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Research Article

A Study on the Mechanical Properties of Oil Palm Mesocarp Fibre-Reinforced Thermoplastic

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Oil palm mesocarp fibre obtained from a palm oil processing mill was washed with detergent and water to remove the oil and sun-dried to enhance good adhesion to Linear Low Density Polyethylene (LLDPE). The fibre was pulverized and filtered through a sieve of pore size 300 microns. The Oil Palm Mesocarp Fibre Reinforced Thermoplastic (OPMFRT) was produced with a form of hand lay-up method and varying fibres weight ratio in the matrix from 5 wt% to 25 wt% in steps of 5 wt%. Tensile test was carried out to determine the tensile strength, tensile modulus, and elongation at break of the material. The hardness and impact strength of the composite were also determined. The results showed that tensile modulus and hardness of the OPMFRT increased by 50% and 24.56%, respectively, while tensile strength, impact strength, and percentage elongation of the OPMFRT decreased by 36.78%, 39.07%, and 95.98%, respectively, as fibre loading increased from 5 wt% to 25 wt%. The study concluded that the application of the OPMFRT developed should be restricted to areas demanding high rigidity and wear resistance.

1. Introduction

Over the past few decades, there has been a growing interest in the use of natural fibres in composite applications. These types of composites present many advantages compared to synthetic fibres, such as low tool wear [1], low density, cheaper cost, availability, and biodegradability [2]. Many naturally occurring fibres can be used as composites, but mostly in applications that involve low stress. Some of the fibres are obtained by processing agricultural, industrial, or consumer waste [3].

Natural fibres open up further possibilities in waste management, as they are biodegradable and therefore can lead to highly functional composite materials if used in combination with biodegradable plastic polymers. They have attracted renewed interest as replacements for traditional fibres such as carbon, aramid, and glass in the automobile industry. One such natural fibre is Oil Palm Mesocarp Fibre (OPMF) which is available in appreciable quantity locally in Nigeria [4]. OPMF is residue obtained from oil palm fruits after the oil extraction. OPMF possesses certain characteristics such as low density and biodegradability. It is also nonabrasive. Table 1 shows the chemical and mechanical properties of OPMF.

More often, OPMFs are either left in the palm oil mill as wastes or used locally for cooking. This utilization of the fibres, however, creates huge environmental pollution to the environment. This research, therefore, puts OPMF to better use as filler for biocomposites preparation. The blending of OPMF with LLDPE in the fabrication of polymer/fibre composite and the method of fabrication adopted for this study have not been reported previously.

2. Materials and Methods

Oil Palm Mesocarp Fibre (OPMF) (see Figure 1) was obtained from a local palm oil processing mill in Modakeke area of Osun State. Linear Low Density Polyethylene (LLDPE) (see Figure 2) was obtained from Prince Emmanuel Industrial Chemical Ventures in Agege area of Lagos State.

Table 1: Chemical and mechanical properties of OPMF [5].

	OPMF
Lignin (%)	11
Cellulose (%)	60
Ash content (%)	3
Tensile strength (MPa)	80
Young's modulus (MPa)	500
Elongation at break (%)	17

Figure 1: OPMF from the local oil mill.

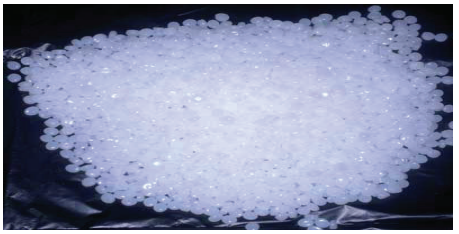


Figure 2: LLDPE.

Figure 3: Sun-drying of the OPMF.

2.1. Fibre Processing. The OPMF was washed with detergent and water to remove the remaining oil still present to enhance good adhesion with the LLDPE. After washing, the fibres were then sun-dried (see Figure 3). The dried fibres were pulverized using a local pepper grinding machine. The ground fibres were then filtered through a sieve of pore size of 300 microns.

2.2. Composite Preparation. A form of hand lay-up method was adopted in the preparation of the composite. The fibres and the plastic were weighed to get the required weight using an electronic weighing balance. The fibres and the plastic were mixed such that the fibre weight ratio in the matrix varied from 5 wt% to 25 wt% in steps of 5 wt%. The mixed fibre and plastic were then heated in an aluminium mold (see Figures 4, 5, and 6) at a temperature of 150°C for 20 minutes, during which the blend was thoroughly mixed to ensure homogeneity (see Figure 7). The mold consists of male and female part connected by hinges. The male part also has an orifice at its centre. Heating continues for another 10 minutes. A G-clamp was then used to ensure proper closure between the mold halves. This allows excess material to flow out through the orifice and the sides of the mold. The mixture in the mold was allowed to cool and take the shape of the mold cavity (see Figure 8) while the mold was still clamped.

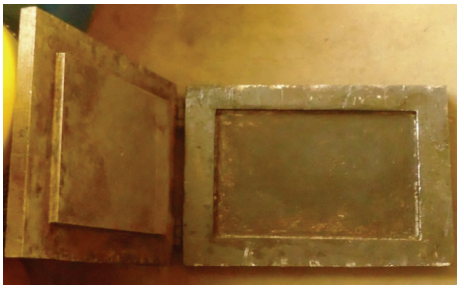


Figure 4: Empty aluminium mold.

Figure 5: OPMF/LLDPE before heating.

Figure 6: Heating of the mold.

Figure 7: OPMF/LLDPE during heating.

Figure 8: Finished OPMFRT (dimension: 295 × 210 × 6 mm).

2.3. Characterization of the OPMFRT. The fibre-reinforced plastic was retrieved from the mold and cut into test specimens. Mechanical testing was used to characterize the composites. Tensile test was carried out using the Instron 3369 (Universal Testing Machine) (see Figure 9) to determine the tensile strength, tensile modulus, and elongation at break of the material. Brinell Hardness (BHN) test was used to determine the hardness of the material and Izod impact test was carried out to determine the impact strength of the OPMFRT.

3. Results and Discussions

3.1. Stress-Strain Curves of Neat LLDPE and OPMFRT. The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each sample has its own unique stress-strain curve. The engineering stress-strain curves of the sample of neat LLDPE and OPMFRT at 25 wt% fibre loading are shown in Figure 10. It will be noted from the figures that with the introduction of fibre into the LLDPE, the amount of strain that the material is subjected to before fracture drastically reduced. This shows that the incorporation of the fibre into the matrix makes the resulting composite more brittle but stiffer than the neat polymer. This behaviour is as a result of the fact that the elasticity of the composite has been suppressed by the presence of the OPMF.

3.1.1. Tensile Strength of the OPMFRT. Figure 11 illustrates the average tensile strength of the OPMFRT produced at different cellulose loadings as compared to pure LLDPE. It shows that neat LLDPE has an average tensile strength of 11.5 MPa which decreased by (36.78%) as the cellulose loading was increased to 25 wt%. The values of the average tensile strength of the OPMFRT at 5 wt%, 10 wt%, 15 wt%, 20 wt%, and 25 wt% fibre loading are 8.97 MPa, 7.96 MPa, 7.88 MPa, 7.64 MPa, and 7.27 MPa respectively, representing 24%, 30.78%, 31.48%, 33.57%, and 36.78% reduction in the tensile strength.

The decrease is due to the poor interfacial adhesion between the hydrophobic LLDPE and hydrophilic fibres. The Scanning Electron Microscope micrographs (see Figure 12) show that while the fibres were fairly evenly distributed within the matrix, agglomeration of the fibres observed however indicates weak interfacial bonding. This showed that washing the fibres with detergent is not sufficient to improve the interfacial bonding. Poor interfacial adhesion acts as a stress concentration point upon application of external forces leading to premature failure due to poor stress transfer from matrix to the fibres [6]. As fibre loading increased, the reduction in the tensile strength per unit percentage increase in fibre loading becomes smaller. This behaviour may be as a result of fibres being more evenly dispersed and the stress more evenly distributed. Higher tensile strength demonstrated by neat LLDPE is due to the flexibility and plasticity of LLDPE. Then et al. [7] in their work with poly(butylene succinate) (PBS)/OPMF composite reported that the value of the tensile strength of neat PBS was 37.31 MPa. However, the value of the tensile strength of the PBS/OPMF composite at 10 wt% and 20 wt% fibre loading was 25.55 MPa and 19.91 MPa, respectively, both representing 31.52% and 46.64% reduction in the tensile strength. The decreasing trend in the tensile strength observed in this study as fibre loading increased is in agreement with that observed by Then et al. [7] and Nam et al. [8].

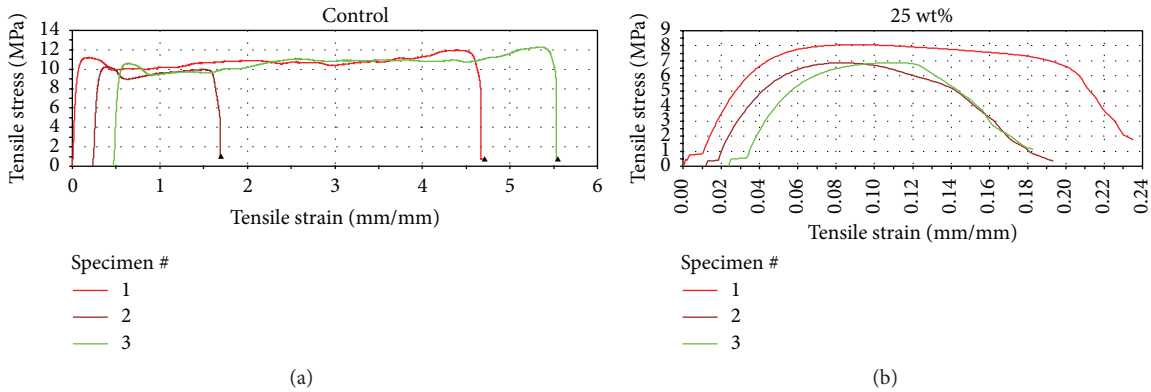
3.1.2. Tensile Modulus of the OPMFRT. Figure 13 illustrates the average tensile modulus of the OPMFRT produced at different cellulose loadings as compared to pure LLDPE. It shows that the tensile modulus of neat LLDPE is 200 MPa and it increased by 50% as the cellulose loading was increased to 25 wt%. The values of the average tensile modulus of the OPMFRT at 10 wt%, 15 wt%, 20 wt%, and 25 wt% fibre loading are 205 MPa, 229.54 MPa, 286.67 MPa, and 300 MPa, respectively, representing 2.5%, 14.77%, 43.34%, and 50.00% increment in the tensile modulus. The value of the average tensile modulus of the OPMFRT at 5 wt% fibre loading is 176.67 MPa which represents an 11.67% reduction in the tensile modulus as compared to that of the neat LLDPE. The reduction may, therefore, be as a result of presence of void in the composite. The neat LLDPE has an ability to elongate more due to its elasticity. As the OPMF derived cellulose loading increased, the elasticity of LLDPE has been suppressed by the presence of the derived cellulose. The increment in the modulus may, therefore, be attributed to the decreased deformability of the interface between the fibres and the matrix material which leads to reduced strain as the fibre loading increased. Then et al. [7] suggested that the enhancement in tensile modulus is probably due to the fibres itself which have higher stiffness than that of the polymer. In their work with PBS/OPMF composite, the value of the tensile modulus of neat PBS was 248.90 MPa. However, the value of the tensile modulus of the PBS/OPMF composite at 10 wt% and 20 wt% fibre loading was 301.50 MPa and 349.60 MPa, respectively, both representing 21.13% and 40.46% increment in the tensile modulus. The increasing trend in the tensile modulus observed in this study as fibre loading increased is in agreement with that obtained by Then et al. [7] as well as Brahmakumar et al. [9] and Sapuan et al. [10].

3.1.3. Percentage Elongation at Break of the OPMFRT. Figure 14 illustrates the average elongation at break of the OPMFRT

Intron 3369 (Universal Testing Machine) (a)

Housefield Balanced Impact Testing Machine (b)

Figure 9: Instron 3369 and Housefield Balanced Impact Testing Machine.



(a) (b)

Figure 10: Typical stress-strain curves of samples of (a) neat LLDPE and (b) OPMFRT at 25 wt% fibre loading.

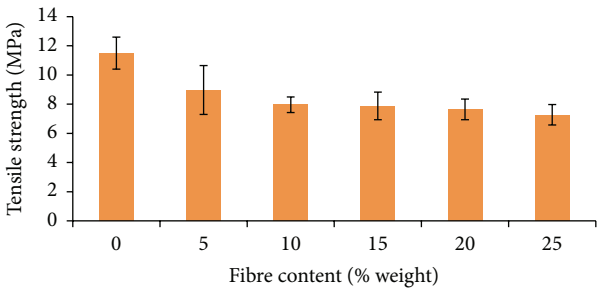


Figure 11: Tensile strength versus fibre content.

produced at different cellulose loading as compared to pure LLDPE. It shows that the elongation at break decreased by 95.98% as the cellulose loading was increased to 25 wt%. The neat LLDPE matrix has an ability to elongate more due to its elasticity and, as such, it has a high value of elongation at break of 489.54%. The values of the average percentage elongation at break of the OPMFRT at 5 wt%, 10 wt%, 15 wt%, 20 wt%, and 25 wt% fibre loading are 59.60%, 53.02%, 25.34%, 20.74%, and 19.70%, respectively, representing 87.83%, 89.17%, 94.82%, 95.76%, and 95.98% reduction in the percentage elongation at break. As the OPMF derived cellulose loading increased, the elasticity of the composite is suppressed by the presence of the derived cellulose. The reduction is attributed to the decreased deformability of a rigid interface between the fibres and the matrix material. Liu et al. [11] reported that the decrease in elongation at break is due to the destruction of the structural integrity of the polymer by the fibres and the rigid structure of the fibres. Then et al. [7] in their work with PBS/OPMF composite reported that the value of elongation at break of neat PBS was 470%. However, the value of elongation at break of the PBS/OPMF composite at 10 wt% and 20 wt% fibre loading was 19.60% and 13.72%, respectively, both representing 31.52% and 46.64% reduction in the elongation at break. Thus, the decreasing trend in the elongation at break observed in this study as fibre loading increased is in agreement with that observed by Then et al. [7] and Rozman et al. [12].

3.2. Impact Strength of the OPMFRT. The effect of various cellulose loadings on the average impact strength for notched

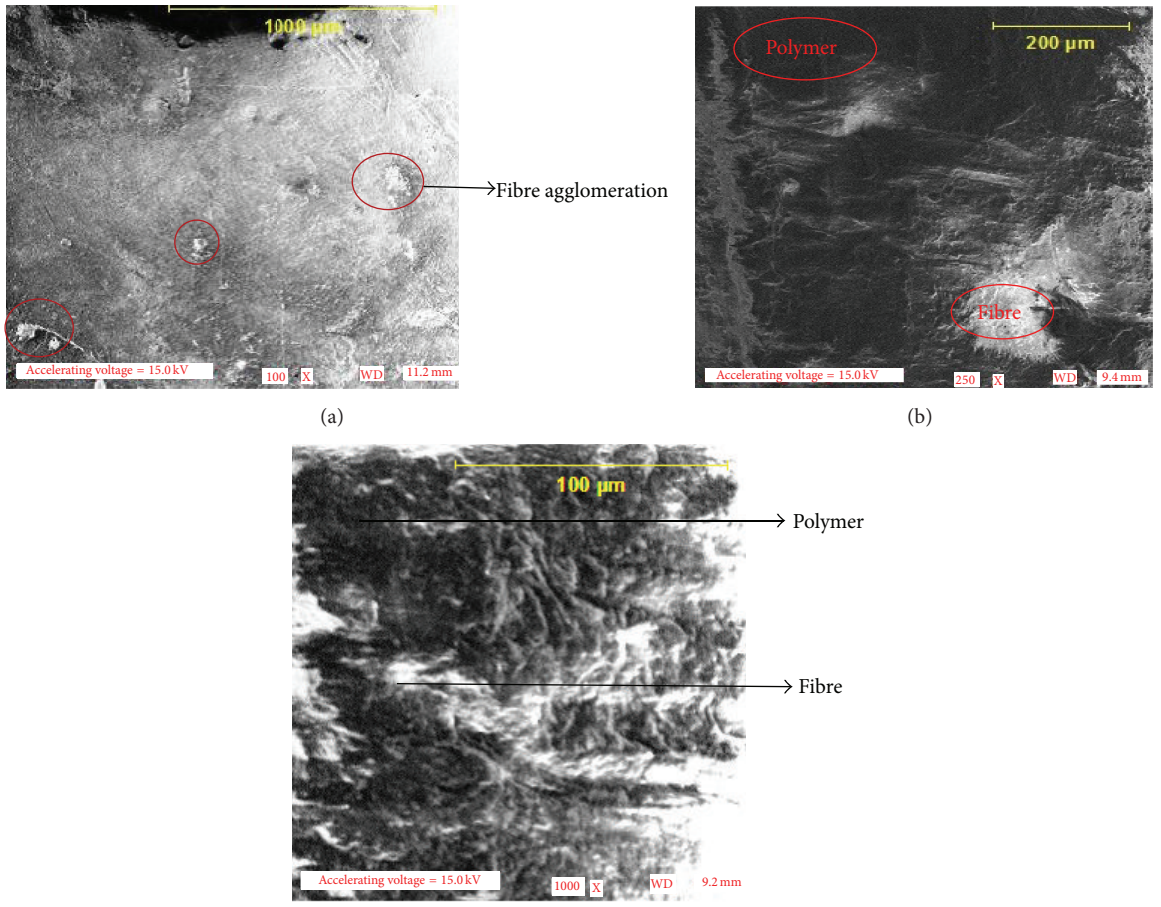


Figure 12: SEM micrographs of the OPMFRT (a) at 10 wt% fibre loading and (b, c) at 25 wt% fibre loading.

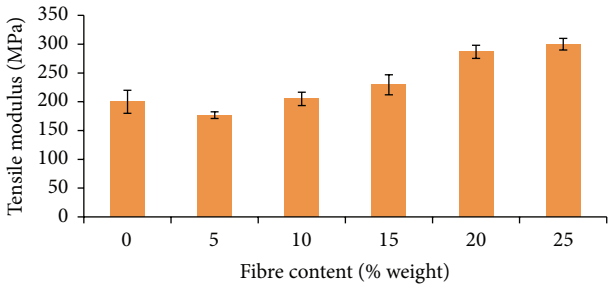


Figure 13: Tensile modulus versus fibre content.

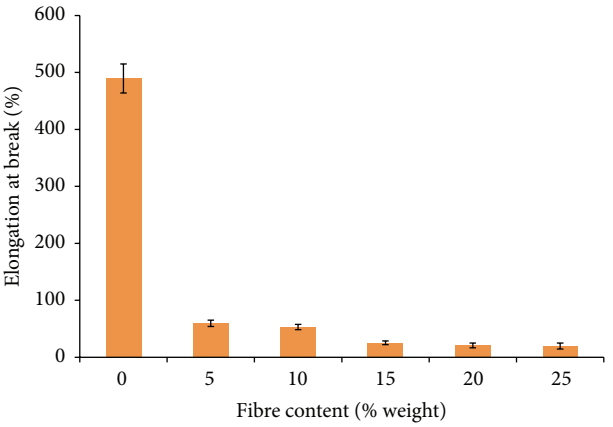


Figure 14: Elongation at break versus fibre content.

samples is shown in Figure 15. Generally speaking, it can be seen that the impact strength decreased with the increase in fibre loading. Higher impact strength demonstrated by neat LLDPE is due to the flexibility, plasticity, and less brittleness of LLDPE, which allows it to absorb and distribute the impact energy efficiently [6]. However, the composite material becomes brittle as a result of the presence of the OPMF, thereby causing a reduction of the impact strength by about 39.07%, as fibre loadings was increased to 25 wt%. Figure 15 shows that while neat LLDPE has an impact strength of 160.27 kJ/m^2, the values of the average impact strength of the OPMFRT at 5 wt%, 10 wt%, 15 wt%, 20 wt%, and 25 wt% fibre loading are 133.70 kJ/m^2, 126.30 kJ/m^2, 114.56 kJ/m^2, 105.52 kJ/m^2, and 97.65 kJ/m^2, respectively, representing 16.58%, 21.20%, 28.52%, 34.16%, and 39.07% reduction in the impact strength. The introduction of the stiff fibre in a ductile matrix restricts the segmental motion of the

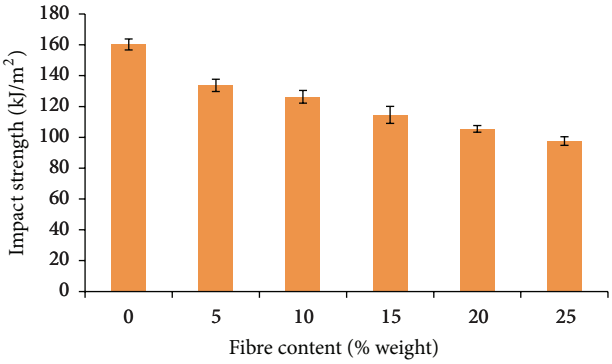


Figure 15: Impact strength versus fibre content.

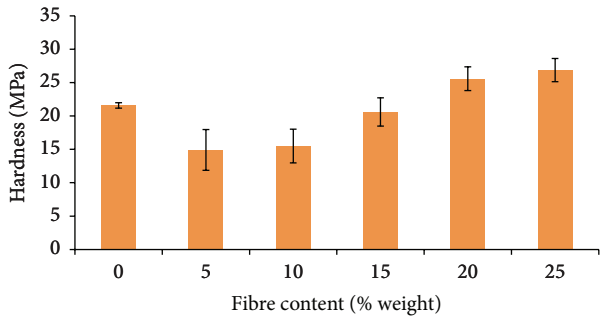


Figure 16: Hardness versus fibre content.

polymer chains, which consequently limit the deformability of the matrix phase, resulting in low impact strength [13]. The decreasing trend in the impact strength observed in this study as fibre loading increases is in agreement with that observed by Then et al. [7].

3.3. Hardness of the OPMFRT. Figure 16 illustrates the average hardness of the OPMFRT produced at different cellulose loading as compared to pure LLDPE. Generally speaking, it can be seen that the hardness increased by 24.56% with increasing fibre loading. The values of the average hardness of the OPMFRT at 20 wt% and 25 wt% fibre loading are 25.6 MPa and 28.88 MPa, respectively, representing 18.63% and 24.56% increment in the hardness. However, the values of the average hardness of the OPMFRT at 5 wt%, 10 wt%, and 15 wt% fibre loadings are 14.91 MPa, 15.5 MPa, and 20.60 MPa, respectively, representing 30.91%, 28.17%, and 4.5% reduction in the hardness as compared to that of the neat LLDPE. Kling et al., 2013 [14], show that, with introduction of fibre in a polymer matrix, there will certainly be considerable amount of voids. The reduction in hardness within 5 wt% and 15 wt% fibre loading may, therefore, be as a result of presence of void in the composite.

4. Conclusion

In this study, OPMFRT has been produced through a form of hand lay-up technique and the mechanical properties at 5 wt% to 25 wt% fibre loadings have been examined. The results from the mechanical tests carried out showed that tensile modulus and hardness of the OPMFRT increased as fibre loading increased from 5 wt% to 25 wt% by 50% and 24.56%, respectively. However, tensile strength, impact strength, and percentage elongation of the OPMFRT decreased as fibre loading increased from 5 wt% to 25 wt% by 36.78%, 39.07%, and 95.98%, respectively. The increase in the tensile modulus and hardness of OPMFRT composite over the neat LLDPE shows that OPMFRT has the potential of being used in certain engineering applications. In cases where stiffness and hardness are requirements the composite can successfully replace neat LLDPE. Furthermore, the amount of polymer to be used in such applications will be significantly reduced. However, in applications where the component will be subject to high tensile and impact forces, the OPMFRT will not be advisable.

Recommendations

(a) Due to the rigidity and hardness of the OPMFRT as observed in this study, its development and use should be enhanced and encouraged for applications in windows and door frames, doors and windows, furniture, vehicle interiors, divider boards, ceiling boards, and so forth.

(b) The mechanical properties of OPMFRT may be improved by incorporating suitable coupling agents and chemical treatment of the fibres as against just washing with detergent to enhance the interfacial adhesion between the cellulose and LDPE matrix.

(c) While the fibre loading in this study has been limited to 25 wt%, the behaviour of the mechanical properties of the OPMFRT can be further explored in subsequent investigations by increasing the percentage of fibre loading beyond 25 wt%.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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