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COMPATIBILITY OF FOUR TROPICAL WOOD SPECIES AND SAGO STEM TO CEMENT AND PROPERTIES OF MANGIUM CEMENT BONDED PARTICLEBOARD

Kompatibilitas Empat Jenis Kayu Tropis dan Batang Sagu dengan Semen dan Sifat Papan Semen Kayu Mangium yang Dihasilkan

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ABSTRACT

The quality of the cement board depends on the compatibility between cement and particles from lignocellulosic biomass. The purpose of this study was to determine the compatibility between cement and particles from four tropical wood namely mangium (*Acacia mangium* Willd), teak (*Tectona grandis* Linn. F.), gelam (*Melaleuca leucadendron* (L.), dadap (*Erythrina variegata* L.), and sago stem (*Metroxylon sago* Rottb.), and to determine the physical and mechanical properties of the mangium cement board produced by adding magnesium chloride ($MgCl_2$) as an accelerator. This research was conducted in two steps. The first step consisted of measuring the hydration temperature of a mixture of cement with particles from the four wood species and sago stems by adding magnesium chloride ($MgCl_2$), with variations of 0%, 2.5%, 5%, and 7.5% based on the cement weight. Two types of mixtures from the first step were then used in the second step, namely the manufacture of cement board. The cement board was made using a weight ratio of mangium particles:cement:water of 1:2.7:1.35. The board is made with a target density of 1.2 g/cm^3. Physical and mechanical testing refers to the ISO 8335-1987 standard. The results of the hydration temperature showed that all of the mixtures were classified into "low inhibition", except for mixture between cement and mangium particles without a catalyst which was included in the classification of "moderate inhibition". While the results of cement board tests indicate that the cement boards made from mangium wood particles with 5% $MgCl_2$ addition had better properties compared to mangium cement boards without catalysts.

Keywords: Cement board, hydration temperature test, physical properties, mechanical properties

ABSTRAK

Kualitas papan partikel semen tergantung dari kompatibilitas antara semen dengan partikel dari biomassa berlignoselulosanya. Tujuan dari penelitian ini adalah untuk mengetahui kompatibilitas antara semen dengan partikel dari empat jenis kayu tropis yaitu kayu mangium (Acacia mangium Willd), jati (Tectona grandis Linn. F.), gelam (Melaleuca leucadendron (L.)), dadap (Erythrina variegata L.), dan batang sagu (Metroxylon sago Rottb.), serta mengetahui sifat fisis dan mekanis dari papan semen kayu mangium yang dihasilkan dengan menambahkan magnesium klorida ($MgCl_2$) sebagai akselerator pada berbagai kadar. Penelitian ini dilakukan melalui dua tahap. Tahap pertama berupa pengukuran suhu hidrasi dari campuran semen dengan partikel dari empat jenis kayu tropis, dan batang sagu, dengan menambahkan magnesium klorida ($MgCl_2$) dengan variasi 0%; 2,5%; 5%, dan 7,5% berdasarkan berat semen. Dua jenis campuran dari penelitian tahap pertama digunakan pada tahap penelitian kedua, yaitu pembuatan papan semen. Pada tahap kedua ini dilakukan pembuatan papan semen dengan menggunakan perbandingan berat partikel mangium:semen:air sebesar 1:2,7:1.35. Papan dibuat dengan target kerapatan 1,2 g/cm^3. Pengujian fisis dan mekanis mengacu pada standar ISO 8335-1987. Hasil penelitian suhu hidrasi menunjukkan bahwa semua campuran diklasifikasikan ke dalam kelas penghambatan rendah, kecuali untuk campuran semen dengan partikel mangium tanpa katalis yang termasuk ke dalam klasifikasi indeks penghambatan sedang. Sedangkan hasil pengujian yang dilakukan terhadap papan semen menunjukkan bahwa papan semen dari partikel kayu mangium dengan penambahan 5% $MgCl_2$ memiliki nilai lebih baik jika dibandingkan dengan papan semen mangium tanpa penambahan katalis.

Kata kunci: Papan semen, pengujian suhu hidrasi, sifat fisis, sifat mekanis

I. INTRODUCTION

The use of cement-bonded particleboard or cement board has been rapidly increased in many countries because of its excellent properties for building purpose. Cement board has high water, fire, termite, and fungal resistance, good weather ability (Wei, Zhou, & Tomita, 2000) and acoustic insulation (Frybort, Mauritz, Teischinger, & Müller, 2008). Cement board is made of strands, particles or fibers from wood or others lignocellulosic biomass mixed with cement and small amounts of additives manufactured into panels used by construction or non-construction industries in the application such as a wall, roof sheathing, floor, fences, and sound barrier (Erakhrumen, Areghan, Ogunleye, Larinde, & Odeyale, 2008; Okino et al., 2004).

The compatibility between cement and particles of lignocellulosic biomass is a problem for cement board manufacturing. The compatibility is influenced by compounds contained in lignocellulosic biomass such as extractives and hemicellulose content. These extractives are generally composed of fatty acid, vanillic acid, carbohydrates, and inorganic materials (Kilic & Niemz, 2012). Hemicellulose and sugars as the chemical compounds of lignocellulosic biomass could decrease the compatibility and the strength of cement board significantly and gives an effect in decreasing compatibility between cement and lignocellulosic particles (Vaickelionis & Vaickelioniene, 2006). Na, Wang, Wang, & Lu (2014) stated that the different components of wooden extractives cause a different inhibitory or retarding degree of cement hydration. The lower amount of inhibitory extractives diffuse into the cement paste is beneficial for the compatibility between cement and lignocellulosic biomass.

Hofstrand, Moslemi, and Garcia (1984) developed an equation to calculate the inhibitory index (I) of a mixture of cement with wood particles. The inhibitory index of any species can be derived from the values of the maximum temperature of hydration, the maximum slope of the exothermic curve, and the hydration time needed to reach the maximum temperature of the inhibited cement when compared respectively with the values of the uninhibited cement. The compatibility of the mixture will be higher if the I-value is getting smaller. Conversely, the compatibility is lower when the I-value is greater. Sudin and Swamy (2006) conducted research using various treatments and additives. Results of their study stated that the use of additives such as $MgCl_2$ and $Al_2(SO_3)_4$ as an accelerator to the mixtures of cement and wood particles could shorten the setting time of wood-cement mixtures.

Previous research to estimate the compatibility or inhibitory index of a mixture of cement with lignocellulosic biomass was carried out using the approach of Hofstrand, Moslemi, and Garcia (1984). Some lignocellulosic biomass used in the measurement of the inhibitory index includes Chinese fir and poplar (Wang & Yu, 2012), vegetable residues (Marques et al., 2016), and eight types of hardwood residues from Amazonia Brasil (Castro et al., 2018). This study aimed to determine the compatibility between cement with four tropical wood and sago trunks and to determine the effect of the catalyst $MgCl_2$ at various levels to its compatibility (inhibition index value). Besides, this study also aimed to determine the physical and mechanical properties of the mangium (*Acacia mangium* Willd) wood-cement board without or with the addition of $MgCl_2$ as a catalyst.

II. MATERIALS AND METHODS

Four tropical wood species, i.e. mangium, teak wood (*Tectona grandis* Linn. f.), gelam (*Melaleuca leucadendron* (L.)), and dadap (*Erythrina variegata* L.*)*, and also the stem of sago (*Metroxylon sagu* Rottb.) were used in this study. The first step of this study was cement hydration test using five kinds of particles. The hydration test was performed using $MgCl_2$ as an accelerator with a variation of 0%, 2.5%, 5%, and 7.5% based on the cement weight. Portland cement-based on the Indonesian standard (SNI) was used as a binder.

The second step of this study was cement boards manufacture. The cement board was developed based on the results of the hydration test. The size of the board was 30 x 30 x 1.2 cm, with a targeted density of 1.2 g/cm^3. The boards were kept for 21 days before tested. Physical and mechanical tests were conducted according to ISO 8335-1987, with four replicates samples for each testing.

A. Hydration Test

The hydration temperature was measured in an insulated box. The cement/lignocellulosic biomass ratio of 6.9:1.0 and a powder size of 20 pass/30 on a mesh (Hermawan, Subiyanto, & Kawai, 2001). $MgCl_2$ was added to each mixture in the range of 0%-7.5% based on the cement weight. The mass water/cement ratios were 0.5. A thermocouple wire was inserted approximately at the center core of cement paste and connected to Graphtec midi LOGGER GL220. All the experiments were conducted at room temperature. To calculate the inhibitory index (*I*) of each species, the following equation (Hofstrand, Moslemi, & Garcia, 1984) was applied:

$$I = 100[((t_2 - t'_2)/t'_2)*((T'_2 - T_2)/T'_2)*((S'_2 - S_2)/S'_2)] ....(1)$$

Remarks (*Keterangan*): t_2 = time to reach the maximum temperature of the inhibited cement (wood-cement-water mixture) (hours); t'_2 = time to reach the maximum temperature of the uninhibited cement (cement-water mixture (hours); T_2 = Maximum temperature of the inhibited cement (°C); T'_2 = Maximum temperature of the uninhibited cement (°C); S2 = the maximum slope of the exothermic curve of the inhibited cement (°C/hours); S'2 = the maximum slope of the exothermic curve of the uninhibited cement (°C/hours) Inhibition index classification is divided into four grades, namely low inhibition ($I < 10$), moderate inhibition ($10 < I < 50$), high inhibition ($50 < I < 100$), and extreme inhibition ($I > 100$) (Okino et al., 2004).

A. Board Manufacture

In this study, the ratio between wood particles to cement was 1:2.7 based on the weight, and water was used 50% of cement weight. Magnesium chloride ($MgCl_2$) at 5% of cement weight was added for all ratios. Wood particles were sprayed until the moisture content 100% and kept for 24 hours. The particles then were mixed with cement using a mortar mixer and added with the rest of the water left with or without $MgCl_2$. The mixtures were hand-matt formed and cold-pressed for 24 hours. The size of the board was 30 cm x 30 cm x 1.2 cm, with a targeted density of 1.2 g/cm^3. The boards were kept for 21 days before tested. Physical and mechanical tests were conducted according to ISO 8335-1987.

To test the effect of the addition of 5% $MgCl_2$ catalyst to the properties of mangium wood cement board, a statistical analysis was carried out in the form of two samples T-test. The significance level used was 5%, which means that if the P-value of the comparison of the two cement boards was less than 5%, the addition of the catalyst had a significant effect on its properties. However, if the P-value was greater than 5%, then the addition of a catalyst had no significant impact on its properties.

B. Scanning Electron Microscope Observation

The test specimens were prepared for SEM observation by cutting small sections from the fractured surfaces of the bending test samples of cement-bonded particleboard with the addition of 5% $MgCl_2$. The small samples were mounted on specimen stubs and then coated with gold for examination under SEM Zeiss EVO 50.

III. RESULT AND DISCUSSION

A. Hydration Test

Hydration temperature data was recorded for 24 hours using a thermocouple device. Based on the hydration temperature measurement data, an inhibition index value was calculated. The value of the inhibitory index is presented in Table 1.

Results showed that all of the mixtures of five tropical wood particles-cement paste with/ without $MgCl_2$ as accelerator were classified as "low inhibition", except for the mixture between mangium wood particles-cement without $MgCl_2$ (moderate inhibition). It means that almost all the mixtures have well compatibility (Okino et al., 2004). This can occur because mangium has a higher hemicellulose content compared to the other wood. High hemicellulose content can inhibit the bond between wood-forming material and cement (Snoeck et al., 2015). For example, mangium wood has a hemicellulose content about 11.27–36.14% (Amini et al., 2017), compared to teak wood which hemicellulose content of 8.4–26% (Gasparik et al., 2019).

B. Physical and Mechanical Properties of Cement-bonded Particleboard

The manufacture of cement-board was conducted to determine the correlation between inhibition index with physical and mechanical properties of cement-board. Cement-board made with consideration of the different inhibitory

Table 1. Inhibitory index of four tropical wood species and sago stem particles with cement paste

Tabel 1. Indeks penghambatan partikel empat jenis kayu tropis dan batang sagu dengan pasta semen

Mixtures (*Campuran*)	Tmax (*Suhu maksimum*, °C)	t max (*Waktu untuk mencapai suhu maksimum, jam*, hours)	Inhibitory Index (*Indeks Penghambatan*)	Classification (*Pengkelasan*)
Cement paste	43.7	11.317		
Cement + mangium (*Acacia mangium* Willd)	34.4	23.883	19.830	Moderate
Cement + mangium + 2.5% $MgCl_2$	43.0	10.950	-0.010	Low
Cement + mangium + 5% $MgCl_2$	41.5	7.917	-0.032	Low
Cement + mangium + 7.5% $MgCl_2$	41.6	6.330	0.292	Low
Cement + gelam (*Melaleuca leucadendron* (L.))	39.0	12.767	0.556	Low
Cement + gelam + 2.5% $MgCl_2$	42.3	9.500	-0.024	Low
Cement + gelam + 5% $MgCl_2$	45.0	8.417	-0.225	Low
Cement + gelam + 7.5% $MgCl_2$	41.4	7.483	0.096	Low
Cement + dadap (*Erythrina variegata* L.)	35.0	18.283	9.174	Low
Cement + dadap + 2.5% $MgCl_2$	38.8	10.633	-0.284	Low
Cement + dadap + 5% $MgCl_2$	40.5	8.700	-0.225	Low
Cement + dadap + 7.5% $MgCl_2$	42.8	7.400	0.159	Low
Cement + sago (*Metroxylon sago Rottb.*)	33.5	13.820	4.132	Low
Cement + sago + 2.5% $MgCl_2$	38.3	9.617	-0.665	Low
Cement + sago + 5% $MgCl_2$	36.9	7.683	0.693	Low
Cement + sago + 7.5% $MgCl_2$	37.8	5.667	-0.785	Low
Cement + teak wood (*Tectona grandis Linn. F.*)	38.8	22.167	7.158	Low
Cement + teak wood + 2.5% $MgCl_2$	38.6	13.550	1.067	Low
Cement + teak wood + 5% $MgCl_2$	38.8	9.867	-0.488	Low
Cement + teak wood + 7.5% $MgCl_2$	37.5	7.933	-0.505	Low

Table 2. The physical properties of cement-bonded particleboard made from mangium wood
Tabel 2. Sifat fisis dari papan partikel semen yang terbuat dari kayu mangium

Mixtures (*Campuran*)	Density (*Kerapatan, g/cm³*)	Moisture content (*Kadar air, %*)	Water absorption (*Daya serap air, %*)	Thickness swelling (*Pengembangan tebal, %*)
Cement board without $MgCl_2$ addition	0.93±0.06	8.44±0.48	36.37±4.70	1.34±0.35
Cement board with 5% $MgCl_2$ addition	1.12±0.13	8.32±0.74	18.82±0.60	1.02±0.22

indexes from the mixtures of cement, wood particles, and catalyst. In this study, two types of cement boards were manufactured, namely cement board with and without the addition of 5% $MgCl_2$. Mangium wood was chosen to be used in the manufacture of cement boards, to find out the physical and mechanical properties of cement boards when using wood particles which have poor compatibility with higher $MgCl_2$ as an accelerator. This was done to determine the quality of cement boards using wood with a moderate inhibition index. The physical properties of mangium bonded cement particleboards are listed in Table 2.

The boards with the addition of 5% $MgCl_2$ showed the best performance for all physical properties. They had higher density, lower in moisture content, thickness swelling (TS), and water absorption (WA). The boards with the addition of $MgCl_2$ have higher density if compared to the board without $MgCl_2$, although almost all of the board have lower density compared to the targeted density (1.2 g/cm^3). The values of density ranged from 0.85 to 1.31 g/cm^3. The values of TS ranged from 0.75 to 1.78%. All of the boards both without $MgCl_2$ and with the addition of 5% $MgCl_2$ fulfil the standard of ISO 8335-1987 for TS (TS<2%). The values of moisture content (MC) ranged from 7.53% to 9.29%. It showed that all of the MC's values met the standard (MC < 12%). The values of water absorption ranged from 18.07% to 41.63 %. The boards with the addition of 5% $MgCl_2$ has better water absorption performance. This happens because the addition of $MgCl_2$ can accelerate the hydration process on the cement board, so that the cement board with the addition of $MgCl_2$ can absorb less water, compared to the cement board without $MgCl_2$.

Compared to cement boards made from *Eucalyptus grandis* wood with a density of 1.2 g/c^3 and addition of 6% $CaCl_2$ as catalyst (Lisboa et al., 2018), cement boards made from mangium wood with the addition of 5% $MgCl_2$ catalyst have relatively similar TS and WA values. The TS value of mangium cement board with 5% $MgCl_2$ addition (1.02%) is relatively similar compared to the TS value of eucalyptus cement board (1.5%). This is a similar thing for the WA values of the two board types which are not too different (18.82% for mangium cement board compared to 20% for eucalyptus cement board).

The mechanical properties of cement-bonded particleboard are listed in Table 3. The boards with the addition of $MgCl_2$ show the best performance for MOR, MOE, IB, and SW.

Table 3. The mechanical properties of cement-bonded particleboard made from mangium wood
Tabel 3. Sifat mekanis papan partikel semen yang terbuat dari kayu mangium

Mixtures (*Campuran*)	Modulus of Rupture (*Modulus patah, MPa*)	Modulus of Elasticity (*Modulus elastisitas, GPa*)	Internal Bond (*Daya rekat internal, MPa*)	Screw Withdrawal (*Kuat pegang sekrup, N*)
Cement bonded particleboard without $MgCl_2$ addition	7.00±1.65	2.26±0.54	0.331±0.068	271.48±44.59
Cement bonded particleboard with 5% $MgCl_2$ addition	9.18±1.02	3.06±0.30	0.779±0.148	487.42±68.34

Table 4. Statistical analysis of cement-bonded particleboard properties using two samples T-Test

Tabel 4. Hasil analisis statistik sifat papan semen menggunakan uji-T dua contoh uji

	Moisture Content (*Kadar air*)	Thickness Swelling (*Pengembangan tebal*)	Water Absorption (*Daya serap air*)	Modulus of Rupture (*Modulus patah*)	Modulus of Elasticity (*Modulus elastisitas*)	Internal Bond (Kuat rekat internal)	Screw Witthdwawal (*Kuat pegang sekrup*)
$MgCl_2$ addition	0.791^{ns}	0.206^{ns}	0.005^{sig}	0.074^{ns}	0.059^{ns}	0.005^{sig}	0.003^{sig}

Remarks (*Keterangan*): ns: not significant at a significant level of 5 %; sig: significant at a significant level of 5%

The values of modulus of rupture (MOR) ranged from 5.49 to 10.01 MPa. The boards with the addition of 5% $MgCl_2$ fulfill the standard of MOR (MOR > 9MPa). The values of modulus of elasticity (MOE) ranged from 1.69 GPa to 3.40 GPa. The boards with the addition of 5% $MgCl_2$ fulfil the standard of MOE (MOE > 3 GPa). Furthermore, the values of an internal bond (IB) ranged from 0.26 MPa to 0.95 MPa, and the values of screw withdrawal (SW) ranged from 224.06 N to 571.10 N. There are also boards with the addition of 5% $MgCl_2$ that fulfill the standard for IB (IB > 0.5 MPa) and SW (SW > 300 N). MOR and MOE values of cement boards from mangium are smaller compared to cement boards from eucalyptus, which respectively have MOR and MOE values of 15 MPa and 7.5 GPa (Lisboa et al., 2018).

The improvement effect because the addition of 5% $MgCl_2$ on the physical and mechanical properties of boards might be due to the proper alkalinity of $MgCl_2$. The alkalinity of $MgCl_2$ could not be expected to trigger the dissolution of the inhibitory extractives but rather to enhance the hydration reaction of cement and the substantial strength development of the board (Hermawan et al., 2001; Sudin & Swamy, 2006).

C. Statistical Analysis

The statistical analysis of the physical and mechanical properties of cement boards with catalyst treatment is listed in Table 4. The addition of 5% $MgCl_2$ provided significant effect for water absorption, internal bond (IB) and screw withdrawal (SW), but not significant for moisture content (MC), thickness swelling (TS), modulus of rupture (MOR), and modulus of elasticity (MOE) at a significant level of 5%.

This shows that the addition of a 5% solution of $MgCl_2$ catalyst to the cement board cannot significantly affect all of its properties at the 5% significance level. For example, using a 5% $MgCl_2$ catalyst on cement boards can significantly reduce WA value from 36.37% to 18.82%. As for TS, although the use of 5% $MgCl_2$ catalyst can reduce TS from 1.34% to 1.02%, but statistically at a significance level of 5% is considered insignificant.

D. SEM Analysis

The bond that occurs between cement and wood particles can be objected using SEM. Figure 1 shows the fractured surface of a mangium cement board with the addition of 5% $MgCl_2$ by SEM.

Figure 1a and 1b show that there was interference with cement hydration, but the formation of calcium silicate hydrate (CSH) and calcium carbonate (CC) did not occur. A mass of amorphous was found that did not develop the interlocking strength potential brought about by CSH and CC, although the cement-board met the standard for mechanical properties. Therefore, the mechanical interlocking process is probably an important mechanism contributing to mechanical strength.

IV. CONCLUSION

All of the cement-wood/stem particle mixtures without and with $MgCl_2$ as accelerator have good compatibility and classified as "low inhibition", except for the mixture between mangium wood particles-cement without $MgCl_2$ (moderate inhibition). Cement-bonded particleboards have been successfully made using mangium wood. The cement board made with the addition of

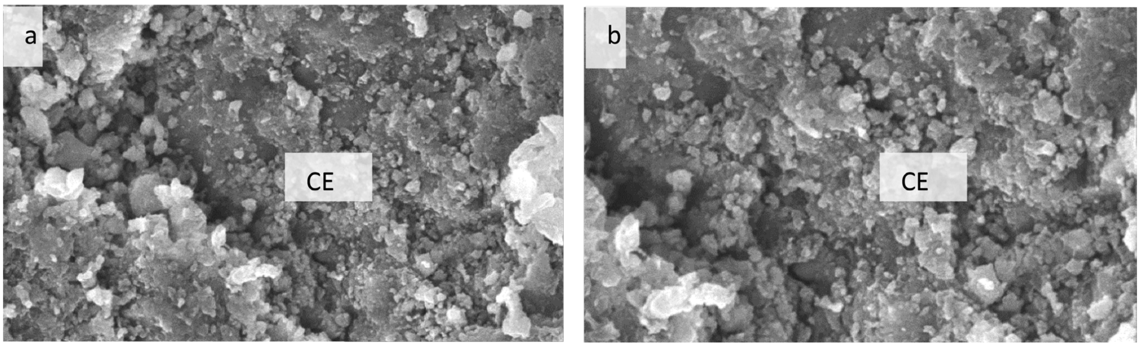

Figure 1. Scanning electron microscopy photographs of fracture surface of mangium cement board with addition of 5% $MgCl_2$, (a) 2000x magnification and (b) 3500x magnification, CE, cement clinker

Gambar 1. Foto pemindaian mikroskop elektron dari patahan permukaan papan semen kayu mangium dengan penambahan $MgCl_2$ 5%, (a) perbesaran 2000x dan (b) perbesaran 3500x, CE, klinker semen

5% $MgCl_2$ has better physical and mechanical properties if compared with the cement-board without $MgCl_2$ and fulfilled the standard for all of the physical and mechanical properties. SEM analysis shows that there was interference with cement hydration, and the formation of calcium silicate hydrate and calcium carbonate did not occur, and probably give a significant effect on the mechanical properties.

AUTHOR CONTRIBUTIONS

DH, IB and GP conducted the ideas, designs and experimental designs; trials and test treatments are car ried out by IB, HS, and JES; DH and IB collected and analysed the data; DH, IB, HS, JES, and GP wrote the manuscript; DH, IB, and GP edited and finalized the manuscript.

REFERENCES

Amini, M. H. M., Rasat, M. S. M., Mohamed, M., Wahab, R., Ramle, N. H., Khalid, I., & Yunus, A. M. (2017). Chemical composition of small diameter wild *Acacia mangium* species. *APRN Journal of Engineering and Applied Sciences, 12*(8), 2698-2702.

Castro, V. G., Azambuja, R. da R., Bila, N. F., Parchen, C. F. A., Sassaki, G. I., & Iwakiri, S. (2018). Correlation between chemical composition of tropical hardwoods and wood–cement compatibility. *Journal of Wood Chemistry and Technology*, *38*(1), 28–34. doi: 10.1080/02773813.2017.1355390.

Erakhrumen, A. A., Areghan, S. E., Ogunleye, M. B., Larinde, S. L., & Odeyale, O. O. (2008). Selected physico-mechanical properties of cement-bonded particleboard made from pine (*Pinus caribaea* M.) sawdust-coir (*Cocos nucifera* L.) mixture. *Scientific Research and Essays*, *3*(5), 197–203.

Frybort, S., Mauritz, R., Teischinger, A., & Müller, U. (2008). Cement bonded composites - A mechanical review. *BioResources*, *3*(2), 602–626.

Gasparik, G., Gaff, M., Kacik, F., & Sikora, A. (2019). Color and chemical changes in teak *(Tectona grandis* L.f.) and meranti *(Shorea* spp.) wood after thermal treatment. *BioResources, 14*(2), 2667-2683.

Hermawan, D., Subiyanto, B., & Kawai, S. (2001). Manufacture and properties of oil palm frond cement-bonded board. *Journal of Wood Science*, 47, 208–213. doi: 10.1007/BF01171223.

Hermawan, D., Hata, T., Umemura, K., Kawai, S., Nagadomi, W., & Kuroki, Y. (2001). Rapid production of high-strength cement-bonded particleboard using gaseous or supercritical carbon dioxide. *Journal of Wood Science*, *47*(4), 294–300. doi: 10.1007/BF00766716.

Hofstrand, A.D., Moslemi, A.A., & Garcia, J.F. (1984). Curing characteristics of wood particles from nine northern Rocky Mountain species mixed with Portland cement. *Forest Products Journal, 2*, 567-70.

Kilic, A., & Niemz, P. (2012). Extractives in some tropical woods. *European Journal of Wood and Wood Products*, *70*(1–3), 79–83. doi: 10.1007/s00107-010-0489-8.

Lisboa, F. J. N., Scatolino, M. V., de Paula Protásio, T., Júnior, J. B. G., Marconcini, J. M., & Mendes, L. M. (2018). Lignocellulosic materials for production of cement composites: Valorization of the alkali treated soybean pod and eucalyptus wood particles to obtain higher value-added products. *Waste and Biomass Valorization*, 11**,** 2235–2245. doi: 10.1007/s12649-018-0488-2.

Marques, M. L., Luzardo, F. H. M., Velasco, F. G., González, L. N., Silva, E. J. da, & Lima, W. G. de. (2016). Compatibility of vegetable fibers with portland cement and its relationship with the physical properties. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *20*(5), 466–472. doi: 10.1590/1807-1929/agriambi.v20n5p466-472.

Na, B., Wang, Z., Wang, H., & Lu, X. (2014). Wood-cement compatibility review. *Wood Research*, *59*(5), 813–825.

Okino, E. Y. A., De Souza, M. R., Santana, M. A. E., Alves, M. V. D. S., De Sousa, M. E., & Teixeira, D. E. (2004). Cement-bonded wood particleboard with a mixture of eucalypt and rubberwood. *Cement and Concrete Composites*, *26*(6), 729–734. doi: 10.1016/S0958-9465(03)00061-1.

Snoeck, D., Smetryns, P., & Belie N. D. (2012). Improved multiple cracking and autogenous healing in cementitious materials by means of chemically-treated natural fibres. *Biosystems Engineering, 139,* 87-89. doi: 10.1016/j.biosystemseng.2015.08.007.

Sudin, R. & Swamy, N. (2006). Bamboo and wood fibre cement composites for sustainable infrastructure regeneration. *Journal of Materials Science, 41,* 6917–6924. doi: 10.1007/s10853-006-0224-3.

Vaickelionis, G. & Vaickelioniene, R. (2006). Cement hydration in the presence of wood extractives and pozzolan mineral additives. *Ceramics - Silikaty*, *50*(2), 115–122.

Wang, X. & Yu, Y. (2012). The compatibility of two common fast-growing species with portland cement. *Journal of the Indian Academy of Wood Science*, *9*(2), 154–159. doi: 10.1007/s13196-012-0081-4.

Wei, Y. M., Zhou, Y. G., & Tomita, B. (2000). Study of hydration behavior of wood cement-based composite II: Effect of chemical additives on the hydration characteristics and strengths of wood-cement composites. *Journal of Wood Science*, *46*(6), 444–451. doi: 10.1007/BF00765802.

APPENDIX 1. Two-Sample T-Test and CI: MC (%), $MgCl_2$

Lampiran 1. Uji-T dua contoh uji dan selang kepercayaan: Kadar air (%), $MgCl_2$

Two-sample T for MC (%)

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	8.443	0.478	0.24
5	4	8.319	0.743	0.37

Difference = μ (0) - μ (5)

Estimate for difference: 0.124

95% CI for difference: (-1.012; 1.260)

T-Test of difference = 0 (vs ≠): T-Value = 0.28 P-Value = 0.791 DF = 5

APPENDIX 2. Two-Sample T-Test and CI: TS (%), $MgCl_2$

Lampiran 2. Uji-T dua contoh uji dan selang kepercayaan: Pengembangan tebal (%), $MgCl_2$

Two-sample T for TS (%)

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	1.339	0.354	0.18
5	4	1.025	0.218	0.11

Difference = μ (0) - μ (5)

Estimate for difference: 0.314

95% CI for difference: (-0.263; 0.891)

T-Test of difference = 0 (vs ≠): T-Value = 1.51 P-Value = 0.206 DF = 4

APPENDIX 3. Two-Sample T-Test and CI: WA (%), $MgCl_2$

Lampiran 3. Uji-T dua contoh uji dan selang kepercayaan: Daya serap air (%), $MgCl_2$

Two-sample T for WA (%)

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	36.37	4.70	2.4
5	4	18.816	0.600	0.30w

Difference = μ (0) - μ (5)

Estimate for difference: 17.56

95% CI for difference: (10.01; 25.10)

T-Test of difference = 0 (vs ≠): T-Value = 7.41 P-Value = 0.005 DF = 3

APPENDIX 4. Two-Sample T-Test and CI: MOR (MPa), $MgCl_2$

Lampiran 4. Uji-T dua contoh uji dan selang kepercayaan: Modulus patah (MPa), $MgCl_2$

Two-sample T for MOR (MPa)

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	7.00	1.65	0.82
5	4	9.18	1.02	0.51

Difference = μ (0) - μ (5)

Estimate for difference: -2.182

95% CI for difference: (-4.671, 0.306)

T-Test of difference = 0 (vs ≠): T-Value = -2.25 P-Value = 0.074 DF = 5

APPENDIX 5. Two-Sample T-Test and CI: MOE (GPa), $MgCl_2$

Lampiran 5. Uji-T dua contoh uji dan selang kepercayaan: Modulus modulus elastisitas (GPa), $MgCl_2$

Two-sample T for MOE (GPa)

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	2.257	0.538	0.27
5	4	3.061	0.299	0.15

Difference = μ (0) - μ (5)

Estimate for difference: -0.804

95% CI for difference: (-1.658; 0.050)

T-Test of difference = 0 (vs ≠): T-Value = -2.61 P-Value = 0.059 DF = 4

APPENDIX 6. Two-Sample T-Test and CI: IB (MPa), MgCl2

Lampiran 6. Uji-T dua contoh uji dan selang kepercayaan: Kuat rekat internal (MPa), $MgCl_2$

Two-sample T for IB

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	0.3313	0.0680	0.034
5	4	0.779	0.148	0.074

Difference = μ (0) - μ (5)

Estimate for difference: -0.4474

95% CI for difference: (-0.6730; -0.2217)

T-Test of difference = 0 (vs ≠): T-Value = -5.50 P-Value = 0.005 DF = 4

APPENDIX 7. Two-Sample T-Test and CI: SW (N), $MgCl_2$

Lampiran 7. Uji-T dua contoh uji dan selang kepercayaan: Kuat Pegang Sekrup (N), $MgCl_2$

Two-sample T for SW

$MgCl_2$	N	Mean	StDev	SE Mean
0	4	271.5	44.6	22
5	4	487.4	68.3	34

Difference = μ (0) - μ (5)

Estimate for difference: -215.9

95% CI for difference: (-320.8; -111.1)

T-Test of difference = 0 (vs ≠): T-Value = -5.29 P-Value = 0.003 DF = 5