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Performance Evaluation Of Bamboo As Reinforcement In Design Of Construction Element

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ABSTRACT: *Traditionally steel is used as reinforcement in concrete structure. But because of cost and availability, replacement of steel with some other suitable materials as reinforcement is now a major concern. It is a fact that the construction industry is the main consumer of energy and materials in most countries. Though bamboo has been used as a construction material, especially in developing country, until today its use as reinforcement in concrete structure is very limited due to various uncertainties. Since bamboo is a natural, cheap and also readily available material, it can be a substitute of steel in reinforcing of concrete structure.*
Authors have tested & evaluated physical and mechanical properties like compressive strength, tensile strength, Flexural test, Bonding strength, water absorption, density etc. of the selected bamboo species in material testing laboratory. Purpose of the experiments on bamboo strips is for validation and justification of these results confirm the application of bamboo as reinforcement element.
Authors have investigated conducted for the tested types of bamboo are evaluated using the same accepted criteria as that of steel. Also authors have evaluated the performance and justification of fabricated underground water tank by replacement of steel to bamboo.

Keywords - *Bamboos, Bambusoideae, Node & end Split, Renewable natural resource, Tangential shrinkage, Water absorption & waterproofing agent*

I. Introduction

Bamboos are giant grasses belonging to the family of the Bambusoideae. It is estimated that 60–90 genre of bamboo exist, encompass approximately 1100–1500 species and there are also about 600 different botanical species of bamboo in the world. Bamboo mainly grows in tropical and sub-tropical regions of Asia, Latin America and Africa. The energy necessary to produce 1 m^3 per unit stress projected in practice for materials commonly used in civil construction, such as steel or concrete, has been compared with that of bamboo.

Bamboo is versatile resource characterized by high strength to weight ratio and ease in working with simple tools. Bamboo is the fastest growing, renewable natural resource known to us. It is a small wonder, therefore, that this material was used for building extensively by our ancestors. It has a long and well established tradition as a building material throughout the tropical and sub-tropical regions. It is used in many forms of construction, particularly, for housing in rural areas. But, enough attention had not been paid towards research and development in bamboo as had been in the case with other materials of construction including timber.

Due to ecological materials and having many advantageous characteristics of bamboo, in the last few years, studies have been made on bamboo as structural material and reinforcement in concrete. Bamboo has great economic potential, especially in the developing countries, because it can be replenished within a very short time. A critical assessment of the present status and future prospects of bamboo housing would be helpful in exploiting that potential.

1.1 History of Bamboo

An archaeological discovery in Ecuador has traced back the use of bamboo for housing to the pre-ceramic for years ago. Although no such hard evidence is available in Asia, it is known that bamboo has been employed since several centuries for several purposes, including housing, in South, East and Southeast Asia. It is the single most important organic building material in these regions. It is used in over 70% of rural houses and extensively employed as informal shelter for the urban poor. At present, there is an acute shortage of housing because of the scarcity of conventional materials coupled with rapid population growth. Many villagers were already adopted weavers of bamboo, thus quickly mastered the frame construction technique. There use of this technology to built catchment tank for rainwater collection. A study of the feasibly of using bamboo as reinforcing material in precast concrete element was conducted at U.S. Army Engineer Waterways Experiment Stations in 1964.

The importance of bamboo as a construction material, particularly for housing, has received renewed attention in recent years, but conceptual application of bamboo as a reinforcement is as old as in 1979. This new born hybrid technology first developed in village areas of Colombia.

1.2 Characteristics of Bamboo

The bamboo Culm, in general, is a cylindrical shell, which is divided by transversal diaphragms at the nodes. Bamboo shells are orthotropic materials with high strength in the direction parallel to the fibers and low strength perpendicular to the fibers. The thickness and strength of bamboo, however, decreases from the base to the top of the bamboo shell. The density of the fibers in the cross-section of a bamboo shell varies along its thickness. On the outer skin of a bamboo shell the fibers are concentrated and more resistant to degradation. This presents a functionally gradient material, grew according to the state of stress distribution in its natural environment.

In view of the hollowness and the fibers in longitudinal direction, bamboo has a very efficient natural structural design and less material mass is needed than materials with a massive section, such as timber. Fig. 1 shows the parts of a bamboo which are usual to most of the species.

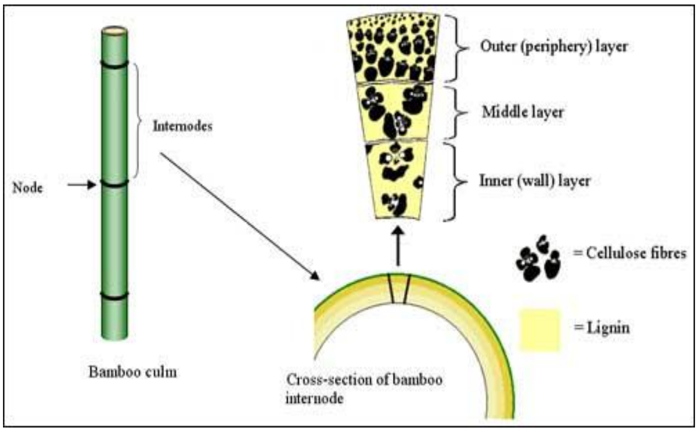

Figure 1 Basic component parts of bamboo

1.3 Physical and Mechanical Properties

A series of tests have been conducted on bamboo reinforced concrete elements for determination of Physical and Mechanical Properties like Compressive strength, Flexural strength, Specific gravity, Modulus of rupture, Safe working stress in tension, Bond stress, Water absorption test, Modulus of Elasticity etc. The density of bamboo is found to vary from 500 to 800 kg/m^3, depending on the anatomical structure such as the quantity and distribution of fibres around the vascular bundles. Density increases from the centre to the periphery of the culm. It also increases from the base to the top of the culm. The maximum density is obtained in about three-year-old culms. Bamboo possesses high moisture content which is influenced by age, season of felling and species. Moisture is at its lowest in the dry season and reaches maximum during the monsoon. Because of the differences in anatomical structure and density, there is a large variation in tangential shrinkage from the interior to the outer-most portion of the wall.

Bamboo gained excellent strength & tensile strength properties, especially in design of reinforced member. Most of the properties depend on the species, and the climatic conditions under which they grow. Strength varies along the culm height. Compressive strength increases with height, while bending strength has the inverse trend. An increase in strength is reported to occur at 3-4 years, and thereafter it decreases. Thus, the maturity period of bamboo may be considered as 3-4 years with respect to density and strength.

II. Bamboo as reinforced element – Reviewed by Researchers

Solomon K. A. [1] constructed an experimental bamboo classroom building at Fumesua, Kumasi, indicated that the cost of materials and construction is competitive and can be reduced further if labor costs and construction times are reduced, and construction methods improved. This can come about only with resort to plantation bamboo, a trained skilled labor pool, and the encouragement of an industry in the production of bamboo modular units. Prasad J. et al. [2] used cement-sand mortar panels with bamboo as reinforcing material to making low cost housing in hilly regions. However, wall and roof elements made of simple bamboo mat do not last long due to their poor strength against static as well as impact loads and durability.

Sakaray H. et al. [3] Studied that the constitutive relationship of the nodes differs from those of inter-nodal regions. Further the nodes possess brittle behavior and the inter-nodal regions possess ductile behavior. The average tensile strength of moso bamboo from present study is 125 N/mm^2, which is half the strength of mild steel. The compressive strength of bamboo is nearly same as the tensile strength of bamboo and this behavior is similar to steel. Bond stress of bamboo with concrete is very low compared HYSD steel bars, due to surface smoothness of bamboo. Water absorption of bamboo is very high and waterproofing agent is recommended.

Wahab R. et al. [4] studied on Cultivated Bamboos vulgarize of two and four-year old were harvested and studied for their anatomy and physical properties. In the physical aspect, basic density was found to be higher in the 4 year-old culms than in the 2 year-old by 5 to 8%, and increases from lower to upper internodes showing that there is a maturing process going on between the two age-groups relative to the tissue type that they possess. Rahman M. M. et al. [5] tested singly and double bamboo reinforced beams of 750 mm length having 150 mm width and depth for tensile strength test o bamboo having three and five nodes are performed. 1 m bamboo sticks of varying cross sections are used in this test. Also flexural strength test of bamboo reinforced beam is done to characterize the performance of bamboo as reinforcement. Agarwal A. et al. [6] established the ratio of tensile strength to specific weight of bamboo is six times greater than that of steel. Therefore, in this study it has been attempted to develop engineered bamboo structural elements for use in rural housing. Usage of bamboo slats derived from bamboo poles to be joined together and treated to bring about requisite structural bonding and strength. Alluding to the above objectives a series of tests have been conducted on bamboo reinforced concrete elements. Salau M. A. et al. [7] done experimental work includes load capacity test, deflection and failure patterns observation of eighteen concrete columns. Varying bamboo, from 4 No to 12No, strips of coated seasoned bamboo of cross-section 8x10mm, were used to reinforce the concrete columns. However, all columns failed in a similar pattern due to crushing of concrete. The bamboo strips showed no sign of slippage and remain unaffected even after concrete failure. Brink F. E. et al. [8] Design procedures and charts for bamboo reinforced concrete are given and conversion methods from steel reinforced concrete design are shown. Plangsriskul N. et al. [9] tested the mechanical properties of bamboo, specifically force required to embed a 0.5" diameter ball 0.016" into the bamboo samples and its bonding strength with concrete. Two coatings, asphalt emulsion and polydimethylsiloxane (PDMS), were applied. The test results indicated that the bonding strength between the bamboo and concrete with the asphalt emulsion coating was the greatest at 339.27psi. The next strongest was the control sample at 319.07psi, then PDMS resulting in 154.20psi.

III. Experimental Work – Testing and Evaluation of Properties of Bamboo

Evaluations of basic properties of bamboo are required for use in bamboo as reinforcement in any construction element. In this study work, three year old bamboo plants of pronounced brown color were selected. Samples of each of 1m were collected from the bottom of the plant having three and five nodes.

3.1 Evaluation of Tensile strength for Elasticity

Bamboo culms are cylindrical shells as shown in Fig. 2 and are divided by nodes as solid transversal diaphragms. The strength distribution is more uniform at the bottom of bamboo than at the top or at the middle of it since it is subjected to maximum bending stress due to wind at the top portion of the culms.

In order to conduct the tensile strength test, it was necessary to prepare the three bamboo sample of 190 mm 2,186 mm^2 and 202 mm^2 area having same gauge length of 505 mm. To prepare the sample, bamboo sticks of 75cm length and around 20 mm width with node at centre were cut and allowed to dry and season for 30 days as shown in Fig. 3. The thickness of the sample varies throughout its length since it is a natural material whose properties cannot be controlled strictly.

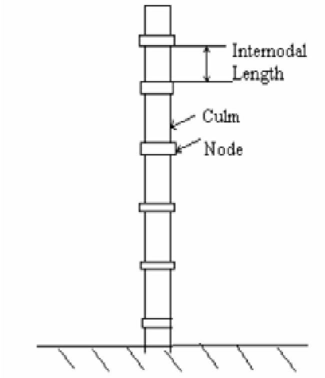

Figure 2 Bamboo culm **Figure 3 Bamboo strip test specimen**

The tensile strength of bamboo strip was tested using Universal Testing Machine (UTM) as shown in Fig.4. Specimen was placed in UTM and tensile load was being applied until rupture. Elongation was measured at regular interval of applied tensile load. The load was recorded at regular interval of elongation for every sample and also load at which three bamboo strips failed was recorded. During these tensile tests, it is observed that all specimens were failed at node and at end point as shown in Fig.5 and Fig.6 respectively.

Figure 4 Set up of tensile strength of bamboo strip.

Figure 5 Failure of bamboo strip (node split)

Figure 6 Failure of bamboo strip (end split)

Table 1, 2 and 3 shows the result of observed value of loads, elongation, stress and strain of tested sample 1, 2 and 3of bamboo strips respectively.

Table 1

Area 190 mm^2		Sample-1	
Load P (N)	Elongation (mm)	Strain	Stress (N/mm^2)
0	0.00	0.0000	0.0000
16000	1.00	0.0020	84.2105
18000	1.50	0.0030	94.7368
20000	2.00	0.0040	105.2631
22000	3.00	0.0059	115.7894
24000	4.00	0.0079	126.3157
26000	5.00	0.0099	136.8421
28000	6.00	0.0119	147.3684
29300	8.00	0.0158	154.2105

Table 2

Area 186 mm^2		Sample-2	
Load P (N)	Elongation (mm)	Strain	Stress (N/mm^2)
0.0	0.00	0.0000	0.0000
16000	1.00	0.0020	86.0215
18000	2.00	0.0040	96.7742
20000	3.00	0.0059	107.5269
22000	4.00	0.0079	118.2796
24000	5.00	0.0099	129.0323
26000	8.00	0.0158	139.7849

Table 3

Area 220 mm^2		Sample-3	
Load P (N)	Elongation (mm)	Strain	Stress (N/mm^2)
0.0	0.00	0.0000	0.0000
20000	0.50	0.0010	99.0099
22000	1.00	0.0020	108.9109
24000	1.50	0.0030	118.8119
26000	2.50	0.0050	128.7129
28000	3.50	0.0069	138.6139
30000	4.50	0.0089	148.5149
32000	5.50	0.0109	158.4158
33300	8.50	0.0168	164.8515

3.2 Evaluation of Flexural strength of Bamboo strips

3.2.1 Ingredients used in preparation of specimen
Cement Ordinary Portland of 53 grade, Fine Aggregate as local sand having fineness modulus 2.69, Coarse Aggregate of 20 mm with surface saturated dry condition, Potable water, Bamboo culms are cylindrical shells and are divided by nodes as solid transversal diaphragms. Bamboo culm was cut in 75 cm length with node at centre. Then whole bamboo culm was cut in 8 strips and individual strip is used.

3.2.2 Preparation of sample [2]
- Plain concrete slab panel (without bamboo) To cast plain concrete slab panel of size 900 mm x 250 mm x 75 mm the mould of same in to in dimensions was used as shown in Fig. 7. In plain concrete Slab panel, no bamboo stick was used.

Figure 7 Mould of size (in to in) 900 mm x 250 mm x 75 mm

Figure 8 Plain concrete slab panel

The concrete of M20 grade was made using mixing machine and then mould was filled in three to four layers. Every layer was temped properly using temping and compacted well and then allowed to settle. After casting, concrete samples were kept in wet place and unmolded after 24 hours and submerged in open water tank for curing up to 28 days as required for the test.

- Singly reinforced concrete slab panel [4]

For casting of singly reinforced slab panel same mould was used as state in previous section. In singly reinforced slab panel bamboo strip was used in tension zone. Fig. 9 shows the cross section of singly reinforced slab panel.

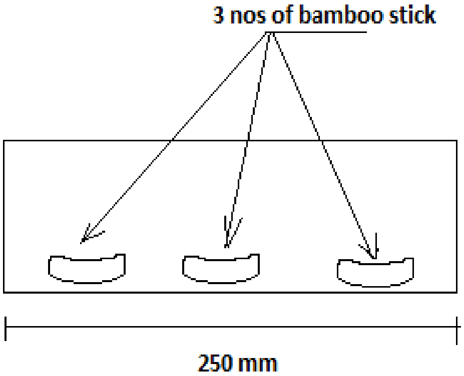

Figure 9 Cross-section of singly reinforced concrete slab panel

To cast singly reinforced slab panel first of all a layer of 20mm was made. Then 3 bamboo strips were place on it as shown in Fig. 10. Then remaining mould was filled with concrete and compacted so that bamboo did not move from its place.

Figure 10 Placing of bamboo in singly reinforced slab panel

Figure 11 Singly reinforced concrete slab panel

♦ Doubly reinforced concrete slab panel

For casting of doubly reinforced slab panel same mould was used as state in previous section. In doubly reinforced slab panel bamboo strip was used in two layer. Fig. 12 shows the cross section of doubly reinforced slab panel.

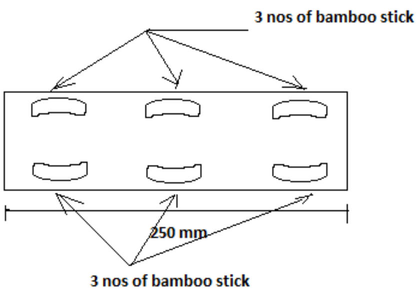

Figure 12 Cross-section of doubly reinforced concrete slab panel

Figure 13 Casting of concrete slab panel with bamboo reinforcement

To cast singly reinforced slab panel first of all a layer of 20mm was made. Then 3 bamboo strips were place on it as shown in Fig. 13. Then remaining mould was filled with concrete so that 20 mm cover would available for bamboo strips in upper layer. After casting, concrete samples were kept in wet place and unmolded after 24 hours and submerged in open water tank for curing up to 28 days as required for the test.

3.2.3 Test procedure [5]

Test setup for all concrete slab panel was same. Fig. 14 illustrates the test setup. Dial gauge was also provided at mid span to calculate the deflection. At regular interval of deflection load was recorded.

Figure 14 Flexural test setup of slab panel

Figure 15 Brittle failure of slab panel

IV. Results and Discussion

Test results of plain , singly and doubly bamboo reinforced are framed as below:

- Plain Concrete Slab Panel

In the plain slab panel test specimen, the first crack occurred vertically from the point of load application which was flexure crack and the crack was widened. Then, crushing of concrete at the point load application was observed. Finally, the slab panel failed at ultimate load of 8.2 kN. Plain concrete slab panel specimen showed the brittle failure (Fig. 15).

- Singly Reinforced Concrete Slab Panel.

In singly reinforced concrete slab panel the crack was seen to be going in a vertical direction. Then the crack got widened. The crack was rising very smoothly and slowly. The slab panel failed at a load of 10.4 kN. The Fig. 16 and Fig. 17 shows the crack development and the failure of the slab panel respectively.

Figure 16 Development of the crack in singly reinforced slab panel

Figure 17 Failure of singly reinforced slab panel

Flexural test results (load versus deflection) of doubly and singly bamboo reinforcement are recorded in Table 4 and Table 5.

Table 4 Flexural test result of doubly reinforced slab panel

Sr. No.	Deflection (mm)	Load (N)	Sr. No.	Deflection (mm)	Load (N)	Sr. No.	Deflection (mm)	Load (N)	Sr. No.	Deflection (mm)	Load (N)
1	0	0	36	1.750	9800	71	3.500	13600	106	5.250	15700
2	0.050	5100	37	1.800	9900	72	3.550	13800	107	5.300	15750
3	0.100	6200	38	1.850	10000	73	3.600	13900	108	5.350	15750
4	0.150	6500	39	1.900	10100	74	3.650	14000	109	5.400	15800
5	0.200	6900	40	1.950	10200	75	3.700	14100	110	5.450	15800
6	0.250	6900	41	2.000	10400	76	3.750	14300	111	5.500	15800
7	0.300	6900	42	2.050	10500	77	3.800	14400	112	5.550	15800
8	0.350	6900	43	2.100	10600	78	3.850	14500	113	5.600	15800
9	0.400	6900	44	2.150	10700	79	3.900	14600	114	5.650	15850
10	0.450	7000	45	2.200	10750	80	3.950	14700	115	5.700	15900
11	0.500	7000	46	2.250	10900	81	4.000	14800	116	5.750	15900
12	0.550	7100	47	2.300	11200	82	4.050	14900	117	5.800	15900
13	0.600	7200	48	2.350	11300	83	4.100	15000	118	5.850	15950
14	0.650	7400	49	2.400	11400	84	4.150	15100	119	5.900	16000
15	0.700	7500	50	2.450	11500	85	4.200	15200	120	5.950	16000
16	0.750	7700	51	2.500	11600	86	4.250	15200	121	6.000	16000
17	0.800	7900	52	2.550	11700	87	4.300	15200	122	6.050	16050
18	0.850	8000	53	2.600	11800	88	4.350	15250	123	6.100	16100
19	0.900	8100	54	2.650	11900	89	4.400	15300	124	6.150	16100
20	0.950	8400	55	2.700	11900	90	4.450	15300	125	6.200	16100
21	1.000	8400	56	2.750	12000	91	4.500	15300	126	6.250	16150
22	1.050	8500	57	2.800	12100	92	4.550	15300	127	6.300	16200
23	1.100	8600	58	2.850	12200	93	4.600	15350	128	6.350	16250
24	1.150	8700	59	2.900	12300	94	4.650	15400	129	6.400	16300
25	1.200	8900	60	2.950	12400	95	4.700	15400	130	6.450	16350
26	1.250	9000	61	3.000	12500	96	4.750	15400	131	6.500	16350
27	1.300	9000	62	3.050	12500	97	4.800	15400	132	6.550	16350
28	1.350	9100	63	3.100	12600	98	4.850	15400	133	6.600	16400
29	1.400	9150	64	3.150	12700	99	4.900	15400	134	6.650	16400
30	1.450	9200	65	3.200	12800	100	4.950	15500	135	6.700	16400
31	1.500	9200	66	3.250	12900	101	5.000	15500	136	6.750	16400
32	1.550	9300	67	3.300	13100	102	5.050	15500	137	6.800	16400
33	1.600	9500	68	3.350	13200	103	5.100	15550	138	6.850	16400
34	1.650	9600	69	3.400	13300	104	5.150	15600			
35	1.700	9700	70	3.450	13500	105	5.200	15650			

Table 5 Flexural test result of singly reinforced slab panel

Sr. No.	Deflection (mm)	Load (N)	Sr. No.	Deflection (mm)	Load (N)
1	0.050	6900	14	0.700	5900
2	0.100	7000	15	0.750	5900
3	0.150	7000	16	0.800	5900
4	0.200	6600	17	1.000	6800
5	0.250	6200	18	2.000	8700
6	0.300	6200	19	3.000	9000
7	0.350	6100	20	4.000	9500
8	0.400	6000	21	5.000	9800
9	0.450	5900	22	6.000	10000
10	0.500	5900	23	7.000	10100
11	0.550	5900	24	8.000	10100
12	0.600	5900	25	9.000	10200
13	0.650	5900	26	10.000	10400

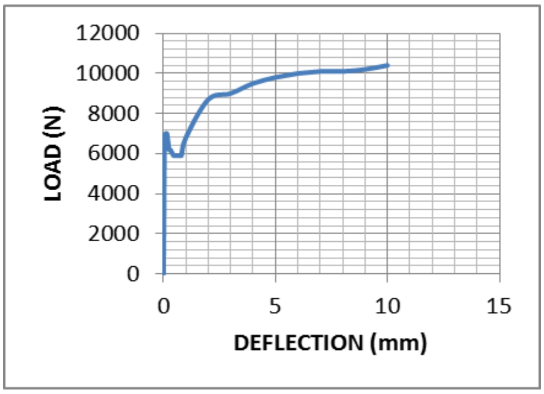

Figure 18 Load v/s deflection curve for singly reinforced slab panel

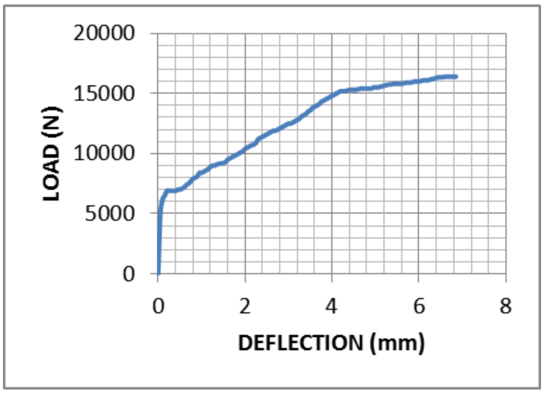

Figure 19 Load v/s deflection curve for doubly reinforced slab panel

The result of tensile test of bamboo strip with ultimate load and elasticity is tabulated below in Table 6.

Table 6 Tension test result of bamboo strip

Sample no.	Area (mm^2)	Ultimate Load (kN)	Stress (N/mm^2)	Elasticity (N/mm^2)
1	190	29.3	154.21	5000
2	186	26.0	139.78	5294
3	202	33.3	164.85	5000

The result of flexural test on slab panel is mentioned in Table 7 as below with elasticity and ultimate load at which panel failed. The ultimate deflection and elasticity of slab panel is also denoted in table

Table 7 Flexural test on slab panel

Sr. No.	Sample Type	Weight (kg)	Ultimate Load (kN)	Ultimate deflection (mm)	Elasticity (N/mm^2)
1	Plain	50.000	8.2	-	-
2	Singly	43.800	10.4	10	3434.67
3	Doubly	45.200	16.6	6.85	5152
Dimension of panel : 900 mm x 250 mm x 75 mm					

V. Concluding Remark

From above test results Elasticity of Bamboo strips are evaluated 5098 N/mm2 which is comparative same as steel. Same as load carrying capacity of bamboo strips with concrete is justifying with steel reinforcement. Replacement of steel reinforced can be possible by using Bamboo as bonding element in concrete. Bamboo is naturally available material as compared to steel but properties as well workability of Bamboo is compatible.

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