Sprayable Molten Waxes as Water Repellents for OSB

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Summary

Oriented strand board (OSB) experiences undesirable thickness swelling when it absorbs water. One solution to this problem is to treat OSB with water-repellents containing waxes. However, aqueous water-repellents cause unwanted surface roughening of OSB, and there are environmental concerns with solvent-borne water-repellents. An alternative solution to these problems is to apply water-repellent waxes as hot-melt systems that contain no water or solvent. Molten waxes were sprayed onto the surface of hot OSB samples, and the water absorption and thickness swelling of treated OSB was assessed. There were no definitive relationships between properties of waxes and the water-repellency of treated OSB, but the most effective treatments were blends of beeswax, which is polar, and a strongly hydrophobic paraffin wax. These treatments reduced the irreversible thickness swelling of OSB samples and have potential as cost-effective post-treatments to improve the short-term moisture resistance of OSB, and possibly other wood composites.

1. Introduction

Oriented strand board (OSB) is the most common load-bearing composite wood panel in North America (Howard and McKeever, 2012). OSB production in North America in 2012 was 15.5 million m^3 and European production exceeded 4.9 million m^3 (UNECE/FAO, 2013). OSB is mainly used for wall sheathing, roof decking, sub-floors, furniture, industrial packaging and formwork (Thoemen et al., 2010). In some of these applications and during transportation, OSB is unavoidably exposed to water for various periods of time (Taylor et al., 2008, Evans et al., 2013). For example, Winterowd et al., (2003) state that "an uncovered sub-floor can accumulate in excess of 50 mm of water during a rainstorm" and "the accumulated water will be left to absorb into the sub-floor panels for several days during the home-building process". Wood panels exposed to water experience undesirable thickness swelling, and there is significant interest in developing cost-effective solutions to this problem.

Several approaches have been tested to reduce the thickness swelling of OSB and other particulate wood composites (flakeboard and particleboard), including increasing resin or wax content of panels, altering their density, or chemically or thermally modifying strands used to make panels (Suchsland, 1962, Haygreen and Gertjejansen, 1971, Winistorfer et al., 1996, Sekino et al., 1999, Linville and Wolcott, 2001, Papadopoulos and Traboulay, 2002, Wan and Kim, 2006, Mendes et al., 2013, He and Evans, 2016). In addition, various post-treatments including coatings and thermal modification of panels can be used to improve the dimensional stability of OSB (Grossman, 1992, He et al., 2000, Del Menezzi and Tomaselli, 2006, Shmulsky and Jones, 2011).

OSB with enhanced dimensional stability has been developed and commercialized in North America for use as sub-floors (Taylor et al., 2008). These enhanced sub-floor products contain higher loadings of phenol formaldehyde resin and wax to increase their dimensional stability or replace the phenol formaldehyde resin with a polymeric methylene diphenyl diisocyanate (pMDI) adhesive. All of the enhanced OSB sub-floor products contain a thick elastic coating on their edges (edge seal) to reduce the edge thickness swelling of OSB (Winterowd et al., 2003). Coatings perform better on a weight basis when they are applied to smooth substrates because they are better able to create an impervious barrier to water. For example, a coatings system was more effective at preventing the absorption of water into OSB when it was applied to smooth sanded samples than rougher unsanded controls, even though smoother OSB samples absorbed less than half the coating material of unsanded OSB samples (Evans and Cullis, 2008). The faces of OSB are rough and, hence, coatings are not used commercially to restrict moisture ingress into OSB, unless preliminary steps such as sanding or filling are used to reduce the roughness of panels prior to application of coatings. An alternative to coatings that can prevent moisture ingress into rough organic and inorganic substrates is application of water repellents (Charola, 2003). Water repellents prevent the penetration of liquid water into materials by changing the surface properties of the material to which they are applied; they perform well on rough textured materials (Charola, 2003). Accordingly, Mantanis and Papadopoulos (2010) dipped OSB samples into an aqueous water-repellent solution containing paraffin wax and found that the water repellent reduced the water absorption and thickness swelling of OSB. Similarly, Semple et al., (2009) found that aqueous wax emulsions sprayed onto OSB reduced the water absorption and thickness swelling of OSB, but the treatment swelled strands at the surface of the OSB causing undesirable surface roughening of panels. This unwanted effect could have been avoided by using solvent-borne water repellents containing waxes, but environmental concerns about solvents excluded this approach. An alternative approach, which is investigated here, is to apply waxes to OSB as hot-melt systems that contain no water or solvent.

Waxes have melting points as low as 40°C and very low viscosities when they are molten. At 10°C above their melting point temperature, the viscosities of wax are always lower than 10 Pa·s (Wolfmeier et al., 2000), which makes it possible to spray molten waxes. When molten wax is applied to a hot surface, the wax in contact with the surface will remain liquid until the wax cools below its congealing point temperature. The surface temperature of freshly pressed OSB can be as high as 250°C, well beyond the congealing point of most waxes (Wolfmeier et al., 2000). Hence, when molten wax is sprayed onto the surface of hot freshly-pressed OSB, it may remain liquid for long enough to flow into the voids between the wood strands, and change the hydrophobic properties of the surface of the OSB. Accordingly, we hypothesize that the moisture resistance and dimensionally stability of OSB will improve when molten wax is sprayed directly onto its surface. This hypothesis is tested using 11 different waxes and five wax blends applied at low levels (0.7% w/w) to hot OSB. Results show that blends of beeswax and synthetic paraffin waxes are able to significantly reduce the moisture induced thickness swelling of OSB, and suggest there is merit in further research to optimize the molten wax treatments.

2. Methods

Wax types and properties

Eleven individual waxes and five wax blends were selected for testing (Table 1). Vaseline, which is "the residuum of petroleum that is left after the greater part of petroleum has been distilled off" (Chesebrough, 1872) was bought from a pharmacy. Merkur 300, which is also a petroleum jelly like Vaseline, was donated by Sasol Wax (South Africa). Carnauba wax (grade T1), beeswax, stearic acid, synthetic beeswax, and microcrystalline wax were purchased from Wicks and Wax (Burnaby, Canada). Soy wax was purchased from Maiwa Supply, in Vancouver, Canada. Synthetic waxes included three Fischer-Tropsch waxes that were donated by Sasol Wax (South Africa). The wax blends were melted together at a 1:1 or a 3:1 weight ratio (Table 1).

Table 1. The names, abbreviations, origin, melting point (MP), viscosity and acid values of the 16 waxes and wax blends that were sprayed on to OSB samples

Wax	Abbrev	Origin	MP °C†	Viscosity cP	Acid value (mg KOH/g)
Sasolwax C	SC	F-T ‡	31	5.30	0
Tekniwax 801	T	F-T	44	7.50	0
Soy wax	S	Vegetable	54	15.8	31.5
Merkur 300	M	Petroleum	55	6.00	0
Beeswax + Sasolwax C (1:1)	BSC	Blend	59	10.2	9.2
Vaseline	V	Petroleum	59	9.50	0
Beeswax + Vaseline (1:1)	BV	Blend	62	11.4	9.2
Stearic acid	SA	Vegetable	63	7.70	215.3
Beeswax	B	Animal	65	14.5	18.5
Sasolwax M3M	M3	F-T	68	8.10	0
Beeswax + Synth Beeswax (1:1)	BSB	Blend	73	16.2	9.2
Microcrystalline wax	MC	Petroleum	73	17.5	0
Synthetic Beeswax	SB	Petroleum	77	8.40	0
Carnauba wax	C	Vegetable	81	22.2	6.8
Sasolwax M3M + EMA*(3:1)	M3E	Blend	85	29.5	8.6
Beeswax + EMA* (3:1)	BE	Blend	87	51.3	22.4

‡ F-T = Fischer-Tropsch; † MP = Drop melting point temperature; * Ethylene maleic anhydride

Melting point temperatures of waxes were determined by measuring their congealing and drop melting points (ASTM, 2008, 2013). Together these two measurements provided an estimate of the melting point range of each wax. The apparent viscosity of each wax was measured using the standard test method, however, the amount of wax used for each measurement was reduced from 800 g to 200 g, because insufficient wax was available for the standard test (ASTM, 2012). Measurements were repeated three times and the average for each wax is given in Table 1. The empirical acid number, an indicator of the polarity of a wax, was measured according to the standard test method (ASTM, 2010).

Measurement of contact angles on glass and OSB

The effect of the different waxes on the contact angles of water droplets on glass and OSB was assessed. Measurements on glass slides and OSB were replicated eleven and six times, respectively. Approximately 20 g of each wax was placed in separate 125 mL glass beakers, which were placed in an oven (100 ± 2°C) until the wax was molten. Individual glass slides were vertically dipped into the separate molten waxes for 1 min, before being removed and placed on a flat surface. The wax was left to solidify and coated slides were placed in a desiccator for a minimum of 1 h before contact angle measurements were made. Care was taken to keep the prepared samples free of surface contamination.

A table saw (Altendorf F45 ELMO) was used to cut a square piece of OSB (150 x 150 x 18 mm^3) from a random location within each of six commodity-grade OSB panels. The panels measured 2440 x 1220 x 18 mm^3 (density, 597 kg/m^3), and were supplied by a commercial company in Western Canada. They consisted of 95% aspen (*Populus* sp.) wood, 4% resin and 1% emulsified wax (w/w). The core to surface ratio of the panels was 1:1, with 4% liquid phenol formaldehyde used in the surface and 4% pMDI adhesive used in the core. The square pieces of OSB were each sub-divided into 17 strips using a band saw (Ryobi BS 902). The strips measured 75 x 15 x 18 mm^3, and surface strands were oriented perpendicular to the length of the strips. A wax treatment was randomly assigned to each of the 16 strips and one strip was left untreated. The 17 samples from each panel were oven dried at 100 ± 2°C for 24 h, and placed in a vacuum oven at 90 ± 1°C. OSB samples were individually placed in a second oven (170°C), between two heated steel plates (1 kg each), for 10 min. This was done to ensure the surface was hot enough to prevent molten wax from solidifying too quickly on the surface of the sample. A disposable pipette was used to apply a 1 µL drop of molten wax close to the center of each sample. Voids at the surface of the sample were avoided when placing the wax droplet on the OSB, and care was taken to ensure the wood grain of the treated area ran perpendicular to the length of the OSB strip. The molten droplet was left to absorb into the OSB surface for ten seconds. The treated OSB samples were conditioned at 20 ± 1°C and 65 ± 5% relative humidity for a minimum of five days.

The sessile drop method was used to measure contact angles of water droplets on treated glass slides and OSB samples. All measurements were made in a climate controlled room (20 ± 1°C and 65 ± 5% r.h.), using a goniometer (KSV CAM 101). A 5 µL drop of distilled water was placed on each wax-coated surface and images were recorded every 1 s for 480 frames and every 15 s for 360 frames thereafter. The left and right contact angles for each image were calculated using software programed with a Young-Laplace algorithm. From each measurement, the initial contact angle (Ci) and the time it took for the contact angle to decrease and form an angle of less than 90 degrees (t<90°) was recorded.

Treatment of OSB with hot melt waxes

Seven commodity-grade OSB panels were supplied by a commercial company (as above). Samples for each experimental replication (block) were cut from a single board. A table saw was used to trim 100 mm from one end of each board. Seven strips, 1220 x 150 mm² each, were then sawn from the freshly-cut side. A cross-cut saw (Omga T55-300) was used to trim 50 mm from the ends of each strip and the remaining lengths were cross-cut into fifty-six 150 x 150 mm² samples. All OSB samples were placed in an oven, at 105 ± 2°C for a minimum of 24 h or until they reached equilibrium moisture content. The oven dry weight of each sample was measured and 17 samples with the most similar weights were selected to reduce the strong effect that density has on water absorption and thickness swelling. A wax treatment (i.e. wax type or control) was randomly assigned to each of the selected samples. The 17 oven dried samples (16 wax-treated + 1 untreated control) in each of the seven experimental blocks were placed in a vacuum oven at 90 ± 1°C and were removed and placed in a second oven (170°C), between two heated steel plates, for 10 min before wax application, as above.

Wax was sprayed onto the exposed upper surface of each sample using a pneumatic hot-melt spray gun with a 0.6 mm nozzle opening (Champ 10s, Glue Machinery Corporation). Each wax was sprayed at 25°C above its melting point. The gun had a constant chamber pressure of 300 kPa and the air pressure at the nozzle tip was 200 kPa. These parameters and the spray pattern employed ensured that wax penetrated into the OSB and did not form a visible waxy coating at the surface of samples (Lötter, 2014). The mass of each sample was recorded immediately after wax application and weight gains of samples were calculated. The average weight gain of samples was 76 g/m² wax (or 0.7% by weight). Treated samples were placed in a climate controlled room at 20 ± 1°C and 65 ± 5% r.h. for a minimum of five days. The edges of samples were sealed with a white silicone sealant (GE Silicone II 100% Silicone # P-WGH291). The silicone was allowed to cure for 2 days and sealed samples were reweighed. Then the mass of the silicone applied to samples was calculated.

Water exposure tests

A float test was used to determine the water absorption (WA) and thickness swelling (TS) of OSB samples (Evans et al., 2013). Approximately 150 L of fresh tap water was poured into a 257 L stainless-steel tank, measuring 1840 x 930 x 150 mm³. Once the temperature of the water in the tank stabilized at room temperature, the samples were placed on the surface of the water. The water in the tank was replaced once a day to reduce the negative effects that changes in water pH levels have on WA and TS. Samples were removed from the tank after 2, 24 and 72 h. They were then placed on a flat surface, lightly blotted with tissue paper to remove excess water and left to dry for 10 min. Samples were weighed and their thicknesses were measured using a digital micrometer. Four thickness measurements were taken per sample, midway along and 15 mm from each edge, and averaged. The samples were placed in a climate controlled room at 20 ± 1°C at 65 ± 5% r.h. and conditioned until they reached a constant moisture content of 12%.

Statistical analysis of data

Analysis of variance for a randomized block design was used to examine the effect of wax type on the following response variables: (1), contact angles of water droplets on glass slides and OSB samples; (2), water absorption (WA) and thickness swelling (TS) of OSB samples after 2 h, 24 h and 72 h exposure to water; (3) permanent thickness swelling of OSB. The design of the experiment accounted for random variation between samples (glass slides or OSB), as well as the fixed effect of wax type. The amount of wax applied to each OSB sample was included as a covariate in the analysis of WA and TS, but was found to have no significant ($p<0.05$) effect. The statistical program Genstat v. 18.2 was used to analyze the data and to check the assumptions of ANOVA (independence of observations, normality and homogeneity of variances). A sub-routine (convsstrt), within Genstat, was used to compare the WA and TS of untreated OSB samples with those of all wax-treated samples, as well as samples treated with each individual wax type. WA, and TS results are presented in graphs. Each graph contains error bars that can be used to estimate whether the water absorption or thickness swelling of samples treated with different waxes are significantly different at the 5% level ($p<0.05$). These error bars were derived from Fisher's Least Significant Difference (LSD) test, which was carried out after ANOVA (Fisher, 1935). Stepwise linear regression using the software RStudio was used to examine the relationships between properties of waxes and water absorption and thickness swelling of OSB samples (RStudio, 2014).

3. Results

Water absorption and thickness swelling measurements

There were significant differences ($p<0.05$) in the water absorption and thickness swelling of wax-treated samples and untreated controls when they were floated on water for 2, 24 and 72h. For each of these time periods the difference in water absorption and thickness swelling of untreated controls and wax treated samples (averaged across all samples) was also statistically significant ($p<0.05$). After 2 h exposure to water, 14 of the wax treatments significantly reduced the water absorption of OSB samples; the two exceptions were the low melting point waxes, Sasolwax C (SC) or soy wax (S) (Fig. 1).

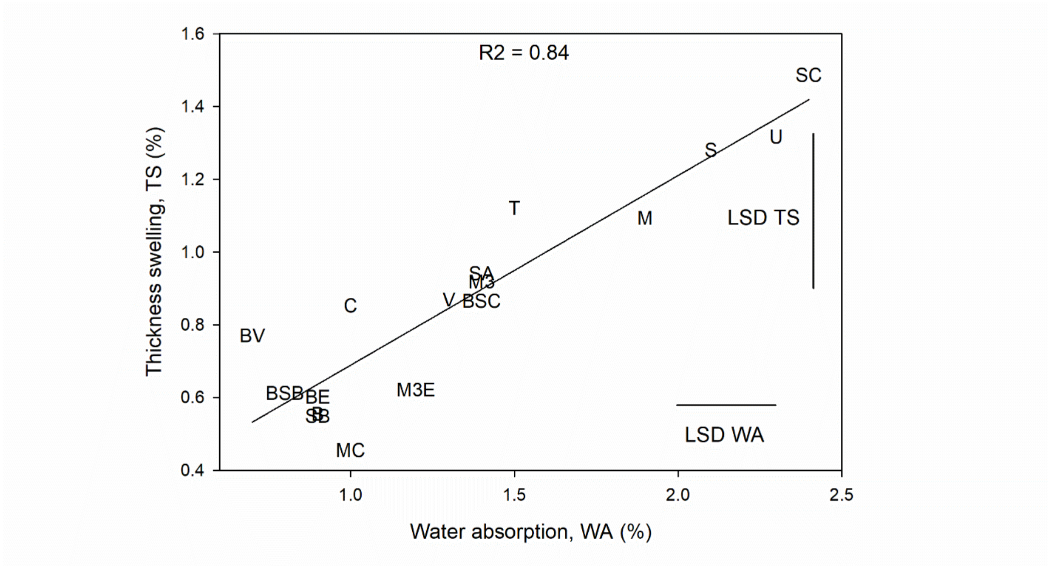

Figure 1. Thickness swelling (TS) and water absorption (WA) of wax-treated and untreated (U) OSB samples floated on water for 2 hours. Differences in TS or WA of treated samples that exceed the length of the relevant error bars (Fisher's Least Significant Difference, LSD) are statistically significant ($p<0.05$). Individual waxes can be identified using the abbreviated labels in Table 1

Blends of beeswax and synthetic waxes were significantly ($p<0.05$) better at restricting water absorption by OSB samples after 2 h than individual waxes, with the exception of the beeswax (B), carnauba (C) or synthetic beeswax (SB) treatments. Ten of the wax treatments were also effective at restricting the thickness swelling of OSB samples. Differences in the thickness swelling of treated samples after 2 h tend to mirror differences in water absorption, as there is a strong relationship ($R^2 = 0.84$) between water absorption and thickness swelling of samples, although some waxes were less effective at restricting thickness swelling than reducing moisture ingress and vice versa. After 24 h the numbers of wax treatments that were effective at reducing water absorption and thickness swelling had decreased to 12 and 6, respectively (Fig. 2). The wax treatments that were ineffective at restricting water absorption were the Sasolwax C (SC), soy wax (S), Merkur 300 (M), and Sasolwax M3M (M3) treatments. Four of the six treatments that were effective at restricting thickness swelling of OSB samples contained beeswax; the others were synthetic beeswax (SB) and microcrystalline wax (MC).

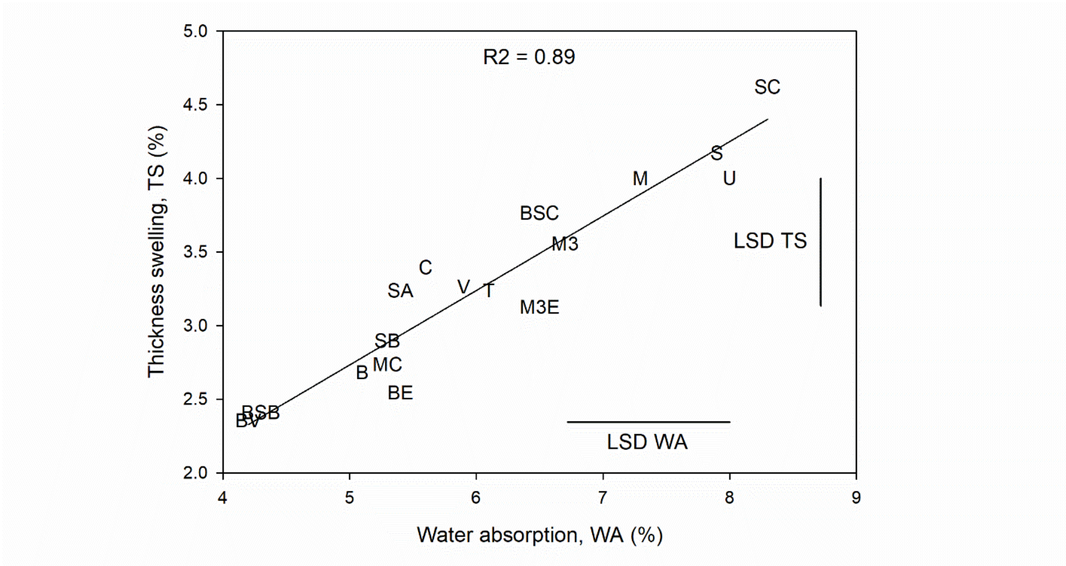

Figure 2. Thickness swelling and water absorption of wax-treated and untreated (U) OSB samples floated on water for 24 hours

After 72 h exposure to water only three of the wax treatments significantly reduced both the water absorption and thickness swelling of OSB samples. These treatments were blends of beeswax with synthetic beeswax (BSB) or Vaseline (BV) and stearic acid (arrowed in Fig. 3). A blend of beeswax and ethylene maleic anhydride (BE) was also effective at restricting thickness swelling, but it had no significant effect (p>0.05) on water absorption.

After samples were floated on water for 72 h they were conditioned until they reached a constant moisture content of 12%. The permanent, irreversible thickness swelling of samples was then measured. There were significant (p = 0.005) differences in the total thickness swelling of samples treated with different wax types, as well as between those samples and untreated samples (Fig. 4).

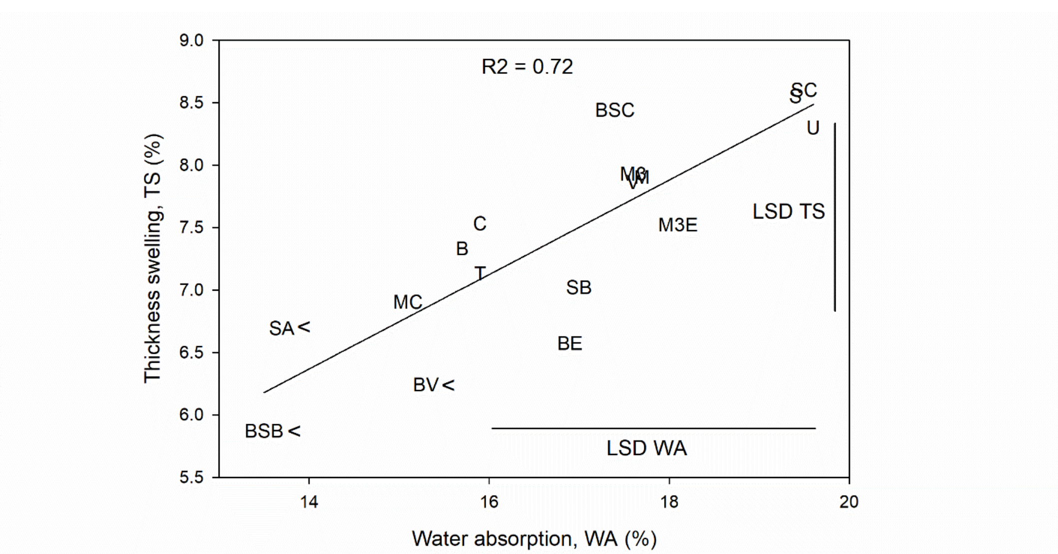

Figure 3. Thickness swelling and water absorption of wax-treated and untreated (U) OSB samples floated on water for 72 hours

Samples treated with four of the different types of wax-treatments swelled significantly ($p<0.05$) less than the untreated control (arrowed in Fig. 4). These wax treatments were the ones that restricted wet thickness swelling of samples floated on water for 72 h (Fig. 3).

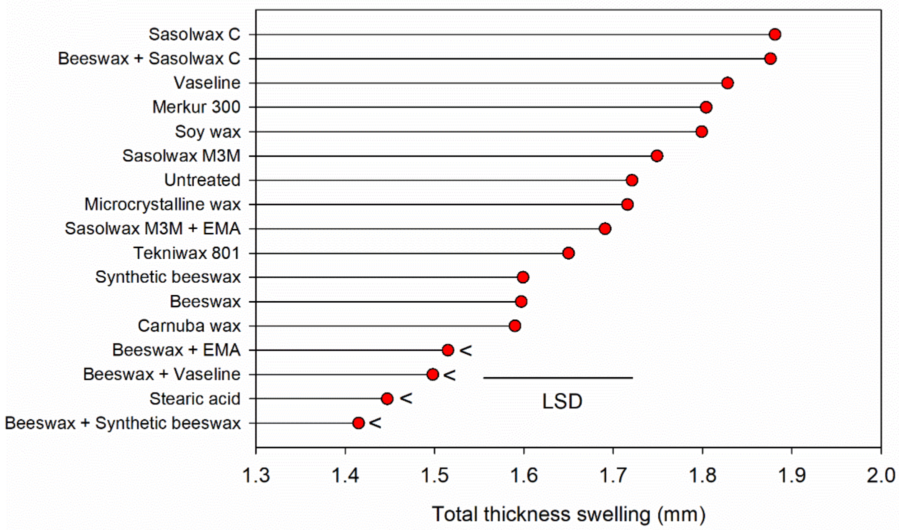

Figure 4. Permanent (irreversible) thickness swelling (TS) of wax-treated and untreated OSB samples after they were floated on water for 72 h and reconditioned to a moisture content of 12%. Differences in TS that exceed the length of the error bar (Fisher's Least Significant Difference, LSD) are statistically significant ($p<0.05$)

Water repellency of wax-treated surfaces

The wax-treated glass slides and OSB samples (treated and untreated) were all hydrophobic as water droplets placed on both surfaces had initial contact angles greater than 90 degrees. The contact angles of wax-treated glass slides and OSB, and also the time it took for contact angles to fall below 90 degrees are recorded in Table 2.

Table 2. Contact angle measurements of 16 waxes on glass and OSB samples

Wax treatment and abbreviation	Initial Contact Angle (°)		Time to 90° (min)	
	Glass†	OSB‡	Glass*	OSB**
Sasolwax C (SC)	101.6	121.9a††	2.3	5.3a
Beeswax + Sasolwax C (BSC)	105.0	122.5a	18.7	31.5b
Vaseline (V)	102.1	118.5a	9.1	14.8a
Merkur 300 (M)	103.7	124.8a	1.35	23.0b
Soy wax (S)	106.9	104.9a	15.4	13.1a
Sasolwax M3M (M3)	106.3	120.0a	17.9	24.5b
Microcrystalline wax (MC)	109.5	114.2b	42.7	23.1b
Sasolwax M3M + EMA (M3E)	109.7	119.8a	18.5	26.1b
Tekniwax 801 (T)	107.2	122.4a	22.0	14.8a
Synthetic beeswax (SB)	103.6	113.7a	14.1	19.9b
Beeswax (B)	105.6	123.8a	14.0	25.7b
Carnauba wax (C)	100.7	114.3a	9.4	23.0b
Beeswax + EMA (BE)	109.5	116.6a	17.8	26.3b
Beeswax + Vaseline (BV)	105.8	122.4a	11.8	25.0b
Stearic acid (SA)	128.1	115.0a	31.8	18.2b
Beeswax + synthetic beeswax (BSB)	108.0	121.8a	15.8	31.0b
OSB control	-	118.6a	-	8.3a

†Differences between treatments that are greater than 3.0 (least significant difference, LSD) are statistically significant (p<0.05); ‡LSD = 9.4; *LSD = 4.0; **LSD = 9.2; †† Treatments that share the same superscripted letter are not significantly (p>0.05) different from untreated OSB

The wax treatments listed Table 2 are ranked according to their effectiveness at reducing permanent thickness swelling of OSB, from the least effective treatments (Sasolwax C, beeswax + Sasolwax C, Vaseline…etc) to the four treatments that had a statistically significant effect at reducing irreversible thickness swelling (beeswax + ethylene maleic anhydride, beeswax + Vaseline, stearic acid and beeswax + synthetic beeswax). The effectiveness of the treatments at reducing water absorption cannot be fully explained by the water repellency of treated glass slides or OSB samples. For example, the water repellency of surfaces treated with the most effective wax blend (beeswax + synthetic beeswax) is very similar to that of one of the least effective treatments (beeswax + Sasolwax C). Furthermore, regression analysis found no strong relationships between wax properties and their ability to restrict water absorption and thickness swelling of OSB samples, although there were modest relationships between melting points of waxes and water absorption of samples floated on water (R2 = 0.5 [2 h], 0.6 [24 h], 0.7 [72 h]). The relationships between melting points of waxes and thickness swelling were less strong and diminished with time (R2 = 0.47 [2 h], 0.38 [24 h], 0.27 [72 h]. These modest relationships between melting point of waxes and water absorption and thickness swelling occurred because some of the least effective treatments were low melting point waxes (Sasolwax C, Soy, Merkur 300 and Techniwax 801, Figs. 1-3) and vice versa (synthetic beeswax, carnauba wax, Sasolwax M3M + ethylene maleic anhydride and beeswax and ethylene maleic anhydride, Figs. 1-3).

4. Discussion

Our results do not provide strong support for the use of sprayable molten waxes treatments as a means of producing highly moisture resistant OSB panels, because only four of our molten wax treatments reduced the permanent thickness swelling of samples. Furthermore, the molten wax treatments were less effective at reducing thickness swelling than the combination of measures used to create highly moisture resistant OSB (sub-floor) panels (Taylor et al., 2008). For example, Taylor et al. (2008) found that the swelling of the leading sub-floor panel in North America when immersed in water for 72 h was less than half that of a standard commodity panel. In contrast, our best treatments reduced swelling of a commodity OSB panel by less than a third. Nevertheless, such treatments provided OSB with short-term moisture resistance and did so without depositing a thick waxy coating at the surface of boards. Hence, the treatments may find applications in situations in which OSB requires temporary resistance to moisture for example when it is transported or used as vertical sheathing, where water does not pool at the surface of panels (unlike sub-floor panels). Our results also suggest how sprayable molten waxes treatments could be improved further, their mode of action and where they might find other industrial applications.

Sprayable molten wax treatments have not been used before as post-treatments to dimensionally stabilize OSB, and hence there is considerable scope to improve them. Our results provide some pointers on how this desirable outcome could be achieved. We found that treatments consisting of blends of waxes were generally more effective than individual waxes with the exception of stearic acid. This finding accords with Borgin's (1961) conclusion that water repellents for solid wood that consist of multiple components are generally more effective than ones composed of a single component. Later work by Borgin and Corbett (1970) examined some of the waxes tested here, for example, beeswax, carnauba wax, petroleum jelly and paraffin waxes as water repellents for radiata pine (*Pinus radiata* D. Don) wood. They found that beeswax was consistently better than carnauba wax or petroleum jelly at dimensionally stabilizing wood. Therefore, they suggested that effective water repellents for solid wood should contain a highly polar wax such as beeswax and a very hydrophobic paraffin wax. Our most effective molten wax treatments also consisted of beeswax and a non-polar synthetic wax. Therefore, our findings for OSB accord with those of Borgin and Corbett (1970), and suggest that future research to improve molten wax treatments for OSB should focus on creating the optimum blend of polar and highly hydrophobic waxes, and possibly other components such as resin. There is less scope to improve the molten wax treatments by increasing the quantity of wax applied to OSB because of the need to prevent the formation of a slippery waxy coating on the surface of the OSB, which is undesirable in some applications, for example roof sheathing (Sigler et al., 1948, Structural Board Association, 2009). Hence, the quantity of wax applied to samples was deliberately chosen to prevent the formation of a visible waxy coating at the surface of OSB. Nevertheless, there is evidence that the formation of a hydrophobic barrier may explain why some of our molten wax treatments were more effective than others.

Some of the most effective wax treatments had high melting points whereas some of the least effective waxes had the lowest melting points, as mentioned above. It's possible that lower melting point waxes remained molten for longer than higher melting point waxes when they were sprayed onto the surface of hot OSB. As a result, the lower melting point waxes may have penetrated more deeply into the composite. Conversely, higher melting point waxes, some of which were the most hydrophobic, may have remained closer to the surface forming an effective water repellent barrier. The formation of such a barrier was used to explain why wood treated with solvent-borne solutions of wax is water repellent (Borgin and Corbett, 1970). Evidence for the presence of such a barrier has been obtained by imaging the spatial distribution of wax in woods fine capillary network. A variety of imaging techniques have been used in such studies, including light microscopy in combination with autoradiography, scanning electron microscopy, **magnetic resonance microscopy** and X-ray micro-computed tomography (Levi et al., 1970, Scholz et al., 2010a,b, Žlahtič et al., 2017). Similar studies are required to better understand the mechanisms responsible for the water repellency of OSB treated with molten wax, and to help explain why molten wax treatments with similar characteristics, for example Beeswax and Sasolwax C and Beeswax and Vaseline differed in terms of their ability to restrict the swelling of OSB.

Molten waxes have been used to treat solid wood (Kollmann, 1951), and the technology has been commercialized in Austria (Tilo, 2018) and Germany (Dauerholz, 2018). The Natwood and Dauerholz products produced in Austria and Germany, respectively, are pressure impregnated with 'liquid' wax and are designed as substitutes for expensive tropical timber. OSB on the other hand is an inexpensive commodity product and the use of higher loadings of wax would be uneconomic. However, unrefined paraffin wax and beeswax are available commercially from ~ $1 to $3 per kg when purchased in bulk and at the application rate used here (0.76 g/m²) the raw material costs of sprayable molten wax treatments are not prohibitive. Furthermore, a patent by Racota (2007), which describes a wax emulsion that can be sprayed onto the surface of OSB before or after hot pressing, suggests that the approach of spraying molten waxes on the surface of hot OSB boards could be feasible. It could also be used to treat other wood composites. Molten waxes have been impregnated into plywood (Mundigler and Rettenbacher, 2005), and they are also being sprayed onto the end grain of massive panelized wood composites such as cross laminated timber (CLT) to reduce moisture uptake by the panels. Failure to restrict moisture uptake by CLT can lead to swelling, shrinkage and checking of the composite (Gülzow et al., 2011). Hence, Gagnon and Pirvu

(2011) recommended the use of water resistant barriers to protect CLT from the elements during building construction. Sprayable hot melt wax treatments appear to be suited to this application since they are inexpensive and can quickly coat large areas with hydrophobes. Further research would be needed to test whether they can provide the necessary water resistance to panelized wood composites during building construction, in addition to the research mentioned above to improve their ability to protect OSB.

5. Conclusions

Sprayable molten waxes treatments were capable of providing moisture resistance to OSB without depositing a thick waxy coating at the surface of the composite. Some of the more effective treatments also reduced the irreversible thickness swelling of OSB. However, the dimensional stability of treated OSB was inferior to that of the highly moisture resistant OSB used for sub-floors in North America. Therefore, we conclude that the sprayable molten wax treatments tested here are unsuitable for this demanding application, but they may be better suited to improving the moisture resistance of OSB used as vertical sheathing where water does not pool at the surface of panels. The treatments may also provide sufficient short-term moisture resistance to OSB during transportation and storage. We were unable to find definitive relationships between the properties of waxes and their ability to dimensionally stabilize OSB, but we conclude that sprayable molten wax treatments for OSB should employ a blend of a polar wax such as beeswax and a strongly hydrophobic wax. We have suggested why these treatments were more effective than other treatments, but acknowledge the need for further research to better understand the mechanisms responsible for the water repellency of OSB sprayed with molten waxes. We conclude that there is potential to further improve the ability of molten wax treatments to dimensionally stabilize OSB. The treatments may also have potential to provide short-term moisture resistance to other wood composites, such as cross-laminated timber panels, which require a water resistant barrier to protect them from the elements during building construction. Further research would be needed to test their effectiveness for this end use.

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