The properties of particleboards made from corn stalks and bagasse at various compositions

A H Iswanto1*, I G Tarigan1, A Nuryawan1 and F Oktaviani1

1 Department of Forestry, Faculty of Forestry, Universitas Sumatera Utara, Medan, Indonesia

*E-mail: apri@usu.ac.id

Abstract. Corn stalks and bagasse are materials that contain lignocellulose and have the opportunity to be used as raw material for particleboard manufacturing. This study aims to analyze the effect of the composition of corn stems and bagasse on the physical and mechanical properties of particleboards. The composition of corn stalk and bagasse as raw material for making particleboard in this study consists of several ratios, namely 100/0, 80/20, 60/40, 40/60, 20/80, and 0/100. The adhesive used in this research was isocyanate. The thickness and target densities were 1 cm and 0.70 g/cm3, respectively. The results showed that the board density value did not reach the target, and the thickness swelling of the board was still quite high. Board with a composition of a mixture of corn stems and bagasse at an 80/20 ratio is a board that has better properties compared to other ratios.

1. Introduction
The need for wood as raw material for the timber industry has increased, while the availability of wood raw materials is experiencing a decline. This condition causes problems for the timber industry in carrying out its production process. To overcome these problems, alternative sources of lignocellulose material other than wood need to be found that have the potential for abundant material availability. One of the timber industries that using lignocellulose as raw materials both wood and non-wood is the particleboard industry. According to [1] the definition of particleboard is an imitation board made of wood or non-wood lignocellulose raw material that bound by using adhesive and hot pressing.

Some lignocellulose materials that have the potential to be developed as raw material for particleboard are sourced from agricultural plant waste. The main consideration why crops are fast cycles so that the potential availability will be sufficient. Among the existing crops that can be used are corn stalks and sugarcane bagasse. Corn stalks and bagasse are agricultural wastes containing lignocellulose and their availability is also abundant. Bagasse is a by-product of sugarcane stalks that have been extracted for sugar and take the form of solid waste. Corn stalks contain 50.57% cellulose, 27.03% hemicellulose, and 16% lignin [2]. Bagasse has a cellulose content of 52.70%, lignin 24.20%, and hemicellulose 17.50% [3]. Several studies related to the use of non-wood cellulose material as particleboard raw materials had been conducted by [4-12].

2. Materials and Methods
2.1. Materials
Corn stalks are obtained from corn farmers around Medan Tuntunggan, North Sumatra, Indonesia. The corn stalks then chopped using a chopping machine. Waste bagasse collected from sellers around the University of Sumatera Utara, it cut into 7 cm length. Bagasse particle soaked into hot water for 2 hours to remove sugar content. Furthermore, particles were dried until the moisture content reaches 9%. The adhesive used in this study was isocyanate resin with a concentration of 10%.

| Table 1. Particle Geometry |
|-----------------------------|
| **Corn Stalks**             | **Bagasse** |
| Length                      | 3.28        | 7.05        |
| Width                       | 0.31        | 2.77        |
| Thickness                   | 0.08        | 1.02        |
| Slenderness Ratio           | 39.26       | 6.91        |
| Aspect Ratio                | 10.71       | 2.54        |

2.2. Methods

2.2.1. Board making
Both raw materials are mixed with an adhesive until evenly distributed. Then put into a board mold with (25 x 25) cm² size with a target density of the board 0.70 g/cm³. The printed board is then compressed using a hot press with a temperature of 160°C, and press time of 5 minutes with 30 kg/cm² of pressure. The board made with 3 replications. The final step was the conditioning of the board for 7 days at room temperature of 25°C. Conditioning was an aim to homogenize the water content and eliminate residual stresses formed during hot pressing.

2.2.2. Physical and mechanical properties of particleboard testing
After the conditioning process is carried out, the next step is cutting the board into test samples of various sizes each by [13] and then testing the boards. Particleboard testing parameters consist of physical and mechanical properties. The examination of physical properties includes density, moisture content, water absorption, and thickness swelling. Testing mechanical properties include Internal Bond (IB), Modulus of Elasticity (MOE), and Modulus of Rupture (MOR). Testing the physical and mechanical properties of particleboard refers to [13].

2.3. Data analysis
To determine the effect of the comparison of the composition of raw materials on the physical and mechanical properties of the particleboard of corn stalks and bagasse, a variety of non-factorial completely randomized design was carried out. As treatment is a comparison of the composition of the raw material of corn stalks and bagasse consisting of 6 levels (100/0, 80/20, 60/40, 40/60, 20/80, 0/100) with three replications.
3. Results and Discussion

3.1. Physical properties

The results of the physical properties testing of the board which includes density, moisture content (MC), thickness swelling (TS), and water absorption (WA) was presented in Table 2.

| No | Parameters | Corn stalk and Bagasse Ratio (CS/B) |
|----|------------|------------------------------------|
|    |            | 100/0 (A-type) | 80/20 (B-type) | 60/40 (C-type) | 40/60 (D-type) | 20/80 (E-type) | 0/100 (F-type) |
| 1  | Density   | 0.65<sup>d</sup> | 0.68<sup>d</sup> | 0.64<sup>cd</sup> | 0.60<sup>b</sup> | 0.62<sup>bc</sup> | 0.53<sup>a</sup> |
| 2  | MC        | 2.65<sup>a</sup> | 2.72<sup>a</sup> | 2.98<sup>ab</sup> | 3.68<sup>c</sup> | 3.44<sup>bc</sup> | 4.38<sup>d</sup> |
| 3  | TS-2H     | 8.86<sup>b</sup> | 6.31<sup>a</sup> | 9.20<sup>b</sup> | 9.78<sup>b</sup> | 11.01<sup>c</sup> | 11.50<sup>c</sup> |
|    | TS-24H    | 13.54<sup>a</sup> | 14.51<sup>a</sup> | 17.09<sup>b</sup> | 19.56<sup>c</sup> | 17.48<sup>c</sup> | 18.07<sup>b</sup> |
| 4  | WA-2H     | 25.30<sup>a</sup> | 28.17<sup>a</sup> | 35.47<sup>b</sup> | 39.85<sup>c</sup> | 41.65<sup>c</sup> | 56.46<sup>d</sup> |
|    | WA-24H    | 69.21<sup>a</sup> | 71.46<sup>ab</sup> | 74.46<sup>bc</sup> | 80.37<sup>d</sup> | 75.19<sup>bc</sup> | 76.44<sup>cd</sup> |

Note: a, b, c, d: In superscript Duncan Multiple Range Test (DMRT) notation that has the same letter shows no significant difference at 95% confidence interval.

3.1.1. Density

The average of particleboard density ranged from 0.53 g/cm<sup>3</sup> - 0.68 g/cm<sup>3</sup>. Overall the particleboard has fulfilled standard which is 0.40 g/cm<sup>3</sup> - 0.90 g/cm<sup>3</sup> but did not meet the density target (0.70 g/cm<sup>3</sup>). It was due to by spring-back effect. The additions of bagasse as much as 40% and so on causes, the spring back value increased. This was because sugarcane bagasse has bulky properties. As a result, when conditioning the board has a high thickness increase. Besides, it is not possible to achieve the target density because there are particles that are wasted during board manufacturing. This is in line with the statement stated by [14].

3.1.2. Moisture content

The moisture content of particleboard is in the range of 2.65% - 4.38%. The highest value was found on type F-boards which were 4.38%, and the lowest value on type A-boards was 2.65%. The moisture content of the board increases with the proportion of bagasse. This is because bagasse has hygroscopic properties so that when conditioning it is easy to absorb water. The analysis of variance showed that the ratio of the composition of corn stems and bagasse significantly affected the density and moisture content of particleboards at 95% confidence intervals.

3.1.3. Thickness swelling

The thickness swelling value for 2 and 24 hours ranged between 6.31 - 11.50%, and 13.54 - 19.56% respectively. Factors that influence thickness swelling were density and water absorption. According to [15] low density of boards tends to have more cavities than higher density particleboards, so that, more water is absorbed by the board and results in an increase of the thickness swelling value. The analysis of variance showed that the ratio of the composition of corn stems and bagasse significantly affected the thickness swelling of particleboards at 95% confidence intervals. The thickness swelling value of the board for 24 hours did not meet the standards that require a thickness swelling value of less than 12% [13].

3.1.4. Water absorption

The value of water absorption for 2 and 24 hours ranged from 25.30 - 56.46%, and 69.21 - 80.37%. Water absorption is affected by the gaps formed in particleboard due to the uneven distribution of adhesives. Water absorption has a negative linear correlation with density. High density will reduce water absorption, where water takes longer to penetrate particleboard [16].
The higher baggage proportion increases in the board's water absorption value. The analysis of variance showed that the ratio of the composition of corn stems and bagasse significantly affected the water absorption of particleboards at 95% confidence intervals.

3.2. Mechanical properties

The results of the mechanical properties testing of the board which include, modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) are presented in Table 3.

### Table 3. Mechanical properties of particleboard

| No | Parameters | 100/0 (A-type) | 80/20 (B-type) | 60/40 (C-type) | 40/60 (D-type) | 20/80 (E-type) | 0/100 (F-type) |
|----|------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1  | MOR        | 154.4bc         | 163.41d        | 154.91bc       | 148.21b        | 144.84b        | 89.67a         |
| 2  | MOE        | 13.066d         | 12.290d        | 10.698c        | 9.995c         | 7.061b         | 3.422a         |
| 3  | IB         | 1.55d           | 1.61d          | 1.36c          | 0.58a          | 1.01b          | 0.634a         |

Note: a, b, c, d: In superscript Duncan Multiple Range Test (DMRT) notation that has the same letter shows no significant difference at 95% confidence interval

3.2.1. Modulus of rupture (MOR) and modulus of elasticity (MOE)

The MOR value in this study ranged from 89.67 - 163.41 kg/cm². The highest MOR value was found on board type B, and the lowest was on board type F. Increased bagasse ratio causes a decrease in board MOR value. It was due to that the bulk density effect of bagasse causes the board density value to decrease so that it has an impact on the decline in MOR value of the board. The analysis of variance showed that the ratio of the composition of corn stems and bagasse significantly affected the MOR of particleboards at 95% confidence intervals.

The lowest MOE value was produced by board type F of 3,422 kg/cm² and the highest was on board type A of 13,066 kg/cm². Increased bagasse ratios cause a decrease in the MOE value. Bagasse contains cork, this causes the board strength was reduced and the MOE value becomes low. According to [17] that cork in bagasse has properties that do not provide strength so that the quality of particleboards becomes poor and requires a lot of adhesive. Another factor that influences MOE was the slenderness ratio (SR). The SR value of the particles used was very low, namely for bagasse of 6.91 and corn stalks of 39.26. According to [1] stated that a minimum SR value of 150 would result in high particleboard strength. Particles with high slenderness ratio (SR) will be easier to orientate so that the strength of the resulting board will increase. The analysis of variance showed that the ratio of the composition of corn stems and bagasse significantly affected the MOE of particleboards at 95% confidence intervals.

3.2.2. Internal bond (IB)

IB values range from 0.58 - 1.61 kg/cm². The lowest value was found on board type D and the highest was board type B. There was a tendency to decrease in IB value as a result of increasing bagasse ratio. This trend was in line with the board density parameters. Giving immersion treatment in hot water for 2 hours did not have a significant effect on reducing sugar content so it was suspected that this was one of the causes of low IB values. The presence of sugar substances is a limiting factor in the adhesion process resulting in the bonding process not going well. The analysis of variance showed that the ratio of the composition of corn stems and bagasse significantly affected the IB of particleboards at 95% confidence intervals.
4. Conclusion
The addition of sugarcane bagasse up to 20% can improve the physical and mechanical properties of particleboard, but higher composition gives the opposite result. Sugar content and the presence of cork on the bagasse are factors that are suspected to influence the properties of the board produced. Board with a composition of a mixture of corn stems and bagasse at an 80/20 ratio is a board that has better properties compared to other ratios.

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