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Ductility Behaviour of Bamboo Reinforced Coconut Shell Concrete Beams

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Abstract: ***This paper presents the study on the ductility behaviour of bamboo reinforced coconut shell aggregate concrete beams together with normal weight concrete beams (NWCB). The grade of coconut shell aggregate concrete, a lightweight concrete (LWC) produced using coconut shell aggregate got from an agricultural waste as lightweight aggregate, referred to hereafter as CSC was 20N/mm^2 at 28 days. The grade for normal weight concrete was 20N/mm^2 using conventional stone aggregates. The beams prepared for study were of size 150 mm x 250 mm x 1500 mm and tested in flexure for the behaviour. Two beams were of normal weight concrete with steel reinforcement (NWCB), two beams were of CSC with steel reinforcement (CSCB), two beams were of CSC with split bamboo as reinforcement (BCSC) and two beams were of CSC with split bamboo wrapped with binding wire as reinforcement (BCSCB) - totally eight beams were tested and their behaviour was reported. From the experimental results, it was observed that the load carrying capacity of the NWC beams were higher than that of CSCB, BCSC, and BCSCB beams. The stiffness behaviour of CSCB beam showed similar trend as that of NWC up to failure. Energy absorption for BCSC beams are higher than that of NWCB, beams, CSCB and BCSCB beams. CSCB beams also exhibited a lot of cracking thus the crack width and crack spacing was small. The CSCB, BCSC and BCSCB beams exhibited higher deflection under constant load until failure, compared to NWC beams. Higher concrete strains for the reinforcement in the CSCB shows stronger bond between CSC and the reinforcement.***

Keywords: Bamboo, reinforced-concrete, coconut shell concrete, energy absorption, stiffness

1. Introduction

A natural material Bamboo occur mostly in tropical and subtropical areas, from sea level to snowcapped mountain peaks, with a few species reaching into temperate areas. The major application of bamboo is for construction and housing [1]. According to study it is estimated that one billion people in the world live in bamboo houses. Since bamboo has been used in construction and currently they are used as props, foundations, framing, scaffolding flooring, walls, roofs and trusses. Bamboos are tied together to make grid reinforcement and placed in soft clay to solve deformation problems in embankments. In rural part of India mostly bamboo is used as reinforcement in mud walls.

From the early times Bamboo is used as a construction material. Bamboos are giant grasses belonging to the family of the Bambusoideae. It is estimated that 60–90 generae of Bamboo exist, encompass approximately 1100–1500 species and there are also about 600 different botanical species of Bamboo in the world. The Bamboo is used in an engineering as well as non-engineering ways. From the early times Bamboo was used in the construction of the houses. Now- a-days concrete is used as the basic material for the construction works. The concrete is good in compression but weak in the tension. So steel is used as reinforcement in the concrete to alleviate the tensile strength. Problems encountered with the steel are high in cost, corrosion, etc. Due to the advantageous characteristics of bamboo, in the last few years, studies have been made on the use of Bamboo as a structural material and reinforcement in concrete, [1]. The main obstacle for the application of Bamboo as a reinforcement is the lack of sufficient information about its interaction with concrete, strength and durability. To improve the bond between bamboo segments and concrete effective water repellant treatment is necessary [7].

2. Previous Research

During the past few years, researchers have found new materials for structural purposes in civil Engineering. Scientist, engineers and designers need training and education for finding ways and means for reducing cost of construction and evolving efficient plans.

[2]. Study of the shear strength of bamboo reinforcement concrete reveals 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. The ductility of tension bamboo is low and failure is characterized by splitting of concrete from the tension reinforcement and brittle failure. The shear capacity is enhanced by increased amount tension reinforcement and addition of web reinforcement. The strength of concrete influences the shear capacity and the failure mode of the concrete in a way that low strength concrete cause concrete crushing before the full shear capacity is reached. The predominant failure mode of bamboo reinforced concrete beams was shear even though they were all adequate in theoretical shear capacity. The highest and lowest failure loads were recorded for the cases of steel stirrups and no stirrups respectively. The cheapest and most economical means of providing shear reinforcement for bamboo-reinforced beams according to the beam performance index (BPI) derived in this research is steel stirrups and the most expensive means is by rattan stirrups irrespective of the grade of concrete. It is therefore recommended that bamboo

reinforced concrete beams are reinforced with steel stirrups to improve on its load carrying behaviour.

[3]. studied on behaviour of coconut shell aggregates concrete with bamboo reinforcements in compression members. This study showed that bamboo treated with epoxy is 1.03 higher than untreated bamboo with epoxy materials in terms of energy absorption. And conventional column is 1.3 times higher than bamboo reinforced coconut column in terms of energy absorption capacity.

[7].Khosrow Ghavami (2004) described the test on beams and columns. It was shown from the tests on the beam and column that the bamboo can satisfactorily substitute the steel and can very well used in construction.

[12].Satjapan studied behaviour of 7 small- scale concentrically loaded short columns with different type of reinforcements to investigate strength capacity and ductility. In this study Bamboo was used as the reinforcement in the concrete without any surface treatment and with treatment of water repellant substance. It was concluded that for column reinforced with bamboo without any surface treatment, strength capacity was found to be sufficient for carrying the axial load while the ductility was found to be low. Also columns reinforced by bamboo treated with water repellant substance, Sikandur-31CFN showed higher strength and ductility than column reinforced by untreated bamboo.

[5]. studied about the mechanical and bond properties of coconut shell concrete. The study showed that coconut shell concrete was having better workability because of the smooth surface on one side of the shells and the size of the coconut shell used. The impact resistance of coconut shell aggregate concrete was high when compared with conventional concrete. Also, the bond strength of coconut shell concrete was comparable to the bond strength of normal and other light weight aggregate concretes.

[9]. Maninder Kaur (2012), stated that the use of coconut shells in cement concrete can help in waste reduction and pollution reduction. The need was to encourage the use of waste product as a construction material in housing to reduce cost. Coconut shells are more suitable as low strength lightweight aggregate when used to replace common coarse aggregate in concrete production. The studies on structural behaviour of coconut shell aggregate concrete together with Bamboo as reinforcement were limited.

3. Materials and their properties

3.1 Conventional concrete

3.1.1 Cement

The cement used for this study is ordinary Portland cement and is conforming to Indian standard IS 8112 of grade 53. The property of cement is given in Table 1

3.1.2 Coarse aggregate

The coarse aggregate is an angular aggregate of igneous origin chosen by shape as per IS 2386 (Part I) 1963, surface texture characteristics of aggregate is classified as in IS 383-1979. The specific gravity of coarse aggregate is given in Table 1

3.1.3 Fine aggregate

The sand is used as fine aggregate and it is collected from nearby river bed area. The sand has been sieved in 4.75 mm sieve. The values of fineness modulus and specific gravity are given in Table 1.

3.1.4 Water

Portable water which is free from all impurities was used for the entire work.

3.1.5 Mix proportion for conventional concrete

Mix proportion in the ratio of **1: 1.8: 2.84, w/c of 0.5** was adopted after designing the same as per IS 10262-2009 for M20 for conventional concrete.

3.2. Coconut Shell Aggregate

The freshly discarded coconut shell collected from a local oil mill was used in this study. Since the different species of coconut shell are processed together, the shells are found to have varying thicknesses of 2–8 mm. After crushing, the shells are flaky and irregularly shaped. For preparing coconut shell aggregates, a crusher was used which was designed, fabricated, and installed in SRM University. Since coconut shell is a flaky material, the sizes of coconut shell lengthwise are restricted to a maximum of 12 mm. To get enough workability with the concrete, the surface texture of the shell was fairly smooth on concave and rough on convex faces. The crushed edges were rough and spiky. Coconut shell aggregates have a relatively high water absorption value nearly, 24%, compared to the conventional aggregate (0.5%); hence, to prevent water absorption by the concrete mix, it is necessary to mix the coconut shells at saturated surface dry condition (SSD) based on 24 hours submersion in potable water. The material property of coconut shell aggregates was shown in Table 2.

3.3 Mix Proportions for coconut shell aggregate concrete (CSC)

Mix proportion of **1:1.47:0.65, w/c ratio of 0.42** used as adopted by [5]. The coconut shell aggregate should be in saturated dry condition (SSD) that is the coconut shells were soaked in water for 24 hours before use. The trial mixes were prepared using the proportions for conventional concrete and as well as coconut shell concrete and the results were shown in Table 3.

Table 1: Materials properties

Materials	*Tests conducted*	*Results*
Cement	Fineness of cement	7% (by sieving)
	standard consistency	31%
	Initial setting time(min)	31.30
	Final setting time(min)	600
	Specific gravity	3.12
Fine aggregate (natural sand)	Specific gravity	2.5
Coarse aggregate (crushed stone) igneous origin	Specific gravity	2.7

Table 2 Material properties of coconut shell **[5]**

SI.NO	*Physical and mechanical properties*	*Coconut shells*	*Crushed Granite aggregate*
1	Maximum size(mm)	12.5	12.5
2	Moisture content (%)	4.20	-
3	Water absorption (24h)%	24.00	0.50
4	Specific gravity	1.53	2.7
5	Impact value (%)	8.15	12.40
6	Crushing value (%)	2.58	6.30
7	Abrasion value (%)	1.63	1.85
8	Bulk density (kg/m3)	650	1650
9	Fineness modulus	6.26	6.94
10	Shell thickness	2-8	-

Table 3: Result of trial mix

S. No.	Mix	Proportions w/c	Compressive strength @ 28 days (N/mm^2)
1	Conventional concrete M20	1:1.8:2.84, 0.5	25.53
2	Coconut shell aggregate concrete M20	1:1.47:0.65, 0.42	23.90

3.4 Reinforcement Materials

3.4.1 Steel

High yield Steel of 10mm diameter was used for the conventional concrete, with a tensile stress of 415 N/mm^2. Similarly 8mm diameter stirrups were used for shear reinforcements. The modulus of elasticity was 200000 N/mm^2.

3.4.2 Bamboo

The bamboos were split along the horizontal axes to yield a cross section of 20mm x 16mm. Tensile strength of bamboo was found to be 112.05 N/mm^2 at 30% moisture content. The modulus of elasticity was found to be 21000 N/mm^2.

4. Experimental Details

4.1 Details of beams

4.1.1 Normal weight concrete beams (NWCB)

Two beams of normal weight aggregate of 150mm x 250mm x 1500mm with high yield steel reinforcements of 10mm diameter were cast.

4.1.2 Coconut shell concrete beams (CSCB).

Two beams of coconut shell aggregate of 150mm x 250mm x 1500mm with high yield steel Reinforcements of 10mm diameter were cast.

4.1.3 Bamboo reinforced coconut shell concrete beams (BCSC)

Two beams of coconut shell aggregate of 150mm x 250mm x 1500mm with bamboo reinforcements of (20mm x 16mm) were cast and shown in Fig.1

4.1.4 Bamboo wrapped with binding wire reinforced coconut shell concrete (BCSCB)

Two beams of coconut shell aggregate concrete of 150mm x 250mm x 1500mm length with bamboo reinforcements of dimensions as above were cast.

4.1.5 Reinforcement Grill Fabrication

The details of the bamboo reinforcements was prepared and shown in Figure 1 and Figure 2. The second arrangement was wrapped with binding wire of 1.5mm diameter at a spacing of 20mm centre to centre while the first without the binding wire, in both arrangements all the bamboo were treated with epoxy. Shear stirrups of 10mm diameter were used at a spacing of 100mm centre to centre.

Figure 1: Treated bamboo reinforcement

Figure2: Treated bamboo reinforcement wrapped with binding wire

(e) Preparation of beams for experiment

After 28 days of curing, the specimen was prepared for testing. The following operations were done before testing:

i) Applying white wash on the specimen for easy identification of cracks.
ii) Marking of centre line.
iii) Fixing of Demec pellets for measuring strains across the depth of the beam to find the shift in the neutral axis.

4.2 Test set up

The test was carried out in a loading frame of 100T capacity. The loading frame consist of two I sections placed side by side (210mm x 600mm) ISHB and (80mm x 250mm) two numbers. All the specimens were white washed in order to identify the cracks easily during the test. The beams were simply supported and two point load was applied at a distance of L/3 from each end support, dial gauge was fixed at the bottom of the beams at the centre of the span to measure deflections. The cracks as and when formed, crack width and ultimate load were observed and recorded. The arrangement of the test set up was shown in Figures 3a and 3b.

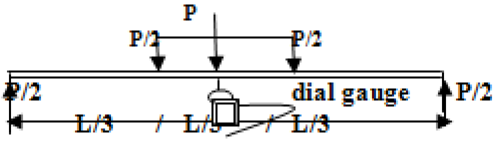

Figure 3a: A schematic beam testing setup

Figure 3b: Experimental setup

4.2.1 Instrumentation

A dial gauge with a least count of 0.001mm was used to measure central deflection of the beams and crack widths were measured with a crack microscope that reads to an accuracy of 0.02mm on the surface of the beams. Proving ring was set to zero before readings were taken. Demec gauge was used to measure deformation/elongation from the zero loads to ultimate load from Demec pellets.

4.2.2 Procedure for testing

The beam specimens were loaded by third-point loading by a hydraulic jack mounted on top of the spreader beam. A spreader beam transfer the load symmetrically to ensure pure bending in the mid-span of the beams. While at bottom a dial gauge was placed at exactly centre of the beam to measure deflections due to the applied loads. The whole set up of the test is shown in Figures 3a and 3b. The load was applied at the centre of the specimen in steps of 2.5kN and for each load step, the Demec readings and deflections were recorded till the specimen failed. The cracks formed were marked on the surface of the specimen. During testing load at first crack and ultimate load for each beam was noted.

4.2.3 Observations made

The flexural failure mode was observed for the both NWCB, CSCB, BCSC and BCSCB beams as shown in Table 4. The yielding of steel, bamboo took place and this was followed by crushing of concrete in the compression zone. Since all the beams were designed as under-reinforced, the failure started by yielding of the tension steel bar before the compression failure of concrete as expected. Also, the stirrup spacing was kept at 100 mm centers in the shear zone and thus all beams failed in typical flexural mode. For both types of concrete, failure started with flexural crack and extended up to the neutral axis. The first flexural crack, after reaching the neutral axis, started to incline to form compression failure zone. And the crushing of concrete took place in that zone during failure.

Table 4: ultimate load and Deflection characteristics of NWCB, CSCB, BCSCB, and BCSCB beams

Beam designation	Ultimate load (kN)	first cracking load (kN)	Experimental deflections (mm)		Ductility ratio (δu/δ)
			Yield stage (δy)	Ultimate stage (δu)	
NWCB1	55	25	1.39	4.212	3.03
NWCB2	57	25	1.302	4.238	3.25
CSCB1	53	22.5	1.39	5.630	4.05
CSCB2	50	22.5	1.362	4.670	3.43
BCSC1	44	15	1.40	11.60	8.29
BCSC2	42	15	1.30	11.10	8.54
BCSCB1	45	15	0.90	6.80	7.56
BCSCB2	47	15	1.10	8.0	7.27

4.3 Analysis of Results

In the Table 4 the ratio of theoretical moment to that of experimental moments for the beams were calculated assuming parabolic compressive stress block for both NWCB and CSCB. The parameters like k_1, k_2, k_3 i.e. stress block parameters were assumed as per standard procedure followed in the analysis of Reinforced concrete beams, the assumptions for RC beams were slightly modified for bamboo reinforced CSCB beams. The first crack width as observed during experiments was also included together with failure load in the Table 4. The experimental moments were calculated based on the values of ultimate loads multiplied by one-third distance for all the beams and shown in Table 5.

Table 5: crack width and ultimate moments.

Beam designation	Failure mode	First crack width (mm)	Theoretical moment (kNm)	Experimental moment (kNm)	M_e/M_t
NWCB1	flexural	0.02	11.88	13.75	1.15
NWCB2	flexural	0.02	11.88	14.25	1.20
CSCB1	flexural	0.04	11.88	13.25	1.15
CSCB2	flexural	0.04	11.88	12.50	1.05
BCSC1	flexural	0.08	10.10	11.00	1.09
BCSC2	flexural	0.08	10.10	10.50	1.04
BCSCB1	flexural	0.06	10.10	11.25	1.13
BCSCB2	flexural	0.06	10.10	11.75	1.16

4.4 Behaviour Witnessed

(a) Conventional concrete (NWCB)

All the beams were theoretically designed against shear failure and were failed in flexural tension of longitudinal reinforcements. The mode of failure is influenced by the concrete compressive strength. A flexural crack was found to propagate towards the neutral axis as the load increased. A further increase in load gradually results in a flexural shear or diagonal cracks in the combined flexure and shear zone that is shear span area as witnessed and shown in Fig.8

(b) CSCB beams

The beam follows the same trend similar to NWC but the cracks are wider than that of NWC. The cracks will finally destroy the bond between concrete and longitudinal reinforcements causing the splitting of the concrete.

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(c) BCSC and BCSCB Beams

Both BCSC and BCSCB failed by a combination of longitudinal bamboo in tension, concrete crushing, flexural shear and diagonal tension. The diagonal cracks will extend into the concrete compression zone which finally causing crushing of the concrete. The longest crack widths were associated with the beams that failed in diagonal tension as shown in Figure 4.

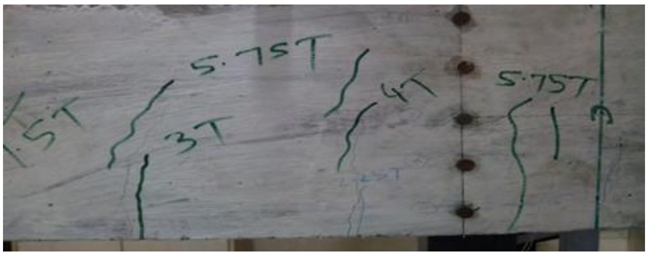

Figure 4: Nature of cracks formed

4.5 Load-Deflection Behaviour

(a) The load-deflection behaviour of NWC beams under ultimate loads is illustrated by typical load-deflection curves as shown in Figure 5. In a simply supported beam subjected to a two-point load, the middle portion of the beam is subjected to maximum uniform bending and zero shear force assuming the self-weight of the beam is negligible. The largest flexural strains therefore occur within this region. Thus, cracking initiates at the bottom of this region from where the cracks developed then spread rapidly towards the top of the beam with increasing applied load to collapse.

(b) The load-deflection curve for reinforced coconut shell concrete CSCS shows similar behaviour with that of conventional concrete beams. In CSCS the cracks developed earlier than in NWC and the cracks widths increased by 0.02mm.

(c) For bamboo reinforced coconut shell concrete beams the deflections significantly increases with increasing applied loads until the appearance of first crack in the concrete. Immediately after the first crack, the deflections increases significantly this is probably due to local bond slippage, the curve continues until ultimate failure of the beams occurred. The beams prior to failure exhibited very long range of deflections indicating a high ductile behaviour of the bamboo. The crack width expands wider than NWC, CSCS and BCSCB beams. A crack width of 0.08mm was observed.

(d) BCSCB beams follows almost similar trend with that of BCSC beams but the cracks width reduces from 0.08mm to 0.06mm. The deflections reduced when compared with BCSC beams (probably due to the presence of binding wire around the bamboo reinforcements). The load-carrying capacities of BCSCB beams are slightly higher by 7.1% than BCSC beams.

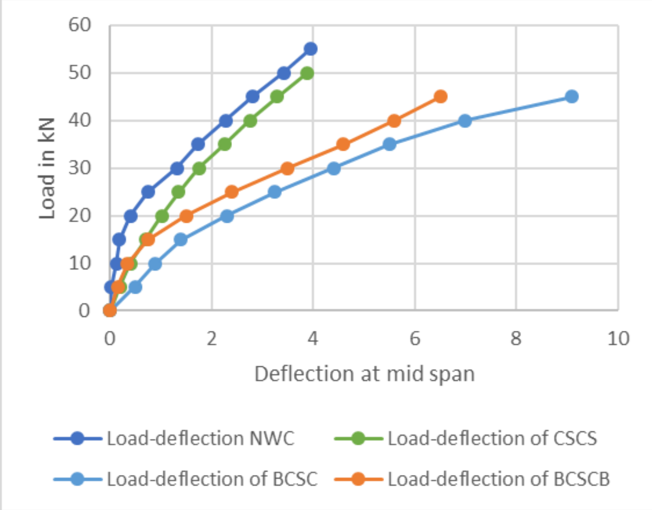

Figure 5: Typical load Vs Deflection graph for NWC, CSCB, BCSC, and BCSCB

4.6 Moment Capacity

Table 5 shows the moment capacity of BCSC, BCSCB, CSCB and NWC beams tested under two-point loading. The theoretical ultimate moments were calculated using the ultimate strength of the reinforcement, while that of bamboo were calculated using the ultimate strength of bamboo with a material factor of safety of 1.30. It can be seen from the result that the experimental moments are 17% higher than that of theoretical calculations. Also, the moments due to BCSC represents 74% that of the NWC.

4.7 Ductility characteristics

As expected the BCSC have shown higher deflections. This is attributed to the lower elasticity modulus of CSC and bamboo compared to that of NWC. The crack occurred at 25 kN for NWC while for bamboo reinforced beams, the crack occurred at 15kN, this may be attributed to low tensile strength of the bamboo reinforcements compared to that of steel. The ductility ratio (μ) is defined as the ratio of deflection at ultimate stage to that of cracking stage and represented as $\delta u/\delta y$.

BCSC beams exhibited higher deflections than NWC beams, the large deflections at near maximum load of the BCSC beams exhibit high ductile behaviour that may give ample warning before total collapse. The maximum deflection prior to final failure was found to be 11.60mm and this shows that the BCSC beams are ductile compared to the NWC. Similarly, addition of binding wire by wrapping the bamboo with it reduces deflection by 11.88%. The ductility ratio were calculated and shown in the Table 4.

4.8 The Energy Absorption Capacity

The energy absorption capacities of the beams were nothing but the area under Load-deflection Graph. The energy absorption of each beam was calculated as defined and tabulated in Table 6. Energy absorption was high for BCSC than NWC, CSCS and BCSCB beams; this is attributed due to the high deflections due to applied loads.

Table 6: Energy absorption capacity

Types of beams	NWCB	CSCB	BCSC	BCSCB
Energy absorption (kNmm)	155	132	255	205

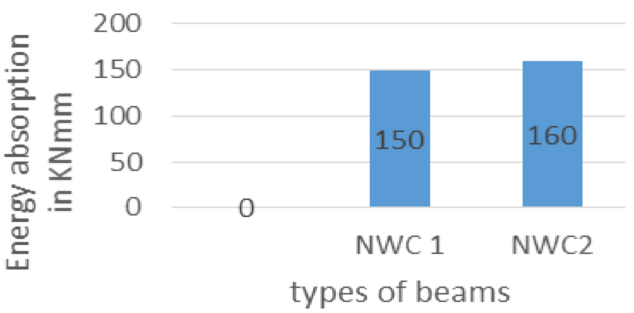

Figure 6a: Energy absorption values for NWC

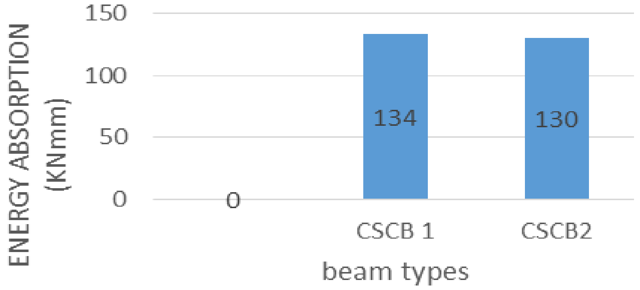

Figure 6b: Energy absorption values for CSCB beams

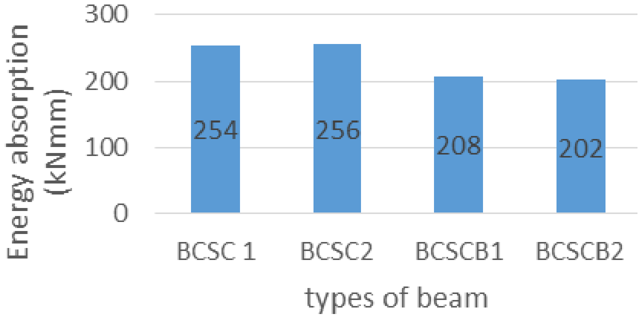

Figure 6c: Energy absorption values for BCSC and BCSCB beams**5.7.4**

4.9 Stiffness (α)

The stiffness of any beam is defined as load per unit deflection using load Vs deflection curves stiffness at various load ratios were calculated and tabulated in Table 5 and Figure. 7. The stiffness behaviour of CSCB beams showed similar trend as that of NWCB beams up to failure. Similarly, the stiffness of BCSCB beams are 37.5% higher than that of BCSC beams at a load ratio of 0.2 and 17.9% lower than NCWB beams. At maximum load ratio the stiffness of BCSCB beams remains constant from 0.8 to 1.0 load ratio, while for BCSC beams the stiffness remains constant from 0.6 to 0.8 load ratio, this is attributed due to the low stiffness of BCSC beams.

Table 7. Stiffness Vs Load ratio

P/P_u	Average Stiffness (kN/mm)			
	NWCB	CSCB	BCSC	BCSCB
0.2	33.5	27.5	12.5	20
0.4	16	25	9.17	11
0.6	12.5	12.5	5.63	10
0.8	9.5	10.5	5.63	8
1.0	9.5	9.5	3.17	8

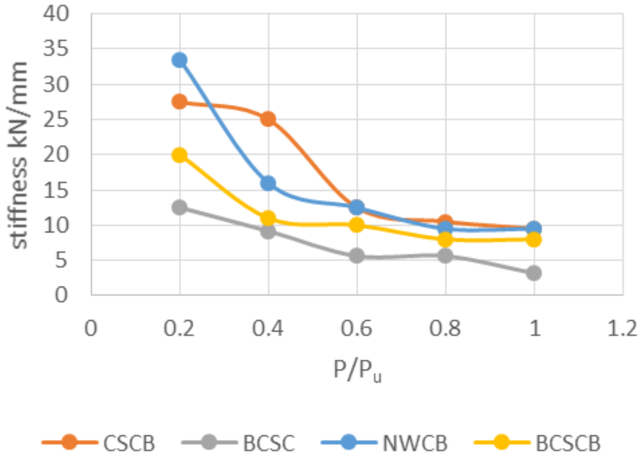

Figure 7: Stiffness Vs Load for all the types of beams.

5. Conclusions

From the research work and experimental result obtained the following conclusions can be made:

1) Tension test performed on bamboo strip revealed elastic behaviour and its ultimate strength was 112.05N/mm^2.
2) The modulus of elasticity of coconut shell concrete was found to be 12075.2N/mm^2 which represents 54%, 57%, 43.88% and 60.36% that of modulus of elasticity of conventional concrete for IS 456, ACI-318, EU and BS 8110 codes respectively.
3) The load carrying capacity of the NWC beams were slightly higher than CSCS, BCSC, and BCSCB beams
4) The stiffness behaviour of CSC beam showed similar trend as that of NWC up to failure
5) Energy absorption was more for BCSC than NWC, BCSC and BCSCB beams. This is attributed due to the high deflections due to applied loads
6) Deflections are higher in BCSC and BCSCB beams when compared to NWC and CSCS beams and by wrapping the split bamboo with binding wire the deflections were slightly reduced in BCSCB beams compared to BCSC beams.
7) The ductility of BCSC and BCSCB beams were higher than that of NWCB and CSCB beams, this is due to the larger deformations by the bamboo reinforcements before failure.

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Author Profile

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