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Literature Review on Bamboo Reinforced Concrete

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Abstract: The use of small diameter whole culm (bars) and/or split bamboo (a.k.a. splints or round strips) has often been proposed as an alternative to relatively expensive reinforcing steel in reinforced concrete. The motivation for such replacement is typically cost—bamboo is readily available in many tropical and sub-tropical locations, whereas steel reinforcement is relatively more expensive—and more recently, the drive to find more sustainable alternatives in the construction industry. This review addresses such 'bamboo-reinforced concrete' and assesses its structural and environmental performance as an alternative to steel reinforced concrete. A prototype three bay portal frame, that would not be uncommon in regions of the world where bamboo-reinforced concrete may be considered, is used to illustrate bamboo reinforced concrete design and as a basis for a life cycle assessment of the same. The authors conclude that, bamboo is a material with extraordinary mechanical properties, its use in bamboo-reinforced concrete is an considered concept, having significant durability, strength and stiffness issues, and dmeet the environmentally friendly credentials often attributed to it.

Keywords: Bamboo, Reinforcement, Structure, Sustainable, New Technology

I. INTRODUCTION

The mechanical properties of bamboo and its availability in developing regions has led to its empirical use as reinforcement in concrete structures. The proposition of its widespread use as a sustainable alternative to steel in reinforced concrete structures, poses key questions to builders, engineers and researchers with regards to its structural capacity and compatibility, as well as constructability and sustain-ability issues. This paper discusses these issues, providing a holistic review of the literature in the field and a structural comparison between steel reinforcement and bamboo reinforcement in a typical concrete structure. The principle scope of this review is intentionally limited to the use of small diameter whole-culm (bars) and/or split (a.k.a. splints or roundtrips) bamboo. Recent advances in bamboo-composite materials may represent a viable bamboo-based concrete reinforcing product that will be only briefly discussed in this paper. Other applications of bamboo-derived materials in concrete structures such as bahareque construction, bamboo fibre reinforcement and bamboo ash admixtures are beyond the scope of this discussion Bamboo is frequently referred as a highly renew-able and high-strength alternative material to timber and, occasionally as a 'strong-as-steel' reinforcement for concrete. The high rate of biomass production and renewability of sustainably managed bamboo plantations are undeniably key benefits of bamboo. None the-less, favourable comparison with steel, in terms of strength, is not valid. In a dry state, bamboo characteristic strengths are, at best, comparable to that of high-gradehardwood—between30 MPa(Oak)and50 MPa(American White Oak). Bamboo is atypically hollow, anisotropic, natural material with high variability of physical and mechanical properties across the section and along the culm. The density of bamboo varies through the cross section (from the inner culm wall to the outer), with typical valuesrangingfrom500to800 kg/m3. In longitudinal tension-dominated failure modes, bamboo typically exhibits a brittle behaviour. The variability of longitudinal mechanical properties of bamboo are similar to those of wood, having co-efficient of variance between 10 and 30% . Due to the absence of radial fibres, however, bamboo is particularly weak in the direction perpendicular to the fibres, making it especially susceptible to longitudinal shear and trans-verse tension and compression failures. Steel, on the other hand, is a man-made, isotropic and ductile material having a density of 7800kg/m3and a tensile yield strength of conventional reinforcing barsbetween400and550 MPa. Additionally, steel is easily shaped to optimise its mechanical efficiency, requiring relatively little material to resist loads in a predictable manner. Such optimisation is not easily accomplished with bamboo without substantial pro-cessing, altering its properties and nature (e.g., Hebel et al.). The oft-repeated claim that bamboo is 'the green steel' is founded in comparable-to-mild-steel values of strength and specific modulus. Some tests of small 'clear' (i.e., defect free) specimens of bamboo have reported ultimate tensile strengths on the order of250 MPa (e.g., Zhouetal. and Lu et al.). However, such results are not representative of the strength that can be mobilised in a full or partial culm: characteristic strength on the order of 40MPa and safe working stress fordesignontheorderof16 MPa— similar to hardwood timber. The tensile modulus of bamboo is on the order of 20 GPa, about 10% of that of steel. The specific modulus—the ratio of elastic modulus per unit density—for bamboo in the longitudinal direction is approximately 25 9 106m2/s2; value comparable to both steel and Douglas Fir. However, unlike steel, the highly anisotropic nature of bamboo results in a specific modulus in the transverse or tangential directions barely a tenth of the longitudinal value; values comparable to nylon and polystyrene. Thus, the mechanical properties of bamboo and its appropriateness for structural applications are often misunderstood. On the other hand, when comparing embodied energy and CO2 footprint during manufacturing of bamboo and steel, a strong argument can be made in favour of bamboo. The embodied energy of medium carbon steel is about 29–35 MJ/kg, while for bamboo culms this value is about 4–6 MJ/kg. Similarly, the carbon footprint of steel is significantly greater than that of bamboo, with 2.2–2.8 kgCO2/kg (equivalent kg of CO2per kg of material) for medium carbon steel and 0.25 kgCO2/kg for bamboo.

II. LITERATURE REVIEW

A. *Bamboo composite for structural concrete*

In this study, simulated acid rain solution was more aggressive towards BFRP than alkaline concrete pore water solution. Performance of BFRP composite in concrete pore water solution complements well with previous study, indicating the ability of bamboo to retain its mechanical properties in the alkaline environment of a concrete matrix. Although Sikadur-31 enhanced the bond strength of BFRP rebar's, the coating was detrimental to the composite as it increased susceptibility of BFRP to alkaline degradation, and did not protect the BFRP from acidic environment. On the other hand, BPA based epoxy coating not only enhanced the durability of the BFRP in acidic environment but also improved the BFRP rebar bonding behaviour, especially with introduction of sand particles.

B. *Designed reinforced bamboo scrimber composite beams*

To expand the application of bamboo in construction such as in large-span members, a new type of RBSC beams was developed by combining the bamboo and reinforcement elements. Based on the results of six type beams, the following main conclusions were drawn: Both the ultimate load capacities and bending stiffness of the RBSC beams could be significantly improved and had a maximum increase of 58% and 82%, respectively, compared with the un-reinforced bamboo scrimber beams. Based on the simplified mechanical model of RBSC beams proposed in this study, the predicted deflection and load capacity matched well with the experimental results. Thus, it could be an effective way to evaluate the bending properties of RBSC beams. For the whole cross-section of RBSC beams, the ratios of bending stiffness and ultimate load capacity contributed by the reinforcement element ranged from 23% to 45% and from 15% to 31%, respectively, when the reinforcement diameter was increased from 12 mm to 20 mm. Three typical failure modes exist: a crack along the longitudinal direction of bamboo element, a crack along the vertical direction of bamboo element, and shear failure.

C. *Frictional properties of Bamboo Reinforced Concrete beams*

Concern for environment and natural resources have broadened during the last few decades. It has come to notice that excessive or insufficient use of natural resources is in fact an abuse to the environment. Proper understanding of sustainability in building construction has undergone vast changes in the recent years. Earlier attention was provided only to technical issues of engineering structures but as time progresses non-technical issues such as economy, social sustainability came into picture drastically. Bamboo reinforced concrete stands to be a good option in the sustainable development of civil engineering construction. Many researches has been carried out in this field which helps us in understanding that use of bamboo in reinforced concrete has a vast scope. From the experimental work it can be concluded that bamboo provides a high tensile strength of 250 N/mm2 or higher which actually depends on the area of cultivation, type of species and cross-sectional area. An improved flexural performance of BRC beam has been observed with the increase in number of days of curing period and increase in the size of bamboo rebar. It is also recommended to use steel stirrups as it improves the flexural as well as shear capacity of beam. Although the aim of the study is to increase the flexural strength but in practical case with the increase in span of the beam the mid span deflection increases which is also an important criterion when serviceability limit state is considered, thus reduction of mid span deflection is another major area of research.

D. *Utilization of Bamboo as Reinforcement in Concrete for Low-CostHousing*

The inclusion of bamboo splints in concrete beams increased the load carrying capacity of the beams but not proportionately. Strength was observed to improved by up to 134.65% above the strength of unreinforced beams at 28-day curing for 2.68% reinforcement volume fraction. For the same section and percentage reinforcement the failure load of mild steel reinforced beam was approximately 1.5 times that of its equivalent bamboo reinforced beams. Bamboo splints imparted post-cracking strength to concrete beams. 1470Bamboo splint deteriorated in concrete with age. Application of impervious surface coating like bitumen makes it more resistant to deterioration. The strength of bamboo reinforced beams is adequate for low-cost housing projects but further work needs to be done before final recommendation on the use of bamboo as reinforcement in concrete can be made.

E. *Axial compressive behaviour of sprayed composite mortar–original bamboo composite columns*

The axial compressive performance of sprayed composite mortar–original bamboo composite columns and BCs were investigated using experiments and calculations, and the following conclusions are drawn. The failure mode of the short columns was strength failure at the ends of the columns, and the failure mode of the slender columns was buckling. The experimental ultimate load and ductility of the short composite column supported by the total cross section were 1.5 and 2.6 times higher than those of the short BC, respectively. The confining effects of the composite mortar on the original bamboo could not enhance the bearing capacity of the latter, and the bearing capacity of the composite column was culated using the superposition method. However, the confining effect of the composite mortar improved the stability of the original bamboo. The finite-element results for the columns agreed well with the experimental results. Thus, the buckling capacities of the slender composite columns and slender BCs with different slenderness ratios were obtained using FEMs. Considering the effects of the change of the cross-sectional dimensions and the initial deflection of the columns on the stability, a calculation method for the buckling coefficient of slender columns based on the edge fiber yield was proposed, and the results of this method agreed with the finite-element results and experimental results.

F. *Performance of bamboo reinforced concrete masonry shear walls*

Providing bamboo reinforcement in concrete block shear walls results in enhanced shear capacity and ductility compared to unreinforced masonry. Even without horizontal reinforcement, the addition of vertical bamboo reinforcement provided additional shear capacity, while also giving a relatively ductile failure compared to unreinforced masonry. Bamboo reinforced shear walls also showed remarkably similar behaviour to one reinforced with steel. The performance of walls QS.B.2, which had four vertical cores reinforced with bamboo, and QS.S.1, which had four vertical cores and three bond beams reinforced with steel were very similar in terms of both ductility and ultimate resistance. The slightly lower ultimate resistance of the bamboo-reinforced wall was attributed to a lower axial load applied to it, along with the lack of bond beams. In addition, given the variability in the materials the difference in performance for these two walls cannot be considered significant.

The use of low strength block compared to regular strength block did not significantly affect the shear wall behaviour, other than an expected decrease in ultimate shear resistance. The decrease in shear resistance was approximately proportional to the decrease in compressive strength of the masonry used in the construction.

G. *Bamboo as reinforcement in structural concrete elements*

Environmental concerns have broadened during the last two decades. Initially it meant to analyse visible catastrophes such as a dying forest or dead fish on a shore and we slowly came to realize that any excessive or inefficient consumption of resources is in fact an abuse of the environment. The understanding of sustainability in building construction has also undergone changes over the years. First attention was given to the issue of limited resources, especially energy, and how to reduce the impact on the natural environment. Now, emphasis is placed on more technical issues such as materials, building components, construction technologies and energy related design concepts as well on non-technical issues such as economic and social sustainability. Since 1979 research has been carried out in Brazil on non-conventional materials and technologies. New building components were developed using vegetable fibre as reinforcement of cement mortar and bamboo as reinforcements in beams, columns, slabs and permanent shutter forms in concrete slabs and columns. Our concern was as well the dissemination of our work, which has occurred through publications and special courses. The Brazilian Association of the Sciences of Non-conventional Material Technologies, abmtenc, was founded to further the dissemination and the cooperation between engineers, architects, designers and civil servants related to housing.

III. CONCLUSION

From this literature study of a Bamboo, anyone can conclude that bamboo as a natural material which is eco-friendly and economic material. Though it has low stiffness and strength compared to steel, it can used as reinforcement in limited storeys. And bamboo must be treated before using as a reinforcement in concrete.

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