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ORIGINAL ARTICLE

Performance characteristics of treated kenaf bast fibre reinforced cement composite

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Abstract This study investigated the effect of pretreatment on the properties of kenaf fibre cement boards. Homogenous fibre cement boards were made from kenaf bast fibres, cement and water. The fibres were cut into smaller sizes, mixed with cement and water and formed in rectangular moulds. After demoulding, the boards were cured for 28 days. The fibres were treated at three levels which included hot water, calcium chloride ($CaCl_2$), hot water + $CaCl_2$ and a control (untreated). The fibre cement boards were tested for Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bond (IB), Water Absorption (WA), Thickness Swelling (TS) and Linear Expansion (LE). The results showed that the mean MOR ranged from 1.31 to 8.25 MPa; the mean MOE from 78.0 to 1636.3 MPa for all treated boards. Mean water absorption ranged from 27.52 to 67.64% and the mean thickness swelling from 14.51 to 48.01% for all treated boards. Statistical analysis showed that the effect of the pretreatment was significant on the properties evaluated ($p < 0.05$). The study concluded that boards produced from hot water combined with CaCl2 treated fibres exhibited the best mechanical and physical properties.

Keywords Fibre cement boards · Kenaf bast fibres · Mechanical properties · Physical properties · Pretreatment

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Introduction

Fibre cement composites have been used in building applications for over a century but the technology to develop better products has been improving with time. Since the wake of changes in building regulations and the health hazard associated with the use of asbestos fibres, different synthetic fibres have been used to reinforce cement mortar and concrete including glass, steel and a number of annual crops and agricultural residues (Mohr et al. 2004; Ismail 2007; Moslemi 2008). Natural fibres are affordable, renewable and readily available and have formed a core in modern research in fibre reinforced concrete. The major advantage of natural fibre reinforcement is to impart additional energy absorbing capacity and enable the composite to withstand load to a higher strain limit (Frybort et al. 2008; Jevtic et al. 2008).

This study utilized Kenaf bast fibres as reinforcement in cement matrix. Kenaf fibre is obtained from the stems of kenaf plant (*Hibiscus cannabinus*). They are less costly to process and more readily biodegradable after processing. Kenaf fibre is increasingly been used as a reinforcement material in composite applications including thermoplastics and cement matrices. A number of researches have been conducted on the suitability and reinforcement mechanism of Kenaf fibre in cement and concrete applications. Ribot et al. (2011) reported high tensile strength of 500 MPa in concrete reinforced with kenaf fibres. Omoniyi et al. (2015) found that compressive strengths of kenaf reinforced composite mortar increased at 2% fiber volume with 10 and 20 mm lengths and decreased for other mixes studied at all curing ages from 3 to 28 days. Basher (2013) incorporated Kenaf bast fibre in cement composite board. The author found that although the strength properties increased, the internal bonding was significantly reduced.

The separation of Kenaf fibre from cement creates a weak inter-particle bonding within the board (Basher 2013).

Improvement of the compatibility between natural fibres and cement has been the subject of many researches to date. Because of the inhibiting contents of lignocellulosic fibres, some aggressive species can hinder or completely stop the hydration of cement and degrade the physical properties. As a result, many species have to be treated before they can be suitable for the production of cement bonded composites (Frybort et al. 2008; Moslemi 2008). Different treatment methods have been applied on wood fibres. Some of these include conventional hot or cold water extraction (Eusebio et al. 2000; Amiandamhen and Izekor 2013), chemical extraction (Alberto et al. 2000) and fungi treatment (Thygesen et al. 2005). Not much information is available in the literature on the treatment of kenaf fibres for cement based applications. This study investigates the effect of hot water and calcium chloride ($CaCl_2$) treatments on the mechanical and physical properties of Kenaf bast fibre cement composite boards.

Materials and methods

The kenaf bast fibres were obtained from the Institute of Agricultural Research and Training (IAR&T), Moore Plantation, Ibadan. The fibres were cut into smaller sizes of 3–4 cm. This was done to avoid balling problem during mixing and to facilitate homogeneous mixing of the composite. Ordinary Portland cement was used as the binding material. Other materials used include: water, wooden rectangular mould, cellophane sheets, paper tape and $CaCl_2$.

Sample preparation

The fibres were separated into four parts for three treatments and the control. The treatments were hot water; $CaCl_2$ and a combination of hot water + $CaCl_2$. The hot water treatment was carried out by soaking the fibres in aluminum bath at 70 °C for 1 h. Thereafter, the water was drained and the fibres were air-dried to a moisture content of about 12%. The chemical treatment was applied by the addition of $CaCl_2$ (3% cement weight) in the water used during the board manufacture. Each treatment and the control were replicated three times. The fibre: cement mixing ratio was 1:1.5 (292.8 g kenaf fibres to 439.2 g Portland cement). With a target board density of 1.2 g/cc and a known mould dimensions, the required mass of materials was calculated based on the ratio. The weighed samples were mixed thoroughly. Water (316.2 ml) was added to the mixture and stirred until a homogenous paste was formed. The quantity of water used for mixing was adapted from Badejo (1988) and Simatupang et al. (1995). For samples treated with $CaCl_2$, 13.18 g (3% cement weight) was dissolved in water prior to wet mixing.

Board formation and test

The boards were formed in a rectangular mould of 350 mm × 350 mm × 6 mm. The wood and cement paste was transferred to the mould and was pressed at 1.23 MPa using a hydraulic cold press. The boards were demoulded after 24 h and air-cured for 28 days. The boards were trimmed to avoid edge effects. The boards were converted into test sample sizes according to ASTM (1998) and conditioned at 20 °C and 65% RH for 96 h before testing.

Test for mechanical properties

The strength test conducted were modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IB). Three test samples were randomly selected from the boards for each test. The samples were tested using a 3-point bending test with an automated universal testing machine at cross head speed of 5 mm/min.

Test for physical properties

The physical properties evaluated include water absorption (WA), thickness swelling (TS) and linear expansion (LE). Samples were tested for dimensional stability after 24 h water immersion. Durability on prolonged immersion in water for 48 h was also observed. Three test samples were randomly selected from the boards for each test. The samples disintegrated on prolonged immersion. Increase in weight and dimensions of the samples after 24 h immersion was calculated from the relationship;

$$X(\%) = \frac{M1 - M0}{M0} \times 100 \quad (1)$$

X is the physical property; M_1 is the final measurement after immersion (mm); M_0 is the initial measurement before immersion (mm).

Data analysis

The experiment was arranged in a completely randomized design (CRD) with three treatments and a control. Analysis of variance procedure was conducted to investigate the effect of the pretreatments on the mechanical and physical properties of the boards. Duncan's Multiple Range test was used in the separation of means where significant differences occurred.

Results and discussion

Effect of pretreatment on modulus of rupture (MOR)

Fibre cement boards produced from treated fibres have high MOR than those without treatment, as shown in Table 1. The boards produced from a combination of hot water + $CaCl_2$ treated fibres have the highest mean MOR of 8.25 MPa, followed by boards produced from hot water treated fibres with a mean value of 6.94 MPa. Boards produced from $CaCl_2$ treated fibres have a mean value of 1.31 MPa while boards from untreated fibres have the lowest mean MOR of 0.45 MPa. This shows that pretreatments such as hot water + $CaCl_2$ have positive effect on the MOR of kenaf bast fibre cement boards. Lima et al. (2015) reported positive increase in strength properties in the study of the interaction of Portland cement and Pinus wood. This result is similar to the report of Amiandamhen and Izekor (2013) and Basher (2013) that $CaCl_2$ treated samples generally have higher MOR than untreated samples. Ferraz et al. (2011) also reported that $CaCl_2$ + hot water treated samples had high MOR values in Coir fibre cement composites.

Effect of pretreatment on modulus of elasticity (MOE)

The mean values of MOE of the fibre cement boards produced ranged from 10.3 to 1636.3 MPa as shown in Table 1. Fibre cement boards produced from hot water treated fibres have the highest mean MOE of 1636.3 MPa, followed by those produced from hot water + $CaCl_2$ treated fibres with a mean value of 1429.2 MPa. Boards made from $CaCl_2$ treated fibres have mean value of 78 MPa while boards produced with untreated fibres have the lowest mean MOE of 10.3 MPa. This shows that treatment of Kenaf fibre has a positive effect on MOE of fibre cement boards. The positive effect of pretreatment enhances compatibility and mechanical properties of wood cement composites (Eusebio et al. 2000; Frybort et al. 2008). The result obtained is similar to the report of Ferraz et al. (2011) with hot water treatment having the highest MOE value. Amiandamhen and Izekor (2013) reported an improvement in MOE with increase in fibre size. However, Clausen et al. (2001) and Li et al. (2004) reported that particle geometry and not pretreatment has a greater influence on stiffness of manufactured wood fibre cement boards.

Table 1 Mechanical properties of kenaf fibre cement boards

Pretreatments	Mechanical properties		
	MOR (MPa)	MOE (MPa)	IB (MPa)
Hot water	6.94 ± 2.14	1636.30 ± 131.54	0.17 ± 0.01
$CaCl_2$	1.31 ± 0.81	78.00 ± 26.04	0.04 ± 0.02
Hot water + $CaCl_2$	8.25 ± 2.91	1429.20 ± 169.28	0.15 ± 0.08
Control	0.45 ± 0.15	10.30 ± 5.29	0.02 ± 0.01

Each value represents mean data with standard deviation of 3 replicates

Effect of pretreatment on internal bond strength (IB)

The mean values of IB strength of the fibre cement boards produced ranged from 0.02 to 0.17 MPa, Table 1. Fibre cement boards produced from hot water, $CaCl_2$, hot water + $CaCl_2$ treated fibres have mean IB strength values of 0.17, 0.04, and 0.15 MPa respectively. Boards produced from untreated fibres have mean IB strength of 0.02 MPa. Although pretreatment has a positive influence on the internal bond strength, the low values suggest weak internal bond in the composites. Basher (2013) also observed lower IB strength when Kenaf was incorporated into cement matrix as a result of de-bonding at the fibre-matrix interface. From this study, hot water treatment possibly cleans and fibrillates the fibre surfaces, thereby enabling fibre–fibre bonding. The resultant effect is a significant increase in the IB strength.

Effect of pretreatment on water absorption (WA)

The fibre cement boards produced have mean WA rates of 27.52–90.62%. Boards produced from untreated fibres have the highest mean WA of 90.62%, followed by boards from $CaCl_2$ treated fibres with WA of 67.64%. Boards produced from hot water + $CaCl_2$ treated fibres have the lowest mean WA of 27.52%. This could be as a result of better compaction in the matrix of the treated fibre-cement boards. On the other hand, boards from $CaCl_2$ treated fibres tend to absorb water, probably due to the hygroscopic nature of the salt. This effect was reduced when the fibres were first treated with hot water. This result showed that fibre cement boards produced from hot water treated fibres have lower WA rates compared to $CaCl_2$ treated boards. This demonstrated that hot water treated fibres are more dimensionally stable (Fig. 1).

Effect of pretreatment on thickness swelling (TS)

The mean TS of the fibre cement boards ranged from 14.51 to 48.01%. Boards from $CaCl_2$ treated fibres have the highest mean TS of 48.01%, followed by the untreated

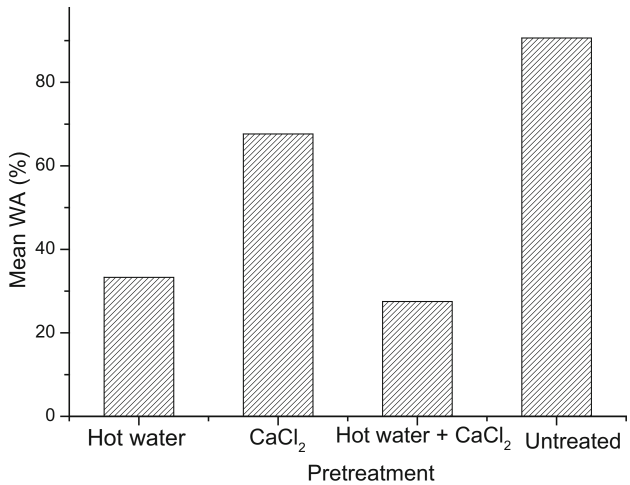

Fig. 1 Mean percentage water absorption of the boards

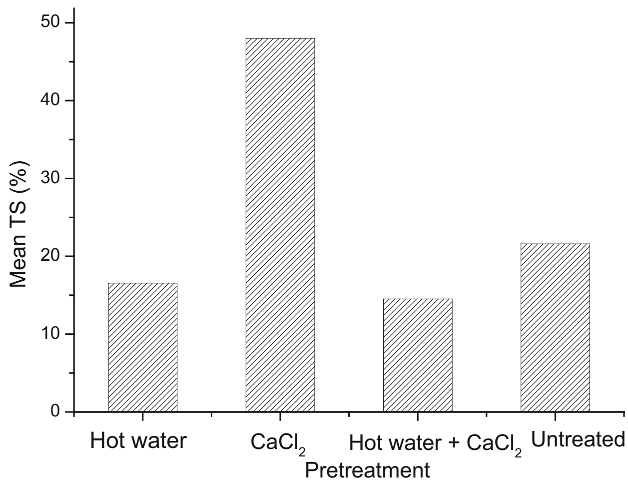

Fig. 2 Mean percentage thickness swelling of the boards

fibres with a mean value of 21.59%. The boards made from hot water and a combination of hot water + $CaCl_2$ treated fibres have lower TS values of 16.55 and 14.51% respectively. This result shows that hot water treatment is an effective method of reducing thickness swelling thereby making the boards more dimensionally stable. This improvement could be explained by better inter-fibre contact as a result of improved bonding ability with cement (Semple and Evans 2004; Frybort et al. 2008). High values of TS were also reported for untreated wood particles by Eusebio et al. (2000). However the low TS values reported for $CaCl_2$ treated fibres were contrary to the results of this study. $CaCl_2$ treated boards exhibited highest TS rate probably due to migration of moisture to the edges of the boards. Frybort et al. (2008) reported that TS, as an important attribute concerning dimensional stability is highly correlated with cement-wood ratio (Fig. 2).

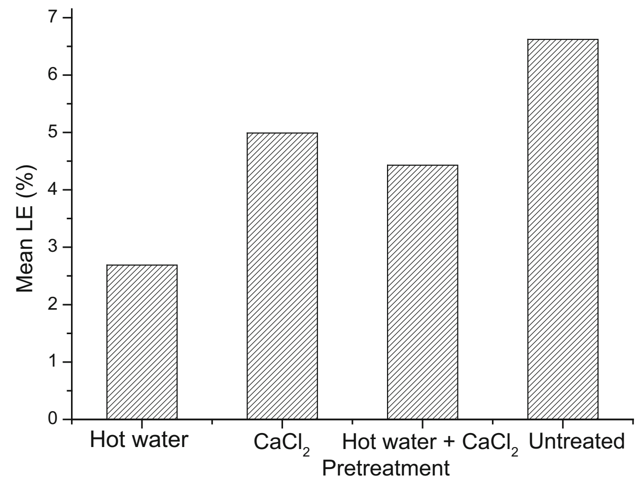

Fig. 3 Mean percentage linear expansion of the boards

Table 2 ANOVA procedures for the properties of the boards

	Mechanical properties			Physical properties		
	MOR	MOE	IB	WA	TS	LE
F value	13.52	7.23	9.40	152.59	3.45	2.81
$p > F$	0.0017	0.0115	0.0053	<0.0001	0.0715	0.108

Table 3 Duncan's multiple range test for the fiber cement boards

Pretreatment	MOR	MOE	IB	WA	TS	LE
Hot water only	6.94^{a}	1636.30^{a}	0.17^{a}	33.29^{c}	16.55^{b}	2.69^{b}
$CaCl_2$ only	1.31^{b}	78.00^{b}	0.04^{b}	67.64^{b}	48.01^{a}	4.99^{ab}
Hot water + $CaCl_2$	8.25^{a}	1429.2^{a}	0.15^{a}	27.52^{c}	14.51^{b}	4.43^{ab}
Control	0.45^{b}	10.3^{b}	0.02^{b}	90.62^{a}	21.59^{ab}	6.62^{a}

Data in the same column with the same letter are not significantly different ($p \leq 0.05$)

Effect of pretreatment on linear expansion (LE)

Fibre cement boards produced from hot water, $CaCl_2$, $CaCl_2$ + hot water treated fibres, and untreated fibres have mean LE of 2.69, 4.99, 4.43 and 6.62% respectively. Boards produced from untreated fibres have the highest mean LE of 6.62% while the boards produced from hot water treated fibres have the lowest mean percentage of 2.69%. This observation demonstrated that pretreatment helps to decrease linear expansion by improved fibre-cement bonding which restricts expansion of the fiber cement boards (Fig. 3).

Data analysis

Table 2 shows that all variables considered in the production of the fibre cement boards were significant on the mechanical properties and water absorption WA. However, the main effects were not significant for TS and LE ($p < 0.05$). The pretreatment effect was highly significant on WA.

Table 3 shows the mean separation of the treatments in the properties evaluated. It would be observed that there was no significant difference in hot water and hot water + $CaCl_2$ treatment on the mechanical and physical properties of the fibre cement boards. Also, there was no significant difference in the mechanical properties of $CaCl_2$ treated and untreated fibre boards.

Conclusion

Pretreatment of kenaf bast fibres has a positive effect on the properties tested on fibre cement boards. MOR, MOE and IB strength were higher in boards produced from treated fibres than in boards produced from untreated fibres. TS, WA and LE were lower in treated boards compared to untreated boards. Boards produced from hot water + $CaCl_2$ treated fibres had the best mechanical and physical properties. All the properties except IB of the hot water treatment met or exceeded the minimum requirement for cement bonded particle board (EN-634). Kenaf bast fibres can be used to reinforce cement composites for building applications. Hot water treatment of the fibres is sufficient to improve compatibility with Portland cement and properties of the composites.

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References

Alberto MM, Mougel E, Zoulalian A (2000) Compatibility of some tropical hardwood species with Portland cement using isothermal calorimetry. Forest Prod J 50:83–88

Amiandamhen SO, Izekor DN (2013) Effect of wood particle geometry and pretreatments on the strength and sorption properties of cement bonded particle boards. J Appl Nat Sci 5(2):318–322

Badejo SOO (1988) Effect of flake geometry on properties of cement-bonded particle board from mixed tropical hardwoods. Wood Sci Technol 22:357–370

Basher ABA (2013) Properties of Kenaf bast fibre cement composite board. Dessertation, Universiti Putra Malaysia, Peninsular Malaysia

Clausen CA, Kartal SN, Muehl J (2001) Particleboard made from remediated CCA-treated wood: evaluation of panel properties. Forest Prod J 51(7/8):61–64

Eusebio DA, Soriano FP, Cobangon RJ, Evans PD (2000) Manufacture of low-cost wood-cement composites in the Philippines using plantation-grown Australian species: I. Eucalyptus. Wood-Cement Composites in the Asia-Pacific Region, Canberra, pp 105–114

Ferraz MJ, Menezzi HS, Teixeira DE, Martins SA (2011) Coir fiber cement composites. Bioresources 6(3):3481–3492

Frybort S, Raimund M, Alfred T, Muller U (2008) Cement bonded composites—a mechanical review. BioResources 3(2):602–626

Ismail MA (2007) Compressive and tensile strength of natural fibre-reinforced cement based composite. Al-Rafidain Eng 15(2):42–45

Jevtic D, Zakic D, Savic A (2008) Modeling of properties of fibre reinforced cement composites. J Arch Civil Eng 6(2):165–172

Li W, Shupe TF, Hse CY (2004) Physical and mechanical properties of flake board produced from recycled CCA-treated wood. Forest Prod J 54(2):89–94

Lima AJM, Iwakiri S, Ramirez MGL (2015) Study of the interaction of Portland cement and Pinus wood for composites using Bragg sensors in optical fibers. BioResources 10(4):6690–6704

Mohr BJ, El-Ashkar NH, Kurtis KE (2004) Fibre cement composites for housing construction: state of the art review. NSF Housing Research Agenda Workshop, Orlando, FL, pp 112–128

Moslemi A (2008) Technology and market considerations for fibre cement composites. In: 11th international inorganic-bonded fibre composites conference (IIBCC), Nov 5–7, Madrid, pp 113–129

Omoniyi TM, Duna S, Othman MW (2015) Compressive strength characteristics of Kenaf fibre reinforced cement mortar. Adv Mater 4(1):6–10

Ribot NMH, Ahmad Z, Mustaffa NK (2011) Mechanical properties of Kenaf fiber composite using co cured inline fiber joint. Int J Eng Sci Technol 8(3):269–272

Semple KE, Evans PD (2004) Wood-cement composites—suitability of Western Australian mallee eucalypt, blue gum and melaleucas, RIRDC/Land and water, Australia/FWPRDC/MDBC

Simatupang MH, Habighorst C, Lange H, Neubauer A (1995) Investigations on the influence of the addition of carbon dioxide on the production and properties of rapidly set wood-cement composites. Cement Concrete Comp 17:187–197

Thygesen A, Daniel G, Lilholt H, Thomsen AB (2005) Hemp fiber microstructure and use of fungal defibration to obtain fibers for composite materials. J Nat Fibers 2:19–37