Comparative Analysis Of The Tensile Strength Of Bamboo And Reinforcement Steel Bars As Structural Member In Building Construction

Ogunbiyi, Moses A., Olawale, Simon O., Tudjegbe, Oke E., Akinola, S. R.

Abstract: This study aims at testing and comparing the tensile strength of bamboo and steel reinforcement bars as structural material for building construction. Tensile strength tests were carried out on various sizes steel and bamboo; categories of reinforcement bars such as; 10mm, 12mm, 16mm, 20mm and 25mm of both high-yield and mild-yield steel reinforcement bars were both tested along with same sizes of bamboo with 10mm cross-sectional thickness. Results are presented in tables and graphs and show that the tensile strength of high-yield steel bars outstrips that of mild-yield and bamboo respectively. The study finds that the breaking force (FB) for 10mm (HY) = 24.42KN; tensile strength = 457.13N/mm2; yield stress = 379.02 N/mm2 and breaking elongation = 39.67mm respectively. For 12mm (HY), breaking force (FB) = 52.14 KN; tensile strength = 689.12 N/mm2; yield stress = 551.30N/mm2 and breaking elongation = 36.58mm. 16mm (HY) results in breaking force (FB) = 126.67KN; tensile strength = 771.61N/mm2; yield stress = 494.10N/mm2 and breaking elongation = 70.87mm. The same factors for 20mm yields, breaking force (FB) = 163.97KN; tensile strength = 713.40N/mm2; yield stress = 614.74N/mm2 and breaking elongation = 61.57mm. While the 25mm (HY) produces, breaking force (FB) = 306.17KN; tensile strength = 792.90N/mm2; yield stress = 678.46N/mm2 and breaking elongation = 52.36mm respectively. Mild Steel (MY) 10mm yields, breaking force (FB) = 14.76KN; tensile strength = 290.49N/mm2; yield stress = 233.17N/mm2; and breaking elongation = 78.86mm. 12mm (MY) results in breaking force = 40.35KN; tensile strength = 508.08N/mm2; yield stress = 376.17N/mm2 and breaking elongation = 84.10mm. 16mm (MY) yields, breaking force (FB) = 79.72KN; tensile strength = 508.71N/mm2; yield stress = 349.10N/mm2 and breaking elongation = 111.39mm respectively. For 20mm mild steel, breaking force (FB) = 83.04KN; tensile strength = 372.98N/mm2; yield stress = 284.64N/mm2 and breaking elongation = 47.40mm. While the 25mm (MY) steel bar results show, breaking force (FB) = 163.04KN; tensile strength = 701.74N/mm2; yield stress = 599.77N/mm2 and breaking elongation = 56.84mm. On the other hand, bamboo yields for the same size width and constant thickness of 10mm, the 10mm-25mm bamboo sizes result as; 10mm (bamboo); breaking force (FB) = -2.1KN; tensile strength = 31.55N/mm2; yield stress = 0.00N/mm2 and breaking elongation = 0.00mm. 12mm width with 10mm thickness yields, breaking force (FB) = -1.28KN; tensile strength = 31.07N/mm2; yield stress = 0.00N/mm2; and breaking elongation = 0.00mm. 16mm (bamboo), breaking force = 1.85KN; tensile strength = 68.82N/mm2; yield stress = 49.45N/mm2 and breaking elongation = 30.40mm. For the 20mm width size bamboo with same 10mm thickness, breaking force (FB) = -0.12KN; tensile strength = 62.66N/mm2; yield stress = 50.23N/mm2 and breaking elongation = 18.20mm respectively. Finally, the 25mm (bamboo) size gives, breaking force (FB) = 4.76KN; tensile strength = 94.60N/mm2; yield stress = 50.19N/mm2 and breaking elongation = 21.11mm. The study concludes that due to the minimal breaking force (FB) of bamboo, it cannot be employed as a main structural member in building and other engineering works but can be used as portioning wall, ceiling, roof and other areas of engineering construction that is not heavy load-bearing.

————————————————◆————————————————

1 INTRODUCTION

Bamboo and steel are structural materials with different engineering qualities used for the construction of buildings and other engineering construction related purposes. The rapid growth and maturity rate of bamboo, sustainability, aesthetics, and acceptability; its strength properties, low cost, makes it worth investigating as a substitute structural material for steel. However, bamboo is relegated and underrated to steel as a structural material in construction generally, as such; it has been mainly employed for none/or marginal engineering purposes. The current study assessed bamboo for its tensile strength and ability to carry load in comparison to steel to highlight its acceptability or otherwise of bamboo as a substitute for steel as structural member in engineering construction. According to [5], due to a unique rhizome dependent system of growth, bamboo is known to have over 1200 different species worldwide which makes it a common and easily accessible material; it is also known to have been widely used in building construction in different parts of the world. Some species of bamboo can grow as tall as 35inches within a 24-hour period. Bamboo has a high compressive strength than wood, brick and concrete and exhibits a tensile strength that rivals steel. Bamboo has several properties of engineering material like steel used in construction but unlike wood, bamboo is known to have more evenly distributed yield stress strength; this is due to the absence of ray and knots in its stem. Today, bamboo is employed in building construction not only because of strength but other properties which makes it favorable for construction works such as; resistant to pest, sturdiness, flexibility and availability. Bamboo has been used in constructing; walls, support structures, piers, roof, floor and room dividers amongst other things. These engineering structures are constructed with bamboo not for aesthetics alone but the amazing engineering qualities of the material. Steel on the other hand has dominated in engineering construction because of its load bearing strength, yield stress strength etc. According to [4], bamboo has strong mechanics and good adaptability, it is easy to be processed which causes it to be used for wide range of architectural and industrial purposes. The comparative tensile strength of bamboo is about that of wood but has a compressive strength 10% higher than wood. Although, the tensile strength of steel is 2.5-3.0 times higher than bamboo and the specific gravity 6-8 times that of bamboo; but by counting their tensile strength/unit weight (bamboo vs steel), the tensile strength of bamboo is 3-4 times that of steel. It is based on this fact that the study sets out to compare the tensile strength of bamboo to steel as structural engineering material.

2 METHODOLOGY

2.1 Materials

1. High Yield; 10mm, 12mm, 16mm, 20mm and 25mm steel reinforcement bars produced locally.
2. Mild Yield; 10mm, 12mm, 16mm, 20mm and 25mm steel bars produced locally.
3. Locally available bamboo culm cut to same sizes as the steel.

Tensile strength test to measure the force required to break a material and the extent to which the material is elongated before breaking was carried out. ASTM D-638, specimen of steel and bamboo was placed at different times in the holding grips of a universal test machine (see Fig1. and Fig2. below) at specified grip separation points and pulled until failure. The test speed was determined by the material specification. An extensometer was used to determine the elongation and tensile modulus of the tested materials.

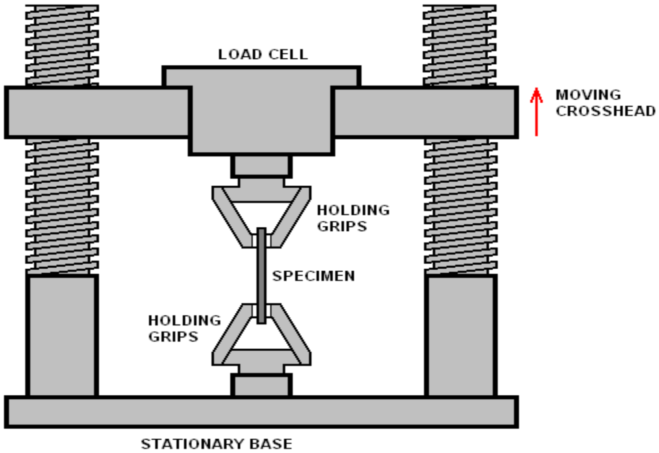

Fig. 1. *Tensile Machine*

Fig. 2. *Hydraulic Universal Test Machine*

2.2 Criteria for Testing the Sample Materials (Steel & Bamboo)

The test parameters are:

Test:	Universal tensile test
UTM type:	Machine
Load cell:	Force1000
Extensometer:	XHead
Test area:	lower test area
Sample dimensions:	
Length data:	Le = 205mm; Lc = 205mm
Test Rates:	V0 = 30mm/min; V1 = 6MPa/s
Rate switch points:	F0 = 10kN
End of test criterions:	Force = 1000kN; dF = 50%

*Note that the same test parameters were used for testing all the samples i.e. bamboo, high and mild yield steel from 10mm-25mm respectively.

3 RESULTS

TABLE 1

FINAL HIGH YIELD STEEL TENSILE STRENGTH PROPERTIES

High yield steel bar	10mm	12mm	16mm	20mm	25mm
Max Tensile Force(kN)	35.90	77.94	143.08	224.12	389.21
Tensile Strength(N/mm²)	457.13	689.12	711.61	713.40	792.90
Yield Stress(N/mm²)	379.02	551.30	494.10	614.74	678.46
Breaking Force(kN)	24.42	52.14	126.67	163.97	306.17
Breaking Elongation (%)	19.25	26.10	35.27	30.72	26.11
Breaking Extension(mm)	39.67	36.58	70.87	61.57	52.36

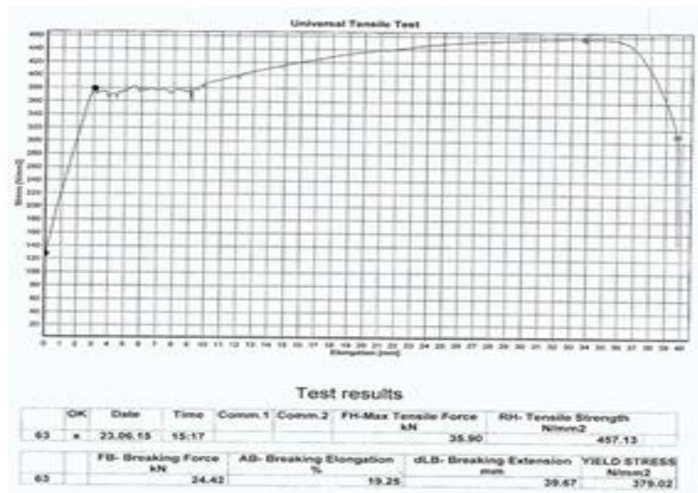

Fig. 3. *Test Result of the Tensile Test on 10mm High Yield Steel Bar.*

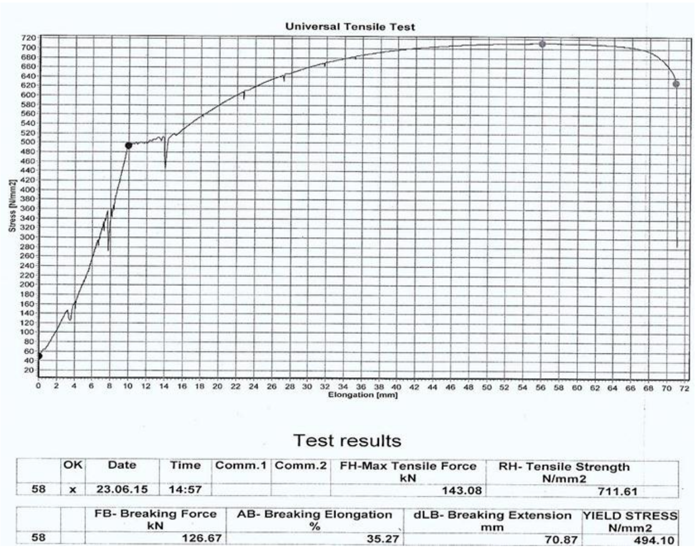

***Fig. 4.**. Test Results on the Tensile Test on 12mm Re-bars.*

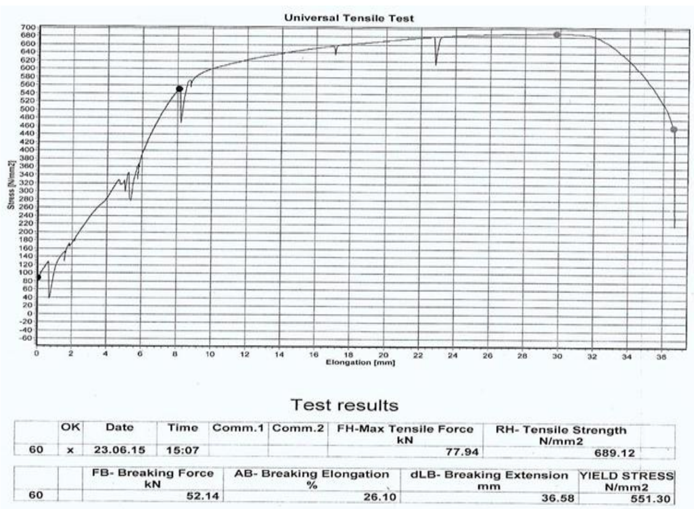

***Fig. 5.** Test Results on 16mm High Yield Steel Rod.*

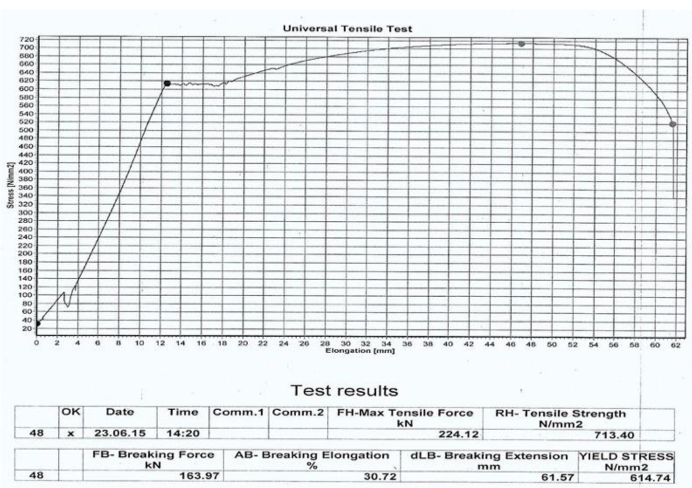

***Fig. 6.** Test Results on 20mm High Yield Steel Bars.*

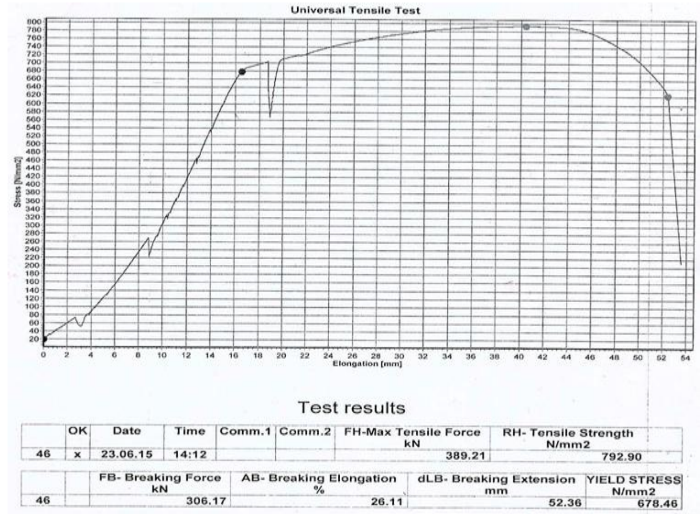

***Fig. 7.** Test Results on 25mm High Yield Reinforcement Bars.*

TABLE 2
FINAL MILD STEEL REINFORCEMENT-BAR TENSILE PROPERTIES

Mild Steel	10mm	12mm	16mm	20mm	25mm
Max Tensile Force(kN)	22.82	57.46	102.28	117.17	220.46
Tensile Strength(N/mm²)	290.49	508.08	508.71	372.98	701.74
Yield Stress(N/mm²)	233.17	376.17	349.10	284.64	559.77
Mild Steel	10mm	12mm	16mm	20mm	25mm
Breaking Force(kN)	14.76	40.35	79.72	83.04	163.04
Breaking Elongation (%)	51.61	39.57	55.53	23.68	29.65
Breaking Extension(mm)	78.86	84.10	111.39	47.40	58.84

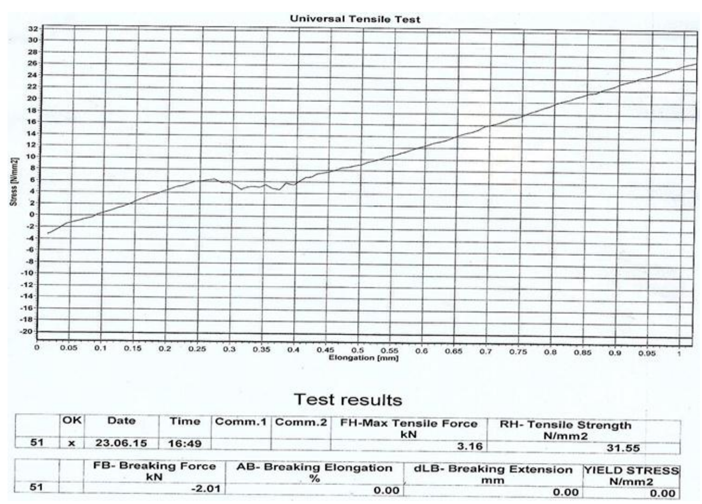

***Fig. 8. 10**mm Tensile Strength Test Result for Mild Steel.*

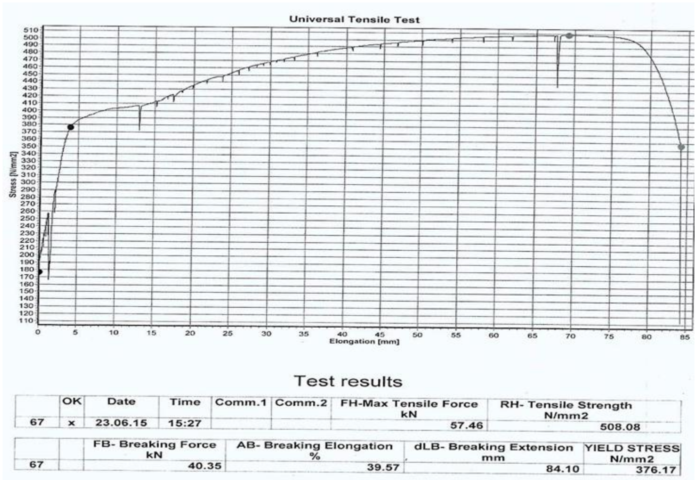

Fig. 9. *Tensile Strength Test Result for 12mm Mild Steel.*

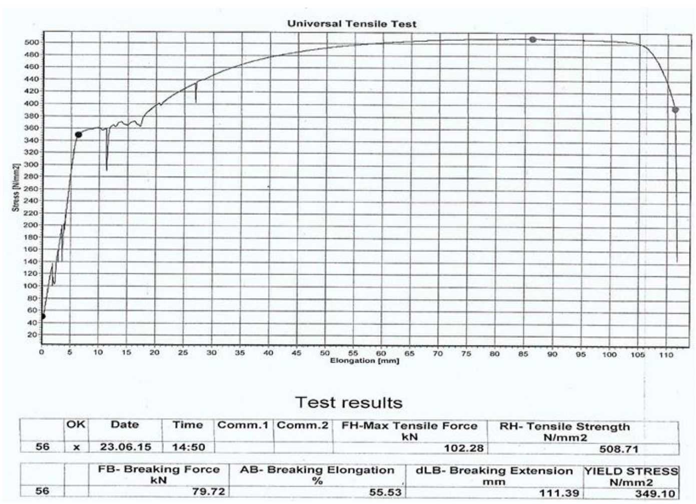

Fig. 10. *16mm Mild Steel Tensile Strength Test Result.*

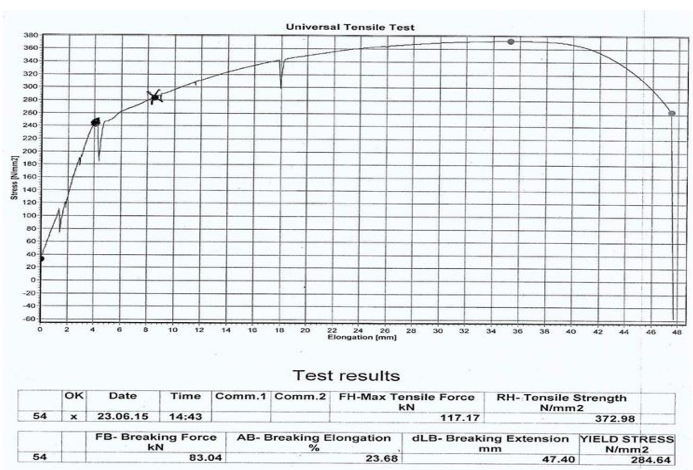

Fig. 11. *20mm Mild Steel Tensile Strength Test Result.*

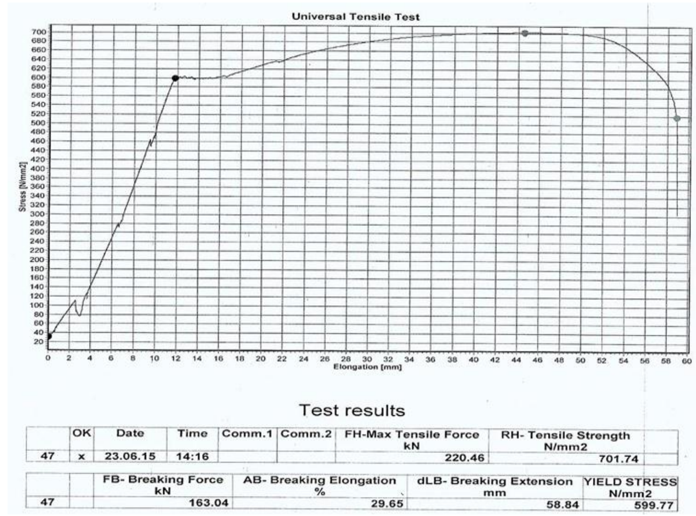

Fig. 12. *25mm Mild Steel Tensile Strength Test Result.*

TABLE 3
FINAL BAMBOO TENSILE STRENGTH PROPERTIES

Bamboo	10mm× 10mm	12mm× 10mm	16mm× 10mm	20m× 10mm	25mm ×10m m
Max Tensile Force (kN)	3.16	3.73	13.38	12.53	18.92
Tensile Strength (N/mm²)	31.55	31.07	68.82	62.66	94.60
Yield Stress (N/mm²)	0.00	0.00	49.45	50.23	50.19
Breaking Force (kN)	-2.01	-1.28	1.85	-0.12	4.76
Breaking Elongation (%)	0.00	0.00	15.07	12.10	10.91
Breaking Extension (mm)	0.00	0.00	30.40	18.20	21.11

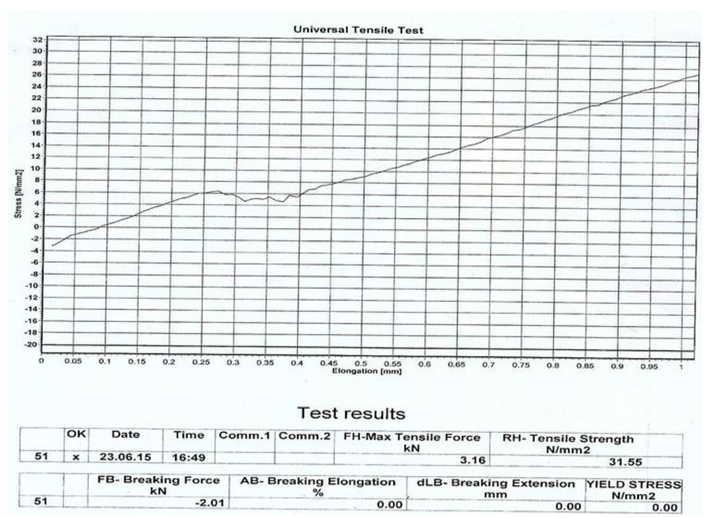

Fig. 13. *10mm Bamboo Tensile Strength Test Result.*

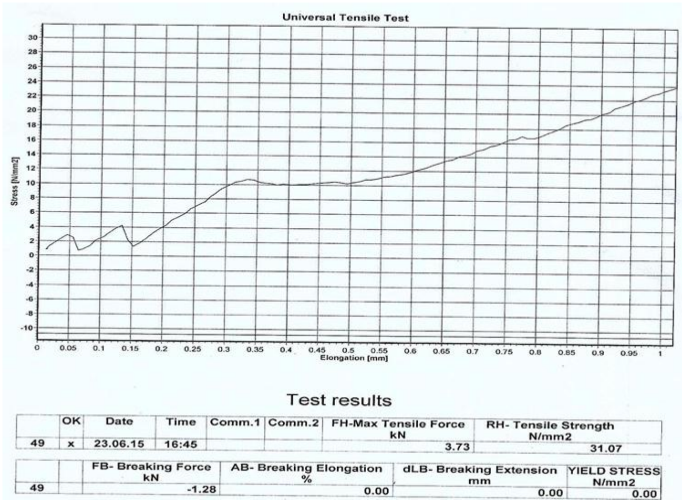

Fig. 14. *12mm Bamboo Tensile Strength Test Result.*

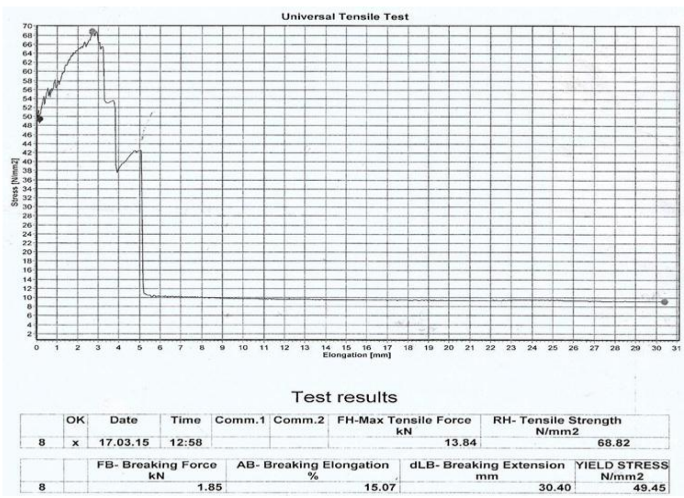

Fig. 15. *16mm Bamboo Tensile Strength Test Result.*

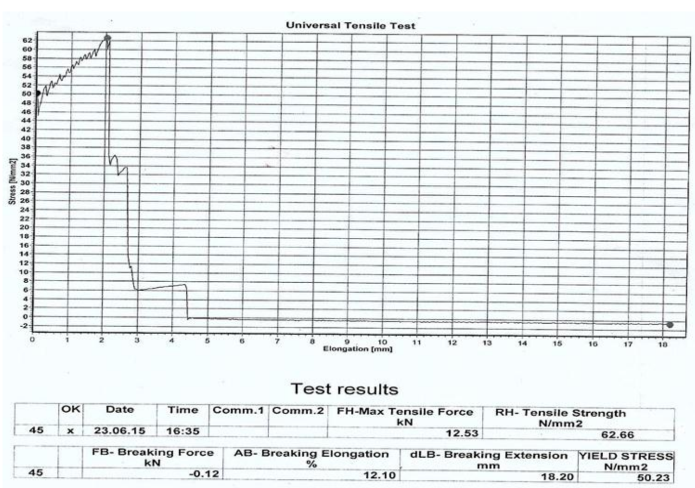

Fig. 16. *20mm Bamboo Tensile Strength Test Result.*

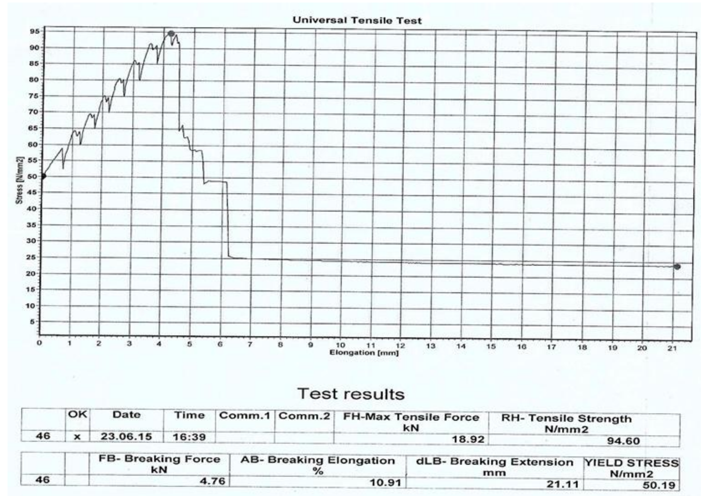

Fig. 17. *25mm Bamboo Tensile Strength Test Result.*

TABLE 4
TEST RESULTS SHOWING THE COMPARATIVE TENSILE STRENGTH PROPERTIES OF STEEL AND BAMBOO

	High Yield Steel Bar		Mild Steel Bar		Bamboo	
Sample Size	Tensile Strength (n/mm²)	Breaking Elongation (%)	Tensile Strength (n/mm²)	Breaking Elongation (%)	Tensile Strength (n/mm²)	Breaking Elongation (%)
10mm	457.13	19.25	290.49	51.61	31.55	0.00
12mm	689.12	26.10	508.08	39.57	31.07	0.00
16mm	711.61	35.27	508.71	55.53	68.82	15.07
20mm	713.40	30.72	372.98	23.68	62.66	12.10
25mm	792.90	26.11	701.74	29.65	94.60	10.91

4 DISCUSSION

Table: 1-4 shows that high yield steel bar has the highest resistance to tension giving a tensile strength ranging from 457N/mm² -792N/mm²; Yield stress of 379N/mm²- 678N/mm² and a tensile force ranging from 35kN - 389kN. Mild steel on the other hand, has tensile strength values from 290N/mm²-508N/mm²; Yield stress from 223N/mm²- 376N/mm² and a tensile force ranging from 24kN – 220kN. Bamboo can be said to be very poor in tension giving a tensile strength of 31N/mm²- 94N/mm²; Yield stress of 0N/mm² - 50.19N/mm² and a tensile force value of 3kN – 19kN. The ductility of steel allows it to undergo plastic deformation and necking before breaking. Bamboo undergoes brittle failure. i.e., it breaks sharply without plastic deformation. This property is demonstrated from the result of breaking elongations obtained. Mild steel is most ductile giving a breaking elongation ranging from 30% - 52%; followed by high yield steel with a value of 19% - 26%. Finally Bamboo which undergoes brittle failure gives a breaking elongation of 0% - 15%. Although this work does not include investigating bamboo as reinforcement in structural concrete; a similar work by [6] that investigates bamboo as reinforcement in structural concrete elements, concludes that bamboo can substitute steel satisfactorily as reinforcement in concrete structures. The study highlights that bamboo as structural elements can be utilized in many building constructions which are at variance with the present study. A study that correlates the present findings is reported in [13] that bamboo can be used and has been employed in many engineering applications in construction for hundreds of years because of its high strength-to-weight ratio and its relative ease of use. Its properties are such that it has potential for reinforcing weaker (lightweight) materials. Gleeson (2002) in [13], reviews the use of bamboo in lightweight construction and concludes that although, bamboo has potential for use as reinforcement in specific circumstances, it is by no means the easiest material to use and considerably more research is required if its potential is to be realized. For example, Datye et al. (1978) in [13] state that, "bamboo reinforced cement concrete has not met with any degree of success mainly due to the low elastic modulus of bamboo, its poor bond with concrete and its tendency for volume change due to moisture absorption". On the other hand, Subrahmanya (1984) in [13] concludes that "… notwithstanding the future requirements (of research), bamboo reinforced cement composites can be effectively used on the basis of existing knowledge". Thus it is important to note that limitations of bamboo reinforcement and, in particular, its low elastic modulus are a limiting factor in many reinforcement uses of bamboo for heavy construction works.

5 Conclusion

Several samples of bamboo and steel were tested and analyzed to examine their Tensile Properties. This test was carried out on high yield and mild yield steel including bamboo. Tensile test was carried out on 10mm, 12mm, 16mm, 20mm and 25mm high yield and mild yield steel bars. Bamboo also was prepared to about equivalent dimension having cross-sectional area of 10mm × 10mm, 12mm × 10mm, 16mm × 10mm, 20mm × 10mm and 25mm × 10mm. The tensile test result indicates that bamboo unlike steel has a very poor tensile property and undergoes brittle failure when loaded. This is a huge disadvantage of using bamboo as a structural member in building construction. Therefore, the study concludes that due to the minimal breaking force (FB) of bamboo, it cannot be employed as a main structural member in buildings and other heavy engineering works but can be used for partition walls, ceilings, roofs and other areas of lightweight engineering construction that is not heavy load-bearing.

References

[1] S. Amada, "Bamboo: A Natural, Super-advanced and Intelligent Material," *In Proceeding of the 2nd International Conference on Non-Conventional Construction Materials (NOCMAT-97),* Bhubaneswar, India, 1997, pp. 1–9, 1997.

[2] S. Amada, T. Munekata, Y. Nagase, Y. Ichikawa, A. Kirigai and Y. Zhifei, "The Mechanical Structures of Bamboo in Viewpoint of Functionally Gradient and Composite Materials," *Journal of Composite Materials*, 30(7), pp. 800-819, 1996.

[3] M. F. Ashby, "Materials Selection in Mechanical Design," Oxford Pergamon Press; 1992.

[4] Chinese Bamboo Research Council (CBRC), "Cultivation of Bamboo," Books 1&2, 2009.

[5] D. Farrelly, "The book of Bamboo," San Francisco (CA), Sierra Club Books, pp. 340, 1984.

[6] K. Ghavami, "Bamboo as reinforcement in structural concrete elements: cement and concrete composites," pp. 637-649, http:// www.sciencedirect.com . 2004

[7] K. Ghavami, R.V. Hombeeck, "Application of Bamboo as a Construction Material: Part I: Mechanical Properties and Water Repellent Treatment of Bamboo, Part II; Bamboo Reinforced Concrete Beams," *In Proceeding of Latin American Symposium on Rational Organization of Building Applied to Low Cost Housing*, CIB, Sa˜o Paulo, Brazil, pp. 49–66, 1981.

[8] K. Ghavami, "Application of Bamboo as a Low-Cost Construction Material," *In Procoft International Bamboo Workshop*, Cochin, India, pp. 270–279, 1988.

[9] K. Ghavami, "Ultimate Load Behaviour of Bamboo Reinforced Lightweight Concrete Beams," J. Cement Concrete Compos, pp. 281–288, 1995.

[10] ICBO, AC 162 "Acceptance Criteria for Structural Bamboo," ICBO Evaluation Service Ltd., California, USA, 2000.

[11] J. A . Janssen, "The Importance of Bamboo as a Building Material: Bamboo's ," *Procoft International Bamboo Workshop*, Kerala Forest Research Institute, India & IDRC, Canada, pp. 235–241, 1988.

[12] W. Liese, "The Structure of Bamboo in Relation to its Properties and Utilization," *In Procoft International Symposium on Industrial Use of Bamboo*, Beijing, China, pp. 95–100, 1992.

[13] South East Asia Community Access Programme (SECAP), Technical Paper No. 1, "Development of Local Resource Based Standards, for the Royal Government of Cambodia," 2008.

[14] R. N. Swamy, "New Reinforced Concretes; Concrete Technology and Design," Vol. 2, Blackie and Son, Glasgow, 1984.

[15] U. G. K. Wegst, H. R. Shercliff and M. F. Ashby, " The Structure and Properties of Bamboo as an Engineering Material," University of Cambridge, UK, 1993.