RATIONALIZING INTERNAL BOND AND THICKNESS SWELL TEST SPECIMEN SIZE[1]

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ABSTRACT

A criterion for rationalizing internal bond and thickness swell test specimen size of wood composite panels is presented, based on the concept of horizontal density distribution. The criterion utilizes the characteristic curve of the horizontal density variation relative to the specimen size. Using specimen sizes within the less sensitive range of the characteristic curve, stable and less variant internal bond and thickness swell results were obtained. Using this criterion for studying the specimen size effect, an equal specimen size of 100 mm × 100 mm is suggested for the internal bond and thickness swell tests of the commercial waferboard material studied. The criterion is recommended for future testing standard development for internal bond and thickness swell specimen size designations.

Keywords: Horizontal density distribution, internal bond, specimen size, standard, thickness swell, waferboard, wood composites.

INTRODUCTION

Present testing standards for wood composite panel materials in North America specify a specimen size of 50 mm × 50 mm for the internal bond (IB) and 150 mm × 150 mm for the thickness swell (TS) tests (Canadian Standard Association 1993; American Society for Testing and Materials [ASTM] 1994). This specification of the specimen sizes was based on the ASTM standard D 1037-49T (1949), which was originally intended for fiber-based panels. The deficiency of using these specimen sizes to evaluate IB and TS for current structural panels has been recognized (McNatt 1984). For example, the variation in IB for waferboard/OSB (oriented strandboard) may be unnecessarily large when evaluated by the 50-mm × 50-mm specimens.

Another drawback of the current specimen size designation is the unequal specimen sizes for IB and TS tests, even though these two properties are both measuring product performance in the same direction, perpendicular to the board surface. Recently, a TS specimen size change from 25 mm × 25 mm to the equivalent IB specimen size of 50 mm × 50 mm has been recommended in Europe for furniture grade particleboard (Heimeshoff 1991).

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TABLE 1. *Number of specimens used for internal bond and thickness swell tests at respective specimen sizes.*

Internal bond		Thickness swell	
Specimen size (mm × mm)	Sample size	Specimen size (mm × mm)	Sample size
15.7 × 15.7	120	20.6 × 20.6	48
25.0 × 25.0	100	29.0 × 29.0	48
42.3 × 42.3	100	35.9 × 35.9	44
48.2 × 48.2	85	41.8 × 41.8	46
54.1 × 54.1	75	50.1 × 50.1	32
75.0 × 75.0	75	75.0 × 75.0	18
100.6 × 100.6	70	100.2 × 100.2	18
150.3 × 150.3	62	149.8 × 149.8	23
199.7 × 199.7	29		

This anticipated transition in Europe suggests that equal IB and TS specimen size should also be considered in North American practice.

To address these concerns, a criterion to rationalize wood composite test specimen size needs to be developed. The structural phenomenon of horizontal density distribution (HDD) involves a specimen size effect (Xu and Steiner 1995), which may provide an insight into development of a criterion for IB and TS specimen size designation.

MATERIAL AND METHODS

Sixteen commercial aspen waferboard panels measuring 1.22 m × 0.6 m each were procured (board density: 670 kg/m^3; board thickness: 11 mm). Four panels were used in a previous study to examine the HDD phenomenon (Xu and Steiner 1995); the remaining twelve panels were used in the present study.

IB and TS specimens were randomly chosen from these twelve panels (Xu 1993), and the number of specimens at respective specimen sizes is listed in Table 1. A series of water exposure times of 2, 6, 12, 24, and 48 h were used for the TS test. ASTM D 1037-93 (ASTM 1994) was followed to determine other testing conditions for the IB and TS evaluations.

RESULTS AND DISCUSSION

Internal bond

The strength of a material follows the Weibull distribution if the failure of the material is governed by the weakest link (Weibull 1939).

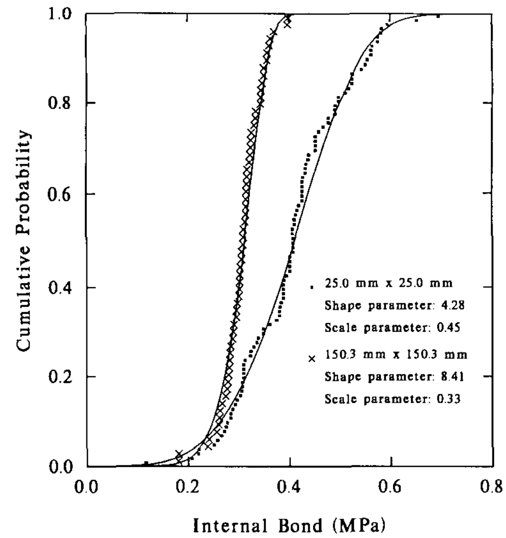

FIG. 1. Two parameter Weibull distribution fit to internal bond determined at specimen sizes of 25.0 mm × 25.0 mm and 150.3 mm × 150.3 mm.

The Weibull distribution has been applied to characterize strength properties of many materials, including that of wood (Madsen 1992). The Weibull distribution can also be used to model IB behavior of wood composites as demonstrated by the good agreement between the two parameter (2-P) Weibull model and the cumulative distribution of IB data, for specimen sizes of 25.0 mm × 25.0 mm and 150.3 mm × 150.3 mm, respectively (Fig. 1).

One property of the Weibull distribution is that the variation of strength decreases as the testing volume (V) increases. For the 2-P Weibull distribution, Weibull (1939) showed that the standard deviation (δ) of strength could be expressed as

$$\delta = m(I_{k/2} - I_k{}^2)^{0.5}/V^{1/k} \qquad (1)$$

in which, k and m are the shape and scale parameters, respectively, in the Weibull distribution formula, while $I_k = \int_0^\infty e^{-z^k}\,dz$ and $I_{k/2} = \int_0^\infty e^{-z^{k/2}}\,dz$.

Applying Eq. (1) to the IB data, the following equation is obtained,

$$\delta = mt^{-1/k}(I_{k/2} - I_k{}^2)^{0.5}/A^{1/k} \qquad (2)$$

as V = tA, A is the cross-sectional area (spec-

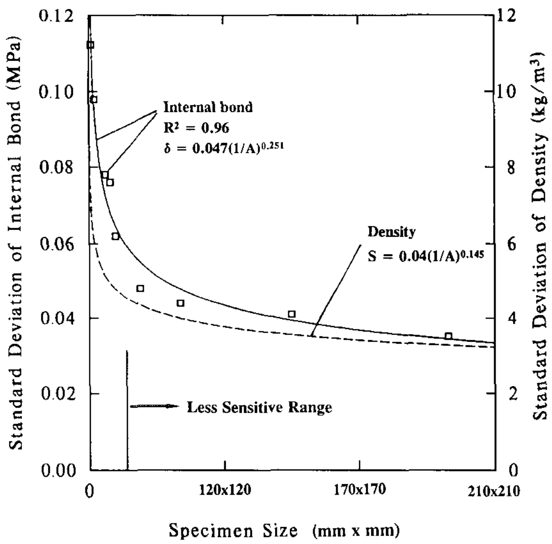

FIG. 2. Influence of specimen size on standard deviation of internal bond and on standard deviation of horizontal density.

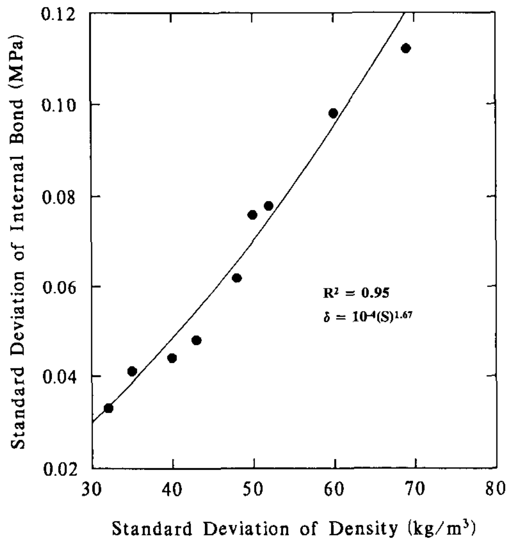

FIG. 3. Relationship between standard deviation of density and standard deviation of internal bond.

imen size) of the IB specimens, and t is the thickness of the specimens (board thickness). Equation (2) can be simplified as

$$\delta = e(1/A)^f \quad (3)$$

where, $e = mt^{1/k}(I_{k/2} - I_k^2)^{0.5}$, and $f = 1/k$. Both e and f are to be determined by the fit (regression) analysis of the experimental data. The fit of Eq. (3) on IB data determined at several specimen sizes is shown in Fig. 2. A good match was evident between the experimental data and the model equation.

Standard deviation (S) of horizontal density is also specimen-size-dependent and decreases as specimen size increases; an expression as

$$S = c(1/A)^b \quad (4)$$

was developed to model this relationship. The characteristic curve of the variation of horizontal density in relation to the specimen size of the waferboard is also shown in Fig. 2. The less sensitive range was discussed in a previous study and was determined to be at specimen sizes larger than 50 mm × 50 mm − 70 mm × 70 mm for the waferboard (Xu and Steiner 1995).

By combining Eqs. (3) and (4), a relationship between the mechanical property (IB) and the physical property (density) was obtained,

$$\delta = \alpha(S)^\beta \quad (5)$$

in which, $\alpha = ec^{1/\beta}$ and $\beta = f/b$. As expected, a good agreement was obtained between the theoretical model [Eq. (5)] and the experimental observations (Fig. 3).

Thus, variation of IB decreases as variation of HDD decreases. Three factors were recognized as contributing to HDD: variation in wood density, nonuniformity of the forming process, and the presence of voids (Suchsland and Xu 1989). While the density variation at specimen sizes smaller than the less sensitive range was mainly attributed to the presence of voids, the smaller density variation within the less sensitive range reflected forming nonuniformity; the influence of voids and the variation in wood density was believed to be minimized within the less sensitive range (Xu and Steiner 1995). Accordingly, the variation of IB evaluated within the less sensitive range was small and reflected mainly the influence of forming nonuniformity. For example, approximately 40% reduction in standard deviation of IB resulted if a specimen size of 100 mm × 100 mm (within the less sensitive range) is

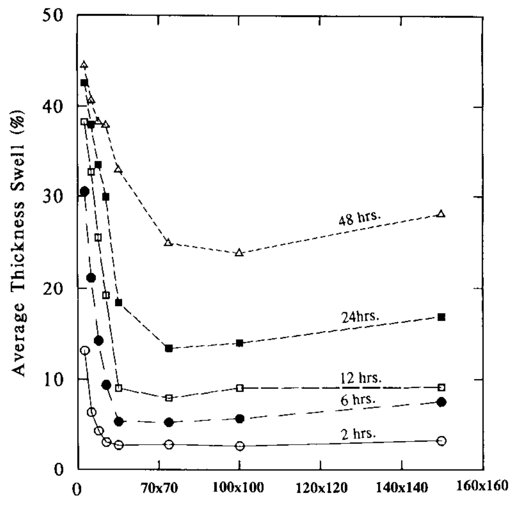

FIG. 4. Influence of specimen size on average thickness swell for five water exposure times.

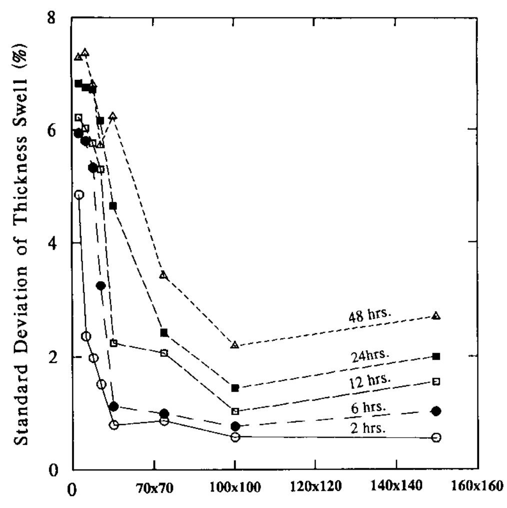

FIG. 5. Influence of specimen size on standard deviation of thickness swell for five water exposure times.

used rather than the current standard specified specimen size of 50 mm × 50 mm for the waferboard. Further increase in specimen size within the less sensitive range did not significantly benefit the variation reduction (Fig. 2).

The merit of selecting IB specimen size within the less sensitive range can also be explained physically. Since voids are not main factors in controlling density variations within the less sensitive range, the influence of this structural feature (voids) on IB is also likely minimized. However, if IB is evaluated at smaller specimen sizes, a direct testing of large voids existing within some IB specimens would result in large variations of IB values. This concept of avoiding the overwhelming influence of strength-degrading features has been applied in lumber engineering studies, where the lumber specimens tested are considerably larger than the strength-reducing defects contained in the lumber (knots and localized slope of grain) (Madsen 1992).

The IB test has been used widely for quality control, product development, and product comparisons. The reduced variation by using a specimen size within the less sensitive range would be beneficial for all these purposes. For example, reduction in sample size, confidence improvement in experimental data, and making fewer statistical errors are all associated with reduced variations (Fisher 1950).

Average IB was also found to decrease as the specimen size increased. However, this size dependence was explained through the Weibull (1939) theory and was not directly related to HDD by the same mechanism (Xu 1993).

Thickness swell

Similar to the HDD phenomenon and IB property, the average TS and the standard deviation of TS for several water exposure times showed similar response to the specimen size changes (Figs. 4 and 5). Average TS decreased as the specimen size increased when the specimen size was smaller than the less sensitive range and leveled off within the less sensitive range. One explanation of this specimen size dependence was probably due to water being absorbed more readily into the specimen when specimen size was small compared to large specimens; rapid swell occurred for small specimens since water uptake is a prerequisite for the thickness release.

One model concept based on the horizontal density distribution phenomenon also provided insight into this specimen size response.

According to Suchsland (1973), high density areas in a TS specimen tend to swell more, whereas low density areas swell less and tend to restrain the swell of the former. This mutual opposing nature may also have partly led to the TS behavior (Fig. 4). For example, when the specimen size was within the less sensitive range, individual TS specimens were not considerably different as far as their horizontal density characteristic was concerned; uniform TS resulted across different specimen sizes accordingly. When the specimen size was smaller than the less sensitive range, individual specimens swelled more freely due to the diminution of mutual restraint of high and low density areas within individual specimens, which might have contributed to the increased overall TS values.

The behavior of the standard deviation of TS in relation to the specimen size can also be explained through the same concept (Suchsland 1973). A small and uniform variation of TS resulted within the less sensitive range, since density variation (structural characteristics) among TS specimens was also small and not sensitive to the change of specimen size. When specimen size was smaller than the less sensitive range, variation of TS increased as individual specimens swelled more freely, and large differences of TS values resulted among specimens due to the large differences in their densities.

Present TS specimen size in North America is 150 mm × 150 mm, which falls within the less sensitive range for the waferboard. However, this size can be reduced to 100 mm × 100 mm to equal the proposed IB specimen size for the waferboard as the mean and the standard deviation of TS at these two specimen sizes were similar (Figs. 4 and 5). This reduction of specimen size can reduce the size of the water soaking tank or other TS testing containers substantially, especially if a large number of TS tests are desired. The same mechanism in controlling the variations of both IB and TS justifies an equal testing size, which will also make specimen preparation quicker, easier, and safer (it is more difficult and more risky to prepare 50 mm × 50 mm IB specimens than 100 mm × 100 specimens).

CONCLUSIONS

Similar to the horizontal density distribution phenomenon, internal bond and thickness swell test results demonstrated a profound specimen size effect. A criterion for designating an equal specimen size for internal bond and thickness swell tests was developed. This criterion should be considered for future testing standard development. The main findings of this study are:

1. As predicted by the Weibull theory, variation of internal bond decreased as the specimen size increased. A relationship between variation of internal bond and variation of horizontal density was established.
2. The mean and the standard deviation of thickness swell decreased as the specimen size increased below the less sensitive range, and leveled off within the less sensitive range.
3. A specimen size of 100 mm × 100 mm is recommended for both the internal bond and thickness swell tests for the waferboard.

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