The properties of cement boards reinforced with coconut coir fiber (Cocos nucifera) as building materials

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Abstract. Cement board is a composite made from lignocellulosic biomass or other materials and bonded with cement, that has advantages such as fire and termite resistance, and can use for some purposes. The cement board's quality is affected by the biomass's chemical components, especially hemicellulose and extractives. Treatment to reduce the content of these two compounds in fiber can improve the cement board quality. This study aimed to evaluate the cement board's properties reinforced with coconut coir fiber (CCF). Pretreatment was performed on fibers by soaking in cold water for 24 hours and soaking in hot water for 1 hour to reduce the chemical compounds. The ratio between fiber-cement used varied to 1:2.75, 1:3.0, and 1:3.25 based on weight, while magnesium chloride (MgCl₂) uses at 2.5% of cement weight as an accelerator. The mixtures hand-matt formed and cold-pressed for 24 hours, with a density of the board was 1.25 g/cm³. The panels kept for 28 days before tested. Physical and mechanical tests conducted according to ISO 8335-1987. Results showed that the cement board's physical and mechanical properties made from CCF soaked in hot water at the ratio fiber to the cement of 1:3.25 is the best properties compared to others.

1. Introduction
Coconut plants (Cocos nucifera) are one of Indonesia's plantation commodities that have very high potential. The coconut plantations in Indonesia in 2018 will reach 3,417,951 hectares, with copra equivalent production of around 2.8 million tons [1]. The increased production of coconut also causes a high potential for by-product materials such as coconut fiber. This coconut coir fiber (CCF) can utilize the high potential of various applications, including cement boards as building materials.

Cement board and its application for building purposes have rapidly increased in many countries because of its excellent properties, such as good weather ability and acoustic insulation, high resistance for water, fire, termite, and fungal. Cement board can make from part of lignocellulosic biomass, such as strands, particles, or fibers, mixed with cement, water, and small amounts of additives manufactured into panels and other products in an application such as a wall, roof sheathing, tiles, floor, fences, and sound barrier [2]. Previous studies state that using CCF in brick making using cement produces better properties than other lignocellulosic biomass such as rice husks and corncob [3].

The lignocellulose to cement compatibility is a problem for CB development. Lignocellulose-cement compatibility decreases as the extractive content increases [4]. These extractives are generally
composed of terpenes, fatty acids, tannins, carbohydrates, and inorganic materials \[5,6\]. Another compound that affects the compatibility and strength of cement boards is hemicellulose. The presence of 0.1% of hemicellulose can decrease the cement board’s compatibility and strength \[7\].

Several pretreatments to fiber to improve compatibility with cement, including by providing immersion treatment with water, whether cold or hot water, conducting hydrothermal treatment, and giving immersion treatment in chemicals. Pretreatments to fibers use to reduce the presence of inhibitors contained in the biomass. Another thing that influences the properties of cement boards is the ratio between lignocellulosic biomass and the cement. The right comparison is needed to produce good cement board properties. It relates to how many areas can be covered by cement to its biomass to have a good bond between cement and its biomass.

This study aimed to determine the effect of giving hot and cold water immersion treatment on coconut coir fibers and the difference in a weight ratio between coconut coir fibers with cement to the physical and mechanical properties of the cement board.

2. Materials and Methods

2.1 Materials

The material used in this study is Ordinary Portland Cement (OPC), coconut coir fiber (CCF) with the size of 1-2 cm, and magnesium chloride (MgCl\(_2\)) as an accelerator.

2.2 Methods

2.2.1 Fibers pretreatment.

Coconut coir fiber (CCF) in this study divided into three parts, namely CCF which uses without treatment, given immersion treatment in cold water (water in room temperature) for 24 hours, and fiber treated with immersion in hot water (water with the temperature of 100\(^\circ\)C) for 1 hour.

2.2.2 Cement board manufacture.

In this study, the ratio between coconut coir fiber to cement used varied to 1:2.75, 1:3.0, and 1:3.25 based on weight. Water used about 60% of cement weight. Magnesium chloride (MgCl\(_2\)) at 2.5% of cement weight add for all ratios. CCF was sprayed with 40% of water and kept for 24 hours. The particles were then mixed with cement using a mortar mixer and added with 60% of water left and MgCl\(_2\). The mixtures’ hand-matt formed and cold-pressed for 24 hours. The size of the board was 25x25x1.2 cm, with a targeted density of 1.25 g/cm\(^3\). The boards kept for 28 days before tested. Physical and mechanical tests are conducts according to ISO 8335-1987 \[7\].

3. Results and Discussions

3.1. Chemical compound of fibers

The chemical content of CCF, especially for hemicellulose and extractives based on the different fiber pretreatments, is shown in table 1.

| CCF pretreatment     | Extractives / hot water solubility (%) | Hemicellulose (%) |
|----------------------|---------------------------------------|-------------------|
| Untreated CCF        | 4.5                                   | 14.5              |
| Immersion in cold water | 1.8                                | 14.5              |
| Immersion in hot water | 0.5                                 | 12.0              |

Based on Table 1, it can see that the pretreatment of CCF in the form of immersion in cold water can reduce the extractive content from 4.5% to 1.8%. However, this treatment could not reduce the hemicellulose levels of CCF. Meanwhile, by immersing in hot water, CCF treatment can reduce both the extractive and hemicellulose. The extractive content of CCF decreased from 4.5% to 0.5%, while
hemicellulose decreased from 14.5% to 12.0%. It occurs because hemicellulose can only decompose when heated using a temperature of 100°C [9].

3.2 Physical properties of cement board

3.2.1 Density
The average value of cement board density ranged from 1.236 to 1.264 g/cm³ (figure 1). The density value is getting higher as more cement is used (fiber-cement ratio 1: 3.25). It indicates that more cement can better cover the fibers than the use of less cement on cement boards. From the cement board’s higher cement content, the more cement can cover fiber better with the same surface area of fiber than the cement board’s lower cement content.

![Figure 1. The density of the cement board.](image)

The same thing happens when viewed from the initial treatment of the fiber. The cement board's highest density value is obtained by cement board with hot water immersion treatment for fiber, followed by cement board with fiber soaked in cold water for 24 hours. In contrast, the cement board's lowest density values with fiber without being given a pretreatment. It shows that fiber immersion treatment, both with cold water and hot water, can reduce the fiber's inhibitor substances to form a better bond with cement [10].

3.2.2 Moisture content
The moisture content (MC) of the cement board ranged from 10.01% to 11.44% (figure 2). It showed that all of the MC's values met the ISO 8335-1987 standard (MC < 12%). Like the density, fiber's ratio to cement and the pretreatment of the fibers also influence the cement board's moisture content.
Figure 2. The moisture content of the cement board.

Cement boards with a higher cement amount will cover more fibers in forming bonds and obtain good compatibility. Likewise, the treatment of immersion in hot water against fibers can reduce the water content of CCF so that the cement board will have a good bond and reduce moisture on the cement board [10,11].

3.2.3 Thickness swelling
The cement board's thickness swelling (TS) ranged from 1.226% to 1.332% (figure 3). It showed that all TS's values met the ISO 8335-1987 standard (TS<2%). The ratio of fiber to cement and the fibers' pretreatment also influences the cement board's TS value.

Figure 3. Thickness swelling of cement board.

Like the other physical properties, cement boards with a higher cement amount will have good compatibility than the cement board with less cement [8]. Also, for fibers' treatment, the immersion fibers in hot water can reduce the inhibitor substances so that the cement board will have good compatibility and minimize the cement board's thickness swelling. Compared to the cement board from eucalyptus (TS between 0.75-1.78%) [14], TS values of cement boards with CCF have nearly the same value, and both meet ISO 8335-1987 standards.
3.2.4 Water absorption
The cement board's water absorption (WA) ranged from 15.614% to 21.886% (figure 4). The fiber's ratio to cement and the fibers' pretreatment also influences the cement board's WA.

![Figure 4. Water absorption of cement board.](image)

The higher the amount of cement causing the lower the water absorption. Similarly, thickness swelling that the pretreatment of the fiber also influences the value of water absorption. The best cement board is obtained by cement board with fiber treated by soaking in hot water. Compared to the cement board from eucalyptus wood (WA about 20%) [14], WA values of cement boards with CCF have similar values.

3.3. Mechanical properties
3.3.1 Modulus of rupture
The modulus of rupture (MOR) of cement board ranged from 78.206 to 99.116 kg/cm² (figure 5). Compared to the ISO 8335-1987 standard (MOR > 90 kg/cm²), only cement boards with a fiber-cement ratio of 1: 3.25 using all kinds of fibers that meet the standards.

![Figure 5. Modulus of rupture of cement board.](image)
The ratio of fiber to cement influencing the MOR value of the cement board. The greater the amount of cement used, the greater the MOR value. Meanwhile, the treatment of fiber also affects the MOR value. The more cement use, the more CCF coverage by the cement, so that the bonding will be better. Meanwhile, the CCF immersion treatment with hot water produces cement boards with better MOR values than cement boards with untreated and treated fibers with cold water immersion. It happens because the CCF fiber with hot water treatment decreases the hemicellulose content and the extractives [13]. Meanwhile, only a decrease in CCF extractives in the CCF immersion treatment with cold water and without reducing the hemicellulose content.

The use of fiber with hot water immersion treatment for 1 hour produces a cement board with the highest MOR value [13]. In comparison, the cement board with fiber without being treated delivers the lowest MOR value. MOR values of cement boards from CCF are smaller compared to cement boards from eucalyptus (150 kg/cm²) [14].

3.3.2 Modulus of elasticity
The average modulus of elasticity (MOE) of the cement board ranged from 21235 to 35786 kg/cm² (figure 6). Compared to the ISO 8335-1987 standard (MOE > 30000 kg/cm²), only cement boards with a fiber-cement ratio of 1: 3.25 using fibers immersed in cold and hot water meet the standards.

![Figure 6. modulus of elasticity of cement board.](image)

The ratio of fiber to cement and the kind of fiber treatment can influence the MOE value. The greater the amount of cement used, the greater the MOE value. Meanwhile, the treatment of fiber also affects the MOE value. The use of fiber with hot water immersion treatment for 1 hour produces a cement board with the highest MOE value. Like MOR, the MOE is also affected by the amount of cement and fiber's chemical component. The lower the hemicellulose and extractive, the better the MOE and other mechanical properties [13]. In comparison, the cement board with fiber without being treated has the lowest MOE value. The MOE values of cement boards from CCF are smaller than cement boards from eucalyptus (75000 kg/cm²) [14].

3.3.3 Internal bond
The cement board's internal bond (IB) ranged from 42.2 to 74.46 kg/cm² (figure 7). Compared to the ISO 8335-1987 standard (IB > 50 kg/cm²), almost all cement board meet the standards, except for...
cement board without pretreatment for its fibers at the fiber to the ratio of 1:2.75 and 1:3.0, and cement board with soaking in cold water at the fiber to cement ratio of 1:3.0.

![Figure 7. Internal bond of cement board.](image)

The fiber to cement ratio and fiber treatment can influence the IB value of the cement board. The greater the amount of cement used, the greater the IB value. The treatment of fiber also affects the IB value. The best cement board based on IB value obtained with a fiber to cement ratio of 1:3.25 using fiber with immersion in hot water. The phenomena are similar to the other mechanical properties, affected by how much coverage the cement has to the fiber and the fibers' hemicellulose and extractives content.

3.3.4 Screw withdrawal
The screw withdrawal (SW) ranged from 38.732 to 52.292 kgf (figure 8). Compared to the ISO 8335-1987 standard (SW > 30 kgf), all cement boards meet the standards.

![Figure 8. Screw withdrawal of cement board.](image)
The more amount cement used, the higher the SW value. Simultaneously, the cement board with fiber that is treated by immersion using hot water produces the highest SW value compared to other cement boards. The results also showed that the screw withdrawal property also affected by cement coverage to fiber and the content of hemicellulose and extractives.

4. Conclusion
Cement boards have successfully made using coconut coir fiber. Cement board with fiber cement ratio of 1:3.25 and using hot water immersion treatment of CCF fiber gave the best cement board properties. The cement board's physical and mechanical properties increase with the cement amount because the more cement used, the more CCF coverage by the cement so that the bonding will be better. The cement board's physical and mechanical properties made from fiber treated with hot water immersion are better than the cement board without treatment and treated with cold water immersion. It happens because the CCF fiber with hot water treatment decreases the hemicellulose content and the extractives, where the reduction of these two chemical components can improve the cement board's mechanical properties.

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