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Evaluation of the Impact Strength and Morphology Properties of *Musa Acuminata* Fiber Composite/$CaCo_3$ Powder

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Abstract. *Banana stem (Musa Acuminata, MA) fiber is a free agricultural waste obtained after harvesting the fruit. When compared to synthetic fibers, banana fiber has significant weaknesses in composite production, such as low interfacial bond strength between the fiber and the matrix. The purpose of this research is to improve the impact strength of banana stem fiber composites by adding $CaCO_3$ powder. The hot press technique is used to create composites. In the production of polyester composites, woven MA and $CaCO_3$ stem fibers are prepared. An impact testing machine and a scanning electron microscope were used to investigate the effect on morphological properties and impact strength. The study's findings revealed that a polyester composite containing 10% banana stem fiber and 25% $CaCO_3$ had the highest impact strength of 45.27 KJ/m^2, which was associated with strong adhesion between the $CaCO_3$-fiber and the polyester matrix. Fiber pullout, matrix cracking, and fiber debonding were all observed in the composite fracture morphology. The resulting composite properties could be used to replace palm fiber/fiber glass composites.*

Keywords: *polyester composite; Musa Acuminata fibers;* $CaCO_3$ *Powder; Impact Strength; Morphology, SEM.*

1. Introduction

Combining two or more materials in the composition of polymer composites is currently preferred because it is known to produce composites with higher mechanical properties than a single material [1,2]. Furthermore, the properties of this single Fiber reinforced polymer (FRP) composite may fail to meet the desired level of characteristics under certain conditions. To achieve an optimal level of overall composite quality, fabrication parameters are frequently optimized [3-5]. In order to form new composites, it is possible to incorporate more than one type of reinforcing fiber in one matrix [6-8]. This technique is known to provide the flexibility to change the composite's behavior. Due to various unfavorable properties as compared to bio-fibres, the usage of synthetic polymeric materials is currently not receiving much attention internationally [9]. Despite the fact that natural fibers offer various benefits, lignocellulosic fibers are hydrophilic and absorb moisture, limiting

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their usage in engineering fields [10,11]. Banana has long been used as a dish and fruit, but it is also a good source of fiber. Banana fibers may be obtained from the stem of the bunch, both of which are agro-waste products that are widely available in most regions of the world. Natural fiber from banana stems, which is abundant and environmentally friendly, has emerged as a viable option for reinforcing polymer composites. Researchers have thoroughly investigated the physical, mechanical, and thermal properties of banana stem fiber reinforced composites. An experimental study was carried out to investigate and characterize the effect of volume fraction fiber on the mechanical properties of natural fiber composite structures. The optimal tensile strength of the banana stem fiber/polyester (vol. fraction 10%/90%) composite is 51,863 N/mm^2 and the strain value is 5,754 N/mm^2. Composites also have the highest energy and impact values, with 0.8093 Joule and 0.0101 Joule/mm^2, respectively [12]. A hybrid composite of *Musa Paradisiaca* banana stem fiber and *Areca catechu. L* fiber with a volume fraction of 0%-15% kapok banana fiber and 15-30% areca fiber was found to have the highest tensile strength of 5.81 MPa-16.33 MPa [13]. The volume fraction of 10% pineapple leaf fiber in the composite has the maximum impact strength of 0.01657 Joule/mm2 which makes it appropriate for helmet raw materials [14]. Banana stem fiber is a free agricultural waste obtained after harvesting the fruit. Handling banana stem fiber with alkaline NaOH, permanganate ($KMnO_4$), and acetylation treatment is known to increase surface roughness, decrease hydrophilic properties, and increase cellulose fiber from 63.40% to 82.23% [15].

Filling the composite with calcium carbonate powder ($CaCO_3$) has also been considered in providing different physical and mechanical properties. $CaCO_3$ loadings of 1-3 wt% are known to improve composite tensile, flexural, and thermal stability properties over composites without $CaCO_3$ fillers [16]. It is known that mixing $CaCO_3$ and nano-$CaCO_3$ micro fillers in a screw extruder at 150 RPM at 180-200 °C results in better thermomechanical properties. Furthermore, nano-$CaCO_3$ was found to increase the composite's crystallization temperature by 14%, and the permeability was greater than 7.0 g/m^2 x 24 hours [17]. Geopolymer paste from fly ash reinforced with basalt fiber with 3% nano $CaCO_3$ provides the highest compressive strength and hardness values, while 2% nano $CaCO_3$ provides the highest flexural strength, impact strength, and fracture toughness [18]. Furthermore, the addition of nano $CaCO_3$ improves the microstructure, densifies it, and accelerates the geopolymerization reaction. According to the findings of the previous study, the use of $CaCO_3$ in changing the properties of composites should be investigated further for various mixtures of other natural ingredients for broader functions.

Therefore, the purpose of this research is to create and assess the impact strength properties and impact fracture morphology of the *Musa Acuminata* fiber/$CaCO_3$ powder composite. The findings of this study could be used by the general public, researchers, and industrialists to develop advanced

materials and commercial products from the *Musa acuminata*/$CaCO_3$ powder composite.

2. Methods

2.1. Materials

Banana bark (*Musa acuminata*, MA) collected in central Lombok, West Nusa Tenggara, Indonesia. Table 1 shows the chemical composition of the fiber. PT. Justus Kimia Raya Surabaya, Indonesia, manufactured the polyester resin and methyl ethyl ketone peroxide (catalyst). Table 2 displays the polyester resin specifications. PT. Centranusa Inti Prima Industry, Indonesia, also supplied $CaCO_3$ powder.

Table 1. Chemical properties of *Musa acuminata* stem fiber

Chemical contents	Percentage (%)
Cellulose	64,5
Lignin	9
Hemicellulose	19
Water content	8

Table 2. Specifications of polyester resin

Properties	Values
Density	0.601 - 2.20 g/cc
Tensile Strength, Ultimate	10.0 - 123 MPa
Elongation at Break	0.50 - 2.4 %
Modulus of Elasticity	1.00 - 10.6 GPa
Izod Impact, Notched	1.23 - 9.08 J/cm
Charpy Impact, Notched	0.300 - 4.50 J/cm²

2.2. Extraction of MA fiber

The extraction of MA fiber is depicted in Figure 1. To begin, cut the banana stem and remove the outer skin of the banana stem (Figure 1a). To remove the fibers, the bark is combed with a plastic comb (Figure 1b). The fibers are then dried in the hot sun to remove the water content (Figure. 1c).

Figure 1. Fiber extracted from the stem bark of Musa acuminata (MAF), (a) Banana stems are cut, (b) MA stem bark is swept, and (c) MA fiber is dried.

2.3. MAF chemical treatment

The dry MAF (Figure 2a) was immersed in 5% NaOH solution for 2 hours at this point (Figure 2b). The MAF was then removed from the chemical solution and drained (Figure 2c), rinsed with water, and dried (Figure 2d).

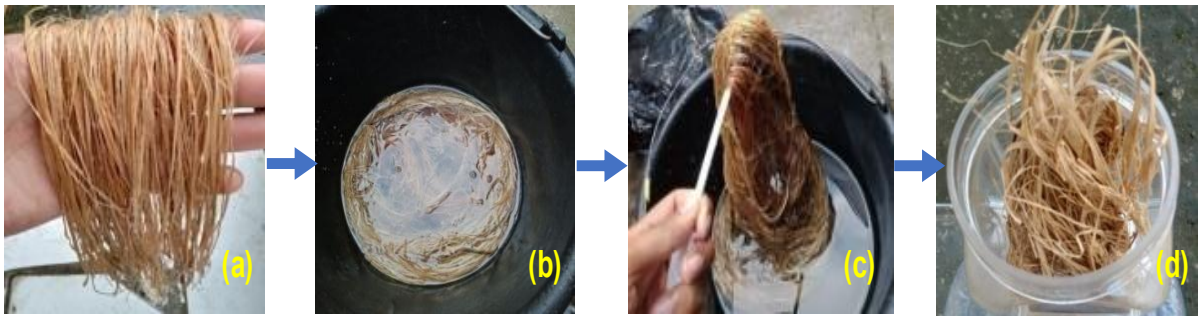

Figure 2. Chemical treatment of MA fiber, a). MA fiber (MAF), b). MAF immersion in 5% NaOH solution, c) Removal of MAF in 5% NaOH solution, and d) MAF treated NaOH

2.4. Composites Manufacturing.

The hot press technique is used to create composites. Table 3 displays the composite material ratio. The process began with $CaCO_3$ mixed with polyester and manually stirred to form a dough.

The mixture was then poured into a mold filled with woven MAF (Figure 3a), closed, and subjected to a pressure of 50 MPa at 105 ^{o}C (Figure 3b), before cooling to room temperature. The composite had been lifted and was ready to be characterized (Figure 3c).

Figure 3. Composite manufacturing process. (a). Pouring of the resin mixture and CaCO3, (b) Composite pressing, and (c) Composite samples ready for testing.

Table 3**.** Ratio of fiber, $CaCO_3$ and polyester resin in polyester composites.

The composite sample codes	$CaCO_3$ vol. fraction (%)	Fiber vol. fraction (%)
BSA	5	
BSB	10	25
MS	20	
CS	25	

2.5. Characterization

2.5.1. Impact Strength

The Charpy method was tested for impact using the IT-30 model impact testing machine. ASTM D-256 standard dimensions were used to prepare and shape the samples [19]. Each composite variation has 5 repetitions.

2.5.2. Scanning electronic microscopy (SEM)

The surface morphology of the composite was evaluated from the fracture of the impact test composite sample using the SEM FEI Inspect S50. To understand the bonding and inner structural changes, as well as to increase the conductivity of the sample, the surfaces were coated with a thin layer of gold sputtering using a JEOL sputter ion coater, and the morphology was observed using SEM at 20 kV.

2.5.3. Tensile Strength

Tensile testing is useful for determining stress-strain relationships. The dimensions of the tensile test samples were determined using the ASTM D-3039-07 tensile property test procedure.

3. Results and Discussion

3.1. Impact strength analysis

The impact strengths of the composites' BSA, BSB, MS, and CS are shown in Figure 4. Figure 3 shows that increasing the volume fraction of $CaCO_3$ powder in polyester from 5-10% (vol. fraction) increases the impact strength of the composite (see BSA and BSB composites). This could be due to the fiber-powder-polyester interface's strong and tight bonding, allowing the composite to withstand the applied energy [20,21]. The presence of $CaCO_3$ powder, which evenly fills the gaps between the woven fibers, can increase the composite's strength. The BSB composite sample had the highest impact strength of 45.26 KJ/m^2 when compared to the other composites. Conversely, when the $CaCO_3$ powder content in the polyester resin is higher (20-25%), the fiber and $CaCO_3$ are not sufficiently evenly wetted by the polyester matrix, resulting in a weaker polyester- $CaCO_3$ -fiber interface, a lower ability to withstand impact energy, and a lower impact strength of the composite.

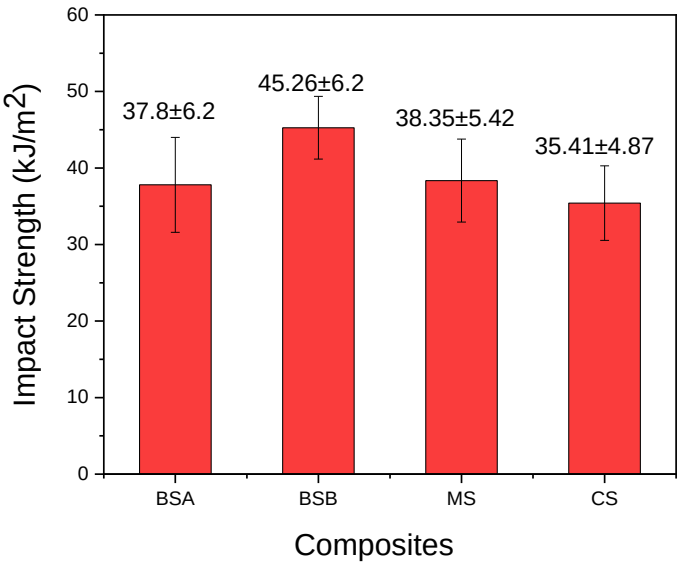

Figure 4. Impact strength of a MAF/ $CaCO_3$ reinforced polyester composite

3.2. SEM Analysis

Figure 5 depicts scanning electron micrographs of the impact tested samples. In general, composite impact strength failure is caused by three factors: fiber tension, matrix fracture, and fiber

debonding from the resin. Fiber pull-out, on the other hand, can be a significant energy dissipation mechanism in fiber-reinforced composites. Figures 5a and 5b show strong fiber-powder $CaCO_3$-matrix bonds and lower fiber pulling, which help to explain why the BSB composite has a high impact strength compared to other composites. In contrast, the CS and MS composites exhibited a lack of interfacial bonding and matrix cracking (Figures 5c and 5d). The energy required for fiber pulling increases as the interfacial shear stress increases. The fiber-matrix debonding is aided by interfacial shear stress. Fiber-matrix debonding has been shown to limit stress transfer, resulting in low stress absorption in fibers and powders. This is due to the fact that the interface shear stress governing stress transfer is constant from the applied load after fiber-matrix debonding [22,24]. This explains why adding more $CaCO_3$ to the resin results in a significant reduction in impact strength. The developed composite has higher impact strength results than the palm fiber/glass fiber hybrid composite, which has a tensile strength of 3-5 Kj/m^2 [24].

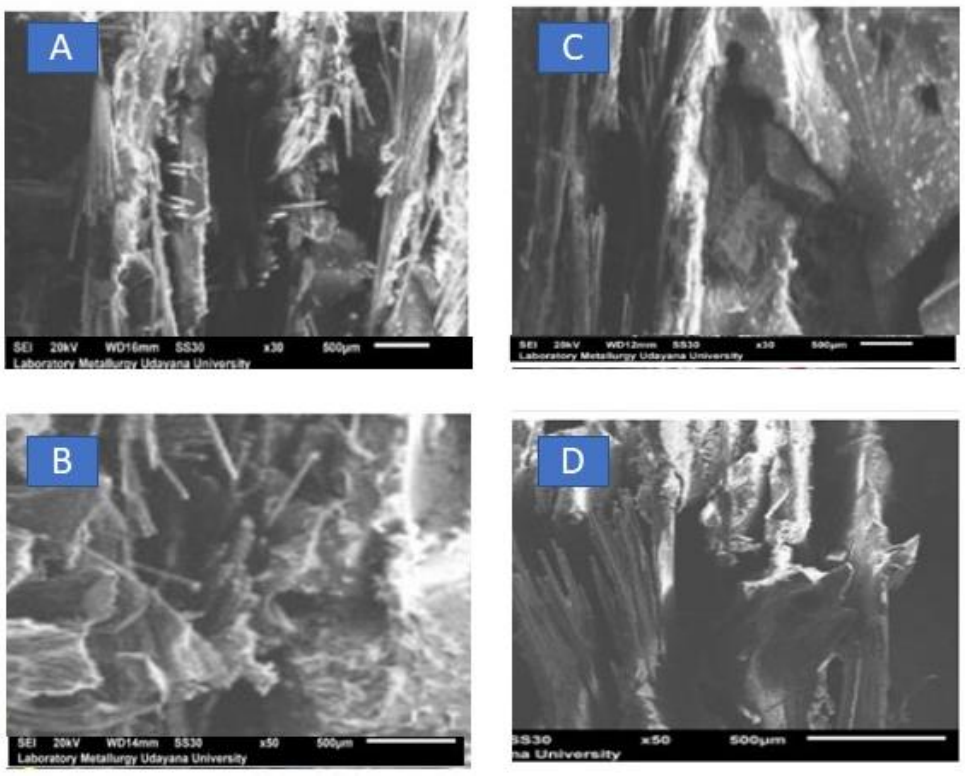

Figure 5. SEM photo of polyester composites: (a) BSA composite, (b) BSB composite, (c) MS composite and (d) CS composite.

3.3. Tensile strength analysis

Figure 6 showed that the tensile strength of the composite sample increased significantly after reinforcement with $CaCO_3$. For example, with 20% (vol. Percentage) $CaCO_3$, the tensile strength of the polyester and composite was 12.84 Mpa. This demonstrates that the addition of $CaCO_3$

increased the strength of fiber composites. Electrostatic adsorption between polyester and reinforcement may have been aided by the presence of a polar group in the matrix. Different charges operating on the matrix or reinforcement surfaces cause this phenomenon. The polyester reinforcement interface will be strengthened as a result of this process. That will keep them together and make them more resistant to deformation. This aided in enhancing the tensile strength of the composite. The even distribution of reinforcement has effectively slowed the chain's movement during deformation. The tensile strength of the composites will be increased as a result of this mechanism [24]. The tensile strength of the CS sample was reduced due to the weaker attachment of the resin to the fibers and $CaCO_3$ where part of the fibers was not wetted by the resin and there were a high number of vacancies.

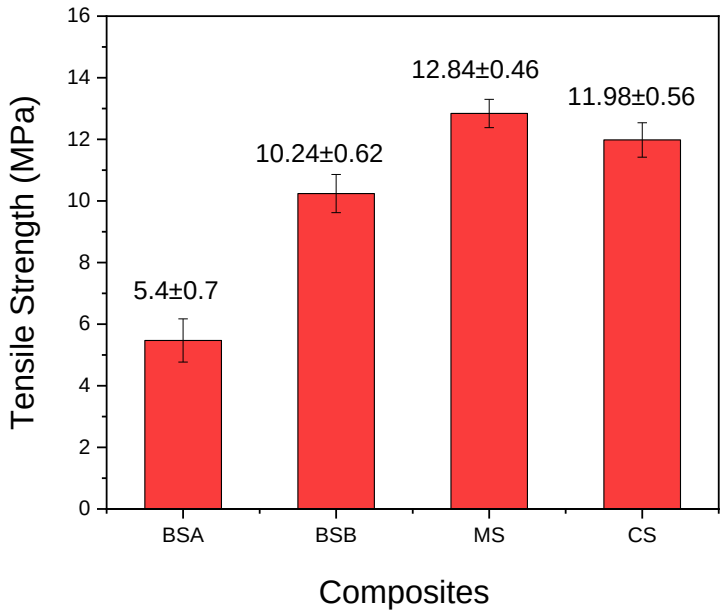

Figure 6. tensile strength of a MAF/ $CaCO_3$ reinforced polyester composite

3.4. Density of the composites

The results obtained for the composites are shown in Figure 7. It was observed clearly that as the wt% $CaCO_3$ increased in the polyester matrix, the density of the composites produced decreased. The decreases in the density of the composites were attributed to the fact that the BPF has a lower density than the polyester. This result shows that lower-weight structural components can be produced with the application of MAF in composites.

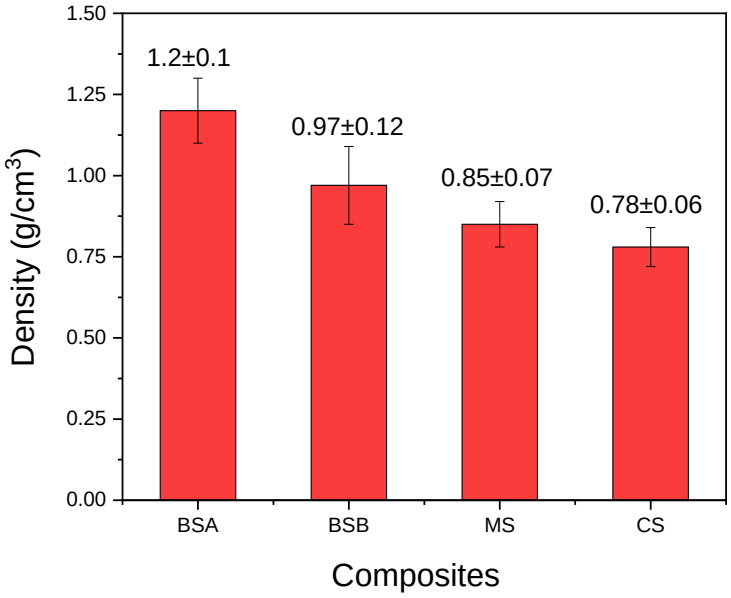

Figure 7. Density of a MAF/ $CaCO_3$ reinforced polyester composite

4. Conclusions

The use of CaCO3 powder to modify MAF composite materials has been investigated. The results of this investigation show that when CaCO3 is added to a maximum of 10% of the MAF/Polyester composite, the impact strength dramatically rises (vol. fraction). The strongest impact strength was 45.26 KJ/m2 for the BSB composite sample, which was due to the strong fiber-CaCO3-resin interfacial connection. The impact strength of the CS sample is the lowest at 35.41 Kj/m2. When 5-20% CaCO3 was added to the composite, the tensile strength qualities improved dramatically (MS sample). The significant quantity of CaCO3 causes the composite's strength and density to diminish - the fiber is not thoroughly wetted by the polyester, matrix fracture, and fiber debonding. The MAF/Polyester composite has greater mechanical qualities than the palm fiber/glass fiber hybrid composite and is ideal for building applications.

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