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Comprehensive Evaluation of Printing Process Parameters and Tensile Properties of Coconut Polypropylene Filament Composites in Additive Manufacturing

Noryani Muhammad[1,2]*, Mohd Aiman Jamaludin[3], Nuzaimah Mustafa[4], Yuzliza Yusuf[4], Mohd Adrinata Sharuzaman[1,2] and Nurul Hanim Razak[1, 2]

[1]Fakulti Teknologi dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2]Centre for Advenced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3]Quality Department, HTM Hengtech Industry Sdn Bhd, 40470 Shah Alam, Selangor, Malaysia
[4]Fakulti Teknologi dan Kejuruteraan Industri Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ABSTRACT

The printing process parameters are important in producing coconut polypropylene (CcPP) products by filament composite in the additive manufacturing industry. Fused deposition modeling techniques in 3D printing applications have considered multiple parameters to meet good finishing parts. This study uses comprehensive measurements to identify the best printing parameter for evaluating the composite properties. Complete deposition, unwrapping, good finishing, and adequate heat are the qualitative printing process parameters used to finalize the optimum nozzle and bed temperature of the CcPP filament composite. The range between 50°C to 80°C and 225°C to 245°C for bed and nozzle temperatures were used to achieve a well surface and successful production. After multiple trials of printing the CcPP filament composite, the optimal bed and nozzle temperatures were found to be 80°C and 230°C, respectively. Two types of infill density were used to analyze the effect on the tensile properties of CcPP filament composite. The result showed that 50% infill density was higher for both 1% and 5% fiber loading than 25% infill density for tensile strength with 15.65 and 22.87 MPa compared to 12.93 and 16.59 MPa. The same pattern as the score of Young's moduli of 50% infill density was

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E-mail addresses:
noryani@utem.edu.my (Noryani Muhammad)
aimanjamal.htm@gmail.com (Mohd Aiman Jamaludin)
nuzaimah@utem.edu.my (Nuzaimah Mustafa)
yusliza@utem.edu.my (Yusliza Yusuf)
adrinata@utem.edu.my (Mohd Adrinata Shaharuzaman)
nurulhanim@utem.edu.my (Nurul Hanim Razak)
* Corresponding author

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higher than 25% infill density for 1% and 5% fiber loadings with 479.52 and 641.23 MPa compared to 400.17 and 493 MPa. Qualitative and quantitative measurements of printing process parameters and properties help reduce the time and cost and benefit 3D printer users in the industry.

Keywords: Coconut/ PP composite, printing parameter, qualitative and quantitative analysis, tensile testing

INTRODUCTION

Fused Deposition Modelling (FDM) is one of the 3D printing methods that classified additive manufacturing techniques that have been gaining popularity in recent research, both academic and industry. The industry of additive manufacturing techniques is becoming increasingly popular due to their numerous advantages, including the ability to create a wide variety of complex shapes and structures while properly managing materials. FDM technology in manufacturing serves the same purpose as injection molding, primarily used for mass customization on productions. Moreover, the FDM technique can produce various personalized products and end parts that reduce production costs and make each product unique (Kristiawan et al., 2021).

Furthermore, no costs are incurred in the creation of precisely designed products. There are massive materials used in the 3D printing industry. Common materials in the FDM technique are thermoplastic polymers such as poly-lactic acid (PLA), polypropylene (PP), polyethylene (PE), and polystyrene (PS). The filament's thermo-plasticity, which influences the filament's capacity to form bonds between layers during the printing process and solidify at room temperature after printing, is a crucial task since FDM structures are constructed from layers of thin filament. Many processing parameters influence the mechanical characteristics of the printed object, such as layer thickness, width, and filament orientation (Le Duigou et al., 2020). Creating the filament's substance has proven difficult due to the complicated FDM process. The material's properties can influence the printing parameters, such as the nozzle's temperatures and the printer's bed. Extrusion consistency, good adhesion and good finishing are the other factors to be considered during the printing process for a high-quality printed part.

A recent study introduced the capability of natural fiber-reinforced composite to reduce the use of synthetic materials in the industry, which can benefit the user and the manufacturer (Mastura et al., 2022). The performance of two natural fibers (hemp and flax) with four synthetic materials (aramid, boron, carbon and glass) was compared using Young's modulus score; a significant difference was shown between these materials using hypothesis testing. The maximum score of Young's moduli for synthetic and natural fiber, which are aramid and flax, is 424.8 GPa and 57.3 GPa, respectively. Hybridization of these two materials can overcome the limitation of both natural and synthetic fibers.

Natural fiber-reinforced composite is made up of two materials: natural fiber and polymer matrix. Multiple benefits to both user and manufacturer include environmental friendliness, health and safety. Natural fibers such as cotton, wool and bamboo can offer comfort and aesthetic elements compared to synthetic materials. The manufacturer can also benefit from the cost-effectiveness of using local natural fiber, resulting in lower transportation costs. The industry can support regulation compliance, such as environmental regulation and sustainability standards. The combination of different ratios of the materials also influences the filament composite's mechanical, physical, and thermal performance (Radzi et al., 2017). Recently, this composite has demonstrated a good agreement with better physical, mechanical, chemical, and environmental properties than single fiber or polymer (Hamid et al., 2022; Ilyas et al., 2022; Muhammad et al., 2022).

Numerous studies have reported composite materials' ability to replace metal-based materials in many industries, such as automotive, food packaging, marine, aircraft, and medical (Alsubari et al., 2021; Hawary et al., 2023). In the application of 3D printing, the FDM technique is interesting for the industry in employing the filament composite. The printing process becomes more crucial to the design engineers when setting up the printing process parameters of the filament composite. Different filament composites have different characteristics based on combining two types of materials (Jumaidin et al., 2017). The crystallinity, flowability and thermal properties of the filament composite are very important to make sure the filament composite is printable. The filament composite's unique characteristics make the 3D printing process difficult. There are huge printing process parameters that should be considered during the printing process of filament composite, such as layer thickness, printing speed, nozzle and bed temperature, filling pattern, infill density, and build orientation (Alafaghani et al., 2021; Muthe et al., 2022). Identifying the printing process parameters before printing the filament composite is important.

The performance of the printed composite is affected by the printing process parameters setting during the printing process. The composite's tensile, flexural, and impact properties differ significantly based on the printing process parameters set up (Jeon et al., 2020). There is a relationship between the mechanical properties of printed parts using FDM and the process parameters for PLA and ABS polymers (Ahn & Wright, 2002; Hanon et al., 2021). A hybrid polypropylene composite with jute and coir also performs differently in tensile, flexural, impact, and hardness (Beg & Hasan, 2020). Filament composite in 3D printer technology offers many advantages, especially sustainability and environmental friendliness, supporting the fourth industrial revolution. The challenges and considerations during the printing process are critical in addressing the material selection properties and identifying the correct printing process parameters.

Qualitative measurements are essential to finalize a particular filament composite to achieve an excellent finishing printed part with an optimum time, cost, and minimum waste materials. Based on the literature, minimal studies mentioned the qualitative measurements of printing process parameters such as complete deposition, unwarping, good finishing, and adequate heat for nozzle and bed temperature. This present study focuses on the best combination of nozzle and bed temperatures using qualitative assessments to produce good finishing during printing. The current study also contributes to the 3D printing industry by addressing the effect of infill density on the tensile properties of coconut polypropylene (CcPP) filament composite. Quantitative measurements, such as infill density, were used to analyze the overall performance of the mechanical properties of the composite.

MATERIALS AND METHODS

Preparation of CcPP Filaments Composite

Coconut fibers (coir) were collected from small- and medium-sized companies in food manufacturing in Melaka, Malaysia. The coconut fibers were processed to a smaller mesh size using a DF-15 hammer mill grinder (Pulveriser, Shenzhen, China) and further sieved to obtain an average fiber size of 125–300 µm. Recycled PP polymer was obtained as 2 mm pellets from a plastic industry at Ayer Keroh, Melaka. The fiber coconut fiber was dried in an oven at 70°C for 24 hours before extrusion. Different coconut fiber loadings of 1%, 3%, and 5% were mixed with PP and extruded using a single extruder from the Composite Laboratory, Universiti Teknikal Malaysia Melaka (UTeM). In this extrusion process, a temperature of 165°C and 300 RPM speed were used to produce the requirement diameter of filament composite, less than 1.75 mm. The filament was stored in a desiccator to maintain quality before printing.

Preparation of 3D Printed Sample

Ender-3 3D printer (Creality, Shenzhen, China) with a nozzle diameter of 0.8 mm was used to print the composite filament of CcPP. In this study, the best two printing parameters, nozzle temperature and bed temperature, were examined in relation to the printability of CcPP filaments from three different percentages of fiber loading (1%, 3%, and 5%). These three fiber loadings were used to select the best nozzle and bed temperature for the sample printing process. Nozzle temperatures were set at 225°C to 245°C and bed temperatures of 50°C and 80°C. Other printing parameters were fixed, as shown in Table 1. Wall line count, horizontal expansions, and top and bottom thickness

Table 1
Printing parameter settings

Parameters	Settings
Layer Height (mm)	0.2
Wall Thickness (mm)	1.6
Nozzle Temperature (°C)	225, 230, 235, 240 and 245
Bed Temperature (°C)	50 and 80
Printing Speed (mm/s)	70
Print Cooling	No
Build Plate Adhesion Type	Brim
Infill Pattern	Triangle

were defaulted for PP material. The printed samples were designed using SolidWorks 2016 CAD and Ultimaker Cura 4.10 software.

In the first stage, the temperature of the printing nozzle and print bed with the best printability results for the CcPP filaments with different fiber loadings (1%, 3%, and 5%) were identified and selected for further evaluation based on the qualitative evaluation. In the second stage, 3D printed specimens were produced using the selected temperature of the nozzle and print bed with the best printability results to evaluate the effects of infill densities (25% and 50%) and fiber loadings (1%, 3%, and 5%) on the tensile properties.

Evaluation of the Printability

Figure 1 depicts the process flow chart to identify the printability of CcPP filament composite using qualitative and quantitative measurements. Four qualitative measurements were used to identify the printability of the filament composite: complete deposition, unwarping, good finishing, and adequate heat. Yes (/) and No (X) were used to complete the assessments of these four elements while printing each sample. Complete deposition means the sample was successful and uniformly laid down the material layer by layer, with no gaps and defects. Unwarping means no uneven cooling or contraction deformation of the printed sample, which retains its intended shape. Moreover, good finishing refers to achieving a smooth and aesthetically pleasing surface. Adequate heat in this study means two appropriate types of temperatures: bed and nozzle temperatures during the printing process. Correct temperature influences material flow, adhesion, and overall print quality. It is very important to prevent nozzle clogging,

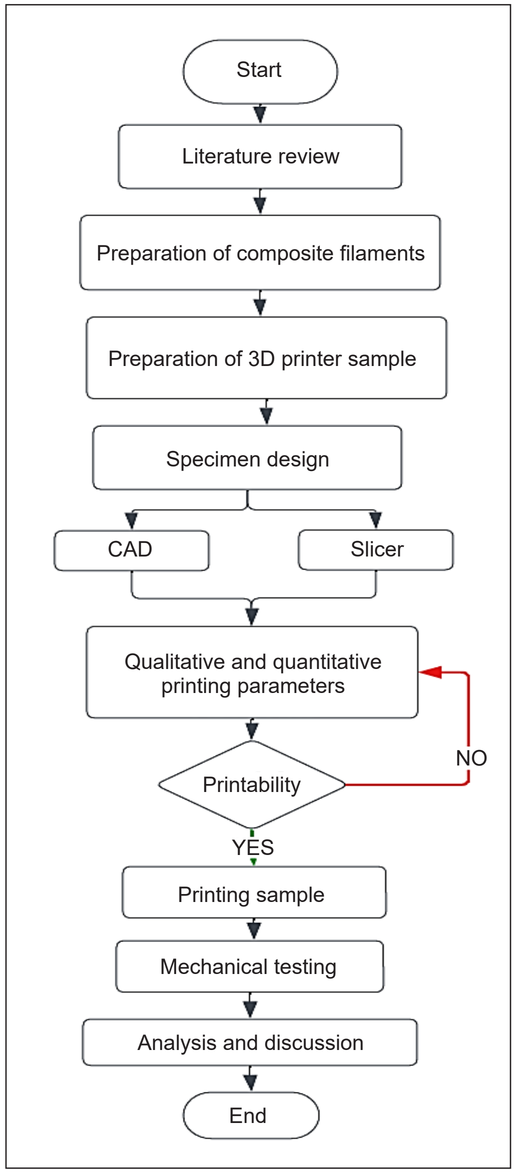


Figure 1. The process flow to identify the printability of filament composite using qualitative and quantitative measurements

unwarping, and poor layer adhesion. The quantitative printing process parameters involved infill density, which were 25 and 50%.

Evaluation of Tensile Properties

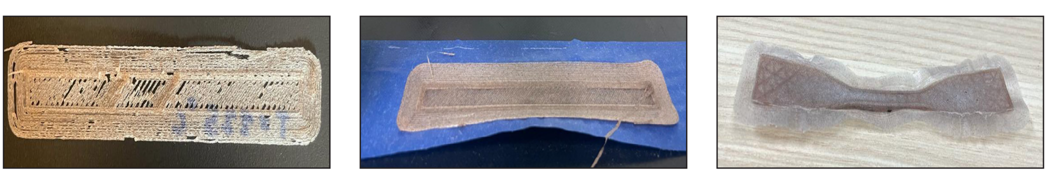
The tensile test samples were printed in accordance with ASTM D638, type IV. Tensile properties are measured to analyze the effect of infill density and fiber loading on the printed composite. A minimum of 50% of the grip section of the dumbbell-shaped specimen was clamped to the universal testing machines, then pulled by an amount of 10 kN of load with the speed of 10 mm/min to break the middle section of the specimen. The average, standard deviation and bar chart were used to analyze the tensile properties in this study.

RESULTS AND DISCUSSION

Qualitative and Quantitative Measurements of Printability for CcPP Filament Composite

The temperature of the nozzle and print bed is crucial in 3D printing process applications; the successful printing of filaments composite depends on the printing process parameters. The qualitative measurements were used to identify the ideal temperature for the printing nozzle and bed to print with CcPP filaments composite of different fiber loadings (1%, 3%, and 5%). Appropriate temperature settings are critical for melting the filament composite to ensure adhesion to the print bed. Specific temperature ranges are required for different filament composites to achieve optimal flow and bonding (Kristiawan et al., 2021). These issues are crucial to overcome the limitations in 3D printing applications, such as clogging, weak layer adhesion, warping, and surface defects (Ali et al., 2023; Jeon et al., 2020). Figure 2 (a) shows a printed sample with incomplete layer adhesion, (b) early warping, and (c) heavy warping. It is very important to identify the correct bed and nozzle temperature to print the sample. Bed temperature helps ensure the first print layer adheres properly to the building part. Warmer bed temperature can improve the adhesion of the filament to build a platform, reducing the chances of detachment or warping while printing the sample.

Temperature is critical in 3D printing as different materials have different melting temperatures. Jeon et al. (2020) reported significant differences in the samples printed with different nozzle and bed temperatures for four printing materials (PLA, lay-wood, ABS,



(a) (b) (c)

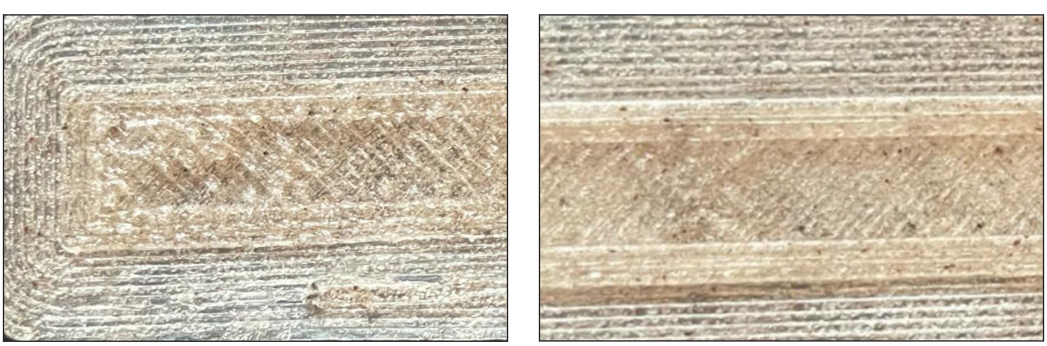
Figure 2. Incomplete layer thickness: (a) early warping; (b) heavy warping; and (c) CcPP filament composite

and nylon). Multiple printing trials of the samples were implemented between the range of nozzle and bed temperature to finalize the best combination. Table 2 shows the qualitative and quantitative measurements of printability for the CcPP filament composite in this study. The four qualitative measurements used in this study were complete deposition, unwarping, good finishing, and adequate heat for nozzle and bed temperatures.

Table 2
Qualitative and quantitative measurements of printability for CcPP filament composite

Temperature		Measurements of Printability			
Nozzle (°C)	**Bed (°C)**	**Complete Deposition**	**Unwarping**	**Good Finishing**	**Adequate Heat (Nozzle and Bed)**
225	50	X	X	X	X
230	50	/	X	X	X
230	80	/	/	/	/
235	80	/	/	X	X
240	80	/	/	X	X
245	80	/	X	X	X

Figures 3 (a) and (b) show the sample quality from the nozzle temperature of 245°C and 230°C, respectively. The sample from the nozzle temperature of 245°C had an unsatisfactory outcome with a poor surface finish and rough texture in Figure 3(a). High temperatures can rapidly melt CcPP filament composite, resulting in uneven flow and deposition (Khan & Mishra, 2020). Figure 3(b) shows better finishing on the sample's surface with a nozzle temperature of 230°C and bed temperature of 80°C. Additionally, there was no early warping, and the smooth printing process was finished with a complete sample for the tensile testing standard. After multiple trials with maximum observation during the printing process on the qualitative measurements, the best combination of bed and nozzle temperature to produce good surface finishing was identified with the printing setting as follows: 230°C for the nozzle temperature and 80°C for the bed temperature.

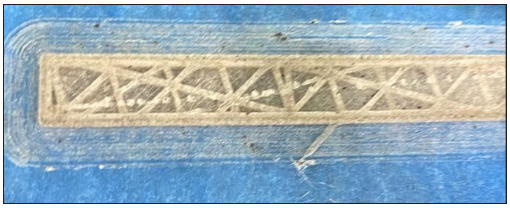


(a) (b)

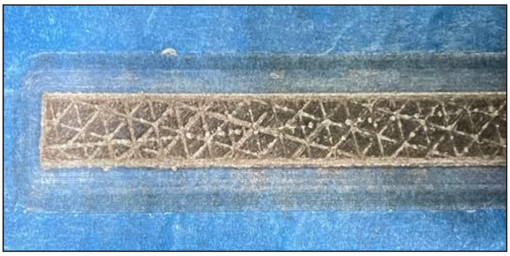
Figure 3. The printing quality of CcPP filaments composite: (a) 245°C; and (b) 230°C

The selected nozzle and bed temperatures were used to print tensile testing samples with different fiber loading and infill density. Three samples were printed for each testing combination (fiber loading x infill density), with 18 printed tensile testing samples.

The infill density is another parameter affecting the printing sample's quality (Samykano et al., 2019). Figures 4 (a) and (b) show the CcPP filament composites with 25% and 50% infill density, respectively. The 25% infill density sample was lighter than the 50% infill density because less material was used to fill the sample's interior compared to the 50% infill density. Higher empty spaces were observed on printed samples with 25% infill density (Figure 4a) compared to 50% infill density (Figure 4b). Higher infill densities can provide greater strength and durability, but it will lead to higher time and material consumption. Previous studies on bamboo-filled PLA-based material showed a significant effect of infill density on the tensile strength and fatigue properties (Müller et al., 2022). Mechanical behavior is affected by the infill density and the infill pattern, as Tanveer et al. (2022) mentioned.



(a)



(b)

Figure 4. The printed sample from CcPP filaments composite with: (a) 25%; and (b) 50% infill densities

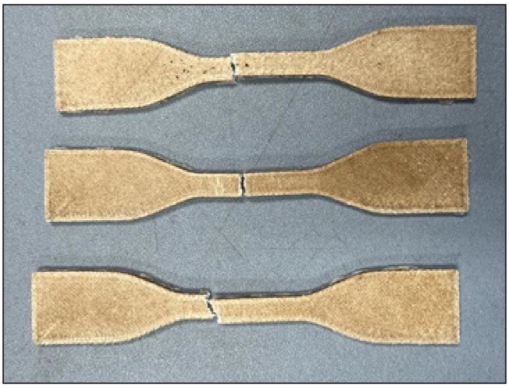


Figure 5. The tensile test samples

The effect of infill density on the tensile properties was further analyzed in this study. A previous study by Müller et al. (2022) proved that infill density significantly affects the tensile strength and fatigue properties of low-cycle stress bamboo-filled PLA-based materials in FDM 3D printing applications. Figure 5 shows the successful samples for tensile testing of the CcPP filament composite.

Tensile Properties of CcPP Filament Composite

Figures 6 and 7 present the tensile strength and tensile modulus of the CcPP composite. The highest tensile strength for 25% infill density was produced by 3% fiber loading with 17.23 MPa, while for 50% infill density, samples with 5% fiber loading had the highest tensile strength of 22.87 MPa. This finding is equivalent to the tensile modulus shown in Figure 7. The tensile modulus increased with increments in the percentage of fiber loading. The highest tensile modulus of 641.23 MPa was contributed by 50% infill density with 3% fiber loading. Among the samples with 25% infill density, 5% fiber loading had the highest tensile modulus of 493 MPa. A higher infill density provides more material to resist deformation, resulting in a stiffer overall structure. The solid internal structure improves the load-bearing capacity of the printed object, leading to a higher modulus of elasticity (Płatek et al., 2020). Various factors affect the properties of the composite; for 3D printed parts, printing process parameters can be a factor that contributes to inconsistent output. Measuring the relationship between the printing process parameters is important to avoid relevance output (Attoye et al., 2019; Hanon et al., 2021). A previous study on the effect of infill density on tensile mechanical properties of 3D printed carbon-fiber nylon composite found that 50% infill density with a triangle pattern produced a higher tensile property

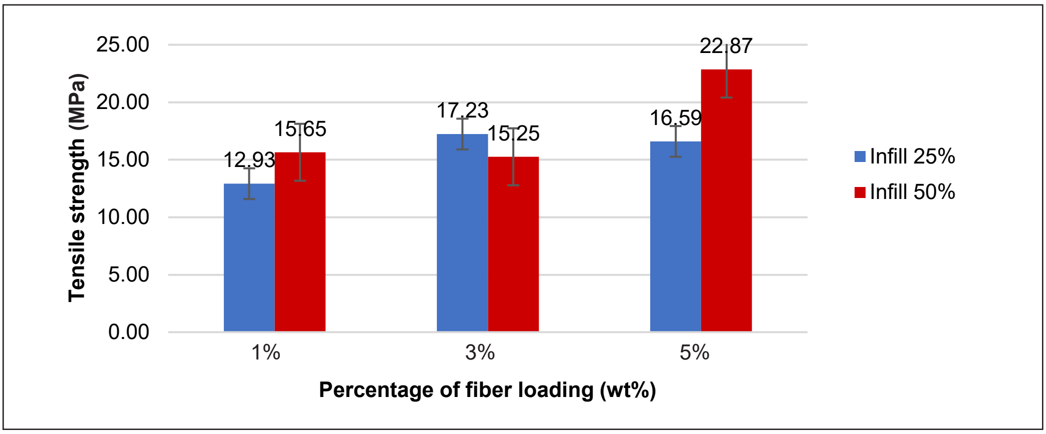


Figure 6. The Tensile Strength of CcPP for 25 and 50% infill densities

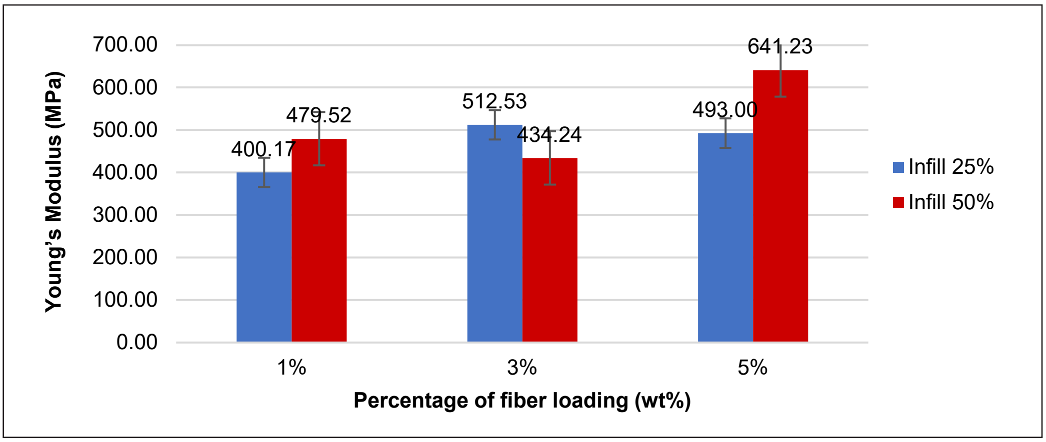


Figure 7. The Young's Modulus of CcPP for 25 and 50% infill densities

compared to 30 and 100% infill densities (Ali et al., 2023). The review of Tanveer et al. (2022) mentioned that appropriate infill density highly depends on the type of application for the printed part. Furthermore, a large number of printed parts can be replicated to increase accuracy during the data collection and analysis. The demand for natural fiber composite in 3D printing is increasing yearly. The development of bio-composite filament in the 3D industry needs a good understanding of material and technology (Birosz et al., 2022; Lalegani & Mohd Ariffin., 2020).

CONCLUSION

This study's first stage presents the best nozzle and bed temperature on the CcPP filament composite printability. Complete deposition, unwarping, good finishing, and adequate heat for the nozzle and bed temperature were the qualitative measurements used to assess the 3D printability of the CcPP filament composite. The result revealed that the highest printability ratings of CcPP filament composite were obtained with the printing nozzle temperature of 230 °C and bed temperature of 80 °C. Two infill densities (25% and 50%) with three different fiber loadings of filament composite (1%, 3%, and 5%) were used to analyze the effect on the tensile properties of the filament composite in the second stage of this study. The highest tensile strength of 22.87 MPa and Young's Modulus of 641.23 MPa were obtained from composite printed with 50% infill density and 5% fiber loading. The lowest tensile strength of 12.93 MPa and Young's Modulus of 400.17 MPa were obtained from composite printed with 25% infill density and 1% fiber loading. Moreover, at 1% and 3% fiber loadings, the effect of infill density on tensile strength and modulus was not significant; however, the effect of infill density on tensile strength and modulus became significantly different at 5% fiber loading. Further study on the physical and other mechanical properties, such as flexural testing, impact testing, and surface roughness, should be conducted to analyze the CcPP filament composite's performance further. The findings of the interconnection between the printing process parameters and mechanical properties can assist the design engineer in optimizing the usability of the material.

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REFERENCES

Ahn, S., & Wright, P. K. (2002). Anisotropic material properties of fused deposition modeling ABS. *Rapid Prototyping Journal*, *8*(4), 248–257. https://doi.org/10.1108/13552540210441166

Alafaghani, A., Ablat, M. A., Abedi, H., & Qattawi, A. (2021). Modeling the influence of fused filament fabrication processing parameters on the mechanical properties of ABS parts. *Journal of Manufacturing Processes*, *71*, 711–723.

Ali, Z., Yan, Y., Mei, H., Cheng, L., & Zhang, L. (2023). Effect of infill density, build direction and heat treatment on the tensile mechanical properties of 3D-printed carbon-fiber nylon composite. *Composite Structure, 304,* 116370.

Alsubari, S., Zuhri, M. Y. M., Sapuan, S. M., Ishak, M. R., Ilyas, R. A., & Asyraf, M. R. M. (2021). Potential of natural fiber reinforced polymer composites in sandwich structures: A review on its mechanical properties. *Polymers*, *13*(3), 1–20. https://doi.org/10.3390/polym13030423

Attoye, S., Malekipour, E., & El-mounayri, H. (2019). Correlation between process parameters and mechanical properties in parts printed by the fused deposition modeling process. In S. Kramer, J. L. Jordan, H. Jin, J. Carroll & A. M. Beese (Eds.), *Mechanics of Additive and Advanced Manufacturing*, Volume 8, Conference Proceedings of the Society for Experimental Mechanics Series (pp. 35–41). Springer. https://doi.org/10.1007/978-3-319-95083-9_8

Beg, D. A., & Hasan, M. F. (2020). Study of mechanical properties of polypropylene natural fiber composite. *International Journal for Research in Applied Science & Engineering Technology. 8*(9), 255-259. https://doi.org/10.22214/ijraset.2020.31453

Birosz, Tamas, M., Ledenyak, D., & Ando, M. (2022). Effect of FDM infill patterns on mechanical properties. *Polymer Testing*, *113*, 107654. https://doi.org/10.1016/j.polymertesting.2022.107654

Hamid, H. A., Omar, G., Muhammad, N., Azmmi, N., & Hasan, R. (2022). Proceedings optimization of natural polymer additives towards tribological behavioural of bio-oil extracted from peel waste of *musa aluminata balbisiana*. *Materials Today: Proceedings*, *51*, 1316–1322. https://doi.org/10.1016/j.matpr.2021.10.392

Hanon, M. M., Dobos, J., & Zsidai, L. (2021). The influence of 3D printing process parameters on the mechanical performance of PLA polymer and its correlation with hardness. *Procedia Manufacturing*, *54*, 244–249. https://doi.org/10.1016/j.promfg.2021.07.038

Hawary, O. El, Boccarusso, L., Ansell, M. P., Durante, M., & Pinto, F. (2023). An overview of natural fiber composites for marine applications. *Journal of Marine Science and Engineering*, *11*(1076), 1–52. https://doi.org/10.3390/jmse11051076

Ilyas, R. A., Zuhri, M. Y. M., Aisyah, H. A., Asyraf, M. R. M., Hassan, S. A., Zainudin, E. S., Sapuan, S. M., Sharma, S., Bangar, S. P., Jumaidin, R., Nawab, Y., Faudzi, A. A. M., Abral, H., Asrofi, M., Syafri, E., & Sari, N. H. (2022). Natural fiber-reinforced polylactic acid, polylactic acid blends and their composites for advance applications. *Polymers*, *14*(202), 1–39. https://doi.org/10.3390/polym14010202

Jeon, H., Park, J., Kim, S., Park, K., & Yoon, C. (2020). Effect of nozzle temperature on the emission rate of ultrafine particles during 3D printing. *Robotics and Computer-Integrated Manufacturing*, *30*, 306–314. https://doi.org/10.1111/ina.12624

Jumaidin, R., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2017). Thermal, mechanical, and physical properties of seaweed/sugar palm fibre reinforced thermoplastic sugar palm Starch/Agar hybrid composites. *International Journal of Biological Macromolecules*, *97*, 606–615. https://doi.org/10.1016/j.ijbiomac.2017.01.079

Khan, M. S., & Mishra, S. B. (2020). Minimizing surface roughness of ABS-FDM build parts: An experimental approach. *Materials Today: Proceedings*, *26*, 1557–1566. https://doi.org/10.1016/j.matpr.2020.02.320

Kristiawan, R. B., Imaduddin, F., Ariawan, D., Ubaidillah, & Arifin, Z. (2021). A review on the fused deposition modeling (FDM) 3D printing: Filament processing, materials, and printing parameters. *Open Engineering*, *11*(1), 639–649. https://doi.org/10.1515/eng-2021-0063

Lalegani, D. M., & Mohd Ariffin, M. K. A. (2020). The effects of combined infill patterns on mechanical properties in FDM process. *Polymers*, *12*(12), 2792. https://doi.org/10.3390/polym12122792

Le Duigou, A., Correa, D., Ueda, M., Matsuzaki, R., & Castro, M. (2020). A review of 3D and 4D printing of natural fibre biocomposites. *Materials and Design*, *194*, 108911. https://doi.org/10.1016/j.matdes.2020.108911

Mastura, M. T., Noryani, M., Hazliza Aida, C. H., Nuzaimah, M., Shaharuzaman, M. A., Zakaria, N. H., & Loh, Y. F. (2022). Statistical analysis of the performance of young's modulus of natural fiber composites and synthetic fiber composites. *Jurnal Teknologi*, *84*(6–2), 151–162. https://doi.org/10.11113/jurnalteknologi.v84.19366

Muhammad, N., Shaharuzaman, M. A., Taha, M. M., & Buniamin, F. F. (2022). Prediction of mechanical and physical properties of hybrid composites using ROHM. *Proceedings of Mechanical Engineering Research Day 2022*, *August*, 95–96.

Müller, M., Jirků, P., Šleger, V., Mishra, R. K., Hromasová, M., & Novotný, J. (2022). Effect of infill density in FDM 3D printing on low-cycle stress of bamboo-filled PLA-based material. *Polymers*, *14*(22). https://doi.org/10.3390/polym14224930

Muthe, L. P., Pickering, K., & Gauss, C. (2022). A Review of 3D / 4D printing of poly-lactic acid composites with bio-derived reinforcements. *Composites Part C: Open Access*, *8*(April), 100271. https://doi.org/10.1016/j.jcomc.2022.100271

Płatek, P., Rajkowski, K., Cieplak, K., Sarzyński, M., Małachowski, J., Woźniak, R., & Janiszewski, J. (2020). Deformation process of 3D printed structures made from flexible material with different values of relative density. *Polymers*, *12*(9). https://doi.org/10.3390/POLYM12092120

Radzi, A. M., Sapuan, S. M., Jawaid, M., & Mansor, M. R. (2017). Influence of fibre contents on mechanical and thermal properties of roselle fibre reinforced polyurethane composites. *Fibers and Polymers*, *18*(7), 1353–1358. https://doi.org/10.1007/s12221-017-7311-8

Samykano, M., Selvamani, S. K., Kadirgama, K., Ngui, W. K., Kanagaraj, G., & Sudhakar, K. (2019). Mechanical property of FDM printed ABS: Influence of printing parameters. *International Journal of Advanced Manufacturing Technology*, *102*(9–12), 2779–2796. https://doi.org/10.1007/s00170-019-03313-0

Tanveer, M. Q., Mishra, G., Mishra. S., & Sharma., R. (2022). Effect of infill pattern and infill density on mechanical behaviour of FDM 3D printed Parts-a current review. *Materials Today: Proceedings, 62*, 100-108. https://doi.org/10.1016/j.matpr.2022.02.310