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The influence of cement-wood particle ratio and type of accelerator on physical properties of *Falcataria moluccana* (MIQ) Barneby & J.W. Grimes

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Abstract

Cement-bonded particle board is composed by wood fibers or particles and cement to produce a robust and adaptable board. The board has some essential functions and attributes such as excellent wear resistance and durability, moisture resistance, strong fire resistance, high sound insulation qualities, and as a thermal insulation. This study aimed to analyze the effects of the cement/wood particle ratio and the type of accelerator on the physical properties of cement-bonded particle board made from Sengon (*Falcataria moluccana* (MIQ) Barneby & J.W. Grimes) wood. The boards were prepared form the variation of cement/wood ratios (70/30, 60/40, and 50/50 w/w) and two types of accelerators ($MgCl_2$ and $CaCl_2$). The target density and thickness of the board were 1.2 g/cm^3 and 12 mm, respectively. The wood particles were boiled at 100°C for 30 min. The physical properties of cement plates were evaluated according to ISO 8335:1987. The results showed that the board using both $MgCl_2$ and $CaCl_2$ accelerators reached hydration temperatures higher than the controls, with values of 54°C (9th hour) and 59°C (sixth hour), respectively. We found that Sengon wood possessed great potential in the production of cement-bonded particleboard. Statistical analysis showed that most treatments in this study caused significant difference according to the physical properties tested (thickness, density, thickness swelling and water absorption). The greatest properties were achieved from enhanced cement/particle ratio and $CaCl_2$ accelerator.

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Introduction

Cement-bonded particleboard is known as one of the essential wood composite products because it incorporates cement as an adhesive, consisting of 10–70% wood particles and 30–90% Portland cement (w/w) (Nasser *et al.*, 2014). This type of composite is one of the innovative products in the industry that is environmentally friendly due to its composition of cement and lignocellulose materials, such as wood, non-wood, and agricultural waste. This product has various advantages over resin-binding composites, including resistance to water, fire, fungi, and insects, as well as to changes in moisture and weather, due to its high dimensional stability. The product also has good air-resistance properties. The board surfaces can be painted or laminated (Badejo, 1988; Moslemi, 1989; Dinwoodie and Paxton, 1991; Seng and Sudin, 1992; Sotannde *et al.*, 2012; Nasser *et al.*, 2014). Based on these superior properties, the cement-bonded particleboard may serve as an alternative to the substitute material for roof, ceiling board, floor, partition, wall coating, and others (Sulastiningsih *et al.*, 2000).

Falcataria moluccana, locally known as sengon, is a fast growing tree species from the family of Fabaceae. The tree is native to Indonesia, Papua New Guinea, the Solomon Islands, and Australia (Soerianegara and Lemmens, 1993). *Falcataria moluccana* is widely planted in the development of industrial plantation forests and also community forests with promising prospects in Indonesia, especially under the agroforestry system (Krisnawati *et al.*, 2011).

The utilization of *F. moluccana* as a raw material in cement-bonded particle boards is one of the alternatives to increasing its value. *Falcataria moluccana* is widely cultivated in tropical regions, where this plant species is considered a great material in terms of sustainability and continuity for industry. However, it has several obstacles in the production of this type of composite, including long pressing times in the manufacturing process until the maximum hydration temperature of the cement adhesive is reached. Several factors affecting the binding process in the production of cement particle board include the ratio of cement and wood particles, mixing, and the use of accelerators (additive). This factor plays a key role in determining the quality of the particle cement board and its commercial use.

The study aims to analyse the influence of the mixing ratio of cement and wood particles and the type of accelerator on the physical properties of the cement board particles produced from *F. moluccana* wood particles.

Materials and methods

The *F. moluccana* wood was collected from the Educational Forest of the Faculty of Forestry, Mulawarman University, which is located in Samarinda City, East Kalimantan, Indonesia. The cement used in this study was Portland Type I (Tonasa Corp. Indonesia) which is commercially available. Magnesium chloride and and $CaCl_2$ were used as accelerators at 5% of the cement weight.

Preparation of wood particles

The wood samples were debarked before the conversion into wood particles by hammer mill. The obtained wood particles were sieved into sizes of 1/4 inches (6.35 mm) and 3/16 inches (4.76 mm). The wood particles obtained were washed for 30 min and rinsed twice. The wood particles were then humidified for 1 week and placed in the oven at a temperature of 90°C for 7 hours. A uniform wood particle size of 40 mesh was used for hydration testing.

Determination of hydration temperature

Hydration testing was performed to analyze the suitability of the used wood particle as a raw material in the production of cement-bonded board. The experiments were conducted according to the Sandermann and Kohler methods (1964) with slight modifications (Kamil, 1970). The measurement of hydration temperature was tested based on the mixtures as shown in Table 1.

Table 1. Combination treatment of hydration temperature

Treatment	Cement (g)	Water (g)	Particles (g)	$MgCl_2$ (g)	$CaCl_2$ (g)
A	200	100	-	-	-
B	200	100	20	-	-
C	200	100	20 (boiled)	-	-
D	200	100	20 (boiled)	10	-
E	200	100	20 (boiled)	-	10

All the ingredients for each treatment were mixed into a plastic container until they reached a homogenous solution, and then they were placed in a vacuum flask. Through the thermal cover, a thermometer was tightly inserted into the solution. The experiments were carried out every hour. The temperature and time were recorded until the maximum temperature was achieved. According to Kamil (1970), the hydration classification for Indonesian timber is good (> 41°C), moderate (36–41°C), and poor (< 36°C).

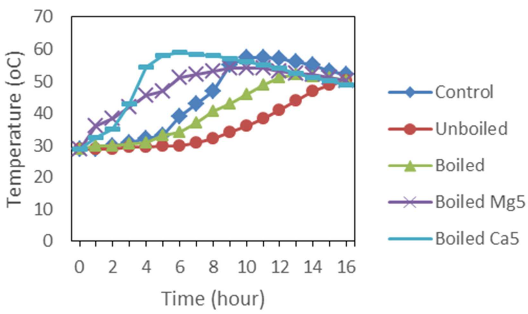

Fig. 1. Temperature and hydration time of wood particles

Manufacture of cement-bonded particleboard

The panels were made in the sizes of 300 mm x 300 mm × 12 mm. The target density and thickness were 1.2 g/cm³ and 12 mm, respectively. The ratio of cement to particles had been set to 70:30, 60:40, and 50:50 (w/w). The accelerators used were $MgCl_2$ and $CaCl_2$, with a concentration of 5%. The calculation of raw materials used the Simatupang (1995) formula. The manufacturing process began with the spraying of the accelerator solution onto the wood particles. During mixing, the cement powder had been spread, and the mixing process was completed when the mixture looked homogeneous (10 min mixing process). The paste was poured into the mold and pressed at 40 bars for 24 hours. The next day, the board was removed from the tools and left for a week at room temperature. The panel was cut according to the size of the test sample and conditioned in a constant room (20°C and RH 65%) for 3 weeks. The manufacturing process and testing the boards can be seen in Fig. 1.

Testing of the physical properties

Testing of the physical properties of cement boards was done based on ISO 8335:1987. The parameters tested included thickness, density, thickness swelling and water absorption.

Data analysis

Data for each treatment were statistically studied by analysis of variance (Anova). The statistical design for the experiment was 3×2 factorial in a completely randomized design. The design for the experiment involved two variables; the first variable is the mixing ratio of cement to particles at three levels of 70:30, 60:40, and 50:50 (w/w) and the second variable is accelerator type at two levels of $MgCl_2$ and $CaCl_2$.

Results and discussion

Hydration

Fig. 2 shows that the maximum control of the hydration temperature of the mixture was 57.5 °C at 10 hours. All treatments reached maximum temperatures above the standard value of more than 41°C, indicating the desired properties. Preliminary treatment with boiling and the use of accelerators increased the hydration temperature. This achieved temperatures higher than the controls, which reached 54°C at 9 hours and 59°C at 6 hours, respectively. The use of the $CaCl_2$ accelerator demonstrated higher temperatures obtained with a faster time.

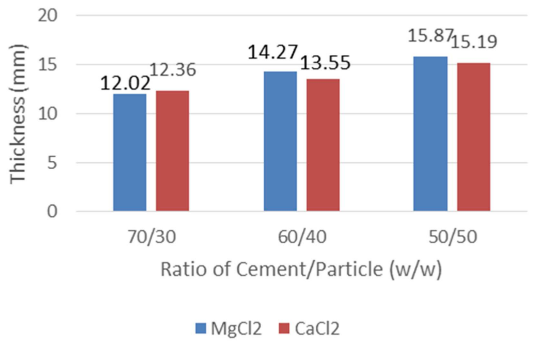

Fig. 2. Thickness of cement-bonded particle board

Thickness and density

In this study, the target thickness and density of the board were 12 mm and 1.2 g/cm3, respectively. The results showed a variation in the thickness of the board with a range of 12.02–15.87 mm and a range in the density of 0.87–1.18 g/cm3. The thickness and density of the board on each treatment can be seen in Fig. 3 and 4.

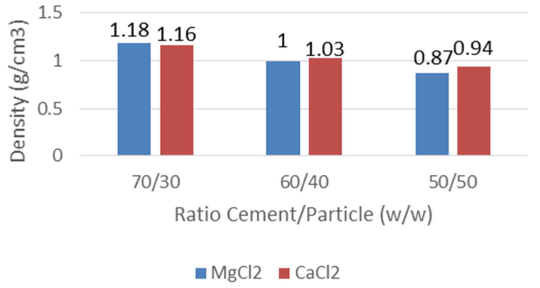

Fig. 3. Density of cement-bonded particle board

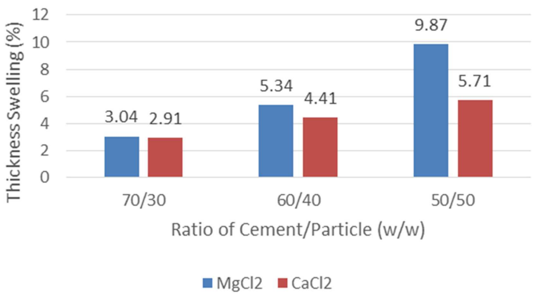

Fig. 4. Thickness swelling of cement-bonded particle board

Fig. 3 shows the highest thickness of the board with a cement/particle ratio of 50/50 and the $MgCl_2$ accelerator with a value of 15.87 mm. The lowest thickness of the board was found on the board with a ratio of 70/30 and $MgCl_2$ of 12.02 mm. Fig. 4 shows that the highest density was achieved by treatment with a ratio of 70/30 and $MgCl_2$ with a value of 1.18 g/cm3. The lowest density on the board was achieved by treatment with a 50/50 ratio and $MgCl_2$ with a value of 0.87 g/cm3. The thickness and density of the board that met the target were only the result of the treatment of 70/30 using both $MgCl_2$ and $CaCl_2$ as accelerators.

Anova tests (Table 2) showed that the treatment of the cement/particle ratio and the type of accelerator, as well as their interaction, had a significant impact on the thickness and density of the board studied. The variation in the thickness of the board results in a variation in board density. Density was related to thickness. There was a significant difference in thickness due to the spring back properties of wood particles. According to Fuwape (1995), the return rate was the percentage of the difference between the thickness of the board and the thickness obtained. The difference like reflux was evident in treatments that used different ratios. There was a tendency that the greater the cement/particle ratio, the greater the thickness due to its small reversible nature. In contrast, the higher the proportion of wood particles (from 30 to 50%), the board could be thicker. The high proportion of wood particles could decrease the weight of cement. The small amount of cement covered the wood particles to reduce the binding strength between the particles and cement. Thus, the pressure is released even though the board still experiences a large spring back, which affects the enhancement of thickness. The thickness could increase with a reduction in the cement/particle ratio. This phenomenon occurred because the volume of wood was larger than the amount of cement for the same weight. Hence, in the process of pressing with the same pressure, a smaller and smaller ratio of cement to particle will produce a thicker board.

It appeared that there was a tendency for thinner boards to be produced with the addition of $CaCl_2$ accelerator, resulting in a thinner board thickness with a higher density. $CaCl_2$ accelerator was more reactive than $MgCl_2$, which can be seen from its hydration temperature test. The addition of $CaCl_2$ provided a higher (reactive) heat, resulting in better cement and particle bonding, making the board more stable and having a smaller spring back.

As previously explained, thickness and density were two parameters of the physical properties investigated. Density was closely related to thickness. It appeared that there was a tendency to increase the ratio of cement particles using the $CaCl_2$ accelerator, which affected the small thickness with high density. The thickness and density of the board that met the target were only the result of the treatment of the 70/30 using both $MgCl_2$ and $CaCl_2$ accelerators.

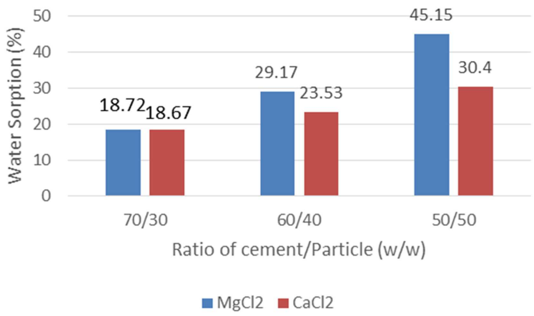

Fig. 5. Water absorption of cement-bonded particle board

Table 2. Analysis of the effect of the cement/wood particle ratio and the type of accelerator on the physical properties of pan

Parameter	Cement/particles (R)	Type of accelerator (A)	R × A
Thickness	539.23*	17.88*	17.61*
Density	19*	6.40*	5.12*
Thickness swelling	218.42*	84.00*	42.38*
Water absorption	215.66*	81.35*	32.18*
F table	3.32	4.17	3.32

Note: * (significant)

Thickness swelling and water absorption

The range of thickness swelling values for the boards was 2.91–9.87%. The distribution of thickness swelling based on the treatments can be seen in Fig. 5. It could be seen that the lowest thickness swelling value was achieved by treatment of the 70/30 ratio with the $CaCl_2$ accelerator at 2.91%, while the highest thickness swelling was obtained by processing the 50/50 ratio with the $MgCl_2$-accelerators at 9.87%. The water absorption ratio ranged from 18.67 to 45.15%. Figure 6 shows that the treatment of the 70/30 ratio with $CaCl_2$ had the lowest water absorption value of 18.67%, while the highest was achieved by the processing of the 50/50 ratio with the $MgCl_2$-accelerator. The 70/30 ratio with both $MgCl_2$ and $CaCl_2$-accelerators had better stability on the board than others. At a ratio of 60/40 and 50/50 (w/w), the board that used the $CaCl_2$ accelerator possessed better stability than that of using $MgCl_2$. Dimensional stability of cement particle board according to ISO 8335:1987 was only based on thickness swelling properties, while water absorption values were not desired. When compared with the ISO 8335:1987 standard, all treatments did not meet the standard thickness swelling value of cement-bonded particleboard, which required a value of less than 2%.

Based on the statistical analysis (Table 2), the interaction of all factors showed significant effects on thickness swelling and water absorption. These factors were considered to be the physical properties that were strongly related to the dimensional stability of the board. Dimensional stability was the most important property when the product was used outdoors or in other places with high humidity. There was a tendency for a high proportion of wood particles to contribute to unstable boards due to high thickness swelling and water absorption. Adding more wood particles reduced the binding energy between the particles and cement. The high proportion of wood particles resulted in a large amount of water being absorbed due to its hygroscopic characteristic. The high addition of cement could form hydration products ($CaCO_3$ and

CSH). $CaCO_3$ and CSH created holes in the board, which easily penetrated water and increased swelling.

Some chemicals, such as $CaCl_2$, $MgCl_2$, Na_2SiO_3, and $Ca(OH)_2$, can reduce the barrier of cement and wood. Boards produced with the addition of the $CaCl_2$ accelerator revealed better dimensional stability than those with the $MgCl_2$-accelerator. $CaCl_2$ was more reactive than $MgCl_2$, which can be seen from its hydration temperature test. The hydration temperature increased with the addition of the $CaCl_2$ accelerator, which provided higher heat. The strong bonding between wood and cement could reduce water penetration. Based on the previous study of Matoski *et al.* (2013), the manufacture of cement board using the wood particle from *Pinus* sp. with four accelerators ($MgCl_2$, $CaCl_2$, Al_2SO_4, and Na_2SiO_4) formed small crystals. $CaCl_2$ accelerated the initial reaction between C_3A and gypsum found in cement to form long, crystalline etrinxites. This crystallization formed a complex grid that made the mixture waterproof. Therefore, the combination of wood powder and the $CaCl_2$ accelerator provided the best physical performance.

Sotannde *et al.* (2012) reported that using wood residues of *Afzelia africana* showed the dimensional stability of the cement-bonded particle board at a cement/particle ratio of 72/28 (w/w) using $CaCl_2$ and $MgCl_2$-accelerators, in which the obtained board could meet the standard compared to other treatments used. Based on this result, we found that our study did not meet the criteria of the commercial board since it produced a lower concentration. The similar tendency of thickness swelling and water absorption values on the 70/30 ratio was better than others with the addition of accelerators.

Conclusion

The results of the hydration temperature test showed that the Sengon wood was a great material in the production of cement-bonded particleboard since it was compatible with cement. The cement/particle ratio and type of accelerator, as well as their interaction, mostly had a significant influence on the properties of the board. The high ratio with the addition of $CaCl_2$ accelerator improved the properties of the board.

In the production process, the thickness and density of the board met the target were those of the board produced from 70/30 ratio with using 5% $MgCl_2$ or $CaCl_2$. Some of the board fulfilled the great physical properties according to ISO 8335:1987.

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