J. Mater. Environ. Sci. 6 (12) (2015) 3634-3642 *Awoyera et al.*
ISSN : 2028-2508
CODEN: JMESCN

Influence of Steel and Bamboo Fibres on Mechanical Properties of High Strength Concrete

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Received 03 Apr 2015, Revised 14 Aug 2015, Accepted 16 Aug 2015
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Abstract
This paper evaluated the influence of steel and bamboo fibres on high strength concrete. Samples of concrete cubes, beams and cylinders cast with varying proportions of steel and bamboo fibres were subjected to compression, flexural and splitting tensile strength tests respectively. A total of sixty three cubes of 100mm x 100mm x 100mm, fourteen beams of 100mm x 100mm x 500mm, and cylinders of diameter 100 mm and length of 150 mm were tested. The results revealed that concrete containing 1.0% bamboo fibre produced the greatest effect on flexural strength (81% increase in strength), and also on splitting tensile strength (101% increase). However, it was discovered that bamboo fibre has little or no impact on the compressive strength of high strength concrete. Steel fibre-reinforced concrete generally produced an appreciable increase in compressive, flexural and splitting tensile strengths than the bamboo fibre-reinforced concrete.

Keywords: steel fibres, bamboo fibres, high strength concrete, flexural strength, compressive strength, split tens ile trength

Introduction
Reinforced concrete production generally involves a systematic reinforcing with steel to form a composite material, so as to complement the undesirable properties in concrete and steel. Concrete is known to be strong in compressive strength but very limited in tensile strength, and vice versa is the case for steel. Moreover, the conventional steel-reinforced concrete construction is widely used all over the world and as a result there is scarcity and also increased production costs due to depletion of the natural sources of materials [1]. These impediments have driven enormous development in the built environment for creation of contemporary concrete technologies such as: the use of waste and local materials for concrete production or perhaps for its property improvements. Consequently, investigations by scholars have revealed sustainable materials which could substitute or replace the natural materials. Waste tyres, steel slag and recycled concrete have been suggested as replacement for natural coarse aggregate [2-4]; laterite, pulverised plastics, saw dust, waste paper, sheet glass powder and crushed granite fines for fine aggregates [5, 6]; rice husk ash, wood ash, fly ash, and bagasse ash for cement [7-9]. Importantly, conventional reinforcements are also being replaced with local fibre materials in concrete making. Shende and Pande [10] studied the mechanical properties of steel fibre reinforced concrete, it was revealed that compressive strength, split tensile strength and flexural strength increases with increasing fibre contents for the percentages of fibre considered. Nataraja [11] investigated the splitting tensile strength of steel fibre reinforced concrete (SFRC) using a typical 100 mm cube specimen. The results of flexural, compression and splitting tensile tests indicated that the splitting tensile strength of SFRC was 0.67

times the flexural strength, and 0.09 times the compressive strength. Fibre-reinforced concrete can be used to improve the performance of concrete structural members such as deep beams, columns and floors on grade in terms of crack-reduction, toughness and ductility [12]. Similarly, Lee [13] discovered that a larger volume of longer fibres would give better mechanical performance to concrete if it is uniformly distributed. However, there could be an increased problem of workability and uniform distribution with increasing volume and length of fibres. Also, researchers have investigated bamboo as a viable replacement for steel in reinforced concrete. Bamboo is a natural perennial grass-like composite, and is one of the fastest growing woody plants in the world. According to Chu [14], one of the first major studies on the use of bamboo in a cement matrix came as early as 1914. Bamboo as matter of fact could be re-harvested every three years, which would replenish its availability. Chauhan et al. [15] investigated some physical and mechanical properties of bamboo at different age of the bamboo and the height of the Culm.

Considering its engineering characteristics as reinforcement in concrete, only few research have been done in this regard. Moroz et al. [16] researched the performance of bamboo reinforced concrete masonry shear walls, it was revealed that the addition of vertical bamboo reinforcement provided additional shear capacity, while also giving a relatively ductile failure compared to unreinforced masonry. In another related study, Wu and Zongjin [17] articulated that bamboo could be utilized as reinforcement in cementitious composites due to its superior properties like high strength to weight ratio, high tensile strength and other factors like low cost, easy availability and harmless to the environment during service.

Many other application of bamboo includes its use in the construction of water tanks as reported by [18, 19]. On the other hand, Ghavami [20] utilized bamboo as reinforcement for production of lightweight concrete beams and it was understood from his study that bamboo provides an improved results.

Adom-Asamoah and Afrifa [21] in their study of the shear strength of bamboo reinforcement concrete revealed that concrete members reinforced with sections of bamboo culms, which had been split along their horizontal axes, developed considerably higher load capacities than unreinforced concrete beams of similar sections.

In addition, Satjapan [22] investigated the Compressive strength and ductility of short concrete columns reinforced with bamboo. It was revealed that 1.6 % of steel reinforcement in a column cross-section could be replaced by 3.2% of treated reinforcing bamboo in order to achieve similar behaviour, strength and ductility.

However, most of the available literatures dwelt more on the normal use of steel and bamboo fibres in concrete, but none has considered their use for production of high strength concrete.

Hence in order to ascertain the variation in mechanical properties of steel and bamboo fire-reinforced concretes, this study was aimed at evaluating influence of steel and bamboo fibres on the flexural, splitting tensile and compressive strengths of high strength concrete.

2. Materials and methods

2.1. Materials

The materials used for this investigation were locally sourced with the exception of the steel fibre which was imported. The materials used in the concrete mix include the following:

Ordinary Portland cement, Fine aggregate, Coarse aggregate, Water, Steel fibre, Bamboo fibre, Super-plasticizer. River sand was used as fine aggregate and granite crushed stone aggregates of maximum size 20 mm were used as coarse aggregate. The steel fibres used were the hooked-end type, 25 mm long and 0.38 mm in diameter (aspect ratio 65.79) with a density of 7947 kg/m^3; as shown in Figure 1. A fibre content of 60 kg/m^3 (0.75% by volume of concrete) was adopted and maintained throughout the investigations.

Bamboo cums were obtained from the rain forests of South-West Nigeria. These were cut into small relatively uniform strips using a sharp knife. The dimensions of the strips were measured with the aid of Vernier Callipers. The bamboo fibres were 38.44 mm long and 1.8mm diameter (aspect ratio 21.36) with a density of 500 kg/m^3. Figure 2 presents the bamboo fibres used.

Super plasticizer was used in order to improve the workability of the concrete mix without increasing water demand, minimize segregation and bleeding, and to achieve major increases in strength at early ages without increasing cement content. CONPLAST SP 430 super plasticizer admixture having a specific gravity of 1.2 was used.


Figure 1. Steel Fibres used (Hooked-end type) [23]


Figure 2: Bamboo material used

2.2. Mix Design

The concrete mix was designed in accordance with [24] method. Several trial mixes were prepared and slump determined before the final mix proportions and required amount of super plasticizer for acceptable slump could be established. A water – cement ration of 0.4 was maintained for all mixes. To compensate for the reduced workability at higher volumes of steel fibre, the percentage of super plasticizer by weight of cement used was increased from 0.25% for concrete without fibre to 0.35% for concrete with fibre. The design mix obtained was 1:1.7:2.5. The equivalent weights of the materials are: Cement (425 kg), Sand (722 kg), Granite (1083 kg) and Water (170 kg).

Tables 1 and 2 present the description of mixes and summary of design mix proportions respectively.

Table 1: Description of Mixes

Mix No	Mix ID	Description
1	G	0% fibre
2	1	0.5% steel fibre
3	F	0.75% steel fibre
4	2	1% steel fibre
5	B1	0.5% bamboo fibre
6	B2	0.75% bamboo fibre
7	B3	1% bamboo fibre

Quantities	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (Kg)
Per m^3 of concrete	525	637	1039	210
Per $0.005m^3$ of concrete (trial mix)	2.63	3.19	5.20	1.05

Based on trial mixes, the design mix was adjusted to obtain an optimum mix. The final optimum mix used is as presented in Table 3.

Table 3: Final Mix Proportions

Quantities	**Cement (kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**Water (Kg)**
Per m^3 of concrete	425	722	1083	170

The total volume of concrete for each mix was calculated based on the number of samples to be cast per mix as presented below:

A. Cubes (0.1m x 0.1m x 0.1m)

Vol. of cube = 0.1m x 0.1m x 0.1m = $0.001m^3$
No. of samples = 9
Total vol. of cubes per mix = 9 x 0.001 = 0.009 m^3

B. Cylinders (0.1m dia. x 0.15m long)

Vol. of cylinder = $0.001m^3$ = $0.00118m^3$
No. of samples = 2
Total vol. of cylinders per mix = 2 x 0.00118 = 0.00236 m^3

C. Beams (0.1m x 0.1m x 0.5m)

Vol. of beam = 0.1m x 0.1m x 0.5m = 0.005 m^3
No. of samples = 2
Total vol. of beams per mix = 2 x 0.005 = 0.010 m^3
Total = 0.009 + 0.00236 + 0.010 m^3 = 0.02136 m^3
Add 30% for slump test and waste = 0.00641 m^3
Total volume of concrete per mix = 0.02136 + 0.00641 m^3
= 0.0278 m^3

2.3. Sample Preparation

A total of 63 cubes, 14 cylinders and 14 beams were cast for this study. The cubes were of dimension 100 mm x 100 mm x 100 mm, the beams were 500 mm long and 100 mm x 100 mm in cross section while the cylinders were 100 mm in diameter and 150 mm long.

Manual method of mixing was employed on a clean batching bay. The concrete ingredients were mixed manually on a plain surface. The fine aggregates (cement and sand) were first poured on the plain surface and mixed thoroughly in the dry state until homogeneity was achieved. The coarse aggregates were then added and mixed properly with the fine aggregates after which the fibres were added to the mix. Water was then added along with the required dosage of super plasticizer to improve workability of the mix. This procedure was followed for all of the mixes.

Figure. 3: Moulds for concrete cubes and beams

After about five minutes of thorough mixing, the freshly mixed concrete was filled into rigid plywood moulds for the cube and beam samples, and into PVC plastic moulds for the cylinder. The moulds were coated with diesel oil prior to filling in order to enhance easy removal of the samples. Placement of the concrete into the moulds was carried out in three layers and a standard tamping rod was used to ensure adequate compaction of the concrete. A steel hand trowel was used to finish the top surface after tamping.

2.4. Testing

The samples were removed from the moulds after 24 hours and kept in a curing tank at 32 ± 2^{o}C until testing. The samples were tested in the laboratory at 7, 21 and 28 days.

For the compressive strength tests, a total of 63 cubes samples of 100mm x 100mm x 100mm each were cast. Three each were tested to determine the compressive strength at 7, 21 and 28 days of curing.

In accordance with the requirements of [25], the cube, while still wet, was placed with the cast faces in contact with the platens of the testing machine, that is, at right angles to the direction of casting. The load on the cube was applied at a constant rate of stress at about 0.4 N/mm^2 second. The compressive strength was reported to the nearest one decimal place.

Also for the Flexural Strength test, a total of 14 beam samples of 100 mm x 100 mm x 500 mm each were cast. Two each were tested to determine the flexural strength at 28 days of curing. The flexural test was performed in alignment with the procedures of [26, 27] using the centre-point loading method. According to standard procedure, the beams were placed so that the reference direction of loading was perpendicular to the direction of casting. Deformation was measured at the centre point of the beams. The flexural strength (or Modulus of Rupture) is the maximum tensile stress in the beam at peak load given by the equation:

$$\boldsymbol{\sigma = \frac{PL}{BH^2}} \qquad (1)$$

Where: P = Peak load, in Newton, L = Beam span length, in millimetres, B = Beam width, in millimetres, H = Beam height, in millimetres.

Lastly, splitting tensile strength test was performed on the cast cylinder samples after 28 days curing. The test was conducted according to the provisions of [28]. The samples were loaded centrally along their length until failure. Loading was applied at a constant rate by the testing machine. The splitting tensile strength of each sample is given by:

$$\boldsymbol{f_{ct} = \frac{2F}{\pi LD}} \qquad (2)$$

Where:
fct = tensile splitting strength, in Megapascals
F = maximum load, in Newtons
L = Length of the sample, in millimetres
D = Diameter of sample, in millimetres

3. Results and discussion

3.1. Compressive Strength of Cubes

The results of compressive strength of the concrete cubes are shown in Figure 4. It was realised that the concrete reinforced with steel fibre has the highest compressive strength followed by the plain concrete (without any fibre). The concrete with bamboo fibre has the lowest compressive strength. This development could be attributed to the fact that steel fibres reduce permeability, cracks and also improves ductility of concrete [23].

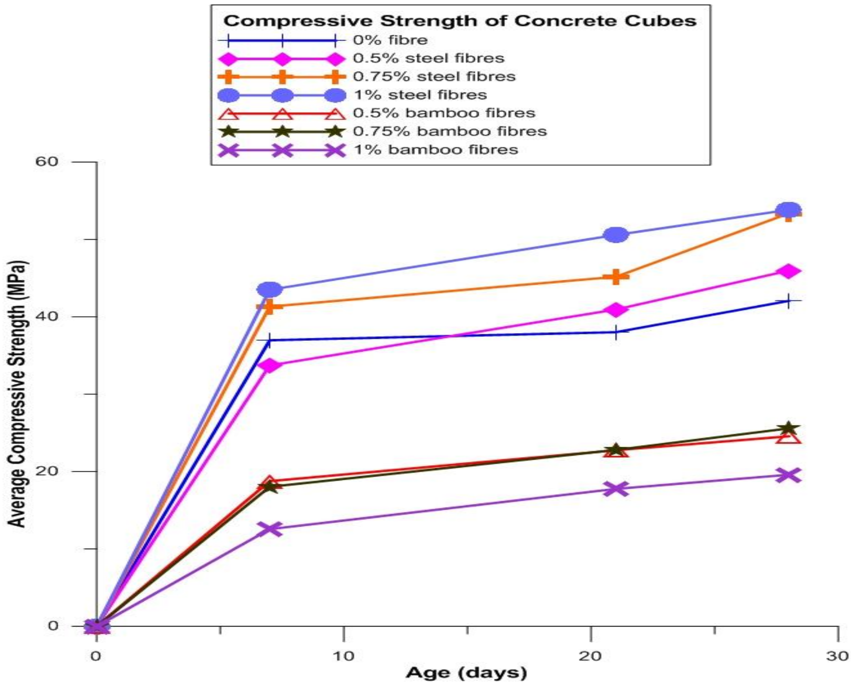

Figure 4: Compressive Strength plot against age of concrete cubes

The compressive strength of steel fibre reinforced concrete is seen to increase with volume of fibre, rising from 45.97MPa for 0.5% fibre volume to 53.83MPa for 1.0% fibre volume at 28 days. Hence, addition of 1.0% fibre produced a 28% increment in compressive strength of the plain concrete. Bamboo fibre did not produce a similar effect as the compressive strength of the concrete was reduced when the fibre was added. Furthermore, increments in the volume of bamboo fibre did not produce corresponding increase in the concrete compressive strength. There was little or no marginal increase in the compressive strength of the concrete when bamboo fibre volume was increased from 0.5% to 0.75%; and there was considerable reduction in concrete strength upon increasing the fibre volume to 1.0%. This suggests that increase in volume of bamboo fibre in concrete has little effect on the compressive strength of concrete and only up to a certain percentage after which further addition of fibre may result in reduced strength.

3.2. Flexural Strength

The flexural strength of the concrete is highest for Bamboo fibre reinforced concrete (14.21 MPa for concrete with 1.0% bamboo fibre content). This is closely followed by the 0.75% of Bamboo fibre reinforced concrete (12.35 MPa) while plain concrete has the least flexural strength. Figure 5 shows the load – deflection curves for different mixes and figure 6 shows the results of the flexural strength tests.

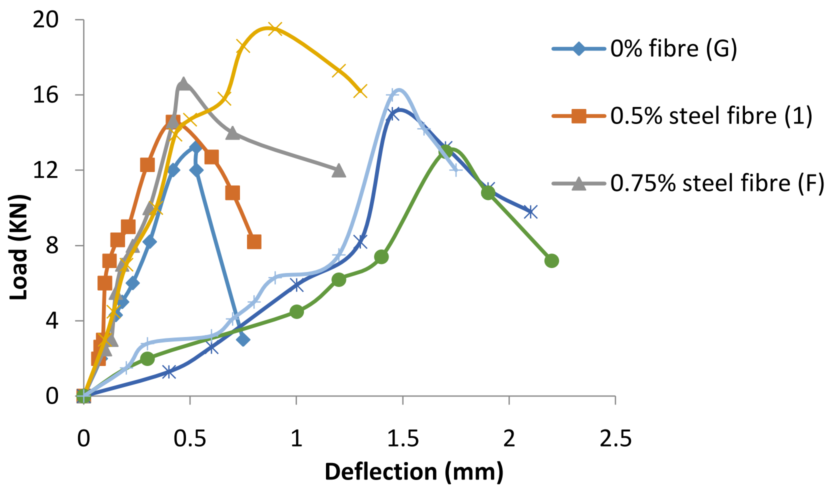

Figure 5: Load – Deflection curves for concrete beams

A sample computation of the flexural strength is shown below using the equation:

$$\boldsymbol{\sigma = \frac{3PL}{2BH^2}} \qquad (3)$$

Where: σ = Flexural strength in Megapascals, P = Peak load, in Newtons, L = Beam span length = 500 mm B = Beam width = 100mm, H = Beam height = 100mm.
For sample no. 1, Mix 1 with peak load of 12.80kN, flexural strength is 7.68 N/mm^2.

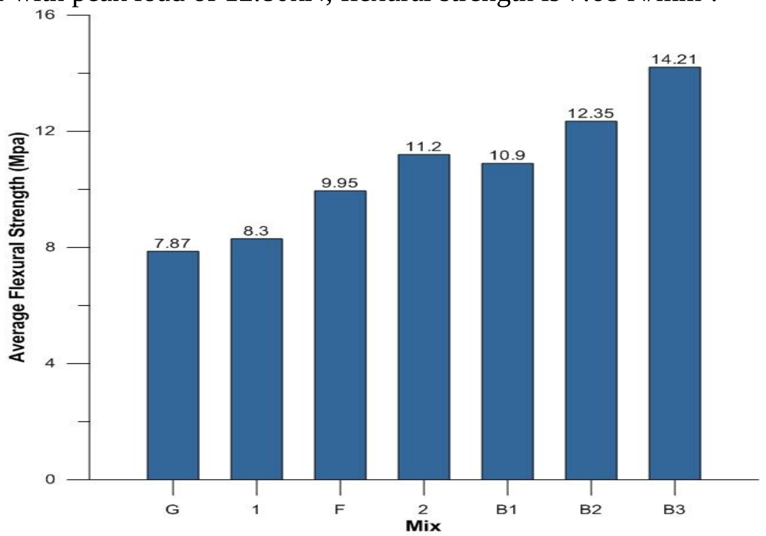

Figure 6: Flexural strengths of the different mixes

Deflection is however greatest in bamboo-fibre-reinforced beams compared to beams with steel fibre and beams without any fibre. For both steel and bamboo fibres, the flexural strength increases with the volume of fibre in the concrete, although there is little difference between the strength of beams with 0.5% bamboo fibre and those with 0.75% bamboo fibre.
Addition of 1.0% steel fibre increases the flexural strength of the concrete by 42.3% as against 81% increase for addition of 1.0% bamboo fibre.
This showed that even after the concrete had failed in tension, the fibres still hold the concrete together, thereby preventing total failure of the beam. It was inferred that high fibre content prevents cracks in the concrete, thus allowing even greater load to be sustained than in beams with lower fibre contents. The load-deflection curves confirm the positive contribution of fibres to concrete flexural strength. The plain concrete beam fails almost immediately the ultimate load is reached (hence the sharp descent of the curve) unlike the fibre reinforced concrete which still undergoes further deflection before failing completely.

Failure in all the beams occurred within the middle third span where bending moment is maximum. This shows that there was no horizontal shear failure at the level of loading.

3.3 Splitting Tensile Strength Test

The results of splitting tensile test show that concrete containing 1.0% bamboo fibre produced the highest splitting tensile strength of 8.10 MPa for bamboo fibre- reinforced samples, followed by the 0.75% volume of bamboo. Figure 7 shows the Splitting tensile strengths results of the different mixes.

A sample computation of the splitting tensile strength is shown below using the equation:

$$f_{ct} = \frac{2F}{\pi LD} \quad (4)$$

Where: fct = tensile splitting strength, in Megapascals

F = maximum load, in Newtons

L = Length of the sample = 150 mm

D = Diameter of sample = 100 mm

For sample no. 1, Mix 1 with peak load of 93.70 kN, splitting tensile strength

$$f_{ct} = \frac{2 \, x \, 93.70 \, x \, 1000}{\pi \, x \, 150 \, x \, 100}$$

= 3.98 N/mm^2

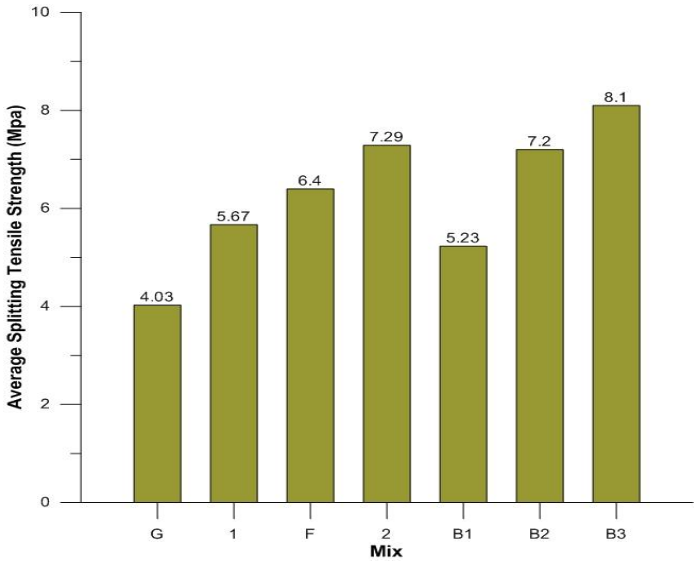

Figure 7: Splitting tensile strengths of the different mixes

Generally, the addition of bamboo fibres seems to have almost the same trend on the splitting tensile strength of concrete as the addition of steel fibre, with similar strength values obtained for corresponding fibre volumes. Furthermore, the splitting tensile strength is seen to increase with increasing fibre content (for both steel and bamboo fibres).

At 1.0% steel fibre volume, the splitting tensile strength of plain concrete is increased by almost 81%. Similarly, at 1.0% bamboo fibre content, the splitting tensile strength of the plain concrete increases by 101% showing that the addition of bamboo fibre makes a significant contribution to the tensile strength of concrete

Conclusion

The influence of steel and bamboo fibres on the mechanical properties of designed high strength concrete has been investigated. The following conclusions were drawn from the study:

i. The results of the research showed that bamboo fibre provides little or no impact on the compressive strength of high strength concrete. However, steel fibre reinforced concrete produced an appreciable compressive strength. This result affirmed the fact that steel fibre improves properties of concrete. It can be deduced that compressive strength reduces with increasing bamboo fibre content. Thus, plain concrete developed compressive strength than bamboo fibre reinforced concrete for all categories of samples tested.

ii. The flexural and splitting tensile strengths of high strength concrete were significantly enhanced by the addition of bamboo fibre. Concrete containing 1.0% bamboo fibre produced the greatest effect on flexural strength (81% increase in strength). This same bamboo fibre content produced the greatest effect on splitting tensile strength (101% increase). The inference from the above is that bamboo fibre may not be suitable for use in high strength concrete since it does not improve the concrete compressive strength.

iii. The results however confirm that the fibre is good for reinforcing concrete subjected to tensile loading as it plays an important role in limiting the propagation of cracks in the concrete and delaying the ultimate failure of the concrete.

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