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EFFECT OF MOISTURE CONTENT ON PHYSICAL AND MECHANICAL PROPERTIES OF BAMBOO

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ABSTRACT

Bamboo is a giant grass and not a tree. Bamboo completes its growth within some months and matures at the age of around three years, there is no secondary growth. Moisture content of bamboo varies along its height location and with seasoning period, which affects all physical and mechanical properties. It is one of the important factors in deciding the life of bamboo. This paper presents results of experimental investigations made to evaluate the physical and mechanical properties of the bamboo species *Dendrocalamus strictus* and its utilization potential as building material may be as whole or in the split form. In the present study moisture content, specific gravity, water absorption, dimensional changes, tensile and compressive strength at different height location are worked out. The moisture content varies along the height for green bamboo or at any time after harvesting. The top portions had consistently lower moisture content than the middle or basal at all stages of seasoning. Specific gravity on oven dry mass basis decreases from top to bottom and is independent of moisture content. Water absorption is inversely proportional while dimensional changes, tensile and compressive strength are directly proportionate to moisture content.

Keywords: Bamboo; water absorption; specific gravity; tensile strength; compressive strength

1. INTRODUCTION

Bamboo is one of the replenishable, low cost and low energy intensive, extreme product of nature which is used as construction materials in hut type dwellings in developing countries and is also well established source of paper pulp [1]. The use of bamboo for housing is perhaps as old as mankind, however, the superior strength and mechanical properties of bamboo and its potential for use as reinforcement for cement matrices started at the beginning of twentieth century. This was followed by several field applications in China. It

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is known that during the Second World War, the American and Japanese armed forces had used bamboo reinforcement in emergency military structures [2].

Bamboo is a natural composite material which grows abundantly in most of the tropical countries. It is considered as 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 [3]. The bamboo culms are divided into segments by solid transversal diaphragms or nodes. Its outermost layer, the bark, consists of epidermal cells that contain a waxy layer called cutin. The innermost layer is composed of sclerenchyma cells. The middle layer is formed by fibers, veins and sap conduits which are randomly disposed in the transversal section and wrapped in a tissue, called parenchyma. On an average, 30% of the culms are composed of parenchyma, 60% by fibers and 10% by veins and sap conduits [4].These percentages change from species to species and they directly influence the physical and mechanical properties of the bamboo, which in turns related to the fiber volumetric ratio. Bamboo culms are have properties such as high strength in the direction parallel to the fibers, which run longitudinally along the length of the culm, and low strength in a direction perpendicular to the fibers. Fiber distribution is more uniform at the base than at the middle or top since bamboo is subjected to maximum bending stress due to wind. Similarly, when bamboo is covered with heavy snow, it can bend till it touches the ground without breaking. The mechanical properties vary with height and age of the bamboo culm. The density of fibers in cross-section of a bamboo shell varies with thickness as well as height. The nodes divide the bamboo into number of segments, each segment acts as short column and prevents buckling and also, play a role of axial crack arresters. This implies that, bamboo has greater flexibility than any type of wood. The properties such as a lightweight, flexibility and toughness due to its thin walls with discretely distributed nodes and its good tensile strength up to 350 N/mm^2 make it a promising material for construction [3,5,6].

Bamboo is used as structural material for scaffolding at construction sites in India, China and other countries as it is a tough, flexible, light weight and low cost material. It was found that energy required for producing steel is 50 times more than that required for bamboo to carry same force [7]. Its abundance in tropical and subtropical regions make it an economically advantageous construction material. Research findings indicate that the strength of bamboo increases with age. The strength decreases at a later age. Bamboo reaches its full growth in just a few months and reaches its maximum mechanical strength in just three years [5,7] . One of the amazing aspects of bamboo is the way it interacts with the environment. It has been discovered that bamboo can prevent the pollution by absorbing large amount of nitrogen from waste water and reducing the amount of carbon dioxide in the air [1,8].

The moisture content of bamboo is the decisive factor for its use as structural element as all mechanical and physical properties are functions of it. The life span of bamboo also depends upon the moisture content, as it attract the fungi and borer insects. The rotting process is faster in bamboo having more water content. Bamboo is more prone to insect attack than other trees and grasses because of its high content of nutrients. This study was aimed with experiments to relate the variation of key mechanical and physical properties of bamboo with its moisture content. The moisture content along the height of bamboo culm is also not constant, so also the physical and mechanical properties.

2. PHYSICAL AND MECHANICAL PROPERTIES

Like other plants, bamboo possesses very high moisture content. Fresh cut green bamboo may have 100% percent moisture on dry weight basis. Moisture Content (MC) can be as high as 150% for the innermost layers to 70 percent for the peripheral layers. The vertical variation from the top (82%) to the bottom (110%) is comparatively less. Abd. Latif noted in 1993, that the MC range of *Bambusa bluemeana* is 57-97% and that for *Dendrocalamus strictus* is 55-95%. The moisture content of bamboo varies vertically from the bottom to the top portions and horizontally from the outer layer to the inner layers [9,10].

Unlike wood, bamboo has no secondary growth; all gains after it reaches its full height are due to the addition of material to cells after the first year. Fibers in bamboos are grouped in bundles and sheaths around the vessels. The epidermal walls consist of an outer and inner layer; the latter of which is highly lignified. Fiber length and fiber width varies within one internode. Fiber percentage is higher in the outer one- third of the wall and in the upper part of the culm, contributing to its superior slenderness as reported by Grosser and Liese in 1971. Specific gravity of the peripheral layers is more than the inner layers at all height locations of bamboo. 60-70% of the total weight of bamboo is the contribution of 40% fibers which are only by volume, rest is by parenchyma and vessels and capillaries. The specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on the anatomical structure and the species [10,11,12].

The physical and mechanical properties of bamboo vary with the age of the bamboo and the height of the culm. Species of bamboo in tropical belt shows maximum strength at third to fourth year of age [1,7,12]. It is found that older culms of *Dendrocalamus strictus* became 40-50 percent stronger and stiffer than young ones [12].

3. EXPERIMENTAL PROGRAMS

The objectives of this study were to find out the effect of moisture content and height location on

1) Specific gravity
2) Water absorption and dimensional changes
3) Tensile strength and compressive strength of bamboo

4. MATERIALS AND METHODS

For this study three years old and approximately 10 m long bamboo of *Dendrocalamus strictus* variety culms, harvested in January 2009, from Chandrapur forest of Maharashtra state of India were used. In India the bamboo harvesting season starts normally in January and lasts up to May, however, schedule may vary according to government policies. The outer diameter of the bamboo was ranged between 30 mm to 50 mm at the base with the average node spacing of 385 mm. The average values of geometric properties of the culms are shown in Table 1. Fifteen defects free and randomly chosen culms were purchased from local market in February 2009, which then divided into three groups. The first group was tested immediately after purchase i.e. 30 days after harvesting. Other two groups were kept in open atmosphere for three months, thereafter; each bamboo was cut into three parts and kept in laboratory, to protect it from the possible rains. Second group was tested after 6 months of harvesting and third group after 12 months of harvesting. During these 11 months, atmospheric temperature variation was from 8°C to 43°C. All were tested for moisture content, specific gravity, water absorption, dimensional changes, compressive and tensile strength.

Table 1: Average values of geometric properties of bamboo

Sr. No.	**Height location**	**Outer diameter (mm)**	**Node spacing (mm)**	**Wall thickness (mm)**	**Cross sectional area (mm^2)**
1	Top	33.12	352	6.45	540.15
2	Middle	34.85	348	8.48	702.16
3	Basal	42.64	344	10.70	1073.12

4.1 Moisture content and specific gravity

4.1.1 Moisture content

Moisture content of bamboo were determined using specimen of size approximately 25x25 mm derived from representative bamboo used for mechanical tests like tension or compression. The samples were weighed and then dried in oven at a temperature of 103+-2^0C for 24 hours as per Indian Standard [13,14]. The moisture content is calculated on the oven dried mass basis.

4.1.2 Specific gravity

The specific gravity is worked out as per above mentioned Indian code of practice using specimen of size approximately 25x25 mm from intermodal region the mass of the specimen was weighed correct to 0.001g and the volume to $1mm^3$ for density calculation[13,14]. The calculated density is then corrected density on dry mass basis, knowing the moisture content of the specimen.

4.2 Water absorption and dimensional changes

Though bamboo appears to be a low cost alternative to steel, water absorption is one of the main drawbacks of bamboo, when it is used as reinforcement in concrete. The percentage water absorption by bamboo was studied on several specimens of *Dendrocalamus strictus* as a whole bamboo as well as splints with different moisture content and height locations. The range of specimens covers basal, middle and top, with and without node after one, six and twelve months of harvesting. For the first day, the hourly observations were noted; thereafter the interval of readings was 24 hours for seven days. All bamboo specimens were untreated and dimensional variations in them were compared due to absorption of water.

4.3 Tension and compression test

4.3.1 Tension test

The chosen bamboos were divided into splints which are further shaped as specimens for tension test. The splints were shaped so as to have uniform width throughout without disturbing the inner and outer curvatures. The area of cross section of the specimen was kept low to avoid slippage at tabs at the ends or grips of the tension testing machine as shown in Figure 1.

Figure 1. Tension test specimen with and without node, with end tabs

The material structure of bamboo is not uniform along the length due to nodes. Also, the information given in literature referred so far with regards to, the effect of the node on tensile strength of bamboo, found to be limited and hence it was desired to study this effect. Half of the specimens were taken from inter-nodal zone and remaining from the nodal region. Specimens extracted from basal, middle and top part of bamboo were tested. Care was exercised while preparing samples with nodes so that a node was at the center of the gauge length. To avoid crushing of bamboo within the grips of the Universal Testing Machine (UT100), aluminum tabs were pasted to the specimen in the grip length.

4.3.2 Compression test

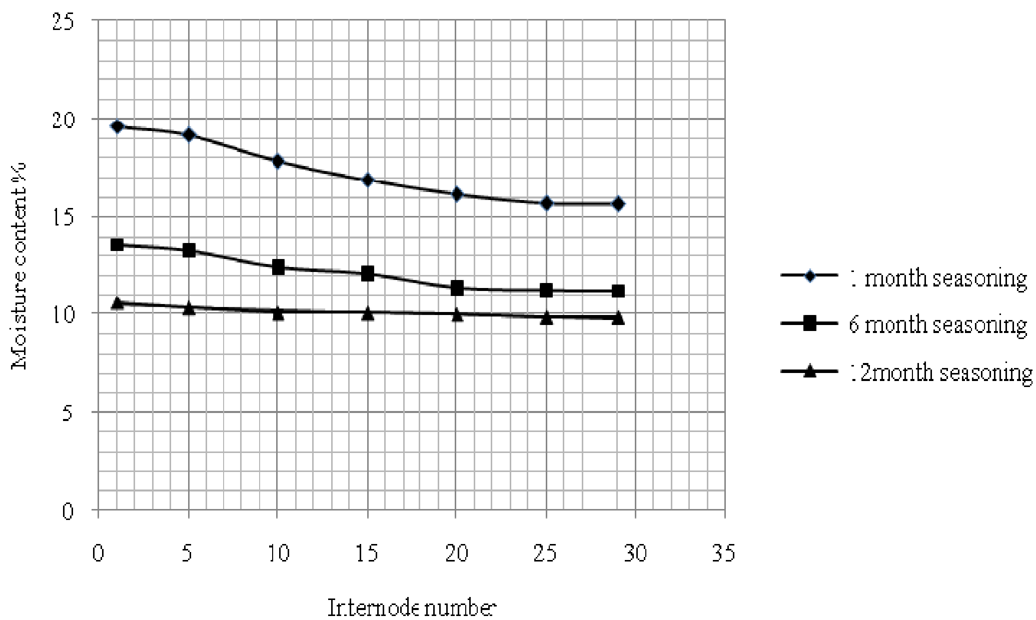
The compression test were carried out on whole bamboo specimen having length, eight times the thickness of bamboo as per Indian standard [13,14] with some modifications shown in Figure 2. Samples made from the internodes and having nodes from different height locations for one, six and twelve months seasoning were used. The compression test parallel to grain was performed with whole bamboo samples using the same machine (UT100). The effects of moisture content, height, and presence of node were evaluated.

Figure 2. Compression test specimen from internode region before and after the test

5. RESULTS AND DISCUSSIONS

5.1 Moisture content and specific gravity

Moisture content is an important parameter of bamboo. It governs the mechanical properties and plays vital role in deciding life of bamboo. Normally green bamboo has average 60 to 75% moisture content depending upon the age, season, geographical location, species and watering methods. There is a strong relation between insect attacks and the levels of starch plus humidity content of bamboo culm. Drying bamboo is fundamental to its conservation for various reasons. Bamboos are seasoned by air drying keeping in vertical position. The moisture content reduces from bottom to top for green as well as bamboo at all stages of seasoning. The variation of moisture content along the height for representative bamboo is presented in Graph 1.



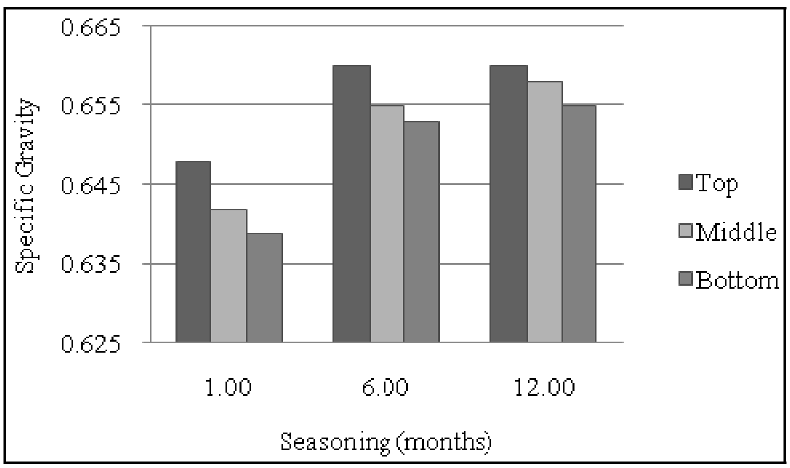
Graph 1. Variation in moisture content

Bamboo with low humidity is less prone to mould attacks especially when humidity content is less than 15%. Physical and mechanical properties of bamboo increase with a decrease in its humidity content. [3]

The moisture content and specific gravity of air dried bamboo for different locations and seasoning periods are listed in Table 3. Though specific gravity based on oven dried mass does not show much variation along height or air drying period, top portions consistently had higher specific gravity than the middle and bottom portion for each stage of seasoning. All results are calculated at the moisture content mentioned in Graph 2.

Table 3: Moisture content and specific gravity

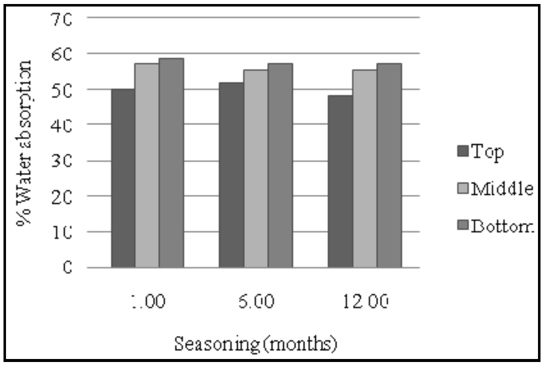
Seasoning period (Month)	Location	Moisture content (%)	Specific gravity
One	Top	16.09	0.648
	Middle	17.35	0.642
	bottom	19.13	0.639
Six	Top	11.38	0.660
	Middle	12.09	0.655
	bottom	13.46	0.653
Twelve	Top	9.98	0.660
	Middle	10.05	0.658
	bottom	10.31	0.655



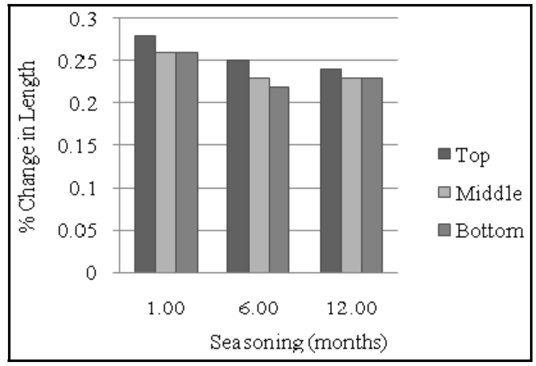
Graph 2. Moisture content and specific gravity

5.2 Water absorption and dimensional changes at 7 days

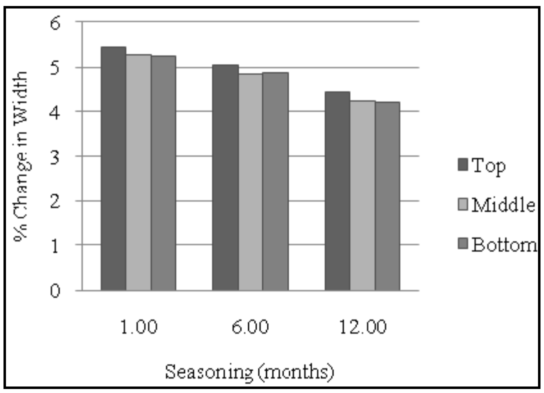
Water absorption by bamboo specimen, when soaked is at faster rate for the initial 72 hours; thereafter it declines for all specimens at all height locations. It is inversely proportional to the moisture content within the test sample. The dimensional changes are proportional to the water absorption and vary with seasoning. Along the height, dimensional changes observed to be prominent at top portion than that at bottom of bamboo culm. The results of water absorption at seventh day are shown in Graph 3 to 8.



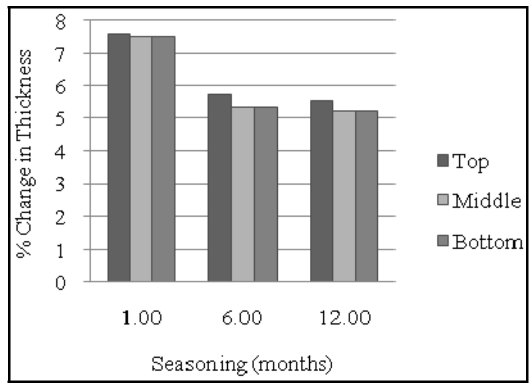
Graph 3. % Water absorption



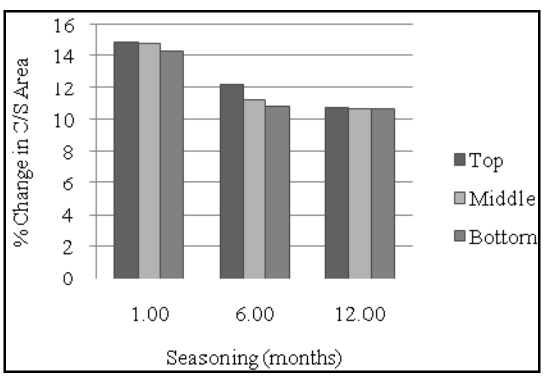
Graph 4. % change in length



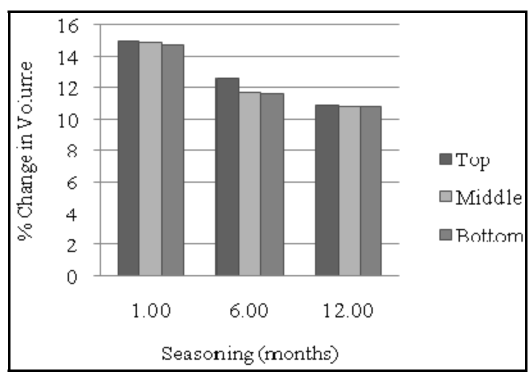
Graph 5. %Change in width



Graph 6. %Change in thickness



Graph 7. %Change in cross section

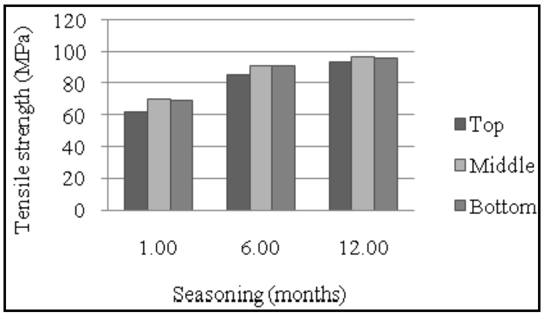


Graph 8. %Change in volume

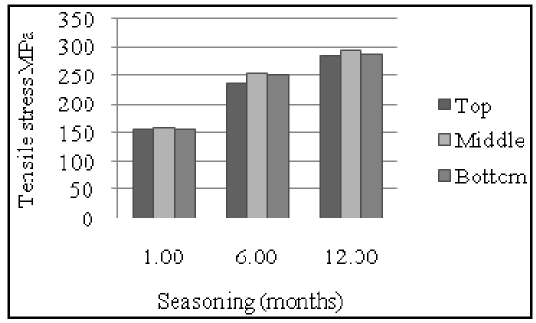
5.3 Tension and compression test

5.3.1 Tension test

The tensile stress of bamboo in the longitudinal direction increased with the increase of seasoning period i.e. inversely proportional to moisture content. The middle portion of bamboo had the highest tensile stress at levels of seasoning. There were no significant difference between bottom and middle portion. One month seasoned bamboo had the lowest tensile stress with an average of 61.98MPa at top in specimen with node. One year seasoned bamboo had the highest tensile stress with an average of 293.12MPa at middle segment for specimen from internode region. The modulus of elasticity in tension (Et) is lowermost 0.18 $x10^5$ MPa for one month seasoned bamboo at bottom while it is maximum 0.22 $x10^5$ MPa for one year seasoned bamboo at middle segment from internode. The tensile stress (*ft*) data parallel in longitudinal direction of bamboo at different levels of seasoning are presented in Graph 9-10.



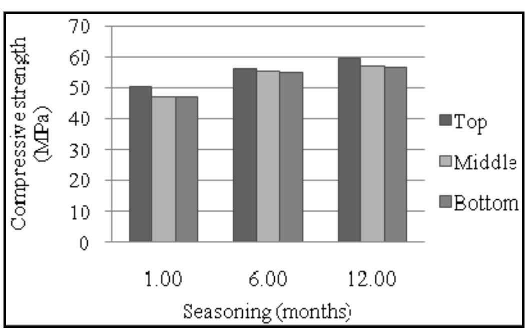
Graph 9. Tensile strength (with node)



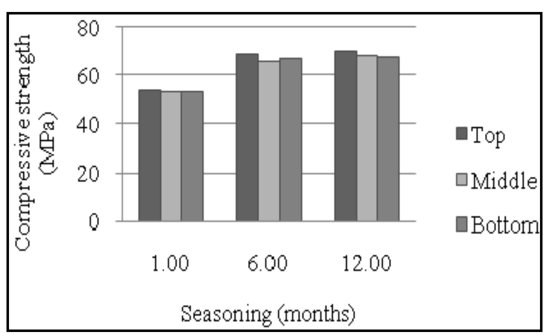
Graph 10. Tensile strength (without node)

5.3.2 Compression test

The compressive stress of bamboo in the longitudinal direction increased with the increase of seasoning period i.e. inversely proportional with moisture content. The top portion of bamboo had the highest compressive stress at levels of seasoning. There was no significant difference between bottom and middle portion. One month seasoned bamboo had the lowest compressive stress with an average of 47.12 MPa at bottom segment for specimen containing node. One year seasoned bamboo had the highest compressive stress with an average of 69.89 MPa for top segment from internode region. The modulus of elasticity in compression (Ec) is lowermost value of 4266 MPa for one month seasoned bamboo at bottom while it is maximum 4638 MPa for one year seasoned bamboo at middle segment. The compressive strength data in longitudinal direction of bamboo are presented in Graph 11-12.



Graph 11. Compressive strength (with node)



Graph 12. Compressive strength (without node)

6. CONCLUSIONS

1. Moisture content decreases from bottom to top for green as well as bamboo at any stage of seasoning.
2. The specific gravity based on the oven dry mass does decreases from top to bottom but showing 1 to 2% variation and show no difference period of seasoning.
3. Rate of water absorption is at faster rate for the initial 72 hrs. and declines thereafter.
4. The change in length is very less as compared to that in width and thickness of bamboo splints after water absorption for all levels of seasoning.
5. Though the water absorption is less at one month seasoning than at six and twelve months, the dimensional changes are more. The percentage of dimensional change, at seventh day of water absorption, for thickness is more at levels of seasoning. It is 7.59% for one month seasoning which reduces to 5.55%, at 12 months of seasoning at top level segments.
6. The percentage change in cross section is 15% at one month seasoning against 10 % that for six and twelve months.
7. The percentage change in cross sectional area is almost equal to that of volume due to water absorption at levels of seasoning as the percentage in change is ranging 0.28 to 0.23%.
8. The tensile strength of middle portion of bamboo is always larger than that of top and bottom.
9. The compressive strength of top portion of bamboo is always larger than that of middle and bottom.
10. No significant difference is recorded between bottom and middle portions for tensile, compressive strength and Young's modulus.
11. The compressive strength at 16.09% moisture content is 54.29 MPa increases to 69.89 MPa at 9.98% for the top segment of bamboo.

REFERENCES

1. Janssen JJA. Designing and building with bamboo, INBAR, Working Paper No. 20, 2000.
2. Janssen JJA. Bamboo in building structures, PhD thesis, Eindhoven University of Technology, Holland, 1981.
3. Lakkad SC, Patel J M. Material properties of bamboo, a natural composite, *Fiber Science and Technology*, **14**(1981) 319-22.
4. Jin T,Yunhai M, Donghui C, Jiyu S, Luquan R. Effect of vascular fiber content on abrasive wear of bamboo, *Wear*, **259**(2005) 78-83.
5. Ghavami, K. Ultimate load behavior of bamboo-reinforced light weight concrete beams, *Cement & Concrete Composites*, **17**(1995) 281-8.
6. Wakchaure MR, Kute SY, Mehetre PR. State of the art- bamboo reinforced concrete, *Proceedings of International Conference on Innovative World of Structural*

Engineering, Aurangabad, 2010, pp. 484-489.

7. Ghavami K. Bamboo as reinforcement in structural concrete elements, *Cement & Concrete Composites*, **27**(2005) 637-49.
8. Rebecca R. Bamboo in sustainable contemporary design, INBAR, Working Paper No. 60, 2010.
9. Janssen JJA. Bamboo in building structures , PhD Thesis, Eindoven University of Technology, Netherlands, 1981.
10. Trevor DD. Bamboo composite materials for low-cost housing, PhD Thesis, Queen's University, Canada, 1999.
11. Ghavami K. Rodrigues Cand. Paciornik S, Bamboo: Functionally graded composite material, *Asian Journal of Civil Engineering (Building & Housing)*, **4**(2003) 1-10.
12. Xiaobo Li. Physical, chemical, and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing, MS Thesis, Louisiana State University, 2004.
13. Bureau of Indian Standards, IS-6874, *Methods of Tests for round Bamboo*, 1997.
14. Bureau of Indian Standards, IS-8242 *Methods of Tests for split Bamboo*, 1997.