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 Dihanisman

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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 (MgCl₂) 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 (MgCl₂), 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/cm³. 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% MgCl₂ 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 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 fisik dan mekanis dari
papan semen kayu mangium yang dihasilkan dengan menambahkan magnesium klorida (MgCl\textsubscript{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\textsubscript{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\textsuperscript{3}. Pengujian fisik 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\textsubscript{2} memiliki nilai lebih baik jika dibandingkan dengan papan semen mangium tanpa penambahan katalis.

Kata kunci: Papan semen, pengujian suhu hidrasi, sifat fisik, 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 extracts 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\textsubscript{2} and Al\textsubscript{2}(SO\textsubscript{4})\textsubscript{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. The mass water/cement ratios were 0.5. A thermocouple wire was inserted approximately at the center core of cement paste and connected to Graphitec 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:

\[
I = 100\left(\frac{(t_2 - t'_2)}{t'_2}\right)^{\left(\frac{T_2 - T'_2}{T'_2}\right)^{\left(\frac{S_2 - S'_2}{S'_2}\right)}}
\]

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); \(S_2\) = 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, 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 Graphitec 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:

\[
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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).

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

| Mixtures                                      | Tmax (Suhu maksimum, °C) | $t_{\text{max}}$ (Waktu untuk mencapai suhu maksimum, jam, hours) | Inhibitory Index (Indeks Penghambatan) | Classification (Pengkelasan) |
|-----------------------------------------------|---------------------------|-----------------------------------------------------------------|----------------------------------------|-----------------------------|
| Cement paste                                  | 43.7                      | 11.317                                                          | 19.830                                  | Moderate                    |
| Cement + mangium (Acacia mangium Willd)       | 34.4                      | 23.883                                                          | -0.010                                  | Low                         |
| Cement + mangium + 2.5% MgCl$_2$               | 43.0                      | 10.950                                                          | -0.032                                  | Low                         |
| Cement + mangium + 5% MgCl$_2$                 | 41.5                      | 7.917                                                           | -0.292                                  | Low                         |
| Cement + mangium + 7.5% MgCl$_2$               | 41.6                      | 6.330                                                           | 0.096                                   | 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 + dabad (Erythrina variegata L.)        | 35.0                      | 18.283                                                          | 9.174                                   | Low                         |
| Cement + dabad + 2.5% MgCl$_2$                 | 38.8                      | 10.633                                                          | -0.284                                  | Low                         |
| Cement + dabad + 5% MgCl$_2$                   | 40.5                      | 8.700                                                           | -0.225                                  | Low                         |
| Cement + dabad + 7.5% MgCl$_2$                 | 42.8                      | 7.400                                                           | 0.159                                   | Low                         |
| Cement + sago (Metroxylon sagu Rothb.)         | 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 (Tretona 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                         |

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
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% MgCl₂. 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 MgCl₂ 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% MgCl₂ 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 MgCl₂ have higher density if compared to the board without MgCl₂, although almost all of the board have lower density compared to the targeted density (1.2 g/cm³). The values of density ranged from 0.85 to 1.31 g/cm³. The values of TS ranged from 0.75 to 1.78%. All of the boards both without MgCl₂ and with the addition of 5% MgCl₂ 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% MgCl₂ has better water absorption performance. This happens because the addition of MgCl₂ can accelerate the hydration process on the cement board, so that the cement board with the addition of MgCl₂ can absorb less water, compared to the cement board without MgCl₂.

Compared to cement boards made from *Eucalyptus grandis* wood with a density of 1.2 g/cm³ and addition of 6% CaCl₂ as catalyst (Lisboa et al., 2018), cement boards made from mangium wood with the addition of 5% MgCl₂ catalyst have relatively similar TS and WA values. The TS value of mangium cement board with 5% MgCl₂ 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 MgCl₂ show the best performance for MOR, MOE, IB, and SW.

| Mixtures (Campuran) | Density (Kerapatan, g/cm³) | Moisture content (Kadar air, %) | Water absorption (Daya serap air, %) | Thickness swelling (Pengembangan lebar, %) |
|--------------------|---------------------------|-------------------------------|-------------------------------------|--------------------------------------|
| Cement board without MgCl₂ addition | 0.93±0.06                | 8.44±0.48                      | 36.37±4.70                         | 1.34±0.35                             |
| Cement board with 5% MgCl₂ addition | 1.12±0.13                | 8.32±0.74                      | 18.82±0.60                         | 1.02±0.22                             |

| 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 MgCl₂ addition | 7.00±1.65                | 2.26±0.54                      | 0.331±0.068                          | 271.48±44.59                          |
| Cement bonded particleboard with 5% MgCl₂ addition | 9.18±1.02                | 3.06±0.30                      | 0.779±0.148                          | 487.42±68.34                          |
The values of modulus of rupture (MOR) ranged from 5.49 to 10.01 MPa. The boards with the addition of 5% MgCl₂ 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% MgCl₂ fulfill 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% MgCl₂ 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% of MgCl₂ catalyst to the cement board cannot significantly affect all of its properties at the 5% significance level. For example, using a 5% MgCl₂ catalyst on cement boards can significantly reduce WA value from 36.37% to 18.82%. As for TS, although the use of 5% MgCl₂ 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% MgCl₂ 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 MgCl₂ as accelerator have good compatibility and classified as “low inhibition”, except for the mixture between mangium wood particles-cement without MgCl₂ (moderate inhibition). Cement-bonded particleboards have been successfully made using mangium wood. The cement board made with the addition of

| MgCl₂ addition | 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 Withdrawal (Kuat pegang sekrup) |
|----------------|-----------------------------|----------------------------------------|-----------------------------------|-----------------------------------|------------------------------------------|------------------------------------|--------------------------------------|
|                | 0.791*                      | 0.206*                                 | 0.005*                            | 0.074*                            | 0.039*                                   | 0.005*                             | 0.003*                               |

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

The statistical analysis of the physical and mechanical properties of cement boards with catalyst treatment is listed in Table 4. The addition of 5% MgCl₂ 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 MgCl₂ catalyst to the cement board would not significantly affect all of its properties at the 5% significance level. For example, using a 5% MgCl₂ catalyst on cement boards can significantly reduce WA value from 36.37% to 18.82%. As for TS, although the use of 5% MgCl₂ catalyst can reduce TS from 1.34% to 1.02%, but statistically at a significance level of 5% is considered insignificant.
5% MgCl₂ has better physical and mechanical properties if compared with the cement-board without MgCl₂ 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 carried 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.

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APPENDIX 1. Two-Sample T-Test and CI: MC (%), MgCl₂

**Lampiran 1. Uji-T dua contoh uji dan selang kepercayaan: Kadar air (%), MgCl₂**

| Two-sample T for MC (%) | MgCl₂ | 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 (%), MgCl₂

**Lampiran 2. Uji-T dua contoh uji dan selang kepercayaan: Pengembangan tebal (%), MgCl₂**

| Two-sample T for TS (%) | MgCl₂ | 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 (%), MgCl₂

**Lampiran 3. Uji-T dua contoh uji dan selang kepercayaan: Daya serap air (%), MgCl₂**

| Two-sample T for WA (%) | MgCl₂ | N  | Mean  | StDev  | SE Mean |
|--------------------------|-------|----|-------|--------|---------|
| 0                        | 4     | 36.37 | 4.70   | 2.4    |
| 5                        | 4     | 18.816 | 0.600  | 0.30   |

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), MgCl₂

**Lampiran 4. Uji-T dua contoh uji dan selang kepercayaan: Modulus patah (MPa), MgCl₂**

| Two-sample T for MOR (MPa) | MgCl₂ | 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: (4.71; 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), MgCl₂

**Lampiran 5. Uji-T dua contoh uji dan selang kepercayaan: Modulus modulus elastisitas (GPa), MgCl₂**

| Two-sample T for MOE (GPa) | MgCl₂ | 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), MgCl₂**

| Two-sample T for IB | MgCl₂ | 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), MgCl₂

Lampiran 7. Uji-T dua contoh uji dan selang kepercayaan: Kuat Pegang Sekrup (N), MgCl₂

Two-sample T for SW

| MgCl₂ | 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