Construction and Building Materials 77 (2015) 130–138

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental study on stress–strain relationships and failure mechanisms of parallel strand bamboo made from phyllostachys

Dongsheng Huang [a,*], Yuling Bian [a,b], Aiping Zhou [a], Baolu Sheng [a]

[a] School of Civil Engineering, Nanjing Forestry University, Nanjing 210037, China
[b] Wuxi Institute of Commerce, Wuxi 214000, China

HIGHLIGHTS

- PSB has better properties than commonly used structural woods.
- Strengths and moduli of PSB in principal direction and plane were reported.
- Failure mechanisms of each stress state were studied.
- Stress–strain relationships of PSB were functionally established.

ARTICLE INFO

Article history:
Received 12 March 2014
Received in revised form 4 October 2014
Accepted 7 December 2014
Available online 9 January 2015

Keywords:
Parallel strand bamboo
Stress–strain relationship
Failure mode
Transversely isotropic composite

ABSTRACT

Parallel strand bamboo (PSB) is a high strength and transversely isotropic biocomposite composed of long narrow bamboo strands adhesively bonded under high pressure, which has been shown more and more attractive structural applications in building and construction engineering. To well understand the stress–strain relationships and failure mechanisms is fundamental to apply this material in construction use. This paper aimed at studying the uniaxial properties in each principal material direction and the pure shearing properties in each principal material plane by experiments. Stress–strain relationships and failure mechanisms in each stress state were investigated. It was found that PSB has higher and more consistent strength than the commonly used woods in construction engineering. The stress–strain relationships may be classified into 4 types, which depend on the failure modes of PSB. In parallel to grain direction, tensile damage almost entirely contributes to the break of fibers, shows the highest strength and linear brittle behavior among all stress states. In other cases, when the expanding of failure cracks is restricted by fibers, the damage presents progressive process and higher strength, and the stress–strain relationships exhibit nonlinear behaviors. When damages take place in matrix or in fiber–matrix interface without fibers involved in, the material shows lower strength, and the stress–strain curves present linear and brittle behavior. Strength of tension parallel to grain is nearly as twice as that of compression parallel to grain. In perpendicular to grain direction, the strength of tension is much lower than the strength of compression. The shearing strength which is perpendicular to grain is as about 3 times as that of shearing in parallel to grain direction. Shearing in transverse-to-grain plane presents lowest modulus and strength than those shearing in other two directions.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Parallel strand bamboo (PSB) is a high strength biocomposite composed of long narrow bamboo strands adhesively bonded under high pressure. The strands are often made from *Phyllostachys*, a common bamboo species widely harvested in South China. Usually, about 4- to 5-year-old bamboo culms are chosen to make the strands because bamboo grows so fast that it attains maturity within 4–6 years. Bamboo culms were firstly cut into about 2 m long strips with the section of approximately 15 mm in width and 3 mm in thickness, and then dried at about 80 °C temperature till the moisture content less than 11%. The strips are then flattened into thin strands by crushing, impregnating them with phenolic resin and gluing together parallel aligned strands under high pressure, thus obtaining the required PSB composite. This results in a product having consistent properties and high load-carrying ability due to the defects of raw bamboo, such as the part of lower strength bamboo in the top of the culm or the part

* Corresponding author.

http://dx.doi.org/10.1016/j.conbuildmat.2014.12.012
0950-0618/© 2014 Elsevier Ltd. All rights reserved.

of worm damaged, may be eliminated in the manufacturing process. Therefore, PSB has highly distinctive microstructure and very favorable mechanical properties, particularly a lower variability of both modulus and strength. PSB is manufactured to a moisture content less than 11 percent, making it less prone to shrinkage, warping, cupping, bowing or splitting. It is well suited for using as beams and columns for post and beam construction, and for large members in residential construction and as intermediate and large members in commercial building construction [1]. Since the sustainable and green buildings are gaining the interest of designers looking to conserve energy and minimize the environmental impact of building construction, PSB is becoming a more and more attractive structural material used in building engineering. Up to now, however, lots of engineering behaviors of PSB composite, such as constitutive relations, failure mechanisms, and failure criterion, are not yet well understood due to lack of studies on this material. In fact, natural bamboo itself can mechanically be considered as a 2-phase composite [2], in which the long and parallel cellulose fibers serve as reinforcement and the other tissues serve as matrix [2,3]. Hence the mechanical properties of bamboo in the longitudinal direction (parallel-to-grain direction) are significantly distinct from those in transverse direction (perpendicular-to-grain direction) [4]. As the bamboo strands are laid out parallel to each other in longitudinal direction while they are approximately uniformly distributed in transverse direction, PSB material can be ideally treated as a transversely isotropic composite. It has been found that PSB composite exhibits distinct nonlinearities in constitutive relations, especially in compressive stress–strain relationship [5]. Consequently, great errors may be incurred by using linear principal based method, which are currently used in the design of wooden structures [6], to evaluate the load-carrying capacity or deformation of PSB components in ultimate state.

Damage mechanism and constitutive law play an important role in structural analysis and design. Many researches have been implemented to study the damage mechanism or to predict the uniaxial strength of fibrous composites [7–10]. Nonlinear uniaxial stress–strain relationships of wood composites have been taken into account to evaluate the structural behaviors of wood structures [11–15]. However, materials are often subjected to multiaxial loading and been in complex stress state when they are involved in structural use. Accordingly, failure criterion should be taken into account for the structural application of PSB composite. By extending von Mises yield isotropic criterion [16] to orthotropic materials, Hill proposed a polynomial form of failure criterion for orthotropic materials [17]. Six material constants, namely 3 tensile and compressive strengths in principal axes and 3 shear strengths in principal planes, should be determined by uniaxial tests for Hill's criterion. The differences between tensile and compressive properties were neglected in Hill's theory; hence this criterion is not suitable for PSB composite because the tensile strength of it is significantly distinct from the compressive strength. Tsai [18] developed Hill's theory and proposed a failure criterion for anisotropic fiber reinforced composites, but the distinctions between tension and compression of the material are still ignored. In order to consider the differences between tensile and compressive properties of materials, Hoffman [19] developed a criterion which is as follows

$$C_1(\sigma_2-\sigma_3)^2+C_2(\sigma_3-\sigma_1)^2+C_3(\sigma_1-\sigma_2)^2+ \\ C_4\sigma_1+C_5\sigma_2+C_6\sigma_3+C_7\tau_{23}^2+C_8\tau_{31}^2+C_9\tau_{12}^2=1 \quad (1)$$

In which, σ_i and τ_{ij} (i,j = 1, 2, 3) are normal stresses in the directions of 3 principal material axes and the shear stresses in 3 principal material planes; C_k (k = 1, 2, ..., 9) are material constants, which are determined by uniaxial and pure shearing experiments in corresponding axes and planes. Perhaps Hoffman criterion can be applied to assess the strength of PSB composite under multiaxial stress state.

Failure criterion only establishes the correspondence between damage and stress state for materials. To predict the overall responses of structures, however, the entire stress–strain behaviors of structural materials from loading to failure must be taken into account. For this reason, this paper aimed at studying the failure mechanisms and stress–strain relationships of PSB composite under the uniaxial and pure shearing loading. PSB was treated as a transversely isotropic composite. The properties of both tension and compression in 3 principal material axes as well as the shearing properties in 3 principal planes of PSB composite were investigated by uniaxial and pure shear experiments. The corresponding failure mechanisms and the stress–strain relationships were investigated.

2. Description of PSB composite

Since natural bamboo may be treated as a fiber reinforced composite with orthotropic properties [1], it is reasonable to ideally treat PSB as an orthotropic composite as engineered wood or other bamboo products be treated [20,21]. 3-D Descartes coordinate system was employed in this study to describe the mechanical properties of PSB composite. The coordinate axis-1 was taken alone the parallel to grain direction, i.e., the longitudinal direction of PSB composite, and the coordinates axis-2 and -3 were taken alone the other two transverse directions perpendicular to axis-1, as shown in Fig. 1. Therefore, totally 9 elastic constants, namely 6 tensile and compressive moduli in each principal direction and 3 shear moduli, i.e., shearing in parallel to grain, in perpendicular to grain and in transverse-to-grain plane, should be needed to describe the elastic stiffness of this composite. Because the fibers are parallel and continuously aligned in axial-1 direction and approximately uniformly distributed in axial-2 and -3 directions, the material properties are almost the same in any direction in planes 2–3 which are perpendicular to axial-1. This results in a reasonable assumption that the PSB is a transversely isotropic material. Hence there are actually 7 elastic constants needed to described the stiffness of PSB composite, namely, 4 tensile and compressive moduli represented by E_{11}^t, E_{11}^c, E_{22}^t, and E_{22}^c, and 3 shear moduli represented by G_{21}, G_{23}, and G_{12}. Where, the first one of the two subscripts indicates the normal direction of the plane under consideration, and the second one indicates the direction of the component of stress. The superscripts t and c represent tension and compression, respectively.

Similarly, 7 strength parameters, say, tensile and compressive strength, f_{11}^t, f_{22}^t, f_{11}^c, and f_{22}^c, and shear strength, S_{21}, S_{23}, and S_{12} respectively, are needed to describe the strength of PSB composite. All the elastic constants and the strengths mentioned above can be determined by uniaxial and pure shearing experiments for PSB composite.

3. Brief to experiments

In order to investigate the failure mechanisms and the stress–strain relationships of PSB composite, 4 types of uniaxial

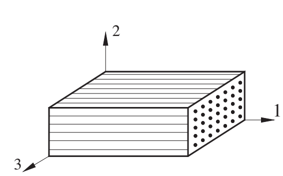

Fig. 1. Priciple direction of PSB composite.

Download English Version:

https://daneshyari.com/en/article/6721446

Download Persian Version:

https://daneshyari.com/article/6721446

Daneshyari.com