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Research Article

Optimizing Mahogany Peel Powder-Polyester Composites for Sustainable Automotive Interior Panels: Effects of Filler Content on Mechanical and Thermal Properties

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ABSTRACT

The purpose of this study is to investigate the effect of mahogany peel powder (MPs) content on the mechanical properties of polyester composites, with an emphasis on flexural strength and modulus. MPS and polyester resin were made in proportions of 7:93, 15:85, 20:80, and 30:70 (% vol.). The composite was created utilizing the press molding technique. The composites' physical, thermal, morphological, and mechanical properties were examined. The findings revealed that at a powder concentration of 7%-20%, the composites' tensile strength, elastic modulus, bending strength, and heat resistance tended to be higher due to the strong interaction between the MPs and matrix. The composite with a 20% volume percentage of MPS had the maximum tensile strength and flexural strength, 42.34 ± 3.84 MPa and 74.95 ± 6.04 MPa, respectively. Meanwhile, at a 30% powder concentration, the mechanical and thermal characteristics of the composite degraded due to particle aggregation and lower adhesion between the powder and the matrix. These findings suggest that the created composite could be employed as a material for automotive interior panels.

1. Introduction

Polymer-based composite materials have become the preferred material in a variety of applications in industry due to their outstanding mechanical, physical, and thermal characteristics. One of the most challenging obstacles in composite research is selecting reinforcing elements that increase both mechanical and physical properties while also being ecologically friendly. *Swietenia macrophylla* (Mahogany) fruit peel waste powder has great promise as a reinforcing element in polymer composites, particularly since it is frequently underutilized [1, 2].

Mahogany is a tree that grows in several parts of Indonesia, particularly on the islands of Lombok, Sumatra, and Java. Mahogany grows swiftly, reaching heights of 35-40 meters and trunk diameters of up to 1.5 meters. This tree's compound leaves are dark green, elliptical, and alternately placed. Mahogany wood is commonly utilized in the crafting and building industries due to its strength, hardness, and resistance to

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pests. The skin of the mahogany tree is grayish brown and rough, which helps to protect it from harsh environmental conditions. Mahogany fruit is round or oval in shape, measuring about 5-10 cm in diameter [3,4]. When fully ripe, this fruit has a firm outer peel and turns brown. The seeds inside the fruit are perfectly organized and usually dark brown. Mahogany seeds have a bitter taste because of their high alkaloid composition. Mahogany fruit, particularly the seeds, includes a variety of bioactive substances that are valuable to health, including saponins, flavonoids, and alkaloids. These chemicals have been shown to have antioxidant, antidiabetic, and anti-inflammatory activities [5,6,7]. As a result, mahogany seed extract is commonly used in traditional medicine to treat a variety of health issues, including hypertension, diabetes, and digestive disorders. Mahogany fruit peel (MFP) is one of the wastes that has not been fully exploited and is frequently discarded, producing environmental issues. Besides piling up in landfills, this garbage has the potential to generate methane, which contributes to climate change. Mahogany is recognized for its strength and hardness; the powder from the fruit skin is predicted to improve the composite's mechanical, physical, and thermal qualities. Usage of this waste can also serve as a more environmentally friendly raw resource than synthetic or non-organic products.

According to studies, MFP contains 65.14 ± 4.8% protein, 6.61 ± 0.7% water, 24.83 ± 0.79% crude protein, and 11.37 ± 1.1% crude fat. These phenolic chemicals are renowned for their antioxidant and antibacterial characteristics, which can help bio-composite materials resist deterioration [8,9]. Other research, such as Gumaling et al. [5], created bio-oil from mahogany seeds using microwave pretreatment before extracting with ultrasonic solvents. They found that microwave pretreatment enhanced bio-oil yield by 5%, with an optimal treatment of 43% in 7 minutes, compared to 6 hours using the traditional oven heating approach. They also said that pretreatment did not harm the existing chemicals (functional groups) [5,9]. This prior work demonstrates that the exploration into the application of Swietenia macrophylla is still focused solely on its physicochemical qualities, with no consideration given to its broader properties as fillers for polymer composites.

Scientists and manufacturers have recently published studies on the reinforcement of polymer composites with natural waste, including banana stem fiber reinforced composites, sisal-reinforced composites, and composites packed with natural powders such as rice husks and carbon. The impact of incorporating fibers or powders on the mechanical and physical characteristics of composites has been studied and characterized. Kalbin et al. [10] reinforced epoxy composites using jute mats and unidirectional banana fibers. They found that adding synthetic fibers to natural fibers decreased crystallinity, making them appropriate for usage in harsh settings. Ghernaout et al. [11] created a biocomposite made of high-density polyethylene (HDPE) and Yucca treculeana L. (YTF) cellulose fiber. The fiber was treated with 3% $NaHCO_3$ for 4 hours. The inclusion of YTF (10%-30%) greatly increased the storage modulus (E′), with the greatest value of 223 MPa. Wasti et al. [12] used a wet-laid approach followed by compression molding to create polypropylene (PP) composites reinforced with coconut fiber (40 wt%) and glass fiber (0-30 wt%). They found that hybridized PP/coir composites with glass fiber were 6-20% lighter than 40 wt% glass fiber reinforced PP, with increased tensile strength by 49-182%, modulus by 54-130%, flexural (strength - 41-104%, modulus by 64-193%), and impact properties (157 - 474%) when compared to 40 wt% coconut fiber reinforced PP composites. Pardi et al. [3] studied the properties of polyester composites using 5-15% Purun Fiber (PF) filler in parallel, random, and weaving patterns. They reported that adding 10% PF resulted in a composite with a density and water absorption rates of 0.96 g/cm3 and 10.1%, respectively. The composite's maximum mechanical properties were 813.95 MPa, 9345.74 MPa, 14.06 MPa, and 58.84 MPa, respectively, and it was resistant to 500 ^{o}C.

Composites made from natural fibers and biodegradable polymers have shown tremendous potential as alternatives to traditional materials due to their superior mechanical and thermal capabilities, as well as their environmental friendliness [14,15]. Adding bamboo, wood, and other fibers to a polymer matrix improves tensile strength, thermal resistance, and morphological stability [14,15,16]. Furthermore, renewable fiber-reinforced polyester-based biocomposites have excellent mechanical properties for use in the automotive, construction, aerospace, or household appliance industries [17]. The use of biodegradable polymers and fibers in automotive applications is growing, as is the desire for lightweight, robust, and ecologically friendly materials [18]. Recent research has also demonstrated that the microscopic structure, fiber shape, and interfacial characteristics between the matrix and reinforcement all have a significant impact on biocomposites' mechanical performance [16]. Thus, fiber integration in various polymer systems, including polyester, is thought to contribute significantly to the

development of green materials for long-term industrial applications [17,19].

Polyester is a polymer that is widely utilized in a variety of applications due to its lightweight, corrosion-resistant, and inexpensive production costs [20,21]. However, using polyester as a matrix has limitations, including poor mechanical strength and low thermal stability [21]. Fortunately, one innovative solution to the waste problem while improving the performance of polyester composites is to develop composites based on mahogany fruit peel waste, which is inexpensive, abundant, and sustainable, making it an appealing choice for composite reinforcement. However, a complete analysis of the interaction of mahogany powder and polyester matrix, as well as its impact on the composite's mechanical, physical, and thermal characteristics, is still required.

The goal of this study is to convert mahogany fruit peel waste into powder and use it as a reinforcing material in polyester-based composites. The study focuses on determining the level of performance enhancement in the produced composites by measuring mechanical parameters such as tensile and flexural strength. Physical properties such as density and thermal resistance are also evaluated to provide a thorough understanding of the composite performance. The findings of this study are likely to lead to the development of new and sustainable composites that not only meet industrial standards for vehicle interior panels but also promote the efficient use of agricultural waste.

2. Materials and Methods

2.1. Materials

Waste from mahogany fruit peels (MFP) was collected at Dompu, Lombok, Indonesia. Polyester resin was used as a matrix, and the methyl ethyl ketone peroxide (Mexpose), as its catalyst provided by PT. Justus Kimia Raya in Jakarta, Indonesia. Polyester resin has a tensile strength of 12.07 MPa and a density of 1.2 g/cm^3 [22].

2.2. Extraction of Powder Mahogany's

To make the refining process easier, this method begins by slicing the skin of the mahogany fruit. After chopping, the skin is ground with a grinder, sieved through a 200-mesh screen, and then dried for 24 hours at 60 °C in an oven. Extraction of MFP into powder (henceforth known as MPs) is shown in Fig. 1.

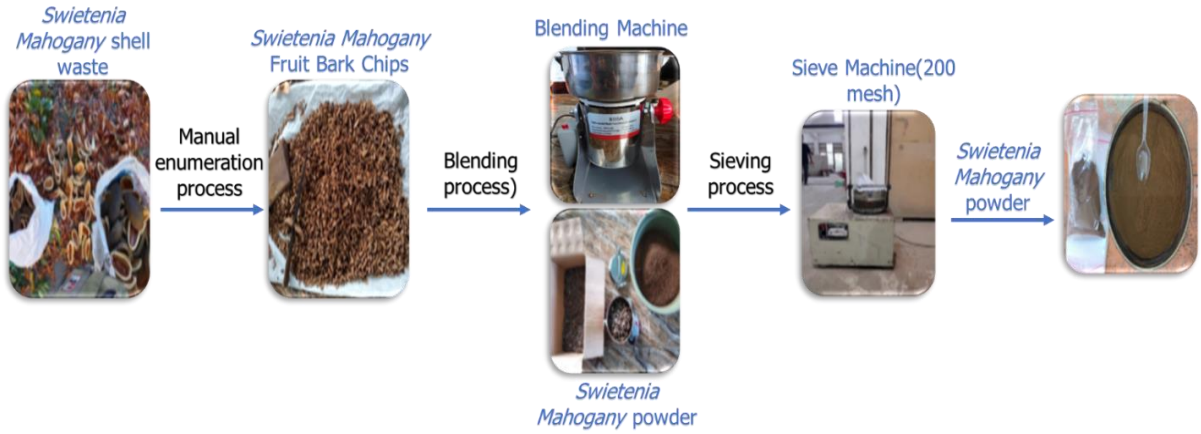

Fig. 1. Extraction of Mahogany powders

2.3. Fabrication of Composites

This procedure involved mixing MPs with polyester matrix and Mexpose (2% polyester concentration) in accordance with the preset ratio shown in Table 1. The blend was transferred into the mold. After closing the mold and applying pressure of 75 MPa at 105 °C, it was allowed to cool naturally. After being taken out of the mold, the composite specimen was prepared for characterization. Figure 2 shows the procedure used to create polyester composites loaded with MPs.

Table 1. Ratio of MPs, polyester in different composites

Samples codes	Vol. Fraction (%)	
	MPs	Polyester
AKT	7	93
BKM	15	85
CKL	20	80
DKM	30	70

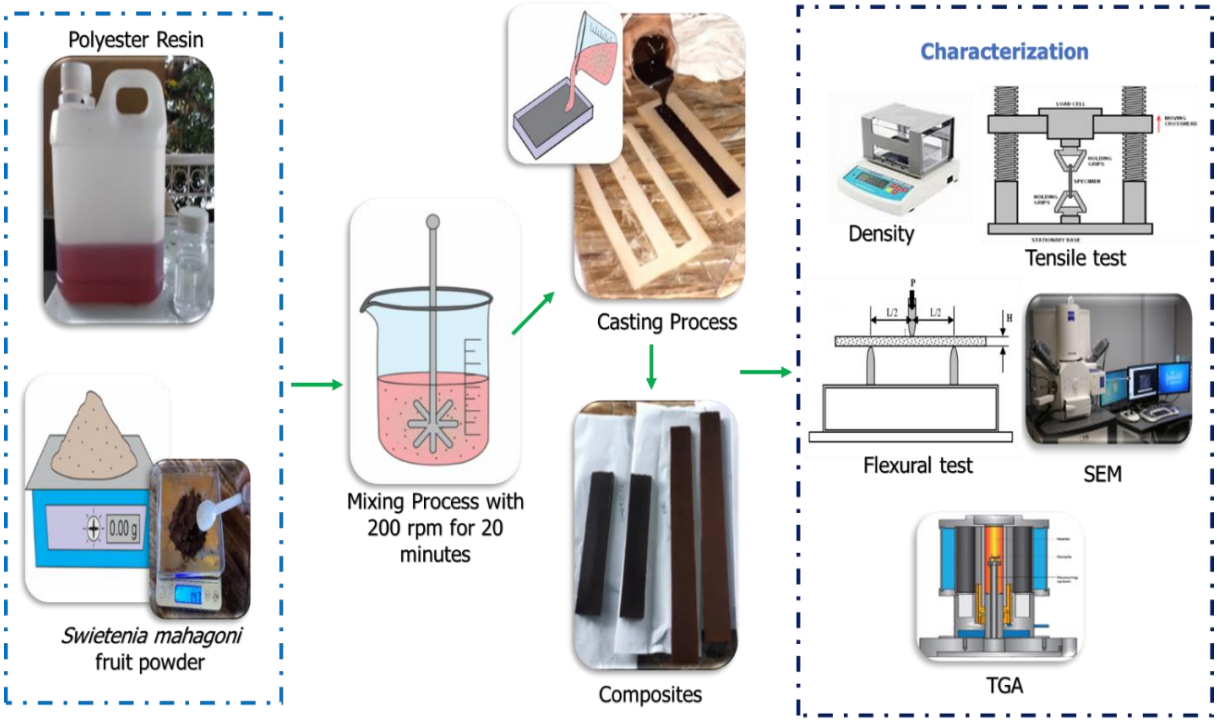

Fig. 2. Fabrication of a mahogany powder-Polyester Composites

2.4. Tensile Test

Composite tensile testing is defined by the ASTM D3039 standard (ASTMD 3039M-17) [23] and is conducted at a temperature of 26.7 °C (R.H = 56%) using a universal tensile machine, brand RTG-1310 INSTRON, and a load cell of 5 kN. The sample tensile test has a measurement length of 75 mm and a stretching rate of 2 mm/min.

2.5. Microstructure by SEM

With scanning electron microscopy (SEM), the failure morphology of the polyester-MPs composites tensile test was examined. Using a Phenom Pharos Desktop SEM with a current and voltage of 8 mA and 5 kV, respectively, this SEM observation was performed. The sample surface was covered with a 3 µm thick layer of gold before observation.

2.6. Bending Test

To ascertain the composite's flexural strength value, a bending test was carried out using ASTM D790 standard procedures (ASTM D 790-17)[25]. A specimen with dimensions of 152 mm in length, 25.4 mm in width, and 6 mm in thickness was used to accomplish this. Three-point bending was done using a Universal Testing Machine, RTG 1310 INSTRON, 5 ton, with a speed of 2 mm/s and a distance between the supports of 60 mm. There were three repeats of each of the four distinct biocomposite sample types. There were three repeats of each of the four distinct bio-composite sample types.

2.7. Density

The purpose of density testing for composites is to ascertain the final composite board's density. The final board's density is influenced by the sample densities that were used. At room temperature, density is determined using the ASTM D1895 standard. A sample that has been weighed in order to determine its volume is used for the density test. To compute the density, apply the following Eq. (1) [13,24].

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

Where:

$\dot{\rho}$ =Density (gr/cm^3);

m = Mass of the composite (gr);

v = Volume of the composite (cm^3)

2.8. TGA

Each measurement was performed using 70 µL aluminum oxide pans and a Mettler-Toledo. Gas flow rates of 50 mL/min were used to test both gases in an environment of nitrogen (quality 5.0). Before being tested, materials were dried in an inert environment at 200 °C for ten minutes in the TGA instrument. The experiment involved a first segment of heating (25–500 °C) in a nitrogen atmosphere, followed by a second segment of cooling (200–400 °C) in nitrogen and another heating phase.

3. Results and Discussions

3.1. Density Analysis

Figure 3 illustrates the impact of MPs on composite density. Figure 3 showed that the composite density increased as the number of MPs used increased. With an MP fraction of 7%, the AKT sample (1.39 ± 0.08 g/cm3) displayed a reasonably high-density value, whereas the BKM, CKL, and DKM samples, which had MP contents of 15%, 20%, and 30%, exhibited a decline. The density values of the DKM, CKL, and BKM samples were 1.03 ± 0.1 g/cm3, 1.09 ± 0.1 g/cm^3, and 1.36 ± 0.1 g/cm3, in that order. The experimentally obtained density values agree well with the theoretically calculated composite density values (Figure 3). With the inclusion of MPs, which can form interfacial bonds with polyester and reduce the likelihood of cavity formation, the composite density value decreases.

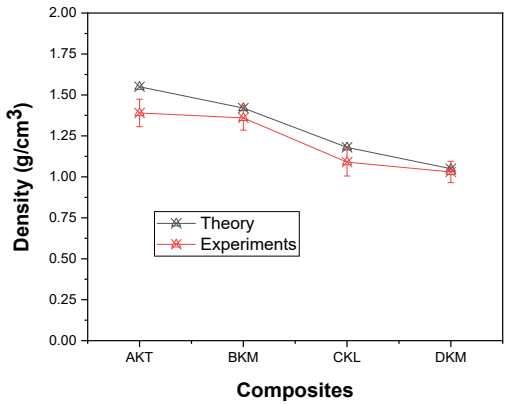

Fig. 3. Density of reinforced MPs composite polyester

3.2. Tensile Strength Analysis

Figure 4a presents the effect of MPs content on the tensile strength of the polyester composites. The results indicate that the tensile strength increases progressively as the MPs content rises from 7% to 20%, but begins to decline when the content exceeds 20%. The composite sample labeled CKL, containing 20% MPs, exhibits the highest tensile strength of 42.34 ± 3.8 MPa. This enhancement in tensile strength within the 7–20% MPs range is attributed to the homogeneous distribution of the powder within the polyester matrix, which facilitates effective stress transfer between the matrix and the reinforcement. At these concentrations, the good interfacial adhesion between the matrix and MPs enables the powder to act as a reinforcing agent, restricting the mobility of polymer chains and thereby improving the composite's resistance to deformation under tensile load [13,26]. Additionally, the absence of agglomeration at lower MPs contents contributes to better powder dispersion and matrix-MPs interaction, which collectively enhance the tensile performance of the composite. However, when the MPs content is increased to 30% (sample DKM), the tensile strength of the composite decreases to 33.72 ± 4.2 MPa. This reduction in tensile strength can be attributed to several factors, primarily the poor interfacial adhesion between the MPs particles and the polyester matrix, as well as the agglomeration of the powder at higher concentrations. The excessive presence of MPS leads to particle clustering, which creates stress concentration points and structural discontinuities within the composite. Such agglomeration hinders effective stress transfer from the matrix to the reinforcement and weakens the overall integrity of the composite. Moreover, as the powder content increases, the amount of matrix available to adequately coat and bind the MPs particles becomes insufficient, resulting in the formation of voids and micro-defects. These defects contribute to inefficient load distribution and ultimately compromise the tensile performance of the composite.

3.3. Elongation Analysis

The impact of MPs on the composite's elongation is depicted in Figure 4b. In the AKT sample, this investigation produced the highest elongation results, measuring 3.57 ± 0.22 (%). In the meantime, the DKM sample yielded the lowest elongation value, 2.57 ± 0.25%. The elongation data show that MPs can lower the composite's elongation value. This could be because the composite material's elasticity has decreased. MPs particles tend to establish a stiff structure in the polyester matrix at increasing levels of powder loading. Since MPs are a stiff and inelastic substance, they cannot aid in the matrix's plastic deformation. These hard particles inhibit the polyester matrix's capacity to stretch when a tensile stress is applied, despite the polyester matrix's characteristic elasticity and substantial elongation. Consequently, the composite exhibits a markedly diminished capacity to flex before fracture. Furthermore, a greater likelihood of powder agglomeration or clumping in the matrix exists with larger powder concentrations. Under tensile loading, this agglomeration produces stress concentration areas that may serve as the starting point for a composite crack [27,28]. Another factor that accelerates the material's failure under tension is inhomogeneity in the powder distribution, which also decreases the continuity of the matrix. As a consequence, with larger MP concentrations, this interface may become weak and fracture, lowering the composite's overall elongation value. It is also possible that the interfacial

strength between the powder and the matrix is weaker than the strength of the matrix itself.

Several studies have found that weak interfacial bonds between fibers as well as the matrix are the primary failure mechanism in biocomposites, causing microscopic damage like debonding, fiber pull-out, and the development of cracks in the interface zone [29,30]. In addition, fiber form and distribution in the matrix have a major impact on composite damage behavior. Non-uniform filler dispersion and void development in the composite structure have been shown to accelerate material failure when subjected to tensile or flexural loads [31,32]. Previous research with casuarina fiber and mango seed waste filler revealed that thermal degradation, decreased mechanical toughness, and an increase in the number of pores caused by processing are the primary factors contributing to the decline in structural integrity of biocomposites [32,30,33].

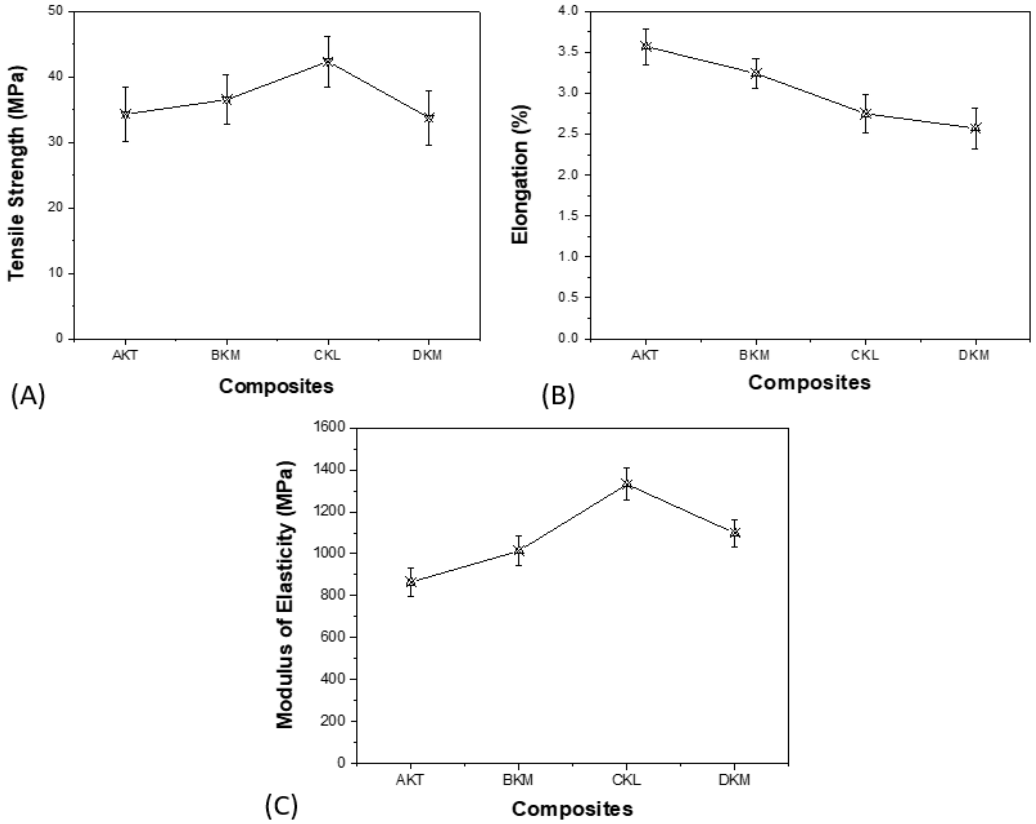

Fig. 4. Polyester/MP_S composites, (a) tensile strength, (b) Elongation, and (c) Modulus of elasticity

3.4. Modulus of elasticity analysis

When the MP_S content of polyester composites is between 7% and 20%, Figure 4c displays a high tensile modulus of elasticity value. The samples with the highest modulus of elasticity values were the CKL sample, which had a value of 1331.65 ± 76 MPa; the BKM and AKT samples had values of 1013.92 ± 72 MPa and 864.68 ± 68 MPa, respectively. The increased stiffness of the material could be the cause of the increase in the modulus of elasticity value. The best reinforcing effect is produced when MP_S particles are uniformly dispersed throughout the polyester matrix at a powder concentration of 7%–20%. The introduction of powder particles in moderate numbers increases the overall stiffness of the composite because MP_S is stiffer than the polyester matrix. Hence, a greater modulus of elasticity value indicates that the material can resist more elastic deformation. Nevertheless, the composite's modulus of elasticity drops when the MP_S concentration reaches 30% (DKM sample). The main causes of this decline are the detrimental impacts of powder agglomeration and the decreased efficacy of powder reinforcement at high doses. When the powder content is high, MP_S particles have a tendency to agglomerate and form inhomogeneous zones inside the matrix. Due to this agglomeration, the powder's stiffness contribution is decreased as a result of less efficient load transmission from the matrix to the powder particles [33,34].

The binding between the powder and the matrix is also weakened by a larger powder content, which results in weak spots in the composite structure that lower the overall elastic

modulus and, eventually, lessen the composite's capacity to withstand elastic deformation.

3.5. Flexural Strength Analysis

The influence of MPs on the composites' flexural modulus and flexural strength is depicted in Figure 5. Due to the powder's ideal distribution throughout the matrix, Figure 5a demonstrates that the composites' flexural strength and flexural modulus are generally high when the powder content is between 7% and 20%. The CKL sample had the greatest values of flexural strength (74.95 ± 6 MPa) and flexural modulus (2498.57 ± 85), respectively. Powder is equally distributed and functions as an effective reinforcement at a concentration of 7%–20%, enhancing the stiffness and bending load-bearing capacity of the composite. To increase the flexural strength and flexural modulus, the hard MPs particles help distribute the stress applied during the flexural test (Figure 5b). Furthermore, the effective transfer of stress from the polyester matrix to the powder is ensured by the strong interaction between the powder particles and the matrix at this concentration, making the composite more robust and stiffer overall. The flexural strength and flexural modulus of elasticity of the composite, on the other hand, dropped to 1834.96 ± 96 MPa and 1834.96 ± 96 MPa, respectively, when the powder concentration reached 30% (Figures 5a-b). The reduction in adhesion between the powder and matrix at high concentrations and the agglomeration of powder particles were the causes of this decline. Mahogany particles have a propensity to group when there is a high powder percentage, creating weak spots in the composite structure. Because of this agglomeration, the stress distribution becomes non-uniform, which decreases the composite's capacity to handle flexural loads effectively [35,36,37]. Furthermore, a high powder content may limit the quantity of matrix that can be used to bind powder particles together, weakening the interfacial binding and raising the risk of cracking. Due to ineffective stress transfer from the matrix to the powder, this situation lowers the composite's modulus of elasticity and total flexural strength.

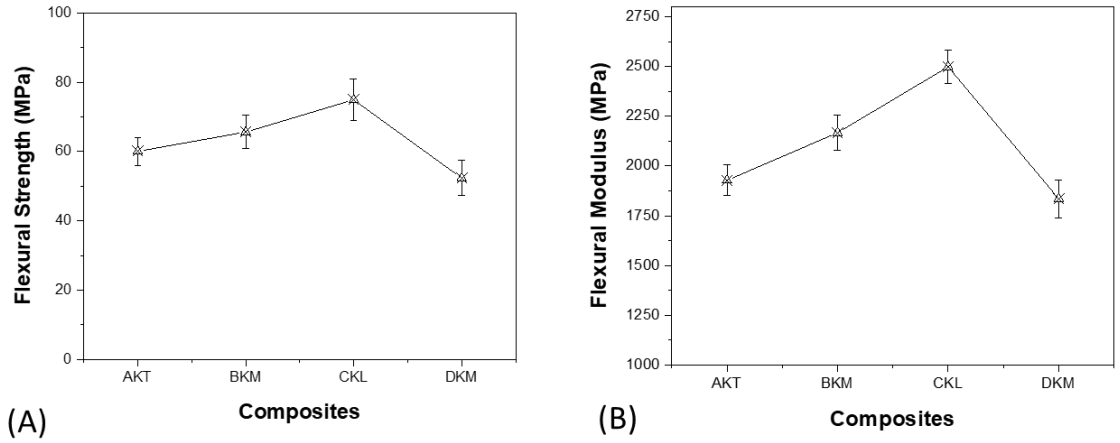

Fig. 5. (a) Flexural strength, and (b) Flexural Modulus of MPs reinforced composite polyester

3.6. Microstructure Analysis

Large pores and some inclusions are spread across the composite surface (Sample AKT), depicted in Figure 6a, which has a generally homogenous structure. Despite a few tiny bumps and depressions, the fracture surface seems to be comparatively flat, suggesting that the MPs powder is distributed quite evenly throughout the polyester matrix. The presence of voids or empty spaces in the material, indicated by the presence of several big pores, may be the reason for the composite's comparatively poor tensile strength. SEM image of the BKM surface (Figure 6b) reveals deeper and more pointed cracks and lines. These cracks show areas of substantial internal stress, which suggests that the interaction between particles and the polyester is not as good as it could be.

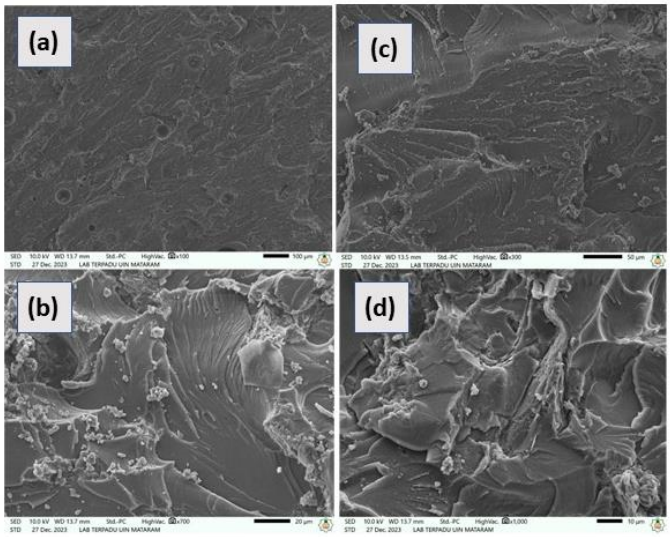

Fig. 6. SEM photos of composites fracture samples, (a) AKT, (b) BKM, (c) CKL, and (d) DKM

The quantity of particles that are visible scattered across the CKL sample's surface is depicted in Figure 6c. Particles of MPs are seen to aggregate. The tendency of MPs to form clusters can result in weak areas in the composite. Furthermore, there are signs of a substandard interface between the powder particles and the polyester matrix, which may serve as the initial point of failure when the material is loaded. The rough surface of the DKM composite, which has numerous protrusions and depressions, is depicted in Figure 6d. This surface pattern illustrates how the polyester matrix and mahogany powder interact. There are a few spots on the surface that suggest there are tiny fissures and gaps that might have developed during the composite's creation. The MPs also seem to be dispersed quite equally throughout the polyester matrix, as seen in the SEM picture. Darker patches in relation to the surrounding matrix can be used to identify certain mahogany powder particles. The MPs and matrix seem to interact quite well, yet there are a few places where it doesn't seem like the powder and matrix are completely bonded (debonding), which could have an impact on the composite's overall mechanical properties. Some weak spots that are assumed to lower mechanical strength are the presence of voids, cracks, and debonding. When MPs are added to a composite at a concentration of 7%–20%, the particle dispersion becomes more uniform, and the powder serves as an efficient reinforcement, enhancing the composite's mechanical qualities and bolstering its high tensile strength. MPs agglomeration, void formation, and interfacial adhesion issues were observed at higher MPs content (30% vol.) (Figure 6d), which contribute to the mechanical performance reduction. This is assumed to lower the efficiency of stress transfer. The mechanical characteristics of the powder decline at large concentrations because there is less matrix available to bind the powder [37,38,39].

3.7. Stability Thermal Analysis

The TGA/DTG of polyester/MPs composites is displayed in Figure 7. The polyester composites loaded with MPs have consistent thermal characteristics, as evidenced by the four TGA/DTG images (7a, 7b, 7c, and 7d) that display comparable thermal behaviors in the three temperature ranges examined. The evaporation of water and volatile substances causes an initial weight loss of around 5–10% during the first stage, which occurs in the temperature range of ~50–150°C. The breakdown of the polyester matrix is indicated by a notable weight loss of roughly 30–40% in the second stage, which occurs in the temperature range of ~300–500°C. The third stage is linked to the complete breakdown of the polyester matrix and mahogany powder, leaving carbon residues, and occurs in the temperature range of about 500–800°C, resulting in a weight loss of roughly 20–30%. The DTG peaks have comparable locations; there may be a small variation in their intensity. This might be the result of small differences in sample preparation or fluctuations in the percentage of loading mahogany powder. The little discrepancies in the weight loss percentage at each stage could be attributed to variances in the test circumstances or sample composition [39].

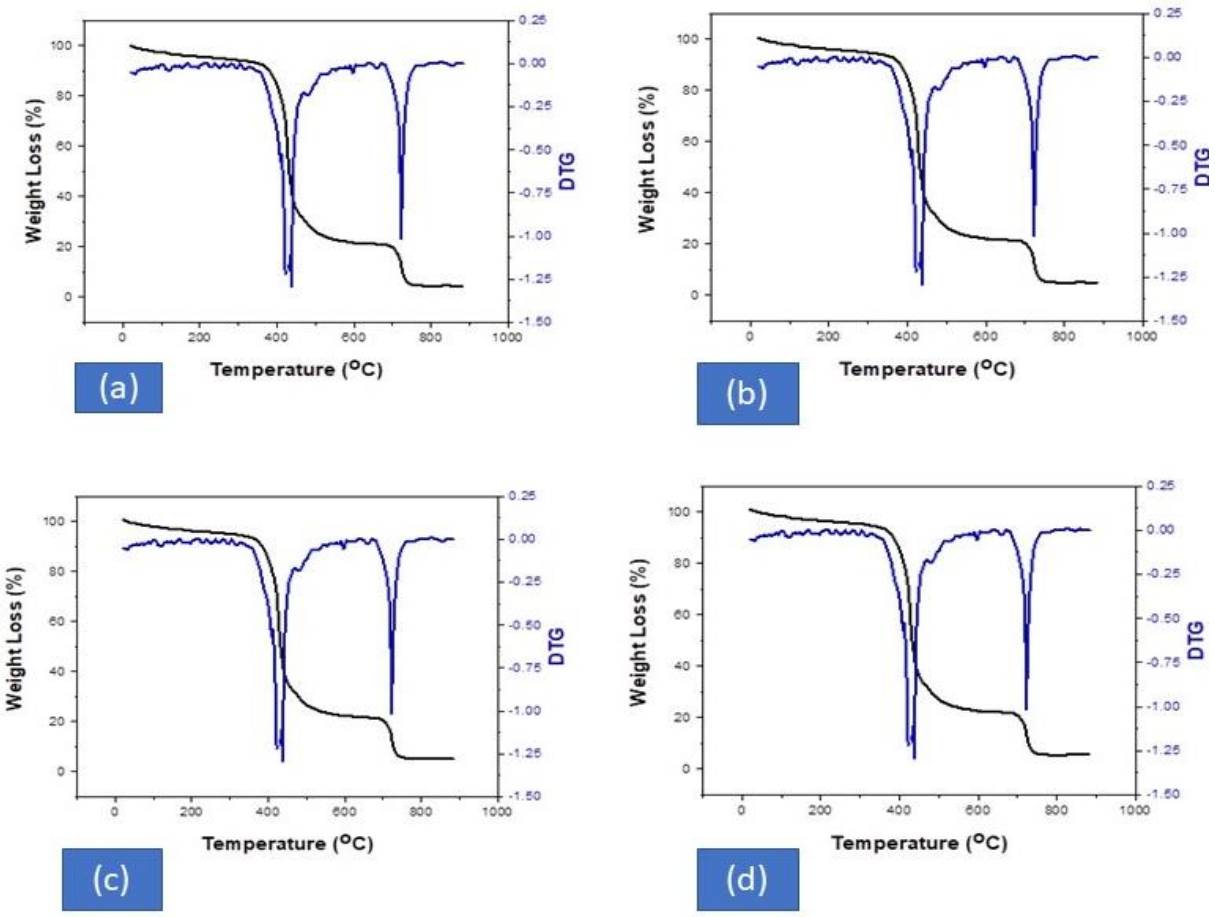

Fig. 7. TGA/DTG of composite polyester/MPs samples, (a) AKT, (b) BKM, (c) CKL dan (d) DKM.

The use of MPs as reinforcement in polyester composites offers significant environmental benefits. This method provides an effective technique for reusing agro-industrial waste that would otherwise be dumped or burnt, contributing to environmental damage and increasing landfill use. By integrating MPs into composite materials, the quantity of organic waste produced during mahogany fruit processing can be minimized, hence helping waste management programs and boosting circular economy principles. Furthermore, the creation of bio-based composites from renewable resources is consistent with sustainable material innovation, minimizing reliance on synthetic fillers and increasing the adoption of environmentally friendly alternatives. Although this study did not contain a full quantitative life cycle assessment, the findings highlight MPScomposites' potential as a sustainable material solution with good environmental consequences.

4. Conclusions

This study focuses on the mechanical, physical, and thermal characteristics of polyester composites reinforced with leftover fruit peel powder from Swietenia macrophylla King (mahogany), with the goal of using the materials as car panel materials. The thermal behavior of the four varieties of polyester/MPs bio composites exhibited comparable thermal stability, suggesting that the polyester composites containing mahogany powder possess uniform thermal properties. Because of their consistency, these composites may find stable uses in high-temperature settings, including car panels. The composite with 20% MPs content (sample CKL) yields the best ideal tensile strength of 42.34 ± 3.84 MPa and flexural strength of 74.95 ± 6.04 MPa, respectively. The thermal and mechanical characteristics of the composite tend to deteriorate when the MPs concentration reaches 30% because of the MPs agglomeration. Large pores, fissures, uneven particle distribution, and accumulation of particles are becoming more noticeable in the composite material's otherwise pretty strong structure, as seen by SEM pictures. These features may have an impact on the material's overall strength and modulus of elasticity.

Furthermore, the use of MPs waste as a reinforcement material is considered industrially feasible due to its local availability and low cost. The simple fabrication process and potential scalability of this composite system offer promising prospects for sustainable and cost-

effective material development in automotive and structural applications. Although these promising findings, the research is restricted to laboratory-scale manufacturing and characterization, with no long-term durability testing. Additional study is required to maximize the surface treatment of MPs to enhance interfacial adhesion, hence improving composite performance. Future research may also look at the environmental aging behavior, recycling, and large-scale manufacture of these biocomposites, to enable their wider applicability in the automotive and other structural sectors.

Author Contributions

Nasmi Herlina Sari: Writing – original draft, Investigation, Data curation, Formal Analysis.

Suteja, Deni Wardani, I Putu Lokantara: Investigation, Writing – review & editing, Supervision, Project administration.

Availability of data and materials

All data are available from the authors.

Declaration of competing interest

The authors declare no competing interests.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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