Determination of the Feasibility of Bamboo Reinforcement for Concrete Beams

Tushar Pundir[1], Reeta Joshi[2]

[1]Tushar pundir, Assistant Professor, Dept. of Civil Engineering, Roorkee College of Engineering, Uttarakhand, India
[2]Reeta joshi, Assistant Professor, Dept. of Civil Engineering, Roorkee College of Engineering, Uttarakhand, India

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Abstract - *Creating nations have the most popularity for steel-strengthened cement, yet frequently don't have the way to deliver the steel to satisfy that need. Copious, maintainable and amazingly strong, bamboo has potential later on to turn into a perfect substitution in places where steel can only with significant effort be created.in preliminaries of elasticity, bamboo outflanks most different materials, fortification steel notwithstanding. It accomplishes this quality through its empty structure developed over centuries. This lightweight structure likewise makes it simple to reap and ship. Bamboo is astounding decision for fortification in solid pillars in light of its higher quality as contrast with steel by weight, the rigidity of bamboo is about 28,000 lake for each square inch versus steel 23,000 psi. This examination assessed the achievability of the utilization of bamboo as a potential support in concrete basic individuals. To accomplish this goal a progression of tractable tests were directed on three kinds of bamboo followed by four twisting trial of solid shafts fortified with bamboo. The test outcomes were contrasted and plain and steel strengthened solid bars conduct.*

***Key Words*: bamboo, steel, strengthened, structure, in**

1. INTRODUCTION

In many nations, concrete is generally utilized as the establishment for the Infrastructure. Concrete is utilized to a great extent since it is prudent, promptly accessible and has reasonable structure properties, for example, its capacity to help huge compressive burdens. Be that as it may, the utilization of cement is restricted on the grounds that it has low elasticity. Therefore, it is strengthened, and one of the more famous fortifying bars (rebar) is Steel has a moderately high elasticity, as high as 115 ksi(792 N/mm2), supplementing the low rigidity of cement. It is accessible and reasonable in most created nations however shockingly not all pieces of the world. In numerous nations, none or next to no steel support is utilized in development, which is apparent from the disintegrating of structures .Steel reinforcement at some point may no longer be available. Even today there exists a need for more economical and readily available substitute reinforcements for concrete. In certain pieces of the world numerous structures are developed uniquely with cement or mud-blocks. This is perilous if there should be an occurrence of seismic action. These structures have little any expectation of remaining on account of a seismic tremor. Steel support would be a perfect arrangement, yet cost is an extensive issue. Researchers and specialists are continually looking for new materials for auxiliary frameworks; utilizing bamboo as conceivable fortification has picked up fame Bamboo is mammoth grass, not a tree. Bamboo culms are a tube shaped shell separated by strong transversal stomachs at hubs and make them captivating properties, for example, high quality toward the path corresponding to the filaments, which run longitudinally along the length of the culm, and low quality toward a path opposite to the strands. The thickness of strands in cross-segment of a bamboo shell changes with thickness just as tallness. Fiber dispersion is more uniform at the base than at the top or the center. This is on the grounds that bamboo is exposed to most extreme bowing worry because of wind at the top part of the culm (Ghavami 2004) Bamboo is a characteristic Functionally Graded Material (FGM). It is a composite with various leveled structure. The quality of bamboo is more noteworthy than the majority of the timber items. The mechanical properties differ with stature and age of the bamboo culm. Research discoveries show that the quality of bamboo increments with age. The ideal quality worth happens somewhere in the range of 2.5 and 4 years. The quality reductions at a later age (Amanda and Untao 2001). The capacity of the hubs is to forestall clasping and they assume a job of hub break arresters. One significant issue with bamboo is that it is a living creature which is dependent upon growths and bug assaults. Bamboo is more inclined to bug assault than different trees and grasses as a result of its high substance of supplements. So as to battle this issue, it gets important to get the bamboo shield it from nature. One of the astonishing parts of bamboo is the manner in which it communicates with nature. It has been found that bamboo can forestall contamination by retaining a lot of nitrogen from squander water and lessening the measure of carbon dioxide noticeable all around (Steinfield 2001)) Bamboo arrives at its full development in only a couple of months and arrives at its most extreme mechanical quality in only barely any years. Its bounty in tropical and subtropical districts makes it a financially worthwhile material. A portion of the positive perspectives, for example, a lightweight plan, better adaptability, and sturdiness because of its slim dividers with discretely disseminated hubs and its extraordinary quality make it a decent development material. Bamboo is utilized as basic material for framework at building locales in India, China and different nations as it is an intense, adaptable, light weight and ease material. In nature when bamboo is secured with overwhelming day off, will twist until it contacts the ground without breaking. This infers bamboo has more prominent adaptability than wood.

Bamboo has been and is being utilized in a wide assortment of utilizations, for example, diversion, safeguard, lodging and development. With respect to entertainment bamboo has been utilized to develop an assortment of instruments. Notwithstanding the way that bamboo can be utilized in expressions of the human experience, it can likewise be eaten. The market for bamboo shoots has developed quickly in the most recent years. Truth be told Taiwan sends out $50 million dollars worth of shoots that are eaten around the world. One of the significant uses of bamboo is for development and lodging. It is evaluated that one billion individuals live in bamboo houses. It can likewise be utilized to make furniture. Over a time of multi year the fares of bamboo furniture nearly multiplied in Philippines. In India and China bamboo is utilized in development of transitory suspension spans. In Tokyo and Hong Kong it is utilized as framework in elevated structures.

1.1 Comparison between Bamboo and Steel

One of the properties that would make bamboo a decent substitute to steel in strengthened cement is its quality. The quality of bamboo is more prominent than most timber items which are beneficial, however it is roughly a large portion of the elasticity of steel. Bamboo is effectively available as it develops in pretty much every tropical and subtropical area, this brings down the expense of development and expands the quality of the structures that would some way or another be unreinforced. One significant issue with bamboo is that it draws in living being, for example, growths and creepy crawlies. Bamboo is more inclined to creepy crawlies than different trees and grasses since it has a high substance of supplements. So as to battle this issue, it gets important to get bamboo shield it from the earth. Steel doesn't have this issue yet it additionally should be covered so as to shield it from rusting. Bamboo is extremely light in weight contrasted with steel. Because of its low modulus of flexibility, bamboo can split and redirect more than steel support under similar conditions. These angles put bamboo on the rundown of practical development materials. These properties, when joined, recommend that bamboo will make a fine expansion to the present determination of materials, however it is fundamental that individuals as a rule be made progressively acquainted with its qualities and shortcomings.

1.2 Literature review

This section presents a literature review spanning the range of the complex biology of Bamboo for understanding to prior research conducted on mechanical behaviour and different applications of the Bamboo

Bamboo, proper treatments that should be applied to Bamboo, and the methods that should be employed when utilizing Bamboo as concrete reinforcement. The positive attributes of Bamboo are listed, supporting its environment-friendly nature. Some negative attributes of Bamboo were also given, focusing on its tendency to absorb water. The properties of Bamboo were found to be based upon a functionally graded construction, with its most important property being that its ratio of strength to specific weight is six times greater than steel. Test results showed the ideal value for the percentage of Bamboo in concrete to be 3%f the cross-sectional area of concrete beam, allowing for the highest applied load, and the necessity for drying and water repellent treatments. This study concluded that Bamboo can substitute steel satisfactorily, and that there is a need to establish the characteristic strength of Bamboo for design purposes. The United States Naval Civil Engineering Laboratory (1966, 2000) detailed a study giving a lot of directions on the best way to appropriately develop an assortment of structures and auxiliary components utilizing Bamboo. This investigation proposed not to utilize green, unseasoned Bamboo for general development, nor to utilize un-waterproofed Bamboo in concrete. Concerning Bamboo strengthened solid, it was discovered that the solid blend plans might be equivalent to that utilized with steel, with a droop as low as functionality will permit. It was suggested that the measure of Bamboo fortification in concrete be 3 4% of the solid's cross-sectional zone as the ideal sum. It reasons that Bamboo fortified cement is a potential elective light development technique with ease.

Amada et al. (1997) investigated the mechanical and physical properties of Bamboo. They conducted a thorough investigation into the structure and purposes of the nodes, which they found to strengthen the Bamboo culm. They also commented on the advantage Bamboo has over other natural building materials with its fast growth rate.

Masani (1977) led a top to bottom examination sketching out the best possible approaches to use Bamboo in development. A posting of the positive parts of Bamboo is given, refering to models relating to its efficient, mechanical, and ecological properties. At the point when utilized as fortification in solid, ways are given to protect a superior presentation, remembering dialogs for waterproofing, pressure-treating, solid plan, and shaft structure. This investigation found that the Bamboo support region ought to be multiple times the run of the mill steel support territory, and that in any event, when fine splits create on the outside of Bamboo, the heap conveying limit of the part isn't diminished. The main negative properties of Bamboo given are its helplessness to assault by creepy crawlies, parasites and dried bamboo is inclined to burst into flames.

Amada and Unto (2001) considered the break properties of Bamboo. In logical inconsistency to different examinations, this investigation expresses that the rigidity of Bamboo strands nearly relates to that of steel. The fundamental revelation is that the break properties of Bamboo rely on the cause of crack. In the hubs, it is discovered that the normal break strength is lower than the base estimation of the whole culm, proposing that the strands in the hubs don't contribute any crack opposition. Richter scale) earthquake. They found no cracking in the concrete, the Bamboo to be extremely resilient to earthquakes, and the cost to be split in half compared to mud-and-brick construction.

A study reported in International Network for Bamboo and Rattan (INBAR)(2005) compared Bamboo to other plants such as trees by looking at how fast it grows the basics of the plant, its habitat, its history and its modern uses. For instance, we see that the same height tree takes just as many years to replace as Bamboo takes days. A single Bamboo clump can spread 15 km inits lifetime. Bamboo is the most diverse group of plant in the grass family and has tropical and subtropical distribution spreading from 46N to 47S latitude, giving many cultural uses for Bamboo. Steinfeld (2001) investigated the amazing current employments of Bamboo around the globe. In the United States, it is totally utilized as adornment. A discourse is introduced on the surprising element Bamboo brings to the table as referenced in different articles. Another unique element about Bamboo is that reaping Bamboo doesn't hurt the plant, delivering a greater amount of its timbers. Bamboo structures are certainly a possibility of things to come in the US; anyway in Asia, the Pacific islands, and South and Central America, they are very conventional. The primary anticipation of Bamboo structures in America are construction standards. There are not institutionalized codes for structures of Bamboo however there are endeavors towards them. Bamboo is additionally as yet being taken a gander at as away to clean natural contamination. It is a purchaser of Nitrogen, which could before long be a piece of an enormous exertion to forestall air contamination.

The American Bamboo Society (2005) gave a complicated assortment of particular terms followed by their definitions identifying with Bamboo. It likewise has a glossary of inquiries and answers normal to another person to the theme. These inquiries extended from distinguishing Bamboo, protecting Bamboo, discovering help with your Bamboo, to different points not as shutting associated with the exploration of this task.

2. Experimental Program

Exploratory program of this examination comprising of malleable testing of bamboo materials and four-point bowing trial of bamboo fortified solid pillars. Tractable tests include example readiness, use of epoxy to the examples to apply end-taps, test set-up and instrumentation. Bar testing incorporates bar configuration, solid blend structure, bamboo arrangement, support planning, structure readiness, solid throwing, and the conduction of the tests. The pillar test arrangement and instrumentation are depicted in detail. At last, the stacking history and testing methodology are displayed.

Tensile Test

2.1.1 Specimen Preparation

So as to lead the tractable tests, it was important to set up the bamboo tests. To begin with, the examples were sliced to the best possible size and shape. The length of the examples was to a great extent controlled by the separation between the hubs. The vast majority of the examples tried were somewhere in the range of 9 and 12 in (229 and 305 mm) long. The widths of the examples were decreased since a portion of the first examples were too solid to be in any way broken. The thickness, alongside the width, varied between the examples since Bamboo is a characteristic material whose physical properties change. Thus a cautious dimensioning of the example was done before testing the bamboo. The dimensions were measured at five points along the length of the sample. To calculate average dimensions of the test specimen. The five points included the midpoint, the ends, and two points approximately halfway between the middle and the ends. The distance between these points was measured and recorded, along with the width and thickness. These dimensions are pictured below in Figure 2.1. Measuring the dimensions of the specimens made it possible to determine the average stresses and strains in each sample. Since the information given in literature is limited with regards to the effect of the node on bamboo's strength, it was desired to investigate this effect. Thus, some samples with nodes were selected to compare their behaviour to un-noded samples. The samples with nodes were prepared so that a node was at the center of the gauge length. To protect the bamboo from being crushed by the grips of the testing machine, aluminium tabs were fabricated and applied to the bamboo samples as shown in Figure 2.2. Figure 2.2 also shows a size representation of the aluminium tabs.

Fig(2.1) Photograph of the Aluminium Tabs

Fig(2.2)Size Representation of Aluminum Tab

These figure represent finished test specimen for tensile test. For some of the first samples, the tabs were bent into a gentle curve in order for better contact to be made with the bamboo. However, after several trials it was determined that this was not necessary. When the bamboo and tabs were curved, the grips of the machine were only contacted the bamboo at three places. For this reason, the grips had to be tightened down with more force than the bamboo could withstand, often causing the aluminium tabs to lose their bond with the bamboo. This behaviour was also related to the bonding agent that was being used: an epoxy with a tensile strength of 1000 psi (6895 KN/m2). At approximately 1000 pounds (4.4 KN) of load, the grip would fail due to a spike in the strain (elongation). Thus new epoxy was used called "JB Weld" brand weld; it has a tensile strength of 4000 psi (27580 KN/m2) Since this study aims at using bamboo as reinforcement for concrete beams, the bamboo samples were waterproofed in order to be consistent with the reinforcement prepration.

2.1.2 TEST SETUP

For tensile strength testing a MTS QTEST/150 machine was used. This machine is able to apply tensile loads of up to 34 kips (151 kN) which is shown in Figure2.6

2.2 BEAM TEST

2.2.1 Beam Design

Since it is the purpose of this research to determine the feasibility of the use of Bamboo as reinforcement in concrete, it is necessary to compare its behaviours to steel, the traditional reinforcement. Therefore beam designs were in accordance with ACI and ASTM standards and specifications. In the beginning of the beam design, the width-to-depth ratio of 0.4 was assumed, along with a width of the bamboo bars of in (19 mm), as suggested by reference (U.S. Naval Civil Engineering Laboratory 1966, 2000) concerning bamboo reinforced concrete. Per ACI 318-02, the clear cover (the distance from the outside of the beam to the reinforcement, is between 1.5 to 2 in (38 and 51mm) for steel reinforced concrete, and the clear spacing between reinforcement be the greater of 1 in (25 mm) or 1.33 times the maximum aggregate size, with a minimum of 1 in (25 mm). Both the clear cover and the spacing were chosen to be 1.5 in (38 mm).Considering these dimensions and those that would allow for practicality of testing and construction, a width of 8 in (203 mm) and a depth of 20 in (508 mm) was chosen for the test beam. Since the behaviour of bamboo reinforced concrete is not known, it was important for this research to observe how bamboo reinforced concrete responded to the variance of the a/d ratio, and to compare with the expected behaviour of steel reinforced concrete. The maximum feasible a/d ratio that can be tested on a beam with span length 7 ft (2.13m)is approximately 2. Thus, two values of a/d were employed in designing the beam test matrix: a/d = 2.0; and a/d = 1.5

2.2.2 Test Variables

The test variables used are: (1) Bamboo type; (2) a/d ratio; and (3) percent of reinforcement. The types of Bamboo used were Moso and Solid. The percentages of reinforcement tested were 1%, 2%, 3% and 4%. The a/d ratios were selected to be 1.5 and 2. All of the Bamboo received a waterproofing coating.

2.2.3 Reinforcement Preparation

There is very limited information in literature regarding bamboo reinforced concrete concerning the design and construction of the actual reinforcement. Therefore it was the aim of this research to design the process of fabricating the reinforcement for the beams. Since it was desired to reuse the formwork in which the concrete was poured, it was necessary to construct a free-standing reinforcement. Many methods were attempted before developing an efficient and successful method of creating the reinforcing structure. It was known from literature that the finest width of the Bamboo strips was in (19 mm) (Mardjono 1998), providing the maximum area with the least amount of curvature. Since the beam was 8 ft (2.43 m) long, it was determined that the Bamboo culms needed to be cut 8 ft (2.43 m) long and in (19mm) wide without adjusting their thickness, as this could reduce the strength of the strips. After the Bamboo was cut, it was waterproofed. Thompson's brand deck water sealer was applied in a thin coat using a paintbrush to all of the strips. A thin coat is necessary to reduce the negative bonding effects that the waterproofing may have on the Bamboo. Next the Bamboo was cured for 24 hours before it could be handled. Benefiting from this project's location in Texas during summer, the Bamboo was left outside to cure. Choosing the best method to attach the Bamboo strips together required careful consideration. Different ideas consisted of using thin string or fishing line to tie the strips together. String or fishing line would not support bamboo bars well enough for the reinforcement to stay in the desired shape. The method eventually preferred for tying the Bamboo bars together was twisting ties. After much deliberation, it was decided to tie each layer separately, and then tie the layers together. For the design of 4% reinforcement, five layers of reinforcement were provided. This was determined by measuring the cross-sectional area of each strip of Bamboo, calculating the average area, then calculating how many strips at that given cross-sectional area would provide 4% cross-sectional area of the entire beam (For the remaining tests this method was changed to calculating the exact cross-sectional area of each strip, adding the total, and then calculating the required number of strips. This allowed for a more accurate calculation. Before tying the strips together, they were cut to the exact length needed. Generally with steel reinforced concrete beams, a hook length, is employed at the ends of the beam to enhance the bond between the reinforcement and the concrete. Due to the nature of Bamboo, it is impossible to provide this hook length Therefore, the Bamboo strips of about 8 ft (2.4 m) long, were cut to 7 ft 9 in (2.667 m), to providing 1.5 in (38 mm) cover on either side of reinforcement Another component of the reinforcement is the stirrup, which provides shear reinforcement.Typical steel stirrups constructed were either open loop or closed loop stirrup. Bamboo, stirrups made of Tonkein was constructed .Tonkin Bamboo was chosen because of its flexible nature. Tonkin Bamboo culms were split vertically with a knife, waterproofed, then bent into shape and secured with steel wire. This proved to be very difficult to manufacture. The closed loop type shown in Figure 2.16 was impossible to construct for the same reasons that providing the development length was impossible. Therefore, it was decided to make the U-shape without curving the ends. For the first beam, each layer of reinforcement was made by securing each bar at each end and in the middle with small bamboo splints and steel wire. Considering the cross section dimensions and the width of the Bamboo strips, the spacing from the outsides of the outer two strips needed to be 5 in (127 mm). When the middle strip was placed in the center between them, a distance of 1.33 in (34 mm) between each strip was provided. Once all the layers were made, they were stood on one side and attached together a distance of 1.5 in (3.81 cm) center to center per ACI 318-02, again using Bamboo splints and steel wire. Next, thin strips of waterproofed Tonkein were attached at 6 in (152 mm) spacing along the longitudinal of the reinforcement with steel wire. The compression reinforcement was then attached to the stirrups with steel wire at a distance of 17 in (431 mm) from the bottom of the reinforcement, as determined from the beam dimensions. With the trimming of any excess Bamboo, the first reinforcement was complemented. The method used to construct the first reinforcement was tedious and slow. A more efficient method was needed for the following reinforcements. Instead of steel wire, steel rebar ties were employed to attach the Bamboo to the splints. Using the special rebar tie tool, this method proved to be more efficient. Also, instead of attaching the separate layers together with bamboo splints, the new technique involved tying the layers directly to the stirrups. This also proved to be much faster, and more structurally sound, as the use of splints in the first reinforcement caused the Bamboo to shift. Thus, a more efficient and successful method was developed to construct the reinforcement.

2.2.4 Formwork Preparation

Formwork was constructed to support the freshly placed concrete and the Bamboo reinforcement of the beam. Basic concerns were accuracy of the design, pertaining to length and shape, as well as the finish of the beam. Elements used in the construction of the formwork were in (19 mm) BC plywood. The BC plywood ensured a clean smooth finish to the concrete, and the supports would help keep the measurements shaped after the concrete was placed inside the formwork Lifts were attached beneath the form to enable easy movement by a forklift after the curing had taken place and the beam was ready for testing. shown in fig 2.3

Fig (2.3) Formwork preparation before concreting

2.2.5 Concrete Mix Design, Pouring, and Compression Tests

The concrete used for the beams was made using the Portland Cement Type I/II, limestone sand as the fine aggregate, and limestone coarse aggregate with a maximum size of 3/4 in (19 mm). The concrete mix proportions were 1:3:2.2 (cement: coarse aggregate: fine aggregate) and a water-cement ratio was 0.45. The mix was designed for seven day strength of 4000 psi (27560 kN/m2), and a slump value of approximately 4 in(102 mm) to insure consistency concrete. The mix design's ingredients and amounts are given in Table 2.1.

Table 2.1

Ingredients for Concrete Mixture Water Cement Coarse Aggregate Fine Aggregate

lb /yd3 kg/m3, lb/yd3 kg/m3, lb/yd3 kg/m3, lb/yd3 kg/m3
280, 166, 611, 362, 1850, 1097, 1280.4, 759

A typical beam had the dimensions of 1m x 0.2m x 0.4m and the volume of 8.89 ft3 (0.252 m3). A single beam's concrete mix was then reduced from the original mix design and designed for a rounded 10 ft3 (0.283 m3) mix.A water reducing agent was also added to the mix with a 3/100 cement weight. The mix for a 10 ft3 (0.283 m3) beam is shown in Table 2.2

Table 2.2 Ingredients for Concrete Mixture (One Beam)

Water Cement, Coarse Aggregate, Fine Aggregate, Water Reducing Agent

lb kg lb kg lb kg lb kg fl.oz. ml
80 36 226.3 103 685.2 311 497.9 226 6.76 200

After mixing the concrete in two batches, it was taken to the formwork. A 1.5 in (38 mm) clear cover was first placed in the bottom of the form and then the reinforcement was placed on top of that. Concrete was then placed into the form and around the Bamboo reinforcement. Using steels rods, the concrete was pushed down in between the reinforcement as well as in the more open areas to help ease out air pockets. Rubber mallets, acting as vibration tools, were then hit along the outside wall of the formwork to vibrate the concrete into spots that the steel rods might not have reached, and to settle the concrete in all the space provided. When all the concrete was added to the formwork, the top was finished off smoothly and the curing process began. Cylinders were also prepared (as per ASTM standards) for compression tests. This was done by pouring them full of the same concrete used in the beam. The cylinders cured so that they could be tested in compression to tell the strength of the concrete at that point in the curing process. If several cylinders were made, tests could be performed each day of the curing process. To find the strength of the concrete, the concrete would be removed from the cylinder and placed under a compressive load using a hydraulic compression machine. The machine would increase the load onto the concrete cylinder until failure was reached. When the concrete cylinders reached the desired values, the test could begin for the respective beam. shows a concrete cylinder, and shows a concrete cylinder loaded to failure in the compression machine.

Fig (2.4) Mixer making M20 Grade

Fig (2.5) After Concreting the Formwork

2.2.6 Test Set-Up and Instrumentation

The test set-up began with picking up the beam with the forklift. The beam was then placed under the testing machine . The beam was carefully placed to provide the supports at the measured placement of 6 in (153 mm) from each end. With the forklift and the research team, the concrete beam and steel support beam were pushed sideways into place above the cylinder and between the bar frame of the hydraulic compression machine being used for the four point bending test.

Instrumentation consisted of a dial gauge and a laser displacement device, both which were placed at the center of the beam to measure maximum deflection. Strain gauges were also attached to the Bamboo reinforcement, being placed in the critical areas of the beam to follow and record the strain behavior. One strain gauge was placed on a stirrup a distance'd' from the support. A second strain gauge was placed in the center of the bottom layer of reinforcement, in the area of maximum bending moment (L/2). The third strain gauge was place a quarter of the way from one end of the reinforcement (L/4). A schematic of the strain gauge placement.

Strain gages are very delicate devices, and they could not be applied on top of the waterproofing agent due to a chemical reaction between those and the adhesive. Therefore, to safely apply the strain gauges, the desired sections were taped over before waterproofing. Then the adhesive was applied to those sections. It then had to cure for 24 hours, providing a smooth, guarded surface for the strain gauges. After the curing, the strain gauges were applied, after which they also had to be pressed to cure for 24 hours so that they could be soldered. A photograph of strain gaged reinforcement A CEA-06-250 UW-350 strain gages supplied by Vishay micro measurements were used.

3. EXPERIMENTAL TEST RESULTS

3.1 Tensile Test Results

The first set of tensile tests was conducted on different species of Bamboo to find a pattern of behaviour based on the structure of Bamboo as a plant. These tests were performed on several specimens with and without nodes. The results suggested two vague patterns. The first pattern observed was that if a node was present, the failure often occurred at the node as shown in Figures 3.1 and 3.2, which shows four different test specimens after failure at the nodes. The second pattern observed was that specimens with nodes often held a larger load before reaching failure in contrast to those without a node. Examination of the node structure shows that the fibers in the nodes are much denser than those of the internodal regions. Also, the fibers which are straight elsewhere become chaotic in the node. Tests and study of Bamboo nodes indicate that the node may be very brittle and stiff, suggesting the reason why the specimen fails at the nodes. Test sample suggested the internodal regions of the Bamboo elongated until it reached a limiting value and then the load was transferred to the node. It seems that constitutive relationship of the nodes differs from those of internodal regions with nodes having a brittle behavior while internodal regions exhibit a more ductile behavior. However, the ultimate strength of the node is anticipated to be higher than other regions. Tensile tests were conducted on Tonkein Bamboo, which was used as the stirrup reinforcement in the concrete beams. The Tonkein specimens followed the pattern previously discussed. shows that the samples with nodes carried a higher load than those without a node. Specimens failed quickly and straight across the nodes.

Fig (3.1)Compression Test

Fig (3.2) Concrete Cylinder

3.2 Conclusions

Based upon the tests conducted, the following conclusions are at the forefronts:

1. The failure loads varied with the compression strength of the concrete, providing a lower failure load for lower compression strengths.
2. The beam with 4% Bamboo reinforcement produced an over-reinforced failure mode.

3. The load carrying capacity of the Moso Bamboo was higher than that of Solid Bamboo. Also Solid bamboo deflected less than Moso indicating that Moso behaved in more ductile manner.

4. Tensile tests indicated that presence of nodes in Solid Bamboo samples did not affect the behaviour.

5. The constitutive relationship of the nodes differs from those of internodal regions with nodes having a brittle behaviour while internodal regions exhibit a more ductile behavior

6. The waterproofing agent chosen provided poor bonding. Bond-enhancing applications should be required to strengthen the bonding between the concrete and the Bamboo.

7. The stirrups were developed using flexible Tonkein Bamboo. The size selected for stirrups was [illegible] in (13 mm) to obtain flexibility. This stirrups design provided small resistance to shear forces.

8. Based on the limited number of testing conducted, it was concluded that Bamboo can potentially be used as substitute steel reinforcement. However, for regions of the world that availability of steel is limited and plain concrete members are commonly being used, the use of reinforced bamboo concrete is highly recommended

9. The breaking patterns of the tensile tests were overall inconclusive. However, there was an indication that the fracture points of the tensile samples containing nodes occurred at the nodes, which was also verified in the beam tests.

10. In general, samples failed by: (1) node failure; (2) end-tap failure; and (3) failure at the vicinity of the end-tap.

11. The failure load patterns of the tensile samples were overall inconclusive. However, the samples with nodes generally failed at higher loads than those samples without nodes

Recommendations

1. This project suggests many recommendations for future research.

2. Different clear cover dimensions are suggested to be used. The cover used is based on protecting steel from corrosion. Since Bamboo does not corrode in concrete, the cover could potentially be less.

3. More a/d ratios with different beam lengths should be tested. Increasing in beam length would allow for testing of larger a/d ratios.

4. Beam tests with different percentage of Bamboo reinforcement should be investigated.

5. The same test matrix used in this project using steel stirrups could be used, creating a hybrid beam.

6. The stirrups were designed per ACI requirements. Smaller distances between the stirrups are suggested to provide better shear resistance capability since the section of stirrup sizes is limited to the capability of bamboo to bend.

7. An extensive study to evaluate the behavior of different types of bamboo is recommended as the bamboo type and behavior is different at different regions of the world.

8. The development of finite element models for each type of Bamboo is suggested. This would assist identification of bamboo behavior with different geometric variables.

9. Low frequency fully cyclic experimental tests could be conducted to identify the behavior of Bamboo reinforced concrete in earthquake induced ground acceleration.

10. In this study two different types of epoxy were used .However, if available, a stronger epoxy is suggested while testing tensile samples to eliminate the variable of grip failure.

11. Accommodating bonding applications to investigate the necessary conditions for better bonding between the concrete and Bamboo.

12. Pressure treatment of Bamboo is suggested before conducting four-point bending tests to provide a greater Bamboo strength.

13. Long-term studies investigating the durability of Bamboo reinforced concrete should be conducted.
14. Further experimental coupled with numerical studies are recommended to better understand the effects of nodes on tensile strength of bamboo.
15. The effect of thickness on the strength of bamboo tensile samples is suggested to be investigated by conducting tensile tests on samples with the same dimensions as those used in concrete.
16. Variation of Bamboo tensile specimen length is suggested to determine if this is a factor for tensile strength.
17. More tensile tests is suggested to investigate the relationship between the tensile strength of bamboo and its performance as reinforcement in concrete.
18. To investigate the behavior of bamboo in flexure, it is suggested to conduct four-point bending tests with bamboo itself.

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