The Value of Transitioning from the Lap Shear to an Internal Bond for Testing Plywood*

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Abstract

The lap shear test has been the standard for bond strength testing in plywood for years. Its goal is to predict the long-term durability of the plywood panels. This test has also been used for root cause analysis by mill quality management teams to identify issues. There are several problems with the test, two significant problems being, (1) the only bond tested is the one that is next to the veneer tested, and (2) the test is highly subjective to the accuracy of the kerfing. This paper will address the first problem, which is the larger issue. During the long-term exposure of the panel, the bond lines most likely to fail are the exposed surface or, more likely, the weakest bond. The lap shear test does not test all the bonds simultaneously, so there is no way to ensure the weakest bond is tested on each sample. The data included in this article clearly showed that there was a difference between the bond lines that would be missed in the standard lap shear test. Lastly, the main bonds tested are in the center of the panel; therefore, the result would be biased and may not be an accurate representation of how the panel would perform in the field. These deficiencies are remedied by shifting to the standard internal bond testing common in other wood products.

Lap Shear Testing

Exterior plywood panels that meet the standards for American Panel Association (APA) Product Standards 1 (PS1; APA PS1 Standard 2010) are often guaranteed for 50 years. These panels can be subjected to full exterior exposure, so the bond quality of this product is critical. To test that quality, samples are prepared by cutting them to size and then kerfing both sides of the sample to the veneer that is being tested (Fig. 1).

The samples are then subjected to accelerated aging via a vacuum-and-pressure cycle in water (discussed later). The samples are tested wet by pulling them apart in a lap shear test. The resultant samples are dried and then evaluated to see the percent of wood failure versus adhesive failure in the test (Figs. 2 and 3).

To pass the test, wood must show on 85 percent of the sample for sheathing and 80 percent for other grades. This indicates that the adhesive strength of the glue-to-wood and the cohesive strength of the glue-to-glue bonds are stronger than the wood-to-wood cohesive bond. As a bonus, a skilled person in bond reading can evaluate the bond and determine the cause of many failures, which can provide data and guidance to the mill on how to improve the bonding. The test, however, does have a major flaw because it only tests a single bond line (Fig. 4).

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Figure 1.—Kerfed sample for lap shear.

Figure 2.—Testing lap shear sample.

Figure 3.—Lap shear sample.

In the lap shear test, the other bond lines are not stressed. If the bond line tested is the weakest, then the results are valid; but if another bond is weaker, then the test does not show the true weakness of the panel. If samples are made that test each bond line, one can get a better idea of the strength of the whole panel, but this is very time consuming and still may miss weak spots in bond lines not tested in that sample.

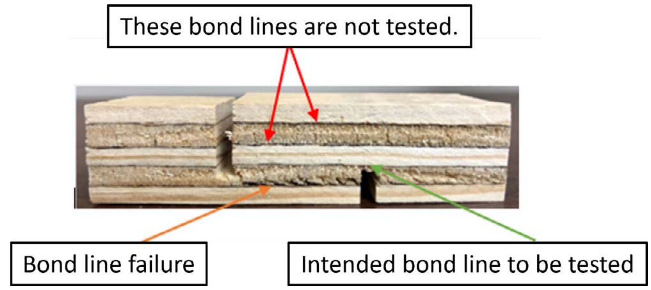

Figure 4.—Anatomy of lap shear.

Internal Bond (IB) Testing

An alternative method to lap shear is to do the same accelerated aging cycle followed by testing the sample in tension (internal bond [IB]) such that all bond lines are tested simultaneously (Fig. 5).

In IB testing all bonds are stressed at the same time and the weakest bond will fail first. This test currently is used in other wood products such as oriented strand board (OSB), particle board (PB), and medium density fiber board (MDF). The main differences between the lap shear and IB tests are the size of the sample, the mode of failure, and whether tested wet or dry. The area tested in the lap shear test is a 1-inch by 1-inch sample while the IB test is traditionally a 2-inch by 2-inch area (Fig. 6). One issue that will need to be

Figure 5.—Sample in Instron equipment.

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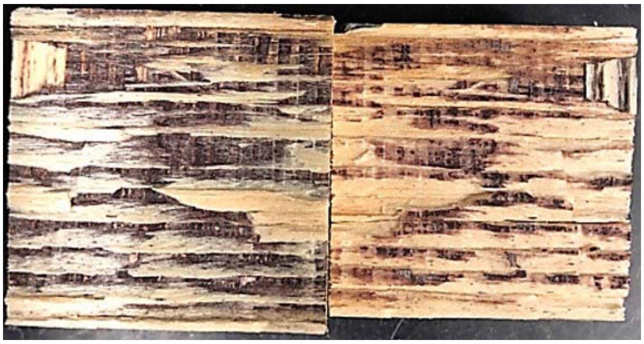

Figure 6.—Internal bond (IB) sample. After breaking the sample, the %wood failure can be determined. In this case the %wood failure would be 85%.

addressed is adjusting the aging test to get the optimum effect of the accelerated aging.

The lap shear fails in a shear mode whereas the IB fails in tension. The final main difference is the lap shear samples are tested wet and then dried before the wood failure is read. The IB samples must be dried after cycling to ensure good adhesion to the testing blocks, allowing them to be placed in the tensile fixture (Table 1). As in the lap shear test, if significant defect is found in the bond line (such as void) the sample is removed from the testing.

Materials and Methods

Panels were made in the lab as well as obtained from a local big box store. Lab panels were 5-ply, 12-inch × 12-inch × 5/6-inch. They were pressed at 315°F (157°C) for 360 seconds at 175 pounds per square inch (psi). Spread rates were 26.0 g/ft^2, double glue line (28.6 lbs/1,000 ft^2 field equivalent, single line). Store-bought conditions are unknown. Panels were then tested via lap shear and IB methodology.

Sample preparation

Lap shear sample preparation.—The samples were cut into 1-inch by $3^1/_8$-inch strips per the PS1 standard. The samples were carefully kerfed (standard kerf line is 1/8 in.) to the different veneer lines (58 kerfed to center and 38 kerfed to both the face and back). The samples were then subjected to the accelerated aging test (described later), followed by testing via the Globe tester, with head speed of 16 in/min, per the PS1 standard. The samples were then dried overnight and then the wood failures of the samples were read by a trained operator.

IB block sample preparation.—The samples were cut into 78 2-inch by 2-inch squares carefully maintaining the orientation such that the top of the panel was known. The samples underwent the accelerated aging test, (described later) and were dried overnight. They were glued to aluminum IB blocks and then tested with an Instron machine (Illinois Tool Works Inc., Glenview, Illinois), utilizing a 30-kN load cell. The speed of the test is determined by the thickness of the panel at 0.08 in/in/min. The force required to break the sample was recorded in psi, using the following calculation: IB $_{(psi)}$ = (Max load$_{(lbf)}$/width $_{(in)}$) × length$_{(in)}$, where lbf means pounds at failure. The wood failure was then read by a trained operator and the bond line at which the failure occurred was recorded.

Table 1.—Lap Shear versus Internal Bond (IB) Test Methods: Differences between the lap shear and IB test methodology.

	Lap shear test	IB test
Failure mode	Shear	Tension
Testing area	1 in. by 1 in.	2 in. by 2 in.
Sample tested	Wet	Dry

Accelerated aging test description

The standard vacuum-and-pressure test listed in PS1 was used. In this test, the prepared samples were submerged in room temperature water. They were first subjected to 29 inches of vacuum for 30 minutes to remove the air from the sample. Then the vacuum was released, and the sample was subjected to 70 psi of pressure to force the water into the wood structure. This pressure was maintained for 30 minutes and then released. The samples were removed from the water and tested according to the methods described above.

Results

Break location

Chi square.—Chi square analysis was used to determine the randomness of the location of the break. There are two center bond lines—one face, and one back bond line in a 5-ply panel; therefore, if the breaks were completely random, the ratio of breaks should be 1:2:1 (Face:Center:Back). If the ratio is statistically different from this, it would indicate that the bonds were not equivalent (Table 2).

With this chi square score, the probability that data on the location of the break are consistent with random chance is less than 0.001 percent. This analysis strongly supports that the three bonds were not of even strength. Current procedures for the lap shear test do not check every bond line, so this important fact would not have been identified without the use of IB testing.

Bayesian analysis.—The chi square analysis indicated that the break location was not consistent with the location of the breaks if they were to be completely random. However, to confirm and determine whether the breaks were preferentially not in the core, a Bayesian analysis was conducted. The experiment was treated like a Bernoulli experiment where the break was either in the core or not. A noninformative prior with the Beta distribution described by Beta (1,1) was chosen in

Table 2.—Chi Square Test Analysis: With 78 samples and the 1:2:1(F:C:B) predicted ratio gave the Expected (E) values. The resulting chi square value supports that the data were not from random breaks.

	Face	Core	Back
Observed (O)	28	22	28
Expected (E)	19.5	39	19.5
O − E	8.5	−17	8.5
$(O - E)^2$	72.25	289	72.25
$(O - E)^2/E$	3.71	7.41	3.71
$\Sigma(O - E^2/E) = 14.83$ χ^2 score with 2 degrees of freedom.			

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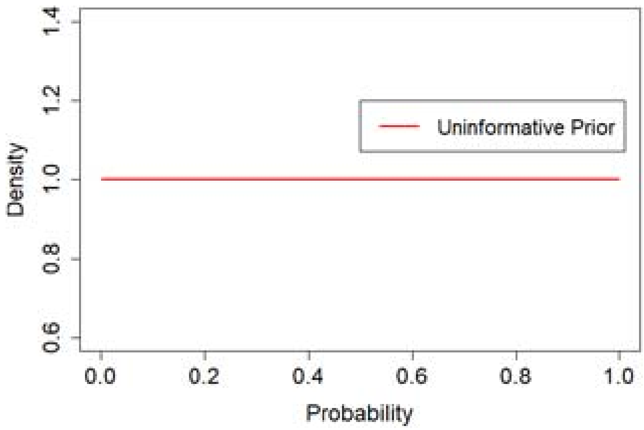

Figure 7.—Beta (1,1) prior distribution. This prior will not provide any bias to the data.

Program R (R Studio [R Core Team 2016] in Anaconda Environment [Anaconda Software Distribution 2021]) and was used to evaluate the distributions. Figure 7 is the Beta (1,1) prior distribution, indicating this prior will not provide any bias to the data.

The equation to determine the approximate mean of the posterior distribution (Boone 2021a) is given below:

$$\text{Beta distribution} = (23, 57) \tag{1}$$

$$p(\theta) = \frac{\propto + \sum_i^n x_i}{\propto + \beta + n} \mp Z^2_{\frac{E}{2}} \sqrt{\frac{(\propto + \sum_i^n x_i)(\beta + n - \sum_i^n x_i)}{(\propto + \beta + n^2)(\propto + \beta + n + 1)}} \tag{2}$$

The value of the variables in the equation are the following:

$$\propto = 1, \beta = 1, n = 78, \sum_i^n x_i = 22 \tag{3}$$

$$p(\theta) = \frac{1 + 22}{1 + 1 + 78} \mp Z^2_{\frac{E}{2}} \sqrt{\frac{(1 + 22)(1 + 78 - 22)}{([1 + 1 + 78]^2[1 + 1 + 78 + 1])}} \tag{4}$$

$$p(\theta) = \frac{23}{80} \mp 1.96 \sqrt{\frac{(23)(57)}{([80]^2[81])}} \tag{5}$$

$$p(\theta) = \frac{23}{80} \mp 1.96 \sqrt{\frac{1,311}{518,400}} \tag{6}$$

$$p(\theta) = 0.29 \mp 1.96 \times 0.5 \tag{7}$$

$$p(\theta) = 0.29 \mp 0.098 \tag{8}$$

The percent of the breaks in the center are 29 percent ± 9.8 percent for the 95 percent credible interval based on normal distribution. This value is the percent of breaks that occurred on a set bond line. The range is somewhat large because that is controlled by many random factors such as wood roughness; but, this should be by definition random if the expected value is well outside of the obtained range, so this is strong indication that a systematic variation has occurred.

The credible interval can also determined using a Beta distribution given by the equation (Boone 2021b) below. The values of the variables are the same.

$$\text{Beta distribution} = \left(\propto + \sum_i^n x_i, \left[\beta + n - \sum_i^n x_i\right]\right) \tag{9}$$

$$\text{Beta distribution} = (1 + 22, [1 + 78 - 22]) \tag{10}$$

$$\text{Beta distribution} = (23, 57) \tag{11}$$

Figure 8 is the posterior distribution for the frequency of the center breaks.

The credible interval (see Table 3) for the center breaks also does not include 50 percent (the expected result for completely random breaks), so this strongly indicates that the breaks were not random. A similar analysis on the face and back was conducted and the results are listed in Table 3.

The results support there being a difference between the obtained results and the expected results. The center bond lines broke less frequently than expected. This indicates that these bonds were weaker than the bonds in the center.

IB strength and wood failure results

Figure 9 shows wood failure and strength of the IB samples. The ANOVA analysis of the wood failure and bond strength shows no statistical difference between the bond lines. The bond line that breaks in this test will be the weakest bond and, because there is inhomogeneity in the

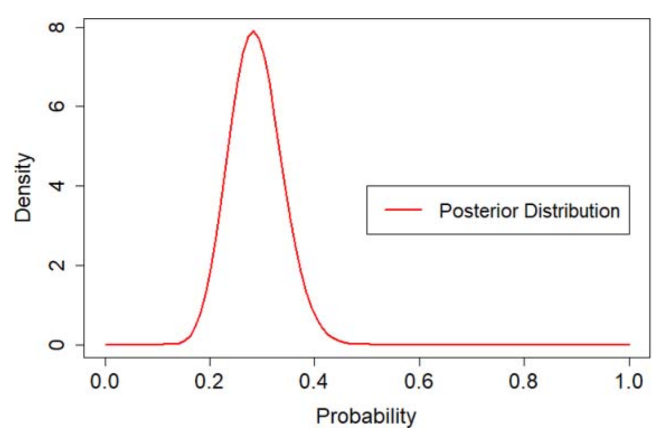

Figure 8.—Posterior distribution for the center bond data.

Table 3.—Beta Distribution from R: The credibility interval is based on the beta distribution and is slightly shifted from the confidence interval from the other analysis because the earlier analyses were based on a normal, not beta, distribution.

	Mean %	95% Credibility Interval
Face	36.1	26.1–50.5
Back	36.1	26.1–50.5
Centers	28.6	19.4–39.1

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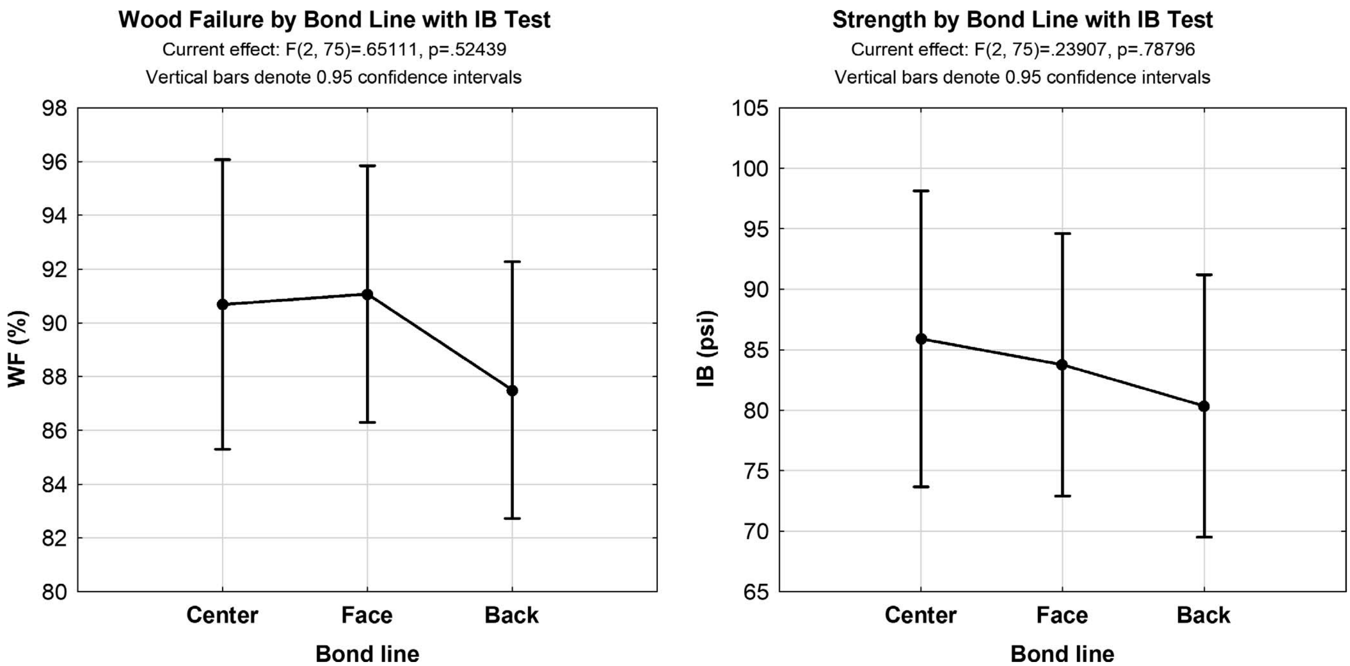

Figure 9.—Wood failure and strength of the IB samples.

wood, even the center bonds will have weak spots at times and breaks will occur at those locations.

Lap shear test

Figure 10 shows the lap shear wood failure results. The ANOVA analysis indicated at the 95 percent confidence level that there was a difference between the different bond lines in wood failure. A subsequent Scheffe test indicated that the difference was between the center glue lines and the back.

In this study, multiple samples were kerfed such that different bond lines were tested. The samples were randomly placed into the different groups for testing, which allowed for the difference in bond quality to manifest in the results. The study showed that the center bond line had better wood failure than the back.

Difference in wood failure between lap shear and IB test

Figure 11 shows wood failure by test method. The ANOVA analysis indicated at the 95 percent confidence

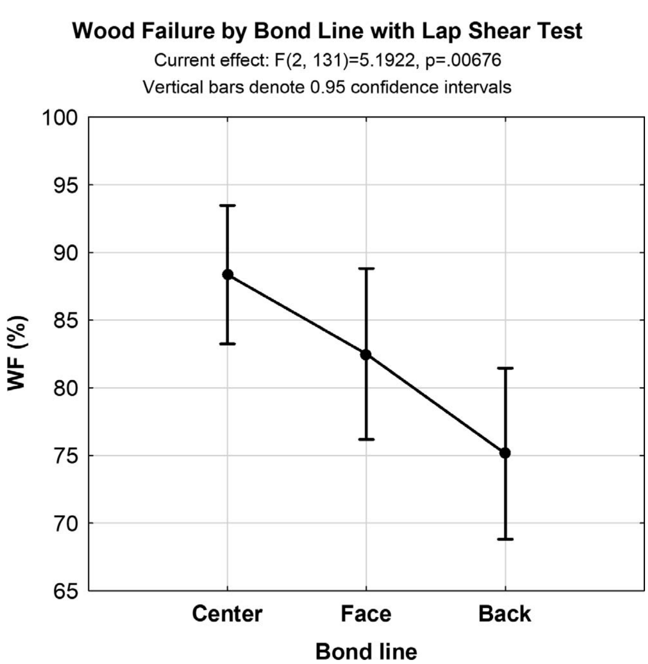

Figure 10.—Lap shear wood failure results.

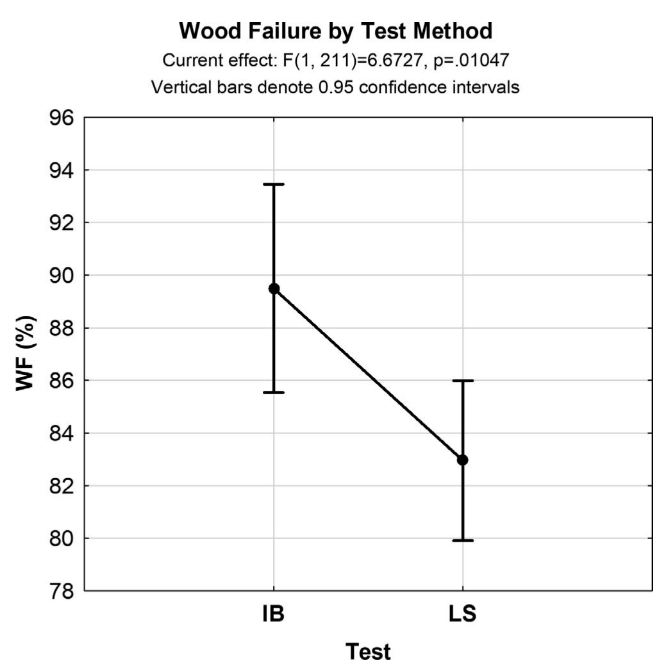

Figure 11.—Wood failure by test method.

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level that there was a difference in the wood failure by the different test methods. A subsequent Scheffe test indicated that the IB test had higher wood failure values than did the lap shear test. The average of the wood failure for the IB test was 89.5 percent while the overall wood failure by the lap shear test was 82.9 percent, which was a statistical difference.

Conclusions

This study demonstrates the inherent weakness of the lap shear test. It only tests the bond designated by the kerfing; therefore, it may not test the weakest bond in that section of the panel. The center bond lines were shown to break less frequently than they should have, indicating a better bond. This was shown in the lap shear test but only when the center bonds were the one that were stressed in the testing. The nature of bonding is such that one cannot always guarantee which bond will be weakest, so a test that simultaneously tests all bond lines is the best way to determine overall panel quality. Even if one tested all glue lines using the lap shear test, the weak spot may be biased to a glue line; therefore, there is still a degree of randomness, and the test may still miss issues. Also, this test is done perpendicular to the bond instead of along the bond, so the IB is not affected in the same way as lap shear by factors such as grain angle and lathe checks. One issue noted was that the wood failure of the IB samples was higher than that of the samples tested by lap shear. There could be several factors involved in that fact. One could be that the effect of the accelerated aging may be greater on the smaller lap shear sample. A second factor is that the larger sample size of the IB block may not be as affected by a small bond defect. Finally, there may be an effect from the different testing mode—shear versus tension. However, the results do still follow the same trends. Modification of the accelerated aging conditions would likely eliminate the difference. With the advantages listed in this work—such as ensuring the weakest bond line is tested, the added information from the bond strength, and the reducing the effect of factors like lathe checks and grain angle—this would be a better test to use as the standard for plywood.

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