BENDING STRENGTH AND STIFFNESS OF NO. 2 GRADE SOUTHERN PINE LUMBER

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Abstract. Southern pine is the most important species group planted and used for lumber products in the United States. Most southern pine trees come from managed forests, with relatively short rotations and excellent growth yields. The accelerated growth volume allows trees to reach merchantable size in 16-22 yr. However, these trees may contain large amounts of juvenile wood which can negatively impact the bending properties of lumber. In 2010, the Southern Pine Inspection Bureau (SPIB) began to reevaluate the mechanical properties of southern pine lumber, which resulted in changes in design values. The objective of the study herein was to summarize the growth characteristics and bending properties of No. 2 grade 2 × 4, 2 × 6, 2 × 8, and 2 × 10 samples collected from across the geographical growing range (southern United States). Each piece met the requirements for No. 2 grade southern pine lumber. Overall, 34.5% of the sample contained pith, averaged 4.6 rings per inch, and contained 43.8% latewood. The sample's average specific gravity, MOE, and MOR were 0.54, 10.1 GPa, and 41.7 MPa, respectively. The mean MOE found in this study was higher than the current design value required for No. 2 southern pine lumber. For allowable design bending strength (F_b), the results showed that, as dimension stock size increased, the F_b decreased from 11.2 MPa for 2 × 4 s to 7.1 MPa for 2 × 10 s. The F_b values determined herein exceeded the new published design value and also met the previous SPIB design values. These results suggest that the timber resource quality might have increased since the housing crisis of 2008-2010.

Keywords: Visual grading, mechanical properties, growth characteristics.

INTRODUCTION

Southern pine is the most commercially important species group used for lumber, and most of this lumber available in the market is visually graded (Gaby 1985). Limits for strength-reducing characteristics such as maximum sizes and locations of knots, slope of grain, and minimum density permitted for a specific grade are the primary bases for the visual grading of structural lumber. The visual grading process includes examination of the four faces of each piece. Among other factors, an evaluation of the major strength-reducing characteristics determines the grade.

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Table 1. Previous and new design values for southern pine No. 2 grade lumber adjusted to 15% MC (AFPA 2005; ALSC 2013).

	Previous design value (2012 and prior)		New design value (2013 and after)	
Lumber size	MOE (GPa)	F_b (MPa)	MOE (GPa)	F_b (MPa)
2 × 4	11.0	10.3	9.7	7.6
2 × 6		8.6		6.9
2 × 8		8.3		5.5
2 × 10		7.2		5.2

F_b, bending strength.

A variation of up to 5% is allowed among visually graded lumber packages to account for differences among inspectors. If a lumber package contains less than 95% of the pieces at or higher than the stated grade, reexamination is required. Advantages of visual grading include the following: it can be performed by an inspector without expensive tools or capital equipment; it is fast and ideal for small sawmills and local markets; it provides rapid sorting; and it has wide market acceptability. However, visual grading is necessarily conservative and can be labor intensive. Moreover, the visual grade might not reflect the actual strength and stiffness of each piece (Kretschmann and Hernandez 2006).

Classification of lumber using visual grading is based on human inspection or on automated imaging with cameras combined with laser-based systems and sometimes X-rays to feed data to computer systems which are able to identify various characteristics (Bharati et al 2003). Regardless of the system used, visual grading requires that the major strength reducing characteristic be quickly identified and assessed. There are many characteristics that affect the mechanical properties

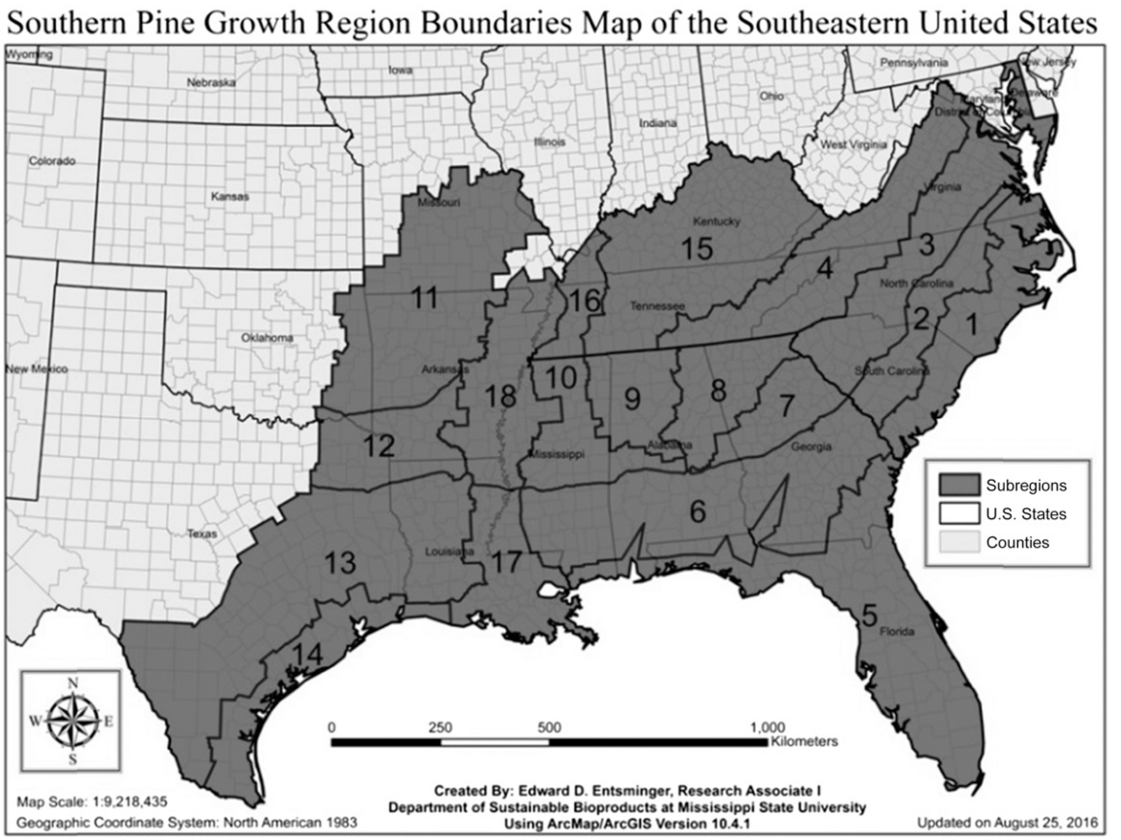


Figure 1. Map of southern pine growth regions of southern pine (Shelley 1989).

Table 2. Summary statistics for number of rings per inch (RPI) and percentage of latewood (LW) for No. 2 grade southern pine lumber by size.

			RPI			LW (%)		
Size	*N*	Pith (%)	Mean	Median	COV (%)	Mean	Median	COV (%)
2 × 4	363	21.5	4.9 a	4.7	42.3	44.0 ab	43.0	26.7
2 × 6	388	30.7	4.8 ab	4.0	46.7	45.0 a	44.5	25.0
2 × 8	291	43.6	4.5 b	3.7	57.0	42.5 b	41.1	25.0
2 × 10	181	54.7	4.0 c	3.2	55.3	43.1 ab	41.1	25.1
Overall	1223	34.6	4.6	4.0	49.3	43.8	43.0	25.7

COV, coefficients of variation. Significant differences in mean RPI and LW among sizes are indicated by different letters at $\alpha = 0.05$.

of lumber, but only the most critical characteristics are considered. In southern pine lumber, the most common strength-reducing characteristic is knots.

During the 1990s and early 2000s, the Southern Pine Inspection Bureau (SPIB) conducted nondestructive tests on 400 specimens per year using No. 2 2 × 4 lumber to assess potential changes in resources (Kretschmann et al 1999). In 2010; SPIB conducted a study to reevaluate the mechanical properties as a follow up to the In-Grade program of the late 1980s. In 2011, an In-Grade resource monitoring program noted that the mechanical properties of southern yellow pine dimension lumber were less than those published in the then-current edition of the National Design Specification. Subsequently, a full In-Grade test program was initiated, and the change was shown to be nontrivial. Thus the design values for southern pine were more fully investigated and were subsequently changed (SPIB 2012). The results of the tests showed a decrease in stiffness and strength in the No. 2 2 × 4 lumber. Furthermore, mechanical tests were performed on other dimensions (2 × 8 and 2 × 10) and grades (Select Structural and No. 2). Ultimately, this evaluation program resulted in changes in southern pine design values (ALSC 2013). Table 1 shows the changes in design values for southern pine dimensional lumber.

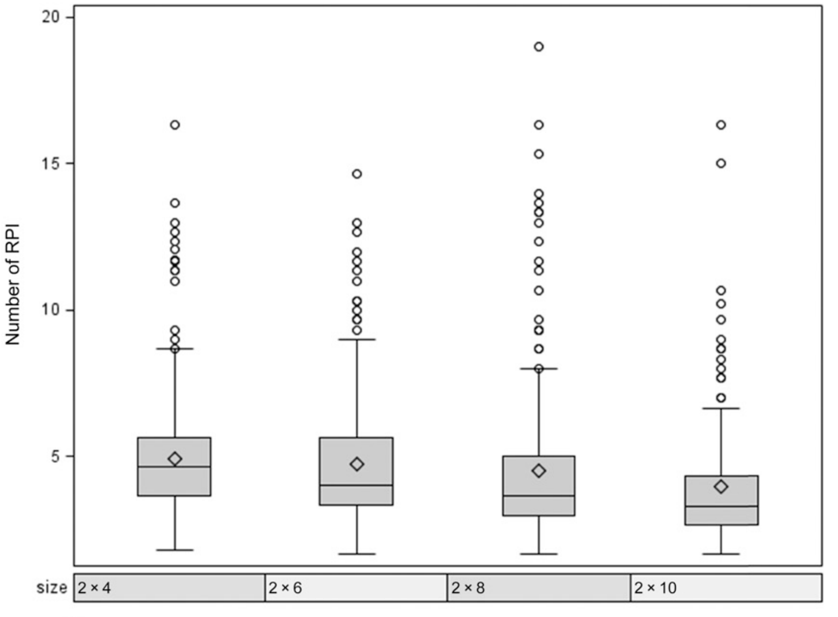
One of the reasons for the change in strength and stiffness values could be that an extraordinary amount of juvenile and/or low-quality trees entering the market from large land-holding companies trying to financially stay afloat during the 2010 era (Kretschmann et al 2010). Essentially, during the housing crisis of 2008-2010, lumber production was cut by approximately 50/5 and it appears that unusually low value trees were preferentially processed. Since the housing crisis, the monitoring of the timber resource has continued, and mechanical properties of southern pine lumber have indicated a steady recovery and rebound. During 2008-2010, there was a much greater proportion of material being tested that had a higher incidence of combination knots and increased frequency of other grade-controlling characteristics, such as slope of grain (SPIB 2012).

This situation calls for further scientific investigation into potential improvements that could be made toward refining the visual characteristics that are used to assign lumber grades. The objectives of this

Table 3. Summary statistics for specific gravity (SG), MOE, MOR, and bending strength (Fb) for No. 2 grade southern pine lumber by size adjusted for 15% MC.

	SG			MOE (GPa)			MOR (MPa)			
Size	Mean[a]	Median	COV (%)	Mean	Median	COV (%)	Mean	Median	COV (%)	F_b (MPa)
2 × 4	0.55 a	0.54	11.4	10.2 b	10.2	23.9	51.1 a	49.7	34.3	11.2
2 × 6	0.54 a	0.53	10.9	9.7 c	9.3	22.7	41.6 b	40.4	37.8	9.2
2 × 8	0.54 a	0.53	10.0	10.5 a	10.5	20.6	39.0 c	37.5	33.2	8.1
2 × 10	0.55 a	0.53	10.5	10.3 ab	10.1	23.5	39.6 bc	39.2	35.3	7.1
Overall	0.54	0.54	10.0	10.1	10.0	23.0	41.7	41.6	37.3	—

COV, coefficients of variation.
[a] Significant differences in mean SG, MOE, and MOR among sizes are indicated by different letters at $\alpha = 0.05$.



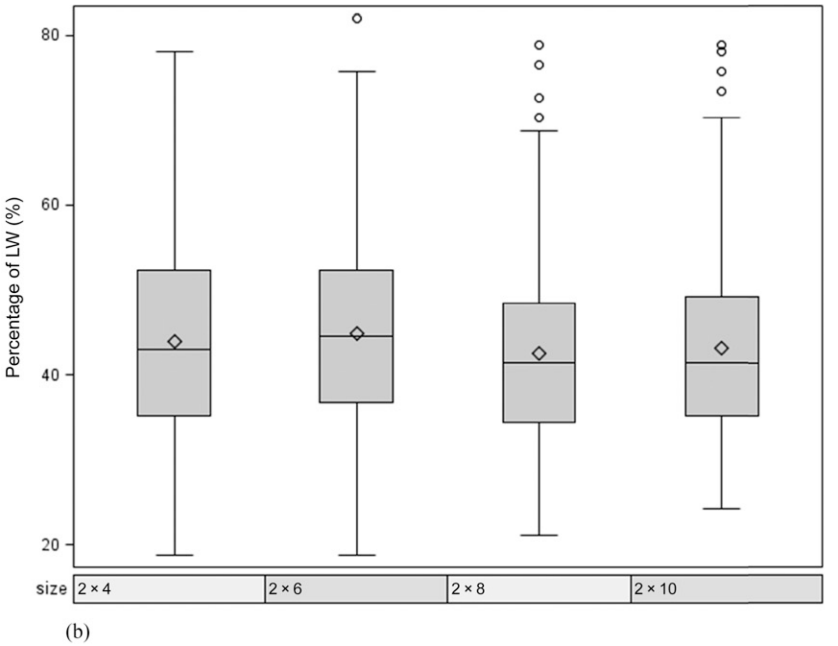


Figure 2. Boxplot distribution of (a) number of rings per inch (RPI) (b) and percentage of latewood (LW) (%).

study were to: 1) collect an experimental sample that represents production-weighted southern pine No. 2 grade lumber; 2) summarize the nature of specific characteristics of 2 × 4, 2 × 6, 2 × 8, and 2 × 10 No. 2 grade southern pine lumber (presence of pith, number of rings per inch [RPI], and percentage of latewood [LW]); 3) measure bending strength (F_b) and stiffness; 4) assess the statistical distribution of

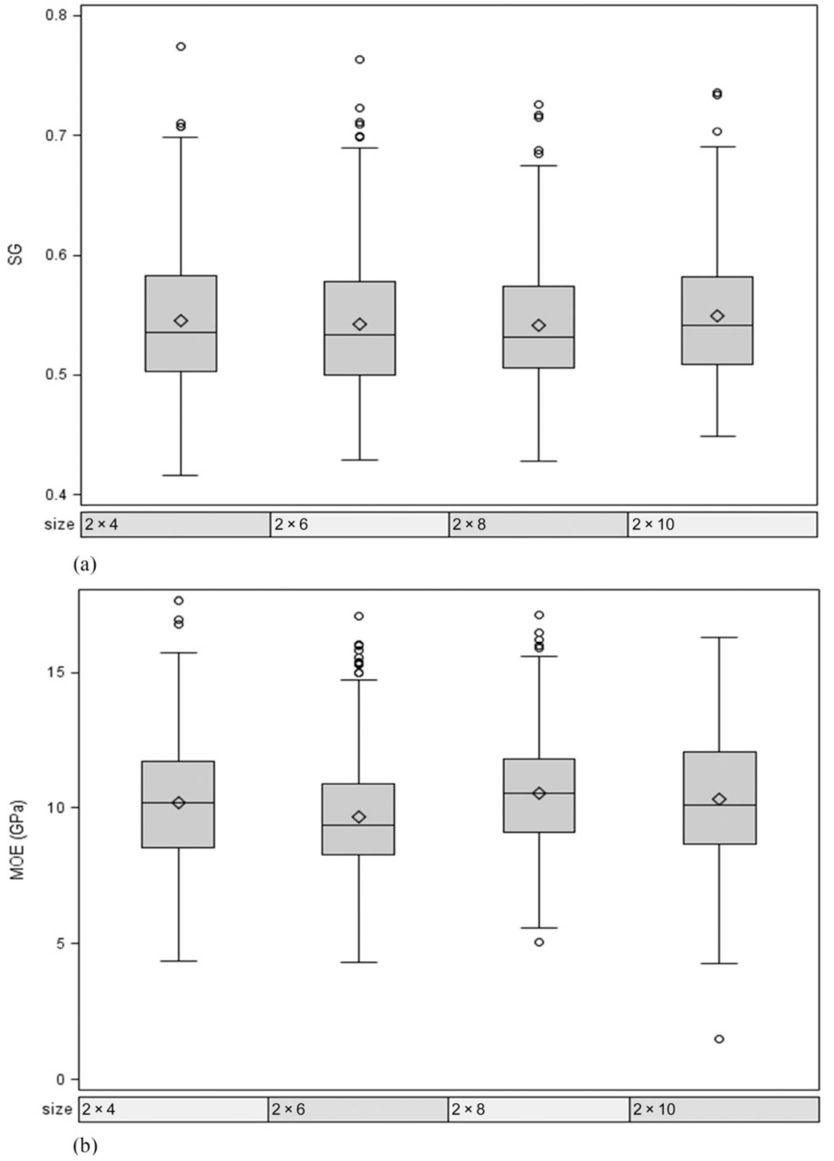


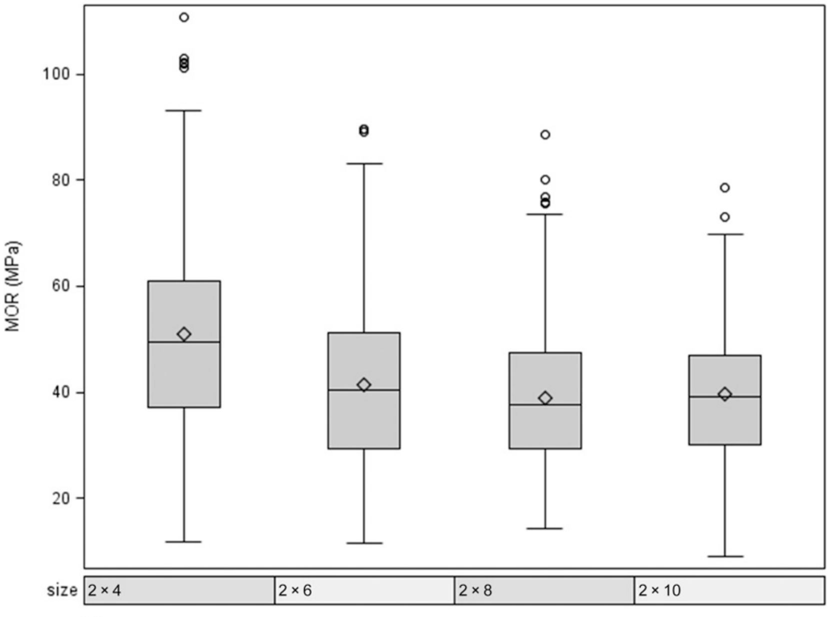
Figure 3. Boxplot distribution of (a) specific gravity (SG), (b) MOE, (c) and MOR by size of No. 2 southern pine lumber.

specific gravity (SG), MOE, and MOR data; and 5) compare these results of mean MOE and allowable design F_b with previous and current design values.

MATERIAL AND METHODS

Test Material

A production-weighted sample of southern pine No. 2 grade lumber 2 × 4 ($n = 363$), 2 × 6 ($n = 388$), 2 × 8 ($n = 291$), and 2 × 10 ($n = 181$) was collected from 15 of the original 18 regions spread across the southern United States (Fig 1). Three regions were not sampled because of low production. Specimens were obtained from commercial sawmills via the stream of commerce (ie building suppliers across the southern United States). The lumber was graded under the oversight of SPIB and Timber Products Inspection



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(TP). No. 2 grade lumber was chosen because it accounts for the largest volumetric production of pine in the southern United States (SFPA 2005). The specimens were transported to the testing laboratory and regraded by a certified grader from either SPIB or TP to ensure that the specimens were No. 2 grade (on-grade, which are the boards that were bought as No. 2 and the grader certified that they were No. 2 grade).

Specimen Preparation and Testing

Data collected on each specimen included dimensions, weight, SG, MC, presence of pith, number of RPI, and percentage of LW. All six faces of the specimens were inspected to evaluate the presence of pith. If pith appeared on any side of the length, it was classified as containing pith. The RPI and LW were measured at each end of each piece according SPIB grading rules (SPIB 2014), and an average value for RPI and LW was calculated and recorded for each piece. The average MC of the lumber sample was 11.1% ± 1.7%.

Table 4. Summary of goodness of fit for specific gravity (SG), MOE, MOR, and bending strength (Fb) for No. 2 grade southern pine lumber by size.

	SG	MOE	MOR
2 × 4			
Normal	0.005	0.250[a]	0.005
Lognormal	0.089[a]	0.005	0.005
Weibull	0.010	0.010	0.022
2 × 6			
Normal	0.005	0.005	0.010
Lognormal	0.005	0.116[a]	0.005
Weibull	0.010	0.010	0.045
2 × 8			
Normal	0.005	0.250[a]	0.005
Lognormal	0.010	0.005	0.046
Weibull	0.010	0.010	0.010
2 × 10			
Normal	0.006	0.114[a]	0.060
Lognormal	0.184[a]	0.005	0.016
Weibull	0.010	0.010	0.143[a]

[a] Indicates the goodness-of-fit tests that failed to reject.

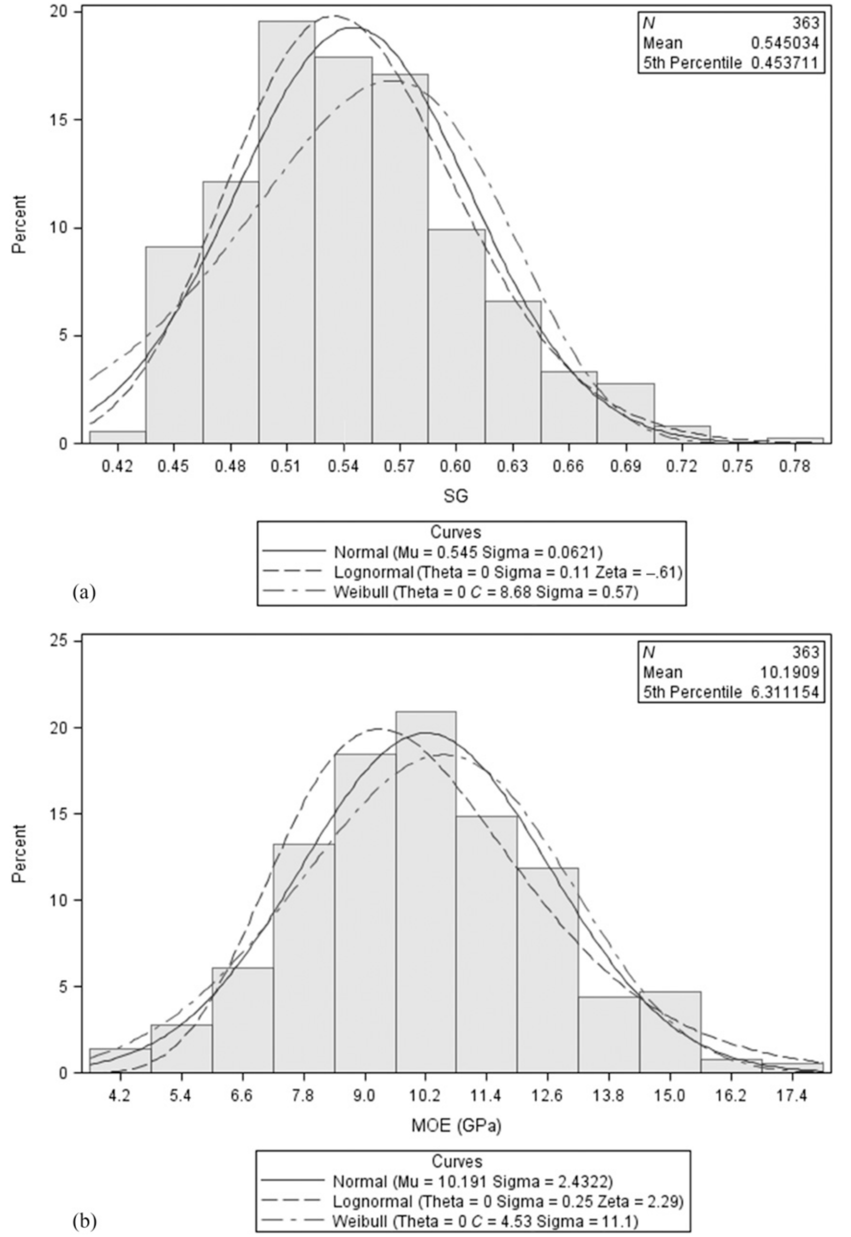
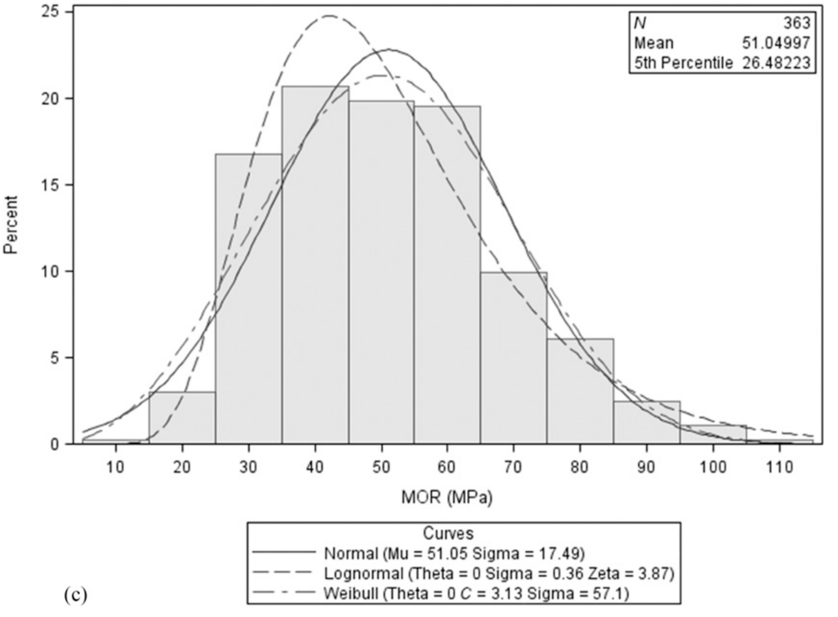


Figure 4. Distribution of (a) specific gravity (SG), (b) MOE, (c) and MOR in 2 × 4 of No. 2 southern pine lumber.

The edgewise bending test setup adhered to the specifications of ASTM D 198 (2014c) via four-point loading, and the span-to-depth ratio was 17 to 1. The tension face and the grade characteristics were randomly selected without respect to positioning (ASTM D 4761 2014b). MOE was determined using a deflectometer (at mid-span) synchronized with the load in the elastic range, and MOR was determined from the maximum load.

A series of adjustments were needed to compare the results with previous studies and to the design values which are published at 15% MC (Evans et al



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2001; ASTM D 1990 2014a). The F_b was calculated using the nonparametric 5th percentile at 75% confidence per ASTM D 2915 (ASTM 2014a).

Statistical Analysis

The statistical analyses and associated graphs were completed according to ASTM D 2915 (2014a) using SAS version 9.4 (SAS Institute 2013). The means, medians, and coefficients of variation were calculated for the RPI, LW, SG, MOE, and MOR. Means tests for RPI, LW, SG, MOE, and MOR at an $\alpha = 0.05$ level using PROC GLM function in SAS were performed for each lumber. The SG, MOE, and MOR data were tested for goodness of fit using the Cramer–von Mises test for normal, lognormal, and three-parameter Weibull distributions selected by PROC UNIVARIATE and the histogram option in SAS.

RESULTS AND DISCUSSION

Table 2 summarizes the basic characteristics of the specimens. More than one third (34.6%) of the specimens contained pith. The average RPI for the sample was 4.6; the average LW was nearly 50%. The 2 × 10 size had the highest number of specimens that contained pith (54.7%), and the 2 × 4 specimens had the least number of pieces that contained pith (21.5%). The results suggest that, at least in this sample, as lumber size (width) increases (2 × 4, 2 × 6, 2 × 8, and 2 × 10), the percentage of specimens that contained pith also increases (21.5%, 30.7%, 43.6%, and 54.7%, respectively). This finding may be due in part to breakdown optimization at sawmills. Larger dimension pieces tend to come from inner regions of the logs. All sizes met the requirements of RPI and LW for southern pine No. 2 lumber.

There was a statistically significant difference found in RPI ($p < 0.0001$) among sizes (Table 2). The 2 × 10 size was significantly lower in RPI (4.0), whereas the 2 × 4 had the highest RPI mean value (4.9). The data show that as width increases, RPI decreases. There was a statistically significant difference found in LW ($p = 0.0390$) among the sizes (Table 2). For LW, 2 × 8 specimens were statistically lower (42.5%), whereas 2 × 6 had the highest LW mean value (45.0%), see Table 2. According to SPIB rules (2014), No. 2 grade should have approximately

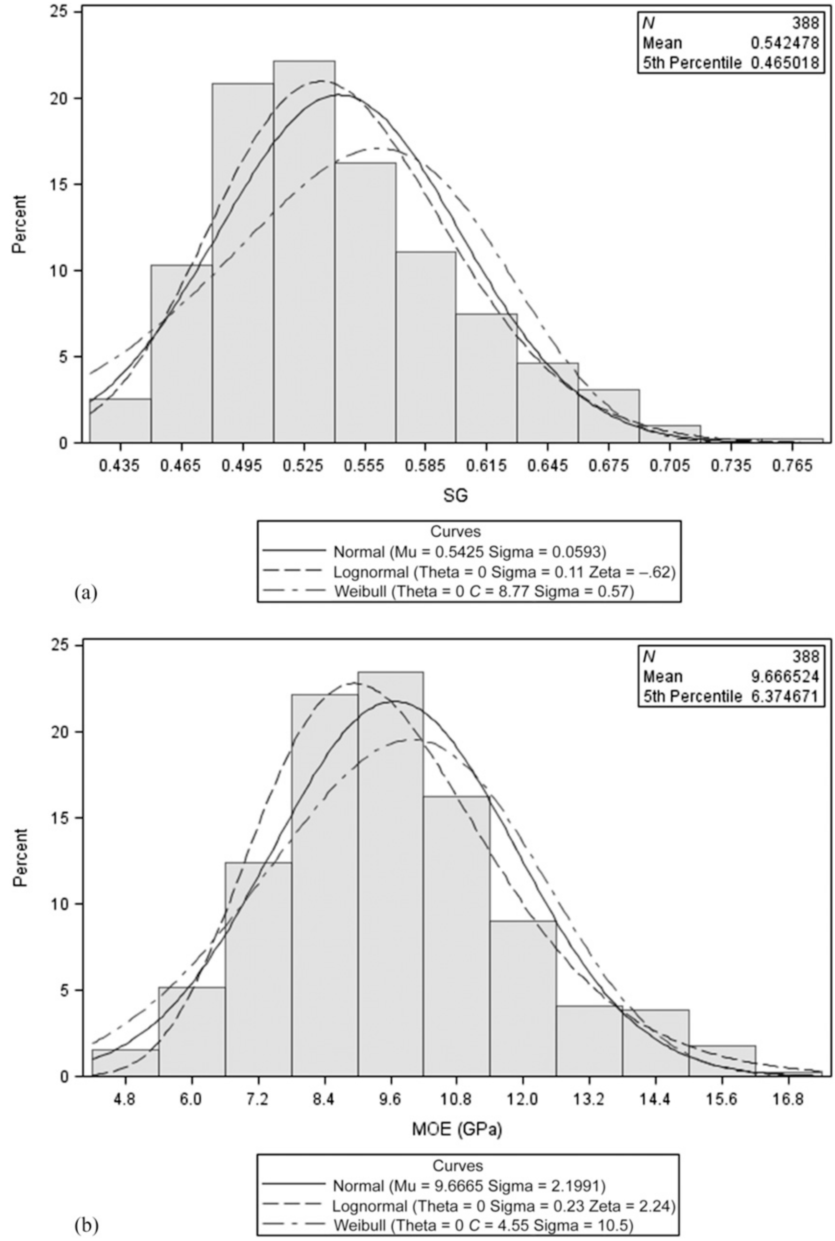

Figure 5. Distribution of (a) specific gravity (SG), (b) MOE, (c) and MOR in 2 × 6 of No. 2 southern pine lumber.

four or more annual RPI on either end of the piece, or contain at least an average of 1/3 LW (SPIB 2014). All of the specimens met current grading requirements of RPI and LW No. 2 grade. The boxplot for LW and RPI vs size are shown in Fig 2.

The summary statistics for SG, MOE, and MOR are presented in Table 3. The SG mean value for the sample was 0.54. There was no statistically significant difference found in SG ($p = 0.5226$) among sizes (Table 3), with only a slight variation in the mean by size. The mean SG for all

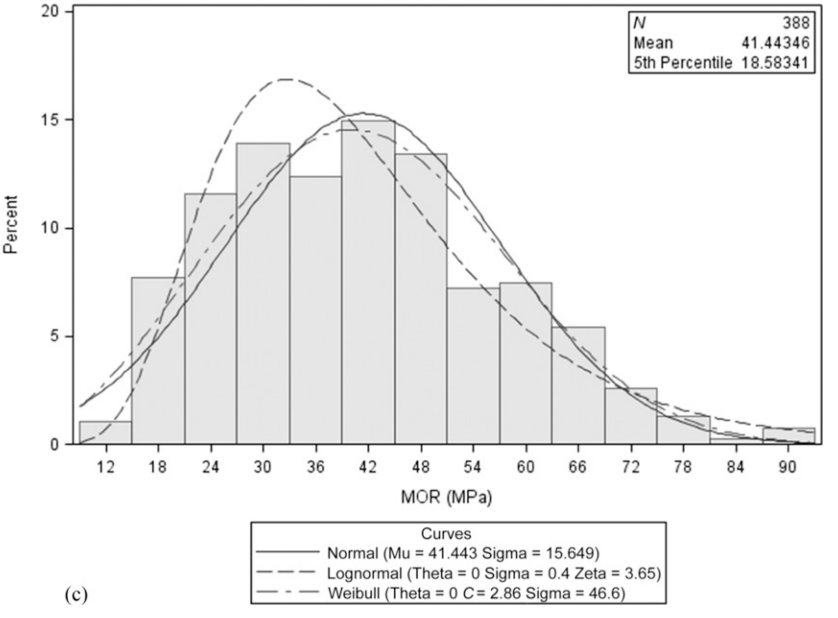

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Figure 5. (Continued)

specimens had characteristics of mature wood described by Zobel et al (1972). Comparing the results with a previous study on No. 2 grade, southern pine 2 × 4 lumber conducted by Dahlen et al (2014b), the sample had a greater SG value (0.48). The sample also had a higher SG value (0.51) than what is referred to in the Wood Handbook (FPL 2010) for loblolly pine when adjusted to 15% MC. The boxplot for SG vs size is shown in Fig 3(a).

The MOE mean value was 10.1 GPa, and it ranged from 9.7 to 10.5 GPa. The MOR mean value was 41.7 MPa, with a range from 39.2 to 49.7 MPa. The F_b values for 2 × 4, 2 × 6, 2 × 8, and 2 × 10 lumber were 11.2, 9.2, 8.1, and 7.1 MPa, respectively. There were significant differences found in MOE ($p < 0.0001$) and MOR ($p < 0.0001$) when comparing the sample by size. The boxplot for MOE and MOR vs size are shown in Fig 3(b) and (c).

Table 4 summarizes the goodness-of-fit test for SG, MOE, and MOR among sizes. For the 2 × 4 size, the goodness-of-fit tests failed to reject the lognormal distribution for SG ($p = 0.089$, Fig 4(a)) and MOE ($p > 0.250$, Fig 4[b]) data. However, none of the distributions (normal, $p < 0.005$; lognormal, $p = 0.006$; and three-parameter Weibull, $p = 0.022$) appeared to adequately fit the MOR data (Fig 4[c]).

For the 2 × 6 size, the normal distribution adequately fits the SG data ($p = 0.184$), whereas lognormal distribution adequately fits the MOE data ($p = 0.116$, Fig 5[b]). However, all the distributions tested (normal, lognormal, and three-parameter Weibull) failed to reject the MOR data ($p < 0.010$; $p < 0.010$; $p < 0.045$, respectively, Fig 5[c]).

For the 2 × 8 size, the goodness-of-fit tests failed to reject normal distribution for MOE data ($p > 0.250$, Fig 6[b]). All distributions tested (normal, lognormal, and three-parameter Weibull) failed to reject the SG data ($p < 0.005$; $p < 0.010$; $p < 0.010$, respectively, Fig 6[a]) and MOR data ($p < 0.005$; $p = 0.046$; $p < 0.010$, respectively, Fig 6[c]).

For the 2 × 10 size, the goodness-of-fit tests failed to reject the lognormal distribution for SG data ($p > 0.184$, Fig 7[a]). The normal

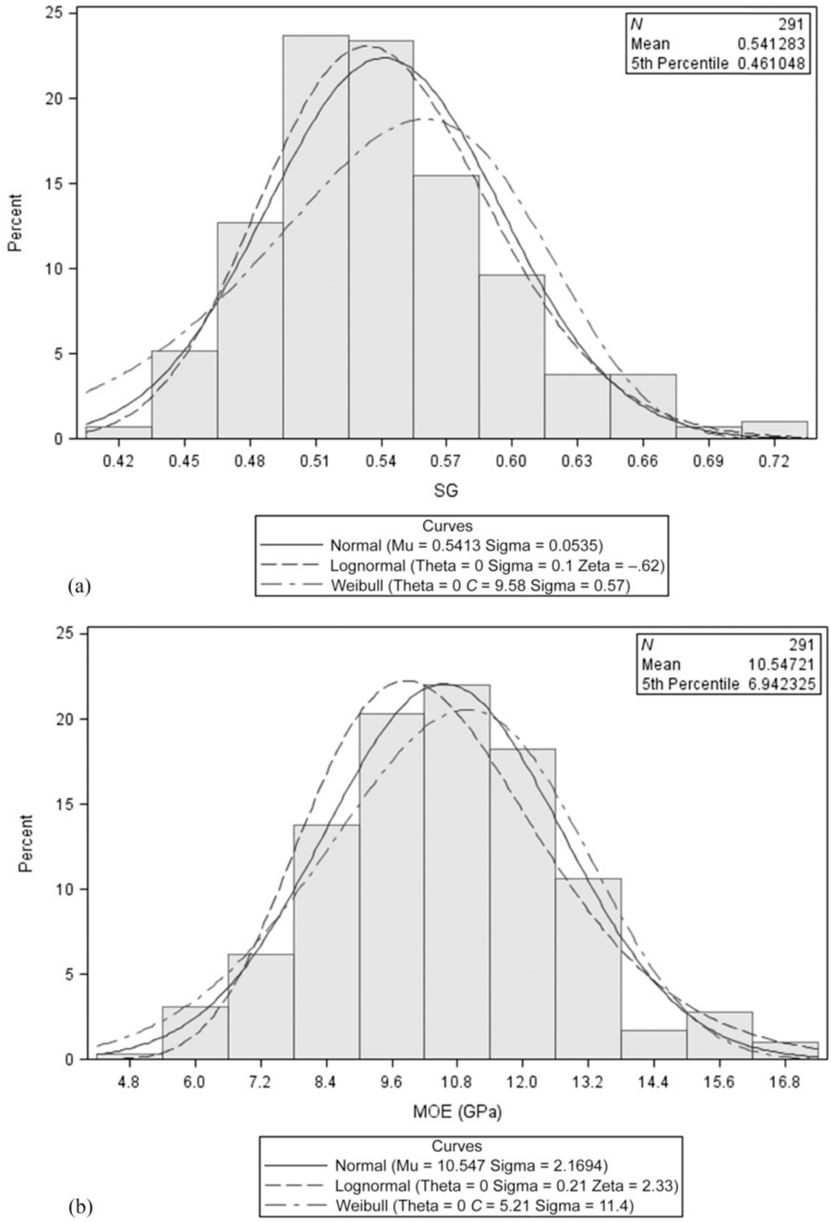

Figure 6. Distribution of (a) specific gravity (SG), (b) MOE, (c) and MOR in 2 × 8 of No. 2 southern pine lumber.

distribution adequately fit the MOE data ($p = 0.114$, Fig 7[b]). The Weibull distribution most adequately fit the MOR data ($p = 0.143$, Fig 7[c]) among all distributions tested.

Galligan et al (1986) reported that the significance of differences in fit depends somewhat on the intended use of the information. In this type of data set, one practical concern is the comparison of 5th percentile. The authors concluded that no single distributional form fits all mechanical properties equally well, but the Weibull distribution dominated the selections using this exploratory "best-fit" procedure. However, Dahlen

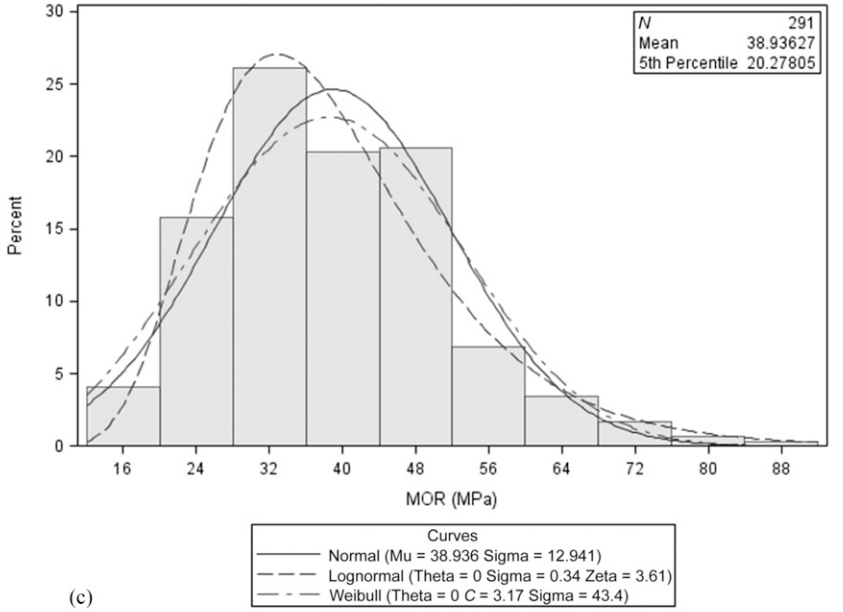

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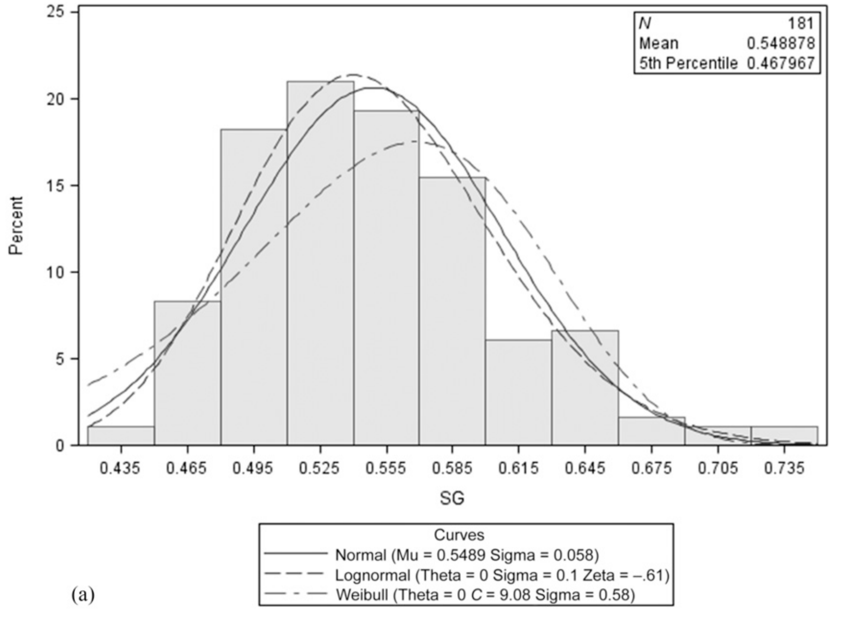
Figure 6. (Continued)

et al (2012a) reported that a lognormal distribution was a better fit for MOE data, whereas normal and lognormal distributions better fit the MOR data than Weibull for southern pine No. 2 2 × 4 data. In another study using southern pine No. 2 2 × 4 samples, the lognormal distribution was the best fit for SG, whereas gamma was the best fitting distribution for MOE and MOR data (Dahlen et al 2014c).

The MOE mean value of the 2 × 4 and 2 × 6 lumber exceeded the new 9.7 GPa design value (ALSC 2013); the 2 × 8 and 2 × 10 MOE mean values were comparable with the previous 11.0 GPa mean design value (AFPA 2005) after rounding according to ASTM D 1990 (2014d) and were greater than the new published design value. The overall mean MOE (11.0 GPa) was slightly lower than the mean reported in a previously reported study dealing with southern pine 2 × 4 No. 2 grade (Dahlen et al 2014c). This value was also slightly lower than the MOE mean value (10.7 GPa) reported in a prior study which used wide dimensional (2 × 6, 2 × 8, 2 × 10, and 2 × 12) southern pine No. 2 grade lumber (Dahlen et al 2014b). The overall MOR was 41.7 MPa and was slightly higher than the values reported by (Dahlen et al 2014b) (40.7 MPa) for 2 × 6, 2 × 8, 2 × 10, and 2 × 12 southern pine No. 2 grade and lower than the MOR value (48.3 MPa) determined in a prior test of southern pine 2 × 4 No. 2 grade (Dahlen et al 2014c).

The F_b values were calculated using the nonparametric 5th percentile. The results showed that F_b decreased as lumber size increased. The F_b values found herein for 2 × 4 and 2 × 6 (10.3 and 8.6 MPa, respectively) exceeded the previous design value (AFPA 2005), whereas 2 × 8 and 2 × 10 (8.3 and 7.2 MPa, respectively) met the previous design value after rounding according to ASTM D 1990 (2014d) published by ALSC (2013).

Different results have been reported in early 2000s. Biblis (2006) found that 40% of the 2 × 4 No. 2 lumber and 56.7% of the 2 × 6 No. 2 lumber tested from a 19-yr-old plantation of loblolly pine did not meet the required F_b value. For E, 83% of the 2 × 4 and 97% of the 2 × 6 did not meet the required E value. These previous studies indicated that plantation wood,



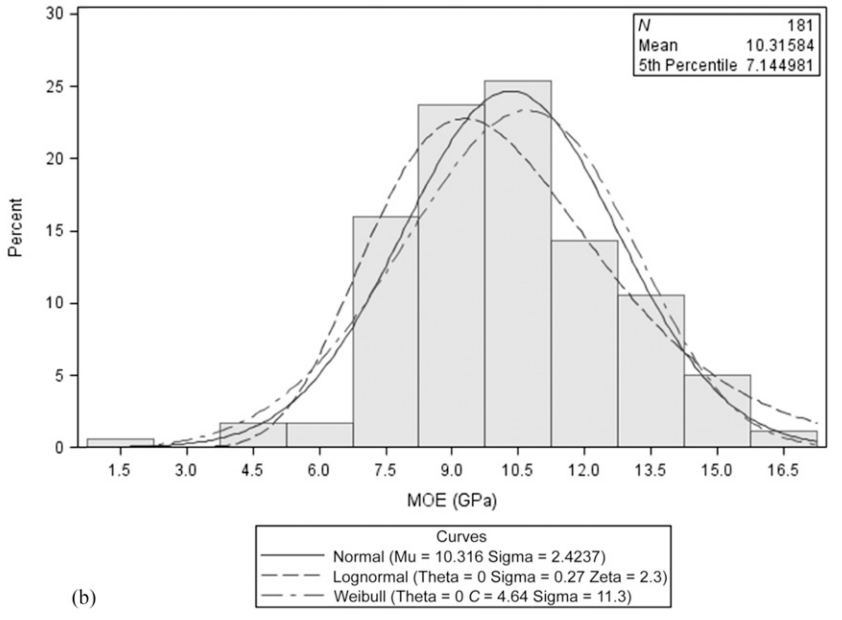
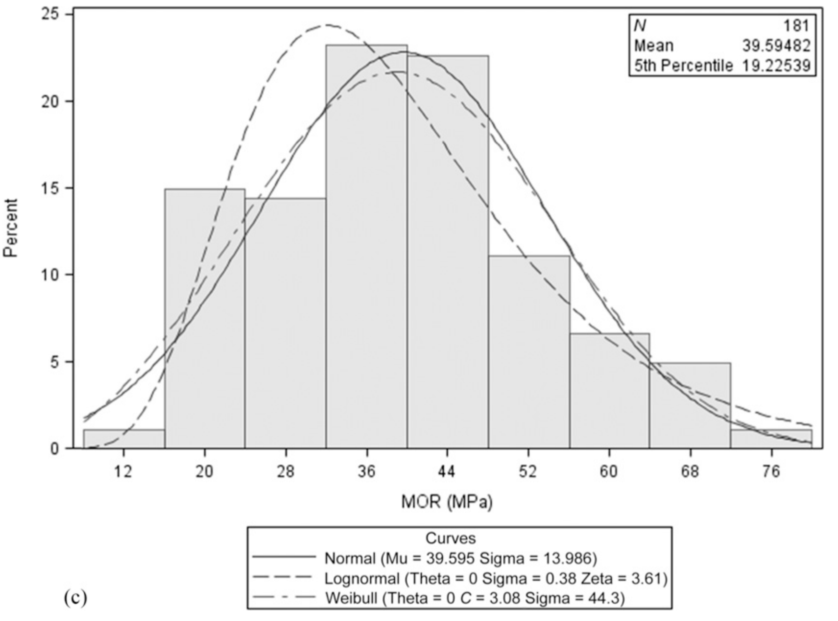


Figure 7. Distribution of (a) specific gravity (SG), (b) MOE, (c) and MOR in 2 × 10 of No. 2 southern pine lumber.

which accounts for much of the lumber production over the past several decades, is inherently weaker and less stiff. Other studies on plantation wood confirm this low strength (Biblis and Carino 1999; Biblis and Meldahl 2006).

The results developed therein suggest that the current timber source used as the production-weighted sample in this study might have had a relatively higher quality than what was used to produce lumber that was sampled in prior tests



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of No. 2 grade southern pine in 2010 (SPIB 2012) and higher than the material from plantation reported by other authors. These results show that the continued monitoring of the timber source is recommended, and indicate that the mechanical properties of the contemporary resource may have largely recovered as compared with the specimens investigated during the 2010 housing crisis and economic recession.

CONCLUSIONS

The results present an overall characterization of commercially grown and produced southern pine No. 2 grade, 2 × 4, 2 × 6, 2 × 8, and 2 × 10 lumber sampled from production-weighted growing regions. Overall, 34.6% of the pieces contained pith, and as the width increased, the number of pieces that contained pith also increased. The overall RPI and LW mean values were 4.6 and 43.8%, respectively. The sample met the requirements for RPI and LW for No. 2 grade southern pine lumber (SPIB 2014).

The SG mean value was 0.54, and there were no statistically significant differences among sizes. The MOE for 2 × 4 and 2 × 6 specimens exceeded the new (published) design value, whereas 2 × 8 and 2 × 10 specimens met the previous (SPIB 2012 and prior) design value. The F_b for all sizes tested met the previous design value. The results yielded in this research suggest that the timber source used herein likely had a higher quality than that which was used to produce the lumber sampled in or around 2010 during the time of the economic recession of approximately 2008-2010.

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