TENSILE PROPERTIES OF LOBLOLLY PINE GROWTH ZONES

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ABSTRACT

For the determination of tensile properties of the earlywood or latewood zone of loblolly pine, modified standard ASTM tensile specimens were machined so that the critical sections at mid-length of specimens (2½ inches length of uniform cross section) consisted entirely of either earlywood or latewood. Specimens were tested to failure in both the green and air-dry condition.

Specific stress and specific stiffness of latewood in the air-dry condition are more than 50% and 63% higher, respectively, than corresponding values for earlywood. More than one-third of the tensile strength of latewood is attributed to factors other than density. Moisture affects the specific strength of latewood more than the specific strength of earlywood. The moisture effect on specific stiffness is approximately the same for both earlywood and latewood. The property affected most by moisture is the specific stress at proportional limit.

Same growth zones were tested by microtome sections of approximately 100 μm in thickness. Maximum tensile properties of any growth zone obtained from microtome sections were approximately one-half of the values obtained for the same zone from modified standard tensile specimens.

This paper presents partial results of a large study that concerns several mechanical properties of earlywood and latewood zones of southern yellow pine in relation to anatomical characteristics. More specifically this paper concerns the following objectives:

1) To determine and compare the tensile properties of earlywood and latewood zones of loblolly pine (*Pinus taeda* L.), in the green and air-dry conditions, by testing modified standard ASTM tensile specimens.

2) To determine the tensile properties of loblolly solidwood by standard clear tensile specimens and to establish a combined relationship between tensile properties and specific gravity for earlywood, latewood, and solidwood.

3) To compare the tensile properties of each growth zone obtained by modified standard specimens with tensile properties of the same zone previously obtained from matched microtome sections.

BACKGROUND

Wood exhibits its greatest strength in tension parallel to the grain. Tensile strength parallel to the grain of small clear specimens is approximately 2 to 3 times greater than compressive strength parallel to the grain, about 1½ times greater than static bending strength and 10 to 12 times greater than shear strength (Biblis 1966; Wangaard 1950; Werren 1964). Wood is anisotropic; the ratio of tensile strength parallel to the grain to that of perpendicular to the grain is frequently as high as 40 to 1 (Biblis 1966; Wangaard 1950). This high degree of anisotropy may explain the effects of grain slope on tensile strength parallel to the grain.

Tension parallel to the grain is an important property since it occurs in cases of structural uses of wood and wood products, either alone or in combination with compression and shear, as in static bending. Nevertheless, the tensile parallel to the grain properties have not been fully determined for all commercially structural woods. The reason for this is that although the importance and magnitude of tensile strength have been long recognized, the mechanical fastenings of tension structural members were governing the allowable working stresses which were appreciably smaller than the tensile stresses. The determination of the allowable tensile stresses for various commercially structural species was not needed. Instead, the static bending allowable working stress of the same grade and species was used for tensile members. With the development of better mechanical fasteners and synthetic adhesives for wood bonding, a high proportion of the tensile strength of wood can now be used in modern design of wood structures. The need for determining the tensile parallel to the grain properties of all commercially structural species for the most efficient structural utilization of wood was emphasized (Werren 1964).

In recent years, attempts have been made not only to determine tension properties of structural grades and sizes of several softwoods, but also to establish relationship between maximum tensile strength and stiffness for grading purposes. The relationship between maximum tensile strength and modulus of elasticity is not as well defined as is the relationship between static bending strength (modulus of rupture) and modulus of elasticity. Doyle and Markwardt (1967) found the correlation coefficient of the relationship between tension parallel to grain and pure modulus of elasticity (combining three structural grades and three sizes of southern pine) to be only 0.65. On the other hand, Kramer (1964) after testing 540 southern yellow pine specimens representing three structural grades and three sizes, found a much higher correlation coefficient (0.875) for the relationship between modulus of rupture and pure modulus of elasticity.

Wood from southern yellow pine, like most other conifers and ring porous hardwoods, is highly heterogeneous in structure. Coniferous wood can be considered a natural laminate-composite in which the alternating laminas of earlywood and latewood zones, in a radial direction, constitute a periodic type of heterogeneity. The average specific gravity of southern yellow pine latewood is approximately three times greater than that of earlywood (Fitzgerald 1968; Forsaith 1933).

In order to analyze mathematically the mechanical behavior in tension parallel to grain of coniferous wood, and particularly the relative contribution of earlywood and latewood to the properties of the "natural laminate-composite," it is necessary to determine accurately the periodic variations in tensile strength and elastic properties in consecutive growth rings. The same data also could be used for an experimental verification of the theory of transverse anisotropy of wood and of radial shrinkage.

Determination of tensile strength variation in successive growth rings of several conifers was first attempted by Wardrop (1951). This study, however, was concerned more with the relationships between tensile strength and various anatomical characteristics of tracheids than it was with the strength variation. The strength parameter in his study was breaking loads of tangential microtome sections 80 μm in thickness. Since the thickness of these microspecimens could have varied as much as $\pm$ 10 per cent from the nominal thickness of 80 μm, the determined relationships could be only qualitatively justifiable. Wardrop concluded, from observations of failures in the microspecimens, that tension failure occurs within cell walls rather in the middle lamella, and he stated the following: "This does not necessarily imply that the intercellular adhesion per unit area of contact surface between cells is greater than the strength of the tracheids, because the line of failure involved in the separation of cells is very much greater than that involved in the rupture of the cell walls." Wardrop's conclusion, with respect to the failure location, was not justified by his test. He did not consider the fact that his microspecimens contained several longitudinally and/ or obliquely cut tracheids. Such a surface exposes several weak points in cell walls where failure can be initiated.

Kloot (1952), who first tested wood microspecimens in tension, was more cautious in his conclusions. He seriously questioned the effect of cut tracheids on the tensile strength and on the nature and occurrence of failures. He actually observed a different type of failure in earlywood than he did in latewood microspecimens. The observed failures in earlywood indicated a rupture of cell walls, while failures in the latewood microspecimens occurred in the middle lamella. The same differentiation in failures between earlywood and latewood microspecimens of Douglas fir was observed by Wellwood (1962) and Kennedy and Ifju (1962).

With respect to the influence of cut fibers on the strength of microspecimens, Kloot (1952) questioned the ability of cut fibers to carry proportional load and stated that "the effective cross section of the specimen is in doubt and thus also is the computed maximum tensile stress." Wellwood (1962), on the other hand, believed that microtome specimens give greater tensile strengths than standard specimens of the same materials. He specifically stated with regard to Douglas fir that, "Springwood microtensile samples appear to be about 23 per cent stronger than conventional samples of comparable density. Summerwood, on the same basis, is about 27 per cent stronger." Wellwood (1962) compared the tensile strength of Douglas fir microspecimens with the tensile strength obtained by Van Vliet (1959) on standard (ASTM) tension specimens of the same species. Wellwood's conclusion, however, was not justified since his comparison of microspecimen tensile strength with that of standard specimens is not valid for the following reasons: Van Vliet (1959) did not test specimens with specific gravities equal to those of the earlywood microspecimens; therefore an extrapolation of Van Vliet's data could represent only an imaginary material. Furthermore, Wellwood's specimens were not matched with Van Vliet's specimens. It is well known that strength properties of unmatched specimens, from the same species, can vary more than 100 per cent; therefore, the comparisons were not justified.

Relationships between tensile strength and specific gravity as well as between stiffness and specific gravity for microspecimens of Douglas fir were accepted as being linear by Ifju, Wellwood, and Wilson (1965). However, it appears that a curvilinear relationship (with a decreasing rate of change of curve slope as the specific gravity increases) would have fitted their plotted data even better than a linear relationship. The author (1968) found, from the analysis of variance and F-test of the relationship between tensile strength and specific gravity of loblolly pine microspecimens, that a curvilinear relationship fits the data significantly better than does a linear relationship. It also was shown that a curvilinear relationship between stiffness and specific gravity of the same microspecimens was significantly better than was a linear relationship.

EXPERIMENTAL PROCEDURE

A 38-year-old loblolly pine was selected in Lee County, Alabama, for this study. The tree was healthy, straight, and clear to ¾ of the height. The annual growth rings were approximately cylindrical with narrow transition zones between earlywood and latewood. The width of the growth rings varied from 3/16 inch to 5/16 inch; widths of earlywood and latewood zones were approximately equal.

Eight-foot logs were cut from the bole and quarter-sawn into planks 3 inches in thickness. The planks were then cross-cut into 4 ft lengths. The first (lower) 4 ft sections were designated as material for green specimens and then immersed in a tank with running clean water. The second 4 ft sections were end-coated, stickered, air-dried, and designated as material for air-dry specimens.

Modified ASTM Standard Tensile Specimens

Tensile specimens used in this study were similar to standard tension specimens described in ASTM Standards D-143-52 with the following exception. For specimens machined to test earlywood or latewood alone, critical sections of the specimen (2½ inch length of uniform cross section) consisted entirely of either earlywood or latewood, Fig. 1. Thickness of critical sections of these specimens was variable (depending upon the width of the zone tested). Care was taken during machining not to include the transition zone in test sections.

Specimens were taken to represent the entire tree length. Juvenile wood was