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Effect of Infill Density, Printing Speed and Layer Thickness on Mechanical Properties of Pineapple Leaf Fibre-Reinforced PLA in FDM 3D Printing

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ABSTRACT

The integrated of bio-based and sustainable composite materials had advanced the additive manufacturing (AM) industry, particularly for fused deposition modelling (FDM). Natural fibre-reinforced composites are gaining prominence due to their eco-friendly properties and compatibility with thermoplastics. This study investigates the influence of infill density and layer thickness on the mechanical properties of a novel pineapple leaf fibre (PALF)-reinforced poly-lactic acid (PLA) composite filament used for 3D printing. The composite filament was fabricated through a structured process involving fibre crushing, sieving, mixing with PLA matrix and extrusion. To study the effects of infill density and layer thickness, a series of tensile and flexural test specimens were fabricated in accordance with ASTM D638 and D790 standards, respectively. A design of experiments (DoE) approach, specifically the Taguchi method, was employed to systematically evaluate the influence of layer thickness (0.1 mm, 0.2 mm, 0.3 mm), printing speed (25 mm/s, 50 mm/s, 100 mm/s) and infill density (25%, 50%, 100%), on the mechanical performance. The results revealed a significant correlation between the chosen FDM parameters and the mechanical properties of the PALF/PLA composite. Higher infill density generally contributed to improved tensile and flexural strength due to increased internal material support and reduced void formation. Conversely, lower infill densities, while reducing material consumption and printing time, exhibited reduced mechanical strength. Layer thickness also demonstrated the least influence on the mechanical properties. However, increased layer thickness reduced build time and material overlap. The interaction between infill density and tensile performance is also confirmed in this study with the score of r□0.9799 and r□0.9806. Negative effect between the printing speed and all mechanical properties with the range values between r□-0.0569 and r□-0.3608. The study concludes that optimizing these parameters is essential to balance mechanical strength, material efficiency, and printing time. This research contributes to the growing body of knowledge on sustainable 3D printing materials and provides practical insights for optimizing process parameters when using natural fibre composites. It highlights the potential of pineapple leaf fibre as a valuable reinforcement in biodegradable thermoplastics, promoting a circular economy and sustainable manufacturing practices.

Keywords: Pineapple leaf fibre; poly-lactic polymer; taguchi method; tensile testing, flexural testing; correlation analysis

INTRODUCTION

Additive manufacturing (AM), commonly known as 3D printing, has revolutionized the manufacturing landscape with its ability to produce complex geometries, reduce material waste, and enable rapid prototyping. Among the various AM techniques, Fused Deposition Modeling (FDM) stands out for its cost-effectiveness, versatility, and growing applicability in industrial and consumer-level fabrication (Qamar Tanveer et al. 2022). As FDM becomes increasingly adopted in various sectors such as automotive, aerospace, construction, biomedical and consumer goods. There is a growing interest in sustainable, bio-based materials that can be integrated into this technology. One promising avenue lies in the development and optimization of natural fibre-reinforced composites. Agricultural waste, such as fibre, crop residues, fruit shells and peels are increasing daily in Malaysia. Pineapple leaf fibre (PALF), flax, hemp, jute, kenaf and coir are the example of high demand natural fibre in Malaysia (Sharvini & Stringer, 2025). Rice husk, wheat straw and corn stalks are the examples of interesting crop residues materials used in research for materials sciences recently. Sugarcane bagasse, banana peels and coconut shell also increase as renewable material that can increase material performance. This renewable, sustainable resource not only can benefit the automotive and aerospace industries for 25 years back but also help recognize of socio-economic and behavior dimension of adopting renewable energy by social science domain (Bathaei & Štreimikienė 2023). This research review from 432 research works from year 2010 mentioned it important to use more environmentally friendly products to produce fewer greenhouse gas emissions and lessen the negative effects of climate change. Nowadays multiple industries are under pressure to reduce carbon emissions and environmental impact, are turning to bio-based materials to replace or supplement traditional synthetic fibers and polymers, such as those incorporating pineapple leaf fibre (PALF) into a polymer matrix like polylactic acid (PLA). These composites offer an eco-friendly alternative to conventional petroleum-based materials while maintaining mechanical integrity suitable for engineering applications.

Pineapple leaf fibre, a byproduct of pineapple cultivation, is rich in cellulose, making it lightweight, biodegradable, and high in tensile strength. Its integration into PLA, a biopolymer already established in 3D printing promise can offers a sustainable solution to waste valorization and polymer enhancement (Ilyas et al. 2021). However, the successful use of PALF/PLA composites in FDM is highly dependent on a range of process parameters that influence the final mechanical properties such as tensile and flexural performance of printed parts (Murariu et al. 2022). Among these parameters, infill density, printing speed, and layer thickness play a pivotal role in determining the mechanical performance of 3D-printed objects. Each of these parameters affects material deposition, inter-layer bonding, and overall structural integrity, thereby influencing mechanical properties such as tensile strength tensile modulus, flexural strength and flexural modulus (Shahar et al. 2022).

Infill density determines the amount of material used within the interior of a 3D-printed object and directly impacts its weight and strength. A higher infill density generally results in stronger parts but also increases material consumption and print time (Ali et al. 2023). On the other hand, lower infill densities reduce weight and production cost but may compromise mechanical performance. In PALF/PLA composites, this balance becomes more complex due to the heterogeneous nature of the material and the need for optimal fibre-matrix bonding. Printing speed is another critical parameter that affects the quality of printed layers and their adhesion (Vatandaş et al. 2022). Faster printing speeds may result in poor layer bonding and inadequate extrusion, especially in fibre-reinforced composites where the presence of natural fibres can increase the risk of nozzle clogging and uneven flow. Conversely, slower speeds allow for better fibre alignment and layer fusion but increase production time (Yang & Yeh, 2020). Thus, identifying an optimal printing speed is essential for maximizing the mechanical properties without sacrificing efficiency.

Layer thickness, which refers to the height of each deposited layer, also significantly influences the surface finish and inter-layer adhesion. Thinner layers generally yield smoother surfaces and stronger inter-layer bonding, enhancing the mechanical performance of the final part (Hanon et al. 2020). However, they also require more printing time and higher precision. In composite filaments, where fibre size and distribution can vary, the impact of layer thickness becomes more pronounced and warrants thorough investigation. Despite the increasing interest in natural fibre-reinforced filaments, comprehensive studies examining the interactive effects of these three critical parameters on the mechanical properties of PALF/PLA composites in 3D printing remain limited. Understanding how infill density, printing speed, and layer thickness influence mechanical performance is essential for advancing the application of bio-based materials in additive manufacturing. Moreover, optimizing these parameters will contribute to the development of sustainable, high-performance components suitable for a range of functional applications. In addition, the quantitative measurement like Pearson correlation coefficient that describe the relationship between the printing process parameter and the mechanical properties can help the decision makers like design and manufacturer engineers during the production plan (Attoye et al. 2019).

This study aims to investigate the combined effects of infill density, printing speed, and layer thickness on the mechanical properties of 3D-printed PALF/PLA composite specimens. By employing systematic experimental design and mechanical testing, this research seeks to identify the optimal parameter settings that enhance the structural performance of natural fibre-based 3D-printed materials. The findings are expected to provide valuable insights for sustainable material development, contributing to both environmental sustainability and technological advancement in additive manufacturing.

METHODOLOGY

MATERIALS AND SAMPLING PREPARATION

The materials, process fabrication of filament, design of experiment using Taguchi method, mechanical testing, and statistical analysis on PALF/PLA composites are discussed. The raw pineapple leaf fibre is from local distributor, Pontian, Johor. IngeoTM Biopolymer 2003D pellets that are 100% pure PLA were supplied by Mecha Solve Engineering in this study. Figure 1 shows the raw of pineapple leaf fibre and pure PLA pallet. In general, the methodology in this study was shown in Figure 2, start with preparation of the PALF fibre, including the process of cutting the long fibre to 2-3cm, then the fibre is grinding to small size.

Finally, the fibre is sieve into the size of between 125-250 µm (micrometer). The PALF fibre and the pallet of PLA are mixed up using the internal mixer with the temperature of 180°C and speed of 50 rpm to achieve a homogenous blend between the fibre and the polymer. These approached can improve the distribution of the fibre by physical observation compare to hot press method (Muhammad et al. 2024). In this study, 5% fibre loading is used for fabrication of the filament composite. The best performance of tensile strength up to 27.31±1.55MPa was reported previously for 5% fibre loading compared to 1% and 3% (Mohamad et al. 2024). The composite is crush to smaller size for final stage of fabrication the filament composite which is extrusion process. The composite is extruding using single extruder with the temperature setting of 160°C and speed of 360 rpm. This setting is used to maintain the diameter of the filament between 1.65 mm and 1.75mm.

FIGURE 1. The raw materials for PALF/PLA composites

The specimens are design followed by the standard of mechanical properties which are American Society for Testing & Material, ASTM D638 and D790 for tensile and flexural testing. AutoCAD and Ultimaker Cura 5.3.0 software are used based on L9 orthogonal array suggested by Taguchi method. In total, 45 samples are printed for tensile testing and 45 samples for flexural testing as shown in Figure 3 and Figure 4. Statistical analysis such as optimization using Taguchi Method and Pearson correlation coefficient are used to finalize the best printing process parameters that optimize mechanical properties in this study.

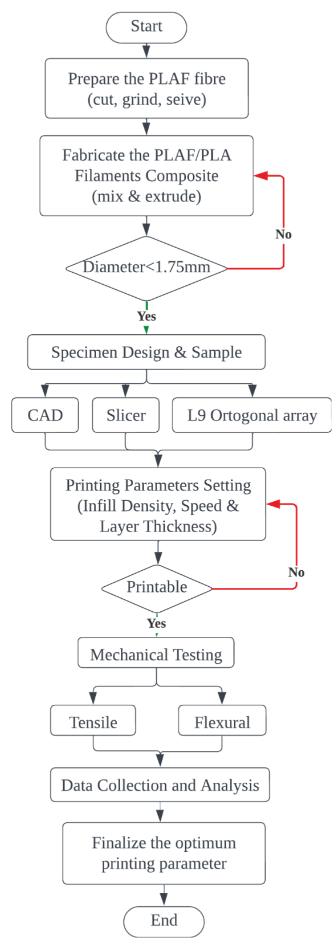

FIGURE 2. The flowchart in this study

DESIGN OF EXPERIMENT USING TAGUCHI METHOD

The Taguchi Method was employed to systematically optimize the printing parameters in the fabrication of PALF/PLA filament composite using FDM. This method utilizes a robust design approach to enhance quality and performance while minimizing variability. An L9 orthogonal array was selected to study the influence of three key process parameters which are layer thickness (in millimeters), print speed (in millimeter per second), and infill density (in percentage). Each of these printing parameters has three different levels. This design enabled efficient experimentation with a reduced number of trials while capturing significant interactions which are from 3^3 number of samples to 9 runs in this study. Nine runs with detailed levels of each parameter were shown in Table 1.

FIGURE 3. The sample speciment of PALF/PLA (ASTM D638 Type I)

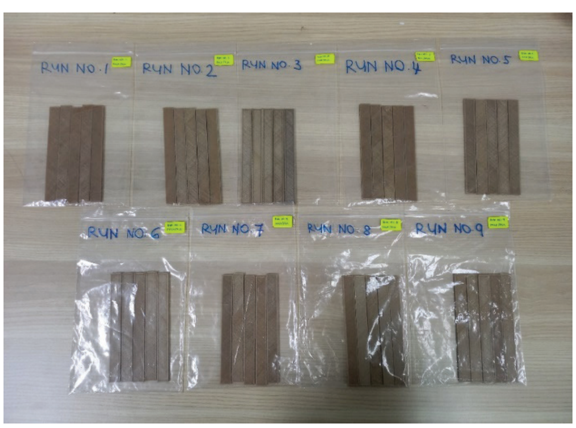

FIGURE 4. The samples speciment of PALF/PLA (ASTM D790)

Each experimental run was conducted five times to the corresponding output responses such as tensile strength, tensile modulus, flexural strength and flexural modulus. An average score for the properties is calculated using Equation 1. The variation between the measurements for the properties is measured by calculating the standard deviation (*s*) using Equation 2. The Signal-to-Noise Ratio (*SNR*) also measured for each response to identify the optimal level of each parameter, with "larger-the-better" criteria applied as appropriate. The main effect plot for *SNR* also plotted for every mechanical property in this study to confirm the optimum level. Equation 3 is used to calculate the *SNR* for tensile and flexural properties (Sukindar et al. 2024). This methodology ensured a reliable and efficient process for improving the mechanical properties of PALF/PLA printed components while minimizing material waste and production time.

TABLE 1. Nine runs sampling of L9 orthogonal array

Run	Layer thickness (mm)	Printing speed (mm/s)	Infill density (%)
1	0.1	25	25
2	0.1	50	50
3	0.1	100	100
4	0.15	25	50
5	0.15	50	100
6	0.15	100	25
7	0.2	25	100
8	0.2	50	25
9	0.2	100	50

$$\bar{y} = \frac{\sum y_i}{n} \tag{1}$$

$$s = \frac{1}{n}\left(\sum y^2 - \frac{\left(\sum y_i\right)^2}{n}\right)$$

(2)

$$SNR = -10\log_{10}\left(\sum \frac{1/y^2}{n}\right)$$

where *n* is number of sample and *y* is the response variables.

MECHANICAL PROPERTIES OF PALF/PLA

The mechanical properties of the PALF/PLA are evaluated using tensile and flexural testing, followed by ASTM D638 and D790 standard. Rectangular specimens with dimensions of 12.7 mm wide, 126 mm long, and 3 mm thickness were tested using the Instron 8872 Universal Testing Machine (UTM) as shown in Figure 5. The specimens were placed in the UTM grips, ensuring more than half of the grip length was in contact. Specimen measurements and test with the speed of 5 mm/min and load cell of 50 kN (in kilonewton) capacity during the testing. Maximum load, tensile stress, and tensile strain were recorded.

FIGURE 5. The Instron 8872 UTM Machine for Tensile Testing

Flexural tests, also known as 3-point bending tests, were performed according to ASTM D790 standard. Rectangular specimens with dimensions of 126 mm length, 12.7 mm width, and 3 mm thickness were used, with the speed of 5 mm/min. The tests were conducted by using the Instron 5585 Universal Testing Machine (UTM) as shown in Figure 6. The specimen was placed on two supporting pins, and the loading pin was positioned at the midpoint. Specimen measurements and test speed (2-5 mm/min) were input into the computer. Maximum load, flexural stress, and flexural strain were recorded.

FIGURE 6. The Instron 5585 UTM Machine for Flexural Testing

THE PEARSON CORRELATION COEFFICIENT

The relationship between two parameters of mechanical properties and the printing process parameters was measured using Pearson correlation coefficient, (r) as shown in Equation 3. A linear correlation between two parameters such as tensile strength and layer thickness, tensile modulus and infill density and flexural strength and printing speed are important to explain the effect between two parameters. The relationship between mechanical properties and printing process parameter can have positive or negative effects. The level of interconnection between two parameters can be strong, moderate and weak (Noryani et al. 2018). This result can help design and manufacturer engineers to finalize the important printing parameters to certain design and product requirements.

$$r = \frac{SS_{xy}}{\sqrt{SS_{xx} \times SS_{yy}}} \quad (3)$$

where SS_{xy} is the sum of square of interaction between mechanical property and printing parameter, SS_{xx} is the sum of square of printing parameter and SS_{yy} is the sum of square of mechanical property.

RESULT DAN DISCUSSIONTENSILE TESTING OF PALF/PLA

Both tensile strength and tensile modulus are measured to study the performance of PALF/PLA composite specifically for FDM technology to support the industry 4.0 that facilitates rapid prototyping, on-demand production and can provide personal and complex preference from the user and industry. Figure 7 shows the tensile performance for different printing parameter settings. The highest was run no.7 with 37.097±1.75 MPa and the lowest was run no. 6 with 17.601±2.76 MPa. Interfacial bonding between the composite is one of the factors that might influence the strength of the materials. Previous study on wood/PLA filament composite found the range of tensile strength between 7.53 and 10.15 MPa. These results are from the experimental and predicted using Taguchi method (Sultana et al. 2024). The performance of the material is important to 3D printing applications to design a product that meets the product design specification. Different printing parameters will result in different strengths of the composite as shown in Figure 7. It is important to study the optimum printing level for each printing parameter by using Taguchi analysis. The tensile modulus in Figure 8 shows significant difference between the performance of tensile modulus with all 9 runs. The highest and lowest performance score was run no. 7 and run no. 8 with 1.383±0.05 GPa and 0.721±0.12 GPa respectively. Despite, the maximum score of kenaf reinforced PLA composite only reach 1.2 GPa for same application using FDM (Jamadi et al. 2023). Another previous study mentioned the range of tensile modulus for wood/PLA composite are between 0.16 and 0.20 GPa (Sultana et al. 2024). Another factor such as chemical treatment is one of the important factors that can improve the performance of the composite. Chemical treatment believed can clean and rough the fibre surface, enhance interfacial bonding with the composite, reduce moisture sensitivity and increase fibre crystallinity (Ganapathy et al. 2023). In fact, the mechanical strength is improved by combining more than 1 material for different polymers such as PLA and Acrylonitrile butadiene styrene (ABS). The tensile modulus increase from 0.15 GPa for pure PLA to 0.26 GPa for composite PLA (Abeykoon et al. 2020). Another published work mentioned untreated kenaf/PLA composite score better tensile strength with 27.27 MPa compared to kenaf/PLA composite treated by green treatment like superheated steam that did not give any environmental impact (Alaa et al. 2023).

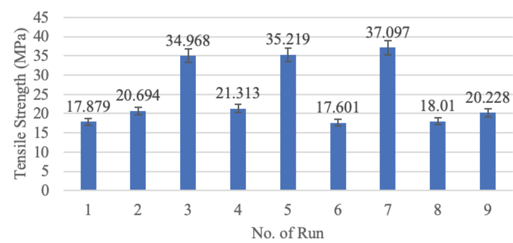

FIGURE 7. The average tensile strength of PALF/PLA for 9 runs.

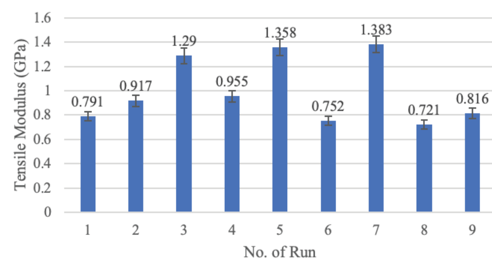

FIGURE 8. The average tensile modulus of PALF/PLA for 9 runs

FLEXURAL TEST OF PALF/PLA

In this study, flexural testing is performed to evaluate the bending strength and flexibility of the composite materials. Moreover, the flexural test is used to understand how the PALF/PLA filament composites behave under bending or flexural loads, this is very important for applications where the material will experience bending forces. Figure 9 presents bar graph of the average flexural strength of 9 runs PALF/PLA composite with varying printing process parameters. Run number 3 (layer thickness=0.1, printing speed=100 & infill density=100) exhibits the highest flexural strength with 56.282±8.764 MPa, attributable to the inherent stiffness of the PLA matrix. Run number 8 score the lowest flexural strength (layer thickness=0.2, printing speed=50 & infill density=25) with 41.69±10.447 MPa. In general, there are no significant difference on the flexural strength performance of PALF/PLA composite. Previous study discussed the effect of heating PLA/

Aluminium composite on the flexural performance, it shown an increment on flexural strength by 5-8% after heating the composite which maximum flexural strength up to 86.6 MPa (Ganapathy et al. 2023).

The maximum flexural modulus was run no. 4 (layer thickness=0.15, printing speed=25 & infill density=50) with 3.291±0.240 GPa. While the lowest flexural modulus was run no. 8 (layer thickness=0.2, printing speed=50 & infill density=25) with 2.125±0.289 GPa. This finding is consistent with the score of flexural strength of PALF/ PLA composites. This finding confirms the with printing setting of layer thickness=0.2, printing speed=50 & infill density=25 produce lowest bending strength and flexibility of the composite materials in this study. Smaller fibre size can contribute to high strength both tensile and flexural properties compare to bigger fibre size, it improved the bonding between the material because more surface area of the fibre in between the polymer (Jamadi et al. 2023).

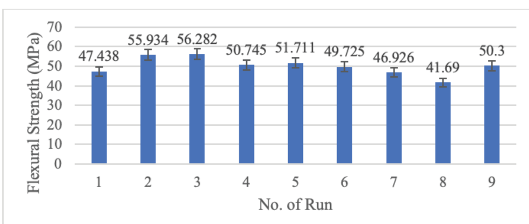

FIGURE 9. The average flexural strength of PALF/PLA for 9 runs

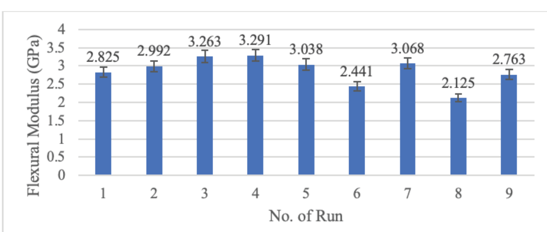

FIGURE 10. The average flexural modulus of PALF/PLA for 9 runs

THE OPTIMUM PRINTING PROCESS PARAMETER FOR MECHANICAL PROPERTIES OF PALF/PLA COMPOSITES

SNR score is measured to identify the importance of the printing parameters toward the mechanical performance in this study. The parameters were ranked according to their performance (Sukindar et al. 2024). For mechanical properties, *SNR* are calculated using 'larger is better' concept. Table 2 show the infill density was the most important parameter to tensile strength of PALF/PLA composite, printing speed is the second parameter important and layer thickness score the third places. Details show in Figure 11, the main effect of each level of printing parameter are plotted. The best combination of printing process parameters that can optimize the tensile strength was layer thickness of 0.2 mm, printing speed 25 mm/s and infill density of 100%. A review regarding the effect of infill density on mechanical behavior mentioned an increasing the infill density can increase the mechanical strength of the materials due to inter-layer bonding between the consecutive layers during the printing process (Qamar Tanveer et al. 2022). Other study used 100% infill density to maintain the strength to finalize the best fibre loading between 5% to 20% for kenaf/PLA composite (Hamat et al. 2023).

TABLE 2. The SNR for tensile strength of PALF/PLA

Level	Layer Thickness	Speed	Infill Density
1	27.41	27.67	25.02
2	27.47	27.45	26.34
3	27.54	27.30	31.07
Delta	0.13	0.37	6.04
Rank	3	2	1

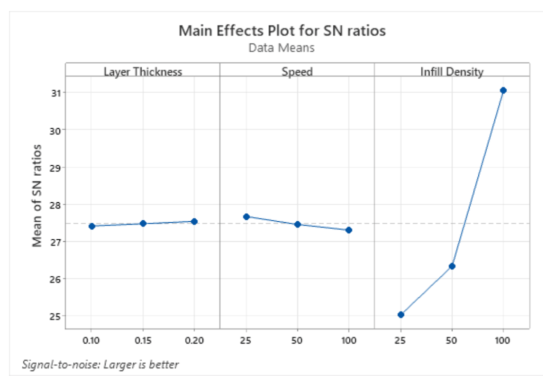

FIGURE 11. The main effect of tensile strength

Tensile modulus is an important key determinant of how the composite behaves under mechanical load. It is important to many industries to decide the materials that meet specific stiffness requirements without compromising on weight, durability and functionality. Table 3 described the rank score of printing parameters toward tensile modulus. Infill density, printing speed and layer thickness are the sequence of important of them. Detail effect of each level of printing parameter is plotted in Figure 13. Layer thickness of 0.1 can provide a better tensile modulus of the composite. Printing speed of 100 mm/s can result in better strength modulus compared to printing speed of 25 and 50 mm/sis. 100% infill density promised a good strength of the composite. As well as for PLA and ABS composite score higher modulus compare to 50% infill density that promise can improve printed structures for 3D printing application (Abeykoon et al. 2020). Another factor that can affect the tensile performance of the composite in 3D printing was the infill pattern, triangular pattern reported have better performance compare to other infill pattern because they have more sheared or contact points per unit area (Qamar Tanveer et al. 2022). Printing speed is not an important parameter to tensile modulus but also effect the physical properties such as surface finishing of printed parts (Mat et al. 2020).

TABLE 3. The SNR for tensile modulus of PALF/PLA

Level	Layer Thickness	Speed	Infill Density
1	-0.1924	0.1267	-2.4511
2	-0.0725	-0.3120	-0.9729
3	-0.5970	-0.6767	2.5621
Delta	0.5245	0.8034	5.0132
Rank	3	2	1

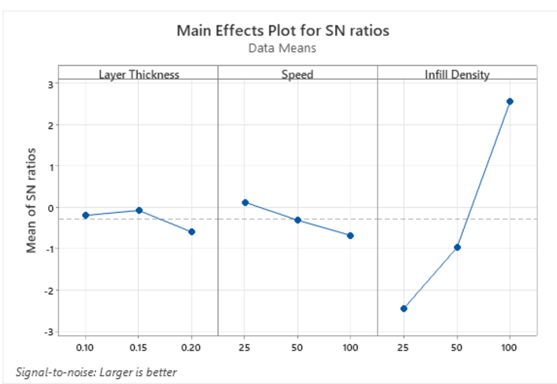

FIGURE 12. The main effect of tensile modulus

Another important mechanical property for polymer composite is flexural strength and modulus. Both flexural properties are very important to design and manufacturing engineer because the performance on flexural properties lead to durability, manufacturability of printed parts subjected to bending loads. Different applications of printed parts required different standards. Table 4 and Figure 13 show the *SNR* and main effect plot for flexural strength, the most influence printing parameters was layer thickness, and the least important parameter is printing speed for flexural strength of PALF/PLA composites. The best combination of printing process parameters that can optimize the flexural strength are layer thickness of 0.1 mm, printing speed of 100 mm/s and infill density of 50%. Another property such as elongation at break also need 0.1 mm layer thickness for PLA polymer composites with score 3.13 % (Hanon et al. 2021). Previous study found that the performance of flexural strength of kenaf/ABS composite in FDM application is in between the range of 26.48 to33.02 MPa (Han et al. 2022).

TABLE 4. The SNR for flexural strength of PALF/PLA

Level	Layer Thickness	Speed	Infill Density
1	34.49	33.69	33.28
2	34.10	33.88	34.36
3	33.29	34.32	34.24
Delta	1.21	0.64	1.08
Rank	1	3	2

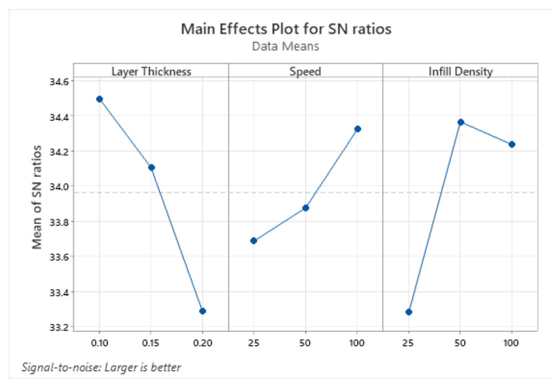

FIGURE 13. The main effect of flexural strength

Infill density significantly influences the performance of flexural modulus of PALF/PLA composite in this study. Layer thickness rank number 2 and the last printing parameter was printing speed. To optimize the flexural modulus, the design engineer should use printing setting of layer thickness of 0.1 mm, printing speed of 25 mm/s and infill density of 100%. This result can help the industry to reduce materials waste with cost and time effectively. Ignoring these properties can lead to product deformation, premature failure, or excessive costs due to overdesign. Therefore, engineers must rigorously evaluate flexural characteristics to achieve optimal performance and cost-effectiveness in real-world applications. A hybrid composite found that a higher fibre powder such as wood powder leads greater flexural properties and hardness of the composite (Thiem et al. 2024). It is consistent with another types of composite which are kenaf/ABS composite in 3D printing applications (Aida Che Hamid et al. 2022).

TABLE 5. The *SNR* for flexural modulus of PALF/PLA

Level	Layer Thickness	Speed	Infill Density
1	9.604	9.701	7.773
2	9.250	8.573	9.564
3	8.371	8.950	9.887
Delta	1.233	1.129	2.114
Rank	2	3	1

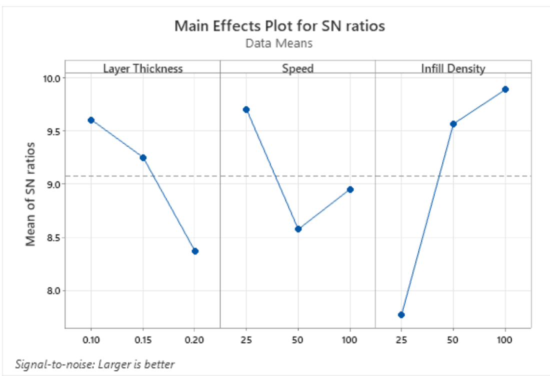

FIGURE 14. The main effect of flexural strength

THE RELATIONSHIP BETWEEN MECHANICAL PROPERTIES AND PRINTING PARAMETERS OF PALF/PLA

Further analysis can describe how strong the relationship between the mechanical properties and printing process parameters can give extra information to increase the trustworthy between the user and the manufacturer. Table 6 shows the *r* values for all combinations of two parameters. There is strong positive linear relationship between infill density and tensile modulus with r=0.9799. Equal finding between infill density and tensile strength with r=0.9806. Table 6 also shows a negative linear correlation between printing speed, and all the mechanical properties include the printing time with the value of *r* in range of -0.0569 to -0.3608 for mechanical properties. It concludes that once printing speed increases, the mechanical properties are decreasing. Moreover, it is very weak positive linear relationship between layer thickness and tensile strength with r=0.0310.

Identify the relationship between printing process parameters and the mechanical performance of the composite can further optimize the regression model to estimate the performance with an appropriate printing conditions (Murariu et al. 2022). The interconnection between the parameters also help the production to manage the total cost include raw and manufacturing cost (Noryani et al. 2020) . Furthermore, this method can be used to compare two different polymer composite that finalize the performance of mechanical properties of printed part using FDM technology(Attoye et al. 2019).

TABLE 6. The Pearson coefficient correlation between printing parameters and Mechanical Properties

Printing Parameter / Properties	Layer Thickness	Printing Speed	Infill Density
Flexural Strength	-0.6625	-0.3608	0.4336
Flexural Modulus	-0.4249	-0.2108	0.6793*
Tensile Strength	0.0310	-0.0569	0.9806**
Tensile Modulus	-0.0416	-0.1424	0.9799**
Printing Time	-0.3106	-0.7948*	0.3808

*. Correlation is significant at the 0.05 level.
**. Correlation is significant at the 0.01 level.

CONCLUSION

This study has comprehensively investigated the effects of layer thickness, printing speed and infill density on the mechanical properties of 3D-printed pineapple leaf fibre (PALF)/polylactic acid (PLA) composites using the fused deposition modeling (FDM) technique. With the growing emphasis on sustainable materials and green manufacturing technologies, the use of natural fibres such as PALF in polymer composites represents a promising solution to reduce environmental impact while maintaining acceptable mechanical performance for functional applications.

The key findings from the experimental analysis demonstrate that the most influence printing parameters to mechanical properties was the infill density, followed by the printing speed and the least important was the layer thickness. High infill densities generally contributed to improved mechanical strength and stiffness due to the reduction in voids and enhanced internal support structure. Specifically, an infill density of 100% resulted in specimens with the highest tensile and flexural strength, attributed to the increased material continuity and load-bearing capacity within the printed structure. In contrast, lower infill densities, such as 25%, while advantageous in terms of material savings and faster production times, led to a noticeable deterioration in mechanical integrity.

Similarly, consistent results were found that the best combination of printing process parameters for better tensile was layer thickness of 0.2 mm, printing speed 25 mm/s and infill density of 100%. In contrast, different combination printing parameters to optimize the flexural properties, layer thickness of 0.1 mm, printing speed 100 mm/s and infill density of 50% are suggested for flexural strength but layer thickness of 0.1 mm, printing speed 25 mm/s and infill density of 100% for flexural modulus. There is very strong linear relationship between infill density and both tensile performance of PALF/PLA composite with the value of *r*=0.9799 and *r*=0.9806. There is negative effect between all mechanical properties and the printing speed in this study.

Overall, the findings affirm that optimizing infill density, printing speed and layer thickness is vital for achieving desired mechanical properties in PALF/PLA composite prints. The selection of appropriate parameters must be tailored to specific applications needed. It is important to decide whether prioritizing strength, cost-efficiency or production speed. Furthermore, the incorporation of pineapple leaf fibre, an agricultural by-product, as reinforcement in PLA matrix enhances the sustainability of 3D printing materials while leveraging the high cellulose content and mechanical advantages of the natural fibre.

This research not only supports the viability of PALF as a reinforcing material in biodegradable polymer composites but also adds valuable insight into the process-structure-property relationships in FDM 3D printing. Prospective research should focus on expanding the parameter space to include nozzle temperature, raster angle, and fibre treatment methods. Additionally, microstructural analysis and long-term durability testing will be essential for validating the practical applications of these composites in real-world functional parts.

In conclusion, the careful tuning of 3D printing parameters, particularly infill density, printing speed and layer thickness, significantly enhances the mechanical performance of PALF/PLA composites, thereby promoting the use of renewable, biodegradable materials in advanced manufacturing processes.

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DECLARATION OF COMPETING INTEREST

None.

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