

Development of Pine Bark and Acacia Bark for Particleboard Adhesive Based on Oil Palm Empty Fruit Bunches

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Abstract: Organic adhesive particleboard has the opportunity to be developed to replace particleboard with formaldehyde adhesives which can be detrimental to health. Acacia bark (ATB), pine bark (PTB), and empty fruit bunches of oil palm (EFB) are by-products that have no economic value but have potential as raw materials for particleboard. This study aims to determine particleboard's physical and mechanical properties based on EFB with adhesive ATB and PTB and reduce using formaldehyde adhesive. The combination of using PTB and ATB powder for particleboard adhesive is a novelty in this research. The composition of the particleboard consists of 20-30wt% ATB and PTB powder with 80-70wt% EFB and 5-6% moisture content. The length of EFB fiber used is 0.1-2.0 cm, and the size of ATB and PTB powders is that it passes 40 mesh sieves and is retained by 50 mesh. Hot press time 15-25 minutes. Quality assessment is carried out using Japanese Industry Standard A 5908-2015 for panel products. The test results show that the particleboard meets the standard and prove that ATB and PTB can be used as organic adhesives and have great potential to replace non-organic adhesives.

Keywords: acacia bark, pine bark, particleboard, physical properties, mechanical properties.

基於油棕空果束的刨花板膠粘劑松樹皮和洋槐皮的研製

摘要: 有機粘劑刨花板有機會被開發以用可能有害健康的甲醛粘劑代替刨花板。相思樹皮、松樹皮和油棕空果串是沒有經濟價值但具有作為刨花板原料潛力的副產品。本研究旨在確定基於和油棕空果串的刨花板與粘劑相思樹皮和松樹皮並減少使用甲醛粘劑的刨花板的物理和機械性能。將松樹皮和相思樹皮粉末結合用於刨花板粘劑是本研究的一個創新點。刨花板的成分由 20-30 重量%相思樹皮和松樹皮粉末組成，其中和油棕空果串為 80-70 重量%，水分含量為 5-6%。所用和油棕空果串纖維的長度為 0.1~2.0 厘米，相思樹皮和松樹皮粉末的尺寸為通過 40 目篩並被 50 目截留。熱壓時間 15-25 分鐘。使用日本工業標準 A 5908-2015 對面板產品進行質量評估。試驗結果表明，刨花板符合標準，證明相思樹皮和松樹皮可作為有機膠粘劑，具有替代無機膠粘劑的巨大潛力。

关键词：相思樹皮、松樹皮、刨花板、物理性能、機械性能。

1. Introduction

Non-organic adhesives of particleboards emit formaldehyde which damages human health [1-9]. This fact has encouraged people to find organic ones that are safe. Organic adhesives have evolved over the decades [2], especially for particleboards. Various organic adhesive materials have been developed, such as bagasse [4], totora [5], maize, potato, tapioca and wheat starch [1], banana stalks [7], palm kernel kernels with the addition of ammonium dihydrogen phosphate [8], corn stalks [10-11], Miscanthus stalks [6], soft and hardwoods [12], hemp fiber [13], coir pith [14], bamboo [15] oil palm trunks [16], rice stalks [17], durian rind [18], oil palm trunk and acacia wood [19], black spruce and aspen bark [20], corns tarch [10, 21]. Tannins, or vegetable tannins, are chelate complex polyphenolic compounds derived from plants that taste bitter. Tannins react by agglomerating proteins or other [22] organic compounds, including amino acids and alkaloids. Pine tree bark (PTB) and acacia tree bark (ATB) contain tannins up to 23% [23] and ATB 48% [22-24] respectively. Therefore, they are very likely to be organic adhesives for particleboards. In this work, we studied the potential of three agricultural by-products, namely oil palm empty fruit bunches (EFB), ATB, and PTB, which were processed into particleboards with properties that meet the requirements.

Acacia and oil palm trunks have been used in particleboard [1, 25, 26], but none has used ATB or PTB. Combining PTB and ATB powders to make particleboard adhesives is necessary to study since both contain many types of tannin. Besides, PTB and ATB, as plantation by-products, are renewable. In plantations of pine and acacia trees managed by paper industry companies, the woods are used as raw material for paper, while the barks are left behind as a by-product or waste. Suppose the study shows that both materials are suitable for particleboards, then the use of non-organic-adhesives can be reduced. Particleboards are beneficial for heat insulation, sound insulation, and building interiors. The physical and mechanical properties of particleboards were also characterized. Variations in particleboard behavior were studied concerning the binder parameters discussed in this study.

2. Materials and Methods

2.1. Preparation of Raw Materials

EFB was first washed in a vessel with running water for half an hour then dried in the sun from 09.00-15.30, at which the radiation ranged from 400 to 770 Watt.m^{-2} , based on the solarimeter. The air temperature in the city of Padang at that time was around 26-30°C

with sunny weather. The weight of the fiber before drying was 30 kg with moisture content of 8%. The drying time was 3-6 days. Then, the fiber was cut into 0.1-2 cm [27] and dried in an oven to get a 5-6% moisture content. Each panel required 496-435 g, and the maximum target density was 0.9 g.cm^{-3} . Pine tree bark and acacia tree bark cut using a double blade cutting machine were sieved. The powder passing the 40 mesh ($400 \mu\text{m}$) sieve but retained by the 50 mesh ($297 \mu\text{m}$) one was used as the raw material for the adhesive, as shown in Fig. 1. PTB and ATB powder was dried in an oven to get 5-6% moisture content. Each panel required 124-186 g of ATB and PTB powder.



Fig. 1 Raw materials of particleboard

2.2. Particleboard Making

The size of each particleboard panel made was 25 cm x 25 cm x 1.1 cm with a target density of 1 g.cm^{-3} . The raw materials were EFB, ATB, and PTB, with weight percents of 80:10:10, 75:12.5:12.5, and 70:15:15. The hot pressing times were 15, 20, and 25 minutes at 170°C, 180°C, and 190°C. Each panel weighs 688 g, so that the composition of particleboard in weight percent, namely: EFB and ATB - PTB are 550:138, 516:172, and 482:206 g, respectively referring to the initial experiment, to facilitate the mixing of ATB - PTB powder, 300 mL of distilled water was added to prevent the ATB-PTB powder from being separated from the surface of the EFB fiber. Stirring was done for 10 minutes with a rotation of 45 rpm using a mixer to get a mixture to be put into the mold and cold-pressed for 5 minutes to get a final thickness of 3 cm. After removing the mold, the panel was hot-pressed until it reached a final thickness of 1.1 cm. The sequence of cold pressing, hot pressing, and product processes is shown in Figs. 2-3. The press capacity of the hot pressing machine was 20 tons (3.2 MPa). The application pressure for molding particleboards was 2.5-2.8 MPa at a thickness of 1.1 cm. The maximum temperature was 250°C. A thermostat was used to keep the temperature of the heating plate constant. The number of panels produced was 30. The cooling of particleboards was done in an enclosed space for seven days at an ambient temperature of 26-28°C.

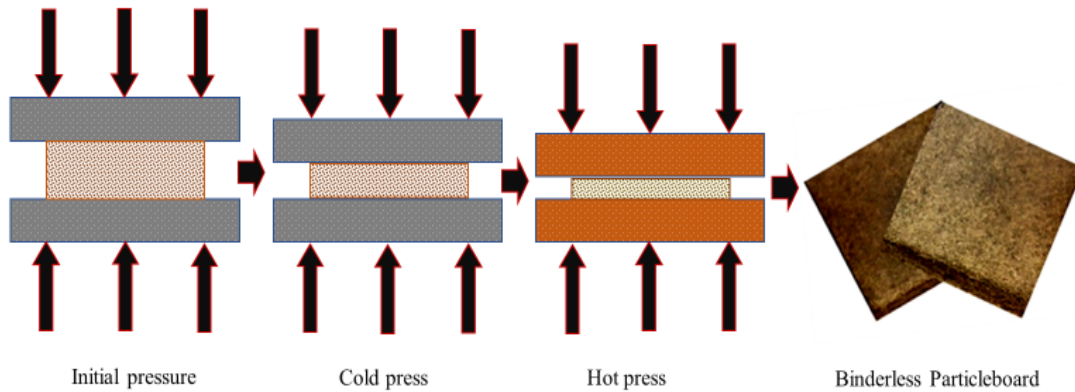


Fig. 2 Manufacture binderless particleboard

2.3. Physical and Mechanical Properties Testing

2.3.1. Physical Properties Test

The physical properties tested were density, moisture content, water absorption, thickness expansion, while the mechanical properties were modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond strength (IB). The testing standards referred to JIS A 5908-2015 [28]. The moisture content was calculated using Equation 1. The initial weight before drying was W or W_1 . Panel drying was carried out in an oven at 103°C for 24 hours; the test object was weighed every 6 hours, and; the final weight was recorded as W_2 . Water absorption and thickness swelling were calculated using Equations 2 and 3. The initial thicknesses before and after immersion were t_1 and t_2 , respectively.

$$\text{Moisture content} = ((W_1 - W_2) / W_2) \times 100\% \quad (1)$$

$$\text{Water absorption} = ((W_2 - W_1) / W_1) \times 100\% \quad (2)$$

$$\text{Thickness swelling} = ((t_2 - t_1) / t_1) \times 100\% \quad (3)$$

2.3.2. Mechanical Properties Test

The physical properties tested were modulus of elasticity, modulus of rupture, and internal bonding referred to ASTM D1037-99; the calculations followed by equations 4, 5, and 6. The 10 KN Universal Testing Machine was used for MOE and IB testing. The standard deviation and average value were calculated from four replications of testing. The value of density, TS, WA, MOR, and IB of the boards was corrected for each target composition.

$$\text{Modulus of elasticity} = (\Delta FL^3) / (4b \cdot h^3 \cdot \Delta y) \quad (4)$$

$$\text{Modulus of rupture} = (3 \cdot \Delta FL) / (2b \cdot h^2) \quad (5)$$

The internal bonding was calculated by equation:

$$\text{Internal bonding} = F/A \quad (6)$$

3. Results and Discussion

3.1. Density and Moisture Contents

Fig. 3 shows the results of the calculation of the density of particleboards at the composition of EFB:ATB:PTB of 70%:15%:15% with hot-pressing times of 15, 20, and 25 minutes. The average density obtained was $0.82 \text{ g} \cdot \text{cm}^{-3}$, which met the standard value

for a medium particleboard density of $0.4\text{--}0.9 \text{ g} \cdot \text{cm}^{-3}$ [28]. The length of hot pressing time allows the particleboard to evaporate more water so that its weight is reduced and reaches density equilibrium at the end of the pressing time. Fig. 4 shows that the moisture content of the particleboard meets the standard but tends to decrease with increasing hot pressing time. At each hot pressing time of 15, 20, and 25 minutes, the decrease in water content showed a significant difference indicated by a deviation of $p < 0.05$. It takes time to remove moisture content from the particleboard under hot compression. At 15 minutes, the moisture content is 11.45% (the highest), and the compression time is 25 minutes, the moisture content is 10.34% (the best). Both meet the JIS standard, which is $< 14\%$. The difference in moisture content with hot pressing time is reasonable because both surfaces of the particle board are covered by a hot press plate so that it prevents the hot steam from escaping into the free air, and the only open path is on the thick side of the particleboard so that compression time plays a role in releasing water vapor freer of air. On the other hand, the role of compression temperature, which varies from 170°C , 180°C , and 190°C , is relatively small for moisture content and density.

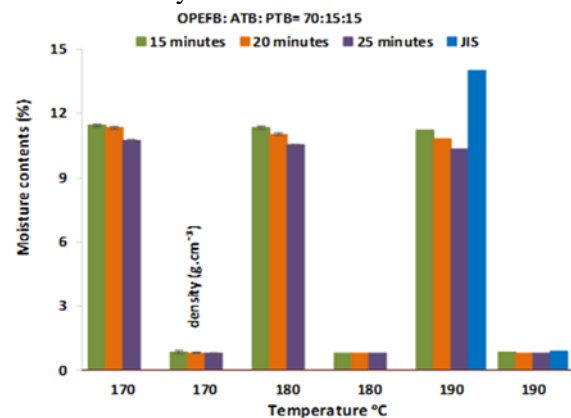


Fig. 3 The density and moisture content

3.2. Water Absorption and Thickness Swelling

Particleboard at composition 80:10:10 is 95.91%, and 56.37% is the highest, at composition 70:15:15, is 89.55% and 56.37% is the lowest, as shown in Fig. 4.

This tells us that the particleboard with the more predominant number of fibers will absorb the water predominantly as well. Research conducted by Nadhari, Ishak, et al. shows the same trend [1]. On the other hand, this particleboard product exhibits dimensional instability to moisture, which is a drawback in its application. Composition, pressure, temperature, and time have changed EFB, PTB, and ATB into particleboard products. On the other hand, the thermo-compression process has also triggered the formation of new bonds involving the fiber elements. One of the important elements in fibers to form bonds is cellulose that, with tannins, can form a bond, as shown in Fig. 5. XRD results of particleboard on all identified compositions show that *S. tabernaemontani* cellulose contains the highest intensity, the structure is $C_{21}H_{28}N_2O_3$ then cellulose, the structure is $C_6H_{10}O_5$, and melting point cellulose is 260-270°C.

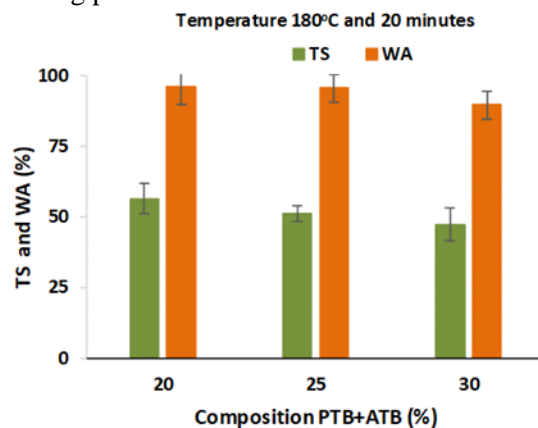


Fig. 4 TS and WA of the particleboard

On the other hand, tannins are complex polyphenolic compounds with a structure of $C_{76}H_{52}O_{46}$ and a melting temperature of 102°C. Applying a hot pressing temperature of 170-190°C with a time of 15-25 minutes has helped trigger the melting of the tannins and form a bond with the cellulose, which produces *S. tabernaemontani* cellulose and provides reinforcement of the particleboard product. The composition of ATB and PTB on particleboard has an important role in increasing the intensity of *S. tabernaemontani* cellulose; increasing the composition of ATB and PTB can increase the intensity of *S. tabernaemontani* cellulose (Fig. 5). Based on the elements cellulose and *S. tabernaemontani* cellulose, which consists of C, H, N, and O, it is believed that these elements form hydrogen bonds.

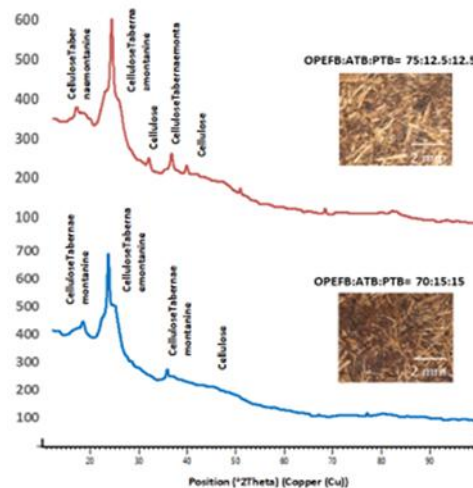


Fig. 5 XRD of the particleboard with two compositions

3.3. Modulus of Rupture and Internal Bonding

Fig. 6 shows a graph of the MOR values of the three EFB: ATB: PTB compositions, namely 80:10:10, 75:12.5:12.5, and 70:15:15. The value of the MOR test was analyzed using the program, and the results showed that the deviation was $p < 0.05$. The data in Fig. 7 indicate that the MOR meets the minimum standard of JIS. The lowest value was 8.06 MPa at composition 80:10:10 with a pressing time of 15 minutes, and the highest value was 8.27 MPa at composition 75:12.5:12.5 with a pressing time of 20 minutes a temperature of 180°C. At 25 minutes of compression, the MOR values decreased in all compositions, telling us that the hot pressing time and temperature greater than 20 minutes and 180°C are not good for ATB and PTB adhesive particleboard. In all hot pressing time variations, the composition's superiority is 75:12.5:12.5, with compression pressure of 3.2 MPa. Nadhari Wan et al. (2014) studied the particleboard properties of oil palm trunks (OPT) and acacia trees (AT) with a particle size of 5-500 m, hot compression pressure of 12 MPa, target density of 1 g.cm^{-3} , the best MOR was 19.96 MPa at composition OPT: AT= 70:30. Although the MOR yields differ, indicating differences in the particle size of the raw material, density, and composition, these three play an important role in manufacturing particleboard without synthetic adhesive [2]. Liping et al. [29] uses kenaf fiber to improve the mechanical properties of the composite. Its tensile strength and tensile modulus increase with the increasing number of fibers in the composite [29]. This particleboard is not a good conductor of heat because it is made of organic material and does not have metal elements; the top and bottom surfaces in contact with the heating plate obtain sufficient heat energy. Observations on the cross-section of the test object before and after the flexural test showed that there was no boundary line of fiber bonds in the middle of the cross-section, telling us that the area is getting sufficient heat to trigger the melting of the tannins to

bind the cellulose, although it is hindered by the low

thermal conductivity of the raw material.

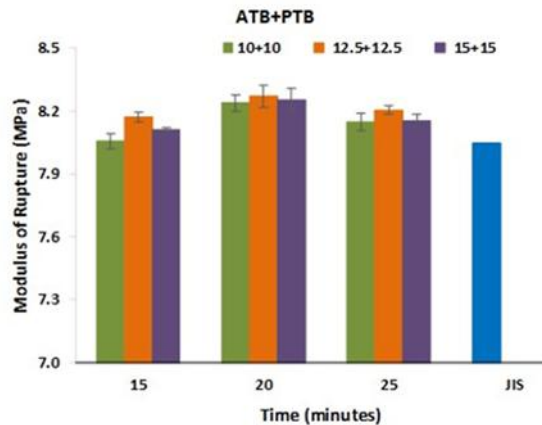
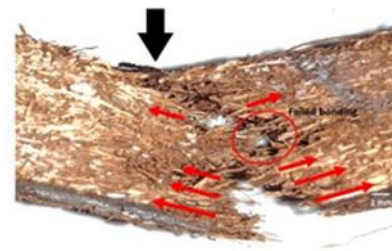


Fig. 6 Modulus of rupture



3.4. Internal Bonding

Fig. 7 shows the particleboard IB, and the average value meets the standard. The increase in the composition of PTB and ATB in particleboard tends to increase the IB value. At 20 minutes of pressing time, the best IB value is obtained for all compositions and the compression time of 25 minutes tends to decrease. In general, the trend is close to the similarity with Fig. 7. From the three variations in composition and time, the IB value is 0.15-0.162 MPa. The particleboard test conducted by Nadhari Wan et al. (2014) at the composition of 70:30 obtained an IB value of 0.2 MPa, and in other compositions, the value was lower [22].

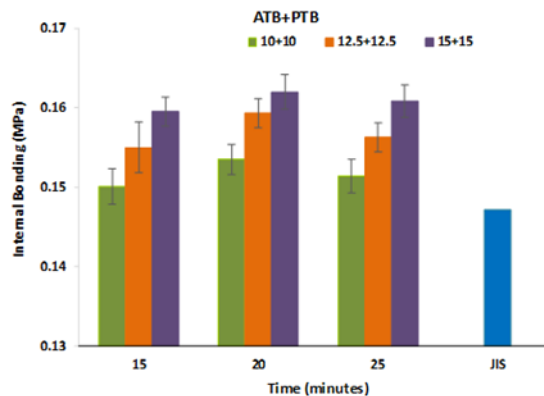


Fig. 7 Internal bonding

4. Conclusion

The experimental results showed that pine bark and acacia bark as organic adhesives were feasible to produce particleboard and reduce non-organic adhesives. The properties of the particleboard meet the standards, and at the composition of 25 wt%, ATB and PTB have good mechanical properties. The weakness of this particleboard product is its low dimensional stability in wet and humid places. The combined application of PTB and ATB as a particleboard adhesive is a novelty in this research because a search for journal publications in the last ten years shows that no research has been found combining PTB and ATB as a particleboard adhesive. The limitation of this study is that it has not discussed the mechanism of binding of

PTB and ATB powders containing tannins with EFB fibers.

References

- [1] NADHARI W.N.A.W., ISHAK N.S., DANISH M., ATAN S., MUSTAPHA A., KARIM N.A., HASHIM R., SULAIMAN O., and YAHAYA A.N.A. Mechanical and physical properties of binderless particleboard made from oil palm empty fruit bunch (OPEFB) with addition of natural binder. *Materials Today: Proceedings*, 2020, 31: 287-291. DOI: 10.1016/j.matpr.2020.06.009.
- [2] SAAD A., and KASIM A. Characteristics of Particleboard Made from Trees Pine Bark, and Oil Palm Empty Fruit Bunches. *International Journal of Scientific and Technology Research*, 2020, 9(9): 320-327. DOI: <http://www.ijstr.org/final-print/sep2020/>.
- [3] AYRILMIS N., KAPTI T., GÜREL A., and OHLMEYER M. Reducing formaldehyde emission from wood-based panels by modification of UF and MUF resins with condensates obtained from kiln-drying of wood. *Holzforschung*, 2018, 72(9): 753-757. DOI: 10.1515/hf-2017-0194.
- [4] NADHARI W.N.A.W., KARIM N.A., BOON J.G., SALLEH K.M., MUSTAPHA A., HASHIM R., SULAIMAN O., and AZNI M.E. Sugarcane (*Saccharum officinarum* L.) bagasse binderless particleboard: Effect of hot pressing time study. *Materials Today: Proceedings*, 2020, 31: 313-317. DOI: 10.1016/j.matpr.2020.06.016.
- [5] HÝSKOVÁ P., GAFF M., HIDALGO-CORDERO J.F., and HÝSEK Š. Composite materials from totora (*Schoenoplectus californicus*. C.A. Mey, Sojak): Is it worth it? *Composite Structures*, 2020, 232: 111572. DOI: 10.1016/j.compstruct.2019.111572.
- [6] KLÍMEK P., WIMMER R., MEINLSCHMIDT P., and KÚDELA J. Utilizing Miscanthus stalks as raw material for particleboards. *Industrial Crops and Products*, 2018, 111: 270-276. DOI: 10.1016/j.indcrop.2017.10.032.
- [7] NADHARI W.N.A.W., DANISH M., NASIR M.S.R.M., and GENG B.J. Mechanical properties and dimensional stability of particleboard fabricated from steam pre-treated banana trunk waste particles. *Journal of Building Engineering*, 2019, 26: 22-25. DOI: 10.1016/j.job.2019.100848.
- [8] KOMARIAH R.N. MIYAMOTO T., TANAKA S., PRASETIYO K.W., SYAMANI F.A., SUBYAKTO N., UMEZAWA T., KANAYAMA K., and UMEMURA K. High-

- performance binderless particleboard from the inner part of oil palm trunk by addition of ammonium dihydrogen phosphate. *Industrial Crops and Products*, 2019, 141: 111761. DOI: 10.1016/j.indcrop.2019.111761.
- [9] NASIR M., KHALI D.P., JAWAID M., TAHIR P.M., SIAKENG R., ASIM M., and KHAN T.A. Recent development in binderless fiber-board fabrication from agricultural residues: A review. *Construction and Building Materials*, 2019, 211: 502-516. DOI: 10.1016/j.conbuildmat.2019.03.279.
- [10] PRASETIYO K.W., OCTAVIANA L., ASTARI L., and SYAMANI F.A. Physical-Mechanical Properties and Bonding Mechanism of Corn Stalks Particleboard with Citric Acid Adhesive. *Tropical Wood Science and Technology*, 2018, 16(2): 131-140.
- [11] ATOYEBI O.D., OSUEKE C.O., BADIRU S., GANA A.J., IKPOTOKIN I., MODUPE A.E., and TEGENE G. A. Evaluation of particle board from sugarcane bagasse and corn cob. *International Journal of Mechanical Engineering and Technology*, 2019, 10(1): 1193-1200, DOI: iaeme.com/IJMET/index.asp.
- [12] GAO J., KIM J.S., and DANIEL G. Effect of thermal modification on the micromorphology of decay of hardwoods and softwoods by the white-rot fungus *Pycnoporus sanguineus*. *Holzforchung*, 2017. [Online] Available from: <https://www.degruyter.com/document/doi/10.1515/hf-2017-0190/html>.
- [13] ALMUSAWI A., LACHAT R., ATCHOLI K.E., and GOMES S. Proposal of manufacturing and characterization test of binderless hemp shive composite. *International Biodeterioration and Biodegradation*, 2016, 115: 302-307. DOI: 10.1016/j.ibiod.2016.09.011.
- [14] AHMED E., DAS A., HANNAN M., and SHAMS M. Particle board from coir pith. *Bangladesh Journal of Scientific and Industrial Research*, 2016, 51(3): 239-245. DOI: 10.3329/bjsir.v51i3.29436.
- [15] Waste V. Hybrid Particleboard Made from Bamboo. *Bioresources*, 2016, 11(1): 306-323.
- [16] YUSOF M., LAMAMING J., HASHIM R., YHAYA M.F., SULAIMAN O., and SELAMAT M.E. Flame retardancy of particleboards made from oil palm trunk-poly(vinyl) alcohol with citric acid and calcium carbonate as additives. *Construction and Building Materials*, 2020, 263: 120906. DOI: 10.1016/j.conbuildmat.2020.120906.
- [17] KUROKOCHI Y., and SATO M. Effect of surface structure, wax, and silica on the properties of binderless board made from rice straw. *Industrial Crops and Products*, 2015, 77: 949-953. DOI: 10.1016/j.indcrop.2015.10.007.
- [18] PENJUMRAS P., RAHMAN R.A., TALIB R.A., and ABDAN K. Mechanical properties and water absorption behaviour of durian rind cellulose reinforced poly (lactic acid) biocomposites. *International Journal on Advanced Science, Engineering and Information Technology*, 2015, 5(5): 343-349. DOI: <http://dx.doi.org/10.18517/ijaseit.5.5.574>.
- [19] PAPAPOPOULOU E., and CHRISSAFIS K. *Particleboards from agricultural lignocellulosics, and biodegradable polymers prepared with raw materials from natural resources*. Elsevier Ltd, 2017.
- [20] TUDOR E.M., ZWICKL C., EICHINGER C., PETUTSCHNIGG A., and BARBU M.C. Performance of softwood bark comminution technologies for determination of targeted particle size in further upcycling applications. *Journal of Cleaner Production*, 2020, 269: 122. DOI: 10.1016/j.jclepro.2020.122412.
- [21] MAHIEU A., ALIX S., and LEBLANC N. Properties of particleboards made of agricultural by-products with a classical binder or self-bound. *Industrial Crops and Products*, 2018, 130: 371-379. DOI: 10.1016/j.indcrop.2018.12.094.
- [22] WAN S.T.N., ROKIAH H., SALIM H., OTHMAN S., JIA B., KUSHAIRI S., MOHD A., and MASATOSHI S. Measurement of some properties of binderless composites manufactured from oil palm trunks and Acacia mangium. *Measure Journal*, 2014, 50: 250-254. DOI: /10.1016/j.measurement.2014.01.002.
- [23] EKA F.C. Microwave-assisted Tannins Extraction from Pine Bark: Effect of Microwave Power, Solvent Type and Extraction Time. *Journal of Integrated Design and Process Science*, 2017, 6(4): 155-161. <http://jurnal.untirta.ac.id/index.php/jip> Submitted.
- [24] ZHANG J., XI X., LIANG J., PIZZI A., DU G., and DENG S. Tannin-based adhesive cross-linked by furfuryl alcohol-glyoxal and epoxy resins. *International Journal of Adhesion and Adhesives*, 2019, 94: 47-52. DOI: 10.1016/j.ijadhadh.2019.04.012.
- [25] BASKARAN M., HASHIM R., SULAIMAN O., HIZIROGLU S., SATO M., and SUGIMOTO T. Optimization of press temperature and time for binderless particleboard manufactured from oil palm trunk biomass at different thickness levels. *Materials Today Communications*, 2015, 3: 87-95. DOI: 10.1016/j.mtcomm.2015.04.005.
- [26] BASKARAN, M., HASHIM R., SAID N., RAFFI S.M. and BALAKRISHNAN K. Properties of binderless particleboard from oil palm trunk with addition of polyhydroxyalkanoates. *Composites Part B*, 2012, 43(3): 1109-1116. DOI: [10.1016/j.compositesb.2011.10.008](https://doi.org/10.1016/j.compositesb.2011.10.008)
- [27] SAAD A., KASIM A., and SANTOSA G. Effect Of Fiber Length Of The Oil Palm Empty Fruit Bunch On Manufacture Particle Board With Urea Formaldehyde Adhesive Toward The Characteristics *International Journal of Scientific and Technological Research*, 2018, 7(11) 108-114. <http://www.ijstr.org/research-paper-publishing.php?month=nov2018>.
- [28] JAPANESE INDUSTRIAL STANDARDS. *JIS A 5908-2015*. Japanese Standards Association, Tokyo, 2015. [Online] Available from: https://www.techstreet.com/standards/jis-a-5908-2015?product_id=1923469
- [29] LIPING H.E., CHAOXIONG P.I., CHEN D., TAN B., ZHANG B., and YUAN J. Effect of Fiber Content on Mechanical Properties and Vibration Damping Characteristics of Bast Fiber Reinforced Composites. *Journal of Hunan University Natural Sciences*, 2018, 45(12): 66-72. DOI: 10.16339/j.enki.hdxbzkb.2018.12.010.

參考文:

- [1] NADHARI W.N.A.W., ISHAK N.S., DANISH M., ATAN S., MUSTAPHA A., KARIM N.A., HASHIM R., SULAIMAN O. 和 YAHAYA A.N.A. 添加天然粘合劑的油棕空果串製成的無粘合劑刨花板的機械和物理性能。今日材料：訴訟，2020，31：287-291。DOI：10.1016/j.matpr.2020.06.009。
- [2] SAAD A. 和 KASIM A. 由樹木松樹皮和油棕空果束製成的刨花板的特性。國際科技研究雜誌，2020，9(9)：320-327. DOI: <http://www.ijstr.org/final-print/sep2020/>。

- [3] AYRILMIS N.、KAPTI T.、GÜREL A. 和 OHLMEYER M. 通過用木材窯幹獲得的冷凝物改性 UF 和 MUF 樹脂來減少人造板的甲醛排放。木材研究, 2018, 72(9): 753-757. DOI: 10.1515/hf-2017-0194。
- [4] NADHARI W.N.A.W.、KARIM N.A.、BOON J.G.、SALLEH K.M.、MUSTAPHA A.、HASHIM R.、SULAIMAN O. 和 AZNI M.E. 甘蔗(釀酒酵母)甘蔗渣無粘合劑刨花板: 熱壓時間研究的影響。今日材料: 訴訟, 2020, 31: 313-317。DOI: 10.1016/j.matpr.2020.06.016。
- [5] HÝSKOVÁ P.、GAFF M.、HIDALGO-CORDERO J.F. 和 HÝSEK Š. 來自龍虎(加州鯨魚 s. 卡爾·安東·馮·邁耶, 大豆) 的複合材料: 值得嗎? 複合結構, 2020, 232: 111572. DOI: 10.1016/j.compstruct.2019.111572。
- [6] KLÍMEK P.、WIMMER R.、MEINLSCHMIDT P. 和 KÚDELA J. 利用芒草莖作為刨花板的原材料。工業作物和產品, 2018, 111: 270-276。DOI: 10.1016/j.indcrop.2017.10.032。
- [7] NADHARI W.N.A.W.、DANISH M.、NASIR M.S.R.M. 和 GENG B.J. 由蒸汽預處理的香蕉樹幹廢料顆粒製成的刨花板的機械性能和尺寸穩定性。建築工程學報, 2019, 26: 22-25。DOI: 10.1016/j.job.2019.100848。
- [8] KOMARIAH R.N.、MIYAMOTO T.、TANAKA S.、PRASETIYO K.W.、SYAMANI F.A.、SUBYAKTO N.、UMEZAWA T.、KANAYAMA K. 和 UMEMURA K. 通過添加磷酸二氫銨從油棕樹幹內部製成的高性能無粘合劑刨花板。工業作物和產品, 2019, 141: 111761. DOI: 10.1016/j.indcrop.2019.111761。
- [9] NASIR M.、KHALI D.P.、JAWAID M.、TAHIR P.M.、SIKENG R.、ASIM M. 和 KHAN T.A. 農業廢棄物無粘合劑纖維板製造的最新發展: 綜述。建築與建材, 2019, 211: 502-516。DOI: 10.1016/j.conbuildmat.2019.03.279。
- [10] PRASETIYO K.W.、OCTAVIANA L.、ASTARI L. 和 SYAMANI F.A. 玉米秸稈刨花板與檸檬酸粘合劑的物理機械性能和粘結機制。熱帶木材科學與技術, 2018, 16(2): 131-140。
- [11] ATOYEBI O.D.、OSUEKE C.O.、BADIRU S.、GANA A.J.、IKPOTOKIN I.、MODUPE A.E. 和 TEGENE G.A. 從甘蔗渣和玉米芯中評估刨花板。國際機械工程與技術雜誌, 2019, 10(1): 1193-1200, DOI: iaeme.com/IJMET/index.asp。
- [12] GAO J.、KIM J.S. 和 DANIEL G. 熱改性對白腐真菌密孔菌對硬木和軟木腐爛的微觀形態的影響。木材研究, 2017。[在 線] 可 從 : <https://www.degruyter.com/document/doi/10.1515/hf-2017-0190/html> 獲取。
- [13] ALMUSAWI A.、LACHAT R.、ATCHOLI K.E. 和 GOMES S. 無粘合劑大麻碎屑複合材料的製造和表徵測試提案。國際生物降解和生物降解, 2016, 115: 302-307. DOI: 10.1016/j.biod.2016.09.011。
- [14] AHMED E.、DAS A.、HANNAN M. 和 SHAMS M. 來自椰殼的刨花板。孟加拉國科學與工業研究雜誌, 2016 年, 51 (3) : 239-245。DOI: 10.3329/bjsir.v51i3.29436。
- [15] 廢物 V. 由竹子製成的混合刨花板。生物資源, 2016, 11 (1) : 306-323。
- [16] YUSOF M.、LAMAMING J.、HASHIM R.、YHAYA M.F.、SULAIMAN O. 和 SELAMAT M.E. 用檸檬酸和碳酸鈣作為添加劑的油棕樹幹聚(乙烯)醇製成的刨花板的阻燃性。建築與建築材料, 2020, 263: 120906. DOI: 10.1016/j.conbuildmat.2020.120906。
- [17] KUROKOCHI Y. 和 SATO M. 表面結構、蠟和二硫化砷對稻草製成的無粘合劑板性能的影響。工業作物和產品, 2015, 77: 949-953。DOI: 10.1016/j.indcrop.2015.10.007。
- [18] PENJUMRAS P.、RAHMAN R.A.、TALIB R.A. 和 ABDAN K. 榴蓮皮纖維素增強聚(乳酸)生物複合材料的機械性能和吸水行為。國際先進科學、工程和信息技術雜誌, 2015, 5(5): 343-349。DOI: <http://dx.doi.org/10.18517/ijaseit.5.5.574>。
- [19] PAPAPOPOULOU E. 和 CHRISAFIS K. 使用自然資源原料製備的農業木質纖維素和可生物降解聚合物的刨花板。愛思唯爾有限公司, 2017。
- [20] TUDOR E.M.、ZWICKL C.、EICHINGER C.、PETUTSCHNIGG A. 和 BARBU M.C. 軟木樹皮粉碎技術在進一步升級再造應用中確定目標粒度的性能。清潔生產雜誌, 2020, 269: 122. DOI: 10.1016/j.jclepro.2020.122412。
- [21] MAHIEU A.、ALIX S. 和 LEBLANC N. 由具有經典粘合劑或自粘的農業副產品製成的刨花板的特性。工業作物和產品, 2018, 130: 371-379。DOI: 10.1016/j.indcrop.2018.12.094。
- [22] WAN S.T.N.、ROKIAH H.、SALIM H.、OTHMAN S.、JIA B.、KUSHAIRI S.、MOHD A. 和 MASATOSHI S. 測量由油棕樹乾和金合歡製成的無粘合劑複合材料的某些性能。測量雜誌, 2014, 50: 250-254。DOI: /10.1016/j.measurement.2014.01.002。
- [23] 伊卡足球俱樂部微波輔助從松樹皮中提取單寧: 微波功率、溶劑類型和提取時間的影響。集成設計與工藝科學學報, 2017, 6(4): 155-161. <http://jurnal.untirta.ac.id/index.php/jip> 已提交。
- [24] ZHANG J.、XI X.、LIANG J.、PIZZI A.、DU G. 和 DENG S. 糠醇-乙二醛和環氧樹脂交聯的單寧膠粘劑。國際膠粘劑雜誌, 2019, 94: 47-52。DOI: 10.1016/j.ijadhadh.2019.04.012。
- [25] BASKARAN M.、HASHIM R.、SULAIMAN O.、HIZIROGLU S.、SATO M. 和 SUGIMOTO T. 優化由不同厚度水平的油棕樹幹生物質製成的無粘合劑刨花板的壓制溫度和時間。今日材料通訊, 2015 年, 3: 87-95。DOI: 10.1016/j.mtcomm.2015.04.005。
- [26] BASKARAN M.、HASHIM R.、SAID N.、RAFFI S.M. 和 BALAKRISHNAN K. 添加聚羧基鏈烷酸酯的油棕樹幹無粘合劑刨花板的性能。複合材料 B 部分, 2012, 43(3): 1109-1116。DOI: 10.1016/j.compositesb.2011.10.008
- [27] SAAD A.、KASIM A. 和 SANTOSA G. 油棕空果束纖維長度對用脲醛膠粘劑製造刨花板的影響國際科技研究雜誌, 2018, 7(11) 108-114. <http://www.ijstr.org/research-paper-publishing.php?month=nov2018>。
- [28] 日本工業標準。日標 5908-2015。日本標準協會, 東京, 2015 年。[在 線] 來自:

https://www.techstreet.com/standards/jis-a-5908-2015?product_id=1923469

[29] LIPING H.E., CHAOXIONG P.I., CHEN D., TAN B., ZHANG B., 和 YUAN J. 纖維含量對韌皮纖維增強複合材料力學性能和減振特性的影響。湖南大學自然科學學報, 2018, 45(12): 66-72. DOI : 10.16339/j.enki.hdxzbzkb.2018.12.010。