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Physical and Mechanical Properties of Sugarcane Bagasse Epoxy Bio-Composite: Effect of Composition and Particle Size

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Abstract: Bagasse is a waste from sugarcane processing in sugar factories. The amount of this waste is quite a lot in Indonesia. In this study, biocomposites have been successfully made from bagasse using epoxy resin as a matrix. The objective of this study was to examine the effect of the composition and particle size of bagasse on the physical and mechanical properties of biocomposites. The particle sizes of bagasse used in this study were 20, 40, and 60 mesh. The biocomposite was prepared by a press method at room temperature. The ratio of bagasse to epoxy resin for each particle size was 40/60, 50/50, 60/40, and 70/30 wt.%/wt.%. The physical properties (density, water absorption) and mechanical properties (modulus of rupture (MOR) and modulus of elasticity (MOE)) of biocomposites have been evaluated. The results show that the density of biocomposites decreases with increasing bagasse composition. Meanwhile, it increases with the decreasing particle size. The water absorption of biocomposites increases significantly with increasing composition of bagasse. However, it can be lowered by reducing the particle size of bagasse. The flexural strength (MOR) and the modulus of elasticity (MOE) of bagasse biocomposites decrease with increasing bagasse composition. However, the MOR and MOE increase for smaller particle sizes of bagasse. For 70 wt.% bagasse composition with a particle size of 60 mesh, the MOR and MOE of biocomposite are 7.8 kgf/mm^2 (76.44 N/mm^2) and 440 kgf/mm^2 (4,312 N/mm^2), respectively which meet the ANSI requirements to be applied as particle board.

1. Introduction

Wood is commonly used for a non-structural material such as doors, windows, furniture, home appliances, etc. The amount of wood demand continues to increase from time to time as the population increases and the economy develops. Such as in Indonesia, the amount of wood needed is about 60 million tons of cubic meters each year. On the other hand, in 2021 the average log production was around 48 million cubic meters (Ministry of Environment and Forestry Indonesia, 2021). The amount of wood production continues to decline from year to year. This has led to a lot of forest encroachment. According to the United Nations Environment Program (UNEP), there are currently around 40-55% of illegal logging in Indonesia (UNEP, 2023). This problem has had a very significant impact on climate change, the occurrence of global warming.

One alternative solution to meet the needs of wood is to make particle board. The particle board is a type of composite or biocomposite consisting of at least two materials, namely filler (reinforcement) and adhesive (matrix) (Jr. William, 1994; Azzaoui *et al.*, 2016). The current particle boards that exist on the market today generally use fillers from wood or sawdust. However, the amount of wood or sawdust is limited. So, it is necessary to find fillers from materials other than wood. Other fillers that can be used for the manufacture of biocomposites or particle boards are agricultural wastes such as rice straw (Akyldiz *et al*. 2015, Ismail *et al*. 2020, Pang *et al*. 2022), coconut shells (Bledzki *et al*. 2010, Somashekhar *et al*. 2018, Ismail *et al*. 2022), empty oil palm bunches (Faizi *et al*. 2022, Ghazilan *et al*. 2017, Hanan *et al*. 2020), and bagasse (Verma *et al*. 2012, Prasad *et al*. 2020, Anggono *et al*. 2017). In addition, the adhesives used for particle boards today in commercial applications are mostly made of urea formaldehyde which is not good for health. Thus, it is necessary to use other adhesives that are relatively safe for health. Azzaoui *et al.* and Akartasse *et al*., proposed a new composite based on hydroxyapatite by a new method of synthesis dissolution precipitation, for commercial application in wastewater purification. It was utilized to remove hazardous metal ions from wastewater (Azzaoui *et al.* 2023 and Akartasse et al., 2022).

Sugarcane is one of the most numerous crops in Indonesia. According to the Directorate General of Plantations, the area of sugarcane plantations in Indonesia in 2021 reached 443.5 thousand hectares. Total sugarcane production in 2022 is 2.4 million tons (BPS, 2022). Generally, sugarcane is used as a raw material in sugar factories. In production in sugar factories, bagasse is produced as residue. Thus, there is a lot of bagasse produced from sugar factories every year in Indonesia. However, until now this waste (bagasse) has not been utilized optimally yet. Meanwhile, a previous study reported that bagasse contains about 50% cellulose (Pandey *et al*., 2000). Thus, bagasse is a lignocellulose waste material that can be used as fillers in the manufacture of biocomposites or particle boards.

Several studies on the utilization of bagasse for composites have been conducted. Cao *et al.* (2006) made composites from bagasse fibers using polyester adhesives. However, the performance of mechanical properties was low. Cao *et al.* (2006) did not report the physical properties of their composite. Cerqueira *et al.* (2011) examined composites made from bagasse fibers using polypropylene as an adhesive. The mechanical properties obtained are quite good. However, this study used only 5-20% bagasse fiber, more adhesive composition. Agunsoye *et al*. (2013) developed a composite from bagasse by using polyethylene as an adhesive. The particle size of bagasse used was 100 μm with a bagasse composition of 10 to 50 wt.%. The results suggested that an even distribution of particles was a very important factor in the mechanical properties of composites. Anggono *et al.* (2017) developed biocomposites from bagasse using polypropylene as a matrix. However, the composition of bagasse was only 20, 25, and 30%. Pramono *et al*. (2019) conducted a bagasse biocomposite study using epoxy resin adhesives. However, the composition of bagasse used was very small, namely 4%, 8%, and 12%. In addition, the measured mechanical property was only tensile strength. Shabiri *et al.* (2014) also researched bagasse biocomposites using epoxy resin adhesives. However, the composition of bagasse of this study was only 0 – 50%.

Research on the use of sugarcane bagasse is still being carried out. Recently, Alokika *et al*. (2021) showed that cellulosic and hemicellulosic fractions of bagasse have quite potential for many value-added products. Sugarcane bagasse can be used for diverse applications (Mahmud *et al*., 2021). Bagasse is a green reinforcement that can enhance aluminum-based composite (Lakhanpal *et al*., 2024). Particleboard can be produced by sugarcane bagasse (Cangussu *et al*., 2023). Sugarcane bagasse ash has the potential as a partial substitute for cement in producing concrete (Sobuz *et al*., 2024). Sugarcane bagasse can be also utilized for thermal insulation and sound-absorbing materials (Mehrzad *et al*., 2022). Furthermore, sugarcane bagasse can be used as an adsorbent to remove heavy metals (Lemessa *et al*., 2023).

The above studies show that generally, the composition of bagasse used in the manufacture of biocomposites is smaller than 50%. Only one study had a bagasse composition of 50% (Shabiri *et al*., 2014). On the other hand, it is expected that the composition of biofiber in making biocomposites is greater than 50%. In addition, there is no study reported how bagasse particle size influences the physical and mechanical properties of biocomposites. Previous research has shown that the particle size of fillers affects the physical and mechanical properties of biocomposites significantly (Ismail *et al*., 2020). In this regard, it is necessary to develop bagasse biocomposites whose filler composition is more than 50%. In addition, it is also necessary to investigate the effect of filler size on the physical and mechanical properties of biocomposites. This study aims to develop biocomposites with a bagasse composition of more than 50% and examine the effect of filler size on the physical and mechanical properties of biocomposites.

2. Methodology

2.1 Material

Bagasse was collected from sugarcane juice sellers in Banda Aceh City, Indonesia. The bagasse was cleaned with tap water and dried under the sun. Next, the bagasse was cut to a length of about 2 cm and put in the oven at 100 °C until the weight was constant. Then, the bagasse pieces were milled using a grinder and sifted using a sieve so that 20, 40, and 60 mesh bagasse particles were obtained.

The adhesive (matrix) used was Avian brand epoxy resin sold in the market. The ratio of the resin and hardener was 1:1.

2.2 Biocomposite fabrication

Bagasse was mixed with epoxy resin using a mixer at a constant speed (300 rpm) for about 30 minutes to obtain the homogeneous mixture. The ratio of bagasse to epoxy for each particle size was 40/60, 50/50, 60/40, and 70/30 wt.%/wt.%. The mixture (dough) was fed into a mold made of steel plate with the size of 150 mm x 150 mm x 10 mm. Then, the mixture was placed on a hydraulic press machine to be pressed with a load of 7 tons for 30 minutes at room temperature to obtain biocomposite samples.

2.3 Biocomposite characterisation

The physical properties of biocomposites measured were density and water absorption. The density was measured according to ASTM D2395. The density was determined using **Eqn. 1**.

$$\rho = \frac{m}{V} \qquad \textbf{Eqn. 1}$$

Where ρ is the density of biocomposite; m is the mass of the sample; V is the volume of the sample. Water absorption was tested according to ASTM D570 standard. The water absorption of the biocomposite was determined using **Eqn. 2**.

$$WA = \frac{w_2 - w_1}{w_1} x100\% \qquad \textbf{Eqn. 2}$$

Where WA is water absorption of biocomposite; w_1 is the initial weight of the sample (before immersion into water); w_2 is the weight of the biocomposite after being immersed in water for 24 hours.

The mechanical properties of the biocomposites tested are modulus of rupture (MOR) and modulus of elasticity (MOE) according to ASTM D 790-03. The equipment used for mechanical properties characterization was a universal testing machine produced by Hung Ta. The MOR of a biocomposite was calculated using **Eqn. 3**.

$$MOR = \frac{3.F.S}{2.b.t^2} \qquad \textbf{Eqn. 3}$$

F is the maximum load; *S* is the support span; *b* is the sample width; and *t* is the sample thickness. The MOE of a biocomposite is calculated using **Eqn. 4**.

$$MOE = \frac{\Delta P}{\Delta y}\frac{S^3}{4.b.t^3} \qquad \textbf{Eqn. 4}$$

Where $\Delta P/\Delta y$ is the slope of the load force with respect to deformation; S, b and t are the same as in **Eqn. 3**.

3. Results and Discussion

3.1 Physical properties of biocomposite

Biocomposites have been successfully made from bagasse using epoxy resin as adhesive. The sample size is 150 mm x 150 mm with a thickness of about 5 mm. A photo of a bagasse biocomposite sample prepared in this present study is shown in **Figure 1**. The sample surface gets rougher with the increasing bagasse composition.

Figure 1. Photo of bagasse biocomposite sample

The density of bagasse biocomposites using epoxy adhesives is shown in **Figure 2**. The smallest density value is found under the condition of the largest particle size (20 mesh) with a bagasse composition of 70 wt.%, which is 0.479 g/cm^3. A small amount of epoxy resin can affect the small density, so the pressing process is not able to form a good bond between bagasse particles and epoxy resin adhesive. This situation causes the emergence of high porosity, so the density obtained is low. For a bagasse composition of 70 wt.% with a particle size of 60 mesh, the density of bagasse biocomposites is 0.70 g/cm^3. The largest density is 0.852 g/cm^3, obtained under conditions of particle size of 60 mesh with a bagasse composition of 40 wt.%. For a composition of 50 wt.% bagasse, density value from this study, 0.650 g / cm^3 was obtained, where the value was almost the same as the density value in the previous study for the composition of bagasse 50 wt.% and polyethylene adhesive 50 wt.% (Agunsoye *et al*., 2013). The density value obtained from this study is also almost the same as the biocomposite density value of rice straw using epoxy resin adhesive, where the density value is 0.87 g/cm^3 for a composition of 80 vol.% rice straw with a particle size of 60 mesh rice straw (Ismail *et al*., 2020).

The density value of the particle board is directly proportional to the weight % addition value of the resin. The more resin, the higher the density value of the biocomposite. This is because the specific gravity of the raw materials used, the specific gravity of epoxy resin (1.17 g/cm^3) is higher than the particles of bagasse (0.12 g/cm^3). In addition, the smaller the particle size (60 mesh), the density value of the biocomposite increases, as shown in **Figure 2**. This is because the smaller the particle size, the better the interaction between bagasse particles and adhesives. Thus, biocomposites become denser and increase in density. Interestingly, we can significantly increase the density of biocomposites (see **Figure 2**) by reducing the filler size from 20 mesh (841 microns) to 60 mesh (250 microns). The results of this study are in line with previous research that decreasing particle size can increase the density value of biocomposites (Ismail *et al*., 2020).

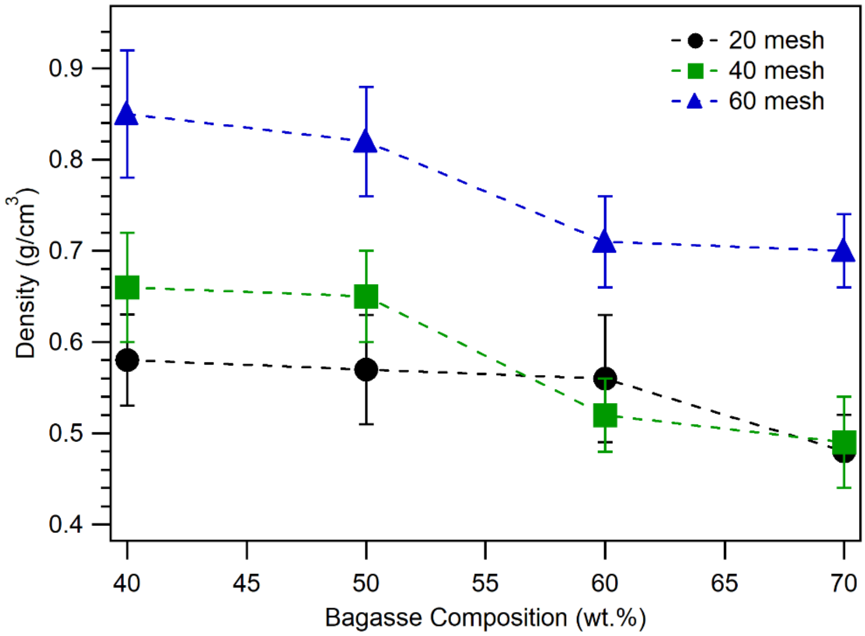

Figure 2. Bagasse biocomposite density

Variations in the composition of bagasse particles and adhesives produce biocomposites with certain qualifications, based on ANSI (American National Standard Institute) for particleboard. Biocomposites with a particle size of 20 mesh for all compositions have a density smaller than 0.6 g/cm^3, so they belong to the LD (Low Density) particle board category. Likewise, biocomposites with a particle size of 40 mesh with bagasse composition of 60 and 70 wt.% belong to the LD particle board category. For several biocomposites included in the category of MD (Medium Density) particle board which has density values ranging from 0.64-0.8 g/cm^3 (40 mesh with bagasse composition of 40 and 50 wt%; 60 mesh with bagasse composition of 60 and 70 wt.%). For a particle size of 60 mesh with a bagasse composition of 40 and 50 wt.%, biocomposites have a density of more than 0.8 g/cm^3, so they are included in the HD (high-density) particle board category.

Water absorption is the ability of a material to absorb water after soaking for a certain period, usually, water absorption is expressed in percent based on mass changes. The water absorbency value of bagasse biocomposite soaked for 24 hours in the water for various compositions and particle sizes of bagasse is shown in **Figure 3**. The highest water absorption value on 20 mesh bagasse particles with a bagasse composition of 70 wt.% is 96.21% and the lowest water absorption value on 60 mesh particles with a bagasse composition of 40 wt.% is 40.23%. The high amount of bagasse composition results in increased water absorption due to a large part of the surface of bagasse particles is not bound and is not well protected by adhesives. The water absorption can be significantly lowered by reducing the particle size from 20 mesh (841 microns) to 60 mesh (250 microns). This is due to a decrease in porosity in biocomposites which results in decreased water absorption. This trend is similar to that which has been observed in rice straw biocomposites using epoxy resin adhesives. The value of water absorption is around 40% for the composition of 80 vol.% straw (Ismail *et al*., 2020).

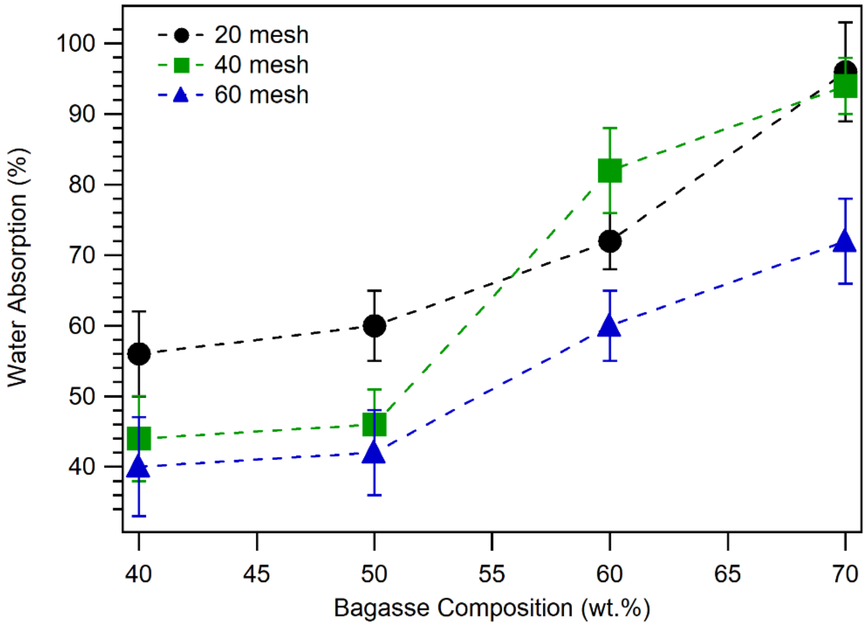

Figure 3. The water absorption of bagasse biocomposites

Previous research has shown that bagasse contains 50 cellulose (Pandey *et al*., 2000). Cellulose particles have groups that are reactive to water molecules or are hydrophilic, so they easily absorb water or moisture. The high level of cellulose contained in the filler (reinforcement) affects the magnitude of water absorption value in a biocomposite. This causes the water absorption capacity of bagasse biocomposites to be relatively high.

3.2 Mechanical properties of biocomposite

The modulus of rupture (MOR) of bagasse biocomposites has been determined. The results are shown in **Figure 4**. The highest MOR value was obtained at a particle size of 60 mesh with a composition of bagasse composition of 40 wt.%, which is 9.46 kgf/mm^2 (92.77 MPa). The value of flexural efficacy from this study is greater than the value of bending efficacy of previous studies (bagasse with a polyester adhesive) which is 50 MPa (Cao *et al*., 2006). However, the MOR value for bagasse particles measuring 20 mesh with a bagasse composition of 70 wt.% is relatively low at 1.38 kgf/mm^2 (13.52 MPa).

Figure 4 shows that particle composition and size greatly affect the bending strength of biocomposite materials. The MOR value decreases with increasing composition of bagasse. This is because the bond between bagasse particles and adhesives decreases with increasing bagasse composition or decreasing the amount of adhesive. However, by reducing the size of bagasse particles, the total contact surface area between bagasse particles and adhesives increase (Ismail *et al.*, 2022). This resulted in the MOR value of the biocomposite increasing significantly as seen in **Figure 4** (bagasse composition 70 wt.%). For a composition of 70 wt.% bagasse, the MOR values are 4.2 kgf/mm^2 (41.16 N/mm^2) and 7.8 kgf/mm^2 (76.44 N/mm^2) respectively for particle sizes of 40 mesh and 60 mesh. According to ANSI (American National Standard Institute), the MOR value requirements of biocomposites for particle boards are 14.9 N/mm^2 (H-1 type), 18.5 N/mm^2 (H-2 type), and 21.1 N/mm2 (H-3 type). Thus, the bagasse biocomposites produced in this study meet the MOR requirements to be used as H-3 type particle board.

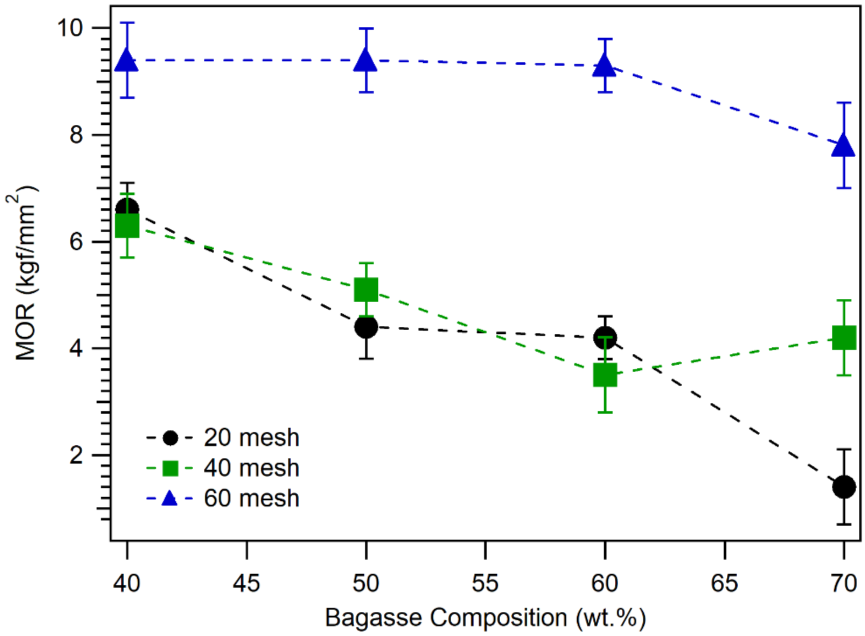

Figure 4. The modulus of rupture of bagasse biocomposites

The flexural elasticity modulus (MOE) of bagasse biocomposites has been measured, and the results are shown in **Figure 5**. The MOE value decreases with increasing composition of bagasse. This is due to the reduced bond between bagasse and adhesive (epoxy resin), which results in pore (increased porosity) and decreased density. However, the MOE value may increase with the reduction of the size of the bagasse article, as seen in **Figure 5**. As the size of bagasse particles decreases, the total contact area between bagasse particles and adhesives increases; better mixing of bagasse particles with adhesives; thereby reducing porosity and increasing the density of biocomposites. This causes the MOE value of the biocomposite to increase.

For bagasse composition of 70 wt.%, the MOE value of the biocomposite is 180 kgf/mm^2 (1,764 N/mm^2) for a particle size of 40 mesh and 440 kgf/mm^2 (4,312 N/mm^2) for a particle size of 60 mesh. MOE value required by ANSI for H-1 type particle board; is 2,160 N/mm^2; type H-2 is 2,160 N/mm^2; and type H-3 is 2,475 N/mm^2. Thus, bagasse biocomposites with a particle size of 60 mesh and a pulp composition of 70 wt.% can be made into H-3 type particle board.

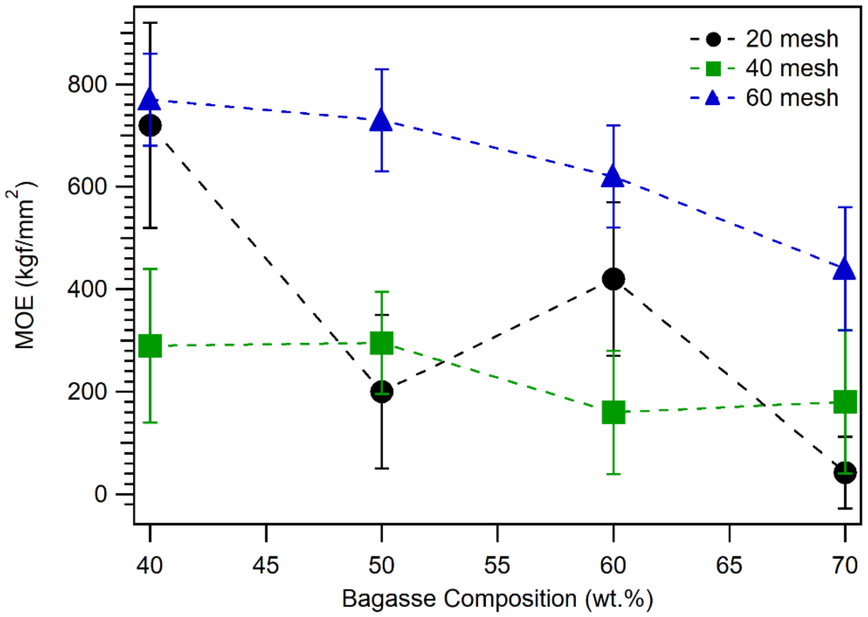

Figure 5. The modulus of elasticity of bagasse biocomposites

Conclusion

Biocomposites have been successfully made from bagasse using epoxy resin adhesives. The density of biocomposites decreases with increasing bagasse composition. However, the density increases with the decreasing particle size. For the highest composition of bagasse (70 wt.%) and the smallest particle size (60 mesh), a density of 0.70 g/cm^3 was obtained. Based on density, the developed bagasse biocomposite belongs to the medium-density particle board type. The water absorption of bagasse biocomposites is also influenced by the composition of bagasse and the particle size of bagasse. Water absorption increases significantly with increasing composition of bagasse. However, water absorption can be lowered by minimizing bagasse particles. The value of flexural strength (MOR) and the modulus of elasticity (MOE) of bagasse biocomposites decreases with increasing bagasse composition. However, MOR and MOE increase with the reduction of bagasse particle size. For a bagasse composition of 70 wt.% with a particle size of 60 mesh, the MOR and MOE values of the biocomposite are 7.8 kgf/mm^2 (76.44 N/mm^2) and 440 kgf/mm^2 (4,312 N/mm^2) respectively. Bagasse biocomposite with a composition of 70 wt.% with a bagasse particle size of 60 mesh meets ANSI requirements to be applied as particle board.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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