Construction and Building Materials 101 (2015) 784–790

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study on variation of mechanical properties of a cantilever beam of bamboo

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HIGHLIGHTS

- We conducted free vibration tests on bamboo from different slice of bamboo.
- We pointed out variation of material properties in frequency spectrum.
- We showed that frequency spectrum analysis is a powerful tool to determine material properties especially for bamboo.
- We showed that material damping of bamboo has no relationship with material's properties.

ARTICLE INFO

Article history:
Received 21 May 2015
Received in revised form 22 September 2015
Accepted 15 October 2015

Keywords:
Bamboo
Dynamic properties
Natural frequency
Damping ratio

ABSTRACT

This paper aims to study mechanical properties' variation of bamboo using frequency spectrum analysis (FSA). Two commonly used species of bamboo in Brazil, *Dendrocalamus giganteus* (DG) and *Phyllostachys áurea* (PA), are investigated. A series of free vibration tests are carried out using different slices from wall-thickness of bamboo in bending mode. Damping, natural frequency and dynamic Module of Elasticity (MOE) are calculated for each specimen. To validate experimentally obtained results, a Finite Element Analysis (FEA) for Functionally Graded Materials beam (FGMs) is used with applying equations of variation of volume fraction of the investigated species bamboo.

1. Introduction

Vibrational behavior of a structure depends on boundary conditions of the structure and material used in the structural elements. In case of the boundary conditions, there are numerous studies focused on this topic in both analytical and experimental approaches for several areas of engineering [1–4]. However, in case of influence of the material properties on dynamic properties of a structure, there are a few investigations concerning this aspect of dynamic structural analysis [5,6]. This effect is not sufficiently studied in the literature due to lack of a good mathematical model to define variation of material's properties for non-isotropic materials [7].

Bamboo, due to its exceptional characteristics, has been used in construction over too long time. However, engineering use of bamboo as a construction material has begun over a few decades. There still is a relative lack of bamboo's engineering data in literature that basically is due to a huge variety of this material in several aspects such as physical, mechanical, dynamic and thermal characteristics. This variety leads to a big scatter of experimental results [8,9].

Functionally graded materials (FGMs) are recent known composite materials that can be described as inhomogeneous composites that are made from two or more components with different materials. The most interesting point of this kind of material is that the material properties can be determined precisely with the volume fraction of its constituents and the properties vary regularly from one side to another. FGM plates and beams have been investigated vastly in several aspects such as thermal and conductivity, vibrational and viscoelasticity [10,11]. Natural bamboo also can be considered as a unidirectional continuous fiber reinforced composite that the distribution of its fibers across thickness of the material is gradient. It has been proved through an image analysis that the bamboo is a natural FGM [12,13].

In image analysis, the distribution of regions with high density of vascular bundles is registered. These vascular bundles are

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http://dx.doi.org/10.1016/j.conbuildmat.2015.10.078
0950-0618/

composed of cellulose micro-fibers inside of a matrix of parenchyma cells, some equations for this variations across the thickness in function of radial position based on different curve fitting models are obtained in previous studies [14,15]. In this paper, a second order equation developed in [14] is considered that defines distributions of fibers along the wall-thickness of the bamboo species used in this study.

There are too many studies addressing variation of physical and mechanical properties of bamboo based on experimental results [8,9,15]. However the reported results have shown a relatively big variety. This variety between reported results is due to different conditions of bamboo plantations such as kind of soil, altitude of plantation and so on that can effect on mechanical and physical properties of bamboo even between two bamboos with the same species but planted in two different places. Therefore, in this work frequency spectrum analysis (FSA) is proposed to reduce this variation and increase reliability of engineering data measurements of bamboo.

In case of dynamic properties, there are only a few investigations that are carried out regarding dynamic properties of bamboo that are related to viscoelastic and thermo-dynamical properties of bamboo's microstructure e.g. material damping and loss factor ($\tan\delta$) for different modes of vibrations [16,17]. In this paper, variation of both mechanical and dynamic properties of bamboo as a function of radial position in wall-thickness is investigated. Resonance frequencies are obtained for specimens that are taken from different positions of wall-thickness. These resonance frequencies are used to calculate dynamic Module of Elasticity (MOE) then loss factor and damping ratio are calculated based on vibration responses of a simples cantilever bamboo beams.

2. Materials

The samples are dried by holding them under a covered place in a vertical position for three weeks. These samples are treated by surface scorching as a traditional insecticide treatment. All experimental tests are carried out under natural moisture content and room temperature (between 25 °C and 28 °C and 52–66% humidity). The samples are chosen from 10 first lower nodes of bamboo that the internode distance is small. Therefore all the specimens have two or three nodes along their lengths. Sample's age ranges between 2 and 3 years old, approximately.

The variation of concentration of fibers across wall-thickness is studied by dividing species of DG and PA into two and three slices, respectively (see Fig. 1). Also changing of bamboo's strength between two sides of a single specimen is bolded in this paper to show the concentration effect of the fiber on the mechanical properties of bamboo. The nomenclature used for sample categorization is presented in Table 1.

3. Initial measurements

Moisture content of the samples is measured according to (ISO/TC 165 N314) for species of PA 13.03% and for DG 12.73%. Density Measurement is carried out for each specimen according to variation of fiber concentration across the wall-thickness by weighing the mass of each specimen and measuring the geometric dimensions, 20 of observations are carried out. The Poisson constant is obtained by using four unidirectional strain gauges, two at the top and two at the bottom, each surface containing a longitudinal and a transverse gage on a separate peace of bamboo with the same species.

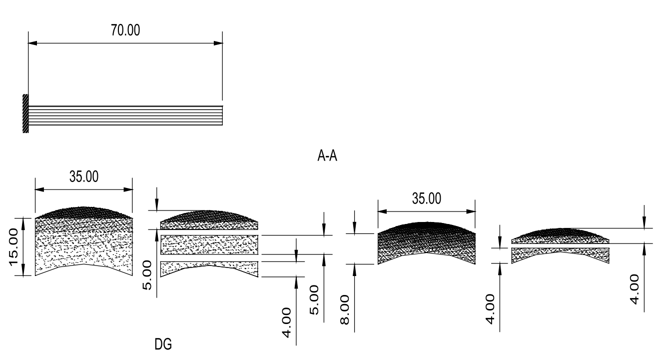
Static MOE is determined according to the variation of concentration of fibers. A scheme of the length and dimensions of the specimens together with the test setup for static cantilever flexural test is shown in Fig. 1. The flexural strength was measured by clamping each specimen in a cantilever position with an incremental monotonic load applying at the free end using standard mechanical testing machine. The load–deflection curve is obtained for specimen that is presented in Fig. 2 only in linear region of deformation e.g. up to 100 mm. The static MOE can be approximated for small deformations from equation

$$E_{\text{static}} = \frac{PL^3}{3\delta I} \quad (1)$$

where (L) is free length of the cantilever beam and the ratio ($\left(\frac{P}{\delta}\right)$) corresponds to the load–deflection ratio obtained experimentally.

Table 1
Nomenclature used for sample categorization.

Nomenclature	Description
DG-FS-Up	*Dendrocalamus giganteus*-full segment-concentration of fibers in up side
DG-FS-Down	*Dendrocalamus giganteus*-full segment-concentration of fibers in down side
DG-EXT	*Dendrocalamus giganteus*-external slice
DG-MID	*Dendrocalamus giganteus*-middle slice
DG-INT	*Dendrocalamus giganteus*-internal slice
PA-FS-UP	*Phyllostachys áurea*-full segment-concentration of fibers in up side
PA-FS-Down	*Phyllostachys áurea*-full segment-concentration of fibers in down side
PA-EXT	*Phyllostachys áurea*-external slice
PA-INT	*Phyllostachys áurea*-internal slice



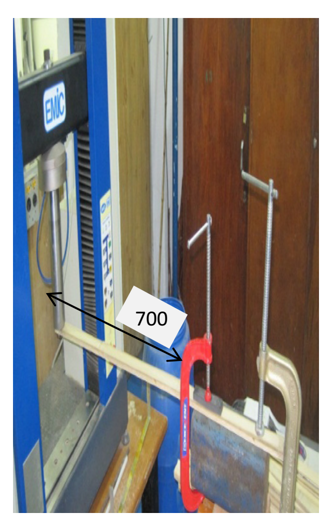


Fig. 1. (a) Dimensions of specimens in (mm) $L = 70$ (cm) (b) set up of static flexure test.