Effect of particle treatment and adhesive type on physical, mechanical, and durability properties of particleboard made from Sorghum Bagasse

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Abstract. Refers to chemical content of sweet sorghum stalk especially for Numbu varian, sorghum bagasse is suitable for materials of particleboard. The objective of the experiment was to evaluate of particle treatment on physical, mechanical, and durability properties of particleboard made from sorghum bagasse. For particle treatment, Sorghum bagasse immersed in cold water and hot water for 24 and 1 hours respectively. Particleboards were produced in size 25 by 25 cm² with thickness and density target of 0.8 cm and 0.7 g/cm³. Amount of 10% Urea formaldehyde (UF) and 7% isocyanat (MDI) adhesive level used for manufacturing of board. Particle and adhesive were blended with rotary blending. Afterward, it was placed into mat former with size of 25 by 25 cm². Mat was pressed by hot press machine. The pressing was conducted on 130°C temperature for UF resin and 160°C for MDI resin, pressure of 25 kg/cm² and pressing time for 10 minutes. The results showed that particle soaking in hot water produced of lower thickness swelling compared to untreated board. Similar trend also occur on particleboard which was bonded with MDI resin. MDI as exterior adhesive resulted good performance in dimensional stability of sorghum bagasse particleboard. For UF bonded particleboard, immersing in hot water resulted in the low MOR, MOE and IB parameter. It’s contrary with MDI bonded particleboard.

1. Introduction

SEAMEO-BIOTROP had been developed of Sorghum since 2009 for food, feed, and energy [1,2]. Sorghum plant can produce of stalk around 15 ton/ha/3 month. Thanapimmetha [3] reported that sorghum stalk contains of cellulose, hemicellulose, and lignin content amount of 58.23%, 25.42% and 14.95% respectively. While Iswanto et al. [4] reported that Numbu variant of Sorghum respectively has 45.28, 17.39, and 32.76% of alpha cellulose, hemicellulose and lignin content. Lawal and Ugheoke [5] stated that alpha cellulose content of sorghum stalk is 48%. According to the chemical content and shorting harvested cyclic resulted in sorghum bagasse is potential to be develop as a raw material of particleboard. Maloney [6] determined the particleboard as one of the wood based panels product made from wood or other lignocellulosic materials that converted into particles and it was bonded by thermosetting or thermoplastic adhesive using hot pressing process.

The utilization of sorghum bagasse for wood substitution as particleboard materials were expected will give the value added of sorghum bagasse and to decrease of forest degradation. However, we found some problems in using sorghum bagasse as raw material for particleboard. As an agromaterial, it is not only voluminous but also contains hydrophobic properties on its polymer cellular walls which...
related to the abundance of hydroxil groups. It has negative impact to mechanical and dimensional properties due to relative moisture content of the environment and microorganisms attack. The aim of this research was to analyze the influence of particle treatment on physical, mechanical, and durability properties of particleboard.

2. Materials and methods

2.1. Materials
Sorghum bagasse was collected from SEAMEO-BIOTROP. It was cut into 2 cm length. Adhesives using in this research were urea formaldehyde (UF) and MDI Isocyanat.

2.2. Methods

2.2.1. Treatment of particles. A part of strands was immersed in hot water at 80°C for 1 hours, and immersed in cold water for 48 hours [7].

2.2.2. Particleboard manufacturing. Single layer particleboard was produced with the size and targeted density 2.5 cm by 2.5 cm by 1 cm and the 0.70 g/cm³, respectively. About 10% UF (Solid content: 63%) and 7% MDI (Solid content 97%) were used as a binder. Mixing process of particles and adhesive was conducted in Rotary drum blender. Furthermore, the mats were hot–pressed at 130°C for UF and 160°C for MDI, 25 kg/cm² pressure for 10 min, and then the boards were room conditioned for 1 week in room temperature. The replication of each treatment was triplicate.

2.2.3. Evaluation of particleboard:

- **Physical and mechanical test.** After conditioning for 7 days at room temperature, the next step was to evaluate of board properties refers to JIS A 5908 (2003).

- **Durability test to subterranean termite attack test.** Durability test refers to Indonesian Standard (SNI) 01.7207–2006. Specimen with size 2.5 cm by 2.5 cm was dried at 103°C temperature up to constant weight. Sample was burried in the round jam pot (450–500 mL capacity, with a wide-mouth and a bottom area of 25–30 cm²) that had filled 200 g of sand at 7% moisture content below water holding capacity. Amount of 200 of subterranean termite (Coptotermes curvignathus Holmgren) was put in the jam pot then the jam pot placed in a dark room for 4 weeks. At the end of the test, mass loss and mortality value of each specimen was determined according to SNI 01.7207–2006. Antifeedant value and feeding rate were also calculated. Model of durability test to termite attack is shown in Fig 1. The classification of board durability to subterranean termite based on mass loss refers to SNI 01.7207- 2006.

![Figure 1. The durability test to termite attack (SNI 01.7207-2006).](image-url)
3. Results and discussion

3.1. Density and Moisture Content (MC)

The density and MC parameters in this research showed on Fig 2 and 3. The board density value for UF and isocyanate adhesives were 0.65-0.79 g/cm$^3$ and 0.68-0.77 g/cm$^3$, respectively. The final particleboard density was determined by wood type (wood density), the pressure, the amount of wood particle on the mat, adhesive content and other additional materials [8]. All boards in this research were categorized to medium density and had met the standard requirements.

![Figure 2. Density of particleboard.](image)

![Figure 3. Moisture content of particleboard.](image)

The particle immersion treatments decreased the moisture content of particleboard. The immersion was intended to remove extractive substances. Pari et al. [9] stated that cold water immersion would decrease the content of extractive substances on wood (tannin, gum, sugar and pigment). This condition would enhance adhesive’s penetration ability to cell walls and help the sticking process, therefore the water vapor accessibility would be decreased.

Moisture content on isocyanate adhesive was very low compared to UF adhesive. According to Teco [10] and Marra [11], MDI and wood did not only produce mechanical bond, but chemical bond. Therefore, the bond was stronger, more stable and had better performance. Compared to other exterior type of adhesive, MDI was less used but better result. The wood had chemical function groups called hydroxil groups. MDI on isocyanate groups (−N=C=O) reacted to these hydroxil groups and formed urethane chains. The moisture content of particleboard in this research had met the JIS A 5908 (2003) standard of 5-13%.
3.2. Thickness Swelling (TS) and Water Absorption (WA)

The TS and WA parameters in this research showed on Fig 4 and 5. TS of boards using UF were 4 to 6 times larger than the ones using isocyanate adhesives. Meanwhile, the WA was 3 to 4 times bigger. Sauter [12] stated that bond quality and adhesive properties influence the thickness swelling [13]. Due to its chemical properties, the 100% MDI solids isocyanate was more waterproof than the water-based UF adhesive [14]. Pan et al. [15] also stated that particle bonds resulted from UF adhesive was weaker than isocyanate adhesive. Therefore, UF adhesive absorbed more water and significantly influence TS and WA values.

The TS and WA values were very high, in particular when hydrophobic substances were not added in the process. According to Nemli et al. [16], the addition of hydrophobic substances such as paraffin and wax was able to decrease the thickness swelling value. We found that the samples still absorbed free and bonded water when immersed. Free water was situated on cell hollows, intercellular rooms and bond cracks between adhesive and wood, while bonded water was situated on the cell walls and possibly on wood-adhesive network [17].

Particle treatment caused of decreasing the extractive content, its consequently of the adhesive’s ability to penetrate the wood and bonding with free hydroxyl groups went smoothly. It resulted in the minimized of the hygroscopic particleboard. The JIS A 5908 (2003) standard required the maximum TS of 12%. The particleboard using UF and untreated isocyanate adhesives had not met the standard, while particleboard using isocyanate adhesive with immersion treatment had met the standard.

![Figure 4. Thickness swelling of particleboard.](image)

![Figure 5. Water absorption of particleboard.](image)

3.3. Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

The MOE value of the board using UF adhesive had not met the standard, while the ones using isocyanate adhesive had met the JIS A 5908 (2003). The differences in resin levels significantly affected to the mechanical properties of glued material. Immersion treatment of board using isocyanate adhesive increased the MOE value.
Boards using UF adhesive produced of decreasing of MOE and MOR values. UF adhesive was sensitive to pH changes. As stated by Boonstra et al. [17] immersion treatment using hot water decreased the pH level of particle that allow the forming of acetic acid and formic acid. Provisional estimates of low MOE and MOR values was the adhesive over-curing, which was affected by temperature and time in the compressing process. A decrease in pH level should be followed by a decrease of temperature or compression time.

Hot water immersion treatment would reduce alkaline extractives, lower pH level and increase the buffer capacity of absolute acid of the particles [18]. The changes on chemical composition and wood particle properties caused by hot water would affect mechanical properties of the board. The structure (cell walls components) change and particle surface properties causing the probability of hot water treatment to increase the board’s properties as showed by boards using isocyanate adhesive.

![Figure 6. Modulus of elasticity of particleboard.](image)

![Figure 7. Modulus of rupture of particleboard.](image)

### 3.4. Internal Bond (IB)

The board’s IB value using UF adhesive had not met standard, while the ones using isocyanate adhesive had met the JIS A 5908 (2003). The particleboard’s internal bond strength was affected by wood specific adhesion properties, the adhesive spread and compression time [19]. We assume lower IB value using UF adhesive was caused by over-curing as consequently of high temperature and compression time. Therefore we expect to reduce the gap density between wood surface and the core, thus the density profile would less steeper.
3.5. Durability of particleboard

Weight loss, termite mortality, antifeedant and feeding rate values presented in Fig 9. The result of study about the extractive content of sorghum bagasse of numbu variant showed that the solubility value on NaOH-1% was 30.25 %. The high extractive content value caused the lower sorghum bagasse durability against the destructive organism. Pari et al. [9] declared that NaOH 1% solubility was the sign of chemical component damage of wood cell walls caused by wood destroying fungi. It could also the sign of degradation by light, heat or oxidation.

UF adhesive had better durability against subterranean termite compared to isocyanate adhesive. Immersion treatment of the particle was able to increase board durability against termite attack, as stated by Iswanto [20]. Sorghum Bagasse particleboard classified into moderately to durable (Class II-III) according to SNI 01.7207–2006 standard of board durability against subterranean termite attack.

4. Conclusion

Sorghum bagasse was suitable to be used as particleboard raw material using isocyanate adhesive. Particleboard immersions on the hot and cold water were able to fix the physical and mechanical properties to meet standard requirement. However, the use of UF adhesive on sorghum stalk resulted in several properties such as thickness swelling, MOE and IB did not meet the standard requirement. Sorghum Bagasse particleboard durability against subterranean termite attack classified as moderately to durable class.
References

[1] Supriyanto 2011 Development of Sorghum for Food, Feed, and Energy (Indonesia: SEAMEO BIOTROP)

[2] Supriyanto 2012 Production of Liquid organic fertilizer derived from sorghum waste in ethanol production (Indonesia: SEAMEO BIOTROP)

[3] Thanapimmetha A, Vutibunchon K, Saisriyoot M and Srinophakun P 2011 Chemical and Microbial Hydrolysis of Sweet Sorghum Bagasse for Ethanol Production Proc. in World Renewable Energy Congress 2011 (Sweden 8-13 May 2011)

[4] Iswanto A H, Fatraisari F, Supriyanto 2012 Pemanfaatan Limbah Batang Sorghum (Sorghum bicolor (L) Monch) Sebagai Bahan Baku Papan Partikel Workshop on the Current Status and Challenges in Sorghum Development in Indonesia (Bogor 25-26 September 2012)

[5] Lawal S A and Ugheoke B I 2010 AU J T 13 (4) 258-60

[6] Maloney TM 1993 Modern Paritcleboard and Dry-Process Fiberboard Manufacturing (San Francisco, USA: Miller Freeman Inc)

[7] Iswanto AH, Febrianto F, Wahyudi I, Hwang WJ, Lee SH, Kwon JH, Kwon SM, Kim, NH, Kondo T 2010 J Fac. Agr. Kyushu Univ 55 (2) 371–77

[8] Kelly MW 1977 Critical Literature Review of Relationship Between Processing Parameter and Physical Properties of particleboard, General Technical Report FPL-10 US Department of Agriculture Forest Service and Forest Products Laboratory University of Wisconsin

[9] Pari G, Roliadi H, Setiawan D, Saepuloh 2006 J Penelitian Hasil Hutan 24 (2) 89-101

[10] Teco 2005 Resins Used In The Production Of Oriented Strand Board, Tech tips No 14 USA

[11] Marrat AA 1992 Technology of Wood Bonding Principles in Practise, (USA: Van Nostrand Reinhold, New York)

[12] Sauter S L 1996 Developing composites from wheat straw Proc. of the 30th International Symposium of Washington State University on ParticleboardComposite Materials, Pullman, Washington pp 197–214

[13] Boquillon N, Elbez G and Schonfeld U 2004 J. Wood Sci 50 230–35

[14] Vick CB 1999 Adhesive bonding of wood materials, In: Wood Handbook: Wood as an engineering material, USDA Forest Serv (USA: Forest Prod. Lab Madison) pp 1–24

[15] Pan Z, Yi Zheng, Zhang R, Jenkins BM 2007 Industrial Crops and Products 26(2) 185-94

[16] Nemli G, Hiziroglu S, Usta M, Serin Z, Ozdemir T, Kalaycioglu H 2004 Effect of residue type and tannin content on properties of particleboard manufacture from black locust For. Prod. J. 54 (2) pp 36-40

[17] Boonstra MJ, Pizzi A, Zomers F, Ohlmeyer M, Paul W 2006 J Holz als Roh-und Werkstoff 64 157-64

[18] Xing C, Zhang SY, Deng J 2004 Holzforschung 58 408-12

[19] Peniyati D 1992 Pengaruh Peredaman Panas dan Dingin selumbar Pada Empat Tingkat Umur Kayu Sengon (Parasenianthes falcataria (L.) Nielsen) Thesis of of under graduate school of Bogor Agricultural University

[20] Iswanto AH 2014 Characterization of Jatropha curcas L Fruit Hulls and Its Utilization to Produce High Quality Particle Board Dissertation of graduate school of graduated school of Bogor Agricultural University