Evaluation of Stiffness of Concrete Beams Reinforced with Dry and Green Bamboo

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ABSTRACT

This project was conducted to determine the feasibility of bamboo reinforcement for concrete beams as a cheaper alternative to steel for low cost housing. The bamboo selected for use was *Dendrocalamus giganteus*, in both green and dry forms, which was both untreated and uncoated.

Bamboo samples were made; 10 for the dry bamboo and another 10 for the green bamboo. Tensile test was then carried out using the Hounsfield tensometer. These samples were tested under gradual loading administered by the tensometer until failure occurred and the failure load was recorded. It was found out that green bamboo had a higher average value of tensile stress which was 120.0 N/mm^2 whereas that of the dry bamboo was 45.3 N/mm^2.

Pull-out test was also conducted on the bamboo as well as the steel, in order to allow for a comparison. This was done by a pull-out machine in the laboratory. It was found that steel reinforcement was pulled out an average length of 7.75 cm using a force of 23.5 kN while it only took a force of 1 kN to pull out an average length of 6.9 cm of the green bamboo and 7.05cm of the dry bamboo.

Lastly, beams of the same specifications and dimensions were cast, replacing only the tensile reinforcement with bamboo in relation to its tensile strength. This was done so as to enable easy comparison between bamboo and steel. The beams were then tested under a four point loading until failure. The beam with steel reinforcement (control) failed at a load of 38 kN, the beams with green bamboo reinforcement failed at an average load of 25 kN while the beam with dry bamboo failed at a load of 22 kN.

After all the tests conducted, it was concluded that while steel reinforcement performed better under testing, bamboo can potentially be used as a cheaper alternative in concrete beams although further research in the field needs to be conducted.

1.1 Background

It has been observed that the timber demand worldwide is increasing at a speedy rate but the supply is depleting. Bamboo is regularly used for scaffolding, bridges and housing commonly as a temporary exterior structural material. In many regions of the tropics that are over populated, certain bamboo provide the one satisfactory material that is appropriately cheap and ample to meet the great need for economical housing [1].

The fact that it grows speedily means that it absorbs large quantities of CO_2. This in turn means that its cultivation for subsequent use in the building industry would help in reducing the rate of climate change [1].

Research has shown that certain species of bamboo have ultimate tensile strength similar to that of mild steel at yield point and it ranges from 140N/mm^2- 280N/mm^2.

Bamboo can withstand more tension than compression. The fibres run axially and the outer zone is where there are the highly elastic vascular bundles which have a high tensile strength. This tensile strength has been found in some cases to be higher than that of steel. However, constructing connections that are able to convey this tensile strength is not achievable. Axial parallel elastic fibres that have a tensile strength of up to 400 N/mm^2 can be found in the silicated outer skin. This can be compared to extremely strong wood fibres which can withstand a tension up to 50 N /mm^2 [2].

Bamboo, like other woods, changes dimension with change in moisture content. It has been found that bamboo is a hygroscopic material and therefore its moisture content varies with change in humidity and the temperature of the surrounding environment Bamboo can be used to replace reinforcement in building constructions [3].

Bamboo has significant elasticity making it suitable for construction in earthquake prone areas. Due to the low weight of bamboo, it is easily transported and worked therefore making the use of cranes and other big machinery unnecessary [3].

Due to its high content of silicate acid, bamboo is very good at resisting fire. When filled up with water, bamboo can withstand a temperature of 400^0 C while the water inside cooks [3].

The main reason that bamboo is viewed as a temporary material is because it lacks natural durability. It is vulnerable to insect attacks and fungi. It can have a service life of as low as a year when in contact with the ground. Durability of bamboo can be increased considerably by suitable specifications and designs as well as careful use of safe and environmentally friendly preservatives for example boron [4]. Bamboo used as reinforcement absorbs water during the casting and curing of concrete and thus increases in size. Cracking of concrete may occur due to the differential thermal expansion of bamboo in relation to concrete [4].

The shrinkage and swelling of bamboo in concrete, results in a major limitation in the usage of bamboo as a replacement for steel. In order to improve the bond between bamboo and concrete, an effective waterproof treatment is required.

Materials and Methods

Material Sampling and Preparation

Steel, river sand, and course aggregates used in the study were sourced from materials suppliers in Nairobi county. Steel was cut to the specific sizes required in the casting of the beams. No preparation was required for the sand. Two course aggregates sizes 10mm and 20mm and class 32.5R Portland Pozzolana cement Bamboo were used

The bamboo used in this study was the "giant bamboo" specifically the specie *Dendrocalamus giganteus.* Three culms cut approximately 1 m from the ground were acquired, two of which were green and one which was dry. Table 1 summarizes dimensions of the bamboo samples collected for use as reinforcement.

Table 1: Description of the bamboo samples obtained

	Sample A (Green)	**Sample C (Dry)**
Length (m)	8.15	3.1
Diameter, smaller end (cm)	6.75	9.0
Diameter, larger end (cm)	12.7	11.75
Thickness, smaller end (cm)	0.7	0.5
Thickness, larger end (cm)	1.3	1.05

Design of Beams

A conventional control beam of dimensions 100mm width x 180mm depth x 2000mm length was designed to BS 8110 and reinforced using mild steel round bars, 2R12 bars bottom reinforcement, 2 R6 bars top reinforcement, and R6 links @ 150 CTRS.

Based on this control beam the equivalent amount bamboo (based on relative tensile strength of the bamboo, approximately 120 N/mm^2 green bamboo and 45.3 N/mm^2 green bamboo, and steel bars, approximately 250 N/mm^2) was calculated for bamboo reinforced beams. Both steel and bamboo tensile strengths were determined from tensile tests results. Total cross sectional area of green bamboo reinforcement was found to be 3.33%, and dry bamboo 6.89%, of the concrete cross section, compared to the 4% limit of the standard.

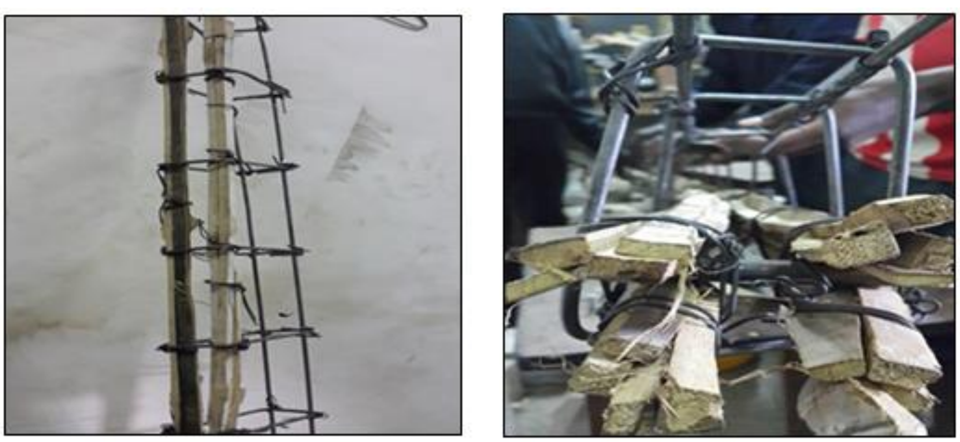

Figure 1: Arrangement of green and dry bamboo reinforcement

Concrete Mix

Class 25 concrete was used in making the beams, Table 2 summarizes he relative quantities of the concrete mix. A total of 9 cubes (150 x 150 x 150mm for concrete compression strength), 2 cylinders (150mm diameter by 300mm height for concrete tensile splitting test), and 4 beams were prepared

Table 2: Concrete mix constitutents

Concrete Constituent	Mass per Cubic Meter (kg)
Aggregate (20mm)	900
Aggregate (10mm)	400
Sand	480
Cement	380
Water	190

Testing

Moisture content of bamboo – Moisture content tests were done on bamboo samples of approximately 40mm. The moisture content was determined the same day that the bamboo culms were cut and brought to the laboratory.

Specific gravity of bamboo - The specific gravity test was carried out immediately after the moisture content test.

Tensile test on bamboo - Tensile test on the bamboo specimens was carried out in the timber laboratory using the Hounsfield Tensiometer. A total of 20 specimens were tested, 10 of dry bamboo and 10 of green bamboo. The specimens were cut in the laboratory to relatively uniform thicknesses ranging from 2-3 mm.

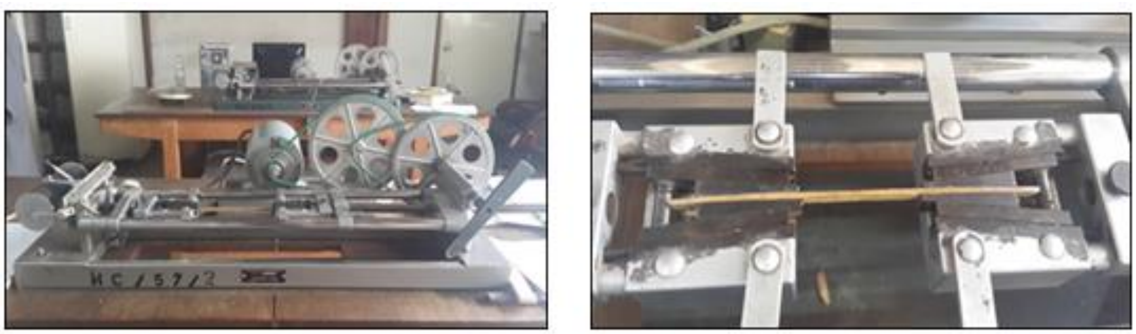

Figure 2: Hounsfield tensiometer

Concrete Slump - The slump test was done according to BS 1881:102-1983 in order to check the workability of the concrete mix [15].

Concrete Compaction Factor - The compaction factor test was done according to BS 1881:103-1993 [16].

Concrete Mechanical Properties - The concrete cubes (3 Nos) and cylinders (2 Nos) were tested at the age of 28 days.

Concrete Beam Test - Four beam samples were cast, three being for bamboo and one for steel as the control. The load on each beam was gradually applied in increments of 5 KN, recording the deflection at the free end for each load increment. The load value at which the first crack occurred as well as the crack pattern was noted and the failure load for each was recorded.

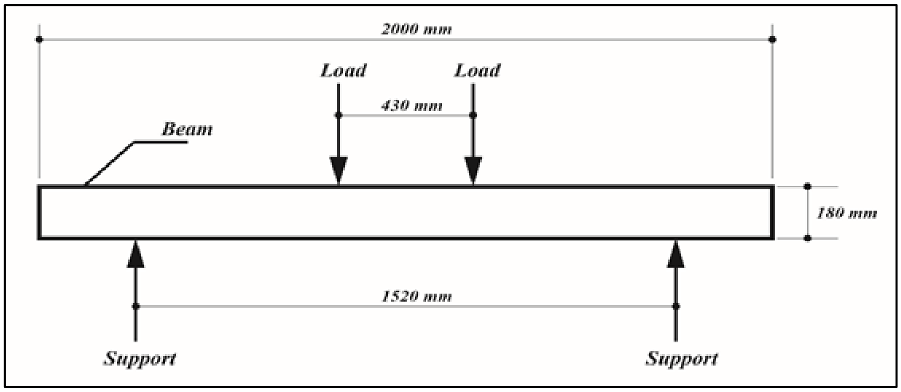

Figure 3: Four point loading beam arrangement

Pull out test - Six cube samples were made for this test, that is, for the dry bamboo, green bamboo and for steel; two samples in each case. The reinforcement were placed centrally in the cube and then the concrete was poured around them as shown in Figure 4. The test was carried out after 28 days of curing.

Figure 4: Pull out test samples and test setup

Results and Discussion

Moisture content of bamboo

Moisture content of the bamboo determined as given in Table 3

Table 3: Moisture content of the bamboo samples obtained

Bamboo Sample	Average Moisture Content (%)
Green	41.08
Dry	23.87

From these results green bamboo had a much higher moisture content compared to that of dry bamboo. These results are important for the comparison of how the two samples performed when used as reinforcement.

Specific gravity of bamboo

Specific gravity of the bamboo were determined as given on Table 4

Table 4: Density and specific gravity of the bamboo samples obtained

Bamboo	Average Density	Average specific

Sample	(g/cm^3)	gravity
Green	0.71	0.71
Dry	0.52	0.52

From these results it was noted that the average density of green bamboo was higher than that of dry bamboo. This was partly due to the higher moisture content in the green bamboo.
Commonly the density of bamboo is given as 0.3 - 0.4 g/cm^3 [7, 8, 9]. This density is true for bamboo that has been seasoned and dried to reduce the moisture content. However, it was seen that the average density of dry bamboo was 0.52 g/cm^3. In this case, the sample had not been seasoned though it was dry when it was cut. It was noted then that the density of the sample was not that far off from the one expected, the difference being the slight increase in moisture content.

Tensile Strength of Bamboo

It was noted that in the testing of the dry bamboo samples, with the exception of one or two samples which failed at the centre, the rest failed and broke just after one of the grips but still within the gauge length.
Commonly when testing timber for tensile test, failure is supposed to occur at the centre of the gauge length but this is not what occurred in this study. This can be explained by the fact that timber samples are normally machine cut and thus they have a uniform cross-section, however the samples were not machine cut as they were supposed to be very thin and this was not possible to achieve with a machine. They had to be cut to the final dimensions by hand and this led to a variation in the cross-section. Failure thus occurred in the areas with least cross-sectional area. Also failure may have occurred in the areas where the bamboo had imperfections. It is also possible that failure occurred near the grips due to stress concentrations at the grip.
Failure in almost all the green bamboo samples occurred at the centre of the gauge length (distance between the grips). The samples either broke cleanly and separated or snapped at failure but remained as a single piece as shown on Figure 5.

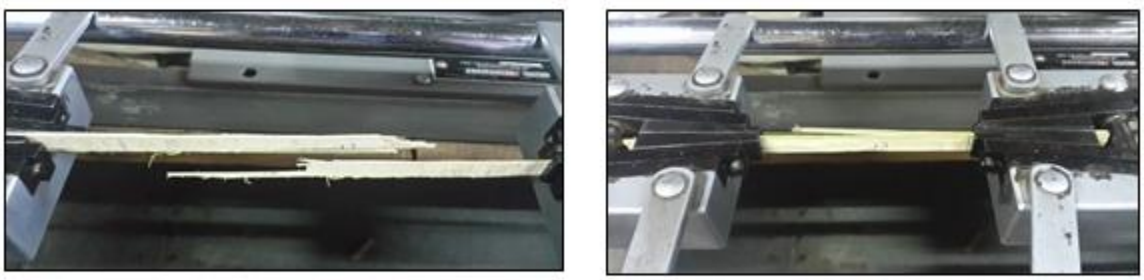

Figure 5: Failure mode of the green bamboo samples at the; full breakage, and, centre failure but not separating fully

Failure that occurred just after the grips and off-centre was attributed to the non-uniform cross-section area of the sample or imperfections in the bamboo itself. Table 5 shows the results obtained from the tensile test on the bamboo samples

Table 5: Results from the tensile test

Bamboo Sample	Average Tensile stress (N/mm^2)	Average Strain	Average True extension (mm)
Dry	45.28	0.075	9.7
Green	119.98	0.082	14.7

From Table 5, the average strain for the green bamboo was 9.3% higher than that of the dry bamboo. The true extension was also higher in green bamboo than in dry bamboo (Sample C) and this may be due to the higher moisture content in the green bamboo (Sample A).

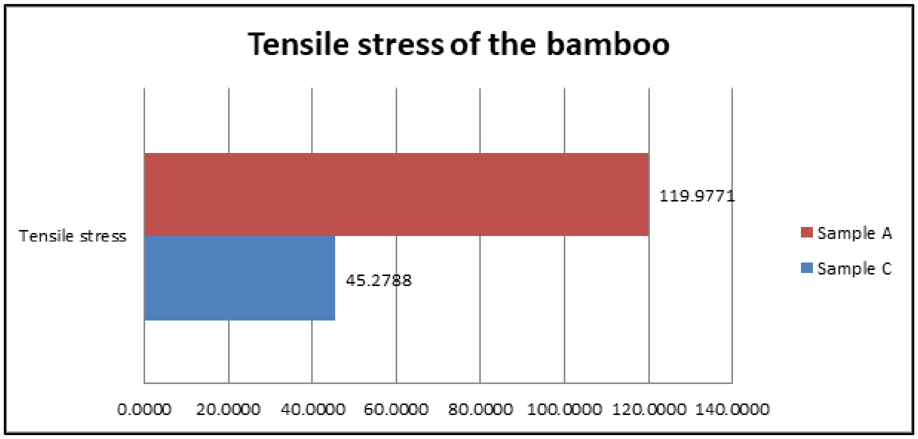

Figure 6: Tensile stress of the bamboo samples

It is important to note that tensile stress was higher in the green bamboo than in the dry bamboo; more than double the amount in the latter. This was an observation that was unexpected since strength is supposed to increase with decrease in moisture content. However, it was noted that when the dry bamboo was procured there was rot in the upper end of the culm. The sample used for testing was cut below the area of rot and from visual inspection it appeared to be in good condition. This may not have been the case as the rot may have infiltrated into the fibres in areas that could not be seen and caused decrease in the strength of the bamboo.
The observed values are comparable to other studies including; 124.2 N/mm^2 [6], 120 N/mm^2 [10], and 121.5 N/mm^2 [11]. Elastic modulus of the tested bamboo samples (Table 5) is presented in Table 6

Table 6: Elastic modulus of the bamboo samples

Bamboo Sample	Elastic modulus, E (N/mm^2)
Dry	603.72
Green	1463.14

Elastic modulus measures the resistance of a material to being deformed elastically when a force is applied to it. From the results above, it was seen that green bamboo had a higher E value than dry bamboo and thus stiffer. With this consideration, it is generally expected that green bamboo reinforced concrete beams will have less deflection than the dry bamboo reinforced concrete beams. Standard deviation for results presented in Tables 5 and 6 are presented in Table 7

Table 7: Standard deviation for tensile stress and strain of the bamboo samples

Bamboo Sample	SD for tensile stress	SD for strain
Green	15.9956	0.0187
Dry	10.1756	0.0224

The standard deviation for tensile stress is higher in the green bamboo than in the dry bamboo. This shows that the values of tensile stress in the dry bamboo are closer to the mean and better clustered than those of the green bamboo. The standard deviation for strain for green bamboo was lower than that of dry bamboo meaning that the values for strain for the green bamboo were closer to the mean. However, even if the standard deviation between the two was different, they varied by a small margin and it can be said that they both relatively give values that are close to the mean.

Concrete Slump

The slump observed was a true slump of 10mm which indicated low workability. This might have contributed to honey combing observed in the beam samples as presented in later sections of this paper.

Concrete Compaction Factor

Observed compaction factor was 0.92, within expected limits for the normal of concrete ie 0.8 – 0.92 [12].

Concrete Compressive Strength

Average 28-day Cube Crushing strength was determined as 28.4 N/mm^2, in line with the targeted compressive strength of 25 N/mm^2.

Concrete Tensile Splitting Strength

The 28-day tensile strength of the concrete was determined as 2.33 N/mm^2. This was within the expected range of approximately 10% of the compressive strength

Pull out Test

Table 8 shows the results obtained from the pull out test

Table 8: Pull out test results

	Maximum load (KN)	Average maximum load (KN)	Length pulled out (cm)	Average length pulled out (cm)
Steel	23	23.5	6.5	7.75
	24		9.0	
Green bamboo	1	1	7.0	6.90
	1		6.8	
Dry bamboo	1	1	7.2	7.05
	1		6.9	

The total length embedded in the concrete was 150 mm for all the samples indicated above.

It was noticed that while it took an average force of 23.5 KN to pull out an average length of 7.75 cm of the round steel reinforcement, it only took a force of 1 KN to pull out an average length of 6.9 cm of the green bamboo and 7.05 cm of the dry bamboo. From the tests conducted on the concrete as seen previously, the concrete was shown to have achieved the required strength of class of 25 which was the design mix. This indicated that the observed pull out results were not caused by the concrete itself. Therefore it was concluded that the results from the test showed that the bond between the steel and the concrete was of a greater strength than that of the bamboo and concrete.

As stated earlier the bamboo strips were not coated with anything prior to casting. Bamboo naturally has a smooth surface and this could have led to the poor bonding with the concrete.

The anchorage length of the bamboo therefore needs to be approximately 23.5 times greater in order to prevent slip. This is important to note because the additional length required of the bamboo in order to provide sufficient anchorage length may prove difficult to achieve. It may then be difficult to design using this material in terms of the detailing required especially if the structure is a complex one.

Concrete Beams

Control beam (steel reinforcement beam)

The observed load at first crack was at 15 KN and the testing proceeded until failure. It was noted that at failure, the cracks formed had widths between 1-2 mm and occurred mainly in the area between the loads as shown in Figure 7.

Figure 7: Appearance of cracks at failure

Figure 8 shows the load deflection relationship of the control beam

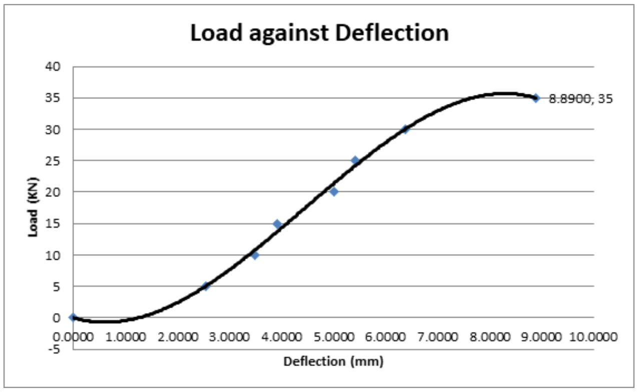

Figure 8: Load against Deflection for control beam

The observed maximum load at failure was **38 KN** and the maximum deflection **8.89 mm**. These results line up with what was expected failure load of between 35 and 40 KN and deflection of 8 to 9 mm.

Bamboo Reinforcement Beam (green)

The average load at first crack was at 5 kN and the final failure load 24.5 kN at an average deflection of 13.4mm. The load deflection curve for this beam is illustrated on Figure 9.

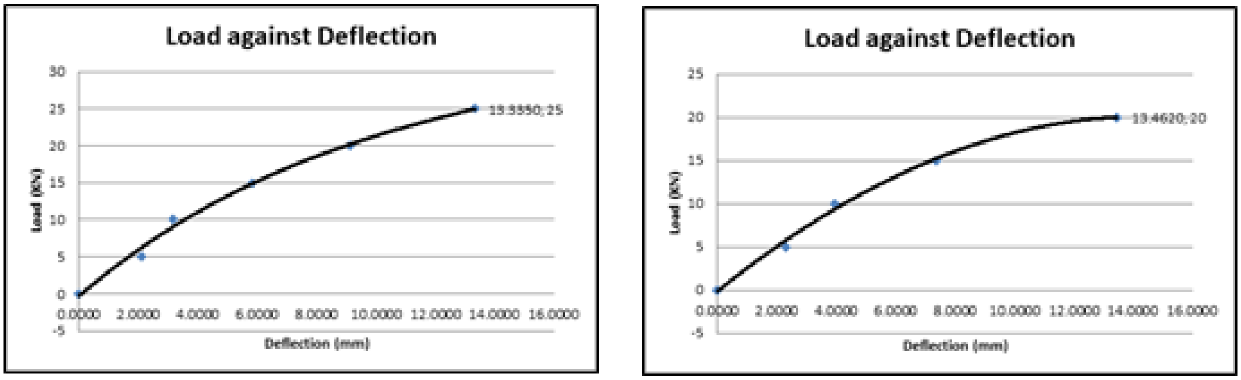

Figure 9: Load deflection curves for green bamboo reinforcement beam samples

The average failure load shown above (24.5 kN) is significantly lower than the one obtained from the control beam (38kN); a difference of 13 kN. The average deflection (13.4mm) was higher than the value obtained from the control beam (8.89mm) by a margin of 4.5mm.

It was noticed (Figure 10) that at failure the cracks on the green bamboo beams were wider and deeper than on the control beam as shown in the figure above. The measured crack widths ranged from 4mm to a maximum of 10mm which was greater than what was obtained from the control beam whose maximum crack width was 2mm. Also it was seen that the depth of the cracks in the green bamboo samples was approximately 170mm deep whereas for the control beam it was 130mm deep. It was noticed that for the green bamboo samples, there was only one major crack that was apparent at failure and this occurred at the point of loading. All this could have been partly caused loss of bond between the bamboo and the concrete.

Figure 10: Cracks on the green bamboo reinforced beam sample

Bamboo Reinforcement Beam (Dry)

The load at which first crack occurred was at 5 KN and the final failure at 22 kN, at a deflection of 12.7mm. This failure load was significantly lower than the value obtained from the control beam (38 kN) by a margin of 16 kN whereas the deflection was higher than that of the control beam (8.89mm) by 3.81mm. Figure 11 shows load deflection relationship for the concrete beam reinforced with dry bamboo

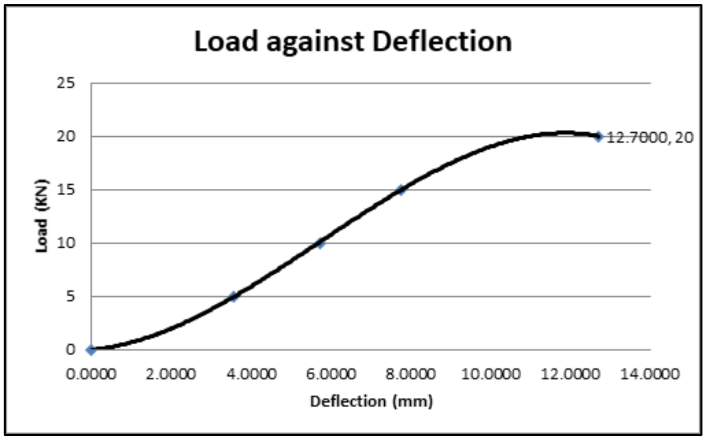

Figure 11: Load against Deflection for dry bamboo sample

From the concrete results shown previously, the concrete was shown to have achieved the required strength of 25 N/mm^2. This suggests that the results obtained above, for both the concrete beam reinforced with green bamboo and the one reinforced with dry bamboo, were not due to the effect of the concrete itself.

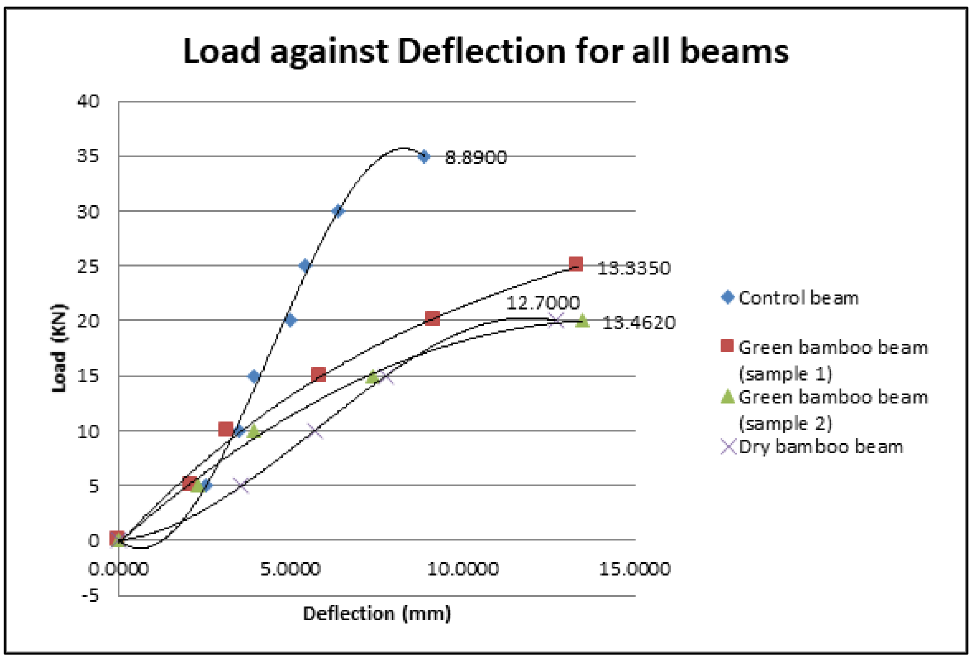

Figure 12: Load against deflection for all beams

Figure 12 shows a comparison of the load deflection curves for the control, the green and dry bamboo reinforced concrete beams. The behaviour pattern of all the beams under loading was similar as they all produced smooth curves.

The known elastic modulus for steel is 205,000 N/mm^2 and the deflection obtained from the control beam was 8.89mm. The calculated elastic modulus of the green bamboo was 1463.14 N/mm^2 and that of dry bamboo was 603.72 N/mm^2. From this, it was expected that the green bamboo would create less deflection (13.4mm). However, it was seen that it was the dry bamboo (12.7mm) that gave a lower value for deflection. This can be attributed to the fact that a linear relationship was assumed to calculate the value for elastic modulus when this is not the case.

The average value of failure load for the green bamboo samples was higher than that of the dry bamboo sample by 13.6% therefore indicating that the green bamboo performed better in this case. Also less of the green bamboo was used during casting as only 6 strips were used in each beam compared to the 16 strips used for the dry bamboo. Due to the number of reinforcements placed in the dry bamboo beam sample, the beam ended up having honeycombs due to inability of concrete being able to penetrate in between the reinforcements. This also made it difficult to note the crack pattern.

Figure 13: Honeycombs on the dry bamboo beam sample

From the figure above, a change in the concrete is seen where the honeycombs stop. It is at this level where the bamboo reinforcements begin. It was theorized that the bamboo reinforcement acted as a sieve for the concrete and did not allow some of the aggregates to pass through and therefore made the concrete to segregate at this level. Honeycombs expose the reinforcement to the environmental conditions as well as reducing the load bearing capacity and can be very dangerous to the life of the structure. They are therefore to be avoided. Taking into account how all the beams reinforced with bamboo performed, it was concluded that the green bamboo samples performed better in general.

For all the bamboo samples tested, it was seen that the failure load was significantly lower than the one for steel. This could be due to many reasons including (i) lack of homogeneity of the bamboo reinforcements, (ii) No coating was made on the bamboo reinforcements to water proof them, thus making them susceptible to shrinkage and greater loss of bond, (iii) Honeycombing reduced the bending capacity of the beams with dry bamboo reinforcement, (iv) grouping of the bamboo reinforcement could also have caused some of the loss in bending capacity, especially for the dry bamboo reinforced samples

The mode of failure for all samples was by bending. At failure all bamboo reinforced beam samples, the bamboo snapped and broke apart whereas for the control in as much as the steel deformed, it remained in one piece. This points towards a brittle failure for the bamboo reinforced samples, an undesirable property in reinforcement for concrete.

It is essential for safety of structure that the reinforcement be ductile enough to undergo large deformations before fracture. According to BS 4449:1988, the minimum elongation at fracture for mild steel should be 22% [13, 14]. Bamboo seems to be a brittle material as it did not appear to undergo much deformation before it fractured.

Conclusions

1. The density of bamboo tested ranged from 0.52-0.74 g/cm^3. This is comparatively low when compared to density of mild steel which is approximately 7.85 g/cm^3. Thus bamboo can be transported and worked easily compared to steel without use of heavy machinery example cranes.
2. In the tensile test, the green bamboo samples tested turned out to have a higher tensile strength than the dry bamboo samples by a value of 165%.
3. The control beam (steel) failed at a higher load than the beams reinforced with bamboo. However, the beams reinforced with green bamboo performed better than the beam reinforced with dry bamboo by 13.6%.
4. While the mode of failure for the control beam was a ductile failure, the beams reinforced with bamboo underwent a brittle failure.
5. All the beams tested failed due to bending and not due to shear.
6. From the pull out tests conducted, it was concluded that the bond between the bamboo and concrete was very poor compared to the bond between steel and concrete.

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