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Evaluation of Mechanical Properties of Different Bamboo Species for Structural Applications

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***Abstract**: The aim of this research was to investigate fundamental mechanical properties of different bamboo types which are relevant to construction work .Four bamboo species imported from IHBT Palampur were tested namely Dendrocalumus Hamiltonii, Bambusa Nutans, Bambusa Tulda, Bambusa Balcoa. These species were subjected to three point bending test, tensile test parallel to grain, compression test parallel to axis of culm, shear test parallel to fibre. The results showed that Bambusa Nutans possess excellent mechanical properties in compression and tensile strength, which indicates it can be used as construction material. Most of the bamboo species are hollow but this study takes into account a bamboo which is nearly solid named as Bambusa tulda.The research revealed out that solid bamboo is not too far from hollow one in terms of mechanical properties and can equally be utilized for construction work.*

***Keywords**: Bamboo fiber, Bamboo species, Indian Bamboo, Mechanical properties, UTM*

I. INTRODUCTION

Bamboo is a type of grass which is mostly found in the tropical, subtropical and temperate zones around the world. India comes at second place after China in terms of production of bamboo. Bamboo has been used as fertilizer, food, cosmetic, crafts, medicine, paper and clothing. Bamboo can play a vital role in the construction industry because of quick growth ,renewable and biodegradable, including capability to sequester carbon ,however, it is primarily limited to rural building, owing to lack of building codes. Lack of research regarding bamboo's mechanical properties is known to be one of the variables connected with low bamboo use in construction. Therefore this study is conducted.

In this study four bamboo types available in IHBT Palampur which are suitable for structural applications were recognized and subjected to common mechanical properties such as Bending Strength, Compression Parallel to Culm's axis, Shear Strength Parallel to fibre, Tensile strength parallel to grain. These four species of bamboo include Dendrocalumus Hamiltonii, Bambusa Nutans, Bambusa Tulda, Bambusa Balcoa.

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II. OBJECTIVES

The primary goal of this research is to compare the mechanical properties of the distinct species of bamboo. Specifically, the objective was to determine (a) the compression strength parallel to axis of culm (b) the tension strength parallel to the grain (c) the bending strength using the modified three-point load test of the bamboo (d) the shear strength parallel to the fiber. Tests have been performed for the middle portion of the bamboo species.

III. METHODOLOGY

Mechanical Properties of different bamboo species are evaluated in accordance with Standard IS 6874. The tests conducted involves a) Compression test b) Tension test c) Bending test d) Shear test under the universal testing machine (UTM) Model-UTE 40 having a maximum capacity of 400KN available at NITTTR Chandigarh Sec-26.

A. Compression Test Parallel to Grain

The maximum compressive strength of bamboo is evaluated by testing the bamboo culms in universal testing machine.

A (1) Preparation of specimen for compression test

Specimens for the compression test were drawn from undamaged samples collected in static bending experiments. Test samples have been taken from the internodes. The sample specimens cannot comprise a node because the findings of these specimens would not yield precise outcomes as the nodes are the toughest part in a bamboo plant. Test samples are therefore drawn from the segment between two branches (internodes), as this is the weakest component of a bamboo stick. They were sliced with the help of the hacksaw after holding the lengthy bamboo culms in the bench vice. The length of the sample taken was equivalent to the outer diameter as shown in Fig.1.

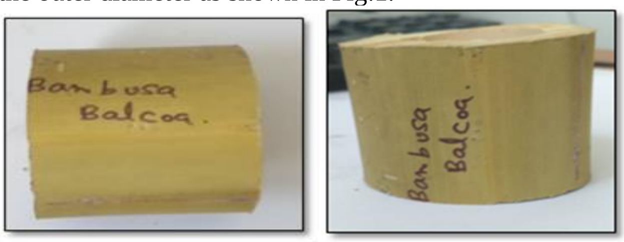

Fig.1. Test specimen for compression test

A (2) Compression test set-up

The test sample was placed between the top and bottom plate of the Universal Testing Machine and compression load is implemented gradually until crack is detected either in the form of cracking or deformation at the contact surface. The compression test set-up is shown in fig.2.

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Failure of the bamboo specimen in compression test generally occur either as the deformation of the surface having contact with plates or in the form of cracking. Splitting of the bamboo specimen is rarely seen during loading. The typical appearance of the specimen at failure can be seen in fig.3.

Fig.2 Compression Test Set-up

Fig.3 Failure of bamboo specimens under compression test

B. Tensile Strength Parallel to Grain

The maximum tensile strength of bamboo is evaluated by testing the bamboo specimen made after shaping the bamboo culm in particular form. Specimens for tensile strength tests have been drawn from the undamaged section of samples used in bending tests. The test method followed for Bamboo was the same as for steel. The dimensions of the bamboo specimen were evaluated with the assistance of the Vernier calliper and fed into the UTM software so that the built-in software calculator can generate the test outcomes.

B (1) Preparation of specimen for tensile testing

First, the bamboo was split into two parts lengthwise, with the aid of hammer, chisel, and hacksaw as shown in the fig (4). The inner shape of the bamboo can be readily seen after this procedure. Each of the two halves is further furnished in order to achieve the rectangular cross-section of the samples with the same set of instruments used in the first step.
Further markings have been made on the specimen so that all specimens have equal dimensions in order to carry out a comparative study with the same set of parameters. Then, with the help of a bench grinder, it was rounded to the shape of a dumbbell as shown in Fig.6.

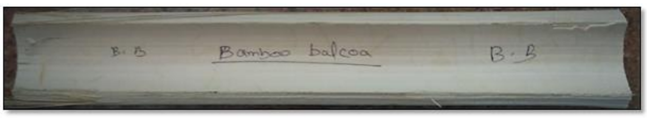

Fig.4 Bamboo piece after splitting

Fig.5 Bamboo piece having rectangular cross -section

Fig.6 Bamboo specimen after grinding

B (2) Gripping of bamboo specimen for tensile testing

A significant factor in the tensile test is proper gripping. Bamboo is a comparatively smooth material compared to those used in UTM for the purpose of gripping. Early failure at the gripping end was noticed at the moment of tension trials as shown in Fig.7, probably owing to elevated lateral compression stress.

Fig .7 Failure observed at gripping end

In addition, the bamboo specimen's surface is very slippery and therefore the samples encountered slip during the tensio n test in some cases.Copper wire was spirally wrung at both ends of the sample to fix this gripping issue. Fig .6 shows th e implementation of the copper spiral around the edges of th e bamboo sample.

Fig.8 Copper wire spiraled around bamboo tensile test specimen to avoid crushing

But even after the bamboo samples were wrapped with copp er wire, there was still the sliding issue, although bamboo sa mples were not getting damaged due to lateral compression f orces.Thus, in order to prevent slipping, the m-seal is pasted over the copper wire spiraled onto the Bamboo sample as sh own in Fig.9

Fig.9 Test specimen

B (3) Tensile Test set-up

Universal testing machine is used for tensile test. The grip of the test device shall ensure that the load is positioned along the longitudinal axis of the experiment unit and must counter the longitudinal twisting of the sample article. Fig.10 shows the specimen under the tension test.

Fig.10 Tensile test setup

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Fig.11 Failure in tensile specimen

C. Shear Strength Test Parallel to Grain.

Maximum shear stress for bamboo is a significant variable in the design of suitable joinery structures and ties. Shear stress can happen in two directions, parallel to grain and perpendicular to grain. Test for shear strength Parallel to Grain was performed employing the specifications of IS 6874. As shown in Fig, a tetra-shear device was manufactured. The specimen was set up in the device to predetermine the shear failure .The upper face of the specimen was loaded and simply supported at lower end. This results in four shear areas

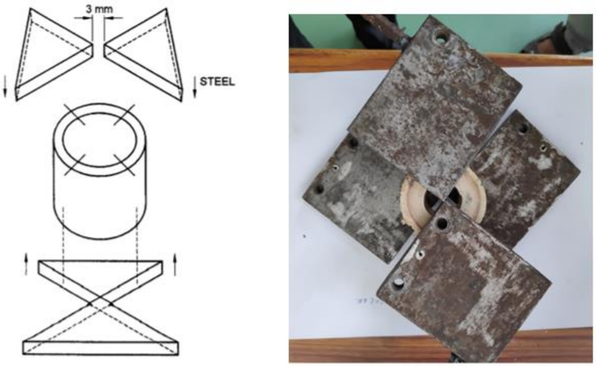

Fig.12 Tetra Shear apparatus

C (1) Test specimen for shear testing

Samples for the shear strength experiments shall be taken fr om the undamaged sections of the samples used in the bendi ng tests. The sample tested are from the internode. The sample length shall be equal to the sample's outer diameter. The end planes shall be flat must make right angle to the length of specimen. Before experimentation, each sample is thoroughly evaluated. The height of the test piece and the density of the culm are evaluated in the 4 areas where shear occurs. This is essential because the density of a bamboo culm is not uniform and the sample cross-cutting may not be performed completely.

As shown in the fig.13, the specimen shall be positioned between steel triangular blocks such that the centre of the moving head is vertically above the centre of the specimen's cross-section. A slight force not surpassing 1 KN have been applied to the position the sample. The peak load at which the sample fails is are observed. Failure of the bamboo specimen in shear test generally occur in the form of splitting of bamboo in two halves. Bamboo specimen at failure after shear test will look like as shown in fig.14

Fig.13 Shear Test setup

Fig.14 Failure in shear specimen

D. Static Bending Strength test

Structural behaviour has been deeply influenced by bending strength, it is essential to estimate the deflection of each component of a framework before it is constructed. The three-point bending experiment is the most frequently used technique to determine the deflection of a beam or column.

Test samples, free from faults such as fracture and cracks, were drawn from straight, non-tapered culms.

To obtain superior outcomes, the experiment sample must b e safe from taper. An appropriate testing machine was used to measure load to the closest 100 N and deflection to the closest 1 mm. A modified three-point load set-up was employed as shown in fig.15

Fig.15 Test setup for bending test

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IV. RESULTS AND DISCUSSIONS

A. Compression test results

Mechanical properties of the different bamboo species were calculated according to IS 6874 standards. The bamboo's compressive strength is taken as the load when the bamboo culm collapses divided by the bamboo culm's average area. The compression test is performed for two specimens of each bamboo type. The average of the two tests is taken as the average compressive strength.

Calculation:

The maximum compressive strength σ_{ult} in N/mm^2 is calculated as follows:

$$\sigma_{ult} = \frac{F}{A} \qquad (1)$$

Where

F_{ult} = Maximum force (N)

A=Cross-sectional area = $\frac{\Pi}{4}[(O.D)^2 - (I.D)^2]$ in mm^2

O.D. = Outer diameter (mm)

I.D. = Inner diameter (mm)

Table- I: Compression test results

Bamboo type	Test 1					Test 2					Average
	Comp. Strength (in MPa)	Max. force in (KN)	Input data(in mm)			Comp. strength (in MPa)	Max. force in (KN)	Input data(in mm)			Comp. strength (in MPa)
			O.D	I.D	Gauge length			O.D	I.D	Gauge length	
Dendrocalamus Hamiltonii	59.13	68.84	58	41.7	52.66	53.70	68.40	55.28	37.88	54.7	56.4175
Bambusa Tulda	50.729	102.14	51.6	10	51.88	81.95	135.80	47	10	53.72	66.3405
Bambusa Nutans	118.036	135.58	47.7	28.52	49.28	78.45	111.50	48.20	22.68	52.02	98.244
Bambusa Balcoa	41.217	64.78	53.12	28.66	53.38	68.17	93.98	51.78	30.44	48.36	54.694

Table- II: Graph for load vs. displacement in the Compression test

S No.	Bamboo type	Graph for Load vs. Displacement	
		Test 1	Test 2

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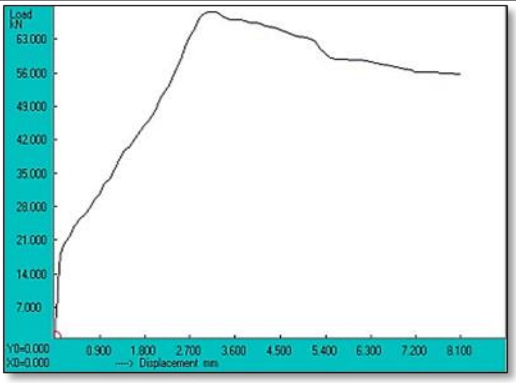
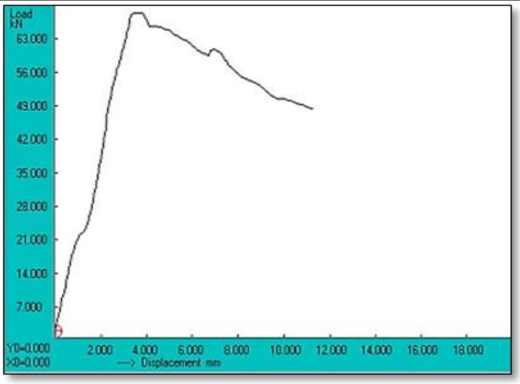
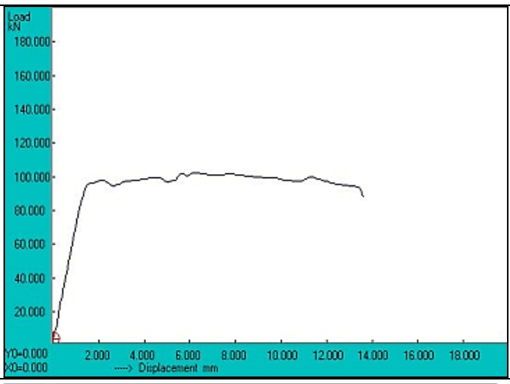
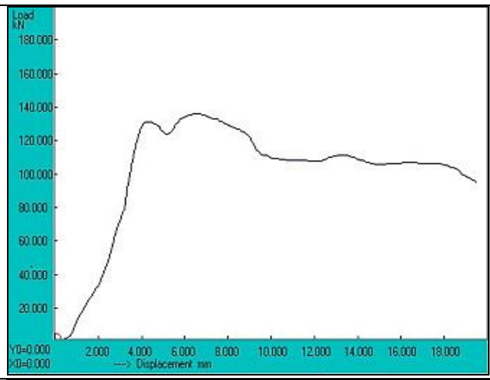
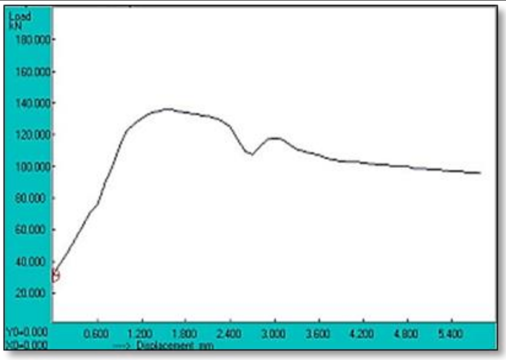
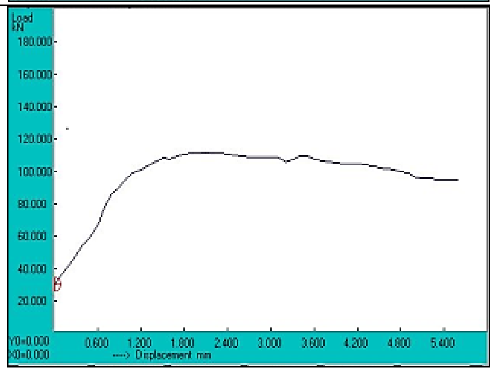
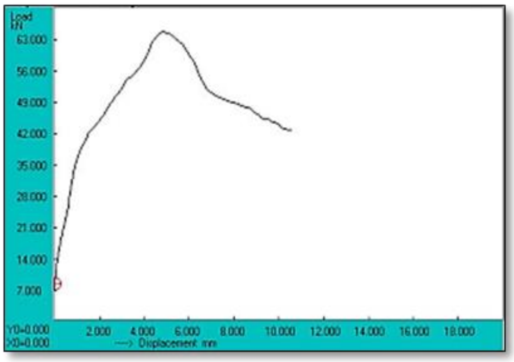
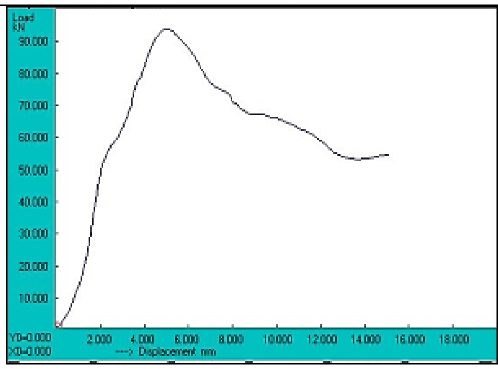
1.	**Dendrocalamus Hamiltonii**		
2.	**Bambusa Tulda**		
3.	**Bambusa Nutans**		
4.	**Bambusa Balcoa**		

B. Tensile test results

The tensile tests were conducted for two samples of each bamboo species. Their failure pattern, ultimate and yield strength will be discussed in the following section.

Calculation:
The maximum Tensile strength σ_{ult} in N/mm^2 is calculated as follows:

$$\sigma_{ult} = \frac{F}{A} \quad (2)$$

Where

F_{ult} = maximum load in N;

A=area of the cross-section of the test specimen in mm^2

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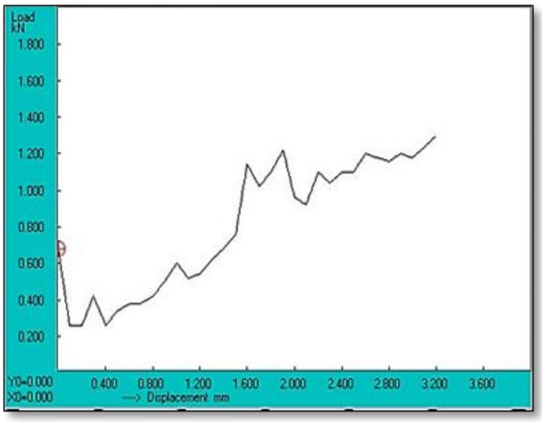
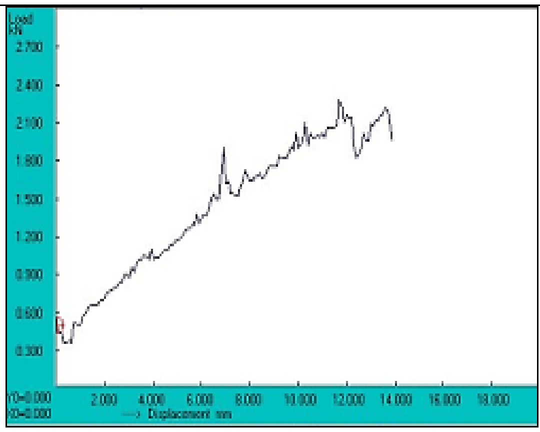
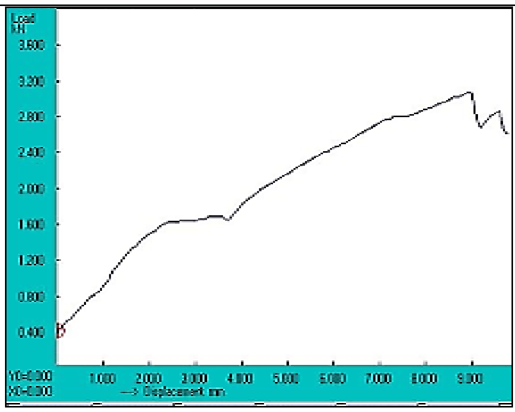
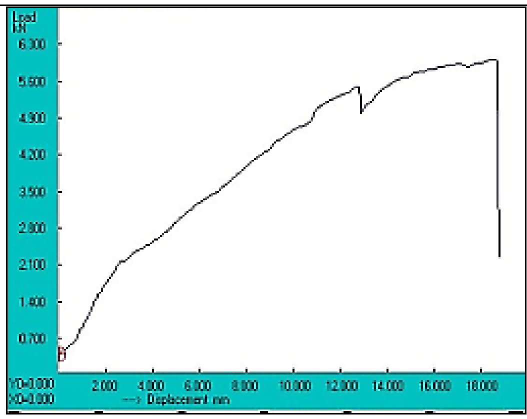
Table- III: Tension test results

Bamboo type	Test 1					Test 2					Average
	Tensile strength (MPa)	Max. force (KN)	Input data (mm)			Tensile strength (MPa)	Maximum force (KN)	Input data (mm)			Tensile Strength (MPa)
			O.D	I.D	Gauge length			O.D	I.D	Gauge length	
Dendrocalamus Hamiltonii	57.218	1.300	4	5.68	45	100.352	2.280	4	5.68	45	78.785
Bambusa Tulda	191.250	3.060	4	4	40	201.23	6.020	4.86	4.74	38.86	226.288
Bambusa Nutans	216.250	3.460	4	4	35	201.091	3.480	4.16	4.16	36	208.6705
Bambusa Balcoa	73.906	0.980	3.4	3.9	33	77.733	1.300	4.52	3.7	58.38	75.8195

Table- IV: Graph for load vs. displacement in the Tension test

S N.	Bamboo type	Graph for Load vs. Displacement	
		Test 1	Test 2
1.	**Dendrocalamus Hamiltonii**		
2.	**Bambusa Tulda**		

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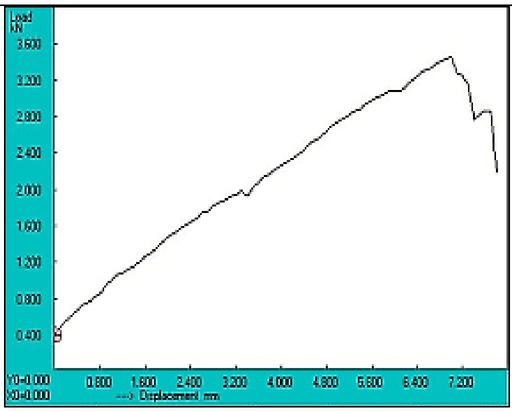
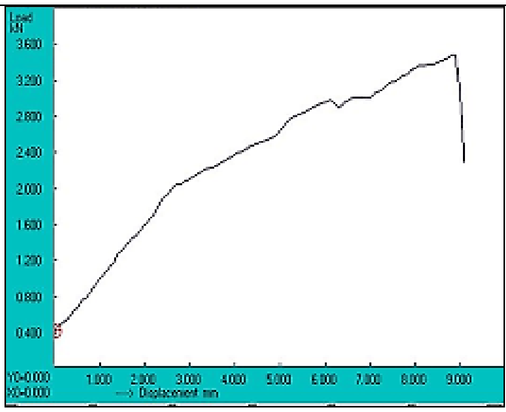
<tr><td>3.</td><td>Bambusa Nutans</td><td>
</td><td>
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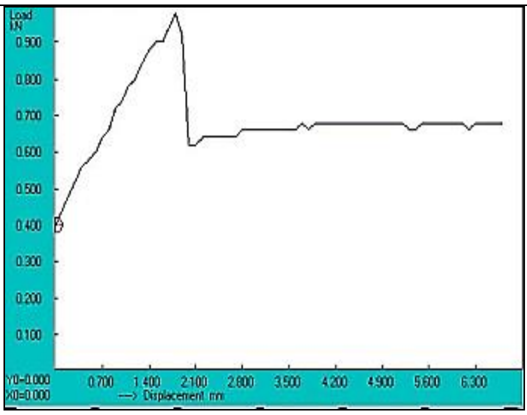
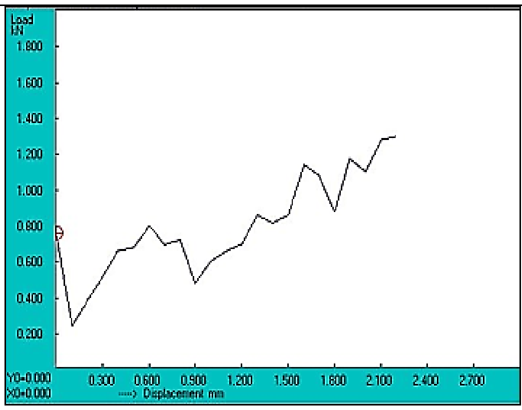
<tr><td>4.</td><td>Bambusa Balcoa</td><td>
</td><td>
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C. BENDING TEST RESULTS

The modified three-point setup was used in order to obtain the bending strength of bamboo. Until a crack sound was noticed, the bamboo was loaded. The cracking noise may be triggered by the bamboo dividing in the basal part or by the final bending where the third-point load is connected. In attempt to bring into consideration the taper effect of the bamboo, the following equation is included in the bending strength calculation .Bending strength was calculated using the equation.

Calculation

a) The moment of inertia I in mm^4, shall be determined as follows:

$$I = [(O.D)^4 - (I.D)^4] \quad (3)$$

O.D = outer diameter (mm)
I.D = wall thickness (mm)

b) The ultimate strength (σ_{ult},) is calculated as follows:

$$\sigma = \frac{1}{6I}\left(FL\frac{D}{2}\right) \quad (4)$$

Table V. Bending test results

Bamboo Type	Bending Strength (Mpa)	Max. force (KN)	Input data (mm)			Graph load vs. Displacement	Failure
			O.D	I.D	Dist. Bet. support		

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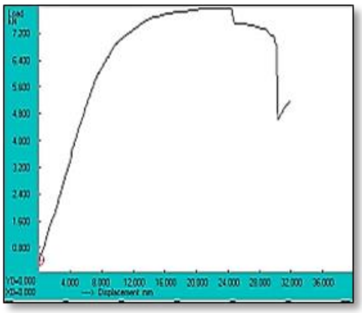
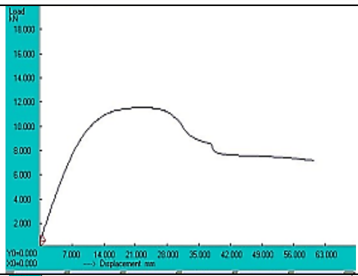
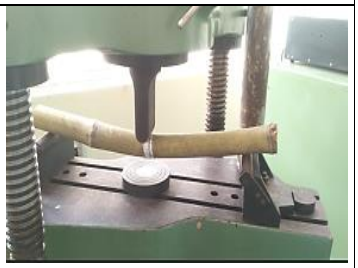
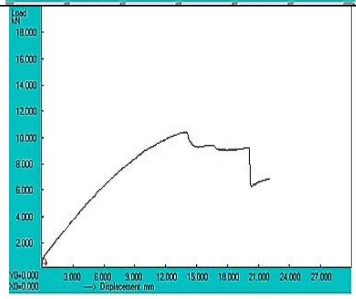
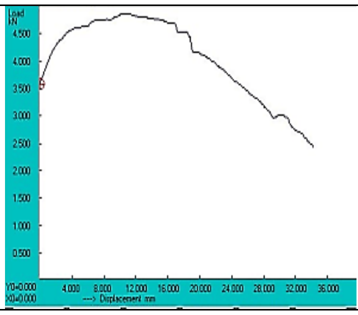
Dendrocalamus Hamiltonii	3.694	7.940	60	29.4	487		
Bambusa Tulda	6.606	11.54	48.2	10	487		
Bambusa Nutans	7.699	10.40	49.7	27.4	487		
Bambusa Balcoa	4.240	4.860	50.7	33.34	487		

D. Shear test results parallel to the grain

The shear strength parallel to the grain is drawn as a load when the bamboo culm was about to separate up divided by the bamboo culm's average thickness multiplied by the bamboo culm's length. It should be observed that the bamboo culm is split into four components for a single load so that the complete area calculated equals four surface areas.

The shear strength parallel to the grain is computed using the equation.

$$\sigma_{ult} = \frac{F}{Lt} \quad (5)$$

Where
F_{ult}= maximum load (N)
t = wall thickness mean (mm)
L= length of specimen (mm)

Table VI. Shear test results

Bamboo type		**Test 1**					
	Shear strength (in MPa)	**Peak load (in KN)**	**Input data(in mm)**			**Graph Load vs. displacement**	**Failure**
			O.D	**I.D**	**Gauge length**		

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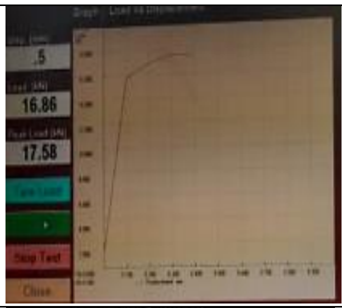
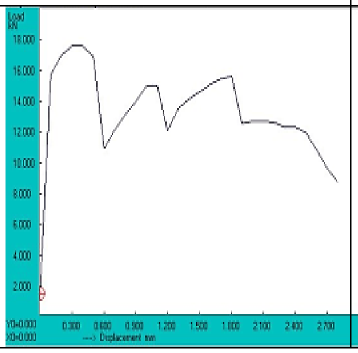
Dendrocalamus Hamiltonii	19.56	17.580	57.44	37.88	52.34		
Bambusa Tulda	2.707	5.8	52	10	51		
Bambusa Nutans	10.954	12.24	48.58	24.12	45.68		
Bambusa Balcoa	13.893	17.580	53.38	29	51.9		

V. CONCLUSION

Following are the conclusions drawn from experimental studies:

1. Bambusa nutans is the strongest among all in terms of compressive strength at an average of 98.244 MPa.
2. Bambusa tulda has the stronger tensile strength at an average of 226.288 MPa followed by Bambusa nutans at an average of 208.670 MPa.
3. Bambusa nutans has the stronger bending strength at an average of 7.669 MPa.
4. Dendrocalamus Hamiltonii has the stronger shear strength at an average of 19.56MPa followed by bambusa balcoa and bambusa nutans .

The results showed that Bambusa Nutans possess excellent mechanical properties in compression and tensile strength, which indicates it can be used as construction material. The research revealed out that bambusa tulda which is almost a solid bamboo is not too far from hollow one in terms of mechanical properties and can equally be utilized for construction work.

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