

Tensile and thickness swelling properties of strands from Southern hardwoods and Southern pine: Effect of hot-pressing and resin application

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Abstract

Tensile and the moisture-induced thickness swelling properties of wood strands are among the most fundamental parameters in modeling and predicting engineering constants of strand-based composites such as oriented strandboard (OSB). The effects of hot-pressing and resin-curing on individual strand properties were investigated in this study. Strands from four Louisiana-grown species—willow (*Salix* spp.), yellow-poplar (*Liriodendron tulipifera* L), red oak (*Quercus* spp.) and southern yellow pine (*Pinus taeda* L.)—were tested. It was found that the properties of strands were different from the various wood species and that hot pressing and resin-curing significantly modified the strand properties. This indicated that an adjustment of strand mechanical and swelling properties from the solid wood values is necessary for better prediction of engineering constants of strand composites. Among the four species tested, yellow-poplar strands demonstrated the best initial and postprocessing tensile and thickness swelling properties. The willow strands were initially inferior but showed significant improvements in their properties after hot pressing and resin-curing. This indicated that willow, a low-density and low-strength species, could be used as a good supplement material for OSB furnish.

Strands are the basic elements for composing strand-based composites such as oriented strandboard (OSB). Their mechanical and dimensional properties and even the storage time have significant influence on the overall composite performance (Carll 1998). For simplicity, several studies assumed that the properties of strands derived from solid wood carried over to the panel (Suchsland 1972, Suchsland et al. 1995, Xu and Suchsland 1997). Nevertheless, this might not be an accurate assumption for estimating engineering constants of strand composites. Tensile modulus and strength of sweet-gum strands, for example, were much lower than these of solid wood of the same species (Price 1975); similar observations were made for Douglas-fir strands (Geimer et al. 1985, 1997). Furthermore, during the OSB manufacturing processes (flaking, drying, blending, mat forming, and hot-pressing), strands inevitably suffer from moderate to severe mechanical modifications that could alter the strand performance significantly. Thus, understanding strand behavior during OSB manufacturing processes is one of the most im-

portant steps for predicting engineering constants of OSB panels. However, it is almost impossible to quantify the extent of physical damage imposed on strands during the entire manufacturing process (Geimer et al. 1985). Stepwise inves-

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tigation of the influence of each processing factor on the strand properties provides an alternative to assess the damage associated with a particular process.

One of the major strand modifications during hot-pressing is probably the densification during hot-pressing in which strands are subjected to thermo-mechanical stresses. The influence of such densification on the strand properties is complicated since strands in different locations (face or core) undergo different densification processes because of different temperatures and pressures. Limited studies have been found in investigating the effect of hot-pressing and strands' location in the mat on their tensile properties. Price (1975) found about 9.01 percent increase in tensile modulus of sweetgum strands in the face layer and about 7.94 percent reduction in the core layer due to different strand densification ratios and temperature. He also observed the similar trend on the tensile strength of pressed strands. Extensive study on the effect of hot-pressing among several processing parameters on the strand properties was performed at the USDA Forest Products Laboratory (Geimer et al. 1985). Two levels of pressing temperature, two press closing times, and two different pressures were considered in their study. Pressed strands showed the evidence of thermo-mechanical modification, i.e., the plasticization induced by heat as well as the densification of strands by compression. It was found that high press temperature enhanced tensile strength of strands at both core and face layers. The reason suggested by the authors was that under the high pressing temperature the lignin inside wood strands was modified and redistributed, which reinforced the strands as it cooled.

The resin usually provides a thin coating on the strand surface. Resin penetration into the strand formed a hard surface that might affect elasticity or thickness swelling (TS) properties. This effect on resinated-strand properties has never been documented in forest product literature. Engineers in the area of advanced composite predicted such effect on effective modulus of composite materials using equations, such as the rule of mixture or Halpin-Tsai equation (Lee and Wu 2003). Resins not only work as a binder, but also provide a good media for heat transferring. Its influence on the strand performance at the face layer might be different from that at the core layer considering the difference in time and temperature of exposure between face and core layers in the hot-pressing process.

Studies on plywood and other wood composite panels indicate that hot-pressed panel products are prone to have very large TS under high relative humidity (RH) environment because of the spring back (Gerard 1966, Kelly 1977, Hsu 1987). Overlooking such effects will lead to the prediction of TS potential and other mechanical behavior that deviate from true performance of OSB. Because the utilization of various hardwood species as OSB furnish has recently increased, we choose to study 3 southern hardwoods and the most common southern softwood used in OSB. The purpose of this study was to investigate the tensile and thickness swelling properties of strands from selected southern wood species under the influence of hot-pressing and/or resin curing.

Materials and methods

Strands from four Louisiana-grown species—willow (*Salix* spp.), yellow-poplar (*Liriodendron tulipifera* L), red oak (*Quercus* spp.) and southern yellow pine (*Pinus taeda* L.)—were prepared using a CAE 915-mm disc flaker. Final strand

dimensions were 15.24 cm in length, 2.54 cm in width, and 0.0508 to 0.127 cm in thickness. For each species, 120 strand samples were randomly selected from a population larger than 1,000 strands. Strands of each species were equally divided into three groups: control (with no treatment), hot-pressed, and hot-pressed with resin applied. Strands in the control group were tested after conditioned under 65 percent RH at 25 °C for several weeks. Strands in the hot-pressed group were marked and mixed with other regular strands to form a randomly oriented mat. Phenol formaldehyde resin with 45 percent solid content was applied to the strands in the hot-pressed and resinated group at a loading level of 6 percent based on the oven-dried weight of strands. Each resinated strand was then wrapped with aluminum foil, and the wrapped strands were then mixed with other non-resinated strands to form a mat with random strand orientation. A similar hot-pressing condition used in a typical OSB manufacturing process was applied. The mat was hot-pressed for 7 minutes under press temperature of 200 °C and the initial pressure of 45.7 kg/cm². The target density of pressed board was 0.75 g/cm³. Strands with their vertical positions at either face or core layers were collected from the pressed board and conditioned under 25 °C and 65 percent RH for a month before being tested.

Tensile properties and TS tests of strands were carried out according to the procedures described in the ASTM Standard D-1037 (1999) which is specified for wood composite panels. Wavy strands with uneven surfaces due to overlapping with other strands required special attention to determine the thickness. A certain point on every strand was selected for thickness measurement and marked. A Mitutoyo digital gage with 0.0025-mm accuracy was used to provide consistency in measurement with the same pressure to the mark. TS was evaluated after reaching equilibrium at environment condition of 95 percent RH and 25 °C. The tensile property tests were performed with an MTS testing machine equipped with hydraulic-pressure-driven grips and MTS extensometer (2.54-cm gage length). Most of tension failures occurred near the grips, but still within the middle section. The slope of stress-strain curve obtained was used in determining the tensile modulus of elasticity (TenE) and the maximum failure load was used to calculate the tensile strength (TenS). All broken strands were then oven-dried for moisture content (MC) measurement.

Results and discussions

Physical properties of strands

After hot-pressing, strands located in the face and core layers showed fairly distinguishable differences in the shape and extent of damage. Both resinated and non-resinated strands in the face layer showed a darker strand surface as a result of exposure to the hotter press platen. The dark color resulted from the pyrolytic degradation of xylan and surface dehydration and charring of lignin (Hancock 1963, Elder 1990). Meanwhile, strands in the core layer exhibited more variation in thickness and had curly deformed or sometimes cracked surfaces because of overlapping with other strands. The lighter color of strands in the core layer indicated that they had been exposed to a short cooler thermal condition when compared with the darker strands in the face layers. The test results explained later in this study showed different performances between face strands and core strands. Generally, after hot-pressing, willow and yellow-poplar strands were in very good

The average strand thickness and specific gravity (SG) of four different control groups and their standard deviations (SD) are shown in **Table 1**. Among the four selected species in this study, southern pine strands had the largest average thickness values and SDs. After hot-pressing, all face strands became thinner than the core strands because of higher compression and plastic deformation under higher temperature for longer period time. Strands placed in the face layers also had a relatively uniform thickness as compared with those in the core layer, because one side of the strands had directly contacted with the hot-press platen where the contacting surface was flat. Average compression ratios based on the strand thickness before and after compression were 1.288, 1.176, 1.256, and 2.158 for willow, yellow-poplar, red oak, and southern pine, respectively. Average compaction ratios (defined as the ratio of board SG to strand SG) were 1.94, 1.63, 1.29, and 1.38 in the same species order given above.

Tensile modulus of elasticity (TenE) and tensile strength (TenS) of strands under different treatments were summarized in **Table 1**. Large variations in the distributions were observed among different species. Compared to willow, southern pine and red oak showed a large range of TenE and TenS values, indicating a significant variation in the mechanical properties of these two species. The average tensile properties of willow strands were significantly lower than other species. It was reported that the strength and stiffness of wood material is highly related to its density (Backman 2001). The lower strength and stiffness of willow strands were due to its low density. Yellow-poplar strands showed the highest value of average TenE, and southern pine strands showed the highest value of average TenS. Though they had the highest average SG, red oak strands did not provide the highest tensile performances. The reason might be that red oak strands contained a lot of large vessels aligned across the longitudinal direction, which could produce microchecks and reduce the strength. Large variations and reductions in strand strength were observed as compared with solid woods. Particularly, average TenS (or tensile strength) of strands was about 31.1 percent of that reported for solid wood of willow, and 44.2 percent for yellow-poplar, 36.2 percent for red oak, and 73.4 percent for southern pine (Wood Handbook 1999).

There were many process parameters that could affect the properties of strands (Kelly 1977). In this study, effects of hot-pressing, resin application and curing, and location in the mat were investigated. Specifically, strands were classified as hot-pressed while in the face layer (HP-Face), hot-pressed while in the core layer (HP-Core), resinated and hot-pressed while in the face layer (RHP-Face), and resinated and hot-pressed while in the core layer (RHP-Core). **Table 1** shows the average TenE values of strands under different treatments. Generally, there was no obvious pattern to the effects of hot-pressing and resin-curing on TenE values. Hot-pressing increased the TenE values for willow strands, but reduced the TenE values for red oak strands. With southern pine, on the other hand, hot-pressing increased TenE values for face strands and decreased TenE for core strands. A similar observation was made on the effect of resin-curing and hot-pressing. The reason was that hot-pressed strands suffered damage to different extents from being compressed while

Species	Control group ^a				Hot-pressed group ^a				Hot-pressed and resinated group ^a						
	Thickness (mm)	Density (g/cm ³)	TenE Pa	TenS	TenE		TenS		TenE		TenS				
					Avg.	Face	Core	Avg.	Face	Core	Avg.	Face	Core	Avg.	Face
Willow	0.965 (0.144)	0.386 (0.072)	5.95 (0.85)	22.7 (7.6)	6.95 (1.38)	7.67 (0.69)	6.59 (1.52)	45.4 (18.3)	54.6 (23.6)	6.65 (2.34)	8.05 (2.00)	5.05 (1.59)	39.6 (13.2)	40.3 (15.6)	38.9 (10.4)
Yellow poplar	0.660 (0.137)	0.459 (0.064)	6.97 (0.70)	48.5 (18.1)	8.02 (2.83)	8.74 (1.79)	7.29 (3.24)	36.0 (19.7)	42.5 (17.3)	9.45 (3.31)	11.39 (2.83)	6.65 (2.21)	47.8 (22.2)	60.4 (19.0)	33.3 (14.9)
Red oak	0.787 (0.144)	0.586 (0.072)	5.83 (1.00)	40.7 (38.7)	6.39 (3.31)	7.36 (2.34)	6.04 (4.00)	20.3 (21.0)	15.1 (11.2)	5.72 (2.69)	7.45 (3.38)	4.81 (1.65)	19.5 (9.7)	23.7 (10.7)	17.3 (8.5)
Southern pine	1.052 (0.166)	0.539 (0.100)	5.66 (1.70)	58.7 (25.3)	7.29 (3.17)	9.74 (3.24)	6.19 (2.55)	42.1 (20.2)	43.4 (22.2)	7.69 (4.00)	9.90 (4.48)	6.21 (2.83)	35.7 (21.8)	48.5 (25.3)	27.3 (14.4)

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Table 2. — Thickness swelling (TS) and equilibrium MC (EMC) of strands under various treatments.

Species	Control group			Hot-pressed group			Hot-pressed and resinated group			
				TS ^b			TS ^b			
	EMC ^a	TS ^b	EMC ^a	Avg.	Face	Core	EMC ^a	Avg.	Face	Core
	----- (%) -----									
Willow	19.2 (2.3)	9.4 (3.3)	20.6 (0.8)	24.1 (12.5)	27.2 (15.6)	22.6 (10.7)	18.2 (1.1)	13.6 (9.0)	18.4 (11.6)	9.6 (5.2)
Yellow poplar	19.9 (0.7)	5.8 (4.4)	18.1 (0.9)	12.8 (8.0)	11.3 (8.3)	13.2 (8.0)	17.8 (1.7)	11.3 (8.1)	14.7 (8.8)	9.1 (6.4)
Red oak	20.1 (1.0)	5.8 (3.1)	15.4 (0.4)	9.6 (7.1)	12.9 (9.0)	7.0 (3.4)	16.9 (2.9)	8.9 (7.4)	10.0 (8.9)	8.2 (7.9)
Southern pine	21.3 (1.7)	10.6 (8.8)	19.7 (0.9)	26.4 (13.5)	25.6 (12.5)	25.4 (15.2)	19.2 (0.6)	28.4 (19.7)	29.8 (27.5)	27.5 (13.3)

^aResults are given as average values with SD in parentheses.

^bTS was measured after reaching equilibrium at 95 percent relative humidity.

overlapping or crossing over each other. This physical damage could prevent the strands from being tested for their true stiffness and strength. However, the only consistent observation for all species was that the average TenE value of face strands was always larger than the core strands for both treatments (hot-pressed or resinated and hot-pressed), especially, with resin application. This was due to the larger densification and less physical damages in the face strands. It was noted during stress-strain test that after hot-pressing the strands, particularly in the core layer, showed a distinctive stress-strain curve since the strands were deformed into irregular, nonuniform, and wrinkled shapes.

Table 1 also shows the average TenS values of strands under different treatments. Similar to the observation for TenE, the effect of hot-pressing and resin-curing on TenS was dependent upon different species, and there was no particular pattern. Hot-pressing and resin-curing had negative effect on TenS performance for yellow-poplar, red oak, and southern pine, but they increased the TenS values significantly for willow strands. Similar to the results in TenE for willow, the TenS properties of face strands were higher than the values of core strands after being hot-pressed because of different strand densification ratios and temperature. The observation for face strands agreed well with the results of an earlier work by Price (1975), where the tensile properties of hot-pressed sweetgum strands increased at face layer and reduced at core layer. The low density of willow strands made it easy for the densification and resin penetration which could reinforce the strands. Although having inferior tensile performance when tested as untreated, the willow strands after being resinated and hot-pressed had similar tensile properties as other species, sometimes even outperforming other species (e.g., red oak). This was a very interesting observation that might help to utilize the low-density and low-strength willow species. However, a further study is needed to fully investigate the overall performance of OSB made from willow or mixtures of willow and other strands.

Thickness swelling (TS)

The average TS values measured between 0 and 95 percent RH for the four species under different treatments are presented in **Table 2**. It was noted that during thickness measurement strands became softened after reaching equilibrium condition at 95 percent RH, and the previous indentations and press marks on the surface of strands were more or less alleviated. This made it difficult to keep consistent thickness measurements. Some strands that showed irregular thickness swelling or shrinking had to be measured again. The MC of strands conditioned under 95 percent RH listed in **Table 2** showed fairly consistent equilibrium MC among the different

treatments, except for red oak strands, which had a significant drop after being hot-pressed and resinated. Because of microscopic surface damage when sliced and relatively small surface-to-volume ratio, the TS of strands could be different from the TS of solid wood products. Willow and southern pine strands showed TS values as much as twice the TS values of the corresponding solid woods, while the strands and solid woods for yellow-poplar and red oak had very similar TS values (Wood Handbook 1997).

Hot-pressing during the OSB manufacturing process had significant impact on the strand's TS. Generally, TS values increased after hot-pressing for all four species. It was reported that heat treatment could increase the hydrophobicity of wood because of the migration of wood extractives to the surfaces and the pyrolytic product of hemicellulose and lignin (Hemingway 1969). The results of this study were due to the significant spring back of compressed strands. The influence of hot-pressing was varied among different species. The average TS values of willow and southern pine strands increased about 3 times after being hot-pressed, while yellow-poplar and red oak showed smaller increases. The significantly increased TS values for willow and southern pine strands after being hot-pressed was due to their higher compression ratios (ratio of thickness before and after pressing), which produced large spring backs after the boards were released from the hot-press. The high compression ratios in the face layer might also explain why face strands usually had higher TS than the less compressed core strands.

The resin curing had different influences on the TS behavior of different species. It has been widely believed that resin can serve as a swelling-resistant agent. However, in this study that widely-held belief did not hold true. For example, it was found that the TS of resinated southern pine strands (the most commonly used species in southern OSB) was increased. This may be due to the higher compression ratio of southern pine strands, which reduced the stabilizing effect of resin application. It was encouraging to find that resinated willow strands after being hot-pressed demonstrated significant improvement in their TS performance for both face and core layers. This may indicate that the resin penetration was easier for the low-density strands than for the high density strands, and thus had greater effect on improving TS properties. Generally, the resinated and hot-pressed strands had different TS behaviors from the control strands. In modeling the moisture-induced swelling behavior of OSB, these differences needed to be considered.

Conclusion

Tensile and thickness swelling properties of strands from three major southern hardwood species and one softwood spe-

cies under different treatments were investigated. The results of this study showed a significant reduction of tensile properties of strands when compared with the respective solid woods. The results also indicated that the properties or performance of strands after hot-pressing and resin-curing were different from the untreated strands. The effects of hot-pressing and resin-curing on the strands' properties varied for different species. Hot-pressing and resin-curing increased tensile properties for willow strands but reduced the performance for red oak strands. For all species, the tensile properties of strands in the face layers were higher than the strands in the core layer except the TS property (which behaved in the opposite way) because of the larger densification and less damage in the face layers.

Tested as untreated strands, yellow-poplar strands demonstrated good tensile and TS properties compared to low-density willow strands, which illustrated inferior performances. However, after being hot-pressed and resinated, willow strands showed significant improvement in their performances, which were similar to or sometimes even outperformed other species. This information might help develop techniques for utilizing the low-density and low-strength willow species as potential OSB furnish.

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