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Durability of Thermally Modified Balsam Fir and Eastern Hemlock

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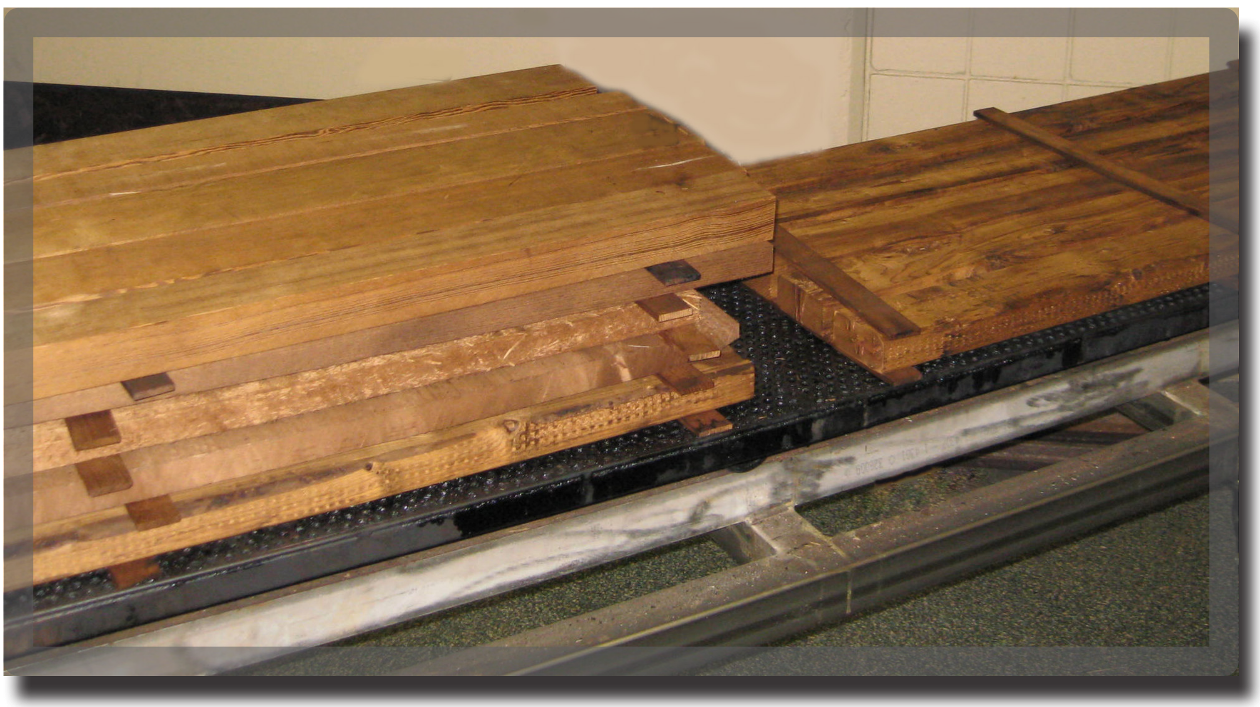

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Abstract

Hazardous fuels such as woody biomass and small-diameter trees accumulate in the forest, contributing to increased risk of wildfires. Two tree species that specifically contribute to this problem in the Midwest and Northeast of the United States are balsam fir and eastern hemlock. If the durability of these two species against fungal decay could be improved, markets for lumber made from these species would increase, contributing to removal of them from the forests. Thermal modification of the wood from these species may improve the fungal durability. In this study, we performed soil-block tests on specimens cut from thermally modified wood of these two species. The fungal species used were two brown rot fungi, *Gloeophyllum trabeum* and *Postia placenta*, and two white rot fungi, *Trametes versicolor* and *Irpex lacteus.* The soil-block tests showed that the thermal modification treatments improved the fungal durability of both wood species for all species of fungi.

Keywords: wood protection; fungal biodeterioration; thermal modification; wood utilization; hazardous fuels; usage guidelines

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Durability of Thermally Modified Balsam Fir and Eastern Hemlock

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Introduction

National forests and other public and private lands display fire regimes that vary in both frequency and severity (Moser 2016). Unfortunately, hazardous fuels such as low-quality woody biomass and small-diameter trees accumulate in the forest, leading to increased fire risks. Wind damage, disease, and invasive insects can also lead to increased fuels. And, climate change is likely to increase the risk for both larger and more frequent wildfires and large-scale disease and insect epidemics (Patton-Mallory 2008). Unfortunately, many of these hazardous fuels accumulating in the forest have little economic value; thus, removal of the material is very expensive and often delivers small or no economic returns (Moser 2016). Therefore, finding economically viable uses for these hazardous fuels is becoming more urgent.

In Region 9 of the U.S. Forest Service (the Midwest and Northeast), there are two tree species that are contributing to the problem of hazardous fuel build up: balsam fir (*Abies balsamea* (L.) Mill.) and eastern hemlock (*Tsuga canadensis* (L.) Carriere). Balsam fir is a species of interest regarding forest fires for several reasons. Because of its shade tolerance, it can become established in the understory of multiple forest types and eventually take over stands when the pre-existing overstory declines due to age or harvest and the balsam understory is left untreated. In these situations, multiple age classes can grow at the same time creating a ladder fuel situation that can turn a ground fire into a devastating crown fire. Also, the spruce budworm can defoliate and kill trees, adding to the potential fuel load for forest fires. A lack of sustained markets for balsam fir has reduced active management of stands, adding to fuel loads (SRI 2018). Eastern hemlock is a shade tolerant softwood species that grows from Nova Scotia down through the Appalachian plateau (Brisbin 1970). It has fairly low specific gravity compared with other commercial softwood species, but the wood is commonly used for lumber. The heartwood of eastern hemlock is pale brown with a reddish hue. The sapwood is not distinctly separated from the heartwood but may be lighter in color. The wood is coarse and uneven in texture (old trees tend to have considerable shake). It is moderately light in weight, moderately hard, moderately low in strength, moderately limber, and moderately low in shock resistance. An important characteristic of eastern hemlock is that it has poor self-pruning abilities; therefore, as trees age, they accumulate hard knots, which decrease the volume of marketable lumber except in older trees. Eastern hemlock is a concern because of increasing numbers of dead and dying stands caused by hemlock woolly adelgid (*Adelges tsugae* (Annand)) (HWA), an introduced scale insect that has been causing a tree health crisis in the United States for more than a decade (McManus and others 2000). There have been many treatments and control measures evaluated for HWA, one of which is salvage logging, which is an important aspect to managing hemlock stand health and minimizing the devastating impacts of this pest. But hemlock is considered a secondary class of forest product. Therefore, finding new, higher value uses for hemlock would increase the likelihood of logging. As with balsam fir, stressed, dead, and dying hemlock increases the risk of catastrophic wildfire and reduces property values for public and private landowners.

To potentially expand markets for these species, the University of Minnesota Duluth, Natural Resources Research Institute (NRRI) and the USDA Forest Service, Forest Products Laboratory (FPL) evaluated the durability of thermally modified balsam fir and eastern hemlock in an American Wood Protection Association (AWPA) E10-16 (AWPA 2019a) laboratory soil-block durability test. These data could be used by forest products industry stakeholders to develop new markets for thermally modified balsam fir and eastern hemlock.

Thermal Modification Technology Overview

Thermally modified wood is often used for higher volume products, such as solid wood flooring, external cladding, and exterior decking. The first prominent work (Stamm and others 1955) heated solid wood in a vacuum; this wood (“Staybwood”) was heated from 93 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, a collection of well-known processes, subjects wood to heat (typically 140 to 240 °C) for up to 60 hours in specialized kilns, usually in a reduced-oxygen, inert environment. This imparts advantageous properties, including darker color, drastically reduced equilibrium moisture content (EMC) and mass, and degradation of water-binding hemicelluloses (Sivonen and others 2002, Hakkou and others 2005, Repellin and Guyonnet 2005, Esteves and others 2006, Rapp and Sailer 2001).

Methods

Thermal Modification Process

Prior to thermal modification, balsam fir and eastern hemlock lumber was equilibrated to constant weight at approximately 23 ± 2 °C and 65% relative humidity (±5%) in the NRRI mechanical testing laboratory. The balsam fir and eastern hemlock lumber was either 25 or 50 mm thick (before conditioning) at random lengths from 1.22 to 2.24 m. The lumber was then thermally modified at either 170 or 180 °C in the 0.5-m^3 closed, pressurized thermal modification kiln (IWT/Moldrup, Lerbaek Moelle, Denmark) in the NRRI thermal modification pilot plant. To increase air flow, 6.35-mm-thick wood stickers were placed between the layers of lumber. Once reached, the target temperature was maintained for either 75 or 110 min (depending on lumber thickness). A fine water spray was used to cool the lumber prior to removal from the kiln.

AWPA E10 Laboratory Soil-Block (Bottle) Durability Testing

Twenty 19-mm^3 test blocks were cut from each thermally modified specimen (balsam fir and eastern hemlock lumber modified at two temperatures) and also from the unmodified control specimen. Fungal laboratory durability tests were performed on each test block using the AWPA E10 soil-block bottle methodology (AWPA 2019a). Two brown rot fungi, *Gloeophyllum trabeum* MAD-617 and *Postia placenta* MAD-698, and two white rot fungi, *Trametes versicolor* MAD-697 and *Irpex lacteus* MAD-517, were used in the experiments. Cultures were grown and maintained on 2% malt extract agar (MEA) + 0.1% yeast extract plates prior to experiments. Soil bottle assays were conducted according to AWPA E10 (AWPA 2019a) with five replicate blocks per fungus and treatment including untreated controls. Briefly, two 5-mm plugs from the edge of actively growing cultures of brown rot fungi were added to sterile soil bottles containing 40- by 30- by 3-mm pine feeder strips. The same process was performed with white rot fungi except maple feeder strips were used. Fungi were allowed to grow and colonize the feeders for 3 weeks in a 27 °C, 70% humidity incubator prior to adding test blocks. Test blocks were conditioned to stable weight at 27 °C and 30% humidity. They were then weighed and propylene-gas-sterilized overnight in vials separated by treatment. One block was added to each bottle on top of the colonized feeder in a sterile hood. Bottles were replaced in the controlled humidity incubator for 12 weeks, and then blocks were removed and scraped clean of fungal tissue. Initial weights of the test blocks were taken so that a final moisture content could be calculated for comparison between treatments. Then blocks were oven-dried at 60 °C for 4 hours to stop fungal growth, followed by 1 week of conditioning at 27 °C and 30% humidity. Finally, conditioned weights were recorded. Percentage weight loss from the initial weight of conditioned blocks was calculated and reported.

Results

The thermal modification treatments improved the durability of both balsam fir and eastern hemlock when subjected to all fungi, with the 180 °C treatment generally imparting greater durability than the 170 °C treatment. Figure 1 shows a visual comparison of a thermally modified block and an unmodified control block exposed to the brown rot fungus *G. trabeum*.

Moisture Content Comparisons

Moisture content is a key factor in resistance to fungal decay and dimensional stability. Fungi require available moisture for the diffusion of low-molecular-weight compounds to initiate and facilitate the decay process. As a result, decay progression is typically only seen in wood above fiber saturation in the range of 40% to 80% moisture content. A key claim of both thermally and chemically modified woods is that the process improves material resistance through modification of the wood cell wall to exclude moisture. This has clearly been

Figure 1. Example image of decay caused by *Gloeophyllum trabeum* MAD-617 on unmodified balsam fir specimen (left) compared with a specimen thermally modified at 180 °C (right).

demonstrated in acetylated and furfurylated wood and, to a lesser extent, in thermally modified wood. Results from the current study are shown in Table 1, which reveals that for the brown rot fungal strains, there is a dose-type response with final moisture content decreasing with increasing treatment temperature; however, neither white rot fungal strain showed the same trend. Interestingly, the wood cell moisture contents all reached levels in the range where wood decay is known to occur even where percentage weight loss was very low. Therefore, the moisture exclusion properties of thermally modified balsam fir and eastern hemlock may ultimately be overcome as reported for other wood modification technologies (Hill 2007). This has been studied by Zelinka and others (2020) in acetylated wood, but thermally modified wood could also benefit from similar attention because the mechanisms are similar, albeit less pronounced.

Fungal Decay Resistance

When subjected to decay by *G. trabeum*, the balsam fir and eastern hemlock unmodified control specimens experienced 60.3% and 46.8% weight loss, respectively (Fig. 2). Fungal resistance was somewhat improved at the 170 °C treatment temperature with resultant weight losses of 28% and 35%, respectively, but this would still be considered nondurable. Resistance improved markedly to 9.7% and 0.6% weight loss at the 180 °C treatment temperature. There does appear to be a dose-dependent response with fungal resistance increasing with treatment temperature. The caveat to thermal modification is that higher temperature treatments tend to reduce the mechanical properties of wood, which can limit the overall utility of the material (Kubojima and others 2000, Ates and others 2009).

When specimens were subjected to decay by *P. placenta*, similar results were found, especially at the 180 °C treatment temperature (Fig. 3). However, the eastern hemlock specimens thermally modified at 170 °C experienced only 8.9% improvement in weight loss compared with the control specimens, whereas balsam fir thermally modified at 170 °C had a 53.8% improvement in weight loss compared with the control specimens.

When exposed to *T. versicolor*, the unmodified balsam fir control specimens had 61.4% weight loss. This was reduced substantially to 27.4% and 7.0% weight loss at the 170 and 180 °C treatment temperatures, respectively (Fig. 4). The improvements in mass loss of eastern hemlock thermally modified at 170 °C were not as great as those of balsam fir when exposed to *T. versicolor*, but when thermally modified at 180 °C, the eastern hemlock mass loss was 1.0%, which was a 98% improvement compared with the control specimens.

Compared with the control specimens, the thermally modified balsam fir experienced mass loss improvements when subjected to decay by *I. lacteus* (Fig. 5), and the overall decay rate was reduced compared with the other fungi used in this study. Interestingly, the unmodified eastern hemlock control specimens had lower mass loss (6.7%) than those thermally modified at 170 °C (12.6%), but the eastern hemlock specimens thermally modified at 180 °C had the lowest mass loss of all the specimens exposed to *I. lacteus* at 1.24% (Fig. 5).

Discussion and Recommendations

Thermal modification of balsam fir and eastern hemlock does improve moisture-excluding properties and fungal decay resistance in a dose-dependent manner. However, thermal modification, even at 180 °C, was not sufficient to completely prevent moisture contents from reaching levels conducive to decay in an AWPA E10 soil bottle assay. Moisture cycling is an extremely important consideration for decay of wood in use above ground (Brischke and Rapp 2008), and to the extent that thermal modification lowers the hygroscopicity of wood, this makes it an ideal strategy for wood protection in outdoor aboveground exposure. The studies described in this report subject wood to a possible worst-case scenario in which conditions are ideal for the development of decay, but complementary field and demonstration tests of this material are also needed to determine long term performance of this material under fluctuating moisture (wetting and drying) regimes. Additional studies are also

Table 1—Average moisture content of thermally modified and unmodified control blocks exposed to decay fungi for 12 weeks (unadjusted for mass loss caused by decay)

	Moisture content (% ± standard deviation)					
	Balsam fir			Eastern hemlock		
Fungus	Unmodified	170 °C	180 °C	Unmodified	170 °C	180 °C
G. trabeum	222.47±36	201.50±15	146.79±34	205.95±29	155.06±32	88.79±23
P. placenta	181.42±48	158.34±41	109.29±20	165.27±52	121.67±18	97.76±22
T. versicolor	85.55±23	85.86±56	62.28±28	86.87±23	95.50±53	76.36±17
I. lacteus	48.84±16	82.68±32	66.88±23	42.22±13	71.33±25	68.30±20

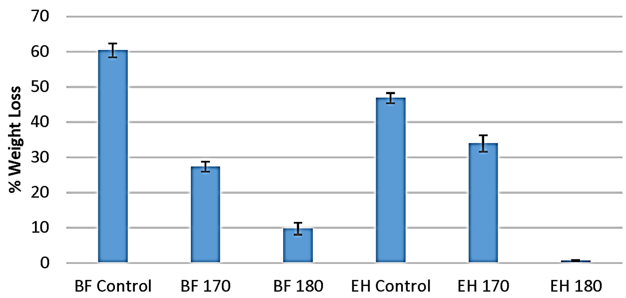

Figure 2. Weight loss of thermally modified and unmodified control blocks (balsam fir (BF) and eastern hemlock (EH)) after exposure to *G. trabeum*. Bars indicate standard error of five replicates.

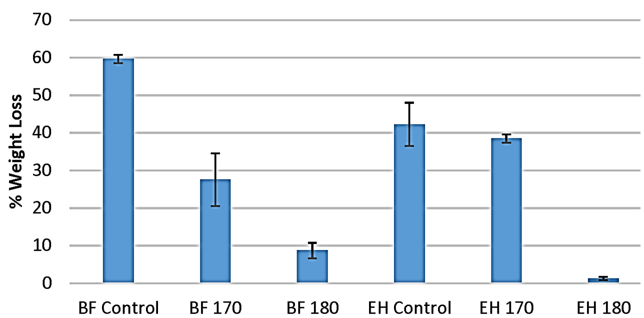

Figure 3. Weight loss of thermally modified and unmodified control blocks (balsam fir (BF) and eastern hemlock (EH)) after exposure to *P. placenta*. Bars indicate standard error of five replicates.

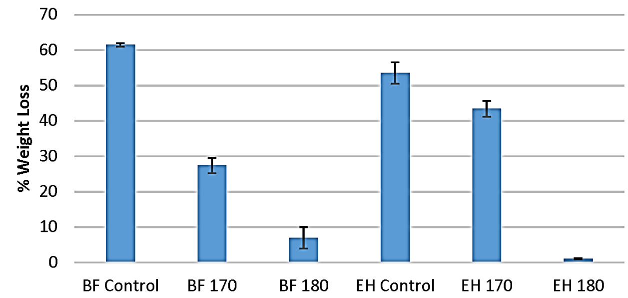

Figure 4. Weight loss of thermally modified and unmodified control blocks (balsam fir (BF) and eastern hemlock (EH)) after exposure to *T. versicolor*. Bars indicate standard error of five replicates.

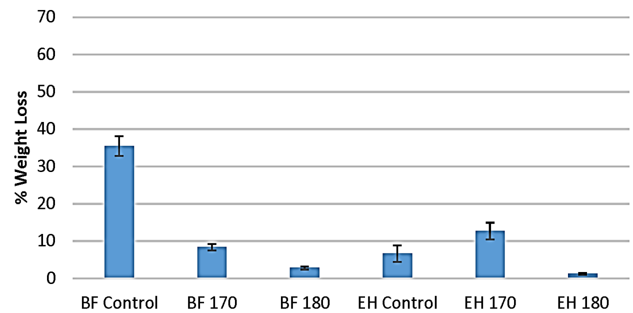

Figure 5. Weight loss of thermally modified and unmodified control blocks (balsam fir (BF) and eastern hemlock (EH)) after exposure to *I. lacteus*. Bars indicate standard error of five replicates.

needed to explore the decay resistance of thermally modified wood under different treatment conditions (i.e., different treatment temperatures and dwell times) and thermally modified wood treated with additional agents to impart suitable decay resistance for applications in which the wood could be exposed to moisture for extended periods, such as in AWPA Use Categories UC3A and higher (AWPA 2019b).

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