This paper presents the study on the flexural 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 obtained from agricultural waste as lightweight aggregate, referred to here as CSC was 20N/mm² at 28 days. The grade for normal weight concrete was 20N/mm² using conventional stone aggregates. The beams prepared for study were of size 150 mm x 250 mm x 1500 mm and tested in flexure. Three beams were of normal weight concrete with steel reinforcement (NWCB), three beams were of CSC with steel reinforcement (CSCB), three beams were of CSC with split bamboo as reinforcement (BCSC) and three beams were of CSC with split bamboo wrapped with binding wire as reinforcement (BCSCB) - totally twelve (12) beams were tested and their behaviour was reported. From the experimental results, it was observed that the load carrying capacity of the NWCB beams were 8.04%, 23.21% and 17.86% higher than CSCB, BCSCB, and BCSCB* beams respectively. The stiffness behaviour of BCSC beam showed similar pattern with that of NWCB up to failure. CSCB beams also exhibited various cracks thus, the crack width and crack spacing was small. The CSCB and BCSCB beams exhibited higher deflection under constant load until failure, compared to NWCB beams. Higher concrete strains for the reinforcement in the CSCB shows stronger bond between CSC and the reinforcements.

**Keywords:** bamboo, reinforced-concrete, coconut shell, stiffness, flexure.

### 1. INTRODUCTION

Bamboos are giant grasses belonging to the family of the *Bambusoideae*. It is estimated that 60–90 genera of Bamboo exist, encompassing approximately 1100–1500 species and there are also about 600 different botanical species of Bamboo in the world. Bamboo occurs mostly in tropical and subtropical areas, from sea level to snow-capped mountain peaks, with a few species reaching into temperate areas. The major application of bamboo is for construction and housing (Yu et al., 2003; Ghavami, 2008; VanderLugt, 2006). 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.

At the present 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 stress. Problems encountered with the steel are high 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 (Bhagat et al. 2006; Haruna and Lakshmi, 2013).
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 an effective water repellant treatment is necessary (Ghavami, 2008). Notwithstanding the use of bamboo in numerous construction activities, rarely there has been little attempts to apply it in engineering design calculation prior to the commencement of any fabrication/erection based on the theory of Structural Engineering (Ghavami, 2008). The problem lies on limited reliable information on mechanical properties of bamboo to be reliably used for designing structural sections using bamboo.

Concrete was generally been utilized as construction material due to its abundance and broad accessibility. The advantages of concrete as construction material were fully known as they are strong, durable, versatile, easy to set up, and affordable. However, its self-weight was a draw back with regards to earthquake resistant structure. One of the effort made to decrease the self-weight was substituting natural concrete aggregate with coconut shell aggregate. The availability of coconut shell in some part of the world was considered to be the solution for solving the drawback.

2.0 Literature survey

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.

Bamboo is a rapid growing wooden material which belongs to the grass family of Poaceae (Agarwal et al. 2014). It attains its optimum strength within three to four years and reaches the maturity period in five years. It exhibits relatively high tensile strength in which some of the species possesses tensile strength equal to that of a mild steel. Due to these behaviors bamboo, researchers has focus their attention in utilizing bamboo materials as reinforcement in concrete. Rahman et-al (2011) reported that utilizing bamboo material as reinforced in concrete beams can increases the load carrying capacity of the beam. Furthermore, they have reported an increase in the ultimate load carrying capacity of almost three times than that of unreinforced concrete. Similarly, the ductility properties of bamboo reinforcements in concrete beams is higher than that of steel due to its lower modulus of elasticity in comparison to that of steel (Haruna and Lakshmi, 2013; Yamaguchi et al., 2013).

Terai and Minami, (2011) reveal that the ductility of bamboo reinforced concrete columns is dependent on concrete strength and the crack pattern in bamboo reinforced concrete is similar to that of steel reinforced concrete members. Mark and Russel, (2011) reported the findings on shear strength of bamboo reinforced concrete and disclosed that concrete elements reinforced with bamboo culms developed noticeable enhanced load capacities than unreinforced concrete beams of the same sections. The ductility of bamboo is found to be low and identified by cracking failure of concrete from the bottom reinforcement. The shear capacity was improved by adding more number of tensile reinforcement. The shear ability was influenced by concrete strength and the deteriorating pattern of the concrete. However, low strength concrete yields in concrete crumbling prior to the attainment of the complete shear capacity. The major failure pattern of bamboo reinforced concrete beam was shear although, they are all sufficient in the theoretical shear capacity (Ghavami, 2005). The maximum and minimum failure loads were observed using steel stirrups and without stirrups. Ghavami, (2005) and Ghavami, (1988) reported that bamboo can satisfactorily replace steel as reinforcement material and can be well
utilized in construction applications. Moreover, Leelatanon et al., (2010) uses treated and untreated bamboo reinforcing materials and evaluate their strength capacities and ductilities. They also disclosed sufficient strength capacity for axially loaded untreated reinforced bamboo column with low ductility. Similarly, columns reinforced by bamboo treated with water repellant substance, Sikandur-31CFN revealed improved strength and ductility than column reinforced by untreated bamboo.

Durability of bamboo as reinforcing materials in concrete structures were quarried by some researchers (Ghavami, 2005; Lee et al., 1996). Indecision regarding bamboo durability were based on findings on durability of natural fibres used as OPC-based composites reinforcement. On the other hand Lima et al (2008) reported the durability of bamboo reinforcement in an alkaline and water environment and they have found that the tensile strength of the bamboo almost remains the same before and after immersion in both water and alkaline solutions. In another work by Toledo, (1997) reported a quite opposite findings and concluded that bamboo materials are highly sensitive to alkaline environment.

Gunasekaran et al, (2011) reported that the bond strength of coconut shell concrete was comparable to that of normal and light weight aggregate concretes. They have also observed high impact resistance in coconut shell aggregate concrete than that of conventional concrete. In another similar research Kaur (2012) reveals that use of coconut shells in OPC concrete can aid in elimination of environmental pollution. He further stated that coconut shell aggregate are appropriate for low strength lightweight concrete when utilized as a substitute to replace conventional coarse aggregate in concrete production. Studies on structural behaviour of coconut shell aggregate concrete together with bamboo as reinforcement are limited. In this present study bamboo was utilized as reinforcement and coconut shell was used as aggregates to examine its flexural and mechanical properties.

3.0 EXPERIMENTAL PROCEDURES

3.1 Specimen Preparation and Fabrication

Light weight concrete mixture which comprises of coconut shell aggregate with maximum diameter of 12.5 mm, cement, fine aggregate and water were prepared to make up the lightweight concrete. The compressive strength of the concrete was set to minimal strength of 20 MPa with a mix proportion of 1: 1.8: 2.84 for conventional concrete and 1: 1.47: 0.65 for coconut shell concrete (CSC). Water to cement ratio of the mixture used were 0.5 and 0.42 for conventional and CSC respectively. Bamboo (SP-dera) and steel material were used for the reinforced beam. The bamboo specimen was splitted to make it into averagely 16 mm in diameter which have average tensile strength of 112.05 MPa. The details of the bamboo reinforcements was prepared as can be seen in Fig.1 (a) and (b). The first arrangement was wrapped without binding wire while the second with binding wire. In both arrangements, all the bamboo were treated with epoxy chemical to improve the bond between the bamboo and concrete. Shear stirrups of 8 mm diameter were used at a spacing of 100 mm for all the beam specimens. Steel reinforcement utilized in this work was 10 mm in diameter having tensile strength of 410 MPa. The beam specimens of 1500 mm length, 250 mm depth and 150 mm breadth were prepared.

![Fig.1 specimen preparation: (a) bamboo reinforcement without binding wire](image)
The beam specimens were achieved by constructing the formwork using ply wood of 15 mm. Once the formwork is ready to be used then the steel and bamboo reinforcement’s arrangements were placed on the formwork. Finally, lightweight concrete mixtures were poured into the formwork for both conventional and coconut shell concrete respectively. The day after the casting, the specimens were covered with gunny bags to maintain temperature during curing time of the concrete until the period of 28 days. Besides casting of concrete beam, cylinder specimens were also cast then cure in water tank provided in the laboratory for 28 days. The beam specimens were divided into four groups and namely: NWCB (Group 1), CSCB (Group 2), BCSCB (Group 3) and BCSCB’ (Group 4) respectively. The detail of the beam considered in this study are presented in Table 1.

All the beam cast are 1500mm long and of grade 20 concrete, that is M20 concrete.

Table 1. Details of beams for test

<table>
<thead>
<tr>
<th>Beam types</th>
<th>Cross section (mm)</th>
<th>Reinforcement</th>
<th>Number of specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional concrete</td>
<td>NWCB</td>
<td>10mm Ø steel (4 numbers of bar)</td>
<td>3</td>
</tr>
<tr>
<td>Coconut shell concrete + steel reinforcement</td>
<td>CSCB</td>
<td>10mm Ø steel (4 numbers of bar)</td>
<td>3</td>
</tr>
<tr>
<td>Coconut shell concrete with bamboo as reinforcement</td>
<td>BCSCB</td>
<td>Split bamboo 20mm x 16mm treated with epoxy (4 numbers)</td>
<td>3</td>
</tr>
<tr>
<td>Coconut shell concrete with bamboo reinforcement wrapped with binding wire</td>
<td>BCSCB’</td>
<td>Split bamboo 20mm x 16mm treated with epoxy, (4 numbers) 8mm Ø stirrups were provided at 100mm c/c for all specimens.</td>
<td>3</td>
</tr>
</tbody>
</table>
3.2 Instrumentation and testing

A day before the specimens attain its age of 28 days, the beams were carefully removed from wood form work and painted with white wash powder to ease visual observation at the time of the test. The beam was placed on the loading frame and supported at 100 mm from each beam end that produced beam clear span of 1500 mm. Two symmetrical points load acting at one-third of the beam clear span. The source of the load was a hydraulic jack connected with load cell of 100 KN maximum capacities. 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. Prior to the beam testing, cylinder specimens were tested in terms of compressive strength and its modulus of elasticity.

Prior to load application on the set up, all the equipments were properly monitored to ensure that they are in their correct position. The beam specimens were then loaded gradually at an incremental stage. When the instrumentation is okay then the load was released and the instrumentation was set to rest. At the time of the test, the loads were applied incrementally at 2.5 KN. At any load increment the visual observations were carry out to authenticate any crack occurred. The cracks that appear in the beam due to the load acting were marked to ease analysis after testing was completed. The observations of cracks pattern proceeds until the beam failure. Flexural test set up of bamboo beam is clearly presented in Fig. 2 (a) and (b).

4.0 RESULT AND DISCUSSION

4.1 Failure pattern

The flexural failure mode was observed for all the beams NWCB, CSCB, BCSC and BCSCB beams as shown in Table 2. The yielding of steel, bamboo took place and this was succeeded by crushing of concrete in the compression zone. The failure pattern was initiated by yielding of the tension steel prior to the failure of the compression zone as all the beams were designed as under-reinforced sections. Also, the stirrup spacing was kept at 100 mm center to center in the shear zone and therefore, all beams failed in typical flexural mode. For both types of concrete, failure initiated with flexural crack and extended up to the neutral axis. The first flexural crack occurred after the neutral axis, then it begins to incline to form compression failure zone. The crushing of concrete appeared in that zone during the failure. The first cracking, ultimate loads, deflections at yield and ultimate stage and of the beams were presented in table 2.
**Table 2** Ultimate load and deflection characteristics of BCSC, BCSCB, CSCB and NWCB beam

<table>
<thead>
<tr>
<th>Beam designation</th>
<th>Ultimate load (kN)</th>
<th>First cracking load (kN)</th>
<th>Experimental deflections (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yield stage(δy)</td>
</tr>
<tr>
<td>NWCB 1</td>
<td>55</td>
<td>25</td>
<td>1.390</td>
</tr>
<tr>
<td>NWCB2</td>
<td>57</td>
<td>25</td>
<td>1.302</td>
</tr>
<tr>
<td>CSCB 1</td>
<td>53</td>
<td>22.50</td>
<td>1.390</td>
</tr>
<tr>
<td>CSCB 2</td>
<td>50</td>
<td>22.50</td>
<td>1.362</td>
</tr>
<tr>
<td>BCSC 1</td>
<td>44</td>
<td>15.0</td>
<td>1.40</td>
</tr>
<tr>
<td>BCSC 2</td>
<td>42</td>
<td>15.0</td>
<td>1.30</td>
</tr>
<tr>
<td>BCSCB 1</td>
<td>45</td>
<td>15.0</td>
<td>0.90</td>
</tr>
<tr>
<td>BCSCB2</td>
<td>47</td>
<td>15.0</td>
<td>1.10</td>
</tr>
</tbody>
</table>

**4.2 Analysis of the Results**

The ratio of theoretical moment to that of experimental moments for the beam were calculated by assuming parabolic compressive stress block for both NWCB and CSCB as depicts in table 3. The stress block parameters were assumed as per standard procedure followed in the analysis of Reinforced concrete beams (Barbosa et al. 1998; MacGregor, 1998), the assumptions for RC beams were slightly modified for bamboo reinforced CSCB beams. The first crack width as observed during experiment was reported together with failure load and presented in Table 2. The experimental moments were calculated based on the values of ultimate loads multiplied by one-third distance for all the beams (MacGregor, 1998)

**Table 3** Crack load, ultimate load, and ultimate moments.

<table>
<thead>
<tr>
<th>Beam designation</th>
<th>Failure mode</th>
<th>Ultimate P_u (kN)</th>
<th>Cracking P_c (kN)</th>
<th>Crack width (mm)</th>
<th>M_T (kNm)</th>
<th>M_e (KNm)</th>
<th>M_e/M_T</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWCB 1</td>
<td>Flexural</td>
<td>55</td>
<td>25</td>
<td>0.02</td>
<td>11.9</td>
<td>13.8</td>
<td>1.15</td>
</tr>
<tr>
<td>NWCB2</td>
<td>Flexural</td>
<td>57</td>
<td>25</td>
<td>0.02</td>
<td>11.9</td>
<td>14.3</td>
<td>1.20</td>
</tr>
<tr>
<td>CSCB 1</td>
<td>Flexural</td>
<td>53</td>
<td>22.5</td>
<td>0.04</td>
<td>11.9</td>
<td>13.3</td>
<td>1.15</td>
</tr>
<tr>
<td>CSCB 2</td>
<td>Flexural</td>
<td>50</td>
<td>22.5</td>
<td>0.04</td>
<td>11.9</td>
<td>12.5</td>
<td>1.05</td>
</tr>
<tr>
<td>BCSC 1</td>
<td>Flexural</td>
<td>44</td>
<td>15.0</td>
<td>0.08</td>
<td>10.1</td>
<td>11.0</td>
<td>1.09</td>
</tr>
<tr>
<td>BCSC 2</td>
<td>Flexural</td>
<td>42</td>
<td>15.0</td>
<td>0.08</td>
<td>10.1</td>
<td>10.5</td>
<td>1.04</td>
</tr>
<tr>
<td>BCSCB 1</td>
<td>Flexural</td>
<td>45</td>
<td>15.0</td>
<td>0.06</td>
<td>10.1</td>
<td>11.3</td>
<td>1.13</td>
</tr>
<tr>
<td>BCSCB2</td>
<td>Flexural</td>
<td>47</td>
<td>15.0</td>
<td>0.06</td>
<td>10.1</td>
<td>11.8</td>
<td>1.16</td>
</tr>
</tbody>
</table>
4.3. Behaviour Witnessed

(a) Conventional concrete (NWCB)
All the beams were theoretically designed against shear failure and 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 displayed in Fig.3

(b) CSCB beams
The beams follows the same fashion similar to NWC but the cracks are wider than that of NWC. The cracks finally destroy the bond between concrete and longitudinal steel reinforcements causing the splitting of the concrete.

(c) BCSCB 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 were extended into the concrete compression zone which later result in crushing of the concrete. The longest crack widths were related with the beams that failed in diagonal tension as shown in Figure 3.

Fig. 3 Nature of cracks formed.

4.4 Load-Deflection Behaviour
The load-deflection curves (Fig. 4 a, b, c and d) have been utilized for witnessing experimental load types such as first crack load, yield load and ultimate load. The first crack load is the load causing cracks initially on the surface of the beam designated by altering the order of the line in the load-deflection curve. Crack load is a load that is represented by the change in direction of the curve between the points of initial crack load prior to the curves reaching its maximum value, while the ultimate load is the load that can be preserved by the cross section of the beam.

The load-deflection behaviour of NWCB beams under ultimate loads is illustrated by a typical load-deflection curves as shown in Figure 4. In a simply supported beam subjected to a four-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 similar to that reported by (Alengaram et al., 2008).

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

It is worth mentioning that the deflections significantly increase with increasing loads until the appearance of first crack in the concrete in bamboo reinforced coconut shell concrete beams (BCSCB). Immediately after the first crack, the deflections increase 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 widths expands wider than NWC, CSCS and BCSCB* beams. A crack width of 0.08mm was observed.

However, BCSCB* beams obey almost similar trend with that of BCSCB beams but, the cracks width reduces from 0.08mm to 0.06mm. The deflections reduced when compared with BCSC beams (most likely due to the presence of binding wire around the bamboo reinforcements). The load-carrying capacity of BCSCB
beams are slightly higher by 7.1% than BCSCB* beams. However, from the behaviour point of view it is clear that bamboo beams wrapped with binding wire tend to resist more flexure and more ductile compared to the unwrapped bamboo beams.

4.5 Moment Capacity
Table 3 shows the moment capacity of BCSC and NWC beams tested under four-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.

4.6 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 Fig. 5a to 5d show the variation of stiffness of the beams. From the figures it can be seen clearly that the stiffness of NWCB beams are 34 kN/mm while that of CSCB beams are 30 kN/mm, the variations between them is attributed to the earlier formation of crack in CSCB than in NWCB beams. Moreover, for BCSCB and BCSCB* the stiffness also differs from 12.5 kN/mm to 20 kN/mm, the increase in stiffness of BCSCB* is due to the presence of binding wire on the bamboo reinforcements.
5.0 CONCLUSION

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

(i) The load carrying capacity of the NWCB beams were 8.04%, 23.21% and 17.86% higher than CSCB, BCSCB, and BCSCB* beams respectively.

(ii) The stiffness behaviour of CSCB beam showed similar trend as that of NWCB up to failure while that of BCSCB and BCSCB* followed the same fashion with small variations at unique load ratios of unity.

(iii) Deflections are higher in BCSCB and BCSCB* beams when compared to NWCB and CSCB beams and by wrapping the split bamboo with binding wire the deflections were slightly decrease in BCSCB* beams in comparison to BCSCB beams.

(iv) Partial safety factor for bamboo reinforcements was adopted as 1.3. With this value the estimated load carrying capacities correspond with experimental values.

REFERENCES


