UNDERSTANDING THE STRUCTURAL PROPERTIES OF MOSO BAMBOO TO ENGINEER SUSTAINABLE STRUCTURAL BAMBOO PRODUCTS

Patrick Dixon¹, Lorna Gibson¹

ABSTRACT: This document presents the study of unprocessed Moso bamboo’s structure and mechanical properties, and the relation of two through modeling. Mechanical test results are presented, as well as models developed from micrographs.

KEYWORDS: Moso bamboo, Structural Bamboo Products, Sustainability

1 INTRODUCTION

Bamboo belongs to the grass family Gramineae (Poaceae) [1], the majority of bamboo culm tissue consists of inhomogeneously distributed dense vascular bundles embedded in a matrix of foam-like parenchyma cells [1]. The bundles consist of vessels surrounded by sclerenchyma fibers [1, 2]. The bamboo structure is graded, with the volume fraction of vascular bundles increasing radially [1, 2]. A similar more gradual trend occurs up the height of the culm [1, 3].

This grading has a profound effect on the mechanical properties of bamboo. Nogata and Takahashi, and more recently Shao et al., demonstrated the radial dependence of the mechanical properties of Moso bamboo. For instance, the longitudinal tensile modulus increased from about 5 GPa to about 25 GPa for inner and outer specimens, respectively [3, 4].

Bamboo resources are widely abundant, and compared to other construction materials such as, steel, concrete and timber, bamboo is a more sustainable alternative. Bamboo’s sustainability advantage over timber may be surprising, but studies have shown bamboo grows and reaches maturity significantly faster than wood [5]. Due to its commercial importance, Moso bamboo (Phyllostachys pubescens) is the species of interest for the current project.

The ultimate goal of this project is to develop, with our collaborators, sustainable structural bamboo products (SBP), analogous to wood products. At MIT, the initial goal is to relate the microstructure to the mechanical properties of as-received and densified bamboo, to allow optimization of bamboo elements for structural bamboo products.

2 MATERIALS & METHODS

2.1 MATERIALS

The lower 15 internodes of dried Moso bamboo culms were obtained from Bamboo Craftsman Company (Portland, Oregon). The outer diameter of the culms varied from 16.8 cm (bottom) to 12.4 cm (top). Specimens were air-dry (MC ~ 7%).

2.2 METHODS

2.2.1 Microscopy and Image analysis

The bamboo structure was imaged using a JOEL JSM-6610LV Scanning Electron Microscope. Surfaces were prepared by grinding and polishing. Image analysis was performed with Image J manually.

2.2.2 Modeling

Micrographs and image analysis were used to obtain the volume fraction of vascular bundles and the solids fraction of the vascular bundles as function of radial position, as well as a solids fraction for the parenchyma cells. The bundle volume and solids fraction were fit exponentially and linearly respectively to model the grading of the bamboo.

Solid cell wall fiber properties were obtained from extrapolations of experimental property-density plots, and solid cell wall parenchyma properties were estimated from literature [6]. The parenchyma matrix was modeled as a foam. Composite single lamina equations were then used to model different mechanical properties.

2.2.3 Flexure

Small longitudinal bending specimens were cut at different radial positions within the culm wall thickness from three internodes to determine the positional variation of flexural properties. The cortex was removed and four strips were cut by splitting. The beams had the following nominal dimensions: length, 100 mm; width, 7

¹ Patrick Dixon, 8-032B, 77 Mass Ave, MIT, Cambridge, MA 02139, USA. Email: pdixon7@mit.edu
² Lorna Gibson, MIT, USA
mm; and thickness, 1-4 mm. Specimen density was measured. Three sets were taken from each internode. Beams were tested with outer surfaces face up, speed 1 mm/min and the span to depth ratio no less than 20.

2.2.4 Compression
Small compressive specimens for testing in the longitudinal and radial directions were cut. Radial compression is relevant as collaborators at the University of British Columbia densify bamboo elements in this direction before processing into SBP. Blocks were fabricated using the entire culm wall thickness from three internodes. These blocks were split in the middle to create an inner and outer piece, and some blocks were cut from the middle for the longitudinal specimens. A set of at least three tests was done using each of these types of specimens, with crosshead speeds of 0.5 mm/min (longitudinal) and 0.3 mm/min (radial).

3 RESULTS
Figure 1 is a micrograph displaying the structure of Moso bamboo for the eleventh internode.

![Figure 1: Moso Bamboo Structure, Eleventh Internode](image)

Two major constituents are notable in the tissue: parenchyma and vascular bundles. A radial increase in vascular bundles is apparent.

Figure 2 shows data for the flexural modulus (MOE) plotted against radial position, r, normalized by the total wall thickness, a, for the eleventh internode. Also plotted is an initial model for MOE constructed from microscopy results of the eleventh internode.

![Figure 2: MOE vs. Radial Position, Eleventh Internode](image)

The model neglects the contribution of the parenchyma cells.

Figure 3 displays the longitudinal and radial compressive strength against density.

![Figure 3: Longitudinal and Radial Compressive Strength](image)

The longitudinal compressive strength increases linearly with density, while the radial compressive strength is relatively constant around 20 MPa. Models for compressive strength are currently being developed.

4 CONCLUSIONS
Bamboo can be modeled as a fiber-reinforced composite, with a parenchyma matrix and vascular bundle fibers as a first approximation. The structure is clearly graded, and the volume fraction of vascular bundles is significantly higher in the outer regions of the culm wall. The results suggest that the sclerenchyma fibers dominate longitudinal elastic properties.

ACKNOWLEDGEMENT
This material is based upon work supported by National Science Foundation under 6926667.

REFERENCES