# Compression Properties of Small Clear Southern Yellow Pine Specimens Tested across Five Decades

Rubin Shmulsky  Frederico José Nistal França  J. Tedrick Ratcliff
Benjamin Farber  C. Adam Senalik  Robert J. Ross
R. Daniel Seale

## Abstract

Southern yellow pine (SYP) is one of the most used softwood species in the world. Most of this raw material come from fast-grown plantation trees. It is of interest to determine if SYP clear wood properties may have changed over the long term, in particular whether such properties may have declined. Herein, specific gravity (SG), ultimate compression strength parallel to grain (UCS‖), and UCS perpendicular to grain (UCS⊥) from three samples were compared: Sample 1 tested in 2014; Sample 2 from molding and millwork producers tested in 2017–2019; and Sample 3 from a study conducted in the mid-1960s. With respect to specific gravity (SG), the wood in Sample 1 was significantly lower than that from Samples 2 and 3. With respect to UCS‖, all three samples were statistically different. Adjusting to 12 percent moisture content had no influence on the mean separation of UCS‖. With respect to UCS⊥, no statistically significant differences were detected among the test data from any of the three samples. However, for the UCS data generated from the SG and moisture content–related model, Sample 2 was higher than Sample 3, and Sample 3 was higher than Sample 1, and these differences were statistically significant. Overall, these findings do not suggest that broad or consistent changes or declines of these wood strength properties have occurred during the past five decades.

Southern yellow pine (SYP) is a natural and renewable resource with a high strength-to-weight ratio. It is used abundantly as a construction material across the United States. Due to the material quality, it can be used in many applications, ranging from residential lumber to industrial products (Gaby 1985).

In order to apply wood as a structural application, a standardized classification is needed. This classification can be conducted by visual and/or mechanically grading. (Iniguez et al. 2007). Most of the research conducted on SYP lumber is focused on bending properties (Dahlen et al. 2014; Yang et al. 2015, 2017; França et al. 2018, 2019, 2020). Bending properties of wood are often the desired properties to focus on; however, there are select minor properties, such as compression parallel and perpendicular to grain, that should be investigated (Knowles et al. 2006).

Compression strength both parallel and perpendicular (UCS‖ and UCS⊥, respectively) to grain are important design properties. With respect to short columns and open web trusses, compression parallel to grain stress or strength is often the limiting factor (Shmulsky and Jones 2019). Additionally, in the case of braced mass timber panels, compression parallel to grain strength at the member level has a strong influence on overall performance at the assembled panel and constructed building levels. Compression perpendicular to grain strength is similarly important in mass timber construction. Cross-laminated timber panel floors are subjected to direct compression perpendicular to grain in multistory construction, and with increasingly tall wood buildings into the 7- to 15-story range, the live- and dead-load compression stresses become very high (Karacebeyli and Douglas 2013).

The authors are, respectively, Head and Warren S. Thompson Professor of Wood Science and Technology, Assistant Research Professor, Executive Vice President Mississippi Forestry Association, and Research Associate II, Dept. of Sustainable Bioproducts, Mississippi State University, Starkville (rs26@msstate.edu, fn90@msstate.edu [corresponding author], tratcliff@msforestry.net, bf720@msstate.edu); Research General Engineer and Supervisory Research Gen. Engineer, USDA Forest Products Lab., Madison, Wisconsin (christopher.a.senalik@usda.gov, robert.j.ross@usda.gov); and Warren S. Thompson Professor of Wood Science and Technology, Dept. of Sustainable Bioproducts, Mississippi State Univ., Starkville (rds6@msstate.edu). This paper was received for publication in August 2020. Article no. 20-00039.

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Species-, grade-, and size-specific design values can change over time based on resource changes. Ongoing resource monitoring seeks to keep the pulse of these properties over time. At a fundamental level, basic wood properties influence in-grade performance. Small clear mechanical properties, particularly as outlined in ASTM D143 (ASTM International 2017), are a commonly accepted means of assessing basic wood properties.

The objective of the work herein was to statistically compare the specific gravity (SG) and ultimate compression strength (UCS), both parallel and perpendicular to grain, of SYP across an approximate 50-year span from the mid-1960s and in the 2014–2019 time frame as a means of assessing resource changes, particularly property reductions, over time.

## Materials and Methods

During 2014–2015, as part of a study sponsored by the USDA Agricultural Research Service, a production-weighted sample of in-grade pine lumber was procured from throughout the SYP-producing geographical area. Details of the production-weighted sampling methodology are provided in França et al. (2018). While No. 2 grade SYP lumber was procured therein, it was subsequently regraded by certified grading personnel and then mechanically tested. Subsequent to full-scale or in-grade testing, small clear specimens were machined from the remnants of the full-scale specimens. From those, the small clear compression parallel and perpendicular to grain strengths were determined. UCS data from that study are examined and considered herein as Sample 1. Sample 1 contained 1,676 specimens of each compression test.

During 2017–2019, as part of a study sponsored by the USDA Forest Service, Forest Products Laboratory, high-grade molding and millwork types of materials were evaluated. Therein, high-grade white oak, red oak, hard maple, yellow poplar, and SYP boards were procured from the membership of the Stairbuilders and Manufacturers Association. Approximately 21 manufacturers from 15 states (shown in Fig. 1) donated solid wood material during the 2017–2019 time window. Lumber specimens were received as approximately 1-inch thick, 4 to 8 inches wide, and 36 to 48 inches long. This lumber was in general clear, free of major defects, and not grade stamped. All lumber, including the SYP, was of a relatively high grade that would be consistent with clear wood stair treads or risers. Each of the participating members of the Stairbuilders and Manufacturers Association procures material from multiple sources. As such, the SYP that was tested was considered to reasonably approximate high-quality (clear wood) SYP from around the production region. UCS data from that study were examined and considered herein as Sample 2. Sample 2 contained 276 parallel to grain specimens and 276 perpendicular to grain test specimens.

During the mid-1960s, the USDA Forest Service, Forest Products Laboratory, conducted a study on SYP (Doyle and Markwardt 1966) wood properties. That study focused first on in-grade lumber properties from 1,349 test specimens. Subsequent to full-scale or in-grade edgewise bending testing, undamaged small clear specimens were machined from the remnants of a portion of the full-scale specimens. From those, the small clear compression parallel and perpendicular to grain strengths were reported. UCS data from that study are examined and considered herein as Sample 3. Sample 3 contained 245 parallel to grain specimens and 291 perpendicular to grain test specimens. Table 1 summarizes information of samples used in this study.

Among each sample, the specimen dimensions varied slightly. For Samples 1 and 2, specimen size was guided by ASTM D143 ''secondary method'' (Fig. 2). For Sample 3, it appears that specimen sizes were also guided by ASTM D143 guidance, and UCS perpendicular to grain specimens were limited to actual material thickness. Target specimen dimensions are shown in Table 2. Actual specimen dimensions were recorded at the time of testing and used for stress calculations.

In each case, the specimens were conditioned at approximately 70°F and 65 percent humidity prior to testing. In this manner, the target equilibrium moisture content (MC) of all specimens was 12 percent prior to testing. This environmental conditioning minimized moisture variation among specimens and samples at the time of testing. That said, some moisture variation existed among specimens in all cases. To account for variation among moisture-equilibrated specimens, MC adjustments were made to the data, and both non–moisture-adjusted and moisture-adjusted comparisons were analyzed for differences in compression strength.

### Moisture adjustments

Compression parallel to grain test data were adjusted to 12 percent MC following ASTM D1990 (ASTM International 2019), Annex A1 (Eq. 1). Per ASTM guidance, adjustments greater than 5 percent were avoided:

$$S_2 = S_1 + \left\{ \frac{(S_1 - 1400)}{(34 - M_1)} \right\} \cdot (M_1 - M_2) \qquad (1)$$

Here, $S_1$ is the UCS‖ at tested MC, $S_2$ is the UCS‖ at 12 percent MC, $M_1$ is the MC at the tested condition, and $M_2$ is the MC at Condition 2 (12%).

The ASTM D1990 standard does not have an equation to adjust compression perpendicular to the grain. However, predicted UCS perpendicular values were calculated by an equation published by Kretschmann and Green (1996) (Eq. 2). There, the authors studied the effect of moisture in southern pine, and the equation uses SG and MC to predict compression parallel to the grain values. As presented herein, these values are informative in an academic sense; however, they do not necessarily correspond or relate to the actual UCS perpendicular data as tested:

$$\begin{aligned} \text{UCS}\perp = & -2.532 + 0.0347 \cdot \text{MC} + 0.000232 \cdot \text{MC}^2 \\ & + 12.341 \cdot \text{SG} - 5.3852 \cdot \text{SG}^2 - 0.2285 \cdot \text{MC} \cdot \text{SG} \end{aligned} \qquad (2)$$

Here, UCS⊥ is the ultimate compression stress perpendicular to the grain, MC is the moisture content (%), and SG is the specific gravity.

### Statistical analysis

Analysis of variance was calculated at the $\alpha = 0.05$ significance level. Least significant difference testing was used for multiple comparisons, as that is a relatively liberal means of finding significances and, conversely, would be a conservative option for supporting the notion that no statistical differences have occurred over time.

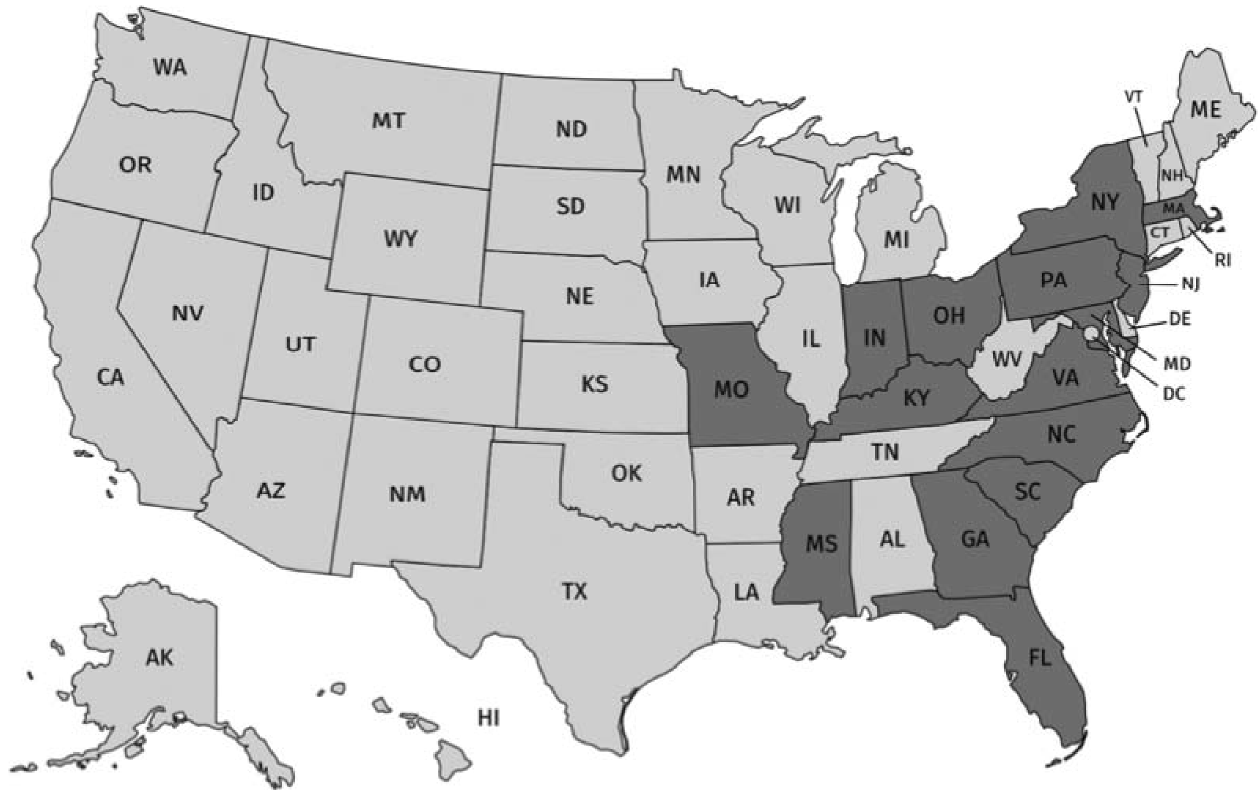



*Figure 1.—Origin source of the raw material acquired from the Stairbuilders and Manufacturers Association, highlighted in gray*

*Table 1.—Summary of sample identification, time frame, origin of material, and sample size for compression strength parallel to grain (UCS||) and compression strength perpendicular to grain (UCS⊥).[a]*

| ID | Time frame | Origin of material | *N*, UCS\|\| | *N*, UCS⊥ |
|---|---|---|---|---|
| Sample 1 | 2014–2015 | SYP-producing geographical area | 1,676 | 1,670 |
| Sample 2 | 2017–2019 | SMA samples from 15 US states | 276 | 276 |
| Sample 3 | Mid-1960s | SYP study (Doyle and Markwardt 1966) | 245 | 291 |

[a] SYP = southern yellow pine; SMA = Stairbuilders and Manufacturers Association.

Analysis of variance was performed on SG, UCS parallel to grain (both moisture-adjusted and non–moisture-adjusted data), and UCS perpendicular to grain (both non–moisture-adjusted data and predicted UCS as calculated from SG and MC) from each of the three samples.

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. Analysis of variance was used for multiple comparisons, as that is a relatively liberal means of finding significances that would be a conservative option for supporting the notion that no statistical differences have occurred over time.

*Table 2.—Ultimate compression strength target specimen dimensions.*

| Orientation | Sample group | Thickness (in.) | Width (in.) | Length (in.) |
|---|---|---|---|---|
| Parallel to grain | Sample 1 | 1 | 1 | 4 |
| | Sample 2 | 1 | 1 | 4 |
| | Sample 3 | 1 | 1 | 4 |
| Perpendicular to grain | Sample 1 | 1 | 1 | 6 |
| | Sample 2 | 1 | 1 | 6 |
| | Sample 3 | 1.5 | 2 | 6 |

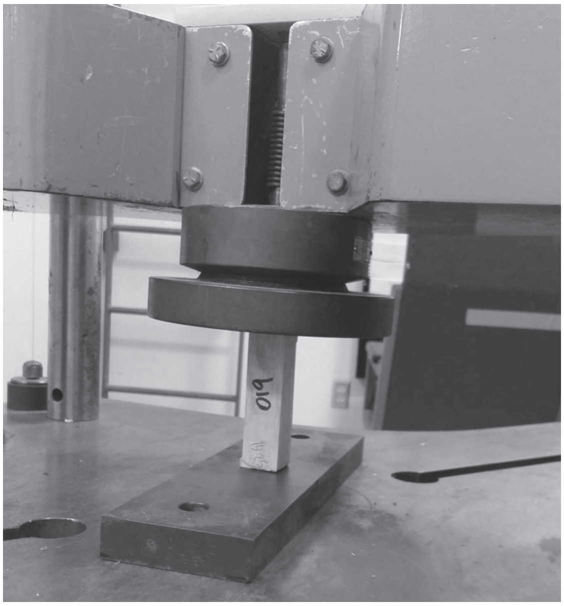
## Results and Discussion

Table 3 illustrates the descriptive statistics and means comparison of SG among the three samples. The *P* value for significance among SG values for the three samples was <0.0001. The overall SG mean value for all samples tested

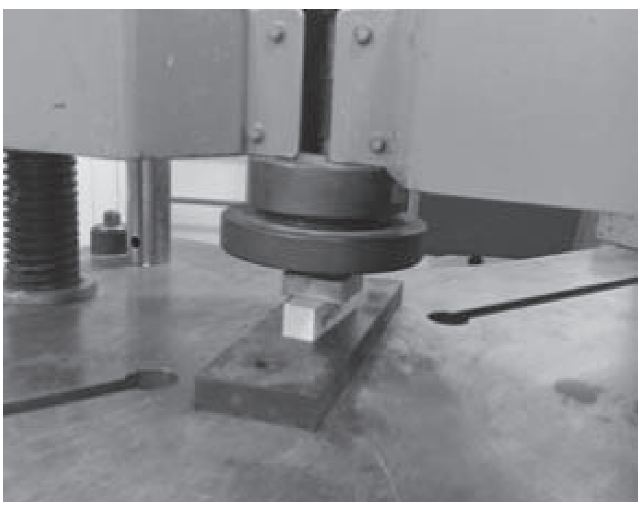
*Table 3.—Descriptive statistics and mean separation of specific gravity for Samples 1, 2, and 3.*

| ID | *N* | Mean | Coefficient of variation (%) | Min | Max | Mean separation[a] |
|---|---|---|---|---|---|---|
| Sample 1 | 1,676 | 0.47 | 12.8 | 0.32 | 0.69 | A |
| Sample 2 | 276 | 0.52 | 12.8 | 0.33 | 0.72 | B |
| Sample 3 | 245 | 0.50 | 12.9 | 0.37 | 0.73 | B |

[a] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level.



(a)



(b)

*Figure 2.—Test setup: (a) compression parallel to the grain and (b) compression perpendicular to the grain.*

was 0.50 with a range from 0.32 to 0.73. The SG mean values found in this research are similar to the ones reported by other studies (Newlin and Wilson 1917, Markwardt and Wilson 1935, Dahlen et al. 2014) that found an average value of 9 rings per inch and an SG average around 0.54 for SYP lumber. In this study, rings per inch averaged 4, and SG averaged 0.48.

Tables 4 and 5 illustrate the descriptive statistics and means comparison of UCS parallel to grain among the three samples, where Table 4 presents non–moisture-adjusted values, while Table 5 presents moisture-adjusted values. The *P* value for significance among UCS parallel to grain values for the three samples was <0.0001 regardless of moisture adjustment. Because statistically significant differences were detected, mean separations were calculated and are listed.

*Table 5.—Descriptive statistics and means separation for moisture-adjusted ultimate compression strength (UCS) parallel to the grain for Samples 1, 2, and 3. UCS parallel to grain for each specimen is adjusted to 12% moisture content.*

| ID | N | Parallel (psi) | | | | Mean separation[a] |
|---|---|---|---|---|---|---|
| | | Mean | Coefficient of variation | Min | Max | |
| Sample 1 | 1,676 | 7,220 | 19.1 | 3,761 | 12,056 | A |
| Sample 2 | 276 | 6,889 | 22.1 | 3,495 | 10,949 | B |
| Sample 3 | 245 | 6,601 | 17.1 | 3,702 | 10,247 | C |

[a] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. *P* value < 0.0001.

Tables 6 and 7 provide the descriptive statistics and means comparison of UCS perpendicular to grain among the three samples. Table 6 presents non–moisture-adjusted UCS perpendicular to grain values, while Table 7 presents predicted UCS perpendicular to grain values based on Equation 2. The *P* value for significance among UCS perpendicular to grain values for the three samples, non–moisture adjusted, was 0.0659. As statistically significant differences were not detected among these samples, mean separation was not necessary.

The *P* value for significance among UCS perpendicular to grain as calculated by Equation *2* was <0.0001. Because statistically significant differences were detected, mean separations were calculated and are listed in Table 7.

Figure 3 presents the mean SG data for the three samples in graphical form. Figures 4 and 5 present the mean UCS parallel to grain and mean UCS perpendicular to grain data for the three samples, respectively, in graphical form.

With respect to SG, the wood in Sample 1 (0.47) was significantly different (lower and less dense) than that from Samples 2 and 3 (0.52 and 0.50, respectively). The SG of the wood in Samples 2 and 3 was not statistically different.

For UCS‖, all three samples were statistically different. In both scenarios, non-adjusted and adjusted 12 percent MC, Sample 1 (11,783 and 12,056 psi, respectively), was higher than Sample 2 (10,845 and 10,949 psi, respectively), and Sample 2 was higher than Sample 3 (10,730 and 10,247 psi, respectively), and these differences were statistically significant. Adjusting to 12 percent MC had no influence on the mean separation of UCS‖.

With respect to UCS perpendicular to grain, no statistically significant differences were detected among

*Table 4. Descriptive statistics and means separation for ultimate compression strength parallel to the grain for Samples 1, 2, and 3.*

| ID | N | Moisture content (%) | Parallel (psi) | | | | Mean separation[a] |
|---|---|---|---|---|---|---|---|
| | | | Mean | Coefficient of variation | Min | Max | |
| Sample 1 | 1,676 | 14.2 | 6,635 | 19.2 | 3,559 | 11,783 | A |
| Sample 2 | 276 | 12.1 | 6,859 | 22.0 | 3,590 | 10,845 | B |
| Sample 3 | 245 | 13.0 | 6,366 | 17.2 | 3,493 | 10,730 | C |

[a] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level. *P* value < 0.0001.

*Table 6.—Descriptive statistics for ultimate compression strength perpendicular to grain for Samples 1, 2, and 3.*[a]

| | | | Perpendicular (psi) | | | |
|---|---|---|---|---|---|---|
| ID | Moisture content (%) | $N$ | Mean | Coefficient of variation | Min | Max |
| Sample 1 | 14.2 | 1,676 | 1,807 | 27.8 | 790 | 4,042 |
| Sample 2 | 12.1 | 276 | 1,808 | 30.4 | 837 | 3,604 |
| Sample 3 | 12.6 | 245 | 1,734 | 24.6 | 945 | 3,231 |

[a] No statistically significant differences, at the $\alpha = 0.05$ level, were detected among these three samples. $P$ value = 0.0659.

the test data from any of the three samples. However, for the UCS data generated from the SG- and MC-related models, per Equation *2*, Sample 2 was higher than Sample 3 (1,419 and 1,303 psi, respectively), and Sample 3 was higher than Sample 1 (1,097 psi), and these differences were statistically different.

## Conclusions

The findings presented herein appear to suggest that some changes in basic wood properties may have occurred during the 50-year interval that was examined. In the case of SG, the lumber from the mid-1960s was not different from that used in stairway parts during the late 2010s. However, each of these samples had higher SG than that of structural pine lumber as sampled in the mid-2010s. The significant difference between Samples 1 and 2, taken from the supply chain at similar points in time, indicates that sampling method is highly influential. The staircase industry uses clear wood for appearance with higher strength in their chain supply.

In the case of UCS parallel to grain, statistical differences were detected among each of the samples. For that property, the small clear specimens from the mid-2010s structural lumber sample were the strongest, followed by the late 2010s stair parts sample, with the sample from the mid-1960s being the weakest (both moisture adjusted and non–moisture adjusted). This finding appears to refute the notion that UCS parallel to grain properties have declined during the past five decades.

For the compression perpendicular specimens, there were no statistically significant differences among any of the samples. This finding suggests that UCS perpendicular to grain properties have declined during the past five decades.

Overall, these findings do not suggest that broad or consistent changes or declines of these wood strength properties have occurred during the past five decades. This finding appears encouraging. Also, these findings seem to support the notion that sampling from the resource should be done with great thought and care, as it can be highly influential with respect to the findings.

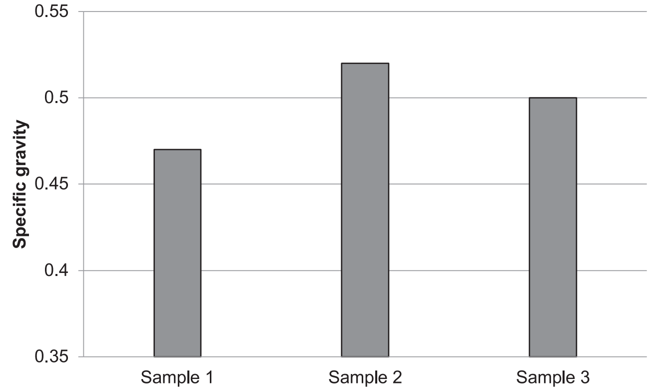



*Figure 3.—Average specific gravity comparison among the three samples.*

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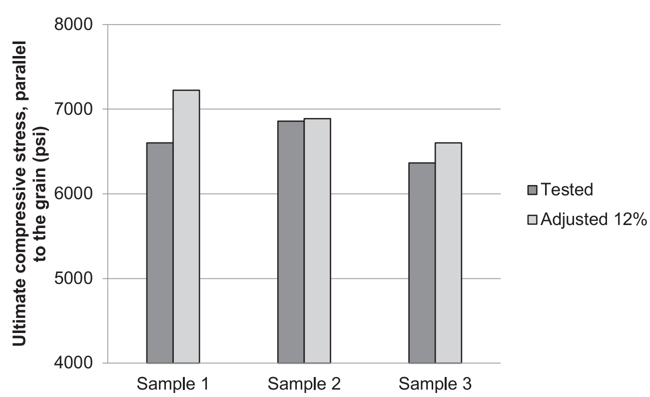


*Figure 4.—Ultimate compression strength (UCS) parallel to grain comparison among the three samples. "Tested" refers to the UCS perpendicular to grain data as tested, and "12%" refers to the predicted values based on Equation 2.*

*Table 7.—Descriptive statistics and means separation for predicted ultimate compression strength (UCS) perpendicular to the grain at 12% target moisture content (MC) for Samples 1, 2, and 3, as calculated by Equation 2. UCS perpendicular to grain for each specimen is calculated based on specific gravity (SG) and MC.*

| | | Perpendicular (psi) | | | | |
|---|---|---|---|---|---|---|
| ID | $N$ | Mean | Coefficient of variation | Min | Max | Mean separation[a] |
| Sample 1 | 1,676 | 1,097 | 23.3 | 281[b] | 1,981 | A |
| Sample 2 | 276 | 1,419 | 18.2 | 606 | 1,927 | B |
| Sample 3 | 245 | 1,303 | 19.2 | 749 | 1,973 | C |

[a] Samples with the same letter are not statistically different at the $\alpha = 0.05$ level.

[b] The lower values, such as this minimum, derive from specimens with relatively low SG values. $P$ value < 0.0001.

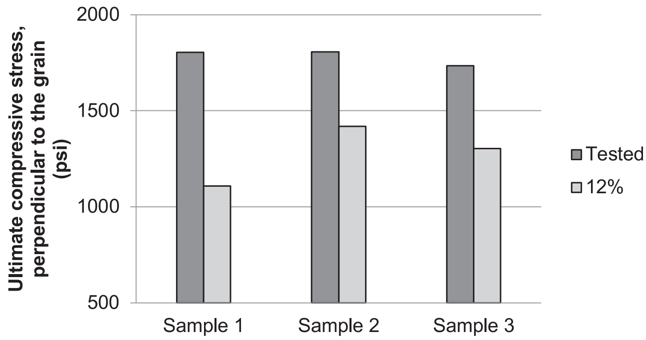


*Figure 5.—Ultimate compression strength (UCS) perpendicular to the grain comparison among the three samples. "Tested" refers to the UCS perpendicular to grain data as tested, and "12%" refers to the predicted values based on Equation 2.*

necessarily reflect the view of the U.S. Department of Agriculture. The authors thank Mississippi State University, College of Forest Resources, Department of Sustainable Bioproducts, and the Forest and Wildlife Research Center. This publication is a contribution and was accepted as a journal article SB 986 of the Forest and Wildlife Research Center, Mississippi State University.

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