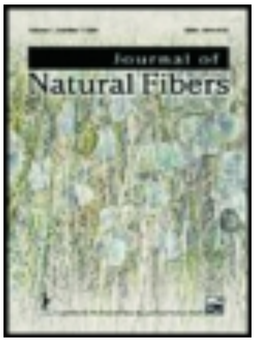

Journal of Natural Fibers

ISSN: 1544-0478 (Print) 1544-046X (Online) Journal homepage: http://www.tandfonline.com/loi/wjnf20

Proposed Method for Determining Cross-Sectional Area of Guadua angustifolia Bamboo Fibers

P. Luna & J. Lizarazo-Marriaga

JOURNAL OF NATURAL FIBERS
https://doi.org/10.1080/15440478.2017.1414655

Proposed Method for Determining Cross-Sectional Area of *Guadua angustifolia* Bamboo Fibers

P. Luna and J. Lizarazo-Marriaga

Department of Civil and Agricultural Engineering, Universidad Nacional de Colombia, Bogotá, Colombia

ABSTRACT

This paper summarizes a research aimed to develop a methodology for determining the cross-sectional area of *Guadua angustifolia* bamboo fibers. The method includes the immersion of fibers into a resin, surface preparation, acquisition, and analysis of optical micrographs using commercial software. Measured areas were compared with other values obtained for thereof, from a standard gravimetric methodology commonly used on natural fibers, which showed substantial differences among calculated areas. Random samples were subjected to both methods using data distribution functions, and the analysis was carried out to determine their statistical goodness. Analysis of fibers diameter distributions reveals they are very well described by a lognormal distribution function. Furthermore, standard gravimetric methods tend to overestimate the fibers' cross-sectional area in an average value of 15%, which could result in similar magnitude differences on the determination of some mechanical properties such as the tensile strength and the modulus of elasticity.

摘要

本文研究的目的是开发一种方法来确定的guaduaangustifolia竹纤维的横截面面积。该方法包括将纤维浸入树脂、表面制备、采集和使用商业软件分析光学显微照片。从自然纤维上常用的标准重量法与其他计算值进行比较，显示出计算区域之间的巨大差异。使用数据分布函数对随机样本进行这两种方法，并进行分析以确定它们的统计优度。纤维直径分布的分析表明它们很好地用对数正态分布函数来描述。此外，标准重量法往往高估了纤维的横截面积，平均值为15%，这可能导致在确定一些力学性能，如拉伸强度和弹性模量时，存在着类似的大小差异。

KEYWORDS

Guadua angustifolia bamboo fibers; cross-sectional area; digital image analysis

关键词

guaduaangustofolia竹纤维; 横截面积; 数字图像分析

Introduction

Determining the cross-sectional area of fibers is essential to assess their mechanical properties in terms of the modulus of elasticity and tensile strength. According to Parthasarathy (Parthasarathy 2001) and ASTM C1557 (ASTM 2014), their assessment should be made from readings made in cross sections matching the fracture planes of fibers. In literature, there are several methods to determine fibers' cross-sectional areas, among which the most commonly used is the diameter measurement from optical observations (obtained by optical or scanning electron microscopes) and the subsequent calculation of the area assuming a cross section with circular or elliptical shape (Gassan, Chate, and Bledzki 2001; Liu et al. 2013; Nitta et al. 2013; Ray, Das, and Mondal 2004; Tan, Ng, and Lim 2005; Torres and Cubillas 2005; Wang et al. 2015; Wei, Cao, and Song 2010; Yong and Yi-Qiang 2008; Yu et al. 2011). In another study, Morimoto et al. (Morimoto, Goering,

CONTACT P. Luna plunat@unal.edu.co Department of Civil and Agricultural Engineering, Universidad Nacional de Colombia, Carrera 30 # 45 –03, Building 406, Bogotá, Colombia.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/wjnf.

and Schneider 1998) proposed a methodology for determining the diameter of the cross section of ceramic fibers by using optical interference techniques. Likewise, the Fresnel diffraction method has been used to measure the diameter of natural or synthetic fibers (Glass 1996; Glass, Dabbs, and Chudleigh 1995; Murali and Mohana 2007).

The mechanical properties of natural fibers are highly variable (Bledzki and Gassan 1999; Faruk et al. 2012; Kabir et al. 2013; Yu et al. 2011), mainly due to differences in the organization of their anatomical structure, growth conditions, the stem position, the maturity of the plant, and the harvest time, among others (Hughes 2011; Summerscales, Hall, and Virk 2011). Considering these variations, Osorio et al.(Osorio et al. 2010), Moreno et al.(Osorio, Espinosa, and García 2009), and Osorio et al.(Osorio et al. 2011) suggest determining the cross-sectional area (A) from a gravimetric indirect measurement in terms of the fiber density (ρ), mass (m), and length (L), by using Equation (1). Moreover, Alves et al. (Alves et al. 2013) and Ramirez et al. (Ramirez et al. 2011) obtained the cross-sectional area from image analysis carried out on SEM micrographs taken from the failure plane of the fibers, without considering the slope thereof with respect to the image plane.

$$A = \frac{m}{\rho \times L} \tag{1}$$

Lara-Cuzio and Garcia (Lara-Curzio and Garcia 2009) employed Monte Carlo simulations to estimate the error magnitude in determining fiber resistance when the area used for the calculation does not match to the fracture plane. The obtained results showed that the error magnitude grows when increasing the variability of the fiber diameter along its length, which for some cases may be ± 10%.

This paper describes a methodology to determine the cross-sectional area of *Guadua angustifolia* bamboo fibers. This proposed new method allows estimating more accurately the cross-sectional area of fibers at the failure plane, and ensures that the perpendicular axis of the image cross-section matches the observer's eyes axis, thus avoiding optical distortions. It is intended to overcome the issues related to the traditional procedures where large errors in the determination of cross-sectional areas can be expected. Although the fibers' cross-sectional area estimation seems to be a simple issue, it has a high impact in the calculation of some mechanical properties of fibers such as the tensile strength or the modulus of elasticity.

Methodology

Description of the new proposed methodology Area Proposed Method (APM)

The purpose of this method, (APM) is to ensure that the area measurements be carried out on a plane perpendicular to the longitudinal axis of the fiber, which can be achieved by arranging the fibers within a (transparent) resin before taking micrographs. This procedure ensures that the perpendicular axis of the cross section of the observed image matches the observer axis, thus avoiding optical distortions of the image.

Initially, the fibers must be fixed perpendicularly to the length of a straight and rigid element; the length of this element must match the size of the mold used during the resin curing. Subsequently, the straight element (with the attached fibers) is inserted into the mold to dump the resin, which must be translucent to allow clear observation of the cross section of the fibers. It is recommended to apply mechanical vacuum or vibrations during the initial resin curing, in order to prevent a large number of air bubbles from getting trapped, thus making the observations difficult. Once the resin has been hardened, the straight element is removed, and the surface must be polished by using sandpaper of different grain sizes (starting with coarse grains and finishing with a fine grain). Finally, the micrographs were obtained using a conventional optical microscope (working at the necessary resolution in agreement with the dimensions of the cross section of the fiber), in order to perform the digital analysis of the images obtained.

Figure 1 shows the performed procedure: 1 cm-long fibers were fixed to a rigid timber element, which was previously cut so that its length could match the diameter of the mold used during the resin curing. The fibers attachment to the timber element was made using an instant adhesive (composition *ethyl-2-cyanoacrylate* 80–95% and *poly-methyl methacrylate* 5–10%). The resin employed corresponds to an epoxy with reference Twins A, with catalyst reference Twins B, which was used in equal volumetric ratios. Once the wood element was inserted into the mold, the dumping of the resin (resin + catalyst) was conducted. To decrease the amount of trapped air, the set was introduced into a vacuum chamber, which was adjusted to work at a pressure of −50kPa for 60 min. Subsequently, the set was left on a flat, horizontal surface for 24 h, time after which the full curing of the resin was achieved.

The polish of the surface was performed using different grain-size sandpaper: 80, 120, 240, 320, 400, and 600 along with a cloth to improve its finish. The micrographs were taken using a

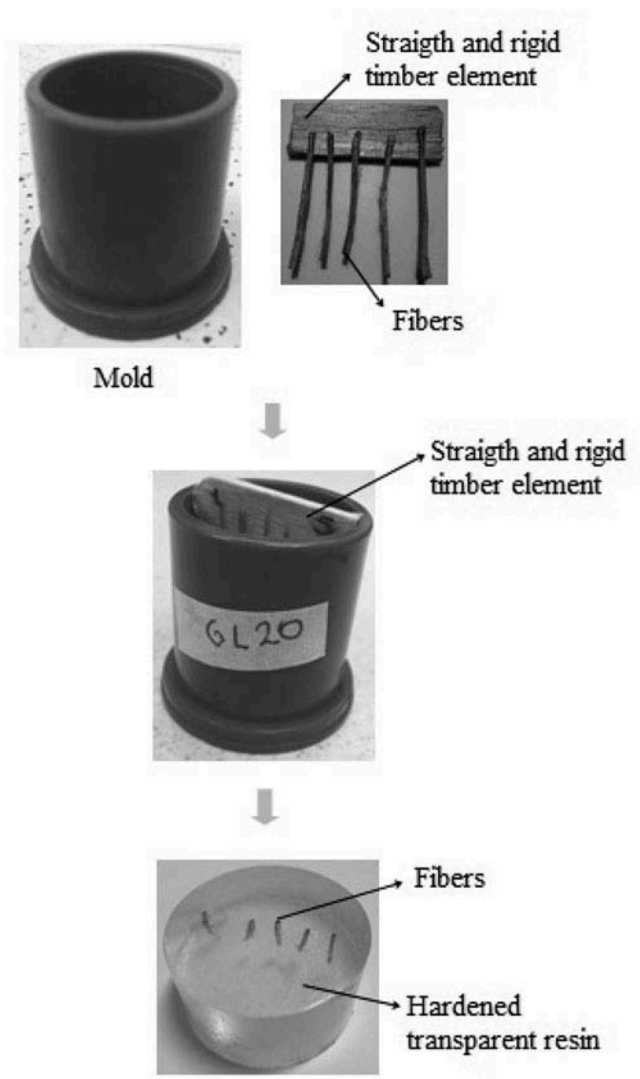

Figure 1. Proposed methodology for determining the cross-sectional area of *Guadua angustifolia* bamboo fibers.

metallographic microscope Leco500, working at 100× magnification. A captured image is shown in Figure 2. The calculation of the cross-sectional area was achieved by using the ImageJ software.

Gravimetric method (AGM)

The indirect gravimetric method was used to calculate the cross-sectional area of *Guadua angustifolia* bamboo fibers using Equation (1), where the used density was 1.4 g/cm^3 reported by Osorio et al. (Osorio et al. 2011). These results were compared with the cross-sectional area measurements performed using the aforementioned procedure explained. For this, a total of 120 fibers were used to calculate and measure the cross-sectional areas. As shown in Figure 3, each single fiber area was calculated by using the gravimetric method (AGM), and their measurement was accomplished following the optical methodology proposed in this paper (APM).

Results and discussion

Figure 4 shows the linear correlation between the areas obtained from both methodologies by using the least squares regression analysis. It is to be noted that the coefficient of determination R^2 obtained (0.688) is considered acceptable in the field of natural materials. However, it shows that there are some deviations of the area due to the experimental methods used. The figure also shows that the values significantly differ, as in most cases, the measurement taken from gravimetric calculations (AGM method) overestimates the fibers' cross-sectional area. The foregoing is attributed to some aspects of the method applied, which requires a prior determination of the density of the material. It is believed that the experimental method to determine density is a very important source of uncertainties, for example, natural fibers are highly hygroscopic (Fernandes et al. 2015; Kushwaha and Kumar 2010; Li, Tabil, and Panigrahi 2007; Sapuan 2014), and their density is highly moisture-dependent.

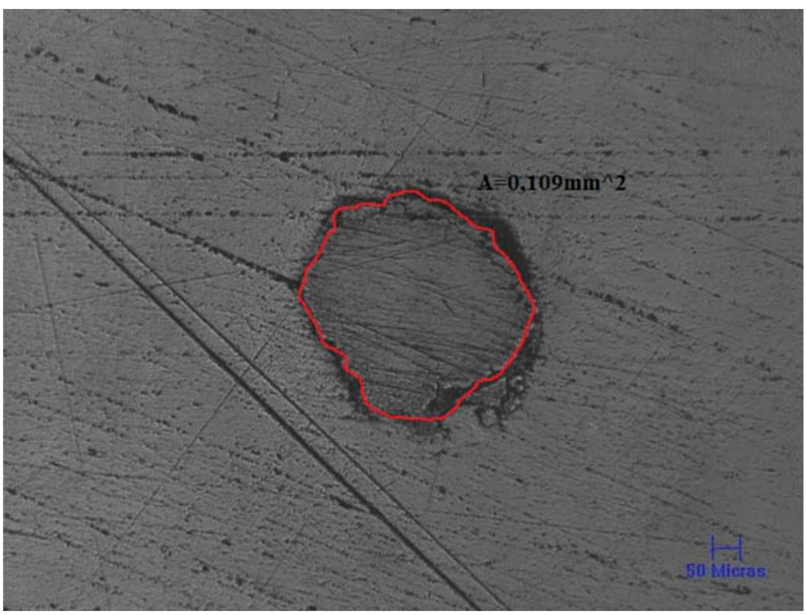

Figure 2. *Guadua angustifolia* bamboo fiber cross-sectional area.