Development and Characterization of Oil Palm Empty Fruit Bunch Fibre Reinforced Polylactic Acid Filaments for Fused Deposition Modeling

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ABSTRACT

In recent years, Natural Fibre-Reinforced Composites (NFRC) making its impact in all applications, and they have reached their way into the field of Additive Manufacturing (AM) as well. This increases the demand for natural fibre based filaments in the field of AM. Hence, this research aims to develop filaments made of Polylactic acid (PLA) reinforced with Oil Palm Empty Fruit Bunch Fibre (OPEFBF) and to investigate its physical, thermal and mechanical properties. PLA with 10, 20, 30, and 40 wt.% of OPEFBF were melt blended, hot-pressed, and successfully extruded as filaments. Later, its physical, thermal, water absorption, biodegradation, and mechanical properties are investigated. OPEFBF reinforced filaments show lesser values of densities, increased Tensile Modulus (TM), better bio and thermal degradation compared to the pure PLA. However, its rate of water absorption is high with reduced Tensile Strength (TS) than the pure PLA. Later these filaments reinforced with different OPEFBF contents are 3D printed using Fused Deposition Modeling (FDM) technology. Filaments with lesser fibre content were easy to print. Filaments with 10 wt.% OPEFBF was continuously printed whereas, filaments with higher fibre content clogged in the nozzle. Overall, PLA reinforced with OPEFBF has been developed and successfully applied to the field of additive manufacturing by FDM.

Keywords: *Additive Manufacturing, Fused deposition modeling, Natural fibre-reinforced composite, Bio-degradable filament, Oil palm empty fruit bunch fibre.*

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Introduction

In this present era, Additive Manufacturing (AM) is one of the recognized technologies in all applications because AM helps in developing products with complex shapes and geometry [1]. There are varieties of techniques under AM. Fused Deposition Modelling (FDM) is one of that which is simple and economical. There are only selected thermoplastic polymers which are used in FDM because of its melting and printing temperature [2]. Later, natural fibre/filler reinforced composite (NFRC) filaments come into the business because they are cost-effective and exhibit lower environmental impacts [3]. Out of all the NFRC filaments, PLA-based NFRC receives much attention because of its biodegradability [4]. Table 1 shows the available PLA based NFRC filaments for additive manufacturing.

Table 1: List of PLA based NFRC filaments for AM

Matrix	Filler/Fibre	Filler Content (%)	Properties Tested*	References
PLA	Paulownia Wood	25	T.S	[5]
PLA	Orange Wood	25	T.S	
PLA	Poplar Wood	10, 30	T.S, F.S, I.S	
PLA	Wood powder	0 – 50	F.T, F.S	
PLA	Aspen Sawdust	5	T.S	
PLA	Bamboo	15, 20	F.T	
PLA	Pine Lignin	5	T.S	
PLA	Cork powder	5	T.S	
PLA	TMP	10 – 20	F.T, T.S	
PLA	Sugarcane	3 – 15	T.S, F.S	
PLA	Flax	15	F.T	
PLA	Harekeke	0 – 30	T.S	
PLA	Hemp	0 – 30	T.S	
PLA	Oil Palm Fibre	0 – 40	F.T	This Study

* F.T: Filament Testing, T.S: Tensile Strength, F.S: Flexural Strength, I.S: Impact Strength.

It can be seen from Table 1 that natural fibres/fillers from wood, bamboo, sugarcane, pine, flax, hemp, harakeke are used as reinforcement for PLA. Fibres from oil palm can also be used as reinforcement in producing filaments for additive manufacturing. To demonstrate this, Marwah et al., reinforced fibres from oil palm fronds with high-density polyethylene and produced filaments which were suitable for AM [6]. Ahmad et al., reinforced oil palm fibres with acrylonitrile butadiene styrene and produced filaments which were suitable for AM [7]. Similarly, fibres from Oil Palm Empty Fruit Bunch (OPEFB) can be reinforced with PLA to produce filaments for AM. Oil palm is one of the essential crops, especially in countries like Malaysia and

Indonesia. These two countries are being active contenders for oil palm cultivation and palm oil production [8]. During the production of palm oil, numerous biomasses like fronds, empty fruit bunches, trunks, and shells are produced. Out of all, OPEFB is the second abundant biomass produced after fronds, and it covers 70% of the fibrous portion produced from the tree itself [9]. Almost 65% of OPEFB are being wasted, and therefore researchers are finding a way to use it effectively. These OPEFBF are used in producing low-value products like papers and fibreboards [10]. However, developing high-value products remains a challenge. Hence, this research takes up the challenge of developing filaments for additive manufacturing using OPEFBF, which can be a significant turning point in the field of 3D printing. Only a few pieces of research have been recorded for investigating the mechanical strength of the filament made of natural fibre composite. Kariz et al., produced filaments made of PLA reinforced with wood fibres and studied its morphological, rheological, and mechanical properties. Filgueira et al., fabricated filaments made of PLA reinforced with thermomechanical pulp fibres and analyzed its water uptake and mechanical properties of it. They all have concluded there wasn't a satisfactory mechanical strength obtained from the filaments and they have stated voids and porosity formation in the filament due to the addition of fibres as the main reason [11], [12]. To further investigate the reason for the decrease in mechanical properties of the PLA based natural fibre reinforced filaments, this research has been performed. There are PLA based filaments reinforced with fibres or fillers of wood, dried distilled grains, kraft lignin, hemp, and harakeke, which are in research stages [13]. Additionally, there are also PLA based filaments reinforced with pine wood, bamboo fill, straw, lay wood, and cherrywood fibres, which are commercially available under various trade names [14]. Table 2 shows some of the commercially available PLA based natural fibre reinforced filaments along with the trading companies.

Table 2: List of PLA based NFRC filaments available commercially [14]

Matrix	Natural Fibre/Filler	Company
PLA	Bamboo/bamboo fill	ColorFabb, NL
PLA	Pine/wood fill	ColorFabb, NL
PLA	Laywood/cherrywood	CC products, DE
PLA	Straw plastic/dried crop residues	Jinghe co., CN

As shown, there are a lot of PLA based NFRC filaments that are in the research stage as well as in the commercialization stage. This research was performed to initiate the PLA based filaments reinforced with oil palm fibres into the field of additive manufacturing by FDM technology. There have been many kinds of analysis available on studying the thermal, biodegradation, and water absorption properties of the composite. They all have concluded that reinforcement of natural fibres into the polymer matrix improves the thermal degradation, increases the water absorption rate, and become easily degradable. However, filaments made of a natural fibre-reinforced composite is a recent trend and hence needs further investigation. Therefore, PLA reinforced OPEFBF filaments, which are produced by extrusion, are studied for its thermal, biodegradation, water absorption properties and are tested for 3D printing by FDM technology.

Materials

PLA pellets were supplied by NatureWorks Corporation. The grade provided was Ingeo™ Biopolymer 2003D with a specific gravity of 1.24 and a melt flow index of 6 g/10 min. Oil Palm Empty Fruit Bunch Fibres (OPEFBF) were outsourced from the nearest palm oil mill. The diameter of the fibres was ranging from 0.2 mm to 0.5 mm, with the length ranging from 20 mm to 40 mm.

Methods

Preparation of the Composite

Fibres are soaked, rinsed, and cleaned to get rid of impurities. The cleaned fibres are sun-dried, followed by oven drying at 60℃ for 24 hours to reduce the moisture content. Later, the dried fibres are grinded and sieved to less than 0.5 mm. PLA pellets are placed in an oven at 60℃ for 24 hours. Once PLA pellets are dried, they are placed in a crucible along with 10, 20, 30, and 40wt.% of dried OPEFBF at different batches and heated at around 210℃ inside an oven. The temperature considered was slightly higher than the average melting temperature of PLA because of the convection inside an oven. Melted PLA, along with fibres, are manually mixed and kept inside an oven. This mixing and heating process was repeated until the materials all well blended to form a composite lump. Further, the composite lumps are pre-heated at 180℃ for 5 minutes in GT-7014-H hydraulic moulding press, and they are hot-pressed with the pressure of 2 tons for 15 minutes, followed by cold pressing for 5 minutes. Improper dispersion of fibres was noted at few places, and it doesn't count much since the composite will undergo further extrusion (melting and winding).

Filament Formation

PLA-OPEFBF composite lumps which are produced by hot-press are crushed into smaller pieces using a mechanical hammer. The crushed composites are then placed into an extruder to produce filaments with different fibre contents.

This pre-process (melt blending and hot-press) reduces the sedimentation of OPEFBF when directly placed into an extruder along with PLA pellets. Table 3 shows the formulation of PLA-OPEFBF composites and filaments.

Table 3: Formulation of PLA-OPEFBF composites and filaments

Code	PLA (wt.%)	OPEFBF (wt.%)
0	100	0
10	90	10
20	80	20
30	70	30
40	60	40

The extruder used was the Wellzoom Desktop Single Screw Extruder. Barrel temperature was kept at 180°C, and the temperature of the die was maintained at 185°C, considering the melting temperature of pure PLA. The screw speed of 20 rpm was maintained. Figure 1 shows the overall methodology used in this research.

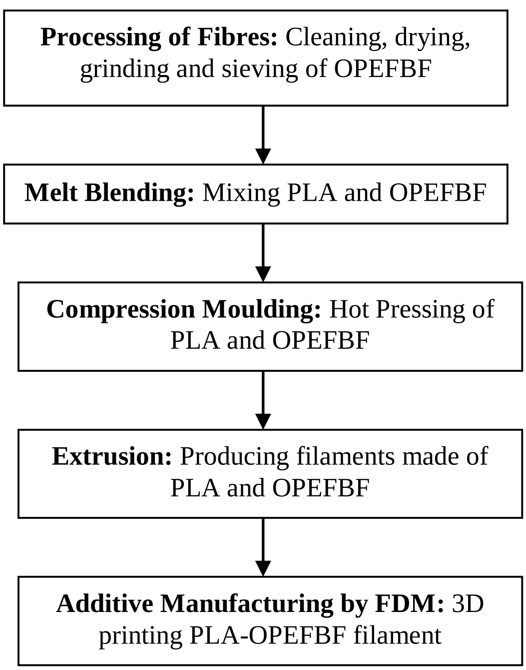

Figure 1: Overall methodology of this research.

Density Calculation

Composites as per type V specimen of ASTM D638 standard and filaments portion with a diameter of approximately 1.75 ± 0.5 mm, length of 90 mm were cut, and their densities (ρ) were calculated using the Equation (1),

$$Density\ (\rho) = \frac{Mass\ of\ the\ composite/filament\ (grams)}{Volume\ of\ the\ composite/filament\ (cu.cm)} \qquad (1)$$

Morphological Observation

PLA-OPEFBF filaments were observed under the SWIFT M5 Multi Phase 100 microscope that has 6 volts, a 20-watt halogen bulb for illumination. Filaments were observed under a magnification factor of 4x.

Thermo Gravimetric Analysis

Thermal analysis was carried out using a Pyris Diamond TGA 8000 from PerkinElmer. Samples weighing around (5±1 mg) underwent thermal scanning with the nitrogen atmosphere at a rate of 20 ml/min from 25°C to 600°C. The heating rate of 10°C/min was considered for the composites and filaments. Composite reinforced with 10wt.% OPEFBF was used to compare with the filament since it has fewer voids compared to the other fibre compositions.

Water Uptake Test

PLA and OPEFBF reinforced filaments with different fibre contents approximately with the length of 60 ± 1 mm, and a diameter of 1.75 ± 0.5 mm were immersed in 100 mL of distilled water for 30 days (720 hours). The filaments were initially dried at 30°C for 24 hours, and the initial dried weight was measured using Shimadzu TX423L top loading balance with a repeatability of 0.001 g. The samples were taken out after 30 days, and the weight change was measured. This change in weight over time helps in understanding the water absorption properties of the filaments. Water uptake of the filaments was calculated by the following Equation (2) [15],

$$Water\ Uptake\ (\%) = \frac{W_i - W_0}{W_0} \times 100 \qquad (2)$$

where, W_0 (g) is the dry weight of the filaments, and W_i (g) is the weight of the filaments after immersion.

Soil Burial Test

Soil burial test was conducted to explain the degradation properties of the filaments. Filaments with a diameter of 1.75 ± 0.5 mm and a length of 60 mm (both pure PLA and OPEFBF reinforced) were buried under the soil for 4 weeks. Organic soil outsourced from Kim Wei Nursery, Malaysia, was used. It contains coco peat, red burnt soil, fine sand, charcoal, and microbes as constituents. The average atmospheric temperature was around 30°C, with 80% humidity. The buried filaments were taken out after 4 weeks, washed cleanly, and are placed in an oven at 50°C for 12 hours before weighed. Loss of weight over the buried time helps in understanding the degradation properties of the filaments. The loss of weight of the filaments was measured by using the following Equation (3) [16],

$$W_{Loss}\,(\%) = \frac{W_i - W_0}{W_i} \times 100 \tag{3}$$

where, W_{loss} is weight loss (%), W_i (g) is the initial weight of unburied filaments, and W_0 (g) is the weight of the buried filaments.

Mechanical Testing

Filaments with a diameter of approximately 1.75 ± 0.5 mm and 90 mm length were considered for testing. Tensile testing was performed in an Instron Universal Testing Machine (load cell of 50 kN) at the speed of 20 mm/min as per ASTM D638. Three samples of filaments were considered for each of the formulations. Figure 2 shows the tensile testing setup of PLA-OPEFBF filament.

Figure 2: Tensile testing setup of PLA-OPEFBF filament.

Results and Discussions

Properties of PLA-OPEFBF Filaments

PLA-OPEFBF filaments were successfully produced by extrusion. Figure 3 shows the successfully extruded PLA-OPEFBF filaments with different fibre contents. At higher loadings of fibre content, the processing might be complicated since the fibres will agglomerate in the matrix, which in turn might affect the properties of the filaments [17]. Hence OPEFBF content for filaments considered was less than 40wt.%.

Figure 3: Successfully extruded filaments (Code: 0, 10, 20, 30, and 40).

Filaments produced with 10wt.% OPEFBF content was easy to produce, and as the fibre content tends to increase, OPEFBF starts to agglomerate in the matrix. Filaments with higher fibre contents were hard to process since they did not flow evenly through the nozzle of the extruder. Their diameter was a bit inconsistent, ranging from 1.7 mm to 1.8 mm. Filaments with different fibre content exhibit distinct colour shades and tend to become darker as the content of the fibre increases. Pure PLA filament was consistent in diameter with no voids in it. An increase in fibre content to the filament made them porous, causing shape irregularity and necking by exhibiting crests and troughs around the fibre area. Figure 4 shows the microscopic image of the successfully extruded filaments.

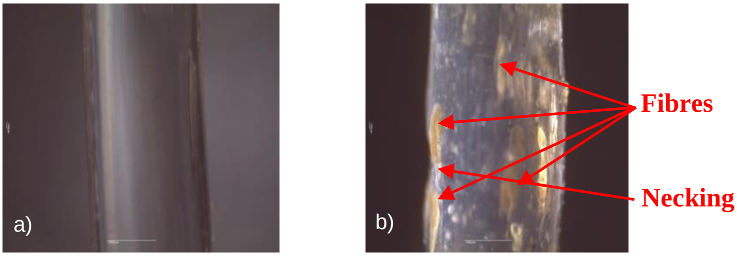

Figure 4: Microscopic image of the successfully extruded filaments (4x) a) PLA filament and b) Sample code 10 filament.

On an overall basis, it was seen that fibre content over a confined region in the composite was higher than the filament. Table 4 shows the densities of PLA-OPEFBF composite and filaments. There was an unusual trend in densities of the filaments can be seen. It might be due to the inconsistency in the diameter of the filaments upon addition of OPEFBF. However, the densities of the filaments reinforced with OPEFBF was found to be lower than the pure PLA filaments. This is because; addition of natural fibres to the polymer filaments makes them porous. This porous nature helps in producing filaments with lower density. This is in accordance with the other research, where they have produced filaments made of PLA reinforced with wood fibres [11].

Table 4: Densities of PLA-OPEFBF composite and filament

Code	Density of the composite (g/cm^3)*	Density of the filament (g/cm^3)*
0	1.17	1.34
10	1.05	0.97
20	1.03	0.87
30	1.03	1.10
40	1.10	1.20

*****Average value of three specimens

Thermal Properties of PLA-OPEFBF Composites and Filaments

Figure 5 shows the effect of fibre content on the thermal degradation of the composite. It can be seen from Figure 5 that the first step of a decrease in mass happens between 100°C to 150°C. This might be due to the loss of moisture content present in the composites. The second and third loss curve occurs between 250°C to 450°C might be due to the loss of constituents like lignin, cellulose, and hemicellulose [18]. The second degradation curve of the PLA starts at around 280°C to 300°C, and the third degradation curve occurs at around 360°C to 380°C. This is the typical PLA curve which confirms the PLA and has been reported by the previous paper [19]. PLA with 10wt.% OPEFBF reinforcement shows better thermal degradation with the second loss curve at around 350°C to 400°C and third loss curve at around 420°C to 450°C.

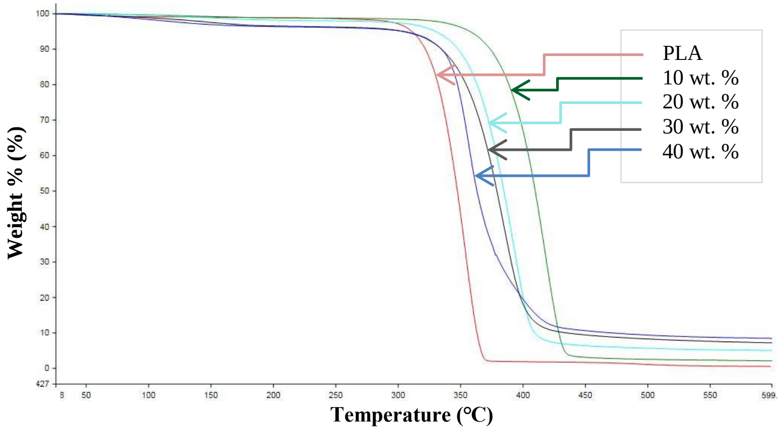

Figure 5: Effect of fibre content on thermal degradation of the composites.

Further increase in fibre content beyond 10wt.% reduces the thermal degradation temperature both at the second and third loss curve. However, all the composites reinforced with OPEFBF exhibit increased thermal degradation compared to pure PLA. It is evident from the above discussion that all the composites possess better thermal stability nearer to 210°C and ensures the composites will not degrade at the 3D printing temperature (210°C). Table 5 shows the char residue values at 600°C. PLA with 10wt.% OPEFBF has a lower mass residual at 600°C and PLA reinforced with 40wt.% OPEFBF has the highest mass residual at 600°C.

Table 5: Char residue values at 600°C

Code	Char Residue at 600°C
40	0.424
30	0.356
20	0.255
10	0.122
10 (Filament)	0.057
0	0.028

Figure 6 shows the comparison of the thermal degradation of PLA-OPEFBF composite and filament.

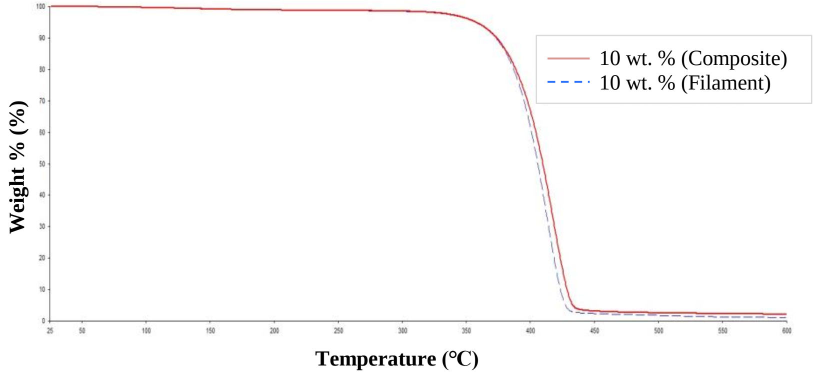

Figure 6: Thermal degradation of PLA-OPEFBF composites and filaments.

It can be seen from Figure 6 that the thermal degradation temperature of the composite is slightly higher than the filaments. It is due to the increased fibre content in the case of the composite, which exhibits higher restricted molecular mobility than the filaments. It can also be seen that the mass residual at 600°C for the composite is slightly higher than the filament. Hence, the result says the filaments might have a slightly lesser fibre content compared to the composites. This reduction of fibre content is due to the sedimentation effect that happened in the extruder. Again, the OPEFBF reinforced composites get melted in the heating compartment and guided to the spool winder during extrusion. At this stage, few portions of OPEFBF are deposited in the extruder itself, which was visible during flushing the extruder at each batch.

Water Absorption Properties of PLA-OPEFBF Filaments

Figure 7 shows the effect of fibre content on the water absorption properties of the filaments.

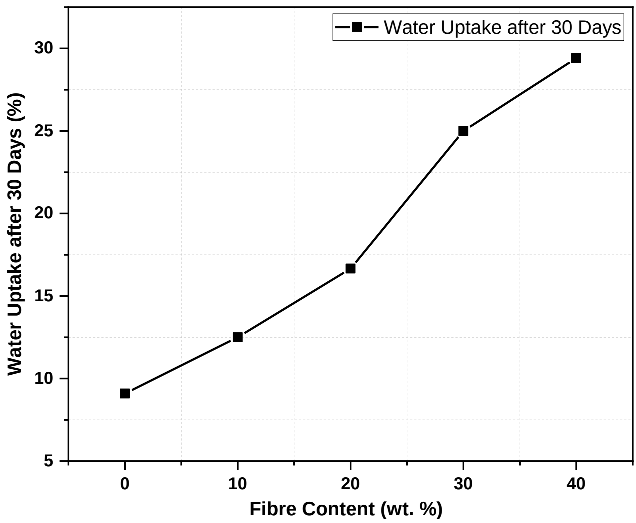

Figure 7: Effect of fibre content on water absorption of the filaments.

It was found that the water uptake content of the OPEFBF reinforced filaments was higher than the pure PLA filaments. The number of OH group increases when OPEFBF are used as reinforcement. These free OH groups tend to form hydrogen bonding when it comes in contact with the water, which leads to the increased weight of the filaments [20]. It can also be seen in Figure 7 that the water absorption of the filaments increases with an increase in fibre content. This is due to increased porosity and hydrophilic sites in the filament, which allows penetration of water molecules, thereby causing an increase in the mass of the filaments. The initial weight of the PLA to 40wt.% OPEFBF reinforced filaments were in the range between 0.11 gms to 0.17 gms respectively, and after 30 days, they were in the range between 0.12 gms to 0.22 gms. Water absorption of the filament reinforced with 40wt.% OPEFBF was 29%, which is 20% higher than the pure PLA filament.

Bio-Degradation Properties of PLA-OPEFBF Filaments

Figure 8 shows the effect of fibre content on the degradation properties of the filaments. It can be noticed from Figure 8 that the weight loss percentage for the OPEFBF reinforced filaments was higher compared to the pure PLA. PLA shows a weight loss of 9% and PLA reinforced filament with 10wt.% to 40 wt.% OPEFBF shows a weight loss of 14% to 21%. This is because OPEFBF is easily degradable in the soil. It can also be noted that the addition of OPEFBF increases the degradation rate. The addition of OPEFBF to filaments caused increased porosity due to poor adhesion between the matrix and the reinforcement.

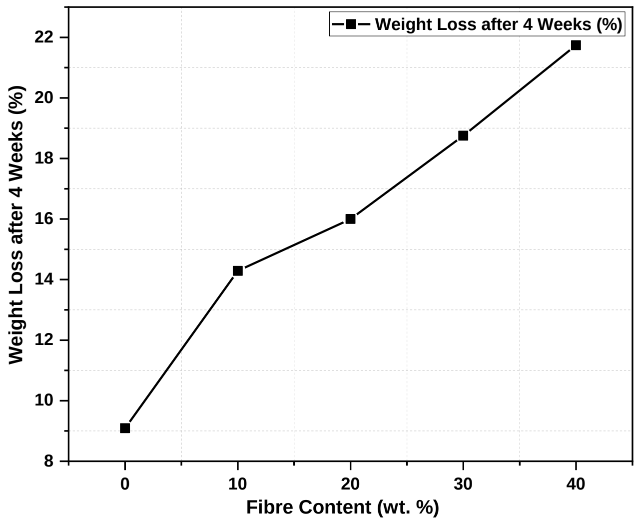

Figure 8: Effect of fibre content on the bio-degradation of the filaments.

This porosity in the filaments allows constituents of the soil and atmospheric moisture and makes the filaments swell in the first stage. In the second stage, fibres would start to aggregate, and wearing might happen, and at the last stage, the polymer chains start to degrade into carbon dioxide and water [16]. This whole mechanism would guarantee the produced PLA-OPEFBBF will be bio-degradable. PLA reinforced with 40wt.% OPEFBF shows 21% weight loss after 4 weeks, 12% higher than pure PLA.

Mechanical Properties of PLA-OPEFBF Filaments

Figure 9 shows the variation of Tensile Modulus (TM) of the PLA-OPEFBF filaments with varied fibre content, respectively. It can be seen from Figure 9 that the TM of the filaments increases upon the addition of OPEFBF. It is due to the stiffness of each OPEFBF involved in the reinforcement [17]. An 18% increase in TM than pure PLA for the 40 wt.% filaments has been recorded.

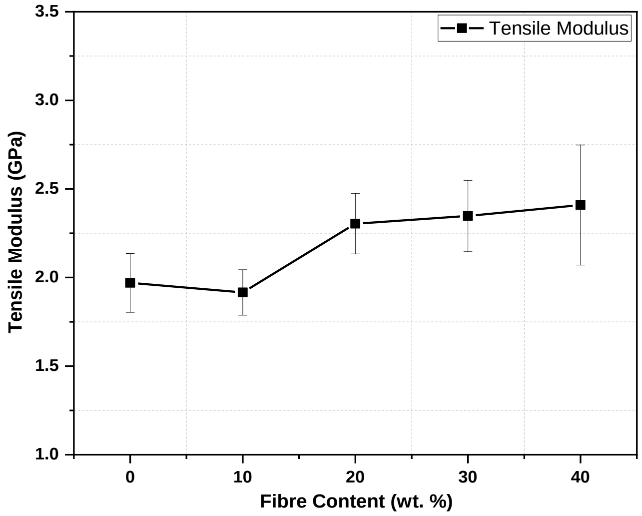

Figure 9: Tensile modulus of the filaments with varied fibre content.

Table 6 shows the tensile modulus and tensile strength of the PLA-OPEFBF with varied fibre content.

Table 6: Tensile modulus and tensile strength of the PLA-OPEFBF filament with varied fibre content.

Code	Tensile Modulus (GPa)	Tensile Strength (MPa)
0	1.97 ± 0.17	35.90 ± 1.36
10	1.92 ± 0.13	22.79 ± 2.38
20	2.30 ± 0.17	13.85 ± 2.04
30	2.35 ± 0.20	12.53 ± 2.22
40	2.41 ± 0.34	12.84 ± 1.84

Figure 10 shows the Tensile Strength (TS) of the PLA-OPEFBF filaments with the varied fibre content. It can be seen from Figure 10 that the TS of the OPEFBF reinforced filaments decrease upon the addition of fibres. This reduction in TS is due to the increased void content upon the addition of fibres. This is in accordance with the researches when NFRC based filaments are produced with PLA as a matrix [11], [12]. The reduction of fibre content during the conversion of PLA-OPEFBF composite to the filament has happened could also be the reason for the reduction in the mechanical properties of the filaments.

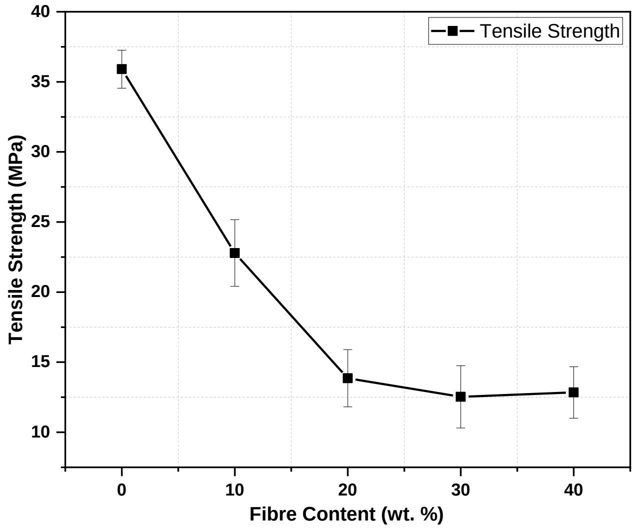

Figure 10: Tensile strength of the filaments with varied fibre content.

The reduction of fibre content in the filament is due to the sedimentation effect during the extrusion. It means that the extrusion hasn’t happened effectively in producing filaments with enough reinforcement. Pre-treating the natural fibres could be considered an option to increase the interference between the polymer and reinforcement, which increases the mechanical properties of the filament [12]. We have not considered treating the fibres because we felt the usage of chemicals used during the pre-treatment might affect the 3D printers. However, in recent times, many researchers used different chemicals for treatments, compatibilizers, toughening agents, and plasticizers to improve the adhesion between the polymer and reinforcement and have successfully 3D printed the filaments [5]. Hence, further studies will be performed to increase the mechanical properties of the PLA-OPEFBF filament by adopting those techniques, as mentioned above.

3D Printing of PLA-OPEFBF Filaments

PLA-OPEFBF filaments produced by extrusion are 3D printed using FDM technology with the help of Raise 3D N2 Plus printer. The diameter of the nozzle was 0.4 mm, and the printing temperature considered was 210℃ at a rate of 70 mm/s. It was harder to print the filaments with higher fibre content because of the increased inconsistent diameter regions. Also, increased fibre content increases the probability of nozzle clogging during the process. Filaments with 10wt.% OPEFBF was more accessible to 3D print since it has lower regions of inconsistent diameter. Table 7 shows the results of 3D printing the PLA-OPEFBF filament with different fibre content.

Table 7: Results of 3D printing the PLA-OPEFBF filaments with different fibre content

Code	Meting Temperature	Results of 3D Printing
10	210℃	Successful and Continous
20	210℃	Successful and Non-Continous
30	210℃	Unsuccessful
40	210℃	Unsuccessful

Filament with lower fibre content flows evenly and smoothly through the nozzle, and as the fibre content increases, the process becomes complicated. We know the fact that FDM is a melt extrusion method, and it works in the way that OPEFBF reinforced filament enters into a heating compartment, gets heated up, and the melted portions are passed out through the nozzle of the 3D printer. During this process, a few portions of OPEFBF get sedimented, which inturn clogged the nozzle, and as the fibre content increases, the higher the chance of getting clogged. Figure 11 shows the results of 3D printing the PLA-OPEFBF filament with different fibre content. Also, the temperature of the 3D printing process was kept constantly at 210℃ for the filaments with different fibre contents. This temperature may not be ideal for the filaments with different fibre contents since increasing the percentage of OPEFBF would change the melting temperature of the resulting mixture. As a result, 3D printing the filament with a higher fibre content of OPEFBF turns to be tedious. Hence, further investigation is needed to identify the exact process temperature for the filaments with different fibre contents. 3D printed structures were found to be hollow with inconsistent filament flow, and cavities have been noticed at fewer places. This was due to the slip-stick extrusion defect during the printing process, which causes poor surface finish and poor adhesion amongst the layers. Similar justification has been addressed by Stoof et al., when they initiated the 3D printing of natural fibre-reinforced composites [21].

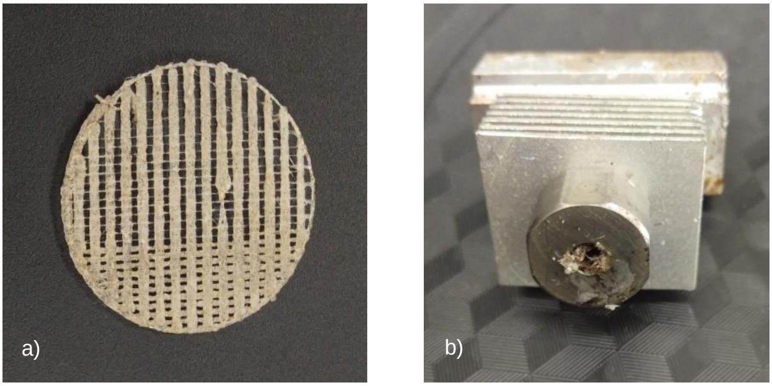

Figure 11: Results of 3D printing the PLA-OPEFBF filaments with different fibre content. a) Successfully 3D printed code 10 filament b) Clogged nozzle during 3D printing of code 30 filament.

Conclusion

PLA reinforced with varying contents of OPEFBF filaments have been produced and investigated for its physical, thermal, water absorption, biodegradation, and mechanical properties. TGA results infer that the OPEFBF reinforced filaments offer better thermal degradation than the pure PLA, and it also proves that the filament can withstand the process temperature (210°C) of 3D printing without degradation. 40 wt.% OPEFBF reinforced filament shows an increase in 18% of tensile modulus over pure PLA. The mechanism involved in bio-degradation reveals the filaments are environment friendly. However, these OPEFBF reinforced filaments with increased water absorption and reduced tensile strength, hinder it from being applied for real-time applications. Increased porosity due to the addition of fibres and decreased amount of reinforcement in the filaments due to sedimentation effect inside the extruder has been provided as reasons for the reduced tensile strength. Later, these filaments are tested for 3D printing. Filaments reinforced with 30 and 40 wt.% of OPEFBF gets clogged in the 3D printer. Clogging in the nozzle is due to inconsistency in the diameter of the filaments as the fibre content increases. Also, few portions of OPEFBF gets sedimented in the heating compartment of the 3D printer gets carried away and clogged the nozzle of the printer. However, filaments reinforced with lesser contents of OPEFBF gets successfully printed. By doing so, this research shows the importance of producing filaments from the agricultural and industrial waste of oil palm, which can contribute to the community of additive manufacturing for commercialization. Further studies will be performed to make the filaments more effective and to be applied for real-time applications.

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