Bamboo Concrete Bond Strength

Vijay R. Wairagade, Ishwar P. Sonar

***Abstract*: Bamboo reinforced concrete is expected to be an alternative to steel reinforced concrete as a building material. Steel, when used for construction activities, is energy intensive and causes pollution. In this context, the use of bamboo, which is a fast growing, affordable and ecologically friendly solution; especially in a tropical country like India, is being considered as a suitable material for structural applications. It is potentially superior to steel in terms of its weight to strength ratio. However, the bond strength is a major concern for the bamboo to be a reinforcement in structural composites.**

The goal of this paper is to investigate the bonding properties of a newly developed bamboo-reinforcement composite in concrete, through pull-out tests. Various coatings are applied to the bamboo to determine the different bonding behaviours between the concrete and newly developed BRC. To improve the bonding at interfacial of bamboo concrete composite; easily applicable, adoptable and economical technology have been developed. The results of this study demonstrate that the bamboo-reinforcement composite develops adequate bonding with the concrete matrix with the hope that the newly developed material could contribute, on a large scale, to sustainable development.

***Keywords* : Bamboo, reinforcement, properties, pull-out test.**

I. INTRODUCTION

Bamboo is one of the fastest growing plants and has good viability. It has been used in constructions for thousands of years in Asia and takes little energy to harvest and transport. It also has low manufacturing costs compared to steel and is therefore expected to be used widely in countries and regions that have no advanced manufacturing technology and construction techniques. The use of such renewable resources by the construction industry will help to achieve a more sustainable pattern of consumption of building materials. The research and investigations reported in **International Network for Bamboo & Rattan** (INBAR 2002) [1], have revealed the advantages of using bamboo as a construction material as: its ecological value, it's competitive mechanical properties, and it's social and economic value and low energy consumption.

Alireza Javadian, Mateusz Wielopolski, Ian F.C. Smith and Dirk E. Hebel (2016) [2] investigated bamboo concrete bond behavior through pull out test. The chemical action at the bamboo concrete interface is studied through different coatings, sand blasting and steel wire wrapping treatment. The test result show that the proposed treated grooved bamboo reinforcement shows highest bond strength compared to treated plain, untreated plain and untreated grooved bamboo reinforcement. **Pankaj R. Mali and Debarati Datt** (2019) [3] studied bamboo concrete bond strength where a new technology is developed. They investigated the bonding properties of a newly developed bamboo reinforcement composite (BRC) though pull-out tests. It was concluded from their study that the BRC without coating develops adequate bonding with the concrete matrix but an epoxy-based coating with sand particles could provide extra protection without loss of bond strength. **Atul Agrawal, Bhardwaj Nanda and Damodhar Maity** from IIT, Kharagpur (2014) [4], carried out a series of experimental investigations in their research project and observed from the pull-out test that the average bonding strength after treatment is found out to be maximum of 0.588 MPa. Furthermore, the bamboo samples broke during the slippage despite the tensile strength of the bamboo sample being much higher than the maximum bond stress.

Nindyawati and Baiq Sri Umniati (2016) [5] considered bond strength as a major concern for the natural fiber as reinforcement and accordingly carried out study on bond strength of bamboo reinforcement in light weight concrete. Splints were coated with paint and sprinkled with sand. The results obtained shows that the bond strength of bamboo is 60% of the bond strength of steel. **Tomothy Clancy Fergusson-Calwell** (2015) [6] carried out research work with clear conclusions that bamboo can in fact be used as reinforcement in a residential concrete house. The work lead to theoretical viability of bamboo reinforced concrete. However, water absorption is an unfavorable inherent material limitation, further affects the bonding issues, which needs to be taken care of before being used as a structural material. **Muhtar, Sri Murni Dewi, Wisnumurti and As'ad Munawir** (2016) [7] worked on bond-slip improvement of bamboo reinforcement in concrete using hose clamps. For increasing the bond-slip interaction between the surfaces of the bamboo reinforcement and the concrete, coating treatments with water resistant material was used., along with the addition of hooks, wire rope wrapping and a few other techniques. The test result shows flexural capacity, ductility and stiffness of the bamboo reinforced beam where the beam with bamboo reinforcement coated with water resistant material and hose clamp had increased, compared to other beams. **Khosrow Ghavami** (2005) [8], studied bonding on treated and untreated bambootypes. The treated specimens were wrapped with 1.5 mm steel wire on embedded 40 mm spacing. The test results showed that the treated bamboo, 0.97 N/mm2, was more effective than the untreated bamboo, 0.52 N/mm2, with up to 90% improved bond stress.

Masakazu Terai and Koichi Minami (2012) [9] conducted experiments to obtain the results of bond strength between bamboo and surrounding concrete and

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compared it with bond stress of steel with concrete. Specimens of bamboo with different surface conditions were tested for pull-out test to determine the bond-stress between the bamboo and concrete. Results of their study have shown that bond stress corresponding to fully treated bamboo with synthetic resin (1.2-1.35 MPa) was higher than bond stress corresponding to partially treated with synthetic resin or untreated bamboo (0.6-0.85 MPa), though its value was about half compared to that of for deformed steel bars (2.43 MPa) be due to not alignment. **Harish Sakaray, N.V. Vamsi Krishna Togati and I.V. Ramana Reddy** (2012) [10] carried out investigations on the Moso type of Bamboo to find out it's tensile stress, compressive stress, modulus of elasticity, water absorption capacity, shear stress and bonding stress. They concluded that the nodes of the bamboo pose ductile behavior. They also found out that compressive strength of the bamboo is parallel to its tensile strength and the behavior is same as that of steel. Since bamboo absorbs water, it would have to be waterproofed. **Nithi Plangsriskul & Nicholas Dorsano** (2011) [11] focused on how to achieve the highest strength of bamboo reinforced concrete in there project titled 'Materials characterization of bamboo and analysis of bonding strength and internal strength as a structural member in reinforced concrete' presented at California Polytechnic State University, San Luis Obispo. Both concluded that the pull-out strength of bamboo is about 30% of steel but can be improve with coating and surface roughness or by wrapping the bamboo.

Kent A. Harrie, Bhavna Sharma and Michael Richard (2012) [12] believed on standardization of test methods for greater engineering acceptance. Study provides an overview of existing standard test methods, their use and practical utility in a field environment. Focus is placed on efforts to develop standard test methods. **Youngsi Jung** (2006) [13] investigated the pull-out characteristics in concrete. The test results indicated that the bond strength for bamboo was lower than steel and FRP. **Atul Agarwal** et al. (2011) [14] studied axial compression and bending test performed on plain, steel, & BRC members. A total of 12 columns, comprising of 3 columns each of plain, RC members, untreated BRC members and treated BRC members (with varying percentage of reinforcements), were casted using design mix M20 as per IS code and tested. The load deformation curves displayed significant nonlinearity, indicating that bamboo has the capacity to absorb energy. Plain concrete and untreated BRC showed brittle behavior whereas the plain steel and BRC showed more ductile behavior. Moreover, the results exhibited that the maximum load carrying capacity of steel reinforced column was nearly equal to that of a treated bamboo reinforced column.

Nindyawati, Shri Murni Dewi and Agoes Soehardjono (2013) [15] compared the bond strength between pull-out test and the beam bending test. It is observed that the results of bamboo pull out test (0.41 MPa) is smaller than the beam bending test (1.49 MPa). **M. M. Kamall, M. A. Safan and M. A. Al-Gazzar** (2012) [16] evaluates the potentials of self-compacting concrete (SCC) mixes to develop bond strength. A push-out configuration was adopted for conducting the bond test. The results demonstrated inconsistent normalized bond strength in the case of the larger bar diameter compared to the smaller one. **Leena Khare** (2005) [17] performed tensile tests on three types of bamboo (Moso, Solid and Tonkin) to obtain their constitutive relation, followed by two-point bending tests on six concrete beams reinforced with bamboo to identify their behavior compared to steel reinforced concrete beams. They concluded that bamboo reinforcement increased the load carrying capacity by about 250 percent as compared to the initial crack load in the concrete beam. **Sreemathi Iyer** (2002) [18], conducted a survey on different types of building and their patterns of failure after the devastating earthquake in Bhuj, Gujrat. The survey report exhibited that a lot of lives and damage could have been saved, if some alteration in the conventional building design had been used in buildings. Using bamboo as a reinforcing material with the brick masonry wall was one the proposal of that report. The report provided the guidelines for building bamboo reinforced masonry buildings. **Humberto C. Lima** et al. (2008) [19] had studied the durability aspect of bamboo to be used as reinforcement in cement concrete mixtures and analyzed that while being used as reinforcement in concrete, bamboo splints have larger dimensions than any other type of fibers, which implies that most of bamboo fibers are entirely enclosed in the parenchyma and are not in direct contact with the alkalinity of the cement matrix. Therefore, the higher number of the fiber end points are less vulnerable to deterioration. Moreover, penetration of products produced due to hydration of cement becomes difficult due to bamboo-splint dimensions. Bamboo splints exposed to a series of wetting and drying were analyzed and a probable declination in the tensile strength and Young's modulus was explored. Therefore, the durability performance of the bamboo was explored based on the results of tensile test obtained before and after the bamboo being exposed to 6 months of ageing. **Dr. I.P. Sonar** (2010) [20] also conducted experiments to verify the bond stress by applying oil paint and silica powder which shows higher bond compared to others coating treatment. Also, the coating material is easily available in the market and easy to apply on bamboo surface. **Harendra Nath Mishra** (1988) [21] , "Structural use of Bamboo in Rural Housing", Timber Engineering branch, Forest Research Institute, Dehradun, Indian Forester, mention bond stress as 5.6 kg/cm^2 .

In this study, basic properties by means of carrying out physical and mechanical tests are evaluated to check the suitability of bamboo culms as a reinforcement. The important point of this research is to study the bond strength of bamboo and concrete. Series of pull out test are carried on Universal testing machine with laboratory designed attachments to understand the better bond strength through bamboo-composite reinforcement. Several coatings and other material used for the improvement of the bonding is discussed in experimental procedures. M30 grade concrete is used throughout this study.

II. MATERIALS AND METHODS

A. Selection of Bamboo samples and preparation of

bamboo splints and half bamboo culms

As per the guidelines provided in IS codes 15912-2012, 9096-2006, 6874-2008, 8242-1978 , National Building Code of India SP-7:2005 (Part 6, Section 3B), FRI Dehradun, IPIRTI Bengaluru, Technical literature by the International Network for Bamboo and Ratan (INBAR), BMTPC - Ministry of Housing & Urban Poverty Alleviation, Government of India and ISO 22156:2004 – Bamboo Structural Design, the Moso bamboo culms (locally called as Kolkata bamboo) procured from the easily available local open market of Pune city, Ahmednagar and nearby Talegaon. The samples selected are minimum 4 years age, 40mm to 70mm in diameter, collected in winter so that it will contain minimum starch and having brownish in appearance. For air dry, samples are kept in open for 3 to 4 weeks.

Fig. 1 Local bamboo market stock yard

Fig. 2 Bamboo specimens for various tests

The applicability and usefulness as reinforcing material and to select appropriate kind of bamboo specimen, series of tests are conducted on the selected bamboo samples to find out physical and mechanical properties. For this purpose 27 bamboo culms of minimum 5.2 meter length and diameter in the range of 40mm to 70mm are selected and segregated in 3 sets each set having 9 selected bamboo as per average diameter and nodes. The average property of these selected and prepared specimens as per the guidelines are mentioned in Table 1 & 2. Suitable bamboo splints and half bamboo culms are used for bamboo concrete bond test.

Table 1 Mechanical properties

Sr. No.	Type of Test	Parameter	Strength
1	Tension	Young's Modulus (GPa)	117
2	Compression	Compressive Strength (MPa)	59.03
3	Static Bending	Bending Strength (MPa)	107.8
4	Shear	Shear Strength (MPa)	22.31

Table 2 Physical properties

Sr. No.	Type of Test	Location/Position	Result
1	Moisture Content (%)	-	117
2	Shrinkage (%)	Length	0.13
		Diameter	3.82
		Thickness	6.61
3	Density (kg/m^3)	Top	702.0
		Middle	708.2
		Bottom	708.9

The bond strength test is conducted on bamboo splints and half bamboo culms. Bamboo splints ae first coated with oil paint and then dry sand sprinkled on samples. Few specimens are then wrapped with GI wire in multiple ways. It is ensured that layer of paint is uniform throughout the surface. This coating will further ensure that bamboo specimens will remain water repellent and thus helps in better bonding with concrete. M30 grade concrete mix is used for the entire casting of cubes embedded with prepared bamboo splints and half bamboo culms.

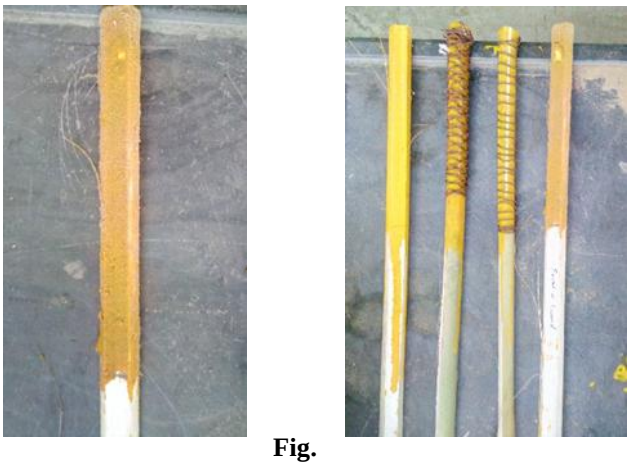

Fig. 3 Bamboo splints for pull out test

For half bamboo culms, GI wire is wrapped in various pattern considering the spacing of cross wire in both directions.

Fig. 4 Wire wrapped culms for pull out test

Fig. 5 Pull out test specimens

B. Method of Test

Very important and dominating property which need to be evaluated is to measure the interfacial strength (bond strength) between the bamboo and concrete. The current research basically aims at conducting bond strength through pull out test. Further this study and the outcome of tests are used in evaluating the strength of bamboo reinforced concrete beam by performing two point loading test on UTM of 400KN capacity. For the complete study the concrete of design mix M30 grade is used. Concrete mix is designed as per IS 10262:2009. The IS 456:200 specifies the characteristic compressive strength of M30 as 30 N/mm^2.

Fig. 6 Pull out testing in UTM

Fig. 7 Pull out testing in UTM

Accordingly test are carried out for half bamboo splints and full bamboo. To apply the load along the longitudinal axis, proper grips of the testing machine are required which are designed and fabricated in the laboratory for half bamboo culms. The attachments developed in the laboratory are filed for the patents. For bond strength of bamboo splints embedded in concrete cubes of size 150 mm X 150 mm X 150 mm, 03 samples each for 05 different bond improvement arrangements (i.e. plain bamboo, oil paint, oil paint with sand, oil paint & wire wrapped in one direction and oil paint & wire wrapped in both direction) are prepared. For bond strength of half bamboo culms embedded in concrete cubes of size 150 mm X 150 mm X 150 mm, 03 samples each for 04 different bond improvement arrangement (i.e. plain bamboo, oil paint, oil paint & wire wrapped in one direction and oil paint & wire wrapped in both direction) are prepared. Oil paint offers high degree of adhesion to sand and attributes low shrinkage on curing. This will enhance the interfacial strength of bamboo splints and concrete. Bamboo splints of desired size are inserted into the concrete blocks up to the 30 mm. from the bottom of the mould. Next day these specimens are demoulded and kept in curing tank for 28 days prior to pull out test. The test is carried out in the Universal Testing Machine of 400 KN. Total 27 samples i.e. 15 for splints and 12 for half culm are tested and the average results are presented in the section III. For test procedure IS 2770 (part I): 2007 is referred.

III. RESULTS AND DISCUSSIONS

The outcome of the procedure intended on bamboo splints and half bamboo culms detailed in part II are discussed in this paragraph. As discusses earlier in section II, pull out test are carried out on bamboo splints and half bamboo culms. To apply the load along the longitudinal axis, proper grips of the testing machine are required which are designed and fabricated in the laboratory for half bamboo culms. A comparative study is carried out to find out the easily available, adoptable and applicable alternative to enhance the interfacial bonding property between bamboo splints and the concrete. Bamboo splints and half bamboo of desired size are inserted into the concrete blocks up to the 30 mm. from the bottom of the mold.

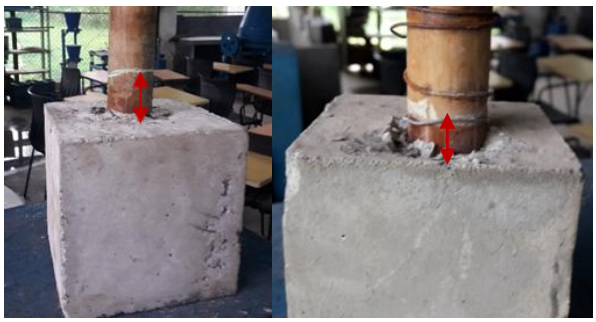

Fig. 8 Failure pattern during pull out test

To work out the interfacial strength of the all 27 specimens, the equation F/(S*L) is used,

In this equation pull out load is denoted by F, perimeter of the bamboo splints is represented by

S and L represents the length of bonded interface. The details of all 27 cubes and the results are detailed in Table 3 & 4.

Table 3 Pull out test results of bamboo splints

Sr.No.	Type	Treatment	Specimen	Sample No.	Width (mm)	Thickness (mm)	Contact Perimeter (mm)	Contact Length (mm)	Contact Area (mm^2)	Pull out Load (KN)	Bond stress (Mpa)	Average Bond stress (Mpa)
1	Splint	Plain	Culm 1	P1	19	6	50	260	13000.0	5.9	**0.45**	**0.45**
2			Culm 2	P2	20	6	52	260	13520.0	5.7	**0.42**	
3			Culm 3	P3	18	7	50	260	13000.0	6.2	**0.48**	
4		Oil paint	Culm 1	P4	18	5	46	260	11960.0	5.6	**0.47**	**0.50**
5			Culm 2	P5	20	6	52	260	13520.0	6.6	**0.49**	
6			Culm 3	P6	19	6	50	260	13000.0	7.2	**0.55**	
7		Oil paint + sand	Culm 1	P7	16	5	42	260	10920.0	6.4	**0.59**	**0.58**
8			Culm 2	P8	17	6	46	260	11960.0	7.2	**0.60**	
9			Culm 3	P9	20	8	56	260	14560.0	7.9	**0.54**	
10		Oil paint & wire in one direction	Culm 1	P10	19	6	50	260	13000.0	11.2	**0.86**	**0.80**
11			Culm 2	P11	20	5	50	260	13000.0	10.8	**0.83**	
12			Culm 3	P12	18	7	50	260	13000.0	9.2	**0.71**	
13		Oil paint & wire in cross	Culm 1	P13	18	5	46	260	11960.0	10.4	**0.87**	**0.87**
14			Culm 2	P14	17	6	46	260	11960.0	9.4	**0.79**	
15			Culm 3	P15	19	9	56	260	14560.0	13.8	**0.95**	

Table 4 Pull out test results of half bamboo culms

Sr.No.	Type	Treatment	Specimen	Sample No.	Thickness (mm)	Diameter (mm)	Contact Perimeter (mm)	Contact Length (mm)	Contact Area (mm^2)	Pull out Load (KN)	Bond stress (Mpa)	Average Bond stress (Mpa)
16	Half Round	Plain	Culm 1	P16	7	45	133.32	260	34663.2	21.2	**0.61**	**0.56**
17			Culm 2	P17	7	42.7	126.098	260	32785.5	16.9	**0.52**	
18			Culm 3	P18	8	38.3	111.142	260	28896.9	16	**0.55**	
19		Oil paint	Culm 1	P19	8	44	129.04	260	33550.4	18.1	**0.54**	**0.60**
20			Culm 2	P20	6	43.7	130.378	260	33898.3	26	**0.77**	
21			Culm 3	P21	7	42	123.9	260	32214.0	16.2	**0.50**	
22		wire in one direction	Culm 1	P22	9	43.3	125.702	260	32682.5	25.2	**0.77**	**0.89**
23			Culm 2	P23	8	41.7	121.818	260	31672.7	28.7	**0.91**	
24			Culm 3	P24	9	39.7	114.398	260	29743.5	29.9	**1.01**	
25		wire in cross	Culm 1	P25	7	38.3	112.282	260	29193.3	32.4	**1.11**	**1.12**
26			Culm 2	P26	7	36.3	106.002	260	27560.5	30.1	**1.09**	
27			Culm 3	P27	9	34	96.5	260	25090.0	28.7	**1.14**	

The results described in the above two tables shows that the average bond strength between the bamboo splints and concrete is highest i.e. 0.87 MPa for oil paint sprinkled with sand and wrapped with wire in both direction (cross). The enhancement in strength is almost 193%. Similarly the average bond strength between the half bamboo culms and concrete is again maximum i.e. 1.12 MPa for oil paint sprinkled with sand and wrapped with wire in both direction (cross). The enhancement in strength is almost 200%. Hence, the bamboo coated with oil paint is selected for all further studies. It is found from the series of experiments that, many of the samples underperformed due to slippage of bamboo splints from the concrete cubes as shown in Fig.8. However, in some cases, during the slippage, it is observed that bamboo samples are broken in spite of having much more tensile strength compared to its bonding strength between bamboo splints and the concrete. The reason may be the non-alignment of the bamboo splints which further leads to remarkable eccentricity in the testing machine.

IV. CONCLUSION

The applicability and the viability of the bamboo splints as a reinforcement in concrete has been worked out through number of test and systematic examination of research. The procedure intended to establish the quality and performance includes dimension study, density, moisture content, shrinkage, water absorption, compression, shear, bending test and tensile strength test. In this present research the emphasis is on pull out testing of bamboo splints and half bamboo culms embedded in concrete.

Pull out test carried out in present research shows the interfacial bond strength is highest for coating with oil paint, sprinkled with fine sand and wrapped with cross wire. For treated improved bamboo splint (0.87 MPa) the bond strength enhances to 1.9 times than plain bamboo splints (0.45 Mpa). For treated improved half bamboo culms (0.56 MPa) the bond strength enhances to almost twice that of plain half bamboo culms. The average bond

strength of treated and improved samples are found to be more comparable with design bond strength values. This study also explores the potential of new type of economical and easy to apply treatment (oil paint). To further improve the effectiveness of the surface treatment for the better bonding between bamboo and concrete, needs further investigations and experimentation to assess its structural performance and durability aspect. However this research shows the significant improvement in the bond strength between bamboo and concrete.

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