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EVALUATION OF CHEMICALS INCORPORATED WOOD FIBRE CEMENT MATRIX PROPERTIES

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Abstract

Wood fibre cement (WFC) boards are well established commercially and widely used in many developed countries. The combination of the properties of two important materials, i.e., cement, and previously treated fibrous materials like wood or agricultural residues; which made up the board, contributed in the performance of the board as building material. In this work, the WFC matrix (WFCM) samples are produced to determine the physical properties of WFCM such as the density and water absorption. The wood fibres are incorporated/treated with three different chemical additives; calcium formate ($Ca(HCOO)_2$), sodium silicate ($Na_2.SiO_3$) and magnesium chloride ($MgCl_2$) prior to mixing with cement. The mechanical properties of the WFCM, with or without chemicals treatment of fibres, such as the compressive strength and flexural strength are evaluated. Three wood/cement ratios (50:50, 40:60, 30:70) are used and the percentages of water and accelerator were 80% and 3% based on the cement weight, respectively. Three moisture-conditioned samples; accelerated aging, dry and wet conditions are used for flexural test. The results reveal that the wood/cement ratio, chemical additives and moisture content had a marked influence on the physical and mechanical properties of the matrix. Finally, it has been shown that the 40:60 wood/cement ratio samples with prior chemicals treatment of the fibres that undergo accelerated aging conditioning achieve higher strength then dry and wet-conditioned boards.

Keywords: WFC matrix, Wood fibre, Chemical additives, Wood/cement ratio, Moisture conditioning, Compressive strength, Flexural strength.

1. Introduction

Currently, it is a great deal to use natural fibre as construction material in cement composite. Since thousands years ago, natural fibres have been used as reinforced inorganic materials such as straw and reeds for brick and mortar. Other fibres such as coconut, bamboo, wood, wool or chips, dust, seed and fruit are also used in cement and sand-based products [1-5]. Fibres may be natural or manmade [6, 7]. Coconut, bamboo and sisal fibres are presently used as reinforced materials in concrete constructions [8-10].

Wood is strong, lightweight, abundant, non-hazardous and relatively inexpensive. Wood fibre cement (WFC) composites have been used in the fabrication of building materials for more than 60 years. The development and uses of WFC mixtures attest to their attraction as building materials. The raw materials used are compatible with a range of processing methods to provide a variety of products that are easily machined with conventional wood working tools. In the beginning, wood wool cement board (WWCB) or wood-cement composites boards, particularly low density boards are mainly used for insulating purposes. For some applications, wood-cement boards are competitive with reinforced concrete because of their relatively low density [11]. In 1973, a Swiss company called Durisol is among the first manufacturers that produced a building panel consisting of small wood particles bonded in a cement matrix [12].

Wood fibres come from different wood species. The properties of the WFC board are highly dependent on the quality of the wood fibre. Wood fibre inhabits the setting of the cement and reduces its suitability as WFC board. WFC boards consist of organic wood wool enclosed in inorganic cement paste. Like all cellulose materials, the wood, depending on the species, is either in greater or lesser extent inhibits the setting of the cement. This is caused by wood sugars and other compounds that leach out of the wood in contact with the cement paste. Paribotro [13] proposed the need of fibre pre-treatment and had evaluated the effect of aqueous extraction of wood wool by soaking it in cold water for 1, 2 and 3 days or soaking it in hot water for 1, 2 and 3 hours. Wei et al. [14] added specific chemical additives such as $CaCl_2$, $MgCl_2$ and $Al_2 (SO_4)_3$ to improve the compatibility of the wood and the cement.

Variation of sugars and other chemicals in the wood wool inhibit the setting of cement-water mixture. Hence, accelerators are added to hasten the setting of the matrix. Chemicals are added at the mixing stage to modify some of the properties of the boards. Magnesium chloride ($MgCl_2$), sodium carbonate (Na_2CO_3), sodium hydrogen carbonate ($NaHCO_3$), various hydrates of sodium silicate (Na_2SiO_3), calcium chloride ($CaCl_2$) or combinations of these chemicals were used for the production of cement bonded board and the relationship between hydration and mechanical properties of these boards were determined by Fei et al. [15]. Sukartana et al. [16] evaluated the use of magnesium chloride in the range of 1-10% to accelerate the curing of WW cement board and reported positive result on the resistance to termite attack. In recent years, several treatments have been developed to modify wood fibre for special applications of the board. English et al. [17] also determined the effect of different levels of $MgCl_2$ and bamboo/cement ratio for the manufacturing of bamboo cement boards. The accelerator is usually added to the water bath that the wood wool is soaked in before it is mixed with the cement. Combinations of magnesium chloride ($MgCl_2$), calcium formate ($Ca (HCOO)_2$) and sodium silicate (Na_2SiO_3) chemicals are used for the production of WFC matrix in this study.

This research is to better understand the behaviours and improve the properties of Kelampayan fibre inclusion in concrete materials. The details of the experimental investigation on the density and water absorption, compression and flexural strength of WFC matrix samples with chemical modifications of the wood fibre are looked into in this study. Three different moisture conditions are prepared in order to assess the optimum bending properties of the specimen.

2. Materials and Methods

2.1. Wood fibre

The wood wool originates from the Kelampayan or Laran timber grown in Malaysian forest. The scientific name of this wood species is A*nthocephalus Chinensis*. The timber is soft and light with density of 370-465 kg/m^3. Normally, the wood/fibre from this timber is used in the manufacturing of plywood, packing cases, wooden sandals and chopsticks. The wood fibres are approximately 0.2 to 0.5 mm thick and 1.5 to 5 mm wide as shown in Fig. 1. The wood-wool is soaked in water for 3 days to reduce the amount of aqueous extraction of the fibres. Then, it is let dried in hot sun for 24 hours to establish the fibres at normal moisture content.

Fig. 1. Wood Fibres.

2.2. Chemical additives

Three chemicals: magnesium chloride ($MgCl_2$), calcium formate ($Ca(HCOO)_2$) and sodium silicate (Na_2SiO_3) were used for the manufacture of WFC matrix. The dosages of the chemicals were 3% of the weight of cement, following recommendation by the Builder's Guide [18]. These chemicals were to accelerate the setting of the wood cement mixture and to increase the early stage strength of the boards. The detailed chemical compositions of the fibre after treatment with these three chemicals are out of the scope of this paper. The chemicals for treating the wood fibre were in powder or crystalline powder form. The treatment was usually done at normal room temperature.

2.3. Methods

2.3.1. Mix design proportion

WFC matrixes were prepared using chemical additives and without chemical additives, Ordinary Portland cement and water. Three different types of wood/cement ratio, which were, 50:50, 40:60 and 30:70 were used for WFC mixtures. The consumption of raw materials of WFC matrix is shown in Table 1. The amounts of chemicals in Table 1 are presented as the sum of the equal amount of the three chemicals.

Table 1. Raw Materials Consumption for WFC Matrix.

Wood/Cement ratio	Wood fibre (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Chemical (kg/m^3)
50:50	312.50	312.50	250.00	9.37
40:60	312.50	468.75	375.00	14.06
30:70	305.55	712.95	570.36	21.40

2.3.2. Mixing

Firstly, the wood fibre for the matrix was mixed evenly with the diluted aqueous solution of magnesium chloride ($MgCl_2$), calcium formate ($Ca(HCOO)_2$) and sodium silicate ($Na2SiO_3$) chemicals. After 5 minutes, cement was sprinkled through the wet wood fibres. The cement and wood fibre were mixed thoroughly by horizontal mixer and then transferred to the steel mould.

2.3.3. Samples

Twenty four cubes were prepared from chemically treated wood fibre with three different wood/cement ratios and another 24 cubes were prepared in exactly the same manner without chemicals for comparing the changes in density, water absorption and compressive strength. The dimensions of the cubes are 100×100× 100 mm as shown in Fig. 2. For the bending test, small sizes of WFC boards were fabricated and tested at three different moisture conditions with two different ratios (40:60 and 30:70). The board length is 531 mm, with 480 mm clear span when set up for testing [19]. The details of number of test samples are shown in Table 2. The tested boards are rectangular in cross section, with a constant width and depth of 75 mm by 20 mm.

(a) Compressive strength test

(b) Bending test

Fig. 2. WFC Cubes and Board.

Table 2. Number of Samples.

Wood/Cement ratio	Compressive strength (treated and untreated fibres)	Compressive strength (treated and untreated fibres)	Flexural strength (treated and untreated fibres)	Water absorption (treated and untreated fibres)
	7 days	28 days	28 days	28 days
50:50	6	6	-	-
40:60	6	6	6	6
30:70	6	6	6	6

2.3.4. Curing

In this study, two type of curing were adopted. For compression test, specimens were removed from the moulds after 24±2 hours from casting. After demoulding, the cubes were preserved in water at temperature of 19°C to 21°C. The cubes were tested after 7 days and 28 days according to BS 1881 [20]. However, for bending test the small boards were cured in dry air. The boards were marked, weighed and stored in normal room temperature. At the age of 28 days, specimens were prepared for the specified test.

2.3.5. Moisture condition of WFC boards

After 28 days of dry air curing, the WFC boards (two different wood/cement ratios) were conditioned with three different moisture conditions following ASTM procedure [19]. The properties of the panels depend on the moisture content at the time of test. In dry condition, specimens were tested as normal air dry without any supplemental conditioning to alter the moisture content. Water soaked specimens were tested in the soaked condition. The boards were submerged in water at 20±1ºC for 24 hours before the test and were tested within 30 minutes upon removal from the water.

The accelerated aging test was done to obtain a measure of the inherent ability of a material to withstand several exposure conditions and maintain its mechanical and physical properties. Accelerated aging can increase the stiffness of boards. Before evaluating the properties, the specimens were prepared and subjected to six cycles of accelerated aging. First the specimens were immersed in water at 49±2°C (120±3ºF) for 1 hour. Then, the samples were exposed to steam and water vapour at 93±3ºC (200±5ºF) for 3 hours. Next, the samples were froze at -12±3ºC (10±5ºF) for 20 hours and then heated at 99±2ºC (210±3ºF) in dry air for 3 hours. Again the samples were exposed to steam and water vapour at 93±3ºC (200±5ºF) for 3 hours. Lastly, the specimens were heated in dry air at 99±2ºC (210±3ºF) for 3 hours. After the completion of the six cycles of accelerated aging, the specimens were conditioned at a temperature of 20±3ºC (68±6ºF) and a relative humidity of 65±2% for at least 48 hours before testing.

2.4. Testing

2.4.1. Water absorption and density

The water absorption is expressed as the weight percentage for the specimen after 24 hours submersion in water to the dry samples. First, the test samples were set in dry condition according to ASTM [19]. The samples were submerged under 25 mm of water at normal room temperature for 24 hours. The amount of water absorption is calculated from the increase in weight and expressed as the percentage by dry weight. To determine the density, samples were to be taken just before doing the compression and bending tests. The samples were weighted using weighing scale and the volumes of the samples were calculated. Density is calculated by dividing the weight to the volume of the samples.

2.4.2. Compressibility

The compressive tests were conducted using 5000 kN automatic compression machine. The sample was placed between the loading surfaces of the testing machine vertically as shown in Fig. 3. The specimens were tested with an increasing load 2.4 kN/s until failure occurred to obtain the maximum compressive load. The procedures in BS 1881 [20] were followed in the compression tests.

Fig. 3. Compression Test.

2.4.3. Bending

For the bending test of small board specimens, the tests were performed to determine the modulus of rupture (MOR) and modulus of elasticity (MOE). The specimens were tested using 3 Tonne INSTRON Universal Testing Machine as shown in Fig. 4. The support was rounded and the specimen was loaded at the centre of span with the load applied to the top surface of the specimen. Loading was maintained at a uniform rate through a loading block. The bearing block was 76 mm in width. The load was applied continuously throughout the test at a uniform rate of motion of the movable crosshead of the testing machine.

Fig. 4. Experimental Setup for Bending Test.

According to ASTM [19] the speed of testing is expressed by Eq. (1)

$$V = \frac{\varepsilon L^2}{6d} \quad (1)$$

where V (mm/min) is the rate of motion of moving head (= 9.6 mm/min), ε is the unit rate of fibre strain = 0.005, L (mm) is the span, and d (mm) is the thickness of specimen.

The flexural test was carried out in accordance with the ASTM D 1037, using a universal testing machine. The load was applied perpendicular to the plane of the panel (face down) and parallel to the plane of the panel (face up) to determine the maximum load, MOR and MOE. MOR can be calculated using Eq. (2) for three point bending test

$$MOR = \frac{3PL}{2BD^2} \quad (2)$$

where *MOR* (MPa) is the flexural strength, *P* (N) is the maximum load, *L* (mm) is the length of sample, *B* (mm) is the width of sample, and *D* (mm) is the thickness of sample.

Modulus of rupture and modulus of elasticity are calculated from the curves produced from static bending test as in Eq. (3)

$$MOE = \frac{P_i L^3}{4bd^3 y} \quad (3)$$

where *MOE* (MPa) is the modulus of elasticity, *b* (mm) is the width of specimen, *d* (mm) is the thickness of specimen, *L* (mm) is the length of span, P_i (N) is the load at proportional limit, and *y* (mm) is the amount of deflection at proportional limit.

3. Results and Discussion

3.1. Compressive strength and density

The compressive strength and density for the WFC matrix samples at 7 days and 28 days (wet cured) are listed in Tables 3 and 4. From Tables 3 and 4, it can be observed that the chemicals used for treatment of wood fibre do not significantly influence the matrix density but do significantly affect the matrix strength.

Table 3. Compressive Strength and Densities of WFC Cubes with Chemical Treatment of the Wood Fibre.

Wood/Cement Ratio	No.	After 7days		After 28days	
		Density (kg/m^3)	Compressive Strength (MPa)	Density (kg/m^3)	Compressive strength (MPa)
50:50	SAM1	1020	1.41	1030	1.65
	SAM2	1030	1.62	1040	1.71
	SAM3	1050	2.10	1060	2.50
40:60	SAM1	1360	4.95	1380	5.53
	SAM2	1340	3.8	1360	3.95
	SAM3	1330	4.05	1350	4.45
30:70	SAM1	1400	3.50	1410	3.79
	SAM2	1420	2.95	1430	3.01
	SAM3	1440	3.84	1450	4.04

Table 4. Compressive Strength and Densities of WFC Cubes without Chemical Treatment of the Wood Fibre.

Wood/Cement Ratio	No.	After 7days		After 28days	
		Density (kg/m^3)	Compressive Strength (MPa)	Density (kg/m^3)	Compressive strength (MPa)
50:50	SAM1	1030	NS	1040	NS
	SAM2	1040	NS	1060	NS
	SAM3	1030	NS	1030	NS
40:60	SAM1	1400	1.09	1410	1.95
	SAM2	1300	1.02	1320	1.05
	SAM3	1320	1.03	1330	1.03
30:70	SAM1	1400	1.01	1410	1.03
	SAM2	1360	0.93	1370	0.98
	SAM3	1340	0.90	1360	0.95

NS= Not significant

The strength of WFC matrix (100×100×100 mm) cubes prepared with chemical and without chemical is compared. The compressive strength without chemical for wood/cement ratio 50:50 could not be determined because the cubes were very soft and already broken during the fixing with the testing machine. So, the values are recorded as not significant (NS) in Table 4 and taken as zero in the Figs. 5 and 6. Figures 5 and 6 show the trends of the average compressive strength of three samples of two type of WFC mixture with different wood/cement ratio (50:50, 40:60 and 30:70) after 7 days and 28 days curing.

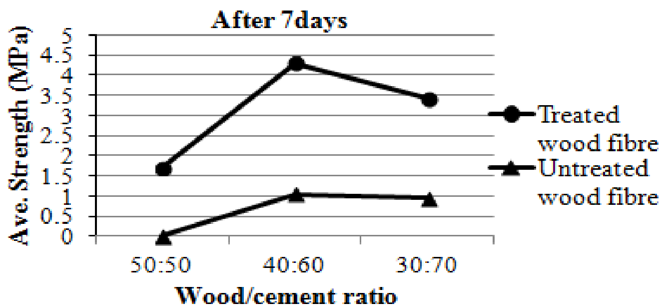

Fig. 5. Average Compressive Strength for Different Wood: Cement Ratio at 7 Days.

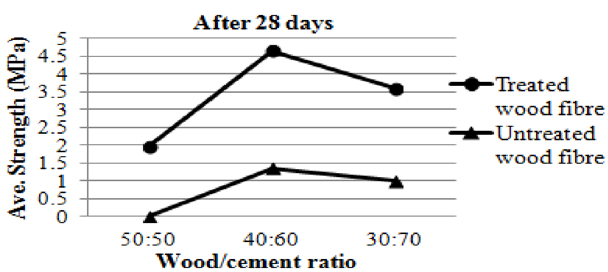

Fig. 6. Average Compressive Strength for Different Wood: Cement Ratio at 28 Days.

The 7 days average compressive strength of WFC mixture that was made with chemicals is 1.71 MPa, 4.3 MPa and 3.43 MPa, which are greater than the strength of WFC matrix that was made without chemicals. At 7 days the compressive strength with chemical additives increased 65% compared to the ones without additives. At 28 days, the average strength of mixtures (40:60) that were made with chemical additives is the highest at 4.65 MPa and the WFC that is made with 50:50 ratio is the lowest. The increment of strength is 62.7% at 28 days. Excess amount of cement in the WFC matrix with chemicals inclusion at wood/cement ratio of 30:70 had contributed negatively to the strength and had made the matrix brittle and failed at low strength. The maximum compressive strength value of 5.53 MPa for 40:60 wood/cement ratio observed in this study is higher than $CaCl_2$ treated coconut husk cement composite strength of 4.1 MPa reported by [21]. However, the value is much lower than those reported by

Sotannde et al. 2012 [22] with the compressive strength of 19.9 N/mm^2 for wood cement flake boards. The reason for high strength of the flake boards compared with the WFC matrix could be attributed to the pressing cycle for 24 hours at the time of production of wood cement flake boards, which had eliminated the voids as much as possible. Another reason for low strength of WFC matrix is the wet cured process. Since dry air curing is a good predictor for strength properties of wood cement composite, this type of curing will be investigated in future study.

The performance of WFC matrix sample at different wood/cement ratio with chemically treated wood fibre and without chemically treated wood fibre on average densities are summarized in Fig. 6. Pre-treatment with chemicals do not significantly affect the density of boards, however the wood/cement ratio significantly increase the density of WFC matrix after 7 days and 28 days curing.

Generally the higher the fibre content, the lower the matrix density. This is common observation in wood fibre matrix since wood particles generally tend to have lower bulk densities then cement. As shown in Fig. 7, 30:70 wood/cement ratio matrix samples produced are relatively denser composites than 50:50 and 40:60 matrix samples. The maximum density evaluated for WFC matrix is 1450 kg/m^3 which is in the range of lightweight concrete according to ACI 213R [23] but the compressive strength does not meet the standard.

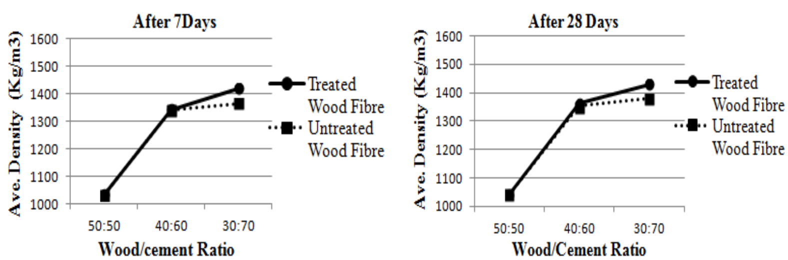

Fig. 7. Average Density for Different Wood/Cement Ratios.

3.2. Water absorption

The chemicals included in the WFC matrix significantly affect the matrix water absorption. Table 5 shows the water absorption of the WFC cubes for both treated and untreated wood fibre.

Table 5. Water Absorption of Different Wood/Cement Ratio Matrix with or without Chemical Treated Wood Fibre.

Wood/Cement Ratio	No.	Water absorption - with Chemicals (%)	Water absorption - without chemicals (%)
40:60	1	28	62.76
	2	31.82	63.76
	3	25.6	66.44
30:70	1	32.6	55.15
	2	29.78	53.75
	3	33.33	54.2

There are highly significant differences and interactions between WFC matrix with chemicals and without chemicals and wood/cement ratio that had influenced the water absorption as shown in Fig. 8. Boards made from fibre without chemical treatment exhibit high value of water absorption at 64.32% but the value decrease at lower ratio of wood/cement. This may be explained by the fact that wood fibre, like all lignocelluloses is hygroscopic, with a relatively high affinity for water.

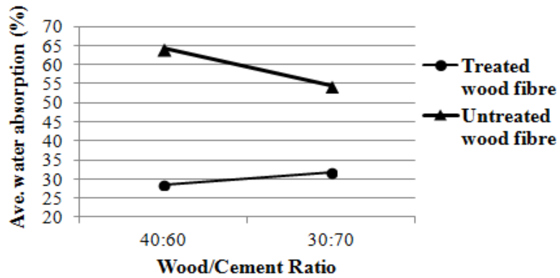

Fig. 8. Average Water Absorption for Different Wood/Cement Ratio.

On the other hand, water absorption by boards containing chemicals is not significantly altered by the decrease in wood/cement ratio. The average water absorption increases from 28.5 to 31.9% for w/c ratio of 40:60 to 30:70 because chemicals decrease the fibre affinity of water by reducing hygroscopic property. The water absorption for wood cement composites produced at similar density range and soaked in cold water for 24 h are matrices with bagasse (41.52%), coconut husk (30.55%) and sawdust (28.93%) are recorded by Oyagade [24] and spruce (6.5–28.1%) by [25].

3.3. Flexural properties

Static bending test were made to determine the apparent modulus of elasticity and flexural strength of the WFC small panels. Table 6 shows the static bending properties of WFC composite boards vary with different conditions and wood/cement ratio.

Table 6. Bending Properties of WFC Composite Boards for Different Conditions with Different Wood/Cement Ratio.

	Conditions	Sample No.	Wood/cement ratio	Density (kg/m^3)	MOE (MPa)	MOR (MPa)
Face Up	Acc. Aging	SAM 15	40:60	1259	19560.75	10.09
		SAM 14	30:70	1270	10606.21	5.47
	Dry	SAM 3	40:60	1250	5784.89	6.73
		SAM 2	30:70	1260	9062.23	4.81
	Wet	SAM 7	40:60	1306	14980.40	7.60
		SAM 6	30:70	1315	9641.60	5.18
Face Down	Acc. Aging	SAM 16	40:60	1255	2941.25	2.04
		SAM 5	30:70	1265	2340.19	2.03
	Dry	SAM 8	40:60	1255	1512.26	1.21
		SAM 1	30:70	1260	1550.90	1.10
	Wet	SAM 4	40:60	1310	1679.80	1.41
		SAM 13	30:70	1320	1940.35	1.46

Experimental result (Fig. 9) shows the modulus of elasticity (*E*) is slightly higher for 30:70 wood/cement ratios for dry board (22%) at face up and wet board (7.2%) at face down boards. On the other hand, accelerated aging board's shows the highest value for any condition and case. The development of *E* values of concrete is influenced by the type of coarse aggregate, type of cement, w/c ratio of mix, admixture aggregate size and curing age [26]. In Fig. 9, the change of wood/cement ratio and moisture content significantly affect the modulus of elasticity.

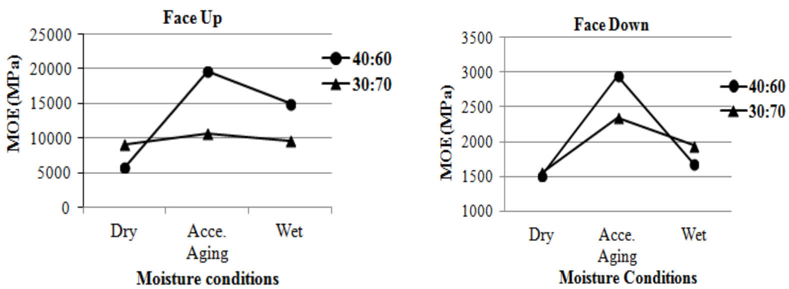

Fig. 9. Modulus of Elasticity of WFC Matrix Boards.

The specimens for 40:60 wood /cement exhibit higher flexural strength compared with 30:70 wood/cement ratios as shown in Fig. 10. The strength depends on the percentage of wood fibre of WFC mixture and in all case accelerated aging boards give the highest value. The decrease in the strength of boards is due to the decrease of fibre volume percentage and its results the decrease in the bond strength of WFC boards.

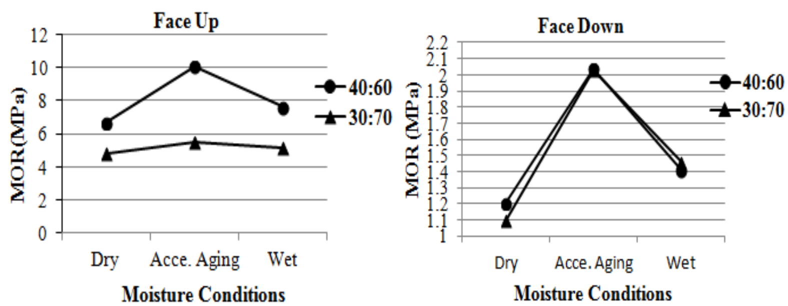

Fig. 10. Flexure Strength for Different Conditions with Different Wood/Cement Ratios.

The ASTM [19] standard for wood base fibre and particle panels does not specify minimum bending or stiffness values. According to ISO 8335 [27], the density should not be less than 1000 kg/m^3. Minimum MOR and MOE required by this standard are 9 MPa and 3000 MPa respectively. The wet and dry WFC matrix boards prepared in this study do not conform to the minimum strength properties set out in ISO 8335 [27]. However, the WFC boards after accelerated aging moisture condition met the ISO standard. Table 7 shows the comparison of some previous researches with the current results.

Table 7. Density and Mechanical Properties for Different Fibres.

Type of Fibres	W/C ratio	Chemicals	Density (kg/m^3)	Compr. strength (MPa)	MOR (MPa)	References
Bamboo fibre	1:2.7	$Al_2(SO_4)_3$ + Na_2SiO_3	1250	-	9.41	Sudin, 2006 [27]
Flake fibre	1:3.5	$CaCl_2$	1320	19.9	5.38	Sotannde, 2012
Flake+ Sawdust	1:3.5	$CaCl_2$	1320	24.7	9.54	Sotannde, 2012
Coconut Husks	-	$CaCl_2$	942.7	4.1	2.2	Olorunnisola, 2008
Kelampa-yan wood fibre	40:60	$MgCl_2$+ Na_2SiO_3+ Ca $(HCOO)_2$	1380	5.53	10.09	Current study

4. Conclusions

This study has presented the results of an experimental investigation on the physical and mechanical properties of WFC matrix. It is found that the compressive strength of WFC matrix increases with the decrease of wood/cement ratio from 50:50 to 40:60. For 30:70 wood/cement ratio matrixes, the strength decreases and shows brittle failure at the ultimate loading. Water absorption is not significantly influenced by wood/cement ratio but is significantly reduced by the presence of chemical additives. The water absorption of treated wood fibre matrix is in the same range with other wood cement composite materials. Accelerated aging boards exhibit the highest mechanical properties compared to the dry and wet boards and meet the minimum requirement of ISO 8335 Standard. The authors proposed that the accelerated aging boards with 40:60 wood/cement ratios as the mix design that attain the optimum set of mechanical properties in comparison with other moisture conditions and ratio.

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References

1. Duvaut, G.; Terrel, G.; and Lene, V.E. (2000). Verijenko optimization of fiber reinforced composites. *Composite Structures*, 48(1-3), 83-89.
2. Ismail, M.A. (2007). Compressive and tensile strength of natural fibre-reinforce cement base composites. *Al-Rafidain Engineering*, 15(2), 42-51.
3. Mulinari, D.R.; Baptista, C.A.R.P.; Souza, J.V.C.; and Voorwald, H.J.C. (2011). Mechanical properties of coconut fibres reinforced polyester composites. *Procedia Engineering*, 10, 2074-2079.

4. Zain, N.M.; Hassan, N.H.; Ibrahim, M.; and Wahab, M.S. (2011). Solid freeform fabrication of prototypes using palm oil fly ash via 3D printing. *Journal of Applied Sciences*, 11(9), 1648-1652.
5. Zain, M.F.M.; Abd, S.M.; Hamid, R.; and Jamil, M. (2010). Potential for utilising concrete mix properties to predict strength at different ages. *Journal of Applied Sciences*, 10(22), 2831-2838.
6. Kelly-Yong, T.L.; Lim, T.L.S.; and Lee, K.T. (2011). Gasification of oil palm empty fruit bunch fibers in hot compressed water for synthesis gas production. *Journal of Applied Sciences*, 11(21), 3563-3570.
7. Feng, L.Y.; Tahir, P.M.; and Hoong, Y.B. (2011). Density distribution of oil palm stems veneer and its influence on plywood mechanical properties. *Journal of Applied Sciences*, 11(5), 824-831.
8. Dawood, E.T.; and Ramli, M. (2011). Evaluation of flowable high strength concrete used as repair material (review study). *Journal of Applied Sciences*, 11(12), 2111-2113.
9. Hamid, M.A.; Sarmidi, M.R.; Mokhtar, T.H.; Sulaiman, W.R.W.; and Aziz, R.A. (2011). Innovative integrated wet process for virgin coconut oil production. *Journal of Applied Sciences*, 11(13), 2467-2469.
10. Sudin R.; and Swamy N. (2006). Bamboo and wood fibre cement composites for sustainable infrastructure regeneration. *Journal of Materials Science*, 41(21), 6917-6924.
11. Bejo, L.; Takats, P.; and Vass, N. (2005). Development of cement bonded composite beams. *Acta Silv. Ling. Hung.*, 1, 111-119.
12. Wolfe, R.W.; and Gjinolli, A.E. (1996). Cement- bonded wood composites as an engineering material. *Recycle Wood and Paper in Building Applications*. Forest Product Society.
13. Paribotro, S. (2000). Effect of aqueous extraction of wood-wool on the properties of wood-wool cements manufactured from teak (Tectonagrandis). *Wood Cement Composites in the Asia Pacific Region. Proceeding of a workshop held in Canberra, Australia*, 24-28.
14. Wei, Y.M.; Zhou, Y.G.; and Tomita, B. (2000). Hydration behavior of wood cement-based composite I: evaluation of wood species effects on compatibility and strength with ordinary Portland cement. *Journal of Wood Science*, 46(4), 296-302.
15. Fei, M.L.; Hidefumi, Y.; Orlando, R.P.; Yasuo, T.; Hikaru, S.; and Shuichi, K. (2000). Manufacture of cement bonded boards from wood and other lignocellulosic materials: Relationships between cement hydration and mechanical properties of cement-bonded boards. *Proceedings of a workshop held at Rydges Hotel*, Canberra, Australia.
16. Sukartana, P.; Rushelia, R.; and Sulastiningsih, I.M. (2000). Resistance of wood– and bamboo–cement boards to subterranean termite Coptotermesgestroi Wasmann (Isoptera: Rhinotermitidae*). Wood-Cement Composites in the Asia-Pacific Region Workshop*, *Canberra Australia*, 107, 62-65.
17. English, B.; Youngquist, J.A.; and Krzysik, A.M. (1994). *Lignocellulosic composites*. In: Gilbert, R.D., Ed., *Cellulosic polymers, blends and composites.* New York, Hanser publishers, 115-130.

18. Builder's Guide on Wood wool cement board. Forest products research and development institute. *Australian Centre for International Agricultural Research*.
19. ASTM standard (2006). Standard test methods for evaluating properties of wood-base fiber and particle panel materials. D 1037-06a.
20. BS 1881: Part 3. 1970. Methods of making and curing test specimens. *British Standard Institution* (BSI), UK.
21. Olorunnisola, A.O. (2009). Effects of husk particle size and calcium chloride on strength and sorption properties of coconut husk-cement composites. *Industrial Crops and Products*, 29(2-3), 495-501.
22. Sotannde, O.A.; Oluwadare, A.O.; Ogedoh, O.; and Adeogun, P.F. (2012). Evaluation of cement bonded particle board produced from *Afzetia Africana* wood residues. *Journal of Engineering Science and Technology* (*JESTEC*), 7(6), 732-743.
23. ACI 213R, Guide for structural lightweight aggregate concrete. *American Concrete Institute, Farmington Hill, MI*, www.concrete.org.
24. Oyagade, A.O. (2000). Thickness swelling component and water absorbation of cement-bonded particleboards made from gmelina wood, bagasse and coconut husk. *Nigerian Journal of Forestry*, 30(1/2), 10-14.
25. Fuwape, J.A.; and Fuwape, I.A. (1995). Technical assessment of three layer cement wood particleboard. *Nigerian Journal of Forestry*, 24(1/2), 57-60.
26. Alexander, M.G.; and Milne, T.I. (1995). Influence of cement blind and aggregate type on the stress-strain behavior and elastic modulus of concrete. *ACI Materials Journal*, 92(3), 227-235.
27. International Organisation for Standardisation (1987). Cement bonded particleboard: Board of Portland of equivalent cement reinforced with fibrous wood. *Reference number ISO 8335 International Standard Organisation*.