Mechanical and Physical Properties of Thermally Modified Plywood and Oriented Strand Board Panels

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Abstract

Thermal modification can increase resistance to biological degradation, reduce equilibrium moisture content, and improve the dimensional stability of solid wood. In this study, oriented strand board (OSB) and two types of plywood were thermally modified as a posttreatment at 140°C, 150°C, 160°C, 170°C, and 180°C. Plywood moduli of rupture (MOR) and elasticity (MOE) decreased up to 54 and 22 percent, respectively, at the 180°C treatment, while OSB MOR and MOE decreased up to 25 and 4.3 percent, respectively. Internal bond strength of plywood decreased with increasing temperature, while OSB experienced minimal change. Screw-holding strength of all panels was more adversely affected by increasing temperatures than nail-holding strength, with OSB experiencing 17 and 27 percent maximum reductions in nail- and screw-holding strengths, respectively. Thickness swell performance of all panels improved with increasing temperature, with plywood exhibiting 41 and 77 percent improvements at the 160°C and 180°C treatments, respectively. Mass increase (when subjected to a water soak) of OSB decreased 12 percent at the 150°C treatment, after which it increased.

These results suggest that thermal modification posttreatments can improve the thickness swell and water absorption performance of plywood and OSB panels. However, some mechanical properties decreased significantly at treatment temperatures exceeding 160°C. The results provide a technical baseline that may help advance thermal modification technology from primarily solid-wood-only applications toward new, high-volume engineered wood markets. With further research, it may be possible to optimize the treatment technique(s) to ensure that the panels retain sufficient mechanical strength for the desired end-use applications.

Thermally modified wood is currently used primarily for solid wood flooring, external cladding, and decking products. Thermal modification can impart advantageous properties in wood, including attractive darker color, reduced equilibrium moisture content (EMC), reduction of mass, degradation of water-binding hemicelluloses (Sinoven et al. 2002, Hakkou et al. 2005, Repellin and Guyonnet 2005, Kocaefe et al. 2008), and elimination of many volatile organic compounds. The result is a high-value, high-performing solid wood product with increased moisture resistance, decreased swelling and shrinkage due to weathering and atmospheric moisture changes, and increased resistance to biological degradation (Syrjanen and Kangas 2000, Rapp and Sailer 2001, Tjeerdsma et al. 2002, Weiland and Guyonnet 2003, Esteves et al. 2006, Spelter et al. 2009). Thermal modification can also reduce environmental impacts because it is an eco-friendly alternative to some chemical preservatives (Younsi et al. 2006).

There is a sufficient scientific understanding of the impacts that thermal modification processing has on the performance of solid wood components. There is very little scientific understanding, however, of the impacts of thermal modification processing—especially using the closed, pressurized process—on the performance of engineered wood products (EWPs). Solid scientific information is required for industry practitioners and their customers to fully understand the potential for thermally modified EWPs. Therefore, the objective of this study was to identify the impacts that thermal modification has on the performance of plywood and oriented strand board (OSB).

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This article reports on the bending properties, internal bond strength, nail- and screw-holding strengths, hardness, and thickness swell and water absorption of OSB and two types of plywood panels that were thermally modified as a posttreatment at 140°C, 150°C, 160°C, 170°C, and 180°C in a closed, pressurized thermal-modification kiln. The results of this study provide scientific understanding that may advance thermal-modification technology from primarily solid-wood-only applications toward new, high-volume engineered wood product markets that are growing due to increased demand, bolstered in part by the current rebound in US construction.

Wood Thermal Modification Technology Review

Thermally modified solid wood

The first prominent work (Stamm et al. 1960) heated solid wood in a vacuum at 93°C to 160°C in a bath of molten tin, lead, and cadmium. The technique increased dimensional stability but decreased some mechanical properties. Modern thermal modification of solid wood subjects wood to heat (typically 130°C to 240°C) for up to 60 hours in specialized kilns, usually in a reduced-oxygen, inert environment. Open (nonpressurized) and closed (pressurized) thermal-modification processes are available. The open processes are much more widely used and understood by the industry. The change in performance properties is determined by species and intensity of the heat-treatment cycle (intensity is a function of time, temperature, atmospheric conditions/air composition inside the kiln, and moisture content of the wood; Nuopponen et al. 2003, Boonstra et al. 2006).

Thermal modification imparts chemical changes to the macromolecular components of the cell wall. When heat is applied, hemicelluloses degrade first at approximately 160°C to 220°C (Pavlo and Niemz 2003), resulting in the production of methanol, acetic acid, and volatile heterocyclic compounds (Hill 2006). Degradation of hemicelluloses also increases as temperature increases (Bourgois et al. 1989). Degradation of the hemicelluloses increases the crystallinity of cellulose in the cell wall (Fengel and Wegener 1984). It is generally accepted that cellulose degradation occurs at a higher temperature than that of hemicelluloses. Crystalline cellulose degrades at 300°C to 340°C (Kim et al. 2001), well in excess of the temperatures used in this study. The loss of hemicelluloses also leads to a relative increase in lignin content. It is generally accepted that lignin is the most thermally stable component of the cell wall, with only significant degradation occurring at temperatures exceeding 280°C (Hill 2006).

Thermal modification also converts hydrophilic hydroxyl groups ($^{-}$OH) to C–O–C ether cross-links between wood fibers, converts some hemicelluloses to much less hygroscopic furan-based polymers (Ibach 2010), and reduces wood fiber polymerization. These changes reduce water penetration, thus preventing swelling and shrinking while reducing EMC (Stamm and Harris 1953). Previous work (Boonstra et al. 1998, Tjeerdsma et al. 1998) revealed an average decrease in hygroscopicity of 40 percent and a 40 to 60 percent reduction in EMC (Syrjanen and Kangas 2000, Jämsä and Viitaniemi 2001, Paul et al. 2006, Welzbacher et al. 2007), which increases dimensional stability (Kamden 2002).

Modulus of rupture (MOR) typically decreases at higher treatment temperatures (Kubojima et al. 2000, Bekhta and Niemz 2003, Boonstra et al. 2007, Kocaefe et al. 2008). Modulus of elasticity (MOE), however, can decrease or even increase slightly, depending on treatment intensity. Previous work showed a slight MOE increase for yellow poplar and basswood treated at 200°C and 210°C using the nonpressurized ThermoWood process and a 9.5 percent hardness increase in basswood treated at 200°C (Donahue et al. 2011). Others reported that most mechanical properties decrease with increasing treatment intensity (Santos 2000, Unsal and Ayrilmis 2005, Poncsak et al. 2006, Shi et al. 2007, Ates et al. 2009).

Thermally modified engineered wood products

Donahue (2011) found that MOR and MOE of aspen plywood thermally modified using the ThermoWood process at 190°C increased 5.8 and 27.9 percent, respectively, while MOR and MOE declined for thermally modified birch, pine, and gum plywood. All species showed a marked improvement in linear expansion (up to 54.9%) and volume swell (up to 71.0%). Internal bond strength decreased an average of 42.8 percent for the aspen, birch, and gum plywood and increased 36.8 percent for pine. Hardness dropped an average of 23.9 percent. It was also found that ThermoWood-treated OSB panels yielded 24.1, 6.5, and 39.7 percent improvements in length, width, and thickness swell, respectively. There was a 6.2 percent reduction in MOR but larger decreases in internal bond strength and split resistance (Donahue and Aro 2012).

Chotchuay et al. (2008) examined oriented strand lumber from Parawood strands thermally modified at 190°C and found that compression (39 MPa) and tensile strength (36 MPa) parallel to the grain and flatwise (59 MPa) and edgewise (61 MPa) bending were significantly increased. There was no significant difference in compression and shear parallel to the grain or in internal bond strength. Del Menezzi et al. (2009) thermally treated commercial pine OSB panels by pressing them in a hot press at 190°C and 220°C for 12, 16, or 20 minutes. Dimensional stability, thickness swell, water absorption, and EMC improved. MOR was the only mechanical property that degraded. Similar results were reported elsewhere (Del Menezzi and Tomaselli 2006, Okino et al. 2007, Del Menezzi 2008, Bonigut and Krug 2011).

Growth in Plywood and OSB Markets

In 2011, 11.2 million m^3 of OSB were consumed in the United States (constituting 60% of the structural panel market), and 7.9 million m^3 of softwood plywood was produced (Howard and McKeever 2013). There were also 328,000 m^3 of engineered wood products and 44.2 million m^2 of structural panels used in 2011 for new and major additions in low-rise nonresidential buildings (Adair et al. 2013). In 2012, structural panel production in North America was at its highest level since 2008, with total US and Canadian production at 2.55 million m^2, a 6.5 percent increase from 2011. North American OSB production in 2012 was up 9.6 percent from 2011 to 1.56 million m^2; this was the highest annual total since 2008. US production of OSB in 2012 was 1.03 million m^2, a 10.0 percent increase over 2011. In 2013, OSB production in North America was expected to be approximately 1.78 million m^2 (Wood Based Panels International [WBPI] 2013a) and is expected to grow from 17.6 million m^3 in 2013 to 20.6 million m^3 in 2015 (WBPI 2013b). The US housing market is trending upward, generating higher prices and demand for structural panels, including plywood and OSB; OSB demand, production, and prices were on the increase through the beginning of 2013. Also contributing to the price increases is the fact that many of the mills that shut down during the recession have not yet restarted, leading to a better balance between supply and demand (WBPI 2014).

Despite this market growth, there are regions where environmental conditions result in severe weathering, fungal growth, and insect attack of most wood products—most of these areas have prolonged periods of high humidity, warm temperatures, and moderate to heavy rainfall. This puts many wood products—including EWPs, which are already susceptible to decay and moisture—into conditions above acceptable limits (Baileys et al. 2003). Thus, steps must be taken to ensure protection from damaging conditions during storage, during construction, and while in service. Due to these adverse conditions, even EWPs may perform below acceptable limits. The results in this article help advance the scientific understanding of thermal-modification technology and propel it toward potential applications for new, high-performing thermally modified EWPs. This new technological concept, if advanced toward commercial readiness, may move the industry to increased use of EWPs, even in severe environmental conditions. This may also allow for international market expansion.

Materials and Methods

Materials

Two types of plywood were utilized in this study: commercially available Exposure 1–rated sheathing panels (Type 1) and commercially available Exterior-rated B-C-grade sanded panels (Type 2). The Type 1 panels were phenolic bonded and APA rated for limited exposure to the elements during construction. The Type 2 panels were phenolic bonded and designed for interior and exterior applications and were suitable for repeated wetting and redrying or long-term exposure to weather. Both types were four-ply and manufactured from southern pine. The dimensions of the master panels were 2,400 mm long by 1,200 mm wide by 12 mm thick. All panels were purchased from the Duluth, Minnesota, Home Depot store in April and May 2013 (note that these scattered purchase dates may have introduced variations in panel performance). The OSB panels utilized in the study were produced from a proprietary species mix and methylene diphenyl diisocyanate (MDI) resin. These Exposure 1–rated master panels were 2,400 mm long by 1,200 mm wide by 11 mm thick. Control specimens were trimmed from the plywood and OSB master panels.

Thermal modification procedures

The plywood and OSB specimens were thermally modified as a posttreatment at 140°C, 150°C, 160°C, 170°C, and 180°C in the Moldrup thermal-modification kiln at the University of Minnesota Duluth Natural Resources Research Institute (Fig. 1). All panels were equilibrated at approximately 21°C ± 5°C and 50 ± 5 percent relative humidity (RH) to a constant weight prior to thermal modification. The specimens were then placed in a forced-convection oven maintained at 103°C ± 2°C for 24 hours, at which point no appreciable change in mass was noted when readings were made at approximately 4-hour intervals. The ovendry moisture content of each plywood and OSB panel type was then calculated according to ASTM D4442 (ASTM International 2007). All panels had an average 5.0 percent moisture content.

The plywood and OSB master panels were then cut to 2,400-mm-long by 400-mm-wide specimens and weighed prior to being placed in the thermal-modification kiln. For the plywood panels, four Type 1 panels and four Type 2 panels were thermally modified per kiln charge. The OSB kiln charges contained only OSB. The panels were separated with wood stickers to allow for more effective heat transfer and airflow inside the kiln. Figure 2 illustrates a charge of plywood panels entering the kiln. A dehydrated OSB cover sheet was placed on top of each panel stack to protect the panels from excess water spray.

During each thermal-modification cycle, the temperature and steam pressure inside the kiln was monitored and recorded. For the plywood panels, the absolute pressure inside the kiln was reduced to 0.1 bar (i.e., 90% vacuum) at 80°C, after which the temperature was increased to the desired top temperature and held for 60 minutes. For the OSB panels, the absolute pressure inside the kiln was reduced to 0.1 bar at 45°C, after which the temperature was increased to the desired top temperature and held for 60 minutes. (The difference in temperature at which the vacuum was drawn is different between the OSB and plywood panels because new processing knowledge was gained prior to the OSB treatment.) After the panels were at the top temperature for 60 minutes, the temperature was reduced using an automated fine water spray inside the kiln. The cycle ended when the final temperature of 105°C was maintained for 20 minutes. Figure 3 shows a typical temperature and pressure profile for plywood thermally modified at 170°C. Prior to performance testing, all panels were allowed to equilibrate to a constant weight at approximately 21°C ± 5°C and 50 ± 5 percent RH. At the time of testing, the OSB, Type 1 plywood and Type 2 plywood specimen moisture contents were at 7.3, 7.7, and 8.0 percent, respectively.

Performance testing methods

All performance testing was completed in the University of Minnesota Duluth Natural Resources Research Institute's Mechanical Testing Laboratory. Bending properties were determined according to APA PS2-04 (APA—The Engineered Wood Association 2004) using a three-point bending test. Internal bond strength was assessed according to ASTM D1037 (ASTM International 2006). Nail- and screw-holding strengths were determined according to APA PS2-04. Either three nails or two screws were driven into one face of each specimen. Hardness was determined according to ASTM D1037. For these test specimens, two penetrations of an 11.3-mm-diameter steel ball were made on each face of each specimen (for a total of four penetrations per specimen). The steel ball was driven into the face of the specimen at a uniform rate of motion of 6 mm/min until the ball had penetrated to one-half its diameter. The load required to embed the steel ball to one-half its diameter was recorded as the hardness. Thickness swell/water absorption was determined according to ASTM D1037 using a 24-hour water soak.

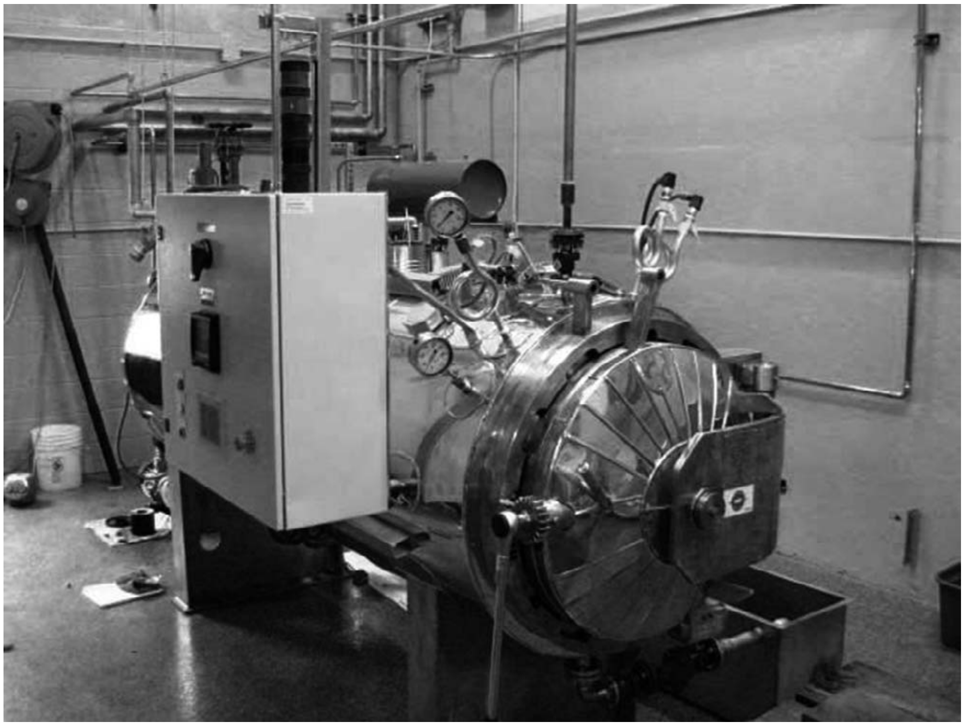

Figure 1.—Thermal-modification kiln at the Natural Resources Research Institute, University of Minnesota Duluth.

Results

Bending properties

The average MOE and MOR for the test specimens are shown in Figures 4 and 5. The MOR for both Type 1 and Type 2 plywood panels generally decreased with increasing treatment temperatures, with the lowest MOR at the 180°C treatment. The Type 2 plywood panels treated at 160°C exhibited a 9.2 percent decrease in MOR compared with the control specimens. These findings agree with others who found that MOR of solid wood specimens generally decreased with increasing temperature, while some species became slightly harder and exhibited increased MOR at lower temperatures (Kubojima et al. 2000, Kocaefe et al.

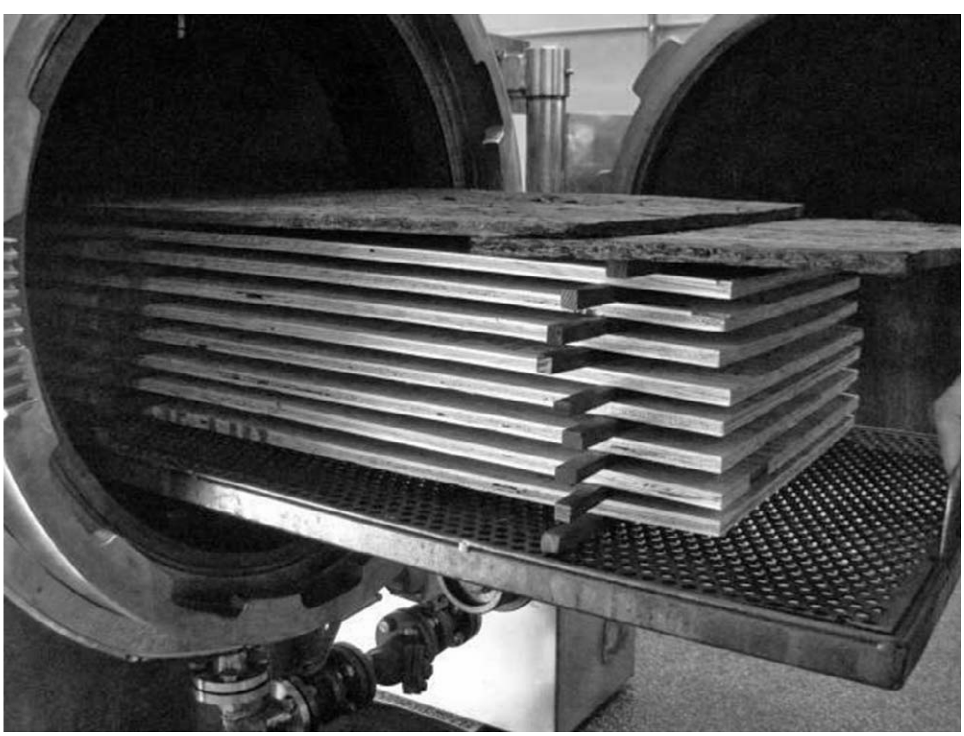

Figure 2.—Plywood panels entering the thermal-modification kiln.

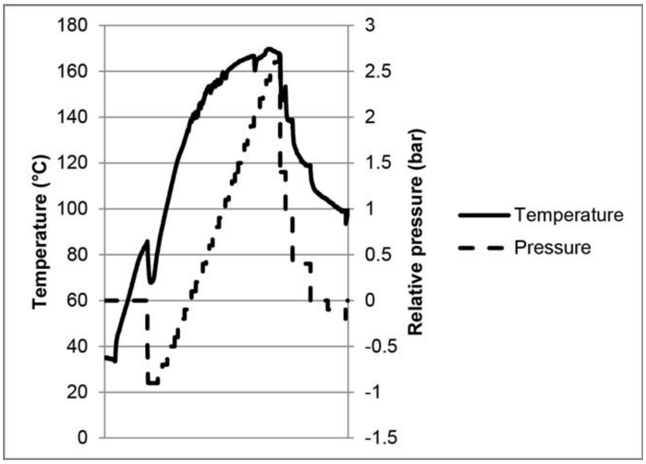

Figure 3.—Temperature and pressure profile for plywood thermally modified at 170°C.

2008). The MOE of the Type 1 plywood panels also declined with increasing treatment temperatures; however, the Type 2 plywood panels exhibited a nonsignificant 2.4 percent decrease in MOE compared with the control specimens and those treated at 180°C ($P = 0.6515$). These findings also agree with Donahue (2011), who found that MOR and MOE decreased for birch, pine, and gum plywood thermally modified at 190°C using the ThermoWood process.

The MOR of the OSB specimens exhibited a nonsignificant 1.5 percent decrease at the 160°C treatment temperature compared with the controls ($P = 0.7956$), while it decreased 24.9 percent at the 180°C treatment temperature. Similar findings were reported by Del Menezzi et al. (2009). The MOE of the OSB experienced very little change. This is in contrast to previous work that showed the MOR of OSB decreased 6.2 percent when thermally modified as a posttreatment at 190°C using the ThermoWood process (Donahue and Aro 2012). It also contrasts to findings by Bonigut et al. (2012), who reported a slight increase in MOR and MOE when OSB panels were posttreated at 180°C using the Mühlböck procedure, in which the wood is treated in the presence of wood gases at normal pressures. This procedure starts with a heating step, followed by a drying phase, another heating step, a thermal modification step, and a controlled cooling phase.

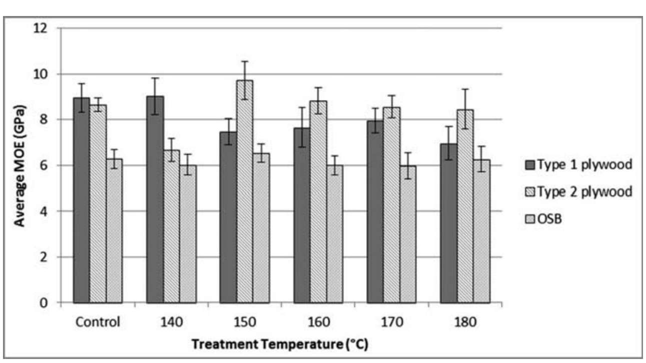

Figure 4.—Average modulus of elasticity (MOE) for thermally modified plywood and oriented strand board (OSB) panels (error bars depict 95% confidence intervals).

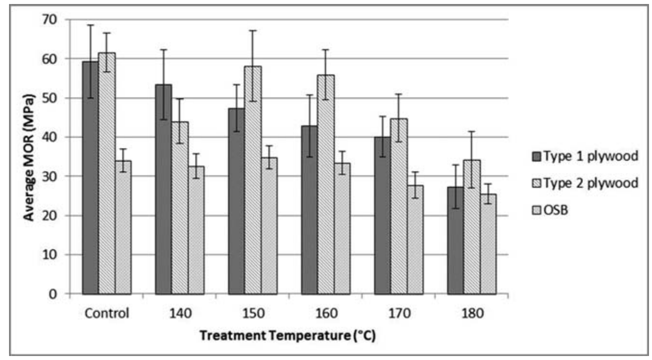

Figure 5.—Average modulus of rupture (MOR) for thermally modified plywood and oriented strand board (OSB) panels (error bars depict 95% confidence intervals).

Internal bond strength

The average internal bond strengths for the test specimens are shown in Table 1. Both Type 1 and Type 2 plywood panels exhibited a general decrease in internal bond strength with increasing treatment temperatures, experiencing reductions of 42.4 and 39.2 percent, respectively, at the 180°C treatment temperature. These findings are similar to Donahue (2011), who found that internal bond strength decreased an average of 42.8 percent for aspen, birch, and gum plywood thermally modified at 190°C using the ThermoWood process. The internal bond strength of the OSB specimens surprisingly increased 21.1 percent at the 150°C treatment temperature before decreasing to 0.35 MPa at the 180°C treatment temperature (a nonsignificant 6.1% decrease compared with the control specimens; $P = 0.4975$). These results are in agreement with Bonigut et al. (2012), who found relatively minor changes in internal bond strength when OSB panels were posttreated at 160°C, 170°C, and 180°C. Chotchuay et al. (2008) also found no significant difference in internal bond strength of oriented strand lumber manufactured from Parawood strands thermally modified at 190°C.

Nail- and screw-holding strengths

The average nail- and screw-holding strengths for the test specimens are shown in Table 2. Compared with the control specimens, the nail-holding strength of the Type 1 plywood specimens decreased 1.7 percent ($P = 0.8128$) at the highest treatment temperature, while the Type 2 specimens decreased 8.3 percent. The nail-holding strength of the OSB specimens increased slightly at 140°C before decreasing. Compared with the control specimens, the OSB experienced a 16.7 percent reduction in nail-holding strength at the highest treatment temperature. Both types of plywood exhibited a general reduction in screw-holding strength as the treatment temperature increased, while the OSB exhibited 9.3 and 23.0 percent decreases at the 150°C and 180°C treatment temperatures, respectively, compared with the control specimens. Because very little previous work has been completed on the nail- and screw-holding strengths of thermally modified plywood and OSB, it is difficult to directly compare the results of the current study with previous work completed by others.

Table 1.—Internal bond strength for Type 1 and Type 2 plywood and oriented strand board (OSB) panels.

	Internal bond strength (kPa) at different treatment temperatures[a]					
	Control	140°C	150°C	160°C	170°C	180°C
Type 1 plywood	997 (149) (n = 10)	809 (195) (n = 10)	691 (209) (n = 20)	761 (230) (n = 20)	514 (119) (n = 26)	574 (165) (n = 26)
Type 2 plywood	870 (222) (n = 20)	980 (265) (n = 20)	810 (174) (n = 20)	644 (180) (n = 20)	755 (224) (n = 25)	529 (264) (n = 27)
OSB	375 (105) (n = 20)	317 (93) (n = 20)	454 (153) (n = 25)	434 (138) (n = 20)	373 (134) (n = 20)	352 (104) (n = 20)

[a] Values are means (standard deviations).

Table 2.—Nail- and screw-holding strengths for Type 1 and Type 2 plywood and oriented strand board (OSB) panels.

	Nail- and screw-holding strengths (N) at different treatment temperatures[a]					
	Control	140°C	150°C	160°C	170°C	180°C
Nail-holding strength						
Type 1 plywood	291 (50) (n = 10)	285 (48) (n = 9)	240 (72) (n = 20)	255 (63) (n = 20)	283 (80) (n = 20)	286 (61) (n = 20)
Type 2 plywood (n = 20)	289 (88)	286 (71)	284 (69)	287 (124)	259 (52)	265 (119)
OSB	168 (35) (n = 14)	194 (30) (n = 14)	169 (30) (n = 14)	147 (30) (n = 20)	156 (28) (n = 14)	140 (37) (n = 11)
Screw-holding strength						
Type 1 plywood	1,929 (181) (n = 5)	1,917 (289) (n = 5)	1,798 (187) (n = 10)	1,759 (322) (n = 10)	1,290 (268) (n = 10)	1,104 (163) (n = 10)
Type 2 plywood (n = 10)	2,218 (189)	2,041 (172)	1,857 (230)	1,992 (210)	1,264 (169)	1,269 (224)
OSB	1,311 (158) (n = 13)	1,317 (186) (n = 13)	1,190 (236) (n = 14)	1,319 (139) (n = 10)	964 (132) (n = 13)	1,009 (79) (n = 10)

[a] Values are means (standard deviations).

Hardness

The average hardness values for the test specimens are shown in Table 3. The Type 1 plywood and OSB specimens exhibited a slight increase in hardness at the 140°C treatment temperature, after which the Type 1 plywood hardness decreased 27.6 percent at the 160°C treatment temperature. The OSB specimens had a 15.0 percent decrease in hardness between the 140°C and 150°C treatment temperatures, before slightly increasing. Overall, the Type 1 plywood, Type 2 plywood, and OSB specimens exhibited reduced hardness of 30.2, 3.3, (nonsignificant, $P = 0.5896$), and 26.7 percent at the 180°C treatment temperature compared with the control specimens. The decrease in hardness of the Type 1 plywood and OSB agrees with previous work by Donahue (2011), who reported an average decrease in hardness of 23.9 percent when birch, pine, and gum plywood were thermally modified at 190°C. The results of the current study, however, contrast with previous work (Leitch and Shahi 2009) showing 43.0, 13.8, and 58.4 percent increases in hardness of black ash, white birch, and tamarack thermally modified at 200°C.

Thickness swell and water absorption

The thickness swell and water absorption values (water absorption is expressed as mass increase) for the test specimens are shown in Figures 6 and 7. The Type 1 and Type 2 plywood specimens treated at 180°C exhibited 63.9 and 77.3 percent reductions in thickness swell, respectively, compared with the untreated controls. The OSB specimens exhibited a 50.9 percent reduction in thickness swell at the 180°C treatment temperature. This finding is similar to previous work showing a 39.7 percent improvement in thickness swell for OSB panels posttreated at 190°C using the ThermoWood process (Donahue and Aro 2010). Similar results were also reported by Bonigut et al. (2012). Both types of plywood experienced a slight mass increase at the

Table 3.—Hardness for Type 1 and Type 2 plywood and oriented strand board (OSB) panels.

	Hardness (N) at different treatment temperatures[a]					
	Control	140°C	150°C	160°C	170°C	180°C
Type 1 plywood	4,990 (1,016) (n = 10)	5,349 (568) (n = 10)	5,048 (1,066) (n = 20)	3,873 (584) (n = 20)	4,339 (1,048) (n = 10)	3,483 (688) (n = 20)
Type 2 plywood	5,236 (762) (n = 20)	4,669 (695) (n = 20)	5,270 (741) (n = 20)	4,301 (893) (n = 20)	5,645 (1,207) (n = 10)	5,064 (1,192) (n = 20)
OSB	5,446 (776) (n = 20)	5,592 (765) (n = 20)	4,751 (909) (n = 20)	5,346 (923) (n = 10)	4,548 (994) (n = 20)	3,992 (650) (n = 12)

[a] Values are means (standard deviations).

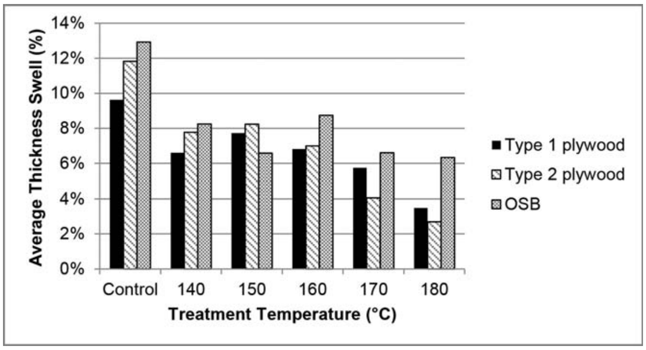

Figure 6.—Average thickness swell for thermally modified plywood and oriented strand board (OSB) panels.

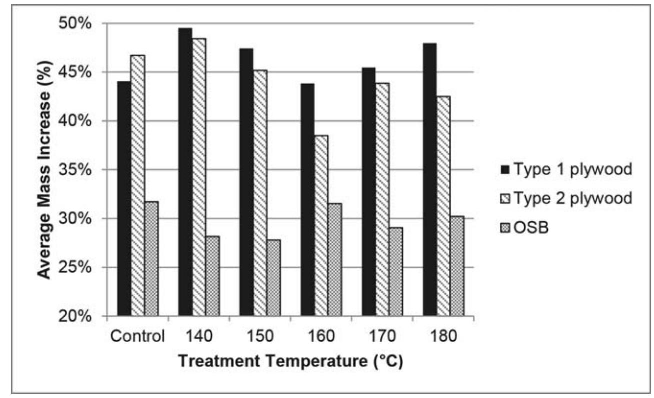

Figure 7.—Average mass increase for thermally modified plywood and oriented strand board (OSB) panels.

140°C treatment temperature before decreasing again at the 160°C treatment temperature, beyond which the water absorption of the Type 1 and Type 2 plywood specimens was 9.6 and 10.4 percent, respectively. The thickness swell of the OSB specimens decreased 49.0 percent at the 150°C treatment temperature (compared with the untreated control specimens) before increasing to 6.33 percent at the 180°C treatment temperature. Overall, the OSB water absorption was similar to previous work by Del Menezzi et al. (2009).

Discussion

In the current study, the decrease in MOR with increasing temperature agrees with previous work (Santos 2000, Unsal and Ayrilmis 2005, Poncsak et al. 2006, Shi et al. 2007, Ates et al. 2009) reporting that most mechanical properties of thermally modified wood decrease with increasing treatment temperatures. Degradation of the hemicelluloses in the wood cell wall, leading to a weaker wood structure, likely explains the decrease in MOR of the plywood and OSB specimens. The decrease in MOR of both types of plywood at relatively low treatment temperatures (140°C and 150°C) was unexpected because hemicellulose degradation does not occur until approximately 160°C is reached. It is unlikely that degradation of the phenolic resin contributed to the MOR decrease, considering others have reported that phenolic-bonded aspen waferboard panels have successfully withstood heat posttreatments at temperatures up to 240°C with minimal reduction in MOR (Hsu et al. 1989). Also, Bonigut et al. (2012) reported an increase in MOR of OSB panels posttreated at 160°C. In the current study, it may be possible that the initial vacuum step excessively dried the wood, causing a slight reduction in wood volume, leading to weakening of the adhesive–wood bond. In addition, the effects of pressure at elevated temperatures (as used in the current study) on the integrity of cured phenolic and MDI resin is not well understood. Care must be taken when comparing thermally modified plywood and OSB to thermally modified solid wood owing to the potential effects of heat and pressure on the strength of the plywood and OSB adhesives. More research is needed to determine these impacts.

The minimal reduction in MOE of the Type 1 plywood specimens and OSB specimens agrees with previous work (Kubojima et al. 2000, Bekhta and Niemz 2003, Boonstra et al. 2007, Kocaefe et al. 2008) and may be due, in part, to the removal of natural resins and hemicelluloses from the wood as well as increased cellulose crystallinity, rendering the wood more brittle and rigid. The significant decrease in MOE found in the Type 2 plywood panels at 140°C was unexpected. More research is needed to determine the cause of this result.

The comparatively minimal reduction in nail-holding strength compared with screw-holding strength at higher treatment temperatures may be explained by the brittle nature of thermally modified wood. As the wood becomes more brittle at higher temperatures, the screw threads would tend to rip away at the brittle fibers, thus reducing screw-holding strength values. However, the smooth-shanked nails would not tear at these brittle fibers nearly as much; thus, the reduction in nail-holding strength may be less pronounced. The general decrease in internal bond strength and hardness of most of the test specimens can likely be explained largely by the decomposition of hemicelluloses, weakening the wood structure. It is also possible that an increase in the size and distribution in the micropores in the cell wall of specimens treated at 180°C, as reported by Hietala et al. (2002), contributed to the decrease in these properties.

The conversion of hydrophilic $^{-}$OH groups to C–O–C ether cross-links between wood fibers and conversion of some hemicelluloses to much less hygroscopic furan-based polymers (Ibach 2010) is probably responsible for most of the improvements in thickness swell with increasing temperatures. The increase in water absorption at the 160°C treatment level for all specimens suggests some splitting of the wood structure, allowing for ingress of water.

Conclusions

This study examined the mechanical and physical properties of OSB and two types of plywood that were thermally modified as a posttreatment at 140°C, 150°C, 160°C, 170°C, and 180°C. The study revealed that plywood and OSB respond differently to thermal modification processing. In particular, plywood MOR, MOE, and internal bond strength tended to decrease with increasing treatment temperatures, while the MOE and internal bond strength of OSB is not affected to such a high degree, as indicated by the statistically insignificant differences between the control specimens and those treated at 160°C and 180°C. Also, the screw-holding strength of all panels appeared to be more negatively affected by increasing treatment temperatures than nail-holding strength. Most important, the thickness swell of all panel types improved substantially at higher treatment temperatures, while mass increase (when subjected to a water soak) of both plywood types improved up to the 160°C treatment temperature.

Despite the relatively small sample sizes used in this study, the results provide a technical baseline and preliminary performance data to public organizations and manufacturers, engineers, and designers in the wood products industry to encourage further investigation, thermal modification technology development, and development of new end-use applications for thermally modified plywood and OSB. With further research, it may be possible to optimize the treatment technique(s) to ensure that the panels retain sufficient mechanical strength for the desired end-use applications.

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