

# A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization

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**Abstract:** *The research is focused on the study of mechanical strength properties of bamboo to establish if bamboo would play a complementary role to wood in both furniture making and construction works as a sustainable material for the wood industries. The research also highlighted the dwindling supply of wood as a main source of material for furniture and construction works in Zimbabwe due to fire destruction of timber plantations. The study investigated on the mechanical properties of the bamboo in Zimbabwe aiming at assessing its suitability. The study showed that there is need for additional resources of material to complement wood. Experiments carried out on the strength properties to include tensile, compressive, bending, stiffness, elasticity, hardness and durability of bamboo to resist different forces or loads on structural members. Results showed that the strength properties of bamboo are higher than most of the soft and hard woods. The study also indicated that different species of solid bamboo is available in Zimbabwe. The research revealed out that solid and hollow bamboo can equally be utilized for both furniture products and construction works. The researcher used observations, interviews and experiments for collecting data. The paper concludes by encouraging schools, colleges, small to medium enterprises and wood industries on the utilization of bamboo as a complementary resource material for furniture and construction works in view of qualifying strength properties and resource sustainability, renewable and availability in Zimbabwe and bamboo plantations to start in all provinces.*

**Keywords-** *Experiments carried out on the strength properties to include tensile, compressive, bending, stiffness, elasticity,*

## I. INTRODUCTION

The researcher in this project wants to test the strength properties of bamboo so to prove its suitability in use as a material for furniture making and all constructional works in the country. In other countries and as well as in Zimbabwe timber plantations are being destroyed by fire and as a result amount of timber harvested in different plantations is becoming less and less each year therefore seen a need for a fast growing plant, bamboo, that produces timber in a shorter period which have strength properties equal or better than timber so the researcher tested for bamboo strength properties. Bamboo is a naturally occurring composite material which grows abundantly in world wide.

It is a type of grass that is the largest in the world which matures in the period of five years. Bamboo have so many species but in Zimbabwe we have two main groups thus hollow and solid stem bamboo which are under utilization. Companies in Zimbabwe like Boarder Timbers Wattle Companies,

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Allied Timbers have faced a problem of plantations destructions by fire due to so many reasons at different periods. As a result of plantations destructed the timber harvested during that year will be less than what was expected if there was no destruction.

Replantation of timber takes about 25 years for hardwood to be fully mature for constructional works but bamboo takes only five years to mature. If the researcher compares the amount of timber which was harvested in the years 1990s and in these years the amount has decreased and most of the plantations being affected by fire which continuous to destroy the plantations year by year.

### 1:1 Aim

The project aims to study and test mechanical strength properties of bamboo so that it can be used for furniture and constructional works in Zimbabwe.

### 1:2 Objectives

- (i) To carry out some test the bamboo mechanical strength properties
- (ii) To establish the bamboo species in Zimbabwe

### 1:3 Scope of the project

The project focuses on studying and testing mechanical properties of bamboo material. It has to address the suitability of bamboo to be used as a material for utilization in the furniture and construction material in alternative to wood or as an additional material to wood.

### 1:4 Background of the study

In Zimbabwe timber plantations are always affected or destroyed by fire and as a result the amount the timber harvested becomes less, as a result ten to fifteen years to come there will be a shortage of timber due to fire destruction, therefore there is need in the country to have bamboo plantations. According to a report on November 11, 2008 which says;

## II. ZIMBABWE: FIRES DESTROY LARGE FORESTRY SURFACES

The wood industry of Zimbabwe has lost millions of dollars in the last months, due to the wild fires which destroyed several plantations. Approximately 15000 hectares of forest have been destroyed. The majority of the trees were 3-9 years old. "This must be the most disastrous fire season ever recorded in this country", declares the director of the Wood Manufacturers Association, Joseph Kanyekanye. It takes 25 years for a tree to reach maturity, in order to have qualitywood. Zimbabwe's wood industry was on the verge of collapse two months ago. This situation was worsened by the simultaneous bursting of the fires, in different locations. It appears that the fires were caused by locals who were preparing their lands for plantation.

Yet, only one arrest has been made in this case. Joseph Kanyekanye insists that the government adopt a “plantation policy”, which, among other stipulations, must ban the lightings of fires at least 5 km away from the edge of the forest. Also Border Timbers' chairman P W stated that illegal squatters from invading the forestry plantations in the east Manicaland province in 2009 set fire to some 7,000 hectares of land. Zimbabwe Border Timbers in Eastern Highlands in 2009 reported that 540 hectares of timber plant were destroyed by fire. According to the few information above there is a need for a fast growing bamboo plant which matures very fast for a fast recovering in timber .When a bamboo plantation is destroyed by fire when rain season comes double or three times the bamboo plants destroyed by fire will shootout for new plants and according to socio-economy bamboo book of( 2009 )CBRC states that bamboo plantation last for 50 to60 years in use without planting new plants.

**1:5 Project Justification.**

Bamboo in Zimbabwe has so many species which is not used beside few hand crafts works done. A bamboo plantation can be harvested three to five times before a timber plantation is harvested .All the plantations which were planted in 2 000 and 2 001 are not yet ready for harvesting because of the years some of the timber takes to mature. Fire is just an out break that just occurs unexpectedly means plantations can be destroyed at any time means many years of suffering when one plantation is destroyed. The following are recorded fire destruction statistics from 2004 to 2009 for Allied Timbers in Zimbabwe- according to the timber plantation Manager of Mutare branch

**Table 1:1 Fire Destruction For Allied Timbers**

Year	Hectors destroyed
2004	515.0
2005	3 879.0
2006	1 063.0
2007	1 9 97.0
2008	14 820.0
2009	116.0

The Manager stated that the affected plantation have been planted but not all hectors and their plantations took 25 years to mature except gum that matures at 12 years .

According to the statistics fire destruction is an every year event and that reduces the amount of timber each year.. Bamboo if affected by fire it hardly gets destroyed as it is fire resistant and when destroyed that same year during rain season new shoots will be obtained which will be double and more than the number of destroyed plants since each plant every year have more than three shoots when maintained . Bamboo plantation benefits the economy from the period of one year up to five and sixty years .Other bamboo benefits according to other researchers includes bamboo shoots as vegetables, paper production can be made out of bamboo, wine, charcoal, tables, soaps, fabric ,vinegar and so many can be produced from bamboo means every part of the bamboo plant is very useful to develop the country.

suitable for furniture and construction works so that it can be used in addition to wood.

**2:0 Related Literatures**

**2:1Bamboo Growth**

Bamboo is very fast in propagations it is the fastest growing plant in the world. It can grow 20-30 cm to 150-200 cm within 24 hours, Cultivation of Bamboo Book 1 and Socio Economy, Mosso can grow up to 15-18m within 30-40 days . A bamboo plantation the first year will grow stably and if well managed in the second year and third year people can harvest for shoots which can be used as vegetable, the fourth and the fifth year it will be mature for use .Bamboo plantation can last for sixty years according to the Utilization of bamboo (2009) book 1 page 1-2

**2:2 Bamboo Densities**

Utilization of bamboo book 2 (2009) bamboo is a porous material its destiny is defined as weight per unit volume which includes materials of cellular walls, microscopic and ultramicroscopic holes. It varies from 0.56 gm/cc to 0.96gm /cc. Minimum density is for dendrocalamus bamboo tested resulted that tensile strength is higher , density varies from 0.5gm/cc to 0.9gm /cc for difference bamboo strength is reached when the bamboo is mature

Bamboo densities are grouped into basic density, fresh density air dried density and absolute dry density. The higher the density of bamboo is the more the strength it has in the same culms. The density of bamboo reflect the mechanical properties. The density is higher in the nodal than in the non nodal position because there are closer vascular bundles and smaller diameter vessels in the top and the outer position of the wall than in the base and the inner position. The density of bamboo increase with the age from 1 to 6 years and they are more stable at 5 to 8 years but decreases slightly after 8 years. Bamboo cellular wall and its content vary and get richer gradually with aging .The variation of bamboo density relates to its geographical distribution in general that is according to the CBRC Utilization of Bamboo Book 1 (2009) page 10.

**2 :3 Coefficient of shrinkage of bamboo.**

The shrinkage rate of bamboo is less that of wood according to Tongji University. The shrinkage differs with the moisture content of bamboo. The highest shrinkage was noted to be along the tangential direction of the inner wall, the average shrinkage value about 0.1 % (from green to air dried bamboo).The structure of Bamboo culms transverse section are to be characterized by numerous vascular bundles embedded in the parenchymatous ground tissue Grosser and Liese( 1971) in bamboo there are no rays or knots which give a bamboo a far more evenly distributed stresses throughout its length.Bamboo is a hollow tube sometimes with thin walls and can be glued very well Jassen (1995). Bamboos' diameter, thickness and internodes length have a macroscopically graded structure while the fiber distribution exhibits a microscopically graded architecture which lead to favorable properties of bamboo Amada et al( 1998).

**2:4 Mechanical properties of bamboo**

According to CBRC( 2008 ) Utilization of bamboo page 14 states the following bamboo have strong mechanics and good adaptability ,easy to be processed which cause it for wide range of usage in architecture and industries.



The table below shows that the tensile strengths of bamboo is about that of wood and the compression strength is about 10% higher than that of wood although the tensile strengths for steel is 2.5 to 3.0 times than that of bamboo , the specific gravity of steel is 6 to8 and density of bamboo is 0.6 to 0.8 .

Therefore by counting their strength per unit weight , the tensile strength of bamboo is 3 or 4 times as high as steel see the table below according to the China Bamboo Research Center.

**Table 2:1 Comparison between strength of bamboo, wood and steel**

Items	Bamboo				Wood				Steel			
	1	2	3	4	5	6	7	8	9	10	11	12
Tensile Strength	197	286	284	197	78	99	145	111	382	-444	-20	>730
Compression Strength	65	55	36	42	40	33	58	47	430	500	600	>730

- 1.phyllostachys pubescen
- 2 .phyllos3 .phyllostachys glauca
- 4 dedroculumus lattiforus
- 5 Chinese pines
- 6 red pine
7. Quercus
8. Sassafras
9. Mild steel
10. Semi-mild steel
11. Semi-hard steel
12. Hard steel

The internodes position is stated to have more tensile strength.

**2:5 Compressive Properties**

The results of the study was that the compressive stress of bamboo perpendicular to the longitudinal direction increased with the increase of the age. One year old bamboo had the lowest of 16.1 MPa compressive stress and a five year old bamboo had the highest compressive stress and in terms of highest compressive stress and highest Young’s` modulus than the middle and bottom . As a result it was noted that compression properties parallel to the longitudinal direction were significantly higher than that perpendicular to the longitudinal direction and vascular bundles distribution had the highest concentration in the outer layer of bamboo. University of Southern California Los Angeles,( CA 90089-2531 )by Andrea Carrasco, Jojn Fronda and Brain Macrae on the mechanical properties , define bamboo as a lightest material and strengthen extreme product of nature which is stable and because of its cavities an extreme light and elastic building materials ,noted that the lignifying cell construction of the bamboo texture and its technical conditions are similar to the original texture of wood where as wood has got a hard center and becomes weaker toward the outer parts and in its inner parts weak what causes a much more stable construction .

According to Aerospace Engineering Department, Indian Institute of technology

**Table 2:2 the strength results obtained after wood, bamboo, steel materials were tested.**

KN /square centimeters	MATERIALS Spruce wood	Bamboo	steel
Elastic modulus	1100	2000	2100
Compressive Strength	4.3	6.2-9.3	14

Tension Strength	Spruce wood 8.9	bamboo 14.8	Steel 16
Bending Strength	6.8	7.6-27.6	14
Shearing Strength	0.7	2.0	9.2

Bamboo as an orthotropic material i.e. it has particular mechanical properties in the three directions, longitudinal, radial and tangential. They recorded that distribution of bamboo cellulose fibers within the bamboo culms is not uniform. Bending elasticity module for a typical bamboo species varies in the range of 8.945-11.691 MPa , the lower values are for green bamboo and higher values for air –dry bamboo. As per reference (1), bending strength value for typical flooring is 94MPa .Hardness modulus –is in the range of 902-1.833 N/mm. Janka ball hardness values reported for a typical species is 1640(1) All the test results presented for the mechanical properties are from the specimens made from internodes regions.

**2 :6 Hardness of bamboo**

Force was applied to specimen. The slope of the initial straight line portion of this curve gives the hardness modulus Aerospace Engineering Department Indian institute.

Tensile strength varies in the range of 111-219 mpa according to State Forest Research Institute (SFRI 34).

**2:7 Tensile Strength**

-A typical bamboo flooring parallel to grain is 105 megapascals (MPa) 15 ,290 psias reported in reference . As reported in reference tensile strength parallel to grains is 200 megapascals for a typical bamboo. Further tensile strength values reported is in the values reported is in the range of 130-138 megapascals.

**III. METHODOLOGY**

**3:0 Type of Data Needed**

The type of data needed by the researcher was the physical characteristics of bamboo, the environmental conditions where bamboo grows its effect to the strength properties, the uses of bamboo, samples of different pieces of bamboo were collected for testing the mechanical properties to determine their contributions to the strength of bamboo as a material for use.

**3:1 Data Collection**

Was collected from both rural and urban areas where bamboo is growing.

**3:2 Observation Method**

Observation and interviews were used to collect the required data. The researcher collected the samples of bamboo which were used when carrying out experiments or tests on mechanical properties while observing the results and also interviewed local people on the utilization of the bamboo in rural are

**IV. DISCUSSION ON FINDINGS**

Tests were carried out to detect the mechanical strength properties of bamboo including physical ,mechanical using different types of bamboo thus wet bamboo ,dry, solid and hollow bamboo about a two year old bamboo was tested for mechanical strength properties and the bamboo culms were observe its physical appearance,



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experiments for mechanical properties were carried out at F.I.T.C. and SAZ(Standard Association of Zimbabwe) in Mutare (Zimbabwe). The researcher tested for the hardness of solid bamboo using the Janka Test.

### Janka Test



Fig 4:1 Universal testing machine



Fig 4:2 Universal testing machine

The hardness of bamboo was tested using the Universal testing machine. A piece of about a two year old bamboo 77x33x25mm was placed on the work table of the machine, the table was raised until it touches the spherical head of the head rest of the work piece.



Fig 4:3 spherical ball pressing the work Fig 4:4 spherical ball fig 4:5 result of worked piece

The machine was put on and the spherical head moved down pressing down into the bamboo work piece and the standard depth the spherical head should enter into the work piece was 5.5mm depth and the forced used to press the spherical head into the work piece was the hardness of the bamboo. The Dial testing indicator recorded that the spherical head had entered 5.5mm deep into to the work piece and the loading speed was 11m per second which resulted in giving the load of 658.5kg hardness of material

was measured and calculated in Nektons therefore to convert 658.5kg is  $658.5 \times 10 = 6585$  Nektons. The hardness of bamboo varies with the species because solid bamboo differs with hollow bamboo as soft wood also differs with hard woods timber. H.E Desch and J.M. Dinwoodie (1968) Timber Structure properties Conversion and use stated hardness of different types of wood e.g the hardness of Douglas fir its hardness is 2 980 Newton's. Comparing the hardness of bamboo 6 585N and 2 980 of Douglas shows that solid bamboos` hardness is twice harder than that of Douglas fir.

Tested for modulus of rupture



Fig 4:6 tested for rupture a piece of bamboo results

The modular of rupture of Douglas fir according to H.E Desch and J.M Dinwoodie (1968) Timber Structure Properties Conversion and Use is given as 93 N/mm<sup>2</sup> and the modular of rupture for a tested solid bamboo work piece above was 6585N/ 2980N x93 N/mm<sup>2</sup> therefore the modular of rupture of a tested solid bamboo 205.5050336 N/mm<sup>2</sup> this means that the modular of rupture of bamboo is higher than that of Douglas fir meaning that is more elasticity than Douglas fir and takes longer time to break than Douglas fir which breaks earlier than bamboo.

### Impact Test



Fig 4:7 Impact machine with a work piece under the load

The impact test was carried out using the impact machine, bamboo work piece of sizes 20x20 x27 was placed on the work table, the machine was put on and a weight load of 15kg was first raised to 80cm but the work piece resisted to break and the distance was raised to 100cm and the work piece deformed means bamboo does not easily deform or loose its shape, therefore the distance raised was the impact on the work piece.

### Bending Test





**Fig 4:8 bending test in process**

A work piece of 270x 20x20 of a two year old bamboo was placed on the work table load exerted on the work piece which amounted to 140 kg, and as a result gave 140kg x 10 N =to 1400N The deformity of the above work piece was found to be 13.3mm.

MOR =3PL/ 2b2 =3x1400x270/2x20x202=4536N

**Elasticity test/tensile strength**



**Fig 4:9 testing tensile strength using**

Universal testing machine

The work piece was mounted on the machine as shown on the machine above the forces where pulled apart so that so that the amount of force and time taken to stretch the work piece was recorded

**Table 4 :1 Mechanical Properties of bamboo and mukwa according to test results at SAZ**

two year old bamboo	Areas focused	Bamboo %Ext Newtons	Mukwa % Ext	Comments
Hardness 300 x33x25mm	1	4.235	4785	- a one year old bamboo almost same with mature mkwa -two year old bamboo
	2	4.81	5.01	
	3	4660	4670	
	4	5.01	5.01	
	1	3668	3464	
	2	3480	3470	
	3	5.01	4380	
Tensile	1	10362	-	Bamboo is very elasticity
Modulars of rupture	1	700	2744	Bamboo does not easily rupture
	2	587	3.32	
	3	11.30		
Density		545 .80344kg/m3	649.77 kg/m3	Bamboo is a hard material

According the researcher and SABS 1099-1976 Standards Association Specification for Hard woods Furniture Timbers see the table below, Density =M/V a piece of 96.82

/1000x34.25/1000x18.73/1000=0,0006211027205. Therefore a bamboo 0.0339 kg D=M/V =0.0339/0,0006211027205=545.80344 kg/m3

**Table 4 :2 Results of Mechanical strength properties of bamboo compared to other hards woods N/ m2**

Strength	Solid bamboo	woods	Yellow pine	Douglas fir	Teak	Saliguna	Oak
Hardness	6 585 N		3 780 N	2 980 N	4 449 N	5 605 N	5 783 N
Rupture	205.5050 336 N		-	93 N	-	-	-
Bending	4 536 N		59.2 -69.6 N	127 00 N	--	-	-
Density	545.8034 4kg/cm3		0.54g /cm3		0.64g /cm3	0.64g /cm3	0.77g /cm3

**4:1 Moisture Content of bamboo**

The moisture content was carried out at Pine Product Company in Mutare and the results are as follows see the table bellow, pictures of researcher testing the moisture content of the bamboo dry .The researcher used a moisture meter to carry out her experiments;



**Fig 4:9 A set of moisture meter for recoding moisture content above**

**Table 4 :3 Result Of Bamboo Moisture Content**

Bamboo	Temperature
Wet bamboo inside	Over 40 degrees C
Wet bamboo outside	40 degrees C
Dried bamboo for five month	17 degrees C
Dried bamboo for more than five months	14 and below degrees C

H.E. Desch and J.M Dinwoodie (1968) Timber Structure Properties, Conversion and uses 7th addition the average moisture content of red wood is 18 degree therefore the tested dried bamboo for five month is 14 degrees comparing the two moisture contents means that bamboo strength properties are stronger than that of red wood because higher temperatures or more of moisture content weakens the strength properties of material.

**V. SUMMARY**

The researcher has found that bamboo strength properties are suitable for use as an additional material and its strength properties are more than most of soft woods and some of the hard woods but the bamboo technology is not much in the country and bamboo is only used for weaved baskets, chair, mats in which few rural people benefits from that. The sold bamboo is not used and the researcher is much more interested in unused solid bamboo.



The researcher has noted that most of the developed countries like European countries use bamboo for most of its big project e.g. construction of bridges ,construction of Bamboo Corridors in Europe , Lamination Boards used as fire proof ceiling in Madrid Airport in Spain according to Socio –economy of bamboo 2009 China National Bamboo Research Centre.

According to the literature review according to [www.bikebamboo.com/bamboo properties](http://www.bikebamboo.com/bamboo_properties) states the following that in wood the strongest fibres are packed in the centre of the truck while in bamboo the stems are full of cavities and distributed most densely in the outer surface region which makes it very stiff, as a consequence the most stable fibres structures in bamboo are most dense in the regions of greatest longitudinal stress. Strong extremely – strong wood fibers can resist up to 5 KN/ cm<sup>2</sup> and steel can resist at most 37 KN/ cm<sup>2</sup> and bamboo the outer fibers of slim bamboo tubes have tensile strength of 40KN / cm<sup>2</sup> all the above makes bamboo a very good material for all constructional works. [http://www.Deboerarchitects.com/bamboo thoughts .html](http://www.Deboerarchitects.com/bamboo_thoughts.html) states that Bamboo have greater shear strength than structural woods and take much longer to come to ultimate failure. It has ability to bend without breaking which makes it suitable for all constructional works .Bamboo is said to be twice compressive strength than that of concrete and roughly the same strength to weight ratio of steel in tension and as a result that make bamboo a good material for all works. Also according to [http://www.calibamboo .com /why bamboo](http://www.calibamboo.com/why_bamboo) states that Bamboo has higher tensile strength than alloys of steel and higher compressive strength than many mixtures of concrete .Bamboo has higher strength weight ratio than graphite and bamboo is used as a standard building material for majority of the world for hundreds of years and these structures have been withstand magnitude of earth quakes for so long ,also states that fencing using bamboo takes 30-50 years without affected by any destructors as a result all the above support that bamboo is a very strong material for use than most of the material that may be preferred. Zimbabwe has so many species of bamboo which are not utilized and the researcher wants Zimbabwe to get developed through utilization of bamboo.

### VI. RECOMMENDATIONS

Through the research carried out the researcher is recommending the following Zimbabwe must start on bamboo plantations to benefit the country, is recommending on the use of the available bamboo starting from now so that all the unutilized bamboo benefits community and result in creation of employment.. A pilot project on the utilization of bamboo have to be started so that it will encourage other timber industries to start on bamboo plantations for benefiting the companies, Colleges and Universities have to start learning more about bamboo technologies and agriculture colleges to have bamboo plantations. The researcher encourages the people in rural areas to have small plantations in their areas so that they will benefit from them as time goes on when bamboo become in full utilization in the country and not to misuse it as noted that during fields visits solid bamboo was used as firewood. The researcher recommend on further studies on bamboo technologies and utilization in this country and in other countries for the benefit of development of Zimbabwe and other undeveloped countries.

### VII. CONCLUSION

Bamboo has proved to be used as an additional material for furniture and constructional works through the tests carried out which shows that a tested bamboo which was not five year old has its hardness as 6 585N and Douglas fir had 2 980 N and its Rupture was 205.505336N for bamboo and Douglas fir was 93 N ,the bending strength was 4 536N for bamboo as a result the researcher recommends the utilization of bamboo in the Zimbabwe as an additional material to wood. literature review of other researchers and showed that most of developed countries are now more into bamboo than wood because of its many advantages over other materials and prototype which had been made shows that bamboo deserve to be used as an additional material to wood in Zimbabwe. It has been proved in chapter two that the properties of bamboo are suitable to be a good material when it was used for e.g countries like the Bamboo Corridor built in Europe Madrian Air port in Spain built using bamboo material and so many bridges in China are built using bamboo material.

The researcher noted that bamboo has less work in cultivation since cultivated only once in sixty years ,have all species that can be used for different purposes ,can be processed even with wood machines easily, accepts wood glues and vanishes, can be air seasoned thereby means it is a material that can be easily started to be used in the country without much difficulties when more researches are carried out for cultivation of bamboo in Zimbabwe.

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