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Experimental Investigation on Bamboo as Sustainable Reinforcement Alternative for Rural Construction

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Abstract

Bamboo is readily available and low-cost material in rural areas and can be cultivated easily. The use of bamboo lowers the cost of construction of the structures and provides a sustainable alternative to steel especially in rural regions. In the present study, oven-dried and epoxy coated bamboo is used as a reinforcement. The bond strength between bamboo reinforcement and concrete is checked by performing pull out test, on the specimens cast in triplicates for samples of oven-dried bamboo (B), plain epoxy coated bamboo (E), epoxy with sand coated bamboo (ES) and epoxy with binding wires (EB), each for 7 days,14 days and 28 days of curing. It is found that the bamboo specimen with plain epoxy coating gives the highest bond strength with concrete amongst all the above-tested specimens. As the plain epoxy-coated reinforcement shows the highest bond strength, it is then checked for flexure using STAAD PRO for a single storied rural housing. It is found that the structure with bamboo reinforcement is safe in flexure.

Key words: Bamboo reinforcement, pull out test, bond strength, flexure, low-cost-construction

Introduction

The ever-increasing demand for natural resources has led to its depletion and increase in a variety of severe problems, resulting in the degradation of the environment. One of the growing concerns is greenhouse gases which are a bigger threat in developing countries. Among these contributors include the iron and steel industry which is estimated to contribute around 6% of the total national greenhouse emission [1]. For example, for the steel manufacturing process, a large amount of energy is required which is mostly obtained by the combustion of coal, resulting in depletion of this natural resource producing by-products like fly ash and smoke which need to be tackled carefully. The production of one ton of steel produces an emission of around 1.8 tons of carbon dioxide. It can be calculated that the energy required to produce one ton of steel can light a moderate household with all facilities for a period of 3 to 4 months [2]. The production of steel thus contributes to global warming. Steel industries play a pivotal role in infrastructure development which in turn is essential for the economic growth of the nation. Possessing both high compressive and tensile strength, steel is widely accepted as a source of reinforcements in concrete and hence its existence has become irreplaceable within construction works. However, steel being an alloy is susceptible to corrosion. Corrosion is a result of chemical or electro-chemical actions which is mostly governed by chloride access and carbonation depth of reinforced concrete (RC) structures. Corrosion can decrease the strength and lifespan of RCC structures and in humid environments, pollutants from the atmosphere can seep through the concrete cover and cause deterioration of steel, formation of cracks and finally in the failure of structures. This creates a need for replacement alternatives for steel either partially or wholly, particularly focusing on the fact that steel is a non-renewableresource. The present study focuses on suitability of a bamboo as a sustainable, environment friendly, and non-corrosive alternative for steel. It can be used in a widespread way in construction in rural areas.

Bamboo is a huge grass which demonstrates rapid growth pattern at the age of around three years, there is no secondary growth. It is a renewable natural resource unlike steel [1]. Bamboo possesses less weight and density as compared to steel. Bamboo would deflect more than steel reinforcement under the same conditions, due to its low modulus of elasticity. According to the research conducted in [3], the tensile stress of bamboo (dendrocallamusgiganteus) is 120 N/mm2. The elastic modulus of bamboo as reinforcement is found as high as 140 GPa. The compressive strength was found to be 55N/mm2. It is also seen that that tensile strength(average) is ¾ - ½ times of steel or more can be seen [4]. Tensile strength is one of the properties that makes bamboo an alternative to steel in reinforced concrete. The strength of bamboo is better than most of the essential timber species, but it is almost 50 % of the tensile strength of steel [5]. The high tensile strength is particularly essential for high rise structures and thus steel is superior at those phases. Bamboo is an easily available material in rural areas and can be cultivated easily; this can reduce the construction cost and increases the strength of the structures in rural regions; which are otherwise unreinforced or under-reinforced. These aspects make bamboo up to the list of feasible construction materials in rural construction.

When commonly used construction materials are compared to bamboo, focussing on energy essential to produce 1 m3 per unit of stress projected in practice.[6] It is also evident from the study that the steel production requires 50 times more energy than for bamboo. For the production of 1 tonne of steel, 1.8 tonnes of CO2 is emitted, In contrast, the bamboo plant absorbs CO2, producing oxygen. Studies have shown that the tensile strength to weight ratio of bamboo is six times greater than that of steel by weight [5]. This leads to the possibility of constructing lightweight structures. The practice of incorporation of bamboo in civil engineering is wide in Indonesia and other developing countries but has yet to be presented in India. According to Khare, 2005, Bamboo is used as scaffoldings by the contractors in India as well as in China; bamboo has been utilized in the construct Green School in Bali, where all structural constituent of the building is obtained from a local bamboo supplier. When the physical and mechanical properties of bamboo and steel are compared, the Modulus of Elasticity of bamboo is1.5 x 104 N/mm2 and that of steel is around steel is 2 x 105 N/mm2 [7]. Structural properties of different bamboo species are also determined and it was found that the bamboo specie named Bambusa Vulgaris borne the highest compression and possess the maximum tensile strength. Bamboo possesses higher compressive and tensile strengths as compared to spruce wood, however, it is lower than steel. The author revealed the fact that bamboo displays high strength properties.

Bond strength is one of the most important factors as far as the strength of the structure is concerned as it ensures that every element of structure i.e., beams, columns, slabs, etc. act like a monolithically to transfer loads to the soil. It is the measure of adhesion present between two surfaces. Sakaray et al., 2012studied the bond strength of steel and bamboo and determined that the bond strength of bamboo is 4.7 times less than that of steel. A similar type of research [8] concluded that bamboo could be considered as an option for construction works. It is also commented that the bamboo is strong against seismic forces.

Bamboo being a porous material in nature can retain water in its pores if exposed to water, it is a great drawback in using bamboo as a reinforcement material as when bamboo is dried it gets shrunk. Bamboo may absorb water from the concrete resulting in cracks by swelling, thereby leading to failure in the future due to successive swelling and shrinkage. The bond strength reduces due to the swelling action of bamboo when it comes to contact of water [9], and to overcome this challenge waterproofing material is necessary.

The tensile strength and moisture content of the bamboo are the prominent properties affecting its property as a reinforcement material. The moisture content of 15% or lower qualifies bamboo for having suitable mechanical properties and also makes it less prone to fungus attacks [7]. An untreated bamboo has an estimated design life of around 10-15 years if it is stored correctly. The treated bamboo has a much longer design life [1]. Application of native latex, dilute varnish, coal tar, water-glass to bamboo with the concrete is also tried in the past [10].

Since bamboo is naturally grown and widely available in India, the major objective of this study is to check the feasibility of using the widely available Dendracalamus Brandisi (DBI) bamboo specie as a reinforcement material in rural construction. The bamboo surface is applied with a variety of enamels to make it hydrophobic and to improve the surface bond between the bamboo and the concrete. The overall performance of the coated bamboo is checked for bond strength and flexure.

Materials and Method

Bamboo, being organic, is susceptible to insects. It is required to treat the bamboo to protect it from atmospheric moisture. Bamboo, if used untreated, can retain water in its pores and swells; it shrinks on drying leading into cracks and thus may lead to failure in the future.

The bamboo specie used in the present study has 12% moisture content under the air-dry condition. The bamboo is coated with epoxy as a waterproofing agent. Since epoxy resin is non-porous, tough, and resistant to impact, it is flexible enough to withstand expansion. Besides, it is highly resistant to chemicals, solvents, and moisture. It has excellent adhesion properties, low shrinkage.

The bond strength between concrete and bamboo is investigated with and without epoxy coatings for the 7th, 14th, and 28th days of curing. Since bamboo is a naturally grown material, its physical properties may vary based on culm to the culm. The range of properties that are tested for the current test specimen of DBI is given in table 1.

Table 1. Physical Properties of DBI Bamboo

Parameter	Value for a Typica Bamboo
Specific gravity	0.575 to 0.655
Average weight	0.625kg/m
Modulus of rupture	60.10 to 156 N/mm^2
Modulus of Elasticity	1.5 to 2.0 x 10^{4}N/mm^2
Ultimate compressive strength	79.4 to 86.4N/mm^2

Preparation of the specimen

The bond strength of bamboo is investigated using the pullout test as per IS 2770- Part I [11]. To prepare test samples (figure 1) for pull out resistance test, the samples are prepared with plain bamboo (O), and plain epoxy coating (E). To check the improvement in the bond strength by providing roughness to the surface, bamboo coated with epoxy plus sand (ES) and bamboo coated with epoxy plus binding wire (EB) are also prepared. For preparing the concrete, materials used were coarse aggregate, cement M20 grade, river sand with D90 = 2.36 mm, and the mix proportion 1:1.5:3 for cement, sand, and aggregates. A total of 36 specimens are cast (Table 2). The mix design is performed in accordance to IS 10262-2009 [12]. The weigh batching method is incorporated for the preparation of a homogeneous mix of concrete with appropriate proportion according to the mix design. As per the mixed design of concrete, the water to cement ratio is kept as 0.4. Reinforcement is provided in the center of the mould leaving a minimum cover (50mm) from the bottom; this is provided to prevent the direct exposure of bamboo from the bottom surface of the concrete.

Table 2. The samples prepared for pull out test

Sample Type	Days of Curing	Number of Sample Specimen
O	7	3
	14	3
	28	3
E	7	3
	14	3
	28	3
ES	7	3
	14	3
	28	3
EB	7	3
	14	3
	28	3

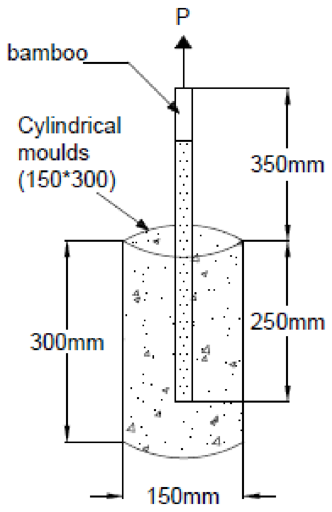

Figure (1): Schematic sketch of the sample specimen used for the pull-out test

Figure 2 shows the specimen before demoulding. After 24 hours the cast is removed and the specimens are placed for curing for a period of (7, 14, and 28 days) as shown in Figure 3. Figure 2 shows the specimen before demoulding. After 24 hours the cast is removed and the specimens are placed for curing for a period of (7, 14, and 28 days) as shown in Figure 3.

Figure (2): Specimen before de-molding

Figure (3): Specimen placed in the curing tank

The specimens are taken out tested in the Universal testing machine (UTM) for pull-out strength evaluation on 7th, 14th, and 28th day respectively. The specifications of UTM are as shown in table 3.

Table 3. Specifications of the UTM

Name	Universal testing machine
Model	TUE-C 400
Manufactured by	Fine spavy associates and engineers
Manufactured on	08/2009
Max. load	400KN
Jaw	Flat
Max. elongation	200mm

The bond strength is calculated by using the formula:

Bond strengt0h =$P_{max}/(L_b * A_p)$

Where, P_{max} = Maximum load at peak.

Abbreviation	Surface Area (mm^2)	Max load at peak (kN)	Bond Strength (N/mm^2)	AvgBond Strength (N/mm^2)
$ES_7 1$	10210	0.98	0.10	0.11
$ES_7 2$	11357	1.40	0.12	
$ES_7 3$	13265	1.44	0.11	
$ES_{14} 1$	14265	4.18	0.29	0.25
$ES_{14} 2$	13685	3.42	0.25	
$ES_{14} 3$	13469	2.80	0.21	
$ES_{21} 1$	12322	5.24	0.43	0.51
$ES_{21} 2$	12887	6.00	0.47	
$ES_{21} 3$	14627	9.34	0.64	

L_b =Bonding length.

A_p =Perimeter of the cross-section of the bamboo.

The bond strength obtained is analyzed to evaluate the most promising alternative from the tested specimens O, E, ES, and EB. The results obtained are used as an input for structural analysis and performing checks for flexure.

Result and Discussion

The physical characteristics and bond strength of 'E' type specimen are given in Table 4. The bond strength is evaluated for 7 (E7 – 1, 2 and 3), 14 (E14 – 1, 2 and 3), and 28 (E28 – 1, 2, and 3) days of curing. On each test day, three samples are tested and the results are averaged out to minimize error.

Table 4. Physical Characteristic and Bond Strength of Specimen with Epoxy Coating as Reinforcement for 7, 14, and 28 Days of Curing.

Abbrevi tion	Surface Area (mm^2)	Max load a peak (kN)	Bond Strength (N/mm^2)	AvgBond Strength (N/mm^2)
$E_7$1	12122	1.14	0.09	0.11
$E_7$2	12267	1.54	0.13	
$E_7$3	12082	1.32	0.11	
E_{14}1	11995	3.08	0.26	0.25
E_{14}2	12040	3.46	0.29	
E_{14}3	10435	2.28	0.22	
E_{21}1	11875	7.52	0.63	0.76
E_{21}2	13542	9.96	0.74	
E_{21}3	14325	13.24	0.92	

To further check the possibility of an increase in the bond strength, surface roughness is introduced by applying sand to the surface matrix of epoxy. The results of the bond strength of this matrix are tabulated in table 4. It is notable to see the decrease in bond strength as compared to the pure epoxy coating. This could be due to the reduction of the surface area of epoxy with concrete due to the coated sand and may be due to weak bonding between epoxy and sand.

Table 4. Physical Characteristic and Bond Strength of Bamboo Specimen with Epoxy and Sand Coating as Reinforcement for 7, 14, and 28 Days of Curing.

To further explore the functionality of EB, the epoxy-coated bamboo is wrapped with steel binding wires, and the bond strength is evaluated. The physical characteristics and bond strength of specimen with epoxy and binding wire coated bamboo as reinforcement is given in Table 5. The results indicate adequate bonding between epoxy and binding wires and are satisfactory.

Table 5. Physical characteristic and bond strength of bamboo specimen with epoxy and binding wire coating as reinforcement for 7, 14, and 28 days of curing.

Abbreviation	Surface Area	Max loa at pea (kN)	Bond Strength (N/mm^2)	Average Bond Strength (N/mm^2)
$EB_7$1	11970	0.72	0.06	0.08
$EB_7$2	14575	1.26	0.09	
$EB_7$3	14030	1.12	0.08	
ES_{14}1	11830	2.48	0.21	0.23
ES_{14}2	12505	2.58	0.21	
ES_{14}3	13615	3.82	0.28	
ES_{21}1	12542	6.72	0.54	0.63
ES_{21}2	12652	7.34	0.58	
ES_{21}3	12925	10.00	0.77	

It is observed in figure 4 that the bond strength increases with an increase in the number of days of curing. The curve shows a uniform rate of increase in bond strength throughout the curing period. An initial setback is observed only in the plain epoxy sample. It may appear so because of the surface smoothness of the plain epoxy sample. The rough texture and binding wires allow for perfect bonding and thus do not allow for flexibility and thus a better bond.

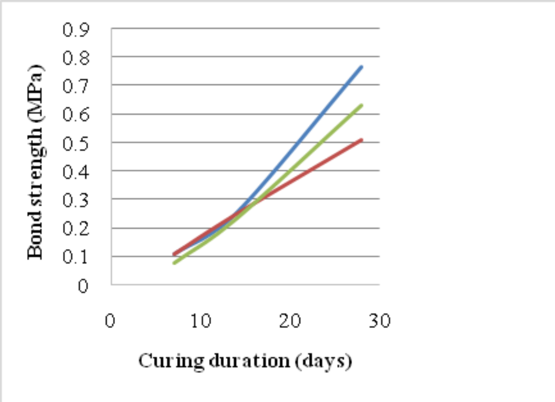

Figure (4): Comparative graph of bond strength for various coating used

It is thus observed that the bond strength for 'E' is highest as compared to 'EB' and 'ES'.

The bond strength of M20 concrete with steel is of the value of 1.26 MPa (IS 456 2000) [13]. The maximum bond strength achieved by bamboo reinforcement is 0.51 MPa. However, with the novelty of epoxy and bamboo into the concrete, a considerable increase in bond strength to weight ratio can be seen. The weight of the member is reduced due to the use of bamboo reinforcement. The maximum bond strength is achieved in bamboo coated with plain epoxy. To check the performance of the bamboo in flexure for rural housing, analysis is done for flexure using Staad Pro considering the results of the most promising alternative from the above that is 'E'.

Using STAADPro.V6i a typical rural residential building is designed to be reinforced completely with bamboo. Figure 5 shows the plan of the rural house considered.

Serviceability limit state (SLS) considers the expected behavior of the structure, generally by using partial factors of 1 and ultimate limit state (ULS) considers complete structural failure utilizing partial factors to increase loads and decrease strength. The self-weight and dead load were evaluated and applied, the minimum live load considered on the roof is 1.5 KN/m2 and 0.5 KN/m2 for services so the total roof live load is considered as 2 KN /m2. Max. groundwater pressure calculated as 2KN/m2 (pressure increases with depth, applied on pad foundation as uplift force), and max. earth pressure calculated as 7.2 KN /m2 is applied to the structure considering the SLS and ULS load combinations. Figure 6 and 7 shows the geometry of loads and the load envelope generated. The suitable moments and forces which are acting on the structural members are obtained. The material used in beams and slabs is M20 whereas for the columns is M40. The ultimate tensile strength of bamboo as obtained from tensile tests is taken as 60N/mm2.

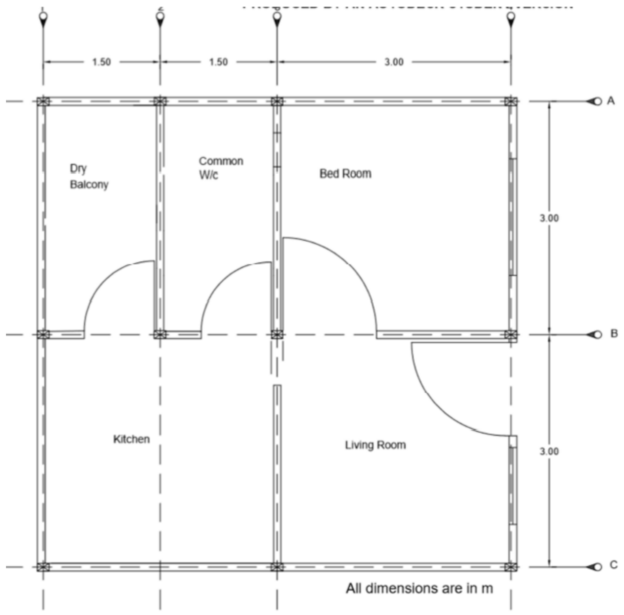

Figure (5): Plan of the rural housing considered for Staad Pro Analysis

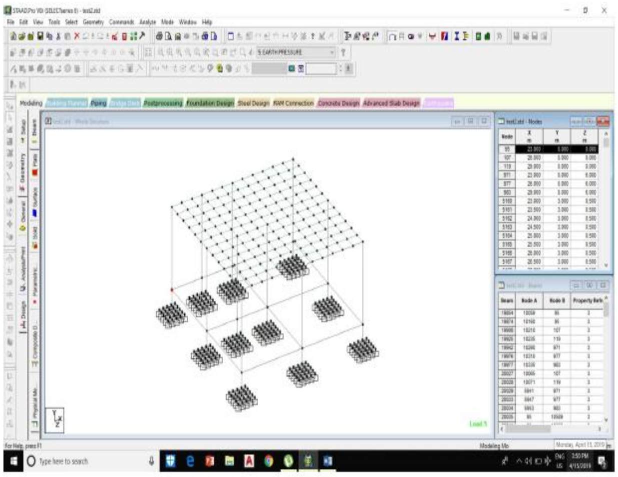

Figure (6): Geometry of loads applied on the structure

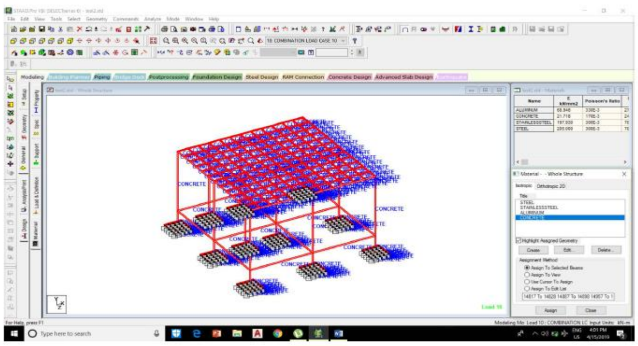

Figure (7): Load Envelope

It was considered that the residential building was in zone II of the Indian seismic zone map and hence no earthquake forces are applied. The wind loads are also not considered as the structure is a low rise residential construction. The post-processing was performed from which the results showed that the base shear in one of the isolated footings (at center) is larger and this is dealt by increasing the area of the isolated footing It was observed that the number of bamboos required as compared with steel was greater and as predicted we required a greater number of bars. It is found that the bamboo reinforcement is safe in flexure.

Conclusion

The present study discusses the feasibility of using Dendracalamus Brandisi bamboo specie as a sustainable alternative for steel in rural housing. To make the bamboo resistant to water, the specimens in the present study are coated with epoxy, epoxy with sand and epoxy with binding wires. All the specimens are tested for 7, 14, and 28 days of curing. The maximum bond strength was observed for epoxy coated samples. It is observed that the bond strength is increased by around 60 % for bamboo coated with epoxy. To check the feasibility of epoxy coated bamboo as reinforcement in rural housing to withstand flexure, analysis is done for epoxy coated bamboo using STADD pro, and design is found to be safe. The bamboo reinforcement is tested for bond strength and flexure. The study concludes that epoxy-coated bamboo specie Dendracalamus Brandisiis a good reinforcing material that can be used in low rise rural construction in place of steel as a good option for low-cost rural housing.

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