EFFECT OF VARIOUS FIBRE LOADINGS OF PINEAPPLE LEAF FIBRE ON POLYLACTIC ACID COMPOSITES FILAMENT

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ABSTRACT: *Recently, natural fibres have been widely utilized because they are firmer and have higher strength comparable to synthetic fibres. Every fibre has various properties, and polymer composites reinforced with natural fibre are known to have superior mechanical properties. In this study, the pineapple leaf fibre/polylactic acid (PALF/PLA) composites filaments are developed with several processes, including grinding, sieving, chemical treatment, and hot compression on the composites with various fibre loadings of 1, 3, and 5%, continued with the crushing and the extrusion processes. Then, mechanical testing for specific flexural and tensile testing was conducted on the PALF/PLA filament composites. The findings showed that the PALF/PLA composites with a 5% fibre loading exhibited the highest mechanical properties in both flexural and tensile properties. In conclusion, 5% fibre loading of PALF/PLA composites filaments can be used as an alternative material to replace pure PLA.*

KEYWORDS: *Pineapple leaf fibre (PALF), natural fibre, Polylactic acid (PLA), fibre loading, mechanical properties*

1.0 INTRODUCTION

Plant-based natural fibres, for instance, those obtained from flax, bamboo, pineapple, and other plants, are renewable and sustainable resources. The primary elements of natural fibres are cellulose, hemicellulose, and lignin. These components are unique to each species of natural fibre, giving it its own set of properties such as mechanical strength, density, absorption of moisture, and sensitivity to heat or UV radiation degradation [1]. Due to their higher specific strength and rigidity compared to glass-reinforced composites, natural fibres are becoming growing in popularity. Additionally, the abundant quantity and superior qualities of these fibres encourage the advantageous use of waste from agriculture as a cellulose source [2].

Each and every fibre has varied properties, and thus, polymer composites reinforced with natural fibres attain superior mechanical characteristics. The various fibre loading and chemical treatments on the fibre have a significant influence on the composites' mechanical characteristics. There are a few techniques to develop a natural fibre composite filament [3], [4], [5], [6]. Table 1 shows the characteristics considered in both techniques, which are fused deposition modelling and hot compression to develop natural fibre reinforced composites. Flexural, tensile, and thermal properties are the common characteristics reported. Printing process parameters are also important characteristics to be studied [3]. Thus, it is necessary to conduct detailed research on the techniques to develop a natural fibre composites filament to ensure a smooth flow till the fused deposition modelling (FDM) application's printing process is finished.

Table 1: Development technique of composites reinforced with natural fibres.

Techniques	Materials	Authors	Characteristics
Fused Deposition Modeling	PLA/Sugar Palm fibre	[3]	- Printing parameter
Fused Deposition Modeling	Thermoplastics/Oil palm fibre	[4]	- Flexural - Thermal
Hot compression	PP/Kenaf fibre and PP/PALF	[5]	- Mechanical
Fused Deposition Modeling	PLA/Woods fibre	[6]	- Tensile - Water absorption

The mechanical characteristics of fibre- reinforced composites can be influenced by various parameters, such as fibre length, loading, and orientation within the matrix [7]. A few studies were performed on the natural fibre composite for FDM's mechanical properties. As an example, Osman et al. established a composite feedstock consisting of ABS and rice straw for use in FDM-style 3D printers. The following weight percentages of ABS and rice straw flour were mixed: 0, 5, 10, 15, and 20 wt.%. The tensile strength significantly dropped with the addition of rice straw (5 wt.%); however, the tensile strength only slightly decreased while rice straw was still added. Flexural strength and modulus decreased steadily as the proportion of rice straw rose. However, the results demonstrated a notable improvement in flexural strength and modulus with the 15 wt.% ABS/rice straw composite [4]. Then, Mazur et al. developed pure PLA filaments and PLA composite filaments reinforced with 30 wt.% of wood particles, 2 bamboo fibres, and cork. The tensile strength of pure PLA with 100% infill density was the highest compared to other infill densities and composite filaments. Tensile strength degradation was similar for all composite materials, with values obtained between 8.2 and 21.1 MPa (elevated temperature) and 19.2 to 26.3 MPa (ambient temperature). The factors that affect the low results of the tensile strength of filament composites are the fibre length, fibre/matrix adhesion, and fibre/matrix strength [8].

There are no previous studies on PALF/PLA composites filament. The present study focuses on identifying the optimum fibre loading of the PALF. Mechanical properties, such as flexural and tensile testing are used to finalize the best fibre loadings for PALF. The finding can help the composite manufacturer in multiple applications. The current study contributes to our knowledge by addressing the optimum fibre loading in fabricating PALF/PLA filament composites.

2.0 METHODOLOGY

The procedure to develop a filament composite starts with the preparation of the pineapple leaf fibre (PALF) by reducing the size of the unprocessed PALF before the grinding and sieving process. Next, the chemical treatment of the fibre was done before integrating up the PALF with polylactic acid (PLA) and various fibre loadings. Then, a hot compression process was carried out on the PALF/PLA composites to mix them thoroughly. The crushing into smaller pellet sizes and the extrusion into composite filament using a single extruder machine were followed afterwards. Finally, after the processes, the composite filaments were ready to be tested for mechanical properties specific to flexural and tensile.

2.1 Grinding and Sieving Processes

The raw PALF, as shown in Figure 1 (a), was cut into smaller sizes of 2-3 cm from the 15-20 cm. Then, the crushing process was done utilising a high-speed industrial grinder bowl shown in Figure 1 (b). The sieving process was followed afterwards using a sieving machine, and the fibre size had an approximate size of 125-250 μm with a physical powder, as displayed in Figure 1 (c).

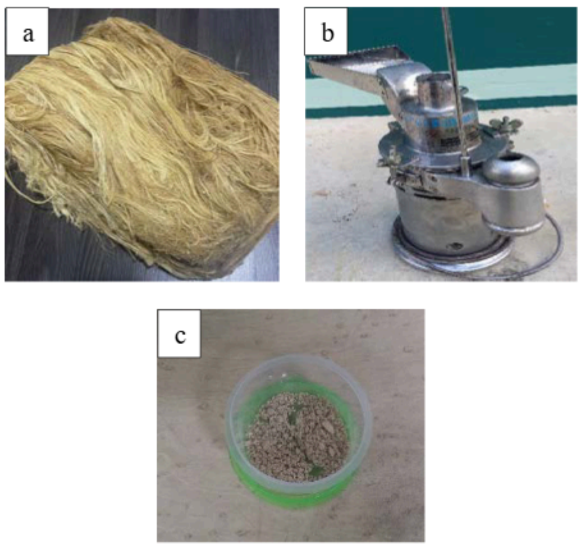


Figure 1: (a) Raw PALF, (b) industrial high-speed grinder bowl, and (c) PALF after sieving process.

2.2 Chemical Treatment Process

Next, the alkaline (NaOH) treatment was done on the PALF. Figure 2 shows the NaOH solution prepared for the chemical treatment process. Before mixing naturally occurring fibres with polymers, giving the fibre surfaces a chemical treatment could be essential to enhance the interaction between the fibres and the matrix [1]. The alkaline (NaOH) treatment process was initiated by soaking the PALF for 3 h at room temperature in 1 wt.% of NaOH solution. Next, distilled water was used to wash the fibres until all traces of NaOH were eliminated. Lastly, the PALF was dried in the oven at a temperature of 80 °C for 2 days consecutively.

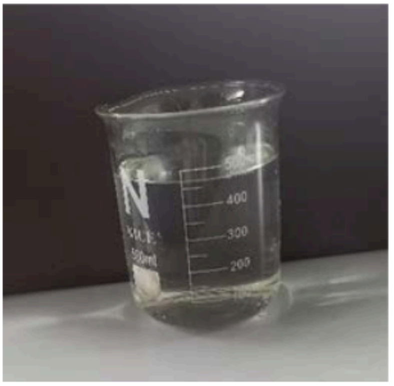


Figure 2: NaOH solution for the chemical treatment process.

2.3 Hot Compression and Crushing Processes

Through the use of hot compression, the PLA and PALF were combined with the composites' 1, 3, and 5% fibre loadings. The composites were put in the mould based on the volume with a weight based on the 1% fibre loading. The hot compression machine was set up with the mould in position at a pressure of 10 MPa for 10 min at 160 °C temperature. Figure 3 shows the hot compression machine running the process of developing the composites. The process was repeated with different fibre loadings at 3 and 5% to produce PALF/PLA composites. Then, composites were crushed into pellet-sized pieces for easier extrusion during the heat compression.

Figure 3: Hot compression machine running the composite development.

2.4 Extrusion Process

Figure 4 shows the single-screw extruder machine employed to extrude the PALF/PLA composites. The extrusion process, as the final procedure, produced the PALF/PLA filament composites. The temperature setting of 155 °C and speed of 40 rpm were applied to successfully extrude the composites filament. In accordance with earlier studies, using a single screw extruder fitted with a conventional single-flighted screw, the PLA pellets and PALF were combined and compounded at 155°C and 40 rpm [9]. So, it can be concluded that the temperature and speed were suitable for the PALF/PLA composites. The composites filament developed are shown in Figure 5.

Figure 4: Single-screw extruder machine.

Figure 5: PALF/PLA composites filaments.

2.5 Mechanical Testing

The PALF/PLA composite filaments were prepared accordingly for flexural and tensile tests.

2.5.1 Flexural Testing

The samples of PALF/PLA composite filaments were prepared by following the standard of ASTM D790 and tested on the SHIMADZU AG-X Plus Series High-Performance Test Frames machine, as presented in Figure 6 (a) [10]. The speed was maintained at 5 mm/min with a load of 1 kN. Based on the ASTM standard, the sample size was 100 mm × 1.75 mm with a span length of 50 mm, as shown in Figure 6 (b). The test was conducted with different fibre loadings, specifically of 1, 3, and 5% in triplicate.

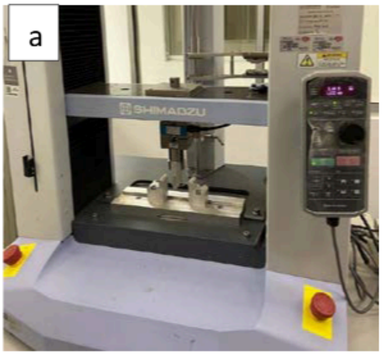
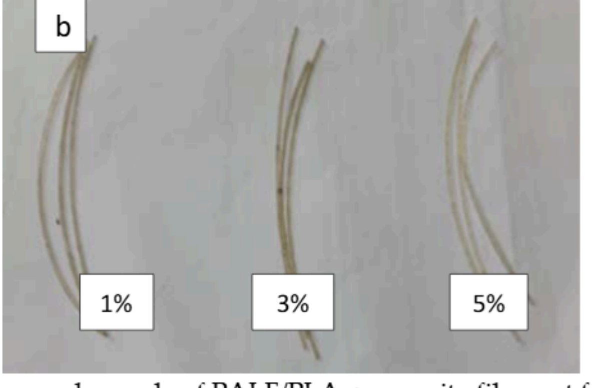


Figure 6: (a) The SHIMADZU AG- X Plus Series High-Performance Test Frames Machine for flexural testing, and



(b) the prepared sample of PALF/PLA composite filament for testing following ASTM standard.

2.5.2 Tensile Testing

The samples of PALF/PLA composite filaments were prepared by following the standard of ASTM D638 and tested on the INSTRON Model 8872 machine shown in Figure 7 (a) [10]. The speed was maintained at 2 mm/min, and the software setup is shown in Figure 7 (b). Based on the ASTM standard, the sample size was 100 mm. The samples were tested with different fibre loadings, specifically 1, 3, and 5%, and repeated in triplicate. The average value of the three samples was calculated for each fibre loading.

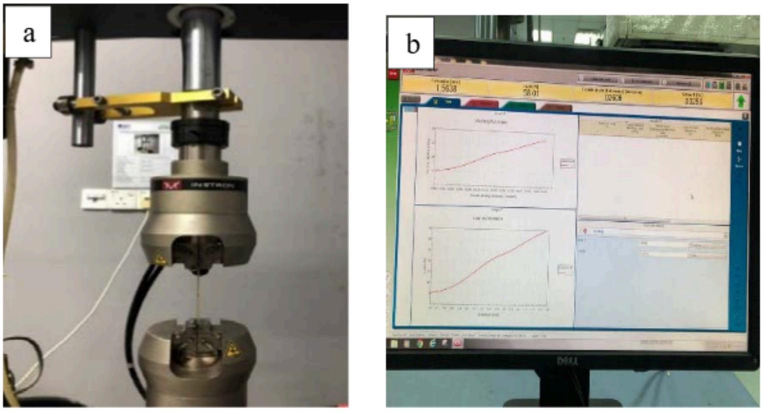


Figure 7: (a) The INSTRON Model 8872 machine for tensile testing, and (b) the software to set up speed and generate results.

3.0 RESULTS AND DISCUSSION

The PALF/PLA composites need additional tests, such as mechanical, to obtain the mechanical properties of the composites. In general, the primary characteristic of a material is its strength, which can be expressed as the greatest level of stress the material can tolerate or as the stress required for a perceptible plastic deformation [11]. Earlier research demonstrated that the use of continuous pineapple leaf fibre as reinforcement increased the tensile strength of the PLA matrix [12]. In addition, PALF comprised a high percentage (70–80%) of cellulose, resulting in its good addition to the polymer matrix and strong mechanical characteristics to-weight ratio in comparison to other agricultural wastes [13]. The advantages of using natural fibre are also well known, such as high specific strength, affordability, light weight, low energy consumption, renewability, non-toxic, non-abrasive, and ecologically friendly material [5]. Therefore, in order to test for printability in 3D printing, filament testing is crucial.

Mechanical, flexural, and tensile tests were conducted on the PALF/PLA composites filament with various fibre loadings to obtain the mechanical properties.

3.1 Flexural Testing

The study focused on the flexural strength of the PALF/PLA composite filament at different fibre loadings: 1, 3, and 5%. The study showed that as the fibre content increased, the flexural strength of the filament composite also increased. As the content of PALF increased, the flexural properties also increased, and at 5% fibre loading, the flexural strength was the highest compared to 1 and 3% fibre loadings. In contrast, the flexural properties of pure PLA were higher and greater compared to the PALF/PLA composite filament, as shown in Figure 3.1.

From Figure 3.1, for PALF/PLA composite filament at 5% fibre loading, the flexural strength was at the highest with a reading of 50.99±18.02 MPa compared to the flexural strength at 1 and 3% with readings of 35.84±10.06 MPa and 42.1±12.33 MPa, respectively. However, the pure PLA without any reinforcement exhibited a higher performance of flexural strength than other PALF/PLA composite filaments with different fibre loadings.

Pure PLA has been determined by researchers to be a good alternative to non-biodegradable polymers in the production of sustainable polymeric composites and displays an excellent matrix element because of its superior tensile and flexural strengths as well as stiffness [14], [15]. Previous research has also shown that a higher fiber content in the composite may lead to lower mechanical strength [15]. Thus, this study finding with a 5% fibre loading in the composite filament serves as a potential replacement for pure PLA filament in fused deposition modeling (FDM) 3D printing as it exhibits comparable flexural properties along with being more environmentally friendly.

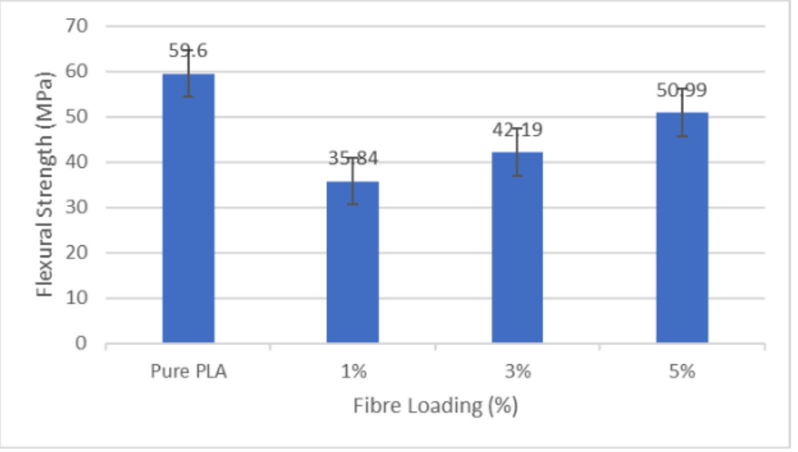


Figure 8: Flexural strength with different fibre loadings.

3.1 Tensile Testing

The study focused on the tensile strength of the PALF/PLA composite filament at different fibre loadings at 1, 3, and 5%. The study showed that as the fibre content increased, the tensile strength of the filament composite also increased. As the content of PALF increased, the tensile properties also increased. At 5% fibre loading, the tensile strength was the highest compared to 1 and 3% fibre loadings. In contrast, the tensile properties of pure PLA were higher compared to the PALF/PLA composite filament, as shown in Figure 3.2.

Figure 3.2 shows that for PALF/PLA composite filament at 5% fibre loading, the tensile strength was at the highest with a reading of 27.31±1.55 MPa compared to the tensile strength at 1 and 3% with the values of 22.03±2.07 MPa and 24.39±2.93 MPa, respectively. Previous research by Morales M. et al. developed recycling polypropylene (rPP)/rice husk (RH) composites. Similar characteristics were shown by various fibre weight ratios, which were found to be advantageous for fibre deployment and might increase its versatility. It is beneficial to use lighter components for some applications involving 3D printing filaments [16]. Thus, 5% fibre loading of PALF is suited well for PALF/PLA composites in 3D printing applications.

On the other hand, the tensile strength of the pure PLA had a higher performance than that of PALF/PLA composite filament with different fibre loadings. PLA is the most widely used material for 3D printing globally and a bioderived and biodegradable polymer [17]. The characteristics of neat polymer were greatly enhanced by the addition of sheets of natural fibre to the PLA matrix [18]. Abundance of research has been done on PLA composites containing bio-derived reinforcements, like flax, hemp, jute, bamboo, and other natural fibres, for 3D printing to improve mechanical qualities and production costs and increase the sustainability of made goods [17]. To emphasize, the strength of the pure PLA was higher than the PALF/PLA filament composite due to poor interface or lower fibre content. To summarize, the studies showed that as the fibre loading decreased, the tensile strength also decreased. The main variables influencing PALF's higher tensile characteristics were its low microfibrillar angle and the highest percentage of cellulose content [19]. The PALF/PLA composite filament with 5% fibre loading could be considered as the alternative material to replace the pure PLA in FDM 3D printing, as the filament composites also exhibited excellent tensile properties along with being more eco-friendly material and lower cost compared to the usage of pure PLA.

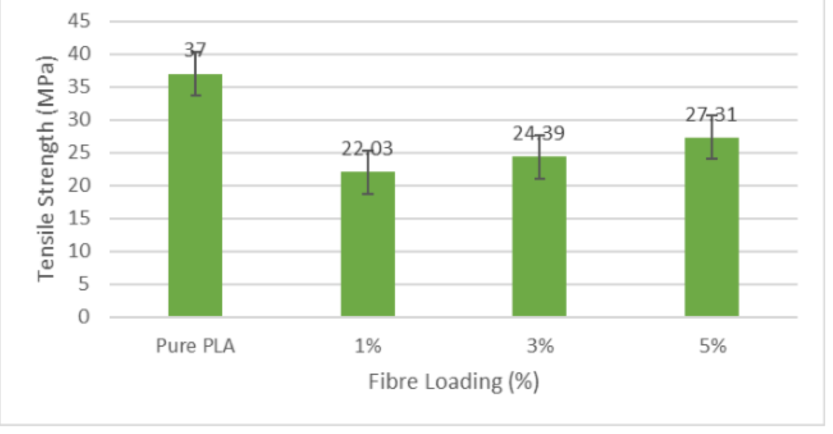


Figure 9: Tensile strength with different fibre loadings.

4.0 CONCLUSION

In conclusion, several processes, such as grinding, sieving, chemical treatment, hot compression, crushing, and extrusion, are essential to successfully develop the PALF /PLA composite filaments. Mechanical tests, specifically tensile and flexural were done on the PALF/PLA composite filament. The study showed and concluded that the PALF/PLA composite filaments with 5% fibre loading had the highest performance of flexural properties and tensile properties. Thus, 5%

fibre content in PALF/PLA composite filament could be used as an alternative material to replace pure PLA in FDM 3D printing.

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