Full Paper

Assessment of the Physical and Mechanical Properties of Treated Kenaf Fibre Cement Composites

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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 boards were manufactured at three pretreatment levels which include hot water, 3% $CaCl_2$, hot water and 3% $CaCl_2$ and a control. The fibre cement boards were tested for Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bonding (IB), Water Absorption (WA), Thickness Swelling (TS) and Linear Expansion (LE). Also nail ability and withdrawal resistance, termite, fungi and fire resistances were also assessed. The results showed that the mean MOR ranged from 1.31 to 8.25 N/mm^2; the mean MOE from 78.0 to 1636.3 N/mm^2 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 effects of the pretreatments were significant on the properties evaluated ($p < 0.05$). The study concluded that hot water combined with $CaCl_2$ treated boards exhibited the best mechanical and physical properties.

Keywords: *Fibre cement boards, kenaf bast fibres, mechanical properties, physical properties, pretreatments*

1. INTRODUCTION

Composites are materials in which a homogeneous matrix component is reinforced by a stronger and stiffer constituent that is usually fibrous but may have a particulate or other shape (Gerstle, 1991). Fibre reinforced composites are composed of axial particulates embedded in a matrix material; the objective of which is to obtain a material with high specific strength and high specific modulus of elasticity good enough for its weight. The strength is obtained by having the applied load transmitted from the matrix to the fibres; hence, interfacial bonding is important. Therefore, a fibre reinforced composite is a building material that consists of three components; the fibres as the discontinuous or dispersed phase; the matrix as the continuous phase; and the fine inter-phase region also known as the interface (Cantwell and Morton, 1991). Fibre cement materials can offer a variety of advantages over traditional construction materials. When compared to wood, fibre cement products offer improved dimensional stability, moisture resistance, decay resistance and fire resistance. When compared to cement based materials without fibres, fibre cement products may offer improved toughness, ductility and flexural capacity as well as crack resistance and nail ability (Mohr *et al.*, 2006).

Synthetic fibres such as glass, roselle and a number of agricultural materials including coffee husk, maize husk, bagasse, and bamboo among others to reinforce cement composite boards (Mohr *et al.*, 2006). As the demand for composite board increases, researchers have to look at possible alternatives to reinforce cement such as natural fibres for the production of value-added composites. Natural fibres exist in abundance and are readily available at low cost being derivable from various parts of vegetable materials such as leaves, stems, fruits, or wood. These fibres can be incorporated into the cement matrix in discrete and discontinuous form. The major advantage of natural fibre reinforcement is to impart additional energy absorbing capacity in the end product. Natural fibres absorb large amounts of water and have high energy absorbing capacity resulting from their low modulus of elasticity (Ismail, 2007). This study investigated the effect of pretreatment of kenaf bast fibres on the mechanical and physical properties of cement composites while observing other durability properties.

2. 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 3cm-4cm. 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 calcium chloride ($CaCl_2$).

2.1. Sample Preparation

The fibres were divided into four portions, three were treated and the untreated was used as control. The treatments were hot water only; hot water + CaCl2; and CaCl2 only. The hot water treatment was carried out by soaking the fibres in aluminum bath at 100 oC for an hour. Thereafter, the water was drained and the fibres were air-dried to a moisture content of approximately 12%. The chemical treatment was applied by the addition of calcium chloride (at 3% of the cement weight) during the board manufacture. Each treatment and the control were repeated at least three times. The fibres and cement were weighed and packed in labeled polythene bags for ease of identification. The fibre cement mixing ratio was 1:1.5 (292.8 g kenaf

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fibres to 439.2 g Portland cement). The weighed samples were placed in a plastic bowl and mixed properly. Water (316.224 ml) was added to the mixture and stirred thoroughly until homogenous slurry was formed. For samples treated with CaCl2, 13.18 g (3% of the cement weight) was dissolved in water prior to wet mixing. The quantity of water used for mixing was calculated from Equation (1) developed by Badejo (1988).

$$Q = 0.6Z + (0.3 - R) \times H \quad (1)$$

Q = Quantity of water (ml)
Z = Mass of cement in the board (g)
R = Moisture content of the fibre material (%)
H = Mass of fibre in the board (g)

2.2. Board Formation

Wooden moulds of 350 mm x 350 mm x 6 mm were used. The mould was placed on a caul plate and covered with cellophane sheet in order to prevent the formed boards from sticking to the plate. The slurry was spread in the mould and was pressed to enhance uniform mat formation and to reduce the thickness of the board. The board formed was labeled using a paper tape to identify boards of different treatments. The labeled board was covered with another cellophane sheet and a wooden plate was placed on it. It was then compressed with a hydraulic cold press under a pressure of 1.28 N/mm^2 to a uniform thickness of 6 m. After 24 h, the boards were demoulded. The demoulded boards were arranged in an out-door environment and allowed to cure for 28 days.

2.3. Board Test

After curing, the boards were trimmed to avoid edge effects and then cut into smaller test sample sizes. The tests carried out on the boards are mechanical and physical properties. Durability properties assessed include termite resistance, fungi resistance, fire resistance, nail ability and withdrawal resistance.

2.3.1. Test for Mechanical Properties

The mechanical properties test carried out include modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB). The mechanical properties of the board produced were determined using test samples of 50 mm (width) by 150 mm (length). Three test samples were randomly selected from the boards for each property test. The samples were tested with an automated universal testing machine at cross head speed of 5 mm/min.

2.3.2. Test for Physical Properties

Sample sizes of 50 mm (length) x 50 mm (width) were used to carry out the test for physical properties. The properties tested for include water absorption (WA), thickness swelling (TS) and linear expansion (LE). Samples were tested for weight and dimensional stability after 24 h and for durability in prolonged immersion in water for 48 h. Three test samples were randomly selected from the boards for each property test. These were completely immersed in distilled water at a temperature of about 20 $\pm$ 2 oC for 24 h. The initial weight and dimensions of the test samples were measured using an electronic balance and a digital caliper respectively. At the end of the immersion period, the samples were drained for about 10 minutes and re-measured. The procedure was repeated for another 24 h but the samples disintegrated on prolong immersion before the end of the period. Thereafter, water absorption, thickness swell and linear expansion after the first 24 h were calculated from the increase in weight and dimensions of the samples after immersion using Equation (2).

$$X\,(\%) = \frac{M1 - M0}{M0} X\, 100 \quad (2)$$

X = Measured physical property
M_1 = Final measurement after immersion (mm)
M_0 = Initial measurement before immersion (mm)

2.3.3. Nail ability and Withdrawal Resistance

This test gives an indication of the ease of nailing, nail holding capacity and nail withdrawal strength. Test samples were nailed at the centre and at the edges to a rod and the fastener were gradually withdrawn. The ease of nailing and withdrawal, ability to hold nails and occurrence of splits were visually observed.

2.3.4. Termites and Fungi Resistance

This test measures the ability of the fibre cement composites to resist attack by termites and decaying fungi. Test samples were inserted in active termite mound. In the latter test, samples were partially earthed in decaying organic humus. The samples were visually observed at monthly intervals for a period of 6 months. Presence or resistance to attack by termites and decaying fungi was physically assessed during the period of observation.

2.3.5. Fire Resistance

This test measures the ability of the composites to withstand sudden fire outbreak. Test samples were placed in burning flame heated with dry wood and were observed quarterly for a period of one hour. The ease or resistance to char by the burning samples was physically assessed at each time interval.

2.4. Statistical Analysis

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

3. RESULTS AND DISCUSSION

3.1. Effect of Pretreatment on Modulus of Rupture (MOR)

Fibre cement boards produced using pretreatments have high MOR than those without pretreatment, Table 1. The boards produced from hot water and additive chemical (3% $CaCl_2$) treatment have the highest mean MOR of 8.25 N/mm^2, followed by boards produced from hot water treatment only with a mean value of 6.94 N/mm^2. Boards produced with $CaCl_2$ treatment only have a mean value of 1.31 N/mm^2 while the untreated boards have the lowest mean MOR of 0.45 N/mm^2. This shows that pretreatments such as hot water and $CaCl_2$ have positive effect on the MOR of fibre cement boards. This result is in line with the findings of Olorunnisola (2007) that $CaCl_2$ treated samples generally have higher MOR than untreated samples. Ferraz *et al*. (2011) also submitted that $CaCl_2$ and hot water treated samples had high MOR values.

Table 1: Mechanical properties of kenaf fibre cement boards

Pretreatments	Mechanical properties		
	MOR(N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)
Hot water only	6.94 ± 2.14	1636.30± 131.54	0.17 ± 0.01
$CaCl_2$ only	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
No treatment	0.45±0.15	10.30 ± 5.29	0.02 ± 0.01

Each value represents mean data with standard deviation of 3 replicates

3.2. Effect of Pretreatment on Modulus of Elasticity (MOE)

The mean values of MOE of the fibre cement boards produced ranged from 10.3 N/mm^2 to 1636.3 N/mm^2 as shown in Table 1. Fibre cement boards produced from hot water treatment only have the highest mean MOE of 1636.3 N/mm^2, followed by those produced from hot water and $CaCl_2$ treatment with a mean value of 1429.2 N/mm^2.

Boards made of $CaCl_2$ treatment only have mean value of 78.0 N/mm^2 while boards produced with no treatment have the lowest mean MOE of 10.3 N/mm^2. This shows that pretreatment has a positive effect on MOE of fibre cement boards. This is similar to the report of Ferraz *et al.* (2011) with hot water treatment having the highest MOE value. However, Amiandamhen and Izekor (2013) reported an improvement in MOE with increase in fibre size. Furthermore, Clausen *et al.* (2001) and Li *et al.* (2004) reported that particle geometry has a greater control on stiffness of manufactured fibre boards.

3.3. Effect of Pretreatment on Internal Bonding (IB)

The mean values of IB of the fibre cement boards produced ranged from 0.02 N/mm^2 to 0.17 N/mm^2, Table 1. Fibre cement boards produced using hot water treatment only, hot water and $CaCl_2$ treatment, $CaCl_2$ treatment only and no pretreatment have mean IB values of 0.17 N/mm^2, 0.15 N/mm^2, 0.04 N/mm^2 and 0.02 N/mm^2 respectively. This result shows that pretreatment has a positive influence on the internal bonding ability of the fibre cement boards. It could be explained that pretreatments fibrillates the fibre surfaces, thereby enabling fibre-fibre bonding.

3.4. Effect of Pretreatment on Water Absorption (WA)

Fibre cement boards produced using different treatments have mean WA ranging from 27.52% to 90.62%. Boards produced with no pretreatment have the highest mean WA of 90.62%, followed by $CaCl_2$ treated boards with 67.64% and hot water treated boards with 33.29% while boards produced from both hot water and $CaCl_2$ treatment have the lowest mean WA of 27.52%. This result shows that fibre cement boards produced using different pretreatments have lower WA percentage compared to those produced with no pretreatment as a result of better bonding in the treated boards. This means that pretreated boards are more dimensionally stable.

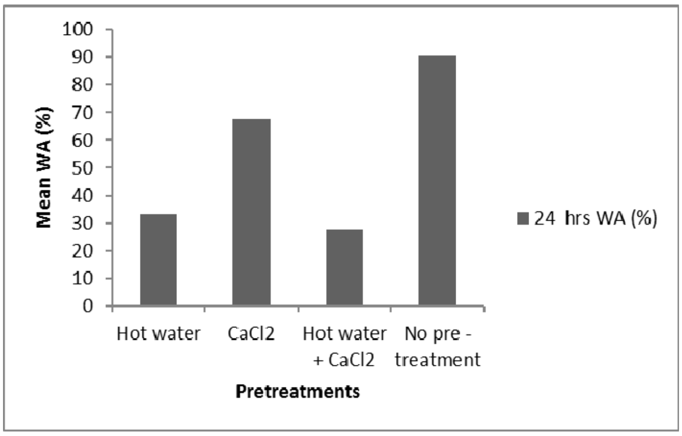

Fig. 1: Mean percentage water absorption of the boards

3.5. Effect of Pretreatment on Thickness Swelling (TS)

Fibre cement boards produced using different treatments have mean TS ranging from 14.51% to 48.01%. $CaCl_2$ treated boards have the highest mean TS of 48.01%, followed by the boards with no pretreatment with a mean value of 21.59%, then the boards treated with hot water only with a mean value of 16.55%. The boards treated with both hot water and $CaCl_2$ have the lowest mean TS of 14.51%. This result shows that pretreatments such as hot water only and both hot water and $CaCl_2$ are effective methods of reducing thickness swelling thereby making the boards more dimensionally stable. Also, pretreatment decreases thickness swelling by enhancing the bonding between fibers and cement. However, $CaCl_2$ treated boards exhibited highest TS percentage. This could be explained as a function of the hygroscopic nature of the additive which increased moisture migration at the edges.

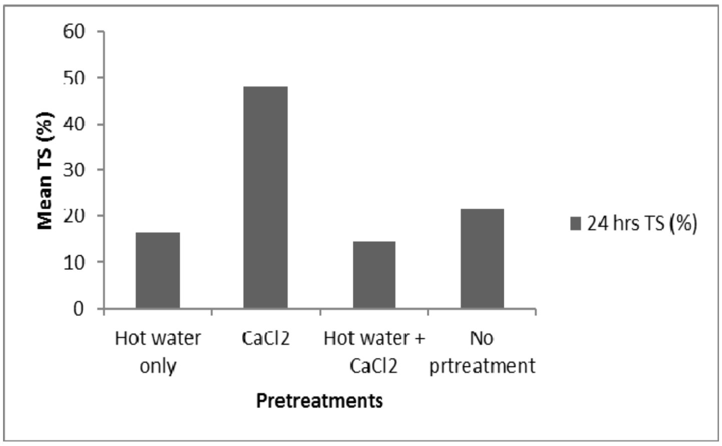

Fig. 2: Mean percentage thickness swelling of the boards

3.6. Effect of Pretreatment on Linear Expansion (LE)

Fibre cement boards produced using hot water only, $CaCl_2$ and hot water, $CaCl_2$ only and no pretreatment have mean LE of 2.69%, 4.43%, 4.99% and 6.62% respectively. Boards produced with no pretreatment have the highest mean LE of 6.62% while the boards produced with hot water treatment only have the lowest mean percentage of 2.69%. This observation shows that pretreatment helps to decrease linear expansion by embedding fibres into the cement matrix which restricts expansion of the fiber cement boards.

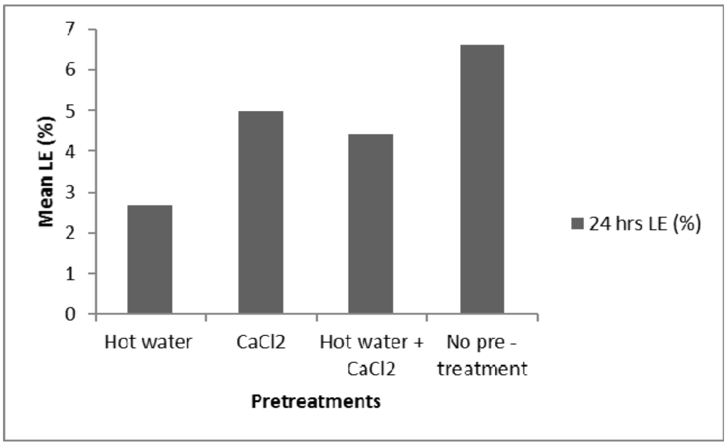

Fig. 3: Mean percentage linear expansion of the boards

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 but the variables were not significant for thickness swelling TS and linear expansion LE ($p < 0.05$). This implies that pretreatments have significant effect on the properties assessed on the fibre cement boards. However, pretreatment effect was highly significant on WA.

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
Pr > F	0.0017	0.0115	0.0053	< 0.0001	0.0715	0.108

Table 3 shows the mean separation of the pretreatments in the properties assessed. It would be observed that there is no significant difference in hot water only and hot water combined with $CaCl_2$ treatment on the mechanical and physical properties of the fibre cement boards. Also, there is no significant difference in $CaCl_2$ treatment and control on the mechanical properties of the fibre cement boards.

Table 3: Duncan's Multiple Range test for the fiber cement boards

Pre treatment	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]
No pretreatment	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 ($p \leq 0.05$)

3.7. Durability Properties

The durability of fibre cement boards in different conditions was also investigated. It was observed that the composites were highly resistant to fungi and termite attack within duration of six months for treated and non-treated boards (Table 4 and 5). This implies that the boards are structurally durable for outdoor applications. The boards were also moderately resistant to fire within a period of 30 minutes. However, the boards showed no resistance at 60 minutes exposure (Table 6). The properties observed in this study can be attributed to the constituents of cement like lime, silica, alumina and metal oxides which are intolerant to insects and fungi. Finally practical demonstrations revealed that the boards produced have high nail holding capacity and can withstand nail withdrawal with little or no splits at the edges.

Table 4: Fungi resistance properties of the composites

Period	Pretreatments			
(Weeks)	No treatment	$CaCl_2$ only	Hot water only	$CaCl_2$ + hot water
4	2	2	2	2
8	2	2	2	2
12	2	2	2	2
16	2	2	2	2
20	2	2	2	2
24	2	2	2	2

Table 5: Termite resistance properties of the composites

Period	Pretreatments			
(Weeks)	No treatment	$CaCl_2$ only	Hot water only	$CaCl_2$ + hot water
4	2	2	2	2
8	2	2	2	2
12	2	2	2	2
16	2	2	2	2
20	2	2	2	2
24	2	2	2	2

Table 6: Fire resistance properties of the composites

Period	Pretreatments			
(Minutes)	No treatment	$CaCl_2$ only	Hot water only	$CaCl_2$ + hot water
15	1	1	2	2
30	0	1	1	1
45	0	0	1	1
60	0	0	0	0

0 – Not resistant
1 – Moderately resistant
2 – Highly resistant

4. CONCLUSIONS

It can be concluded from this study that pretreatments have a positive effect on the properties tested on the fibre cement boards. Modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB) were greater in treated boards than in the untreated boards while thickness swelling (TS), water absorption (WA) and linear expansion (LE) were lower in treated boards compared to untreated boards. Hot water combined with $CaCl_2$ pretreatment produced boards with the best mechanical and physical properties.

Fibre cement boards are generally resistant to fungal and termites attack. Pretreated boards are more resistant to fire compared to untreated boards. Fibre cement boards have high nail-holding capacity and can withstand nail withdrawal with little or no splits at the centre and edges.

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