A Comparison of Geometry Effect on Tensile Testing of Wood Strands

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Abstract

There is currently no ASTM standard for testing the tensile mechanical properties of strands used in wood-strand–based composites. In this study we compared the ultimate tensile strength (UTS) parallel to grain and tensile modulus of elasticity (MOE) for southern pine (*Pinus* spp.) wood strands from an oriented strand board plant in which one treatment consisted of rectangle-shaped specimens and the other treatment consisted of samples milled into a tapered (''dog-bone'') shape. For bone-shaped samples, the measurements observed were 16 and 27 percent higher for MOE and UTS, respectively, than for the rectangular samples, and this was attributed to the generally accepted fact that dog-bone–shaped geometry yields measurements that are closer to true population parameters. Variation in mechanical properties was not statistically different for the two test methods. This study quantified that tensile testing of the rectangular strands will underestimate the true strength and MOE of the southern pine material. Because both methods resulted in similar levels of variability in test results, in-plant testing, using the traditional rectangular sample, may be acceptable for quality control as long as there is a recognition that the UTS and MOE values will be substantially more underestimated than those of smaller, dog-bone–shaped samples. As such, for future standards development, consideration should be given to the geometry of the strand when determining mechanical properties. Given the large amount of studies that use rectangular strands, there may be a need for a methodology to relate test results for rectangular and bone-shaped specimens.

Currently, there are no standards available for testing the tensile strength of wood strands for wood-based composites. Important testing parameters include loading speed, gauge length, fixture type, and specimen geometry. ASTM D143-94 is the closest standard that could be used for solid wood, but it requires a specimen end cross section of 25 by 25 mm (ASTM International 2004). Another standard that has been used for wood strands, even though it was intended for fiber and particle wood composites, is ASTM D1037-06 (ASTM International 2006). ASTM D1037-06 has perhaps been used for strands because of the allowance of a shorter length and thus is more similar to that of wood strands than ASTM D143-94.

The thickness of a wood strand from an oriented strand board (OSB) plant can be as low as 0.6 mm (Nishimura et al. 2004), and thus scaling down the cross-sectional dimensions of the strand to be of similar proportion to that of the ASTM D143-94 standard is difficult. The ASTM D143-94 standard is important because it recommends the milling of samples to follow a ''dog-bone'' shape. We used a bone-shaped tensile specimen in order to lower the ultimate force at failure, which we found to reduce the stress concentrations in the grips and to concentrate failure in a specific area. A gradual taper allows for a smooth transition of load distribution from the edge to the center so as to minimize the possibility for a stress concentration from the sample edge and to focus the failure in the gauge section of the sample (Kretschmann 2008).

To date, many investigators have looked at rectangular wood strands to determine the tensile modulus and strength, while no literature appears to be available comparing the rectangle with the dog-bone shape for strand-sized specimens. Price (1976) was perhaps the first investigator to characterize the tensile strength of rectangular wood strands. In two other studies, strands were notched in the center to localize failure and mimic a dog-bone shape, but no comparison to rectangular strands was performed, nor was

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there any mention of whether the notch was rounded or had sharp corners (Han and Wu 2004, Han et al. 2006). For notched specimens with sharp corners, a stress concentration will likely occur, which could underestimate the ultimate tensile strength (UTS) properties of the flake(s). On the other hand, rectangular specimens may do a better job of averaging out earlywood-to-latewood effects for strands given the magnified effect of wood rings at the microscale level (Hindman and Lee 2007, Jeong et al. 2009). This may be particularly true for southern pine (*Pinus* spp.), which has an abrupt transition between earlywood and latewood. In this case, if a dog-bone shape is to be used, care should be taken to ensure that the earlywood-to-latewood ratio in the center of the dog-bone specimen is representative of the entire piece.

Application of the dog-bone shape is important if more accurate measurements of strength are to occur because of the removal of stress concentrations in the grips (Kretschmann 2008). In that study, when the tensile strength was tested perpendicular to grain, values were 25 percent higher for the dog-bone–shaped specimens (Kretschmann 2008). It was the objective of this study to determine and quantify the effect of specimen geometry on UTS that was measured on specimens from the same population. If significant, this study will allow for a more accurate calculation of material UTS. It would also encourage future ASTM committees and researchers to address the testing of microscale-sized strand samples that are common in today's wood-based composites (Hindman and Lee 2007) and recommend a common standard (with a fixed geometry) such that equivalent comparisons can be made between studies and allow for the most accurate measurement of strand mechanical properties.

Methods and Materials

Sample preparation

To determine the effect of dog-bone geometry versus rectangle geometry on UTS parallel to grain, strands produced by a commercial stranding operation at a local OSB plant were used. The strands used were southern yellow pine (*Pinus* spp.), and they were collected after the fines were screened out from the furnish. Straight grained strands were sorted visually in the laboratory, and all strands with end splitting or warp were rejected. The target dimensions of sorted strands were approximately 127 mm in length, 25 mm in width, and an average of 0.85 mm in thickness.

Bone-shaped strands were made by first scaling the ASTM D1037-06 bone testing dimensions (ASTM length of 25.40 cm and width of 5.08 cm tapering to 3.81 cm) to fit the strands (testing length of 125 mm and width of 25.4 mm tapering to 19 mm; Fig. 1). The general pattern was traced and cut from a cardboard sheet, and then the bone shape was traced onto the sample and cut out with a razor blade. Samples damaged during cutting of bone geometry were discarded. This happened more frequently than expected as a result of unseen microdefects from the stranding process. This resulted in a smaller sample size for the dog-bone–shaped specimens ($n = 24$) than for the rectangle-shaped specimens ($n = 67$). Rectangular strands were produced at 125-mm length and 25.4-mm width. Strands with observable defects were not selected (for either geometry). Strands were conditioned at 22°C and 50 percent relative humidity.

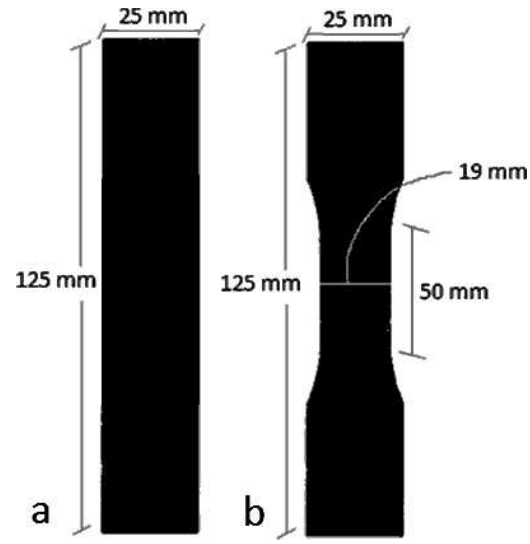

Figure 1.—(a) Rectangle-shaped and (b) dog-bone–shaped tension parallel-to-grain test specimens.

Tensile testing

Axial tension tests were conducted using a Zwick-Roell load frame equipped with 10 kN load cell and computer controlled screw-drive crosshead. Screw-type grips were used. The grips were serrated to reduce slippage. Preliminary testing found a gauge length of 76.2 mm, an extensometer gauge length of 50.8 mm, and a loading rate of 0.254 mm/min to yield the lowest variance in UTS and modulus of elasticity (MOE), which agreed with Jeong et al. (2008) and was therefore used for the testing protocol. Extensometer calibration was conducted at 0.254 mm/min. A verification was also performed in which the extensometer travel matched the crosshead travel through the extensometer range. The crosshead was also calibrated prior to verification by the supplier. The rectangle- and bone-shaped samples were then tested, and the stress–strain curve was obtained. The slope of the stress-to-strain curve was used for MOE, and the UTS was computed by dividing the maximum stress to failure by the cross-section area, which was measured with calipers (0.001 cm).

Results and Discussion

The ranges of mechanical properties for this study (4.3 to 5 GPa [MOE] and 27.9 to 35.5 MPa [UTS]) were similar to those of other studies of southern pine, which ranged from 2 to 12.9 GPa (MOE) and from 13.5 to 58 MPa (UTS; Han et al. 2006; Cai et al. 2007; Hindman and Lee 2007; Jeong et al. 2008, 2009). The wide ranges of mechanical properties in previous studies were often attributable to the ranges in juvenile wood percentage, specimen size differences, and purposeful attempts to isolate latewood or earlywood rings. Besides geometry, a key difference between our study and previous studies was that our flakes were obtained from a disk strander from an OSB plant and microdefects were present, which likely lowered our values when compared with other studies. These microdefects were sometimes observed as they expanded into larger fractures and were located away from the center of the tapered section.

As seen in Figures 2a and 2b, the specimen with bone geometry yielded higher values for the two mechanical

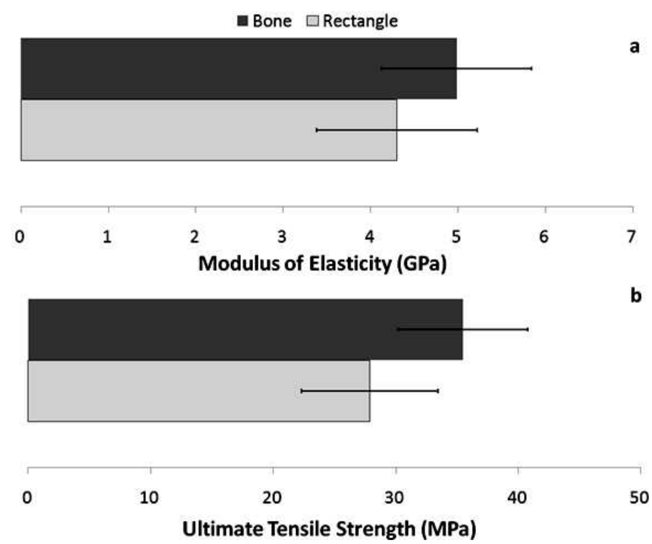

Figure 2.—The (a) modulus of elasticity and (b) ultimate tensile strength of wood strands from an oriented strand board plant. Error bars represent one standard deviation.

properties when compared with the rectangle-shaped specimens. The differences in MOE and UTS were statistically significant ($\alpha = 0.05$). For bone-shaped geometry specimens, the measured values for MOE and UTS were 16 and 27 percent higher than the rectangular specimens. A similar finding was observed for southern pine tested in tension perpendicular to grain in which the measured values of the dog-bone–shaped samples were 25 percent higher than the values of the rectangle-shaped small clear wood samples (Kretschmann 2008). Kretschmann attributes the higher apparent strength to the reduction in stress concentration in the grips through tapering. The increase in MOE for tapered specimens was not expected because it was computed from the elastic portion of the stress-to-strain curve. It should be noted that this parameter was barely significant ($P = 0.049$) and thus it may be a reasonable candidate for Type I error. Assuming it was not a Type I error, the difference could be attributable to an increased probability of a critical microdefect (for example a fracture not detectable by the eye) as a result of the larger area of the rectangular specimen.

There was a small reduction in variation when comparing the rectangle- to dog-bone–shaped geometry for both MOE and UTS (Figs. 2a and 2b). However, the reductions in variation were not statistically significant via the F test, which suggests that rectangle-shaped samples may give acceptable results for mechanical properties if one is not concerned with a systematic offset in the measured strength values. When compared with other studies, the coefficient of variation was considerably higher for both mechanical properties as a result of the size effect (Kretschmann and Bendtsen 1992); i.e., as samples become smaller in dimension the samples are more likely to vary in mechanical properties as a result of a more pronounced influence of a single growth ring or defect (Bažant 1999). Despite our efforts, it is likely that some samples with microdefects were still included in the tested population, and this may have added to the variation in UTS. Furthermore, this additional variation is probably more reflective of a real manufacturing process in contrast to well-prepared flakes in a laboratory (Kohan et al. 2012).

Summary

As expected, the measured value of UTS and MOE for dog-bone–shaped specimens was different from that measured for rectangular specimens. The value of this study is twofold in that (1) the effect of the stress concentration on the ultimate stress values measured in the rectangular OSB strand samples for southern pine has been quantified, and now the experimentally determined ratio can be used to obtain more realistic estimates of the strength from data published for rectangular specimens for southern pine, and (2) this study highlights the need for ASTM standards that address samples of this dimension.

There were no significant differences in variation of UTS and MOE between the two sample geometries, which supports the premise that rectangle-based strand testing can be used if an estimate of the lower bound of true material strength is acceptable. Such a finding is positive given the commitment of so many studies to the use of rectangle-shaped strands. Also, cutting the dog-bone shape for this study was quite difficult because of the microdefects that often occurred during stranding at the plant, and future studies may benefit from a different sample preparation method, such as stamp and press method. For plant-based studies, it may be more efficient to use rectangle-shaped specimens, which can help reduce the cost of obtaining an adequate sample size and thereby result in improvement of the estimation of statistical parameters for UTS and MOE, with the provision that this method will yield values for both properties that are lower than those that can be obtained from dog-bone–shaped specimens. In other cases, such as laboratory-prepared strands, shaping the strand to a dog-bone geometry may not be excessively difficult and will result in a more accurate estimate of the material properties and will be more appropriate for input into models or simulation studies. It should also be pointed out that owing to wider sections, the rectangle-shaped specimens do a better job of averaging ring effects, while localized rings have a more pronounced effect on dog-bone–shaped specimens. However, for this study, care was taken to ensure that the annual ring count of the reduced cross section was representative of the entire piece, and this was demonstrated with the statistically similar variance between treatments. Overall, the end use of the data may dictate which test method is more appropriate. For example, detailed finite element analyses of the composite performance should use the results from the dog-bone–shaped tests, while other design methods or in-plant quality control processes may only require the results from the rectangular tests.

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