Experimental study on LBL beams

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Abstract. Six specimens were made and tested to study the mechanical properties of LBL beams. The mean ultimate loading value is 68.39 MPa with a standard deviation of 6.37 MPa, giving a characteristic strength (expected to be exceeded by 95% of specimens) of 57.91 MPa, and the mean ultimate deflection is 53.3 mm with a standard deviation of 5.5 mm, giving the characteristic elastic modulus of 44.3 mm. The mean ultimate bending moment is 20.18 kN.m with a standard deviation of 1.88 kN.m, giving the characteristic elastic modulus of 17.08 kN.m. The mean elastic modulus is 9688 MPa with a standard deviation of 1765 MPa, giving the characteristic elastic modulus of 6785 MPa, and the mean modulus of rupture is 93.3 MPa with a standard deviation of 8.6 MPa, giving the characteristic elastic modulus of 79.2 MPa. The strain across the cross-section for all LBL beams is basically linear throughout the loading process, following standard beam theory.

1 Introduction

Laminated bamboo lumber (LBL) is one kinds of engineered bamboo materials which could be used in structural engineering. More and more scientists are interested in LBL and some studies have been done [1-11].

Some researchers have investigated the basic mechanical properties of LBL. Tensile, compressive and bending performance of layered laminate bamboo composite (LLBC) have been studied by Verma and Charier [12], and the specimens have a cross-section of 16mm x 10mm. Yeh and Lin [13] investigated how the growth height influence the bending strength of LBL, and both un-jointed and jointed specimens with the length of 1000mm and the cross-section of 30mm x 30mm have been tested. Considering the glue spread rate and moisture content influencing factors, Lee et al. [14] studied the bending properties of 24 laboratory-manufactured LBL specimens, and found the elastic modulii ranging from 7411 MPa to 9204 MPa and rupture strengths between 67.7 MPa and 107.2 MPa.

As for the structural elements, Li et al. [15-20] examined the mechanical performance for the columns in detail, and proposed a tri-linear model with an elastic portion, and elasto-plastic portion and a purely plastic portion. A fine stress-strain relationship model for LBL under axial compression was also put forward by Li et al. [16] based on the short compression tests. Considering many influencing factors, both the LBL columns under axial compression and eccentric compression have been

investigated by Li et al. [17-20], and the ultimate bearing capacity calculation equations were proposed. The axial compression performance of LBL column piers along three directions were studied and compared by Su et al. [21], and the relationship models for load-axial displacement along three compression directions could be used the same tri-linear model.

As for the structural beam members, Sinha et al. [22] evaluated the potential application for the laminated bamboo lumber (LBL) and bamboo glulam beams (BGBs)'s in structures. Li et al. [23-26] also investigated the mechanical performance for LBL beams considering the influencing factors of shear span ratio and height to width ratio, and the ultimate load calculation equations were proposed. Zhang et al. [23-26] has studied how AFRP efect on parallel bamboo strand lumber beams.

As mentioned above, even though some studies about LBL beams have been done by some researchers, the work is still limit and more research on the mechanical properties of LBL beams need to be done. Thus, this study examines in detail at the behaviour of specimens constructed from laminated bamboo lumber.

2 Materials and test methods

2.1 Specimens

The lower growth portion of the Moso bamboo (Phyllostachys pubescens, from Fujiang province) tubes were chosen with the age of 3–5 years to produce the specimens. After removing the outer skin (epidermal)

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and inner cavity layer (pith peripheral) by a planer, all the culm strips were then dried and charred. With the final thicknesses of 7 mm and the widths of 21 mm, the strips were produced and made into laminated bamboo lumbers. Six beam specimens were made with the size of 50 mm × 160 mm × 1960 mm and the cross-section for the beam specimen could be seen from Fig. 1.

Fig. 1. Cross-section for beam specimen

2.2 Test methods

The beam test arrangement could be illustrated in Fig. 2. Five Laser Displacement Sensors were arranged to measure the displacements of the specimen. The beams were strain gauged longitudinally at the middle cross section, with five strain gauges pasted on one side face at even spacing through the depth, and one strain gauge pasted on each of the bottom face and the top face, as shown in Fig. 2. A microcomputer-controlled electro-hydraulic servo universal testing machine (Fig. 3) with a capacity of 300 kN was chosen for the beam tests. Four-point loading method was used for the tests and the clear span for the beam is 1770 mm. All beam specimens were divided into three even parts by four loading points.
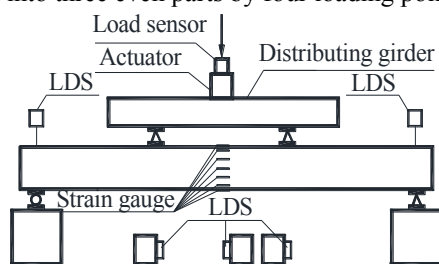

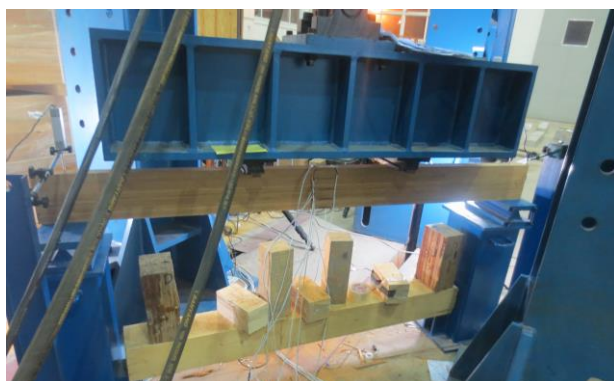**Fig. 2.** Test scheme for beam specimen

Fig. 3. Test photos for beam specimen

2 Failure Analysis

All beam specimens behaved elastically at the loading beginning, and then showed a small amount plastic deformation with the increasing of loading. The stiffness of the beams decreased. As the vertical displacement became bigger and bigger, cracks (accompanied by a slight noise) appeared on the bottom surface of the beam. All test specimens split along the longitudinal direction once the outer bottom surface strips separated along the depth direction, and the whole specimen was damaged quickly. Cracks always started at the natural bamboo joint area on the tensile surface but none clear failure could be found in the top surface. Brittle tensile failure happened to all test specimens. The final failure photos for the top surface, bottom surface and two side surfaces could be seen from Fig. 4.

(a) Top surface

(b) One side surface

(c) The other side surface

(d) Bottom surface

Fig.4. Failure photos for the beams

3 Test results and combined analysis

3.1 Test results

The test results for six beam specimens are presented in table 1. SDV means standard deviation; COV means coefficient of variation; CHV means characteristic value, calculated on the basis that 95% of samples will exceed the characteristic value (mean ultimate value – 1.645 x standard deviation). F_{max} is the maximum bending load; w is the ultimate deflection; M is the ultimate bending moment; the modulus of elasticity (MOE) and the modulus of rupture (MOR) were calculated using Eqs. (1) and (2), respectively

$$MOE = \frac{a\Delta F}{48I\Delta w}(3L^2 - 4a^2) \qquad (1)$$

$$MOR = \frac{3F_{max}a}{bh^2} \qquad (2)$$

Where a is the distance between loading support and loading points which is 590 mm for these tests; ΔF is the load increment in elastic stage; w is the ultimate deflection of the middle span point; Δw is the deflection of the middle span point under ΔF; L is the span of the beam which is 1770 mm for the tests; I is the moment of inertia of the beam; F_{max} is the maximum bending load; b is the width which is 50 mm; and h is the height of the beam cross-section which is 160 mm.

Table 1. Test results for group JLH180

Specimen	F_{max} /kN	w /mm	M /kN.m	MOE /MPa	MOR /MPa
JLH160-1	61.63	44.7	18.18	9219	84.1
JLH160-2	78.83	56. 8	23.26	10057	107. 4
JLH160-3	68.79	54.0	20.29	10104	93.7
JLH160-4	72.35	61.1	21.34	11427	98.8
JLH160-5	64.49	52.4	19.03	6435	88.2
JLH160-6	64.25	51.1	18.95	10887	87.8
Mean	68.39	53.3	20.18	9688	93.3
SDV	6.37	5.5	1.88	1765	8.6
COV	0.09	0.10	0.09	0.18	0.09
CHV	57.91	44.3	17.08	6785	79.2

According to these 6 beam specimens, the mean ultimate loading value is 68.39 MPa with a standard deviation of 6.37 MPa, giving a characteristic strength (expected to be exceeded by 95% of specimens) of 57.91 MPa, and the mean ultimate deflection is 53.3 mm with a standard deviation of 5.5 mm, giving the characteristic elastic modulus of 44.3 mm. The mean ultimate bending moment is 20.18 kN.m with a standard deviation of 1.88 kN.m, giving the characteristic elastic modulus of 17.08 kN.m. The mean elastic modulus is 9688 MPa with a standard deviation of 1765 MPa, giving the characteristic elastic modulus of 6785 MPa, and the mean modulus of rupture is 93.3 MPa with a standard deviation of 8.6 MPa, giving the characteristic elastic modulus of 79.2 MPa.

3.2 Load-displacement response

The load-displacement curves for beam specimens could be seen from Fig. 5. The load-displacement response is consistency in the original elastic stage. When the loading value was bigger than 28 kN, five curves kept good consistency except one curve.

Micro-cracks within the material were audible and are also observed in small drops along the load-displacement curves for all test specimens, no cracks were visible before the ultimate state. The overall behaviour for all the beams is substantially the same, with an initial elastic response followed by non-linear softening, and a brittle failure.
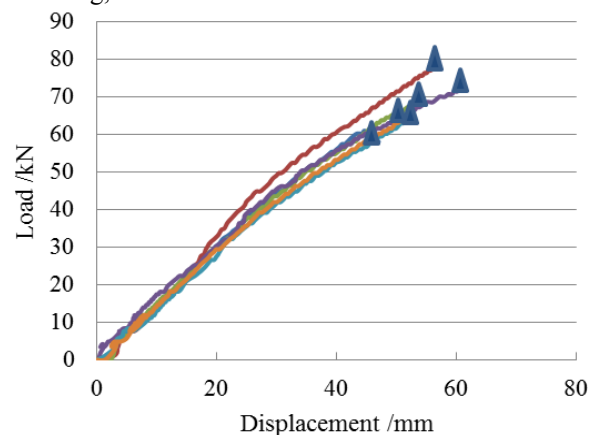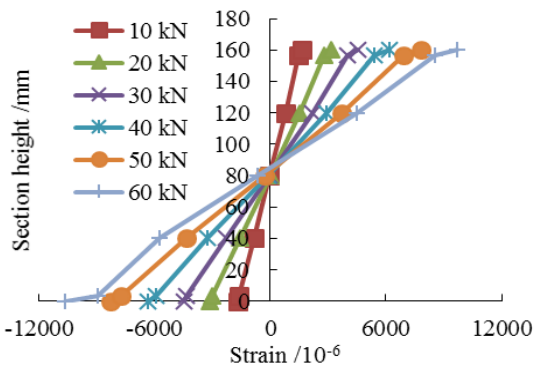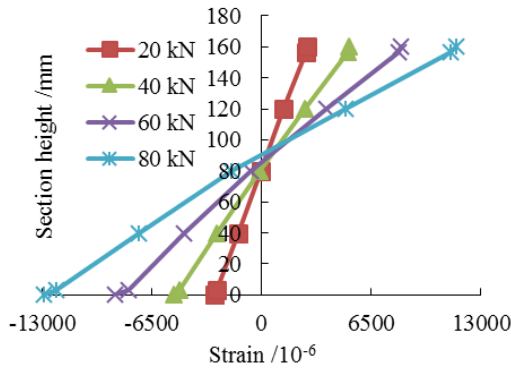

Fig.5. Load-displacement responses

3.3 Strain profiles

The strain profiles through the loading for the mid-span cross-section for all test beams could be seen from Fig. 6. The strain across the cross-section for all LBL beams is basically linear throughout the loading process, following standard beam theory.
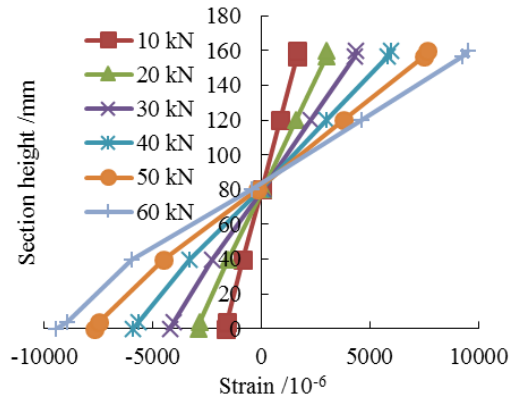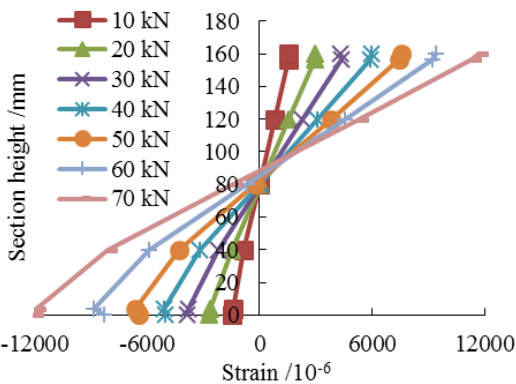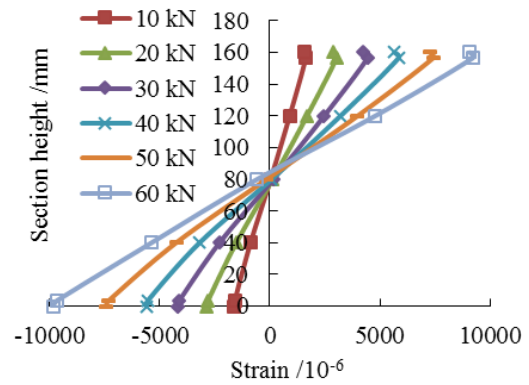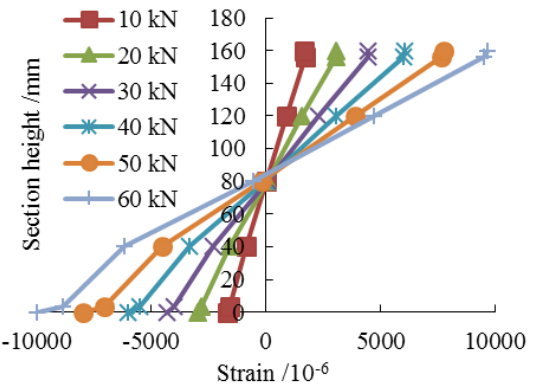
(a) JLH160-1

(b) JLH160-2

(c) JLH160-3

(d) JLH160-4

(e) JLH160-5

(f) JLH160-6

Fig.6 Typical strain profile development for the mid-span cross-section

4 Conclusions

Six specimens were made and tested to study the mechanical properties of LBL beams. According to analysis of the test data, the following conclusions can be drawn.

(1) Characterized by brittle tensile failure, all LBL beams experienced three stages which are elastic stage, elastic-plastic stage and damaged stage.

(2) The mean ultimate loading value is 68.39 MPa with a standard deviation of 6.37 MPa, giving a characteristic strength (expected to be exceeded by 95% of specimens) of 57.91 MPa, and the mean ultimate deflection is 53.3 mm with a standard deviation of 5.5 mm, giving the characteristic elastic modulus of 44.3 mm. The mean ultimate bending moment is 20.18 kN.m with a standard deviation of 1.88 kN.m, giving the characteristic elastic modulus of 17.08 kN.m. The mean elastic modulus is 9688 MPa with a standard deviation of 1765 MPa, giving the characteristic elastic modulus of 6785 MPa, and the mean modulus of rupture is 93.3 MPa with a standard deviation of 8.6 MPa, giving the characteristic elastic modulus of 79.2 MPa.

(3) The strain across the cross-section for all LBL beams is basically linear throughout the loading process, following standard beam theory.

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