



Potency to Recycle Hydrapulper Reject Waste of Paper Mill into Composite Particleboard

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ABSTRACT

Solid waste of paper mill hydrapulper rejects (HR) has a relatively high plastic content, with around 45-49% composition of the total HR. About 99% of the plastic has the category of High-Density Polyethylene (HDPE). HDPE is a type of Polyethylene (PE) plastic which has high recyclability and may be reformed at high temperature. This study tries to describe the potential of producing particleboards derived from HR using a hot-press method. Molded HR was being hot-pressed at a pressure of 25 kgf/cm² for 5 – 15 minutes of residence time, with a variation of the amount of HR from 150-500 g, and variations in hot-press temperature of 150-180°C. Products were then analyzed for parameters such as moisture content, density, water absorption, thickness swelling, and internal bond and compared to SNI 03-2105-2006 and JIS A 5908-2003 standard. The results showed that most of the samples were relatively accepted to the SNI, with only a few data could meet JIS. The best results are obtained at HR weight of 250 g with 165 and 180°C pressing temperature and pressing time more than 10 minutes. The addition of HDPE pellets showed an increment of density and decrement of moisture content of particleboard, while the addition of Maleic Anhydride (MA) showed some decrements of moisture content and water absorption of particleboard.

1. INTRODUCTION

Corrugating medium and Kraft liner industries in Indonesia usually using waste paper as one of their raw material sources. Mixed waste paper as a raw material may usually consist of many impurities such as plastic, glass, metal, etc. The impurities are usually rejected from the hydrapulper inlet and separated as hydrapulper rejects (HR). The components contained in the HR waste from the paper mill consist of bundles of fibers, foils and plastic pieces that may depend on the quality of the waste paper input.

Plastics content on HR is usually relatively high. A study reported about 45% plastic content on HR without prior separation (Haynes, Malloch, Cuddy, & Nicodimos, 2009), while the contents were slightly higher (49,25%)

after a metal separation treatment from HR (Setiawan, Purwati, Surachman, Bastari, & Hardiani, 2014). There are several types of plastic wastes that have thermoplastic characteristics and can be formed repeatedly with high temperature such as Polyethylene (PE) (Atuanya, Ibbadode, & Igboanugo, 2011; Faruk & Matuana, 2008; Li, Zheng, Pan, & Hartsough, 2009), Polypropylene (PP) (Ashori & Nourbakhsh, 2014; Septiari, Karyasa, & Kartowarsono, 2014), and Polystyrene (PS) (Mawardi, 2009). A study has reported that 99% of the total plastics content of HR is a type of High Density Polyethylene (HDPE) plastics (Setiawan & Surachman, 2015). HDPE is a type of PE plastic that has high recyclability and thermoplastic characteristic. The proportion of plastic in HR can be seen in Table 1.

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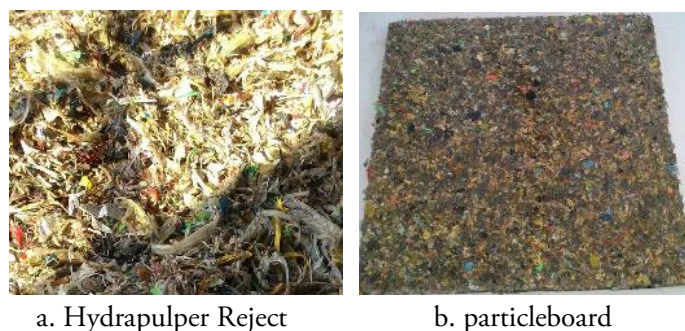
Table 1. Hydrapulper Rejects Proportion

Proportion	Without metal separation (Haynes et al., 2009)	With metal separation (Setiawan et al., 2014)
Fiber (paper, cardboard, etc.)	21.00%	50.75%
Plastics	45.00%	49.25%
Metals	10.00%	-
Others	24.00%	-

Plastic waste is very difficult and will likely to take a long period of time to decompose in the natural environment. One alternative solution for the management of plastic waste is to recycle them into other derivatives product such as particleboard. Plastics as raw materials for particleboard has characteristics advantage of plastic hydrophobicity which may provide water and moisture resistant characteristics to the particleboard. Also, plastic materials are not preferred by termites, so termites will automatically be avoided without prior preservation treatment, thus no termites repellent addition would be needed to the particleboard.

Generally, the applied HR management is through the disposal to landfills or reducing the amount of HR through incineration without further recycling process (Gavrilescu, 2008). With high fiber and plastic content within it, HR waste has good potential to be used as raw material for particleboard manufacturing. The process of recycling HR into particleboard is one solution to convert solid waste and its treatment cost into economical raw materials. Moreover, the handling of HR may also produce other environmental benefits, including reducing the cost of processing HR waste which has been transported out of the factory to be processed at the third party, cleaning the factory from accumulated HR waste to improve cleanliness, and also improve the factory image in order to support the green industry program.

Particleboard is one type of composite product / wood panel made of wood particles or other lignocellulosic



a. Hydrapulper Reject

b. particleboard

Figure 1. HR from paper mill and product of particleboard from HR

material, which bonded with adhesive or other bonding material then hot-pressed (Maloney, 1977). Composites are formed from two different types of material, namely: (1) Reinforcement, which is less ductile but rigid and strong, (2) The matrix, generally more ductile but has the strength of lower rigidity.

Previous study has showed a potential of waste paper as particle board (Harshvardhan, Muruganandam, & Ranjitha, 2016). This research was conducted to study the potential to recycle HR as a raw material of particleboard.

2. METHODS

HR was obtained from corrugating medium and Kraft liner paper mill production process with waste paper (recycled paper) as raw material. HR volume was around 5-10% of the production capacity with 50-70% moisture content. Before the shredding process, HR was dried under the sun to reduce the moisture content to less than 10%. Maleic Anhydride (MA) was used for coupling agent additive while HDPE pellet was used for additional adhesive for particleboard sample. MA ($C_4H_2O_3$) has a melting point at $52.56^\circ C$ and the boiling point at $202^\circ C$ (at 760 mm Hg) with 98.06 g/mol of molecular weight (CAMEO Chemicals, 1999), while HDPE has melting point at $126-135^\circ C$ (Matmatch, 2019).

Equipment used at this study are shredder machine and hot-press machine which has maximum 50 kgf/cm^2

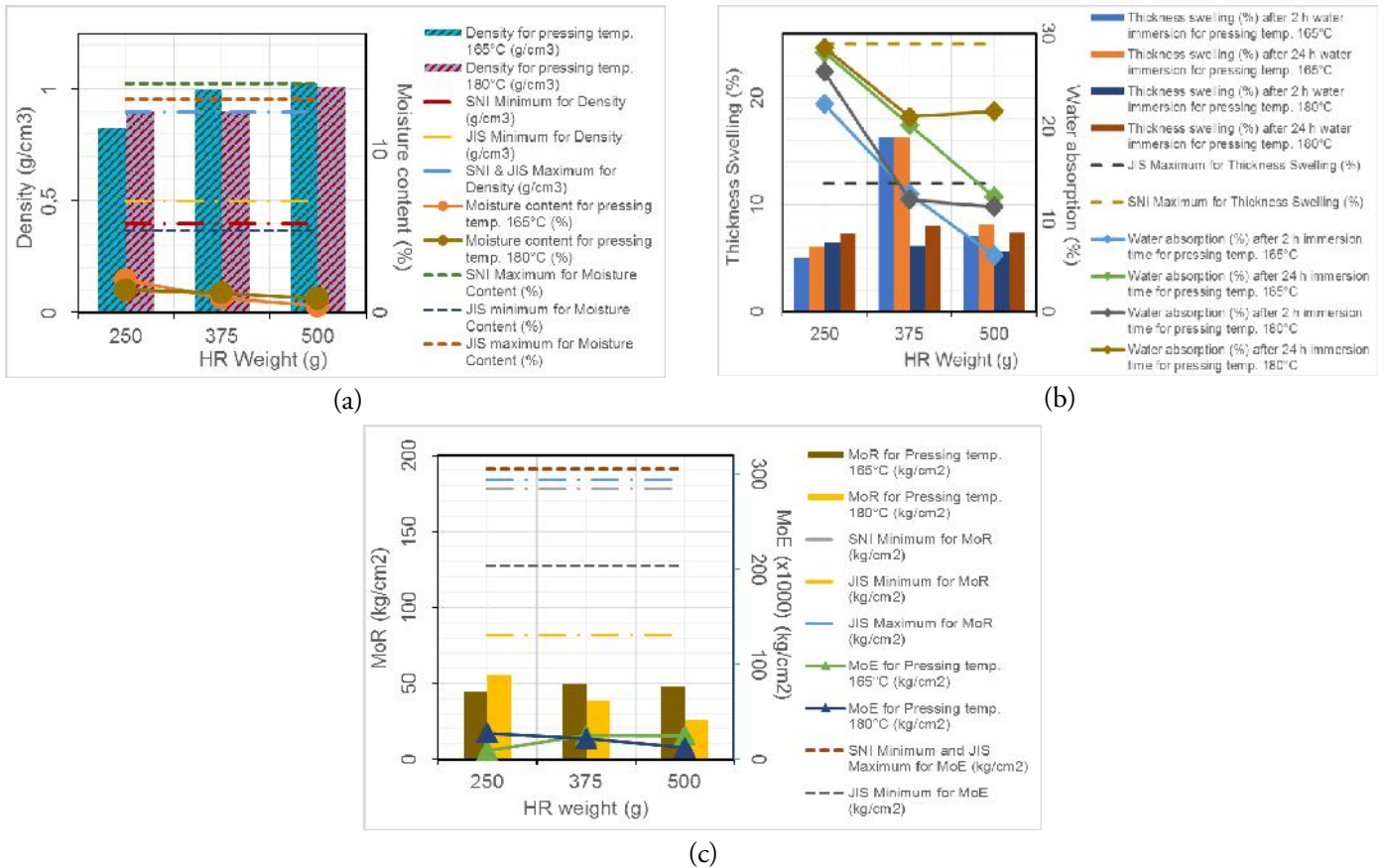


Figure 2. Effect of different HR weight and pressing temperature on density, moisture content, thickness swelling, water absorption, MoR and MoE

constant pressure, which would fit one mold (20 x 20 cm² wide size) and temperature variation up to 200°C. Shredding of HR was carried out in a shredding/cutting machine. The machine has a blade with approximately 4 mm holes screen (4 mm mesh) for output of shredded HR with the size about 4 mm. Particleboard molding of HR was carried out using a 20 x 20 cm² mold size made of stainless steel with 1 cm thickness target. Teflon sheet was used at the molding process to avoid sticking product to the mold. The size of the mold (20x20 cm²) was chosen to fit perfectly with the hot-pressed machine previously owned by Center for Pulp and Paper. Molded HR was then being hot-pressed with a hot-press machine, carried out on 25 kgf/cm² pressure for variation of 5 – 15 minutes residence time. Product of particleboard samples was then removed from the hot-press machine and then cooled down at the room temperature. A variation of HR weight from 150-500 g and hot-pressing temperature of 150-180°C were used in this study. Shredded MR was mixed either with MA (2.5 to 10

wt%) or with HDPE plastic pellets (2.44 to 9.09 wt%) and then inserted into mold and hot-pressed. The previous study showed that variation on MA size was insignificant (Wardani, Massijaya, & Machdie, 2013).

Particleboard products were then tested for physical properties including density, moisture content, thickness swelling, and water absorption, and also internal bond, modulus of rupture (MoR) and modulus of elasticity (MoE) as mechanical properties. Thickness swelling and water absorption were tested after 2 and 24 hours of water immersion. Collected data were then compared to Indonesian standards according to SNI 03-2105-2006 which are density 0,4-0,9 g/cm³, moisture content <14%, thickness swelling <12%, internal bond >1,5 kg/cm², MoR ≥178 and MoE ≥30,600. Japanese standard of JIS A 5908-2003, was also being compared. Subsequent reference for SNI and JIS refers to SNI 03-2105-2006 and JIS A 5908-2003 respectively. Although water absorption is not one of

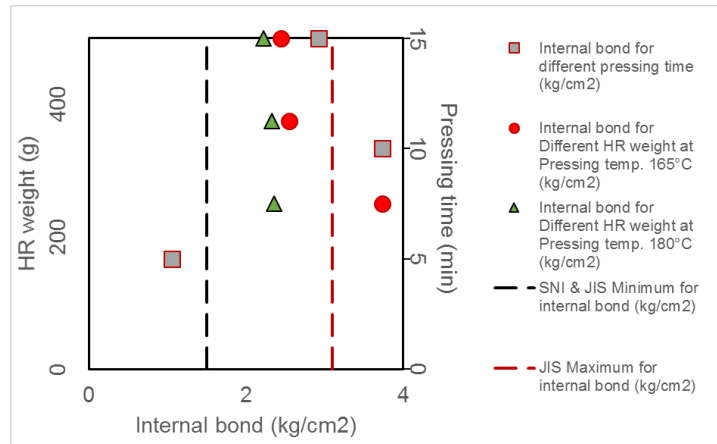


Figure 3. Effect of different HR weight and pressing time on internal bond

standard referred from SNI or JIS standard, it was tested and analyzed to study its potential as an exterior utility.

Particleboard density was measured according to this equation:

$$\text{Density (g/cm}^3\text{)} = W / V$$

W is weight in g, where V is volume in $\text{cm}^3 = \text{length (cm)} \times \text{wide (cm)} \times \text{thick (cm)}$. According to Indonesian standard (SNI), the value of density should be fall between $0.40 \text{ g/cm}^3 - 0.90 \text{ g/cm}^3$.

Particleboard moisture content was measured according to this equation

$$\text{Moisture content (\%)} = (W_i - W_d) / B_k \times 100\%$$

W_i is initial weight in g, while W_d is oven dry weight in g. According to SNI, the value of moisture content of particleboard should not exceed 14%.

Particleboard thickness swelling was measured according to this equation:

$$\text{Thickness swelling (\%)} = (T_2 - T_1) \times 100 \% / T_1$$

T_1 is particleboard initial thickness before water immersion in mm, while T_2 is thickness after water immersion in mm. According to SNI, the value of thickness swelling after water immersion should not exceed 25%, based on standard for particleboard with thickness $\leq 12,7$ mm.

In this study, the particleboard surface was also being studied using Scanning Electron Microscope (SEM) to analyze surface morphology and to compare surface fibers-HDPE arrangement between HR with and without the addition of WA or HDPE. The data were also compared with commercial GRC (Glass-fiber Reinforced Cement) Particleboard. The analysis of the heavy metals on the immersion water from procedure 2.2.5 were also conducted to study its leachate potential considering its possible utility as house exterior. The leaching procedures were conducted based from SNI 19.6365:2000, while the heavy metals analysis were conducted based from SNI 6989.71:2009 (Cr), SNI 6989.16:2009 (Cd), SNI 6989.6:2009 (Cu), and SNI 6989.8:2009 (Pb). The results were then compared to Indonesian standards from KEP-03/BAPEDAL/09/1995.

3. RESULT AND DISCUSSION

3.1. Effect of sample weight and temperature

Figure 2a showed that the addition of sample weight may increase the density of particleboard and make it more rigid and compact. The increment of density was occurred due to more fibers and plastics at the same particleboard thickness (1 cm). Additional of HR weight from 250 g to 500 g may increase density from 0.83 to 1.03 g/cm^3 at 165°C pressing temperature, and from 0.9 to 1.01 g/cm^3 at 180 pressing temperature.

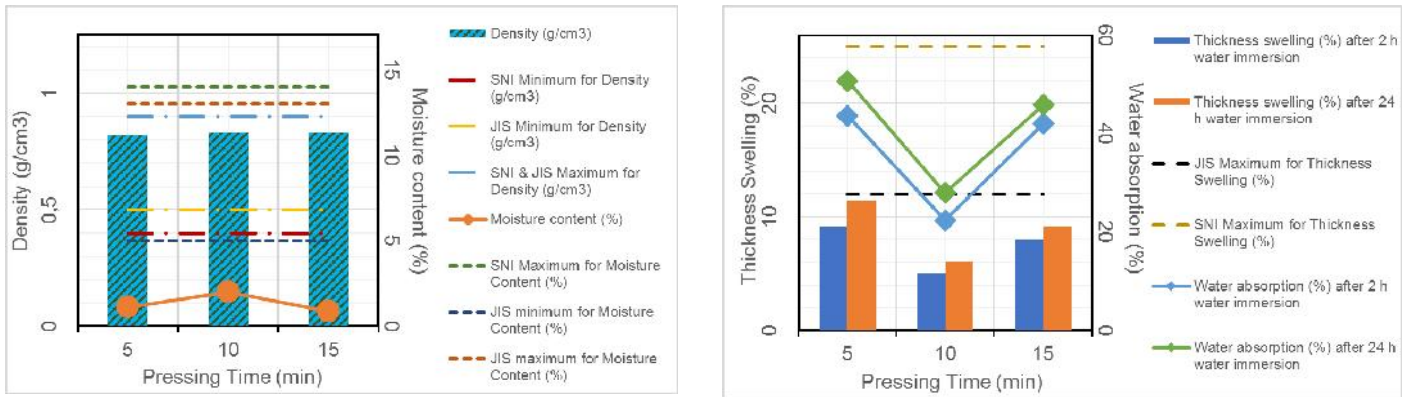


Figure 4. Effect of pressing time on density, moisture content, thickness swelling and water absorption at a constant HR weight (250 g) and pressure temperature (165°C)

Beside density increment, more HR weight would also indicate a decrement to particleboard moisture content, from 2.01% at 250 g HR weight into 0.41% at 500 g HR at 165°C pressing temperature. The decrement also occurred at 180°C pressing temperature. The moisture content decrement was occurred due to less particleboard space that could be filled with water.

Figure 2a showed that HR weight more than 250 g did not show adequate data for both SNI and JIS standard except for a sample for 375 g and 180°C pressing temperature. It was also showed that all moisture contents were adequate for SNI standard but inadequate for JIS standard.

Another effect caused by the weight HR addition was the decrement of water absorption of particleboard, both after 2 and 24 hours of water immersion (Figure 2b). Particleboard from 250 g HR with 165°C pressing temperature has water absorption of 22.42 %, while particleboard from 500 g HR with the same pressing temperature has a lower water absorption (6,03 %). The longer water immersion time, water absorption increased, while with more HR weight will give a lower water absorption. The same effect also tended to occur at the particleboard with 180°C pressing temperature. While the effect on thickness swelling is not clearly showed on all treatment, it can clearly showed that at 180°C and water immersion for 2 hours, the addition of HR weight caused a decrement of thickness swelling. Meanwhile, all data showed that more immersion time will give higher thickness

swelling and water absorption value, which are coherent with the previous study (Khanjanzadeh, Bahmani, Rafighi, & Tabarsa, 2012).

From Figures 2a and 2b, it was also indicated that the increment of pressing temperature from 165°C into 180°C, tend to increase density (for HR weight 250 g) and water absorption value but tend to decrease thickness swelling (with the exclusion of HR weight 250 g) and internal bond (Figure 3), which were coherent with results from Li *et al.*, (2009). It was showed from Figure 2b that particleboards with HR weight of 250 and 500 g both with 165 and 180°C pressing temperature, and particleboard with HR weight 375 g and 180°C pressing temperature have surpassed the SNI and JIS thickness swelling value.

Meanwhile, at Figure 2c it was clearly seen that all samples have low MoE and MoR, and far from adequate for SNI nor JIS standard. Chemical addition of MA to particleboard mixture was made to study its effect on MoR and MoE and discussed later on subsequent section.

From Figure 3 it was seen that the highest internal bond value was reached at 250 g HR weight and 165°C pressing temperature, while the lowest one was reached at 500 g HR weight and 180°C pressing temperature. It was showed that HR weight increment may not guarantee an increment in particleboard internal bond value. The increasing amount of HDPE also supposed to be may increase particleboard internal bond, however the impurities within HR might have interfered with the internal bond value.

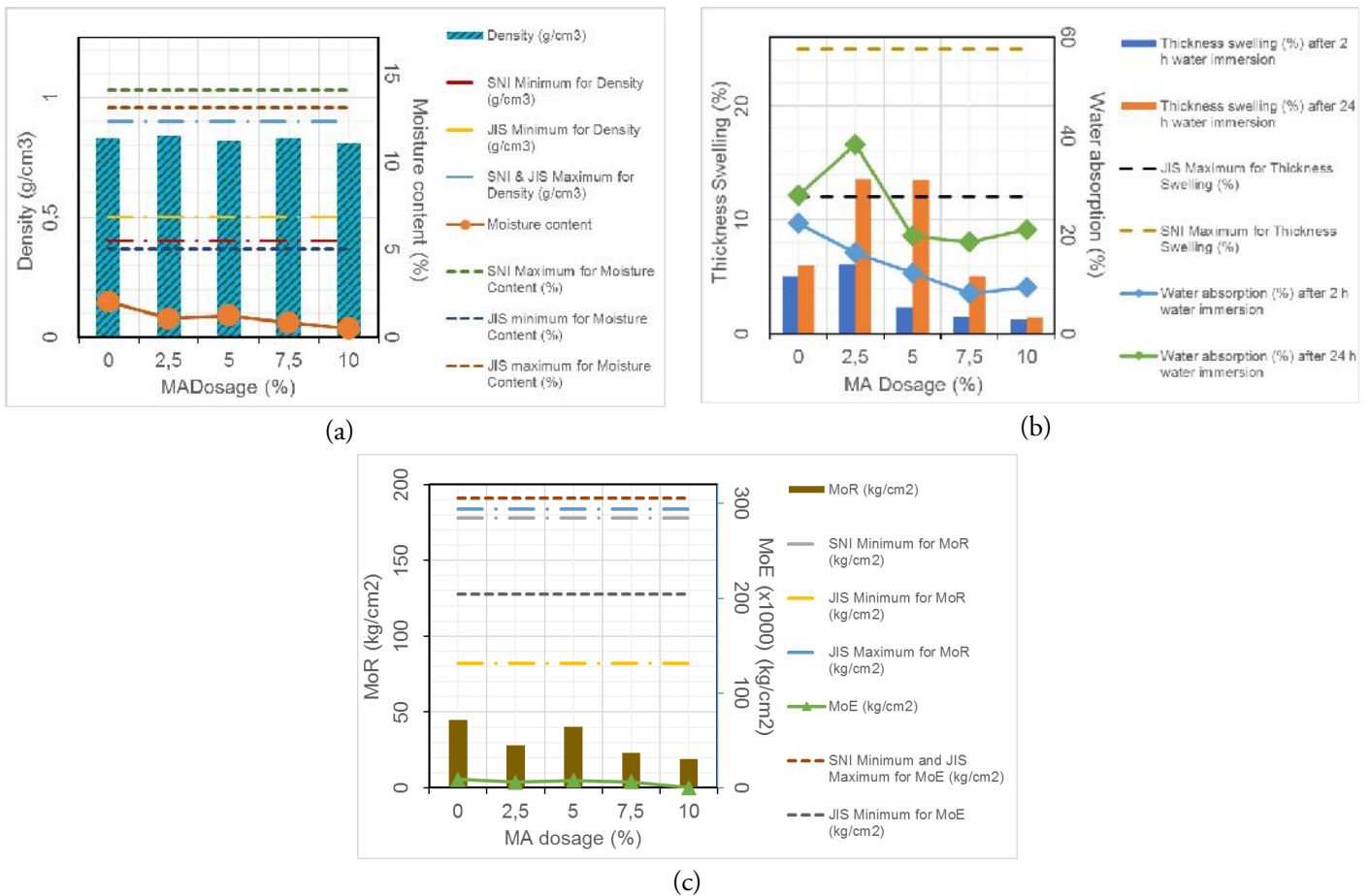


Figure 5. Effect of MA dosage on density, moisture content, thickness swelling, water absorption, MoR and MoE at a constant HR weight (250 g) and pressure temperature (165°C) for 10 minutes

Most of the samples are adequate for SNI for internal bond, with only 5 minutes pressing time sample showed an inadequate data for SNI standard. Meanwhile, JIS standard was not achieved for samples with 250 g HR weight, 165°C pressing temperature, and less than 15 minutes pressing time.

2.2. Effects of pressing time

The data on Figure 4a showed that there were no significant density differences (0.82-0.83 g/cm³) at the pressing time variation in this study (5-15 minutes). The best internal bond was reached at pressing time of 10 minutes which was 3.73 kg/cm³ (Figure 3), which also gave the smallest thickness swelling (5.07 and 6.08% respectively for 2 and 24 hours) and water absorption (22.42 and 28.01% respectively for 2 and 24 hours), and were adequate

for SNI standards for particleboard. Additional pressing time more than 10 minutes did not give any better results (Figure 4b). All samples showed adequate density and thickness swelling both for SNI or JIS, while moisture content was only adequate for SNI.

2.3. Effects of MA addition

Generally, the MA addition will going to have some increment effects on mechanical and physical properties of particleboard such as density (Fathanah, 2011; Li et al., 2009). In this study, density was increase from 0.83 to 0.84 g/cm³ at the 2.5% MA addition to the HR particleboard (Figure 5a). The density increment was probably caused by a more compact of particleboard matrix because the additional MA has dissolved some of the impurities and

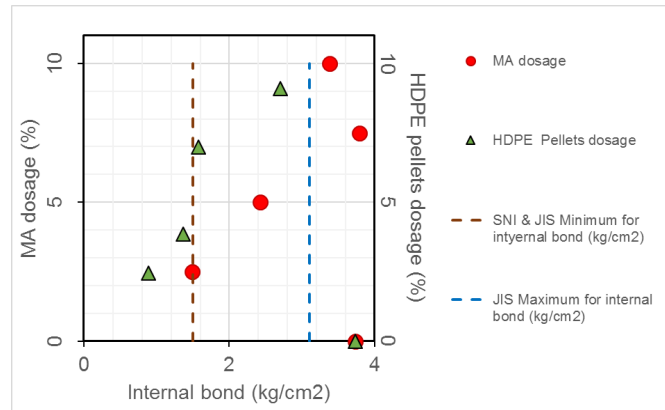


Figure 6. Effect of MA and HDPE dosage on internal bond

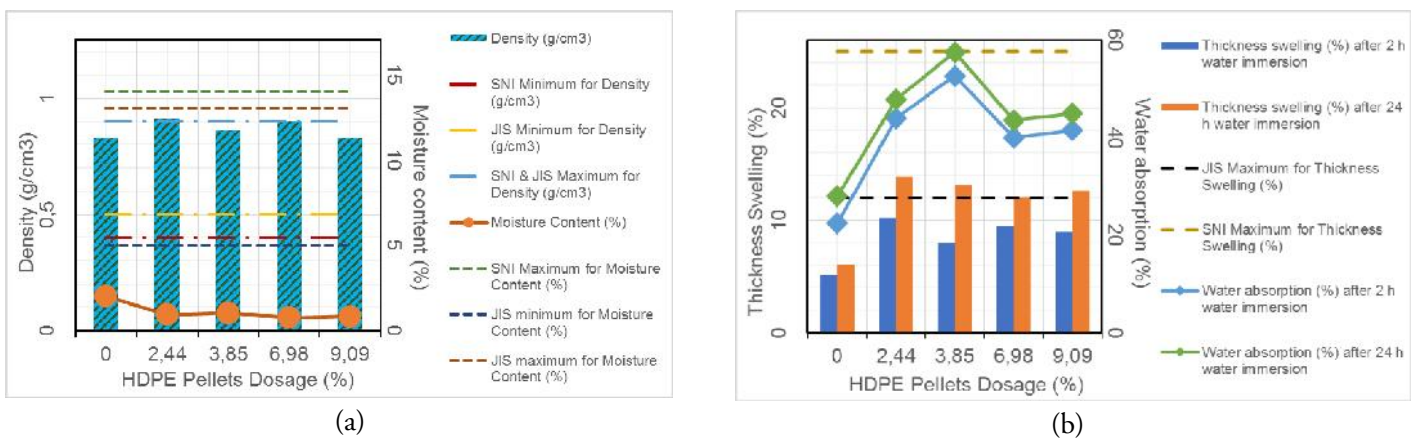


Figure 7. Effect of HDPE dosage on density, moisture content, thickness swelling and water absorption at a constant HR weight (250 g) and pressure temperature (165°C)

filled some particleboard pores by fines (Sawpan, Pickering, & Fernyhough, 2011).

The increment of density also may be occurred due to the crystallinity increment from MA reaction with the end of crystallinity chain which may caused an opening in hydrogen bond and conversion crystallinity to be more amorphous (Sawpan et al., 2011). However, further addition of MA did not show any increment to density of particleboard.

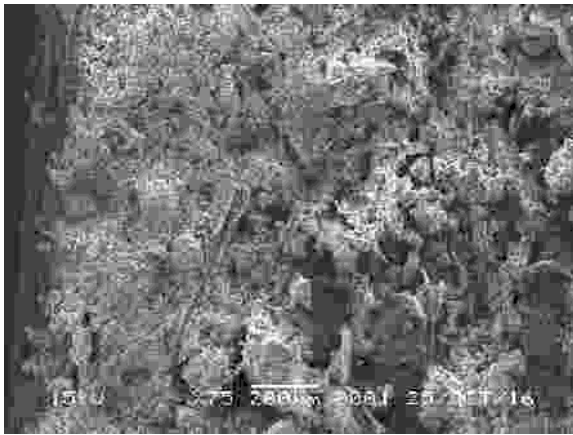
On the other side, similar with some previous results (Fathanah, 2011; Mishra, Naik, & Patil, 2000; Nourbakhsh & Ashori, 2010), the MA addition may decrease moisture content and internal bond due to its function as compatibilizer. However, MA dosages more than 2.5% caused a decrement of water absorption and increment of internal bond in this study (Figures 5b and 6).

We will study furthermore the effect of MA addition with SEM analysis and discussed later on this paper.

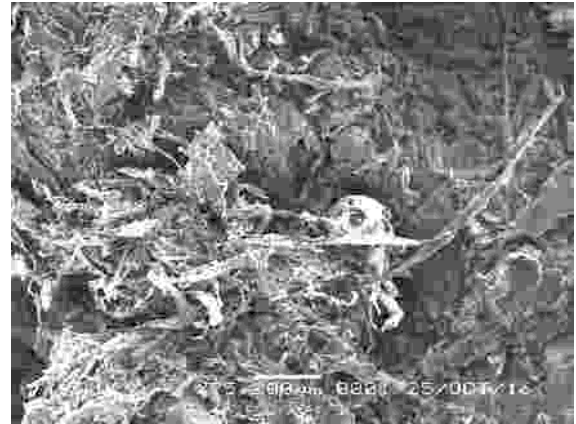
Nevertheless, the data on Figure 5 and 6 showed that the addition of MA dosage may change the properties of the particleboard, and most of the properties has showed an adequate quality for SNI or JIS standard for given parameters. However, MoR and MoE values were still far from adequate, and moreover the addition of MA was negatively affected to the quality of the particleboard (Figure 5c).

2.4. Effects of the addition of HDPE pellets

Theoretically, the addition of HDPE pellets to the particleboard may increase density and internal bond, while also decrease moisture content, water absorption, and thickness swelling, due to its hydrophobic property.



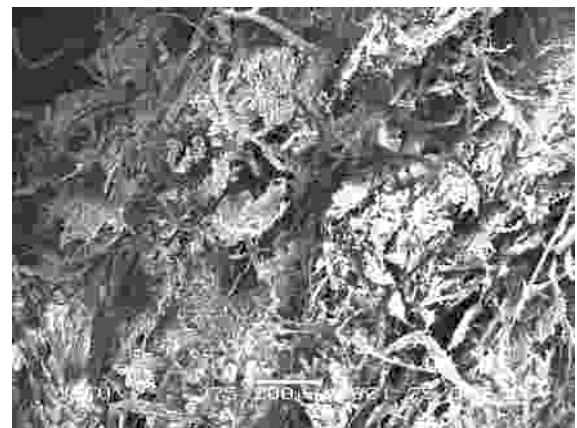
a. GRC Particleboard



b. HR without MA or HDPE addition



c. HR with MA addition



d. HR with HDPE addition

Figure 8. SEM analysis on MA or HDPE addition

Previous study also showed that the addition of HDPE content may increase internal bond, and decrease water absorption and thickness swelling of particleboard (Li et al., 2009). In this study we found that HDPE addition may indicated an increment of density and decrement of moisture content, however this study also indicated an increment of thickness swelling and water adsorption due to HDPE addition. We will also study furthermore the effect of HDPE addition with SEM analysis and discussed later on this paper.

The data indicated that the addition of HDPE pellets may change the properties of the particleboards. For all given parameters (density, moisture content, and thickness swelling), the addition of HDPE pellets above 3.85% showed an adequate quality for SNI standard, and

only for the addition of HDPE pellets above 6.98% showed an adequate result for both SNI and JIS standard (Figure 7).

2.5. SEM Analysis

From SEM data, it was indicated that GRC particleboard has smaller fiber size and fewer fiber content, compared to HR samples that relatively has larger fiber size and more fiber content. The large size and fibers contents may potentially create porosity and entry points for water infiltration, as water might infiltrate through the uncovered fiber that filled the particleboard. Furthermore, mixing and homogeneity of fiber and adhesive also took an important effect on physical properties of particleboard (Iswanto, Febrianto, Hadi, Ruhendi, & Hermawan, 2012). A less homogeneity particleboard may create porosity

Table 2. Heavy metals content on particleboard

No	Parameters	Results (mg/L)	KEP-03/BAPEDAL/09/1995
1	Ag	< 0.01	5.0
2	As	< 0.01	5.0
3	Ba	0.10	100
4	Hg	< 0.01	0.2
5	Zn	0.53	50
6	Cu	< 0.01	10
7	Pb	< 0.01	0.5
8	Cd	< 0.01	1.0
9	Cr	< 0.01	5.0
10	Se	< 0.01	1.0

(Gawdzinska, Wojnar, Malinski, & Chraponski, 2010) thus created possible entry points for water infiltration.

MA addition which has hygroscopic characteristic may react with HDPE which has hydrophobic characteristic, and may cause a decrement of moisture content of particleboard. As seen on Figure 8 (c), MA addition to particleboard created a more clotted surface and caused a more compact particleboard compared to particleboard without it (b). However, there are still more fiber content compared to GRC particleboard which leads to potential entry points for water infiltration. On the other side, the addition of HDPE pellets caused an increment of density and decrement of moisture content, however as indicated on Figure 8 (d), there were a lot of large fiber size and fiber contents on the particleboard. This may increase the thickness swelling and water adsorption due to entry points for water infiltration from the fibers.

2.6. Heavy Metals Analysis

Table 2 and 3 showed that the HR particleboard and the water from the particleboard immersion process contained low heavy metals content below the applied regulation. These tests ensured that the heavy metals content from the particleboard and from the leachates that originated from HR particleboard were still acceptable to

Table 3. Heavy metals concentration on soaked water of particleboard

No	Sample	Concentration (mg/L)			
		Cr	Cd	Cu	Pb
1	R-165-15	nd	nd	nd	nd
2	RPE-9.09	nd	nd	nd	nd
3	GRC-Particleboard	nd	nd	nd	nd
KEP-03/BAPEDAL/09/1995		nd	nd	nd	nd

Note: nd = not detected

the Indonesian standard, and thus HR particleboard is safe to be utilized as an interior and exterior.

4. CONCLUSION

Although all the samples could not meet MoR and MoE standards for both SNI and JIS, the results showed that most of the samples were relatively accepted to other standards on the SNI. Meanwhile, besides water content, most of the samples were also relatively accepted to JIS standards. Best results were achieved at the HR weight of 250 g with 165 and 180°C pressing temperature, and pressing time more than 10 minutes. The addition of HDPE pellets indicated an increment of density and decrement of moisture content, while the addition of MA indicated some decrements of moisture content and water absorption. Mixing and homogeneity of fiber and adhesive also took an important effect on physical properties of particleboard. A less homogeneity particleboard may create porosity and entry points potency for water infiltration.

There was no significant heavy metal concentration found on the HR particleboard nor the soaked water of HR particleboard. Thus according to this study, application of HR particleboard both for interior or exterior utilization are relatively safe to the environment.

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