Transactions on the Built Environment vol 66, © 2003 WIT Press, www.witpress.com, ISSN 1743-3509

Semi-destructive methods for evaluation of timber structures

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Abstract

This paper describes newly developed semi-destructive testing methods that can be used to examine the in-situ mechanical properties of timber structural members. The methods can be used to measure tensile modulus of elasticity and strength, density and moisture content. Special devices to extract micro-tensile and compression specimens were developed and tested in a laboratory environment. The technique gives direct measurements of tensile strength and modulus of elasticity of the material without compromising the integrity and strength of the structure under investigation.

1 Introduction

Wood is the oldest structural material, and a significant number of timber structural elements can be found in many historic buildings. As a natural material, wood is susceptible to biological degradation such as fungi and insect infestation. Degradation well in progress can be relatively easily detected by visual observation, and some correlations can be drawn between degradation and mechanical properties. Various solutions are available depending upon deterioration and function of the particular element. If the wooden elements have load-bearing functions, then it is important to determine the residual structural capacity to make a qualified determination about repairs and replacements. This residual capacity depends on material strength, remaining effective cross sections and the degree and size of healthy macroscopic defects

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such as knots or slope of grain (fibers). While the macroscopic defects can be determined by visual inspection, the material strength is largely unknown and must be estimated indirectly from information about wood specie, density and moisture contents (under the material strength we understand the strength of the clear wood material). The methods that can be used to estimate wood mechanical properties can be classified as destructive, semi-destructive and nondestructive. Destructive methods provide the best estimate of strength but are not applicable for in-situ elements. Semi-destructive methods extract small specimens from the members such that the specimen size is negligible with respect to size of the member. Destructive tests are then performed on the extracted samples. Thus, the methods are nondestructive with respect to the members and destructive with respect to the extracted sample. Nondestructive methods measure some physical parameters such as stress wave or ultrasound velocity and correlate these parameters with mechanical properties. Thus, nondestructive tests can be classified as indirect methods while destructive and semi-destructive tests are direct methods to obtain strength parameters. The accuracy and reliability of these methods decrease with decreased levels of destructiveness. No single method can give a full description of wood mechanical properties and a combination of methods is required to achieve desirable reliability of the strength prediction.

In evaluation of load-bearing historical timber structures, one needs to know the load capacity of an entire member such as beam or roof rafter. Member strength is a global property that is correlated with the material strength but is greatly affected by macroscopic defects and variability within the member. Nondestructive tests can give a qualitative picture about the overall member strength (in terms likely strong, likely weak, etc.) but without any other information about destructive parameters, the quantification of test results is difficult and unreliable.

In this paper, two semi-destructive techniques will be discussed: (1) core-drilling technique and (2) micro tension specimens. The core-drilling technique has been discussed in the past (1) and only few remarks on the method will be included.

2 Core-drilling technique

Core drilling has been used in timber, masonry, mortar and concrete evaluation for some time. Usually, the core drilling involves extracting small-diameter core from the material and testing the core in compression. In isotropic or quasi-isotropic, macroscopically homogeneous materials one can test the core in compression along the longitudinal axis of the core. This, however, is impossible in anisotropic material such as wood where all properties are directionally dependent. The strength properties of wood along fibers are the most important since they directly control parameters such as bending, tensile and compressive strength along fibers. The strength across fiber is of a lower importance since compressive strength (mostly seen in bearing) rarely yields to a

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catastrophic failure. Tension across fibers is not permitted in most solid wood members. The

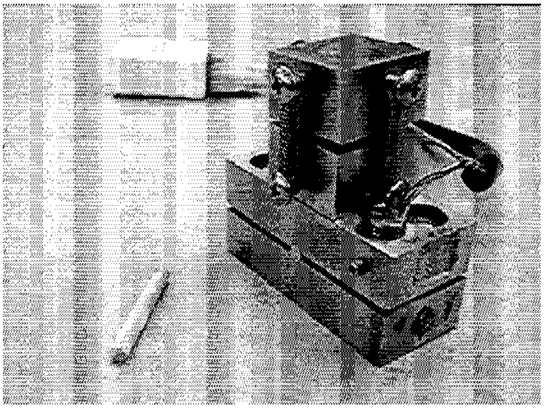

Figure 1: Core and testing fixture for measurements of compressive strength and modulus of elasticity.

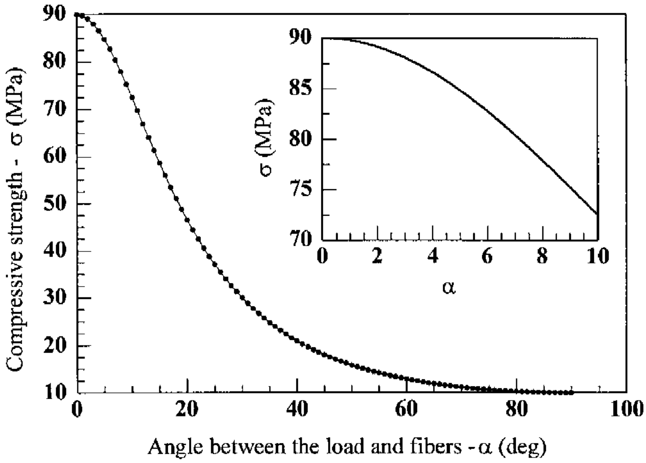

Figure 2. Effect of misalignment between wood fibers and load on compressive strength.

differences in strengths along and across fibers are significant (design value for tension across wood fibers may be zero) and accurate orientation of the load with respect to fibers is critical in estimating the material strength. Therefore, a concave compression head is used to induce parallel-to-grain force – see Figure

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1. The core is loaded in the direction perpendicular to the longitudinal core axis and this generates a relatively complex stress-state. Two miniature LVDT's are used to measure the deformation of the core.
The slope of the load-deformation curve is correlated with material modulus of elasticity and the yield point corresponds to the compressive strength of the material. One cannot calculate the modulus of elasticity from this test directly due to the non-uniform strain and stress distribution but the slope of force-deformation curves maps into the modulus of elasticity directly. From Figure 1, it follows that maintaining the correct orientation of fibers with respect to the applied load (0 degrees) is difficult and a slight error in orientation will result in reduced apparent strength and modulus elasticity. The sensitivity of the strength measurements to error in angle of force with respect to fibers is shown in Figure 2, inset. Clearly, the core-drill technique suffers from sensitivity to an error in specimen orientation but will always result in conservative estimates of material strength. The conservative estimate will result not only from an error in specimen orientation but also from an increase in variability of test data that will result in a conservative estimate of the lower 5th percentile.

2 Tension micro specimen technique

One of the challenges in nondestructive evaluation of historic timber structural members is to estimate the strength in bending since bending along with compression along fibers are predominant types of loading. While compressive strength can be relatively accurately predicted from the core tests, the bending

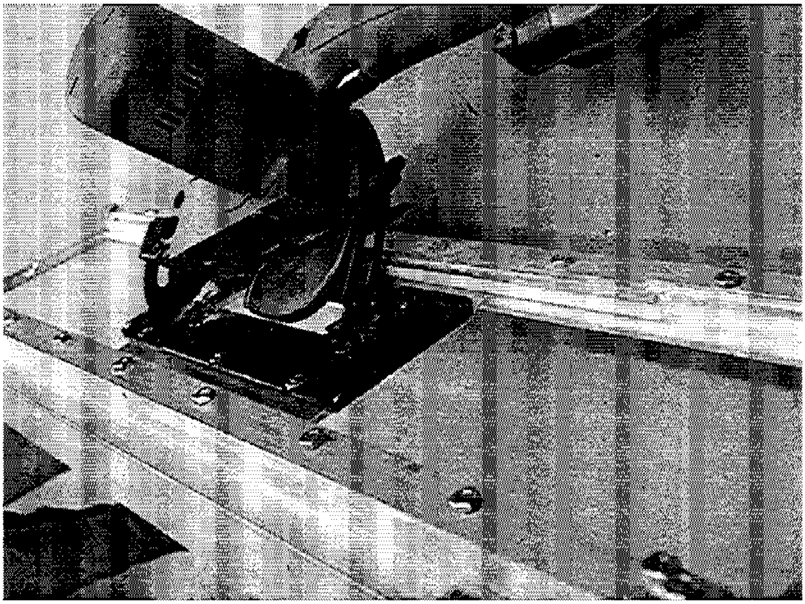

Figure 3. Fixture to extract prismatic specimens from large timbers.

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strength will require much larger specimens. If one knows the material strength (see our definition above) in tension and compression, one can design a member under bending. The correlation between tensile and compressive strength of wood is weak because of different failure phenomena in tension and compression. Therefore, it is desirable to have information about tensile strength. The following technique can be used to extract specimens of small cross sections from the timbers such that the cross-sectional area of specimens is significantly smaller than the area of the beams. This is achieved by a small-diameter thin kerf saw inclined 45° with respect to the surface of the beam – Figure 3. This means that two cuts are required to obtain a prismatic specimen of a triangular cross-section. The side of the triangle can be adjusted from 3-8 mm in length depending on the depth of the cut. The typical test specimen is shown in Figure 4.

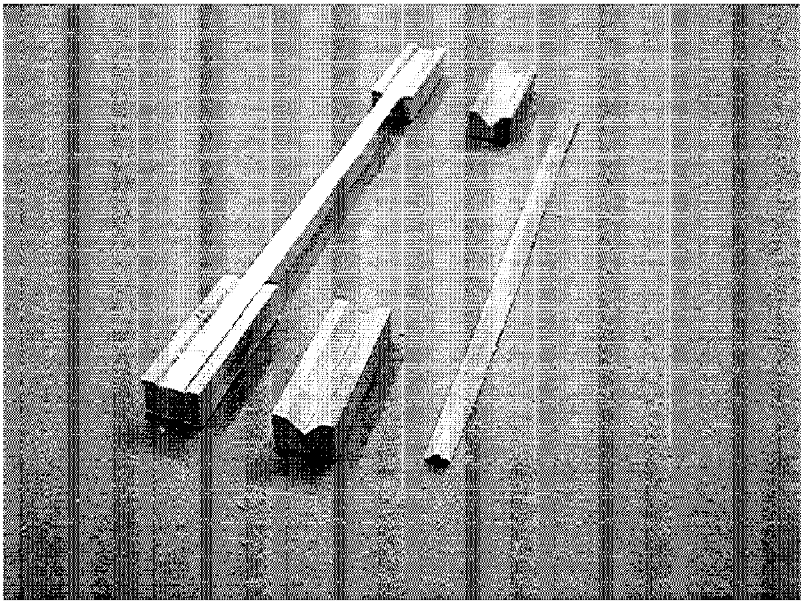

Figure 4: Tension specimen cut from form an existing beam. The triangular cross section has the side length of 4 mm.

The ends of specimens are attached with the epoxy adhesive to grooved wooden blocks so that potential end effect due clamping is minimized. Tensile tests are performed in standard testing equipment using a special set of grips – Figure 5. A displacement transducer is used to measure deformation so that the modulus of elasticity in tension along fibers can be obtained. A typical load-deformation curve for a specimen is shown in Figure 6. The cross-sectional area of the specimens is comparable to the cross-sectional area of the ASTM tension

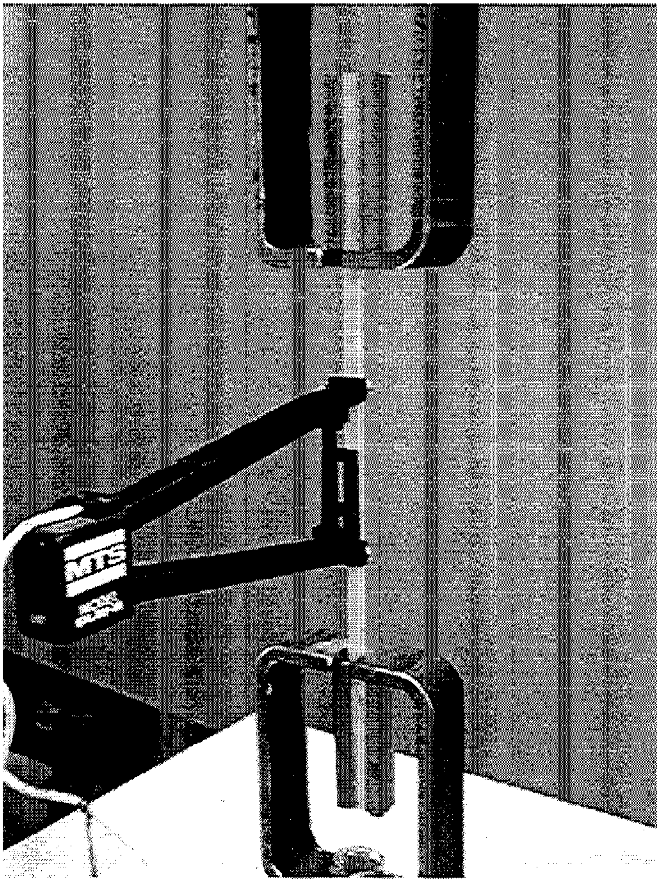

Figure 5. Testing of tensile micro specimen in tension.

specimen (about 8 mm^2) that is required for small-clear specimens of wood (2). This means that the values obtained from this test are directly comparable with the standard tests, and no correlation is needed. To induce failure in the central portion of the triangular specimen, it is recommended to reduce the cross section of the mid part. Such reduction can be done by sanding, but caution must be exercised to maintain a smooth plane to avoid variation on cross sections.

Experiments were performed in the laboratory with several different species that included Red Oak, Western Cedar, Hard Maple, and Yellow Pine. The goal of the test was to observe failure modes and investigate the feasibility of the technique in strength evaluation of in-situ timbers. Figure 6 shows typical test

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results. The modulus of elasticity in tension and tensile strength can be easily obtained.

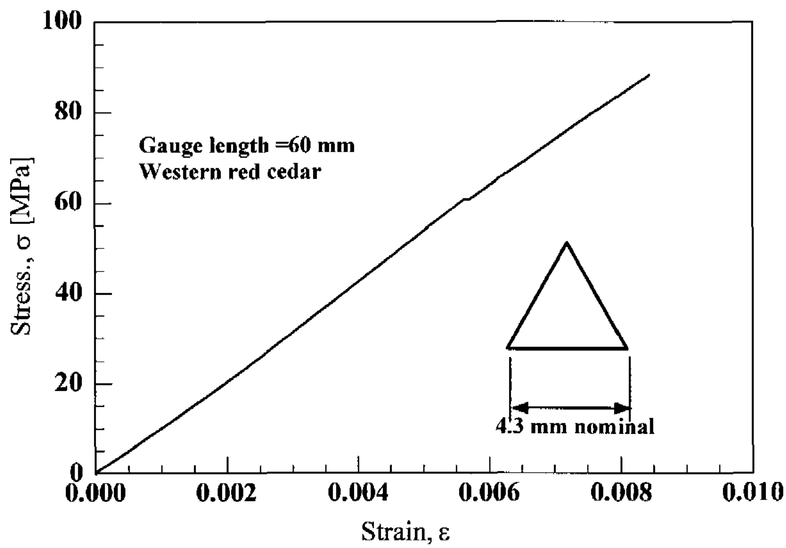

Figure 6. Stress-strain relationship for tensile micro specimen.

3 Conclusions

The nondestructive (indirect) methods used to estimate mechanical properties suffer from relative unreliable results. The methods can give reasonable comparative measurements (standard versus tested member) but suffer from errors resulting from weak correlation between destructive and nondestructive parameters. Destructive methods are sometimes used to obtain direct strength measurements, but they require an extraction of the timber, which may be unacceptable in historic structures. Moreover, several members must be extracted to minimize the errors resulting from variability of material.

The semi destructive methods can bridge the gap between nondestructive (indirect) and fully destructive (direct) methods of strength measurement. The weakness of the semi-destructive methods is in the size of specimens that increase the variability of test results. This means that careful spatial distribution of samples and statistical experiment planning and evaluation is crucial to obtain representative data. The small specimens yield only material properties that must be further processed to calculate strength of full-size timbers. This is done via correlations with macroscopic parameters such as size and location of natural defects. The nondestructive (indirect) methods such as ultrasound or stress wave analysis can play a role in minimizing the errors.

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