Decay of Thermally Modified Engineered Wood Products

H. M. Barnes
M. D. Aro
Amy Rowlen

Abstract

In this study, rated plywood, oriented strand board, laminated strand lumber, and laminated veneer lumber were thermally modified as a posttreatment at 140°C, 150°C, 160°C, 170°C, and 180°C using a closed, pressurized treatment method. Eastern larch oriented strand board manufactured from heartwood and sapwood was also thermally modified as a posttreatment at 160°C and 180°C. All specimens were subjected to laboratory soil block durability tests according to American Wood Protection Association E10-12 utilizing *Gloeophyllum trabeum* (brown rot) and *Trametes versicolor* (white rot) fungi. Heat treatment caused a reduction in weight loss for most substrate and fungi combinations.

For purposes of this discussion, mass loss refers to loss due to fungal degradation. Thermal modification improves advantageous properties in wood, including an attractive darker color, reduced equilibrium moisture content, and degradation of water-binding hemicelluloses (Sinoven et al. 2002, Hakkou et al. 2005, Repellin and Guyonnet 2005, Kocaefe et al. 2008). The result is a product with increased moisture resistance, decreased swelling and shrinkage, and increased resistance to biological degradation (Syrjänen and Kangas 2000). Thermal treatment has also been reported to be the most environmentally sound method for increasing the dimensional stability of wood (Olarescu et al. 2014).

The increased resistance to biological decay is potentially due to the loss of hemicelluloses and other sugars (Ibach 2010), reduced water absorption, release of extractives with antifungal properties, generation of modified wood polymers that become unrecognizable to fungal enzymes, and a decrease in cell wall porosity that retards the penetration of fungal enzymes (Lekounougou et al. 2009).

Previous soft-rot durability results with ash, oak, beech, pine, spruce, and fir utilizing a closed, pressurized thermal modification process showed mass loss reductions ranging from 13 to 97 percent, depending on temperature, when subjected to 32 weeks of soil contact exposure (Ohnesorge et al. 2009). The investigators also reported a maximum 10 percent mass loss for pine thermally modified at 180°C when subjected to a brown and white rot fungi monoculture test. In addition, when thermally modified at 180°C, all species had increased durability sufficient to reach at least Durability Class 2 (Durable) when classified according to CEN/TS 15083-1 (British Standards Institution 2005).

For basswood thermally modified at 210°C, Donahue et al. (2011) reported a drop in mass loss of 22 and 60 percent compared with unmodified basswood exposed to *Trametes versicolor* and *Gloeophyllum trabeum* fungi, respectively. A study by Santos and Del Menezzi (2012) revealed no durability improvement against *T. versicolor* for tropical pine boards undergoing thermomechanical treatments. Resistance to termites and other insects has not been proven. Long-term ground-contact applications are not recommended owing to severe losses in mechanical strength.

While there is an increasing amount of durability data for thermally modified solid wood, there is limited information on the impacts of thermal modification processing, especially using the closed, pressurized process as used in this study, on the performance of engineered wood products

The authors are, respectively, Thompson Distinguished Professor of Wood Sci. & Technol., Dept. of Sustainable Bioproducts, Mississippi State Univ., Mississippi State (hb1@msstate.edu [corresponding author]); Scientist, Wood Utilization, Natural Resources Research Inst., Univ. of Minnesota–Duluth (maro@d.umn.edu); and Research Associate II, Dept. of Sustainable Bioproducts, Mississippi State Univ., Mississippi State (amy.rowlen@msstate.edu). This paper was presented at the 71st International Convention of the Forest Products Society, Session 3.2 Bioenergy & Biorefining, June 26, 2017, Starkville, Mississippi. Approved as Journal Article SB901, Forest & Wildlife Research Center, Mississippi State University. This paper was received for publication in October 2017. Article no. 17-00060.

Forest Prod. J. 68(2):99–104.
doi:10.13073/FPJ-D-17-00060

(Aro et al. 2014). Therefore, the objective of the current study was to investigate the impacts that thermal modification processing has on the durability of commercial plywood, oriented strand board (OSB), laminated strand lumber (LSL), and laminated veneer lumber (LVL).

Donahue and Aro (2010) found that OSB panels thermally modified at 190°C had 6.5, 24.1, and 39.7 percent improvements in width, length, and thickness swell, respectively. There was a 6.2 percent reduction in modulus of rupture but larger decreases in split resistance and tensile strength perpendicular to the surface. Others discovered improved swelling and water absorption properties as well as increased tensile strength for particleboard panels made from thermally modified Scots pine and Norway spruce chips (Boonstra et al. 2006). Similar results were found by Borysiuk et al. (2007). For OSB made from *Cupressus glauca*, Okino et al. (2007) found that thermal treatment caused a significant decrease in the mass loss for the fungi *Pycnoporus sanguineus* and *G. trabeum* while remaining almost unchanged for *Ganoderma applanatum* and *Neolentinus lepideus*. Mechanical properties were reduced for board bonded with 8 percent urea-formaldehyde resin, while boards bonded with 5 percent resin were not significantly different.

Chotchuay et al. (2008) studied oriented strand lumber from parawood strands thermally modified at 190°C and found that tensile strength parallel to the grain (36 MPa), compression (39 MPa), and edgewise bending (61 MPa) were significantly higher than untreated controls. There was no significant difference in compression parallel to the grain or internal bond strength.

Poncsak et al. (2007) studied laminated lumber from bonded thermally modified yellow poplar, Scots pine, jack pine, and aspen lamellas. Shear strength of most samples was reduced 30 to 50 percent, but Scots and jack pine had only moderate decreases of 5 and 11 percent, respectively. The interfacial bonding for jack and Scots pine was much stronger than yellow poplar and aspen. In addition, Sernek et al. (2007) studied thermally modified spruce lamellas and found no significant decrease in shear strength. Also, shear strength did not vary significantly with treatment temperature. More results are described in Aro et al. (2014).

Methods and Materials

Material preparation

The plywood, OSB, LVL, and LSL utilized in this study were obtained from commercial sources. In addition, a laboratory-manufactured OSB made from sapwood or heartwood eastern larch (OSB-EL) was included. Details for the materials are given in Table 1.

Prior to thermal modification, the plywood and OSB master panels were cut to 2.4-m-long by 0.4-m-wide specimens and then weighed. All panels were equilibrated at approximately 21°C ± 5°C and 50 ± 5 percent relative humidity to constant mass prior to thermal modification. The ovendry moisture content of the plywood and OSB was then calculated according to ASTM D4442 (ASTM International 2007). The average density of the plywood and OSB was 743 and 717 kg/m^3, respectively. All LSL and LVL specimens were equilibrated to constant mass at approximately 23°C ± 2°C and 35 ± 5 percent relative humidity prior to thermal modification. The average density of the LSL and LVL was 735 and 503 kg/m^3, respectively.

To prepare feedstock for the tamarack (*Larix laricina*) OSB panels, six mature (90-yr-old) and six juvenile (30-yr-old) trees were selected from the Thunder Bay, Ontario, Canada, area. Details on the processing and manufacture of OSB produced from this feedstock can be found in detail elsewhere (Aro et al. 2014).

Thermal modification procedures

The commercial plywood, OSB, LSL, and LVL specimens were thermally modified postmanufacture treatment at 140°C, 150°C, 160°C, 170°C, and 180°C. Thirteen eastern larch sapwood and heartwood OSB panels were thermally modified as a posttreatment at 160°C and 180°C. All product groups were thermally modified in separate charges. The specimens were separated with ¼-inch-thick wood stickers to allow for more effective heat transfer and airflow inside the kiln. The nominal wood capacity of the kiln was 0.5 m^3. A dehydrated OSB cover sheet was placed on top of each specimen stack to protect the material from excess water spray during the cooling cycle. The kiln was heated by means of pumping a heat-transfer oil into the jacket of the double-wall kiln jacket. During the thermal modification process, moisture evaporated from the wood and was retained in the kiln. In addition, an acid hydrolysis mechanism was generated from thermal decomposition of wood substances; this generated acidic gases that were also retained in the kiln during the process. A fine water spray was then introduced during the cooling cycles via five equally spaced nozzles along the ceiling of the kiln.

During each thermal modification cycle, the temperature and pressure inside the kiln were monitored and recorded. After the commercial plywood and OSB specimens remained 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. For the commercial LSL and LVL specimens, the top temperature was maintained for 135 minutes, and the cycle ended when the final temperature of 105°C was maintained for 60 minutes. For the 160°C OSB-EL treatment group, the panels were held at the top temperature for 75 minutes, and the cycle ended when the final temperature of 108°C was maintained for 75 minutes. For the 180°C OSB-EL treatment group, the panels were held at the top temperature for 45 minutes, and the cycle ended when the final temperature of 108°C was maintained for 45 minutes.

Durability testing

The test included 38 combinations of rated plywood, OSB, LSL, LVL, OSB-EL, chromated copper arsenate (CCA-C), and untreated southern pine (*Pinus* spp.) and sweetgum (*Liquidambar styraciflua*) controls for a total of 41 combinations (Table 2). Groups marked as matched controls are samples taken from the same board or panel as the corresponding temperature prior to heat treatment. Replicates for each combination were taken from different boards or panels. Samples were generated from board remnants from other studies.

The decay test was carried out in accordance with the AWPA E10-12 ''Standard Method of Testing Wood Preservatives by Laboratory Soil-Block Cultures'' (American Wood Protection Association 2012). *G. trabeum*

Table 1.—List of materials used in the study.[a]

Substrate	Species	Resin	Size (parent material) (L × W × T)	Matched control (%) at heat treatment
Rated plywood, sanded, exterior B-C, 4-ply	Southern pine	PF	2.4 m × 1.2 m × 11 mm	5.0
OSB, exposure 1 rated[b]	Proprietary species mix	MDI	2.4 m × 1.2 m × 11 mm	5.0
LSL	Proprietary hardwood species mix	Polymeric MDI	1.27 m × 241 mm × 45 mm	4.8
LVL	Proprietary softwood species mix	PF	1.27 m × 241 mm × 45 mm	5.9
OSB, laboratory heartwood, sapwood	Eastern larch (*Larix laricina*)	MDI	530 m × 530 mm × 12.7 mm	Sapwood, 6.2 Heartwood, 7.0

[a] PF = phenol-formaldehyde; MDI = methylene diphenyl diisocyanate; OSB = oriented strand board; LSL = laminated strand lumber; LVL = laminated veneer lumber.
[b] Exterior and exposure 1 ratings explained at http://www.norbord.com/na/blog/exterior-and-exposure-1-ratings-explained (accessed February 24, 2016).

Table 2.—Treatments for samples evaluated using American Wood Protection Association Standard E10.[a]

Substrate	Treatment (°C)
Rated plywood	140
	150
	150 MC
	160
	170
	180
Oriented strand board	140
	140 MC
	160
	160 MC
	180
	180 MC
Laminated strand lumber	140
	140 MC
	150
	150 MC
	160
	160 MC
	170
	170 MC
	180
	180 MC
Laminated veneer lumber	140
	140 MC
	150
	150 MC
	160
	160 MC
	170
	170 MC
	180
	180 MC
Tamarack oriented strand board	Heartwood control
	Sapwood control
	160 heartwood
	160 sapwood
	180 heartwood
	180 sapwood
Southern yellow pine, control	Untreated control
Southern yellow pine, CCA control	CCA 4.0 kg/m^3
Sweetgum	Untreated control

[a] MC = matched control (unheated); CCA = chromated copper arsenate.

(ATCC 11539) and *T. versicolor* (ATCC 12679) were used in this test. Five replicates plus an operational loss sample were tested for each treatment combination shown in Table 2.

Results and Discussion

Average mass loss data for the treated and untreated samples after exposure to *G. trabeum* for 12 weeks are shown in Table 3. Average mass loss data for the treated and untreated samples after exposure to *T. versicolor* for 24 weeks are also shown in Table 3. The data show that the untreated controls had considerable decay, as shown by the mass losses for *G. trabeum* and *T. versicolor*, indicating that these fungi were very active. In most cases, the heat-treated samples' mass loss was less than the respective matched untreated control sets exposed to fungi.

Looking at the differential between heat-treated samples and controls by substrate (Fig. 1), this differential increased as temperature increased. This is indicative of the effectiveness of heat treatment in reducing mass loss from decay. However, only the LVL heat treatments yielded mass losses of the order of magnitude as southern pine treated to an aboveground CCA retention of 4 kg/m^3.

For *G. trabeum*, the differential (untreated – heat treated/untreated) ranged from –0.54 to 49.2 percent, averaging 19 percent (Fig. 1). Two sample groups had slightly higher mass losses for the heat-treated material. For *T. versicolor*, the differential ranged from –6.67 to 28.86 with an average of 10.82. There was no visual evidence of fungal colonization on the sterile controls, indicating that the mass loss was most likely due to leaching of extractives and not actual decay. These data indicate that all heat treatments–substrate combinations tested, except the six matched control comparisons, show some resistance to the fungi tested. For *T. versicolor,* the differential values were more variable, with four combinations showing higher loss for the heat-treated samples.

The effect of heat treatment on the mass loss of various substrates is shown in Figure 2. Excellent correlation between heat treatment temperature and mass loss is shown in Figure 2a for *G. trabeum*. LSL and LVL showed the best reduction in mass loss. For LVL, mass losses of <10 percent were achieved at temperatures >150°C. For LSL and rated plywood, the temperature required was around 180°C. The outlier value for rated plywood at 150°C was not included in the curve-fitting equation. For *T. versicolor* (Fig. 2b), all substrates showed a decrease in mass loss with

Table 3.—Average adjusted mass loss data for the treated and untreated samples after exposure to Gloeophyllum trabeum *for 12 weeks and* Trametes versicolor *for 24 weeks.*[a]

Sample type	Temperature (°C)	Adjusted mass loss (%)		% of control[b]	
		G. trabeum	*T. versicolor*	*G. trabeum*	*T. versicolor*
Rated plywood	140	75.7	81.8		
	150	23.4	52.5	53	86
	150 MC	43.8	61.2		
	160	39.9	44.9		
	170	20.9	60.2		
	180	12.5	43.6		
Oriented strand board	140	69.6	64.5	100	112
	140 MC	69.5	57.8		
	160	67.4	43.1	95	60
	160 MC	70.9	72.0		
	180	51.0	57.0	75	87
	180 MC	68.4	65.8		
Laminated strand lumber	140	52.0	47.2	101	110
	140 MC	51.5	43.0		
	150	47.5	51.2	87	97
	150 MC	54.3	52.8		
	160	32.7	40.7	66	109
	160 MC	49.9	37.4		
	170	26.0	19.6	51	41
	170 MC	50.8	47.3		
	180	3.6	19.0	7	34
	180 MC	52.8	55.2		
Laminated veneer lumber	140 C	24.8	44.7	63	108
	140 MC	39.5	41.3		
	150	10.7	29.5	39	64
	150 MC	27.4	46.4		
	160	2.6	30.8	9	73
	160 MC	30.3	42.4		
	170	3.5	31.7	7	74
	170 MC	47.0	42.8		
	180	0.7	26.0	2	59
	180 MC	37.2	43.7		
Tamarack oriented strand board	Heartwood control	61.4	35.0		
	Sapwood control	61.1	47.8		
	160 heartwood	54.4	41.7	89	119
	160 sapwood	44.4	30.4	73	64
	180 heartwood	18.4	25.4	30	73
	180 sapwood	20.3	21.3	33	45
Southern yellow pine control	Untreated control	47.8	20.4		
CCA control	CCA 4.0 kg/m^3	1.8	0.5		
Sweetgum (*Liquidambar styraciflua*)	Untreated control		66.8		

[a] MC = matched control (unheated); CCA = chromated copper arsenate.
[b] % of control = ratio of observed value/control value at same temperature.

increasing temperature, with the exception of OSB, the mass loss of which increased at 180°C. No treatment reached 10 percent mass loss.

Figure 3 indicates significant reduction in mass loss for the 180°C treatment of heartwood and the 160°C and 180°C treatments of sapwood tamarack OSB. While heat treatment resulted in a lower mass loss for both heartwood and sapwood tamarack OSB, none fell below 10 percent (Fig. 3a).

With *T. versicolor*, mass loss reduction in the heartwood tamarack OSB was not consistent with temperature, while a downward trend was noted for the sapwood OSB (Fig. 3b). The data suggest that heat treatment requires a higher temperature to effect a reduction in mass loss for heartwood panels.

Conclusions

For the most part, heat treatment caused a reduction in mass loss for all substrates and both fungi. Some variation in the differential in mass loss between treated and untreated samples was noted. For engineered wood products, heat treatment seems an effective way to reduce susceptibility to fungal deterioration. The impact of heat treatments on other properties should be investigated, as should susceptibility to termite attack.

Acknowledgments

This work was supported by the National Science Foundation Partnerships for Innovation Building Innovation Capacity (PFI BIC) subprogram under grant no. 1237798 to the University of Minnesota–Duluth. Any opinions, find-

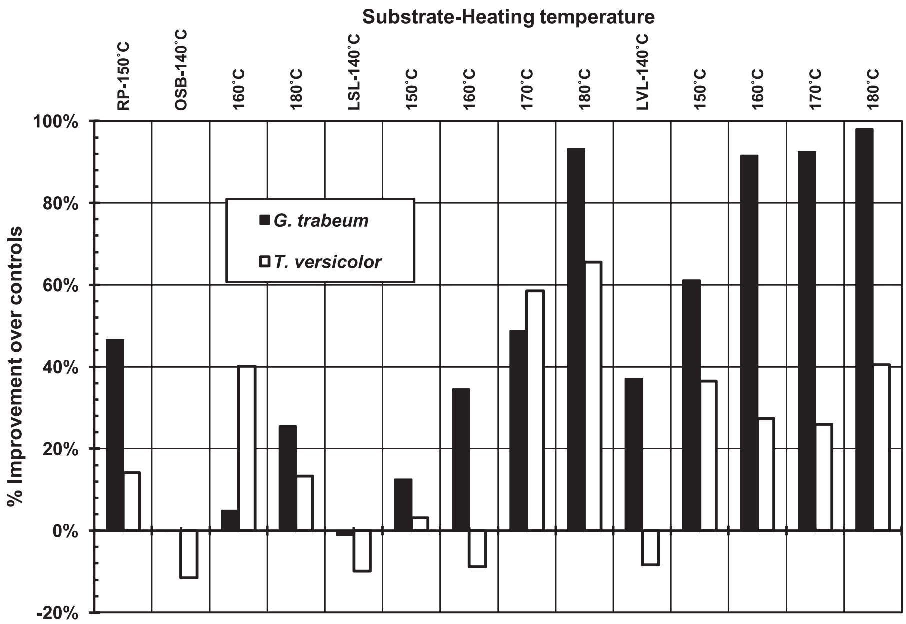

Figure 1.—Improvement in mass loss as a percentage of control values.

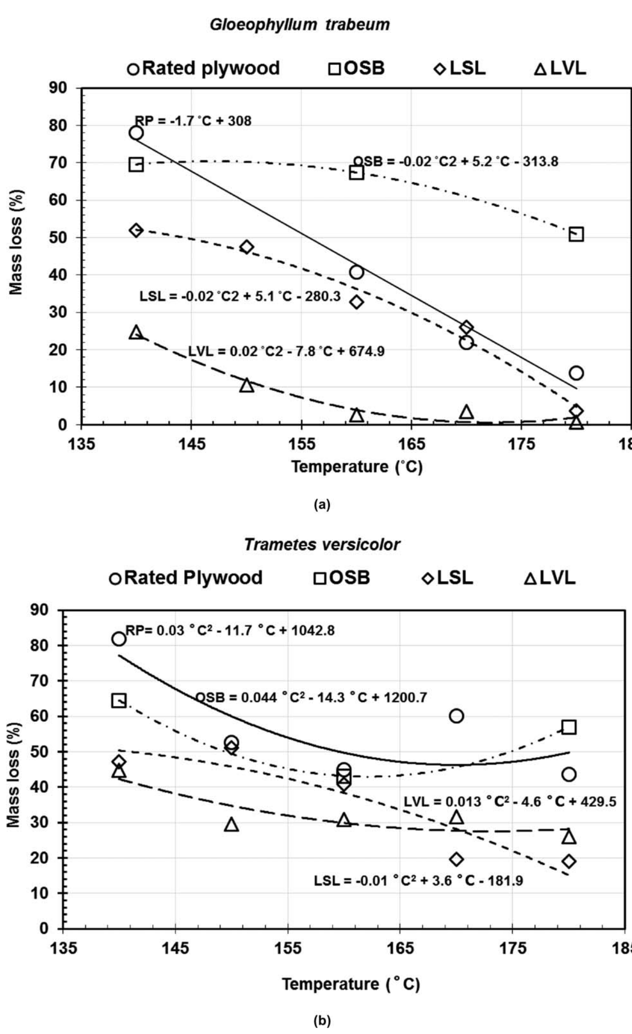

Figure 2.—Weight loss as a function of heating temperature for various substrates decayed by (a) Gloeophyllum trabeum *and (b)* Trametes versicolor. *OSB = oriented strand board; LSL = laminated strand board; LVL = laminated veneer lumber.*

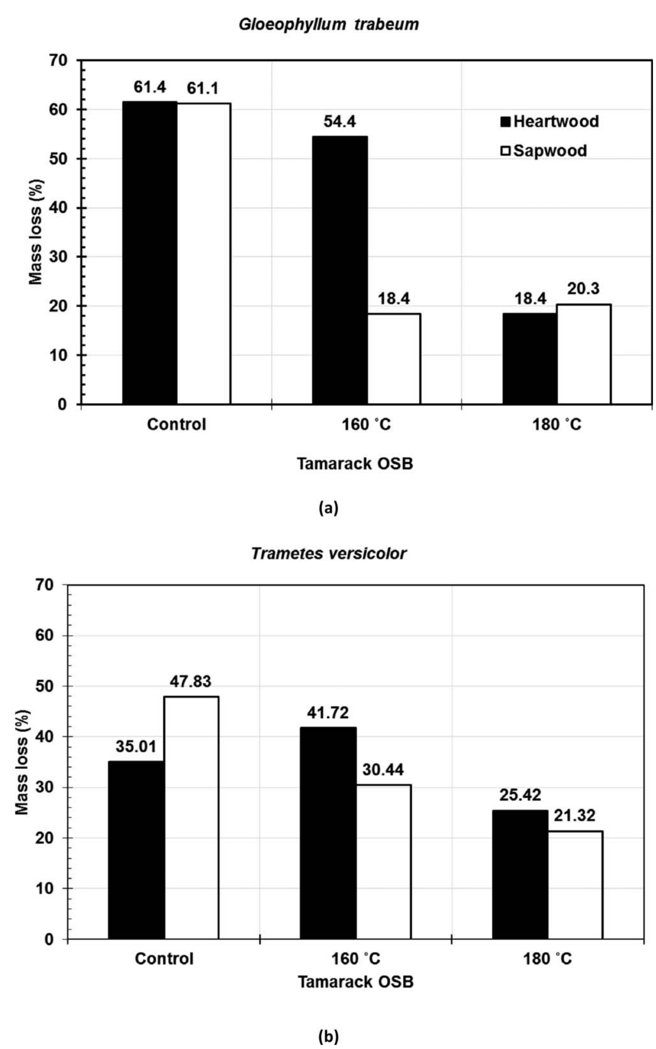

Figure 3.—Mass loss as a function of heating temperature for tamarack oriented strand board decayed by (a) Gloeophyllum trabeum *and (b)* Trametes versicolor.

ings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We would also like to thank Lakehead University for providing and preparing the eastern larch used in this project.

Literature Cited

American Wood Protection Association. 2012. Standard method of testing wood preservatives by laboratory soil-block cultures. AWPA E-10-12. *In:* 2012 AWPA Book of Standards. American Wood Protection Association, Birmingham, Alabama.

Aro, M., B. Brashaw, and P. Donahue. 2014. Mechanical and physical properties of thermally modified plywood and oriented strand board panels. *Forest Prod. J*. 64(7/8):281–289.

ASTM International. 2007. Standard test methods for direct moisture content measurement of wood and wood-base material, method B. ASTM D4442. *In:* Annual Book of ASTM Standards. ASTM International, West Conshohocken, Pennsylvania.

Boonstra, M. J., A. Pizzi, F. Zomers, M. Ohlmeyer, and W. Paul. 2006. The effects of a two stage heat treatment process on the properties of particleboard. *Holz Roh- Werkst*. 64(2):157–164.

Borysiuk, P., M. Maminski, M. Grzeskiewics, P. Parzuchowski, and A. Mazurek. 2007. Thermally modified wood as raw material for particleboard manufacture. *In:* Proceedings of the Third European Conference on Wood Modification, October 15–16, 2007, Cardiff, UK; University of Wales Bangor Biocomposites Centre, Bangor, UK. pp. 227–230.

British Standards Institution. 2005. Durability of wood and wood-based products. Determination of the natural durability of solid wood against wood-destroying fungi, test methods. Part 1. Basidiomycetes. CEN/TS 15083-1. British Standards Institution, London.

Chotchuay, V., B. Kyokong, and W. Ouypornprasert. 2008. Strength and reliability of oriented strand lumber made from heat-treated parawood strands. *Songklanakarin J. Sci. Technol*. 30(5):649–657.

Donahue, P. and M. Aro. 2010. Performance testing of thermally-modified OSB. University of Minnesota-Deluth (UMD) Natural Resource Research Institute (NRRI). Confidential report. NRRI/TR-2010/36. University of Minnesota–Duluth.

Donahue, P., M. Aro, S. French-Coda, and W. Chen. 2011. Thermally-modified eastern hardwoods as high-tech fenestration and exterior shuttering. USDA Wood Education and Resource Center Project 09-DG-090. Final Accomplishment Report. September 22, 2011.

Hakkou, M., M. Pètrissens, A. Zoulalian, and P. Gèrardin. 2005. Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. *Polym. Degrad. Stabil*. 89(1):1–5.

Ibach, R. 2010. Specialty treatments. *In:* The Wood Handbook: Wood as an Engineering Material. General Technical Report FPL-GTR-190. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. pp. 19-1–19-16.

Kocaefe, D., S. Poncsak, and Y. Boluk. 2008. Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. *BioResources* 3(2):517–537.

Lekounougou, S., M. Petrissans, J. P. Jacquot, E. Gelhaye, and P. Gerardin. 2009. Effect of heat treatment on extracellular enzymatic activities involved in beech degradation by *Trametes versicolor*. *Wood Sci. Technol*. 43(4):331–341.

Ohnesorge, D., A. Tausch, I. Krowas, B. Becker, and F. Fink. 2009. Hydrothermal modification of wood by the WTT process. Technical report. Albert-Ludwig University, Freiburg, Germany.

Okino, E. Y. A., D. E. Teixeira, and C. H. S. DelMenezzi. 2007. Post-thermal treatment of oriented strandboard (OSB) made from cypress (*Cupressus glauca* Lam.). *Maderas Cienc. Tecnol*. 9(3):199–210.

Olarescu, M. C., M. Campean, M. Ispas, and C. Cosereanu. 2014. Effect of thermal treatment on some properties of lime wood. *Eur. J. Wood Wood Prod*. 72(4):559–562.

Poncsak, S., S. Q. Shi, D. Kocaefe, and G. Miller. 2007. Effect of thermal treatment of wood lumbers on their adhesive bond strength and durability. *J. Adhes. Sci. Technol*. 21(8):745–754.

Repellin, V. and R. Guyonnet. 2005. Evaluation of heat-treated wood swelling by differential scanning calorimetry in relation to chemical composition. *Holzforschung* 59(1):28–34.

Santos, C. and C. Del Menezzi. 2012. Effect of thermo-mechanical treatment on natural durability and wettability of wood from a tropical pine species. Presented at the Sixth European Conference on Wood Modification, September 17–18, 2012, Ljubljana, Slovenia.

Sernek, M., M. Humar, M. Kumer, and F. Pohleven. 2007. Bonding of thermally modified spruce with PF and UF adhesives. *In:* Proceedings of the 5th COST E34 International Workshop, September 6, 2007, Bled, Slovenia; University of Ljubljana, Slovenia. pp. 31–38.

Sinoven, H., S. L. Maunu, F. Sundholm, S. Jämsä, and P. Viitaniemi. 2002. Magnetic resonance studies of thermally modified wood. *Holzforschung* 56(6):648–654.

Syrjänen, T. and E. Kangas. 2000. Heat treated timber in Finland. *In:* Proceedings, International Research Group on Wood Protection. Document IRG/WP 00-40158. International Research Group on Wood Protection, Stockholm. 9 pp.