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Uncertainty in Improving Durability Aspects and Mechanical Properties of Bamboo Reinforced Concrete

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***Abstract*— The construction industry uses the most of clean energy and also produces most of the carbon dioxide in the present global world. The production of one ton of steel and concrete emits more than two tonne and one tonne respectively of carbon dioxide whereas production of one tonne of bamboo consumes more than one tonne of carbon dioxide from the atmosphere. In SAARC countries like India where about two-third of the population live below poverty line, there is a great need of some other suitable construction material in terms of cost, availability and environment friendly. Towards this, many researchers in the past has emphasized on the use of Bamboo as reinforcement. Bamboo offers competitive strength to mass ratio, compared to re-bars. Since it is a natural material, the necessity to understand their long term behaviour regarding its acceptance as a suitable construction material in general is important. Due to the advantageous characteristics of bamboo, efforts should be made to popularize the use of bamboo.**

In this study, a review of the existing research work on Bamboo Reinforced Concrete with the emphasis on the various factors, which are considered as demerits in making bamboo reinforced concrete construction, as a tool is presented. This uncertainty study may serve the goal of making the dream of common people, to have their own home, come true.

Keywords*— Bamboo Reinforced Concrete, Durability, Mechanical Properties, Economic and Environmental Friendly Reinforcement.

I. INTRODUCTION

Bamboo is a perennial, woody grass belonging to the group of angiosperms and the order monocotyledon. Bamboo is a fast growing species and a high yield renewable resource. All over the globe, bamboo has about 76 genera – embracing about 1500 species. India is rich in bamboo resources (having about 22 genera and 136 species). Bamboo shells are orthotropic materials with high strength in the direction parallel to the fibres and low strength perpendicular to the fibres respectively [Ghavami, 2005]. It is a functionally gradient material, evolved according to the state of stress distribution in its natural environment. The bamboo culms are divided into segments by diaphragms or nodes and its outermost layer. The barker consists of epidermal cells that contain waxy layer called cutin. The innermost layer is composed of sclerenchyma cells. The middle layer is formed by fibres, veins and sap conducts which are randomly disposed in the transversal section and wrapped in a tissue, a kind of matrix called parenchyma [Lima et al. 2008]. Bamboo is natural cheap, natural, widely available and most importantly strong in both tension and compression. Bamboo is also an environment friendly plant because it absorbs a lot of nitrogen and carbon dioxide in the air for its growth. Although bamboo is considered to be vulnerable to environment degradation and insect attacks, it can be suitably treated with chemicals to improve its durability and mechanical properties.

A. Durability of Bamboo as concrete reinforcement

The durability varies with the type of species, age, conservation condition, treatment and curing. There is a strong relation between insects attack and the levels of starch plus humidity content of bamboo culm. There is only a slight deterioration in the mechanical properties as compared to initial treated bamboo after 10 years [Lima et al. 2008] when a bamboo reinforced beam after tested is exposed to open air. Working as reinforcement in concrete, bamboo splints usually have large dimensions. This fact means that the great majority of bamboo fibres completely encased in parenchyma and they are not directly exposed to the alkalinity of cementious matrix, therefore the higher number of the fibre end points is not detrimental. In addition the bamboo splint dimension make the penetration of cement hydration produces much more difficult. The density of the fibres in the cross section of a bamboo shell varies along its thickness. The thickness decreases from the base to the top of the bamboo shell. Fibre Distribution is more uniform at the base than at the top or the middle part, since bamboo is subjected to maximum bending stress at the base, owing to the wind and its own weight. The carbohydrate content of bamboo plays an important role in its durability and service life. Durability of bamboo grains mold, fungal and borers attack is strongly associated with the chemical composition.

The fire resistance of bamboo is good because of the high content of silicate acid filled up with water; it can stand a temperature of 400^0 C, while the water cooks inside [Shaw, 2012].

B. Mechanical properties of bamboo and its behaviour as reinforcement in concrete

The tensile stress of bamboo can reach upto 370 N/mm^2 [Mark and Rusell, 2012]. The elastic modulus of bamboo as reinforcement is found as high as 51428.6 MPa and the yield strength of 109 MPa [Ahsan et al., 2011]. The ratio of tensile strength to specific weight of bamboo is six times greater than that of steel. The strength distribution at the bottom of the bamboo culm is more uniform than at the top. The strength of bamboo also increases with age and maximize after 3-4 years. In the nodes the average fracture toughness is lower than the minimum value of the entire culm. In establishing the mechanical properties of bamboo, in the elastic range, the rule of mix for the composite material is used. The properties of the fibres and matrix with their volumetric fractions are taken into account. It is concluded that vascular bundle size (radial/tangential ratio) and fibre length correlated positively with modulus of elasticity and stress at proportional limits. The correlation between fibre length and shear strength was negative. The fibre wall thickness correlates positively with compression strength and modulus of elasticity but negatively with modulus of rupture. However the bond stress of bamboo is approximately five times lower than steel.

II. REVIEW

Brink and Rush (1966) proposed the design procedure and chart for concrete construction and conversion method from steel reinforced concrete design with the modified characteristics of bamboo reinforcement to estimate the ultimate load carrying capacity of the precast concrete elements with bamboo reinforcing. It also showed that of full cross section of concrete only 80% is considered effective in rectangular tied. Rahman et al (2000) studied the stress-strain diagram with number of node as a variable parameter from which he found that it possess low modulus of elasticity. The study proposed that bamboo reinforced concrete beams with steel stirrups will improve its load carrying behaviour. Iyer (2002) bamboo to be worthy and cost effective material to be used as reinforcing in bearing masonry for seismically safe houses. The study makes the comparison of bond strength in presence and absence of node in mortar block. It concluded that for better shear resistance larger area of bamboo splint is preferred and for better bonding lesser splint area is advisable. Alito (2005) recommended the use of high early strength cement to minimize cracks caused by swelling of bamboo when it cannot be totally waterproofed. The study also considered the moisture content, dry density and radial shrinkage variation of bamboo with node and without node.

Ghavami (2005) shows that microstructure of bamboo as a functionally gradient material has been a most important parameter in determining structural properties (flexural as well as axial). He also studied the thickness vs internode number and young's modulus vs density feature. Khare (2005) studied that the fracture points of the tensile samples containing nodes occurred at the node which was verified experimentally. The study showed that the specimens with nodes behaved in a less ductile manner with higher strength than those without nodes.

Lima et al (2008) presented the results of an experimental investigation made to evaluate bamboo durability to be used as concrete reinforcement. This specific study concerns the durability of bamboo exposed to tap water and calcium alkaline solutions. Bamboo splints were exposed to cycles of wetting-drying and possible decay in tensile strength and Young's Modulus was investigated. The experimental tests in this study showed that the strength is comparable to steel. The 'stress vs strain' curve as found to be linear up to the failure.

Leelatanon (2010) study showed that the strength capacity of short columns reinforced by bamboo without surface treatment could resist axial load as required structurally by ACI318-05 but ductility was low. The study also showed that treated bamboo showed higher strength and ductility which suggests that surface treatment has more effect on increasing strength and ductility. He also studied the axial force vs axial deformation curve. Dorsano and Plangsriskul (2011) studied the material characterization of bamboo and analysis of bonding strength. The project studied that bamboo with nodes have higher pull out strength and the compression test vs non dimensional radial distance curve. The paper also studied the comparison of pullout strength for different coatings. The study concluded that fibre density and internal strength both increases towards the outer edge of the bamboo culms and the maximum stress locations throughout the bamboo culms are located in the middle of the internode and closest to the peripheral edge.

Ahsan et al. (2011) studied the testing of finished bamboo sample with G.I. wire spiral at both end. The paper also studied the tensile strength, proof strength and modulus of elasticity from stress-strain curve. The study proposed that bamboo shows some nonlinearity before failure. Mark and Rusell (2011) study recommended the use of steel stirrup to enhance performance of bamboo reinforced concrete by using the sufficient amount of web reinforcement to increase the shear capacity of the beams. The failure load will not give adequate warning before failure (low ductility). It was seen that the maximum bending moment positions coincided with the nodal position resulting in failure loads higher than expected. The paper proposed that post cracking energy absorbed is affected by span-depth ratio, grade of concrete, percent tension reinforcement and shear reinforcement.

Salau et al. (2012) showed that the load bearing capacity of the column increased with increase in percentage of bamboo strips reinforcement but the increase is not proportional to the percentage of bamboo. The paper showed that the column failed due to the crushing of concrete not due to the slippage. In this study the stress vs strain curve was found to be linear up to the failure. The study greatly recommended the use only in light loaded structure, low rise building and not suitable for water retaining structure. Liese et al. (2012) studied the preservation of bamboo for the construction of houses for the low income people. This study considered the treated bamboo sample for reinforcement to increase the durability and laid emphasis on method of preservation for better durability. Tada et al. (2012) conducted the strength experiments and the experiments of water content. The paper studied the mechanical properties and the water content variation. The study showed the variation in dry density due to natural drying and forced drying.

Sakaray et al. (2012) focuses on the study of natural material so as to reduce the energy consumption and CO_2 emission. The paper showed that the compressive stress value obtained for central node specimen is greater than that of end node specimen and without node specimen. The study also showed that nodes possess brittle behaviour and intermodal region possess ductile behaviour.

Sevalia et al. (2013) study used the cage of bamboo prepared using bamboo stirrups for reinforcing in cement concrete columns elements. The paper studied the variation in compressive strength with different coatings. Umniati et al. (2013) studied the joint characteristics of bamboo reinforced concrete using bamboo mechanical bamboo anchors in cyclic loading. The paper studied the load strain relationship. It also studied the max lateral load capacity and max lateral displacement. The study showed that the flexure failure occurred before shear joint failure in mechanical anchors. The study conclude that the greater the ratio of the head area to the bar area the greater the amount of energy absorbed by the beam column joint. Sevalia (2013) study presents the evaluation of the feasibility of the use of bamboo as reinforcement. In this study the bamboo is used as reinforcement without any treatment and stirrup. The stress vs strain curve was studied for single and doubly reinforced concrete beams.

TABLE I
Comparison of properties between Mild Steel, Concrete and Bamboo [Bhalla. (21)]

MILD STEEL	**CONCRETE (Grade M 30)**	**BAMBOO (Dendrocallamus Giganteus) [Ghavami, 2007]**
Ultimate strength = 410 MPa	Tensile strength = 3.8 MPa	Tensile strength = 120 MPa
Yield strength = 250 MPa	Compressive strength = 38 MPa	Compressive strength = 55 MPa
Young's modulus = 200 GPa	Young's modulus = 27 GPa	Young's modulus = 140 GPa
Density = 7850 kg/m^3	Density = 2400 kg/m^3	Density = 700 kg/m^3

TABLE II
Stiffness Factors of Some Material [Bharti, (1)]

Materials	**Stiffness Factor**
Concrete	10
Mild Steel	27
Timber	18
Bamboo	33

Fig. 1 Bamboo as Reinforcement

III. Uncertainty In Bamboo Reinforced Concrete Construction

Even after so much of research work done so far in this field, the Bamboo Reinforced Concrete Construction (BRCC) is still an active area of research. After so many years of continuous work in this area, it is far away from large scale use for construction. Some aspects of uncertainty or limitations of using BRCC are as follows:

a. Since bamboo is a natural material there is a lot of variation in the properties among different specimens depending on the type of species, locality of its origin, season of harvesting and etc.
b. Bamboo requires proper harvesting, seasoning and storage which needs considerable amount of time.
c. It has great water absorbing capacity and low value of elastic modulus.
d. It requires suitable adhesive for better bonding and to prevent water absorption.
e. Cracking under ultimate load can't be prevented.
f. Durability of bamboo has been suspected from ages by many scientists.
g. Samples with nodes failed at higher loads than those without it.
h. Required skilled labour for preparation of bamboo splint cages.
i. The cost of fabrication is very high as compared to steel reinforced construction.
j. Bond stress of bamboo is 4.7 times less than steel.
k. Yield strength of bamboo is to be known through offset method.
l. Factor of safety is variable and quite high.
m. There is a lack of proper analysis tools.
n. Standard design procedure is not developed till now being the biggest hurdle.

IV. Discussions

Bamboo has excellent properties as a potential reinforcement for low cost housing. Better ductility behaviour and local availability favours its mass use. It cannot be used directly after cutting down without using suitable treatment to prevent it from yeast, bacteria etc which is a very tedious and laborious process and sometime it is required to make it suitable for use as reinforcement. The strength parameter cannot be generalized for different types of bamboo as strength for different species is different. The water absorbable capacity cause voids on drying due to shrinkage (swelling and shrinking of bamboo). But as bamboo is weak in shear it cannot be used as shear reinforcement in R.C.C structure. Bamboo is weak at node section major failure in bamboo occurs at node. Since the variation may be quite significant in some cases the factor of safety to be assumed in the design process should be high as compared to conventionally used factor of safety to accommodate the variation in strength and ensure the safety of the structure constructed.

V. Conclusions

It is the versatility that helped bamboo meander its way through Oriental cultures, becoming an integral part of the rich and the poor alike; a bare necessity as well as a commodity of pleasure. The ecological impact of bamboo would be hard to set aside. Bamboo, as with any natural material, has a very high degree of variation depending upon location, soil conditions, climate, species, maturity of the plant, season of harvesting etc. Based on the several experimental investigations in the past it can be said that bamboo can efficiently replace the steel as reinforcement for low cost residential structure. The numerical data of several engineering parameter supports it. Based on the literature available, it was found that the research work in using bamboo as reinforcement in concrete is vast. However for smaller applications such as house hold articles, bamboo reinforcement using light weight concrete the number of publications available are scarce. Bamboo reinforced concrete can be made for benches, tables and stools in schools, parks, hotels, railway stations etc to make eco-friendly environment and for low cost construction. The positive aspects of bamboo such as a lightweight design, better flexibility and toughness due to its thin walls with discretely distributed nodes and its great strength makes it a better building material.

However, it can only be said right now that there is a large scope and a growing need to understand bamboo which could be environmental friendly and comfortable alternative for steel in this age of sustainable development. It is rightly being said that Bamboo is a *Green Gold*, as we can see, the topic on bamboo remains evergreen as the plant itself.

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