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Mechanical Performance of Cement Composites Reinforced with Raffia Palm Fabric

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Abstract: The utilization of plant based (natural) fabrics as reinforcement in composite materials is fast growing in the engineering field, due to their environmental friendliness and appreciable mechanical properties. This study was carried out to evaluate some flexural properties (flexural strength and flexural deflection) and water absorption rate of raffia palm fabric reinforced cement composite samples. Ordinary Portland cement (grade 42.5N) was used as the binding material. Cement to fine aggregate (450 µm) mix ratio of 1:3 (by weight) was employed for the composite production, while a water to cement ratio (w/c) of 0.4 was adopted. For the purpose of this study, cement composite beams were reinforced with raffia palm fabrics in 1-fabric, 2-fabrics and 2-layer configuration. All the cement composite samples were prepared and tested in accordance to ASTM standard procedures. Results from the flexural tests showed that the flexural properties of the composite samples were highly influenced by the raffia palm fabric reinforcement. The composite samples reinforced with 2- layers generally had higher flexural properties, when compared to the results obtained from the composite reinforced with 2-fabrics and 1 – fabrics reinforcement. The ultimate flexural deflection attained in the 2-fabrics and 2-layers configurations were comparable, but slightly highly in the 2-layers. A mean deflection of 6.12 mm was recorded in the composite reinforced with 2-layers, which was higher than the mean deflection of 5.56 mm recorded for the composite reinforced with 2-fabrics. For all cases, the unreinforced cement composite (control Samples) had the poorest flexural properties. In terms of the water absorption rate, the 2- layers fabrics composite samples had the highest water absorption rate when compared to the 1-layer fabric reinforced composite samples and the control samples. These results will be useful in the building industry and in the design and development of natural fabric reinforced concrete structures.

Keywords: Cement, Raffia Palm Fabric, Composite Material, Flexural Properties, Water Absorption

1. Introduction

Concrete is a composite material which has high compressive strength but low tensile and flexural characteristics. Concrete is a widely used as a construction material due to its ability to be cast into various shapes and sizes. Several varieties of concrete exist, e.g. all in aggregate concrete, sandcrete concrete, no fine concrete, etc. The tensile and flexural properties and durability of concrete can be altered by making appropriate changes in its constituents and by adding some special constituents [1-2]. Reinforcement materials are necessary to improve the tensile strength and ductility of concrete structures. Approximately 200 kg of steel reinforcement is required for each cubic meter of concrete [3]. Despite the good reinforcement properties of steel, it still has some drawbacks, which include rusting of steel within concrete structures and the fact that steel is expensive and comes from a non-renewable resource with a high energy demand. In Europe, about 90,000 reinforced and pre-stressed concrete bridges require maintenance, repairs and strengthening; while in America, upgrading of concrete structures is estimated at about $20 trillion [1, 4].

Natural fibres are prospective reinforcing materials, but their utilization in the engineering field previously was relatively more empirical than practical [5]. Due to the increasing environmental problems (climate change, soil pollution, etc.), the use of plant based (natural) fibres as replacement for replacing synthetic fibres in composites materials is gaining much popularity [6]. Plant based fibres are environmental friendly, cost effective, locally available, non-hazardous to human health and have robust specific strength and stiffness [7]. Uguru and Umurhurhu [7] reported that among various plants based fibres, raffia palm fibre has relative high tensile properties when compared to other synthesized and plant based fibres. In addition, Dittenber and GangaRao [8] observed that natural fibres showed a good potential as a substitute to synthesize fibres employed in the production of composites for infrastructural applications.

There is an increasing awareness in the use of plant based (natural) fabrics as reinforcements in cement composites due to their better results when compared to other materials. Some researchers have focused on the effect of fibre/fabric surface modification on the mechanical properties of fibre reinforced composites. Assarar *et al*. [9] reported that the tensile strength of flax/epoxy composite was as high as 300MPa, which was close to that of glass/epoxy composites. According to Pacheco-Torgal and Jalali [3] when plants fibres (e.g. sisal, hemp, coir, raffia palm, pineapple, sugar cane bagasse, etc.) are used as reinforcement in cementitious materials, they give better results in terms of flexural strength when compared to unreinforced cementitious materials. Fabrics provide excellent anchorage and bond development and improve composite behavior [10]. Motaleb [11] observed that the tensile strength of polyester composites reinforced with alkali treated jute fabric increased by about 40%, when compared to the unreinforced composites. Analysis embarked upon by Puri *et al.* [12] showed a significant increase in the flexural strength of concrete when natural aggregates were replaced with recycled concrete aggregates. In contrast, the flexural strength of the concrete decreased when natural aggregates were replaced with PVC aggregates and pulverized leather waste. Peled *et al*. [13] reported that woven fabrics improved the mechanical properties of cement composites. Mechanical properties of fabric reinforced composites depend not only on its constituents, but the bonding between the reinforcement and the matrix. The bonding can be affected by the curing condition, mixing method, production method, fibre type and the treatment applied to the fibre's surface [14].

The objective of this study was to study some flexural properties (flexural strength and ductility) and the water absorption rate of raffia palm fabric-reinforced sand-cement composites. The cement composite samples were produced and tested in accordance to the America Society for testing Materials (ASTM) standard procedures. The water absorption rates of the samples were also investigated in this study. Data obtained from this study will be useful in the production of high quality concrete structures using natural fabrics as reinforcement materials, especially in large mass concrete structures which are susceptible to internal cracking, and structures with surfaces susceptible to surface cracking.

2. Materials and Method

The material properties and experimental set-up used for this study are described below.

2.1. Materials

2.1.1. Cement

Ordinary Portland cement of grade 42.5 satisfying the requirements of Nigeria Industrial standard (NIS) was used for the concrete production.

2.1.2. Raffia Palm Fabric

The raffia palm fibres used for the weaving of the fabric were purchased from a local market located at Ozoro, Delta State, Nigeria. They were air-dried in the laboratory at an ambient temperature of 25±4°C for two weeks. The thickness of the fibres was measured with the aid of a digital micrometer, and the fibres thickness ranged between 0.021 and 0.028 mm. The fibres were woven into a fabric by indigenous craftswomen, using traditional methods.

2.1.3. Fine Aggregate

Fine aggregate which was free from deleterious materials was collected from a river bed. It was air dried in the laboratory for a period of one week, and then sieved with a 450 µm stainless steel sieve. The fine aggregate passing through the 450 µm sieve size was added to the mixture to produce matrix that easily flows, since a higher flowing (workable) matrix will tend to produce better bonding between the fabrics and the concrete matrix [15].

2.2. Method

The cement composite samples used for this study were reinforced in three different ways, which were:

i. one fabric layer between two concrete layers;
ii. two fabric layers in placed directly on top of each other between two concrete layers;
iii. two fabric layers separated by a 5 mm-thick layer of concrete.

The unreinforced cement composite was considered as the "control", which will be used as the reference point.

2.2.1. Cement Composite Production

Cement to fine aggregate (450 µm) mix ratio of 1:3 (by weight) was employed for the composite production, while water to cement ratio (w/c) of 0.4 was adopted. Mechanical mixing method was employed in the mixing of the cement, fine aggregate and water. Care was taken so that the accurate weight of the cement and fine and water were used. The concrete samples were prepared in accordance to ASTM standard size. The beam moulds were of size 500 mm by 100 by 100 mm. During the casting, a suitable amount of the premixed sand-cement concrete was poured into the already prepared (oiled) mould (about 50% of the mould's depth) and rammed properly to sufficiently remove all air bubbles. Then the raffia palm fabric was gently spread over the concrete and fixed at the edges, after which the mould was filled to the top and rammed again 36 times to remove all the voids. The cast composite samples were covered with a dark PVC sheet for 24 hours, before they were de-moulded and cured for 28 days by total immersion in water.

2.2.2. Flexural Test

Flexural test was carried out the cement composite samples using the 3-point loading method, in accordance to ASTM C 78 standard procedure. A Concrete Compression Testing Machine (STYE 2000), manufactured in China, with a maximum loading capacity of 1000 KN was employed for the flexural test. During the test, individual beams were placed in the machine, and loaded slowly until failure of the beams occurred. A digital caliper was attached to the compression testing machine to measure the central deflection of the samples. The failure force and the corresponding deflection were displayed on the screens of the machines and recorded. Flexural strength of the concrete beams was computed using equations 1 [16].

Flexural strength

$$S = \frac{3WL}{2bd^2} \quad (1)$$

Where:

S = Flexural strength of the concrete beam at the cross-sectional plane of failure (MPa),

W = Maximum failure load indicated by the testing machine (N),

L = Concrete beam Span (mm),

b = Average width of the concrete beam at the plane of failure (mm),

d = Average depth of the concrete beam at the plane of failure (mm).

2.2.3. Water Absorption Rate

In the determination of the water absorption rate of the cement composite samples, the composite samples were dried in an electric laboratory oven at 60°C for 24 hours. Their weight were taken with the aid of electronic weighing balance, before they were totally immersed in water at room temperature (25±5°C) for 12 hours. The weight of the samples was taken at intervals of 60 minutes (1 hour), within the 12 hours duration. Water absorption rate was calculated by using Equation (2).

$$Water\ absorption\ = \frac{M_a - M_b}{M_b} \quad (2)$$

M_a = weight of block after soaking in water

M_b = weight of block before soaking in water

All the laboratory tests were carried out at the Department of Civil Engineering Technology's concrete laboratory, at Delta State Polytechnic, Ozoro, Nigeria. The tests were carried at room temperature (24±4°C).

3. Results and Discussion

3.1. Flexural Strength

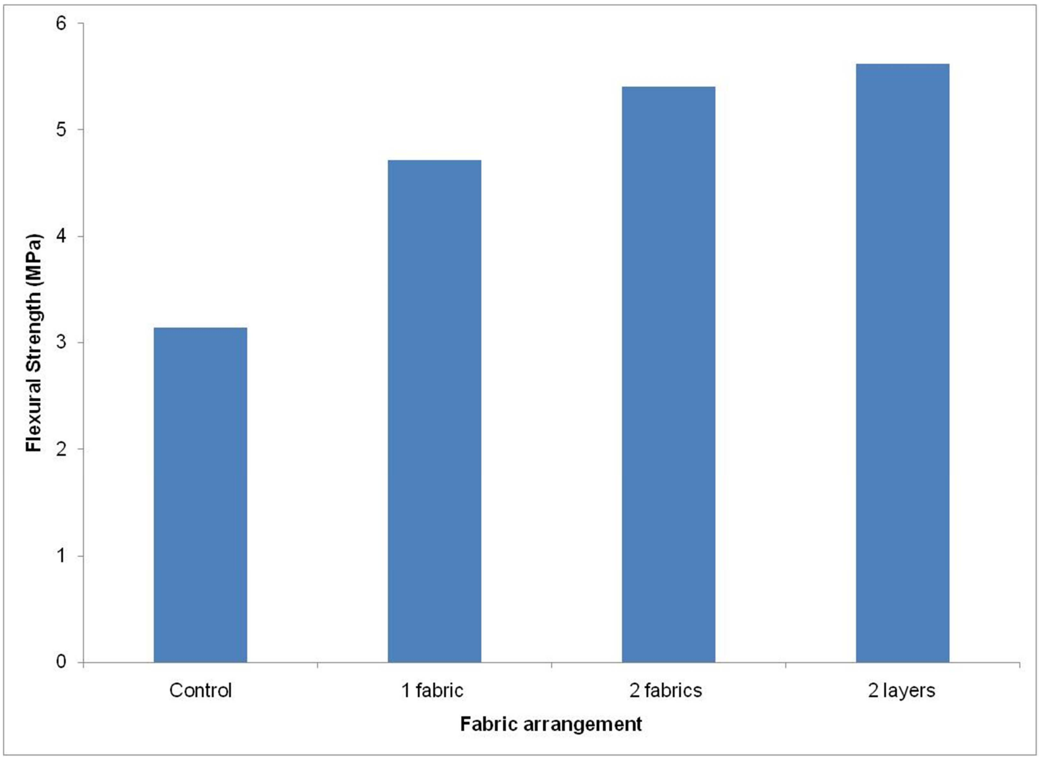
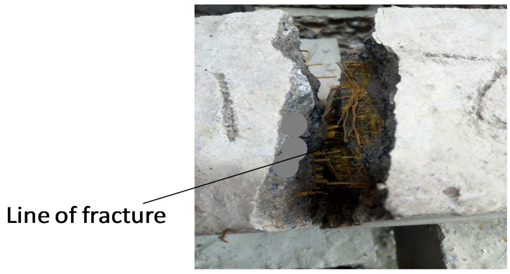


Figure 1. *Flexural strength of raffia palm fabric reinforced cement composite samples.*

The result of the flexural strength of the raffia palm fabric reinforced cement composite is presented in Figure 1. The result shown in Figure 1 depicted that fabric reinforcement had significant effect on the flexural strength of the cement composite samples, and the flexural strength increased with increase in the number of fabrics used as reinforcement. The flexural strength varied from 3.144 MPa (for the control) to 5.624 MPa for the composite reinforced with 2-fabric layers. As seen in Figure 1, the flexural strength of the composite reinforced with two layer of fabric separated by a 5 mm-thick layer of concrete, was higher (5.624 MPa), when compared to the result obtained for the composite reinforced with two fabrics placed directly on top of each other (5.415 MPa). This could be attributed to decline in the quality of matrix–fabric interface, and sliding of the fabrics when they are in contact with each other. In addition, bonding has a significant effect on the composite material, determining both its strength and ductility [15]. Similar results were obtained by [15, 20]. El Messiry *et al.* [20] reported that the flexural properties of jute fabric reinforced cementitious composites increases as the fabric layers increased from 1 to 3. In addition, Colombo *et al*. [15] observed that the tensile strength of the concrete reinforced with textile fabric increased from 11.36 MPa to 24.42 MPa at the textile fabric layers increased from 1 to 2. According to Aho and Ndububa [21] mortar reinforced with raffia palm fruit peel fibres improved its flexural strength but resulted in a reduction of its compressive strength. The flexural strength of fiber cement sheets was significantly improved using pultrusion of the Jute/polymeric matrix fabric [22]. The thickness of the two fabrics placed directly on top of each other could lead to poor penetration of the fabric openings by the matrix, thereby reducing mechanical anchoring of the fabrics in the composite sample. This could be one of the reasons why lower flexural properties were recorded in the 2-fabric layers placed directly on top of each other when compared to the 2-fabric layers separated by a 5 mm-thick layer of concrete. The results from this study showed that a better interaction between the fabric and the matrix in a cement composites, will lead to a better performance of the composite sample.

The failure pattern of the composite samples containing the different configuration of fabric reinforcement, are shown in Figure (2a, 2b and 2c). As shown in Figure 2a, the unreinforced composite beam fractured into two fairly symmetrical havles with a fairly plane fracture surface. Figure 2b and 2c revealed that the inclusion of the raffia palm fabric in the concrete composite totally altered the macrostructure and the failure pattern. The concrete beam reinforced with 2 fabric layer (Figure 2c) did not disintegrate clearly into two fairly symmetrical parts at the failure point of the concrete beam, unlike what was observed in the unreinforced concrete beam (Figure 2a). The cracking nature of cement composite and the resulting stress-strain curve, toughness, and strength are influenced by the physical and the mechanical properties of the fabric and cement matrix, the interface bond, and the fabric anchorage (Peled and Mobasher, 2007). The penetration of matrix in between the openings of the fabric (s) is a controlling factor in the performance of the cement based fabric composites and it is dependent on the size of the fabric opening and the viscosity of the cement-sand matrix. Fabrics incorporated in cement concrete structures induces tortuosity in the path of propagation of cracks promoting crack deflection processes, and lead to enhance strength and ductility of such structures [13].

a: unreinforced cement composite beam (control).



b: 1-fabric layer reinforced cement composite beam.

c: 2-fabric layer reinforcement.

Figure 2. *Failure of the fabric reinforced and control beams at the end of the testing.*

3.2. Flexural Deflection

Figure 3 shows typical load-deflection curves of the composite samples reinforced with the raffia palm fabrics and the unreinforced composite sample. As shown in Figure 3, the reinforced composite samples were more ductile than the unreinforced composite samples. The ultimate deflection attained in the 2-fabrics and the 2-layer configurations (composite samples) were comparable, but slightly highly in the 2-layer. A mean deflection of 6.12 mm was recorded in the composite samples reinforced with 2-layers, which was higher than the mean deflection of 5.56 mm recorded for the composite samples reinforced with 2-fabrics placed one on top of the other. Furthermore, the deflection of the 1-fabric composite sample was lower (3.42 mm), when compared with the deflection obtained in the 2-fabrics reinforcement (5.56 mm). These results portrayed that the number of fabric layers in the composite contributed greatly to the ductility of the samples.

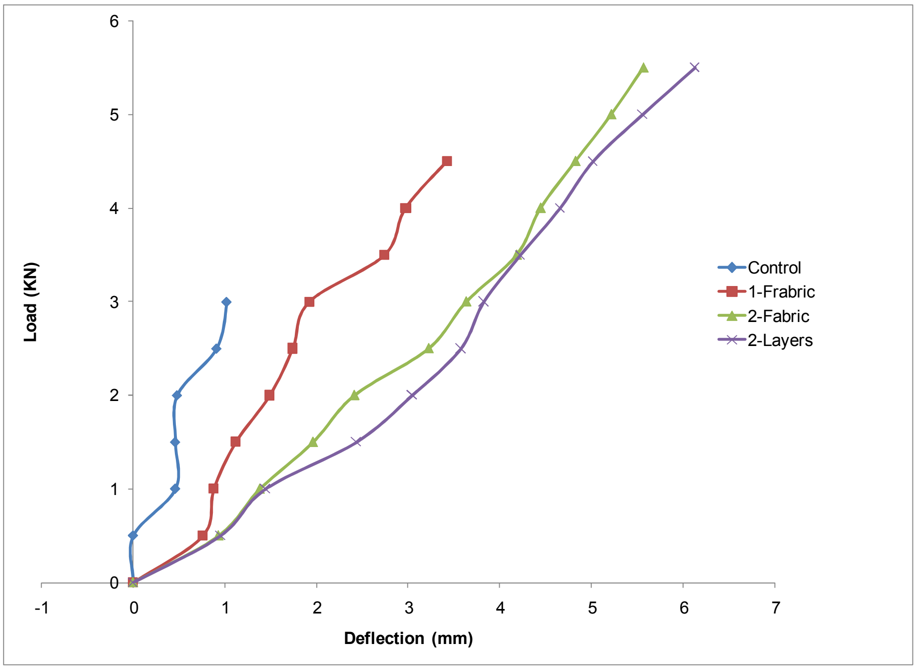


Figure 3. *Load-deflection curves in flexure of composite reinforced with raffia palm fabrics.*

These trends are generally similar to those of the flexural deflection recorded by [16] for fibre reinforced concrete samples. According to Akpokodje *et al.* [16] the flexural deflection of raffia palm reinforced concrete increased from 2.92 mm to 3.97 mm as the fibre content increased from 1% to 3%. Motaleb [11] reported about 40% increase in tensile elongation in pineapple fabric reinforced polyester resin composites. Owen [17] stated that jute fabric reinforced epoxy composites are stiffer and stronger than unreinforced epoxy composite. According to Owen [17], the flexural strength of jute fabric reinforced epoxy composites increased by about 78%, while the deflection increased by about 70%. According to Reis [18] cementitious composites reinforced with coir fibres gave a better result when compared with results obtained from cementitious composites reinforced with synthetic fibres. Islam *et al*. [19] observed that reinforcing concrete with 0.5% vol. coir fibres enhanced its flexural strength by 60%.

3.3. Water Absorption

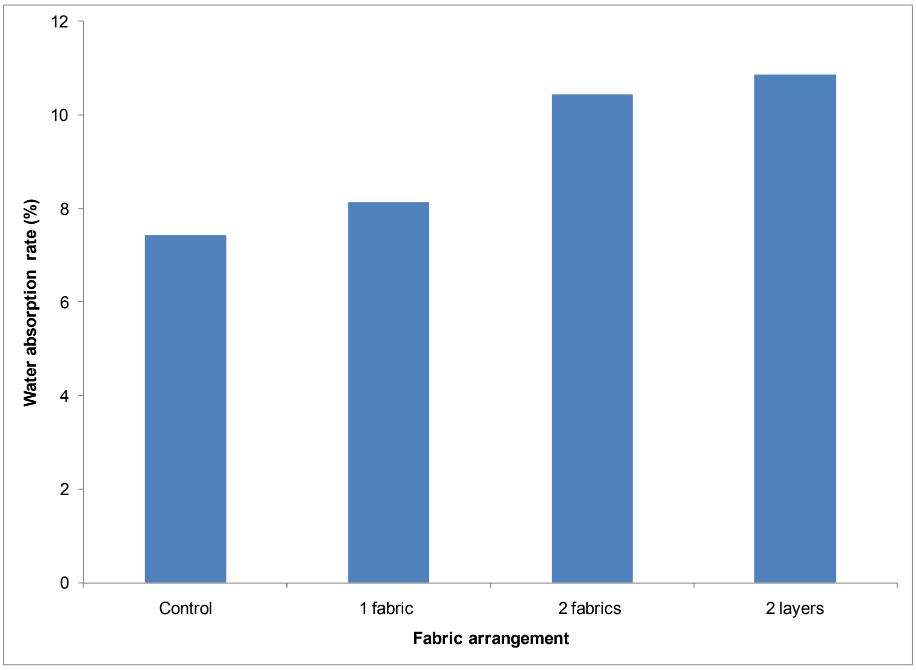


Figure 4. *Water absorption rate of cement composite beams.*

The water absorption rate of the raffia palm fabric reinforced concrete samples are shown in Figure 4. The water absorption rate increased with increase in the fabric quantum and number of layers. The composite samples reinforced with 2- fabric exhibited higher water absorption rate than the samples reinforced with 1-fabric. For the cases, the unreinforced composite samples had the lowest water absorption rate (7.42%), while the maximum water absorption rate (10.86%) was observed for the 2-layers reinforcement within the 60 minutes soaking duration. Water absorption is very important in determining the degradability of a material under moist condition. The results showed that the flexural properties of the concrete samples were influenced by the quantity of fabrics used, i.e. the higher the fabric quantum and number of layers, the greater the flexural strength properties of the reinforced fabric concrete. Therefore, it is recommended to use more than one fabric layer in concrete production

4. Conclusion

This study focuses on the effect of raffia fabric reinforcement on the mechanical performance of sand-cement composite samples. All the composite samples were prepared and tested in accordance to ASTM standard procedures. The results obtained from the tested indicated that the flexural properties of the cement composite samples were highly influenced by the fabric reinforcement. The results showed that the flexural properties of the concrete samples were influenced by the fabrics quantity used, i.e. the higher the fabric quantity, the greater is the flexural strength properties of the reinforced fabric concrete. The flexural strength varied from 3.144 MPa (for the control) to 5.624 MPa for the composite reinforced with 2-fabric layers. Ultimate deflection attained in the 2-fabrics and 2-layers configurations composite samples were comparable, but slightly highly in the 2-layers. Mean deflection of 6.12 mm was recorded in the composite samples reinforced with 2-layers, which was higher than the mean deflection of 5.56 mm recorded for the composite samples reinforced with 2-fabrics. These results will be useful in the building industry and in the design and development of natural fabric reinforced concrete structures.

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