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Fabrication and mechanical characterization of binderless boards from sugarcane bagasse fibers

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Abstract
Agricultural waste management is a pressing environmental concern, as traditional disposal methods like incineration contribute to pollution. This study explores the fabrication and evaluation of binderless boards made from sugarcane bagasse fibers, eliminating the need for synthetic binders. Bagasse fibers were processed at mesh sizes of 20 and 40, then hot-pressed at 190°C under 9.6 MPa pressure for 15 and 25 minutes, achieving a targeted thickness of 10 mm. The physical and mechanical properties, including density, water absorption, thickness swelling, Modulus of Rupture (MOR), and Modulus of Elasticity (MOE), were analyzed. Results showed that particle size and pressing time significantly influenced board properties. The highest performance was observed in the E25 sample (40-mesh, 25-minute pressing), with a density of 0.52 g/cm³, MOR of 2.69 MPa, MOE of 293.82 MPa, water absorption of 134.66%, and thickness swelling of 16.80%. These findings suggest that optimizing particle size and pressing conditions enhances binderless board strength and dimensional stability, making sugarcane bagasse a viable raw material for sustainable panel production.

Keywords:
sugarcane bagasse, boards, binderless, physical properties, mechanical properties

1 Introduction

Sugarcane is a raw material for the sugar industry and is one of the plantation commodities that has a strategic role in Indonesia's economy. Sugarcane stems have shoots from the base of the stem that form clumps [1]. As much as 35-40% of the sugarcane processing process produces bagasse. In 2021, Indonesia has a sugarcane plantation area of around 490.01 thousand hectares, with sugarcane production reaching 145,100 tons, where this volume will produce around 67.35 tons of sugarcane and around 26.94 tons of bagasse [2].

The impact of bagasse on the environment and health is influenced by several factors, including (1) waste management; good management can reduce the potential for pollution; (2) Hazardous substance content: If bagasse contains hazardous substances or pesticides, this can pollute the soil and water sources; (3) Spread of disease: Poor management can make bagasse a breeding ground for pests and diseases, and (4) Greenhouse gas emissions: The process of decomposing bagasse can produce methane gas, which contributes to climate change. Proper management is essential to minimize the negative impacts of bagasse [3].

One effort to increase the value of bagasse waste can be made by forming it into a composite product. Composite is a material produced from engineering or a combination of two or more materials on a macroscopic scale to form a new, more useful material [4]. Composite materials have many advantages compared to conventional materials, including having adjustable strength, lighter density, corrosion resistance, and wear resistance. Likewise, bagasse as a composite filler has several advantages, such as being available in large quantities, lightweight, biodegradable, and having good insulating properties.

At present, researchers are focusing on the technology of natural fiber-reinforced composite materials with a focus on the aspects of environmentally friendly materials and biodegradability. The use of matrix or adhesive in the formation of fiberboard composites traditionally will be very beneficial in maintaining good physical and mechanical properties. Polymer-based matrices have been widely used in the composite board formation industry due to their low cost and good performance. However, the problems of biodegradability or ease of decomposition in a short time and the emissions generated can have negative impacts on the environment and health [5]. Due to concerns about the environment and health, the formation of composites without synthetic adhesives or using bioadhesives or composites without binders (self-bonding) is a promising strategy from an economic and environmental perspective.

Composites formed by self-bonding or composites without using any synthetic materials as a matrix can be said to be binderless composites [6];[7]. Binderless composites are harmless, biodegradable, and, of course, environmentally friendly in terms of waste disposal and recycling. In addition, binderless composites do not have formaldehyde emissions and do not depend on petroleum-based chemicals such as resins. Reducing or eliminating the use of relatively expensive resins will reduce production costs, make them more economical, and make the products formed more environmentally friendly. Natural fibers containing lignocellulose, glucose, and several other components will form a bond from within due to the activation of these components by applying heat and pressure [8].

Several researchers have previously reported the results of investigations of binderless composites based on natural fibers. The effect of heating time on the formation of binderless bagasse fiberboard has been reported by [9]. The focus of this study was on heating times of 20, 30 and 40 minutes and mechanical and physical testing. The pressing time of 30 minutes had the highest Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) values, which were 15.16 MPa and 1710 MPa, respectively. The composite had water absorption and thickness expansion performance ranging from 8% to 25%. Investigations of thermal conductivity and sound absorption of binderless panels made of oil palm wood as bio-insulating materials have been reported by [5]. The panels were produced from oil palm wood by hot pressing, with different fibre sizes and pressing times. The results showed that fibre size had a significant effect on the characteristics of the binderless panel but not on the pressing time. Another study on the water absorption performance of binderless bagasse composites against drying temperature has been reported by [10]. Various drying temperatures were applied during the pressing process as independent variables varying from 110ºC, 130ºC, 150ºC, 170ºC, and 190ºC. The most optimal drying temperature in the study was 190ºC. On average, the fiberboard had a water absorption of 37.06%. In addition, several previous researchers have also published sugarcane bagasse composites with various polymer matrices [11], [12], [13], [14], [15].

From the results of the literature search conducted, the discussion or production results of bagasse-based binderless composites still need to be improved. Several previous researchers focused more on the pressing time and pressing temperature on the mechanical and physical properties. However, there is one aspect that has yet to be reviewed, namely the formation of bagasse binderless composites by reviewing the aspects of particle size and shorter pressing time.

This study aims to manufacture bagasse binderless boards with different particle sizes and pressing times. The binderless boards are produced by binderless composites from bagasse fiber. The manufacture of binderless boards uses the hot press method and uses 20 and 40 mesh particles. Physical and mechanical properties such as density, water absorption, thickness swelling, and modulus of rupture are evaluated.

2 Materials and methods

2.1 Materials

Bagasse fibers that function as binderless board reinforcements were collected from sugarcane milling waste in the city of Lhokseumawe, Aceh, Indonesia, without distinguishing the type of sugarcane. The collected bagasse is cut into small pieces and dried to reduce the water content. The dried bagasse is ground using a disc mill and sorted using mesh sieves number 20 and 40.

2.2 Production of binderless boards

Binderless boards reinforced with bagasse fiber are formed by hot pressure using hot press equipment. The process of forming binderless boards begins by drying bagasse particles using an oven until they reach a water content of 8-12%. The bagasse particles are then inserted into a mold with dimensions 150 x 150 x 30 mm. The bagasse particles are then hot pressed using a hot press at a temperature of 190^{0}C with a time variation of 15 and 25 minutes. The pressing is carried out in two stages, namely the first stage for 5 minutes and the second stage for 10 and 20 minutes [5]. For each particle size variation, binderless boards are produced with a pressing pressure of 9.6 MPa, a target thickness of 10 mm, and a density of 0.5 g/cm^3. Table 1 shows the formulation for manufacturing conditions for bagasse fiber binderless boards.

Table 1. Manufacturing formulation of binderless boards from sugarcane bagasse fiber

Code of Binderless	Mesh Size	Pressing Times (min.)	Pressure (MPa)	Temp. (°C)
D15	20	15	9.6	190
D25	20	25		
E15	40	15		
E25	40	25		

2.3 Evaluation of mechanical properties of binderless boards

2.3.1 Physical Properties Testing

This testing includes density, Water Absorption (WA), and Thickness Swelling testing (TS) of binderless boards. For each physical test, as many as three specimens with dimensions 50×50xt mm were prepared from each binderless board variation.

The density value is an important factor in determining the type of material to be used in the manufacture of binderless board products. It is the comparison value between the board mass and volume, Eq. (1). This water absorption test aims to determine the percentage of water absorbed by the sample soaked for 24 hours. Water absorption can be calculated using Eq. (2). The thickness swelling test aims to determine the magnitude of the change in dimensions (thickness) of the specimen before and after immersion for 24 hours. The thickness swelling of water can be calculated using Eq. (3).

$$\text{Density} = \frac{\text{Massa}}{\text{Volume}} \quad (1)$$

$$\text{WA} = \frac{B_2 - B_1}{B_1} x100\% \quad (2)$$

$$TS = \frac{T_2 - T_1}{T_1} x100\% \quad (3)$$

where B1 is the weight before soaking (g), B2 = weight after soaking (g), T1 is thickness before immersion (g), T2 is thickness after, immersion (g)

2.3.2 Mechanical Testing

The mechanical testing conducted is MOR and MOE. The specimens were prepared according to the ASTM D790A standard. MOR testing uses the three-point bending method with a press speed of 2 mm/minute. The calculation of MOR and MOE values is carried out using Eqs 4 and 5. Where: F = maximum load (N), h (mm), b = width (mm), and L = support distance (mm) Eqs (4-5).

$$\sigma = \frac{3.F.L}{2.b.h^2} \quad (4)$$

$$E = \frac{F.L^3}{4.\partial.b.h^3} \quad (5)$$

3 Results and discussion

Fig. 1 shows the binderless boards reinforced with sugarcane bagasse fiber produced with particle sizes of 20 and 40 mesh. All binderless boards have smooth surfaces with a brown color. The binderless boards with 15-minute pressing times produce a lighter brown color compared to the boards produced with longer pressing times (25 minutes). Furthermore, Table 2 shows the results of physical and mechanical property tests of all adhesive-free boards studied in this study.

Table 2. Physical and mechanical properties of all binderless boards

Binder-less	Physical properties			Mechanical properties	
	Density (g/cm^3)	WA (%)	TS (%)	MOR (MPa)	MOE (MPa)
D15	0.48	294.89	55.3	1.47	116.43
D25	0.49	152.20	28.91	2.18	201.06
E15	0.50	140.09	20.05	2.44	259.96
E25	0.52	134.66	16.80	2.69	293.82

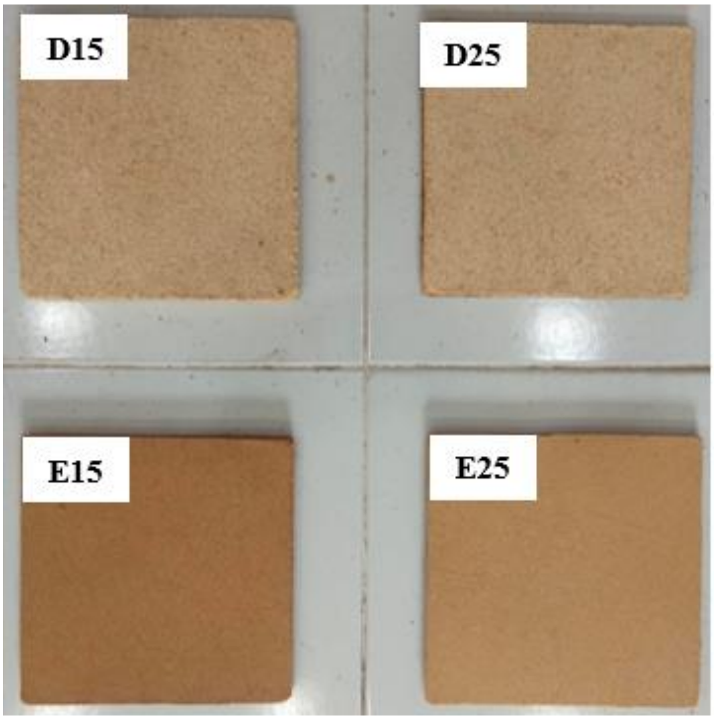

Fig. 1. The binderless boards reinforced sugarcane bagasse fiber

3.1 Density and WA properties of binderless boards

The results indicated the average densities of the D15, D25, E15, and E25 binderless boards of sugarcane bagasse were 0.48, 0.49, 0.50, and 0.52 g/cm^3, respectively (Fig. 2). This shows that the binderless boards are more compact with small-sized particles and the long-time press. A previous study [16] similarly reported that the composites made of larger particles generated more pores, which eventually decreased their density, and contrast with tiny particles resulted in a denser mat. Furthermore, Fig. 2 shows the relation between density and WA. In this experiment, the water absorption values of binderless boards decreased with increasing binderless board density. It is that the contribution of small particle size has a positive effect on density. Where with high density, better structural compactness will be formed and will produce fewer pores so that water will have difficulty entering the composite structure. Their findings are in line with the results of previous tests conducted by [5] and [17]. Density significantly affects the water performance of binderless boards. The bulk density of fibrous materials significantly affects their porosity, which results in different water absorption behaviors at different densities. In this case, density is directly proportional to the increase in water absorption resistance.

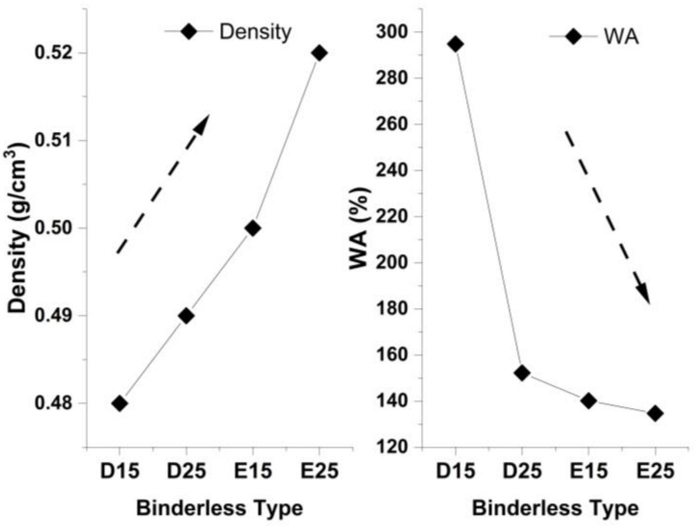

Fig. 2. The effect of pressing time and particle size on the density and WA of binderless boards

3.2 Water absorption and thickness swelling properties of binderless boards

The WA and TS values measure the effect of moisture on the fiber-reinforced composite board, where the lower the percentage, the better the water resistance of the composite board (Fig. 3). Fig. 4 presents the average WA and TS values, respectively, for binderless boards D15, D25, E15, and E25. It was found that the bagasse fiber binderless boards with sample D15 showed the lowest resistance to water penetration and showed the highest TS percentage after being soaked in water for 24 hours. From the Fig. 3, the TS trend follows the trend of WA performance. The percentage of WA value of the binderless boards produced with 20 mesh particles ranged from 152% to 294%. The WA value for the binderless boards produced with 40 mesh particles with a pressing time of 15 and 25 minutes showed 140% and 134%, where sample E25 showed better water absorption resistance than other samples. This phenomenon shows that the role of particle size and pressing time has a positive effect on WA and TS performance. Indra *et al.* found that the rate of water penetration into particleboard was greatly influenced by pressing temperature, pressure, and time [16].

In general, the water resistance of binderless boards from sugarcane bagasse is very poor. Cellulose in sugarcane bagasse tends to attract water and bind water molecules through hydrogen bonds due to the availability of hydroxyl groups. A study conducted by Araújo Junior et al. reported that covalent cross-links found in the inter-fiber bonds play an important role in the water resistance of particleboard because these bonds are more stable than hydrogen bonds in water [18]. This finding is similar with a previous research by Lamaming *et al.* [19] and Milawarni *et al.* [20], who reported that particleboards made from old palm oil wood to tiny particle size had lower water absorption capacity than coarse particle sizes.

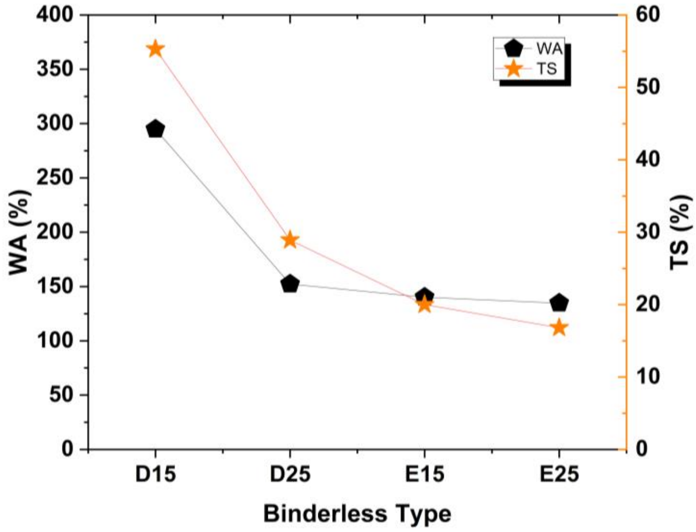

Fig. 3. The WA and TS of binderless boards

3.3 MOR and MOE properties of binderless boards

Based on Fig. 4, the average MOR for static bending of binderless boards samples D15, D25, E15, and E25 were 1.47, 2.18, 2.44, and 2.69 MPa, respectively. At the same time, MOE ranged from 116.43 MPa to 293.82 MPa. Higher MOR and MOE values were obtained for binderless board produced with a particle size of 40 mesh and a pressing time of 25 minutes (E25). The use of small particle sizes and longer pressing times during hot compression has given positive effects on the MOR and MOE of binderless boards reinforced with bagasse fiber. Longer hot-pressing times have provided opportunities for chemical components, such as sugar and starch, to form their bonds. Fine particles can produce better interlocking to improve the bond between individual particles. Similar findings from previous studies [5] reported that large particles reduce the flexural properties of boards produced from oil palm trunks. Other findings from previous studies conducted by [19] and [21] reported that large particles reduce the flexural properties of oil palm trunks produced by boards and Washingtonian palm trees.

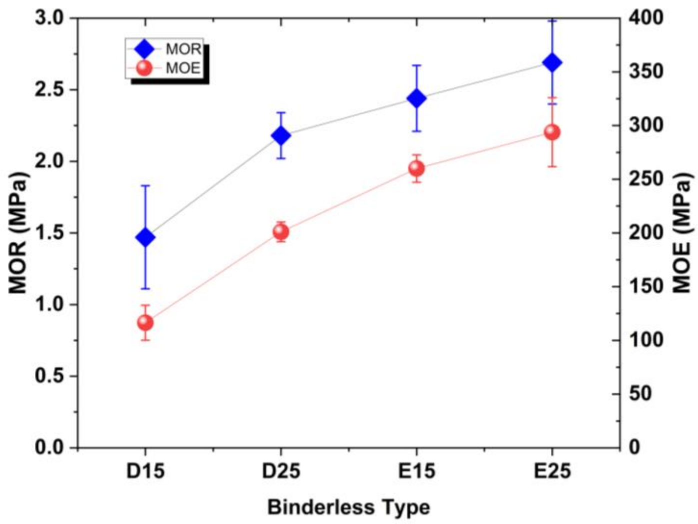

Fig. 4. The MOR and MOE of binderless board

Particle size has a significant effect on flexural properties because it affects the interlocking mechanism between particles [22]. Furthermore, the results of this study were strengthened by [23], [24], and [25], which stated that the bending strength value of the composite is also influenced by particle size, density, and amount of filler. The MOR and MOR findings in this study are better than those of binderless bagasse boards produced by Jamaludin et al., where binderless bagasse boards were produced at a temperature of 180 C for 10 minutes using a particle size of 20 mesh [26].

3.4 Relation between physical and mechanical properties

Fig. 5 shows the relationship between the physical and mechanical properties of bagasse binderless boards with different particle sizes and pressing times. It is clear from Fig. 5 that increasing density with decreasing particle size and increasing pressing time leads to increasing MOR. It also affects water absorption and thickness swelling. Water resistance and dimensional stability show an increase with increasing pressing time and reducing particle size. On the contrary, short pressing time and increasing particle size have resulted in reduced water resistance, low dimensional stability, and decreased MOR values of bagasse binderless boards. The findings of this work indicate that the physical properties of binderless boards are correlated with mechanical properties.

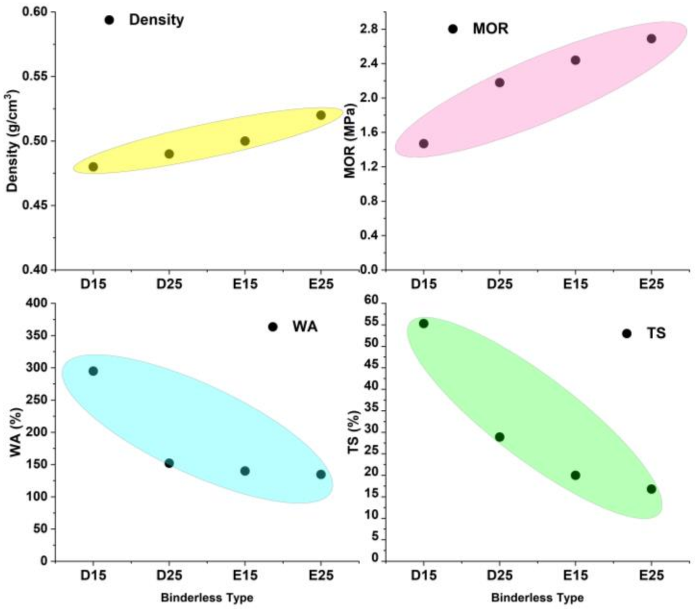

Fig. 5. Relation between physical and mechanical properties of binderless board

4 Conclusion

This research produced binderless boards from sugarcane bagasse fibers with dimensions of 150 × 150 × 10 mm. The results show that both particle size and pressing time significantly affect the physical and mechanical properties of the boards. Increased pressing time and smaller particle sizes improved density, which in turn enhanced water resistance, dimensional stability, and mechanical strength. Among all tested samples, E25 with 40-mesh and 25-minute pressing exhibited the best overall performance, achieving a density of 0.52 g/cm³, MOR of 2.69 MPa, MOE of 293.82 MPa, water absorption of 134.66%, and thickness swelling of 16.80%. These results confirm that optimizing fabrication parameters can improve the durability and structural integrity of binderless boards, promoting sugarcane bagasse as a sustainable alternative for eco-friendly construction materials. Future research should explore durability, environmental factors, and scalability for commercial applications

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