Correlations between Grain Angle Meter Readings and Bending Properties of Mill-Run Southern Pine Lumber

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Abstract

Metriguard's grain angle meter (Model 511) measures grain angle in wood by assessing permittivity. This study evaluates the correlations between grain angle meter readings and bending properties of 1,400 kiln-dried 2 by 4 specimens of southern pine (*Pinus* spp.) lumber and considers its utility for providing supplementary data for predicting the strength of lumber. The results showed that in mill-run lumber, the correlation between grain angle and modulus of rupture (MOR) was –0.420. In addition, in graded lumber, the correlation between grain angle and MOR got progressively stronger as the grade went down. With a few technical modifications, applying this device in a mill production setting could prove useful for supplementing other nondestructive methods for assessing bending strength in lumber.

Introduction

Nondestructive testing methods have been widely used to predict the bending strength of wood members. Previous studies have shown that there is a strong correlation between modulus of rupture (MOR) and modulus of elasticity (MOE; for example, Senft and Angleton 1962). For this reason, MOE is frequently used to predict MOR. There are two types of MOE: static MOE and dynamic MOE. Static MOE can be measured by static bending. Dynamic MOE can be measured by transverse or longitudinal vibration.

Like MOE, grain angle is correlated with lumber strength (Luxford 1918, Wilson 1921, Senft and Angleton 1962, Forest Products Laboratory 2010). At low moisture-content levels, wood can be considered a dielectric material (James and Hamill 1965, Lin 1967). The dielectric constant for wood varies with grain (fiber) direction. Metriguard's grain angle meter (Model 511) is designed to measure grain angle by assessing the difference in dielectric constant (permittivity) between a direction parallel to the grain (a lower dielectric constant) and a direction perpendicular (a higher dialectic constant) to the grain. Measuring a material's dielectric constant can be accomplished by measuring the current flow between two conductors when an alternating voltage is applied. Metriguard's Model 511 has been used in other studies as a predictor of tensile strength in lumber. For example, Schlotzhauer et al. (2014, 2018) have demonstrated the application of the Metriguard Model 511 for measuring grain angle on specimens of spruce (*Picea abies*) and six European hardwoods. There is, however, no information on its application for the determination of grain angles in commercially available full-size lumber specimens.

The objectives of this technical note are (1) to evaluate the bivariate correlations between the grain angle meter readings and MOR and three measures of MOE (static MOE, MOE by longitudinal vibration, and MOE by transverse vibrating) of 1,400 2 by 4 specimens of kiln-dried southern pine (*Pinus* spp.) lumber, both as mill-run lumber and by grade, and (2) to consider its utility for providing supplementary data for predicting the strength of commercial lumber products.

The data reported in this technical note came from a larger currently-in-progress investigation into the statistical

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distributions of mill-run lumber populations (Verrill et al. 2017, 2018; Owens et al. 2018, 2019; Anderson et al. 2019). A mill-run lumber population includes every piece of lumber sawn from logs. Unlike a graded population, it includes all qualities from ''best'' to ''worst.'' Additional results on the rest of the project are forthcoming.

Material and Methods

Sampling

In total, 1,400 specimens of 2 by 4 southern pine mill-run lumber were sampled from four sawmills in northern Mississippi. The dimensions of the lumber were approximately 1.5 by 3.5 by 96 inches (3.81 by 8.89 by 243.84 cm). For each sampling, a kiln package was randomly selected from weekly dry kiln output from which 200 pieces of rough dry lumber were sampled sequentially. Full details of the sampling method can be found in Owens et al. (2019). The mill-run specimens were graded by a Southern Pine Inspection Bureau–certified inspector.

Testing

A third-point static bending test was performed per ASTM International D198-15 (2015) to obtain the static MOR and static MOE (MOE-Stat) values with a span:depth ratio at 17:1. A Wagner L 601-3 handheld moisture meter (Wagner Electronic Products Inc., Rogue River, Oregon) was used to measure the moisture content (MC) before the bending test. The average MC of the specimens was 13.3 percent (SD = 1.67). In addition, two types of dynamic MOE were measured by nondestructive tests employing Fibre-gen's Director HM200 (Fibre-gen Limited, Christchurch, New Zealand; hereafter ''Dir-E'') and Metriguard's E-computer device (Model 340, Metriguard Technologies, Inc., Pullman, Washington; hereafter ''E-comp-E''). The full details of the testing method can be found in Owens et al. (2019).

Grain angle measurement

Metriguard's grain angle meter (Fig. 1) Model 511 (Metriguard Technologies Inc.) was used to measure grain angle. This device is capable of measuring a maximum grain angle of 23.9° with a resolution of 0.1°. The device was held firmly against the wide face of each lumber specimen and slid along the span covering the distance between load heads plus 2.5 inches (6.35 cm) on either side while remaining parallel to the edges of the lumber. The maximum grain-angle reading measured over that distance was recorded by the operator.

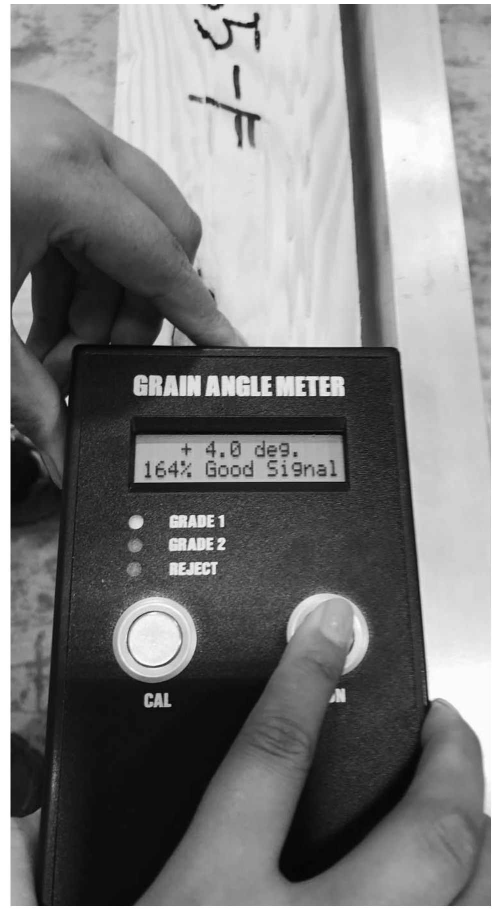

Figure 1.—Metriguard's grain angle meter.

Statistical methods

Bivariate correlations among grain angle, MOR, MOE-Stat, Dir-E, and Ecomp-E were calculated using SPSS 25 (IBM Corp. 2017). Missing values were excluded pairwise. MOR, MOE-Stat, Dir-E, and Ecomp-E values were adjusted to a common MC of 15 percent per ASTM D1990-16 (ASTM International 2016).

Results

Bivariate correlations among mill-run lumber properties

Table 1 shows the bivariate correlations (Peason's correlation coefficient *r*) among grain angle, MOR, MOE-Stat, Dir-E, and Ecomp-E for the mill-run lumber population. Between grain angle and MOR, the correlation coefficient was –0.420. Between grain angle and MOE-Stat, the correlation was –0.314. Between grain angle and Dir-E, the correlation was –0.249. Between grain angle and Ecomp-E, the correlation was –0.251. All the correlations are significant at a 0.01 level.

Bivariate correlations among graded lumber properties

Bivariate correlations between grain angle and MOR in graded lumber are presented in Table 2. For select structural grade, the correlation was –0.231. For No. 1 grade, the correlation was –0.286. For No. 2 grade, the correlation was –0.367. For No. 3 grade, the correlation was –0.457. For ''low grade'' (any material that graded lower than No. 3), the correlation was –0.458. All the correlations are significant at a 0.01 level.

Discussion

From the results above, it is possible to make some fundamental observations:

1. For the mill-run data, the correlation between the grain angle meter reading and MOR was –0.420. This suggests that when grain angle increases, MOR decreases, and vice versa. This is not surprising, considering many previous studies have demonstrated that increased grain angle leads to a reduction in bending strength (Luxford

Table 1.—Pearson's bivariate correlations (r) among grain angle, adjusted modulus of rupture (MOR), adjusted static modulus of elasticity (MOE-Stat), adjusted Dir-E, and adjusted Ecomp-E for the mill-run lumber population.

	Grain angle	MOR	MOE-Stat	Dir-E	Ecomp-E
Grain angle[a]					
Pearson correlation	1	−0.420**[b]	−0.314**	−0.249**	−0.251**
Significance (2-tailed)		<0.001	<0.001	<0.001	<0.001
N	1,398	1,398	1,398	1,393	1,398
MOR[c]					
Pearson correlation	−0.420**	1	0.791**	0.730**	0.712**
Significance (2-tailed)	<0.001		<0.001	<0.001	<0.001
N	1,398	1,398	1,398	1,393	1,398
MOE-Stat[d]					
Pearson correlation	−0.314**	0.791**	1	0.929**	0.924**
Significance (2-tailed)	<0.001	<0.001		<0.001	<0.001
N	1,398	1,398	1,398	1,393	1,398
Dir-E[e]					
Pearson correlation	−0.249**	0.730**	0.929**	1	0.964**
Significance (2-tailed)	<0.001	<0.001	<0.001		<0.001
N	1,393	1,393	1,393	1,393	1,393
Ecomp-E[f]					
Pearson correlation	−0.251**	0.712**	0.924**	0.964**	1
Significance (2-tailed)	<0.001	<0.001	<0.001	<0.001	
N	1,398	1,398	1,398	1,393	1,398

[a] Value from Metriguard grain angle meter Model 511.
[b] ** Correlation is significant at the 0.01 level (2-tailed).
[c] MOR value from a third-point static bending test per ASTM D198-15 (ASTM International 2015). Values were adjusted to a common moisture content of 15 percent per ASTM 1990-16 (ASTM International 2016).
[d] Static MOE value from static bending test per ASTM D198-15. Values were adjusted to a common moisture content of 15 percent per ASTM D1990-16.
[e] Dynamic MOE from Fibre-gen's Direct HM200. Values were adjusted to a common moisture content of 15 percent per ASTM D1990-16.
[f] Dynamic MOE from Metriguard's E-computer device (Model 340). Values were adjusted to a common moisture content of 15 percent per ASTM D1990-16.

1918, Wilson 1921, Senft and Angleton 1962, Forest Products Laboratory 2010). The correlation found in the current study is stronger than the correlation of –0.296 reported by Senft and Angleton (1962).

2. When the data were broken out into grades, the correlation between grain angle meter reading and MOR got progressively stronger as the grade went down. This could be (at least partially) the result of the co-occurrence of steeper grain angles and larger knots. As the grain approaches a knot, it deviates around it. Larger grain deviations commonly occur near larger knots. In those cases, the lumber is weakened in two ways—first by the grain angle deviation itself, and then again by the presence of the knot. (Since the grain of the knot runs at an angle oblique or perpendicular to the longitudinal axis of the lumber, it contributes little to bending strength at that location, much like a hole.) Lumber with larger knots is typically assigned a lower grade. In this way, the co-occurrence of a larger knot could amplify and confound the negative effect grain angle deviation has on bending strength, contributing to the increase in the correlation between grain angle and MOR as grade decreases.
3. Among the three measures of MOE taken, the correlation between MOE-stat and the grain angle meter reading for the mill-run lumber was the strongest (–0.314) followed by Dir-E (–0.249) and Ecomp-E (–0.251).

Since the correlation between grain angle meter reading and bending strength explains approximately 18 percent (r^2) of the variance in the mill-run data and approximately 21 percent (r^2) in the lower-grade materials, its utility as a supplementary nondestructive method in lumber production lines should be considered. The following modifications could improve its suitability to this end.

Table 2.—Pearson's bivariate correlations (r) between grain angle[a] and modulus of rupture (MOR)[b] in graded lumber.

	Select structural	No. 1 grade	No. 2 grade	No. 3 grade	Low grade
Pearson correlation	−0.231**[c]	−0.286**	−0.367**	−0.457**	−0.458**
Significance (2-tailed)	0.001	0.002	<0.001	<0.001	<0.001
N	209	115	393	301	380

[a] Value from Metriguard grain angle meter Model 511.
[b] MOR value from a third-point static bending test per ASTM D198-15 (ASTM International 2015). Values were adjusted to a common moisture content of 15 percent per ASTM 1990-16 (ASTM International 2016).
[c] ** Correlation is significant at the 0.01 level (2-tailed).

The device currently has no automated way to capture the highest grain angle reading over a given span. Accordingly, the operator needs to watch the digital display closely and remember the highest reading. This could likely result in a fair amount of human measurement error. If the machine were equipped with a setting to automatically capture the highest angle measured over a span, it could reduce this source of human error and possibly improve the correlation between grain angle reading and mechanical properties.

Another potential source of error is due to the fact that the device has no guide that keeps the meter parallel to the sides of the lumber. As such, inadvertent bending of the operator's wrist could introduce error into the grain angle readings. To reduce this source of measurement error, the manufacturer might consider making an edge guide attachment that would ensure the device moves in a direction parallel to the length of the lumber. This, too, could improve the correlation between grain angle reading and mechanical properties.

As a next step, the authors plan to incorporate these grain angle data into a large multiple regression analysis along with the other variables collected in this mill-run lumber project to determine to what extent it improves the R^2 on existing and new models.

Conclusion

The results of the correlation analysis in this technical note offer new insight in two areas. First, for the mill-run data, it showed that the correlation between grain angle and MOR was –0.420. To the authors' knowledge, this is the first published assessment of the relationship between grain angle and bending strength in a full, mill-run population of commercially available full-size southern pine lumber. Second, in respect to the relationship between grain angle and MOR among the individual grades, it showed that the correlation got progressively stronger as the grade went down. This suggests that the Metriguard Model 511 might have potential, in an industrial setting, to provide supplementary nondestructive data that could be more useful for assessing bending strength in lower-grade lumber.

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