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How Variability in OSB Mechanical Properties Affects Biological Durability Testing

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Summary

Loss in bending strength of wood has been shown to be a more sensitive measure of decay than is weight loss. Using modulus of rupture as the decay criterion is problematic for oriented strandboard (OSB) because of variation in mechanical properties due to particle orientation and size. Moreover, the small specimen size required for such tests increases the variance in mechanical properties. This study compared the variance in bending strength of ASTM D1037 standard-sized specimens and small specimens from two samples of commercial OSB. The small specimens were found to have a significantly higher level of variance in bending strength than the standard-sized specimens. A simple method of sorting the specimens based on strand orientation on the tensile surface significantly reduced the level of variance measured. The effects of differing levels of variance on the size, design and limitations of the experimental study are presented.

Introduction

The durability of wood and wood-based products has traditionally been evaluated using loss in dry weight as the decay criterion. Many standard methods use this criterion, such as ASTM 2017 (ASTM 1998), EN113 (British Standards Institution 1981) and ENV 12038 (British Standards Institution 1998). However, research has shown that loss in the bending strength or modulus of rupture (MOR) of wood is a more sensitive measure of decay, particularly early decay, than is weight loss (Wilcox 1978; Winandy and Morrell 1993; Kim *et al.* 1996; Curling *et al.* 2000). A method has been developed for evaluating the fungal durability of wood specimens using MOR as the decay criterion (Curling *et al.* 2000). However, the testing of composite board materials with this method has raised the question of how the variability of MOR shown by small test specimens affects test results. The MOR values of composite materials vary as a result of particle composition, orientation and size. These factors are critical in strength-based decay tests but not in weight-based tests.

Variance in bending properties of oriented strandboard (OSB) test specimens is known to be correlated with the size of the wood elements (*e.g.,* strands) that constitute the material and to be inversely related to test specimen size (McNatt and Superfesky 1984; Geimer *et al.* 1999). Variability in OSB strength values can be estimated for ASTM D1037 (ASTM 1996) standard-sized $11 \times 75 \times 300$ mm specimens (McNatt and Superfesky 1984; McNatt 1984, 1986), but variability in strength for the smaller $11 \times 25 \times 300$ mm specimens used for decay tests is not known. These specimens may show considerably greater variation in strength than do standard-sized specimens, which is likely to be related to the positioning and orientation of strands in that portion of the test specimen in which maximum bending moment is developed (Laufenberg 1984; McNatt 1984).

When analyzing changes in bending strength, variance in the data must be taken into account. Higher levels of variance decrease the sensitivity of the experiment by increasing the minimum difference in bending values required for the difference to be statistically significant. The methodology developed for evaluating the decay resistance of solid wood specimens involves the use of matched wood specimens (Curling *et al.* 2000). However, for tests of composite board materials, there are no recognized means for matching test specimens. The number, orientation and size of surface particles are readily observable and are factors known to influence the strength of wood composite boards. We anticipated that sorting test specimens on the basis of surface strand composition, size and orientation might allow for some degree of matching, thus reducing variance, although it was unknown to what extent this would prove viable.

Methods

Samples of commercial southern pine OSB panels were obtained from two different suppliers in the Piedmont area of Georgia and the Mississippi Delta, USA (designated as samples A and B). The panels consisted entirely of southern pine strands. Each sample consisted of fifteen $2.4 \times 1.2 \times 0.01$ m panels.

Test specimens were taken from five panels selected at random from each sample. To remove edge effects, strips (250 mm) were removed from each (longitudinal and horizontal) edge.

Fourteen strips, alternating between 25 mm (the desired test size) and 75 mm (the size specified by ASTM D 1037) in width were cut from each board parallel to the 2.4 m direction. The strips were cut into 320 mm long specimens. One hundred specimens 25 mm wide and fifty specimens 75 mm wide from each sample were then tested using a four-point bending test (third-point loading using a load head span of 270 mm and loading rate of 1.25 mm/min) to determine MOR (Winandy and Morrell 1993; Curling *et al.* 2000). During testing, specimens were discarded if the failure occurred outside the middle third of the test span or if the failure was other than tensile failure.

The 25 mm specimens were visually sorted into six categories based on strand distribution and orientation on the tension surface in the middle third of the span, which corresponds to the area of greatest bending moment. A number of visual characteristics were evaluated so that one specimen could be placed in more than one category. The 75 mm specimens were not categorised.

Sorting categories were based on the following criteria:

1) Unaligned – The majority of strands showed no general or uniform alignment in any direction. 2) Aligned – The majority of strands showed a general or uniform alignment in one direction. This group was further divided into two subcategories: 2a) Angled alignment – The majority of strands were aligned in a direction not parallel (*i.e.*, $\geq 30°$ off the long axis) to the length of the specimen. 2b) Parallel alignment – The majority of strands were aligned parallel (*i.e.*, $< 30°$ off the long axis) to the length of the specimen. 3) Single strand – A single strand accounted for the majority ($\geq 80\%$) of the area of maximum bending moment. 4) Multiple strand – The area of maximum bending moment contained multiple strands. Examples of these categories are shown in Figure 1.

Analysis

The mean bending strength, variance and standard deviation were determined for each category. To compare test data with previously published data, the coefficient of variation for the specimens was also calculated as

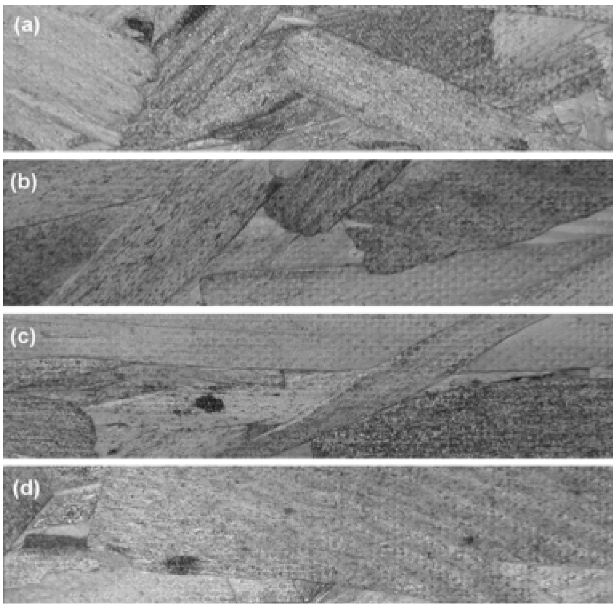

Fig. 1. Examples of sorting categories for 25 mm specimens: (a) unaligned, (b) angled alignment, (c) parallel alignment, (d) single strand. Specimen (a) would also fit into the multiple strand category.

$$Cv = \frac{s}{x} \times 100 \qquad (1)$$

where Cv = coefficient of variation, S = standard deviation of bending strength and x = mean of bending strength.

Results

Differences between samples

The mean, standard deviation and variance of MOR for each sample (A and B) and for both 25 and 75 mm wide specimens are given in Table 1. The differences in the variance between the 25 and 75 mm specimens were tested using an F-test and found to be statistically significant at $p \leq 0.10$ (sample A) and $p \leq 0.05$ (sample B). For both samples, the MOR of the 75 mm specimens was significantly higher (t-test, $p \leq 0.05$) than that of the 25 mm specimens.

Effect of sorting

Table 2 shows the distribution of the specimens in the visual assessment categories. The mean, standard deviation, mean variance, and coefficient of variation of MOR of the specimens in each category are shown in Tables 3 and 4.

For sample A, statistical analysis (F-test) showed that the variance in bending strength of the 25 mm speci-

Table 1. Modulus of rupture of OSB specimens[a]

Group	n	Mean MOR (MPa)	Standard deviation	Variance (%)	COV (%)
A					
25 mm	83	22.6	6.5	41.8	28.7
75 mm	41	26.8	5.2	26.8	19.3
B					
25 mm	92	21.7	4.2	17.5	19.2
75 mm	46	26.3	2.6	6.9	10.0

[a]COV is coefficient of variation.

Table 2. Distribution of 25 mm wide specimens in visual assessment categories

Category	Distribution (%)	
	Sample A	Sample B
Discard[a]	16	8
Unaligned	40	51
Aligned	44	41
Angled	14	19
Parallel	30	22
Single strand	53	44
Multiple strand	31	48

[a]Specimens were discarded when failure during the bending test occurred outside the area of maximum bending moment. Data from these specimens were not used in the analysis.

mens in the multiple strand category was significantly ($p \leq 0.05$) lower than that of specimens in all other categories with the exception of the parallel-aligned category. Bending strength of the parallel-aligned specimens was significantly lower than that of specimens in the unsorted and angled-aligned categories.

For sample B, statistical analysis (F-test) showed no statistically significant ($p \leq 0.1$) differences in the variance of the bending strengths of the sorted 25 mm specimens.

Table 3. Modulus of rupture of 25 mm specimens in sample A

Category	Mean MOR (MPa)	Standard deviation	Variance (%)	COV (%)
Unsorted	22.60	6.50	41.80	27.83
Unaligned	21.51	6.20	38.46	28.83
Aligned	24.16	6.33	40.08	26.19
Angled	27.69	7.28	53.00	26.29
Parallel	22.52	5.18	26.87	23.01
Single strand	23.94	7.08	51.10	29.54
Multiple strand	21.08	4.48	20.09	21.25

Table 4. Modulus of rupture of 25 mm specimens in sample B

Category	Mean MOR (MPa)	Standard deviation	Variance (%)	COV (%)
Unsorted	21.70	4.17	17.45	19.21
Unaligned	20.80	3.81	14.54	18.33
Aligned	22.91	4.36	18.99	19.02
Angled	23.30	4.55	20.73	19.53
Parallel	22.56	4.25	18.13	18.87
Single strand	22.83	4.16	17.35	18.24
Multiple strand	20.74	3.97	15.77	19.14

Table 5. Level of significance of differences in variance between sorted 25 mm and unsorted 75 mm specimens[a]

Category	Significance of difference[b]	
	Sample A	Sample B
Unsorted	0.10	0.05
Unaligned	NS	0.05
Aligned	0.10	0.05
Angled	0.05	0.05
Parallel	NS	0.05
Single strand	0.05	0.05
Multiple strand	NS	0.05

[a]F-test at $p \leq 0.05$.
[b]Levels of significance were $p \leq 0.10$ and $p \leq 0.05$. NS designates not significant.

Comparison of 75 mm and 25 mm specimens

Multiple F-test analyses were performed to determine the significance of differences in the variance of bending strengths of the 25 and 75 mm specimens; the results are shown in Table 5. The variance in bending strength of the unsorted 25 mm specimens was significantly higher than that of the 75 mm specimens. Therefore, any result of no significant difference between any 25 mm category and the 75 mm specimens indicates that sorting into that category reduced the variance in bending strength of those specimens in a value equal to that of the 75 mm specimens.

Comparison of test results with published data

To determine whether the variance in bending strength resulting from our analysis is comparable with that measured in other studies, the coefficients of variation of the data were compared to those of previously published data (Table 6).

Discussion

Effect of sorting

The MOR of the 75 mm wide specimens was significantly ($p \leq 0.05$) higher than that of the 25 mm wide specimens. This may be due to the larger number of strands in the wider specimens, which caused a load sharing effect within the area of greatest bending moment.

The data also show a significant ($p \leq 0.05$) difference in variance in MOR between the samples. For both specimen widths, greater variance occurred in sample A compared with sample B. It is also apparent that using unsorted 25 mm specimens increased the level of variance. The differences in variance between the 25 and

Table 6. Comparison of coefficients of variation of test data and previously published data

Source	Material	Test type	Coefficient of variation for two sizes of specimens	
			75 mm	25 mm
Current study	Commercial OSB, A	4 point	19.27	27.83
Current study	Commercial OSB, B	4 point	9.99	19.21
McNatt (1984)	Commercial OSB	3 point	26.00	–
McNatt *et al.* (1990)	Commercial OSB	3 point	19.30	–
McNatt *et al.* (1990)	Commercial OSB	3 point	29.18	–
McNatt *et al.* (1992)	Lab OSB	3 point	15.40	–
McNatt *et al.* (1992)	Lab OSB	3 point	18.60	–

75 mm specimens were significant at $p \leq 0.05$ for sample B but only at $p \leq 0.1$ for sample A.

In this study, the coefficients of variation (COVs) for the 75 mm specimens from sample A fell within the range shown in previously published data (Table 6). However, the COVs of sample B were considerably lower than that previously reported. In comparison, the COVs of the 25 mm specimens in sample A were at the higher end of the previously published range and those of sample B were in the middle of the range.

Sorting had varying effects on specimen variance. For sample A, sorting specimens into the parallel-aligned and multiple strand categories significantly reduced variance compared to that of unsorted specimens. In addition, sorting specimens into these categories reduced the variance such that the difference between these specimens and the 75 mm specimens was no longer significant. When comparing COVs, it is apparent that sorting sample A into the parallel-aligned and multiple strand categories lowered the calculated variance into the middle of the range of variance values determined from previous data. For sample B, where the initial variance was significantly lower than that of sample A (and that in other published studies), sorting lowered the variance but not to any significant level. In addition, for all categories of sorted specimens in sample B, the variance was still significantly ($p \leq 0.05$) higher than that calculated for the unsorted 75 mm specimens in this sample.

Therefore, where the material had higher levels of variance (*e.g.*, sample A), sorting reduced that variance to acceptable levels, allowing the use of the small (25 mm wide) specimens. This sorting method would be appropriate for studies evaluating the comparative effect of some treatment or process on mechanical properties. However, such a method using small specimens would not be appropriate in studies intended to determine the basic mechanical properties of panels.

Influence on experimental design

The level of variance in experimentally derived data can affect the size and complexity of the study. One important factor is the number of replicates required; enough replicates must be used to make the results statistically valid, but the study must also be kept practical. The number of samples required to statistically differentiate between results can be obtained on the basis of the standard deviation of the mean MOR of the specimens. Equation (2) (Snedecor 1961) is the formula for calculating the number of samples required to get the

Table 7. Number of replicates required to differentiate loss in MOR in sample A

Specimen	Mean	SD	Replicates required to differentiate stated MOR loss			
			10 %	20 %	25 %	30 %
75 mm	26.80	5.20	60	15	10	7
Unsorted 25 mm	22.60	6.50	132	33	21	15
Sorted 25 mm						
Unaligned	21.51	6.20	133	33	21	15
Aligned	24.16	6.33	110	27	18	12
Angled	27.69	7.28	111	28	18	12
Parallel	22.52	5.18	85	21	14	9
Single strand	23.94	7.08	140	35	22	16
Multiple strand	21.08	4.48	72	18	12	8

Table 8. Number of replicates required to differentiate loss in MOR in sample B

Specimen	Mean	SD	Replicates required to differentiate stated MOR loss			
			10 %	20 %	25 %	30 %
75 mm	26.30	2.60	16	4	3	2
Unsorted 25 mm	21.70	4.17	59	15	9	7
Sorted 25 mm						
Unaligned	20.80	3.81	54	13	9	6
Aligned	22.91	4.36	58	14	9	6
Angled	23.30	4.55	61	15	10	7
Parallel	22.56	4.25	57	14	9	6
Single strand	22.83	4.16	53	13	8	6
Multiple strand	20.74	3.97	59	15	9	7

desired level of differentiation at a confidence level of 95%:

$$n = \frac{4\sigma^2}{L^2} \quad (2)$$

where n = number of replicates, σ = standard deviation and L = allowable error.

For example, to detect a difference of 10% between control and test specimens, the maximum allowable error is 5% variation about the mean for both the control and test specimens. Combined together, this gives an error of 10%, below which no statistical significance can be attached. As the minimum level of change to be detected increases, the number of replicates increases.

Tables 7 and 8 show the number of replicates (both control and test) required to statistically detect the given change in MOR using the levels of variance previously described. For both samples, the number of replicates required for detecting a 10% change in MOR is too large to be practical. The number of replicates needed to detect 20% and 30% changes in MOR is more practicable. Table 7 further shows the benefit of sorting the samples into the parallel-aligned or multiple strand categories because of the reduction in number of replicates and/or increase in statistical detection level. Again, however, sorting had no beneficial effect on sample B (Table 8) as a result of the very low variance of the 75 mm specimens.

Conclusions

The use of 25 mm wide specimens with the four-point bending test resulted in greater variance in modulus of rupture (MOR) than did the use of standard 75 mm wide specimens. Where the variance was high (sample A), sorting the 25 mm specimens into the multiple strand or parallel-aligned category lowered their variance to that of the standard specimens, an acceptable level of variance. Although this was not the case for sample B, the levels of variance for the 25 mm specimens were within the range of values previously reported for 75 mm specimens and could therefore be considered acceptable.

The data also show that sorting to reduce variance in the bending strengths of specimens allows detection of smaller changes in bending strength. As the level of variance of a board cannot be judged without testing, sorting is recommended because it reduces variance when it is likely to be high enough to be a confounding factor.

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