PROPERTIES OF WOOD/RECYCLED TEXTILE COMPOSITE PANELS

*David B. DeVallance**†

Assistant Professor
Division of Forestry and Natural Resources
West Virginia University
Morgantown, WV 26506
E-mail: david.devallance@mail.wvu.edu

Jody Gray

Wood Products Specialist
Appalachian Hardwood Center
Division of Forestry and Natural Resources
West Virginia University
Morgantown, WV 26506
E-mail: jody.gray@mail.wvu.edu

Holly Lentz

Assistant Professor and Program Chair
Division of Design and Merchandising
West Virginia University
Morgantown, WV 26506
E-mail: holly.lentz@mail.wvu.edu

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Abstract. This study evaluated the potential to use recycled cotton textiles as filler and possibly reinforcement in the core of oriented strandboard (OSB) panels. Nominal 11.1-mm-thick, 686 × 686-mm OSB/textile fiber composite panels (50% surface and 50% core layers) were fabricated. Recycled textile material (0, 5, 15, 25, and 50% of the total weight percentage in the panel) was blended with mixed hardwood core strands. For each combination of wood and textile material, 10 panels were produced for a total of 50 panels. Internal bond strength, static bending strength and stiffness, water absorption, thickness swell, and nail withdrawal strength properties were evaluated. The major finding of the study indicated that compared with controls (ie panels with 0% textile material), panels with 5% recycled textiles did not have a statistically significant difference in bending strength (modulus of rupture) and elasticity (modulus of elasticity) or nail withdrawal strength. Additionally, although the controls had the greatest average thickness swell, none of the groups tested showed a statistically significant difference ($p = 0.064$). The study indicated that there is potential for adding 5% recycled textiles to the core of OSB panels without significantly decreasing physical or mechanical properties.

Keywords: Oriented strandboard, textiles, composite panels, hardwood strands, composite filler, recycled fiber.

INTRODUCTION

Postconsumer textile waste is a broad category that includes unwanted/discarded household textile and clothing articles. In 2010, 11.9 Mt of textiles were generated (EPA 2010). Estimates indicate that 73-85% of the textile waste (preconsumer and postconsumer) ends up in landfills (Chen and Burns 2006; Secondary Materials and Recycled Textiles Association 2009). This accounts for 5% of total municipal solid waste generation (EPA 2010; Wang 2010). Worldwide, textile production exceeds an estimated 58.1 Mt per year. Recovered textiles are reused, recycled, or used for energy production (Wang 2010).

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* Corresponding author
† SWST member

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Given the large amount of available textile waste, there is potential to recycle this material as a partial fiber substitute in many wood-based composite materials. Of the many wood-based composites, oriented strandboard (OSB) is one of the greatest uses of lower-grade wood in the US. Data from 2007, 2008, and 2009 market surveys revealed that OSB production was 13 million, 11.5 million, and 11 million m^3, respectively (Howard and Westby 2009). Assuming a density of 672 kg/m^3 in 2009, OSB producers in the US used approximately 7.4 billion kilograms of wood. Partially replacing some of the virgin wood raw material with a recycled fiber would probably be both environmentally and economically beneficial.

Textile waste is divided into two categories, preconsumer and postconsumer. Preconsumer waste is comprised of byproduct materials from fiber, yarn, or fabric production. Through the production of raw materials for automotive, furniture, mattress, home furnishing, paper, and other industries, an estimated 75% of preconsumer textile waste is diverted from landfills (Chen and Burns 2006). Postconsumer waste is comprised of any clothing or household textile article that no longer is of use to its original user. The textile recycling industry diverts nearly 2 million tons of postconsumer textile waste from landfills each year (EPA 2010). Approximately 48% of recovered textile waste is recycled as secondhand clothing. The remaining postconsumer waste ends up in landfills (Chen and Burns 2006). The textile recycling industry is one of the oldest and most established recycling industries worldwide (Hawley 2006). Conversion of textile waste into new products, secondary recycling, is a significant type of textile recycling (Hawley 2006). The breakdown of textiles through cutting and shredding creates raw materials that are classified as shoddy (lower-quality knit) and mungo (high-quality woven) (Hawley 2006; Hethorn and Ulasewicz 2008). Current applications for shoddy textiles are in value-added products such as stuffing, automotive components, carpet underlays, casket lining, building insulation, roofing felt as well as low-end blankets. Applications in structural panels, however, have yet to be explored in much detail.

Concern about global environmental problems has spurred the development of less harmful textile or fiber-based composites and materials (Kamath et al 2005; Van Wyk 2007; John and Thomas 2008). Natural fibers such as cotton, kenaf, and flax have the ability to form sufficient bonds with thermoplastic polymer binders to create suitable raw materials for use in automobile applications (Kamath et al 2005). Natural fiber composites, primarily from agricultural products or wastes, have been proposed for use in a varied array of construction applications. Several applications under consideration are roof coverings, insulation, wall and floor coverings, extruded composite sections for decorative panels and frames as well as a variety of board materials (Van Wyk 2007). The extensive array of applications for fiber-based composite boards makes this category a promising market segment (Van Wyk 2007). Research into natural fiber composites, or biocomposites, has recently resulted in several specific new composite materials. Three-layer particleboards produced with sunflower stalks and poplar wood using urea–formaldehyde resins have been shown to exhibit strengths equal to standard particleboards (John and Thomas 2008). Roof structures manufactured from soy oil-based resin and recycled cardboard cellulose sheets have stiffness and strength properties that meet national and state building codes (John and Thomas 2008).

Although various natural fibers have been used to manufacture new composites, most research related to fiber reinforcement of wood materials has been related to reinforcement of timbers and glulam beams with glass-type fibers (Tingley et al 1996; Davids et al 2000; Dagher et al 2002; Lopez-Anido and Xu 2002; Fiorelli and Dias 2003; Gilfillan et al 2003). Reinforcement of OSB panels has also focused on the use of glass fibers (Dagher et al 2002; Cassidy et al 2006). Additionally, other types of reinforcements for wood-based composites have been investigated including metal and woven fiber (Mohebby et al 2011), low molecular resin impregnation

(Wan and Kim 2006), and oil palm empty fruit bunch fibers (Khalil et al 2011). Most current textile research has focused on reinforcements for thermoplastics (Burgueno et al 2005; Kamath et al 2005; Tasdemir et al 2007; Dobircau et al 2009; Martins et al 2010; Zou et al 2011) in both housing and automotive applications. Little to no research has been performed, however, in combining recycled textile fibers and wood materials to manufacture composite materials and in using textile fibers to reinforce wood-based composites. Given this, the objective of this study was to investigate using recycled textiles as core material in OSB. By doing this, waste textiles could be more sustainably used as value-added composite materials.

MATERIALS AND METHODS

Raw Material Selection and Preparation

Studies were carried out to validate that wood residue and recycled textile materials could be combined to form a composite material using standard industrial practices (eg standard resin amounts, press settings, and wood raw materials) and to study the impact of adding varying amounts of textiles in the core of a structural-type composite on mechanical and physical properties. Approximately 180 kg of cotton waste textiles (that otherwise would have been sent to a landfill) were collected from a shirt manufacturing company (Phoenix Textile and Apparel) in West Virginia. The textile material was sent through an Allegheny industrial shredder four times to produce textile fabric pieces of approximately 12.25 × 12.25 mm. Surface and core mixed hardwood strands were obtained from Weyerhaeuser NR Company (Heaters, WV) and represented typical strands used in production. The raw materials were conditioned to equilibrium in an environmental chamber set at 21°C and 25% RH.

Composite Panel Preparation

Nominal 11.1-mm-thick, 686 × 686-mm OSB/textile fiber composite panels (50% surface and 50% core layers) were fabricated. A panel density of 720 kg/m^3 was used for all panels produced. The textile material was blended simultaneously with the mixed hardwood strand core material. Surface strands were blended with adhesive separately. Surface strands and core strand/textile blends were sprayed with 8% liquid phenol formaldehyde (PF) adhesive (55% PF solids content or 4.4% solids content of the total panel weight) in a drum blender. With this procedure, textiles were added to the core layer in varying amounts to fabricate panels with 0% (100/0), 5% (95/5), 15% (85/15), 25% (75/15), and 50% (50/50) of total panel weight being made up of textiles. Panels were pressed using a Williams White (Moline, IL) hydraulic hot press following the press schedule shown in Table 1. For each combination of wood and textile material, 10 panels were produced for a total of 50 panels.

Mechanical Property Testing

Internal bond (ie tension perpendicular to surface) tests were conducted in accordance with ASTM (2006a) using an MTS (Eden Prairie, MN) universal test machine (UTM). Four specimens, 50 mm wide × 50 mm long, were prepared from each panel for a total of 40 specimens per panel type. Specimen thickness, width, and weight were measured prior to testing. Specimen faces were glued between two steel blocks using a hot melt adhesive. Once cooled, specimens were loaded perpendicular to specimen faces until failure at a constant rate of 0.89 mm/min.

Table 1. Panel press schedule.

Panel pressing parameters	
Density	720 kg/m^3
Dimensions (length × width × height)	686 × 686 × 11.1 mm
Adhesive type	Liquid phenol formaldehyde (55% PF solids content)
Adhesive rate	8% (4.4% PF solids content of total panel weight)
Platen temperature	218°C
Total press cycle	290 s
Total cure time	230 s
Cooling procedure	Hot stack until cooled

Load and cross-head movement data were captured at a rate of 0.1 s per sample using an Instron (Norwood, MA) data acquisition system. After failure, maximum load was recorded and internal bond (IB) strength was determined.

Static bending tests were conducted in accordance with ASTM (2006a) using an MTS UTM. Three specimens, 76 mm wide × 317.5 mm long, were prepared from each panel in both the primary and secondary strength orientation for a total of 30 specimens per orientation and panel type. Specimen thickness, width, and weight were measured prior to testing. Specimens were loaded in bending at the center of the 266.7-mm span and at a constant rate of 5.3 mm/min. Load and cross-head movement data were captured at a rate of 0.1 s per sample using an Instron data acquisition system. After failure, maximum load was recorded and modulus of rupture (MOR) and modulus of elasticity (MOE) were determined.

Nail withdrawal testing was performed in accordance with ASTM (2006b) using an MTS UTM. Two specimens, 76 mm wide × 152 mm long, were prepared from each panel for a total of 20 specimens per panel type. Prior to testing, specimen width, length, and thickness (where the nail was driven into the samples) were measured and recorded. For each specimen, two 6d common nails (cleaned prior to testing) were driven in the specimen's center at a right angle to the OSB face such that at least 12.7 mm of the shank portion remained above the surface. Two tests were performed on each individual specimen. A constant rate of motion equal to 2.54 mm/min was maintained during each nail withdrawal test. Load and cross-head movement data were captured at a rate of 0.1 s per sample using an Instron data acquisition system. Ultimate withdrawal load was recorded, and nail withdrawal strength (N/mm depth penetration) was determined.

Water absorption (WA) and thickness swell (TS) tests were conducted in accordance with ASTM (2006a). Two specimens, 152 mm wide × 152 mm long, were prepared from each panel for a total of 20 specimens per panel type. Specimen thickness, width(s), and weight were measured prior to immersing them in water. Thickness measurements were taken at points in the middle of each side of the specimen at 25.4 mm in from the edge. Specimens were submerged in the water bath for 24 h. At the end of the 24-h submergence, thicknesses were remeasured at the same locations and each specimen was weighed. Twenty-four-h TS and WA were calculated.

RESULTS AND DISCUSSION

Panel Fabrication

Results of this study concluded that textiles can be blended, simultaneously, with wood core strand material. In terms of composite panel production, OSB/textile composites were successfully fabricated with no evidence of internal panel blows with the exception of one combination. The composite manufactured with 100% textile core material (50/50) appeared to have bonding-related issues during test specimen preparation. Specifically, in some instances, the 100% textile core composites fell apart during IB specimen preparation. Given this, the 100% textile core composites were omitted from further statistical analysis. Separate testing showed that individually, the textile material was capable of taking up three times as much adhesive than the wood strands when dipped into a container full of resin, removed, and drip-dried. Based on textile uptake tests and 100% textile core results, to fully develop the use of textiles in a composite panel, further research related to the textiles is needed that evaluates resin uptake, amount, and application method (eg separate blending).

Mechanical Properties

One-way analysis of variance (ANOVA) results showed a statistically significant difference ($p < 0.0001$) among composite panel types for average IB strength of the wood composites (Table 2). Further multiple range test analysis showed statistically significant differences among average IB strength of all panel types (Fig 1). Although

Table 2. Internal bond test results.

	Internal bond strength (kPa)			
	Wood/textile (%)			
Summary statistic	100/0	95/5	85/15	75/25
Average	352	283	138	55
SD	152	62	55	28
CV (%)	42	23	42	51
Minimum	55	131	62	7
Maximum	621	434	352	131

CV, coefficient of variation; SD, standard deviation.

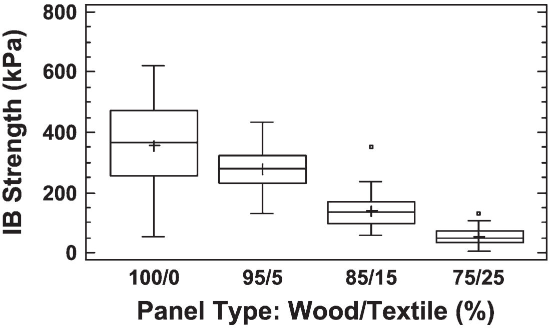

Figure 1. Internal bond strength of different formulations of panels.

IB strength of composites manufactured with textile core material was low, the 95/5 panels did have an average value that would probably be adequate for commodity-type OSB. The other combinations (85/15 and 75/25), however, were significantly lower than commodity OSB. IB tests are not required for structural-use OSB panels in US voluntary product standards but do give some indication of bonding. After inspection of the samples, it appeared that more adhesive may be needed for the textile raw material, because they are more porous than wood strands. Additionally, the results suggested that higher core density (and thus higher core pressure) may be needed during fabrication as the amount of textiles increases.

Table 3. Static bending strength (MOR) test results.

	Static bending strength, MOR (MPa)							
	Primary strength axis (0°)				Secondary strength axis (90°)			
	Wood/textile (%)				Wood/textile (%)			
Summary statistic	100/0	95/5	85/15	75/25	100/0	95/5	85/15	75/25
Average	22.2	19.9	17.8	9.5	17.4	16.9	14.5	9.1
SD	4.3	4.3	4.9	3.4	4.7	3.4	4.4	3.1
CV (%)	19.3	21.5	27.8	35.9	27.2	20.2	30.2	34.4
Minimum	14.5	11.8	9.1	4.4	9.3	9.0	7.0	3.7
Maximum	30.7	29.5	27.0	16.0	29.5	23.4	25.8	15.6

MOR, modulus of rupture; CV, coefficient of variation; SD, standard deviation.

In terms of static bending strength (MOR) (Table 3) in both the primary and secondary strength orientation, ANOVA results showed a statistically significant difference among composite panel types ($p < 0.0001$). Further multiple range test analysis did not show any statistically significant differences in average MOR (primary and secondary) between the control (100/0) and 95/5 panels (Figs 2 and 3). The 85/15 and 75/25 panels were found to have a statistically significant difference in average MOR (primary and secondary) compared with controls. Regarding average static bending MOE (Table 4) in both the primary and secondary strength orientation, ANOVA results showed a statistically significant difference among composite panel types ($p < 0.0001$). Further multiple range test analysis did not show any statistically significant differences

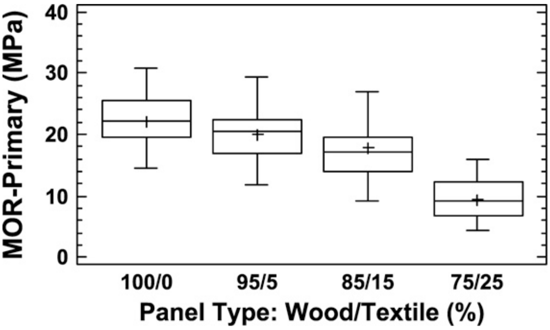

Figure 2. Modulus of rupture (MOR) in the primary orientation for different panel formulations.

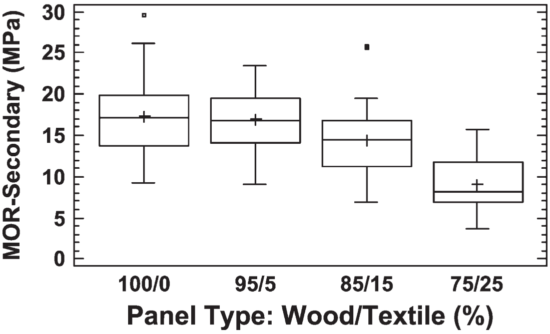

Figure 3. Modulus of rupture (MOR) in the secondary orientation for different panel formulations.

Table 4. Bending MOE test results.

	Static bending MOE (MPa)							
	Primary strength axis (0°)				Secondary strength axis (90°)			
	Wood/textile (%)				Wood/textile (%)			
Summary statistic	100/0	95/5	85/15	75/25	100/0	95/5	85/15	75/25
Average	3357	3185	2816	1760	2435	2443	2130	1522
SD	518	583	518	673	479	462	439	405
CV (%)	15.4	18.3	18.4	38.3	19.7	18.9	20.6	26.6
Minimum	2547	1648	1844	587	1550	1228	1430	713
Maximum	4377	4385	3929	3263	3136	3220	3425	2387

MOE, modulus of elasticity; CV, coefficient of variation; SD, standard deviation.

in average MOE (primary and secondary) between the control (100/0) and 95/5 panels (Figs 4 and 5). The 85/15 and 75/25 panels had a statistically significant difference in average MOE (primary and secondary) compared with controls. These results suggest that adding 5% shredded, recycled cotton textile fabric has no statistically significant effect on bending properties of the composite OSB panel.

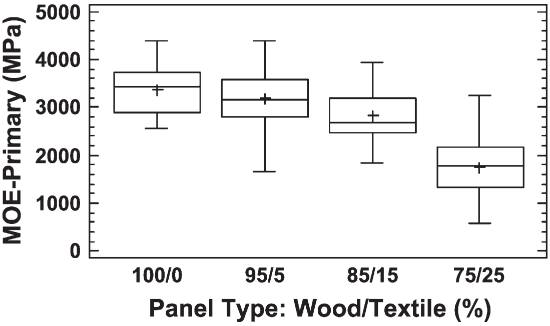

Figure 4. Modulus of elasticity (MOE) in the primary orientation for different panel formulations.

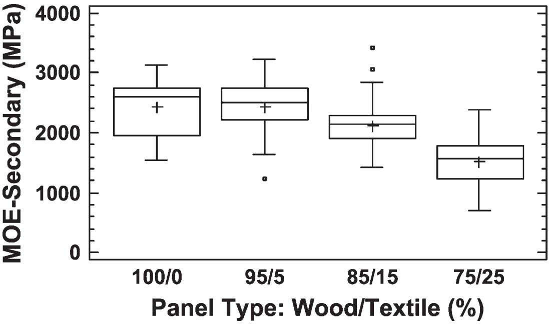

Figure 5. Modulus of elasticity (MOE) in the secondary orientation for different panel formulations.

Regarding nail withdrawal strength (Table 5), ANOVA results showed a statistically significant difference among composite panel types ($p < 0.0001$). Further multiple range test analysis did not show any statistically significant differences in nail withdrawal strength between the control (100/0) and 95/5 panels (Fig 6). The 85/15 and 75/25 panels were found to have a statistically significant difference in average nail withdrawal strength compared with controls. These results suggest that adding 5% shredded, recycled cotton textile fabric has no statistically significant effect on nail withdrawal.

Table 5. Nail withdrawal test results.

	Nail withdrawal strength (N/mm of depth penetration)			
	Wood/textile (%)			
Summary statistic	100/0	95/5	85/15	75/25
Average	15.9	14.7	9.3	10.5
SD	9.1	7.0	5.6	5.3
CV (%)	57.0	47.5	59.9	49.7
Minimum	2.8	4.9	1.4	3.5
Maximum	39.4	35.9	25.0	21.2

CV, coefficient of variation; SD, standard deviation.

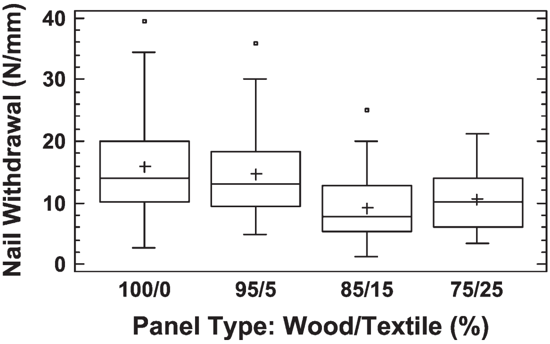

Figure 6. Nail withdrawal strength for different panel formulations.

In general, specimen failures occurred between wood–wood bonds, wood–textile bonds, and textile–textile bonds. Analysis of IB specimens showed that as textile percentage in the core increased, there was an increase in the amount of textile–textile bond failure. As evidenced by the 100% textile core panels, the textile–textile bonding greatly influenced panel IB strength. In terms of bending specimen failures, typical bending-type failures were noted for most of the panels. However, as textile percentage was increased to 25% of the core material, a noticeable amount of planar shear-type failures occurred. This indicated that the textile–textile bonds probably were not as able to resist planar shear forces compared with the wood–wood and wood–textile bonds. Further testing would be needed, however, to determine the differences in shear strength of these different types of bonds.

Physical Properties

For TS (Table 6 and Fig 7), ANOVA results did not show any statistically significant difference among composite panel types ($p = 0.0637$). For WA (Table 7), ANOVA results showed a statistically significant difference among composite panel types ($p < 0.0001$). Further multiple range test analysis did not show any statistically significant differences in WA between the control (100/0) and 95/5 panels (Fig 8). The 85/15 and 75/25 panels had a statistically significant difference in average WA compared with controls. Interestingly, although WA was higher for the 85/15 and 75/25 panels, average TS values were not significantly higher than the controls. This suggests that the cotton fibers absorbed more of the water but did not swell as much as the wood strands. However, WA patterns for the panels with cotton fibers added need further investigation. These results suggest that adding 5% shredded, recycled cotton textile fabric had no statistically significant effect on TS or WA properties of the composite OSB panel.

Table 6. Thickness swell test results.

	Thickness swell (%)			
	Wood/textile (%)			
Summary statistic	100/0	95/5	85/15	75/25
Average	43.9	41.4	40.2	43.6
SD	7.5	3.5	4.2	3.5
CV (%)	17.1	8.6	10.5	8.0
Minimum	36.0	32.4	32.4	37.8
Maximum	67.1	46.7	47.0	49.4

CV, coefficient of variation; SD, standard deviation.

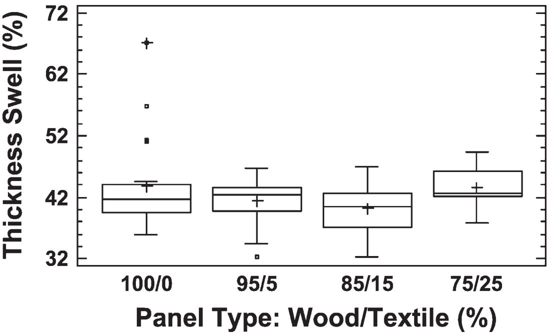

Figure 7. Thickness swell for different panel formulations.

Table 7. Water absorption test results.

	Water absorption (%)			
	Wood/textile (%)			
Summary statistic	100/0	95/5	85/15	75/25
Average	85.4	89.3	92.8	100.2
SD	7.7	3.3	8.4	6.6
CV (%)	9.1	3.7	9.1	6.6
Minimum	76.8	83.3	71.2	84.9
Maximum	102.5	94.3	108.7	110.4

CV, coefficient of variation; SD, standard deviation.

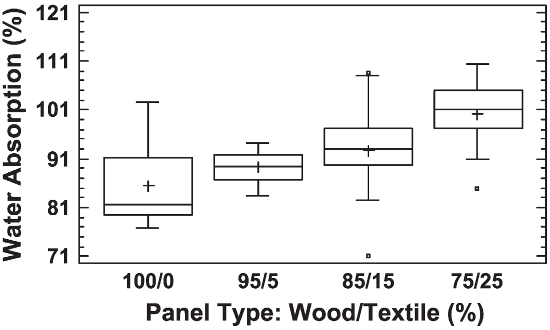

Figure 8. Water absorption for different panel formulations.

CONCLUSIONS

The major finding of this study indicated that compared with the controls (ie panels with 0%

textile material), panels with 5% textile materials (95/5) did not show a statistically significant difference in any evaluated mechanical and physical property, except for IB strength. Additionally, although the controls had the greatest average TS, none of the groups tested showed a statistically significant difference ($p = 0.0637$). The study indicated that 5% recycled textile material could probably be used in the core of existing wood-based structural-type panels without significantly decreasing physical or mechanical properties. Based on 2009 OSB production data for the US (11 million m^3) and an assumed density of 672 kg/m^3, replacing 5% of the panel production weight of wood with textile material would save approximately 370 million kilograms of wood fiber consumption annually in the US.

Further testing to industry standards (ie PS2), however, is needed to determine if the panels would meet all requirements of commodity OSB panels. The remaining OSB/textile fiber composite panels (ie 85/15 and 75/25) appear to be better suited as interior, nonstructural panels. It is expected, however, that IB strength can be increased by adding more adhesive to the textile material and/or pressing at a higher pressure (ie higher core layer density). This research has shown that recycled textile material can be processed and bonded with wood material to form a composite. By manufacturing this type of panel, the amount of textiles sent to landfills could be significantly decreased. Further research is needed to evaluate thermal performance of these types of panels and to study alternative types of recycled textile fabrics and fibers with reinforcement properties.

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