

Effect of Filler Size on the Properties of Oil Palm Empty Fruit Bunch High-Load Filler Biocomposite

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Abstract

This work aimed to study the effect of filler size on the performance of an empty palm oil fruit bunch (OPEFB) high-load filler epoxy resin biocomposite (80 vol.% OPEFB and 20 vol.% epoxy resin). The particle sizes of OPEFBs used to prepare the biocomposites were 60, 80, 100, 120 and 140 mesh. The biocomposite samples were prepared by the press method. The physical (density, porosity, thickness swelling), mechanical, and thermal properties of the biocomposite were evaluated. A universal testing machine, thermogravimetric analysis, and scanning electron microscopy were utilized to characterize the biocomposite samples. The results show that the physical, mechanical, and thermal properties of the OPEFB epoxy resin biocomposite are significantly affected by the particle size of OPEFBs. As the particle size was reduced from 0.250 to 0.105 mm, the density improved from 0.974 to 1.101 g/cm³, the porosity decreased from 15.1 to 9.1 %, and the thickness swelling decreased from 14.2 to 7.4 %. The modulus of rupture and modulus of elasticity improved from 9.7 to 22.8 MPa and 1,667 to 2,403 MPa, respectively. Thermal analysis indicated that finer fillers enhanced thermal stability. The OPEFB biocomposite remained stable up to 300 °C. Smaller filler sizes exhibited improved biocomposite properties, which were attributed to better interfacial bonding and uniform dispersion within the matrix. The results of this study demonstrate that the performance of biocomposites can be significantly enhanced by reducing the size of the fillers. These findings indicate that filler size is crucial for high-load filler biocomposites.

Keywords: Biocomposite, Epoxy resin, Empty palm oil fruit bunches, Filler size, Physical property, Mechanical property, Thermal property

Introduction

A biocomposite is a composite material that consists of 2 main components that are a matrix and a filler, where at least one of these 2 components is derived from natural fibers or a biobased material. Generally, fillers are derived from natural fibers. High-load filler biocomposites consist of a polymer matrix with a high-volume fraction of reinforcing fibers or particles, typically derived from natural sources like wood, hemp, flax, or other plant fibers. The advantage of biocomposites is that they are cheap and environmentally friendly. There are some practical applications of biocomposite across various industries,

such as wall panels, roofing, flooring, insulation, decorative elements, interior components for the automotive industry (door panels, dashboards, seatbacks), etc. Utilizing waste from agricultural, plantation, or forest products to make a biocomposite is a good way to decrease the use of non-renewable resources and maintain environmental sustainability [1-5]. Nonetheless, natural fibers are hydrophilic. They easily absorb water which leads to poor mechanical performance. Water absorbed by a natural fiber in a biocomposite can cause a decline in mechanical properties, such as the modulus of rupture and modulus

of elasticity. This occurs because the absorbed moisture weakens the interfacial bonds between the fibers and matrix, thereby reducing the effectiveness of the load transfer. In practical applications such as construction materials, automotive, or sports equipment, this decrease in mechanical properties can reduce the lifetime and performance of biocomposites. Additionally, water absorption leads to an increase in the composite's weight and dimensional changes, such as swelling. Dimensional changes can affect the size stability of biocomposite components, which is a problem in high-precision applications such as automotive interior panels or furniture products. Uncontrolled swelling can cause structural cracks or deformations of biocomposites. On the other hand, it is expected that the composition of natural fibers in producing a biocomposite should be larger than that of the matrix or polymer composition in order to use more natural fibers than polymers. The properties of a composite are influenced by the composition of the natural fibers [6]. For large compositions of filler (greater than 50 %), the performance of biocomposites decreases [6-9]. Therefore, it is very important to study how to improve the performance of biocomposites with large fiber compositions (high-load filler biocomposite). The impact of moisture on the performance of biocomposite can be minimized by incorporating small fillers or nanofillers.

Several studies have shown that the size of natural fiber fillers plays an important role in determining the overall performance of composites [10-14]. The study of rice straw epoxy resin particleboard found that the particle size of rice straw significantly influences the mechanical and physical properties of rice straw epoxy resin particleboard. This study demonstrated that using smaller rice straw particles in epoxy resin particleboard can enhance its mechanical strength and durability [15]. Kamarudzaman *et al.* [16] studied the effect of OPEFB fiber size on the fracture toughness of polypropylene composite. The OPEFB fiber sizes were 0.180, 0.250, 0.300 and 0.355 mm. The composition of OPEFB was 20 wt.%. They found that the fracture toughness increased from 0.89 MPa (for 0.355 mm fiber size) to 1.16 MPa (for 0.180 mm fiber size). This study also found that the bonding between the fiber and matrix is better in composites with smaller OPEFB fibers. This is because small particles can better penetrate the polymer

matrix, thereby strengthening the interfacial bond [16]. Garcia *et al.* [17] explored the influence of the particle size of Washingtonia palm rachis on the property's boards. The citric acid was used as a natural binder. The size of fillers were < 0.25 mm, 0.25 - 1.00 mm, 1 - 2 mm, 2 - 4 mm and 4 - 8 mm. They found that the density of the board increased from 0.687 (particle size 4 - 8 mm) to 0.812 g/cm³ (particle size < 0.25 mm). The thickness swelling and water absorption also improved as the particle size was reduced. The modulus of rupture increased from 2.77 N/mm² (particle size 4 - 8 mm) to 12.5 N/mm² (particle size < 0.25 mm) [17]. Sharma *et al.* [18] investigated the influence of particle size on the properties of epoxy composites reinforced with food waste fillers. The particle sizes of fillers were 0.100 - 0.250 mm, 0.350 - 0.500 mm and 0.650 - 0.800 mm with a composition of 15 wt.%. Their results showed that the density and flexural strength of the composite increased from 0.9919 to 1.0913 g/cm³ and 36 to 59 MPa as the filler size was reduced from 0.600 - 0.800 to 0.100 - 0.250 mm, respectively [18]. Thus, the above studies show that the properties of biocomposite can be improved by reducing the filler size.

Among the various natural fibers, oil palm empty fruit bunch (OPEFB) fibers have emerged as a promising reinforcement material for polymer composites. Oil palm empty fruit bunches are a waste of palm oil processing. Indonesia has a significant amount of OPEFB. However, this waste has not been used optimally yet. Meanwhile, OPEFB contains 57.8 % cellulose, which is potential to be used as a composite filler [19]. Cellulose plays a crucial role in determining the strength of fibers. The cellulose content in natural fibers significantly influences the overall biocomposite performance. Fibers with higher cellulose contents offer better tensile and flexural strength due to the strong crystalline structure of cellulose microfibrils, which enhances the load transfer efficiency within the composite matrix. Several studies have been utilized OPEFB as a reinforcement in biocomposites. Yusoff *et al.* [20] examined the mechanical properties of randomly short fiber-reinforced composites made of palm fibers and epoxy resin matrix. The palm fiber composition was 5, 10, 15 and 20 vol.%. The addition of palm fiber to the epoxy matrix reduced the flexural strength and flexural modulus of the composite. Ghazilan *et al.* [21] incorporated OPEFB into epoxy

resin with a composition of 20 vol.% OPEFB fiber and 80 vol.% epoxy resin. The results of their study showed that the tensile strength and tensile modulus of the OPEFB biocomposite were 10 and 1,712 MPa, respectively, which are much smaller than the strength of epoxy resin. Kalam *et al.* [22] also showed that the addition of OPEFB to the epoxy matrix resin reduced the mechanical properties of the biocomposite. Hanan *et al.* [23] developed a biocomposite using OPEFB and kenaf as fillers and epoxy as a matrix. The results of their study showed that the tensile and flexural strength decreased with increasing OPEFB composition. Recently, Asyraf *et al.* [24] and Aisyah *et al.* [25] reviewed OPEFB-reinforced polymer composites. They found that OPEFB-reinforced composites are a very promising sustainable material in the future because they are eco-friendly and cost-effective compared to synthetic composites. However, there are challenges, such as high moisture absorption, poor mechanical properties, and low thermal stability. All studies reported in the literature used a low OPEFB composition (low-load filler) or high matrix concentration (polymer). Meanwhile, a biocomposite material is expected to have a more dominant natural fiber composition (high-load filler) than the matrix composition (polymer); for example, the composition of OPEFB is 80 and 20 % that of the polymer.

As discussed above, the particle size determines the composite properties. The performance of a biocomposite can be improved by reducing its particle size (filler size) [10-18]. Thus, by reducing the size of the filler, a good-performance biocomposite can be prepared even with a large filler composition (high-load filler). Nonetheless, the role of filler size, particularly in OPEFB-based epoxy composites with high-load filler, has not been examined. Therefore, this study aims to fill this gap by investigating the effect of different filler sizes on the physical, mechanical, thermal, and morphological properties of OPEFB-epoxy resin biocomposite with a composition of 80 vol.% OPEFB and 20 vol.% matrix. Previous studies have shown that using 4 filler sizes is adequate for observing the effect of filler size on the mechanical and physical properties of composites. For example, Jaya *et al.* [10] used sawdust particles with sizes of 0.630, 0.125, 0.250 and 0.500 mm. Kamarudzaman *et al.* [16] used OPEFB particles with sizes of 0.180, 0.250, 0.300 and 0.355

mm. Abdelmagid *et al.* [14] used *prosopis chilensis* powder with sizes of 0.088, 0.105, 0.125 and 0.149 mm. Thus, we used 5 different filler sizes in this study: 60, 80, 100, 120 and 140 mesh. The matrix used in this work was epoxy resin because it is a non-hazardous material and has excellent adhesion properties. Epoxy resin has several advantages, including: having good mechanical properties, excellent adhesion to various fiber types, and resistance to chemicals such as acids, alkaline. In addition, epoxy has a low water-absorption capacity [26].

Materials and methods

Materials

The oil palm empty fruit bunch (OPEFB) used in this study was obtained from PT. Samira Makmur Sejahtera, a palm oil factory located in Southwest Aceh Regency, Aceh Province, Indonesia. A previous study reported that Indonesian OPEFB contains 37 - 47 % cellulose and 25 - 34 % hemicellulose [27].

The adhesive used for the biocomposite was epoxy resin produced by the Avian company in Indonesia. Its specification is listed below. The color is clear/transparent; the viscosity at 30 °C is 135 - 140 KU; the density at 30 °C is 1.01 - 1.05 g/cm³; mixing ratio of resin and hardener is 1:1 (vol.%); surface dry is about 30 min; hard dry is 24 h.

Material preparation

Oil palm empty fruit bunches were cleaned thoroughly with water to remove dirt such as dust, sand, and other deposits adhering to the fibers. Oil palm empty fruit bunches were placed on a net in an open area that received direct sunlight during the day. Their position was changed as needed to ensure even exposure to sunlight. The OPEFBs were dried under the sunlight for 2 days. The OPEFB fibers were then cut into pieces (about 2 cm in length). Next, the empty fruit bunch fibers were dried using an electric oven at a temperature of 105 °C for 4 to 6 h until their weight remained constant. Next, the empty palm oil bunch fibers were ground using a disk-mill-type grinder to produce OPEFB particles. After that, the OPEFB particles were sifted using an electric sieve so that 60, 80, 100, 120 and 140 mesh OPEFB particles were obtained.

Biocomposite preparation

The instruction from Avian company was followed, where the ratio of epoxy resin and hardener was set at 1:1 to achieve the intended properties. The ratio composition of fillers (oil palm empty fruit bunch particles) and matrix (epoxy resin) was set to 80/20 vol.% for all particle sizes of OPEFBs to obtain high-load filler biocomposites. The oil palm empty fruit bunch was mixed with the epoxy resin homogeneously

by using a planetary type of mixer at a constant speed (300 rpm) for 30 min [13]. Biocomposite samples were prepared using the press method with a 9-ton load at room temperature. A photograph of the OPEFB biocomposite samples ($15 \times 15 \times 0.6 \text{ cm}^3$) is shown in **Figure 1**. The biocomposite samples were stored in a Ziplock bag at room temperature to prevent moisture effects.



Figure 1 A photograph of OPEFB biocomposites.

Characterizations

The physical properties of OPEFB biocomposite were tested according to Indonesian National Standard SNI 03-2105-2006. The measurement was conducted at room temperature with approximately 50 % humidity. The density, porosity, and thickness swelling of the biocomposite were determined using Eqs. (1), (2) and (3), respectively.

$$\rho = \frac{m}{V} \quad (1)$$

Here, m is the mass of the sample; V is the volume of the sample; ρ is the sample density.

$$P = \frac{W_{wet} - W_{dry}}{V_{bulk}} \times \frac{1}{\rho_{water}} \times 100\% \quad (2)$$

where ρ_{water} is the density of water; V_{bulk} is sample volume; W_{dry} is the weight of the biocomposite sample at dried condition (before immersion in water) at room temperature; W_{wet} is the weight of the sample after immersion in water for 24 h at room temperature; P is the porosity of the biocomposite sample.

$$TS = \frac{d_{wet} - d_{dry}}{d_{dry}} \times 100\% \quad (3)$$

where d_{dry} and d_{wet} are the thicknesses of the sample before and after immersion in water for 24 h, respectively; TS is the thickness swelling of the biocomposite sample.

The mechanical properties of OPEFB biocomposite were tested according to ASTM D790. The Universal Testing Machine manufactured by Hung Ta Company was employed to evaluate the mechanical properties of the biocomposites. The modulus of rupture (MOR) of the biocomposite was determined by using Eq. (4).

$$MOR = \frac{3.P.S}{2.b.t^2} \quad (4)$$

where t is the sample thickness, b is the sample width, S is the span, and P is the maximum load. The bending modulus of elasticity (MOE) was determined by using Eq. (5).

$$MOE = \left(\frac{\Delta F}{\Delta y} \right) \frac{S^3}{4bt^3} \quad (5)$$

where t , b , and S are the same as in Eq. (4). $(\Delta F/\Delta y)$ is the slope of the force against deformation.

Thermogravimetric analysis (TGA) was utilized to examine the thermal properties of biocomposites. The TGA was manufactured by Shimadzu (Japan), model DTG-60. The heating rate of the sample for TGA measurement was 10 °C per minute, from 25 to 600 °C.

Scanning Electron Microscopy (SEM) produced by Thermo Fisher Scientific (USA) was also used to analyze the morphology of the biocomposite. The size of the samples was 1×1 cm² with a thickness of 0.6 cm. They were placed on carbon conductive double-sided tape, which was affixed to the stub. The samples were then placed into the SEM chamber, set to a high vacuum mode.

Results and discussion

Physical properties

The density of OPEFB biocomposite has been determined for various particle sizes of OPEFB. The results are shown in **Figure 2**. For a particle size of 60 mesh (0.250 mm), the density of the OPEFB biocomposite was 0.974 g/cm³. The density of biocomposites increased with the decrease in particle size. For a particle size of 140 mesh (0.105 mm), the density increased to 1.101 g/cm³. The density of OPEFB biocomposite from this work was found to be in the range of 0.974 - 1.101 g/cm³ which can be classified as a high-density composite board.

The density observed in this study is about the same as the results from previous studies. The density of

OPEFB biocomposite with the composition of 50 % OPEFB and 50 % epoxy resin, as studied by Hanan *et al.* [23] was found to be 1.020 g/cm³. Hanan *et al.* [23] used OPEFB fiber with the hand-lay-up technique for composite fabrication which differs from this study (press method). The fiber length used by Hanan *et al.* [23] was not reported. The composition unit used differs from this study, where Hanan *et al.* [23] used the composition in weight percentage (wt.%), whereas the composition unit used in this research is in volume percentage (vol.%). Nonetheless, the resulting density of the biocomposite is about the same. This indicates that the fabrication method and filler shape affect the density of the composite. The density of the OPEFB biocomposite (mixed with sawdust, epoxy, and PVA matrix) studied by Lusiani *et al.* [28] was 0.908 - 0.973 g/cm³. However, Karina *et al.* [29] fabricated OPEFB biocomposites by wet layup process, its density was found to be 1.240 g/cm³, which is higher than the value of this present study. The discrepancy is attributed to the different types of resin used. Karina *et al.* [29] used polyester resin. The density of polyester is 1.35 - 1.40 g/cm³, which is higher than that of epoxy resin, whose density is 1.01 - 1.05 g/cm³. Resins play a crucial role in biocomposites, serving as the binding matrix that holds the reinforcing fibers or particles together. Epoxy resin provides strong interfacial bonding due to its polar functional groups that interact well with the hydroxyl groups of natural fibers. Polyester resin also bonds effectively, but its adhesion is lower compared to epoxy [26]. Nonetheless, the density of polyester is higher than that of epoxy. Unfortunately, Karina did not mention the composition of resin and fiber used in the composite fabrication.

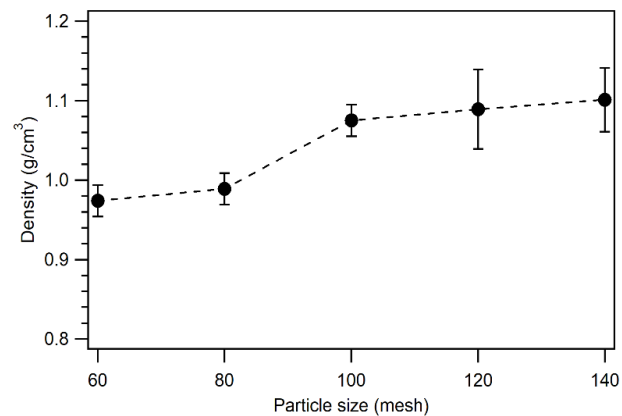


Figure 2 Density of OPEFB biocomposite for various particle sizes.

As shown in **Figure 2**, the particle size of OPEFB affects the density of the biocomposite significantly. The density increased significantly with the decreasing particle size of fillers. This behavior is similar to the previous study by Garcia *et al.* [17] for washingtonia palm rachis composite and Ismail *et al.* [30] for coconut shell composite. Smaller particles of OPEFB can fill smaller gaps or empty spaces between other particles. Thus, the porosity in the biocomposite is reduced because the space inside the filled epoxy resin is more effective. For small particle sizes of OPEFB, the mixing of fillers with adhesives becomes better. Thus, the particles can stick together more tightly. In this way, the biocomposite becomes denser which increases its density value.

Figure 3 shows the results of biocomposite porosity measurements for various particle sizes of OPEFBs. Porosity is a cavity found in composite materials. The porosity reduced significantly from 15.1 % for a particle size of 60 mesh to 9.1 % for a particle size of 140 mesh. Previous research reported that the

porosity of coffee ground biocomposites using epoxy resin adhesives ranged between 12 and 14 % [13]. The porosity of coconut shell particle biocomposites using epoxy resin has a porosity value of 12 - 17 % [30]. Both of them closely align with the findings of this study.

Smaller particle sizes can reduce porosity because fillers with smaller sizes can be distributed evenly within the matrix. The finer filler can fill in the micro-gaps in the matrix, reducing the amount of space or pores that form during the manufacturing process. With better interaction between the matrix and small particles, there is an increase in adhesion thereby reducing the formation of pores. Consequently, the porosity of biocomposite decreases significantly as the particle size of OPEFB is reduced. The porosity is related to its density, where it is inversely proportional to the density value. The denser a material is, the greater its density, but the smaller its porosity. This behavior has been observed in previous studies where the fine filler particles decrease the porosity in the biocomposite significantly [30].

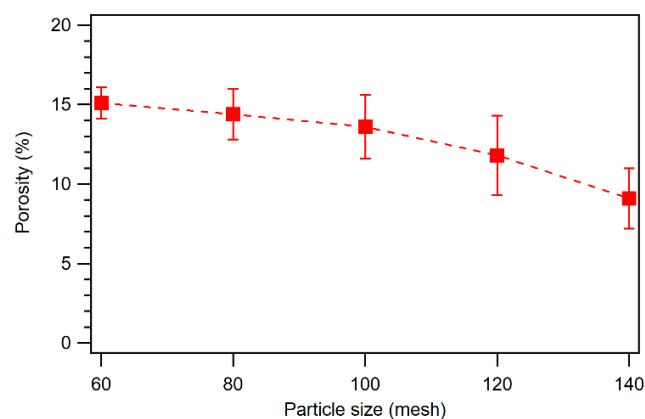


Figure 3 Porosity of OPEFB biocomposite for various particle sizes.

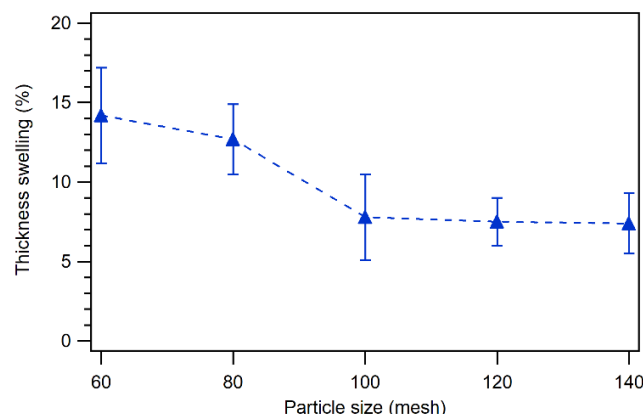


Figure 4 Thickness swelling of OPEFB biocomposite for various particle sizes.

The thickness swelling of OPEFB biocomposite (after being soaked in water for 24 h) from this work is displayed in **Figure 4**. For 60 mesh of particle size, the thickness swelling of OPEFB biocomposite was 14.2 %. As the particle size of OPEFB was reduced to 140 mesh, the thickness swelling of OPEFB biocomposite decreased to 7.4 %. A previous study reported that the thickness swelling of oil palm empty fruit bunch and seaweed composite was 18 % [31]. Coconut shell epoxy biocomposite has 7.5 % thickness swelling [30] which is about the same as the thickness swelling for this work.

This work revealed that reducing the filler size would result in a smaller thickness swelling of the OPEFB biocomposite. The small particle size can reduce the thickness swelling because smaller fillers have a larger total surface area, allowing for better distribution within the matrix. Small particles can fill the micro-gaps between the fibers and the matrix, reducing the number of pores that can absorb water. Better adhesion between the small filler and the epoxy matrix will create a tighter composite structure, reducing the ability of water to seep through and cause swelling. As a result, the composite becomes more stable in humid conditions and has lower thickening properties. Similar behavior has been noted in previous studies, where fine filler particles significantly reduce the thickness swelling of the biocomposite [30].

The results of the research shown above (**Figures 2 to 4**) indicate that the physical properties of the biocomposite improve as the particle size of OPEFB decreases. This happens because smaller particles of OPEFB reduce the porosity of the biocomposite by filling smaller gaps and spaces, leading to better filler-adhesive mixing and tighter particle bonding. This

increases the density of the biocomposite. Even distribution of finer fillers within the matrix minimizes pores formed during manufacturing and enhances matrix-particle adhesion, decreasing porosity and increasing density. Smaller particle sizes also reduce thickness swelling by improving filler distribution and reducing water absorption, resulting in a more stable biocomposite with lower swelling property in humid conditions. Thus, the reduced particle size leads to a biocomposite with lower porosity, higher density, and lower thickness swelling.

The environment can affect the physical properties of OPEFB biocomposites. The humid environment leads to the absorption of water by natural fibers (OPEFB), which increases the mass of the biocomposite, so the density will increase. The moisture absorbed by the OPEFB fibers causes the fibers to expand, which ultimately increases the thickness of the biocomposite, thereby reducing the lifetime and performance of the OPEFB biocomposite in long-term applications. The results of this study show that the physical properties of the biocomposite can be improved by reducing the filler particle size. Thus, the environmental impact on the biocomposite properties can be minimized by using smaller filler particles. The physical property (thickness swelling) of the OPEFB biocomposite developed in this study for 100 - 140 particle sizes comply with ANSI standards for use as particle board, where the thickness swelling of biocomposite should be less than or maximal is 10 %. To minimize the long-term effects of moisture on biocomposite properties, hydrophobic coatings, such as water-repellent sprays or polymers, can be applied to the

surface of the biocomposite. These coatings form a protective barrier that prevents moisture penetration.

Mechanical properties

The modulus of rupture (MOR) and modulus of elasticity (MOE) of OPEFB epoxy biocomposite have been measured for various filler sizes shown in **Figures 5 and 6**. **Figure 5** displays the MOR of biocomposite for various particle sizes of fillers. For 60 mesh (0.250 mm)

of particle size, the MOR was 8.7 MPa. As the particle size of fillers was reduced to 100 mesh (0.149 mm), the MOR increased to 18.9 MPa. For 140 mesh (0.105 mm) of particle size, the MOR was found to be 22.8 MPa. The MOR found from this work is larger than that reported by Khalid *et al.* [32] where its value was 17 MPa for the composition of 50 wt.% of OPEFB and 50 wt.% of PP.

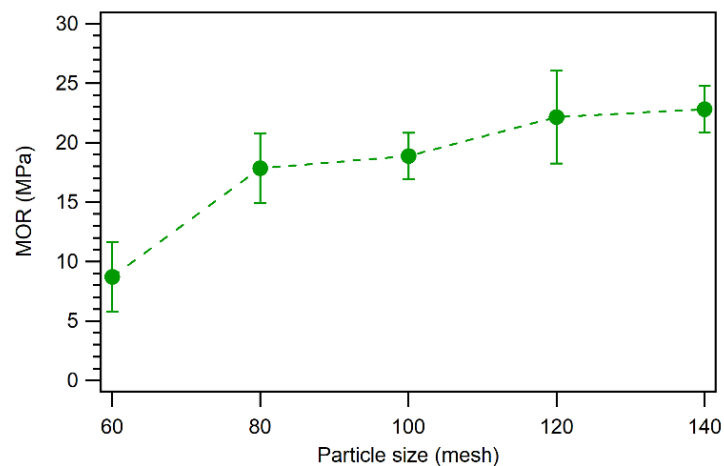


Figure 5 MOR of OPEFB biocomposite for various particle sizes.

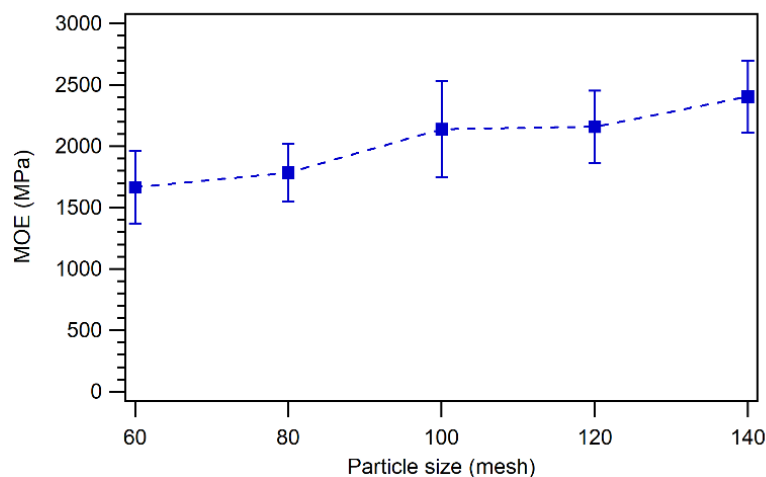


Figure 6 MOE of OPEFB biocomposite for various particle sizes.

The MOE of OPEFB epoxy biocomposite from this work is displayed in **Figure 6**. For 60 mesh (0.250 mm) of particle size, the MOE was found to be 1,667 MPa. As the particle size of OPEFB was reduced to 100 mesh (0.149 mm), the MOE increased to 2,138 MPa. For 140 mesh (0.105 mm) of particle size, the MOE was 2,403 MPa. The MOE found from this work is about the same as reported by Khalid *et al.* [32] where the MOE

was about 2500 MPa. However, the composition of Khalid's work was 50 wt.% of OPEFB and 50 wt.% of PP. Hanan *et al.* [23] found that the MOR biocomposite for 50 wt.% OPEFB and 50 wt.% epoxy resin was about 3,500 MPa which is higher than this work. The discrepancy is due to different compositions; where the composition of this work was 80 vol.% OPEFB and 20 vol.% epoxy resin.

As shown in **Figures 5** and **6**, the mechanical properties (MOR and MOE) of biocomposites are significantly influenced by the particle size of OPEFB. The mechanical properties of biocomposites increased as the particle size of OPEFB was reduced. The MOR and MOE of biocomposite improved by 162 % (from 8.7 to 22.8 MPa) and 44 % (from 1,667 to 2,403 MPa) as the particle size of OPEFB was reduced by 58 % (from 0.250 to 0.105 mm). This behavior is similar to the results of previous studies where the size of the filler greatly affects the mechanical properties of biocomposites [10-18]. Kamarudzaman *et al.* [16] found that the fracture toughness of OPEFB polypropylene composite (20 wt.% of OPEFB) increased from 0.89 to 1.16 MPa as the fiber size was reduced from 0.355 to 0.180 mm. Our results confirm that the size of the OPEFB particles in a biocomposite plays a crucial role in influencing its mechanical properties.

The size of the filler particles affects the bond quality between epoxy resins and OPEFB particles in biocomposites. This influence is related to the total surface area between filler and matrix. The smaller the size of the filler particles, the greater the total surface area available to bond with the matrix. This increases the contact area between the OPEFB and the epoxy resin, allowing for the formation of stronger bonds which allows for better interface bonding between OPEFB and epoxy resin. A stronger interface bond will improve the transmission of load from the epoxy resin to the OPEFB, which contributes to an increase in mechanical properties such as MOR and MOE.

The influence of the environment on the mechanical properties of OPEFB biocomposites is also significant because natural fibers easily absorb moisture from the environment. High humidity or exposure to water can cause the OPEFB fibers in the biocomposite to absorb water, weakening the bonds between the fibers and the matrix. This reduces the efficiency of load transfer from the matrix to the fibers, so the flexural strength is reduced. The findings of this study indicate that reducing the size of the filler particles can enhance

the mechanical properties of the biocomposite. Consequently, the adverse effects of environmental factors on the mechanical properties can be minimized by utilizing smaller filler particles.

According to ANSI standards for particle board grade M-1, the biocomposite must have a minimum MOR of 10 MPa and MOE of 1,550 MPa. In this study, the MOR of OPEFB biocomposites with particle sizes of 80 - 140 mesh ranges from 17.9 to 22.8 MPa, while the MOE values fall between 1,785 and 2,403 MPa. Therefore, OPEFB biocomposites with 80 - 140 mesh particle sizes meet the ANSI requirements for grade M-1 particle boards. Additionally, the OPEFB biocomposite with a 140-mesh particle size meets the ANSI standards for grade H-1 particle boards, which require a minimum MOR of 14.9 MPa and MOE of 2,160 MPa. The advantages of biocomposites include being eco-friendly, made from renewable resources, lightweight, and biodegradable. Nonetheless, biocomposites might not be as durable or long-lasting as traditional composites, particularly in harsh environmental conditions.

Thermal properties

Figure 7 displays data of thermogravimetric analysis (TGA) from OPEFB epoxy biocomposites for various particle sizes, the weight of a biocomposite sample in a function of temperature. There were 2 stages of sample degradation observed. The 1st stage occurred at a temperature of 80 - 120 °C. This degradation was due to the evaporation of water in the biocomposite. The weight of the sample was reduced by about 5 % at this temperature. The 2nd stage occurred at a temperature of 300 - 500 °C. The sample degraded significantly at this temperature which was related to the hemicelluloses, celluloses, and lignin contained in the OPEFB [19,33]. Above 500 °C, the sample weight was almost constant to temperature which was the residue. The residual weight was about 20 % at 600 °C.

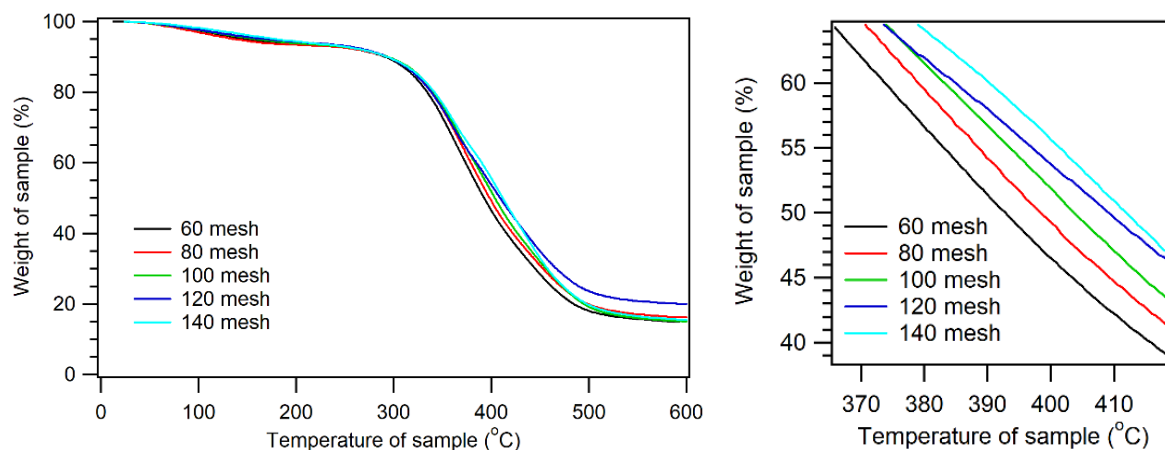


Figure 7 TGA of OPEFB biocomposite for various particle sizes.

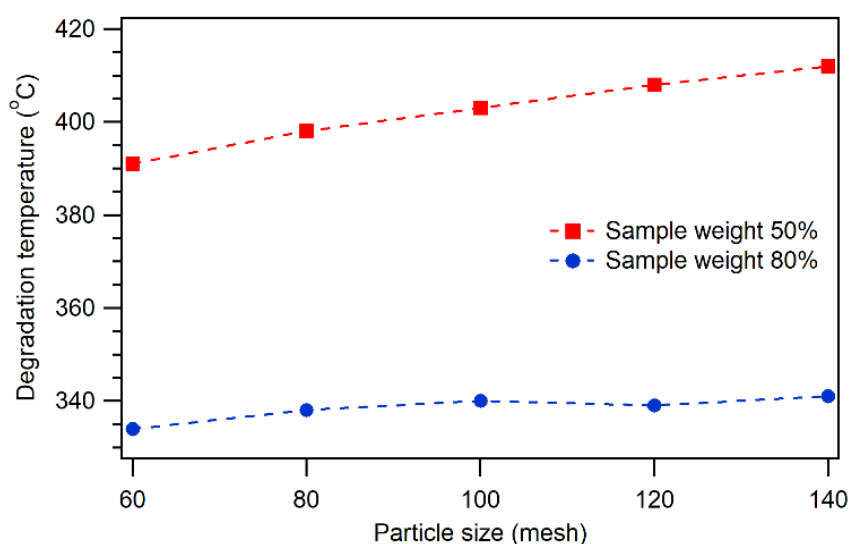


Figure 8 The degradation temperature for various particle sizes.

As shown in **Figure 7**, there was no significant effect of particle size on the thermal property of biocomposite for temperatures below 300 °C. However, the particle size of OPEFB influenced significantly the thermal property of biocomposite for temperatures above 300 °C. The effect of particle size on the degradation temperature of biocomposite for the temperature above 300 °C is displayed in **Figure 8**. For a sample weight of 80 %, the degradation temperature was 334 °C for 60 mesh. For 80 mesh of particle size, the degradation temperature increased to 338 °C. The degradation temperature increased to 341 °C as the

particle size of OPEFB reduced to 140 mesh. For the sample weight of 50 %, the effect of particle size on the degradation temperature was quite significant as shown in **Figure 8**. For 60 mesh of particle size, the degradation temperature was 391 °C. But, for 140 mesh of particle size, the degradation temperature increased to 412 °C. The decomposition temperature of OPEFB for various particle sizes is also displayed in **Table 1**. The decomposition temperature of OPEFB biocomposite is affected by the particle sizes. As the particle size of OPEFB was reduced, the decomposition temperature increased.

Table 1 The TGA results of OPEFB biocomposite for various particle sizes.

Sample weight (%)	Decomposition Temperature (°C)				
	60	80	100	120	140
	(Mesh)				
90	290	292	293	294	295
80	334	338	340	339	341
70	335	360	363	361	365
60	373	378	382	385	390
50	391	398	403	408	412
40	415	422	427	434	436
30	444	453	455	458	467

As shown in **Figure 7** and **Table 1**, the thermal property of the OPEFB biocomposite was significantly influenced by the particle size of fillers. The thermal property increased as the particle size of the filler was reduced. This kind of behavior has been observed in the previous study for coconut shell biocomposit. The increased thermal property was related to the bonding between fillers and matrix [30]. Smaller particle sizes can improve thermal stability due to better interface bonding between the matrix and filler. This strong interaction will slow down the thermal decomposition of the composite matrix. Better thermal stability means that the composite can be used at higher temperatures (up to 300 °C) without undergoing significant degradation.

Morphological property

Figure 9 displays the Scanning Electron Microscopy (SEM) images for OPEFB epoxy

biocomposite samples under 1,500× magnification. **Figures 9(a) - 9(b)** show the SEM images of biocomposite samples with 60 and 80 mesh particle sizes, respectively. There were some agglomerations (the clustering of OPEFB particles within the epoxy resin) and pores (voids) observed. Agglomeration and pores are due to the uneven distribution of OPEFB particles within the epoxy resin because of the large particle size. The surface was also relatively rough. As the particle size of OPEFB was reduced to 100 or 120 mesh, the number of pores and size of agglomerations in the biocomposite were reduced as shown in **Figures 9(c) - 9(d)**. For 140 mesh particle size, see **Figure 9(e)**, the agglomeration and pores became less which indicated that the OPEFB particles mixed well within the epoxy resin. This results in a more even distribution of OPEFB particles in epoxy resins.

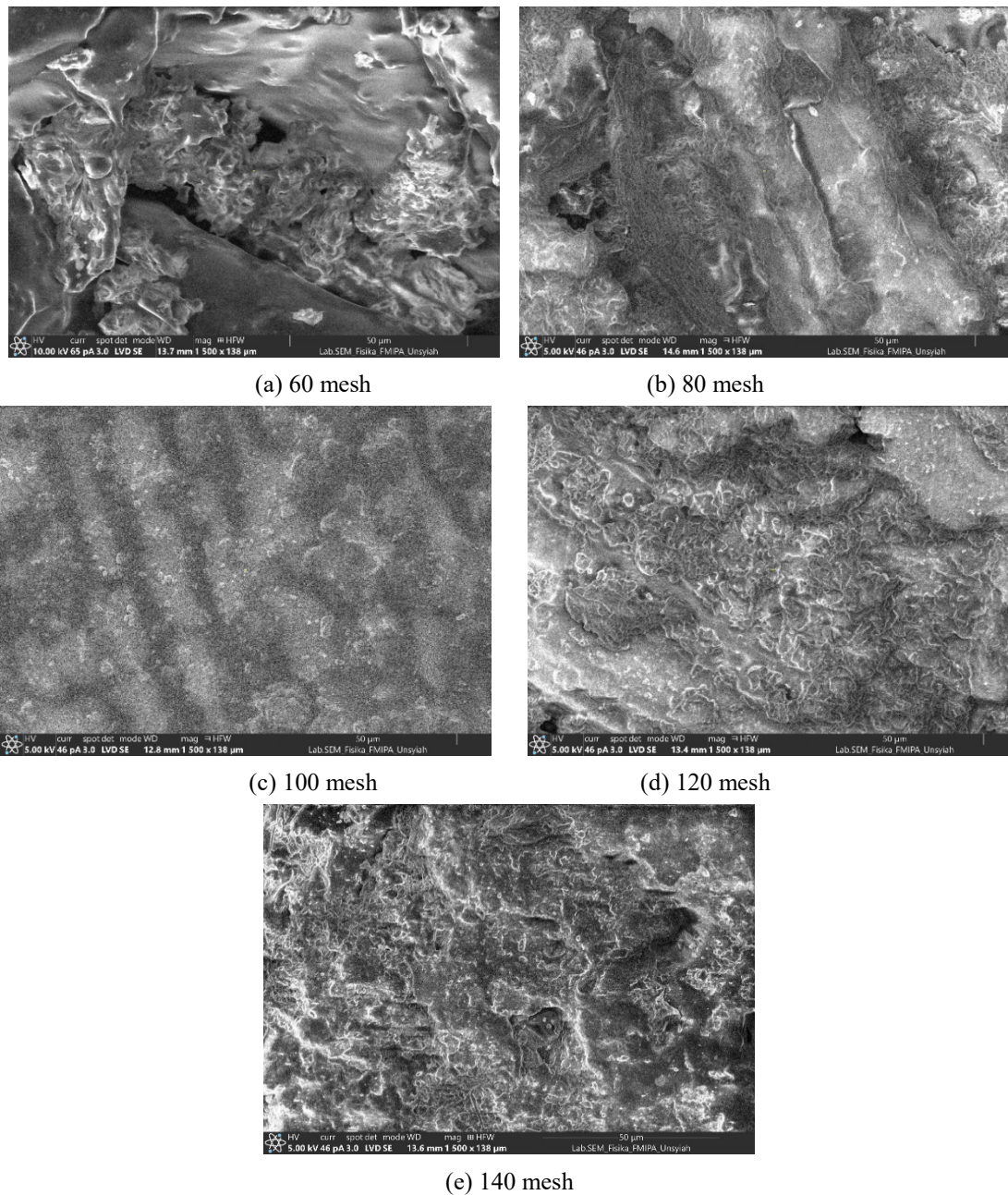


Figure 9 SEM images of OPEFB biocomposite for various particle sizes.

The decrease in the number of pores and agglomeration size is related to the decrease of filler size (OPEFB). Our SEM images indicated that smaller OPEFB particle sizes result in fewer pores and reduced agglomeration within the biocomposite. This leads to increased density and reduced porosity for smaller particle sizes as displayed in **Figures 2** and **3**. As smaller particle sizes reduce the presence of pores, biocomposites become less prone to water absorption. Consequently, the percentage of thickness swelling decreases, as illustrated in **Figure 4**.

Smaller OPEFB particles (140 mesh) are dispersed more evenly within the composite matrix, which can be seen in SEM images as a smoother, more uniform surface. The smooth surface and less void indicate that the composite has a good bond between the filler and the matrix. Better homogeneity will increase the compactness and rigidity of the OPEFB biocomposite and improve the surface area interaction between the OPEFB and epoxy resin, resulting in a biocomposite with better mechanical and thermal properties as shown in **Figures 5** to **8**.

Conclusions

The OPEFB epoxy resin biocomposite for high load filler (80 vol. % of OPEFB and 20 vol.% epoxy resin) has been prepared and characterized for various particle sizes of OPEFB. The best property of OPEFB biocomposite was obtained at 140 mesh of particle size. The density, porosity, and thickness swelling of OPEFB biocomposite were found to be 1.101 g/cm³, 9.1 and 7.4 %, respectively. The MOR and MOE were 22.8 and 2,403 MPa, respectively. The OPEFB biocomposite was stable up to 300 °C. Above 300 °C, samples were significantly degraded. This study revealed that the physical, mechanical, and thermal properties of biocomposite were significantly influenced by the particle size of fillers (OPEFB). As the particle size of OPEFB was reduced, the physical, mechanical, and thermal properties of the biocomposite improved significantly. Smaller OPEFB particles are dispersed more evenly within the composite matrix, which leads to a good bond between the filler and the matrix. The surface area interaction between the OPEFB and epoxy resin increases, resulting in improved material properties. The OPEFB epoxy resin biocomposites for 140 mesh particle size prepared in this work meet the ANSI 208.1 requirement for particle board type H-1. Additionally, the OPEFB biocomposites with 80 - 140 mesh particle sizes meet the ANSI requirements for grade M-1 particle boards. Thus, the OPEFB epoxy resin biocomposite can be commercially produced for cost-effective furniture, including desks, shelves, cabinets, and bookcases, as well as for interior design applications like wall paneling, ceilings, and partitions.

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