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DIMENSIONAL STABILITY OF CONVENTIONALLY CURED AND CO_2-INJECTED LUFFA FIBRE-REINFORCED COMPOSITE ROOFING TILES

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ABSTRACT

Existing housing stock in Nigeria is a source of concern with over 16 million gap in provision. A possible solution is the adoption of cement-bonded composites (CBC) reinforced with locally available natural fibres and appropriately cured. The effects of partial replacement of cement with Rice Husk Ash (RHA) and lime on the dimensional stability of CBC reinforced with *Luffa cylindrica* fibre were investigated. Fibre content was 3%; RHA and lime contents were 0, 10, 20, and 30% (by mass). Control samples were damp-cured for 6 days and air-dried for 22 days. Experimental samples were CO_2-injected and air-dried for 28 days. CO_2- injected samples were denser (1.08 – 1.26 g/cm^3) than the control (0.99 – 1.45 g/cm^3). Samples containing RHA and Lime were also generally lighter. However, RHA and Lime incorporation had significant effects ($p<0.05$) on the 2 h and 24h water absorption respectively, while CO_2-injection had significant effect on 24h thickness swelling of the composite tiles.

KEYWORDS:

Luffa cylindrical; composite; CO_2 injection; dimensional stability

INTRODUCTION

Different bio-fibres are incorporated in cement matrixes to manufacture building materials for low-cost housing given their inherent advantages of low density, low cost, wide availability, renewability, biodegradability, ease of preparation, lower energy consumption, neutrality with respect to Co_2 emission and relative non-abrasiveness compared to traditional reinforcing synthetic fibres (Acharya *et al.* 2011). Some of the natural fibres that have been employed include those derived from jute, hemp, coir, sisal, banana, bagasse and pineapple. Given the biodiversity of the tropical forest, however, fibre resources still abound that could be exploited for cement-bonded composite manufacture.

One of the potential fibre sources for cement-bonded composite manufacture that is widely available in the forest belt of Nigeria is a climber known as Luffa (*Luffa cylindrica*), also spelt ‘loofah’. It is a genus of tropical and subtropical vines in the cucumber (*Cucurbitaceae*) family. Luffa fruits (Figure 1a) are shaped like cucumbers but are larger, 300mm to 600 in length and 100mm to 120mm thick. The exterior is green, sometimes mottled, and smooth with longitudinal lines. The interior is cucumber-like when immature, but quickly develops a network of fibres surrounding a large number of flat blackish seeds (Siqueira 2010, Oshifeso 2014). If the fruit is allowed to fully ripen and then dry out on the vine, the flesh disappears leaving only the fibrous skeleton and seeds, which can be easily removed (Figures 1b and 1c). The fully developed fruit is a source of scrubbing sponge used in bathrooms and kitchens. Though the immature fruit of is cultivated and is popular as a vegetable eaten in China and Vietnam, it largely grows in the wild and is not consumed by humans in Nigeria.


Figure 1a: Green Luffa Pod


Figure 1b: Dry Luffa Fibre


Figure 1C: Processed Luffa Fibre

The chemical composition of luffa fibre as presented by Siqueira (2010) showed that it has a cellulose content of 50-90%, hemicellulose (8-22%), lignin (10-23%), extractives (3.2%) and ash (0.4%). The relatively high cellulose content, coupled with the relatively low extractive content, recommends the fibre as a cement-bonded composite reinforcing material. The density of the fibre (0.82 – 0.92 g/cm^3) is also comparable to that of bamboo (0.91 g/cm^3), but slightly greater than that of *Cissus populnea*, another climber; and slightly lower than those of other common natural fibres such as coir (1.15 – 1.25 g/cm^3), sisal (1.26-1.45 g/cm^3), banana (1.35 g/cm^3), and hemp (1.48 g/cm^3) as reported by Rao and Rao (2007), Siqueira (2010), and Amao *et al.* (2016). This is another factor that recommends the fibre for light-weight fibre-reinforced composite manufacture.

One of the challenges facing building and construction industry in Nigeria is the increase in the prices of cement resulting in an increase in the prices of cement-based materials, particularly roofing materials. One possible solution to this problem is the development alternative low cost cement-bonded roofing materials in which cement is partially replaced with a pozzolana or lime without compromising strength and durability. Potential materials include rice husk ash (RHA) and welder used carbide waste (lime) derived from ethyne (C_2H_2) gas, by the action of cold water on calcium carbide (Olorunnisola and Ogundipe 2014, Nta and Olorunnisola 2016). About one tonne of husk is produced from five tonnes of rice paddy and it has been estimated that some 120 million tonnes of husk could be available annually on a global basis for pozzolana production. As the ash content by weight is about 20%, there are potentially 24 million tonnes of RHA available as a pozzolana (Swamy 1986).

Traditionally, rice husk has been considered a waste material and has generally been disposed of by dumping or burning, although some has been used as a low-grade fuel. Nevertheless, RHA has been successfully used as a pozzolana in commercial production in a number of countries including Colombia, Thailand and India. To achieve the best result, the burning of the husk must be carefully controlled to keep the temperature below 700°C and to ensure that the creation of carbon is kept to a minimum by supplying an adequate quantity of air. At burning temperatures below 700°C, an ash rich in amorphous silica is formed which is highly reactive. Temperatures above 700°C produce crystalline silica which is far less reactive (Cook 1984, Bouzoubaâ and Fournier 2001). Carbide waste (lime) is also usually dumped around welder's workshops in Nigeria. A characterisation of the lime reported by Osabohien *et al.* (2008) showed that it has a density of 2.1g/cm^3, a particle size range of 15-75nm and a relatively high calcium oxide (63.6%).The utilization of RHA and carbide waste in cement-bonded composite manufacture could, therefore, promote waste management and reduce environmental hazards.

Curing method is a critical factor in the hydration of concrete and cement-bonded products as it affects the strength and durability of the final product. The conventional wet curing method has inherent advantages that have been exploited over the years. However CO_2 injection has been recommended as a means of accelerating cement hydration/setting. Accelerated carbonation curing also contributes to a decrease in the alkalinity of the cementitious matrix. It thereby creates a better adhesion interface between the particles of the matrix and fibres and enhances the durability of lignocellulosic fibres. As reported by Geimer *et al.* (1996), cement-bonded composites injected with CO_2 showed better physical and mechanical properties than did conventionally pressed boards. These claims and the effects of rice husk and lime on product properties require confirmation regarding luffa fibre-reinforced composites. The objective of this study, therefore, was to investigate the effects of partial replacement of cement with RHA and lime as well as conventional curing and CO_2 injection on the water absorption and thickness swelling at 2 h and 24 h respectively of the composite roofing tiles reinforced with luffa fibre.

MATERIALS AND METHODS

Materials

Mature dried pods of *Luffa cylindrica* were harvested from a local forest in Ibadan, and duly identified at the herbarium of the Department of Botany, University of Ibadan. The pods were removed to gain access to the fibre which was then sliced to remove the seeds within, shredded and sieved. Only the fibres retained on 425μ_m sieve were used. The fibres were treated by digestion in 10% NaOH solution for 2h at a pressure of 1 atm. Rice husk obtained from local rice processors was converted to ashes by burning it in an incinerator set at a temperature of 600^{0}C. Waste carbide lime, obtained a mechanical workshop, was air dried for 4 days and sieved to remove the lumps. Portland cement (42.5 grade strength) was purchased from the open market.

Methods

Luffa fibre-reinforced composite samples were produced using a 160mm (length) × 50mm (breadth) × 6mm (thickness) metal mould. The luffa fibre was manually dry-mixed with cement in a head pan before distilled water was added. The water requirement was determined using Equation (1) developed by Simatupang (1979):

$$Rq = 0.35C + (0.30 - M)W \quad (1)$$

Where:

Rq = water required (L)

C= Mass of cement (kg)

M= Moisture Content of fibre on dry basis (%)

W= Oven dry mass of the fibre (kg)

The composites were produced at different levels of cement replacement (by mass) with RHA and lime respectively, i.e., 0% (control), 10%, 20%, and 30%. The luffa fibre content was kept constant at 3% by mass of the cementing material. The fibre-cement composite was then placed in the mould and vibrated for 60 s. The cast products were de-moulded after 24 h. One set was damp-cured under wet towels at a room temperature (27± 5^{0}C) for 6 days and air-dried for 22 days. The other set of composite samples was first cured in a CO_2 gas injection chamber. Each sample was gassed for 180 s at a gas pressure of 120 kPa. The CO_2 supply was then terminated and the gas in the system allowed to disperse into the boards over a period of 24 h. The samples were then removed and air-dried for 27 days.

To determine the green density of the composites, the average mass of each sample was measured and divided by the volume. The moisture content of the triplicate samples was then determined using oven dry method at 60^{0}C. The values obtained were used to compute the dry density of the composites. For the determination of water absorption and thickness swelling of the composites, three specimens from each sample were submerged horizontally under 50 mm of distilled water maintained at a room temperature for 24 h. The absorption after 2 h and 24 h respectively were calculated from the increase in the mass of the specimens after immersion in water. The thickness swelling of each specimen was expressed as a percentage of the original thickness.

RESULTS AND DISCUSSION

Density of Composites

The densities of the fibre-reinforced composites are shown in Table 1. Partial replacement of cement with RHA and Lime had some effect on the density. The trend was clear in conventionally cured samples in which there was an obvious decrease in density with increase in RHA and lime contents. The trend was, however, not so clearly established in the $C0_2$-injected samples since there was an increase in the density of the samples containing 30% RHA. CO_2- injection also resulted in an increase in density across board. This general increase may be attributed to better bond formation and reduced porosity. ANOVA (Table 2) showed that the effects of partial replacement of cement and the interaction between CO_2 injection and cement replacement were significant ($p<0.05$). It should be noted that a significant reduction in weight has positive implications for roofing tile handling and installation.

Table 1: The Densities of the Fibre-Reinforced Composite Samples

Level of Cement Replacement in Composite	CO_2-Injected Samples		Conventionally-Cured Samples	
	Actual Density[1] (g/cm^3)	Normalised Density[2]	Actual Density[1] (g/cm^3)	Normalised Density[2]
0% (Control)	1.26	1	1.45	1
10%RHA	1.11	0.88	1.17	0.81
20%RHA	1.22	0.97	1.08	0.74
30%RHA	1.28	1.02	0.99	0.68
10%Lime	1.09	0.87	1.15	0.79
20%Lime	1.08	0.86	1.17	0.81
30%Lime	1.11	0.88	1.07	0.74

[1] *Mean values of three replicate specimens*

[2] *Normalized density is the ratio of the mean density of a sample and that of the control sample*

Table 2: ANOVA on the Effects of Curing and Cement Replacement Level Density

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing Method	0.00326	1	0.00326	0.423315	0.520591	4.195972
Level of Cement Replacement	0.35519	6	0.059198	7.688106	6.06E-05	2.445259
Interaction	0.12399	6	0.020665	2.683777	0.034762	2.445259
Within	0.2156	28	0.0077			
Total	0.69804	41				

Water Absorption (WA)

The WA values recorded at 2 h and 24 h respectively are shown in Figures 2 and 3. The lowest WA values of 17 and 19% were observed in the control specimens at 2 h and 24 h respectively. There was a general increase in WA with increase in the RHA and lime contents. The highest WA values were observed in the samples in which cement was partially replaced with RHA. This is, perhaps, an indication of the great affinity of RHA for water, and an indication of the upper limit of its incorporation in fibre-reinforced roofing tiles. RHA is, perhaps, one of such materials endowed with millions of capillary micro-sponges which enable them to absorb and hold large quantities of water (Sindhumole 2008). The 24 h-WA values of all the other samples compare favourably with the range of values reported by Olorunnisola and Agrawal (2013) for Indian-grown Eucalyptus fibre-reinforced composites (25-31%) and Olorunnisola and Agrawal (2015) for rattan fibre-reinforced composites (19-27%). The CO_2-injected samples also exhibited a general increase in WA. Analyses of variance (Tables 3 and 4) showed that the effects of cement replacement and its interaction with curing method on WA at 2 h and 24 h respectively were significant (p<0.05).

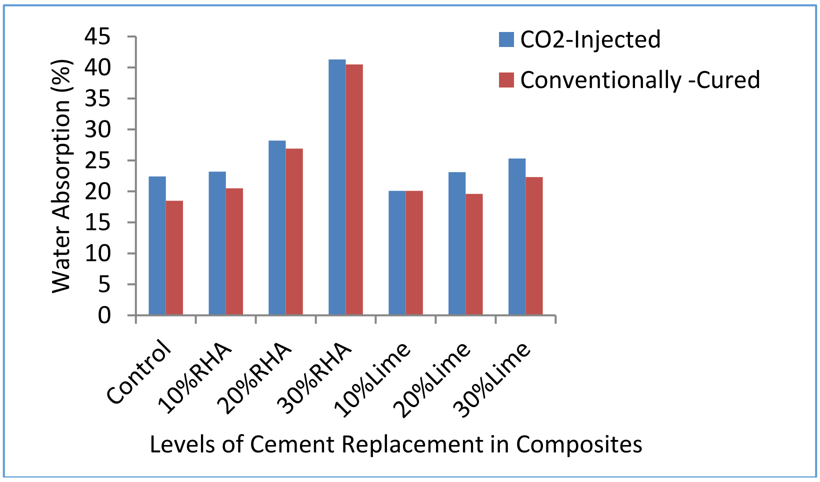

Figure 2: Effects of Partial Replacement of Cement and Curing Method on 2 h WA by the Composites

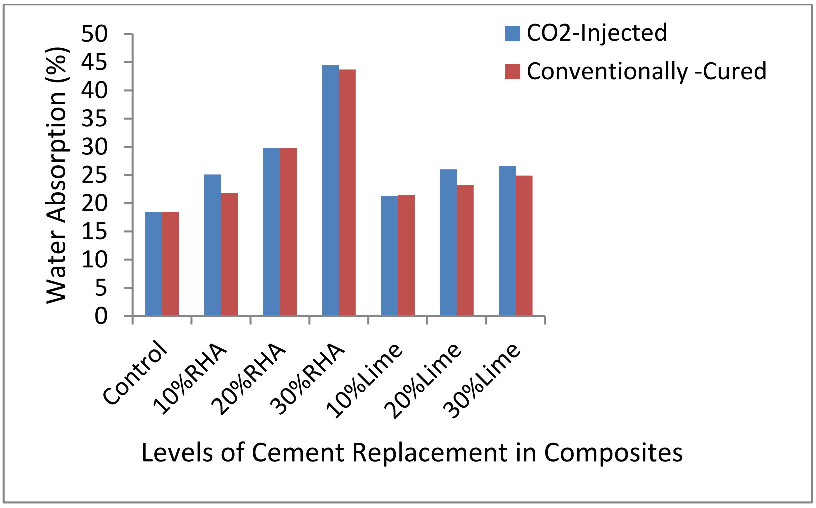

Figure 3: Effects of Partial Replacement of Cement and Curing Method on 24 h WA by the Composites

Table 3: ANOVA of the Effects of Curing and Cement Replacement Level on 2 h Water Absorption

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing Method	0.308571	1	0.308571	0.019467	0.890034	4.195972
Level of Cement Replacement	753.759	6	125.6265	7.925605	4.74E-05	2.445259
Interaction	659.3781	6	109.8963	6.933211	0.000136	2.445259
Within	443.82	28	15.85071			
Total	1857.266	41				

Table 4: ANOVA of the Effects of Curing and Cement Replacement Level on 24 h Water Absorption

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing Method	1.26881	1	1.26881	0.059122	0.809661	4.195972
Level of Cement Replacement	836.419	6	139.4032	6.495738	0.000223	2.445259
Interaction	573.0562	6	95.50937	4.450428	0.002784	2.445259
Within	600.9	28	21.46071			
Total	2011.644	41				

Thickness Swelling (TS)

The 2h and 24h TS values are shown in Figures 4 and 5. The 2h TS values ranged between 0.2 and 1.4%, while the 24 h TS values ranged between 1.2 and 2.6%. CO_2-injection and partial replacement of cement with RHA and lime resulted in a general increase in TS of the composite samples. The 24h TS values again compare favourably with those reported for fibre-reinforced composites from Eucalyptus (0.5 - 2.5 %) and rattan (0.6-4.0%) by Olorunnisola and Agrawal (2013, 2015). Analyses of variance (Tables 5 and 6) also showed that cement replacement had significant effect ($p<0.05$) on both 2h and 24h TS, while CO_2 injection had significant effect ($p<0.05$) on the 24h TS only. These results suggest that to keep the 24h TS values below 2%, (i) the level of partial cement replacement of cement with RHA or lime in the composite should not exceed 10%, and (ii) the composite should, preferably, be conventionally cured.

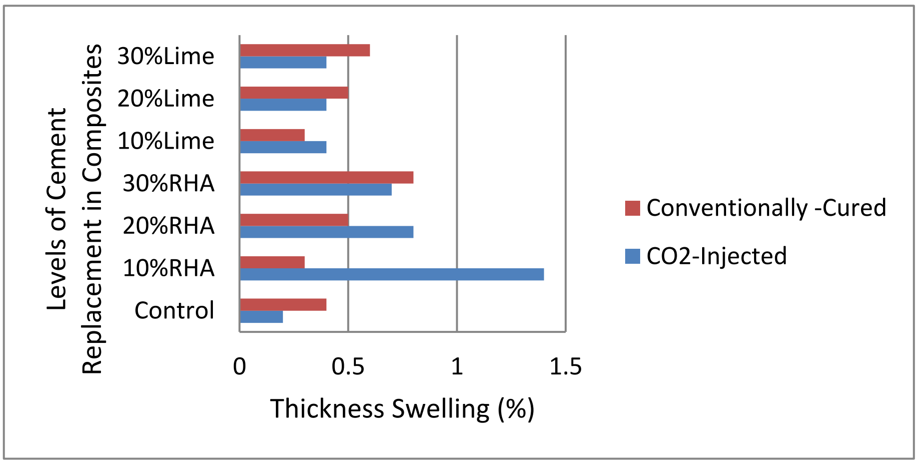

Figure 4: Effects of Partial Replacement of Cement and Curing Method on 2 h TS in the Composites

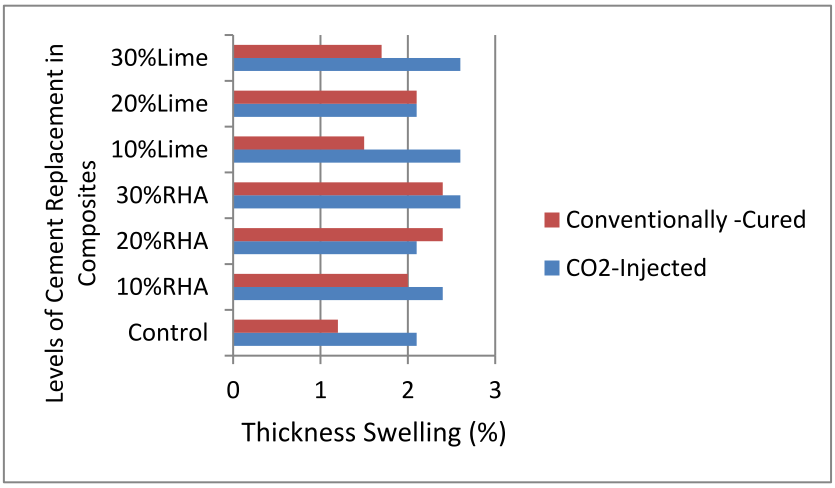

Figure 5: Effects of Partial Replacement of Cement and Curing Method on 24 h TS in the Composites

Table 5: ANOVA on the Effects of Curing and Cement Replacement Level on 2 h Thickness Swelling

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing Method	0.105	1	0.105	2.97973	0.095334	4.195972
Level of Cement Replacement	1.586667	6	0.264444	7.504505	7.35E-05	2.445259
Interaction	1.78	6	0.296667	8.418919	2.88E-05	2.445259
Within	0.986667	28	0.035238			
Total	4.458333	41				

Table 6: ANOVA on the Effects of Curing and Cement Replacement Level on 24 h Thickness Swelling

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing Method	5.215238	1	5.215238	21.26602	8.02E-05	4.195972
Level of Cement Replacement	3.792857	6	0.632143	2.57767	0.040843	2.445259
Interaction	3.588095	6	0.598016	2.438511	0.05052	2.445259
Within	6.866667	28	0.245238			
Total	19.46286	41				

CONCLUSION

Based on the findings of this study, the following conclusions were drawn:

i. Partial replacement of cement with RHA and lime, as well as CO_2 injection had significant effects on the density, water absorption and thickness swelling of luffa fibre-reinforced composite roofing tiles.
ii. To minimize water absorption and thickness swelling significantly, the level of partial cement replacement of cement with RHA or lime in luffa fibre-reinforced composite may not exceed 10%.

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