Flexural Strength Properties of Slurry Infiltrated Fibrous Concrete (SIFCON) Beams using Miraculous Berry (*Thaumatococcus daniellii*) Fiber as Reinforcement

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Abstract - This study investigated the flexural characteristics of slurry infiltrated fibrous concrete made with miraculous berry fiber (thaumatococcus daniellii) thereby assessing its potentials as a replacement for steel reinforcing material for economical construction methods. The stems of the miraculous berry plant were collected, freed of their inner central pith with their hard bark remaining, which are the fibers. They were sun-dried, cut in sizes of 400 mm and 80 mm to fit into 100 x 100 x 500 mm beam molds. The fibers were infiltrated with cement slurry at the tension zone of the beams to 10 mm, 20 mm and 30 mm thicknesses and filled up with 90 mm, 80 mm and 70 mm thickness of concrete. Plain concrete beams without cement slurry and fiber were cast to act as control. The fiber was subjected to tensile test and the cast beams to flexural strength examinations. The result showed that the miraculous berry fiber possessed a tensile strength of 48.38 MPa and the height and volume of the slurry infiltration significantly influence the failure loads that caused deflection, cracking and ultimate failure.

Keywords: Flexural Strength, Ultimate Tensile Strength, Slurry Infiltrated fibrous concrete, Miraculous Berry

1. Introduction

The high cost of building materials in Nigeria is hindering economic construction and making it difficult for individual to own their buildings. Attempts have been made to source for new relatively cheaper and locally available materials in order to bring down the cost of constructions in the country. These materials are of course expected to perform satisfactorily in the use for which they are intended. Therefore, materials selection is an essential stage in any engineering design. Concrete, being the most versatile heterogeneous construction material and the impetus of infrastructural development of any nation [1], its combination with steel as reinforcement in infrastructural developments cannot be over emphasized.

Concrete has appreciable strength in compression but very weak in tension. Due to its weakness in resisting tensile forces, reinforcement is incorporated to complement its good compressive properties. Steel is the most common reinforcing material and it is quite expensive, though available in the market in various sizes.

In order to achieve an economic infrastructural development, a reduction in the cost of construction materials for concrete must be designed. This could be actualized through partial or total replacement of the convectional materials with new initiatives. Many attempts in the past had been made towards achieving reduction in the cost of engineering projects and building structures through researches in the areas of local replacement or substitute for the constituents of the reinforced concrete. The use of maize cobs, rice husk, periwinkle shell, saw dust have been investigated as partial replacement for cement and aggregates, while fiber-glass, bamboo, rattan, and several other materials were investigated as reinforcing bars in concrete [1]-[30].

Olutoge [2],[3] referred to plain concrete as possessing a low tensile strength, limited ductility and little resistance to cracking. Internal micro-cracks which are inherently present in plain concrete develops even before loading, particularly due to volume change or drying shrinkage, and the poor tensile strength of concrete may be due to the propagation of such micro cracks eventually leading to brittle fracture of the concrete. He further stated that the addition of small, closely spaced fiber will substantially improve its static and dynamic properties.

Slurry Infiltrated Fiber Concrete (SIFCON) was developed by David Lamkard in 1979 as a high strength impact resistant material, which could be considered as a special type of fiber concrete with high fiber content. This composite can be considered as a special fiber reinforced concrete. Normally, fiber reinforced concrete contains 1-3% fiber by volume, whereas SIFCON contains 6-20% of fibers. The other major difference is in the composition of the matrix. In SIFCON, the matrix is made of flowing cement mortar slurry as opposed to aggregate concrete in normal fiber reinforced concrete. The casting process is also different for SIFCON. In most cases, SIFCON is fabricated by infiltrating a bed of pre-placed fibers with cement slurry. Slurry Infiltrated Fiber Concrete (SIFCON) composites possess outstanding strength, ductility, and crack/spall resistant properties [31]-[33]. Lankard [31] presented the basic properties of SIFCON (prepared with 12.5% of fibers) such as load-deflection curve, ultimate compressive and flexural strengths, impact and abrasion resistance. [32] Presented the shear response of dowel reinforced SIFCON. They observed that the shear strength of SIFCON is 10 times higher than that of the plain matrix. The behavior of reinforced concrete beams with SIFCON matrix was studied by [32], and reported that use of SIFCON eliminates the need of shear stirrups in RCC beams.

Thaumatococcus daniellii is a plant species from Africa, known for being the natural source of thaumatin, an intensely sweet protein which is of interest in the development of sweeteners. It is a large, rhizomatous, flowering herb native to the rainforests of western Africa from Sierra Leone to Zaire. It is also an introduced species in Australia and Singapore. *Thaumatococcus daniellii* grows three to four meters in height, and has large, papery leaves up to 46 centimeters long. It bears pale purple flowers and a soft fruit containing a few shiny black seeds. The fruit is covered in a fleshy red aril, which is the part that contains thaumatin. In its native range, the plant has a number of uses besides flavoring. The sturdy leaf petioles are used as tools and building materials, the leaves are used to wrap food, and the leaves and seeds have a number of traditional medicinal uses. Common names for this species include 'miracle fruit or miracle berry', 'katamfe or katempfe', 'Yoruba soft cane', 'African serendipity berry' and 'Ewe Eeran' [34].

2. Materials

Ordinary Portland cement of grade 32.5 was used in this study. Sharp river sand and well graded crushed granite of 12.5 mm effective grain size conforming to BS 882 [35] were used for the fine and coarse aggregates respectively and subsequently mixed at a water-cement ratio of 0.45 in accordance with BS 1881 [36]. While, the miraculous berry (*Thaumatococcus daniellii)* were sourced and uprooted from south western Nigeria. The leaves and the root were removed, leaving the stems. The stems were now freed of their soft central pith with the hard bark remaining, which were in strands. The strands were collected together, folded and sun-dried to reduce the moisture content to the nearest minimum. The strands [the fibers] were now cut in 400 mm and 80 mm sizes as shown in Figure 1 below.

Fig. 1. Miracoulus Berry **(***Thaumatococcus daniellii)*** Fiber

3. Experimental Investigations

3.1 Tensile Strength Examination of the fiber

Veneer caliper was used to measure the width and the thickness of the *Thaumatococcus daniellii* fiber, while its tensile strength was investigated using the Hounsfield Tens fomenter as presented on figure 2. The breaking point was recorded as the ultimate tensile strength of the fiber.

Fig. 2. Tensile Strength Test of Miraculous Fiber

3.2 Sampling and Specimen Preparation

Twelve 100 x 100 x 500 mm beam specimens were produced from four samples of concrete with a mix proportion of 1:2:4. Each of the four samples (A-D) had three specimens each, while results of their average of the three specimens were recorded for their flexural examinations. Sample A had 10 mm thick fiber infiltrated cement slurry; Sample B had 20 mm thick fiber infiltrated cement slurry. Sample C had 30 mm thick fiber infiltrated cement slurry, while Sample D which served as the control contained plain concrete without fiber reinforcement and the cement slurry. The fibers were laid on a thin layer of cement slurry in a mat form, the shorter ones (40 mm) over the longer (400 mm) ones before the cement slurry was poured or infiltrated to make a bottom layer of 10 mm, 20 mm and 30 mm thickness for each of the samples A-C respectively. Of course the cement slurry used in this work was pure Portland cement and water mixed to form thick slurry.

Fig. 3. SIFCON Beam Sample Preparation

4. Experimental Results

4.1 Tensile Strength Examination

$$\text{Tensile stress} = \frac{\text{Load}}{\text{Area}}$$

Width of fiber = 5.0 mm

Thickness of fiber = 0.4 mm

Total load at breaking point

= 21. 75 lbs. (96.75 N)

Area = 0.4 mm x 5.0 mm = 2.0 mm^2

Ultimate Tensile Stress = Load /Area
= 96.75/2 = 48.38 Nmm^{-2}

However, this material could be classified as an isotropic material with Ultimate Tensile Strength of the fiber was 48.38 MPa which ranged between 8.80 - 12% of the ultimate tensile strength of mild steel which ranges between 400 – 550 MPa [37] and can thus be used for the as it will still impact some tensile properties to concrete structural elements.

4.2 Flexural Examination

The results of the flexural examinations as shown in figure 3 indicated the failure load of beams increases with curing age and volume of the slurry infiltration, while the control sample which had no SIFCON had the lowest resistance to tensile stress. Figure 4 and 5 shows the deflections and crack widths of the beam samples. The deflections were the same for 10% and 20% SIFCON, beams but lower for 30% SIFCON beams, while the crack width in the 10% SIFCON beams were higher than those of 20% and 30% which were the same. The control sample showed the lowest deflection before failure and has the widest crack width. This justifies the fact that SIFCON beams had higher tensile strength potentials than the plain concrete beams.

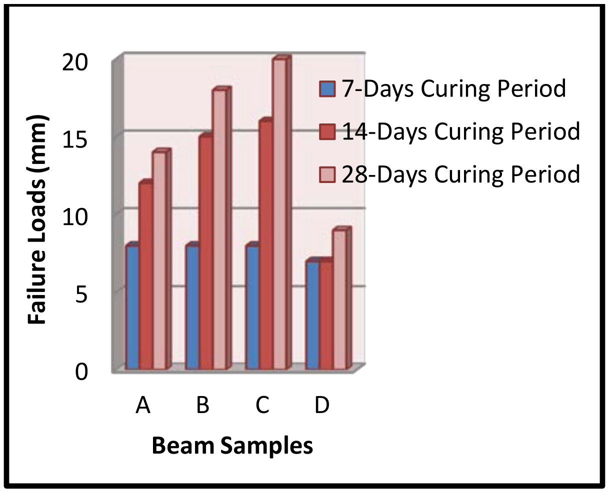

Fig. 4. Failure loads of SIFCON Beams

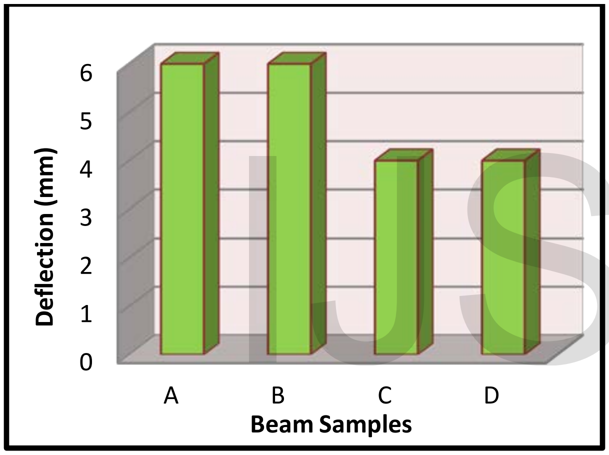

Fig. 5. Deflection of SIFCON Beams

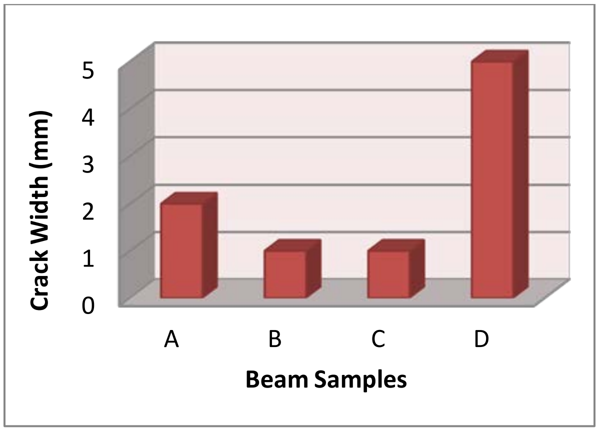

Fig. 6. Crack width of SIFCON Beams.

5. Conclusion

Fiber obtained from the stem of miraculous berry plant could be cheaply used and incorporated into concrete as replacement for steel reinforcement in lightweight concrete works when compared to plain concrete which has a lower tensile strength property.

References

[1] Olafusi, O.S. and Olutoge, F.A. (2012) Strength Properties of Corn Cob Ash Concrete. *Journal of Emerging Trends in Engineering and Applied Sciences* (*JETEAS*), 3, 297-301

[2] Olutoge F.A (2010) Investigations on Sawdust and Palm Kernel Shells As Aggregate Replacement, ARPN Journal Of Engineering And Applied Sciences Vol. 5. No. 4.

[3] Olutoge F.A (2010) The Use of Rice Husk Ash as a Partial Component in Reinforced Concrete Slabs for Real Estate Development: Real Estate and Development Economics Research Journal (Reader Journal), University of Wolverhampton, U.K. Vol. 2, pp. 87-106.

[4] Rukzon, S. and Chindaprasirt, P. (2014) Use of Rice Husk-Bark Ash in Producing Self-Compacting Concrete. *Advancesin Civil Engineering*, 2014, Article ID: 429727.

[5] Elinwa, A.U. and Mamuda, A.M. (2014) Sawdust Ash as Powder Material for Self-Compacting Concrete Containing Naphthalene Sulfonate. *Advances in Civil Engineering*, 2014, Article ID: 129276.

[6] Adewuyi, A.P. and Ola, B.F. (2005) Application of Waterworks Sludge as Partial Replacement for Cement in Concrete Production. *Science Focus Journal*, 10, 123-130.

[7] Adewuyi, A.P. and Adegoke, T. (2008) Exploratory Study of Periwinkle Shells as Coarse Aggregates in Concrete Works. *Journal of Engineering and Applied Sciences*, 3, 1-5.

[8] Olutoge, F.A (1995): A Study of Saw Dust, Palm Kernel Shell And Rice Husk Ash As

Full/Partial Replacement For Sand, Granite, and Cement In Concrete: Unpublished M.Sc Thesis, Department of Civil Engineering, University Of Lagos Nigeria

[9] Olutoge F. A., Quadri H. A. and Olafusi O. S. (2012) Investigation of the Strength Properties of Palm Kernel Shell Ash Concrete, Engineering, Technology and Applied Science Research Vol. 2, No. 6, 315-319.

[10] Olutoge F.A., Bhashya V., Bharatkumar B.H., and Sundar Kumar S. 2010. Comparative Studies on Fly Ash and GGBS High Performance Concrete, Proceeding of National Conference on Recent Trend and Advance in Civil Engineering-TRACE2010

[11] Olanipekun E. A. (2006) A Corporative Study of Concrete Properties Using Coconut Shell and Palm Kernel Shell as Coarse Aggregates, Journal of Building and Environment 41(3): 297-301.

[12] Olutoge F. A. (2006) Structural characteristics of Bamboo (Bambusa Vulgaris) as reinforcement in concrete slabs. Unpublished University of Ibadan Ph.D Thesis.

[13] Adewuyi, A.P., Otukoya A.A., Olaniyi O. A. and Olafusi O. S. (2015) Comparative Studies of Steel Bamboo and Rattan as Steel Reinforcing Bars in Concrete: Tensile and Flexural Characteristics. *Open Journal of Civil Engineering*, 5, 228-238. http://dx.doi.org/10.4236/ojce.2015.52023

[14] Nawy, E.G., Neuwerth, G.E. and Phillips, C.J. (1971) Behavior of Fiber Glass Reinforced Concrete Beams. *Journal of the Structural Division*, 97, 2203-2215.

[15] Nawy, E.G. and Neuwerth, G.E. (1977) Fiberglass Reinforced Concrete Slabs and Beams. *Journal of the Structural Division*, 103, 421-440.

[16] Kankam, J.A., Ben-George, M. and Perry, S.H. (1988) Bamboo-Reinforced Beams Subjected to Third-Point Loading. *ACI Structural Journal*, 85, 61-67.

[17] Kankam, C.K. (1997) Raffia Palm-Reinforced Concrete Beams. *Materials and Structures*, 30, 313-316. http://dx.doi.org/10.1007/bf02486356

[18] Kankam, C.K. (1994) The Influence Of Palm Stalk Fiber Reinforcement on the Shrinkage Stresses in Concrete. *Journal of Ferrocement*, 24, 3-12.

[19] Falade, F.A. and Akeju, T.A.I. (2002) The Behaviour and Analysis of Bamboo Reinforced Concrete under Flexural Loading. *Proceedings of the Fifth International Conference on Structural Engineering Analysis and Modeling*, Accra, 26-28 March 2002, 277-288.

[20] Falade, F.A. and Akeju, T.A.I. (2002) Structural Design and Economy of Bamboo Reinforced Concrete Beams. *Proceedings of the Fifth International Conference on Structural Engineering Analysis and Modeling*, Accra, 26-28 February 2002, 215-228.

[21] Chembi, A. and Nimityongskul, P. (1989) A Bamboo Reinforced Cement Water Tank. *Journal of Ferrocement*, 19, 1-17.

[22] Ghavami, K. (1995) Ultimate Load Behaviour of Bamboo-Reinforced Lightweight Concrete Beams. *Cement and Concrete Composite*, 17, 281-288. http://dx.doi.org/10.1016/0958-9465(95)00018-8

[23] Kankam, J.A., Ben-George, M. and Perry, S.H. (1986) Bamboo-Reinforced Concrete Two-Way Slabs Subjected to Concentrated Loading. Structural Engineering, 64, 85-92.

[24] Alade, G.A., Olutoge, F.A. and Alade, A.A. (2004) The Durability and Mechanical Strength Properties of Bamboo in Reinforced Concrete. Journal of Applied Science, Engineering and Technology, 1, 35-40.

[25] Akeju, T.A.I. and Falade, F.A. (2001) Utilization of Bamboo as Reinforcement in Concrete for Low-Cost Housing. Proceedings of the International Conference on Structural Engineering, Mechanics and Computation, Cape Town, 2-4 April 2001,

1463-1470. http://dx.doi.org/10.1016/B978-008043948-8/50164-8

[26] Mahzuz, H.M.A., Ahmed, M., Uddin, M.K., Hossain, M.M. and Saquib, N. (2013) Determination of Tensile Stress and Bond Stress with Concrete of a Rattan (Calamus guruba). Scholars Journal of Engineering and Technology, 1, 39-43.

[27] Ghavami, K. (2005) Bamboo as Reinforcement in Structural Concrete Elements. Cement & Concrete Composites, 27, 637-649. http://dx.doi.org/10.1016/j.cemconcomp.2004.06.002

[28] Youssef, M.A.R. (1976) Bamboo as a Substitute for Steel Reinforcement in Structural Concrete. In: Fang, H.Y., Ed., *New Horizons in Construction Materials*, Envo Publishing Co., Leligh Valley, 525-554.

[29] Akinyele, J.O. and Olutoge, F.A. (2011) Properties of Rattan Cane Reinforced Concrete Façade Subjected to Axial Loading. *Journal of Civil Engineering and Architecture*, 5, 1048-1052.

[30] Obilade, I.O. and Olutoge, F.A. (2014) Flexural Characteristics of Rattan Cane Reinforced Concrete Beams. *International Journal of Engineering and Science*, 3, 38-42.

[31] David R. Lankard (1984). Slurry Infiltrated Fiber Concrete (SIFCON): Properties and Applications. MRS Proceedings, 42, 277 doi:10.1557/PROC-42-277.

[32] Naaman A. E. and Baccouche M. R.(1995), ACI Structural Journal, 92 pp. 587

[33] H. Sudarsana Rao and N.V. Ramana (2005), 'Behavior of Slurry Infiltrated Fibrous Concrete (SIFCON) simply supported two-way slabs in Flexure'. Indian Journal of Engineering and Materials Sciences. Vol.12, pp. 427-433

[34] Retrieved from https://en.wikipedia.org/wiki/Thaumatococcus_daniellii on Thursday 23rd July, 2015

[35] BS 882 (1992) Specification for Aggregates from Natural Sources for Concrete. British Standards Institution, London.

[36] BS 1881 (2013) Testing Concrete. Methods for Mixing and Sampling Fresh Concrete in the Laboratory, Part 125. British Standards Institution, London.

[37] ASTM A36 / A36M-14, Standard Specification for Carbon Structural Steel, ASTM International, West Conshohocken, PA, 2014.