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Compressive Stress Strain Relationship of Wood Confined with Fiber Composite Sheets

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Abstract: This paper presents the results of an experimental study on the compressive stress-strain relationship of wood confined with fiber composite sheets. Wood cylinders confined with carbon fiber composite sheets along full length were tested by compression load. The tests considered up to three layers of fiber sheets. The results will be used to verify a numerical analysis model, which will be further used to conduct a parametric study of the influential factors. The generated knowledge can be used as reference for strengthening designs of historical timber structures using fiber reinforcing products.

Keyword: Fiber composite sheets, combined wood cylinder, stress strain relationship, mathematic model

Introduction

China has a long history of using wood as the primary construction material. Many timber buildings have survived long time of service, yet with many damages due to natural hazards and human activities. Fig. 1 shows some typical longitudinal cracks in historical timber buildings. These structures need to be retrofitted or strengthened in order to extent their serve life and therefore protect this priceless cultural heritage. Fiber composite sheets have been proved to be efficient and effective in strengthening concrete structures by wrapping around the structural members. Their application in timber structures against the longitudinal cracks has also been increasing; however, little research work has been done on how much the mechanical behavior of wood can be improved by wrapping fiber composite sheets. Similar to testing fiber sheets wrapped concrete members (Gu et al. 2006, Jin et al. 2003), research efforts have been asserted on testing wood cylinders wrapped with fiber composite sheets (Davalos et al. 1999, Chidiaq 2003, Najm et al. 2007).

Figure 1: Longitudinal cracks in historical timber structures

This study has been aimed at developing the stress-strain relationship of wood confined with fiber composite sheets by experimental study. Wood cylinders wrapped with up to three layers of fiber composite sheets along the full length were tested by compression load. The influence of fiber composite sheets on the stress-strain relationship of such confined wood was discussed. The results will be used to verify a numerical analysis model, which will be further used to conduct a parametric study of the influential factors. These results will be presented in a separate paper.

Experimental Study

Twenty specimens in cylindrical shape were produced using Douglas fir and carbon fiber reinforcing sheets. The specimens were classified into four groups based on the amount of fiber composite sheets used: YZ0 with no fiber sheets, YZ1, YZ2 and YZ3 with one, two and three layers of fiber sheets, respectively, wrapped along the full length. For each group of specimens, five replicates were tested to account for the variation of wood quality and workmanship. The material properties of the wood and fiber composite sheets were obtained from material properties tests. The so-obtained moisture content, compressive strength and modulus of elasticity of wood are 15.6%, 24.08 and 8295 MPa, respectively; and the thickness, tensile strength, modulus of elasticity and maximum tensile strain of the fiber sheets are 0.17 mm, 4171.76 MPa, 267.36 GPa and 0.0161, respectively. The geometry and appearance of the specimens are shown in Fig. 2.

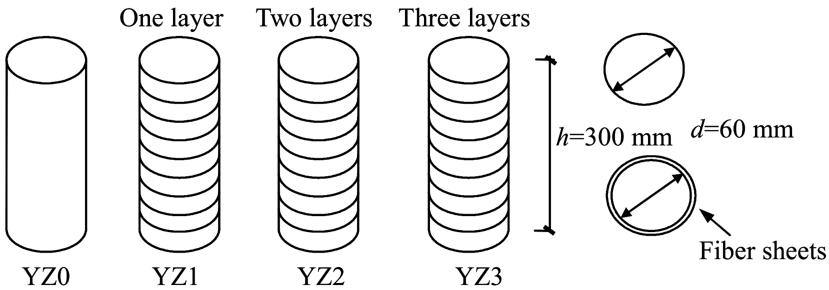

Figure 2: Geometry of the specimens

The specimens were tested on the INSTRON 1345® machine under displacement control. The loading rate was controlled at 0.2 mm/min and the load was removed when the longitudinal displacement of the specimens reached 15.0 mm. The longitudinal displacement of the specimens was measured by the build-in sensors of the INSTRON® machine and the strain gauges attached onto the surface of the wood (underneath the fiber sheets if applied). The circumferential strain of the fiber composite sheets was also measured using strain gauges attached onto the surface of the sheets. The test setup and the locations of the strain gauges are shown in Fig. 3.

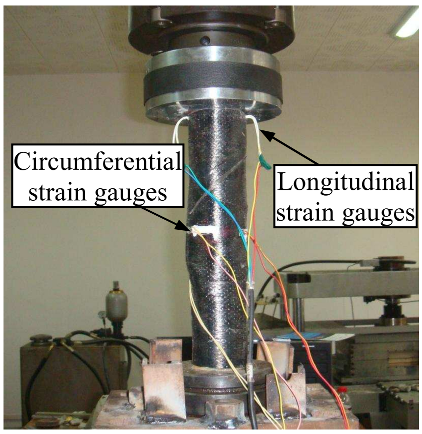

Figure 3: Test setup and strain gauge allocation

Failure Modes

All the specimens were loaded up to failure to construct the complete stress-strain relationship of wood. Various failure modes were observed from the specimens without and with fiber composite sheets (Specimen Groups YZ0 and the other three groups, respectively).

For those tested with fiber composite sheets wrapping, the crushing wrinkles of wood can be observed near the midheight of the cylinders when the load approached roughly 80% of the maximum load. With the increase of the load, the wrinkles became more and more apparent. After the tests, the failed specimens were cut near the failure zone, from which it can be seen that the specimens bulged circumferentially. The magnitude of the bulging decreased from the surface to the core area of the specimen, causing cracks between the two parts. The failed specimens and the cuts made near the failure zone are shown in Fig. 4.

Figure 4: Failure modes and cut image of wood cylinders without fiber sheets wrapping

The specimens wrapped with one, two and three layers of fiber composite sheets exhibited similar failure patters; however, due to the variation of specimen quality, two failure modes were observed even from the specimens of the same group. For the first type of failure mode, the fiber composite sheets started splitting (based on the noise) when the load reached 70% to 80% of the maximum load. Compression wrinkles of the sheets were observed near the midheight when the load approached the maximum load and the wrinkles propagated when the specimen went into the descending branch of the load-displacement curve. At failure, significant lateral deflections were observed, as shown in Fig. 5.

Figure 5: Failure modes of wood cylinders wrapped with fiber composite sheets

For the second type of failure mode, the failure took place near the ends of the cylinder. When the load reached nearly 70% of the maximum load, significant crushing deformation can be observed at these areas. The deformation propagated with the increase of the load until the deformation exceeded the prescribed maximum value. Based on the cuts made near the failure zone of the specimens, it can be seen that the cross-section remained quite complete as in contrast to the unwrapped specimens.

Test Results and Discussion

The test results mainly consisted of the relationship between the longitudinal stress and the longitudinal strain. The longitudinal stress was calculated as the quotient of the applied load and the measured cross-sectional area of the specimens.

Fig. 6 shows the test results of the relationship between the longitudinal stress and strain of the wood cylinders. It can be seen that the results exhibited certain variation due to the specimen quality. Based on the comparison of the test results measured from specimens with different amount of fiber composite sheets, it can be seen that the use of fiber sheets apparently affect the maximum stress as well as the slope of the descending branch of the stress-strain curve. This finding is in conformance with the results obtained by other researchers (Davalos et al. 1999, Chidiaq 2003, Najm et al. 2007).

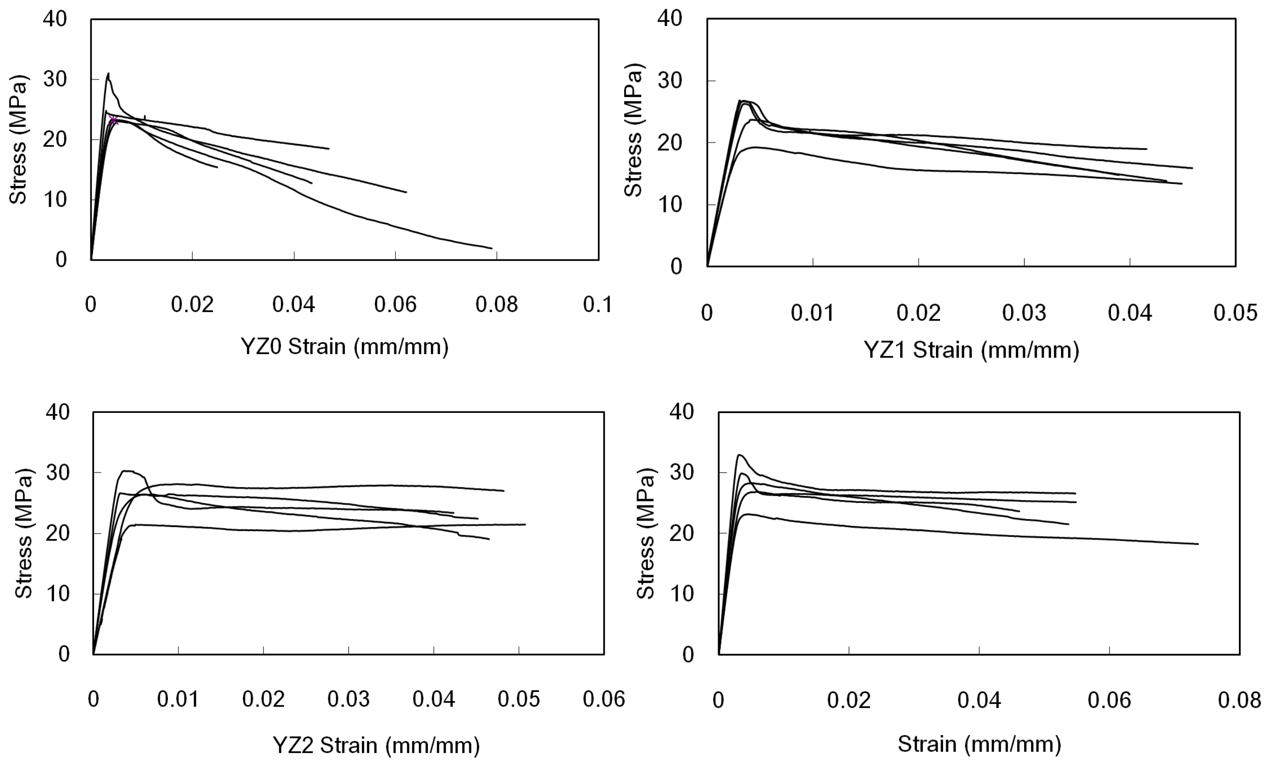

Figure 6: Longitudinal stress and strain relationship of wood cylinders

For better understanding of the influence of the carbon fiber composite sheets wrapping on the stress-strain relationship of the specimens, mean values of the test results were evaluated and listed in Table 1, where it can be seen that use of fiber composite sheets wrapping can lead to high maximum stress as well as the corresponding strain. In the meanwhile, the more sheets wrapped the higher those values become. However, the test results about the initial stiffness of the stress-strain curve of the specimens show an opposite trend. This can be caused by variation of the specimen quality and the application of the fiber composite sheets, i.e., the sheets might not have been applied uniformly and caused load eccentricity to certain extent. This issue will be further studied via a numerical analysis model by considering irregular application of reinforcing sheets.

Table 1: Test results of the key parameters of the stress-strain relationship of confined wood

Group	*Diameter (mm)*	*Height (mm)*	*MC (%)*	*Maximum stress (MPa)*	*Strain*	*Initial stiffness (MPa)*
YZ0	57.50	300.50	16.50	60.43	23.27	5029
YZ1	57.00	301.00	17.50	68.13	26.70	3415
YZ2	57.50	300.50	16.00	68.06	26.21	3187
YZ3	57.00	301.00	15.00	76.20	29.86	3553

Conclusion

This paper presented the results of an experimental study on the compression loading of wood cylinders confined using fiber composite sheets. The results were used to develop the compressive stress-strain relationship of such confined wood. It was found that by use of confining fiber composite sheets, the maximum stress and the corresponding strain can be significantly increased with the amount of fiber sheets used. Further study will conducted by using a numerical analysis model to take into more influential factors on the compressive behavior of wood with circumferential confinement.

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