Scientific Research Journal,
Vol 22, special issue (2025) 37-53
https://doi.org/10.24191/srj.v22is.11946

SCIENTIFIC
RESEARCH
JOURNAL
SRJ
ISSN: 1675-7009
e-ISSN: 2289-649X

Investigating the Influence of Print Settings on PLA Filament Using the Espresso F220 3D Printer

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Received: 30 August 2024
Accepted: 3 September 2024
Online First: 25 January 2025

ABSTRACT

This research focuses on optimizing the 3D printing settings of the Espresso F220 3D printer using Polylactic Acid (PLA) filament. A user-friendly guideline was developed to assist users in identifying critical model sections requiring support structures to prevent printing defects and adjusting retraction settings to minimize stringing. The Support Structure Test (SST), Retraction Test (RT) and Tensile Test (TT) profile setting were evaluated. Results SST the effectiveness of support structure at various angles, where the RT to produce the optimal retraction distance to reduce stringing between towers. In TT investigated the effects of printing temperature (190°C, 210°C, and 230°C) on mechanical strength of PLA material. Model 4, utilizing setting from previous studies, proven the best quality prints with minimal surface damage. TT results proven the higher printing temperature resulted in the strongest PLA material, and suitable for many applications. The research offers valuable insight for optimizing FDM in 3D printing process in engineering applications at UiTM Penang.

Keywords: 3d Printing; Fused Deposition Modeling (FDM); Optimization; Polylactic Acid (PLA); Mechanical Properties

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INTRODUCTION

In recent years, three-dimensional (3D) printing technology has experienced rapid advancements and has become increasingly influential across various industries, including manufacturing, healthcare, architecture, and education. 3D printing allows for the rapid, precise, and cost-effective creation of prototypes and final products, making it a popular choice among professionals and hobbyists alike [1,2] . One of the most widely used 3D printing technologies is Fused Deposition Modeling (FDM), in which thermoplastic filaments such as Polylactic Acid (PLA) are heated and extruded to form objects layer by layer [3]. The Espresso F220 is a notable 3D printer that utilizes FDM technology. This printer is renowned for its high precision, reliability, and user-friendly operation. PLA, the primary filament material used in this study, is a popular choice due to its biodegradability, ease of use, and ability to produce prints with good surface quality [4,5]. PLA is derived from renewable resources like corn starch or sugarcane, making it an environmentally friendly alternative to traditional petroleum-based plastics [6]. Despite the widespread use of 3D printing and PLA filaments, the specific performance characteristics of individual 3D printers like the Espresso F220 have not been thoroughly evaluated in existing literature. Each 3D printer model can exhibit unique strengths and weaknesses based on its design, build quality, and operational parameters. Therefore, it is crucial to conduct detailed assessments of these printers to provide users with accurate information on their capabilities and limitations [7].

This study aims to evaluate the capabilities of the Espresso F220 3D printer across various aspects, including dimensional accuracy, mechanical strength, and surface quality of objects printed using PLA filament. Dimensional accuracy refers to the degree to which the dimensions of the printed object match the intended design, which is critical for applications requiring precise fit and function [4]. Mechanical strength encompasses the durability and load-bearing capacity of printed objects, which is essential for functional parts and prototypes [5]. Surface quality pertains to the smoothness and finish of the printed object's exterior, which affects both the aesthetic and functional aspects of the product. Poor surface quality can lead to increased post-processing time and reduced usability in applications where a smooth surface is required [3]. By systematically evaluating these aspects, this study seeks to provide a comprehensive understanding of the Espresso F220's performance with PLA filament. Understanding the strengths and limitations of the Espresso F220 will aid users and researchers in optimizing the printing process and selecting the best parameters for specific applications. For instance, knowing the optimal printing speed, temperature settings, and layer height can significantly enhance the quality of the printed objects while reducing material waste and production time [1]. This evaluation will also contribute to the broader knowledge base of 3D printing technology and its practical applications, helping to advance the field and promote the adoption of 3D printing in various sectors [7].

Despite the rapid advancements in 3D printing technology based on Fused Deposition Modeling (FDM), there remains a notable lack of studies thoroughly investigating its varying degrees of quality [8]. Figure 1 provides a schematic diagram of the FDM process [9].

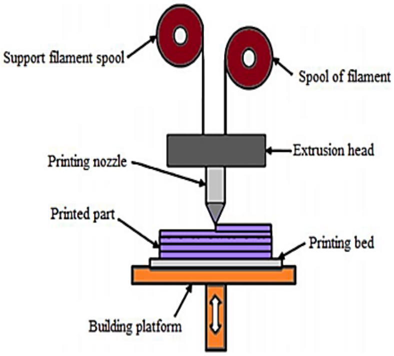


Figure 1: Schematic diagram of the FDM process

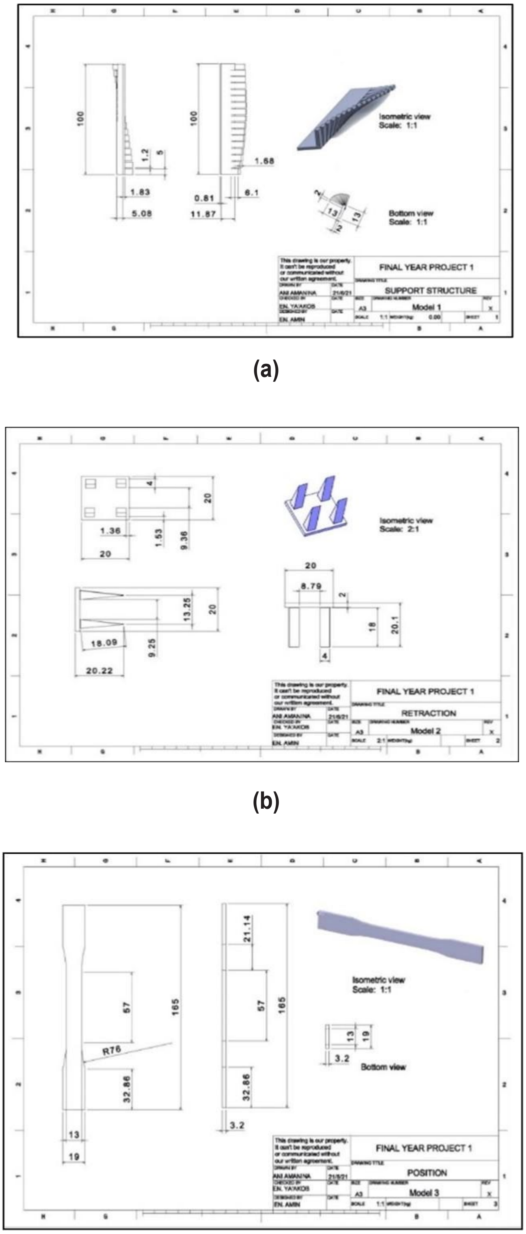
In this process, melted filament is extruded along a specified route onto a build surface. As the material cools, it forms a solid layer that serves as the foundation for the next layer of material. The extrusion head, or spray head, accurately follows the profile of each segment of the component, depositing molten thermoplastic filaments into thin layers that overlay the previously built portion. Various low-melting filamentary materials, such as Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), and Polyphenylene Sulfide (PPS), are melted into liquid form through the heater's extrusion head [10-16].

After each layer is created, the worktable lowers by the height of one layer. The spray head then scans and deposits the next cross-sectional layer until the final layer is complete. This process builds a solid object from the bottom up [11]. Despite the widespread use of 3D printer technology in industry today, numerous process factors must be considered to ensure the quality of the printed part. The manufacturer's default printing parameters do not always guarantee high-quality prints.

METHODOLOGY

Design for Support Structure Test (SST), Retraction Test (RT) and Tensile Test (TT)

This design was created to assess the application of support structures at various angles. The angles help determine how different model orientations affect the need for and impact of support structures on the model's surface finish. The design features 17 rectangular bars, each set at a distinct angle ranging from 5° to 45°. The detailed drawing of the support structure model is shown in Figure 2(a). A simple design of four towers, each with the same base size, as illustrated in Figure 2(b), was developed to observe the retraction behavior from one tower to another during the printing process. This experiment aims to identify methods to minimize stringing and oozing caused by retraction during model printing. For tensile testing, the ASTM D638 standard, which is the industry norm for evaluating the tensile strength of plastics, was followed [16]. The dimensions of the specimens conform to ASTM standards, featuring a "dog bone" shape, as shown in Figure 2(c).



(a)

(b)

(c)

Figure 2: The detail drawing of all structure models. (a) Support Structure Model, (b) Retraction Model and (c) Tensile Model using ASTM D638

Parameter Setting

In this experiment, three parameter settings were used to observe the differences in the resulting models: the UiTM Standard Laboratory Setting (USLS), the Recommended Manufacturer Setting (RMS), and settings recommended by previous studies (RPS). The RMS and RPS profile settings were utilized in this project to determine the optimal profile settings for the Espresso F220 3D printer and to compare the 3D printed models using the USLS. The references or sources of parameter settings are detailed in Table 1.

Table 1: Three references or sources of parameter settings used in experiment

Parameter	UiTM Standard Laboratory Setting (USLS)	Recommended Manufacturer Setting (RMS)	Recommended by Previous Studies (RPS)
Layer Height (mm)	0.2	0.2	0.2
Wall Thickness (mm)	0.8	0.8	0.8
Infill Density (%)	50	50	20
Temperature (°C)	210	230	190
Print Speed (mm/s)	50	30	50
Travel Speed (mm/s)	100	100	100
Infill speed (mm/s)	50	30	50
Outer Wall Speed (mm/s)	50	30	50

PLA Material

There are a variety of materials used in FDM, and as previously stated. PLA is the most widely used material by domestic and industrial 3D printer users. According to [16], the PLA is a bio plastic that is environmentally friendly and safe for human and animal health. PLA is a green material because it is made from completely renewable resources. As a result, it's ideal for making cool drink cups, deli and food take-out containers, and packaging containers. Unlike other plastics that have posed serious disposal challenges, a PLA plastic are compostable and break down quickly when disposed of PLA, as a biopolymer, degrades to natural and non-toxic gases, water, biomass, and inorganic salts when exposed to natural conditions, hydrolysis, or incineration [17].

PLA has a glass transition temperature of 50°C to 70°C and a melting point of 180°C to 220°C. As a result, it can be extruded by most low-energy and cost-effective 3D printers. It is harder than Acrylonitrile Butadiene Styrene (ABS), but PLA has higher friction than ABS, making it more prone to extrusion blockage [18, 19].

Most 3D printer users prefer PLA because it does not always require a heated bed for adhesion between the print and the platform. Non-heated bed printers, on the other hand, face a significant challenge with grapheme-doped PLA, which does not produce high-quality prints on non-heated build plates [17].

Experimental Procedure for Tensile Test (TT)

Specimen Preparation

a) The specimens were fabricated using 3D printer technology in a dog-bone shape where all dimensions were determined according to the ASTM D638 standard.

b) The thickness, width, and gauge length of specimens were measured using a pair of vernier calipers.

TRAPEZIUM2 Software Settings

a) The main window will be displayed on the screen as Figure 3:

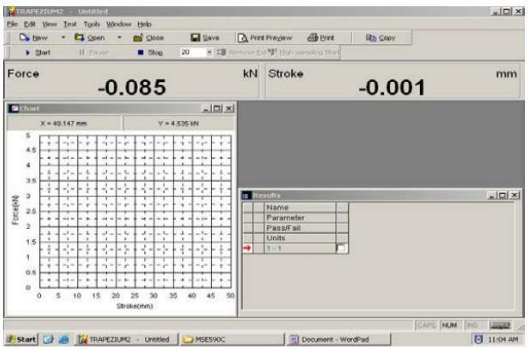
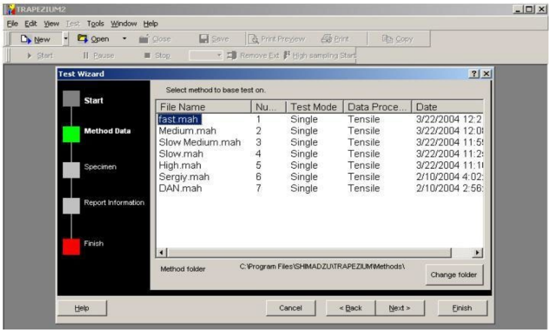


Figure 3: Window of TRAPEZIUM2 software

b) Click on "New" icon that is located on the top-left side of the main window. The "Test Wizard" window will be displayed as Figure 4:



Select method to base test on.

File Name	Nu...	Test Mode	Data Proce...	Date
fast.mah	1	Single	Tensile	3/22/2004 12:2
Medium.mah	2	Single	Tensile	3/22/2004 12:0
Slow Medium.mah	3	Single	Tensile	3/22/2004 11:5
Slow.mah	4	Single	Tensile	3/22/2004 11:2
High.mah	5	Single	Tensile	3/22/2004 11:1
Sergiy.mah	6	Single	Tensile	2/10/2004 4:02
DAN.mah	7	Single	Tensile	2/10/2004 2:56

Method folder C:\Program Files\SHIMADZU\TRAPEZIUM\Methods\

Figure 4: The "Test Wizard" window of TRAPEZIUM2 software

c) Go to the "Test Wizard" window and click on the "Method Data" option of the test wizard toolbar located on the left-hand side of the test wizard window. The method data window will appear and select the appropriate testing method.

d) For the computer to calculate the stress applied on the model, the cross- sectional dimension of the model must be entered into the software. To do so, click on the "Specimen" option of the test wizard toolbar. Then, enter the measured width (13 mm) and thickness (3.2 mm) of the specimen which this step is optional for automatic stress-strain curve generation.

Instrumental Setting

a) Go to the tensile testing instrument. Press the "Return" button on the digital controller for a few seconds until a beeping sound is heard. The sample grips for both the top and bottom grips will be returned automatically to their starting position.

b) Place the sample at the bottom grip. While still holding it vertically with one hand, use another hand to turn its handle in the closing direction as tightly as possible.

c) Use the "Up" or/and "Down" buttons, which are located next to the "Return" button to adjust the position of the upper grip.

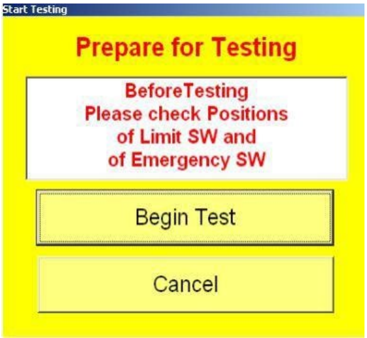
d) Turn the upper handle to the "close" direction as tightly as possible. Visually verify if the sample is gripped symmetrically at its two ends.

Tensile Test

a) At the top of the main window, right-click on the mouse while placing the mouse cursor on the "Force" button located at the top of the main window and select the "Zero" option. Wait for the machine to return the force to zero. This will be indicated by a beeping sound.

b) Similarly, place the mouse cursor on the "Stroke" button, which is next to the "Force" button, and right-click to select the "Zero" option. Again, wait for a few seconds to let the computer return its value to zero.

c) Click on the "Start" icon that is located at the top of the main window. The “Start Testing” window will appear as Figure 5:



Prepare for Testing

BeforeTesting
Please check Positions
of Limit SW and
of Emergency SW

Figure 5: The “Start Testing” window

d) Click on the “Begin Test” button, found on the Start Testing window. Both the upper and bottom grips will start moving in opposite directions according to the specified polling rate. Observe the experiment at a safe distance of about 1.5 meters away and take note of the failure mode when the specimen fails.

e) A plot of Force (kN) versus Stroke (mm) graph will be generated in real-time during the experiment.

Finishing

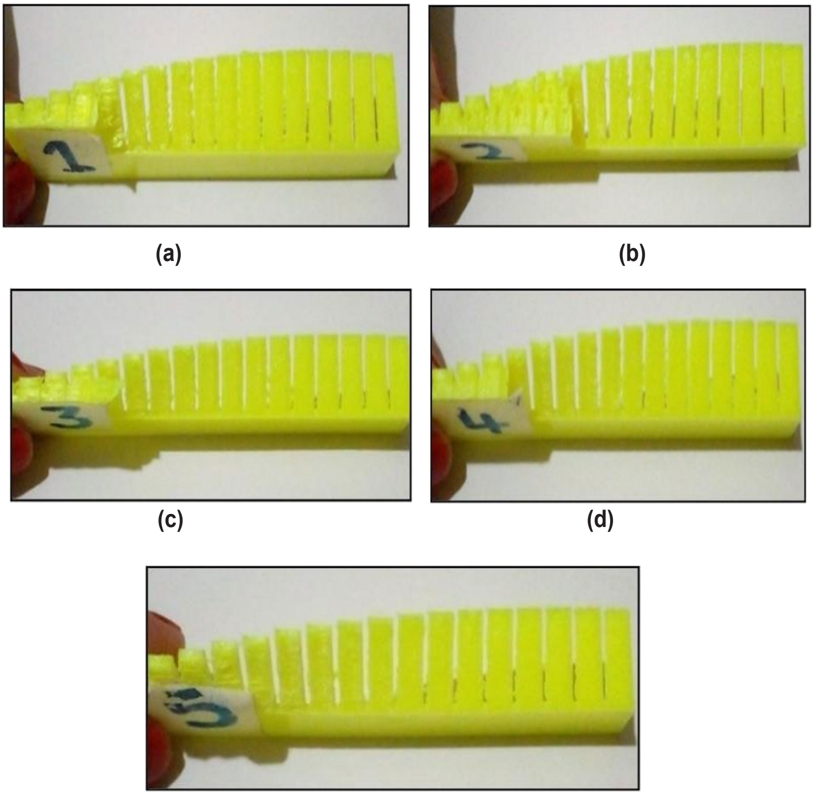
a) The machine will stop automatically when the sample is broken. Click the icon “Export” and type a file name in the box (*.TXT).
b) Turn the two handles to their “OPEN” direction one at a time to remove the sample.
c) Press the “Return” button on the digital controller. Both the upper and lower grips will be returned to their original positions automatically.
d) Repeat section 3.6.3 of the procedure to run more samples. Clean up any broken fragments from the specimen.

RESULTS AND DISCUSSION

Support Structure Test (SST)

The results of the SST for five models printed in different positions are shown in Figure 6. Figure 6(a) illustrates that model 1 produced the best print quality compared to other models, though it displayed an uneven surface from angles 5° to 35°. The support structures used in the model design were difficult to remove, particularly at angles between 5° and 15°. Model 2 and model 3 exhibited surface imperfections, especially at angles 37.4° to 45° and 32.5° to 45°, respectively, but these angles showed relatively better results. The support structures for model 2 were hard to remove at angles 5° to 20° in Figure 6(b), while model 3's support structures were tedious to remove at angles 5° to 22.5° in Figure 6(c). Model 4, shown in Figure 6(d), exhibited surface roughness starting from angle 5° to 12.5°, with support structures that were challenging to remove within this range. Model 4, despite the challenges, produced the best print quality overall.

However, retraction stringing was observed between the sample parts, leaving an impact on the surface when the strings were removed. Model 5 had surface roughness beginning at angle 5° to 25°, with support structures difficult to remove from angles 5° to 17.5° in Figure 6(e). The experiment with the Espresso F220 3D printer indicated that uneven surfaces on printed models were due to necessary support structures required during the printing process. Additionally, the theory that models do not require support structures at a 45° angle was validated, as the model parts at this angle could sustain themselves without additional support.



(a) (b)

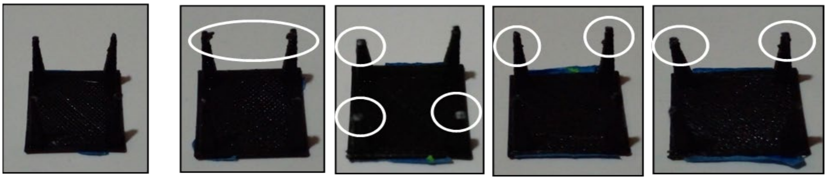
(c) (d)

(e)

Figure 6: Results of RT printing process: (a) model 1, (b) model 2, (c) model 3, (d) model 4, and (e) model 5

Retraction Test

The images of the RT using different positions on the Espresso F220 3D printer are shown in Figure 7. Model 1demonstrated the best retraction, with minimal retraction stringing that did not significantly damage the model surface. Models 2, 3 and 5 in Figures 7(b), 7(c), and 7(e) respectively, showed retraction stringing between the model towers, leaving marks on the surface. Model 3 exhibited the poorest retraction results, with incomplete printing in three parts of the model tower. Model 4 experienced minor retraction stringing that did not severely impact the surface when removed from the model.

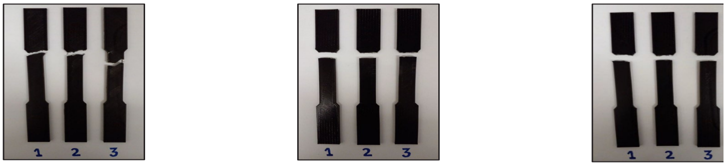


(a) (b) (c) (d) (e)

Figure 7: Modeling results of RT printing process. (a) model 1, (b) model 2, (c) model 3, (d) model 4 and (e) model 5

Tensile Test (TT)

TT was conducted by applying increasing loads to the samples until failure using a Universal Testing Machine. The resulting stress/strain curves were used to determine the mechanical properties of the materials. Three different temperature settings were used for printing ASTM D638 samples to determine the optimal temperature for sample durability [20, 21].



(a) (b) (c)

Figure 8: Samples for Tensile Test at different temperatures: (a) T = 190°C, (b) T = 210°C, and (c) T = 230°C

The failure of the specimens occurred within the gauge length region at different points for each sample, as shown in Figure 8. Table 2 summarizes the average maximum force and stress for each temperature setting. The maximum force results for specimens printed at 190°C, 210°C, and 230°C were 1.04 kN, 1.53 kN, and 1.60 kN, respectively. Correspondingly, the maximum stress increased to 24.89 N/mm^2, 36.74 N/mm^2, and 38.51 N/mm^2. Some specimens exhibited breakage before reaching the yield point, indicating material fragility. The strength of 3D printed PLA specimens is comparable to conventionally used ones, making them suitable for various applications such as packaging, agriculture, sanitary products, and consumer goods like trays, boxes, and containers.

Table 2: Average different of maximum force and maximum stress for Tensile Test

Temperatures (°C)	190	210	230
Maximum Force (kN)	1.04	1.53	1.60
Maximum Stress (N/mm^2)	24.89	36.74	38.51

CONCLUSION

The proposed printing guidelines for the Espresso F220 3D printer at UiTM Penang's Engineering Industry 1 laboratory have been successfully developed. The selection of parameter settings, including infill density, and printing speed, has proven to be crucial for achieving high-quality prints. The effectiveness of these parameters is demonstrated through the results of the Support Structure Test (SST), Retraction Test (RT), and Tensile Test (TT). Specifically, model 4 yielded the best results in the SST, while model 1 performed the best in the RT. The TT results showed that increasing the temperature affected the maximum force and maximum stress of the prints. Overall, these 3D printing guidelines are a valuable reference for achieving optimal printing results with the Espresso F220 3D printer.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Higher Education Malaysia and Universiti Teknologi MARA under grant number: FRGS 2023-1(473188).

REFERENCES

[1] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, 2018. Additive manufacturing (3D printing): A review of materials, methods, applications and challenges, *Composites Part B: Engineering,* 143, 172–196.

[2] D. M. Hajare and T. S. Gajbhiye, 2022. Additive manufacturing (3D printing): Recent progress on advancement of materials and challenges, *Materials Today: Proceedings,* 58, 736–743.

[3] S. C. Ligon, R. Liska, J. Stampfl, M. Gurr, and R. Mülhaupt, 2017. Polymers for 3D Printing and Customized Additive Manufacturing, *Chemical Reviews*, 117(15),10212–10290.

[4] A. K. Sood, R. K. Ohdar, and S. S. Mahapatra, 2010. Parametric appraisal of mechanical property of fused deposition modelling processed parts, *Materials & Design,* 31(1), 287–295.

[5] E. A. Syaefudin, A. Kholil, M. Hakim, D. A. Wulandari, Riyadi, and E. Murtinugraha, 2023. The effect of orientation on tensile strength 3D printing with ABS and PLA materials, *Journal of Physics: Conference Series,* 2596(1), 012002.

[6] X. Wang, M. Jiang, Z. Zhou, J. Gou, and D. Hui, 2017. 3D printing of polymer matrix composites: A review and prospective, *Composites Part B: Engineering,* 110, 442–458.

[7] C. Chua and K. F. Leong, 2014. 3D Printing and additive manufacturing: Principles and applications (with companion media pack) - f*ourth edition of rapid prototyping.*

[8] H. Radhwan, Z. Shayfull, A. E. H. Abdellah, A. R. Irfan, and K. Kamarudin, 2019. Optimization parameter effects on the strength of 3D-printing process using Taguchi method, *AIP Conference Proceedings, American Institute of Physics Inc,* 2129 (1).

[9] J. Mogan *et al,* 2023. Fused Deposition Modelling of Polymer Composite Subjects: A Progress. *Polymers,* 15(1), 28.

[10] Y. Li and Z. Teng, 2024. Effect of printing orientation on mechanical properties of SLA 3D-printed photopolymer, *Fatigue and Fracture of Engineering Materials and Structures,* 47(5),1531–1545.

[11] D. Yadav, D. Chhabra, R. Kumar Garg, A. Ahlawat, and A. Phogat, 2020. Optimization of FDM 3D printing process parameters for multi-material using artificial neural network, *Materials Today: Proceedings,* 21, 1583–1591.

[12] V. Dhinakaran, K. P. M. Kumar, P. M. B. Ram, M. Ravichandran, and M. Vinayagamoorthy, 2020. A review on recent advancements in fused deposition modeling," *Materials Today: Proceedings*, 27,752–756.

[13] W. Tan, Y. Tanoto, N. Jonoadji, and Christian, 2021 A. The Effect of Cooling and Temperature in 3D Printing Process with Fused Deposition Modelling Technology on the Mechanical Properties with Polylactic Acid Recycled Material, I*nternational Review of Mechanical Engineering (IREME),*15, 615.

[14] H. Jia and W. Xu, 2021. Research on 3D Printing layered Algorithm based on FDM Technology, *Journal of Physics: Conference Series,* 1798(1),012027.

[15] Z. Liu, Y. Wang, B. Wu, C. Cui, Y. Guo, and C. Yan , 2019. A critical review of fused deposition modeling 3D printing technology in manufacturing polylactic acid parts, *The International Journal of Advanced Manufacturing Technology,* 102(9), 2877–2889.

[16] J. C. Camargo, A. R. Machado, E. C. Almeida, and E. F. M. S. Silva, 2019. Mechanical properties of PLA-graphene filament for FDM 3D printing, *The International Journal of Advanced Manufacturing Technology*, 103(5), 2423–2443.

[17] F. M. Mwema and E. T. Akinlabi, 2020. Basics of Fused Deposition Modelling (FDM), Fused Deposition Modeling: Strategies for Quality Enhancement, *Springer International Publishing,* 1–15.

[18] A. Rodríguez-Panes, J. Claver, and A. M. Camacho, 2018. The influence of manufacturing parameters on the mechanical behaviour of PLA and ABS pieces manufactured by FDM: A comparative analysis, *Materials*, 11(8).

[19] C. Abeykoon, P. Sri-Amphorn, and A. Fernando, 2020. Optimization of fused deposition modeling parameters for improved PLA and ABS 3D printed structures, *International Journal of Lightweight Materials and Manufacture,* 3(3), 284–297.

[20] Standard Test Method for Tensile Properties of Plastics 1, D638 – 14, 1898.

[21] M. Kamer, S. Temiz, and A. Kaya, 2023. Determination of Energy Consumption During The Tensile Test Sample Production in 3D Printer Working with The Fused Deposition Modeling Method," *Journal of the Institute of Science and Technology*, 13(3), 1998–2007.