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EFFECTS OF PARTIAL REPLACEMENT OF CEMENT WITH RICE HUSK ASH AND CO_2 CURING ON THERMO-PHYSICAL PROPERTIES OF RATTAN PALM FIBRE-REINFORCED COMPOSITE ROOFING TILES

Abel Olorunnisola, University of Ibadan, Nigeria, abelolorunnisola@yahoo.com
Adebiyi Ogundipe, University of Ibadan, Nigeria, biyiogundipe@yahoo.com

ABSTRACT
This study investigated effects of partial replacement of cement with Rice Husk Ash (RHA) and CO_2 curing on thermos-physical properties of rattan cane fibre-reinforced roofing tiles. Mature rattan (*Laccosperma secundiflorum*) canes were sun-dried, hammer-milled, and treated with dilute NaOH (10% w/v). Triplicate samples of 160 x 50 x 6 mm composite tiles were produced with 3% fibre content using 0.5 cement/water ratio. Cement was replaced with 0 (control), 10, and 20% Rice Husk Ash (RHA) (w/w) in samples cured in water and CO_2 gas respectively. Addition of 10% RHA coupled with CO_2 curing significantly reduced the moisture content. Above 10% RHA addition, there was no significant difference in densities of water and CO_2 -cured tiles. There was also no significant difference in the apparent porosity and thermal conductivity of water- and CO_2-cured samples.

KEYWORDS: Rattan cane; Rice husk ash; Composites; CO_2 curing; Roofing tiles

INTRODUCTION
Roofing constitutes a substantial fraction of building construction cost because conventional roofing materials are relatively expensive in many developing countries. In many countries in Sub-Saharan Africa, the most common roofing materials use for residential housings are the aluminium and zinc tiles, asbestos sheets and clay tiles. Cement tiles, also known as concrete tiles manufactured in different colours, shapes, and sizes and made out of cement, sand and colour pigments, are not yet very common. So also, are cement-bonded natural fibre-reinforced composite tiles.For practical purposes, fibre reinforced cement composites (FRCC) are generally defined as composites with two main components, the fibre and the matrix. Cement is the most widely used and versatile inorganic binder in FRCC. Its purpose is to encapsulate the fibres and provide a non-toxic shield against decay thereby enhancing termite, fungi and insect resistance, ductility and energy absorption. It invariably ensures long and trouble-free service life of the composite. However, the negative environmental impact of cement production has led to a search for partial substitutes in FRCC manufacture and rice husk ash has been found quite suitable (Charoenvai*et al.* 2005).

The cementitious matrix itself is considered a composite with several components (basically cement, water and sand). It is generally assumed to represent the first main component of the FRCC. The fibre represents the second main component which is assumed to be discontinuous and usually randomly oriented and distributed within the volume of the composite. The fibre and the matrix (paste, mortar, or concrete), when bonded together, provide an effective composite. The key role of fibres in cement matrix is in delaying and controlling the tensile cracking of the matrix. This controlled multiple cracking reduces deformation at all stress levels, and imparts a well-defined post-cracking and post-yield behaviour. The fracture toughness, ductility and energy absorption capacity of the composite are then substantially improved (Bentus and Mindess 1990). These technical benefits can be utilized both in semi-structural elements such as thin sheets, flat sheets, corrugated and cladding panel as well as in load bearing members (Oladele*et al.* 2009).

Natural fibres are obtained from natural sources, for example, animals (horse hair) and plants (vegetable, wood and leaves). Vegetable fibres are obtained from the various parts of a plant. Hence, vegetable fibres are grouped into three categories depending on the part of the plant from which they are extracted: (a) bast or stem fibres (jute, banana, flax); (b) leaf fibres (e.g., sisal, pineapple, screw pine) and (c) fruit fibres (e.g., cotton, coir, oil palm).Natural organic fibres play very important roles in housing construction, especially in roofing. In general, fibre reinforcement of building materials has been practised since early ages and its application in the construction industry took a large leap forward, with the introduction of asbestos cement in the market, at the beginning of the twentieth century. However, the continued use of asbestos fibreshas been discouraged for related to health hazards. Hence, attention has shifted to vegetable fibres. Apart from being renewable, they have the additional advantages of natural abundance, relative cheapness, plentiful supply, energy efficiency, thermal comfort, quick replenishability and high specific mechanical properties. They, therefore, represent renewable and biodegradable substitutes to asbestos fibres, (Aznizam, *et al.*, 2005).Date palm (*Phoenixdactylifera*) has been investigated as a potential source of fibre for fibre-cement board production (Hassan *et al.*, 2016). Another of sourcepalm fibre that has been found suitable is rattan cane obtainable from spiny, climbingpalms generally found in tropical and subtropical forests of Asia, Africa and the Pacific (Olorunnisola and Adefisan 2002, Olorunnisola and Agrawal2015). Its potentials for roofing tile production have also been investigated by Ogundipe (2009), Olorunnisola and Ogundipe (2012) and Olorunnisola (2018).

In the manufacture of cement-bonded composites, cement hydration often takes 8 to 24 hours, depending on the type of cement used materialsmixed with it, availability of water for hydration and the curing method employed. As noted by Hermwan *et al.* (2001), curing of cement-based products with gaseous CO_2(carbonation) accelerates hardening. The CO_2 reacts with calcium hydroxide to form calcium carbonate. When all the calcium hydroxide has been dissolved and precipitated as calcium carbonate, the calcium silicate hydrate releases Calcium ions in order to maintain the pH. With continuous access to CO_2, the pH eventually decreases. Carbonation thus reduces alkalinity of cement, at a times from a pH of over12.5 to less than 8.5, thereby protecting natural fibre reinforcement in the matrix against chemical degradation (Huijgen*et al.* 2005, Yunusa*et al.* 2012, Jasim, *et al*., 2015, Hassan *et al.*, 2016). However, the effects of CO_2curing coupled with partial replacement of cement with RHA on rattan fibre-reinforced composite roofing tiles have not been fully investigated, which was a major justification for this study.

MATERIALS AND METHODS

Mature, freshly harvested rattan canes (*Laccosperma secundiflorum*) obtained from cane sellers were duly identified in the herbarium of the Department of Botany, University of Ibadan, Nigeria. Proximate analysis involving determination of crude fibre, carbohydrate, fat, ash, and moisture contents of the canes wasconducted in line with Association of Official Analytical Chemists (AOAC 1990) specifications. For composite production, the canes were cross-cut into about 5cm long billets, air-dried for four weeks hammer-mill, and sieved. Particles retained on the 2mm sieve were digested with 10 % solution of sodium hydroxide (NaOH) at 110°C and 1atmosphere for 2 hours. The pulp obtained was washed thoroughly with potable water before the wet fibres were dried at 60°C for 15 mins. The bulk density of the fibres was determined in accordance with ASTM C 948 -81. Fresh ordinary Portland cement was purchased from the open market in 50kg bag. It was stored in an air-tight container prior to use. Rice (*Oryza sativa*) husks were collected from rice processors and burnt to ashes completely at 600°C in an incinerator. The ashes were sieved through British Standard Sieve of 75 microns. The portion passing through the sieve was used. The distilled water used was stored at room temperature (20±2^{0}C).

For composite production, rice husk ash was used as partial replacement for Ordinary Portland cement at 0 (control), 10, 20 and 30 % by weight of cement. Rattan fibre content was fixed at 3% by weight of cement while water/cement mixing ratio was fixed at 0.5. Rattan fibres were manually mixed thoroughly with cement in a container. Distilled water was then added. Composite specimens were produced using 160mm (length) x 50mm (breadth) x 6 mm (thickness) flat metallic moulds. The composite mixture was placed on a vibrating tableand vibrated at 50 Hertz for 60 seconds. Each

composite was demoulded after 24 hours. A set of the composite samples was cured in water in a plastic reservoir at room temperature (22± 5ºC) for 28 days. Another set was injected with CO_2 gas at a pressure of 120 kPa gassing duration of 180 seconds in a sealed chamber and cured in the same sealed chamber for 28 days. The moisture content, density and apparent porosity of the composites were determined in accordance with ASTM C 948-81. Thermal conductivity tests were conducted in accordance with the protocols reported by Behzad and Sain (2007). Data were analysed using Analysis of Variance (ANOVA) at p = 0.05.

RESULTS AND DISCUSSION

Proximate analysis of the Rattan Cane

The proximate analysis results presented in Table 1 indicate relatively high crude fibre (75± 0.1%) and carbohydrate (11.1±0.4%), but relatively low fat (0.3%),ash (6.1±0.05%) and moisture (6.5±0.1%) contents.Crude fibre is chiefly the cellulose material obtained as a residue in the chemical analysis of vegetable substances. It is a measurement of fibre content and thus an indication of how fibrous a material is. The relatively high crude fibre content recorded, therefore suggests that the rattan cane is very fibrous and very high fibre yield should be expected if it is digested. The relatively low moisture content is an indication that the rattan canes could be stored for relatively long period of time without being susceptible to infestation by fungi, moulds and insects. Also, the relatively low fat content is advantageous in cement composite production. Dahunsi (2000) had noted that forest products that have relatively high fat and oil contents might not bond well with cement

Table 1: Proximateanalysis of rattan cane

Parameter	N	Percentage Composition (%)	
		Mean	Standard deviation
Crude fibre	3	75.5	0.1
Carbohydrate	3	11.1	0.4
Fat	3	0.3	0.0
Ash	3	6.1	0.05
Moisture content	3	6.5	0.1

Moisturecontent of the composite tiles

The mean moisture contents of the water- and CO_2-cured composite samples are shown in Figure 1. The values ranged from 9 to 14.1 % for water-cured samples and 5.9 to 13.3% for the CO_2-cured samples. These values are generally low. The mean moisture content of CO_2-cured control sample was significantlylower than that of water-cured samples. There was no clearly identifiable pattern in the moisture contents of the samples containing RHA. However, with the addition of 10% RHA coupled with CO_2 curing resulted in significant moisture content reduction. Reverse was the case for composites contain 20 – 30% RHA whereby RHA inclusion increased the moisture contents of the tiles, perhaps due to its hydrophilic nature (Aznizam*et al.* 2005). The danger of high moisture content is the possibility of fibre degradation.

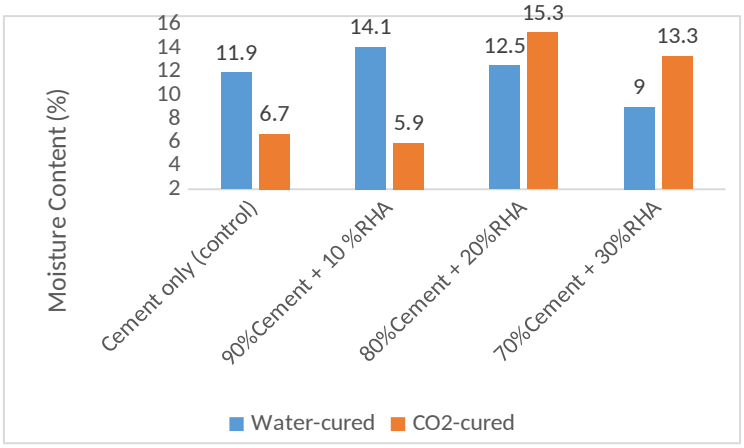

Figure 1: Moisture contents of the rattan cane fibre-reinforced composites

Densities of the composite tiles

The densities of the water- and CO_2-cured composite samples are shown in Figure 2. The values ranged from 974 to 1233 kg/m^3 for the water-cured samples and 931 to 13252 kg/m^3 for the CO_2-cured samples. Excepting the tiles produced with 10% RHA inclusion, there was no significant difference in the densities of water and CO_2-cured tiles. The minimal weight gains observed in the densities of the CO_2 -cured experimental samples was also reported by Moslemi*et* al. (1994)for cement-bonded particleboards and may be attributed to the precipitation of high molecular weight calcium carbonate in the cement matrix. RHAaddition generally lowered the density of the composites, expectedly because of its lower bulk density compared to that of cement. Hence, the densities of all the tiles produced with 30% RHA inclusion were lower than the minimum value of 1000 kg/m^3 expected of fibre-cement composites, and the range of values reported by Olorunnisola (2012) for asbestos roofing sheets (1590 – 2060 kg/m^3) suggesting that the upper limit of its inclusion should be 20%.

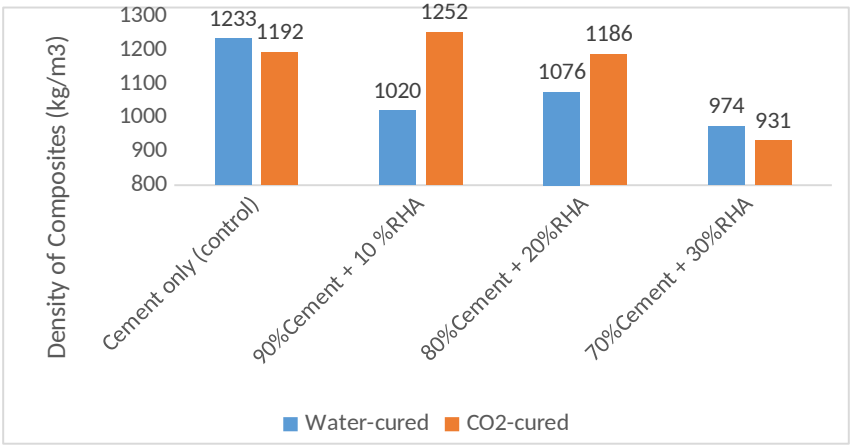

Figure 2: Densities of the rattan cane fibre-reinforced composites

Apparent porosity of the composite tiles

The mean values for apparent porosity of the water- and CO_2-cured composite samples are presented in Figure 3. The values ranged from 11.6 to 13.5 % for the water-cured samples and 5.1 to 23.2% for the CO_2-cured samples.There are no standard values to compare with.Expectedly, the lower the density of the sample, the greater the apparent porosity of the composites. There was, however, no significant difference in the values obtained for water and CO_2-cured samples. Apparent porosity directly affects permeability and it is critical for roof tiles that are typically exposed to permanent weather and environmental conditions. Moisture caused byprecipitation and relative air humidity can reach into the roof tile and possibly lead to damage. For this reason, roofing tiles may have to be

covered with a protective coating to smoothen the surface and fill in the small holes. Painting is one of such protective coatings that can re-seal the small imperfections.Although protective coating has mostly an aesthetic purpose,it may also improve the durability of the tiles.

Thermal conductivity of the composites

The meanthermal conductivity values for the water- and CO_2-cured composite samples are presented in Figure 4. The values ranged from 0.77 to 1.2 W/mK for the water-cured samples, and 0.58 to 1.32W/mK for the CO_2-cured samples.The thermal conductivity values are consistent with the apparent porosity values. Increase in thermal conductivity has been linked with decrease in porosity (Al rim *etal.* 1999), acceptably low and compare favourably with those reported by Ariyadasa*et al.* (2015) for roof tilesmade of clay (0.7106 W/mK), asbestos (0.4733 W/m.K) and cement (0.5619 W/m.K).Appropriate thermal properties of roofing materials tend to improve the thermal comfort. Therelatively low thermal conductivity indicates good insulating property,protection against direct solar radiation and indoor thermal comfort.

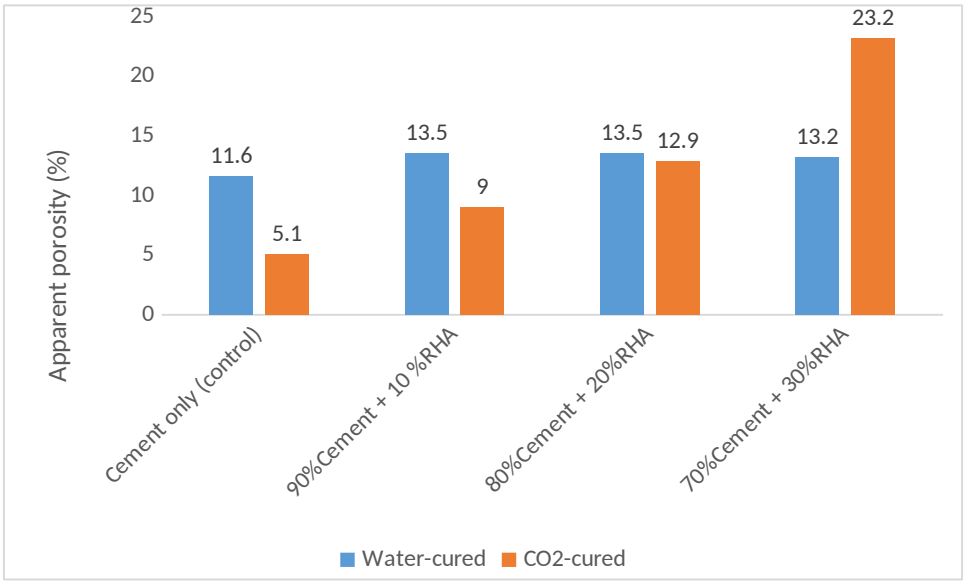

Figure 3: Apparent porosities of the rattan cane fibre-reinforced composites

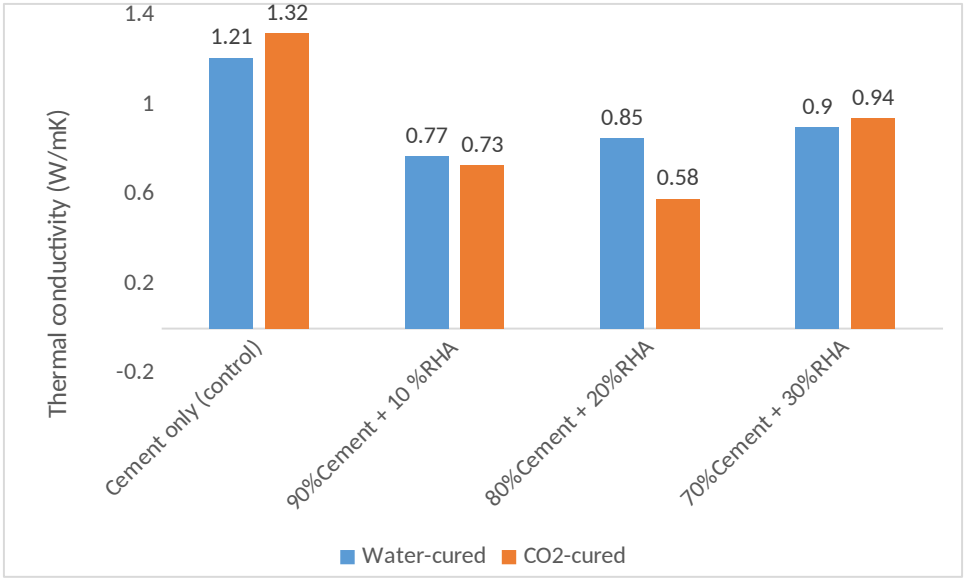

Figure 4: Thermal conductivities of the rattan cane fibre-reinforced composites

CONCLUSIONS

The following conclusions were drawn from the study:

1.Rattan cane is a good source of fibre for fibre-cement composite manufacture with acceptable crude fibre, carbohydrate, fat, ash and moisture contents.

2. It is beneficial to partially replace ordinary Portland cement with up to 10% RHA in the production of rattan-cement composite roofing tiles to lower the density of the tiles.

3.CO_2 gas curing is beneficial in improving the thermos-physical properties of rattan fibre-cement composites.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest associated with the work presented in this paper.

DATA AVAILABILITY

Data on which this paper is based is available from the authors upon reasonable request.