Journal of Civil Engineering Research 2013, 3(1): 16-21
DOI: 10.5923/j.jce.20130301.02

Determination of Several Properties of a Bamboo of Bangladesh

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Abstract The paper attempts to understand several properties of a bamboo (*Bambusa balcooa*) which is easily available in many parts of Bangladesh. All the bamboo samples used in this study were collected from one three years old tree. A total thirty samples were tested to find the ultimate strength. Among them the stress-strain curve of five samples were studied to find out Modulus of Elasticity (MoE) and Yield Strength (YS) using Offset Method. Attempts were also made to understand the bond strength of bamboo with concrete by the experimental setup of Pull out test. Here three types of specimens were prepared. Each type includes two specimens. Pull out test of steel were also made to report a relative comparison. Finally the relative comparison between the unit weight, strength and cost were made.

Keywords Bamboo, Cost, Pullout test, Stress, Strain, Steel, Tension test, Unit weight

1. Introduction

There are more than 33 bamboo species have been found in Bangladesh out of which 7 are occurring naturally in the forests of Chittagong Hill Tracts, Cox's Bazar, Sylhet and northern Mymensingh[3]. Sylhet –a Northeastern district of Bangladesh where bamboo (*Bambusa balcooa*) grows in abundance. It is locally known as *Borak Bash*. This bamboo was taken in this research for testing its several properties. The strength of bamboo is greater than many timber products which are advantageous, but it is quite less than the tensile strength of steel. Tension test is the most basic type of mechanical test. It is easy to perform and relatively inexpensive compared to other tests. The stress- strain characteristics of bamboo have been derived from the results of this tension test.

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℃ by burning fossil fuel[1,20]. Even the flame temperature may reach to 1650℃ (Neville, 1995). Production of every ton cements results in emission of at least one ton of CO_2[2]. Similarly, production of per ton of steel releases over two tons of CO_2 in the atmosphere[17]. 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[16]. Even transportation of the construction material is also associated with the emission of CO_2[15].

K. Gavami carried out several research programs using indigenously available local materials such as bamboo, coconut fibres, sisal and other natural fibres as construction materials[5-10]. For low cost housing, search of low cost material is always a good area of research[11]. Bamboo is one of the oldest building materials. It is easy to work with, structurally strong, suitable for framing, flooring, roofing, lining etc[12, 21]. In Bangladesh, a South-Asian country, bamboo is a common material to build low cost houses especially in rural areas[13,14]. It is also used as a common fuel product in Bangladesh as well as different part of South Asia[4, 18, 19]. Whereas the mechanical properties and behaviour of steel have been thoroughly studied and well documented, there exists no comprehensive data describing the characteristics of bamboo. Therefore, the aim of this study is to provide a preliminary contribution toward the collection of several physical and mechanical properties of bamboo.

2. Objectives of the Research

The study was conducted keeping the following objectives in mind:

1) Understanding the stress-strain relationship of bamboo splints.

2) To compare the Strength-density ratio and Strength-cost ratio with steel.

3) To investigate the bond with concrete.

3. Sample Preparation

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Published online at http://journal.sapub.org/jce

Three years old, any type of fault-free bamboo (*Bambusa balcooa)* was selected from careful visual inspection for tension test. After cutting the bamboo it was kept in open air for two months to be removed from moisture. Thirty specimens were prepared for tension test at the Universal Testing Machine (UTM). Among them five samples were tested to find out the Modulus of Elasticity (MoE) and the yield strength. Based on the result, statistical analysis was also performed using the computer program-SPSS.

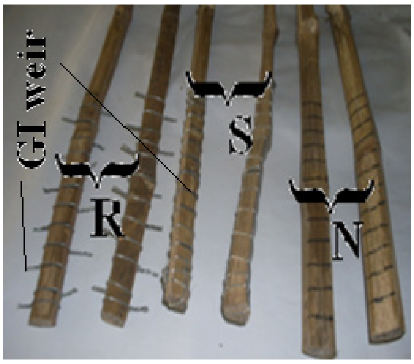

Figure 1. Prepared samples for Pull-out test

Figure 2. Failed bamboo after Tension test in UTM

Standard testing method was used to find out the density (or unit weight) of both steel and bamboo specimens. Existing market price of the 2012 of Sylhet-Bangladesh was taken in count to compare the cost of both steel and bamboo.

To understand bond strength of bamboo with concrete Pull-out test is a common technique. The research was performed by Ordinary Portland Cement (ASTM Type-1 OPC) at a mixing ratio of 1:2:3 having the same water-cement (w/c) ratio (0.485). The fineness modulus (FM) of sand was kept constant at 2.79. To compare the result with steel the bond strength of steel of 414 Mpa was also studied (termed as S1 and S2). Since bamboo surface is smooth so it may offer less bond strength than steel with concrete. To increase the bond strength Galvanized Iron (GI) weir (1.75 mm diameter) was used in two forms (ring and spiral) with bamboo. Therefore three types of bamboo specimens were prepared (Fig 1). They were:

a) Bamboo sample with one knot (termed as 1N and 2N),

b) Bamboo sample with spiral of GI weir having 25mm pitch (termed as 1S and 2S),

c) Bamboo sample with ring of GI weir having 25mm spacing (termed as 1R and 2R).

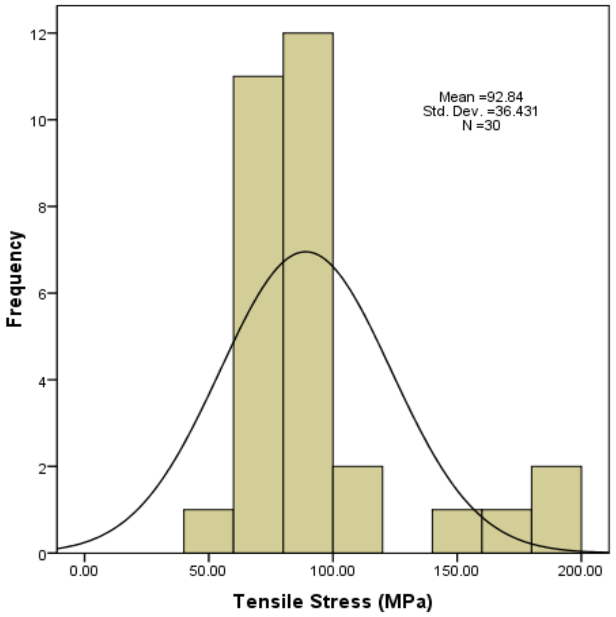

Figure 3. Normality curve of Frequency Vs Stress of the bamboo samples

4. Test Result

4.1. Tension Test

The tensile tests (Fig 2) were conducted at 15.5% moisture content. Their failure pattern, ultimate and yield strength is discussed in the following section. Table 1 shows detailed information about the size of bamboo samples, maximum load and maximum stress taken by each bamboo specimen. Table 2 shows the statistical analysis of the results of Table 1. Fig 3 shows the normality curve of Frequency Vs Stress of the bamboo samples. The Stress-strain curves of five samples are shown from Fig 4-8.

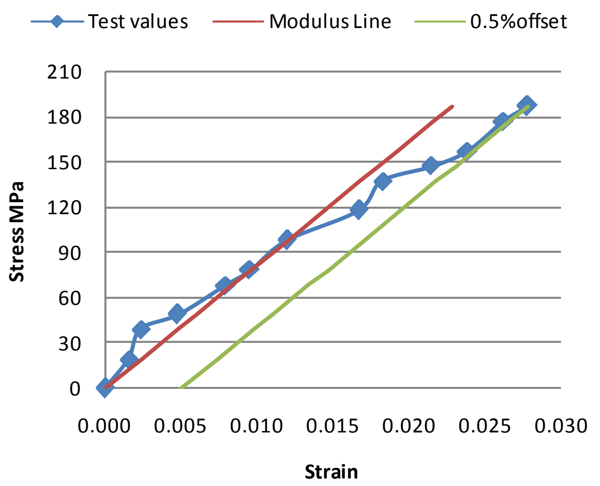

Figure 4. Stress-strain diagram of Sample-1

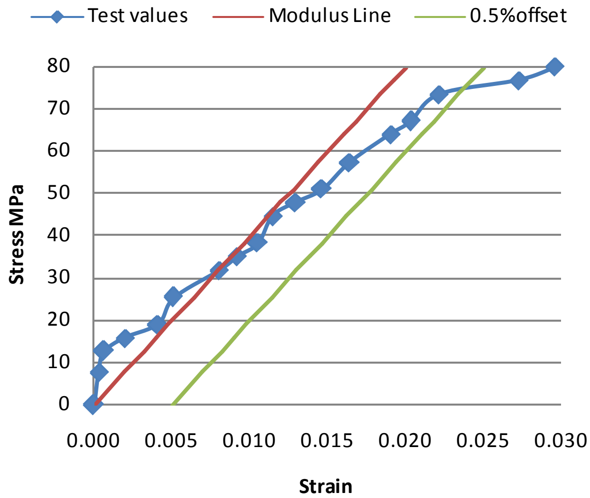

Figure 5. Stress-strain diagram of Sample-2

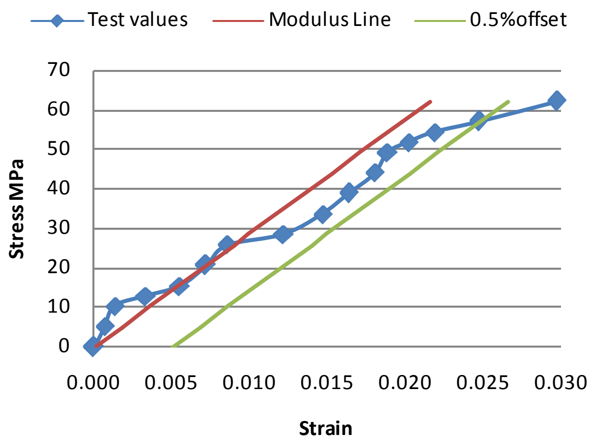

Figure 6. Stress-strain diagram of Sample-3

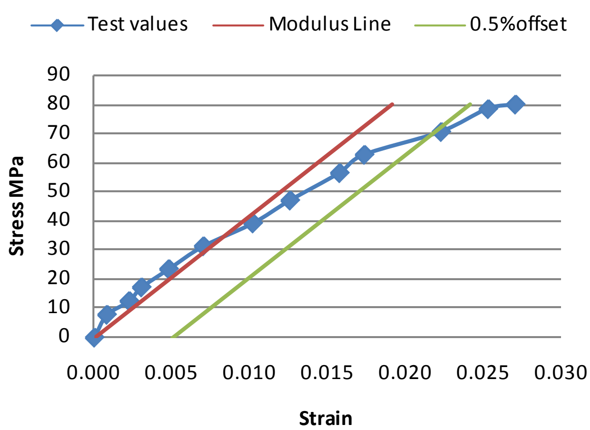

Figure 7. Stress-strain diagram of Sample-4

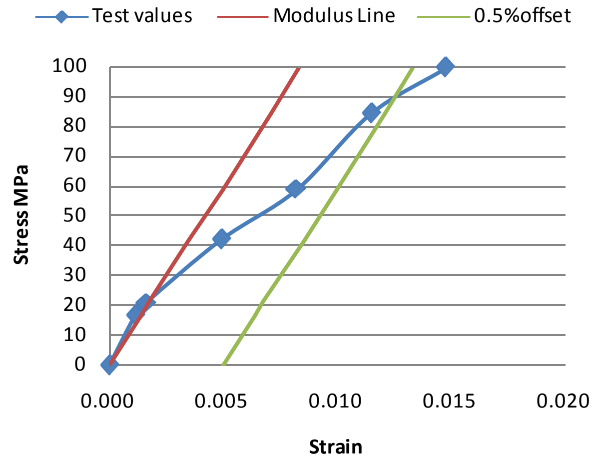

Figure 8. Stress-strain diagram of Sample-5

Table 1. Test Result of Bamboo Specimen

Sample No	Dimension (mm)		Area (mm^2)	Load (KN)	Tensile Stress (MPa)
	Shorter	Longer			
1.0	6.0	20.0	120.0	9.68	80.6
2.0	7.0	20.0	140.0	12.90	92.1
3.0	10.0	18.5	185.0	13.98	75.5
4.0	8.0	17.5	140.0	13.98	99.8
5.0	8.0	19.0	152.0	13.98	91.9
6.0	5.5	17.5	96.3	10.75	111.7
7.0	9.0	18.0	162.0	16.13	99.5
8.0	11.5	13.5	155.3	29.03	187.0
9.0	11.5	13.5	155.3	27.41	176.6
10.0	14.0	13.0	182.0	29.03	159.5
11.0	10.0	18.0	180.0	12.90	71.7
12.0	13.5	16.0	216.0	13.98	64.7
13.0	10.0	23.0	230.0	21.50	93.5
14.0	14.5	19.5	282.8	21.50	76.0
15.0	11.5	19.0	218.5	23.65	108.2
16.0	21.0	23.5	493.5	31.18	63.2
17.0	18.0	19.0	342.0	27.41	80.2
18.0	18.5	25.0	462.5	33.33	72.1
19.0	17.5	24.5	428.8	38.70	90.3
20.0	16.0	17.0	272.0	18.81	69.2
21.0	14.0	24.0	336.0	26.88	80.0
22.0	16.0	19.0	304.0	20.43	67.2
23.0	16.0	22.5	360.0	32.25	89.6
24.0	18.0	23.0	414.0	25.80	62.3
25.0	14.0	16.5	231.0	41.93	181.5
26.0	16.0	19.0	304.0	20.43	67.2
27.0	14.0	24.0	336.0	16.13	48.0
28.0	18.0	19.0	342.0	27.41	80.2
29.0	16.0	22.5	360.0	30.10	83.6
30.0	18.0	23.0	414.0	25.80	62.3

4.2. Pull-Out Test

Figure 9. Pull-out test of steel

Figure 10. Pull-out test of bamboo

The bamboos samples were used to prepare the samples for Pull-out test. The properties of concrete used for this test is presented at Table 3. Each of the concrete samples was of 150 mm dia and 300 mm height. Any form of imperfection (fracture, void, decay, etc) was avoided in the bamboo. Any undulation was trimmed off as well. Dimension was measured at different locations and then the average was calculated. Pull out test was performed both for steel and bamboo to show the relative for comparison. The samples were cured up to 28 days. After that they were tested at UTM (Fig 9 & 10). The detailed result is presented at Table 4.

Table 2. Statistical Analysis by SPSS

Description		Value
Number of samples		30
Mean		92.84
Std. Error of Mean		6.65
Median		80.40
Mode		62.30
Std. Deviation		36.43
Variance		1327.25
Skewness		1.64
Std. Error of Skewness		0.43
Kurtosis		1.93
Std. Error of Kurtosis		0.83
Range		139.00
Minimum		48.00
Maximum		187.00
Percentiles	2	48.00
	25	68.70
	50	80.40
	75	99.58

Table 4. Result of Pull out test of Bamboo

Name	Dia (mm)	a (mm)	b (mm)	Perimeter (mm)	Height (mm)	A (mm^2)	Load (KN)	Average Lode (KN)	Stress generated before failure (Mpa)	Failure Type	Comment
S1	16	----	----	50.27	300	15079.64	79.55	103.74	6.11	Concrete was crushed	Bond stress is ensured
S2	20	----	----	62.83	300	18849.56	127.93				
1N	--	9.25	24	133	300	39900.00	36.55	42.46	1.04	Bamboo failed by tension	Bond stress is not ensured. Since Bamboo failed in each case so it can not be concluded that R or S is better then N.
2N	--	6.75	28.25	140	300	42000.00	48.38				
1R	--	10.5	22	130	300	39000.00	41.93	41.39	1.08	Bamboo failed by tension	
2R	--	7.25	24	125	300	37500.00	40.85				
1S	--	8	20.75	115	300	34500.00	32.25	29.56	0.79	Bamboo failed by tension	
2S	--	15.25	18.75	136	300	40800.00	26.88				

Table 3. Specifications of the concrete used

Cement	FM of Sand	Water Cement Ratio	Unit weight of stone (Kg/m^3)	Mix ratio	28 days Compressive strength (Mpa)	Unit weight of Concrete (Kg/m^3)
OPC-ASTM Type-1	2.79	0.485	1600	1:2:3	27.5	2557

4.3. Unit Weight

A total number of four samples of each type were tested. The elaborate result is shown in Table-5. It is seen from the result that bamboo possesses much less density than that of steel.

5. Discussion

5.1. Stress Strain Relation

Table 5. Unit weight of bamboo and steel

Sample No	Length (m)	Cross-sectional Area (cm^2)	Volume (m^3)	Weight (kg)	Unit Wt (kg/m^3)	Average (kg/m^3)
Bamboo-1	0.51	2.34	0.00011934	0.089	746	812
Bamboo-2	0.52	2.55	0.0001326	0.095	716	
Bamboo-3	0.51	2.16	0.00011016	0.087	790	
Bamboo-4	0.54	1.80	0.0000972	0.097	998	
Steel-1	0.53	0.785	0.000041605	0.31	7451	7872
Steel -2	0.53	0.785	0.000041605	0.33	7932	
Steel -3	0.53	0.785	0.000041605	0.32	7691	
Steel -4	0.53	0.785	0.000041605	0.35	8412	

Table 6. Modulus of Elasticity of bamboo

Sample No	Yield Strength (Mpa)	Average (Mpa)	MoE (Mpa)	Average (Mpa)
Sample-1	157	90	8200	6255
Sample-2	75		3999	
Sample-3	57		2885	
Sample-4	70		4191	
Sample-5	90		12000	

Proper gripping is the most impo7.8rtant factor for tensile test of bamboo. Any slippage at joint or damage of sample due to excessive compression at the grip of UTM may harm the exact strength of bamboo. In this study these possibilities were carefully avoided. The failure pattern of bamboo specimen was typical splitting without any slip at the grip locations. All the splits are parallel to the grain and in maximum cases failure occurred more than one location. From these results it can be concluded that the tensile strength is nearly uniform and failure pattern is very similar for bamboo specimens where failure at grip was avoided.

The gage length varied from 60 mm to 63 mm for all the samples. From the Stress-strain curves of all the five samples the yield strength has been calculated by offset method taking 0.2% Offset. The size related information of these five samples is presented as the Bold latter in Table 1. The corresponding Yield strength and the Modulus of Elasticity are presented at Table 6.

5.2. Comparison of Several Ratios

For being a natural material the weight of bamboo is much less than steel. Bamboo has more then twice the Unit Strength-Weight ratio than that of Steel (Table 7). For the abundance availability the cost bamboo is low. That's why, bamboo has higher Strength-cost ratio than that of steel. Three years old well grown one bamboo costs Taka 300 (1 Dollar ≈ 78 Taka). If its inner dia = 10 cm and outer dia 7.5 cm then its cross-sectional area is $\pi(10^2 - 7.5^2)/4/100/100 = 3.44\times10^{-3}\ m^2$. Considering the effective usable height 6m the volume of one bamboo is $3.44\times10^{-3}\times 6 = 0.021\,m^3$. From Table 5 It seen that volume of 0.51 m long sample (Bamboo-1) is 0.00011934 m3. Therefore the volume of 1 m bamboo is 0.000238 m3. So the equivalent cost is $\frac{300\times 0.000238}{0.021}$ o=3.4 Taka/m. On the other hand, the present market price of #3 is Taka 52000 per ton. The nominal Weight of #3 bar is 0.376 lb/ft which equal to 0.000188 Ton/ft (since 1 lb=0.0005 Ton). Therefore Cost/ft is Taka 9.78. This can be said as 32.08 Taka/m, (since 1m = 3.28 ft). This value is almost 9.5 times higher than that of steel.

Table 7. Ratio of Strength and Unit Weight

Sample Type	Ultimate Strength Mpa	Density Kg/m^3	Ratio	
			Strength-Density	Density-Strength
Bamboo	92.84	812	0.114	8.77
Steel	414	7872	0.052	19.23

5.3. Pullout Test

It is seen from the experimental data (Table 4) that, the bond strength of steel with concrete is more than five times higher than all the three cases of bamboo. Both of the samples of steel were failed due to the crushing of concrete. For bamboo specimens in all cases Bamboo failed by tension rather the splitting out from concrete or the crushing of concrete. Since, it is Bamboo that failed first in each case so it can not be concluded that R or S is better then N. Therefore it is worthless to try to increase the bond strength using GI ring or spiral under the above mentioned condition. It can be said that since bamboo failed in all cases so the actual bond strength can not be reported from this test. Therefore, the values (i.e. 1.04 Mpa 1.08 Mpa and 0.79 Mpa shown in

Tble-4) are the skin friction before the failure of bamboo- not the bond strength. Bond strength can be achieved by reducing the height of concrete. Therefore more tests have to be done in this area.

6. Conclusions

The tensile tests were performed taking the natural state of bamboo. Except air drying (for 60 days) no other chemical and physical treatments were performed. The moisture content was 15.5%. From the Pull-out test the actual bond strength could not be reported. Therefore more tests should be carried out reducing the height of concrete (obviously the than 300 mm), or reducing the values of 28 days compressive strength (less than 27.5 Mpa- as reported at Table-3), or increasing the cross-sectional area of bamboo splints (the value should be more than the values of bamboo shown in table 4). Being a natural material bamboo offers much less strength than that of steel. Yet it exhibits double Strength-weight ratio than that. Strength-Cost ratio of bamboo is also more than nine times higher than that of steel. This scenario certainly provides interesting information for the prospect of more research in this field.

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