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Sorption characteristics of cement composite reinforced with some locally available lignocellulosic materials in Nigeria

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The aim of this study was to investigate the sorption property of wood cement composite produced from bagasse (*Saccharum officinarum*), bamboo (*Bambusa vulgaris*) and coir (*Cocos nucifera* L). The mass of the fibre varies from 1 to 6% of the mass of cement. The result indicated that the mass fraction has significant effect on the sorption properties of the composites. Water absorption (W.A.) rate increases with increase in the fibre content of the composites. Thickness swelling (T.S.) in all the composites was less than 1.7% at 24 h water immersion at room temperature. There was linear correlation between mass fraction, water absorption and thickness swelling of the composites. The relatively low W.A. capacity and T.S. at content less than 3% of mass of cement suggests that they can be employed in outdoor situations and at this level they are dimensionally stable but beyond this level it is not advisable.

Key words: Water absorption, thickness swelling, bamboo, bagasse and coir fibres.

INTRODUCTION

The use of technologically by-product agricultural wastes in various segments of the construction and building industry is increasing continuously. Among the different types of fibres used in cement-based composites, non woody materials offer distinct advantages such as availability, renewability, low cost, and current manufacturing technologies. Fibre-cement composites exhibit improved toughness, ductility, flexural capacity, and crack resistance as compared to non- reinforced cement-based materials. Due to their hygroscopic nature, fibre-cement composites are sensitive to moisture changes in the material itself and in the ambient environment. Generally, flexural strength and stiffness tend to decrease as the moisture content increases. It has been reported (Mai et al., 1983; Coutts and Kightly, 1984; Coutts, 1987) that the decrease in stiffness when wet and the resulting ductility gained changes both the behavior of the fibres as well as the interfacial characteristics between the cement matrix and the fibres. These changes in the properties and in the cement matrix interface leads to changes in the mode of failure of the fibres. In the wet state, it is believed that the bond between the cement matrix is weakened. On the other hand, in the dry state, the bond strength is increased (Mohr et al., 2003).

About 75 genera and 1250 species of bamboo are found in different countries of the world. *Bambusa vulgaris* is the best known and most widely used species in Asia. For building, *Guadua angustitifolia Kunth* is also used and is a common plant in Latin America, especially in Colombia, Peru and Ecuador (Agopyan, 1988; Hidalgo-Lopez, 2003). One of the main shortcomings of

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bamboo is water absorption when it is used as a reinforcement and/or permanent shutter form with concrete. The dimensional variation of untreated bamboo due to water absorption can cause micro or even macro cracks in cured concrete (Ghavani, 2005). Coconut is a tall cylindrical-stalked palm tree, reaching 30 m in height and 60 to 70 cm in diameter. It is a tropical plant for low altitudes. Coconut fibres (coir) can be extracted from either immature or mature fruits. They are lignocelluloses fibres obtained from the mesocarp of the coconut fruit, which constitutes about 25% of the nuts. They are one of the least expensive of the various natural fibres available in the world. They are not brittle like glass fibres; they are responsive to chemical modification and are non-toxic. However, the waste from their disposal causes environmental problems. Tomczak (2007) and Joana et al. (2011) studied coir/cement composites and stated that the composites produced with NaOH presented low dimensional stability because of high values of thickness swelling and water absorption. This is as a result of the alkaline treatment which modified the surface and increased the roughness and the new additional surface area may be used as a new pathway for water absorption. Bagasse is a ligno-cellulosic material left after the removal of sugar and moisture from sugarcane. With an average yield of 80 to 100 tons cane per hectare, the annual yield of sugarcane in Nigeria is two to three million tons 45% of which ends up as bagasse (Wada et al., 2004).

Water absorption is one of the most important characteristics of natural reinforced concrete when exposed to environmental conditions. The availability of moisture is a necessity for decay to occur in a material. A problem associated with natural fibres in composites is their high moisture absorption and dimensional instability (swelling) (Sayyed et al., 2011). Swelling of fibres leads to micro cracking of the composites and eventual degradation of its mechanical properties. Matoke et al. (2012) worked on bamboo fibres and stated that water absorption is a disadvantage in composites. Water absorption in composites influences dimensional stability. The higher the fibre content, the higher the water uptake and vice versa. They also reported that water uptake increases with increase of the filler content. Since lignocellulose fibres are hydrophilic in nature, the increased amount of fibres used as filler in the composite showed significant effect on the water absorption. The percentage water absorption of the composites is expected to achieve equilibrium. As the filler loading increases, the formation of agglomerations increases hence it is difficult to achieve homogeneous dispersion of a filler of high filler loading. This agglomeration of the filler in composite increases the water absorption of the composites.

Dimensional stability of composite is important since construction materials should have the ability to withstand the stresses of shrinkage or swelling due to the changes of temperature and moisture. The initial drying state of the fibres also affects its dimensional stability during subsequent wetting and drying. Fibres which have been dried once prior to introduction to a matrix material are expected to swell less upon rewetting, as compared to fibres which have not been previously dried (Mohr et al., 2003). Results by Mohr et al. (2003) showed that composites produced with fibres which have been dried exhibited superior dimensional stability compared to composites produced with fibres which had never been dried.

Thickness swelling (T.S) is also another important factor that affects dimensional stability and it's highly correlated with the cement- ratio. In general, the higher cement content of a composite, the lower the T.S. In order to minimize T.S., with the negative side effect of decreased MOR, reducing cement-wood ratio is necessary so that water absorption can decrease. (Meneeis et al., 2007). Also, pre-treatment of the fibres has an effect on T.S. Addition of chemicals can decrease T.S. by using $CaCl_2$ as an accelerator. This improvement is caused by better contact as a result of improved bonding ability with cement. Besides $CaCl_2$, hot water soaking of these fibres can effectively reduce T.S. (Semple and Evans, 2004). T.S. is highly dependent on particle geometry. There is an increase in T.S. with increasing particle thickness and decreasing particle length. In summary, lowest T.S. as exhibited by some studied natural fibres-reinforced concrete arises because of sufficient encapsulation of the particles at high cement-ratios and the minimal swelling of the small particles (Frybort et al., 2008). This work was carried out to ascertain the sorption characteristics of three major non-woody products in Nigeria to determine the order of suitability for use in terms of dimensional stability in cement bonded composite boards. The work is limited to evaluation of sorption properties at different fiber contents while density, mixing ratio, particle sizes, ratio of water to cement, type of cement, accelerator, curing time and production methods were constant. Strength characteristics were not considered in this research.

MATERIALS AND METHODS

Material preparation

The following three materials were used for this research and their preparations for composite boards are highlighted below:

1. Bagasse was obtained from Bodija in Ibadan, Oyo State. The raw bagasse was received at about 30% moisture content. It was sun-dried for two weeks, manually depithed and further sun-dried for two weeks to a moisture content range of 7 to 10%. Bagasse was hammer-milled to produce bagasse particles. The hammer-milled particles were passed through sieves of sizes 2.4 mm and 850 μm. Particles that passed through 2.4 mm but were retained on the 850 μm sieve were categorized as coarse particles were used.

2. Coconut husk was procured from Badagry, Lagos State, reduced by grinding in the hammer mill to produce particle fibres of different sizes. The particle fibres were then sieved with sizes listed for bagasse fibres for uniformity purpose.
3. Bamboo specie used is from the family of *B. Vulgaris.* Field trips were made to four locations within the University of Ibadan, Nigeria to obtain bamboo culm samples. Identification was carried out in the herbarium of the Department of Botany, University of Ibadan. The wet bamboo was allowed to dry for four weeks and then sliced to about 60 cm length by 3 cm width with the slicing machine and further reduced to 15 cm length by 1cm width with the knife before it was crushed by an hammer mill. The different fibres were sieved with the same procedure stated above.

The binder used for the study is the Portland cement. It was purchased locally from dealers in standard bags of 50 kg weight. The type of cement available in the country complies with the British Standard BS 12:1958. Additives are used as chemical pre-treatments to improve the compatibility of the non woody fibrous materials with cement. Calcium chloride was used as an additive at a concentration of 3% of the cement weight in the boards. Water source was from the University of Ibadan supply.

Method for the design of the composite board

The only variables used for the composite board production were the mixing ratio and the five non-woody fibrous materials. The fibre content varies from 1 to 6% of the mass of cement. The mixing ratio gives an indication of the proportion of cement to non-wood per oven dry weight of the board. To make the board, the quantity of non-wood required was measured and put in a plastic bowl. To it was added the required amount of water containing the needed amount of additive. The chemical solution was then mixed with the non-wood aggregates. Quantity of cement needed was added to the wet non wood s and mixed thoroughly until a homogenous non-wood -cement mix was formed as reported by Badejo (1988). The composites were produced by vibration. The cement and particles were mixed in dry form until a high level of uniformity was achieved. Water was added to attain a level of plasticity to permit the shaping of the mixture. The slurry was then placed on interphase sheets spread on the surface of the vibrating table and vibrated for about 40 s. The mixture was later transferred to a plastic mould of 75 × 50 × 10 mm. After this, it was cured for 28 days. Five replications of each fibre percentage were made. Thirty boards were manufactured altogether. All the experimental panels were made with the following standard specifications:

Board Type: Homogenous and 1 layered
Board Dimension: 75 mm × 50 mm × 10 mm
Board Density: 1,200 kg/m^3 based on oven dry weight and volume of board.
Binder: Portland cement purchased in standard bag of 50 kg.
Additive: Powdered $CaCl_2$ applied at concentration of 3% of the cement weight in the board.

Water absorption

Water absorption is used to determine the amount of water absorbed by a composite. The water absorption test followed ASTM standard test method D570. The test specimen was in the form of a bar 75 mm long, 50 mm wide and 10mm thick. Before the measurement, the sample was dried in an air oven at 50°C for 24 h, cooled in a desiccator and immediately weighed to the nearest 0.001 g which is then taken as the dry initial weight of the sample. Then the specimen was immersed in distilled water maintained at a temperature of 23 ± 1°C for 24 h. After 24 h, the specimen was removed from water and placed on blotting paper to remove excess water before weighing to the nearest 0.001 g. For each composite, five sub samples were measured. The water absorption of the sample was calculated as percent weight change (w %) as follows:

$$WA = \frac{M2-M1}{M1} \times 100\%$$

Where M_1 = weight of dry piece (g)
M_2 = weight of wet piece (g)
WA = water absorption (%)

Thickness swelling

This test, like water absorption was important in ascertaining dimensional changes. The thickness swelling samples were 75 mm × 50 mm × 10 mm. Five specimens for each material and ratio were tested. The samples were soaked in distilled water for 24 h. The immersed samples were taken out and wiped by dry cloth to remove water from the surface. The thickness was measured using a vernier caliper to the nearest 0.01 along the length at room temperature and average results recorded. The thickness swellings of the samples were calculated according to ASTM standards D1037-03.

RESULTS AND DISCUSSION

Thickness swelling

Table 1 and Figure 1 summarize the data obtained. The range of thickness swelling observed for all the boards from bagasse, bamboo and coir fibres ranged between 0.3 to 1.6% after 24 h of submersion in water. The result further showed that thickness swelling of the boards after immersion in water and chemical treatment had least value for bamboo at 1% fibre content while the largest swelling value was obtained from coir at 6% fibre content. The less the fibre content, the lower the thickness swelling. Therefore, thickness swelling increases with increase in fibre content of the composite. Also, the greater the cement content of the composite, the lower the thickness swelling which means more cement coating on the fibres may have restrained the boards from swelling. It can be observed that bamboo cement composites boards are relatively more dimensionally stable than bagasse and coir cement composites when exposed to water at room temperature. Regression equations were also developed to relate thickness swelling for the three fibres used as shown below:

$$T.S_{\text{bamboo 24 h}} = 0.22 + 0.108_{\text{b.f.c.}} \quad R^2 = 0.937 \qquad (1)$$

$$T.S._{\text{bagasse 24 h}} = 0.233 + 0.2_{\text{ba.f.c.}} \quad R^2 = 0.929 \qquad (2)$$

$$T.S._{\text{coir 24 h}} = 0.193 + 0.225_{\text{c.f.c}} \quad R^2 = 0.940 \qquad (3)$$

Where $T.S_{\text{bamboo 24 h}}$ represents percentage thickness swelling for bamboo after 24 h, $T.S._{\text{bagasse 24 h}}$ represents

Table 1. Mean thickness swelling.

Content (%)	Mean thickness swelling (%)		
	Bagasse 24 h	Bamboo 24 h	Coir 24 h
1	0.4	0.3	0.5
2	0.6	0.5	0.5
3	0.8	0.5	1.0
4	1.2	0.7	1.2
5	1.3	0.7	1.2
6	1.3	0.9	1.6

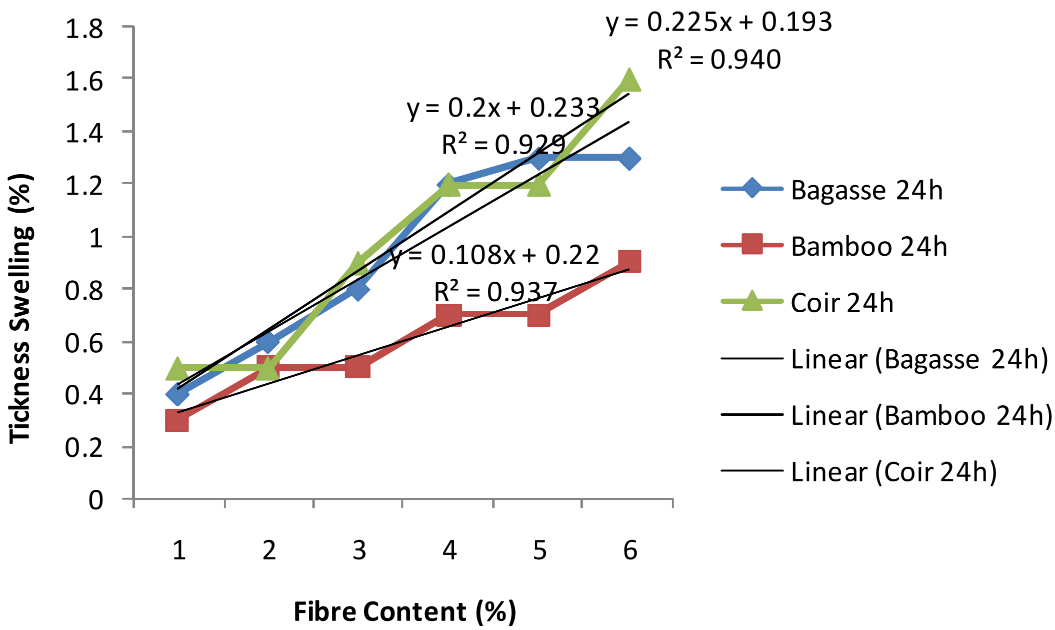

Figure 1. Thickness swelling of some -cement composites.

percentage thickness swelling for bagasse, T.S. $_{coir\ 24\ h}$ represents percentage thickness swelling for coir, b.f.c represents bamboo fibre content, ba.f.c. represents bagasse fibre content and c.f.c represents coir fibre content respectively. As shown in the equations above, there is a strong linear relationship between thickness swelling and fibre content after 24 h of immersion for the three different fibres used. The thickness swellings values obtained compare favourably with the range of values from 0.2 to 0.7% as reported by Olorunnisola (2004).

The mixing ratio of cement: sand: water is 1:3:0.5 is constant for all the homogenous composites produced.

Water absorption

The mixing ratio of cement: sand: water is 1:3:0.5 is constant for all the homogenous composites produced. Water Absorption varied from 3.5 to 7.5% for bamboo, 6.7 to 14.8% for bagasse and 11.2 to 70% for coirs. After 24 h of immersion in water at room temperature the composition at 5% content or below has acceptable water absorption for materials suitable for interior use. Composites manufactured from bagasse and bamboo generally absorb less water than that of coir as shown in Figure 2 and Table 2. Water Absorption showed a positive correlation (R^2 =0.8 for bamboo cement, R^2 =0.7 for bagasse and R^2 =0.9 at 24 h of immersion respectively). This result suggests that coir has more affinity for water and also is a hygroscopic material. As the coconut coir content increases ability to absorb water also increases. Water absorption rate is a primary indicator of the durability of cement component. According to Olorunnisola (2004), the presence of water can cause cracking (associated with swelling and shrinkable phenomena), biodegradation of wood aggregates and the dissolution of the composites. The

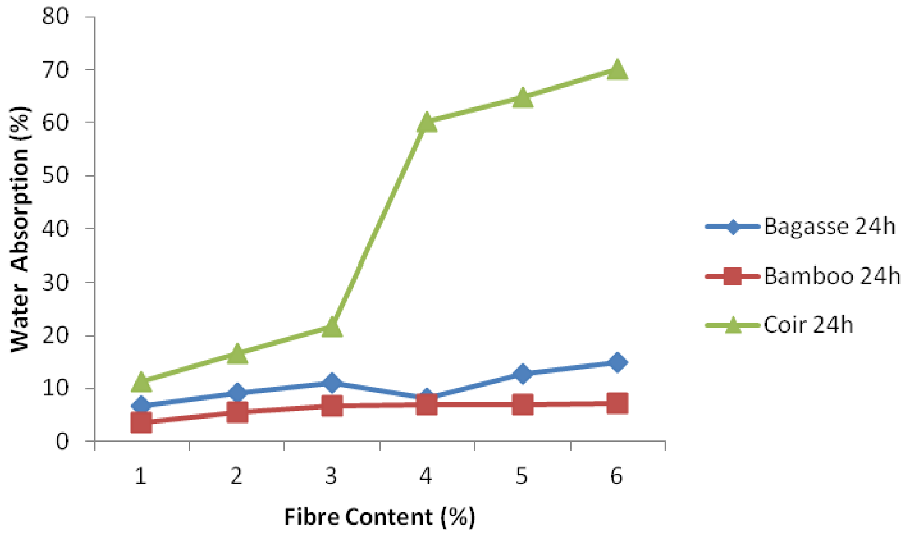

Figure 2. Water absorption of wood-cement composites.

Table 2. Mean water absorption.

Content (%)	Mean water absorption (%)		
	Bagasse 24 h	Bamboo 24 h	Coir 24 h
1	6.7	3.5	11.2
2	9.0	5.5	16.7
3	11.0	6.7	21.7
4	8.1	6.9	60.1
5	12.7	7.0	64.9
6	14.8	7.1	70

relatively high water absorption rate of the coir composites corroborates the findings of Olorunnisola (2004) who noted that the water absorption of vegetables was usually high sometimes reaching over 100% in only 1hr of immersion in water. One way to address this weakness is through the water repellent treatment.

Regression equations were also developed to relate water absorption for the three fibres used as shown below:

$$W.A._{bamboo\ 24\ h} = 3.613 + 0.748_{b.f.c.} \quad R^2 = 0.837 \quad (4)$$

$$W.A._{bagasse\ 24\ h} = 5.513 + 1.391_{ba.f.c.} \quad R^2 = 0.737 \quad (5)$$

$$W.A._{coir\ 24\ h} = -6.933 + 13.62_{c.f.c} \quad R^2 = 0.896 \quad (6)$$

Where $W.A._{bamboo\ 24\ h}$ represents percentage water absorption for bamboo after 24 h, $W.A._{bagasse\ 24\ h}$ represents percentage water absorption for bagasse, $W.A._{coir\ 24\ h}$ represents percentage water absorption for coir, b.f.c represents bamboo fibre content, ba.f.c. represents bagasse fibre content and c.f.c represents coir fibre content respectively. As shown in the equations above, there is a strong linear relationship between water absorption and fibre content after 24 h of immersion for the three different fibres used.

Conclusion

Composite boards were produced using 3 lignocellulose materials at different ratios in cement composite. From the result, the following conclusions were drawn;

1) The W.A. capacity of boards produced by vibrating table was relatively low but the best performance was observed in bamboo composite which meant that they could be employed in outdoor situation provided that the mass fraction is not more than 3% provided other properties are taken into consideration.

2) The sorption properties were relatively low when compared with some other lignocellulose materials reported in the literature. The reason for this is that most of the reported results were produced with the application

of pressure hence relatively high strain recovery due to external pressure during manufacture whereas the composite boards used in this research were produced by vibrating table with no external pressure.

(3) There is linear relationship and positive correlation between thickness swelling, water absorption and percentage of fibre used after 24 h of immersion.

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