Influence of hot water extraction on the physical and mechanical behavior of OSB

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Abstract

This study evaluated the influence of hot water extraction on hemicellulose removal, the concomitant change in wood properties, and finally production of oriented strandboard (OSB) from the modified wood. Three red maple (*Acer rubrum* L.) trees were felled, debarked, and their butt logs used to produce strands of 4-in length with a target thickness of either 0.025 inches, 0.035 inches, and 0.045 inches. Two hot water extraction procedures (320 °F, 90 psig) of 45 and 90 minutes duration (plus 50 minutes of preheating) were used, resulting in an average weight loss of 16.4 and 17.2 percent, respectively. Weight loss was significantly influenced by extraction time ($p = 0.0011$) and tree source ($p = 0.0001$) while the influence of strand thickness was not statistically significant ($p = 0.1026$). One OSB panel (17.6 inches by 12.4 inches by 0.5 inches) was manufactured for each of the 27 material combinations (2 extraction conditions and unextracted control, 3 trees, and 3 strand thickness). Panels were blended individually with a resin load of 3.2 percent pMDI resin, no wax, and an average density of 41.8 pcf (test volume basis). Physical and mechanical properties were determined following ASTM D1037–06 A procedures. Water absorption by OSB produced from both extraction treatments was significantly higher than the control for both 2 and 24 hours immersion while the thickness swell of panels from extracted material was slightly improved after 24 hours. The modulus of rupture (MOR) was not statistically significantly different between the control (5,966 psi) and the 45 minutes of extraction time (6,162 psi) panels, while the 90 minutes extraction time was significantly lower (4,093 psi). Internal bond strength in dry conditions from both extraction times (29 and 45 psi) were significantly lower than the control (117 psi), and similar results were obtained in wet condition (35 and 15 psi).

Biorefineries use biomass derived from grains such as corn, wheat, and barley, as well as oils, sugar cane, and agricultural residues to produce multiple products including ethanol, glycerol, etc. However, the use of grains, oils, and sugar cane for energy production reduces their availability for use as food or feed. Wood (approximately 45 percent of which is cellulose) is an attractive feedstock for the production of biofuel, but the utilization of wood for biofuel has not been economically viable, unless subsidies are provided, in part due to the fact that the remaining solids are not used for other goods (Lasure and Zhang 2004).

Economical conversion of wood into useful chemicals requires efficient use of all major wood components: cellulose, hemicellulose, and lignin. Hemicellulose is the most easily removed of the three major biopolymers since it is an amorphous and branched polysaccharide. The incorporation of hemicellulose extraction within the context of pulp production has been extensively studied. The Department of Energy (DOE) has funded a demonstration project with the stated goal of producing 2.2 million gallons of ethanol annually from 80 tons per day of hemicellulosic extract (RISIINFO.com 2008). The OSB industry is also a potential candidate for this technology as it is composed of large centralized facilities.

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Additionally, the mass transfer of hemicelluloses is facilitated when using thin wood elements such as OSB strands. The demand and production of OSB panels in North America have significantly increased, with an estimated 2008 annual production of 15.6 million tons (26,232 million ft^2, 3/8-inch basis) (Adair 2004).

If 15 percent of the weight of this material were extracted, the result would be 2.3 million tons of feedstock material. Considering that 87 percent of the compounds removed is xylose (Boussaid et al. 1998), and assuming a modest conversion rate from xylose to ethanol of 0.35 tons ethanol/tons xylose (Jeffries 1985), around 0.71 million tons of ethanol could be produced. Based on the density of ethanol (49.25 pcf) and volume conversion of one-cubic foot is 0.178 barrels, the result would be 5.7 million barrels of ethanol.

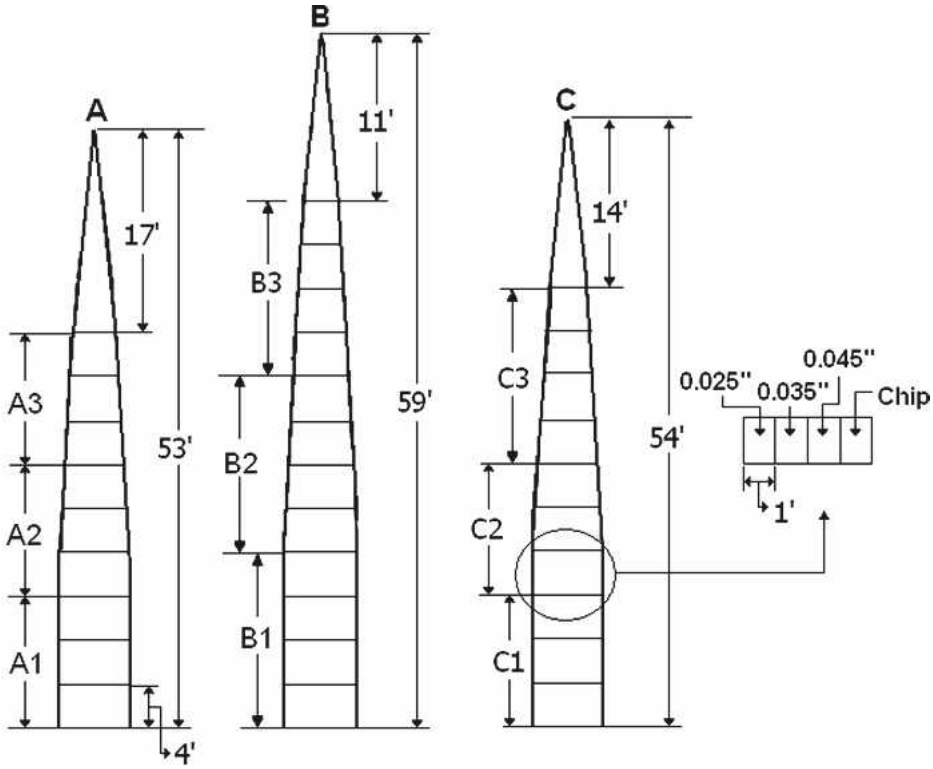

Figure 1. — Three trees showing location of the test specimens.

Background

The main chemical structure of hemicelluloses was identified over 40 years ago (Shimizu 1990). Hemicelluloses are amorphous biopolymers, heteropolysaccharides, relatively easily hydrolyzed by acids to their monomeric components consisting of D-glucose, D-mannose, D-galactose, D-xylose, L-arabinose, and small amounts of L-rhamnose in addition to D-glucuronic acid, 4-O-methyl-D-glucuronic acid, and D-galacturonic acid (Shimizu 1990, Sjöström 1989, Sjöström 1993).

Two different routes for wood fractionation have been developed. Fractionation refers to processes that separate wood into its biopolymeric constituents (cellulose, lignin, and polymeric hemicelluloses). One route is based on the application of organic solvents, originating in the pioneering work of Kleinert and von Tayenthal (Jeoh 1998). The second option is based on steaming lignocellulosic material at elevated temperature, which has been considered for biomass fractionation for more than 30 years.

Prehydrolysis is based on the high reactivity of hemicelluloses under mildly acidic conditions without affecting the cellulose, with the objective of removing hemicelluloses from biomass materials by heating in water at 338 °F (Lai 1990). Autohydrolysis is a steam hydrolysis process at temperatures of 347 to 428 °F by organic solvents or dilute alkali. The objective is to extract lignin, but hemicelluloses are solubilized in the process as well (Lai 1990).

Steam explosion was developed in 1925 by W.H. Mason for hardboard production (Jeoh 1998). It is based on autohydrolysis of lignocellulosic materials at high temperatures (392 to 482 °F), followed by an explosive rapid discharge to disintegrate the substrate. The exploded wood can be separated into hemicellulose (by water extraction), lignin (by alcohol), and cellulose components (Lai 1990). This method guarantees the availability of hemicellulose at an industrial scale (Puls and Saake 2004).

In enzymatic hydrolysis, wood carbohydrates are hydrolyzed by a group of enzymes (Jeoh 1998). The recycling of the enzymes is difficult and thus use is expensive (Sjöström 1993).

Other extraction processes include using hot water, where water and wood chips are placed inside a high pressure vessel at temperatures between 284 and 374 °F, and at different extraction times, generally ranging from 10 to 90 minutes (Yoon et al. 2006). The effect of time and temperature during pure water extraction on wood weight loss may be described by a single parameter, using either the equations of H-factor or Severity factor (SF).

Materials and specimens preparation

In February, 2006, red maple (*Acer rubrum* L.) trees were felled and cut into three logs (bottom, middle, and top), each part 4 foot in length (**Fig. 1**). Each section was debarked mechanically with a chain saw rigged with a debarking head. Strands were produced using a Carmanah 12/48 ring strander at three target thicknesses (0.025 inches, 0.035 inches, and 0.045 inches), 4-inch length, and varying width. Strand thickness was determined with a Mitutoyo digital caliper with precision of 0.0001 inch. Strands were dried and conditioned using a dehumidification dry kiln (100 °F and 60% RH) for 5 days until constant weight was attained. The extraction process would likely be conducted on green strands in industrial application. However, the strands were conditioned to prevent mold during the 6-week period in which the extractions were performed. Additionally, it was necessary to know the MC of the wood prior to the extraction process in order to maintain a liquid-solid ratio of 4 for all experiments (see following section). The MC of the strands was 10.1 percent, determined by an Ohaus MB45 moisture balance with precision of 0.01 percent MC and 0.000035 ounce.

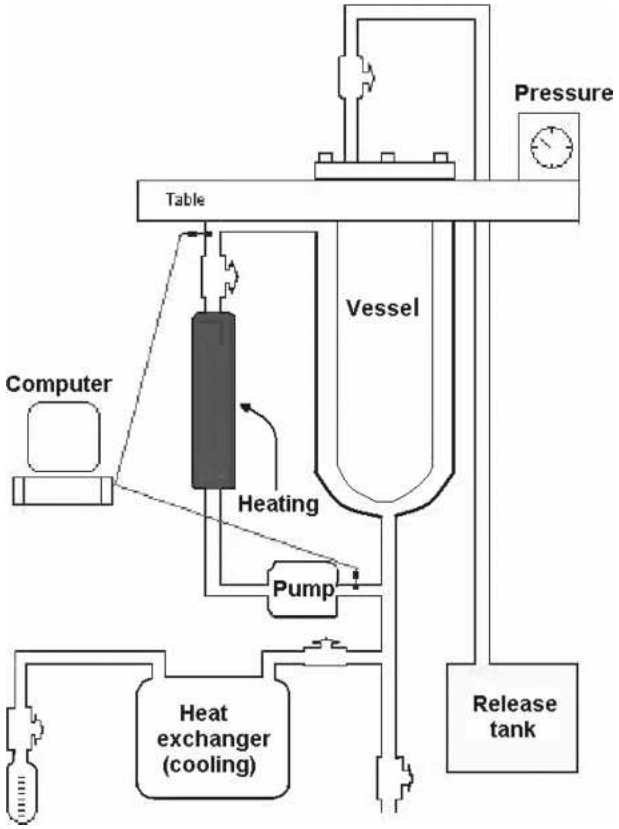

Figure 2. — Digester (reactor) showing its main parts and sensors.

Extraction process

Two hot water extraction procedures were applied to the strands. The strands (1.1 lb batches) were placed inside a high pressure vessel filled (**Fig. 2**) with fresh water subjected to a liquid-solid ratio of 4. The moisture in the wood was included in the ratio calculation. The vessel was heated from room temperature to 320 °F in 50 minutes (preheating time), followed by constant temperature exposure times of 45 or 90 minutes. Three extraction runs were made for each material combination (two extraction times × three strand thickness × three trees) for a total of 54 samples.

The temperature/time profiles of the two extraction conditions were quantified by determining the associated severity factor (SF).

$$SF = \log\left(\int_0^t Exp\left[\frac{(T_r - T_b)}{14.75}\right] dt\right) \qquad [1]$$

Where: t is residence time (minutes), T_r is the reaction temperature (°C), and T_b is Base temperature (100 °C). The energy of activation is 14.75 (kJ/kg mol) assuming that the overall process is hydrolytic and the overall conversion is first order (Overend and Chornet 1987, Mosier et al. 2002). This approach has been used to evaluate the effects of steam explosion pretreatments on biomass (Jeoh 1998).

Water temperature was measured before and after the heater element (**Fig. 2**) at 3 second intervals. The severity factors (SF) calculated using Eq. [**1**] were 3.54 and 3.81 for the 45 and 90 minute extraction times, respectively. The severity factor (SF) associated with first 50 minutes (preheating time) was 2.80. Weight loss of the strands as a result of the extraction process was determined for each extraction run by freeze drying (LABCONCO model LYPH-lock 6) the extracted liquid at −43.6 °F and between 19 and 21 × 10^{-5} PSI vacuum. Every sample was weighed both before and after freeze drying treatment by a laboratory balance (A & D Phonix GH-202) with readability of 2.2 × 10^{-7} pounds. Equation [**2**] was used to determine the weight loss.

$$\%WL = \left(\frac{E\left(\frac{S}{L}\right)}{W}\right) \times 100 \qquad [2]$$

Where: %WL is the percent weight loss, S is the weight in pounds of solid fraction from the freeze drier, L is the weight in pounds of sample of extract put into the freeze drier (sample from E), E is the weight in pounds of liquid extract resulting from each extraction, and W is the weight in pounds of the oven dried wood.

Analysis of the liquid extract (Jara et al. 2006) showed that the pH decreased as the severity factor (extraction time) increased. This is consistent with generation of acetic acid. Jara et al. (2006) found that arabinan, galactan, and manan were the hemicelluloses most extracted at a low SF of 2.8, but when the SF increases, arabinan began to degrade. Xylan is the most abundant hemicelluloses in Red maple (Sjöström 1993), and this pentose sugar began to be removed after a SF of 3.3, extracting a significant portion, 65 percent on original sugar, until a SF of 3.7 (Jara et al. 2006).

OSB manufacture

Following extraction, strands were conditioned using a Nyle dehumidification dry kiln. Unextracted (control) strands were conditioned at 100 °F and a relative humidity (RH) of 60 percent for 5 days until constant weight was attained. The extracted strands were exposed to a temperature of 100 °F and 80 percent RH for 5 days. The MC of the control material was 10.4 percent while the extracted material had an equilibrium MC of 8.1 percent, even though exposed to a significantly higher relative humidity.

Material sufficient for the production of a single panel (2.81 lb dry weight basis) was placed in a Coil spinning disk atomizing resin blender. Resin was applied using a disk speed of 12,000 rpm, a drum speed of 20 rpm, and a resin feed rate of 2.7 ounce/min. for a total blend time of 5 minutes. A polymeric diphenylmethane diisocyanate (pMDI) adhesive (Huntsman rubinate 1840) was added at a target loading of 4 percent solids content based on the ovendry weight of the wood. The actual resin loading was determined to be 3.2 percent based on nitrogen analysis of a sample of resinated strands. No wax was added. Panels were hand-formed using a thick galvanized steel caul plate sprayed with a mold release (Stoner E497) and forming box. The target panel dimensions were 17.6 in by 12.4 in by 0.5 in thickness at a density of 41.8 pcf at 12 percent MC (**Fig. 3**).

Press stops (0.50 in) were used to define the panel out-of-press thickness. A 400-ton capacity 2 ft by 2 ft hydraulic press (Erie Mill and Press) was used for panel manufacture. The press platen temperature was 350 °F. The press schedule was a 30 second close time, followed by 5 minutes at target thickness, with a 30-second decompression cycle.

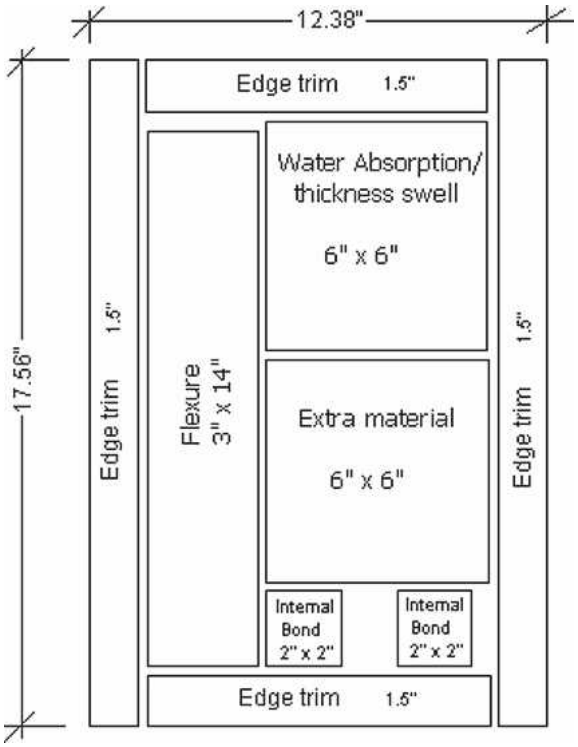

Figure 3 .— Cut up plan for each OSB panel.

After pressing, the panels were edge trimmed and the thickness measured at the midpoint of each edge. The panels were then conditioned at 70 °F, and a RH of 65 percent until constant weight was attained (42 days). Panels were then cut into test specimens (flexure, water absorption, and internal bond) following ASTM D1037–06A specifications (ASTM 2006).

Results and discussion

Hot water extraction

The influence of severity factor, tree source, and strand thickness on weight loss is summarized in **Table 1**. The weight loss response was analyzed with an analysis of variance model. The statistical model results presented only include main factor effects as the initial analysis indicated interactions between treatments was not significant.

The low level of influence of strand thickness on weight loss ($p = 0.1026$) was unexpected and it can be interpreted that diffusion phenomena is not a limiting factor at the process conditions evaluated in this study. One would expect weight loss to decrease as thickness increases for a given extraction time.

Extensive research has been carried out on within tree variations, such as fiber properties, wood chemical and physical properties, and pulping evaluation (Timell 1986, Zobel and van Buijtenen 1989, Hatton and Hunt 1993, Bertaud and Holmbom 2004, Zhu et al. 2005).

In a study of the hot water extraction behavior of Loblolly pine chips (Yoon et al. 2006), extraction time and temperature were found to be directly proportional with wood weight loss. The integrated effect of time and temperature (severity factor) was significantly ($p = 0.011$) related to weight loss. A kinetics extraction rate analysis was beyond the scope of this study but rate of weight loss was clearly nonlinear with minimal additional weight loss (0.73%) after the 45 minutes extraction

Table 1. — Influence of severity factor, tree source, and strand thickness on weight loss during extraction with associated 95 percent confidence intervals.

Factors/levels	Count	Mean	COV	p-value
		-------- (percent) --------		
		Severity factor		
3.54	27	16.44[a] ± 0.33	7.10	0.011
3.81	27	17.17 ± 0.33	4.23	
		Tree Source		
A	18	16.13 ± 0.40	7.78	0.001
B	18	16.88 ± 0.41	4.71	
C	18	17.41 ± 0.41	3.90	
		Strand thickness (inch)		
0.025	18	16.87 ± 0.40	6.70	0.1026
0.035	18	17.05 ± 0.40	6.46	
0.045	18	16.50 ± 0.40	5.72	

[a]Mean value ± 2 SDs (95 percent confidence interval).

Table 2. — Density and MC of commercial, red maple control and extracted OSB panels.

Material source	Count	Density[a]	MC		
			Conditioned	2 hour	24 hour
		(pcf)	---------- (percent) ----------		
Commercial	8	44.62[b] ± 1.0	9.9 ± 0.2	17.4 ± 0.9	35.7 ± 2.3
Control	9	40.3 ± 0.9	10.2 ± 0.1	17.8 ± 0.8	35.4 ± 2.2
SF = 3.54	9	41.8 ± 0.9	6.2 ± 0.1	17.5 ± 0.9	37.1 ± 2.2
SF = 3.81	9	41.4 ± 0.9	6.2 ± 0.1	17.0 ± 0.9	37.4 ± 2.2

[a]Density defined as test weight over test volume after conditioning to 70 °F and 65 percent RH.
[b]Mean value ± 2 SDs (95 percent confidence interval).

(SF = 3.54). This indicates lower SF conditions should be explored.

Physical properties

Physical properties evaluated in this research included density, conditioned MC, and response of the material to water absorption following ASTM D1037–06A, Section 100–107, Method B (ASTM 2006). The initial density, MC after conditioning and after exposure to water are summarized in **Table 2**. While the material from a commercial OSB panel (PS 2 –04, sheathing span 7/16 inch, manufactured in Virginia) had significantly higher density, the average density of the red maple panels fell within the range of values for commercial panels (Hood 2004, Wang et al. 2004).

Panel thickness increase resulting from equilibration from out of press conditions to constant weight occurred within 7 days for OSB from extracted material and was significantly less than that of OSB from unextracted strands (**Fig. 4**). Additionally, the EMC of the panels was lower than that of the control material. This indicates that the removed polysaccharides were predominantly amorphous, as expected, and gives results similar to the theoretical behavior presented by Rowell and Banks (1985).

Following panel equilibration to 70 °F and 65 percent RH, the EMC of the OSB manufactured from extracted strands was significantly lower than both the control (unextracted) and commercial OSB panels (6.2, 10.2, and 9.9% MC, respectively). However, this difference in MC did not carry

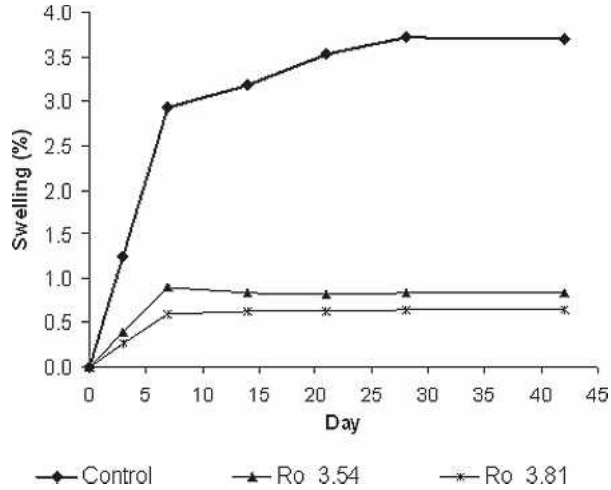

Figure 4. — Stability dimensional determined by thickness swell is plotted for control and both severity factors (SF 3.54 and 3.81).

through following exposure to liquid water (2 and 24 hour immersion), with no statistical difference exhibited. The elimination of MC differences after water immersion indicates an increased moisture uptake rate in OSB from extracted material.

The thickness swell and water absorption determined after 2 and 24 hour water immersion, as specified in ASTM D1037–06A (ASTM 2006) is summarized in **Tables 3** and **4**. Water absorption results after 2 and 24 hour submersion from 0.5 inch thick panels are within the range of values found by Brochmann et al. (2004). Water absorption after 24 hours was significantly greater for both severity factors, but the control and commercial panels showed no difference. The extraction time had a significant effect while strand thickness and tree source did not influence water absorption.

The thickness swell results are slightly lower that the results found by Brochmann et al. (2004) in OSB panels from aspen using a mixed PF and pMDI resin system. The thickness swell of the extracted material was slightly improved after 24 hours, with the commercial panel having the greatest thickness swell. Thickness swell is the more critical value of the two in terms of field performance.

Thickness swell and water absorption are typically highly correlated. However, the relationship is changed when using extracted wood material. Previous studies have shown that extraction of hemicellulose from wood using high pressure steam caused a reduction the thickness swell in both hardwood siding and wood (Lenic 1973, Myers 1982, Wang et al. 2000). Hsu and Bender (1988) reported that hydrolysis of hemicellulose by high pressure steam reduced the thickness swell of particleboard and waferboard. The reduction in hygroscopicity, capillary flow, and dimensional movement is due to process of replacing hydroxyl groups in lignocellulosic materials with acetyl groups (Carll 1997), because of that those carboxylic acid groups are potential sites of ionic charge (Sjöström 1989). Consequently, the actual fiber saturation point (FSP) is modified when the sugars are removed from the wood.

It is known that formic and acetic acid are formed during hydrothermal treatment or hot pressurized water at high temperatures (Alén et al. 1985, Manninen et al. 2002, Sundqvist et al. 2006, Hill 2006). In hardwoods the major hemicellulose component are xylans, 20 to 30 percent of the wood and on the average, 7 acetyl groups for every 10 xylose units are contained at C-2 or C-3 (or both). As the wood is heated, the production of acetic and formic acid from hemicelluloses originate a cellular breakdown production of condensable fractions, with loss of high portion of hemicelluloses, low percent of lignin, constitution water and volatile extractives (Hill 2006 and Jara et al. 2006). In addition, thickness swell and water absorption are typically highly correlated. This decoupling is likely due to the increased cell wall porosity from the extraction as well as the lower starting EMC of the extraction OSB.

Table 3. — Multifactor analysis of variance for 2-hour and 24-hour thickness swell and water absorption (%) at 95 percent confidence level comparing between SF (control, SF 3.54 and SF 3.81), thickness (0.025 inches, 0.035 inches, and 0.045 inches), and tree (A, B, and C).

Source	Degree freedom	p-value			
		Thickness swell		Water absorption	
		2 hour	24 hour	2 hour	24 hour
		Covariate			
MC initial	1	0.2441	0.2828	0.6034	0.0465
		Main effects			
A: SF	2	0.0333	0.4919	0.6690	0.0638
B: Thickness	2	0.5993	0.3895	0.1946	0.1847
C: Tree	2	0.6548	0.3436	0.1066	0.1359
		Interactions			
AB	4	0.5847	0.4517	0.3402	0.4574
AC	4	0.1452	0.1580	0.1295	0.1454
BC	4	0.1386	0.3395	0.1716	0.2485

Table 4. — 2-hour thickness swell and 24-hour water absorption response of commercial, red maple control and extracted OSB panels.

Material source	Count	Thickness swell		Water absorption	
		2 hour	24 hour	2 hour	24 hour
		(percent)			
Commercial	8	1.8[a] ± 0.4	14.0 ± 1.2	6.9 ± 0.8	23.7 ± 2.1
Control	9	1.2 ± 0.3	11.6 ± 1.1	6.9 ± 0.8	22.8 ± 1.9
SF = 3.54	9	1.1 ± 0.3	10.5 ± 1.1	10.7 ± 0.8	29.1 ± 1.7
SF = 3.81	9	1.8 ± 0.3	10.8 ± 1.1	10.1 ± 0.8	29.4 ± 2.3

[a]Mean value ± 2 SDs (95 percent confidence interval).

Mechanical properties

Mechanical properties which were evaluated included bending strength (MOR), bending modulus of elasticity (MOE), bending stress at proportional limit (SPL), and internal bond (IB) strength in both the dry and wet condition. All material was evaluated as per ASTM D1037–06A procedures (ASTM 2006) after the OSB was equilibrated to constant weight. Test results are presented in **Tables 5** and **6**.

The red maple panels had greater MOE values than the commercial panels. However, a direct comparison of performance is of little value due to differences in resin, wax levels and species. There was a significant difference between the two severity factors for the red maple panels. The bending

Table 5. — Flexural and internal bond strength of commercial, red maple control and extracted OSB panels.

Material source	Count	MOR	MOE	SPL	IB dry	IB wet
		(psi)	(ksi)	---------- (psi) ----------		
Commercial	8	3,643[a] ± 1067	568 ± 80.7	2,200 ± 420	91 ± 23.6	23 ± 6.0
Control	9	6,163 ± 636	1,018 ± 76.1	3,775 ± 396	117 ± 22.2	35 ± 5.6
SF 3.54	9	5,966 ± 636	1,168 ± 76.1	3,976 ± 396	29 ± 22.2	15 ± 5.6
SF 3.81	9	4,093 ± 636	936 ± 76.1	2,836 ± 396	45 ± 22.2	15 ± 5.6

[a]Mean value ± 2 SDs (95 percent confidence interval).

Table 6. — Multifactor analysis of variance for mechanical properties at 95 percent confidence level comparing between SF (control, SF 3.54, and SF 3.81), thickness (0.025 inches, 0.035 inches, and 0.045 inches), and tree (A, B, and C).

Source	Degree freedom	p-value				
		MOR	MOE	SPL	IB_dry	IB_wet
		Covariate				
MC initial	1	0.9248	0.5419	0.6792	0.2050	0.4137
		Main effects				
A: SF	2	0.0268	0.0317	0.0704	0.0036	0.0005
B: Thickness	2	0.5452	0.5860	0.5992	0.1488	0.1064
C: Tree	2	0.0819	0.0642	0.2011	0.8435	0.0364
		Interactions				
AB	4	0.9242	0.4780	0.8097	0.9831	0.9936
AC	4	0.2521	0.3144	0.2352	0.9672	0.1688
BC	4	0.4606	0.4089	0.6231	0.6285	0.6740

strength was similar for the control and short extraction time panels while there was a significant decrease in MOR for long extraction.

The stress at proportional limit (SPL) behavior of the red maple OSB panels exhibited the same trend as MOR, i.e., control and low severity factor (3.54) panels were similar, with a decrease in performance at the high severity factor (3.81).

In contrast, the internal bond (IB) of the panels were significantly lowered at even the lower SF value. This was true for both wet and dry conditions. Internal bond performance is highly correlated with the quality of the wood/wood bond. The resin content of the panels was determined to be lower than the target level (4%). However, this reduction was the same for the control and extracted samples and thus not a reason for the measured reduction. Using a sessile drop method, it was determined that Diiodemethane, distilled water, and ethylene glycol all penetrated into extracted strands as a significantly higher rate than into the unextracted wood. It has been shown that pMDI penetrates well into wood (Kamke and Lee 2007). It may be that the modification of the wood strands results in over penetration of the adhesive, resulting in low wood/wood bond strength and hence lower IB.

Conclusions

A hot water extraction process carried out at high temperature (320 °F) and pressure (90 psig) resulted in significant reductions in the wood weight. The extracted material from the red maple was primarily xylan with small amounts of lignin. As the extract is related both to temperature and time, a single measure (severity factor (SF)), was used to quantify both factors.

The severity factor of the extraction process influenced the weight loss with mean values of 16.77 percent and 17.50 percent for SF = 3.54 and SF = 3.81, confirming the results of previous research that the severity factor (SF) is proportional to weight loss. The significant influence of tree source (16.53%, 17.29%, and 17.82% for trees A, B, and C) on weight loss is presumably due to the natural variability in the wood substance. Strand thickness in the range of 0.025 to 0.045 in had a less significant influence and weight loss ($p = 0.1026$) for the two extraction process conditions. The extraction process had noticeable impact on physical and mechanical properties of OSB. Some physical properties were enhanced, such as dimensional stability in strand and panel thickness.

Flexural behavior of the lower SF was equivalent to the control (unextracted) condition but there was a statistically significant reduction at the higher SF value. This indicates that reductions in mechanical properties of the wood occurred at the higher level, presumably due to hydrolysis of the cellulose. In contrast, significant reductions in IB occurred even at the lower SF, indicating a significant impact on bond quality. The use of lower SF conditions may be warranted and the ability to counteract the reduced bond quality will likely be necessary. The use of extracted strands, produced at equivalent panel density, was associated with a higher compaction ratio as a result of the use the lower density furnishes. This may have counteracted marginal reductions in wood properties. Any influence on long-term performance of OSB due to the potential lower pH of the extracted material should also be considered.

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