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Plastic Composite Boards from Oil Palm Empty Fruit Bunches (OP-EFB) with Variation of Pressing Temperature: Physical and Mechanical Properties

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Abstract. *Plastic composite boards are made from OP-EFB (oil palm empty fruit bunches) which function as a filler, while HDPE (high-density polyethylene) plastic is used as a matrix. This study was conducted to analyze the physical and mechanical properties of plastic composite boards from empty palm oil bunches and high-density polyethylene plastic based on the effect of pressing temperature and determine the optimum pressing temperature. The temperature used for pressing were 140 °C, 150 °C, 160 °C, 170 °C, and 180 °C with the addition of coupling agents of MAH (maleic anhydride) and BPO (benzoyl peroxide) initiator. Based on the research that has been carried out, the physical and mechanical properties of the resulting plastic composite board are affected by differences in pressing temperature, with an optimum temperature of 170 °C the results of the testing were density, water absorption, MOR (modulus of rupture) compressive strength parallel to the surface and compressive strength perpendicular to the surface were 0.950 g/cm³, 0.090 %, 134.40 kg/cm², 465.80 kg/cm², and 50.40 kg/cm² respectively and the average test results for all treatments were 0.88 g/cm³, 1.00%, 130.20 kg/cm² and 426.96 kg/cm² respectively. The mechanical physical properties of plastic composites meet SNI 8154-2015 standard on WPC (wood plastic composites), except for MOR and perpendicular compressive constancy of the surface.*

Keywords: *fiber; filler; matriks; HDPE; MOR*

1. Introduction

Oil palm is one of the plantation crops that occupy an important position in the agricultural and plantation sectors. In 2017 in 44 countries, as many as 21.09 million ha of land were planted with oil palm trees [1]. The countries with the highest oil palm cultivation are Indonesia, Malaysia, Nigeria, and Thailand, each with an area of 9.28, 5.11, 3.04, and 0.76 million ha. Production of FFB (fresh fruit bunches) exceeded 317.57 million tons, where Indonesia was the largest FFB-producing country (49.86%), followed by other countries such as Malaysia (32.04%), Thailand (4.59%) and Nigeria (2.44%) [1]. In Indonesia, palm oil is one of the mainstay commodities whose development is so rapid.

The increase in palm oil production in each country from year to year aligns with the increasing volume of waste it produces [2]. OP-EFB (Oil palm empty fruit bunches) is a form of

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fibrous lignocellulosic residue with considerable potential as fiber reinforcement or filler, in view of its signification quantities in the oil palm industry [3]. Utilization of fiber waste, especially in the palm oil industry as a raw material in the development of composites, is a challenge for researchers and industry to obtain higher value-added and efficient products [4].

Palm oil industry waste is a source of waste that is quite large in volume. According to [5], 1 ton of palm oil production will produce waste in the form of 6.5 % or 65 kg of shell waste, 4 % or 40 kg of the wet decanter (palm mud), 13 % or 130 kg of fiber (fiber), and 23 % of empty palm fruit bunches or 230 kg, as well liquid waste as much as 50 %. One solution for managing EFB waste is to use it as a wood substitute filler in the wood plastic composite manufacturing process. OP-EFB has good interfacial adhesion properties, low water absorption resistance when used in lignocellulosic composites, and hydrophilic characteristics (hydroxyl groups in cellulose, lignocellulose, and hemicellulose) [6], [7]. Apart from being used as filler for WPC, OP-EFB is also widely used as nanofibrillated cellulose [8], a potential source of fermentable sugars that can be used for ethanol production [9], as exploratory catalysts for FAME biodiesel production [10] , and others.

Wood composite is a term to describe any product that is bonded together with raw materials derived from sheets or small pieces of wood [11]. Thus, from this understanding, it can be derived that the notion of plastic composite boards is a composite made of plastic as a matrix and wood powder as a filler, which has the combined properties of both [12]. Recently, researchers around the world have studied WPC (Wood Plastic Composites) which is a relatively recently developed group of polymer composites [13], [14], as has been researched the mechanical and physical properties of wood plastic composite made of polypropylene, wood flour and nanocly [15], mechanical properties of composite made of sawdust and high-density polyethylene (HDPE) [16].

Plastic composites board can reduce the use of wood directly by mixing fiber/filler (kenaf fiber, sisal, straw, palm fronds, etc.) with thermoplastic materials. The increasing use of plastic in recent years has also increased the amount of waste. Plastic as waste is very difficult to decompose in the natural environment, so recycling it into other products is the best possibility. Based on this, it is very necessary to research plastic composite boards. Plastic composites are glimpsed as a relatively new group of polymer composites being developed by researchers and industry [17].

This research is expected to be used as a means to reduce the amount of waste, especially plastic waste and waste of oil palm empty fruit bunches. It is hoped that oil palm empty fruit bunches can be used as raw material for filler plastic composite boards from natural fibers because considering a large amount of waste of oil palm empty fruit bunches that have not been utilized. In Indonesia, the availability of natural fiber is abundant and easy to find. Palm fiber is also one of the natural fibers which are abundantly available in many countries and is used as reinforcement in composite and polymer boards [18]. The results of this research are also expected to develop innovations in Plastic Composite Board. The utilization of oil palm empty fruit bunches powder as a composite filler can later be used as an alternative material for industries in Indonesia. One of the uses of empty oil palm bunch waste so that it is not wasted is as a filler material in the manufacture of cellulose composite boards. To produce national standard particle boards, it is necessary to conduct research on the use of temperature in the manufacture of composite boards. The setting of the pressing temperature during the composite manufacturing process largely determines the properties of the resulting composite. This is because increasing the pressing temperature does not exactly improve the properties produced. Therefore, in this study, the pressing temperature used was varied to determine the appropriate optimum compression temperature of the composite plastic board from OP-EFB and HDPE plastic with the pressing time and pressure that have been exhausted according to several studies that have been carried out.

2. Methods

2.1 Materials

The material used in this study was OP-EBF (oil palm - empty fruit bunches) obtained from PTPN (Perseroan Terbatas Perkebunan Nusantara) VI, West Pasaman Regency, West Sumatra which had been chopped and compressed. Types of polyethylene plastics are HDPE (high-density polyethylene) in the form of particles, coupling agents MAH (maleic anhydride) was acquired from Merck, and BPO (benzoyl peroxide) initiator.

2.2 Preparation of OP-EFB and HDPE Plastic

The filler material in the manufacture of this plastic composite board is OP-EFB that have been chopped and pressed to obtain a fiber fraction. Then, the fiber was milled with a Retsch Milling and sifted so that the particles passed through a 60-mesh sieve. The particles were then dried using an oven to obtain a moisture content of <10%. The adhesive used was HDPE plastic and BPO which had been mixed in powder form. Furthermore, sieving was carried out so that the particles pass through a 60-mesh sieve. The ratio of EFB and HDPE plastic was 1:1 to the weight of the board to be made.

The materials needed to make a plastic composite board from OP-EFB and HDPE plastic for each board are according to the below calculation [19]:

1) The dimensions of the panels made are 20 x 20 x 1 cm^3 so that the volume is 400 cm^3
2) Targeted board density is 1.25 g/cm^3
3) The target weight of one panel is calculated by the formula to obtain 500 g
4) Coupling Agents MAH added is 5% of the matrix weight, which is 10 g

5) The initiator, which is benzoyl peroxide (BPO) is added at a rate of 15% of the weight of compatibility (MAH), which is 1.5 g
6) The amount of OP-EFB and HDPE used is 41% each
7) Material requirements for each are: EPEFB powder = 194.25 g; HDPE powder = 194.25 g; MAH = 10 g; BPO = 1.5 g.

2.3 Manufacturing of Plastic Composite Board

The stages in the manufacture of composite plastic boards are as follows: (1) Weigh the materials in the form of EFB, HDPE plastic, MAH, and BPO. (2) Mix the powders with MAH and prepare them. (3) The metal plate is coated with wax paper and a mold is placed on it. (4) Transfer the mixture into a 20 x 20 x 1 cm^3 mold and compaction. (5) Cold pressing in the mold for 20 minutes then the prospective board is removed from the cold press. (6) Press the prospective board on a hot press for ±15 minutes with temperatures according to treatment, namely 140 °C, 150 °C, 160 °C, 170 °C, and 180 °C pressure 15 kg/cm^2.

2.5 Materials Characterization

The analysis carried out on empty oil palm fruit bunches included water content [20], hemicellulose, cellulose, lignin [21], extractive content by the soxhlet method [22], density, water absorption while the observation of the mechanical properties of plastic composite boards consisted of modulus of rupture, and compression strength [23]. After passing through the conditioning process, the composite board will be tested for its properties. The cutting of composite boards is guided by [23]. The pattern of composite board pieces can be seen in Figure 1.

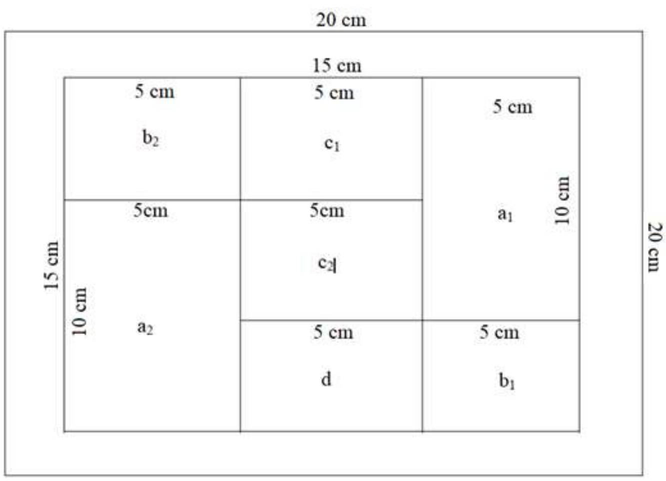

Figure 1. Test Sampling Pattern

Information:

a1 and a2	: Examples of MOR
b1 and b2	: Sample test for water absorption and density
c1 and c2	: Example of compressive strength test perpendicular to the surface
d	: Sample test for pressure parallel to the surface

3. Results and Discussion

3.1 Raw Material Analysis

In this study, before the manufacture of plastic composites board from OP-EFB fibers, a chemical analysis was also carried out on the chemical composition of OP-EFB fibers. The composition obtained can be seen in Figure 2 below.

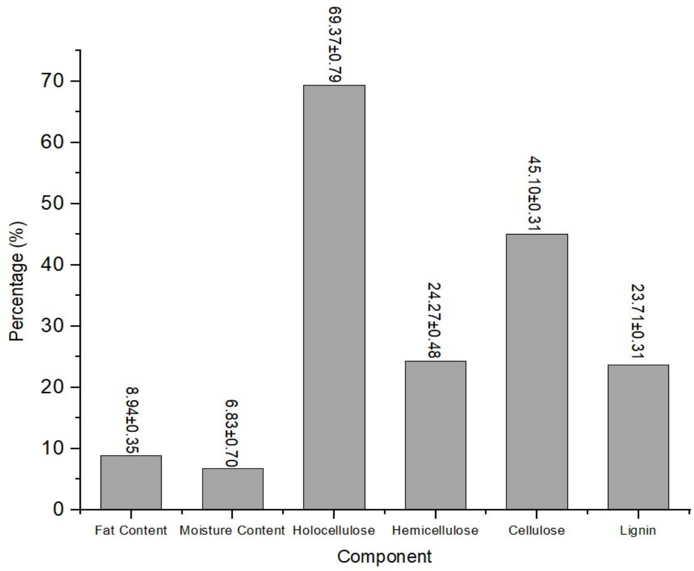

Figure 2. Chemical Components of OP-EFB Fiber

Figure 2 shows the values contained in OP-EFB fiber, namely 8.94% extractive content, 6.83% water, 69.37% holocellulose, 24.27% hemicellulose, 45.10% cellulose, and 23.71% lignin. High cellulose content is needed for the manufacture of plastic composite boards. The content of holocellulose in general is inversely proportional to the amount of lignin. The higher the holocellulose content in the wood, the lower the lignin content [24].

Other researchers found that the chemical composition of OPEFB consisted of 44.4% cellulose, 30.9% hemicellulose, and 14.2% lignin. High cellulose content and low lignin content can generate added value because they are potential resources to be developed. This is due to cellulose biomass being inexhaustible, renewable, biodegradable, recyclable, and also derivatizable [24], [25]. The test results are shown in Figure 3 below.

Water Absorption

Compression

Compression Press Parallel to Surface

Compression Press Perpendicular Surface

Figure 3. Physical and Mechanical Properties of Wood-Plastic Composite Board

3.2 Physical Properties of Plastic Composite Board

3.2.1 Density

Based on the results of the analysis of variance, showed that the difference in compression temperature significantly affected the density of the plastic composite board. The average density value can be seen in Figure 4. The average density of plastic composite boards from OP-EFB increased along with the high compression temperature used. This result was obtained because the compression with a higher temperature facilitated the distribution of the matrix between the OP-EFB fibers to be evenly mixed so that the gaps or cavities on the composite surface became smaller. While pressing at low temperatures, the distribution of particles in the mixture was uneven during the formation of the composite board, so some of the particles agglomerated and resulting in the surface of the board to be not completely covered by the matrix (HDPE adhesive) and OP-EFB as filler was not completely bonded to the matrix, causing the particle density to become low. In line with the statement of low density also occurs because of the matrix pores that have not been filled with filler [18]. In addition, the use of MAH compatibilizer can improve the compatibility between matrix and filler to form better physical and mechanical properties.

3.2.2 Water Absorption

Based on the results of the analysis of variance at the 5% level, it showed that the difference in pressing temperature affects the water absorption of the plastic composite board and no further tests were carried out. The average water absorption value of plastic composite boards from empty oil palm fruit bunches with different compression temperatures decreased along with the high compression temperature used. This is because the high pressing temperature affected the ability of the plastic composite board to absorb water since the palm trunk particles were covered by a hydrophobic HDPE matrix. The higher the P temperature is, the lower the water absorption capacity of the composite board will be [26]. The average value of water absorption can be seen in Figure 4.

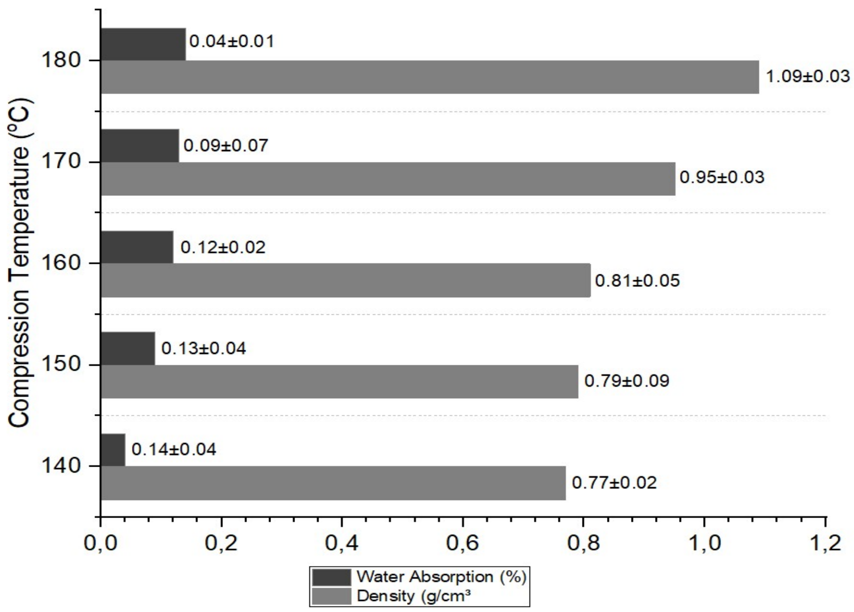

Figure 4. Physical Properties of Plastic Composite Board

3.3 Mechanical Properties of Plastic Composite Board

3.3.1 Modulus of Rupture (MOR)

Based on the results obtained, it can be seen that the MOR of the plastic composite board increased with increasing compression temperature to 170.0^{o}C and decreased at 180.0^{o}C compression temperature. This is due to the compression at low temperatures resulting in a lack of adhesive flow contained in the wood so that the bonding between particles in the composite is not good and also the number of pores as initial cracks is high.

Based on the results of the analysis of variance, it showed that the difference in compression temperature had no significant effect at the 5% level on the MOR of plastic composite boards. The average value of fracture toughness can be seen in Figure 5. a with coefficient of diversity of 3.88%.

3.3.2 Compression Strength Parallel to Surface

The value of compressive strength parallel to the surface of the plastic composite board produced as a whole has met the standard of SNI 8154-2015, which requires the value of compressive strength parallel to the surface of the Wood Plastic Composite of at least 200 kg/cm². The average value of compressive strength parallel to the surface of the plastic composite board obtained was higher than the average value obtained by [27] of 27.88 kg/cm². From the results obtained, the average compressive strength value parallel to the surface of the plastic composite board has increased.

The increase in the value of compressive strength is due to the effect of increasing the compression temperature, The improvement in compression temperature, also increased the quality of the plastic composite boards produced because the matrix distribution between OP-EFB was evenly distributed so that the compressive strength parallel to the surface will also increase. This is in line with the opinion of [11] who stated that with increasing temperature and pressing time, the quality of the resulting composite board will also increase.

In addition, the compressive strength value parallel to the surface is also influenced by the density of the resulting particle board, where the density value is directly proportional to the compressive strength value parallel to the surface. Based on the analysis of variance, it showed that the difference in compression temperature significantly affected the compressive strength parallel to the surface of the plastic composite board. The average compressive strength values parallel to the surface can be seen in Figure 5. b with a coefficient of diversity of 9.36%.

3.3.3 Compression Perpendicular Surface

The highest value of the compressive strength perpendicular to the surface of the plastic composite board was in treatment D (5150.4 kg/cm²) and the lowest compressive strength parallels to the surface of the plastic board was in treatment A (28.3 kg/cm²). When compared with the standard SNI 8154–2015, the value of the compressive strength perpendicular to the surface of the plastic composite board meets the standard only at the compression temperature treatment of 170.0°C, which requires the compressive strength value perpendicular to the surface of the Wood-Plastic Composite with at least 50 kg/cm². The average value of compressive strength parallel to the surface of the plastic composite board increased to 170.0°C and then decreased to 180.0°C.

This happened because when the compression temperature was increased from 170.0ºC – 180.0ºC there was no significant reduction in the dimensions of the pores during compression so the compressive strength perpendicular to the surface decreased.

Meanwhile, according to [28] the higher the given temperature variation, the weaker the interfacial bond. The high-temperature treatment also causes the OP-EFB fiber to burn/oxidize and the composting process occurs, thereby reducing its mechanical properties. The variance analysis showed that the difference in pressing temperature significantly affects the compressive strength perpendicular to the surface of the plastic composite board. The average compressive strength values parallel to the surface can be seen in Figure 5. c with a coefficient of diversity of 0.12%.

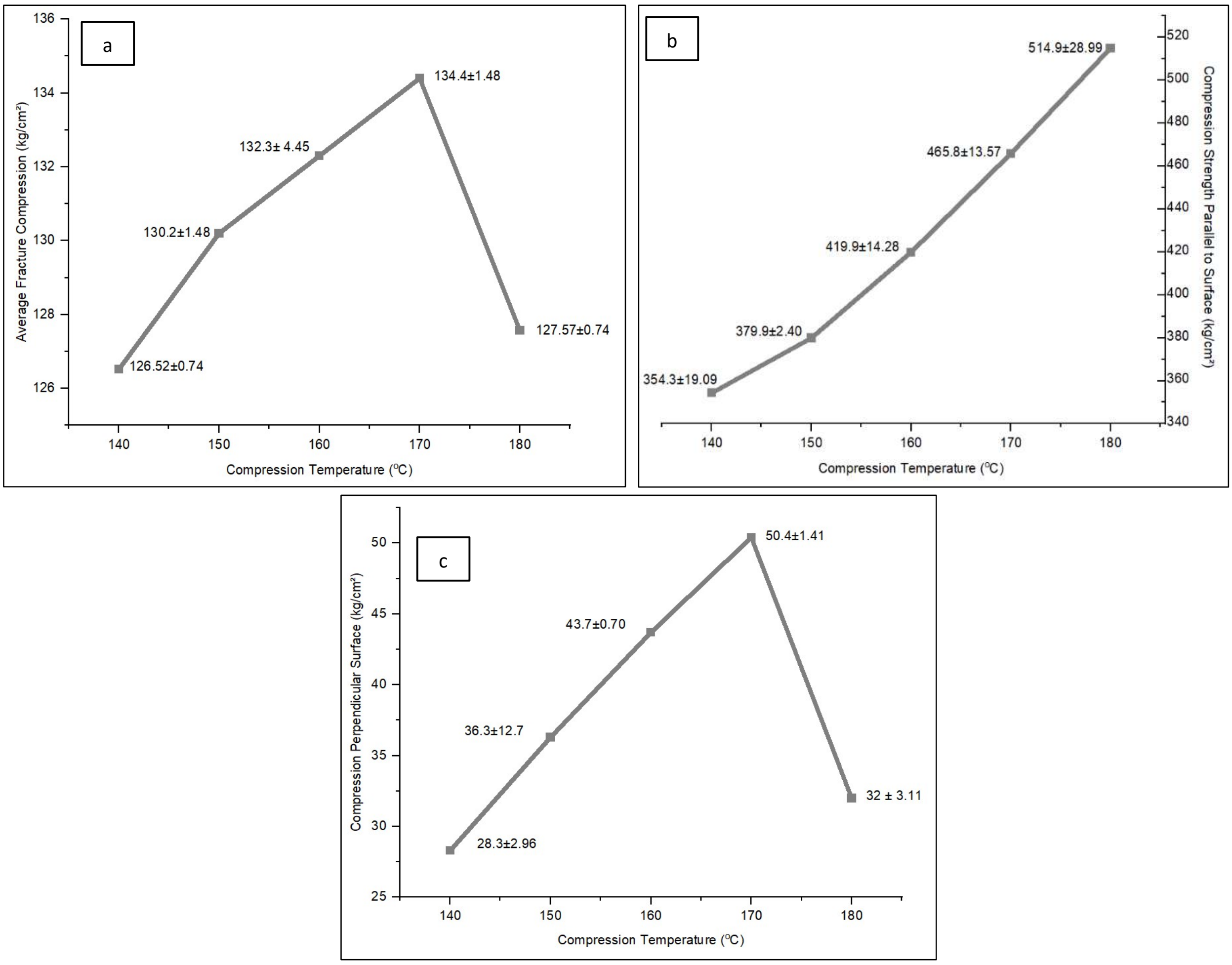

Figure 5. (a) Average fracture compression; (b) Compression Strength Parallel to Surface; (c) Compression Perpendicular Surface

3.4 Recapitulation of Properties of Plastic Composite Boards from Oil Palm Empty Fruit Bunches and HDPE Plastics by Treatment of Differences in Compression Temperature

Data recapitulation of the physical and mechanical properties of wood-plastic composite boards from oil palm empty fruit bunches and HDPE plastic with different compression temperatures can be seen in Figure 6. Based on Figure 6, it can be seen that the difference in compression temperature on the physical and mechanical properties of plastic composite boards from OP-EFB fiber and HDPE plastic which includes density, and compressive strength parallel to the surface has met the standard of [29]. In the compressive strength test perpendicular to the surface, only a treatment compression temperature of 160 ºC met the standards [29].

While in the MOR test, none of the composite plastic boards met the [29] standard, and for water absorption, no SNI required it. Based on the MADM-SAW method, it was found that the best compression temperature was the compression process using a temperature of 170.0ºC. From the mechanical properties test, the MOR of WPC is approximately in the value of 40.49 MPa (parallel to surface) and 26.83 MPa (perpendicular surface) [30]. This result was lower than WPC from sengon sawdust and WPC from pine that had MOR around 14.4 -24.9 MPa [31].

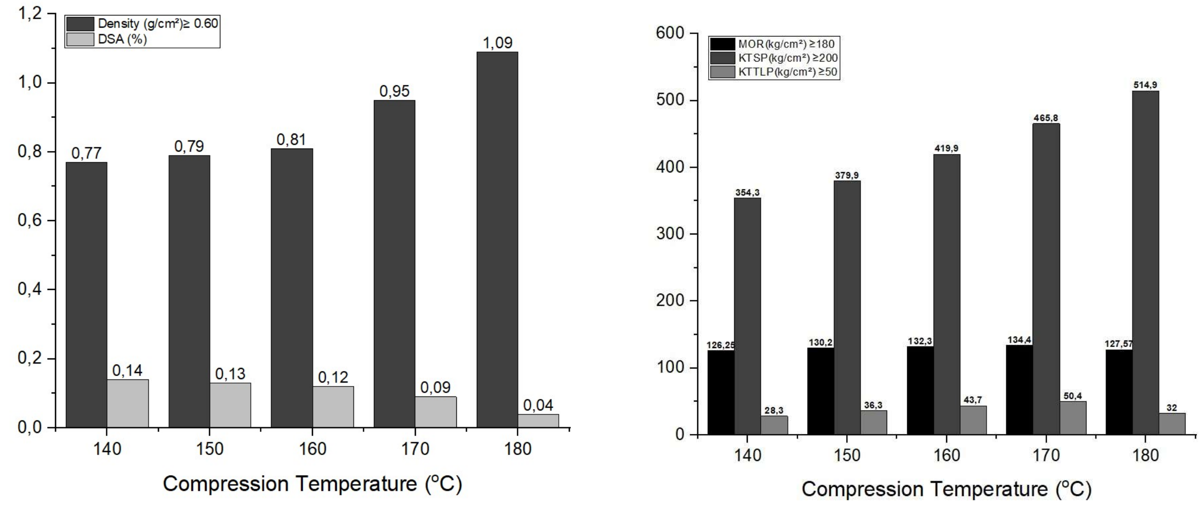

Figure 6. Recapitulation of Properties of Plastic Composite Boards
from OP-EFB and HDPE Plastics

4. Conclusion

The variation in pressing temperature has a significant effect on testing the density, compession press parallel to the surface, and compession press perpendicular surface of plastic composite boards from OP-EFB and HDPE plastic. The Plastic Composite Board (PCB) density test value ranges from 0.77 g/cm²-1.09 g/cm² and has met the SNI 8154-2015 standard with the condition that the density is 0.60 g/cm², the compressive strength value parallel to the surface ranges from 354.3 kg/cm²-514.9 kg/cm² and has met the standards of SNI 8154-2015 with a minimum requirement of 200 kg/cm². The compressive strength perpendicular to the surface only in treatment D has met the SNI 8154-2015 standard with a value of 50.4 kg/cm². SNI 8154-2015 requires the compressive strength value perpendicular to the Wood-Plastic Composite's surface to be at least 50 kg/cm². Based on the MADM-SAW method, it was decided that the best compression temperature for plastic composite boards from OP-EFB and HDPE plastic was obtained in treatment D (compression temperature 170.0ºC) with a density value of 0.95g/cm², the water absorption capacity of 0.09%, fracture toughness of 134.4 kg/cm², the compressive strength parallel to the surface of 465.8 kg/cm², and the compressive strength perpendicular to the surface of 50.4 kg/cm².

References

[1] J. M. L. Thoe, N. Surugau, and H. L. H. Chong, "Application of Oil Palm Empty Fruit Bunch as Adsorbent: A Review," 2019. [Online]. Available: http://tost.unise.org/

[2] Ministry of Agriculture, "Guidelines for Processing Palm Oil Industry Waste," *Directorate of Processing of Agricultural Products*, Jakarta, 2016.

[3] M. A. N. Izani, M. T. Paridah, U. M. K. Anwar, M. Y. M. Nor, and P. S. H'Ng, "Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers," *Compos B Eng*, vol. 45, no. 1, pp. 1251–1257, Feb. 2013, https://doi.org/10.1016/J.COMPOSITESB.2012.07.027.

[4] V. Valle, A. Aguilar, J. Kreiker, B. Raggiotti, and F. Cadena, "Oil Palm Empty Fruit Bunch (OPEFB) Fiber-Reinforced Acrylic Thermoplastic Composites: Effect of Salt Fog Aging on Tensile, Spectrophotometric, and Thermogravimetric Properties," *Int J Polym Sci*, vol. 2022, 2022, https://doi.org/10.1155/2022/6372264.

[5] Mandiri, *Renewable Energy Technology Training Manual*, 2012th ed. Jakarta, 2012.

[6] H.D. Rozman, M. J. Saad, and Z. A. M. Ishak, "Flexural and impact properties of oil palm empty fruit bunch (EFB)-polypropylene composite," *Polym Test*, vol. 22, no. 3, pp. 335–341, May 2003, https://doi.org/10.1016/S0142-9418(02)00109-5

[7] Zulnazri, Suryati, Azhari, B. Wirjosentono, and H. Dahliana, "High Density Polyetylene (HDPE)-Oil Palm Empty Fruit Bunch Filled Micro Composites Using Melt Blending Process," *4th Syiah Kuala University Annual International Conference 2014*, 2014.

[8] R. Rosazley, M. Z. Shazana, M. A. Izzati, A. W. Fareezal, I. Rushdan, and Z. M. A. Ainun, "Characterization of Nanofibrillated Cellulose Produced from Oil Palm Empty Fruit Bunch Fibers (OPEFB) Using Ultrasound," *Journal of Contemporary Issues and Thought*, vol. 6, pp. 28–35, 2016.

[9] Y. Sudiyani and E. Hermiati, "Utilization of Oil Palm Empty Fruit Bunch (Opefb) for Bioethanol Production Through Alkali and Dilute Acid Pretreatment and Simultaneous Saccharification and Fermentation," *Indonesian Journal of Chemistry*, vol. 10, no. 2, pp. 261–267, 2010, https://doi.org/10.22146/ijc.21471.

[10] E. Saputra, H. Sugesti, B. A. Prawiranegara, Y. Aziz, A. Fadli, and O. Muraza, "Waste materials from palm oil plant as exploratory catalysts for FAME biodiesel production," *Applied Nanoscience (Switzerland)*, vol. 12, no. 12, pp. 3703–3719, 2022, https://doi.org/10.1007/s13204-021-02185-9.

[11] T. M. Maloney, "Modern Particleboard and Dry Process Fiberboard Manufacturing," in *MILLER Freeman,Inc*, San Fransisco, 1993.

[12] B. Jian *et al.*, "A Review on Flexural Properties of Wood-Plastic Composites," *Polymers (Basel)*, vol. 14, no. 19, p. 3942, Sep. 2022, https://doi.org/10.3390/polym14193942.

[13] A. Nourbakhsh and A. Ashori, "Preparation and properties of wood plastic composites made of recycled high-density polyethylene," *J Compos Mater*, vol. 43, no. 8, pp. 877–883, Apr. 2009, https://doi.org/10.1177/0021998309103089.

[14] A. Najafi and S. K. Najafi, "Effect of load levels and plastic type on creep behavior of wood sawdust/HDPE composites," *Journal of Reinforced Plastics and Composites*, vol. 28, no. 21, pp. 2645–2653, Nov. 2009, https://doi.org/10.1177/0731684408093320.

[15] K. Murayama *et al.*, "Mechanical and physical properties of wood plastic composites containing cellulose nanofibers added to wood flour," *For Prod J*, vol. 68, no. 4, pp. 398-404, May 2018, https://doi.org/10.13073/FPJ-D-18-00006.

[16] A. Dorostkar, "Investigation on Mechanical properties between of composite made of Poplar and Alder sawdust and high density Polyethylene," *IJISET-International Journal of Innovative Science, Engineering & Technology*, vol. 1, no. 10, pp. 2348-7968, 2014. https://www.academia.edu/70864509/Investigation_on_Mechanical_properties_between_of_composite_made_of_Poplar_and_Alder_sawdust_and_high_density_Polyethylene

[17] P. R. Rao and G. Ramakrishna, "Oil palm empty fruit bunch fiber: surface morphology, treatment, and suitability as reinforcement in cement composites- A state of the art review," *Cleaner Materials*, vol. 6, Dec. 01, 2022. https://doi.org/10.1016/j.clema.2022.100144.

[18] A. A. Kloyosov, "Wood – Plastic Composite," Willey- interscience.

[19] N. Tampubolon, L. Hakim, and T. Sucipto, "Fiber Plastic Composite Made from Old Corrugated Paper and Polyprophylene (PP) with Addition of Maleic Anhydride (MAH) and Benzoil Peroxide (BP)," *Peronema Forestry Science Journal*, vol. 2, no. 1, pp. 131–138, 2013, https://media.neliti.com/media/publications/157028-ID-none.pdf

[20] S. Sudarmadji, B. Haryono, and Suhardi, *Prosedur Analisis untuk Bahan Pangan dan Pertanian - Edisi ke IV*. Yogyakarta: Liberty, 1997, https://onesearch.id/Record/IOS3504.libra-116645216000585

[21] S. K. De Datta, "Principle and Practices of Rice Production," New York: John Willey and Sons,Inc, 1981, p. 618p.

[22] AOAC, *Official Methods of Analysis of The Association of Official Analytical Chemist*. Washington, 2015.

[23] [BSN] National Standardization Agency, *SNI-03-2105-2006. Particle board*. BSN:Jakarta, 2006.

[24] A. B. Junaidi, & R. Yunus, "KAJIAN POTENSI TUMBUHAN GELAM (Melaleuca cajuputi Powell) UNTUK BAHAN BAKU INDUSTRI PULP : ASPEK KANDUNGAN KIMIA KAYU," *Jurnal Hutan Tropis Borneo*, vol. 10, no. 28, pp. 248–291, 2009, https://drive.google.com/open?id=0B-SKClq40GqIU05vbUp4MElkWUk

[25] A. Ferrer, I. Filpponen, A. Rodríguez, J. Laine, and O. J. Rojas, "Valorization of residual Empty Palm Fruit Bunch Fibers (EPFBF) by microfluidization: Production of nanofibrillated cellulose and EPFBF nanopaper," *Bioresour Technol*, vol. 125, pp. 249–255, 2012, https://doi.org/10.1016/j.biortech.2012.08.108.

[26] R. M. Siagian, "Effect of Temperature and Pressure of Felts on the Properties of Fiberboards Made from Timber Industry Waste," Bogor, 1983.

[27] Sushardi and Veranitha, "Composite Boards of Industrial Waste with Polypropylene Plastic Mixing Adhesives," 2015. [Online]. Available: https://www.researchgate.net/publication/340607583

[28] T. Karso, W. W. Raharjo, and H. Sukanto, "Pengaruh Variasi Suhu Siklus Termal Terhadap Karakteristik Mekanik Komposit Hdpe–Sampah Organik," *MEKANIKA*, vol. 11, no. 1, pp. 8–13, 2012. https://jurnal.ft.uns.ac.id/index.php/mekanika/article/view/100

[29] [BSN] National Standardization Agency, *SNI 8154:2015. Plastic Wood Composites*. BSN: Jakarta, 2015.

[30] Y. Arnandha *et al.*, "Physical and Mechanical Properties of WPC Board from Sengon Sawdust and Recycled HDPE Plastic," *Procedia Eng*, vol. 171, pp. 695–704, 2017, https://doi.org/10.1016/j.proeng.2017.01.412.

[31] K. B. Adhikary, S. Pang, and M. P. Staiger, "Dimensional stability and mechanical behaviour of wood-plastic composites based on recycled and virgin high-density polyethylene (HDPE)," *Compos B Eng*, vol. 39, no. 5, pp. 807–815, 2008, https://doi.org/10.1016/j.compositesb.2007.10.005.