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Characterization and Strength Analysis of Reinforced Bamboos and Bamboos Without Reinforcements

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Abstract: This paper investigates the strength of reinforced fresh, reinforced dried and bamboos without reinforcement subjected to static loading condition. Crushing strength test was performed using uniaxial compression machine with maximum loading capacity of 1500 KN. The data is plotted as failure stress to height, specific compressive strength with height, strength to weight ratio versus height, strength to volume ratio versus height. Result shows that the strength increases as the height increases for all structures analysed. All the bamboo structures exhibited elastic behaviour, but the reinforced fresh bamboo showed higher elastic behavior to the transition point. The dried reinforced bamboo proves to have the highest intrinsic strength beyond the transition point. Failure stress to weight ratio also decreases with increases with height for all cases of the structures. The specific compressive strength of both non-reinforced fresh and dried has an appreciable increased up to a transition point and then it decreased with increased with height. Failure stress proves that the strength of reinforced dried bamboo increases with increases in height. Conclusively, the reinforced dried bamboo can withstand higher compressive load than the rest of the bamboo structures.

Key words: Reinforced Fresh Bamboo · Reinforced Dried Bamboo · Failure Stress to Weight Ratio · Strength to Volume Ratio · Load to Height Ratio · Specific Compressive Strength

INTRODUCTION

Bamboo is part of flowering perennial plants in the grass family Poaceae. Bamboo is considered as a composite material [1] and [2]. Most Asian and African countries use bamboo for domestic utilities and building applications. Bamboo's resistance to stretching and its ability to support weight has been investigated by [3, 4] also investigated the crushing strength of bamboo and the fracture behaviour of fresh bamboo. Bamboo plant is strong in both compression and tension. Bamboo has a higher compressive strength than wood, brick or concrete and a tensile strength that rivals steel. Research has shown that tensile strength remains constant in the life span of the bamboo plant, but compressive strength increases as it gets older [5]. The effect of stress concentration on the performance of bamboo using the notched and the un-notched specimen has been investigated by [6]. Although bamboo is a composite material, reinforcing it with other materials like concrete, may increase it tensile, toughness and compressive strength in other to withstand greater loads. Little research work has been carried out in this area. Concrete instead of the normal steel rods would be used as reinforcement in this experimental study. The industry uses of concrete cannot be underestimated. The proportions of each ingredient i.e. cement, sand, gravel and water determine the strength of the concrete [[7]. Concrete material has high compressive strength but weak in tensile strength [8]. Despite all the numerous benefits of the applications of bamboo and concrete, accidents do occur with the use of this material as well as its general constructional usage. The feasibility of using bamboo to reinforce concrete has been studied by [9]. Other mechanical properties concerning the strength of bamboo without reinforcement has been investigated by [10], [11], [12] and [15]. Since bamboo is susceptible to other plant decades, the durability of bamboo depends strongly on the preservative treatment methods. The preservatives treatment methods have been researched by [13] and [14]. Despite all these research capabilities, improvement in the strength of bamboo poses problems to engineers and scientists. One of the ways to improve the strength of bamboo is conducted in this research work. For the purposes of design and reliability, it is imperative to study and understand characters that are extracted from

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subjecting reinforced bamboo and bamboo without reinforcements to compressive loads and to study the force relationships between these samples. This research paper emphasized on reinforced fresh bamboo, reinforced dried bamboo and bamboos without reinforcements subjected to unidirectional compressive loads. A comparative study would be studied among the bamboo structures.

MATERIALS AND METHODS

Materials: The type of bamboo specie used for this research work is bambusa vulgaris. By x-ray diffraction test, the bamboo comprises the following; 4.5 % starch, 2 % deoxidized saccharide, 2.5 % fat and 6 % protein. The bamboo specimens involved both fresh and dried type with different heights. The materials for concrete reinforcement within the bamboo specimen were cement, fine aggregate (sand), coarse aggregates (gravels) and water, measured in their right proportions. The size of the fine aggregate consisted of sand which is able to pass through a 5 mm *BS* sieve at the Geotechnical Laboratory, whereas the coarse aggregate was also graded using sieve complying to *BS* 410:2012, the methods of test being outlined in *BS* 812: part 1:2012. Fig. 3.1 shows the sectional view of the composite material.

Sample Preparation: Four different configurations of specimens were used (i.e. reinforced fresh bamboo, reinforced dried bamboo, fresh bamboo without reinforcement and dried bamboo without reinforcement). Fresh bamboos as received from the forest were free from insect infestation. They were then dried for two weeks at a temperature range of 30-33°C and cut into the needed heights such as 250 mm, 210 mm, 170 mm, 130 mm and 90 mm with a cross-cut saw (i.e. interval of 40 mm). The dried bamboo specimens were then polished with P 1200, P 600, P 400, P 240, P 180 Abrasive paper. These specimens were carefully cut such that, the node lies at the centre of the height. Another fresh bamboo were obtained and cut into the same division as the dried ones and also polished so as to be free of nicks, dents and scratches. The external and internal diameters "D_o and D_i" of the fresh and dried specimen were measured using a micrometer screw gauge and found to be between 82 to 86 mm and also between 72 to 74 mm respectively. The specimens were finally weighed on a scale as shown in Fig. 3.2. (a) and Fig.3.2. (b). Fresh bamboo specimen were also dried in the sun at a temperature between 30-33°C for two weeks. After which the diameter and the thickness of the fresh and dried specimens were measured with a vernier caliper. The bamboo samples were then filled with concrete paste of ratio 1:3:6 and allowed for a week to cure. The maximum

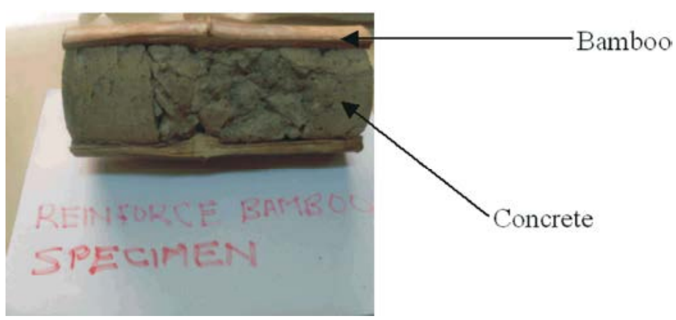

Fig. 3.1: Sectional View of the Composite Material (i.e. Reinforced Bamboo Specimen)

Fig. 3.2: (a) Fresh Reinforced Bamboo on a Scale (b) Dried Reinforced Bamboo on a Scale

Fig. 3.3: (c) Dried Bamboo Specimen without reinforcement

(d) Fresh Bamboo Specimen without reinforcement

Fig. 3.4: (a) Reinforced Fresh Bamboo Under Compressive Test

Fig. 3.4: (b) Reinforced Dried Bamboo Under Compressive Test

Fig. 3.4: (c) Dried Non-Reinforcement Bamboo Under Compressive Test

Fig. 3.4: (d) Fresh Non-Reinforcement Bamboo Under Compressive Test

height of the specimens was 250 mm but was stepped down by 40 mm interval hence obtaining heights of 210 mm, 170 mm, 130 mm and 90 mm.

Unidirectional Compressive Test: This test was carried out using the equipment known as the Uniaxial Compression Machine at room temperature. The experiment involves placing the specimens on the lower platen of the compressive testing machine with maximum loading capacity of 1500 KN and crushing them till it fails.

The dried bamboo and the fresh bamboo specimens were weighed in order to take their initial weight as mass of dried bamboo (W_D) and mass of fresh bamboo (W_F) respectively before filling the inside with concrete. This is necessary to help in the determination of the moisture content of the specimens. The reinforced bamboos were weighed to know (W_1) as weight of reinforced fresh bamboo and (W_2) as weight of reinforced dried bamboo. Fig. 3.4 shows bamboo samples under crushing strength test.

RESULTS AND DISCUSSION

Experimental results are shown in Table 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9 and 2.0. Five specimens of the same height were crushed; average loads of failure of specimen were calculated. For instance, for a height of 250 mm, five specimens of height 250 mm were crushed and average loads of failure were calculated. A similar procedure was followed for the heights of specimen of 210,170, 130 and 90 mm for fresh and dried bamboo specimens, as well as reinforced fresh and dried specimens. From table 1.5 and 1.6, it could be seen that loads of failure decrease with decrease in the height. This is due to the fact that the concrete gave additional strength to the bamboo. Hence, one of the ways to improve the crushing strength of bamboo is to reinforce it with concrete. From table 1.5, it could be seen that the strength increases as the height increases. The strength of the reinforced dried bamboo is higher than that of the reinforced fresh bamboo at the same height and loading. This may be due to the fact that there is high moisture content in the reinforced fresh bamboo than the reinforced dried specimen. From table 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9 and 2.0 it is clear that the average failure stresses also increases with increases in height for all cases for the specimens. Comparatively, the dried reinforced bamboo exhibits higher failure load than the rest of the bamboo structures. It signifies a better structural strength than the rest of the structures. Hierarchically, the dried reinforced bamboo proves to have the highest strength beyond the transition point A (Fig. 3.7) followed by reinforced fresh, then fresh non-reinforced and lastly dried non-reinforced. All the samples show some kind of elastic behavior. Conclusively, the reinforced fresh bamboo exhibits a good elastic behavior to the transition point *A*, then decrease in strength. Apparently, the dried reinforced bamboo can withstand higher failure load than the rest of the bamboo structures. The failure stress of the bamboo is about say 1.5M, 1.9 M, 2.2 M and 3.3 M times the weight of the bamboo per square meter for reinforced fresh, reinforced dried, fresh non-reinforced and dried non-reinforced respectively (See table 1.7, 1.9, 1.8, 2.0 and Fig. 3.5).

Table. 1.1 Detailed Results of Crushing Strength of Fresh Non-Reinforcement Bamboo

Specimen Type	Height (mm)	External Diameter D_o (mm)	Internal Diameter Di (mm)	Area (mm^2)	Load of Failure (KN)	Crushing Stress (MPa)	Thickness T(mm)	Mass (g)	Mass at 110°C	MC %
FRESH	250.0	60.0	40.0	1570.7963	58.3	37.1149	10.0	504.0	404	24.75
FRESH	250.0	55.0	43.0	923.6282	62.2	67.3431	6.0	430.0	330	30.30
FRESH	250.0	46.0	30.0	955.0442	70.0	73.2950	8.0	281.3	181.3	55.16
FRESH	250.0	58.0	44.0	1121.5486	59.5	53.0516	7.0	429.1	329.1	30.39
FRESH	250.0	56.0	36.0	1445.1326	37.2	25.7416	10.0	350.0	250.0	40.00
Average	250.0	55.0	39.0	1203.2299	57.4	51.3093	8.2	398.9	298.9	36.12
FRESH	210.0	45.0	31.0	835.6636	74.6	89.2704	7.0	286.9	186.9	53.50
FRESH	210.0	49.0	29.0	1225.2211	51.8	42.2781	10.0	359.0	259.0	38.61
FRESH	210.0	56.0	44.0	942.4778	64.5	68.4791	6.0	280.0	180	55.56
FRESH	210.0	58.0	42.0	1256.6371	83.0	66.0493	8.0	372.0	272	36.76
FRESH	210.0	54.0	44.0	769.6902	69.0	89.6465	5.0	411.0	311	32.15
Average	210.0	52.4	38.4	1005.938	68.6	71.1447	7.2	341.78	241.78	43.32
FRESH	170.0	60.0	40.0	1570.7963	74.2	28.9662	10.0	291.0	191	52.35
FRESH	170.0	42.0	30.0	678.5840	66.5	97.9982	6.0	365.0	265	37.74
FRESH	170.0	46.0	32.0	857.6548	69.8	75.5549	7.0	260.0	160	62.5
FRESH	170.0	53.6	35.6	1261.0353	73.8	58.5233	9.0	269.0	169	59.17
FRESH	170.0	40.0	26.0	725.7079	81.2	111.8907	7.0	302.0	202	49.50
Average	170.0	48.3	32.7	1018.8	73.1	74.5867	7.8	297.4	197.4	52.25
FRESH	130.0	45.0	29.0	929.9114	76.0	81.7282	8.0	349.0	249	40.16
FRESH	130.0	49.0	37.0	810.5309	73.7	90.9281	6.0	327.0	227	44.05
FRESH	130.0	50.0	30.0	1256.6371	80.5	64.0599	10.0	408.0	308	32.47
FRESH	130.0	40.0	26.0	725.7079	69.5	95.7686	7.0	360.0	260	38.46
FRESH	130.0	56.0	38.0	1328.8937	87.0	65.4680	9.0	278.0	178	56.18
Average	130.0	48	32.0	1010.3362	77.3	79.5905	8	344.4	244.4	42.26
FRESH	90.0	60.0	42.0	1441.9910	64.7	44.8685	9.0	223.0	123	81.30
FRESH	90.0	43.0	27.0	879.6459	77.5	88.1036	6.0	259.0	159	62.89
FRESH	90.0	46.0	30.0	955.0442	83.6	87.5352	7.0	115.1	115.1	86.805
FRESH	90.0	40.0	24.0	804.2477	79.6	98.9745	8.0	333.0	233	42.91
FRESH	90.0	42.0	28.0	769.6902	82.0	106.5364	7.0	358.0	258	38.76
Average	90.0	46.2	30.2	970.1238	77.48	85.2036	7.4	257.6	157.6	62.53

Table 1.2: Detailed Results of Crushing Strength of Dried Non-Reinforcement Bamboo

Specimen Type	Height (mm)	External Diameter D_o (mm)	Internal Diameter Di (mm)	Area (mm^2)	Load of Failure (KN)	Crushing Stress (MPa)	Thickness T(mm)	Mass (g)	Mass at 110°C	MC %
DRIED	250.0	43.0	27.0	879.6459	32.8	37.2877	8.0	362.0	347	4.32
DRIED	250.0	55.0	35.0	1413.7167	60.3	42.6535	10.0	212.0	202	4.95
DRIED	250.0	47.0	35.0	772.8318	36.5	47.2289	6.0	245.0	235	4.69
DRIED	250.0	50.0	32.0	1159.2477	48.2	41.5787	9.0	301.0	286	5.24
DRIED	250.0	58.0	44.0	1121.5486	47.3	42.1738	7.0	260.0	247	5.26
Average	250.0	50.6	34.6	1069.3981	45.02	42.1845	8	276	263.4	4.89
DRIED	210.0	45.0	29.0	929.9114	65.2	70.1142	8.0	199.0	186.9	6.42
DRIED	210.0	60.0	40.0	1570.7963	74.6	47.4918	10.0	211.0	200.0	5.50
DRIED	210.0	57.0	45.0	961.3274	48.5	50.4511	6.0	217.0	204.0	6.37
DRIED	210.0	55.0	45.0	785.3982	53.0	67.4817	5.0	150.0	140.0	7.14
DRIED	210.0	49.0	35.0	923.6282	66.0	71.4573	7.0	280.0	265.0	5.66
Average	210.0	53.2	38.8	1034.2123	61.46	61.3992	7.2	213.6	199.18	6.22
DRIED	170.0	60.0	40.0	1570.7963	51.9	33.0406	10.0	175.0	163	7.36
DRIED	170.0	57.0	39.0	1357.1680	42.5	31.3152	9.0	138.0	130.0	6.15
DRIED	170.0	58.0	42.0	1256.6371	76.5	60.8768	8.0	144.8	136.0	6.62
DRIED	170.0	52.0	40.0	867.0796	80.0	92.2637	6.0	248.0	233.0	6.44
DRIED	170.0	42.0	28.0	769.6902	88.1	114.4616	7.0	169.0	158.0	6.96
Average	170.0	53.8	37.8	1164.274	67.8	66.3916	8	174.96	164	6.71
DRIED	130.0	50.0	34.0	1055.5751	52.7	49.9254	8.0	146.0	136.0	7.35
DRIED	130.0	56.0	36.0	1445.1326	75.0	51.8984	10.0	162.0	152.0	6.58
DRIED	130.0	40.0	28.0	640.8849	56.0	87.3792	6.0	182.0	170.0	7.06
DRIED	130.0	60.0	42.0	1441.9910	70.5	48.8907	9.0	190.0	175	8.57
DRIED	130.0	43.0	29.0	791.6813	80.0	101.0508	7.0	171.0	161.0	6.21
Average	130.0	49.8	33.8	1075.053	66.84	67.8289	8	170.2	158.8	7.15
DRIED	90.0	55.0	43.0	923.6282	49.9	54.0261	6.0	195.0	180	8.33
DRIED	90.0	50.0	40.0	706.8583	63.0	89.1268	10.0	123.0	113.0	8.84
DRIED	90.0	58.0	42.0	1256.6371	68.0	54.1127	8.0	145.0	133	9.02
DRIED	90.0	45.0	35.0	628.3185	59.8	95.1747	5.0	217.5	200.0	8.50
DRIED	90.0	48.0	34.0	901.6371	73.2	81.1857	7.0	169.0	159.0	6.23
Average	90.0	51.2	38.8	883.41584	62.78	74.7252	7.2	169.9	157	8.18

Table 1.3: Detailed Results of Crushing Strength of Reinforced Fresh Bamboo

Specimen Type	Length (mm)	External Diameter -D_o(mm)	Internal Diameter-D_i(mm)	Load of Failure (kN)	Mass of Bamboo(W_F) (g)	Mass of Reinforced Bamboo (W_1)(g)	Volume of the Reinforced Bamboo (m^3)	Density of Reinforced Bamboo (kg/m^3)
Fresh	250.0	86.00	74.00	84.00	516.90	2830.30	1.45×10^{-3}	1948.51
Fresh	250.0	86.00	74.00	83.00	521.54	2785.98	1.45×10^{-3}	1920.69
Fresh	250.0	86.00	74.00	85.00	512.65	2635.56	1.45×10^{-3}	1817.24
Fresh	250.0	86.00	74.00	82.00	519.40	2819.02	1.45×10^{-3}	1944.14
Fresh	250.0	86.00	74.00	84.00	514.29	2677.43	1.45×10^{-3}	1846.21
Average	250.0	86.00	74.00	83.60	516.96	2749.66	1.45×10^{-3}	1895.36
Fresh	210.0	85.00	73.00	80.00	420.60	2187.50	1.19×10^{-3}	1837.82
Fresh	210.0	85.00	73.00	82.00	432.07	2157.89	1.19×10^{-3}	1812.61
Fresh	210.0	85.00	73.00	79.00	418.67	2179.43	1.19×10^{-3}	1831.09
Fresh	210.0	85.00	73.00	80.00	422.60	2189.51	1.19×10^{-3}	1839.50
Fresh	210.0	85.00	73.00	81.00	415.89	2121.99	1.19×10^{-3}	1782.35
Average	210.0	85.00	74.00	80.40	421.97	2167.26	1.19×10^{-3}	1820.67
Fresh	170.0	84.00	72.00	76.00	366.6	1757.00	9.42×10^{-4}	1864.74
Fresh	170.0	84.00	72.00	77.00	371.3	1755.32	9.42×10^{-4}	1863.06
Fresh	170.0	84.00	72.00	72.00	362.7	1723.89	9.42×10^{-4}	1829.09
Fresh	170.0	84.00	72.00	75.00	364.9	1745.67	9.42×10^{-4}	1877.92
Fresh	170.0	84.00	72.00	79.00	357.2	1769.42	9.42×10^{-4}	1877.92
Average	170.0	84.00	72.00	75.80	364.54 9.42×10^{-4}	1750.26 1860.36		
Fresh	130.0	84.00	72.00	68.00	257.90	1314.60	7.21×10^{-4}	1823.67
Fresh	130.0	84.00	72.00	65.00	258.20	1344.21	7.21×10^{-4}	1864.10
Fresh	130.0	84.00	72.00	63.00	261.40	1320.32	7.21×10^{-4}	1830.80
Fresh	130.0	84.00	72.00	70.00	253.70	1322.45	7.21×10^{-4}	1833.60
Fresh	130.0	84.00	72.00	69.00	259.01	1312.43	7.21×10^{-4}	1819.70
Average	130.0	84.00	72.00	67.00	258.05	1322.80	7.21×10^{-4}	1834.37
Fresh	90.0	82.00	71.00	60.00	193.70	926.10	4.75×10^{-4}	1948.03
Fresh	90.0	82.00	71.00	64.00	194.60	932.14	4.75×10^{-4}	1962.11
Fresh	90.0	82.00	71.00	59.00	192.50	919.79	4.75×10^{-4}	1934.74
Fresh	90.0	82.00	71.00	64.00	190.90	937.12	4.75×10^{-4}	1972.63
Fresh	90.0	82.00	71.00	67.00	193.50	916.66	4.75×10^{-4}	1928.42
Average	90.0	82.00	71.00	62.80	193.04	926.36	4.75×10^{-4}	1949.19

Table 1.4: Detailed Results of Crushing Strength of Reinforced Dried Bamboo

Type of Specimen	Length (mm)	External Diameter D_o (mm)	Internal Diameter D_i (mm)	Load of Failure (kN)	Mass of only Bamboo(W_D) (g)	Mass of Reinforced Bamboo (W_2) (g)	Volume of the Reinforced Bamboo (m^3)	Density of Reinforced Bamboo (kg/m^3)
Dried	250.00	86.00	74.00	120.00	516.90	2526.10	1.45×10^{-3}	1742.14
Dried	250.00	86.00	74.00	125.00	529.80	2745.12	1.45×10^{-3}	1893.10
Dried	250.00	86.00	74.00	119.00	499.56	2269.76	1.45×10^{-3}	1564.83
Dried	250.00	86.00	74.00	115.00	510.45	2934.15	1.45×10^{-3}	2023.45
Dried	250.00	86.00	74.00	122.00	512.37	2623.97	1.45×10^{-3}	1808.97
AVERAGE	250.0	86.00	74.00	120.20	513.82	2619.82	1.45×10^{-3}	1806.50
Dried	210.00	85.00	74.00	86.00	405.90	2065.90	1.22×10^{-3}	1692.62
Dried	210.00	85.00	74.00	89.00	411.34	2089.23	1.22×10^{-3}	1712.30
Dried	210.00	85.00	74.00	88.00	399.68	1978.92	1.22×10^{-3}	1621.31
Dried	210.00	84.00	74.00	85.00	407.32	2095.42	1.22×10^{-3}	1717.21
Dried	210.00	85.00	74.00	79.00	402.12	2100.01	1.22×10^{-3}	1721.31
AVERAGE	210.00	84.80	74.00	85.40	405.27	2065.89	1.22×10^{-3}	1692.95
Dried	170.00	84.00	72.00	78.00	327.50	1668.00	9.88×10^{-4}	1688.26
Dried	170.00	84.00	72.00	75.00	332.12	1678.34	9.88×10^{-4}	1698.38
Dried	170.00	84.00	72.00	82.00	309.45	1693.12	9.88×10^{-4}	1713.56
Dried	170.00	84.00	72.00	80.00	325.91	1599.67	9.88×10^{-4}	1618.42
Dried	170.00	84.00	72.00	79.00	329.45	1652.45	9.88×10^{-4}	1672.06
AVERAGE	170.00	84.00	72.00	78.80	324.88	1658.32	9.88×10^{-4}	1678.14
Dried	130.00	83.00	72.00	74.00	229.90	1208.60	7.55×10^{-4}	1599.64
Dried	130.00	84.00	72.00	76.00	249.45	1103.68	7.55×10^{-4}	1460.93
Dried	130.00	83.00	72.00	75.00	234.67	1329.45	7.55×10^{-4}	1760.26
Dried	130.00	84.00	72.00	69.00	227.90	1256.65	7.55×10^{-4}	1663.58
Dried	130.00	83.00	72.00	77.00	238.10	1277.34	7.55×10^{-4}	1691.40
AVERAGE	130.00	83.40	72.00	74.20	236.04	1234.54	7.55×10^{-4}	1635.16
Dried	90.00	84.00	72.00	70.00	185.60	840.60	5.23×10^{-4}	1606.70
Dried	90.00	81.00	72.00	69.00	189.34	880.23	5.23×10^{-4}	1682.60
Dried	90.00	82.00	72.00	72.00	182.85	826.47	5.23×10^{-4}	1579.35
Dried	90.00	84.00	72.00	71.00	190.45	869.00	5.23×10^{-4}	1661.57
Dried	90.00	81.00	72.00	73.00	180.42	831.82	5.23×10^{-4}	1588.91
AVERAGE	90.00	82.40	72.00	71.00	185.73	849.62	5.23×10^{-4}	1623.83

Table 1.5: Results of Reinforced Dried Bamboo

Height of Fresh Bamboo (mm)	External Diameter (mm)	Internal Diameter (mm)	Mass of Only Bamboo (g)	Mass of Reinforced Bamboo (W_1)(g)	Mass of Only Concrete (g)	Average Load of Failure (kN)	Time of Failure (Seconds)
250.00	86.00	74.00	516.96	2830.30	2313.34	83.60	57:62
210.00	85.00	74.00	421.97	2187.50	1765.53	80.40	48:92
170.00	84.00	72.00	364.54	1757.20	1392.66	75.80	39:77
130.00	84.00	72.00	258.05	1314.60	1056.55	67.00	35:02
90.00	81.00	71.00	193.04	926.10	733.06	62.80	29:71

Table 1.6: Results of Reinforced Fresh Bamboo

Height Of Dried Bamboo (mm)	External Diameter (mm)	Internal Diameter (mm)	Mass of Only Bamboo (W_D)	Mass of Reinforced Bamboo (W_2)(g)	Mass of Only Concrete (g)	Average Load of Failure (kN)	Time of Failure (Seconds)
250.00	86.00	74.00	513.82	2619.82	2018.80	120.20	60:62
210.00	84.80	74.00	405.27	2065.89	1660.00	85.40	56:42
170.00	84.00	72.00	324.88	1658.32	1340.50	78.80	47:15
130.00	84.00	72.00	236.04	1234.54	978.70	74.20	42:38
90.00	82.40	72.00	185.73	849.62	655.00	71.00	39:55

Table 1.7: Summaries for Reinforced Fresh Bamboo

Height (mm)	External Diameter (mm)	Internal Diameter (mm)	Area of Bamboo (A_B) (mm^2)	Average Load of Failure (kN)	Mass (g)	Average Failure Stress (MPa)	Failure Stress To Weight Ratio ($1/m^2$)	Load To Height Ratio (KN/m)	Specific Compressive Strength (KN•m/kg)	strength to volume ratio (MPa/m^3)
250.00	55	39	1203.2299	57.4	398.9	47.70	1.220 M	229.60	35.97	158589.58
210.00	52.4	38.4	1005.938	68.6	341.78	68.20	2.036 M	326.67	42.15	322821.46
170.00	48.3	32.7	1018.8	73.1	297.4	71.75	2.462 M	430.00	41.79	414276.77
130.00	48	32	1010.3362	77.3	344.4	76.51	2.267 M	594.62	29.18	582511.25
90.00	46.2	30.2	970.1238	77.48	257.6	79.87	3.164 M	860.89	27.07	914729.71

Table 1.8: Summaries for Fresh Non-Reinforcement Bamboo

Height (mm)	External Diameter (mm)	Internal Diameter (mm)	Area of Concrete (Ac) (mm2)	Area of Bamboo (AB)(mm2)	Average Load of Failure(kN)	Average Failure Stress (MPa)	Time of Failure (Seconds)	Failure Stress To Weight Ratio(1/m2)	Load To Height Ratio (KN/m)	Specific Compressive Strength (KN·m/kg)	strength to volume ratio (MPa/m3)
250.00	86.00	74.00	4300.84	1507.96	83.60	26.09	57.62	0.97 M	334.40	13.717	17993.10
210.00	85.00	74.00	4300.84	1373.66	80.40	25.52	48.92	1.20 M	382.86	13.602	21445.38
170.00	84.00	72.00	4071.50	1470.27	75.80	24.85	39.77	1.45 M	445.90	13.342	26380.04
130.00	84.00	72.00	4071.50	1470.27	67.00	21.97	35.02	1.70 M	515.38	11.977	30471.57
90.00	82.00	71.00	3959.19	1193.81	62.80	21.86	29.71	2.40 M	688.89	11.215	46021.05

Table 1.9 Summaries for Reinforced Dried Bamboo

Height (mm)	External Diameter (mm)	Internal Diameter (mm)	Area of Bamboo (mm2)	Area of concrete (mm2)	Average Load of Failure (kN)	Average Failure Stress (MPa)	Time of Failure (Seconds)	Failure Stress To Weight Ratio (1/m2)	Load To Height Ratio (KN/m)	Specific Compressive Strength (KN·m/kg)	Strength to volume ratio(Pa/m3)
250.00	86.00	74.00	1507.96	4300.84	120.20	37.52	60.62	1.46 M	400.00	20.769	25875.86
210.00	84.80	74.00	1240.93	4300.84	85.40	27.56	56.42	1.36 M	406.67	16.279	22590.16
170.00	84.00	72.00	1470.27	4071.50	78.80	25.84	47.15	1.59 M	463.53	15.397	26153.85
130.00	84.00	72.00	1470.27	4071.50	74.20	24.33	42.38	2.02 M	570.77	14.879	32225.17
90.00	82.40	72.00	1261.16	4071.50	71.00	23.93	39.55	2.87 M	788.89	14.736	45755.26

Table 2.0: Summaries for Dried Non-Reinforcement Bamboo

Height (mm)	External Diameter (mm)	Internal Diameter(mm)	Area of Bamboo (AB)(mm2)	Average Load of Failure (kN)	Mass (g)	Average Failure Stress (MPa)	Failure Stress To Weight Ratio(1/m2)	LoadToHeight Ratio(KN/m)	Specific Compressive Strength(KN·m/kg)	Strength to volume ratio(MPa/m3)
250.00	50.6	34.6	1069.3981	45.02	276	42.10	1.556 M	180.08	40.78	157465.95
210.00	53.2	38.8	1034.2123	61.46	213.6	59.43	2.839 M	292.67	60.42	273623.80
170.00	53.8	37.8	1164.274	67.8	174.96	58.23	3.396 M	398.82	65.88	294218.77
130.00	49.8	33.8	1075.053	66.84	170.2	62.17	3.728 M	514.15	51.05	444870.22
90.00	51.2	38.8	883.41584	74.7252	169.9	84.59	5.080 M	830.28	39.58	1063883.84

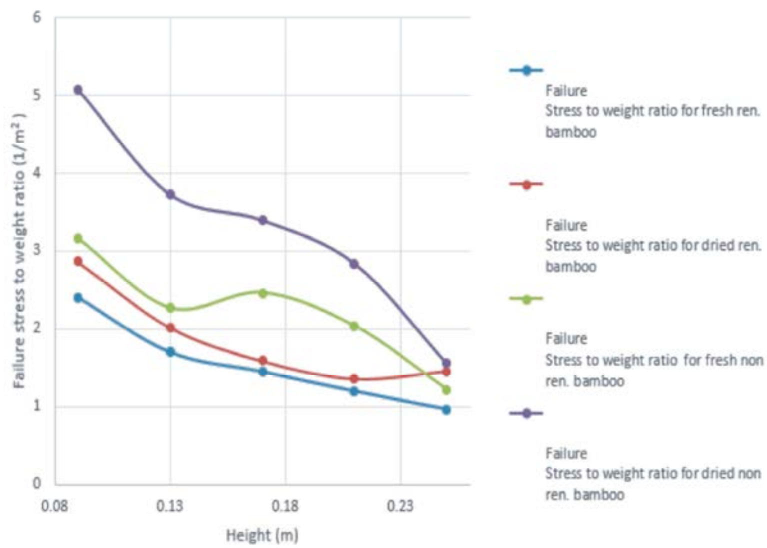

Fig. 3.5: Failure Stress to Weight Ratio VS Height

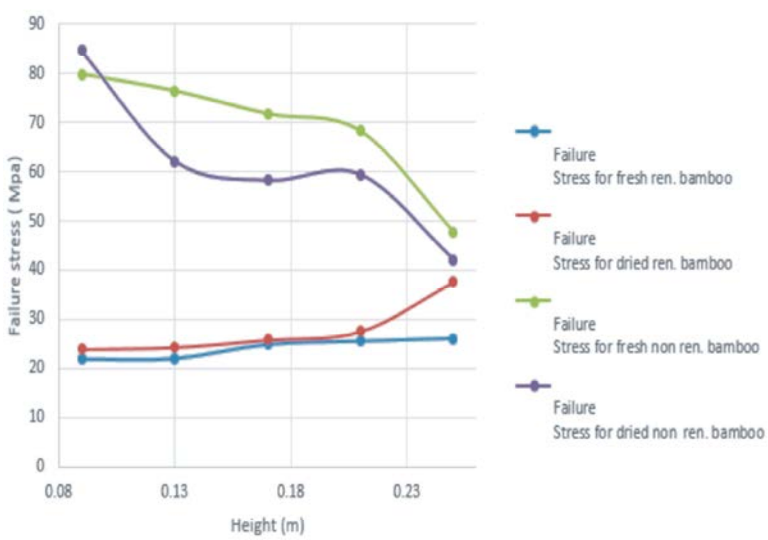

Fig. 3.6: Failure Stress VS Height

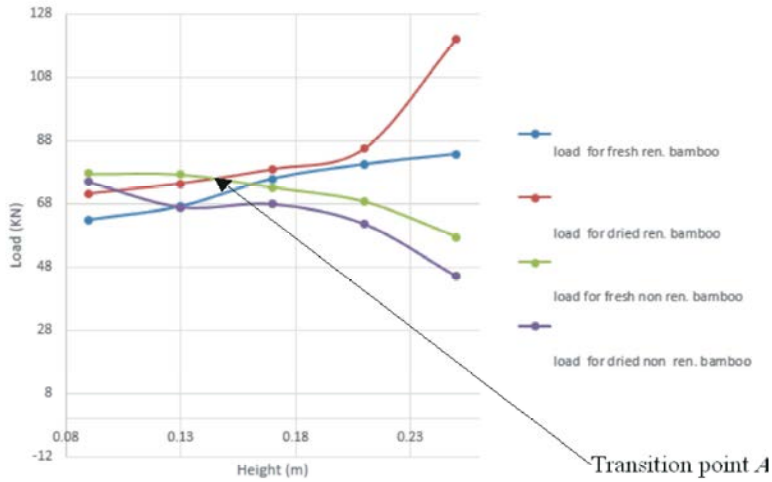

Fig. 3.7: Failure Load VS Height

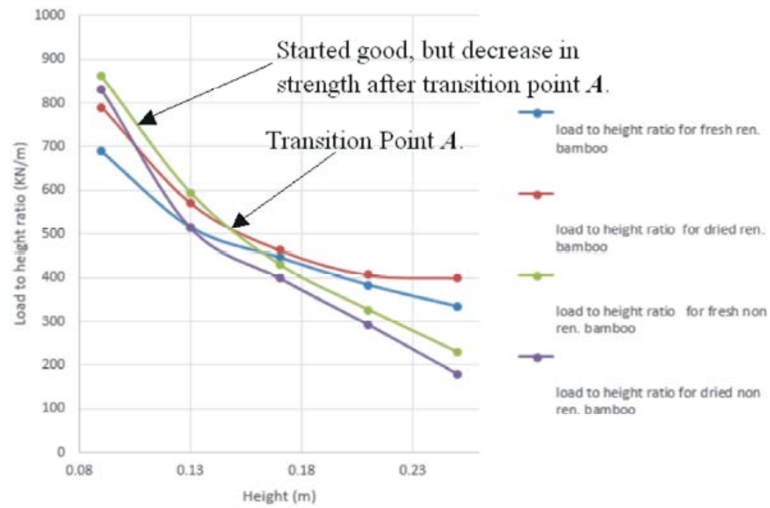

Fig. 3.8: Load to Height Ratio VS Height

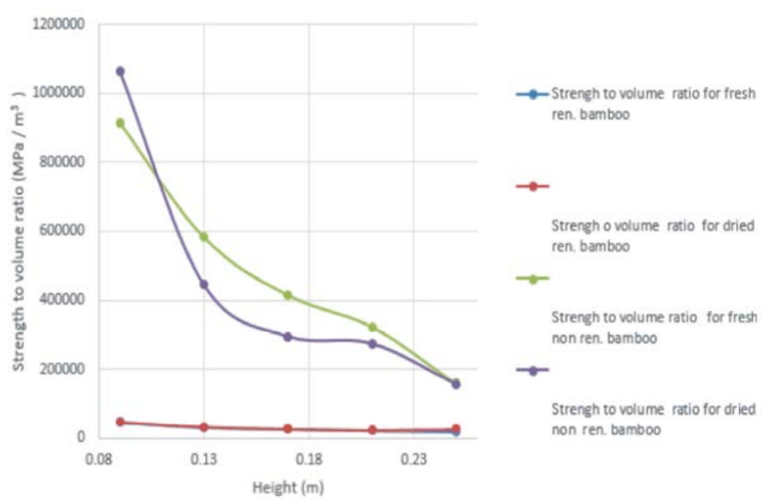

Fig. 3.9: Strength to Volume Ratio VS Height

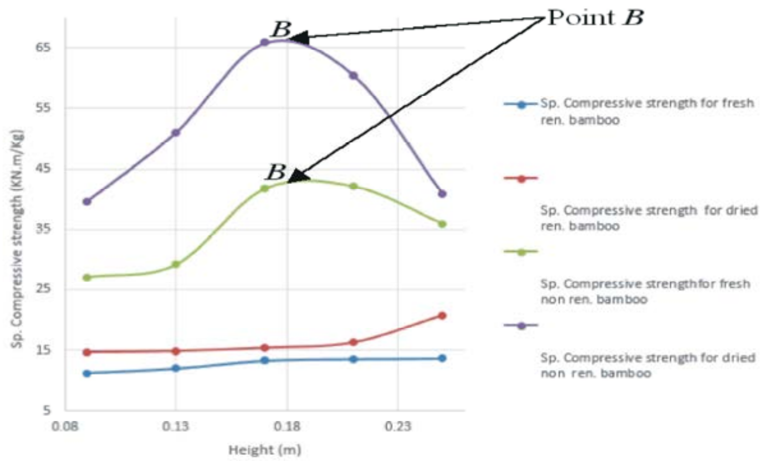

Fig. 4.0: Specific Compressive Strength VS Height

From Fig. 3.5, failure stress to weight ratio verses height also decreases with increases with height for all cases of the bamboo. But, the reinforced dried bamboo showed an intrinsic strength as compared to the rest. At a height of 250 mm the average load of failure for reinforced dried bamboo is 120.20 KN whiles at the same height the average load of failure for reinforced fresh bamboo is 83.60 KN. Hence it is clear that a dried reinforced bamboo is stronger than a fresh reinforced bamboo. Again the percentage difference of the average load of failure between the dried and fresh reinforced bamboo of the same length increases as the length increase and vice versa. From, Fig. 3.6, failure stress verses height also proves that the reinforced dried bamboo had it failure stress increases with increases in height. The rest of the samples had a decreased in strength with increases in height. From Fig. 3.9, strength to volume ratio verses height which explains the pressure exerted on the bamboo samples per cubic meter attracted an increased with increased in height whiles the non-reinforced fresh and non-reinforced dried showed a decreased with increased in height. From Fig. 4.0., specific compressive strength verse height which explains the bending moment per kilogram of the bamboo reveals that the reinforced dried bamboo has a tentative increased in specific compressive strength than the rest. The specific compressive strength of both non-reinforced fresh and dried has an appreciable increased in specific compressive strength up to point say *B* and then it decreased with increased with height (See Fig. 4.0). That shows plastic behavior for both non-reinforced fresh and dried. This experiment was performed to appreciate the deformation behaviour of bamboo after being crushed. The results from this experiment shows that bamboo some of the bamboo samples have good elastic behavior, whiles others have good strength. It is very important since it will enable us to have a complete picture of the mechanical behaviour of bamboo. A thorough understanding of the behaviour is essential for the safe design of structures in which a composite material of concrete and bamboo is involved and better still enhance the inclusion of bamboo as a major component in the design of structures and buildings.

CONCLUSIONS

The following conclusions were arrived at after the crushing tests experiment,

- The strength increases as the height increases for all structures analysed.
- The dried reinforced bamboo proves to have the highest intrinsic strength beyond the transition point.
- Failure stress to weight ratio also decreases with increases with height for all cases of the structures.
- The specific compressive strength of both non-reinforced fresh and dried has an appreciable increased up to transition point and then it decreased with increased with height.
- Failure stress proves that the reinforced dried bamboo had it failure stress increases with increases in height. The rest of the samples had a decreased in strength with increased in height.
- The reinforced fresh bamboo exhibits higher elastic behavior to the transition point.
- The dried reinforced bamboo can withstand higher compressive load than the rest of the bamboo structures.

- Comparatively, reinforced dried bamboo is stronger than fresh reinforced bamboo at transition point.

Recommendations: It is recommended that:

- More construction companies worldwide should be encouraged to use bamboo as an alternative to timber for structural purposes in order to reduce the depletion of our forest reserve.
- Reinforced dried bamboo is stronger beyond the transition point; it is therefore recommended for scaffolding in the construction industry.
- One of the ways to improve the crushing strength of bamboo is to reinforce it with concrete.
- The chemical effect of the concrete on bamboo can be carried out as further work.

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