

MICROMECHANICAL MEASUREMENT OF WOOD SUBSTRUCTURE PROPERTIES

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ABSTRACT

The annual rings of softwoods are visually obvious and represent cylindrical layers of primarily cellulosic material that possess significantly different properties. For simplicity, wood construction products are designed assuming a material homogeneity that does not exist. As rapidly grown plantation trees are used for wood products, fewer rings are contained in an individual wood product with the outcome of each individual ring playing a greater role in product structural performance. The magnitudes of these earlywood and latewood property differences are largely unknown because of the difficulty in measuring small specimens. A cooperative study between the University of Wisconsin-Madison and USDA FS Forest Products Laboratory is underway to quantify the impact of variations in earlywood and latewood proportions. This paper discusses the background, approach, device used to determine modulus of elasticity (E) and shear modulus (G) for earlywood and latewood, difficulties faced with testing wood, and presents preliminary results.

BACKGROUND

A large portion of the nation's future dimension lumber resource will come from genetically improved trees grown on intensively managed plantations. The focus of most tree breeders and forest managers is on increasing volume of wood fiber produced (i.e. "fast growth"). Fast growth can have negative impacts on the structural qualities of the wood products produced [1]. Traditional databases don't always characterize this new wood resource. An unacceptably high variability in stiffness and dimensional stability limits the use of the fast growth plantation wood. Earlywood and latewood property differences are believed to be a key contributor to this variability.

Current structural wood product design properties are developed from macroscale tests and visual inspection of products. Latewood percentage is one of the most widely used wood quality characteristics because it is highly correlated with wood specific gravity and provides a visual index of strength and structural properties, and is an important component in lumber and timber grading rules.

No clearly defined relationships between latewood structure and solid wood properties exist.

We know latewood tracheids can be over twice as strong as earlywood tracheids [2]. Latewood tracheids are also thicker walled with much smaller radial lumen diameters (Figure 1). But there currently are no means to translate these observations to wood product performance.

The ratio of specific gravity of latewood to earlywood in loblolly pine is typically 2 to 1 or greater [3]. While the differences in earlywood and latewood specific gravities have been investigated, actual values of the mechanical properties of earlywood versus latewood are rare and at present we can only infer the consequences of these differences. We believe that in extreme cases, the latewood may be resisting most of the load, with the earlywood acting primarily as spacing material.

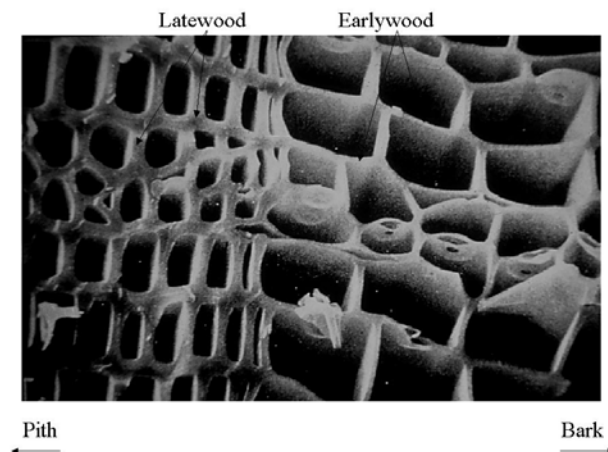


Figure 1—Micrograph of latewood-earlywood transition in a piece of softwood

The micro testing of earlywood and latewood reported in this paper is a portion of a cooperative study between the University of Wisconsin-Madison and USDA FS Forest Products Laboratory underway to quantify the impact of variations in earlywood and latewood proportions.

APPROACH

Ten loblolly trees in a southern pine plantation in Arkansas have been hand selected. The fertilization and pruning history of the plantation have been recorded as well as the location and directional orientation of each stem. Two 1.5m (5-ft) bolts were collected from each stem – one at breast height and the other beginning at approximately 5 m (20-ft) and shipped to the USDA Forest Service Forest Products Laboratory (FPL) in Madison, WI.

Once at FPL the bolts were cut into toothpick size specimens, curved arcs, and full size boards (Figure 2) and stored under controlled environmental conditions.

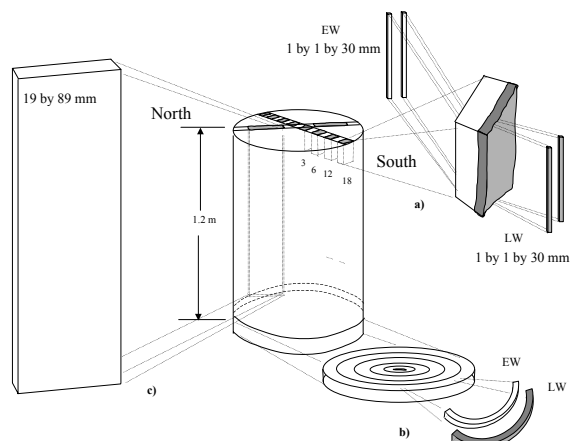


Figure 2—The cut out pattern from the 5-ft bolt for loblolly pine specimens. a) set 1: earlywood and latewood small rectangular specimens for longitudinal E and G, b) set 2: curved arcs of early wood and latewood from disc for tangential E c) nominal 1 by 4 inch board for full size stability measurements.

The small 1 by 1 by 30 mm wood specimens are composed of either earlywood or latewood were tested to determine E and G, in bending and torsion, using a unique micromechanical-testing device. To date eight of the twenty bolts collected have been tested for E and G.

TESTING DEVICE

The E and G were determined from bending and torsion tests respectively using a novel micromechanical-testing device. This broadband viscoelastic spectroscopy (BVS) micro-testing device has been used extensively to study different viscoelastic materials [4,5]. A simplified schematic showing the inner workings of the BVS is shown in Figure 3.

The small specimens 1 by 1 by 30mm specimens are glued at one end to a 330mm brass rod and at the other end cemented to a permanent magnet with cyanoacrylate adhesive. A mirror is attached to the permanent magnet. The rod is attached to a rigid framework that is isolated from building vibration. A diode laser and a split diode light detector mounted to a movable base are used to determine the specimen's deformation. The diodes are connected to a power supply and 30 MHz synthesized function generator controls the current in the Helmholtz coil, thereby controlling the magnetic field or the torque which acts upon the specimen end. The current signal and the voltage from the split diode light detector are output to a digitizing oscilloscope.

The small specimen is deflected by an electromagnetic torque produced by the action of an electric current in the Helmholtz coil upon a permanent magnet at one end. The resulting angular displacement is then measured optically by the split diode light detector. The specimen can be loaded in bending or torsion depending on which pair of coils is connected. Determining E in bending requires the addition of a dove or right angle prism to the micro-mechanics testing instrument. A dove prism must be placed in the beam path to change the direction of the beam motion from vertical to horizontal.

The elastic properties are determined by collecting information on a specimen's dimensions, calibration constants for the split diode angle detector, magnet calibration, distance between specimen and detector, feedback resistance, torque or bending signal in volts, deflection angle signal in volts, and using basic elastic theory describing the deflection of a fixed-free rod.

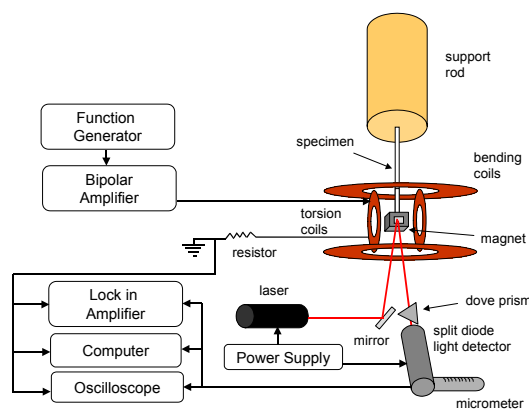


Figure 3—Schematic showing the inner components of the BVS micro tester elastic property measuring device.

DIFFICULTIES

Small wood specimens absorb and desorb water quite freely altering the specimen's dimensions. Care has to be taken to reduce abrupt changes in relative humidity (RH) on the specimens. Significant changes in moisture content results in dimensional changes in the test specimen and a drift in the voltage signal in data collected. As a result when testing small wood specimens guidelines must be imposed to limit changes in relative humidity during testing.

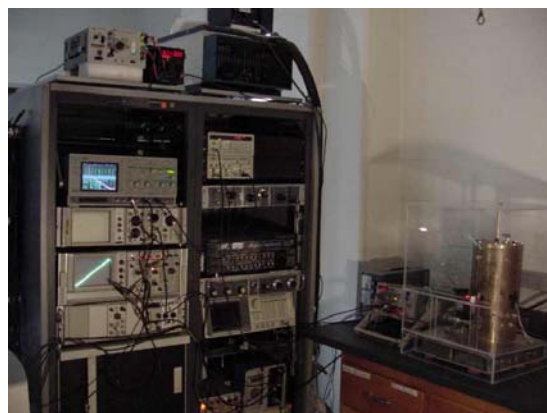


Figure 4—Photograph of the BVS micro tester.

Considerable effort was spent developing methods for controlling environmental conditions around the E - G specimens and the test chamber Figure 4. Relative humidity sensors were placed inside the chamber and where the test specimens were stored. Temperatures and humidity were maintained within at $68 \pm 3^\circ \text{F}$ and a range of relative humidity of $50 \pm 10\%$. The sensitivity of the measurements taken and the size of the specimens involved required that the temperature/humidity conditions in the test chamber and the room be almost identical. The test chamber of the BVS was conditioned using a hose that fed conditioned air into the test chamber. Two fine needle valves and a metering valve were used to mix air from a DRIERITE laboratory air and gas drying unit or air that had been bubbled through a beaker of water to maintain the RH inside the chamber with the laboratory's ambient RH.

When the laboratory's ambient RH fell outside the acceptable range additional steps were taken. To minimize humidity changes the prepared specimens were kept in a sealed case that contained a saturated solution of Sodium Bromide 99+% in water. This solution maintained a stable relative humidity level of approximately 55% RH.

RESULTS

Although further testing is to be conducted, a number of trends in the E and G data are observed. In a majority of cases earlywood and latewood properties increased going from pith to bark. Also, specimens at higher elevations in the same tree almost always had higher E and G values than specimens with similar locations but lower on the tree.

Ratios of E_L of latewood to adjacent earlywood range from 1.0 nearest the pith to as much as 7.0. A typical earlywood longitudinal modulus of elasticity is about 3.4 GPa (500,000 psi). Latewood values are more variable and ranged from 3.4 GPa to 24.1 GPa (500,000 psi to 3,500,000 psi). Figure 5 shows and example of the test results. The earlywood and latewood E_L test results shown are for Bolt 4.

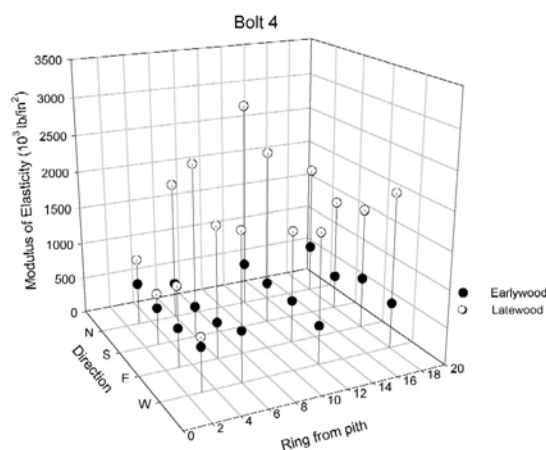


Figure 5.—Modulus of elasticity results for Bolt 4

A typical earlywood shear modulus values was 0.76 GPa (110,000 psi) while latewood values were often two or more times that. Ratios of shear modulus of latewood to adjacent

earlywood range from 1.0 nearest the pith to as much as 4.0. Latewood values had more variability than did earlywood and ranged from 0.69 GPa to 2.5 GPa (100,000 psi to 370,000 psi). Figure 6 shows the results of earlywood and latewood G testing for Bolt 6.

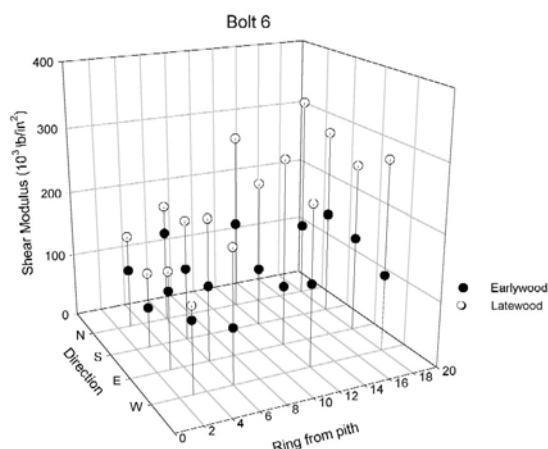


Figure 6—Shear modulus results for bolt 6.

CONCLUDING REMARKS

The BVS micro testing device proved to be a valuable tool in determining the E and G for solid wood pieces of earlywood and latewood. In future papers the E and G results reported here will be correlated with specific gravity, micro fibril angle, grain angle, and longitudinal shrinkage.

ACKNOWLEDGMENTS

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