistent. Taking into consideration the anisotropic structure of FDM printed parts, the absence of standards specially designed for this 3D printing process, and the inconsistency in a number of tested samples throughout the listed literature, it is of utmost importance to investigate the repeatability of mechanical properties of elements produced by FDM additive.

II. Materials and Methods

This study intends to investigate the consistency of the mechanical properties of the specimens produced by FDM additive manufacturing technology. PLA and ABS thermoplastic material specimens were subjected to flexural tests. All specimens for flexural testing of both materials were conducted at a temperature of 23±2 ºC. All of the specimens were produced with a Creality Ender 3 3D printer.

A. Specimens preparation

Up to date, FDM printing technology has no established standards for tensile and flexural tests. The majority of authors adopt the standards of tensile and flexural test specimens of non-FDM. So ISO 178 for the flexural test is frequently used to address this matter [17-19].

ISSN: 2180-3811 Vol. 13 No. 2

B. Procedures

For the dimension of the specimens, the same specimen dimension was utilized for both materials. ISO 178 was utilized as the standard for flexural test specimens. According to ISO 178, the recommended thickness measurement for the specimen was 4 mm, while the length and width measurements were 80 mm and 10 mm, respectively. Figure 1 depicts the dimensions of flexural test specimen.

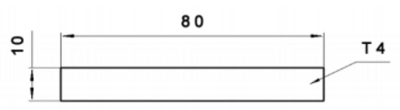

Figure 1: The dimensions of flexural test specimen

C. Fabrication of specimens

The specimens were manufactured using a Creality Ender 3 3D printer. The specifications for the Creality Ender 3 3D printer and printing parameters are shown in Tables 1 and 2, respectively. The Ultimaker Cura slicer defines the 3D object model used by the Creality Slicer software to construct the printer instructions. For ABS and PLA, the standard diameter of 1.75 mm was used.

Table 1: Specifications of Creality Ender 3 3D Printer

Parameter	Value
Print area	220 × 220 × 250 (mm)
Filament	Diameter 1.75 mm (PLA, ABS, TPU)
Printing speed	180 mm/s
File format	STL, OBJ, G-code

Table 2: Printing parameters for both materials

Parameter	ABS	PLA
Layer thickness	0.15	0.15
Raster orientation	0°/90°	0°/90°
Printing speed	90 mm/s	90 mm/s
Nozzle temperature	230℃	215℃
Infill density	100%	100%
Infill pattern	Grid	Grid
Support	Brim	Brim

Following the production of specimens, flexural tests were conducted. For flexural testing, the Instron 5585 Floor Model Testing System was utilized. This apparatus could perform a variety of tests, including tensile tests, compression tests, flexure tests, shear tests, tear tests, cyclic tests, and bending tests. The primary technical

ISSN: 2180-3811 Vol. 13 No. 2

characteristic of the machine is that its load cell capacity can reach 150 kN, which is sufficient for conducting the test for this research. The flexural test yielded values for flexural strength, flexural stress-strain, and flexural modulus for the specimens tested.

The flexural test will yield four types of information: 1) flexural stress-strain, 2) flexural strength, 3) flexural modulus of elasticity, and 4) extension at break. All of the data was analysed in greater depth. Except for flexural stress-strain data, the mean values and standard deviation of all other types of data were calculated using Microsoft Excel. A graph and a table were used to interpret all of the calculated results. The consistency of the material will then be determined through a comparison of the mean and standard deviation values for ABS and PLA.

III. Results

A. Flexural test for ABS material

As shown in Figure 2, the values of the flexural strength obtained varied (4.572 MPa or 6.844% from the mean) between the specimens, with the mean of the flexural strength for ABS being 66.805 MPa and the standard deviation being 1.456 MPa.

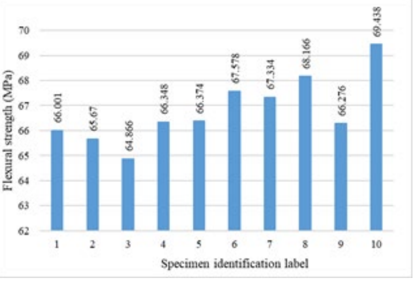

Figure 2: Flexural strength of ABS specimens

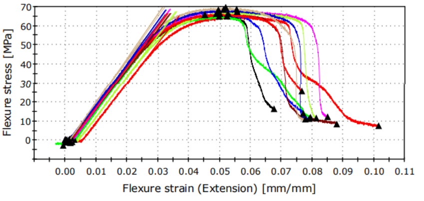

Figure 3: Flexural stress vs strain for ABS specimens


Figure 4: Printed test specimens of ABS material

The highest value of flexural strength between the ABS specimens was 69.438 MPa (specimen 10) and the lowest was 64.866 MPa (specimen 3) as depicted in Figure 3 and 4.

For the extension at the break, as in Figure 5 the mean value was 7.648 mm and the standard deviation was 0.448 mm. The extension varied by 1.570 mm (20.53% from the mean) with the longest extension being 8.323 mm (specimen 7) and the shortest being 6.753 mm (specimen 2).

The mean flexural modulus of elasticity as shown in Figure 6 was 2144.507 MPa with a standard deviation of 56.446 MPa. Specimen 10 (2252.064 MPa) was the highest, while specimen 5 (2084.037 MPa) was the lowest value of the flexural modulus of elasticity that varied by 168.027 MPa.

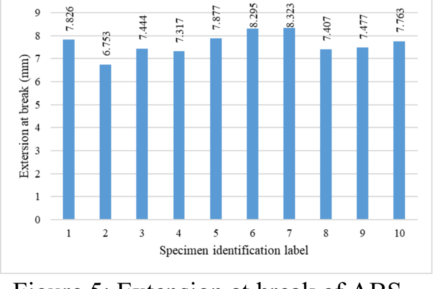

Figure 5: Extension at break of ABS specimens

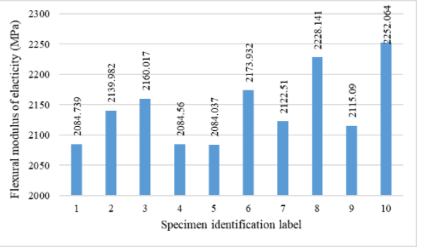

Figure 6: Flexural modulus of ABS specimens

B. Flexural test for PLA material

Figure 7 shows the Flexural strength of PLA specimens. PLA specimens exhibited greater flexural strength than ABS specimens, with a mean value of 71.159 MPa and a standard deviation of 2.085 MPa, respectively. The data for flexural strength varied by 6.182% (8.69% of the mean), with specimen 5 having the highest flexural strength at 73.830 MPa and specimen 3 having the lowest at 67.648 MPa. These results can be observed in Figure 8 and 9.

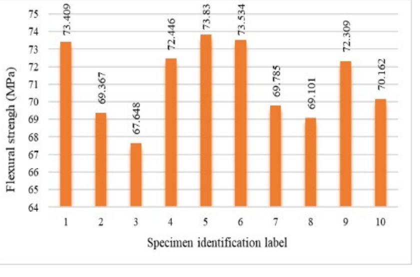

Figure 7: Flexural strength of PLA specimens

ISSN: 2180-3811 Vol. 13 No. 2

Figure 8: Printed test specimens of PLA material

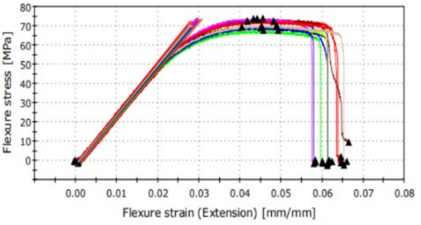

Figure 9: Flexural stress versus strain of PLA material

In contrast, the mean extension at break as in Figure 10 for PLA specimens was 6.775 mm, which is less than for ABS specimens, and the standard deviation was 0.420 mm. The longest extension at break was observed on specimen 3 with 7.391 mm and the shortest was observed on specimen 2 with 6.060 mm, with a variation of 1.33 mm.

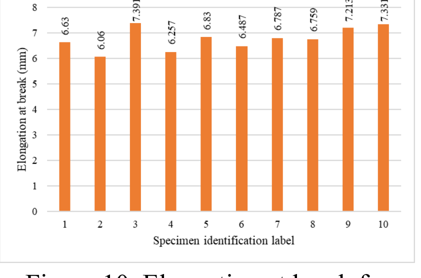

Figure 10: Elongation at break for PLA material

In terms of flexural modulus of elasticity (Figure 11), the mean value was 2542.715 MPa and the standard deviation was 27.947 MPa. The highest value was observed on specimen 9 with 2583.477 MPa, and the lowest value was observed on specimen 4 with 2489.961 MPa. 93.516 MPa was the range of values for the flexural modulus of elasticity.

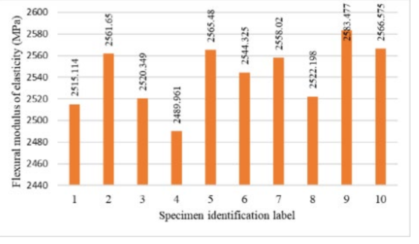

Figure 1: Flexural modulus of elasticity of PLA material

C. Comparison of ABS and PLA flexural properties

Table 3 displays the mean flexural strength of ABS and PLA samples. It was discovered that PLA had a flexural strength of 71.159 MPa, which was 4,354 MPa greater than ABS. However, the mean extension at break of PLA samples was less than that of ABS samples. In addition, the mean flexural modulus of elasticity for PLA was 398.208 MPa greater than that of ABS (2144.507 MPa). Compared to ABS, PLA had approximately 6.52 percent greater flexural strength.

It was determined that, despite the small size of the specimen, PLA could withstand a bending load of up to 131N. However, ABS retained good flexural strength and could withstand up to 124N before failing. PLA had a higher flexural modulus of elasticity (18.56 percent) than ABS. Generally speaking, the flexural modulus of elasticity is inversely proportional to the object's or product's elongation or extension. The material with a high flexural modulus of elasticity will have a low extension or elongation value. Due to its higher flexural modulus of elasticity, PLA exhibited greater stiffness, whereas ABS exhibited less stiffness, or in other words, greater flexibility than PLA. This can also be demonstrated by observing the specimen's condition following the flexure test, as depicted in Figures 12 and 13.

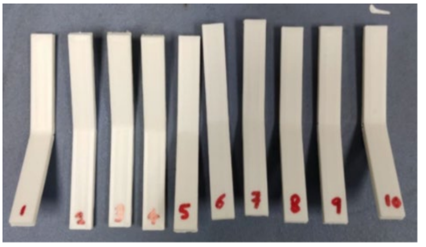

Figure 12: ABS specimens after the test

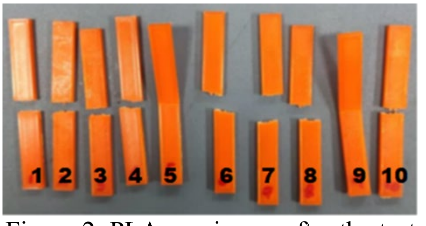

Figure 2: PLA specimens after the test

Table 3: Comparison of ABS and PLA flexural properties

Flexural properties	ABS	Standard Deviation	PLA	Standard Deviation	Different
Mean of flexural strength (MPa)	66.805 MPa	1.456	71.159 MPa	2.085	4.354 MPa
Mean of extension at break (mm)	7.648 mm	0.448	6.775 mm	0.420	0.873 mm
Mean of flexural modulus of elasticity (MPa)	2144.507 MPa	56.446	2542.715 MPa	27.947	398.208 MPa

None of the ABS specimens were completely broken after the flexural test, but for PLA specimens, only 2 out of 10 did not completely break (specimens 5 and 9). As mentioned before, 80% of the PLA specimens break completely because of their high stiffness. ABS specimen 5 in Figure 12 illustrates that the crack on the specimen is only half of its thickness due to its flexibility.

ABS has a smaller standard deviation of flexural strength than PLA, according to Table 3, which indicates that the mechanical properties of ABS are more consistent. The smaller the value of the standard deviation, the tighter the data distribution around the mean. Because the data will be concentrated around the mean, the lower the standard deviation, the greater the consistency. In comparison to PLA, ABS has demonstrated greater flexural consistency. This is due to the ABS's ability to continuously absorb the perpendicular force to the surface, such as in flexural tests. PLA may have a high flexural strength, but its stiffness reduces the uniformity of the specimens.

IV. CONCLUSION

The objective of this study is to examine the consistency of mechanical properties of parts manufactured with FDM technology. ABS and PLA samples have been subjected to flexure testing. All of the samples were created using the same FDM technology machine, the Creality Ender 3, with the same printing parameters for both materials. The flexural strength of ABS has been consistently high. In contrast, PLA possesses a high flexural strength but less consistency in its repeatability. To determine the limit value beyond which FDM-printed parts will deform permanently, it is necessary to comprehend the elasticity of FDM-printed components. During the experiment, ABS was discovered to be more flexible and ductile than PLA, which was discovered to be more rigid and brittle. The thermoplastic ABS material demonstrated greater consistency in terms of its mechanical properties. The fact that different PLA samples had different flexural strengths showed that their mechanical properties were less repeatable

V. Acknowledgement

The authors would like to thank Universitiy Teknikal Malaysia Melaka (UTeM) for the technical support.

VI. References

[1] E. Palermo, "Fused deposition modelling: Most common 3d printing method", *LiveScience*, 2013, [Online] Available: https://www.livescience.com/39810-fused-deposition-modeling.html

[2] R. A. Ilyas, S. M. Sapuan, M. M Harussani, M. Y. A. Y. Hakimi, M. Z. M. Haziq, M. S. N. Atikah,... and M. Asrofi, "Polylactic acid (PLA) biocomposite: Processing, additive manufacturing and advanced applications", *Polymers*, vol. 13, no. 8, pp.1326, 2021.

[3] F. Madaraka Mwema and E. Titilayo Akilabi, "Fused deposition modelling: Strategies for quality enhancement", *Springer Briefs in Applied Sciences and Technology, Manufacturing and Surface Engineering*, *Springer Nature*, 2020.

[4] M. Nofar, D. Sacligil, P.J. Carreau, M.R. Kamal, M-C Heuzey, "Poly (lactic acid) blends: Processing, properties and applications", *International Journal of Biological Macromolecules*, Vol. 125, pp. 307-360, 2019.

[5] A. Manoj and R. Ch, "Biodegradable filament for 3D printing process: A review", *Engineered Science*, vol. 18, pp.11-19, 2022.

[6] Anon, *Polyscience, Inc*. 2021, Poly (lactic acid) (PLA, PDLA, PLLA), [Online], Available: https://www.polysciences.com/default/catalog-products/polymers/biodegradable-polymers/poly-dl-lactic-acid.

[7] A. Rodríguez-Panes, J. Claver, A.M. Camacho, "The influence of manufacturing parameters on the mechanical behaviour of PLA and ABS pieces manufactured by FDM: A comparative analysis", *Materials (Basel)* 2018 Aug; 11(8): 1333. Published online 2018 Aug, Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6119930/

[8] S. Singh, C. Prakash, and R. Singh, "3D printing in biomedical engineering, *Materials Horizons: From Nature to Nanomaterials*", *Springer Nature*, pp.336, 2020,

[9] J. M. A. Chawner, A. T. Jones, M. T. Noble, G. R. Pickett, Viktor Tsepelin, and D. E. Zmeev. "LEGO® block structures as a sub-kelvin thermal insulator." *Scientific Reports 9*, no. 1, pp. 1-4. 2019.

[10] I. Durgun, and R. Ertan, "Experimental investigation of FDM process for improvement of

mechanical properties and production cost", *Rapid Prototyping Journal*, pp.228-235, 2014.

[11] J. C. Camargo, Á. R. Machado, E. C. Almeida, and E. F. M. S. Silva, "Mechanical properties of PLA-graphene filament for FDM 3D printing," *The International Journal of Advanced Manufacturing Technology*, vol. 103, vol. 5-8, pp.2423-2443, 2019.

[12] M. Dawoud, I. Taha, and S. J. Ebeid, "Mechanical behaviour of ABS: An experimental study using FDM and injection moulding techniques," *Journal of Manufacturing Processes*, vol. 21, pp. 39-45, 2016.

[13] O. Lužanin, D. Movrin, and M. Plančak, "Effect of layer thickness, deposition angle and infill on maximum flexural force in FDM-built specimens," *Journal for Technology of Plasticity*, vol. 39, no. 1, pp. 49-58, 2014.

[14] W. Wu, P. Geng, G. Li, D. Zhao, H. Zhang, and J. Zhao, "Influence of layer thickness and raster angle on the mechanical properties of 3d-printed PEEK and a comparative mechanical study between PEEK and ABS. *Materials*, vol. 8, no. 9, pp. 5834-5846, 2015

[15] K. J. Christiyan, U. Chandrasekhar, and K. Venkateswarlu, "A study on the influence of process parameters on the mechanical properties of 3D printed ABS composite, "*In IOP Conference Series: Materials Science and Engineering*, *IOP Publishing*, vol. 114, no. 1, pp. 012109, February 2016.

[16] Z. Abdullah, H. Y. Ting, M. A. M. Ali, M. H. F. M. Fauadi, M. S. Kasim, A. Hambali, and F. Handoko, "The effect of layer thickness and raster angles on tensile strength and flexural strength for Fused Deposition Modeling (FDM) parts," *Journal of Advanced Manufacturing Technology* (JAMT), vol. 12, no. 1 (4), pp. 147-158, 2018.

[17] J. Dobos, M. M. Hanon and I. Oldal, "Effect of infill density and pattern on the specific load capacity of FDM 3D-printed PLA multi-layer sandwich", *Journal of Polymer Engineering*, vol. 42, no. 2, pp.118-128, 2022.

[18] J. Andrzejewski, M. Markowski and M. Barczewski, "The use of nanoscale montmorillonite (mmt) as reinforcement for polylactide acid (PLA) prepared by Fused Deposition Modeling (FDM) - comparative study with biocarbon and talc fillers", *Materials*, vol. 15, no. 15, pp.5205, 2022.

[19] M. Mazurkiewicz, J. Kluczyński, K. Jasik, B. Sarzyński, I. Szachogłuchowicz, J. Łuszczek, ... and M. Małek, "Bending strength of polyamide-based composites obtained during the Fused Filament Fabrication (FFF) process", *Materials*, vol.15, no. 14, pp.5079, 2022.