Journal of Engineering and Technology Research Vol. 3(12), pp. 342 - 350, November 2011
Available online at http:// www.academicjournals.org/JETR
DOI: 10.5897/JETR11.082
ISSN 2006-9790 ©2011 Academic Journals

Full Length Research Paper

Performance evaluation of bamboo with morter and concrete

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Accepted 4 November, 2011

Bamboo has remarkable properties as a construction material, being both light weight and extremely strength and durable. Moreover it grows all over the Bangladesh; a South Asian lower-middle income country where rural people is the majority of the total population. Bamboo having considerable tensile and compressive strength as a construction material is used widely in Bangladesh. But the main problem that it has is less sustainability. But if it is mixed with some durable material like mortar and concrete than its durability as well as the strength taking ability will be much higher. This study concentrates on the strength test of composite members made accompanied by bamboo. It determines the compressive strength of bamboo, the strength of composite column made of bamboo and mortar in its hollow area, and the strength of composite column of bamboo and concrete. Different mixing ratios and cross-sectional areas are used for conducting the study. This study is performed mainly for the rural areas, where bamboo is of ample amount, steel is rare, expensive or transportation cost is high. In coastal area the economic condition of people is very poor. In such type of backward area, such study may be essential for their development as well as an assurance for low cost housing. After the study it is seen that samples constructed as aid of bamboo can offer respectable amount of strength that can be safely used for low-cost housing.

Key word: Compressive strength, column, cement, sand, sample, stone, stone chips.

INTRODUCTION

Bamboo is a natural perennial grass-like composite and contains ligno-cellulosic-based natural fibers. Generally it occurs in the natural vegetation of many parts of tropical, subtropical and mild temperature regions, with about 1250 species identified throughout the world. It reaches its full growth in just a few months and reaches its maximum mechanical resistance in just few years. Therefore Bamboo contains tremendous economical advantage as well (Ashrafuzzaman et al., 2010). Its height ranges from 10 cm to even 40 m in height. Bamboo plays an essential role in the daily life of millions of people in subtropical and tropical regions (Liese, 1987). It is seen that everyday about 2.5 billion people in Asia use bamboo for their everyday work (Scurlock et al., 2000). In Bangladesh, a Southeastern country, bamboo is a common material to build low cost houses especially in rural areas (Rashid, 2007; Shila, 2002). It is also used as a common fuel product in Bangladesh as well as different part of South Asia (Bhatt and Sachan, 2004; Leach, 1987; Miah et al., 2010). Construction industry is one of the most polluting industries in the world. Production of both concrete and steel causes considerable deterioration of the environment. For example cement requires over 1400°C by burning fossil fuel (CS Monitor, 2008; Aziz, 1995). Even the flame temperature may reach to 1650°C (Neville, 1995). Production of every ton cements results in emission of at least one ton of CO_2 (Baba, 2009). Similarly, production of per ton of steel releases over two tons of CO_2 in the atmosphere (Ghavami, 2007). The steel making process is very energy intensive. The majority of energy used in the production of steel comes from coke/coal, electricity, liquid oxygen, and the raw ingredients themselves (www.energytechpro.com, 2004). Even transportation of the construction material is also associated with the emission of CO_2 (Scientific American, 2008). Due to high

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Figure 1. Prepared bamboo sample for compression test.

cost of building materials for low cost housing search of low cost housing material is always a good area of research (Mahzuz et al., 2009). Wood based building materials such as bamboo are the oldest form of building materials. They are easy to work with, structurally strong construction material suitable for framing, flooring, roofing, lining etc (Joseph and Mc-Nally, 2010; Sun et al., 2003). Research and developments are also made for the effective utilization of natural fibres from coconut husk, sisal, sugarcane bagasse, bamboo, jute, wood, akwara, plantain and musamba for making concrete (Aziza, 1981). Due to its superior properties like high strength to weight ratio, high tensile strength and other factors like low cost, easy availability and harmless to the environment during service, bamboo has constantly attracted the attention of scientists and engineers for use as reinforcement in cement based composites (Ashrafuzzaman et al., 2010). Modern uses of bamboo as an alternative for construction products such as concrete, brick and (hard) wood in particular are in increasing demand. Researches are already made pointing how laminated bamboo-frame building could be a direct alternative for wood-frame building, bamboo having a great advantage in yearly yield per forest area compared to wood (Flander and Rovers, 2009). Even bamboo is used to make footbridge now a days (Laroque, 2007). Bamboo is a very kin interest for various researchers to use as reinforcement in concrete elements (Ghavami, 2005; Yao and Li, 2003; Ghavami, 1995; Brink and Rush, 1966). Different researchers have made their research about the mechanical properties of bamboo (Lakkad and Patel, 1981; Amada and Sun, 2001; Li et al., 2002; Chung and Yu, 2002). Diameter and age have significant effect on the compressive strength capacity of bamboo. The sclerenchyma fibers were more closely packed at the top section of the bamboo, resulting in a higher strength capacity of bamboo. The fiber density of sclerenchyma tissue within the bamboo is a good indicator of the strength capacity of bamboo (Lo et al., 2004). Though the tensile strength of bamboo is much lower than that of steel yet it offers respectable amount of tensile strength (200.5 MN-m^{-2}) (Carrasco et al., 2002). On the other hand bamboo in terms of fiber composites and mat composites offers better strength as well (175.27 MN-m^{-2} and 110.5 MN-m^{-2}, respectively) (Jain et al., 1992). However, wide applications of bamboo in civil engineering were limited by its disadvantages in the past. The principal disadvantages in its natural form are its poor bond with concrete, low modulus of elasticity, high water absorption tendencies, low durability, and low resistance to fire. Nowadays, some of these shortcomings can be significantly improved by subjecting the bamboo to appropriate treatments (Ashrafuzzaman et al., 2010).

METHODOLOGY

In order to prepare the study, major steps like work procedure design, sample preparation, laboratory test and comparison of the conducted studies are followed. Four basic types of samples are prepared for study at this test; all are accompanied by bamboo at different form. The basic types of samples are:

a) Bamboo sample alone.
b) Composite sample of bamboo with mortar poured in its hole.
c) Composite sample of bamboo with the mixture of cement, sand and stone chips poured in its hole.
d) Bamboo reinforced column sample where bamboo sticks are used as an alternative of steel.

It is to be noted that all the bamboo samples used for this study were at least of 3 years of age. In the following section the preparation of those samples and the test procedures are discussed.

Preparation of bamboo sample

The bamboo samples selected for the study were air dried and worm free. Bamboo was sized into one feet length as shown in Figure 1.The internodal regions of the stem are hollow. The two ends of the bamboo were kept perpendicular to the surface/length of the bamboo. Three replicates were tested under compression machine and the average was taken as the result.

Preparation of composite sample of bamboo with mortar poured in its hole

Each of the bamboo samples was taken of one feet length as stated above. Then mortar is poured at the hole of the bamboo sample. After curing (28 days) it is prepared for the compression test. Water/cement ratio was fixed (0.45). The mortar was prepared in three (1:5, 1:4 and 1:3) mixing ratios of cement and sand. Three replicates were tested for each ratio. Total 9 samples were made. Curing of mortar was performed for 28 days as shown in Figure 2. Due to swelling and odorous problem of bamboo, at the 16th day of curing the samples were dried two days. Then the curing started

Figure 2. Curing of composite sample.

Figure 3. Prepared bamboo splints.

Figure 4. Preparation of bamboo reinforcement case with tie bar.

Figure 5. Concrete and bamboo case placed mould.

again. Before the final compression test the sample was air dried two days.

Composite sample of bamboo with the mixture of cement, sand and stone chips poured in its hole

Each of the bamboo samples was taken of one feet length as stated above. Then mixture of cement, sand and stone chips (of about 6.25 mm size) are poured at the hole of the bamboo sample. After drying and curing it is prepared for the compression test. Used water/cement ratio was 0.45 as well. The mixture was prepared in three (1: 1.5:3, 1:2:4 and 1:2.5:5) mixing ratios of cement, sand and stone chips. Three samples were tested for each ratio. That is in total 9 samples were made. After the preparation of the sample it was dried for one day in normal weather. Curing of concrete mixture was performed for 28 days as shown in Figure 3. Due to swelling and odorous problem of bamboo, at the 16th day of curing the samples were dried two days. Then the curing started again. Before the final compression test the sample was air dried two days.

Preparation of bamboo reinforced column sample

Here bamboo splints are made to test their effectiveness as an alternative of steel in concrete column. The moulds used to create the samples were circular in shape ($\text{Height}: 300\text{mm}, \text{ Dia}: 150\text{mm}$). Each sample was provided with six number of bamboo splints. Three types of splints of cross sectional area of (12.5×12.5) mm^2, (8.75×8.75) mm^2 and (10.75×10.75) mm^2 were used. Two concrete mix ratios were used for study purpose (1:1.25:2.5, 1:1.5:3). Three samples were made for each mixing ratio and each splint size. That is in total 18 samples were made. For all samples water/cement ratio was taken as 0.45. GI weir was used to hold the bamboo splints in position while concrete is poured in mould (Figure 4). For all sample a clear cover of 12.5 mm was maintained. Concrete mix was prepared with sand, cement and stone$_{(18.75 mm\ size)}$. After the preparation of sample it was dried for one day in normal weather. Curing was performed for 28 days. After 28 days excess portion of the bamboo splints were cut smoothly (Figures 5 and 6). Then the compression strengths of the samples were determined by the

Figure 6. Cutting of the excess portion of bamboo splints.

Table 1. Determination of the compressive stress of bamboo.

Sample no	Outer dia cm	Inner di cm	Cross sectional area cm^2	Load KN	Stress MPa
01	7.44	6.1	14.24	59.1	41.5
02	8.03	6.5	17.46	66.9	38.32
03	7.4	6.2	12.81	55.4	43.22
Average compressive strength of bamboo sample					41.02

Table 2. Determination of stress (ratio 1:5).

Sample no	Outer dia cm	Inner dia cm	Cross sectional area cm^2	Load KN	Stress MPa
01	7.12	5.9	39.8	36.3	9.2
02	6.82	5.65	36.53	28.6	7.83
03	8.1	6.67	51.53	50.9	9.88
Average compressive strength					8.97

compression test machine.

RESULTS

Relation between the ratio of morter and stress

Determination of the compressive stress of bamboo

Three samples of bamboo were tested, each of which was about one foot in height as shown in the Figure 1. Test results are shown in Table 1.

Determination of strength of composite sample of bamboo with mortar poured in its hole

Test results for the ratio 1:5: The results are tabulated in Table 2.
Test results for the ratio 1:4: The results are tabulated in Table 3.
Test results for the ratio 1:3: The results are tabulated in

Table 3. Determination of stress (ratio 1:4).

Sample no	Outer dia cm	Inner dia cm	Cross sectional area cm^2	Load KN	Stress MPa
01	8.01	6.51	50.39	80.1	15.9
02	7.91	6.42	49.14	68.6	13.96
03	7.17	5.69	40.38	29.6	7.33
Average compressive strength					12.39

Table 4. Determination of stress (ratio 1:3).

Sample no	Outer dia cm	Inner dia cm	Cross sectional area cm^2	Load KN	Stress MPa
01	5.606	4.43	24.68	41.2	14.91
02	5.94	5.09	27.71	44.5	16.1
03	8.28	6.49	53.846	57.9	10.753
Average compressive strength					13.92

Table 5. Determination of stress (ratio1:1.5:3).

Sample no	Outer dia cm	Inner dia cm	Cross sectional area cm^2	Load KN	Stress MPa
01	6.29	5.12	31.07	42.8766	13.80
02	7.25	5.93	41.28	58.4112	14.15
03	8.24	6.78	53.326	78.1226	14.65
Average compressive strength					14.20

Table 6. Determination of stress (ratio1:2:4).

Sample no	Outer dia cm	Inner dia cm	Cross sectional area cm^2	Load KN	Stress MPa
01	7.17	5.69	40.37	51.3	12.71
02	7.52	6.23	44.41	57.4	12.925
03	6.91	5.45	37.50	46.7	12.453
Average compressive strength					13.45

Table 4.

Relation between the ratio of (cement+sand+stone chip)

Determination of strength of composite sample of bamboo with the mixture of cement, sand and stone chips poured in its hole

Test results for the ratio 1:1.5:3. The results are tabulated in Table 5.

Test results for the ratio 1:2:4.The results are tabulated in Table 6.

Test results for the ratio 1:2.5:5.The results are tabulated in Table 7.

Relation between the ratio in the basis of their strength capacity

Test of bamboo reinforced sample

Test results for the ratio 1:1.25:2.5: (splint size of bamboo =(12.5×12.5) mm^2):

Total cross sectional area of bamboo = 6 x12.5x12.5 = 937.5 mm^2, the results are tabulated in Table 8.

Test results for the ratio 1:1.25:2.5 (splint size of bamboo = (10.75×10.75) mm^2):

Total cross sectional area of bamboo =6 x10.75 x 10.75 =693.5 mm^2

The results are tabulated in Table 9.

Table 7. Determination of stress (ratio1:2.5:5).

Sample no	Outer dia cm	Inner dia cm	Cross sectional area cm^2	Load KN	Stress MPa
01	8.12	6.42	51.78	63.21	12.21
02	7.4	5.93	43.01	53.31	12.4
03	7.06	5.43	39.21	49.9	12.73
Average compressive strength					12.44

Table 8. Determination of stress.

					For the 1:1.25:2.5		For the ratio 1:1.5:3	
Sample No.	Diameter (mm)	Cross sectional area (mm^2)	Bamboo reinforcement (cm^2)	Bamboo ratio (ρ_b) $\frac{Bamboo\ area}{Gross\ concrete\ area}$	Load KN	Stress MPa	Load KN	Stress MPa
01	150	17670	937.5		410.06	22.48	403.31	22.11
02	150	17670	937.5	0.053	360.81	19.78	366.28	20.08
03	150	17670	937.5		385.07	21.11	374.12	20.51
Average compressive strength						21.12		20.90

Table 9. Determination of stress.

					For the 1:1.25:2.5		For the ratio 1:1.5:3	
Sample No.	Diameter (mm)	Cross sectional area (mm^2)	Bamboo reinforcement (mm^2)	Bamboo ratio (ρ_b) $\frac{Bamboo\ area}{Gross\ concrete\ area}$	Load KN	Stress MPa	Load KN	Stress MPa
01	150	17670	693.5		347.13	19.03	391.82	21.48
02	150	17670	693.5		388.53	21.30	364.09	19.96
03	150	17670	693.5	0.039	409.69	22.46	365.91	20.06
Average compressive strength						20.93		20.50

Table 10. Determination of stress.

Sample No.	Diameter (mm)	Cross sectional area (mm^2)	Bamboo reinforcement (mm^2)	Bamboo Ratio (ρ_b) $\frac{Bamboo\ area}{Gross\ concrete\ area}$	For the 1:1.25:2.5 Load KN	For the 1:1.25:2.5 Stress MPa	For the ratio 1:1.5:3 Load KN	For the ratio 1:1.5:3 Stress MPa
01	150	17670	460	0.026	391.27	21.45	382.69	20.98
02	150	17670	460		374.85	20.55	336.55	18.45
03	150	17670	460		366.64	20.10	381.24	20.90
Average compressive strength						20.7		20.11

Test results for the ratio 1:1.25:2.5 (splint size of bamboo = (8.75×8.75) mm^2):

Total cross sectional area of bamboo = 6 × 8.75 × 8.75= 460 mm^2, the results are tabulated in Table 10.

DISCUSSION

The observed results mainly focus on the strength of the elements where bamboo is used at different forms. It is seen from the study that compression test of bamboo gives an average stress of 41.02 Mpa that is a good value to resist moderate loads especially of low cost buildings because load of low cost buildings are not so high. Such bamboo can be safely used as the feasible alternative of concrete column. If more than one bamboo is used than the resulting composite column can provide more resistance against more load. Table 1 shows the quantitative result of the compressive stress test of bamboo samples. The Composite sample of bamboo with mortar poured in its hole also shown respectable amount of stress before failure. At the mix ratio of 1:3, 1:4 and 1:5 the average stresses are 13.92 Mpa, 12.39 Mpa and 8.97 Mpa respectively. That is the stress got at the mix ratio of 1:3 is 12.35% higher than that of the mix ratio of 1:4, and the stress got at the mix ratio of 1:4 is 38.13% higher than that of the mix ratio of 1:5. It means that at lower stress ratio composite members provide better strength. Tables 2, 3 and 4 show the result of the tests of samples related to these types of sample. Finally the summary of the result is shown in Figure 7. Composite sample of bamboo with the mixture of cement, sand and stone chips poured in its hole have shown higher strength than the composite sample of bamboo with mortar poured in its hole. It is seen from the test results that at the mix ratio of 1:1.5:3, 1:2:4 and 1:2.5:5 the average stresses are 14.20, 13.45 and 12.44 Mpa respectively. That is the stress got at the mix ratio of 1:1.5:3 is 5.58% higher than that of the stress of the mix ratio 1:2:4, and the stress got at the mix ratio of 1:2:4 is 8.12% higher than that of the mix ratio of 1:2.5:5. It means that at lower stress ratio composite members provide better strength. Tables 5, 6 and 7 show the result of the tests of samples related to these types of sample. Finally the summery of the result is shown in Figure 8. At Bamboo reinforced concrete three types of bamboo area are used having the same gross area. Two types of mix ratios are used. The bamboo ratios are, 0.053, 0.039 and 0.026 respectively. It is to be noticed that at higher bamboo ratio there higher resistance against load. Tables 8, 9 and 10 show the result of the tests of samples related to these types of sample. Finally the summery of the result is shown in Figure 9.

Conclusion

Bamboo is one of the oldest materials used for the construction of houses and other structures. As an excellent building materials it is relatively cheap, easy to work with and readily available in most of the countries where bamboo grows. The importance of bamboo as a construction material particularly for housing has received a greater attention in recent years. In Asia, traditional bamboo houses of the low-income group use bamboo for supporting the structure. Even when other materials are used, bamboo forms a major part of the unit. Low cost bamboo houses are a cheap and safe alternative to the shelters of plastic, wood and stone that are currently being used by many homeless people. These houses are made from prefabricated and natural bamboo generally associated with other kinds of building materials like wood, mud, brick and concrete as per necessary so as to make house in different

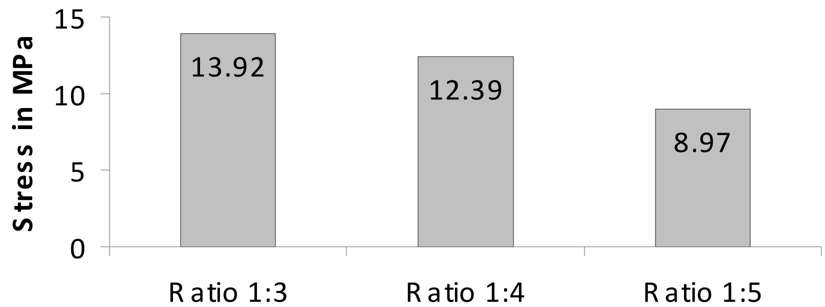

Figure 7. Strength of column at different ratio of mortar.

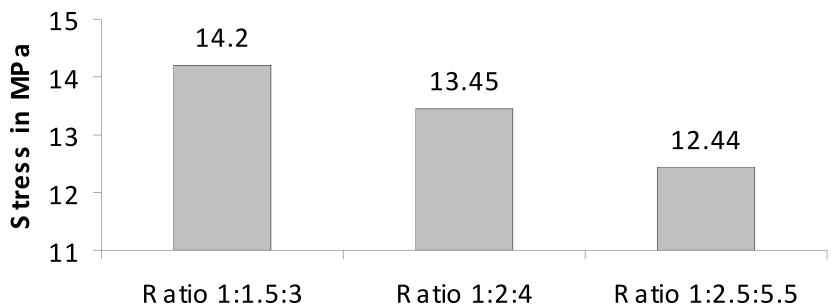

Figure 8. Strength of column at different ratio of concrete.

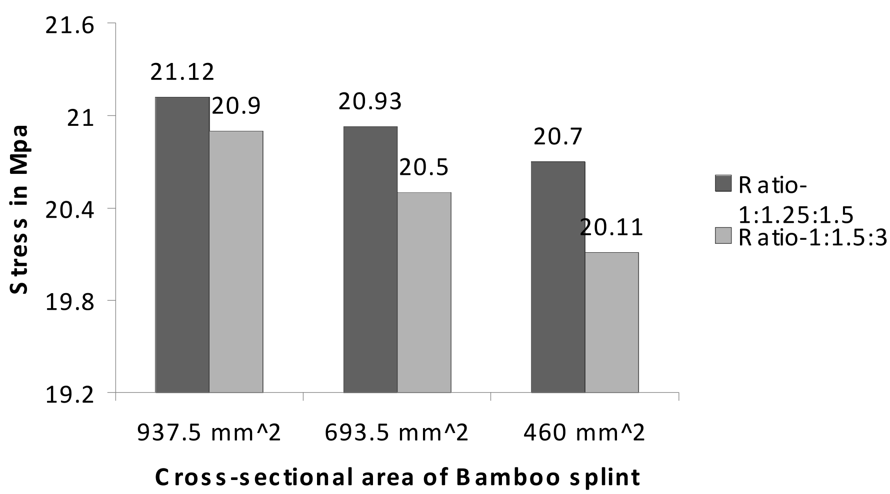

Figure 9. Comparison between the ratio in the basis of their strength capacity.

appearances and to increase durability. The global shortage of housing materials especially in the developing countries is such that it warrants serious consideration. Of all the advantages of bamboo housing technology, the most important is its low cost that does not sacrifice quality, durability or space. In stead it allows an option that is feasible for populations of scarce resourced areas like introducing bamboo in mortar and concrete based on the observed resting strength using different mixing techniques and ratios. Further studies are also necessary to find the more efficient use of bamboo for using it in low cost housing.

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