TECHNICAL NOTE: STRENGTH AND STIFFNESS PROPERTIES OF SMALL CLEAR SPECIMENS TAKEN FROM COMMERCIALLY PROCURED NO. 2 2 × 8 AND 2 × 10 SOUTHERN PINE DIMENSION LUMBER

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Abstract. This technical note focuses on the modulus of rupture (MOR) and modulus of elasticity (MOE) of small clear southern pine (*Pinus* spp.) test pieces cut from commercially procured full-size lumber specimens. A production-weighted sample of 476 No. 2 grade 2 × 8s and 2 × 10s was acquired from retail establishments throughout the southern pine producing region. The specimens were subjected to static bending tests to measure MOR and MOE. From 447 of those specimens, a single small clear beam (3.8 × 3.8 × 61 cm) was extracted and subjected to a static bending test of the same properties. Two-sample *t* tests showed no evidence of statistical difference in either mean MOE or MOR between the small samples taken from the 2 × 8s and the 2 × 10s. Bivariate correlations and r^2 values showed an overall weak relationship ($r = 0.30$, $r^2 = 0.09$) between the small clears and their parent specimens with respect to MOR. A more moderate relationship ($r = 0.60$, $r^2 = 0.36$) was found with respect to MOE between small clears and their parent specimens. In addition, a relatively strong relationship was found between the MOR and MOE values of the small clears themselves ($r = 0.77$, $r^2 = 0.59$). It is intended that subsequent publications will examine similar relationships in other grades and sizes.

Keywords: Southern pine, mechanical properties, modulus of elasticity, modulus of rupture, small clear specimens, lumber, strength, stiffness.

INTRODUCTION

The southern pine species group (*Pinus* spp.) grows throughout the southeastern quadrant of the United States from Virginia to Texas (Forest Products Laboratory [FPL] 1936). Principally composed of loblolly (*Pinus taeda*), longleaf (*Pinus palustris*), shortleaf (*Pinus echinata*), and slash pine (*Pinus elliottii*) (Southern Pine Inspection Bureau [SPIB] 2014), southern pine is a valuable natural and economic resource representing billions of dollars in standing

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inventory and providing thousands of manufacturing jobs.

A widely used structural material for residential home building, southern pine dimension lumber is graded according to the grading rules prescribed by the Southern Pine Inspection Bureau (SPIB) and sanctioned by the American Lumber Standards Committee (ALSC) (SPIB 2014). Around 2010, a nationwide reevaluation of the allowable properties for southern pine dimension lumber was initiated in the United States. This led to a 2013 change in the design values of visually graded southern pine dimension lumber (SPIB 2013), potentially resulting in a change in its utility value.

To better understand the factors that contributed to the design value change for southern pine, a large-scale, comprehensive evaluation of the wood quality and mechanical properties of commercially procured dimension lumber is underway at Mississippi State University. Part of this reassessment involves reexamining the modulus of elasticity (MOE) and modulus of rupture (MOR) of small clear specimens. In the past, small clears had been used to develop design values in dimension lumber but fell out of favor after research showed that the models used to scale up the data may vary in their level of conservatism (Madsen 1976; Bodig 1977; Green et al 1989). For this reason, from around the 1980s onward, design values have been primarily determined by using data from full-size lumber specimens (Green et al 1989). Nevertheless, in light of changing mechanical properties in southern pine dimension lumber, the authors deemed it important to also reevaluate the MOR and MOE of small clear specimens as they serve as a baseline for estimating mechanical properties of clear wood free from the influence of strength-reducing characteristics.

Small clear specimens are particularly useful for assessing possible differences in clear wood quality among different lumber sizes. If the mechanical properties of the small clears taken from two different widths are significantly different, it suggests that they comprise different qualities of clear wood, possibly attributable to log size, percentage of juvenile wood, and/or other factors. The first objective of this

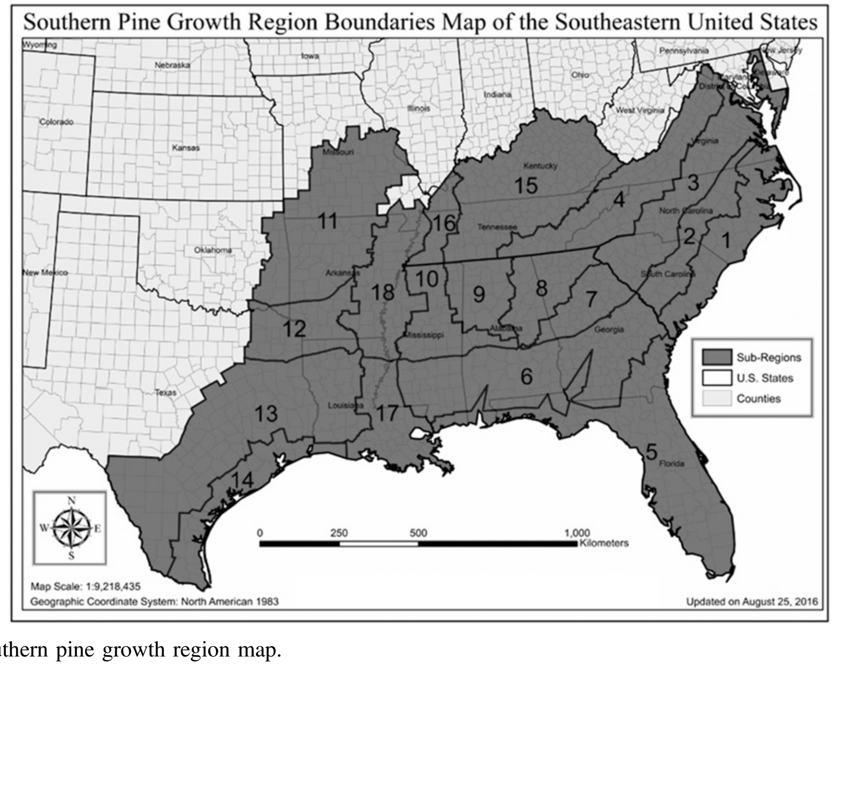

Figure 1. Southern pine growth region map.

technical note is to determine if there is a statistical difference in mean MOE or MOR between the small specimens taken from the 2 × 8s and those from the 2 × 10s.

The second objective of this technical note is to assess the correlations of strength and stiffness between the small clears and their parent specimens. In a forest-through-mill study of loblolly pine, Butler et al (2016) examined the correlations of MOE and MOR between small clears and full-size (No. 1 through No. 3) specimens cut from 93 trees from five 24- to 33-yr-old stands in Georgia. By contrast, the current Mississippi State University study focuses on commercially procured lumber specimens sampled throughout the southern pine producing region. In addition to examining the correlations of each property between small clears and their parent specimens, this study also considers the correlation between MOR and MOE within the small clear and full-size specimen groups themselves.

MATERIALS AND METHODS

Materials

Kiln-dried, surfaced No. 2 southern pine (*Pinus* spp.) dimension lumber of various lengths was selected for use in this study. The sampling occurred as follows: Pine dimension lumber production was determined by geographical region with assistance from appropriate grading agencies and the U.S. Department of Agriculture Forest Products Laboratory. The region map (Fig 1) was similar to the one shown in Green et al (1989). A listing of mill numbers (identifier codes) throughout the pine production area was then developed by region. This action provided a production weighting by region. Next, lumber was procured from the supply chain outlets (retail establishments) throughout the various southern pine producing regions. The supply chain/retail outlets included national chains and smaller regional and independent vendors. A production-weighted sample was then collected from each region. In essence, a retail outlet was surveyed to determine if they stocked candidate lumber from any of the mills or regions of interest. If yes, lumber was procured. If no, then they were omitted. This process was repeated iteratively until enough lumber from each region was contained in the sample. Ultimately, material was purchased from Missouri, Oklahoma, Texas, Arizona, Louisiana, Mississippi, Tennessee, Kentucky, Alabama, Georgia, Florida, North and South Carolina, Virginia, and Delaware. On arrival at the testing location, each specimen was assessed for width, length, number of growth rings, rings per inch, and percentage of latewood. Information about the grading agency and production source was recorded for each piece. Specimens were placed in rooms controlled to 21°C/55% RH to achieve and maintain the desired MC of approximately 10% (FPL 2010).

To confirm the actual grade of the test pieces, the lumber was visually inspected by two certified graders: one from SPIB and another from Timber Products Inspection (TP). Specimens incorrectly stamped at the mill were reassigned the correct grade. Finally, knots were coded for each specimen. In the final count for No. 2 grade, 294 pieces were 2 × 8 (net 38 × 184 mm), and 182 were 2 × 10 (net 38 × 235 mm). In total, 476 pieces, all on-grade, were tested.

Testing

Full-size lumber testing. Full-size lumber testing was performed using a four-point static bending fixture in accordance with ASTM D198-15, Flexure Method (ASTM 2015). Specimens were tested in an edgewise orientation under third-point loading using an Instron universal testing machine. A span-to-depth ratio of 17-to-1 was used. Each piece was loaded into the fixture without respect to defects (ASTM 2013). The tension face of each sample was randomly

Table 1. Two-sample *t* test for modulus of rupture (MOR) of small clear southern pine specimens adjusted to 15% MC.

Specimen source	*n*	Mean (MPa)	SD	*t*	df	*p*
2 × 8	273	74.4	12.0	0.522	445	0.602
2 × 10	174	73.8	11.5	—	—	—

$\alpha = 0.05$, 2-tailed.

Table 2. Two-sample *t* test for modulus of elasticity (MOE) of small clear southern pine specimens adjusted to 15% MC.

Specimen source	*n*	Mean (GPa)	SD	*t*	df	*p*
2 × 8	273	8.97	1.98	0.750	445	0.454
2 × 10	174	8.83	1.95	—	—	—

α = 0.05, 2-tailed.

selected. Deflection was measured with a wire deflectometer at midspan. The minimum time until rupture was approximately 4 min.

MC data were collected from each specimen immediately after testing by cutting a small sample near the point of failure. Each sample was weighed, dried to zero percent MC, and reweighed to calculate the MC on an oven-dry basis. The average MC was approximately 12%. MOE and MOR values were adjusted toward a common MC of 15% per ASTM D 1990-16 (ASTM 2016).[1]

Small clear specimen testing. After destructively testing the full-size specimens, an attempt was made to cut a small, clear, straight-grained 3.8 × 3.8 × 61 cm subspecimen[2] from each full-size test piece. For 29 pieces, extracting a straight-grained subspecimen from the full-size test pieces was not possible because of a lack of clear wood. Of the 476 full-size specimens tested, 447 yielded a small clear test piece.

The small clear destructive bending test was carried out as per ASTM D143-14 (ASTM 2014) using an Instron universal testing machine with a three-point static bending fixture. Each specimen was weighed and measured. Immediately before testing, MC readings were taken with a Delmhorst J-88 pin-type meter (Delmhorst Instrument Co., Towaco, NJ). The average MC was approximately 10%. Center loading was applied to the tangential surface nearest to the pith. A span-to-depth ratio of 14-to-1 was used. Deflection was recorded until the maximum load was achieved. Most specimens failed in compression before breaking in tension. MOE and MOR values were adjusted to a common MC of 15% as per ASTM D 1990-16 (ASTM 2016).

[1] As per ASTM D 1990-16 (ASTM 2016), moisture adjustments greater than 5% were avoided. In cases when a specimen's MC was more than 5% from 15%, the properties were adjusted no more than 5% toward the target moisture content.

[2] Although ASTM D 143-14 (ASTM 2014) recommends a small clear specimen size of 2.5 × 2.5 × 41 cm (the "secondary method") when a full 5.0 × 5.0 × 76 cm specimen (the "primary method") cannot be extracted, this study opted for modified dimensions of 3.8 × 3.8 × 61 cm to embrace the maximum number of growth rings, reduce the influence earlywood and latewood differences might have on the testing results, and capture a cross section that is most representative of the of the full-size test piece.

Table 3. Two-sample *t* test for the modulus of rupture (MOR) of full-size No. 2 southern pine specimens adjusted to 15% MC.

Specimen size	*n*	Mean (MPa)	SD	*t*	df	*p*
2 × 8	294	39.3	13.8	−0.451	474	0.652
2 × 10	182	39.9	14.1	—	—	—

α = 0.05, 2-tailed.

Statistical analyses. Means comparisons and correlation analyses were conducted with SPSS 23 (IBM Corp. 2015). Nonparameteric tolerance limits were calculated with Minitab 17 (Minitab, Inc. 2010).

RESULTS AND DISCUSSION

Means Comparisons

Two-sample *t* tests were performed to determine if there were significant mean differences in mechanical properties between the 2 × 8s and 2 × 10s. First, the small clears were considered. As shown in Table 1, the mean MOR values for the small clear specimens taken from the 2 × 8s and 2 × 10s were 74.4 and 73.8 MPa, respectively. A two-sample *t* test reveals no significant difference between the two means at the 0.05 level ($p = 0.602$). The corresponding mean MOE values of 8.97 and 8.83 GPa for 2 × 8s and

Table 4. Two-sample *t* test for the modulus of elasticity (MOE) of full-size No. 2 southern pine specimens adjusted to 15% MC.

Specimen size	*n*	Mean (GPa)	SD	*t*	df	*p*
2 × 8	294	10.7	2.3	1.14	474	0.254
2 × 10	182	10.5	2.5	—	—	—

α = 0.05, 2-tailed.

Table 5. Correlations of modulus of rupture (MOR) and modulus of elasticity (MOE) between various specimen types for 2 × 8 only.

	Full-size MOR	Full-size MOE	Small clear MOR	Small clear MOE
Full-size MOR	**1**			
Full-size MOE	**0.480** (0.230)	**1**		
Small clear MOR	**0.292** (0.085)	**0.642** (0.412)	**1**	
Small clear MOE	**0.195** (0.038)	**0.642** (0.412)	**0.787** (0.619)	**1**

Bold values indicate Pearson's correlation coefficient. Parentheses indicate r^2 values. All correlations are significant at the 0.01 level. All values for MOE and MOR were adjusted to 15% MC before calculation. For full-size specimens, $n = 294$. For small clear specimens, $n = 273$.

2 × 10s, respectively, are shown in Table 2. The *t* test for these was also not significant ($p = 0.454$). This result suggests that there is no significant mechanical difference in the clear wood between the 2 × 8s and 2 × 10s. The lack of significant difference in both properties does not seem surprising, as both the 2 × 8s and 2 × 10s are likely to have been sawn from larger logs of similar size.

Subsequently, the full-size specimens were considered. As shown in Table 3, the mean MOR values for the full-size specimens taken from the 2 × 8s and 2 × 10s were 39.3 and 39.9 MPa, respectively. A two-sample *t* test reveals no significant difference between the two means ($p = 0.652$), indicating similar average strength performance. The corresponding mean MOE values of 10.7 and 10.5 GPa for the 2 × 8s and 2 × 10s, respectively, are shown in Table 4. The *t* test for these was also not significant ($p = 0.254$), indicating similar average elastic performance.

Strength Ratios

A strength ratio for each specimen pair was calculated by dividing the MOR of the full-size tests piece by the MOR of the matched small clear specimen. The average strength ratios for the 2 × 8s and 2 × 10s were 53% and 54%, respectively.

Nonparametric Tolerance Limits

The lower 5% nonparametric tolerance limits (95% content, 75% confidence) for the MOR of the full-size 2 × 8 and 2 × 10 specimens were 19.9 and 18.4 MPa, respectively.

Bivariate Correlations

Bivariate correlations were assessed for all specimen–property combinations. Correlation coefficients appear in Tables 5-7.

In Table 5, the 2 × 8s exhibited a weak relationship ($r = 0.292$, $r^2 = 0.085$) between the small clears and their parent specimens with respect to MOR and a moderate relationship ($r = 0.642$, $r^2 = 0.412$) with respect to MOE. Although a relatively strong relationship was found between the MOR and MOE values of the small clears themselves ($r = 0.787$, $r^2 = 0.619$), only a moderate relationship was found between the MOR and MOE values of the full-size specimens ($r = 0.480$, $r^2 = 0.230$). Similarly, in Table 6, the 2 × 10s exhibited a weak relationship ($r = 0.301$,

Table 6. Correlations of modulus of rupture (MOR) and modulus of elasticity (MOE) between various specimen types for 2 × 10 only.

	Full-size MOR	Full-size MOE	Small clear MOR	Small clear MOE
Full-size MOR	**1**			
Full-size MOE	**0.622** (0.387)	**1**		
Small clear MOR	**0.301** (0.091)	**0.589** (0.347)	**1**	
Small clear MOE	**0.215** (0.046)	**0.530** (0.281)	**0.736** (0.542)	**1**

Bold values indicate Pearson's correlation coefficient. Parentheses indicate r^2 values. All correlations are significant at the 0.01 level. All values for MOE and MOR were adjusted to 15% MC before calculation. For full-size specimens, $n = 182$. For small clear specimens, $n = 174$.

Table 7. Correlations of modulus of rupture (MOR) and modulus of elasticity (MOE) between various specimen types for 2 × 8 and 2 × 10 (together).

	Full-size MOR	Full-size MOE	Small clear MOR	Small clear MOE
Full-size MOR	**1**			
Full-size MOE	**0.535** (0.286)	**1**		
Small clear MOR	**0.295** (0.087)	**0.621** (0.386)	**1**	
Small clear MOE	**0.202** (0.041)	**0.598** (0.358)	**0.768** (0.590)	**1**

Bold values indicate Pearson's correlation coefficient. Parentheses indicate r^2 values. All correlations are significant at the 0.01 level. All values for MOE and MOR were adjusted to 15% MC before calculation. For full-size specimens, $n = 476$. For small clear specimens, $n = 447$.

$r^2 = 0.091$) between the small clears and their parent specimens with respect to MOR and a moderate relationship ($r = 0.530$, $r^2 = 0.281$) with respect to MOE. Although a relatively strong relationship was found between the MOR and MOE values of the small clears themselves ($r = 0.736$, $r^2 = 0.542$), only a moderate relationship was found between the MOR and MOE values of the full-size specimens ($r = 0.622$, $r^2 = 0.387$).

When the 2 × 8s and 2 × 10s were considered in the aggregate, the correlations exhibited the same pattern. Table 7 shows a weak relationship ($r = 0.295$, $r^2 = 0.087$) between the small clears and their parent specimens with respect to MOR and a moderate relationship ($r = 0.598$, $r^2 = 0.358$) with respect to MOE. Although a relatively strong relationship was found between the MOR and MOE values of the small clears themselves ($r = 0.768$, $r^2 = 0.590$), only a moderate relationship was found between the MOR and MOE values of the full-size specimens ($r = 0.535$, $r^2 = 0.286$). It is also worth noting that although small clear MOE was not highly correlated with full-size MOR ($r = 0.202$, $r^2 = 0.041$), small clear MOR was moderately correlated with full-size MOE ($r = 0.621$, $r^2 = 0.386$).

CONCLUSION

As part of a larger, comprehensive evaluation of the mechanical properties of southern pine dimension lumber sampled throughout the southern pine producing region, the authors deemed it important to also reevaluate the MOR and MOE of small clear specimens, relative to both themselves and to their parent specimens, as these small samples serve as a baseline for estimating mechanical properties of clear wood free from the influence of strength-reducing characteristics. The results of testing showed that the MOE and MOR of the small clears are only slightly to moderately correlated with the same properties of their parent specimens; however, among the small clear specimens themselves, MOE and MOR are strongly correlated. No significant difference in MOR or MOE was found between the clear specimens taken from the 2 × 8s and 2 × 10s. Also, no significant difference in MOR or MOE was found between in-grade specimens in the 2 × 8s and 2 × 10s. Ongoing research will examine similar relationships in other grades and sizes as this comprehensive evaluation of the mechanical properties of southern pine dimension lumber continues.

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