Research Journal of Environmental and Earth Sciences 4(1): 8-15, 2012
ISSN: 2041-0492

Submitted: January 15, 2011 Accepted: April 30, 2011 Published: January 01, 2012

The Effect of Notched Designs on the Performance of Bamboo

[1]L. Gyansah and [2]S. Kwofie
[1]Department of Mechanical Engineering, University of Liberia, T.J.R. Faulkner College of Science and Technology, Division of Engineering, Rutgers University, The State University of New Jersey, USA
[2]Department of Materials Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract: This research was carried out to find out the behaviour of carefully cut-out notches of U, V, Semi-Circular, and Square shapes on bamboo samples at constant length of 250 mm. All specimens were subjected to axial loads using the uniaxial compression machine. The time of failure and maximum loads before failure were obtained accordingly. The compressive stresses of the specimens were evaluated. Results of the entire experiment were carefully analyzed and it was established that U-notched samples had the shortest time of failure; followed by the square notched samples; and then followed by the semi-circular notched samples, and finally the V-notched samples had the longest time of failure. The semi-circular notched samples had the smallest load of failure; followed by the U-notched samples; and then followed by the square notched samples, and finally the V-notched samples had the largest load of failure. The load of failure for the V, U, square, and semi-circular notches are 74.67, 49, 56.67 and 40 kN, respectively. Time of failure for the V, U, square and semi-circular notches are 52.71, 44.22, 45.69 and 50.79 s, respectively. In any design where the uses of notches in bamboo are employed, the designer or engineer should use V-notched shaped designs if load is the baseline for the design otherwise square-notched design is recommended, if stress is the baseline.

Key words: Crushing strength, loading failure, semi-circular notched, square notched, u-notched, v-notched

INTRODUCTION

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. It is considered a composite material because it consists of cellulose fibers imbedded in a lignin matrix. Cellulose fibers are aligned along the length of the bamboo, providing maximum tensile flexural strength and rigidity in that direction (Lakkad and Patel, 1980). Over 1200 bamboo species have been identified globally (Wang and Shen, 1987). Massive plantation of bamboo provides an increasingly important source of raw material for pulp and paper industry in China (Hammett and Youngs, 2002). It has tremendous economic potential and is one of the strongest building materials. As such, it has also been widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses, rafters and purlins; it is also used in construction as structural materials for bridges, water transportation facilities and skyscraper scaffoldings.

Due to its immense advantages, the Liberian Construction industry has begun using bamboo for its constructional works in order to avoid the depletion of our forest reserves. Secondly, bamboo is stronger and has a longer life span than wood. In addition to the above, bamboo is economically cheaper than wood. Furthermore, bamboo is a renewable resource, environmentally safe, and one of the top producers of biomass (plant tissue) known. Up to 88 tons of culms are produced per hectare per year under plantation conditions (depending on species and management) (Oteng-Amoako and Obiri-Darko, 2002).

In buildings, mega structures, bridges, skyscraper scaffoldings where the use of bamboo is employed, most of the stresses are concentrated at where there is a notch and that is where failure is likely to occur (Tomalang *et al*., 1980). Despite the aforementioned advantages of the applications of bamboo, accidents do occur with the use of this material as well as its general constructional usage which is detrimental to the human lives and the environment. .

Hence, the aim of this research is to study and understand the behaviour of bamboo with different types of notches of U, V, semi-circular, square shapes and knowing their effects will help to educate those in the construction industry in particular and the general public on its usage.

LITRATURE REVIEW

Bamboo is a rapid growing fibrous plant available in abundance on the earth. It has tremendous economic

Corresponding Author: L. Gyansah, Department of Mechanical Engineering, University of Liberia, T.J.R Faulkner College of Science and Technology, Division of Engineering, Rutgers University, The State University of New Jersey, USA

potential and is one of the strongest building materials. Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. It is considered a composite material because it consists of cellulose fibers imbedded in a lignin matrix (Xiaobo, 2004). Cellulose fibers are aligned along the length of the bamboo providing maximum tensile flexural strength and rigidity in that direction (Lakkad and Patel, 1980; Zamuco *et al*., 1969). Over 1200 bamboo species have been identified globally (Wang and Shen, 1987). The plant has a very long history with human kind. Bamboo chips were used to record history in ancient China. It is also one of the oldest building materials used by human kind (Abd.Latif *et al*., 1990).

Bamboos mainly consist of the roots, culm and leaves. The culms are the most distinguishable part in bamboo plant species. The culm mainly consists of the strands of microscopic cellulose fibers and the lignin matrix. The cellulose fibers run the length of the culm. The spaces between adjacent strands of fibers are filled with lignin, a thermoplastic resin (Hammett *et al.*, 2001). Generally, cellulose fiber is stronger than the lignin matrix. Also the cross-sectional area of the culm changes from location to location (Abd.Latif *et a l*., 1993; Espiloy, 1987; Grosser and Liese, 1971). Toward the outer surface of the culm, the number of fibrous strands increases rapidly. When considered from the outermost surface inwardly, the number of cellulose strands decrease. They are usually hollow and vary in sizes, diameters, colours and textures. Countless tiny black spots can be seen at the cross-section of the culm (hollow stem). These are the cellulose fibers which run the length of the culm carrying nutrients between roots and leaves (Chen and Qin, 1985; Lee *et al*., 1994; Liese and Weiner, 1997; Limaye, 1948; Limaye, 1952). The rest of stem is lighter coloured lignin. In brief, the total culm comprises about 50% parenchyma, 40% fibers and 10% conducting tissue (vessels and sieve tubes). Hence, the cellulose strand distribution would be different at different sections of the culm. Hence, it is generally observed that the mechanical properties of bamboos vary enormously. Generally, bamboo is an orthotropic material, that is, it has particular mechanical properties in the three directions: longitudinal, radial and tangential. However, it is a biological material (Liese, 1995; Liese, 1987; Maheshwari and Satpathy, 1988; Seema and Kumar, 1992). It is subjected to greater variability and complexity due to various conditions such as years of growth, soil and environmental conditions and the location of culm within the bamboo. Additionally, distribution of cellulose fibers within the bamboo culm is not uniform (Lakkad and Patel, 1980). Fortunately, bamboo is much simpler constructed than wood and the differences among the about 1200 species appear relatively small. Nevertheless, a detailed analysis of the reactions between structure and properties does hardly exist so far. The few case studies were already starting with the work by (Ota, 1951). Some of the species include: *Bambusa balcooa*; *Bambusa bambos*; *Bambusa nutans*; *Bambusa tulda*; *Dendrocalamus giganteus*; *Dendrocalamus strictus*; *Melocanna bambusoides*; *Dendrocalamus hamiltoni*; *Gigantichola macrostachya*; *Phyllastachys bambusoides.* As a cheap and fast-grown resource with superior physical and mechanical properties compared to most wood species, bamboo offers great potential as an alternative to wood. Since bamboo species are invasive and spread very fast, uncared bamboo species also cause environmental problems (Sekhar *et al*., 1962). Increased research during the recent years has considerably contributed to the understanding of bamboo as well as to improved processing technologies for broader uses. It has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. In Asian countries, bamboo has been used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts, chairs, etc (Liese, 1995). It has also been widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses, rafters and purlins; it is also used in construction as structural materials for bridges, water transportation facilities and skyscraper scaffoldings. With the continued rapid development of the global economy and constant increase in population, the overall demand for wood and wood based products will likely continue to increase in the future. According to a FAO (Food and Agriculture Organization) global outlook study on the trends of demand for wood products, there will be an increase in demand of the order of 20% by 2010. The current concern is whether this future demand for forest products can be met sustainably (FAO, 1997). In comparison with wood, the anatomical, chemical and physical-mechanical properties of bamboo exhibit no basic differences among genera and species. Also growth conditions and aging have apparently no significant effect on composition and structure of the tissue (Widjaja and Rlsyad, 1987).

Analysis of mechanical properties is the investigation of behaviour of the materials under different loading conditions. A notch is any cut or action on members or bars that ensures discontinuity or disruption of uniform stress concentrations along the prismatic bars. The disruption causes highly localized stresses over the notched regions. The high localized stresses created by the different types of notches as well as the concentrated loads and reactions, are known as stress concentrations or stress raisers (Gyansah and Ansah, 2010). Information about the deformation behaviour of different bamboo species in different forms is an important requirement for the effective use of these bamboo species for different engineering applications. The specific gravity determines to a large extent the mechanical properties of the culm. It depends mainly on the fiber content, as well as fiber diameter, and cell wall thickness (Lee *et al*., 1994). Along the culm the specific gravity augments with the increase of the fiber percentage. Many investigations have proved this close relationship. A different behaviour of species often results from a different anatomical make-up, as it has been shown for some Philippine bamboos by (Espiloy, 1987), for Indonesian bamboos by (Widjaja and Rlsyad, 1987), and for Malaysian bamboo by (Abd.Latif *et al*., 1990).

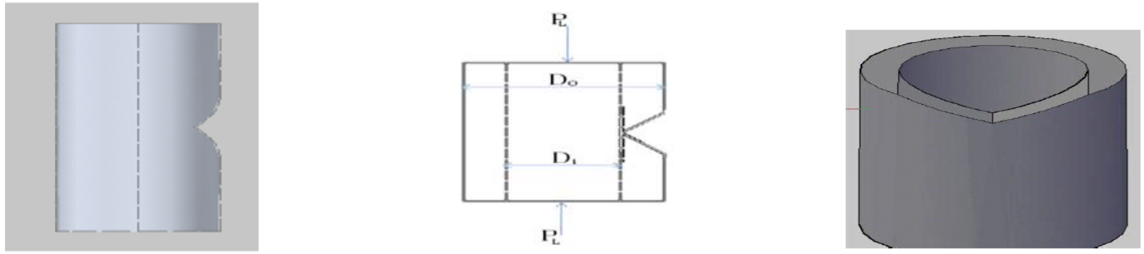
Specific Gravity (SG) is a measure of the density of a substance. The specific gravity of a substance is a comparison of its density to that of water. The specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on the anatomical structure. The moisture content of bamboo varies vertically from the bottom to the top portions and horizontally from the outer layer to the inner layers. Bamboo possesses very high Moisture Content (MC). Green bamboo may have 100% moisture (oven-dry weight basis) and can be as high as 155% for the innermost layers to 70% for the peripheral layers. The vertical variation from the top (82%) to the bottom (110%) is comparatively less. The fiber saturation point of bamboo is around 20-22% (Kishen *et al*., 1956). The MC range of *Bambusa bluemeana* is 57-97% (Abd.Latif *et al*., 1993; Lee *et al*., 1994) revealed that *Phyllostachys bambusoides* has an average MC of 138% and a green SG of 0.48. The density is dependent on the species, the position in the culm and other environmental factors. There is a direct relationship between density and strength. The higher the density of bamboo, the higher the strength. In general, SG and the properties of bamboo drop from the top portion to the bottom. The increase in weight is cumulative and directly related with age. Strength properties are reported to decrease in older culms (Zhou, 1981). Limaye (1948, 1952) found that older culms of *Dendrocalamus strictus* became 40-50% stronger and stiffer than younger ones. Maximum values were found in 3-6 year old culms. (Sekhar *et al*., 1962) found highest values in 3-4 year old culms of *Bambusa nutans*. Bamboo has relatively high axial compression strength, but this is often offset by a lack of straightness resulting in buckling long before the crushing load is reached. Compressive strength properties have been evaluated for the bamboo composite tiles or strips (Gyansah *et al*., 2010). Studies have been carried out as per ASTM D 695-96 (17). Also studies have been carried out using specimens of cuboids shape. The loading was parallel to grains, perpendicular to grains as well as along through-the-thickness direction. The specimens were tested on Hounsfield Universal Testing Machine of capacity 50 kN and the loading rate was 0.9 mm/min. Bamboo has a relatively high modulus of elasticity (in absolute terms higher than mild steel, wood and concrete). When subjected to excessive bending, bamboo splits axially along its length due to failure of the lignin bonding the fibers together, and the bamboo loses its circular form. The fibers remain intact though. Upon release of the load, the bamboo largely regains its original shape. Especially for the construction of the bamboo tube joining, it is important to consider the shearing resistance (Zhou, 1981). The influence of the distance of the shearing surface decreases with growing length of shearing surface. At a wall thickness of 10 mm, the shearing strength is about 11% lower than at a tube with a wall thickness of 6 mm; this could be explained by the distribution of the high-strength fibres per cross section surface. The irregularity of the grain with an interwoven structure provides more shearing strength than the inter-nodes with their axial arrangement of fiber-sheaths and bundles embedded in homogenous parenchyma. The nodal portion with about 20% of culm or weight basis has shorter fibers, lower holo-cellulose content, but higher content of extractives, pentosans, lignin and ash than the inter-nodal portion. Consequently, pulp of the nodal portion has lower strength properties than from the inter-nodal portion, but both portions cannot be separated (Maheshwari and Satpathy, 1988).

MATERIALS AND METHODS

Materials: The bamboo specie used as specimens for this experimental work is known as *Bambusa Vulgaris* and was obtained from the plantation around the University of Liberia forest fields. This experiment was carried out to determine the behaviour of various notches which were carefully cut-out on various bamboo samples at constant length. The equipment used for this experiment was the Uni-axial Compression Machine. The experiments were carried out in the Geological Engineering Laboratory at University of Liberia, Liberia in April, 2011.

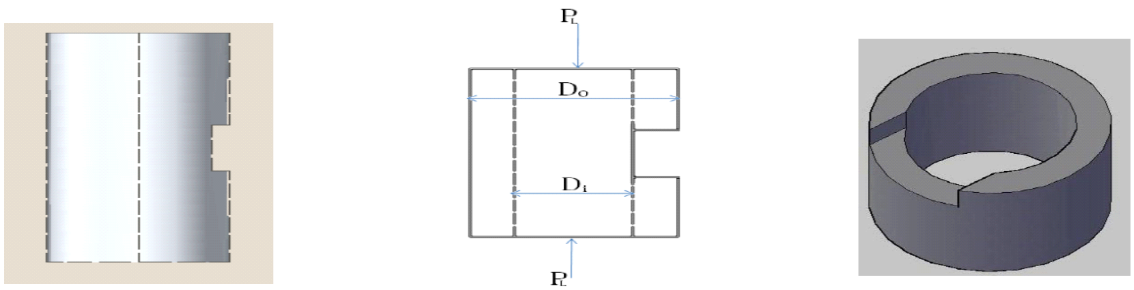
Sample preparation: The dried Bambusa Vulgaris as received from the forest fields were free from insect infestation. The specimens were polished to be free of nicks, dents and scratches. The specimens were dried in the sun for fourteen days between a temperature of 29ºC and 31ºC. The average moisture content was calculated to be 2%. The specimens were polished with abrasive paper. Compressed air was blown on the surface of the specimen to remove dirt particles. Bamboo specimens were taken from the internodes of a single culm. The maximum specimen height for the experiment was 250 mm.

Specimen designs: All specimens had a maximum height of 250 mm. The V-notched specimens had an angle 50º cut on one side. The square notched specimens had a square notched of length 20 mm cut on one side. The



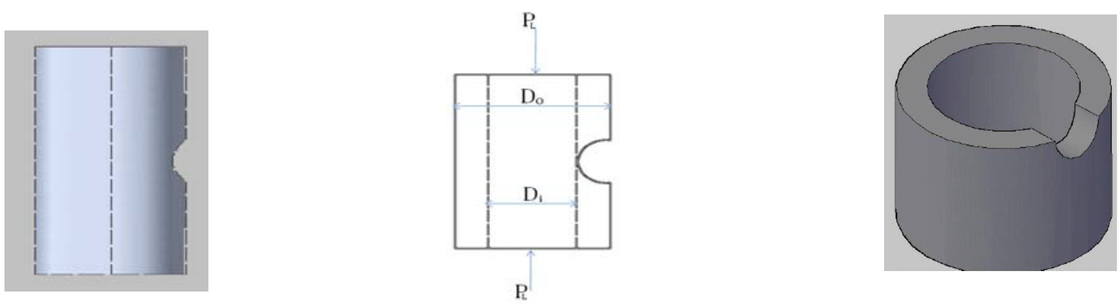
End view of V-notched specimen   Longitudinal section of V-notched specimen   Front view of V-Notched specimen

Fig. 1**:** Sectional views of V-notched specimen



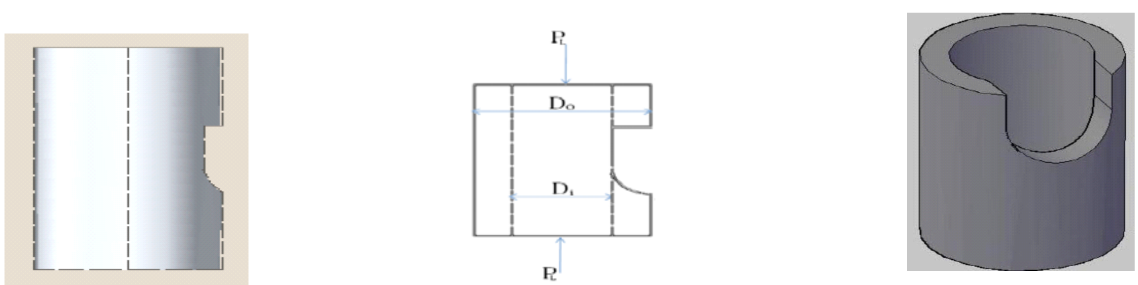
End view of square-notched specimen   Longitudinal section of square-notched specimen   Front view of square-notched specimen

Fig. 2: Sectional view of square-notched specimen



End view of semi-circular-notched specimen   Longitudinal section of semi-circular-notched specimen   Front view of semi-circular-notched specimen

Fig. 3: Sectional views of semi-circular-notched specimen



End view of U-notched specimen   Longitudinal section of U-notched specimen   Front view of U-notched specimen

Fig. 4: Sectional views of U-notched specimen

Fig. 5: v-Notched specimen under uniaxial compressive loading (before crushing)

Fig. 6: V-Notched specimen under uniaxial compressive loading (after crushing)

semi-circular notched specimens had a notched of radius 20 mm cut on one side. The U-notched specimens had a U-notched of radius 20 mm and length 20 mm cut on one side. The diameters of all specimens ranged between about 41 and 70 mm. The geometric specimen configuration are shown in Fig. 1, 2, 3 and 4. P_L is the compressive load and D_O and D_I are the outside and inside diameters**.**

Experiment:

Compressive test: The Crushing test was carried out at the University of Liberia, Geological engineering Laboratory at a room temperature. The equipment used was the Uni-axial Compression Machine with a maximum capacity of 1500 kN. Each specimen had a type of notch on it, namely V-notched, square notched, semi-circular notched, and the U-notched. Each specimen was carefully placed in between the upper and base metal plates in the compression machine. The compression machine was switched on and by hydraulic principle ; the base metal plate gradually rose up till the specimen was held fixed between the plates.

Table 1: Results from the crushing test.

Sample	Inner diameter (m)	Outer diameter(m)	Time of failure (s)	Load of failure (kN)
V1	0.0460	0.0685	56.26	78
V2	0.0499	0.0687	53.16	76
V3	0.0475	0.0686	55.45	70
S1	0.0534	0.0693	52.52	52
S2	0.0552	0.0697	40.18	48
S3	0.0419	0.0628	44.38	70
C1	0.0550	0.0698	54.02	40
C2	0.0558	0.0683	48.55	38
C3	0.0564	0.0685	49.89	42
U1	0.0487	0.0683	43.19	52
U2	0.0583	0.0683	43.72	45
U3	0.0518	0.0691	45.75	50

The stopwatch was then engaged to record the time of failure of crushing. Furthermore, the base metal continued to rise up till the specimen crushed. The load of failure was read from the dial indicator of the Uniaxial Compression machine. The process continued until all specimens were crushed and their loads and times of failures were correspondingly recorded. Figure 5 shows a V-notched bamboo specimen subjected to compressive loading condition whilst Fig. 6 illustrate V-notched specimen after being crushed.

RESULTS AND DISCUSSION

Results from the crushing test are illustrated in Table 1, 2 and Fig. 7 to 11. It was observed from Fig. 11 that the failure stress for the V-notched specimen was 101.41 MPa and the time of failure was 52.71 s. The time of failure for square-notched specimen (Fig. 8) was 45.69 s and the failure stress was 150 MPa. Analyzing Fig. 9, the failure stress induced in the semi-circular specimen was 99.65 MPa and it time of failure was 50.79 s. From Fig. 10, the time of failure was 44.22 s and the failure stress was 82.05 MPa. Analyzing Fig. 11 critically, it can be observed that V-notched and semi-circular notched specimen had a very close failure stresses which explain the fact that their stress concentrations are almost the

Table 2: Final computation of the entire experimental results

Specimen	Time of failure (s)	Load of failure (Kn)	Stress (MPa)	Average time of failure (s)	Average load of failure (kN)	Average stress (MPa)
V_1	49.52	78	97.42	52.71	74.67	101.41
V_2	53.16	76	113.60			
V_3	55.45	70	93.20			
S_1	52.52	52	148.91	45.69	56.67	150.72
S_2	40.18	48	150.72			
S_3	44.38	70	152.54			
SC_1	54.02	40	87.70	50.79	40.00	99.65
SC_2	48.47	38	98.61			
SC_3	49.89	42	112.63			
U_1	43.19	52	65.04	44.22	49.00	82.05
U_2	43.72	45	110.30			
U_3	45.75	50	70.81			

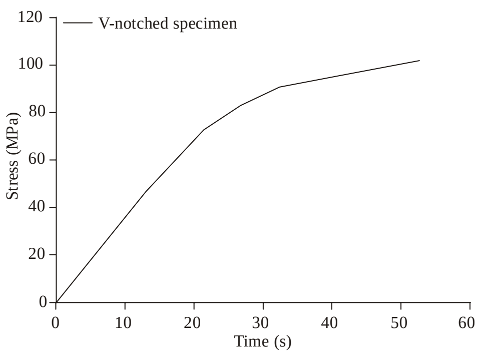


Fig. 7: Stress-time graph for V-notched specimen

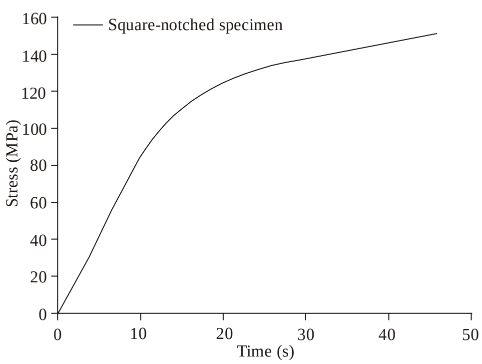


Fig. 8: Stress-time graph for square-notched specimen

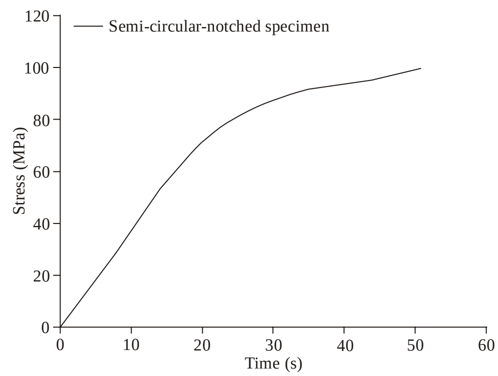


Fig. 9: Stress-time graph for semi-circular notched specimen

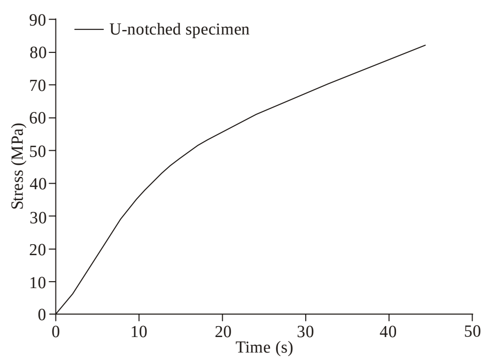


Fig. 10: Stress-time graph for U-notched specimen

same. Conclusively, the U-notched specimen had the shortest time of failure; followed by the square notched specimen; and then followed by the semi-circular notched specimen and finally the V-notched specimen had the longest time of failure. These comparative studies give the designer an idea on how to select a notch for a particular application, either for a machine or structural component. In any design where the uses of notches in bamboo are employed, the designer or the engineer should use V-notched shaped designs if load is the baseline for the design otherwise square-notched design is recommended if stress is the baseline. Builders that use bamboo as a prop for building construction should also be careful in selecting the type of notch to cut-out on the bamboo if the need arises. This statement is recommended because from the research it was clear that the semi-circular notched specimen gave the lowest load of failure (Table 2). This simply means that the bamboo with a semi-circular notched at a length of 250 mm can carry up to 40 kN above this load the bamboo will fail disastrously. The load of failure for the V, U, square, and semi-circular notches are 74.67, 49, 56.67 and 40 kN, respectively. Time of failure for the V, U, square and semi-circular notches are 52.71, 44.22, 45.69 and 50.79 s, respectively. The semi-circular notched specimen had the smallest load

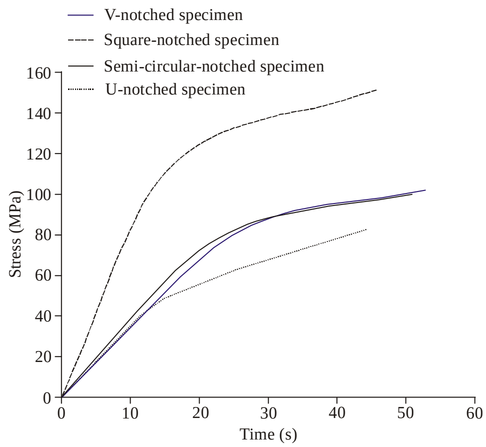


Fig. 11: Stress-time graph for V, U, square, semi-circular notched specimens

of failure; followed by the U-notched specimen; and then followed by the square notched specimen and finally the V-notched specimen had the biggest load of failure. The U-notched specimen had the lowest compressive stress; followed by semi-circular notched specimen; followed by the V-notched specimen; and finally the square notched specimen.

CONCLUSION

- The U-notched samples had the shortest time of failure; followed by the square notched samples; and hen followed by the semi-circular notched samples, and finally the V-notched samples had the longest time of failure.
- The semi-circular notched samples had the smallest load of failure; followed by the U-notched samples; and then followed by the square notched samples, and finally the V-notched samples had the largest load of failure
- The load of failure for the V, U, square, and semi-circular notches are 74.67, 49, 56.67 and 40 kN, respectively. Time of failure for the V, U, square and semi-circular notches are 52.71, 44.22, 45.69 and 50.79 s, respectively.

RECOMMENDATIONS

- In any design where the uses of notches in bamboo are employed, the designer or engineer should use V-notched shaped designs if load is the baseline for the design otherwise square-notched design is recommended, if stress is the baseline.
- Building contractors that use bamboo as a prop for building construction should also be careful in selecting the type of notch to cut-out on the bamboo if the need arises. This statement is recommended because from the research it was clear that the semi-circular notched bamboo gave the lowest load of failure.

ACKNOWLEDGMENT

The authors wish to acknowledge the support of RTI International and the USAID-funded EHELD project in enabling the production of this research. They are also thankful to the management of the geological laboratory of the University of Liberia, Liberia..

REFERENCES

Abd.Latif, M., T. Wan, A. Wan and A. Fauzidah, 1990. Anatomical Features and Mechanical Properties of three Malaysian bamboos. J. Trop. Forest Sci., 2: 227-234.

Abd.Latif, M., A. Ashaari, K. Jamaludin and Z.J. Mohd, 1993. Effects of Anatomical characteristics on the physical and mechanical properties of Bambusa bluemeana. J. Trop. Forest Sci., 6(2): 159-170.

Chen, Y.D. and W.L. Qin, 1985. The Chemical Composition of Ten Bamboo Species. Proceedings of the International Bamboo Workshop, Hangzhou, China. Chinese Academy of Forestry, Beijing China. In: Rao, A.N., *et al.*, (Eds.), International Development Research Center, Ottawa, Canada, pp: 110-113.

Espiloy, Z.B., 1987. Physico-Mechanical properties and Anatomical relationships of some Philippine bamboos. Proceedings of International Bamboo Workshop Hangzhou, China, Singapore, pp: 257-264.

Food and Agriculture Organisation (FAO), 1997. Provisional Outlook for Global Forest Products Consumption, Production and Trade. Forestry Department, Policy and Planning Division, FAO, Rome.

Grosser, D. and W. Liese, 1971. The anatomy of Asian bamboos, with special reference to their vascular bundles. Wood Sci. Technol., 5: 290-312.

Gyansah, L. and A.K. Ansah, 2010. Fatigue crack initiation analysis in 1060 steel. Res. J. Appl. Sci. Eng.Technol., 2(4): 319-325.

Gyansah, L., A.S. Akinwonmi and M. Affam, 2010. The fracture behaviour of Fresh bamboom under uniaxial compressive loading condition. Res. J. Appl. Sci. Eng. Technol., 2(8): 720-726.

Hammett, A.L. and R.L. Youngs, 2002. Innovative forest products and processes: meeting growing demand. J. Forest., 100(4): 6-1

Hammett, A.L., R.L. Youngs, X.F. Sun and M. Chandra, 2001. Non-wood fiber as an Alternative to wood fiber in China's pulp and paper industry. Holzforschung, 55(2): 219-224.

Kishen, J., D.P. Ghosh and M.A. Rehman, 1956. Studies on moisture content, shrinkage, swelling and intersection point of mature (*Dendrocalamus strictus*) male bamboo. Indian Forest Rec., 1: 1-30.

Lakkad, S.C. and J.M. Patel, 1980. Mechanical properties of bamboo, a natural composite. Fiber Sci. Technol., 14: 319-322.

Lee, A.W.C, X.S. Bai and P.N. Peralta, 1994. Selected Physical and Mechanical Properties of Giant Timber Bamboo grown in South Carolina. Forest Prod. J., 44(2): 40- 46.

Liese, W., 1987. Anatomy and properties of bamboo. Int. Bamboo Workshop Hangzhou. Recent Research on Bamboo, Ed. Chino Acad. of Forestry, Peking and IDRC, Canada, pp: 196-208.

Liese, W., 1995. Anatomy and utilization of bamboos. Sci. Cult. The Am. Bamboo Soc., 16(1): 18-31.

Liese, W. and G. Weiner., 1997. Modifications of Bamboo Culm Structures Due to Ageing and Wounding. The Linnean Society, London, pp: 313-322.

Limaye, V.D., 1948. Effect of age and season of felling on the strength properties of bamboo. Ind. For., 74(1): 17-18.

Limaye, V.D., 1952. Strength of bamboo (Dendrocalamus strictus). Ind. For. Rec., 78: 558-575.

Maheshwari, S. and K. Satpathy, 1988. Pulp and papermaking characteristics of nodes, internodes and culm of bamboo *Dendrocalamus Strictus*. IPPTA, 25: 15-19.

Ota, M., 1951. Studies on chemical properties of bamboo stem, Part 7: The influence of the percentage of structural elements on the Specific Gravity and Compressive Strength of bamboo splints. J. Jpn. Forest. Soc., 19: 25-47.

Oteng-Amoako, A.A. and B. Obiri-Darko, 2002. Rattan as a sustainable industry in Africa: The need for technological interventions. In Rattan: Current Research issues and prospects for conservation and sustainable development. Non Wood Forest Prod., 14: 89-100.

Seema, J. and R. Kumar, 1992. Mechanical behaviour of bamboo and bamboo composite. J. Mater. Sci., 27: 4598-4604.

Sekhar, A.C., B.S. Rawat and R.K. Bhartari, 1962. Strength of bamboo (*Bambusa nutans*). India Forest, 88: 67-73.

Tomalang, F.N., A.R. Lopez, J.A. Semara, R.F. Casin and Z.B. Espiloy, 1980. Properties and Utilization of Philippine Erect Bamboo. International Development Research Center and the International Union of Forestry Research Organization, pp: 266-275.

Wang, D. and S.J. Shen, 1987. Bamboos of China. Timber Press, Portland, Oregon, pp: 428.

Widjaja, E.A. and Z. Rlsyad, 1987. Anatomical Properties of Some Bamboo Utilized in Indonesia. In: Rao, A.N., G. Dhanarajan and C.B. Sastry, (Eds.), Recent Research on Bamboo, Proceeding of International Workshop Hangzhou, pp: 244-246.

Xiaobo, L., 2004. Physical, Chemical and Mechanical Properties of Bamboo. MSc. Project Report, Chinese Academy of Forestry, China, pp: 27.

Zamuco, G.I., R.R. Valbuena, C.K. Lindayen and L.R.Roberto, 1969. Fiber morphology: Its role in pulp and paper research. Philippine Lumberman, 15(1): 24-26.

Zhou, F.C., 1981. Studies on physical and mechanical properties of bamboo woods. Nanjing Technology College Forest Production, Vol. 2.