Tension Parallel-to-Grain Properties of Southern Pine Dimension Lumber
ABSTRACT

This study provides an appraisal of the tensile properties of the present structural grades and sizes of southern pine 2-inch dimension lumber; provides a means of evaluating the presently assigned working stresses; and includes pertinent data relating to an appraisal of the possibilities and limitations of lumber grading based on a stiffness evaluation.

The data represent one of the first major compilations of the tensile properties of wood members and are particularly timely because of the increasing importance of tensile stresses associated with modern structural design. Results re-emphasize, for wood, the much greater sensitivity of tensile strength to knots and grain deviations than exists for bending and compression parallel-to-grain strength properties. The study also suggests the need for a review of the presently assigned tensile stress values for other grades and species in relation to the actual tensile strength.

Samples of full-size, kiln-dried 2-inch dimension lumber, from mills in 10 southern states, were studied. In all, 496 specimens represented structural grades No. 1 KD, No. 2 KD, and No. 3 MG KD and nominal sizes 2 by 4, 2 by 6, and 2 by 8 inches. After visual grading, including the evaluation of the grade-strength ratio, all specimens were nondestructively tested in flatwise bending and in torsion and then tested to destruction in tension parallel to grain.

The tensile strength parallel to the grain of the dimension lumber in the No. 1 KD grade varied from 1,570 to 12,640 p.s.i. with an average of 5,480. In the No. 2 KD grade, the tensile strength varied from 1,000 to 10,430 with an average of 3,400 p.s.i., and in the No. 3 MG KD grade it varied from 680 to 9,800 with an average of 2,420 p.s.i. As would be expected, these values are lower than the tensile strength values normally obtained for small clear southern pine specimens.

Modulus of elasticity (true) in flatwise bending compared closely with the modulus of elasticity in tension. The modulus of elasticity is affected by the structural quality of the lumber and decreases as the grade is lowered.

The relationship of tension parallel to the grain versus modulus of elasticity (true) in flatwise bending for all grades and sizes of dimension lumber gave a correlation coefficient of 0.68.

Modulus of rigidity correlated poorly with maximum tensile strength and with modulus of elasticity. The average $E_{FT}/G$ ratio was 12.8.

The average specific gravity of the dimension lumber was 0.52. This value is slightly higher than the value of 0.51 previously reported for shortleaf and loblolly pine. Correlation coefficients of 0.50 for maximum tensile strength and 0.62 for modulus of elasticity in tension versus specific gravity were obtained.
Tension Parallel-to-Grain Properties of Southern Pine Dimension Lumber

by
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FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

During the past several years, an extensive study of the properties of southern pine in relation to strength grading of dimension lumber has been under way at the Forest Products Laboratory, in cooperation with the Southern Pine Inspection Bureau (SPIB). Included in the first phase of the research was an evaluation of the bending and compressive properties of seasoned dimension lumber of different sizes and grades. The results of these studies were presented in U.S. Forest Service Research Paper FPL 64.1

The second phase of the study, which is covered by this paper, relates to the tensile properties of seasoned southern pine dimension lumber and coordinates with the previous work. The data represent one of the first major compilations of the tensile properties of full-size wood members and are particularly timely because of the increasing importance of tensile stresses associated with modern timber design.

Tension parallel to the grain has long been recognized as one of the fundamental properties of wood. Tests of small, clear, straight-grained specimens have shown that tensile strength is far in excess of other strength properties. In fact, it is the high tensile strength along the grain, in contrast to the relatively low shear strength and compressive strength across the grain, that has retarded the development of a satisfactory tension parallel-to-the-grain test method.

The original basic standard methods of test-

1Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

ing small clear specimens of timber, under which the extensive evaluation of the mechanical properties of woods grown in the United States was undertaken, did not include a tension parallel-to-grain test. A tension test was subsequently developed and included in ASTM Standard D 143. It was revised in its present form as the result of an international timber engineering conference in 1947. While research is providing more data on the tensile strength parallel to grain of small clear specimens, the volume of such information is less than that for other strength properties.

Standard test methods for evaluating most mechanical strength properties of timbers in structural sizes have been developed, but none had provided for a tension parallel-to-grain test procedure. For this reason, the initial phase of the southern pine program was limited to evaluating static bending and compression parallel-to-the-grain strength properties in relation to the grading of dimension lumber. During recent years, research at the Forest Products Laboratory and elsewhere has resulted in development of techniques that have led to establishing a satisfactory tension test method adaptable to 2-inch dimension lumber.

This paper presents the results of tension parallel-to-grain tests of full-size dimension lumber and coordinates the results with the bending and compression parallel-to-grain data obtained in the first phase of the study.

Figure 1.—General locations at which samples of dimension lumber were obtained.

**SCOPE**

This study of southern pine dimension lumber was planned to provide a selection of representative samples in a statistically significant quantity from 10 states in the southern pine region. The procedure, for the most part, followed that used in the previous study of the flexural and compressive properties of southern pine dimension lumber. The lumber selected was at 15 percent moisture content or less in structural grades No. 1 KD, No. 2 KD, and No. 3 MG KD and in sizes 2 by 4, 2 by 6, and 2 by 8. In all, 496 tension tests of full-sized specimens were made in this study. Prior to testing to destruction in tension parallel to grain, each piece was visually graded to estimate the grade-strength ratio (for bending) and nondestructively tested in flatwise bending to evaluate modulus of elasticity and in torsion to evaluate modulus of rigidity. After the tests were completed, small clear specimens were cut from the undamaged portions of the broken specimens. The results of the tests of the minor specimens will be reported in a subsequent publication.

**SELECTION OF MATERIALS**

Material used in this investigation consisted of dimension lumber obtained in most instances from one mill in each of the 10 states that produce a majority of the southern pine lumber. The general geographic locations from which the lumber samples were obtained are shown in figure 1.

The mill in each state was selected on the basis of a general survey of southern pine lumber production, which showed that the lumber produced by the mill was representative of the quality and species of lumber produced and marketed in that general geographic area. Selection of the mills was made by the Southern Pine Inspection Bureau in collaboration with the Southern and Southeastern Forest Experiment Stations of the U.S. Forest Service. Selection of the lumber samples at each mill was supervised by representatives of the U.S. Forest Service and the SPIB. For the most part, the lumber samples were obtained at the same mills and in the same manner as those previously obtained for determining the flexural and compression parallel-to-the-grain properties of full-sized dimension lumber.

The grading of the lumber was in accordance with the 1963 Standard Grading Rules published by the SPIB and which conform to the requirements of the American Lumber Standards. The lumber was taken without differentiating between the various southern pine species. It was selected to conform to the kiln-dried grade requirement of not exceeding 15 percent moisture content. All references made to grades in this paper refer to kiln-dried lumber.

The material was sampled to provide specimens for determining the tension properties parallel to the grain of full-size lumber pieces in three sizes and three grades (table 1). The 16-foot material—ten 2 by 4's and five 2 by 8's in grades No. 1 KD, No. 2 KD, and No. 3 MG KD, and five 2 by 6's in grade No. 2 KD—was sampled in each of the 10 states.

The test pieces in each grade were randomly chosen from the lumber stock at each mill. The grades included medium-grain or dense pieces that develop in normal production. One or two bundles of lumber containing a total of 50 to 200 pieces, all in one general grade in one size and length, were selected for sampling. In general, a few additional pieces were randomly chosen from each group of pieces in addition to those specifically required for the study.

The moisture content and the grade of each piece were determined by the SPIB lumber inspector and recorded on each piece at the time of selection. The pieces chosen for the sample that did not meet the required grade, or showed a moisture content greater than 15 percent, were eliminated from the group and the next randomly chosen piece meeting the required grade and moisture content was taken in its place.

Each piece selected in the test sample was identified on one end by a code symbol to show the geographic location, grade, type of test, and specimen number. No reference was made to any particular grain orientation or growth characteristic when the pieces were code marked. At some of the mills, the lumber had received

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a surface treatment of a commercial water-
repellent solution.

The lumber pieces selected were placed in small bundles, wrapped with a moisture-resistant covering, and shipped by motor freight to the U.S. Forest Products Laboratory. Upon receipt, the lumber was removed from the bundles, placed on stickers, and conditioned at 72° F. and 65 percent relative humidity for several weeks before test.

TEST METHODS

In all tests, the specimens were randomly placed in the testing machine, thus disregarding any effort at systematic positioning with respect to hots, grain deviation, warp, or other characteristics. A photographic record was made of one wide face prior to test and of the opposite face after test.

The moisture content of the material at time of test was determined by the ovendrying method on 1-inch-long sections cut from the test specimens. The specific gravity was based on the computed ovendry weight and the volume of the entire piece as determined by measurements at the time of test.

Grade-Strength Ratio Determination

Prior to test, the grade-strength ratio as established for bending strength was determined visually for all specimens. The determinations were made in accordance with the requirements of ASTM D 245.5

Flatwise Flexure

All specimens were first nondestructively loaded in flatwise bending and in torsion to determine their elastic properties. Stiffness in flatwise flexure

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Table 1.—Southern pine dimension lumber selected for evaluation of tensile strength and related properties

<table>
<thead>
<tr>
<th>Size S4S (16-ft. length)</th>
<th>Grade</th>
<th>Reference paragraph</th>
<th>Number of pieces</th>
<th>Extreme fiber in bending and tension parallel to grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 by 4</td>
<td>No. 1 KD</td>
<td>210</td>
<td>100</td>
<td>1,750</td>
</tr>
<tr>
<td></td>
<td>No. 2 KD</td>
<td>214</td>
<td>100</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>No. 3 MG KD</td>
<td>222</td>
<td>100</td>
<td>840</td>
</tr>
<tr>
<td>2 by 6</td>
<td>No. 2 KD</td>
<td>214</td>
<td>50</td>
<td>1,500</td>
</tr>
<tr>
<td>2 by 8</td>
<td>No. 1 KD</td>
<td>210</td>
<td>50</td>
<td>1,750</td>
</tr>
<tr>
<td></td>
<td>No. 2 KD</td>
<td>214</td>
<td>50</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>No. 3 MG KD</td>
<td>222</td>
<td>50</td>
<td>840</td>
</tr>
</tbody>
</table>

1 Grades Nos. 1, 2, and 3 include medium grain or dense pieces as they develop in normal production.


3 An equal number of pieces were selected at 10 different geographic locations.

4 Stress rating from paragraph 201 in 1963 Standard Grading Rules for Southern Pine Lumber, including Supplement No. 4, dated April 5, 1965.

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bending was determined by dead-weight loading at two load points on the specimen, as shown in figure 2. Weights in 7-pound increments were lowered simultaneously to the quarter points of the specimen until a total load of 112 pounds had been placed on the test piece. The midspan deflection was measured relative to the points of support by a taut wire and scale as each pair of weights came to rest on the specimen. This technique provided data for establishing load-deflection curves.

Torsion

The torsion test was conducted on each piece, as shown in figure 3. The specimen was gripped at its ends and a torque applied at one end at the rate of about 0.1 radian per minute. A weighing mechanism at the opposite end provided a measure of the torque. The distortion or twist resulting in the specimen was determined over a central gage length of 144 inches. The angular movement was measured at increasing intervals of load up to 800 inch-pounds of torque by reading the movement of a projected reference line, from an illuminated lantern located at one gage point, on a circular scale attached to the piece at the opposite gage point.

Tension Parallel to Grain

The tension parallel-to-the-grain test method
was for the most part specially developed. The tests were made on the full-size pieces by means of the horizontal loading apparatus shown in figure 4. The cage shown around the specimen is a safety device. The pieces were loaded through wedge-type grips designed to apply a uniform gradient of gripping action to the specimen, ranging from zero stress at the tips of the grips to full stress at some finite length from the tips. The grips were in contact with the specimen over about 15 inches at each end. They were more or less self-alining in that they were spring-mounted on trunnions and were free to move into axial alinement as load was applied. This enhanced the attainment of uniformly distributed stress along and across the test section.

Tension was applied to the specimens by means of a 100-ton-capacity hydraulic ram. A uniform rate of head movement was employed to provide a fiber strain between grips of about 0.0007 inch per inch of length per minute. The elongation observed on each piece was the average of that for the two wide faces, measured over a 120-inch center gage length.

The extensometer assembly mounted in position at one end of the specimen is shown in figure 5. It consists of a rigid U-frame attached to the specimen at four contact points (two on each wide face) by means of hand screws (A); a curved metal spring (B), with one end fastened to the U-frame and the other supporting the dial assembly (D) to which the averaging lever (C) is attached; and two taut wires (E), each fastened at the opposite end of the specimen to a nail in the wide face and passing over a pulley (F) in the U-frame to the end of the averaging lever. The end of the dial spindle rests on the U-frame. Thus, in operation, the dial (with averaging lever) is pulled downward against the spring (B) by the wires as the specimen is elongated.

As the test progressed, 8 to 12 simultaneous observations of strain and load were taken at uniform load increments to provide data for

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6The tension test procedure conformed to the new standard method of conducting tension parallel-to-grain tests included in ASTM Standard D 198, "Standard Methods of Static Tests of Timbers in Structural Sizes."

establishing load–elongation curves. After the load–elongation data were obtained, the dial gage was removed from the specimen, safety enclosures were moved into position around the specimen (fig. 4), and the specimen was loaded to destruction.

PRESENTATION AND ADJUSTMENT OF DATA

Tables 2 to 6 and figures 6 to 26 of this paper present the results of the tension tests of 496 full-size dimension lumber specimens, together with related data. Computations are based on the actual dimensions of the specimens. The notations and formulas used in computing the data are given in Appendix I.

Flexural Modulus of Elasticity Adjustment

The flatwise modulus of elasticity value for each piece was adjusted for shear deformation to the true elastic modulus. In the adjustment, the actual modulus of rigidity value derived for each piece by the torsion test was used. The adjustments were very small (about 0.1 percent) because the large span–depth ratio employed in the tests produces but little shear deformation. In this paper, the modulus of elasticity in flexure used in all relationships (except in table 5) is the adjusted true modulus.

Comparison of Test Data and Assigned Stresses

Comparisons of the tension parallel-to-grain test data with design stresses at 100 percent and 80 percent of the recommended design values are given in table 5 for the various lumber grades, along with data on modulus of elasticity. The tension parallel-to-grain design stress values given in paragraph 201 of the 1963 Standard Grading Rules for Southern Pine (table 1) were adjusted upward for comparison with the test data by applying the inverse of the reduction factors of 9/16 (long-term loading) times 10/13 (other factors, including factor of safety) times 11/10 (normal loading) = 1/2.1. The assigned modulus of elasticity values were unadjusted for grade but were adjusted to the basis of the true modulus by increasing the values 10 percent to compensate for shear deformation.

DISCUSSION OF RESULTS

Significance of Differences of Lumber Properties

To study the properties of the southern pine lumber across the producing range, an analysis of variance was made of the maximum tensile strength and the flatwise modulus of elasticity in flexure for the different grades. The results listed in table 2 show that the difference in the average maximum tensile strength among locations was not significant for the No. 1 KD grade, was significant at the 5 percent level for the No. 2 KD grade, and was significant at the 1 percent level for the No. 3 MG KD grade. The flatwise modulus of elasticity was significant at the 1 percent level for all grades.

Dimensions of Lumber

A study was made to determine the amount of variation in the actual measured dimensions (width and thickness) of the No. 1 KD, No. 2 KD, and No. 3 MG KD grades of lumber used in this study and to compare the actual dimensions with the standard dressed-size requirements. The lumber sample used in this comparison consisted of 499 pieces obtained from one or two mills in each of 10 states (fig. 1). The lumber was kiln dried and surfaced at the mills prior to sampling. The dimensions of each piece on which these comparisons are based were determined at the Forest Products Laboratory, prior to test, after the lumber had been conditioned in a controlled atmosphere for some time. The moisture content determinations made after test showed the wood to be at an average of 12.2 percent.

The average width and thickness measurements, the computed values of flatwise and edgewise moments of inertia (based on actual dimensions of the lumber), and standard deviations are listed in table 3 for the various lumber grades and sizes. These data show that the average thickness was 1.629 inches, which is slightly greater than the standard dressed thickness of 1-5/8 inches. The average widths for all grades at 12.2 percent moisture content were about 0.032 inch less than the standard dressed width for the 2 by 4 size and about 0.050 inch less for the 2 by 6 and 2 by 8 sizes. When adjusted to a 15 percent moisture content basis, however, these average departures in width are actually less than 0.5 percent.
Table 2.--Significance of differences of maximum tensile strength and modulus of elasticity of southern pine dimension lumber from 10 locations

<table>
<thead>
<tr>
<th>Grade</th>
<th>Number</th>
<th>Mean</th>
<th>F^1</th>
<th>Level of significance</th>
<th>Number</th>
<th>Mean</th>
<th>F^1</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1 KD</td>
<td>148</td>
<td>5,480</td>
<td>1.50</td>
<td>N.S.</td>
<td>148</td>
<td>2,012</td>
<td>3.42</td>
<td>1</td>
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<tr>
<td>No. 2 KD</td>
<td>198</td>
<td>3,400</td>
<td>2.42</td>
<td>5</td>
<td>199</td>
<td>1,684</td>
<td>4.68</td>
<td>1</td>
</tr>
<tr>
<td>No. 3 MG KD</td>
<td>149</td>
<td>2,420</td>
<td>4.01</td>
<td>1</td>
<td>147</td>
<td>1,547</td>
<td>4.49</td>
<td>1</td>
</tr>
</tbody>
</table>

^1_{F} is the ratio of two variables.  
^2N.S. is "Not Significant."

Because of the close conformity of actual to nominal dimensions, the average moment of inertia of the lumber in the flatwise direction was slightly less in the No. 1 KD and No. 2 KD grades of the 2 by 4 size, but was equal to or greater in the other grades and sizes than the moment of inertia computed on the basis of the standard dressed-size lumber. The average moment of inertia of the lumber in all grades and sizes for the edgewise direction was less by only about 0.5 to 3 percent than the moment of inertia computed on the basis of sizes associated with standard dressed lumber.

Table 3 also presents the effect of variation in the dimension of the lumber on stiffness based on the formula

\[ S.E.(E) = S \times S.E.\left(\frac{1}{I}\right) \]

where
\[ S.E.(E) = \text{standard error of the modulus of elasticity}, \]
\[ S.E.\left(\frac{1}{I}\right) = \text{standard error of the reciprocal of the moment of inertia}, \]
\[ s = \text{product of the average modulus of elasticity determined by the flatwise flexure tests and the moment of inertia based on standard dressed-size lumber}, \]

These data show that, within the 90 percent confidence limit, the modulus of elasticity computed on the basis of the actual measured dimensions can vary from about 91,000 to 162,000 pounds per square inch (p.s.i.) in the flatwise direction and from about 81,000 to 131,000 p.s.i. in the edgewise direction from the modulus of elasticity based on the standard dressed dimensions.

Visual Grading

All of the dimension lumber included in the tension study was visually graded in accordance with the grading rules of the Southern Pine Inspection Bureau and ASTM Standard D 245.

Table 4 presents a summary of the estimated strength ratio and the actual tensile strength data obtained for the several grades and sizes of southern pine, together with related statistical and other pertinent information.

Research studies for determining the tension parallel-to-the-grain properties of wood have for the most part been limited to small clear specimens. These data for clear wood have shown that the ultimate tensile strength parallel to the grain is substantially higher than the maximum crushing strength parallel to the grain and the modulus of rupture in bending. In the absence of specific tension test data on structural lumber, these relationships have for many years served
Table 3: Summary of average size measurements and related moduli of southern pine lumber.

<table>
<thead>
<tr>
<th>Size</th>
<th>Grade</th>
<th>Number: Moisture</th>
<th>Thickness</th>
<th>Width</th>
<th>Flatwise</th>
<th>Moment of Inertia</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>of pieces:</td>
<td>Standard:</td>
<td></td>
<td></td>
<td>Nominal:</td>
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<tr>
<td></td>
<td></td>
<td>Standard:</td>
<td>deviation</td>
<td></td>
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<td>Standard:</td>
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<td></td>
<td></td>
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<td>w:</td>
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</tr>
<tr>
<td>2 by 4</td>
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<td>12.2</td>
<td>1.625</td>
<td>0.0151</td>
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<tr>
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<td>No. 3 MG KD</td>
<td>100</td>
<td>11.9</td>
<td>1.632</td>
<td>0.0183</td>
<td>3.60</td>
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<tr>
<td>2 by 6</td>
<td>No. 2 KD</td>
<td>50</td>
<td>12.2</td>
<td>1.629</td>
<td>0.0270</td>
<td>5.57</td>
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<td>2 by 8</td>
<td>No. 1 KD</td>
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<td>7.45</td>
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<td>No. 2 KD</td>
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<td>12.3</td>
<td>1.637</td>
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<td>7.46</td>
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<td>No. 3 MG KD</td>
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<td>12.4</td>
<td>1.628</td>
<td>0.0254</td>
<td>7.44</td>
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</table>

Table 3: Summary of average size measurements and related moduli of southern pine lumber.

<table>
<thead>
<tr>
<th>Modulus of Elasticity</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(19)</th>
<th>(20)</th>
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<th>(23)</th>
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<tr>
<td>2 by 4</td>
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<td>12.3</td>
<td>1.626</td>
<td>0.0186</td>
<td>3.59</td>
<td>0.0261</td>
<td>2.049</td>
<td>80.2</td>
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<td>3.59</td>
<td>0.0318</td>
<td>1.722</td>
<td>55.7</td>
<td>1,631</td>
<td>1,722</td>
<td>56.1</td>
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<td>1.632</td>
<td>0.0183</td>
<td>3.60</td>
<td>0.0338</td>
<td>1.535</td>
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<td>1.628</td>
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<td>81.0</td>
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</tr>
</tbody>
</table>

1.Moment of inertia based on standard dressed size of dimension lumber.
2.2 by 4, 1-5/8 by 3-5/8; 2 by 6, 1-5/8 by 5-5/8; 2 by 8, 1-5/8 by 7-1/2.
3.Moment of inertia \( I_1 = \frac{Wt^3}{12} \).
4.Flatwise modulus of elasticity values unadjusted for shear deflection.
5.Column 20 = column 19 x column 9 x column 13.
6.Column 21 = column 19 - (column 20 x 1.64).
7.Column 23 = column 22 x column 14 x column 18.
8.Column 24 = column 22 - (column 23 x 1.64).
as a basis for the design recommendation that 

the extreme fiber stress in bending be used far 
tensile stress parallel to the grain. More recently, 
it has become recognized that the tensile strength 
of structural lumber in all species is more sensi-
tive to such characteristics as knots and grain 
deviations than the strength in bending and com-
pression. As a result, a stress level of 80 percent 
of the assigned fiber stress in bending has been 
suggested in some applications as a more con-
servative stress value for wood in tension parallel 
to the grain.

Table 5 presents the tensile stresses assigned 
in the current standard grading rules, the average 

Table 5.—Comparison of average test results and assigned tension parallel-to-grain

Values for southern pine dimension lumber
tensile strength and modulus of elasticity values obtained in the test, and information relating to the performance of the grades. These data show that about 16 percent of the pieces in the No. 1 KD grade, 54 percent of the pieces in the No. 2 KD grade, and 35 percent of the pieces in the No. 3 MG KD grade had strength values below those presently assigned to the grade. At the 80 percent level of the presently assigned stresses, 5 percent of the pieces in the No. 1 KD grade, 25 percent in the No. 2 KD grade, and 18 percent in the No. 3 MG KD grade had strength values below the assigned stresses.

A comparison of the tension modulus of elasticity obtained in the investigation and the modulus of elasticity listed for the various lumber grades is also given in table 5. These data confirm previous observations to the effect that modulus of elasticity decreases with decrease in grade or quality of lumber.

Maximum Tension Strength
Parallel to the Grain vs.
Flatwise Modulus of Elasticity

Figures 6 to 16 show the relation of flexural modulus of elasticity (flatwise) to tensile strength parallel to grain. These data are of interest in connection with an evaluation of the potential of estimating tensile strength by means of stiffness criteria. The correlation coefficients are statistically about in line with previous data on the relation of stiffness to bending strength. However, the substantial number of low tensile strength values over a considerable range in stiffness raises a question as to the degree of confidence obtainable in the evaluation of tensile strength from a stiffness evaluation. Further study of these relationships is under way at the Forest Products Laboratory. The relationship between the maximum tensile strength and the flatwise modulus of elasticity for all grades and sizes is shown by the regression curves in figure 17.

Maximum Tensile Strength
Parallel to the Grain vs.
Specific Gravity

The relationship between the maximum tensile strength parallel to the grain and specific gravity based on the computed ovendry weight and volume of the entire piece at test is given in figure 18 for all specimens. The correlation coefficient for the different grades and sizes of dimension lumber varied from 0.286 to 0.565 and was 0.501 for all grades and sizes combined. These data illustrate the limitation of specific gravity as a means of evaluating the tensile strength of dimension lumber that contains strength-reducing characteristics.

A graph of the frequency distribution of specific gravity for the dimension lumber of this study is presented in figure 19. These data illustrate the range in specific gravity of the southern pines, as encountered in dimension lumber.

Modulus of Elasticity vs.
Specific Gravity

The relationship between the tension modulus of elasticity and specific gravity of the full-size dimension lumber specimens is given in figure 20 for all grades and sizes of lumber. The correlation coefficient for these data was 0.621. In this study, the correlation coefficient for the modulus of elasticity in flatwise flexure and specific gravity was 0.635. It was 0.614 in the previous investigation.

Modulus of Elasticity in
Flatwise Flexure vs.
Modulus of Elasticity in Tension

The relationship of the modulus of elasticity in flatwise flexure and the modulus of elasticity in tension of the same pieces of dimension lumber is given in figures 21 and 22 for the 2 by 4 and 2 by 8 sizes, respectively. These data show that, except for a few scattered points, the two moduli of elasticity were closely related. The correlation coefficients were 0.898 for 2 by 4’s, 0.937 for 2 by 6’s, 0.971 for 2 by 8’s, and 0.917 for all the material. Twelve specimens in the 2 by 4 size gave moduli of elasticity that differed from the average by more than 400,000 p.s.i. These differences may have been the result of experimental error. The correlation coefficient with these 12 specimens eliminated from the population was 0.965 for the 2 by 4 size.

A frequency distribution of the specimen population, on the basis of 200,000 p.s.i. classes of
flatwise bending modulus of elasticity and tension modulus of elasticity, is given in figure 23. Similar distributions are also shown for the individual grades in the 2 by 4 size in figure 24 and in the 2 by 8 size in figure 25. These data show the general decrease in modulus of elasticity with the lower grades of dimension lumber.

Modulus of Rigidity vs. Modulus of Elasticity in Tension

The modulus of rigidity of the dimension lumber averaged 131,000 p.s.i. for the 2 by 4 size and 145,000 p.s.i. for the 2 by 8 size, with an average for all grades and sizes of 136,1100 p.s.i. The correlation coefficient of the modulus of rigidity versus modulus of elasticity in tension for the various sizes and grades varied from -0.147 to +0.554, with an average of +0.189. The modulus of rigidity appears to be much less affected by grade or quality of material than modulus of elasticity.

The ratios of the average flatwise bending modulus of elasticity (true) to the modulus of rigidity for the different grades and sizes of dimension lumber are listed in table 4. The ratios decrease with grade and range from 11.1 to 15.1, with an average of about 12.8 for all grades and sizes.

Strength Ratio

The relationship between the tensile strength and the visually estimated strength ratio which has been developed for the flexural strength of green lumber is presented in figure 26. The correlation coefficient based on a linear regression was 0.809 for the 2 by 4’s, 0.476 for the 2 by 6’s and 0.754 for the 2 by 8’s. For all grades and sizes, it was 0.697.

Comparison With Previous Data

The comparison in table 6 of the average results from the tension tests in this Investigation with the results obtained from the flexure and compression tests of full-size dimension lumber of the previous investigation shows the effect of grade on the relationships of these properties. As would be expected, the ratios of maximum tensile strength to modulus of rupture and to maximum crushing strength tend to show a decrease with a decrease in the grade of the lumber, while the ratio of maximum crushing strength to modulus of rupture increases with a decrease in the grade of the lumber. These relationships reflect the greater sensitivity of bending and tensile strength over compressive strength to knots, grain deviations, and other strength-reducing characteristics.

The modulus of elasticity, as determined in the tension tests, was in close agreement with that determined on the same pieces in the flatwise bending tests. The correlation coefficient was 0.917. The values in flatwise bending were, however, from 1-1/2 to 11 percent higher than those obtained for the same grades of lumber in the previous investigation. For like grades of lumber, the estimated strength ratios for the material in this study were somewhat lower than those in the previous study. For the most part, all other comparable properties were in reasonably close agreement. The average specific gravity, modulus of rigidity (G), and E_F/T/G ratio for the specimens in this investigation were 0.526, 136,000 p.s.i., and 12.8 percent as compared with 0.524, 140,000 p.s.i., and 11.6 percent, respectively, for the material in the previous investigation.

SUMMARY AND CONCLUSIONS

This paper provides data on the tensile strength and related properties based on 496 specimens of southern pine dimension lumber and provides information on the general relationship between tension strength of structural lumber and assigned stress values. The lumber, comprising grades No. 1 KD, No. 2 KD, and No. 3 MG KD, was randomly selected in 2 by 4, 2 by 6, and 2 by 8 sizes from mills in 10 states in the southern pine region. The material had been dried at the mills to about 15 percent moisture content and was further conditioned to about 12 percent at the Forest Products Laboratory prior to test. The report presents pertinent findings based on an analysis of the data as well as detailed data which can be used for further analysis and study of property relationships and factors of lumber grading.

The tensile strength parallel to the grain of the dimension lumber in grade No. 1 KD varied from 1,570 to 12,640 p.s.i. with an average of 5,480 p.s.i. In grade No. 2 KD, the tensile strength varied from 1,000 to 10,430 p.s.i. with
Table 6.—Average flexural, compressive, and tensile properties of southern pine dimension lumber

<table>
<thead>
<tr>
<th>Size :</th>
<th>Grade :</th>
<th>Number of specimens :</th>
<th>Moisture content :</th>
<th>Specific gravity :</th>
<th>Strength 1 :</th>
<th>Modulus of elasticity :</th>
<th>Strength ratio 4 :</th>
<th>Flexure 8 :</th>
<th>Compression 8 :</th>
<th>Tension 8 :</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 by 4</td>
<td>No. 1 KD</td>
<td>100</td>
<td>12.7</td>
<td>0.542</td>
<td>9,340</td>
<td>1,844</td>
<td>69</td>
<td>58.1</td>
<td>61.1</td>
<td>105.0</td>
</tr>
<tr>
<td>No. 2 KD</td>
<td>100</td>
<td>12.5</td>
<td>0.503</td>
<td>6,740</td>
<td>1,550</td>
<td>1,540</td>
<td>59</td>
<td>70.2</td>
<td>54.1</td>
<td>77.2</td>
</tr>
<tr>
<td>No. 3 MG KD</td>
<td>98</td>
<td>12.3</td>
<td>0.520</td>
<td>5,860</td>
<td>1,452</td>
<td>1,400</td>
<td>53</td>
<td>71.0</td>
<td>39.9</td>
<td>56.2</td>
</tr>
<tr>
<td>2 by 6</td>
<td>No. 2 KD</td>
<td>99</td>
<td>11.4</td>
<td>0.518</td>
<td>6,760</td>
<td>1,617</td>
<td>70.3</td>
<td>51.0</td>
<td>72.6</td>
<td></td>
</tr>
<tr>
<td>2 by 8</td>
<td>No. 1 KD</td>
<td>99</td>
<td>12.4</td>
<td>0.561</td>
<td>10,200</td>
<td>1,916</td>
<td>89</td>
<td>54.3</td>
<td>49.4</td>
<td>90.8</td>
</tr>
<tr>
<td>No. 2 KD</td>
<td>99</td>
<td>12.3</td>
<td>0.518</td>
<td>6,970</td>
<td>1,578</td>
<td>1,627</td>
<td>65</td>
<td>64.8</td>
<td>40.9</td>
<td>63.0</td>
</tr>
<tr>
<td>No. 3 MG KD</td>
<td>98</td>
<td>12.1</td>
<td>0.513</td>
<td>4,990</td>
<td>1,443</td>
<td>1,422</td>
<td>51</td>
<td>85.0</td>
<td>51.6</td>
<td>60.7</td>
</tr>
<tr>
<td>Av. all grades and sizes :</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>67.7</td>
<td>49.7</td>
<td>75.1</td>
</tr>
</tbody>
</table>

1Based on volume at test of full-size piece and weight when oven-dry.
2Strength property for flexure (R) is modulus of rupture adjusted to a 2-in. depth of beam; compression (C) is maximum crushing strength parallel to grain; tension (T) is maximum tensile strength parallel to grain.
3Modulus of elasticity for flexure is edgewise modulus of elasticity (true).
4Strength ratio for tension specimens was determined by the method established for flexure.
5Ratio of maximum crushing strength to modulus of rupture (values from column 6).
6Ratio of maximum tensile strength to modulus of rupture (values from column 6).
7Ratio of maximum tensile strength to maximum crushing strength (values from column 6).
8Data on flexure and compression from U.S. Forest Serv. Res. Pap. FPL 64.

An average of 3,400 p.s.i., and in grade No. 3 MG KD, it varied from 680 to 9,800 p.s.i. with an average of 2,420 p.s.i. These values as would be expected are lower than the tensile strength values normally obtained for small clear southern pine specimens.

An analysis of variance of maximum tensile strength and flatwise modulus of elasticity generally revealed differences in these properties with respect to mill location.

The data show a close correlation between the modulus of elasticity as determined by flatwise flexure and that obtained in the tension parallel-to-the-grain tests. The modulus of elasticity varies with grade of lumber and the tests provide data bearing on the evaluation of this relationship. The flatwise modulus of elasticity of the material used in this study ranged from about 1-1/2 to 11 percent higher than that of similar grades in the previous study of
southern pine dimension lumber.

Precise measurements were made of each piece of dimension lumber in the study at about 12 percent moisture. The average thickness of each grade and size was equal to or thicker (up to 1.637 in.) than the standard dressed thickness of 1.625 inches. In width, all grades and sizes at 12.2 percent moisture averaged about 1 percent less than the standard dressed widths. On the basis of 15 percent moisture content, these average departures in width are actually less than 0.5 percent.

The relationships of maximum tensile strength and flatwise bending modulus of elasticity (true) show a relatively large range in correlation coefficients among the different grades and sizes. The correlation coefficient based on a linear regression was 0.623 for the 2 by 4, 0.548 for the 2 by 6, and 0.736 for the 2 by 8 size. These values closely parallel those obtained in a previous study of dimension lumber for modulus of rupture (edgewise) versus modulus of elasticity (flatwise) and maximum crushing strength versus modulus of elasticity in compression parallel to the grain.

An evaluation of the relation of specific gravity to the properties of dimension lumber for all grades and sizes showed correlation coefficients of 0.501 for maximum tensile strength versus specific gravity, 0.621 for modulus of elasticity in tension versus specific gravity, 0.635 for flatwise bending modulus of elasticity and specific gravity, and 0.547 for modulus of rigidity and specific gravity.

The data show that the modulus of rigidity has a poor correlation with other properties, such as modulus of elasticity and maximum tensile strength. The correlation coefficient between modulus of rigidity and flatwise bending modulus of elasticity for all grades and sizes was 0.189 and between maximum tensile strength and modulus of rigidity was 0.313. The ratio for $E_{FT}/G$ was 12.8.

A comparison of the average results of the tension tests with the results obtained from the flexure and compression parallel-to-grain tests shows the effect of grade on the relationship of these properties. The ratios of maximum tensile strength to modulus of rupture and to maximum crushing strength tend to show a decrease with decrease in grade of lumber, while the ratio of maximum crushing strength to modulus of rupture increases with decrease in grade. These relationships, which are in line with test data on other species, reflect the much greater sensitivity of tensile strength to knots and grain deviations than exists for bending and compression parallel-to-grain strength properties. The study also suggests the need for a review of the presently assigned tensile stress values for other grades and species in relation to the actual tensile strength.
Figure 6.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 1 KD southern pine 2 by 4 dimension lumber.

(M 133 392)
Figure 7.—Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. I KD southern pine 2 by 8 dimension lumber.

(M 133 393)
Figure 8.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 1 KD southern pine 2 by 4 and 2 by 8 dimension lumber.

(M 133 394)
Figure 9.--Relation of maximum tensile strength parallel to grain to flatwise bending modulus of elasticity (true) of No. 2 KO southern pine 2 by 4 dimension lumber.

(M 133 395)
Figure 10.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 2 KD southern pine 2 by 6 dimension lumber.

(M 133 396)
Figure 11.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 2 KD southern pine 2 by 8 dimension lumber.

(M 133 397)
Figure 12.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 2 KD southern pine 2 by 4, 2 by 6, and 2 by 8 dimension lumber.

(M 133 398)
Figure 13.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 3 MG KD southern pine 2 by 4 dimension lumber.

(M 133 399)
Figure 14.--Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 3 MG KD southern pine 2 by 8 dimension lumber.

(M 133 400)
Figure 15.—Relation of maximum tensile strength parallel to the grain to flatwise bending modulus of elasticity (true) of No. 3 MG KD southern pine 2 by 4 and 2 by 8 dimension lumber.

(M 133 401)
Figure 16.—Relation of maximum tensile strength parallel to the grain of three grades and three sizes of KD southern pine dimension lumber to flatwise bending modulus of elasticity (true).

(M 133 402)
Figure 17.--Relation expressed by the linear regression lines of maximum tensile strength to the flatwise modulus of elasticity (true) of three grades of KD southern Dine lumber of three sizes.

(M 133 403)
Figure 18.--Relation of maximum tensile strength parallel to the grain of three grades and three sizes of KD southern pine dimension lumber to specific gravity.

(M 133 404)
Figure 19.--Frequency distribution of the specimen population of KD southern pine dimension lumber by 0.01 classes of specific gravity.

(M 133 405)
Figure 20.—Relation of modulus of elasticity in tension parallel to the grain of three grades and three sizes of KD southern pine dimension lumber to specific gravity.

(M 133 406)
Figure 21.—Relation of the modulus of elasticity in tension parallel to the grain to the modulus of elasticity (true) in flatwise bending of the same pieces of KD southern pine 2 by 4 dimension lumber.

(M 133 407)
Figure 22.--Relation of the modulus of elasticity in tension parallel to the grain to the modulus of elasticity (true) in flatwise bending of the same pieces of KD southern pine 2 by 8 dimension lumber.
Figure 23.--Frequency distribution of the specimen population of the 2 by 4 and 2 by 8 sizes of KD southern pine dimension lumber by 200,000 p.s.i. classes of flatwise bending modulus of elasticity and tensile modulus of elasticity.

(M 133 409)

Figure 24.--Frequency distribution of the specimen population in the three grades of 2 by 4 KD southern pine dimension lumber by 200,000 p.s.i. classes of tensile modulus of elasticity.

(M 133 410)
Figure 25.--Frequency distribution of the specimen population in the three grades of 2 by 8 KD southern pine dimension lumber by 200,000 p.s.i. classes of tensile modulus of elasticity.

(M 133 411)
Figure 26.—Relation of maximum tension strength parallel to the grain to visual strength ratio for three sizes and three grades of KD southern pine dimension lumber.

(M 133 412)
APPENDIX I

Notation

\( a \) - Span, inches
\( a_n \) - Gage length, inches
\( E_F \) - Modulus of elasticity of dimension lumber in flexure flatwise, pounds per square inch
\( E_{FT} \) - Modulus of elasticity of dimension lumber in flexure flatwise adjusted for shear deflection, pounds per square inch
\( E_T \) - Modulus of elasticity in tension parallel to the grain, pounds per square inch
\( G \) - Modulus of rigidity associated with shear strain parallel to the grain and radial or tangential to growth rings, pounds per square inch
\( K_n \) = 0.239 for 2 by 4
\( = 0.272 \) for 2 by 6
\( = 0.288 \) for 2 by 8
\( = 0.297 \) for 2 by 10
A constant based on standard dressed size of dimension lumber
\( \ell \) - Length, inches
\( M.C. \) - Moisture content, percent
\( n \) - number of specimens
\( P \) - Maximum load, pounds
\( P_{\Delta} \) - Load at elongation \( \Delta_t \), pounds
\( r \) - Coefficient of correlation
\( S_t \) - Tension stress parallel to the grain, pounds per square inch
\( S.G. \) - Specific gravity at test
\( S.R. \) - Strength ratio (visual) for stress in extreme fiber in bending
\( S_{y.x} \) - Standard error of estimate, a measure of the variation of data about the regression line
\( t \) - Thickness, inches
\( T \) - Torsional moment, inch-pounds
\( w \) - Width, inches
\( W_D \) - Weight of sample oven-dry, grams
Formulas Used In Computing and Adjusting Data

Flexure--Quarter Point

\[ L = \frac{11 \times 112 \times a^3}{64 \Delta_F w t^3} \]

\[ G = \frac{T a_n}{K_0 \theta t^w} \]

\[ E_{FT} = E_F \left( 1 + \frac{48E_F t^2}{55Ga^2} \right) \]

Tension Parallel to the Grain--

Dimension Lumber

\[ S_t = \frac{P}{t w} \]

\[ E_T = \frac{P a_n}{t w \Delta_t} \]

Moisture Content and Specific Gravity

\[ M.C. = \frac{W_T - W_D}{W_D} \]

\[ S.G. = \frac{W_p}{0.036 + t w k} \]

\[ S.G. \ (ovendry) = \frac{S.G.}{1 + M.C.} \]