Effect of Growth Rings per Inch and Density on Compression Parallel to Grain in Southern Pine Lumber

Nathan E. Irby, Frederico J. N. França,* H. Michael Barnes, R. Dan Seale, and Rubin Shmulsky

The objective of this study was to evaluate the relationship of growth characteristics to compression properties from commercially available southern pine lumber. The in-grade No. 2 southern pine lumber was collected from retail stores across the Southeast United States. For this specific project, 797 samples of 2 × 8 and 2 × 10 boards were examined. The samples were subjected to static bending following ASTM D 198 to determine mechanical properties. The 2 × 8 samples averaged 4.78 growth rings per inch (RPI) and the 2 × 10s averaged 3.95. Average density (ρ) was 477 kg·m^{-3} in the 2 × 8 and 487 kg·m^{-3} for the 2 × 10 specimens. From small clear samples from the parent boards, compression parallel to grain averaged from 43.78 MPa for the 2 × 8 to 46.77 MPa for the 2 × 10. Correlations were run to test significance among growth rings per inch and compressions parallel to grain, across both sizes: 2 × 8 and 2 × 10. Slight significance was found in those correlations and increased in measure from 2 × 8 to 2 × 10. The segmentation of RPI into three distinct groups helped strengthen the findings of effect on compression parallel to grain. Moreover, the addition of density as another test variable further strengthened in relationship per those RPI categorizations. Statistically significant findings for density per RPI segments, R^2 values: for 2 × 8 equal 0.31 (3 or less RPI) to 0.60 (more than 5 RPI). For the 2 × 10 lumber per the same segments, R^2 values: 0.39, 0.46 and 0.25, respectively. The results suggest ρ is a better predictor than RPI alone for compression parallel to grain values.

Keywords: Wood mechanics; Lumber; Density; Growth rings

*Contact information: Department of Sustainable Bioproducts, Mississippi State University, P.O. Box 9820, Starkville, MS 39759 USA; *Corresponding author: fn90@msstate.edu*

INTRODUCTION

Southern pine comprises a large portion of the Southern United States forest. From the Atlantic coast back along the Gulf of Mexico to Texas, southern pine species loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), slash (*P. elliottii* Engelm.), and longleaf (*P. palustris* Mill.), grow prolifically in natural and artificially generated stands. Historically, mixed oak/gum/pine natural regeneration dominated the re-establishment of recently harvested stands; however, more and more artificially replanted softwood "plantations" have garnered more of the recent regeneration norm (Pawson *et al.* 2013). Wood anatomical features have been altered in this new forest type, as it affects tree growth (Taylor and Franklin 2011).

Visual characteristics of pine strength are a fundamental means for material evaluation in usage classification (Madsen 1976). Number of rings per inch, knots, bark seams, wane, shake, and other visual indicators help material graders place southern pine wood into appropriate commodities and subsequent grades (Doyle and Markwardt 1966).

Growth rings in wood not only indicates the age of the tree, but it also contributes to wood strength. The wood growth ring itself is composed of two distinct regions: earlywood and latewood. Earlywood rings presents lighter color due to its anatomical structure, whereas latewood cell walls are thicker, denser, and contain more extractive content than the lighter colored earlywood (Senft *et al.* 1985). Growth ring regional composition can influence overall wood properties (Brashaw *et al.* 2009), especially in relation to strength and stiffness of latewood and earlywood (Biblis *et al.* 1993). The overall number of growth rings is also a key consideration in wood strength. Many visual grading specifications include a "rings per inch" designation. The general operating premise is the more growth rings, the higher the strength.

Many institutions have researched wood mechanical properties for wood building construction (Butler *et al.* 2016). Southern pine lumber usage is dictated by design characteristics such as dimensions, grade, in-service load requirement, and span (Frese 2008). To determine these "design values", small clear samples have been evaluated and tabulated as industry standards rather than testing full-size lumber samples.

Most studies on mechanical properties of wood have focused on two core properties, modulus of elasticity (MOE) and modulus of rupture (MOR) (Dahlen *et al.* 2012, 2014, 2018; Yang *et al.* 2015a, 2017b; França *et al.* 2018), and only few studies have evaluated the compression strength parallel to the grain (the $C_{\parallel}$ value) of wood. Riyanto and Gupta (1995) studied the effect of ring angle on shear strength parallel to the grain of small and clear Douglas-fir samples; Gong and Smith (2000) synthesized information on the failure behavior of softwood submitted to compression parallel to grain. Gindl (2002) evaluated the variation in lignin content in the growth rings and its influence on $C_{\parallel}$ of Norway spruce. The objectives of this project were to: (1) characterize growth rings per inch (RPI), density (ρ) and compression parallel to grain of No. 2 2 × 8 and 2 × 10 southern pine lumber; and (2) evaluate the effect of RPI and ρ on compression parallel to grain in.

EXPERIMENTAL

Materials

This study used No. 2 grade southern pine lumber obtained from retail stores across the southern pine region. Two dimensional sizes were selected, 2 × 8 and 2 × 10. Table 1 summarizes sample size and dimensions of specimens. The data collected in this study included density (ρ), moisture content (MC), rings per inch (RPI), and compression parallel to the grain ($C_{\parallel}$). All specimens were re-evaluated by certified graders from Southern Pine Inspection Bureau (SPIB) or Timber Products Inspection (TPI) to confirm each board as No. 2 grade (as defined by the current southern pine grading rules). All samples had an MC average around 12%.

Table 1. Summary of Sample Size and Dimensions of No. 2 2 × 8 and 2 × 10 Southern Pine Lumber Samples

Nominal Lumber Size (in x in)	n	Width (mm)	Depth (mm)	Length (m)
2 × 8	142	38	184	3.66
	199			4.27
	131			4.88
2 × 10	199	38	235	4.27
	103			4.88

Methods

The measurements of number of rings per inch (RPI) were done by counting the rings in each sample on both ends of the specimens following the procedures from SPIB grading rules (SPIB 2014), then the number of rings were divided by the thickness or the width depending on the grain orientation of the piece (radial or tangential). Actual dimensions (width x thickness) were measured to the nearest 0.01 mm.

Density was determined according to ASTM D 2395 (ASTM 2017). Mass was measured to the nearest 0.01 g, and ρ was calculated according to Eq. 1. The MC was calculated based on mass difference before and after oven dried at 103 ± 2 °C following ASTM D 143 (ASTM 2014),

$$\rho = \frac{m_M}{V_M} \tag{1}$$

where ρ is density (kg · m^{-3}); m_M is mass of specimens at 12% MC, and V_M is volume of specimens at moisture content 12% MC.

Full-size 2 x 8 and 2 x 10 lumber was tested in static bending on an Instron universal testing machine using a four-point fixture and span-to-depth ratio of 17-to-1 in accordance with ASTM D 198 (ASTM 2015). After the bending test was conducted on the full-sized specimens, small clear samples were cut from the remnants, and $C_{\parallel}$ was evaluated according to the ASTM D 143 standard (ASTM 2014). Due to the thickness of the samples (shown in previous Table), the “secondary method” outlined in §8.1 in the standard was chosen. Test specimens measured 2.54 × 2.54 × 10.16 cm (1 × 1 × 4 in). The rate for the load applied was 0.003 in/in (0.00762 cm/cm) of nominal specimen length/min. Figure 1 shows the set up used for the $C_{\parallel}$ test.

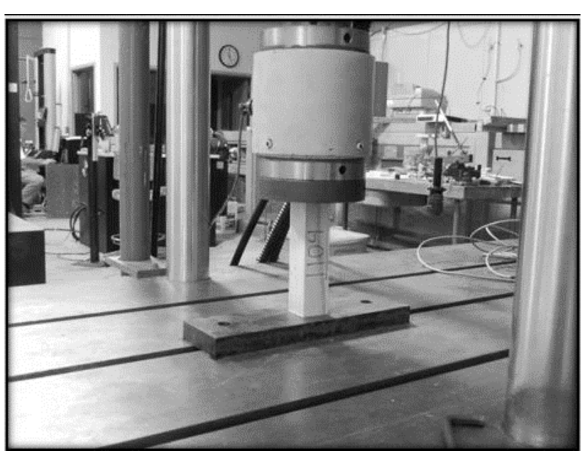


Fig. 1. Sample in testing apparatus for compression parallel to grain evaluation

Statistical analysis

SPSS version 25 (2018) statistical analysis software using Pearson's correlation was used to test $C_{\|}$ and RPI for significance ($\alpha = 0.05$), with subsequent addition of ρ. A linear regression fit line was added to the scatter plots for evaluation of any relationship. Lastly, data was segmented in various groups: RPI (< 3 RPI; 3 ≤ 5 RPI; and > 5 RPI) and ρ (ρ < 0.4; ρ 0.4 ≤ 0.5; and ρ > 0.5) to test if any significance arose among more defined groupings.

Single variable linear regression analyses ($\alpha = 0.05$) were built for each cross section lumber group to correlate the segmentation groups outputs to compression parallel to the grain values. The linear regressions were conducted given the independent variables (*x*, which can be represented by RPI groups, and density) and the dependent variable ($C_{\|}$). The coefficient of determination (R^2), which measures the strength of the relationships between variables, was the main focus.

The mathematical regression models between the independent variables and $C_{\|}$ were assumed to be linear and of the following form:

$$C_{\|} = \text{slope x (independent variable)} + \text{intercept} + \text{error} \qquad (2)$$

RESULTS AND DISCUSSION

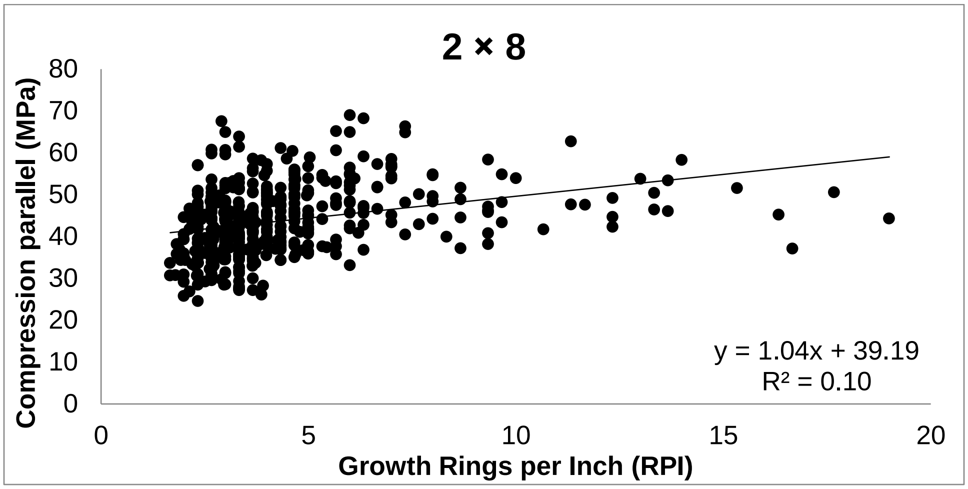
Table 2 shows the results for RPI, ρ, and $C_{\|}$ for 2 × 8 and 2 × 10 specimens. Figure 2 shows the relationship between $C_{\|}$ and RPI of small clear samples obtained from 2 × 8 and 2 × 10 No. 2 southern pine lumber. For 2 × 8 and 2 × 10 lumber sizes exhibited similar densities (477 and 487 kg·m^{-3} respectively). These values are higher than those found by Kretschmann and Brendtsen (1992) studying 2 × 4 from fast-grown southern pine (ranging between 390 and 490 kg·m^{-3}). The 2 × 8 lumber size exhibited slightly higher variation in RPI compared to 2 × 10. The average value for compression parallel was higher in 2 × 10 when compared to 2 × 8 lumber size.

Table 2. Overall Results for RPI, ρ, and $C_{\|}$ of No. 2 2 × 8 and 2 × 10 Southern Pine Lumber Samples

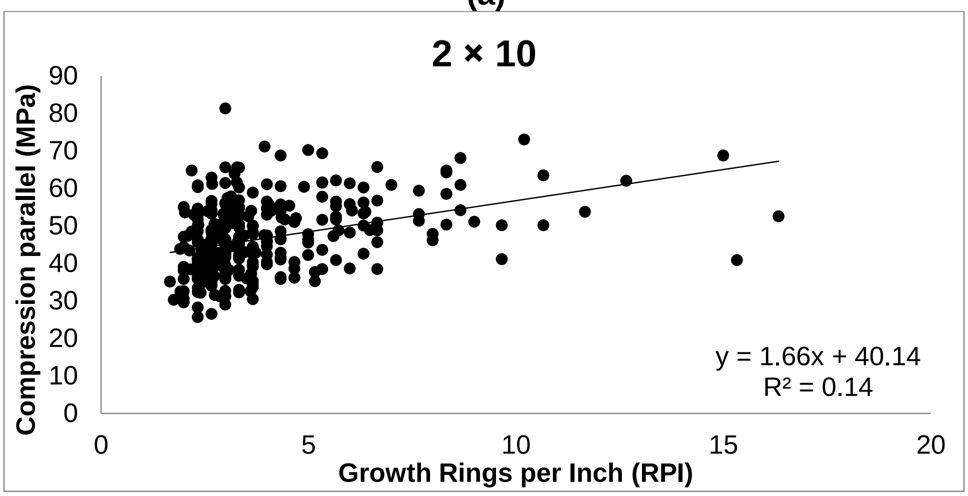
Lumber Size (in x in)	n		RPI	ρ^* (kg·m^{-3})	$C_{\|}$ (MPa)
2 × 8	472	Average	4.78	477	43.78
		Min	1.70	343	24.54
		Max	19.00	701	68.99
		COV	57.47	12.72	18.98
2 × 10	302	Average	3.95	487	46.77
		Min	1.67	352	25.59
		Max	16.33	657	81.24
		COV	55.09	13.34	20.72

$^*\rho$ = density (kg · m^{-3}).

Although the data appeared to be widely varying, the conglomeration of data points was significant for 2 × 8 with an R^2 of 0.10 (Fig. 2a) and for 2 × 10 with an R^2 of 0.14) both at $p = 0.05$ level (Fig. 2b).



(a)



(b)

Fig. 2. Correlation between compression parallel to grain and growth rings per inch for: (a) 2 × 8; and (b) 2 × 10 No. 2 southern pine lumber

As the previous correlations indicated, only slightly casual relationships in RPI to compression parallel to grain values, further refinement of the data was needed to discern the relationship. A data segmentation approach categorized the growth rings per inch data into three distinct groups for further analysis. Those groups consisted of: 1) <3 RPI; 2) 3≤5 RPI; and 3) >5 RPI. Table 3 shows the data breakout per RPI groups and the test variables for the 2 × 8 and 2 × 10 samples, plus statistical output.

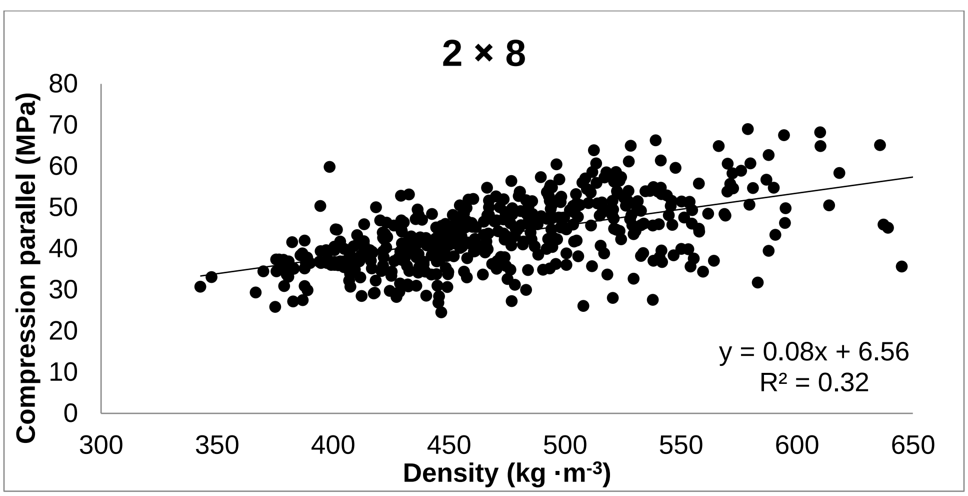
Table 3. Growth Rings per Inch Categories, Compression Parallel to Grain Averages per RPI group, Coefficients of Determination for 2 × 8 and 2 × 10 Lumber, and p-values.

Growth Ring Category	*n*	$C_{\parallel}$ (MPa)	Coefficient of Correlation	R^2	*p*-value
2 x 8					
< 3 RPI	160	40.82	0.281	0.079	$<0.001^{*}$
3 ≤ 5 RPI	214	43.16	0.241	0.058	$<0.001^{*}$
> 5 RPI	98	49.51	0.045	0.002	0.650^{ns}
2 x 10					
< 3 RPI	141	43.28	0.138	0.019	0.103^{ns}
3 ≤ 5 RPI	102	47.82	0.032	0.001	0.796^{ns}
> 5 RPI	59	52.95	0.176	0.031	0.181^{ns}

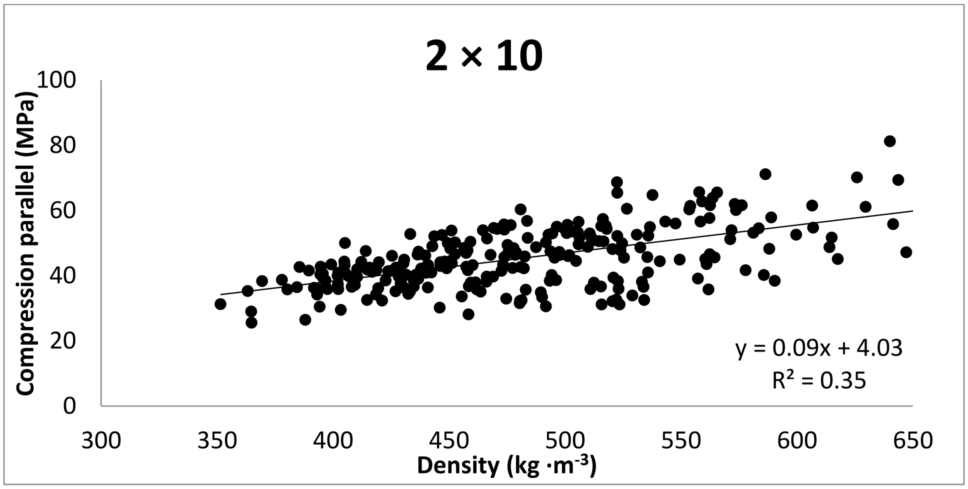
*significant at α=0.05; ^{ns} not significant

The correlations for 2 × 8 lumber showed positive correlations for the less than 3 RPI group and the three to less than or equal to five RPI group. None of the groups for 2 × 10 lumber showed a significant relationship between RPI and compression parallel to grain. As correlations are often sensitive to outliers, the data could be scrubbed further. For instance, in the 2 × 10 dataset, the highest RPI was 16, with a few in the 15 RPI range, pulling the data.

Density was then used as an independent variable to see if a stronger relationship was present. The initial test for compression parallel to grain as the dependent variable and using density as the independent was done across all data for each lumber size, 2 × 8 (Fig. 3a) and 2 × 10 (Fig. 3b). When density was used as an independent variable, R^2 values increased to 0.32 for 2 × 8 lumber and 0.35 for 2 × 10 lumber.



(a)



(b)

Fig. 3. Correlation between compression parallel to grain and density for: (a) 2 × 8; and (b) 2 × 10 No. 2 southern pine lumber

Similar to Table 3 for the growth rings per inch comparison with compression parallel to grain, density was also analyzed in the same fashion. Table 4 illustrates the relationship between density and $C_{\parallel}$ for 2 × 8 and 2 × 10 lumber sizes.

Table 4. Density and $C_{\parallel}$ Correlation Coefficients and R^2 values for 2 × 8 and 2 × 10 Lumber

Independent Variable	*n*	$C_{\parallel}$ (MPa)	Coefficient of Correlation	R^2	*p*-value
2 x 8					
Density (kg·m^{-3})	472	43.78	0.57	0.32	<0.001*
2 x 10					
Density (kg·m^{-3})	302	46.77	0.59	0.35	<0.001*

*significant at α=0.05;

Further tests were done to understand better the density variation in 2 × 8 and 2 × 10 lumber sizes. Table 5 shows the attempt to discern any mean differences between the two lumber sizes. The t test reveals significant difference between the two means at the 0.05 level (*p*-value < 0.001).

Table 5. Two Sample *t* Test for Compression Parallel to Grain of Small Clear Samples Taken from Parent 2 × 8 and 2 × 10 No. 2 Southern Pine Lumber

Lumber Size	*n*	$C_{\parallel}$ mean (MPa)	COV	t test	*p*-value
2 x 8	472	43.74	14.70	4.52	< 0.001*
2 x 10	302	46.70	20.77		

*significant at α=0.05;

The next analysis evaluated density as an independent variable but used the segmentations of the data based on RPI groups: less than 3 RPI, 3 ≤ 5 RPI, and more than 5 RPI. Figure 4 a, b, and c show those values for 2 × 8 lumber across ρ/RPI segments, R^2 = 0.31, 0.19, 0.60, respectively.

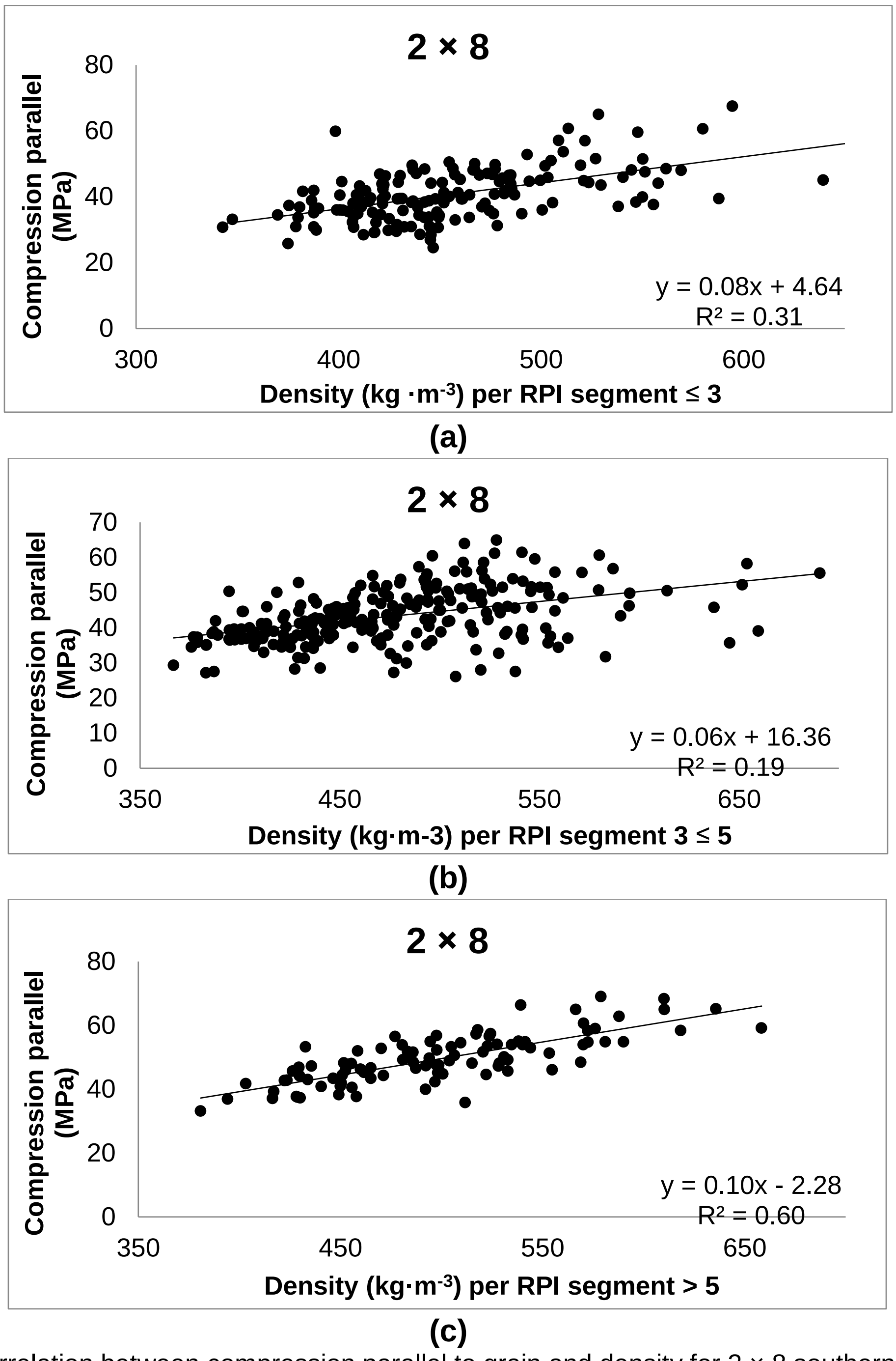


Fig. 4. Correlation between compression parallel to grain and density for 2 × 8 southern pine lumber derived from growth rings per inch segmentation of: (a) 3 RPI; (b) 3 ≤ 5 RPI; and (c) more than 5 RPI

Subsequent analysis of density and the RPI segments for the 2 × 10 data was also evaluated. Figure 5 a, b, and c show those values for 2 × 10 lumber across ρ/RPI segments, R^2 = 0.29, 0.39, 0.20, respectively.

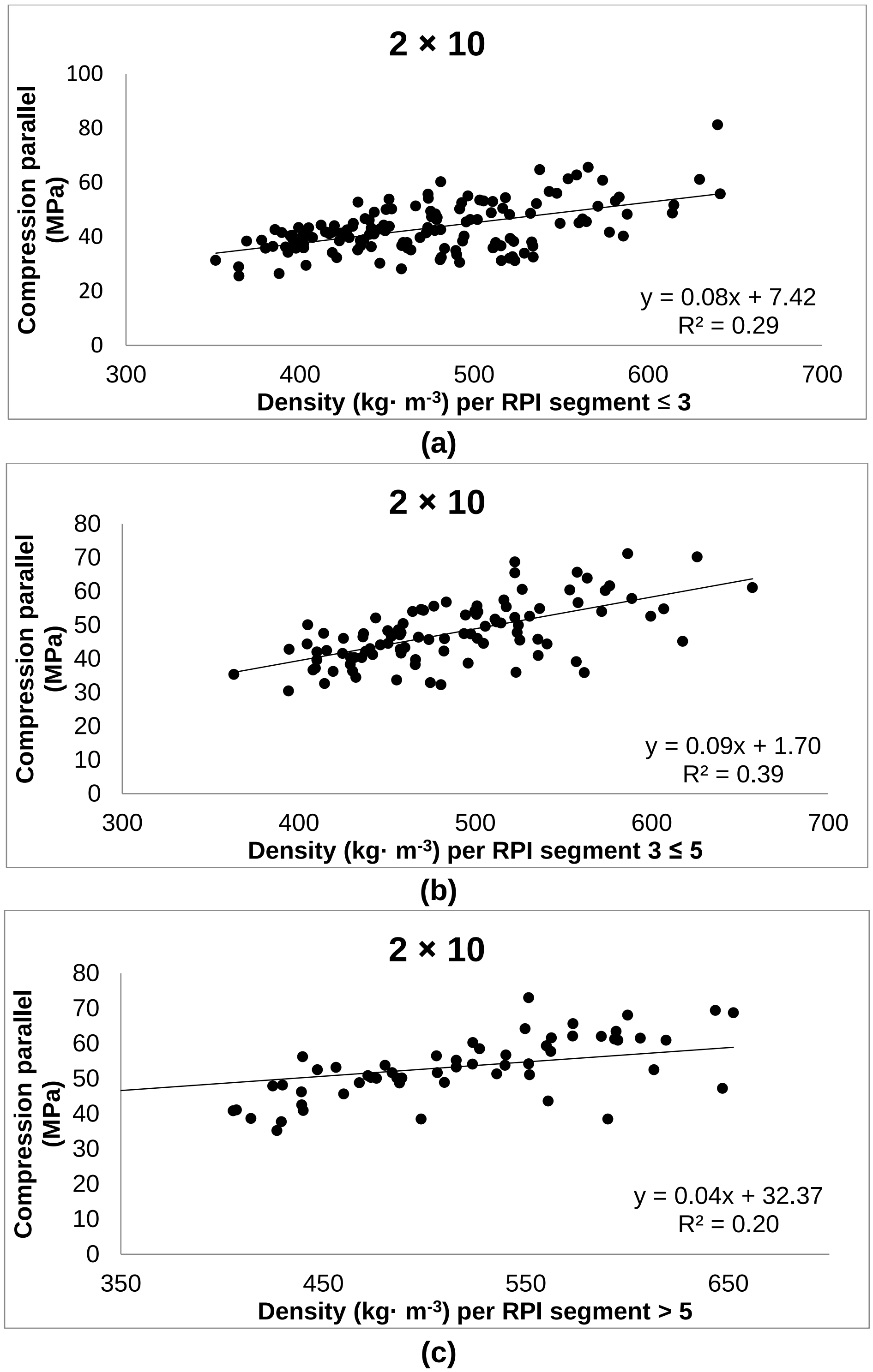
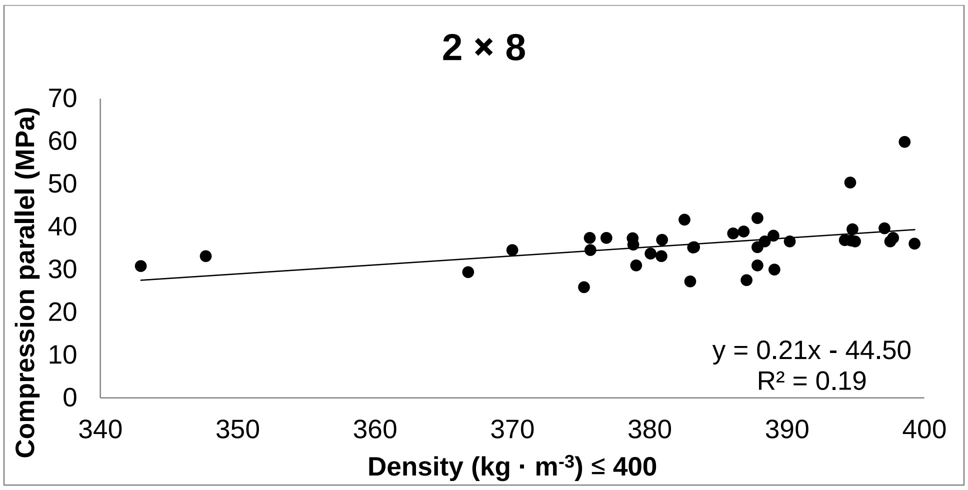


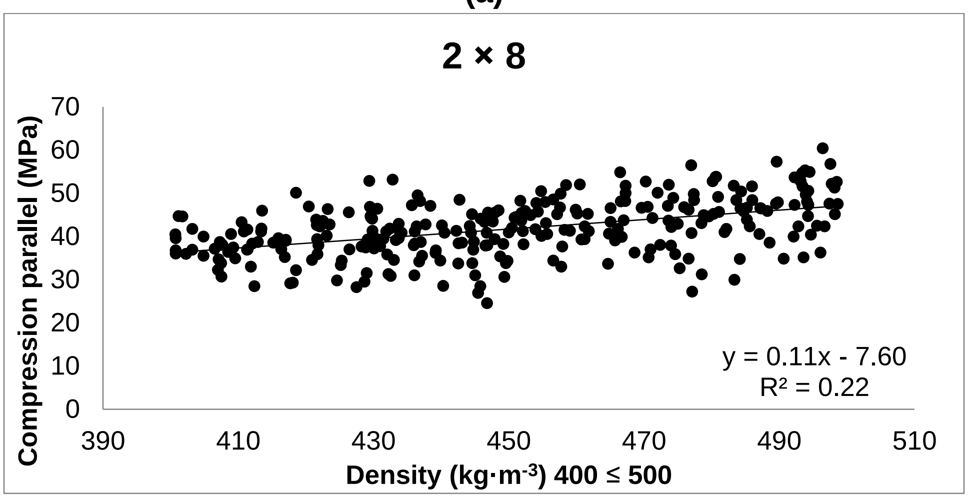
Fig. 5. Correlation between compression parallel to grain and density for 2 × 10 southern pine lumber derived from growth rings per inch segmentation of: (a) 3 RPI; (b) 3 ≤ 5 RPI; and (c) more than 5 RPI

Lumber pieces with more than 5 RPI exhibited higher R^2 values in both lumber sizes. This occurs due to the higher amount of mature wood in the pieces and a more homogenous wood material. Kretschmann and Bendtsen (1992) found lower number of RPI (between 3.7 and 4.4) compared to this study. The material used by the authors had a greater amount of juvenile wood.

The third analysis evaluated segmentations of the density data in increments of < 0.4, 0.4 ≤ 0.5, and ≥0.5. Figure 6 a, b, and c show those relationships for 2 × 8 lumber. R^2 = 0.19, 0.22, and 0.03 respectively.



(a)



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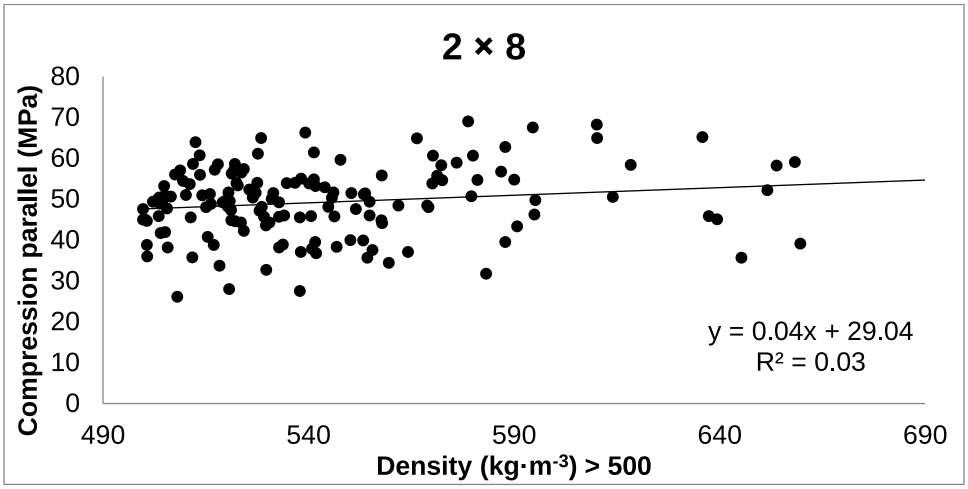
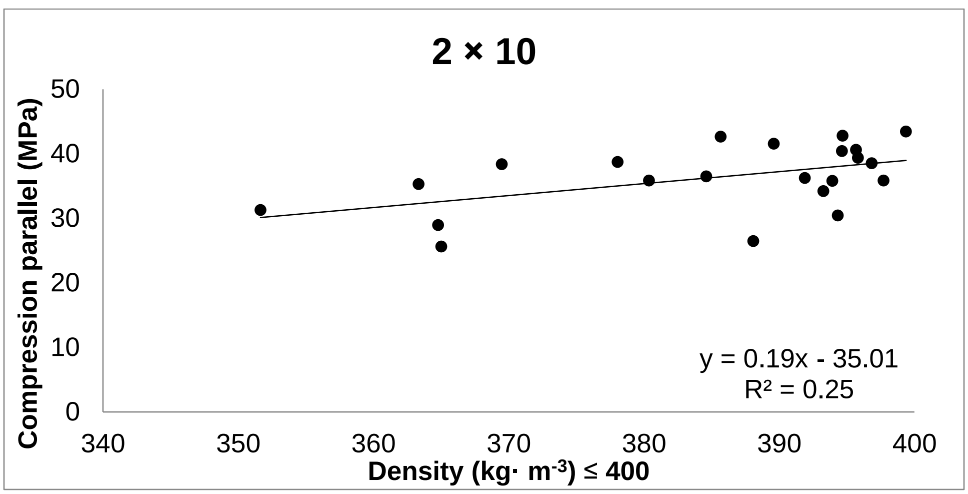


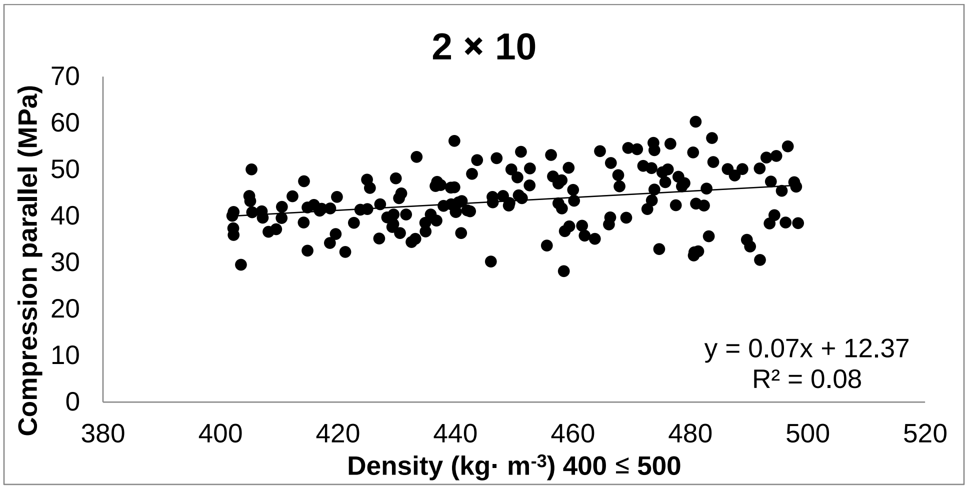
(c)

Fig. 6. Correlation between compression parallel to grain and density segmentation of: (a) less than 0.4; (b) 0.4 ≤ 0.5, and (c) more than 0.5 (ρ) for 2 × 8 southern pine lumber

Figures 7 a, b, and c show those relationships for 2 × 10 lumber from smallest density segment less than 0.4 to more than 0.5 density group: R^2 = 0.25, 0.08, and 0.46 respectively.



(a)



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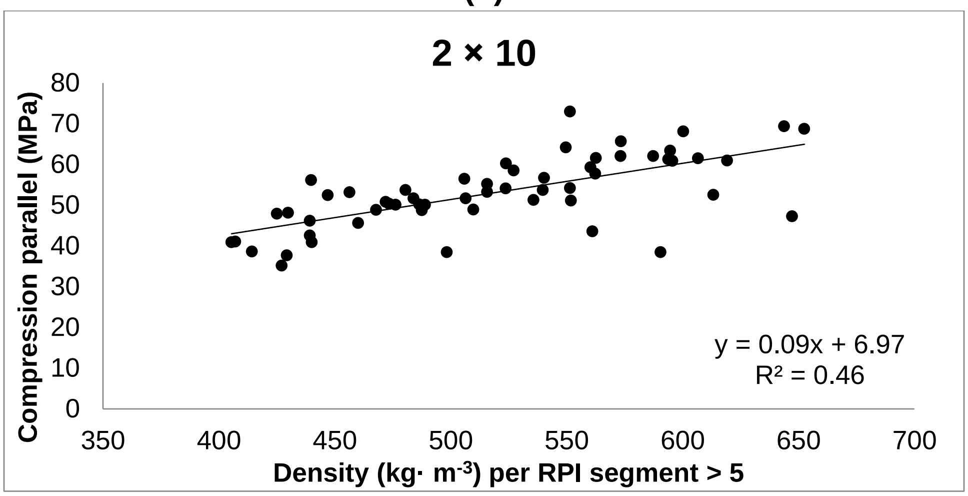

(c)

Fig. 7. Correlation between compression parallel to grain and density segmentation of: (a) less than 0.4; (b) 0.4 ≤ 0.5, and (c) more than 0.5 (ρ) for 2 × 10 southern pine lumber

To summarize the findings, Table 6 shows R^2, standard error and *p*-value for each test across all data and segmentations. The full list of independent variables is listed in the first column. Lumber sizes are represented by rows. Slope, intercept, R^2, standard error of estimate and *p*-value are for compression parallel test and the various independent variables. For 2 × 10 lumber exhibited a stronger relationship between compression parallel and the independent variables. Density as an independent variable predicts CII better than RPI.

Table 6. Summary of R^2 Values for Tests of $C_{\parallel}$ and the Various Independent Variables

Independent Variable	Slope (*m*)	Intercept (*b*)	Coefficient of Determination (R^2)	Standard Error of Estimate	p-value
2 × 8					
RPI	1.04	39.19	0.10	0.14	<0.001
ρ *	0.08	6.56	0.32	0.01	<0.001
ρ/RPI < 3 RPI	0.08	4.64	0.31	0.01	<0.001
ρ/RPI 3 ≤ 5 RPI	0.06	16.36	0.19	0.01	<0.001
ρ/RPI > 5 RPI	0.10	-2.28	0.60	0.01	<0.001
ρ < 0.4	0.21	-44.50	0.19	0.07	0.01
ρ 0.4 ≤ 0.5	0.11	-7.60	0.22	0.01	<0.001
ρ > 0.5	0.04	29.04	0.03	0.02	0.03
2 ×10					
RPI	1.66	40.14	0.14	1.65	<0.001
ρ *	0.09	4.03	0.35	0.09	<0.001
ρ/RPI < 3 RPI	0.08	7.42	0.29	0.01	<0.001
ρ/RPI 3 ≤ 5 RPI	0.09	1.70	0.39	0.01	<0.001
ρ/RPI > 5 RPI	0.09	6.97	0.46	0.01	<0.001
ρ < 0.4	0.19	-35.01	0.25	0.07	0.02
ρ 0.4 ≤ 0.5	0.07	12.37	0.08	0.02	<0.001
ρ > 0.5	0.10	-2.71	0.16	0.02	<0.001

*ρ = density ($kg \cdot m^{-3}$). The coefficients *m* and *b* are used in the generalized model $C_{\parallel} = m$ (independent variable) + b.

Further refinement of the data, removal of blatant outliers, and combinations of other growth characteristics could be explored. Subsequent analyses could be conducted using a less stringent alpha significance level and perhaps show more association among the variables at lower confidence intervals.

CONCLUSIONS

1. The 2 × 8 and 2 × 10 specimens utilized in this study exhibited average growth characteristics conducive to the lumber standard for No. 2 grade southern pine (SPIB 2014).
2. The correlation of growth rings per inch in relation to compression parallel to grain were only slightly significant, and also increased in value from smaller to larger size sample types for the scatter plots.

3. Once the RPI data were segmented, statistical significance showed in the first two groups for 2 × 8 lumber but for none of the groups for 2 × 10 lumber.
4. Because of widespread data distribution and too many outliers could be attributed, in addition to small sample size for at least one of the segments. Further refinement of the data, removal of blatant outliers, and combinations of other growth characteristics could be explored. With that premise, density was added as an independent variable and segmented in two different ways: the first segmentation was done using the RPI group data, and the second utilized density segments from less than 0.4, 0.4 ≤ 0.5, and more than 0.5.
5. The second class of segmentations test, the density groups did not fare as strongly, especially for 2 × 8 lumber.

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