Effect of Pressing Time on the Physical, Mechanical, and Morphological Properties of Composite Made of Gmelina Bark and Recycled Polypropylene

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The effects of pressing time were evaluated relative to the physical, mechanical, and morphological properties of flat-pressed composites made from *Gmelina arborea* bark and recycled polypropylene (RPP). Bark powder (5% moisture content) was mixed with RPP pellets in a weight ratio of 40:60 with added maleic anhydride (MAH) as compatibilizer. The materials were mixed in a rotary blender for 15 min at speed 80 rpm until homogeneous. The mixture was heated from 175 to 200 °C until RPP pellets were completely melted and then cooled to room temperature. Afterwards, the mixture was made into powder and molded using a steel plate mold at 175 to 200 °C and pressure of 30 kg/cm^2 for 2, 4, and 6 min to a targeted density of 1.0 g/cm^3. The tested physical properties were covered density, moisture content, water absorption, and thickness swelling. The mechanical properties modulus of elasticity (MOE) and modulus of rupture (MOR), tensile strength parallel to length of panel were also examined. Research results showed that the properties were significantly affected by pressing time and it can be concluded that the optimum condition was obtained at 4 min of pressing.

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Keywords: Bark-plastic composites; Gmelina bark; Recycled polypropylene plastic; Physical properties; Mechanical properties; Morphological properties

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INTRODUCTION

It is feared that the increasing dependence on the use of wood will reduce several types of wood that are often used in the market, thus affecting the production of forest products. Therefore, we need a way to prevent the extinction of several types of wood. One way to efficiently and wisely use wood is to replace wood as a construction or decoration material by applying the concept of whole tree utilization, which functions to increase the use of non-wood lignocellulosic materials and develop innovative products like building materials for wood substitutes. Bark-plastic composite (BPC) can be used as a way to replace the use of wood in the community. BPC is a polymer composite from a mixture of bark powder (reinforcing material) combined with a matrix thermoplastic polymer, such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), and others. Such composites can additionall include fillers from wood fibers, wood, and other organic materials (Clemons 2002). The use of raw materials that can be made into composite products does not have to come from high-quality materials but can also utilize waste.

Plastic waste or plastic pollution in society is a global problem. Plastic waste is extremely hard to decompose by microorganisms (essentially non-biodegradable). One way to resolve this problem is to utilize waste by making raw materials for composites. This research used bark as filler, so it is called bark-plastic composite (BPC). The BPC is a polymer composite from a mixture of bark and thermoplastic. The term BPC consists of a matrix (reinforcing material) in the form of thermoplastics, such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), *etc.*, and fillers from bark, as substitution of wood filler, and other organic compounds. Raw materials that can be used in composite products do not have to come from high-quality materials and can utilize waste. One of the wastes that are often an issue in society is plastic waste. Plastic waste is very hard to break apart by decomposing microorganisms (non-biodegradable). One way to overcome the problem is to use the material as a component in composite materials. Polypropylene (PP) is commonly used in everyday life, such as in plastic bottles, packers, buckets, containers, *etc*. The material is low in price and is easy to crush or shape. Another advantage of PP when compared to over other types of plastic is that its properties are relatively easily degraded by nature (Sutrisno *et al.* 2021). The production of PP plastics is increasing along with the growth of consumer consumption. Indonesia's per capita plastic consumption increased from 19.8 kg/person/year in 2017 to 22.5 kg/person/year in 2022. Southeast Asia's consumption of 17 kg per capita is low relative to that of developed markets, such as the United States, which consumed 60 kg per capita, Central/Western Europe that consumed 45 kg per capita, and China that consumed 33 kg per capita in the 2016 period. During 2023 to 2024, PP consumption is projected to increase by an average of around 10% per year from 1.80 million tons in 2023 to 1.98 million tons in 2024 (PQM Consultants 2023). Additionally, based on World Bank's data, Indonesia ranks as the 2nd highest plastic waste contributor in the world next to China, with an estimated contribution of around 3.22 million tons of plastic waste annually (World Bank Group 2018). Therefore, to increase the efficiency of the utilization of lignocellulosic materials and reduce the environmental burden of plastic waste in the production of BPC is valuable.

Sutrisno *et al*. (2020) reported that the barks of jabon, gmelina, and surian woods tend to have better thermal stability, but gmelina has the best thermal stability compared to jabon and surian. In addition to having good stability, gmelina bark can be chosen because it is rarely used. The mixing of plastic and gmelina bark powder aims to cover each other's lack of material properties. This study aims to determine the physical, mechanical, and morphological properties of the composite made of gmelina bark powder and recycled polypropylene for BPC, as substitution for building construction materials. According to data from the Central Agency of Statistics (2019; 2020), the production of gmelina round wood increased from 52,400 m^3 in 2018-2019 to 65,600 m^3. Each gmelina round wood contains bark in the range of 9.3 to 12.0% (Saragih 2017). Therefore, with a large production volume, the amount of bark waste is also substantial.

EXPERIMENTAL

Materials

The materials used in this study were *Gmelina arborea* Roxb. (gmelina) bark powder, maleic anhydride (MAH), aluminum foil, and recycled polypropylene (RPP) pellets that were obtained from CV. Metal Rizki Manufacturing, Indonesia.

Methods

Production of samples

Gmelina bark powder (40 to 60 mesh; 5% moisture content) was mixed with RPP pellets in a weight ratio of 40:60, and 5% maleic anhydride (MAH) was added as a compatibilizer. The materials were mixed in a rotary blender for 15 min at speed 80 rpm until homogeneous. The mixture was heated at a temperature of 175 to 200 °C until RPP pellets were completely melted and then the press was opened after a certain length of time, allowing the specimens to cool outside of the press. Afterwards, the mixture was made into powder and molded using a steel plate mold at 175 to 200 ℃ and pressure of 30 kg/cm^2 for 2, 4, and 6 min to a targeted density of 1.0 g/cm^3.

Physical Properties

Density and moisture content

Three specimens measuring 25 × 25 × 10 mm^3 were used for density and moisture testing using the gravimetric method based on ASTM D570-22 (2022) standard. Density was determined by weighing and measuring specimens in air-dry conditions. The moisture content was determined by weighing the specimen in air-dry conditions ($m1$, g) and then drying it in an oven at a temperature of 103 ± 2 °C until its weight was constant ($m2$, g). The density and moisture content (MC) values were calculated using Eqs. 1 and 2:

$$Density\ (g/cm^3) \quad (1)$$

$$MC\ (\%) = \frac{m_1 - m_2}{m_2} \times 100 \quad (2)$$

Water absorption and thickness swelling

Three specimens measuring 25 × 25 × 10 mm^3 were used to determine the values of water absorption and thickness swelling following the ASTM D570-22 (2022) standard. The specimen volume (v_1, mm^3) and weight (m_1, g) were measured in air-dry conditions. Then the specimens were soaked in the water at room temperature for 24 h. Furthermore, the volume of the specimen (v_2, mm^3) and weight (m_2, g) after soaking in water for 24 h were obtained. The water absorption (WA) and thickness swelling (TS) values were calculated using the Eqs. 3 and 4:

$$\text{WA}\ (\%) = \frac{m_2 - m_1}{m_1} \times 100 \quad (3)$$

$$\text{TS}\ (\%) = \frac{t_2 - t_1}{t_1} \times 100\% \quad (4)$$

Mechanical Properties

MOR and MOE

Three specimens measuring 160 × 20 × 4 mm^3 were used for testing MOR and MOE according to ASTM D7031-11 (2019) standard. The MOE and MOR values were calculated by the following Eqs. 5 and 6:

$$\text{MOR}\ \left(\frac{\text{kg}}{\text{cm}^2}\right) = \frac{3\,P\,L^2}{b\,h^2} \quad (5)$$

$$\text{MOE}\left(\frac{\text{kg}}{\text{cm}^2}\right) = \frac{\Delta P\, L^3}{4\, \Delta y\, b\, h^3} \quad (6)$$

where P is maximal load (kg), L is refutation distance (cm), b is length of sample (cm), h is thickness of sample (cm), ΔP is change of the load, and Δy is change of the deflection.

Tensile strength parallel direction

Three samples measuring 120 × 15 × 4 mm^3 were used for testing the tensile strength parallel to the length of the panels according to the ASTM D638-22 (2022) standard. The sample form used for testing the tensile strength is shown in Fig. 1. The tensile strength was calculated using the Eq. 7:

$$Tensile\ Strength\ = \frac{Maximun\ strength\ (kg)}{cross\ seectional\ area\ (cm^2)} \quad (7)$$

where LO = 115 mm, D = 65 mm, R = 14 mm, L = 33 mm, W = 6 mm, WO = 15 mm, and RO = 25 mm. According to Sutrisno *et al*. (2021) the physical and mechanical properties of BPC is compared to flat-pressed particle board with reference to Japanese standards (JIS A 5908-2003).

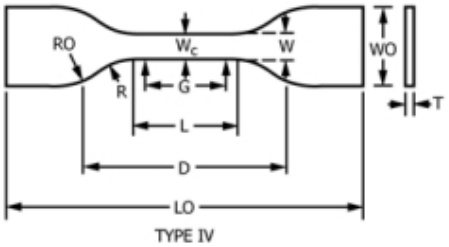

Fig. 1. Sample for tensile strength according to ASTM D638-22 (2022)

Composite Morphology

Composite morphology was studied through microscope using scanning electron microscopy (SEM) JEOL JSM-6360 LA, Japan.

Data Analysis

The data obtained were analyzed using analysis of variance (ANOVA) with Duncan's advanced test at the 5% real level using IBM SPSS software.

RESULTS AND DISCUSSION

Physical Properties

Density

Density is a ratio of weight to volume of the composite. Density will affect shrinkage and expansion, hygroscopicity, and mechanical properties. Figure 2 shows the density values at 2, 4, and 6 min, respectively as 1.04, 1.12, and 1.15 g/cm^3. The density value will be directly proportional to the firmness and strength properties. The results show that the density value is not much different, which indicates that all comparisons between weight and volume are not too different. A pressing time of 6 min shows the highest density

and a pressing time of 2 min shows the lowest density. This is in line with Anasrul (2013), who reported that a longer time to press when molded results in a tighter test sample produced. The density in this study shows higher value than the density from JIS A 5908 (2003) standard, which is 0.9 to 1.04 g/cm^3. This shows that the composite sample was denser than the target. Based on the results of ANOVA analysis, for all treatments, the pressing times of 2, 4, and 6 min were not significantly different from one another.

Moisture content

Moisture content (MC) is the weight of water in the composite relative to the total weight. It is expressed as a percent of free-air or kiln-dry composites. The solid content was determined in this research *via* the oven method. Figure 3 shows that the 4 min pressing time had the lowest water content (6.70%) compared to the other two pressing times. Then a pressing time of 2 min gave 12.01%, and the highest water content was obtained at the pressing time of 6 min (18.07%). The MC value decreased 44.2% when the pressing time increased from 2 min to 4 min and the value decreased 62.9% when the pressing time decreased from 6 min to 4 min. The water content value of pressing time at 2 and 4 min according to the JIS A 5908 (2003) standard states that the maximum water content is 13%. The press time of 6 min did not meet the standard because the value was more than 13%. The lower water content value indicates that the quality of the composite was getting better because the ratio between the amount of water in the composite and the dry weight was a low ratio. The moisture content is affected by temperature and the pressing time for manufacturing, the higher the temperature used will shorten the time used so that it has an impact on the value of low water content. Based on this study, the best water content was at a pressing temperature of 4 min because it has the lowest water content value. Additionally, based on the results of ANOVA analysis with Duncan's advanced test, all treatments of pressing time in 2 min, 4 min, and 6 min were significantly different.

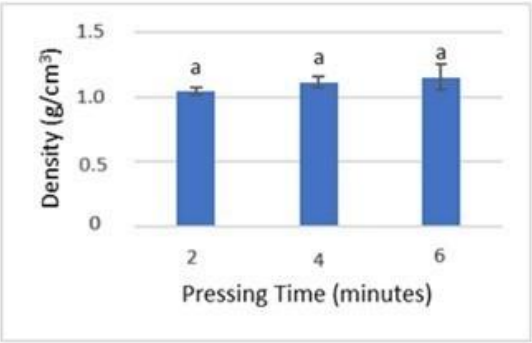

Fig. 2. Density of BPC

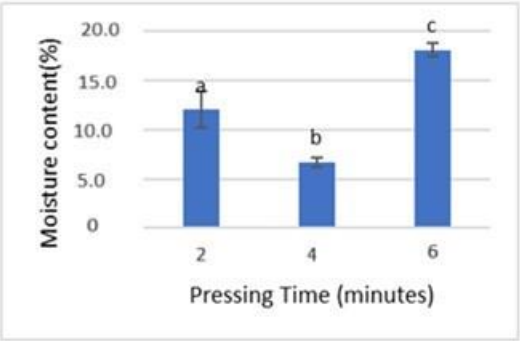

Fig. 3. Moisture Content of BPC

Water absorption

The objective of testing water absorption (WA) of the composites is to know the maximum capacity of the composite to absorb water from air to the saturation limit. The sample of composites in the WA test will increase in weight. This test was done within 24 h by taking the weight before and after soaking in water. Figure 4 shows the WA values based on the pressing time of 2 min, 4 min, and 6 min, respectively, are 3.35%, 4.29%, and 5.28%. Water absorption is affected by the soaking process of a composite, at the time of soaking; water will enter empty cavities in the composite, resulting in reduced cohesiveness

or density between the matrix and filler (Anasrul 2013; Raghu and Goud 2020). That makes it easier for the water or water vapor to enter the composite. The high WA value at pressing time 6 min is thought to occur because of stress after pressing, which does not completely disappear, causing a gap that can be both an entrance and an exit for the soaking water. Water absorption values are not specified in the JIS A 5908 (2003) standard. Thus, this test is to see whether there is resistance when applied outside the room. This air absorption is directly proportional to the thickness swelling, the higher the air absorption, the higher the thickness swelling and *vice versa*. Based on the results of ANOVA analysis with Duncan continued test, the results showed that in the treatment the pressing time of 2 min was significantly different compared to the pressing time of 4 min and 6 min, while 4 min and 6 min were not significantly different.

Thickness swelling

Swelling can occur because of the additional water content in the composite. Thickness swelling (TS) is determined by measuring the volume of the composite test sample before and after soaking for 24 h. Thickness swelling is used to show a change in dimensions of composites, especially the thickness dimensions, caused by soaking in water so that application to composites can be determined. Applications considered were for indoor or outdoor use because they will have an impact on the long-term quality of the composite. Figure 5 shows that the TS values for pressing times of 2 min, 4 min, and 6 min, respectively, were 0.42%, 0.57%, and 0.84%. The TS value in all variations of pressing time was considered a good thickness swelling because it was not more than 12% according to the JIS A 5908 (2003) standard. The pressing time referred to by Trisna and Mahyudin (2012) does not really affect the TS value if the value is still relatively stable because the thickness is more affected by the composition of materials used. Thickness swelling has the same correlation with density, the use of more filler (bark powder) will increase TS to the composite so that more matrix is used, and then the thickness swelling that occurs will be lower (Kasim *et al*. 2007). The TS value was obtained even though it has a standard deviation that does not coincide. However, based on the results of ANOVA analysis with Duncan continued test, in all treatments the pressing time of 2 min, 4 min, and 6 min was not significantly proportional to one another. Water absorption is directly proportional to thickness swelling. The higher the WA capacity, the higher the TS. Based on the results of ANOVA analysis, it was found that in all treatments the pressing time of 2 min, 4 min, and 6 min did not result in water absorption values that were significantly different from one another.

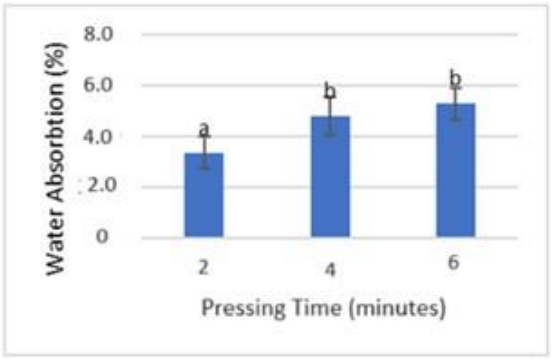

Fig. 4. Water Absorption of BPC

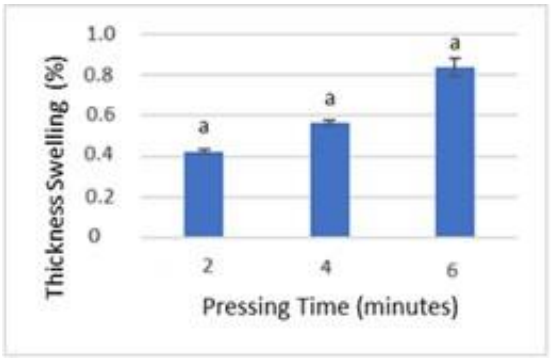

Fig. 5. Thickness Swelling of BPC

Mechanical Properties

Tensile strength

Tensile strength is a mechanical property that shows the strength of the composite to resist external tensile forces. Figure 6 shows the tensile strength values at 2 min, 4 min, and 6 min, respectively were 18.1 kg/cm^2, 31.4 kg/cm^2, and 25.0 kg/cm^2. The tensile strength value increased 42.4% when the pressing time increased from 2 min to 4 min and the value increased 20.5% when the pressing time decreased from 6 min to 4 min. The lowest tensile strength was at pressing time of 2 min, which can occur when manufacturing with a short press time, making the heat unevenly used so that some are compact and some are not yet compact. When the pressing time is too long, it will burn the test sample so that its property decreases when compared to the sample that is heated for a shorter time. The value of tensile strength can be affected by several factors such as the composition of the raw materials used, the methods used in the manufacture of materials, the percentage of the matrix, and the materials used (Junaidi 2018).

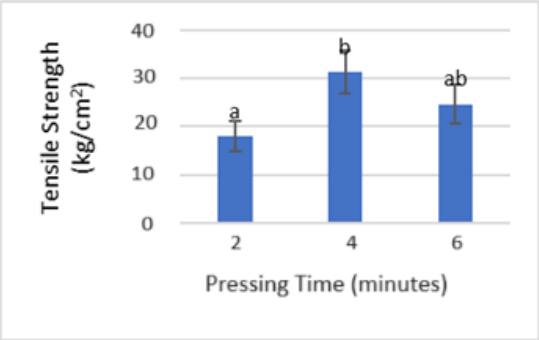

Fig. 6. Tensile strength of BPC

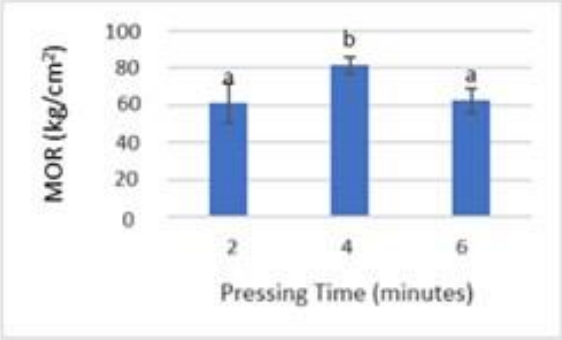

Fig. 7. MOR of BPC

Based on the ANOVA analysis with Duncan continued test, the results showed that the treatment pressing time of 2 min was significantly different to pressing time of 4 min but was not significantly different to pressing time of 6 min, while pressing time 4 min was significantly different compared to 2 min but not significantly different to the pressing time of 6 min**.**

Modulus of rupture

The MOR determines the maximum load capacity that the composite test sample can accept until fracture. This fracture stress can occur when the composite receives the maximum load until the composite is damaged (Mardikanto *et al*. 2011). Figure 7 shows the MOR values at 2 min, 4 min, and 6 min respectively, as 61.4, 81.5 , and 62.4 kg/cm^2. The MOR value at the pressing time of 2 min and 6 min was not much different because the composite's ability to withstand the maximum load was not higher than the pressing time of 4 min. The press time of 4 min had the highest MOR value because of the good compactness of the sample. The MOR value of the composite will decrease as the contain of matrices decreases, if the same composition is used, it can be seen from the homogeneity of the material when mixing and molding the composite. The results of MOR value in this study, press time of 4 min satisfied the JIS A 5908 (2003) standard and has a minimum standard value of 80 kg/cm^2. When longer pressing time was used, a higher MOR value was obtained, but in this research the longest pressing time of 6 min showed a lower value than the composite that was pressed for 4 min. This finding was attributed to heating at a

high temperature of 175 to 200 °C for a long time, which will make the composite charred because it has gone through 2 heating stages. Thus, the inside of the composite has a cavity that allows the mixture not to be homogeneous. The composites that were pressed within 2 min, the value was lower when compared to the pressing time of 4 min because at the time of manufacturing, the time used was shorter so that the composite mixture was not blended so that the composite surface was still covered with a non-unified matrix or filler (Junaidi 2018). Based on the results of ANOVA analysis with Duncan's continued test, the treatment with a press time of 4 min was significantly different to the press time of 2 min and 6 min, while 2 min and 6 min were not significantly different.

Modulus of elasticity

The MOE is the ability of the composite to maintain its original shape because there is a load that will tend to change the size and shape of the composite sample, the value of MOE indicates the elasticity proportion in the composite. Figure 8 shows the results of the MOE with different values. The MOE values were 4,590, 16,600, and 11,800 kg/cm^2, respectively at the press time of 2, 4, and 6 min. The resulting MOE value was lower than the JIS A 5908 (2003) standard that has a standard value of 20.40 kg/cm^2. The value of MOE at 4 min of pressing time showed the greatest value, so at that press time had a good MOE compared to the composite pressed at 2 and 6 min. The composite that was pressed for 2 min had a lower value compared to the pressing time at 4 min and 6 min, indicating that the composite was pressed for 2 min was very stiff so it was not flexible. This is because the time used was too short so that the composite was not fully formed; thus, the surface was not completely covered by the matrix and filler. Previous research by Wardani *et al*. (2013) reported a lower MOE value than this study at 3,010 and 3,020 kg/cm^2. This shows that the composite MOE value in this study had difficulty in matching that of JIS standards. Based on the results of ANOVA, analysis with Duncan's continued test, the treatment the pressing time of 2 min was significantly different to the pressing time of 4 and 6 min, while 4 and 6 min were not significantly different.

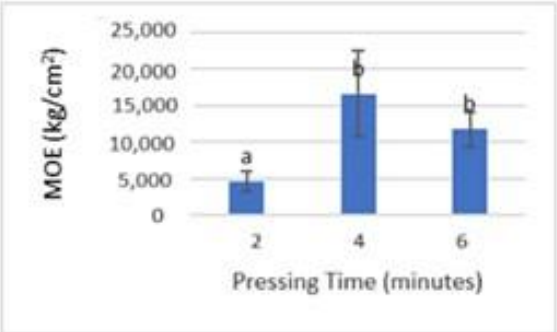

Fig. 8. MOE of BPC

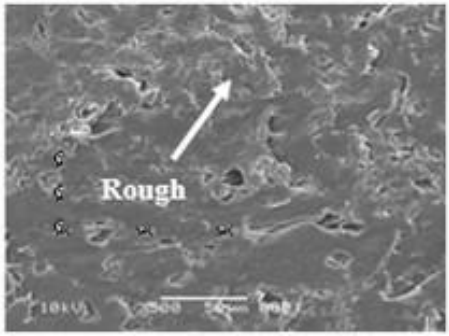

Fig. 9. Morphology of BPC at 2 min pressing time, magnification 500x

Morphological Properties

Composite morphology through microscopic observations (Figs. 9 through 11) showed that an increase in compression time of 2 to 4 min can increase the strength of the bond between the filler and the matrix. Otherwise in compression time of 4 to 6 min, the strength of the bond between the filler and the matrix was decreased, because it relates to

temperature. The temperature used was high (175 to 200 °C), so that if it is pressed for longer the time it will create cracks in the inside of the composite. This is despite the fact that the specimen will appear smooth from the outside. In Figs. 9 and 11 the morphology seems more wavy or rough, as it is caused by the weak adhesion force between the matrix and the filler when compared to Fig. 10. This shows that the compression time of 4 min resulted in BPC that was denser and stronger than the BPC with the resulting press time of 2 and 6 min.

Figure 10 shows the compactness between gmelina bark powder as a filler and recycled polypropylene plastic as a matrix. This compactness is shown from the homogenity of the materials in making composites and the time used. The pressing time of 4 min resulted in a smoother composite surface, and there were only small cavities compared to the composites that were pressed for 2 and 6 min. The compactness of the composite makes for better dimensional stability; a cavity that is not too large makes it difficult for water to enter the composite so it affects the value of physical testing (Kardiman *et al*. 2018). The presence of a cavity in a composite not only affects the physical test; it can also affect the appearance and value of the mechanical property (Sutrisno *et al*. 2021). The mechanical test tended to produce the highest value, which means that in the test it can reach the JIS A 5908 (2003) standard.

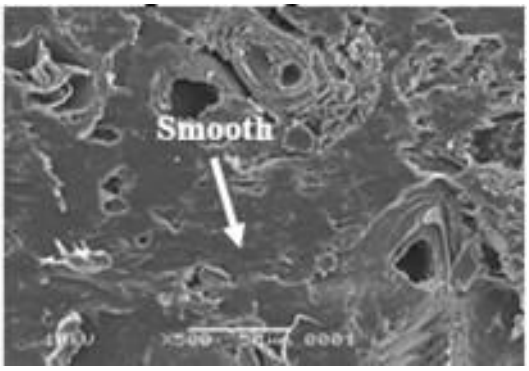

Fig. 10. Morphology of BPC at pressing time of 4 min, magnification 500x

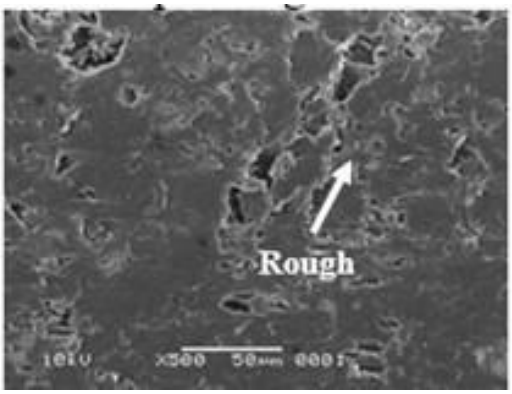

Fig. 11. Morphology of BPC at pressing time of 6 min, magnification 500x

Figure 10 shows that the composite had a smoother surface than the composite that was pressed for 2 min. This result was supported by Lubis *et al*. (2009), who reported that a longer pressing time will make the composite stronger. Additionally, the color appearance of composites was also affected by pressing time, as shown in Figs. 9 to 11. Figure 11 showed the composite prepared with a pressing time of 6 min had darker color than that was pressed for 2 and 4 min as presented in Fig. 9 and 10, respectively, due to the composite being pressed too long at high temperature.

CONCLUSIONS

1. Press time had a significant effect on physical properties except for density and thickness swelling. The moisture content value decreased 44.2% when the pressing time increased from 2 to 4 min, and the value decreased 62.9% when the pressing time decreased from 6 min to 4 min.

2. Press time had a significant effect on all mechanical properties studied. The tensile strength value increased 42.4% when the pressing time increased from 2 to 4 min and the value increased 20.5% when the pressing time decreased from 6 to 4 min.

3. The optimal condition was obtained at a pressing time of 4 min.

ACKNOWLEDGMENTS

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