Study of Flexural Strength and Flexural Modulus of Reinforced Concrete Beams with Raffia Palm Fibers

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This study was carried out to investigate the effects of raffia palm fibre on some mechanical behaviour (flexural strength, flexural modulus, water absorption rate and density) of concrete. A concrete mix ratio of 1:2:4 was used for the concrete beams production, while a water to cement ratio (w/c) of 0.5 was adopted. In the study, three different fibre lengths (10, 20 and 30 mm) and three different fibre content (volume) by mass of fine aggregate (1, 2 and 3%) were considered. According to the results of the preliminary test carried out on the fine aggregate, it had a silt content of 1.6%, a moisture content of 8.3%, and a specific gravity of 2.95. Flexural properties of the beams were tested in accordance with ASTM recommended procedures after 28 curing days. Results obtained showed that fibre volume had significant (p ≤0.05) effect on the flexural strength and flexural modulus of the beams. The flexural strength and flexural modulus decreased linearly as the fibre volume increased from 0% to 3%. According to the results, the fibre reinforced beams were more ductile, when compared to the unreinforced concrete beams. In addition, the densities of the beams decreased with increase in the fibre volume; while their water absorption rate increased with increase in the fibre volume. The low densities and brittleness of the reinforced beams (at low volume) made them good building materials, especially when heavy weight beams are a problem, provided the beams are not exposed to high moisture levels.

Keywords: Raffia palm fibres; concrete, flexural strength, flexural modulus, density

INTRODUCTION

Concrete is one of the most widely used construction material in the construction and building industries, which are among the most active sectors in the world. Concrete is a mineral composite, which consists of fine and coarse aggregates, water, and a binding agent (generally cement), and in some cases admixtures and additives (Lafarge, 2009). Globally, the utilization of concrete in building and construction is twice the total amount of all other building materials used, i.e. wood, steel, plastic and aluminum. According to statistics from the Cement Association of Canada, the annual global production of concrete stands at about 4 billion cubic meters, this is spread unequally in more than 120 countries (Ecosmart, 2019). By 2025, the world population is expected to rise by about 35%, rising up to about 10 billion people. Therefore, about two billion additional human beings will need adequate shelter to ensure their mobility. This will further contribute to the menace of climate change and energy efficiency, because presently the building industry accounts for about 39% of the world’s energy consumption and 42% of its CO₂ emissions (Lafarge, 2009). To curb this menace, sustainable construction methods are been developed for the building and construction industries.

Sustainable construction involves limiting the negative environmental impacts of buildings, while guaranteeing them superior quality in terms of aesthetics, durability and resistance. The International Council of Building (CIB) stated that sustainable construction is responsible for creating and maintaining a healthy built-up environment, based on the efficient use of resources and following ecological principles (Yan and Chouw, 2014). The usage
of plant-based products is of great advantage in sustainable construction, since it creates new prospects for these products, it preserves the natural resources, and it will not alter the conventional construction methods. On the basis of this, the United States Department of Agriculture (USDA) and the United States Department of Energy (USDE) had set goals of having at least 10% of all basic building blocks and concrete produced from renewable and plant-based sources by 2020, which will be increased to 50% by 2050 (Yan et al., 2014). The use of biomaterials to replace these synthetic fibres as reinforcement or partial replacement has been a growing interest for different engineering applications. This is because natural fibres are biodegradability, less dense but with high specific strength, moth-proof, resistant to fungi attacks, provide excellent insulation against sound, flame-retardant, tough and durable (Ali et al., 2012; Yan, 2012; Umurhurhu and Uguru, 2019). The use of chemical/synthesized fibres will inevitably result in environmental pollution. Therefore, the reinforcement of cement-stabilized soil using fibers or blocks obtained from waste materials has emerged as a hot research topic and many studies been conducted by several researchers (Lv and Zhou, 2019).

Researches on new building materials have been on for the past decades, with the sole aim of developing low cost construction materials that can be affordable to the people. Cheap and standard building materials are necessary for the construction of low-cost housing estates, and other structures. Composites are a versatile and valuable family of materials that can solve problems of different applications and facilitate the introduction of new properties in materials (Gon et al., 2012). Park (2009) carried out a series of unconfined compression tests on samples reinforced with fibres. He reported that a fibre reinforced specimen was twice as strong as a non-fibre-reinforced specimen. The author also reported that a specimen with five fiber inclusion layers was 1.5 times stronger than a specimen with one fibre inclusion layer. According to Aho and Ndububa, (2015) concrete beams reinforced with raffia palm fruit peel fibres improved their flexural strength but resulted in reduction of their compressive strength. Ahmad et al. (2014) reported that the flexural strength of beam increases when we use bamboo stick as reinforcement in concrete. The flexural strength of doubly bamboo reinforced beams reached up to 80MPa as compare to 48MPa for concrete beams without any reinforcements. The maximum deflection at the mid span reaches up to 1 mm approximates. Mostafa and Uddin, (2015) studied the behaviour of mortar reinforced with different percent of coconut and banana fibres. They observed that the maximum tensile strength and modulus of rupture of mortar composite increased up to certain fibre content (percent), before the values dropped as the fibre volume increases. Similarly, Estabragh et al. (2012) studied the effects of fibre volume, cement volume, and curing age on the unconfined compressive strength of cement-stabilized clay. They observed that nylon fibres could not only increase the unconfined compressive strength and peak strain of cement-stabilized clay but also facilitate a transition from brittle failure to ductile failure. Reinforced cement has been shown to significantly improve the mechanical properties of soils and is hence widely used in soft soil foundation treatment, backfilling of retaining walls, roadbed reinforcement of roads and railways, etc. (Kim et al., 2008; Lv and Zhou, 2019).

Proper waste disposal and recycling of waste materials have become a critical issue in Nigeria, from the environmental protection point of view. Therefore, the use of plant-based fibres to reinforce concrete beams will not only be beneficial to the engineering field, but also solve significant environmental problem. The objectives of this study were to:

(i) Investigate the flexural behaviour of raffia palm fibre reinforced concrete beams and comparison of these results with that of unreinforced concrete beams.
(ii) Evaluate the effect of raffia palm fibre volume and length on the water absorption rate and density of concrete beams.

MATERIALS AND METHOD

Materials

The following materials were used for the production of the concrete beams.

Cement: Ordinary Portland cement (Manufactured by Dangote), was used as the binder in the production of the reinforced concrete beams. The cement was of grade 42.5, which was in compliance with Nigeria Industrial Standard (NIS, 2003; Esegbuyota et al., 2018).

Water: Fresh tap water (pH 7.5 and electrical conductivity 30 μS/cm) was used for the study. The water met the Nigeria Industrial Standard (NIS) recommendation.

Raffia palm fibres: The raffia palm fibres were purchased from a local market located at Otor - Owhe, Delta State, Nigeria. They were air-dried in the laboratory at an ambient temperature of 29±4°C for two weeks. Thickness of the fibres was measured with the aid of a digital micrometer, and the fibres thickness ranged between 0.027 and 0.032 mm (Figure 1). These fibres were cut in three length sizes (10mm, 20 mm and 30 mm).

Fine aggregate: The fine aggregate used in this study was obtained from Ase River in Delta State, Nigeria (Figure 1). The fine aggregate was air dried at the Civil Engineering soil laboratory, Delta State Polytechnic, Ozoro, Nigeria for two weeks. Sieve analysis was carried out on the fine aggregate to determine their suitability for concrete production.
**Coarse aggregate:** The coarse aggregate was free from deleterious materials like silt, plant roots, etc. (Figure 1). According to NIS recommendation, coarse aggregate which are to be used for concrete production must be clean, hard, and free from chemicals or any materials that could cause the deterioration of concrete.

![Figure 1: Constituent materials](image)

**Method**

**Preliminary analysis of the fine aggregate**

**Sieve analysis:** Sieve analysis was also carried out on the fine aggregate to ascertain their suitability for concrete production in accordance with NIS recommendation. Before the sieve analysis, the fine aggregate was oven-dried with an electric laboratory oven at a temperature of 65±3°C for 24 hours. A set of sieves was then arranged in descending order; the largest aperture sieve was placed at the top, followed by the immediate smaller sieve, until the smallest aperture sieve which was placed at the bottom just before the pan. One kilogram of the fine aggregate was poured into the uppermost sieve of the arranged sieve set, and vibrated vigorously with the aid of a mechanical sieve shaker. After that, each sieve was carefully removed from the set, and the fine aggregate retained in each sieve was weighed and recorded. The cumulative weight of fine aggregate passing through each sieve was calculated as a percentage of the total sample weight (Odeyemi et al., 2018; Akpokodje and Uguru, 2019).

**Moisture content determination:** The moisture content of the fine aggregate was determined gravimetrically, in accordance with the standard procedures described by Akpokodje et al. (2018) and calculated using equation 1.

\[
M_c \left( \text{wet basis} \right) = \frac{\text{weight of wet sample} - \text{weight of dry sample}}{\text{weight of wet sample}} \times 100
\]

(1)

**Specific gravity determination:** The specific gravity of the fine aggregate was determined using standard methods stated by AOAC (2019), and calculated using equation 2.

\[
S_g = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}
\]

(2)

\(W_1\) = Weight of the empty bottle

\(W_2\) = Weight of the bottle filled fine aggregate

\(W_3\) = Weight of the bottle and its content filled with distilled water up to the meniscus.

\(W_4\) = Weight of the bottle filled with distilled water to the meniscus.

All the tests were carried out at the Concrete laboratory of the Department of Civil Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria, at ambient temperature (29±4°C). Four blocks from each sample were tested and the average value was recorded.

**Concrete production**

**Batching of the Constituent Materials:** Weight batching method was applied in measuring the constituent materials (cement, fine aggregate, coarse aggregate, raffia palm fibres and water), used for this study. Batching required stringent quality and quantity control applied systematically for every batch mixed. An electronic weighing balance was used in weighing the constituent materials.

**Mixing:** The concrete was mixed in accordance with the appropriate batching as related to this study. A nominal volumetric concrete mix ratio (in volume) of 1:2:4 (cement: fine aggregate: coarse aggregate) was adopted for the production of the concrete beams, while a water cement ratio 0.5 was applied. The partial replacement of the fine aggregate with raffia palm fibres is shown in Table 1. Mechanical mixing method was employed in mixing the constituent materials; this was to obtain a homogenous mixture.

**Table 1: Proportions of raffia palm fibres in the concrete**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fibre length (mm)</th>
<th>Fibre mass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (control)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
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<td>8</td>
<td>30</td>
<td>1</td>
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<tr>
<td>9</td>
<td>30</td>
<td>2</td>
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<tr>
<td>10</td>
<td>30</td>
<td>3</td>
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</tbody>
</table>

**Concrete beam production:** The concrete beams were produced in accordance with the specifications given in Table 1. During the concrete beams production; the constituent materials were mixed thoroughly to form a homogenous mixture, and the concrete formed was transferred into standard steel mould (500 x 100 x 100 mm) and then rammed thirty six times. The cast concrete beams (Figure 2) were covered with polyethylene sheet and left open in a shade under ambient environmental conditions for twenty four hours, before they were demoulded and cured.
Curing: The concrete beams were cured after 24 hours by total immersion in water for 28 days. Curing was important to the concrete beams, because it facilitates proper hydration and hardening of the concrete (Akpokodje and Uguru, 2019).

Flexural test

The flexural test of the concrete beams was done in accordance to ASTM recommended procedure of three points loading. A Concrete Compression Testing Machine, with a maximum loading capacity of 1000 KN was employed for the flexural test. During the test, individual beam was placed in the machine (Figure 3), and loaded slowly until failure occurred. A digital caliper was attached to the machine to measure the central deflection of the sample. The failure force and the corresponding deflection were displayed on the screen of the machine and recorded. Flexural strength and Flexural modulus of the concrete beams were computed using equations 3 and 4.

\[
S = \frac{3WL}{2bd^2} \quad (3)
\]

\[
F_m = \frac{L^3F}{4bd^2y} \quad (4)
\]

Where:
- \(S\) = Flexural strength of the concrete beam at the cross-sectional plane of failure (MPa),
- \(F_m\) = Flexural modulus of the concrete (MPa or GPa),
- \(W\) = Maximum 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),
- \(y\) = Deflection of the beam corresponding to the load (mm).

Density = \(\frac{\text{Mass}}{\text{Volume}}\) \quad (5)

Water absorption rate: The water absorption rate of the concrete beams was carried out in accordance with standard procedure recommended by BS EN 771. Four dried concrete beams were selected at random and weighed using electronic weighing balance. The beams were completely immersed in cool fresh water (pH 7.5 and electrical conductivity 31 μS/cm) at ambient water temperature (25±5°C) for 24 hours. After which they were brought out of the water, wrapped dry with a trowel, and their weights taken again. The water absorption rate of each beam was calculated using equation 6.

\[
\text{Water absorption} = \frac{M_a - M_b}{M_b} \quad (6)
\]

\(M_a\) = weight of block after soaking in water
\(M_b\) = weight of block before soaking in water

All the tests were carried out at the Concrete laboratory of the Department of Civil Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria, at ambient temperature (29±4°C). Four blocks from each sample were tested and the average value was recorded.
Statistical analysis

The results obtained from this study were subjected to Analysis of variance using SPSS statistical software (version 20.0, SPSS Inc, Chicago, IL). Then the mean was separated using Duncan’s Multiple Range Tests at 95% confidence level.

RESULTS AND DISCUSSION

Fine aggregate analysis

Sieve analysis: The result of the particle size distribution of the fine aggregate is shown in Figure 4. As shown in Figure 4, the fine aggregate was well graded (with a silt content of 1.6%) and met the NIS recommendation. The permissible value for silt content in fine aggregate used for concrete production is 6%. Concrete strength is lowered with increasing silt content present in fine aggregate used for the concrete production. According to Cho (2013), the compressive strength of concrete samples decreased from 5 MPa to 3 MPa when the silt content of the fine aggregate increases from 7% to 9%. Fine aggregate that passed through the 75 µm (No. 200) sieve are considered as the silt content.

![Figure 4: Particle size distribution of the fine aggregate.](image)

Moisture content: The result of the moisture content of the fine aggregate was 8.6% (Table 2). The moisture content was below the maximum value of 12% recommended by the Nigeria Industrial Standard.

Specific gravity: The mean specific gravity of the fine aggregate used for the concrete production was 2.95 (Table 2). High specific gravity of the fine aggregate contributes to the high concrete density.

Mechanical behaviour of raffia palm fibre reinforced concrete

Flexural strength: Results of the flexural strength of the concrete are shown in Figure 5. According to the results (Figure 5), the flexural strength of the concrete decreased with increase in the fibre volume. The concrete flexural strength decreased from 5.56 MPa (for the control) to 2.28 MPa for concrete reinforced with 3% (30mm) fibres. As shown in Figure 5, fibre volume had significant effect on the flexural strength of the concrete. The flexural strength decreased linearly as the fibres volume increased from 1% to 3%. At 1% fibre (10 mm) volume, average flexural strength of 4.01 MPa was recorded; this value decreased to 2.65 MPa as the fibre volume increased to 3% (30 mm). This variation could be attributed to the poor bonding of the reinforcement (fibres) materials, as their volume increased from 1% to 3%, thereby creating voids within the concrete leading to weaker interfacial adhesion. Furthermore, the results showed that fibre lengths did not significantly (p ≤0.05) affect the concrete flexural strength; although there was a gradual reduction in the concrete flexural strength, as the fibre length increased from 10 mm to 30 mm. Islam et al. (2012) observed that the flexural strength of concrete reinforced by 0.5% coir fibres increased by 60%. Ali et al. (2013), reported that using local materials as reinforcement of concrete is more economical than the construction of earthquake-resistant structures with steel reinforcement.

Figure 6 presents the load-deflection curves and failure modes of the unreinforced cement concrete (CC) and the fibre reinforced cement concrete (RCC). It can be seen in Figure 6 that the inclusion of raffia palm fibres inclusion makes concrete more ductile compared to the CC. The unreinforced concrete exhibited brittle failure behaviour. On the average, concrete reinforced with 3% fibres had higher deflection (better ductility) than other RCC samples with 1% or 2% fibre reinforcement. Similar results were obtain by Rai1and Joshi (2014) and Yan and Chouw (2014). Rai1and Joshi (2014) reported that addition of coir fibres to concrete increased its flexural properties by about 10%. Yan and Chouw (2014) observed that concrete reinforced with coir fibres had higher deflection on loading when compared with unreinforced concrete samples.

Flexural modulus: The flexural modulus of the concrete samples is presented in Figure 7. Compared with the control samples, the raffia palm fibres inclusion reduced the flexural modulus depending on the fibre volume and fibre length used. As shown in Figure 7, the unreinforced (control) concrete which was considered as a reference for the evaluation had flexural modulus of 920.91 MPa. The concrete with fibre length of 10 mm (1% volume) had best flexural modulus (392.15 MPa) when compare to the other concrete samples with other fibre lengths and contents. For all the reinforced concrete cases, statistically, fibre lengths did not significantly (p ≤0.05) affect the flexural modulus of the concrete samples. The results obtained

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Moisture content (%wb)</td>
<td>8.6± 0.44</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.95±0.03</td>
</tr>
<tr>
<td>Values are means ± standard deviation</td>
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</tbody>
</table>
Concrete density: As presented in Figure 8, the concrete density decreased with increase in the fibres volume and length. The unreinforced concrete had the highest density (2425 kg/m³), while the 3% (30 mm) fibre reinforced concrete had the lowest density (2117 Kg/m³). As showed in Figure 8, fibre length had no significant (p ≤0.05) effect on the concrete density, but fibre volume significantly (p ≤0.05) influenced the concrete density. This means that fibre length did not play a significant role in the concrete density. Boob, 2014, reported a similar trend for sawdust reinforced blocks, where the density decreased from 2400 Kg/m³ to 1800 Kg/m³, as the sawdust content increased from 0% to 20%. In contrast, Musa and Abubakar (2018) observed an increment in sandcrete blocks density, as the steel fibre reinforcement increased; which they attributed to the higher steel fibre density compare to that of the fine aggregate they replaced.

Water Absorption: The effect of fibre volume and lengths on the water absorption rate of raffia palm reinforced concrete is presented in Figure 9. As shown in Figure 9, the concrete water absorption rate was highly dependent on the fibre volume. The water absorption rate increased linearly as the fibre volume increased from 1% to 3%. The minimum water absorption rate was recorded in the unreinforced concrete (8.14%), while the maximum water absorption rate (13.44%) was recorded in the concrete
reinforced with 30 mm (3% volume) raffia palm fibres, after 28 days of curing. The water absorption rates recorded for concrete reinforced with 1% fibres; across the three fibres lengths, fall within water absorption limits recommended for concrete in the Nigeria Industrial Standard. The higher water absorption rate for the fibre reinforced concrete could be attributed to the cellular structure of the raffia fibres, and the high void ratio induced within the concrete, leading to higher water permeability (Esegbuyota et al., 2019). According to Ugwuishiwu et al. (2013), fibres are responsible for the high absorption of water in fibre reinforced blocks, while the blocks densities decreased with the increase in fibre volume. Water absorption is appreciable to an extent, but excessive of it causes defects in the block work, such as, shrinkage of block after drying, cracking of blocks, opening of the joints, etc. (Boob, 2014). The mechanical properties of raffia fibre are affected by the local climate; e.g. rainfall and temperature during growth; maturity stage of the fibres; fibres extraction method, i.e. type of retting method, separating conditions; storage conditions; age of fibres and type surface treatment. The mechanical mixing of the concrete’s constituent materials increased the distribution of fibres, thereby creating homogeneity of the mixture. This helps to enhance the concrete’s flexural strength, reduce the water absorption rate, and improves the concrete tensile strength. Dahunsi (2000) reported that cement matrices reinforced with natural materials have been adapted to various uses such as construction of reservoirs, pipes, floors and concrete covers.

![Figure 9: Effect of fibre volume and length on concrete water absorption rate](image)

**CONCLUSION**

This study was carried out to investigate the effect of raffia palm fibre volume and length on some mechanical (flexural strength, flexural modulus, density and water absorption) of concrete samples. The concrete samples were prepared and tested according to ASTM recommended standards. Results obtained from the study showed that the mechanical properties of the concrete were highly dependent on the fibre volume. Flexural strength of the concrete decreased from 5.56 MPa in the control (unreinforced) concrete to 2.28 MPa in the concrete reinforced with 3% (30 mm) raffia palm fibre. Similarly, the flexural modulus decreased linearly from 920.91 MPa in the control concrete to 153.15 MPa in the concrete reinforced with 3% fibre. In contrast, the water absorption of the concrete increased with increase in the fibre volume and length. At 0% fibre volume, the water absorption rate was 8.14%, which increased to 12.78% as the fibre volume and length increased to 3% and 30 mm. Results obtained from this study showed the prospects of utilizing raffia palm fibres at low volume reinforcement, in building components that are not exposed to high moisture levels. Flexural strength will however be impaired but ductility is improved.

**REFERENCES**


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