Yellow Pine Small Clear Flexural Properties across Five Decades

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Abstract

When discussing structural southern yellow pine lumber, questions frequently are asked regarding changes over time. This is a significant area of discussion given that structural lumber properties (i.e., design values) were changed around 2012. Climate change, forest management, genetics, processing, and others are listed among the many possible contributing factors. Of interest are these questions: (1) Are changes in bending properties permanent at some fundamental level, or are they somewhat dynamic and responsive to controllable factors? (2) To what degree have the basic southern pine wood mechanical properties changed over time? Related thereto, this research examines the bending properties of small clear pine specimens from three samples. Sample 1 was pulled from a production-weighted sample of in-grade parent lumber. Sample 2 was pulled from commercially available molding and millwork. Sample 3 was pulled from data from the U.S. Department of Agriculture Forestry Products Laboratory from the early to mid-1960s. The flexural properties of small clear specimens among the three samples showed some statistically significant differences. However, there was no clear trend regarding these differences. These results appear to support the notion that while the variability of pine's flexural properties is significant and that while many changes in forest management and production have occurred over the past five decades, the basic density and bending strength of clear southern pine appear generally stable over time.

Southern yellow pine (SYP) lumber is perhaps the most commercially important domestic structural softwood species group in terms of volume and economy (Howard 2007, U.S. Census Bureau 2010). Lumber quality (and utility value) often directly correlate with prices or economic value (Gartner 2005). Landowners across the historic range of SYP have enjoyed its long-standing place as the most commercially important species and, with that, have gone to great lengths to study management techniques that allow them to both preserve and derive the most value from their investment. Historically, lumber production has been chief among those value drivers (Madsen and Nielsen 1992, Wear and Greis 2002, Allen et al. 2005, Kretschmann 2010).

Timberland owners who grow SYP as an investment speculate that the wood fiber produced today will meet the utility value (primarily as strength and stiffness) needs of the future. Gaby (1985) noted that most of the lumber in the market at the time of the study was visually graded; however, strength and stiffness may not always be accurately reflected by the visual grade (Kretschmann and Hernandez 2006). Kretschmann and Hernandez also note, "The grading of timber should be viewed as part of a marketing strategy, designed to ensure that timber buyers obtain the quality of timber appropriate for their needs and timber sellers receive an optimal price for their product." Taking grading into account as it relates to the value of SYP timber grown across the species range, it is imperative for landowners to receive feedback regarding SYP material properties.

Forest Inventory Analysis data from 2017 indicate that of all volume in the U.S. South, standing volume of softwood had increased 133.7 percent on all lands since 1953 and 122.4 percent on private lands over the same time period to

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141,307 and 117,662 million cubic feet, respectively (Oswalt et al. 2019). This level of volumetric increase, occurring mainly on private lands, emphasizes the need to examine SYP utility value periodically to protect and enhance landowner confidence and value along with forest health.

When discussing structural SYP lumber, questions frequently are asked regarding changes over time. This is a significant area of discussion given that structural lumber properties (i.e., design values) were changed around 2012. Climate change, forest management, genetics, processing, and others are listed among the many possible contributing factors. Given that structural lumber design values were reduced at that time, one may wonder whether or to what degree SYP's basic mechanical properties have changed during the past several decades.

With respect to structural lumber, the commercially important southern pine group includes loblolly, longleaf, shortleaf, and slash pines (*Pinus taeda*, *P. palustris*, *P. echinata*, and *P. elliottii*, respectively). Loblolly pine is the single most important species in the southern pine group. It is planted extensively in plantations. Once sawn into lumber, the wood from each of these four pine species is indistinguishable. As such, they are sold under the ''southern pine'' or ''southern pine group'' classification. The basic clear wood bending properties of these four species are enumerated in the Wood Handbook (Ross 2010). Their standing timber volume in the United States, an indicator of commercial importance, is taken from ASTM D2555 (ASTM International 2017b). This information is summarized in Table 1.

In the case of lumber's structural performance, somewhat unlike the stock market, past trends are generally indicative of future performance. In that case, the more mechanical properties have changed over time, perhaps the more one can expect future changes. Conversely, the less basic properties change over time, the more stable the properties should be into the future.

Related thereto, this research examines the bending properties of small clear pine specimens from three samples. Sample 1 was pulled from a production-weighted sample of in-grade parent lumber from throughout the SYP. Sample 2 was pulled from commercially available molding and millwork throughout the eastern half of the United States. Sample 3 was pulled from U.S. Department of Agriculture Forestry Products Laboratory data from the early to mid-1960s.

The objectives of this research were to investigate the extent to which the specific gravity (SG), bending strength (modulus of rupture [MOR]), and bending stiffness (modulus of elasticity [MOE]) of small clear specimens of SYP have changed, particularly with respect to reduction(s), during the interval from approximately 1965 to 2015.

Materials and Methods

Table 2 summarizes the information for samples used in this study. The first sample (hereinafter Sample 1) was production weighted. In that case, in-grade structural lumber specimens were taken from throughout the SYP lumber production range. This range is divided up into numerous (18) production regions. To that end, SYP sawmills were classified according to the regional production map (Green et al. 1989), and then production statistics, by region, were reviewed. Then, in 2014 and 2015, full-size in-grade structural lumber specimens, primarily No. 2 grade, in the 2 by 4-inch through 2 by10-inch size classes, were procured from retailers such that a production-weighted sample was developed. Details regarding this sampling method are provided in França et al. (2018).

After the in-grade lumber was characterized and evaluated, small clear bending specimens were machined from the nonbroken ends of the full-size flexural specimens. In total, 1,689 small clear specimens were tested in Sample 1. Findings from this sample are seemingly attributable to the basic or inherent clear wood flexure properties of SYP global in-grade lumber at the time of sampling.

The second sample (hereinafter Sample 2) was taken from molding and millwork producers. In particular, the membership of the Stairbuilders and Manufacturers Association (SMA) was interested in documenting the strength and stiffness properties of several wood species. The SMA's stair tread and riser sizes and grades are similar to though wider than small clear specimens as described in ASTM D143 (ASTM International 2017a). Among the species of interest were those in the SYP group. SYP constitutes a major portion of stair tread and riser production. These manufacturers, from throughout the eastern half of the United States, were contacted and asked to donate materials from their production for this effort.

In total, lumber donations were requested from the entire SMA membership, approximately 150 member companies. In response, approximately 21 manufacturers from 15 states (Fig. 1) donated material during the 2017–2019 time window. It was assumed that by sampling from a large variety of remanufacturers, the variability associated with this high-quality appearance-grade SYP lumber would be captured. None of this material was grade stamped. In total, 276 small clear specimens were tested in Sample 2. While this sample was not production weighted, it was considered

Table 1.—SYP clear wood SG, MOR, and MOE (at 12% moisture content) along with standing timber volume (an indicator of commercial importance).[a]

SYP species	SG, average (COV = 10%)[b]	MOR (psi), average[b]	MOE (psi × 10^6), average	Standing timber volume ($ft^3 \times 10^6$)[c]	Standing timber volume (%)[c]
Loblolly	0.51	12,800	1.79	57,990	65.2
Longleaf	0.59	14,500	1.98	4,795	5.4
Shortleaf	0.51	13,100	1.75	15,284	17.2
Slash	0.59	16,300	1.98	10,891	12.2

[a] SYP = southern yellow pine; SG = specific gravity; COV = coefficient of variation; MOR = modulus of rupture; psi = pounds per square inch; MOE = modulus of elasticity.

[b] Data taken from Ross (2010).

[c] Data taken from ASTM International (2017b).

Table 2.—Summary of sample identification, time frame, origin of material, and sample size for flexural properties.

ID	Time frame	Origin of material	N
Sample 1	2014–2015	Southern yellow pine–producing geographical area	1,689
Sample 2	2017–2019	Stairbuilders and Manufacturers Association samples from 15 U.S. states	276
Sample 3	Mid-1960s	Southern yellow pine study: Doyle and Markwardt (1966)	281

a reasonable approximation of high-quality SYP lumber from around the production region. Findings from this sample are seemingly attributable to the basic or inherent wood properties of high-quality appearance-grade lumber at the time of sampling.

The third sample (hereinafter Sample 3) was taken from existing data associated with Doyle and Markwardt (1966). Similar to Sample 1, Sample 3's data were taken from a broad sample of in-grade pine lumber. Details regarding this sampling method and corresponding evaluation are provided in Doyle and Markwardt (1966). From that lumber, subsequent to in-grade testing, small clear specimens were tested in bending. In total, 281 small clear specimens were tested in Sample 3. Findings from this sample are seemingly attributable to the basic or inherent clear wood flexure properties of SYP global in-grade lumber at the time of sampling. It is noted that at the time of sampling (around the mid-1960s), southern pine forest management practices were not as widespread or as intensive as they were during the procurement of Samples 1 and 2.

In essence, from each of the three samples, small clear flexural specimens were machined to 1 by 1 by 16-inch size. Specimens were then conditioned at approximately 70°F and 65 percent humidity to an approximate moisture content (MC) of 12 percent.

Each specimen was then tested in center point bending per ASTM D143 (ASTM International 2017a). In each case, actual MC was recorded at the time of testing. Because specimens were environmentally conditioned in this manner, the as-tested values for MOR and MOE were analyzed and reported (Fig. 2). However, because there was some variation in moisture among conditioned specimens, individual observations for MOR and MOE were moisture adjusted to 12 percent MC and subsequently analyzed. Both before-adjustment and moisture-adjusted to 12 percent MC findings are presented herein. With respect to MOE, only the non–shear-adjusted stiffness values were analyzed and reported.

Moisture adjustment

MOR and MOE test data were adjusted to 12 percent MC following the standard ASTM D1990 (ASTM International 2019). For MOR, the adjustment was calculated using the following equation:

$$S_2 = S_1 + \left\{ \frac{(S_1 - 2,415)}{(40 - M_1)} \right\} \cdot (M_1 - M_2) \tag{1}$$

where S_1 is the MOR at tested MC, S_2 is the MOR at 12 percent MC, M_1 is the MC at the tested condition, and M_2 is the MC at condition 2 (12%).

For MOR, the adjustment was calculated using the following equation:

$$S_2 = S_1 \cdot \frac{\left(1.857 - (0.0237 \cdot M_2)\right)}{\left(1.857 - (0.0237 \cdot M_1)\right)} \tag{2}$$

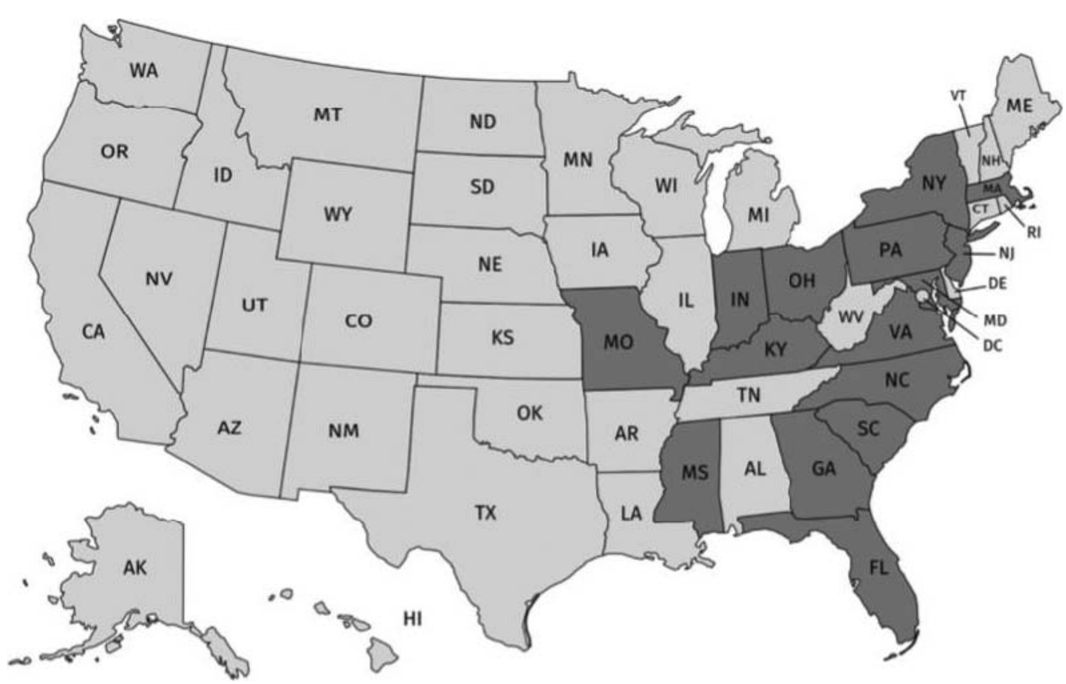

Figure 1.—Origin source of the raw material acquired from the Stairbuilders and Manufacturers Association, highlighted in gray.

Figure 2.—Center point bending test setup (Sample 3).

where S_1 is the MOE at tested MC, S_2 is the MOE at 12 percent MC, M_1 is the MC at the tested condition, and M_2 is the MC at condition 2 (12%).

Statistical analysis

Analysis of variance was performed on the SG, MOR, and MOE data from each of the three samples. In each case, a significance value of $\alpha = 0.05$ was used. In each case, because sample sizes were unequal, a general linear model was used. With this model, the statistical program uses the smallest sample size (which is generally the n associated with Sample 2) to control the overall power or robustness of the testing. As such, the analysis is defensible.

An alternative would perhaps be to randomly choose approximately 300 specimens from Sample 1 in order to reduce its n to more closely match that of Samples 2 and 3. However, that operation has drawbacks, and thus Sample 1 was included in its entirety. Next, mean separations were performed using least significant difference testing. This method is generally aggressive at finding statistical differences. That is, where actual differences may be relatively small, this statistical method may find statistical differences where other methods do not.

Results and Discussion

Table 3 illustrates the descriptive statistics and means comparison of SG among the three samples. The P value for

Table 3.—Descriptive statistics and mean separation of SG for Samples 1, 2, and 3.[a]

ID	N	Mean	COV (%)	Min	Max	Mean separation[b]
Sample 1	1,689	0.48	12.8	0.32	0.69	A
Sample 2	276	0.52	12.8	0.33	0.72	B
Sample 3	281	0.51	13.9	0.38	0.88	B

[a] SG = specific gravity; COV = coefficient of variation.
[b] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. For SG, the least significant difference value = 0.011.

significance among SG values for the three samples was <0.001. Tables 4 and 5 illustrate the descriptive statistics and means comparison of MOR among the three samples. Table 4 presents non–moisture-adjusted values, while Table 5 presents moisture-adjusted values.

The P value for significance among MOR values for the three samples was <0.001 regardless of moisture adjustment. Tables 6 and 7 illustrate the descriptive statistics and means comparison of MOE among the three samples. Table 6 presents non–moisture-adjusted MOE values, while Table 7 presents moisture-adjusted MOE values. The P value for significance among MOE values for the three samples was <0.001 regardless of moisture adjustment.

With respect to SG, the wood in Sample 1 was significantly different (lower, less dense) than that from Samples 2 and 3. The SG of the wood in Samples 2 and 3 was not statistically different (Fig. 3).

With respect to MOR, Sample 2 was significantly different (higher, stronger) than Samples 1 and 3. The MOR of the wood in Samples 1 and 3 was not statistically different. Adjusting to 12 percent MC had no influence on the mean separation of MOR (Fig. 4).

Table 4.—Descriptive statistics and means separation of MOR for Samples 1, 2, and 3.[a]

ID	N	MC (%)	Mean (psi)	COV (%)	Min (psi)	Max (psi)	Mean separation[b]
Sample 1	1,689	14.2	12,651	17.8	5,116	20,301	A
Sample 2	276	12.1	12,987	18.9	6,783	19,189	B
Sample 3	281	12.7	12,935	15.8	7,293	19,211	B

[a] MOR = modulus of rupture; MC = moisture content; psi = pounds per square inch; COV = coefficient of variation.
[b] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. For MOR, the least significant difference value = 391 psi.

Table 5.—Descriptive statistics and means separation of moisture-adjusted MOR for Samples 1, 2, and 3. The MOR of each specimen is adjusted to 12% MC.[a]

ID	N	Mean (psi)	COV (%)	Min (psi)	Max (psi)	Mean separation[b]
Sample 1	1,689	13,544	18.2	5,144	30,343	A
Sample 2	276	13,053	19.2	6,507	20,091	B
Sample 3	281	13,218	16.0	7,328	19,710	B

[a] MOR = modulus of rupture; MC = moisture content; psi = pounds per square inch; COV = coefficient of variation.
[b] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. For MOR, the least significant difference value = 422 psi.

Table 6.—Descriptive statistics and means separation of MOE for Samples 1, 2, and 3.[a]

ID	N	MC (%)	Mean (psi $\times 10^6$)	COV (%)	Min (psi $\times 10^6$)	Max (psi $\times 10^6$)	Mean separation[b]
Sample 1	1,689	14.2	1.41	22.8	0.34	2.45	A
Sample 2	276	12.1	1.42	26.2	0.41	2.56	A
Sample 3	281	12.7	1.68	20.6	0.75	2.70	B

[a] MOE = modulus of elasticity; MC = moisture content; psi = pounds per square inch; COV = coefficient of variation.
[b] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. For MOE, the least significant difference value = 0.058×10^6 psi.

Table 7.—Descriptive statistics and means separation of moisture-adjusted MOE for Samples 1, 2, and 3. The MOE of each specimen is adjusted to 12% MC.[a]

ID	N	Mean (psi $\times 10^6$)	COV (%)	Min (psi $\times 10^6$)	Max (psi $\times 10^6$)	Mean separation[b]
Sample 1	1,689	1.46	22.7	0.35	2.55	A
Sample 2	276	1.42	26.2	0.40	2.53	A
Sample 3	281	1.69	20.6	0.75	2.75	B

[a] MOE = modulus of elasticity; MC = moisture content; psi = pounds per square inch; COV = coefficient of variation.
[b] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. For MOE, the least significant difference value = 0.062×10^6 psi.

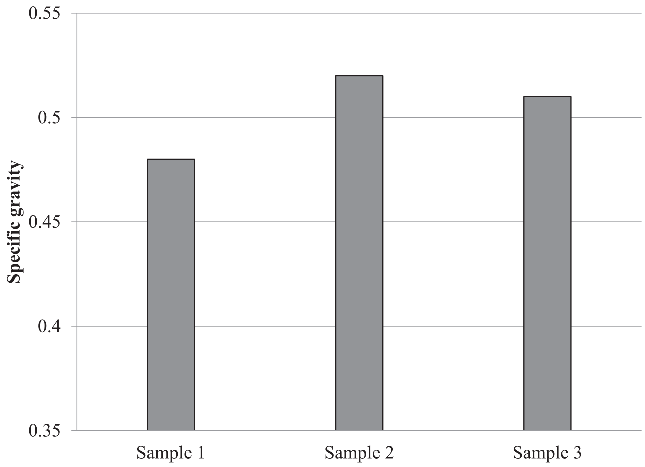

Figure 3.—Average specific gravity comparison among the three samples (least significant difference value = 0.011).

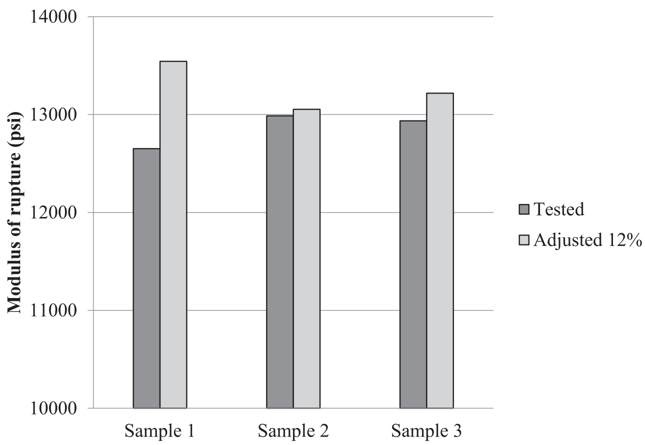

Figure 4.—Modulus of rupture comparison among the three samples (tested least significant difference [LSD] value = 391 pounds per square inch [psi]; adjusted LSD value = 422 psi).

With respect to MOE, Sample 3 was significantly different (higher, stiffer) than Samples 1 and 2. The MOE of the wood in Samples 1 and 2 was not statistically different. Adjusting to 12 percent MC had no influence on the mean separation of MOE (Fig. 5).

Conclusions

Clear wood flexural properties of SYP, from samples taken across approximately 50 years, were compared. Statistical differences were detected in SG, MOR, and MOE among the three samples. However, there was no clear trend across these properties. For SG, one of the contemporary samples (Sample 1) was statistically lower than that of the other contemporary sample (Sample 2) and that of the classic sample (Sample 3) from 50 years ago. Also, for SG, Samples 2 and 3 were not statistically different. For MOR, one of the contemporary samples (Sample 2) was statistically higher than that of the other contemporary sample (Sample 1) and that of the classic sample (Sample 3) from 50 years ago. In addition, for MOR, Samples 1 and 3 were not statistically different. For MOE, the classic sample (Sample 3) from 50 years ago was

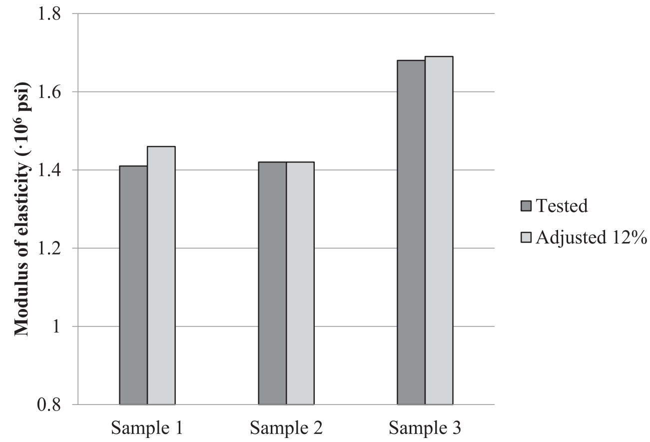

Figure 5.—Modulus of elasticity comparison between the three samples (tested least significant difference [LSD] value = 0.058 $\times$ 10^6 pounds per square inch [psi]; adjusted LSD value = 0.062 $\times$ 10^6 psi).

statistically higher than that of the two contemporary samples (Samples 1 and 2). For MOE, Samples 1 and 2 were not statistically different. Because the MOR and MOE specimens were environmentally conditioned to approximately 12 percent MC prior to testing, there was no difference in mean separation findings from the analysis of variance between specimens as tested versus specimen values adjusted to 12 percent MC.

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