THE EFFECT OF SPECIFIC GRAVITY AND GROWTH RATE ON BENDING STRENGTH OF FINGER-JOINTED SOUTHERN PINE

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ABSTRACT

In this study, the effect of specific gravity and rings per inch on the bending strength of 11 mill-run batches of finger-jointed southern pine lumber was examined. The bending test specimens were prepared according to the Glued Lumber Standard for Southern Pine as outlined by the SPIB. For each finger-jointed board, 8 wood properties were calculated. The 8 wood properties were maximum, minimum, average, and differential specific gravity; and maximum, minimum, average, and differential rings per inch. Multiple linear regression analysis was used to examine the effect of these wood properties on the bending strength (MOR) of the lumber. This relationship was examined for test specimens subjected to an accelerated aging cycle and those not subjected to the cycle. Coefficients of determination (r^2) ranged from 0.06 to 37. For both specific gravity and rings per inch, the differential specimens had the lowest r^2 values, and the average specimens had the highest r^2 values. The relationships found in this study are consistent with strength-wood property relationships for finger-jointed and solid wood specimens reported in previous literature.

Keywords: Finger-joint, specific gravity, rings per inch, southern pine, modulus of rupture.

INTRODUCTION

Environmental and economic concerns combined with an increased demand for wood products have led the forest products industry to make better and more complete use of wood residues. With the demand for forest products continuing to be strong and the available land base for timber production decreasing, the utilization of smaller diameter trees and of whole trees has become even more important. Consequently, the production and marketing of wood products that utilize wood residues are very important. By maximizing the volume of wood uti-

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lized from each tree, land managers can produce the same volume of product while using less of the forest resource.

Finger-jointed wood is one product class designed to better utilize wood residues (Strickler 1980). A finger-joint is a series of small scarf joints distributed along the end of a piece of wood. The finger-joint has been shown to have the required strength for structural application (Madsen and Littleford 1962; Selbo 1963; Tuvey 1998) and is relatively easy to produce. Finger-jointed material has also found extensive usage in non-structural markets such as with moulding stock, siding, window frames, and fascia boards (Jokerst 1981; Tuvey 1998).

Because of the diversity associated with the raw material supply, wood found in finger-jointed stock may be highly variable. The wood used to construct one finger-jointed board does not necessarily come from the same tree and could come from different forest stands or even from different states. Two pieces of wood finger-jointed together may have differing physical and mechanical properties. While wood containing defects such as knots, compression wood, and severe grain deviation is normally excluded from finger-joint manufacture, other wood factors such as ring width, pith, and juvenile wood may typically not be excluded. Because finger-jointed products may be manufactured using highly variable wood material, it becomes more important to understand the nature and variability of the wood material used in their manufacture. Additionally, because of the potential variation associated with the supply of wood material used to manufacture finger-jointed stock, it also becomes important to understand the effect of the wood properties on the strength of finger-joints.

Objective

The objective of this study is to examine the relationship between the mechanical bending strength of finger-jointed southern pine test specimens and the wood properties of the two pieces of wood making up the finger-jointed southern pine test specimens.

LITERATURE REVIEW

Finger-jointed wood

Moody (1970) used specific gravity (SG) and modulus of elasticity (MOE) as independent variables in a linear regression analysis to examine the relationship with ultimate tensile strength of finger-jointed southern pine two-by-six lumber. In order to study the effects of the variation of the two pieces of wood making up a finger-jointed board, one piece of the finger-jointed board was arbitrarily assigned as the ‘A’ piece, and the other piece was designated as the ‘B’ piece. These designations were maintained throughout to ensure that the properties of the two pieces could be kept separate throughout his study. Simple linear regression equations used the average SG of the two pieces of the finger-jointed board and the minimum SG as independent variables. Multiple regression equations were then developed combining each of the two SG values with MOE as independent variables. Correlation coefficients for all models were less than 0.50. It was concluded that these variables both independently and in combination, were poor predictors of tensile strength of southern pine finger-jointed boards (Moody 1970).

Dickens (1996) examined the relationship between tensile strength and several ultrasonic and wood property independent variables in finger-jointed southern pine. The wood property independent variables he examined included percentage of juvenile wood, percentage of compression wood, percentage of juvenile and compression wood, the SG, and the ring count. When using a multiple regression model with the average SG, the maximum SG, the piece of wood with the higher percentage of juvenile and compression wood, the average of the percentage of juvenile and compression wood, and the ring count of the minimum piece as independent variables, he found a correlation coefficient of 0.70 ($r^2 = 0.49$). The strongest simple linear relationship used the maximum percentage of juvenile and compression wood as the independent variable resulting in a correlation coefficient of 0.57 ($r^2 = 0.32$).

Ayarkwa et. al. (2000) examined wood density as an independent variable in simple linear regression equations to predict the modulus of rupture (MOR) and MOE of finger-jointed and solid wood from three tropical African hardwood species: Obeche (*Triplochiton scleroxylon*), Makore (*Tieghemella heckelii*), and Moabi (*Baillonella toxisperma*). Simple linear regression equations were developed for finger-jointed and solid wood specimens to determine the relationship between the dependent variable MOR and the independent variable, wood density. Coefficients of determination for solid wood specimens ranged from 0.18 to 0.42. Coefficients of determination for finger-jointed wood specimens ranged from 0.28 to 0.59.

Solid wood

Bendtsen et. al. (1975) examined the relationship between MOR and SG in juvenile and mature solid wood from each of the four major species of southern pine. Correlation coefficients ranged between 0.87 for slash pine and 0.72 for loblolly pine.

Pearson and Gilmore (1971) examined the relationship between MOR and SG of clear specimens of juvenile and mature wood from 19 loblolly pine trees in North Carolina. They found a strong relationship with a coefficient of determination of 0.87; however, the relationship was weaker when wood from the butt logs was used.

MATERIALS AND METHODS

Eleven batches of southern pine finger-jointed pieces of lumber were strength tested at Stephen F. Austin State University (SFASU). The 11 batches of southern pine finger-jointed lumber came from mills located in the southeastern United States. This testing formed part of a broader mill qualification program conducted by the Southern Pine Inspection Bureau (SPIB). The mechanical strength tests on the finger-jointed lumber conducted at SFASU were the "independent" verification tests of this qualification procedure. These tests were conducted in accordance with the Glued Lumber Standard for Southern Pine (SPIB 1994). The strength results from these mechanical tests, and the wood property results based on a further study of wood samples cut from the specimens, form the basis for this study.

Each of the 11 batches consisted of approximately 70 finger-jointed boards. The thickness of all of the boards as received from the mills was a nominal two inches, and widths were either four, six, or eight inches. The length of each board was approximately 36 inches. Batches 1, 2, 3, and 8 had finger-joints having 0.375-inch finger lengths. Batch 4 had finger lengths of 1.125-inch. Batches 5, 6, 7, 9, and 11 had finger-joints having 0.625-inch finger lengths. Batch 10 had finger lengths of 0.75-inch.

Board selection

Prior to the preparation of mechanical test specimens, the boards were visibly examined for defects, and boards containing knots, decay, excessive slope of grain, or poor machining that could not be avoided during specimen preparation were set aside. Particular attention was given to defects located near the finger-joint. As a result of this process, the 'best' 60 boards from each batch were identified for further processing and preparation of mechanical test specimens. Of these 60 boards, 30 were used to prepare bending test specimens and 30 were used to prepare tension test specimens. If a hidden defect that would potentially impact the strength tests was found after cutting, a new board was selected to replace it. The bending specimens were used for further analysis in this study.

Bending specimen preparation

Specimens were prepared according to the methodology outlined in the Glued Lumber Standard for Southern Pine (SPIB 1994). Prior to preparation, each board was numbered and labeled with an 'A' and 'B' designation to identify the two separate pieces of wood making up the finger-jointed board according to the procedure developed by Moody (1970).

Bending test specimens prepared from boards 1 through 15 were designated as 'flat,' while those from boards 16 through 30 were designated as ‘edge.’ These are shown diagrammatically in Fig. 1. It should be noted that the ‘flat’ and ‘edge’ designations used in this study refer to the orientation of the finger-joint and are not related to the orientation of the growth rings as viewed in the cross-section.

From each of the original 30 boards from which bending test specimens were produced, one of the specimens was designated ‘wet’ and one designated ‘dry.’ The wet specimens were subjected to an accelerated aging cycle as described in the Glued Lumber Standard for Southern Pine (SPIB 1994). In order to avoid a systematic source of error, the wet and dry designations were assigned alternatively to the first and second specimens cut from the boards. In this way, the specimen cut from the nearest side of the two-by-four was not always ‘wet’ or ‘dry.’ It should be noted that because a dry and a wet test specimen were produced from the same single board, these two specimens were considered ‘matched’ allowing for a direct comparison of results between dry and wet test specimens. In summary, this cut-up procedure resulted in a total of 60 bending test specimens for each batch, with 15 specimens identified as dry-flat, 15 as dry-edge, 15 as wet-flat, and 15 as wet-edge.

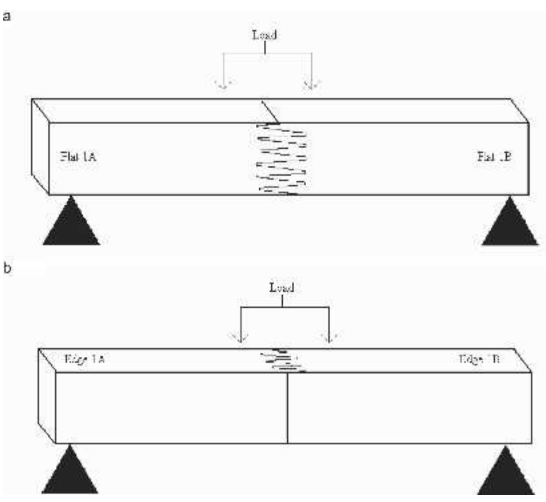

FIG. 1. Diagram of joint orientation in relation to load for a “flat” bending test specimen (a) and an ‘edge’ bending test specimen (b).

Bending tests

The bending specimens were tested to failure using a Tinius Olsen Lo-Cap 6000-pound testing machine. Immediately prior to testing, the cross-sectional dimensions, depth and width, were measured near the finger-joint to the nearest 0.001-inch using a caliper. Specimens were tested to failure using third point loading as specified by the Glued Lumber Standard for Southern Pine (SPIB 1994) with a total span of 25.5 inches with the load applied continuously at a rate of motion not exceeding 0.10-inch per minute. Upon failure, the maximum load was recorded to the nearest pound. MOR was then calculated for each specimen. After the specimens were tested to failure, 2-inch-long wood blocks were removed from each of the A and B pieces of the broken specimen for determination of SG and rings per inch (RPI).

Measurement of wood properties

Rings per inch and specific gravity were determined for each wood sample. The number of complete annual rings was counted on the cross-section of every wood sample and recorded. Rings displaying only partial earlywood or latewood were not counted. Next, the distance in the radial direction across the complete rings counted was measured with a caliper to the nearest 0.001-inch and recorded. The number of rings per inch was calculated by dividing the number of complete rings by the radial distance across the complete rings. SG based on oven-dry volume was calculated for each wood sample.

Calculation of properties

For each broken test specimen, four statistics on two wood properties were calculated. These were maximum SG, minimum SG, average SG, differential SG, maximum RPI, minimum RPI, average RPI, and differential RPI. Maximum SG and maximum RPI were obtained for each broken test specimen by taking the maximum SG and RPI value for the matching A and B pieces from each test specimen. Minimum SG and minimum RPI were obtained for each broken test specimen by taking the minimum SG and RPI value for the matching A and B pieces from each test specimen. Average SG and average RPI were calculated by averaging the SG and RPI values for the matching A and B pieces from each test specimen. Differential SG was calculated for each finger-jointed test specimen by subtracting the SG of the B piece from the SG of the matching A piece and obtaining the absolute value of this difference. Likewise, the differential RPI was calculated for each test specimen by subtracting the RPI of the B piece from the RPI of the matching A piece and obtaining the absolute value of this difference. These differential values were determined in order to have a measure of how the RPI property and SG property differed between the A and B pieces joined together in one finger-jointed board.

Selection of bending test specimens

In order to examine the relationship between the mechanical strength of the southern pine finger-jointed test specimens and their wood properties, only the test specimens with more than 75% wood failure were examined. It was hypothesized that in test specimens with over 25% glue failure, the failure of the glue would potentially mask the relationship between strength and wood properties. Each of the 60 broken bending test specimens from all 11 batches was examined to determine the percent wood failure, using procedures similar to those reported in ASTM standard D 5266–99 (ASTM 1999).

Following the assessment of percent wood failure, each broken test specimen was classified into 1 of 3 wood failure categories. Category 1 consisted of broken test specimens having less than 75% wood failure in the fracture zone. Category 2 consisted of broken test specimens with more than 75% and 90% wood failure in the fracture zone. Category 3 consisted of broken test specimens with 100% wood failure away from the finger-joint. In these specimens, the failure occurred entirely in either the A or B piece of the finger-jointed test specimen.

The test specimens exhibiting category 1 or 3 wood failures were excluded from further study. Because the aim of this work was to examine the relationship between wood properties and strength at the finger-joint, these failures did not appear to fit this purpose. T-tests were used to determine if differences existed between the SG and RPI statistics for the group of samples included in the analysis and those not included in the analysis. No significant differences were found between these two groups.

Analyses

The relationship between mechanical strength and wood properties of the broken bending test specimens was examined using multiple linear regression techniques. The dependent variable used was MOR in pounds per square inch (psi), and the independent variables were the 4 SG properties and the 4 RPI properties described earlier. In order to account for strength differences between the different finger-joint configurations, dummy variables were used in the regression equations.

Prior to conducting the regressions, the assumptions of normality and constant variance were assessed (Neter et. al. 1996).

RESULTS AND DISCUSSION

Strength—SG relationships

Presented in Table 1 are the results of the multiple linear regression analyses for each of the 4 SG independent variables for the dry-flat, dry-edge, wet-flat, and wet-edge bending test specimens.

The strongest significant regression between MOR and wood SG was found when using the average SG independent variable of the wet-edge test specimens ($r^2 = 0.33$). For the dry-edge test specimens, the strongest regression between MOR and wood SG was also found when using the average SG independent variable ($r^2 = 0.28$). The next strongest significant regression within the wet-edge group of test speci-

TABLE 1. *Multiple linear regression results for 4 independent SG variables for dry-flat, dry-edge, wet-flat, and wet-edge bending test specimens exhibiting greater than 75 percent wood failure.*

Specimen type	Independent variable	Sample size	Equation	r^2	Standard error
Dry-flat	Maximum SG	121	$y = 2909.3 + 309.1(x_1{}^{1}) + 4336.4(x_2{}^{2})$*	0.10	1407.0
	Minimum SG	121	$y = 1020.3 + 302.4(x_1) + 8724.1(x_2)$*	0.18	1339.5
	Differential SG	121	$y = 5576.7 + 370.0(x_1) + -2970.2(x_2)$*	0.07	1432.1
	Average SG	121	$y = 1363.3 + 292.6(x_1) + 7516.4(x_2)$*	0.15	1367.3
Dry-edge					
	Maximum SG	150	$y = 796.1 + 312.4(x_1) + 9188.6(x_2)$*	0.20	1423.0
	Minimum SG	150	$y = 261.3 + 240.1(x_1) + 11671.0(x_2)$*	0.28	1352.5
	Differential SG	150	$y = 6241.0 + 442.8(x_1) + -2648.9(x_2)$*	0.08	1528.8
	Average SG	150	$y = -1033.9 + 231.6(x_1) + 13271.4(x_2)$*	0.28	1347.6
Wet-flat					
	Maximum SG	84	$y = 3195.7 + 356.5(x_1) + 2697.6(x_2)$*	0.08	1471.5
	Minimum SG	84	$y = 2066.8 + 332.8(x_1) + 5549.1(x_2)$*	0.10	1453.4
	Differential SG	84	$y = 4731.3 + 395.7(x_1) + -620.6(x_2)$	0.07	1453.4
	Average SG	84	$y = 2147.3 + 332.1(x_1) + 4959.4(x_2)$*	0.10	1459.0
Wet-edge					
	Maximum SG	117	$y = -482.9 + 319.7(x_1) + 10160.4(x_2)$*	0.26	1391.6
	Minimum SG	117	$y = -910.6 + 293.3(x_1) + 12596.9(x_2)$*	0.28	1368.3
	Differential SG	117	$y = 5163.2 + 482.5(x_1) + 991.3(x_2)$*	0.08	1546.0
	Average SG	117	$y = -2528.1 + 253.5(x_1) + 14774.4(x_2)$*	0.33	1325.1

* Denotes that regression equation was significant at an alpha level of 0.05.
[1] X_1 = dummy variable for finger length
[2] X_2 = SG independent variable

mens was when the minimum SG independent variable was used ($r^2 = 0.28$). A similar coefficient of determination ($r^2 = 0.28$) was found for the relationship between the same two variables for the dry-edge group of test specimens.

Coefficients of determination for the relationships between MOR and the SG independent variables for the specimens tested flat (either dry or wet) were lower than those tested on edge. For the specimens tested flat, the highest coefficient of determination of 0.18 was found when MOR was regressed against minimum SG using the dry-flat group of specimens. Out of the 4 SG independent variables examined, relationships using differential SG resulted in the lowest coefficients of determination. It would appear from these results that the absolute difference in wood SG between the A and B pieces within a finger-jointed specimen relates poorly to the MOR of the specimen when broken. These results make sense because the difference in SG between the boards does not account for the magnitude of the SG of each board. For example, if two boards have the same difference in SG, the one with the higher SG will have the higher strength.

The coefficients of determination for the relationship between MOR and wood SG reported in this study appear to be comparable to strength-wood property relationships reported in the literature for finger-jointed wood. Moody (1970) examined the tensile strength of finger-jointed southern pine. In his study, both pith-associated and non-pith-associated wood were examined in tension rather than in bending. He reported that correlation coefficients less than 0.50 ($r^2 < 0.25$) were found when tensile strength and average wood SG or minimum wood SG were regressed. In his study, bending mechanical properties were not examined. Also, in the study by Moody, the southern pine finger-jointed samples were made from A and B pieces originally cut out of the same board. Because of this finger-joint preparation procedure, large differences in SG between the A and B pieces would not be expected.

Dickens (1996) also examined the tensile strength of finger-jointed southern pine. In his study, finger-jointed samples from a number of commercial suppliers were examined. The relationships between tensile strength and wood properties such as percent juvenile wood, percent compression wood, SG, visual density, and ring count of the A and B pieces within the finger-jointed specimens were examined using both simple and multiple regression techniques. The strongest simple linear relationship, with a correlation coefficient of 0.57 ($r^2 = 0.32$), was found when the maximum percent of juvenile wood and compression wood of the A and B pieces was regressed against tensile strength. A focus of the work by Dickens (1996) was the evaluation of ultrasonic parameters to predict joint strength. He found when using both ultrasonic parameters and wood properties in an analysis that minimum SG and one ultrasonic parameter gave a multiple correlation coefficient of 0.69 ($r^2 = 0.48$). Correlation coefficients for the regression of minimum SG and tensile strength alone were not given.

Ayarkwa et. al. (2000) examined the relationship between MOR and wood density for finger-jointed test specimens made from 3 different African hardwoods. Species specific coefficients of determination of 0.59, 0.42, and 0.26 were reported. Specific methods were not provided as to how the wood density of the finger-jointed specimens was determined from the A and B pieces.

Both the coefficients of determination for the regressions of MOR and the wood SG independent variables found in this study (Table 1) and those relationships between similar variables found in the literature for finger-jointed material (Moody 1970; Dickens 1996; Ayarkwa et. al. 2000a) appear consistent with those reported for solid (non-finger-jointed) southern pine. Green and Kretschmann (1997) found a coefficient of determination of 0.40 for the relationship between MOR and SG in 6-inch by 6-inch southern pine timbers. In an extensive study of southern pine, Doyle and Markwardt (1966) found a correlation coefficient of 0.494 ($r^2 = 0.24$) for the regression of MOR and SG based on tests performed on 281 full-size pieces of dimension lumber. Correlation coefficients ranging from 0.241 to 0.581 (r^2 from 0.06 to 0.34) resulted based on regressions using different lumber grades and sizes. Based on results obtained from 281 small clear wood specimens, a correlation coefficient of 0.707 ($r^2 = 0.50$) was found for the relationship between MOR and SG (Doyle and Markwardt 1966). Bendtsen and Senft (1986) also studied bending properties of loblolly pine. However, in their study they examined individual growth rings using specimens measuring 2.25 inches in length by 0.125 inches deep and the width of about one annual ring. They found a correlation coefficient of 0.74 ($r^2 = 0.55$, $n \sim 114$) for the relationship between MOR and SG (Bendtsen and Senft 1986). Pearson and Gilmore (1971) found a coefficient of determination of 0.87 for the relationship between MOR and SG based on small clear wood samples from the juvenile and mature portions from the upper logs of loblolly pine trees. Bendtsen et al. (1975) also examined relationships between MOR and SG for each of the four major species of southern pine. Their results were based on tests using small clear specimens. Regression equations were calculated using both juvenile and mature wood for each of the four species. Slash pine had the highest correlation coefficient of 0.87 ($r^2 = 0.76$), followed by longleaf pine with a correlation coefficient of 0.83 ($r^2 = 0.69$), shortleaf pine with a correlation coefficient of 0.75 ($r^2 = 0.56$), and loblolly pine with a correlation coefficient of 0.72 ($r^2 = 0.52$).

In the present study, bending test specimens were prepared from commercially manufactured finger-jointed material. Although defects were avoided in preparing the test specimens from this material, the selection and preparation of the final test specimens would not be as carefully controlled as in studies where small clear test specimens were used. Hence, coefficients of determination between 0.7 and 0.33 resulting from bending tests in the present study (Table 1) would potentially be more similar to coefficients of determination between 0.06 and 0.40 from studies where commercial or full-size specimens were used (Doyle and Markwardt 1966; Green and Kretschmann 1997).

Relationships between strength and wood SG based on small clear specimens have higher coefficients of determination between 0.52 and

0.87 (Pearson and Gilmore 1971; Bendtsen et. al. 1975; Bendtsen and Senft 1986). Further, it would be expected that some correlation results obtained in the present study based on finger-jointed material might be lower than that obtained for solid wood. The southern pine finger-jointed specimens tested in this study were made up of two pieces of pine oftentimes with quite dissimilar wood properties. This variability coupled with the presence of a finger-joint in the middle of the test specimen would undoubtedly lead to a poorer relationship between MOR and wood SG as represented by an average, minimum or maximum SG of the A and B pieces.

Strength—rings per inch relationships

Presented in Table 2 are the results of multiple linear regression equations for each of the 4 RPI independent variables for the dry-flat, dry-edge, wet-flat, and wet-edge bending test specimens.

The strongest significant relationship between MOR and RPI was found when using the average RPI independent variable of the wet-edge test specimens ($r^2 = 0.37$). This relationship between MOR and average RPI with a coefficient of determination of 0.37 accounts for about 4% more of the variation than the relationship between MOR and average SG for the wet-edge specimens ($r^2 = 0.33$). These two relationships were the strongest of the 32 regressions examined (Tables 1 and 2).

Based on the MOR and RPI properties for the wet-edge test specimens, significant relationships were also found when minimum RPI and maximum RPI were used as independent variables with coefficients of determination of 0.35 and 0.27, respectively. Relationships between MOR and RPI properties having similar coefficients of determination were also found for the wet-flat test specimens. Use of average RPI and minimum RPI as independent variables resulted in coefficients of determination of 0.28 and 0.28, respectively. Use of maximum RPI as the independent variable accounted for about 7% less variation with a coefficient of determination of 0.21.

The eight regression equations for the dry test

TABLE 2. *Multiple linear regression results for 4 independent RPI variables for dry-flat, dry-edge, wet-flat, and wet-edge bending test specimens with greater than 75 percent wood failure.*

Specimen type	Independent variable	Sample size	Equation	r^2	Standard error
Dry-flat	Maximum RPI	121	$y = 4363.6 + 243.3(x_1{}^1) + 135.8(x_2{}^2)$*	0.15	1363.2
	Minimum RPI	121	$y = 4215.3 + 239.2(x_1) + 230.5(x_2)$*	0.18	1338.8
	Differential RPI	121	$y = 5228.3 + 336.8(x_1) + 59.6(x_2)$*	0.06	1434.2
	Average RPI	121	$y = 4110.7 + 220.6(x_1) + 202.7(x_2)$*	0.19	1337.2
Dry-edge					
	Maximum RPI	150	$y = 5104.0 + 393.7(x_1) + 119.4(x_2)$*	0.13	1486.8
	Minimum RPI	150	$y = 4671.7 + 399.5(x_1) + 278.6(x_2)$*	0.17	1451.9
	Differential RPI	150	$y = 5899.3 + 436.3(x_1) + 48.4(x_2)$*	0.07	1531.0
	Average RPI	150	$y = 4676.3 + 379.7(x_1) + 213.9(x_2)$*	0.16	1459.0
Wet-flat					
	Maximum RPI	84	$y = 3276.3 + 250.5(x_1) + 189.6(x_2)$*	0.21	1366.9
	Minimum RPI	84	$y = 3219.9 + 230.1(x_1) + 293.5(x_2)$*	0.28	1306.7
	Differential RPI	84	$y = 4651.6 + 391.5(x_1) + 12.4(x_2)$	0.28	1483.6
	Average RPI	84	$y = 2908.8 + 205.8(x_1) + 286.2(x_2)$*	0.28	1307.4
Wet-edge					
	Maximum RPI	117	$y = 3608.6+ 327.3(x_1) + 220.1(x_2)$*	0.27	1375.5
	Minimum RPI	117	$y = 2926.7 + 421.9(x_1) + 480.2(x_2)$*	0.35	1302.0
	Differential RPI	117	$y = 4976.1 + 424.9(x_1) + 100.8(x_2)$*	0.11	1520.0
	Average RPI	117	$y = 2784.0 + 315.2(x_1) + 401.8(x_2)$*	0.37	1282.1

* Denotes that regression equation was significant at an alpha level of 0.05

[1] X_1 = dummy variable for finger length

[2] X_2 = RPI independent variable

specimens (either flat or edge) accounted for generally less variation than those for the wet test specimens discussed above. The relationship between MOR and average RPI for the dry-flat test specimens had a coefficient of determination of 0.19, while the regression using minimum RPI had a coefficient of determination of 0.18 for the same test specimens. All other regressions for the dry test specimens had lower coefficients of determination ranging from 0.07 to 0.17.

Out of the 4 RPI independent variables examined, relationships using differential RPI as the independent variable resulted in the lowest coefficients of determination. The same result was found for the regressions based on the 4 SG independent variables discussed earlier (Table 1). Just as with SG, it would appear that the absolute difference in RPI between the A and B pieces within a finger-jointed specimen relates very poorly to the MOR of the specimens when broken.

The low coefficients of determination reported in this study are likely due to the fact that the percentage of latewood in the samples was not accounted for. In softwoods, as the percentage of latewood increases, the strength also increases. It is likely that the relationship between RPI and MOR would improve by including %latewood in the regression equation as an additional independent variable.

No previous studies were found that examined the linear relationship between growth rate and MOR for southern pine finger-jointed wood test specimens or for finger-jointed wood made from any other species. Dickens (1996) did examine RPI in finger-jointed southern pine material but examined it as one of many factors in a multiple regression analysis. He found a correlation coefficient of 0.74 (r^2 = of 0.55) for the relationship between tensile strength and 8 predictor variables including, 4 ultrasonic parameters, minimum SG, maximum percent compression wood and maximum percent juvenile wood, minimum RPI and maximum RPI (Dickens 1996). The highest coefficient of determination of 0.37 for the simple linear relationship between average RPI and MOR found in the present study (Table 2) is lower than the coefficient of determination of 0.55 found by Dickens (1996) based on multiple factors including RPI variables.

Results found in the present study for the relationship between growth rate and MOR based on finger-jointed southern pine also appear to be consistent with those reported by others for solid wood. Gerhards (1972) examined the relationship between tensile strength and several independent variables using multiple regression. The material examined was 300 two-by-four inch and 150 two-by-eight inch pieces of southern pine dimension lumber from 10 mills. The independent variables were fractional knot strength ratio, slope of grain, SG, warp, relative latewood, growth rate, and bending stiffness modulus. Growth rate was not a significant variable in any of the multiple regression models when other variables were included.

Leban and Haines (1999) report a coefficient of determination of 0.56 for the relationship between MOE and rings per centimeter for 492 samples from 18 hybrid larch trees. Although not clearly indicated in the paper by Leban and Haines (1999), it appears that wood samples were obtained from both juvenile and mature wood portions of the stem.

Zhang (1995) examined the simple linear relationship between MOR and growth rate in 8 softwood and 8 hardwood species. For the 8 species of softwoods, correlation coefficients ranging from −0.22 to −0.75 (r^2 from 0.05 to 0.56) were found for the relationship between growth rate and MOR. For the 8 species of hardwoods, correlation coefficients ranging from −0.01 to 0.55 (r^2 from <0.01 to 0.30) were found for the relationship using the same variables.

For the dry-edge and wet-flat test specimens, the coefficients of determination for the regressions using maximum, minimum, and average RPI differed from the coefficients of determination for the regressions for the same test specimens when maximum, minimum, and average SG were used as the independent variables. For the dry-edge test specimens, coefficients of determination of 0.17, 0.26, and 0.26 were found when maximum, minimum, and average SG, respectively were used as independent variables (Table 1). In contrast, coefficients of determination of only 0.08, 0.11, and 0.11 were found when maximum, minimum, and average RPI, respectively were used as independent variables based on the same group of dry-edge test specimens (Table 2). For the wet-flat test specimens, coefficients of determination of only 0.03, 0.06, and 0.05 were found when maximum, minimum, and average SG were used as independent variables (Table 1). Again, in contrast, higher coefficients of determination of 0.18, 0.29, and 0.29 were found when maximum, minimum, and average RPI, respectively were used as independent variables based on the same group of wet-flat test specimens (Table 2). These results appear to suggest that the effect of growth rate, measured as RPI in this study, differs from the effect of SG on the MOR strength property. In order to examine these findings further, the simple linear relationship between average SG and average RPI was examined for the dry-flat, dry-edge, wet-flat, and wet-edge test specimens using simple linear regression analysis. Coefficients of determination were found to be 0.10 for the dry-flat specimens, 0.07 for the dry-edge specimens, 0.10 for the wet-flat specimens, and 0.10 for the wet-edge specimens. While all 4 relationships were found to be significant, all 4 coefficients of determination would be considered low and indicate a weak relationship between average RPI and average SG. These results for the relationship between RPI and SG appear to support the results found for the dry-edge and wet-flat specimens showing different relationships between MOR and SG and MOR and RPI. This appears consistent with the result found by Zhang (1995). He examined the relationship between growth rate and SG in *Abies nephrolepis*, and found a correlation coefficient of −0.24 ($r^2 = 0.06$). Zhang (1995) also examined the relationship between MOR and SG and MOR and growth rate. He stated that the relationship between SG and strength properties may differ from that of growth rate and strength properties.

Other studies have also shown similar findings for growth rate, SG, and strength properties. Choong et. al. (1989) found correlation coefficients of 0.24 (n = 310) and 0.34 (n = 325) for the relationship between SG and growth rate in 'outerwood' from 36 longleaf pine and 36 slash pine trees grown in central Louisiana. Pearson and Ross (1984) reported that growth rate did not significantly affect the relationship between MOR and SG based on wood removed from pith to bark in loblolly pine trees grown in stands aged 15, 25, and 41 years.

CONCLUSIONS

The results of this study suggest that the specific gravity and rings per inch of the pieces of wood making up southern pine finger-jointed boards have a significant effect on the bending strength (MOR) of the finger-jointed boards. Of the four SG independent variables, minimum SG and average SG were the best predictors of MOR. Of the four RPI independent variables, minimum RPI and average RPI were the best predictors of MOR.

Each of the test specimens used for analyses in this study had a minimum of 75% wood failure, allowing specimens to have as much as 25% glue failure. This level of glue failure may have masked the relationship between the wood properties (SG and RPI) of the test specimens and the bending strength (MOR). Future work is needed to examine the relationship between wood properties and bending strength of finger-jointed wood specimens in wood specimens exhibiting less than 25% glue failure.

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