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Effect of Various Sizes Extraction of Wood-Wool on the Properties of Wood-Wool Cement Board Manufactured from Kelampayan (*Neolamarckia Cadamba*)

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ABSTRACT

Kelampayan (Neolamarckia cadamba) is used in the production of wood-wool cement board (WWCB). The properties of the boards from one type of fast growing timber species were compared by using lower aspect ratio of wood-wool of various sizes (1.5 mm, 2.5 mm and 3.5 mm) with fixed water: cement ratio. Wood-wool was pre-treated by soaking it in cold water for 24 hours and was used to produce WWCBs. Portland cement was used as a hydraulic binder with water and wood-wool in the ratio of 2:1:1 respectively per weight of WWCB. A total of 162 specimens were prepared and tested on their physical and mechanical properties according to ASTM D1037 (1998) and MS 934 (1986). Experimental investigations were conducted to assess the impact of wood-wool size and WWCB thickness on the properties of WWCBs namely flexural strength (Modulus of Rupture, Modulus of Elasticity), compressive strength, internal bond strength, thickness swelling and water absorption. All WWCBs were produced under the maximum requirements in accordance to international standards for cement-bonded particleboard composite (ISO 8335, 1987and the MS 934, 1986). However, 1.5 mm wood-wool and 25 mm WWCB are more stable because it had lower percentage of thickness swelling and water absorption than 2.5 mm and 3.5 mm board. The results showed that the performance of WWCB with a decrease in wood-wool size provides an optimum value for

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flexural strength (MOR and MOE), internal bond and also density. In terms of WWCB thickness, the results showed that the mechanical properties of WWCB are greatly influenced by the density – as the density increases the mechanical strength also increases. The properties of the composite strength are not in the same trends and are subjected to the type of load conditions. The compressive strength increases when using thicker boards (50 mm and 75 mm), however the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) declined as the thickness of the board increases.

Keywords: *Wood-wool, WWCB, Water absorption, Thickness Swelling, modulus of Rupture, Modulus of Elasticity, Compressive Strength and Internal bond.*

Introduction

The wood used for the manufacture of WWCB was Neolamarckia cadamba and this type of wood is easy to find in Malaysia and it is a fast-growing wood. It is also known as Laran in Sabah, Selimpoh or Entipong or Sempayan in Sarawak, Kadam in India and Kelampayan in Indonesia. In India, the tree and the trunk are believed to cure certain diseases such as sore throat, eye diseases and dysentery. It is an evergreen can be found in South and Southeast Asia and is classified as Light hardwood trees. This tree is a fast-growing tree that is now being planted fo commercialization in Sabah and Sarawak. It can grow up to 45 m high, and flowering usually occurs 4 – 5 years after planting. Kelampayan is classified as Class 4 Non-Durable (less than 2 years) in the test of damage done by Wong et al. (2004) in their review of the Environmental Sustainability of Tropical species with Emphasis on Malaysian tropical hardwood – Variations and Prospects.

Wood-wool Composite Cement Board (WWCCB) is composed from wood-wool and cement whereby the wood-wools are produced by the shredding of logs using a special shredding machine with a different cutting size of 1.5, 2.5 and 3.5 mm. Besides, WWCB has excellent potential as a component of housing building because it is has excellent insulating capabilities of heat and sound when placed between walls (interior and exterior), under floors, etc. Research has been done by Hachmi and Moslemi (1989), Hachmi and Sesbou (1991), Eltem (2006) on the effects of various parameters such as wood species, wood-cement ratio, type of accelerator, the amount of water, soak time and density of the board, the properties of WWCB. The study by Pablo (1989) was focused on WWCB local timber species and has led to the establishment WWCB that use mainly some native species. Lee and Hong (1986), concluded that the bond strength between wood and cement depends mainly on the wood species selected. Badejo (1988) examined the two variables (length scaling, and thickness) of wood-cement panels using sheets of a mixture of three tropical hardwood, and the results showed that two variables are very closely related to the MOR, MOE, water absorption and thickness swelling. The longer and thinner the boards, the stronger, harder and more stable the dimensions of the board are.

Since the performance of wood-wool cement composites is dependent on the choice of wood species used, this study was to explore the potential use of kelampayan in the manufacture of WWCB. Currently, there is no information about the effects of WWCB in the size of wood-wool cement boards made from cement and kelampayan wood fiber. In this study, the physical (thickness swelling, water absorption) and mechanical (flexural strength, compressive strength and internal bond strength) properties of WWCB were studied and the variables were the wood-wool size and thickness of the boards.

Materials and Methods

The wood species used in this study was 4 – 5 year-old *Neolamarckia cadamba*. Ordinary Portland cement is used as a binder between wood-wool because it is has faster setting time. Wood-wool cement boards (600 mm × 2400 mm) of 25, 50 and 75 mm thick, with a density of 0.28 – 0.74 g/cm^3 were produced as shown in Table 1.

Table 1: Specimens Dimension

No.	WWCB Thickness (mm) / Type of test	25	50	75	Total specimens for each test (No.)
		Dimension, B × L (mm)			
1	Density	100 × 100	100 × 100	100 × 100	27
2	Water absorption	100 × 100	100 × 100	100 × 100	27
3	Thickness swelling	100 × 100	100 × 100	100 × 100	27
4	Flexural Strength; (MOR) & (MOE)	100 × 425	100 × 825	100 × 1225	27
5	Internal bond	40 × 40	40 × 40	40 × 40	27
6	Compression test	25 × 100	50 × 200	75 × 300	27

Three wood-wool sizes (1.5, 2.5, and 3.5 mm) were used. *Neolamarckia cadamba* logs were cut into billets, 35 – 40 cm long, that were debarked and made into excelsior of 1.5 – 3.5 mm wide using a vertical-type shredding machine. Wood-wools of three different thicknesses were produced depending on the type of wood-wools shown in Figure 1. Wood-wools were kept in a log pond until they attained a moisture content of approximately 200% before treatment. Green strands were dried in an air-conditioned room at 20°C, 45% relative humidity (RH), until the to roll out low molecular weight carbohydrates that can prevent normal procedures cement. This method was done to remove sugar and excessive extractives from wood.

Wood-wool, cement and water were mixed by hand until all the wood-wool was thoroughly coated with cement paste. The proportion of materials was adjusted to achieve the target board density. Sufficient cement-coated wood-wools for one board were spread out in a wooden forming box and placed on a mould to form a mat. Layers of grease are applied onto the mould for de-moulding and to prevent the board mat from sticking during pressing. Several mats were formed and stacked one on top of each other, separated by the moulds. The mats were compressed to 25, 50 and 75 mm thickness using a concrete blocks as a weight. Compaction by compressing the constituent closer to reduce air voids was needed to make the sample denser. The target thickness was achieved by placing wooden stoppers between moulds. After pressing, boards were kept under compression for 24 hours. They were then unloaded from

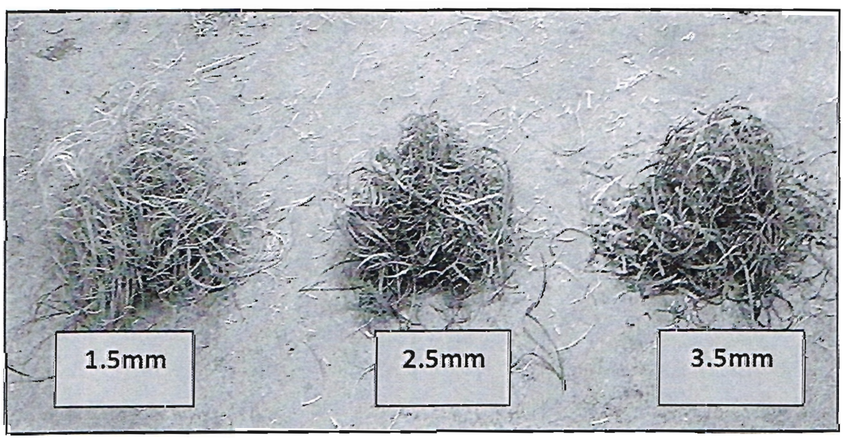

Figure 1: Wood-wool Size

the press and conditioned for three to four weeks (21 – 28 days) and the board is trimmed neatly and packed before being tested.

A total of 162 specimens were prepared from the fabricated wood-wool boards in random as shown in Table 1, according to the requirement of the test. The specimens for density determination were taken from the board by cutting the specimens at different parts of the boards in accordance with Malaysian Standard (MS 934, 1986). Thickness swelling and water absorption of the WWCB specimens were determined according to the American Society for Testing Materials (ASTM D1037-96a, 1998). The specimens were soaked in water at room temperature (20 – 22°C) for 24 hours to determine the short and long-term properties. The weight and thickness of the specimen were measured before and immediately after soaking and used to calculate water absorption and thickness swell and reported as percentages of the values before soaking. The bending strength was measured by the three-point loading test, which was carried out using bending testing machine in accordance with MS 934 (1986). The span length was 16 times the thickness of the board. The displacement at the centre of the span and the loads were recorded. Load was applied in the flat direction (perpendicular to the press direction) and edge-wise (parallel to the press direction) at the rate of 0.5mm/min. The compression test was carried out according to the short column procedure (*procedure C*) in ASTM D1037 (1998) using Compression testing machine at a loading rate of 1.5mm/min. The specimens were tested with load parallel and perpendicular to the board thickness. The tensile test (internal bond test) was conducted according to ASTM D1037 (1998). The specimen size was 40 mm × 40 mm × thickness of boards (25 mm, 50 mm, and 75 mm). Epoxy 2-ton was used for bonding the cement board and metal plate.

Results and Discussions

It is important to know the dimension of the wood-wool fibers, particularly their thickness and width, because most of the board properties depend on them. In this study, an investigation was conducted to access the impact of wood-wool size and WWCB thickness on the properties of WWCBs.

Physical Properties

Board Density

The density of WWCB greatly affects their strength properties. Table 2 presents the weight, volume and density (i.e. weight/volume) of the boards. All boards produced are at the density of 0.28 – 0.74 g/cm^3. The target for determining the density of WWCB was achieved with wood-wool size of 1.5 mm, 2.5 mm and 3.5 mm (with medium density <1 g/cm^3), where the reading of the density is getting lower for bigger size of wood-wool. Wood-wool size of 1.5 mm has the highest density while the density of wood-wool 2.5 mm is lower but higher than that of 3.5 mm. The mean density of boards with 1.5 mm wood-wool is the highest for each thickness of WWCB (0.74 g/cm^3, 0.44 g/cm^3, and 0.47 g/cm^3 respectively). This indicates that the smaller size of wood-wool makes the board denser and easier to compact due to the lesser voids between wood-wool in WWCB.

Table 2: The Physical Measurement of the WWCB

WWCB thickness (mm)	Wood-wool sizes (mm)	Weight (g)	Volume (m3)	Density * (g/cm3)
	1.5	183	246	0.74 (±0.01)
25	2.5	148	301	0.49 (±0.03)
	3.5	93	332	0.28 (±0.03)
	1.5	245	562	0.44 (±0.06)
50	2.5	226	543	0.42 (±0.02)
	3.5	215	557	0.39 (±0.01)
	1.5	391	828	0.47 (±0.02)
75	2.5	364	810	0.45 (±0.02)
	3.5	354	797	0.44 (±0.02)

** The standard deviations are in parentheses "( )". Each value is the mean of three samples*

Water Absorption

Computation of the water absorption by the various boards determined the amount of water each board absorbed when immersed in water for 24 hours at room temperature. ANOVA results for the water absorption shown in Table 3 and illustrated in Figure 2 & 3. Both thickness and wood-wool interaction with the water has a very significant effect on the absorption. In accord with results for thickness swelling, 50 mm board generally had larger water absorption values especially in WWCB with

Table 3: Physical Properties for Each Boards After 24 Hours of Soaking in Water ["( )" is the Standard Deviations]

Thickness of WWCB (mm)	Wood-wool Sizes (mm)	Thickness Swelling (%)	Water Absorption (%)
25	1.5	1.19 (±00.25)	42.3 (±8.2)
	2.5	1.52 (±02.57)	48.5 (±3.5)
	3.5	1.81 (±01.24)	50.8 (±6.4)
50	1.5	0.85 (±00.47)	17.22 (±6.8)
	2.5	1.19 (±00.08)	57.2 (±6.1)
	3.5	1.56 (±02.13)	60.9 (±5.0)
75	1.5	0.18 (±01.56)	34.3 (±16.2)
	2.5	0.49 (±00.07)	38.3 (±31.0)
	3.5	0.52 (±02.55)	46.1 (±14.0)

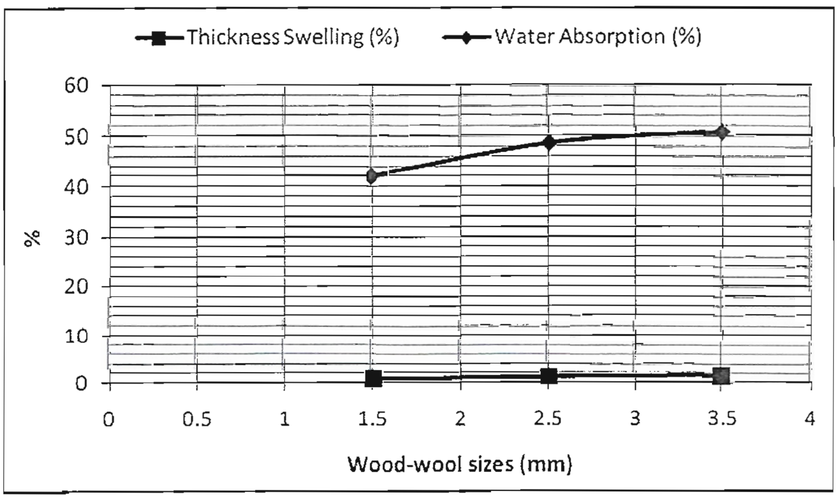

Figure 2: Effects of Wood-wool Size on Thickness Swelling (TS) and Water Absorption (WA) of the Boards

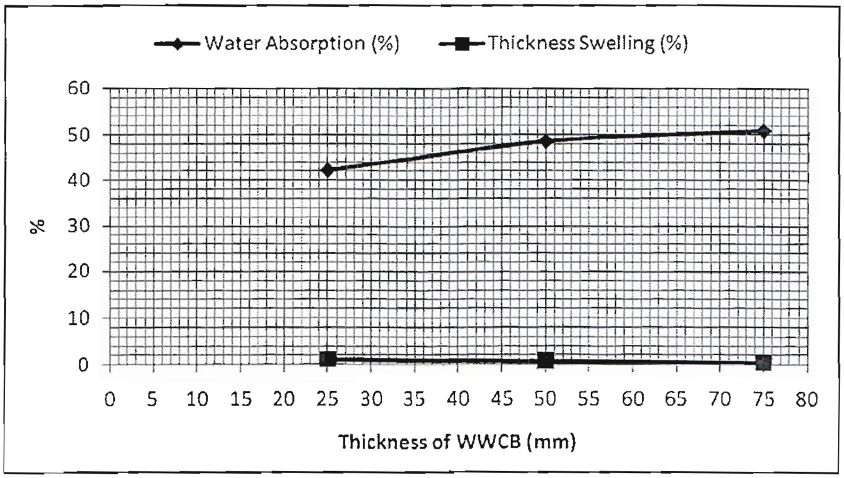

Figure 3: Effects of Thickness of WWCB on Thickness Swelling (TS) and Water Absorption (WA) of the Aoards

3.5 mm wood-wool immerse in water. Again, this may have been due to water soluble extractives not being leached out prior to board production, resulting in poor bond between wood and cement.

Space or voids in the boards may have contributed to a greater absorption of water for each board. Boards with 3.5 mm wood-wool contain more wood than those with 1.5 mm and absorbed more water; thus water absorption is higher. As with thickness swelling, there is a greater positive correlation between the absorption and soaking for boards containing 1.5 mm wood-wool. In the case of boards with a small width, the 24 hours immersion seems sufficient to reduce the absorption capacity. This result relates to the low density of wood-wools. During the experiment, it was observed that wood-wool was bulkier and water was absorbed during the 24 hours of water immersion. Water absorption decreased as the width size of wood-wool increased from 1.5 mm to 3.5 mm.

Thickness Swelling

For external usage, dimension swelling was important. For WWCBs that were water for 24 hours, the maximum thickness swelling for 75 mm board of 1.5 mm wood-wool was 0.18% and the maximum swelling for the same board was 1.81%. In general, it appears that wood-wools of greater sizes have higher thickness swelling. All WWCB do not swell more than 2% after a 24-hour immersion in water; it meets the MS 934 (1986) requirements.

Mechanical Properties

The mechanical properties (flexural strength, compression strength and internal bond strength) of WWCB are summarized in Table 4. From Table 4, it is clear that the effect of wood-wool size was significant on the strength properties (Modulus of Rupture, compressive strength and internal bond strength) of the wood-cement mixtures.

Flexural Strength (Modulus of Rupture and Modulus of Elasticity)

Generally the strength values showed a decreasing trend as the wood-wool size increased from 1.5 to 3.5 mm . The MOR for kelampayan wood-cement mixture increases with a decrease in wood-wool size. In terms of thickness, an increase of WWCB thickness resulted in lower value of Modulus of Elasticity and Modulus of Rupture (bending strength) and there was little effect of varying of wood-wool size, within these limits, on strength properties. The values found in the present study are within this range of MOR. All the boards used in this study had high strength values compared to ordinary cement-bonded boards, and easily passed the JIS A 5908 (2003) standards. There were slight differences in the MOR values of boards containing wood-wools of different thicknesses. Boards made from thin wood-wools tended to give higher MOE values than boards made from thicker wood-wools and they also met the minimum requirements of MS 934 (1986) i.e. boards should be more than 5 MN/m^2.

Compression Strength

For samples 25 mm and 50 mm, the compression failure typically occurred along the diagonal bands similar to compression failure on concrete columns. For 75 mm samples, there were cracks in diagonal band but without any big opening. As shown in Table 4, it was found that for the thicker boards (50 mm and 75 mm) the compressive strength for

Table 4: Summary of Mechanical Properties for Experimental Boards

Thickness of WWCB (mm)	Wood-wool sizes (mm)	Flexural Strength		Compression Strength (MPa)	Internal Bond (kPa)
		MOE (GPa)	MOR (GPa)		
25	1.5	0.16 (±0.026)	1.22 (±0.68)	0.30 (±31.11)	91.54 (±8.05)
	2.5	0.15 (±0.006)	1.05 (±0.27)	0.13 (±4.24)	65.32 (±0.00)
	3.5	0.05 (±0.006)	0.55 (±0.24)	0.08 (±6.36)	61.36 (±0.00)
50	1.5	0.15 (±0.005)	0.77 (±0.01)	1.19 (±10.61)	69.77 (±0.00)
	2.5	0.14 (±0.004)	0.68 (±0.03)	0.700 (±11.81)	30.68 (±0.00)
	3.5	0.14 (±0.004)	0.62 (±0.01)	0.40 (±31.11)	14.35 (±0.00)
75	1.5	0.16 (±0.026)	0.77 (±0.03)	3.08 (±10.94)	33.65 (±0.00)
	2.5	0.12 (±0.001)	0.51 (±0.02)	2.25 (±15.04)	29.69 (±1.05)
	3.5	0.07 (±0.007)	0.23 (±0.04)	1.94 (±2.83)	3.96 (±1.05)

**Each value represents at least 3 replicates. Numbers in parenthesis "( )" are variants'.*

the same series of wood-wool sizes were higher than that of the 25 mm thick board. The compressive strengths of 50 mm and 75 mm boards for all sizes of wood-wool were higher than the value specified in German DIN 1101 which implies that the wood-wool from Kelampayan tree has the potential to be used in the manufacturing of the cement composite board and be used as construction material.

Internal Bond Strength

The mean internal bond for each thickness ranges between 91.54 to 33.65 kPa for 1.5 mm wood-wool, 65.32 to 29.69 kPa for 2.5mm wood-wool and 61.36 to 3.96 kPa for 3.5 mm. An analysis of variance showed that the internal bond was significantly different between different sizes of the wood-wool and thickness of boards. It shows that the board made with 1.5mm and 2.5mm wood-wool have very high internal bond. The results show that the 3.5mm wood-wool substantially reduce the internal bond. As expected, the internal bond strength of small width wood-wool size increased as density increased. All the WWCBs produced are beyond the 0.3Pa, and therefore they met the JIS A 5908 (2003) requirements.

Conclusions

From the results and discussion, it was shown that the properties of WWCB are greatly influenced by the wood-wool size and thickness of the board. It can be concluded that:

i. It is possible to produce medium-density (<1000 kg/m^3) WWCBs to meet the modulus of rupture and modulus of elasticity requirements by using thinner wood-wool size.
ii. The size of wood-wool and thickness of WWCB with untreated wood-wool is extected to produce significant effects in physical properties.
iii. WWCB with 1.5 mm wood-wool provides a higher value of the flexural strength (MOR and MOE), compressive strength, tensile strength and density; therefore, the mechanical properties of WWCB with 1.5 mm wood-wool is stronger than WWCB with 2.5 mm and 3.5 mm wood-wool and are in accordance with the standards set for composite boards.
iv. In terms of WWCB thickness, boards with 25 mm thickness have the optimum value of bending strength (MOR), internal bond strength and density compared to those of 50 mm and 75 mm. However, according to the compression results obtained, the thicker boards performed better than the thinner boards.

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