Proceedings of the SEM Annual Conference
June 7-10, 2010 Indianapolis, Indiana USA

Determination of Fracturing Toughness of Bamboo Culms

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ABSTRACT
Bamboo is an environmental friendly natural composite material reinforced by unidirectional fibers. Bamboo has been used as structural materials in Asia for centuries. In this study, the fracture toughness K_{IC}, of Moso bamboo was investigated by using ASTM E399 test method and the arc-shape bend specimens. The effect of moisture on the fracture toughness K_{IC} was investigated. It can be seen the fracture toughness decreases about 39% if the material under test was water-saturated.

INTRODUCTION

Bamboo is an environmental friendly natural composite material. Culm over 20 meter tall, 6 to18 cm diameter at breast height makes Moso bamboo one of the most important bamboo species for structure use. Vascular bundles act as reinforcements in bamboo and lignin in bamboo acts as a matrix. In Asia, bamboo has been used for centuries. Its strength and flexibility in the wind make it an ideal material for construction and household utilities. Compression, tension and bending properties of bamboo have been discussed for various bamboos. However, the studies of fracture properties such as stress intensity factor K and strain energy release rate G of bamboo are few. Bamboo specimen with crack under tensile test was use to investigate fracture properties of bamboo[1]. The critical value of energy release rate, G_{IC}, of Moso bamboo was measured by symmetric bending tests using double contilever beam specimen and calculated with the compliance of the specimen [2]. The fracture properties of Australian bamboo have been investigated [3]. In this study, the fracture properties of bamboo culms at the structural level were investigated. The fracture toughness K_{IC}s of dry and water-saturated bamboo culms were determined by using the arc-shape bend specimen specified in ASTM E399 based on linear elastic fracture mechanics theory under plane strain condition. The bamboo used for this study is Moso bamboo (Phyllostachys pubescens).

MATERIAL AND METHOD

The Mode I fracture toughness, i.e. the critical value of the stress-intensity factor K_{IC}, is measured by following the test method and arc-shaped bend specimen specified in ASTM E399 for determine fracture toughness under linear-elastic plane-strain condition. The culms between 0.75 and 5 m of a three year old Moso bamboo were used for making specimens. After air-drying, 10 mm wide ring was cut out of the bamboo culms and the arched shape bend specimen used for fracture test was cut from the ring (Fig. 1.).

T. Proulx (ed.), *Time Dependent Constitutive Behavior and Fracture/Failure Processes, Volume 3*, Conference Proceedings of the Society for Experimental Mechanics Series 15, DOI 10.1007/978-1-4419-9794-4_49, © The Society for Experimental Mechanics, Inc. 2011

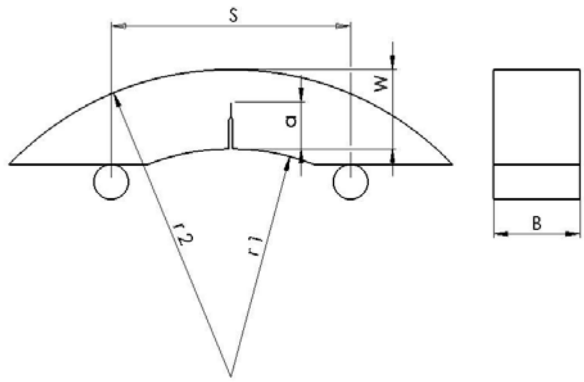


Figure 1: The arched shape bending specimen

For S=4W, The fracture toughness of arc-shape bend specimen can be calculated as follows :

$$K_Q = \frac{P_Q S}{BW^{3/2}}\left[1+\left(1-\frac{r1}{r2}\right)\cdot h_1\left(\frac{a}{W}\right)\right]\cdot f1\left(\frac{a}{W}\right). \tag{1}$$

Where

$$h_1\left(\frac{a}{W}\right) = 0.29 - 0.66\frac{a}{W} + 0.37\left(\frac{a}{W}\right)^2, \tag{2}$$

and

$$f_1\left(\frac{a}{W}\right) = \frac{\left[0.677 + 1.078\frac{a}{W} - 1.43\left(\frac{a}{W}\right)^2 + 0.669\left(\frac{a}{W}\right)^3\right]}{\left(1-\frac{a}{W}\right)^{3/2}}. \tag{3}$$

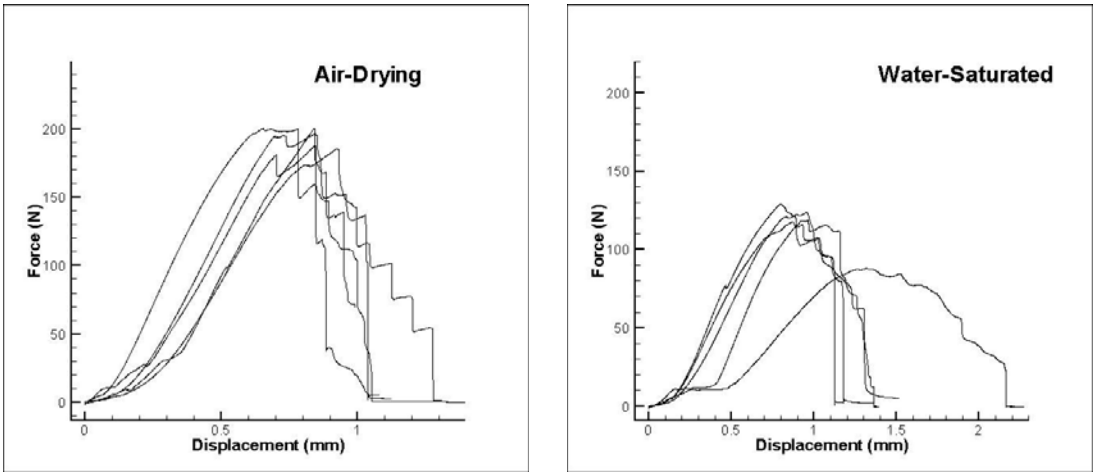
In above equations, P_Q is force(N), B is specimen thickness(m), S is span(m), W *is* specimen width(m), a is crack size(m), r_1 is inner radius(m) and r_2 is outer radius(m). The bend fracture tests were conducted by using Instron tensile test machine and custom made fixture as shown in Fig. 2.

Figure 2: The arched shape bend test

In order to know the effects of moisture on the fracture toughness of Moso bamboo, the bend fracture tests were conducted on both air-drying and water-saturated specimens.

RESULT AND DISCUSSION

The force-deflection curves of specimens under arched shape bend test are shown in Fig. 3. It can be seen that the elastic modulus of water-saturated specimens is lower than that of air-drying specimens. The corresponding fracture toughness of air-drying and water-saturated specimens is listed in Table 1. It can be seen that the fractures toughness of water-saturated Moso bamboo decreases about 39%.



(a) (b)

Figure 3: The force-deflection curves of (a) air-drying and (b) specimens under arched shape bend test.

Air-Drying n=5	K_Q ($Pa\sqrt{m}$)
Average	31.2
STD	2.6

(a)

Water-Saturated n=5	K_Q ($Pa\sqrt{m}$)
Average	19.1
STD	2.6

(b)

Table 1: The fracture toughness of (a) air-drying and (b) water-saturated specimens under arched shape bend tests.

CONCLUSION

The arched shape bend tests show that the fracture toughness of bamboo culm can be affected by the moisture contents. The difference of fracture toughness between air-drying specimen and fully water-saturated specimens is about 39%. This moisture effect should be kept in mind when using Moso bamboo as structure materials.

ACKNOWLEDGEMENT

This research was supported by NSC 96-2221-E-218-048-MY3 from the R.O.C government.

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