ISSN 0511-5728
The West Indian Journal of Engineering
Vol.41, No.1, July 2018, pp.41-46

Development of Oil Palm Fruit Fibre/Cementitious Based Composites for Building Applications

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(Received 21 June 2017; Revised 14 November 2017; Accepted 19 December 2017)

Abstract: *In this paper, cement and red sand were used as the ceramic matrix based material reinforced with oil palm fruit fibre (OPFF) to develop composite for structural applications. The composite was produced by mixing red sand, cement and the fibres (treated and untreated) in predetermined proportions using open mould and hand laying process. Compressive, bending and water absorption properties were examined by carrying out these tests on the cured samples. From the results, it was observed that both treated and untreated OPFF reinforced composite samples showed improved properties. It was also observed that the rate at which the treated OPFF within 0-10 % reinforced sample absorbed water is lower than that of unreinforced sample. Untreated OPFF reinforced composite samples demonstrated better compressive and bending strength potentials when compared to their treated counterparts.*

Keywords: *Cement, sand, oil palm fruit fibre, composites, building application*

1. Introduction

Multifunctional cement–matrix composites are useful as structural materials that provide functional properties, which allow applications such as electrical grounding, electrical contacts for cathodic protection, deicing, electromagnetic interference (EMI) shielding, antistatic flooring and strain sensing. Multi-functionality is attractive for cost reduction, durability enhancement, large functional volume, design simplification and absence of mechanical property loss (which tends to occur if embedded devices are used in place of a multifunctional structural material) (Wen and Chung, 2007). Today's demand for smart structures, capable of detecting stimulus and responding adequately, has created the need for materials with not only good mechanical properties and durability, but also new additional functions. That is the reason why many researches have been focused on the development of multifunctional materials, which combine both structural properties and other functional applications. New functional properties include, for example, self-strain sensing, damage sensing (Baeza *et al*., 2013; Vilaplana *et al*., 2013), thermal control, vibration reduction (Muthusamy *et al.,* 2010) and electromagnetic wave reflection (Zornoza *et al*., 2010).

Natural organic fibres is a new area of research for applications in building materials, their natural abundance, ready availability, plentiful supply, relative cheapness and ability to be replenished are the strongest arguments for their utilisation in the construction industry. Previous research has shown that their use in building composites along with cement in the construction industry gives improved and favorable physical and mechanical properties. Many studies had been carried out on natural fibre, such as kenaf, bamboo, jute, hemp, coir, sugar palm and oil palm (Khairiah and Khairul 2006; Lee *et al*., 2005; Rozman *et al*., 2003;). The advantages of these natural resources are low weight, low cost, low density, high toughness, acceptable specific strength, enhanced energy recovery, recyclability and biodegradability (Myrtha *et al*., 2008). Natural fibre can be divided into four different types which are leaf, bast, fruit and seed. However, one of the major setbacks for these natural resources is their high affinity for water due to the presence of lignin in these natural composites. Oladele *et al*. (2010) showed in their study that chemical treatment can be used to reduce this major problem and improve both tensile properties and surface condition of the fibres for composite development.

Many researches have been carried out on the use of cement and some other ceramics like clay for various applications with the aim of improving their potentials for engineering applications. However, not much effort has been channelled towards improving the quality of red sand which has also been used historically as a building material despite its availability is abundant. Composite of red sand and natural organic fibres is a new area of research for applications in building materials, their natural abundance, availability, relative cheapness, good insulating property and ability to be replenished are the strongest arguments for their utilisation in the construction industry (Oladele *et al.*, 2015). The results of the research into the influence of natural rubber and coconut coir on the bending and water absorption properties of processed red sand reinforced composites by Oladele *et al.* (2015) have revealed the possibility of blending these materials together for the development of ductile fracture materials for structural applications.

Ceramics in general carry flaws and micro-cracks both in the material and at the interfaces even before an external load is applied. Under the condition of an applied load, distributed micro-cracks would propagate, coalesce and align themselves to produce macro-cracks. The micro and macro-fracturing processes can be favourably modified by adding short, randomly distributed fibres of various suitable materials. Fibres not only suppress the formation of cracks, but also abate their propagation and growth.

In general, short fibre reinforced ceramic matrix composites exhibit what is known as quasi brittle behaviour characterised by a more ductile post peak softening in uniaxial tension compared with plain matrix. The class of short fibre reinforced ceramic matrix composites designed to exhibit pseudo strain hardening properties based on micromechanical principles has been referred to as engineered cementitious composites (ECC). The concerns with the inferior fracture toughness of concrete are alleviated to a large extent by reinforcing it with fibres of various materials. The resulting material with a random distribution of short, discontinuous fibres is termed fibre reinforced concrete (FRC). Fibre/matrix bond is of critical importance in FRC's and toughness or energy absorption capability is of primary interest. The major function of fibres in the matrix is in delaying and controlling 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. These technical benefits can be utilised both in semi-structural elements such as thin sheets, flat sheets, corrugated and cladding panel as well as in load bearing members (Oladele, 2009). The aim of this research is to improve the properties of red sand by blending it with cement and palm fruit fibre in both treated and untreated conditions.

2. Materials and Methods

The major materials used for the research were; Oil Palm Fruit Fibres (OPFF), red sand and a slow setting Ordinary Portland Cement which were purchased from Edo State, Nigeria.

2.1.1 Sieving of Red Sand

Red sand was obtained from Afuze in Edo State and sieved to obtain -150 + 106 µm using sieve shaker that operates at 1,500 rpm for 15 minutes as shown in Figure 1 to achieve a uniform fine particle size.

2.1.2 Fibre Preparation

The oil palm fibre used was obtained from Okomu palm oil mill in Edo State, Nigeria and was then washed with water and sun dried for 5 days at about 27 ± 2 ℃ before treatment. The sun dried oil palm fruit fibre was as shown in Figure 2.

Figure 1. Sieve Shaker and Sieves used in Seiving

Figure 2. Untreated Oil Palm Fibre

2.1.3 Chemical Treatment

The oil palm fibre was treated chemically with 1 molar solution of Sodium Hydroxide (NaOH). The treatment was carried out by weighing 120 g of NaOH and dissolving it in 3,000 ml of distilled water. This solution was used to treat 100 g oil palm fibre in a container that was placed inside shaker water bath at a temperature of 50 ^{0}C for 4 hours. The treated fibre was washed with tap water and rinsed with distilled water in order to ensure neutral status before it was sun dried for 5 days at about 27 ± 2 ℃. The fibre was later cut into 10 mm lengths for the production of randomly dispersed short fibre reinforced cementitious composites.

2.1.4. Mixing of Constituents

Prior to mixing, the fibre, red sand and the slow setting cement at room temperature condition were weighed with weighing balance to obtain both the quantity and

Table 1. Mixing Proportion for the Composites (%, g)

Samples	Cement		Red sand		Fibre (Treated and Untreated)	
	(%)	(g)	(%)	(g)	(%)	(g)
Neat	100	0	0	0	0	0
0	97.5	1267.5	0	0	2.5	32.5
5	92.5	1202.5	5	65	2.5	32.5
10	87.5	1137.0	10	130	2.5	32.5
15	82.5	1072.5	15	195	2.5	32.5
20	77.5	1007.5	20	260	2.5	32.5

Where: 0 T, 5 T, 10 T, 15 T and 20 T represent treated fibre reinforced compositions while 0 U, 5 U, 10 U, 15 U and 20 U represent untreated fibre reinforced compositions.

corresponding weight proportions and were properly blended. Water to be added was measured using a measuring cylinder, and then added to the mixture and thoroughly mixed until a homogenous paste was formed. The mixing proportions for the composites were as shown in Table 1.

2.1.5 Production of Composites

The homogenous paste was poured into the cylindrical mould of 100 x 40 mm length and diameter for the compressive test sample and also to a mould of 100 x 30 x 20 mm for the bending test. Before filling the mould and closing it, cellophane sheet was placed between the mould and the paste so as to facilitate easy removal. After the mould was filled to capacity it was compressed within the mould using hydraulic press with a capacity of 20 kN. Constant force was applied for about an hour using the Mini press compression moulding machine. The sample was removed from the mould and then allowed to cure in air at room temperature which ranged between 24 ±2℃ in the laboratory for a period of 28 days. After curing, compressive, bending and water absorption tests were carried out on the samples.

2.1.6 Property Test

1) *Measurement of Compressive Properties*

Compressive test was carried out in accordance to American Standard Testing and Measurement (ASTM (2015a) - ASTM C873 and using INSTRON 3382 Floor Model Universal Tester at a fixed crosshead speed of 10 mm/min. The developed composite samples and the neat sample of 100 x 40 mm were used. Three identical samples were tested for each weight fraction from where the average values were used as the representative values. The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture was used to determine modulus.

2) *Measurement of Bending Properties*

Three point bend tests were performed in accordance to the standard ASTM D 790 M (ASTM 2015b) to measure bending properties using INSTRON 3382 Floor Model Universal Tester at a crosshead speed of 0.3 mm/mm and at a specific strain rate of 10^{-3}/s. The samples were of 100 x 30 x 20 mm. Three samples were tested for each weight fraction used and the average values were taken to represent the actual values.

3) *Water Absorption Test (Swelling Behaviour)*

The dried composite samples and the neat sample were immersed in distilled water and the experiment was carried out at room temperature of 24 ±2℃. The water absorption property of the samples was determined by weighing those samples before immersing them in 700 cm^3 water. This test was done for 7 hours for the various samples. This short time was used to avoid dissolution of the red sand in water if soaked for long time. The samples were examined at an interval of 1 hour by removing, cleaning and then weighing. The weight after a period of 7 hours was taken and the percentage weight gained was used to determine water absorption potential of the materials. The percentage of water content (W_t) was determined using Equation 1:

$$\% W_t = [(W_t - W_o) / W_o] \times 100\% \quad (1)$$

where, W_t is the weight of sample at time t, and W_o is the initial weight of the sample.

3. Results and Discussion

The results of the compressive strength at peak and yield for both treated and untreated palm fruit fibres reinforced cement/red sand based composites and neat were as shown in Figure 1.

Compressive properties describe the behaviour of a material when it is subjected to a compressive load as specified in the standard. Compressive strength and modulus are the two most common values produced. It was observed from the plots that both compressive strength at peak and yield properties increase as the red sand content increases for the treated fibre reinforced composites from 0 – 20% but for the untreated fibre reinforced composites, initial increase from 0 – 10 was followed by a decrease from 15 – 20%. However, sample with 10 % red sand from untreated OPFF gave the best compressive strength at peak with a value of 15.62 N/mm^2 followed by sample from 20 % of red sand with treated OPFF with a value of 14.15 N/mm^2.

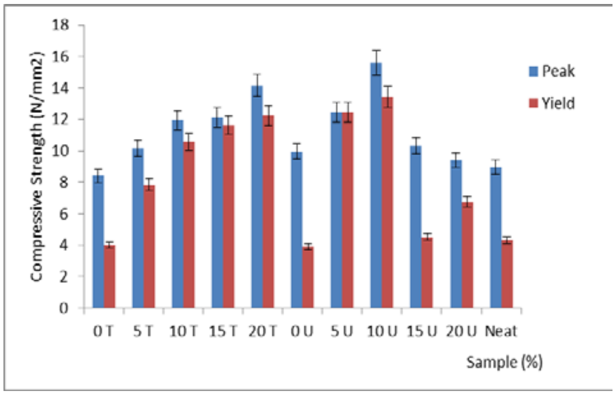

Figure 3. Compressive Strength at Peak and Yield for the Developed Composites and the Neat Sample

Similarly, the yield strength showed that 10 % red sand from untreated OPFF gave the best compressive strength at yield with a value of 13.43 N/mm^2 followed by sample from 5 % of red sand with untreated OPFF with a value of 12.43 N/mm^2. The results showed that, compressive strength of cementitious composites can be improved by blending cement with red sand and OPFF. The best strength was obtained from the blend of the three different materials which revealed that each component has contributed positively to the enhancement of the compressive strength for the developed composites.

The red sand as ceramic material has good compressive strength and, it can be deduced from the results that the compressive strength of the red sand contributes immensely to compressive strength of the developed composites. The fibres on the other hand were noticed to have influence on the interfacial adhesion which was responsible for the trend observed as the red sand content increases for both treated and untreated OPFF reinforced composites. The compressive strength increases as the red sand content increases for the treated OPFF reinforced composites because the treatment aids proper adhesion at the interface.

Due to the presence of lignin, this serves as polymer matrix to the cellulose of the OPFF in an untreated condition (Oladele *et al*., 2010). The initial increase in strength was followed by decrease at 10 % of red sand addition. Optimum properties were obtainable within 10-20% red sand addition for treated OPFF while the optimum were obtainable between 5 and 10 % of red sand with the untreated OPFF addition. The compressive strength of the material can be used for the determination or prediction of the hardness of the materials and their resistance to surface indentation. The neat sample response showed that the compressive strength of cement can be improved by the addition of these additives; red sand and OPFF which are environmental friendly and renewable. The peak and yield values of the neat sample are 8.96 and 4.33 N/mm^2 and these imply about 74% and 210% increase, respectively.

Also, this is a better result compared to the work by del Carmen Camacho *et al*. (2014) in which it was discovered that the addition of CNT to Portland cement mortars does not significantly affect the compressive strength where less than 7% enhancement was achieved at 28 days curing time.

Figure 4 showed compressive modulus of the materials in which it was observed that the moduli of all the untreated OPFF reinforced composites were less than that of the neat sample and that of the treated OPFF reinforced composites. It was noticed that the compressive modulus tends to increase as the red sand content increases while it tends to decrease as the red sand content increases for treated and untreated OPFF reinforced composites, respectively. These responses may be due to the effects of the OPFF fibres as discussed in Figure 3. The results revealed that 15 % red sand based composite from treated OPFF gave the best results with a value of 419.80 N/mm^2 followed by the neat sample with a value of 402.60 N/mm^2.

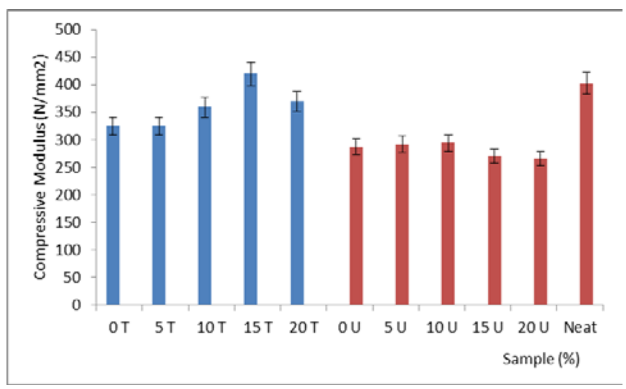

Figure 4. Compressive Modulus for the Developed Composites and the Neat Sample

Figure 5 shows the bending strength at peak and yield. The bending strength of the developed composites was improved compared to the neat sample. Most of the samples did not displayed yield strength and of those with yield strength, only sample without red sand but with treated OPFF showed improved yield strength compared to the neat sample. This performance could be due to treatment of the OPFF that aided strength enhancement and surface modification (Oladele *et al*., 2010). It was observed from the results that sample with 5 % red sand addition from both untreated and treated OPFF reinforced samples gave the best results with values 3.52 and 3.50 N/mm^2, respectively. Compared to the neat sample with a value of 2.50 N/mm^2, this culminated to 40 % enhancement. Also, the bending strength at yield for sample with the best value was 3.25 N/mm^2 from sample without red sand but with treated

OPFF compared to that of the neat sample with a value of 2.11 N/mm^2, which led to about 54 % enhancements. Unlike the work by del Carmen Camacho *et al.* (2014) that revealed that the addition of CNT to Portland cement mortars does not significantly affect the bending strength (less than 6%) at 28 days curing time, the addition of OPFF brought about high enhancement of the bending strength at peak of the developed cementitious composites.

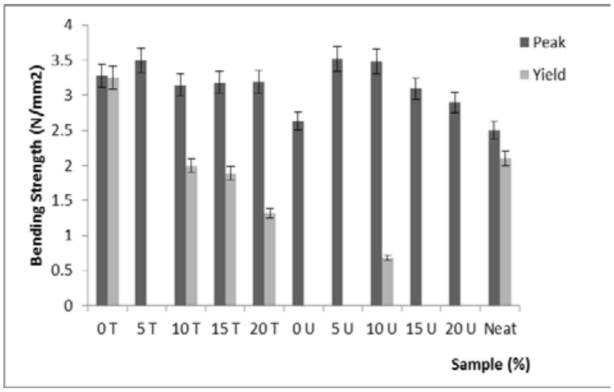

Figure 5. Bending Strength at Peak and Yield for the Developed Composites and the Neat Sample

The bending modulus was as shown in Figure 6. Similar to the results in Figure 4, the moduli of the developed composites were low compared to the neat sample except for the sample developed with 5 % red sand from untreated OPFF with a value of 264.50 N/mm^2. The neat sample followed having marginally exceeded that of 10 % red sand from treated OPFF with values 229.29 and 219.15 N/mm^2, respectively.

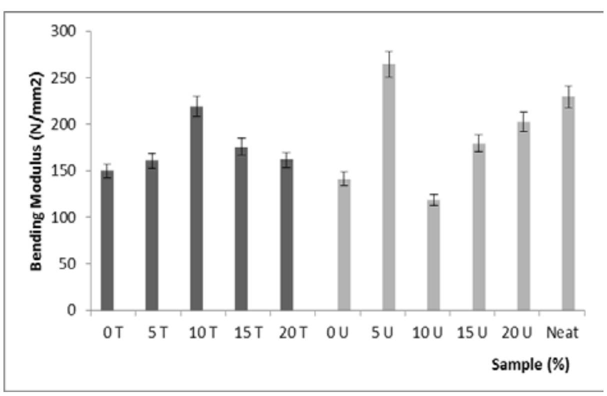

Figure 6. Bending Modulus for the Developed Composites and the Neat Sample

Considering the enhancement by this feat, about 15 % has been achieved. Again, considering the red sand content that aid improved bending strength and modulus, it falls between 5 and 10 % which showed that with less quantity of the red sand, the bending property of cement based material can be improved. This become important as this will reduce the cost of production of high quality building materials thereby allowing the product to be available for consumption at affordable rate.

Rate of water absorption of the materials was as shown in Figure 7. This test was carried on the samples because the target application was building construction (Oladele *et al.*, 2009). This test will help determine the extent at which the formed composites can absorb water in case of water attack in service environment. Since the amount of the fibre used was constant, therefore, the obtained variation will be based on treated and untreated conditions of the fibres in addition to amount of red sand present.

Figure 7. The Rate of Water Absorption for the Developed Composites and the Neat sample after 7 Hours of Immersion

It was observed from the results that the rate of water absorption in both treated and treated conditions of the OPFF increases from 0-15 % of the red sand before reducing which showed that the red sand had similar effect on the developed composite materials. However, it was discovered that the untreated OPFF reinforced samples absorbed more water at the end of 7 hours of immersion than their treated reinforced counterparts. This observed trend may be due to the removal or reduction in the amount of lignin content which is usually responsible for the hydrophilic nature of natural fibres from the OPFF after treatment. The best results were obtained within 0-10 % red sand treated OPFF samples with sample without red sample emerging as the best with a value of 4.55 % followed 4.87 % from 5 % red sand. The neat sample that did not contain OPFF has a value of 6.80 % and this culminated to about 33 % enhancement. It follows that; the addition of these additives can aid the reduction of water absorption tendency of Portland cement in building application. This result depicts a good feat compared to the effect of the addition of CNT to the cement matrix which could imply the development of higher levels of corrosion in aggressive conditions, such as carbonation and contamination by chloride ions as reported by del Carmen Camacho *et al*. (2014).

4. Conclusion

The results from compressive and bending properties revealed that the strengths and moduli of cement based composite materials for structural application can be improved by red sand and oil palm fruit fibre additives, especially for low technology application. The untreated OPFF gave the best response in terms of the mechanical properties while the treated OPFF gave the best response in terms of water absorption behaviour.

Considering the range of red sand addition that gave the best response with respect to these properties, it can be deduced that low content, 5 % of the red sand within the cement based composites can be adopted in addition to the OPFF in both treated and untreated conditions to improve the bending and water absorption properties of cement based materials while high content, 10-15 % improves the compressive properties. The work reveals the potentials in the use of red sand for building application by working on its limitation.

References:

ASTM (2015a), *ASTM C873 / C873M-15: Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds*, American Standard Testing and Measurement (ASTM International), West Conshohocken, PA.

ASTM (2015b), *ASTM D790-15e2: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, American Standard Testing and Measurement (ASTM International), West Conshohocken, PA.

Baeza, F.J., Galao, O., Zornoza, E. and Garcés, P. (2013), "Effect of aspect ratio on strain sensing capacity of carbon fibre reinforced cement composites", *Material Design*, Vol.51, pp. 1085-1094.

del Carmen Camacho, M., Galao, O., Baeza, F.J., Zornoza, E., and Garcés, P. (2014), "Mechanical properties and durability of CNT cement composites", *Materials*, Vol.7, pp. 1640-1651

Khairiah, B. and Khairul, A.M.A. (2006), "Biocomposites from oil palm resources", *Journal of Oil Palm Research*, Special Issue-April, pp.103-113.

Lee, S.M., Cho, D., Park, W.H., Lee, S.G., Han, S.O. and Drzal, L.T. (2005), "Novel silk/poly(butylene succinate) biocomposites: The effect of short fibre content on their mechanical and thermal properties", *Composites Science and Technology*, Vol.65, pp.647-657.

Muthusamy, S., Wang, S. and Chung, D.D.L. (2010), "Unprecedented vibration damping with high values of loss modulus and loss tangent, exhibited by cement-matrix graphite network composite", *Carbon*, Vol.48, pp.1457-1464.

Myrtha, K., Holia, O., Dawam, A.A.H. and Anung, S. (2008), "Effect of oil palm empty fruit bunch fibre on the physical and mechanical properties of fibre glass reinforced polyester resin", *Journal of Biological Sciences*, Vol.8, No.1, pp.101-106.

Oladele, I.O., Akinwekomi, A.D., Aribo, S. and Aladenika, A. K. (2009). "Development of fibre reinforced cementitious composite for ceiling application", *Journal of Minerals and Materials Characterisation and Engineering*, Vol.8, No.8, pp. 583-590.

Oladele, I.O., Okoro, M.A. and Ajileye, J.O. (2015), "The Effect of natural rubber on the bending properties of coconut coir (*Cocos Nucifera*) reinforced red sand composites", *ACTA Tehnica Corviniensis - Bulletin of Engineering, Fascicule*, Vol.2, pp.87-92

Oladele, I.O., Omotoyinbo, J.A. and Adewara, J.O.T. (2010), "Investigating the effect of chemical treatment on the constituents and tensile properties of sisal fibre", *Journal of Minerals and Materials Characterisation and Engineering*, Vol.9, No.6, pp.569- 582

Rozman, H.D., Saad, M.J. and Mohd Ishak, Z.A. (2003), "Bending and impact properties of oil palm empty fruit bunch (EFB) – polypropylene composites: The effect of maleic anhydride chemical modification of EFB", *Journal of Polymer Testing*, Vol.22, pp.335-348.

Vilaplana, J.L., Baeza, F.J., Galao, O., Zornoza, E. and Garcés, P. (2013), "Self-sensing properties of alkali activated blast furnace slag (BFS) composites reinforced with carbon fibres", *Materials*, Vol.6, pp.4776-4786.

Wen, S. and Chung, D.D.L. (2007), "Partial replacement of carbon fibre by carbon black in multifunctional cement-matrix composites", *Carbon*, Vol.45, pp.505-513.

Zornoza, E., Catalá, G., Jiménez, F., Andión, L.G. and Garcés, P. (2010), "Electromagnetic interference shielding with Portland cement paste containing carbon materials and processed fly ash", *Material Construction*, Vol.60, pp.21-32.

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