Synergistic Effect of Strand Angle and Panel Density on Bending Properties of Strand-Based Wood Composites

Xiaohong Liu
Siguo Chen
Robert Wellwood

Abstract

The impacts of panel density and strand alignment, and their synergistic effect, on bending strength and stiffness of strand-based wood composites were investigated experimentally. Fifteen unidirectional strand panels with a range of densities were manufactured. Bending specimens were cut at an angle with respect to the alignment direction at 15-degree increments from 0 to 90 degrees. Bending strength and stiffness with extended ranges of density (480 to 672 kg/m^3) and strand alignment (0 to 90 degrees) enabled these production factors to be simultaneously investigated. The response of the bending properties to changes in density greatly depended on strand angle. A smaller strand angle exhibited a greater rate of bending property change with density. This synergistic effect provided a supplementary basis for focusing efforts in improving strand alignment on the thin layers near the high-density surfaces to enhance bending properties. The data presented in this article should be especially useful when dealing with unidirectional wood strand/veneer products, such as oriented strand lumber, where strand alignment and density are crucial for the intended application.

Oriented strandboard (OSB) and the newest composite lumber product, oriented strand lumber (OSL), are made from hot-pressing resinated strand mats with designed strand alignment into different product thicknesses and densities. Panel density is one of the key characteristics of composites, and it affects most physical and mechanical properties of products, including bending modulus of rupture (MOR) and modulus of elasticity (MOE). Because wood possesses considerably higher tensile and compressive stiffness and strength along the grain than perpendicular to the grain, and because strands are generally cut parallel to the wood grain, it is crucial to achieve desired strand alignment distribution for strand-based wood composite structural products.

Experimental and model simulation studies have demonstrated that panel density and strand alignment play significant roles in determining MOR and MOE of oriented strand wood products. Geimer (1979) tested flakeboards made with uniform densities throughout their thickness and different degrees of flake alignment. Four board density levels and four degrees of flake alignment were used in the experiment. Having established a mathematical relation between board strength or stiffness, board density, and flake alignment, Geimer graphically presented the MOE and density relationship for each flake alignment. McNatt et al. (1992) investigated the effects of strand alignment on strandboard performance. Panels were manufactured in various combinations of random and aligned strands at core and surface layers, and those authors stated that the alignment of surface strands improved bending strength and stiffness of strandboards in the direction of alignment. Xu and Suchsland (1998) used a model to simulate the development of MOE in relation to OSB density. The simulation result indicated that MOE increased linearly with increasing density. Hankinson's formula (Hankinson 1921), which relates strengths parallel and perpendicular to the wood fiber to calculate strength at any given angle, has been used to predict the tensile strength of oriented sweetgum flakeboard (Price and Kesler 1974). Wang and Chen (2001) used an ultrasonic wave method to investigate the efficiency of flake alignment and orthotropic properties of OSB. Their data showed that the relationship between bending proper-

The authors are, respectively, Associate Professor, Shunde Polytechnic, Shunde, Guangdong, China (ysliuxiaohong@sdpt.com.cn); and Senior Scientist and Program Manager (siguo.chen@albertainnovates.ca) and Manager (rob.wellwood@albertainnovates.ca), Forest Products Business Unit, Alberta Innovates–Technology Futures, Edmonton, Alberta, Canada. This paper was received for publication in January 2010. Article no. 10730.

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ties and strand angle could be expressed by Hankinson's formula. In the same article, they also reported that MOR and MOE linearly increased with increasing density. Barnes (2000, 2002) carried out intensive studies on the effect of strand alignment. He emphasized the importance of strand alignment to the bending properties of oriented veneer and strand wood composites, and he stated that nominally 6-inch OSB strands could provide strength properties close to those of solid wood if the strands could be oriented to a mean strand angle deviation of close to 10 degrees.

Most recently, Chen et al. (2008) conducted a pilot plant experiment to test a numerical model of OSB bending stiffness. The model is based on laminate theory (i.e., the composite material is represented as a stack of thin plates) and Hankinson's formula, and it takes into account vertical density profile and strand alignment. Extensive vertical configurations of strand angle distribution were created when forming the strand mats. The results demonstrated that the model prediction generally agreed with the experiment data. The model was then used to explore methods to increase parallel bending stiffness of OSB through improving the mat structure. Jin et al. (2009) tested random OSBs with both uniform and conventional vertical density profiles. Their results indicated that bending MOR and MOE were linearly correlated to the board density, with R^2 between 0.91 and 0.97.

The impact of panel density on bending properties differs remarkably for different degrees of strand alignment (Geimer 1979). A synergistic effect exists; that is, increasing density and improving strand alignment enhance each other's effect on bending properties. A combination of high density and better alignment produces superior bending strength and stiffness. Although a great number of publications deal with the effect of density or strand alignment on bending properties of OSB, few data are available describing the synergistic effect of these two production factors on bending properties of strand-based wood composites using an extended range of density and strand alignment. The graph presented by Geimer (1979) with smoothed curves generated from the mathematic equation (describing dependence of bending MOE on density and flake alignment) was the only source of information found in the literature. A better understanding of this synergistic effect is needed to improve product design and both bending strength and stiffness, especially for high-strength composites.

The objective of this research was to reveal the impacts of density and strand alignment, and their synergistic effect, on bending MOR and MOE of strand-based wood composites through a systemic pilot plant experiment with an extended range of these two production factors. The experiment enabled these two factors to be simultaneously investigated.

Materials and Methods

Panel manufacturing

Laboratory-cut aspen strands 0.034 inch (0.86 mm) in thickness and 5.75 inches (146 mm) in length were used to manufacture 711 by 711 by 11.1-mm^3, three-layer, unidirectional panels at the Alberta Research Council wood composite panel pilot plant. The strands were blended with 2.5 percent powdered phenol formaldehyde resin and 1.2 percent slack wax for both the core and surface strands. The target surface and core furnish moisture contents were 6.5 and 4.5 percent, respectively. Five target panel densities from 480 to 672 kg/m^3 at 48-kg/m^3 intervals were included in the study. Three replicates for each density level were used, resulting in a total of 15 panels.

All strand mats were formed manually. Strands were laid up into a 864 by 864-mm^2 forming box in the strength axis direction. Extra care was taken when laying down individual strands to minimize angular deviation. The formed mats were pressed into panels using a hot press with a platen temperature of 210°C for 190 seconds. The pressed panels were hot stacked inside an insulated box for approximately 15 hours and then kept in a conditioning chamber at 65 percent relative humidity and 20°C for 3 weeks before testing.

Panel testing

To verify the accuracy of strand alignment, the first pressed panel was manually measured for strand angle deviations from the intended alignment direction. Two hundred strands on the top surface of the panel were measured, and the histogram is shown in Figure 1. Although some deviations were inevitable, the majority of strands were well oriented. Approximately 63 and 92 percent of the strands were oriented within 5 and 10 degrees, respectively, of the intended direction. Figure 2 displays a set of the cut specimens with the designated strand angles from 0 to 90 degrees.

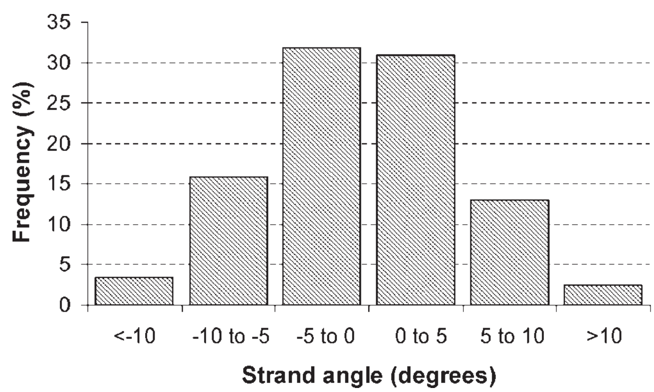

Figure 1.—Frequency distribution of strand angles on the top surface of a pressed panel.

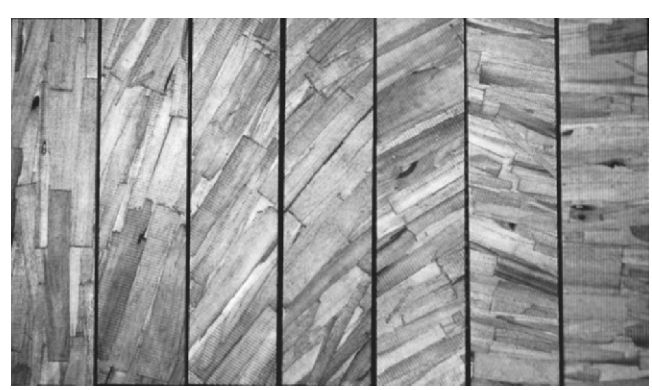

Figure 2.—Specimens cut from a panel with the designated strand angles from 0 to 90 degrees. From left to right: 0, 15, 30, 45, 60, 75, and 90 degrees.

Following the cutting pattern laid out by Chen et al. (2008), seven 315 by 75-mm^2 bending specimens were cut from each panel at an angle with the strength axis using 15-degree increments from 0 to 90 degrees. Testing a specimen cut at an angle θ with the strand alignment direction is equivalent to testing a specimen cut parallel to the major panel axis of the panel having strands aligned at angle θ with the major panel axis. In both cases, the angle between the strand alignment direction and the applied load is θ. Hereinafter, the seven cutting angles will be referred to as strand angles.

The MOE and MOR tests were conducted according to CSA O437.1-93 (Canadian Standards Association 1993). Some delamination occurred in the panels with the highest target density (672 kg/m^3). Specimens observed to have areas of delamination were excluded from the testing.

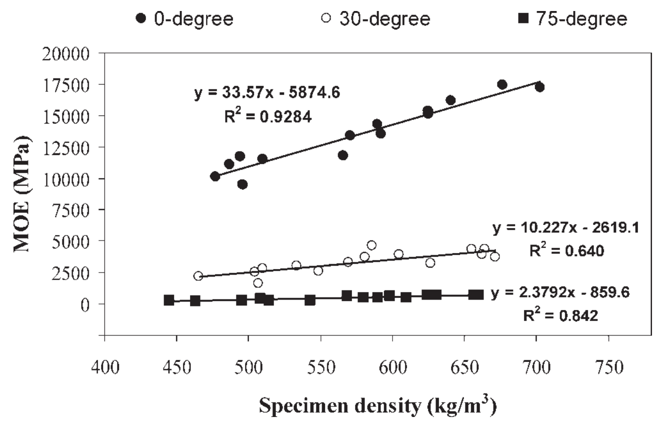

Figure 4.—Effect of specimen density on MOE for different strand angles.

Results and Discussion

Values of MOE and MOR increased linearly with increased specimen density for all seven strand angles. To avoid overcrowding, only data for three strand angles (0, 30, and 75 degrees) are graphically presented (Figs. 3 and 4). Note that although the correlations between MOE and MOR and density were linear for all strand angles, the rates of change in MOR and MOE with specimen density (i.e., the slopes or coefficients of the regression lines) differed considerably. A smaller strand angle exhibited a greater rate of change, indicating the existence of a synergistic effect. In the higher-density region, the contribution of large strand angles to MOR and MOE is considerably smaller in comparison to those of small angles.

Because large strand angles have much smaller average values of MOR and MOE, on a percentage basis, the difference in the response of bending properties to density would be less significant between large and small strand angles. Much of these observed remarkable differences in the rate of change may have stemmed from the pronounced nonlinear response of bending strength and stiffness to strand angle as described by Hankinson's formula. The contribution of strands with large angles (>60 degrees) is insignificant compared with strands with small angles (<10 degrees). Although the relative change of MOR and MOE with strand angle may be similar for high- and low-density panels, the absolute contribution of well-oriented strands for high-density panels will be much greater than that for low-density panels.

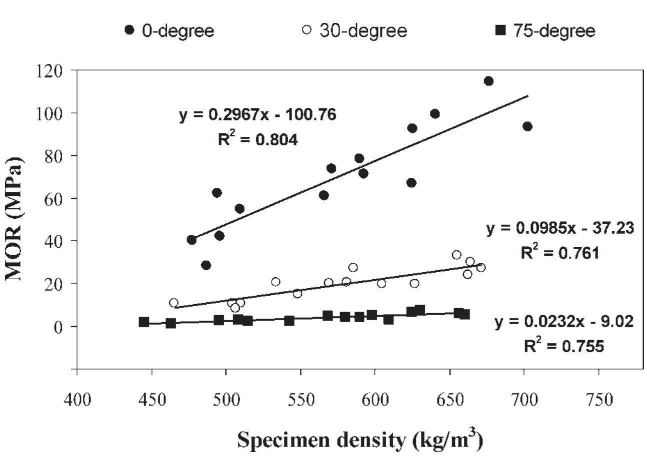

Figure 3.—Effect of specimen density on MOR for different strand angles.

Because of the combined result of gradients of temperature, moisture content, and pressure in the strand furnish during pressing, the density distribution through the thickness of hot-pressed wood composites is commonly characterized by high-density surface layers and a low-density core layer. Previous studies have found that strand alignment in the surface layers is important for controlling bending stiffness and that improving surface strand alignment resulted in higher strength and stiffness (McNatt et al. 1992, Geimer et al. 1993). The synergistic effect identified in this research, in addition to the influence of distance from neutral axis on bending behavior, suggests that improving strand alignment in the thin layers near the high-density surfaces would be most fruitful in enhancing the bending properties.

Plotting the coefficient values, which are the rates of MOR and MOE change with density, of all seven regression lines against the strand angles (Figs. 5 and 6), it becomes obvious that a two-phase linear regression effectively describes the dependence of the rates of MOR and MOE change with density on strand angle. The most striking feature shown in Figures 5 and 6 is that the 45-degree strand angle clearly divided the two linear phases. The rate of change decreased rapidly as the strand angle increased from 0 to 45 degrees, but it decreased slowly as the strand angle further increased from 45 to 90 degrees. This result implies that in numerical modeling or product design, the relation

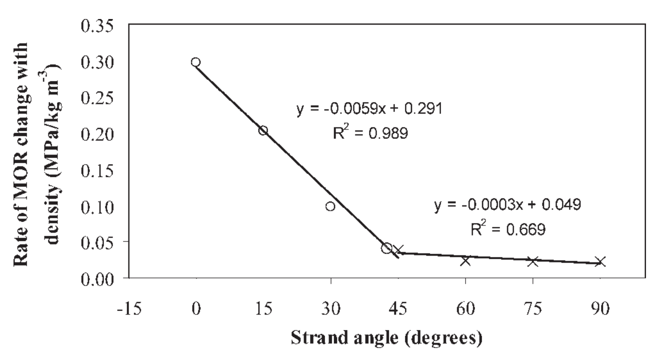

Figure 5.—Dependence of the rate of MOR change with density on strand angle.

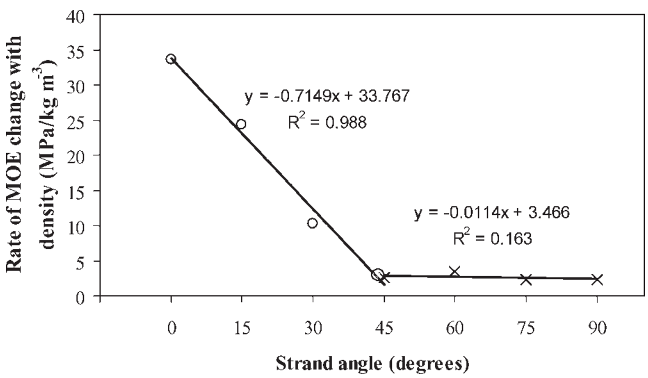

Figure 6.—Dependence of the rate of MOE change with density on strand angle.

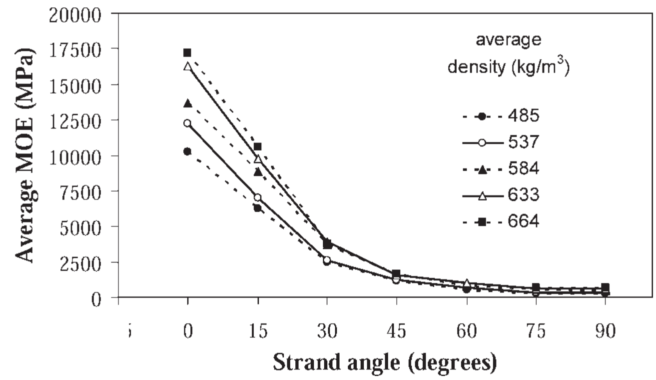

Figure 8.—Effect of strand angle on average MOE for different average densities.

between bending MOR or MOE and density needs to be determined differently for different strand angle ranges. Once the strand angle gets larger than 45 degrees, the change of the coefficient with strand angle is so small that using a constant value may be sufficient in many practical applications.

To examine how strand angle affects the average values of MOR and MOE at each level of density, we calculated the average values of MOR and MOE and the corresponding average density of the specimens from each of the seven strand angles for each of the five target densities. As shown in Figures 7 and 8, the response curves generally followed the pattern described by Hankinson's formula (Forest Products Laboratory 1999, Chen et al. 2008). MOR and MOE decreased rapidly as the strand angle deviated from 0 degree. At the 30-degree strand angle, only 20 to 30 percent of the maximum MOR and MOE (at 0 degree) remained. When the strand angle increased to 45 degrees, approximately 85 percent of MOR and 90 percent of MOE were lost. This result indicates that it is important to have a high percentage of the strand population oriented within 0 and 30 degrees with respect to the strength axis. Strand angles greater than 45 degrees contributed very little to the overall panel bending properties in the major alignment direction.

It can also be observed from Figures 7 and 8 that the difference in bending property values between different average densities decreased with increasing strand angle. For strand angles greater than 45 degrees, the curves were nearly indistinguishable from each other at this scale, implying an insignificant effect of both density and strand angle on MOR and MOE at large strand angles.

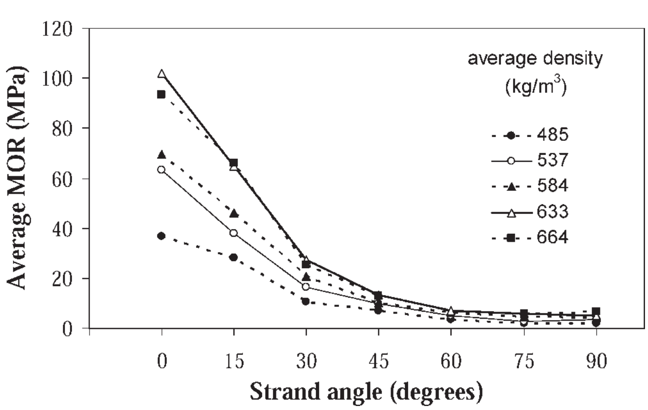

Figure 7.—Effect of strand angle on average MOR for different average densities.

Conclusions

Based on the results of this study, the following conclusions can be drawn.

1. The response of bending MOR and MOE to changes in density depends on strand angle. Test results showed that a smaller strand angle exhibited a greater rate of MOR and MOE change with density, indicating a synergistic effect of density and strand alignment on bending properties.
2. The dependence of the rates of change (i.e., the slope of MOR and MOE change with density) on strand angle is best described by two linear phases, with the 45-degree strand angle being the dividing point. In this study, the rates of change decreased rapidly as the strand angle increased from 0 to 45 degrees. Further increases in strand angle did not significantly change the rates.
3. The synergistic effect presented in this study provides a supplementary basis for focusing efforts in improving strand alignment on the thin layers near the high-density surfaces to enhance the bending properties.
4. The results provided in this research expand the knowledge database. The information should be especially useful when dealing with unidirectional wood strand/veneer products, such as OSL, where strand alignment and density are crucial for the intended application.

Acknowledgment

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