Field Testing in Canada XXVII: Thermally Modified Wood

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Summary

Thermal modification has been reported to improve the decay resistance of many species; however, there are few data on Canadian species, including white spruce, western hemlock, and Pacific silver fir. Moreover, there are no data comparing the performance of these materials to western redcedar, which is thermally modified wood's primary competitor in many markets. Accordingly, a laboratory decay test, one simulated field test, and two field tests were undertaken to evaluate the performance of white spruce, western hemlock, and Pacific silver fir thermally modified using two different cycles. Thermal modification was associated with reduced extent of decay, with higher temperature modifications generally providing greater decay resistance. However, in above-ground applications the highest level of thermal treatment was not as decay resistant as western redcedar. In ground contact, thermally modified spruce and hemlock performed similarly to western redcedar. The decay resistance of these thermally modified woods is much less than observed in comparable tests of wood treated with ACQ or CA-B to CSA standards. It is therefore recommended that the use of thermally modified hemlock, Pacific silver fir, and white spruce should be restricted to above-ground, appearance applications in climates where only a modest amount of decay resistance is needed to provide an acceptable service life.

1. Introduction

Thermally modified wood is produced by exposing wood to high temperatures (150 to 240°C) in the absence of oxygen (Syrjänen and Kangas 2000). Several systems have been commercialized based on different heating media and schedules. Thermally modified wood is generally darker, more dimensionally stable, and more resistant to decay. Thermal modification processes have been reviewed by Militz (2002, 2008) and its properties have been reviewed by Esteves and Pereira (2009) and Militz (2008).

Several groups have evaluated the durability of thermally modified wood, mostly of European and Japanese species, in laboratory and field tests. Durability is affected by treatment schedule, with higher temperatures and longer times associated with greater fungal resistance, as well as by wood species (Metsä-Kortelainen and Viitanen 2009). In laboratory testing, the durability of thermally modified wood varies from slightly durable to highly durable depending on the wood species, the treatment, and the test fungi (Dirol and Guyonnet 1993; Kim *et al*. 1999; Kamdem *et al*. 2002; Welzbacher and Rapp 2002; Mazela *et al*. 2003; Mburu *et al*. 2007; Shi *et al*. 2007; Vidrine *et al*. 2007; Welzbacher and Rapp 2007; Momohara *et al*. 2008; Metsä-Kortelainen and Viitanen 2009; Lekounougou and Kocaefe 2013; 2014). In ground proximity field tests thermally modified wood has performed as well as or better than moderately durable Douglas-fir heartwood, but not as well as preservative treated wood (Welzbacher and Rapp 2007). In ground contact, performance is generally poor (Welzbacher and Rapp 2005; Flæte *et al*. 2009). It has been consistently shown that thermally modified woods are less resistant to decay than preservative-treated wood (Kim *et al*. 1999; Shi *et al*. 2007; Welzbacher and Rapp 2007; Metsä-Kortelainen *et al*. 2011), but there is a lack of data on how it affects the normally low decay resistance of hem-fir or white spruce, and how it compares to naturally durable species such as western redcedar (WRC). This last comparison in particular is important for the North American market where WRC is widely used in applications where thermally modified wood could be considered as a possible substitute (e.g. decking, fencing, or siding).

The objective of the present work was to evaluate the performance of western hemlock, Pacific silver fir, and white spruce thermally modified using two different temperature cycles in laboratory decay tests, accelerated above-ground tests, a coated above-ground field test, and a ground contact field test.

2. Methods

2.1 Material Preparation

Hem-fir and SPF nominal 2x4s were thermally modified under two treatment cycles by SEESIn Wood Ltd (Abbotsford, BC) using the Thermowood® process. Treatment 1 had a maximum temperature of 190°C (Thermo-S). Treatment 2 had a maximum temperature of 212°C (Thermo-D). These process parameters are defined in more detail by the International Thermowood Association (Thermowood 2017). Western hemlock and Pacific silver fir were distinguished and separated using near infrared spectroscopic models. Spruce was separated from SPF using pine heartwood indicator (AWPA 2011) and Ehrlich's reagent (Barton 1973). Unmodified samples of all species were used as controls. Western redcedar was included as a naturally durable reference. Due to limited material availability, not all groups were evenly replicated in each decay test (Table 1).

Table 1 Sample Replication in Decay Tests

Material	Modification	AFS – Mycelial Inoculum	AFS – Spore Inoculum	L-Joint	Stake
Western hemlock	None	6	6	13	12
	T1	7	5	10	12
	T2	7	8	16	15
Pacific silver fir	None	6	5	11	10
	T1	5	7	13	12
	T2	6	5	10	12

White spruce	None	10	9	19	19
	T1	4	3	7	6
	T2	6	6	12	12
WRC	Unmodified	6	6	12	12

2.2 Laboratory Decay Testing

This test followed the ASTM standard D 2017-05 (ASTM 2005) except where indicated. Generally the test method consists of conditioning and weighing wood blocks, and exposing them to decay fungi actively growing in soil and on a non-durable southern pine sapwood feeder strip. Test blocks are incubated until the non-durable southern pine sapwood control blocks, run in parallel, reach a threshold weight loss of 50%. The test blocks are then re-conditioned and re-weighed to determine weight loss, which is indicative of the decay resistance of the test blocks. Twenty replicate test blocks, cut from a minimum of ten different boards, were included in each test group. Blocks were conditioned to constant weight in an oven at 40°C before and after exposure to decay fungi. Hemlock and fir, untreated and modified at both temperatures, as well as the western redcedar reference and the southern pine control were exposed to *Postia placenta* (Fr.) M. Lars. *et* Lomb. Ftk 120F or *Gloeophyllum trabeum* (Pers. *ex* Fr.) Murr. Ftk 47D. Weight losses of experimental samples were measured when southern pine controls had reached an average of 50% to 55% weight loss. Average weight losses were used to specify decay resistance class based on the criteria described in ASTM D 2017, where 0 to 10% is classified as highly resistant, 11 to 24% is classified as resistant, 25 to 44% is classified as moderately resistant, and greater than 45% is classified as slightly or non-resistant.

2.3 Accelerated Field Simulator

Ten 200-mm-long mini-boards were cut from the nominal 2x4s from each species/treatment group. Each mini-board was coated on one end with two coats of epoxy resin (Intergard 740, International Marine Coatings) to prevent rapid drying. Samples were labeled with stainless steel tags and placed in the FPInnovations' Accelerated Field Simulator (AFS). This chamber provides warm, humid conditions that support rapid growth of decay fungi (Morris *et al.* 2009). The ambient conditions were set at 20°C and a relative humidity of 90%. The mini-boards were exposed to a spray schedule of four days of spray with the spraying for 5 seconds every 120 minutes, followed by 3 days of no spray. All of the mini-boards were exposed to natural air-borne inocula brought into the AFS by air-circulation. In addition, petri plates containing the fruiting bodies of *Gloeophyllum sepiarium*, *Oligoporus placentus*, *Dichomitus squalens,*and *Tyromyces palustris* on a cellulose/malt extract medium were placed on six racks suspended from the ceiling of the chamber. The method of producing fruitbodies followed that described by Choi *et al*. (2002). After adjusting water spray cycles to optimize moisture content, 19 mm cubes colonized by *G. sepiarium* were attached to approximately half of the samples from each treatment group. These blocks were replaced with freshly infected blocks once after 8 months of exposure. Samples were rated for decay after six months and thereafter on an annual basis using the AWPA decay rating system:

Decay Rating	**Condition of the board**
10	Sound: no evidence of decay.
9.5	Trace or suspicion of attack.
9	Minor softening on end-grain or on sides of checks, or up to 3% of any given cross-section decayed
8	Small pockets of decay on end-grain or on sides of checks, or up to 10% of any cross section decayed.
7	Moderate decay or sample has between 10-30% of any given cross section decayed. Presence of a fruitbody of a recognized wood-rotting basidiomycete (often the first sign of decay) is an automatic rating no higher than 7
6	Severe decay. Sample has between 30-50% of any given cross section decayed.
4	Very severe decay with greater than 50% of a cross section affected, likely to seriously affect load-bearing capacity but not broken when stressed as described below
0	Failure when stepped on sharply by a person of moderate weight (60 – 80 kg). This could be breakage of the board or severe surface collapse, or an inspection tool can pass totally through the board

2.4 L-Joint Test

Samples from each species/treatment group were prepared according to AWPA E9 (AWPA 2009) with the following modifications. The dimensions were reduced to 36 x 36 mm since thicker wood was not available for all groups. Assembled L-joints were coated with one coat of Benjamin Moore white water-based latex primer and one coat of Benjamin Moore white exterior latex top coat. Distal ends were coated with two coats of epoxy resin (Intergard 740, International Marine Coatings) and covered with stainless steel end caps. Painted L-joints were broken apart and re-assembled to ensure consistent timing of coating failure at the joint. Samples were installed in FPInnovations field test site in the University of British Columbia's Malcolm Knapp Research Forest in Maple Ridge, BC. This test site has annual precipitation of 2150 mm with mean daily minimum and maximum temperatures of 1°C and 6°C in January, and 12°C and 23°C in July, and an updated Scheffer Index of 63 (Morris and Wang 2008). Samples were installed in February 2012 and inspected in August or September in subsequent years. Decay ratings were given based on AWPA scale described above.

2.5 Ground Contact Stake Test

Nominal 2x4 inch samples from each species/treatment group were prepared according to AWPA E7-08 (AWPA 2010). Samples were installed at FPInnovations' test site within the Petawawa Research Forest near Chalk River, Ontario. This test site has annual precipitation of 822 mm with mean daily minimum and maximum temperatures of -18°C and -7°C in January, and 13°C and 25°C in July, and an updated Scheffer Index of 48 (Morris and Wang 2008). The soil is a dark brown loam to 9 cm, a light brown loam to 18 cm, and coarse sand below. The soil pH is 6.0 at the surface and 5.4 at a depth of 9 cm. The average moisture-holding capacity of the soil is 25%, with a grassy ground cover. There are areas where soil inhabiting, strand-forming, wood-rotting basidiomycetes, including *Leucogyrophana pinastri*, *Tapinella atrotomentosa*, *Hypholoma fasciculare*, *Serpula himantioides*, and *Oligoporus balsameus* are very active. Samples were installed in October 2011 and inspected annually for decay based on the AWPA scale described above.

3. Results and Discussion

3.1 Laboratory Decay Testing

The weight loss of southern pine sapwood blocks exposed to *P. placenta* that were removed from test was consistently greater than 50% after nine weeks of incubation. Those exposed to *G. trabeum* passed the 50% mark after ten weeks of incubation.

As summarized in Table 1, the southern pine sapwood control, as well as the unmodified hemlock, fir and spruce were highly susceptible to decay by both fungi. Hemlock modified at 190°C was classified as moderately resistant to both fungi. Fir modified at 190°C was classified as non-resistant to *P. placenta* (though just above the cut off for moderately resistant), and moderately resistant to *G. trabeum*. Hemlock modified at 212°C was classified as resistant to both fungi, while fir was classified as moderately resistant to *P. placenta* and resistant to *G. trabeum*. Spruce modified at 190°C was moderately resistant to both fungi, while spruce modified at 212°C was resistant to both fungi. The western redcedar reference was on the boundary between resistant and highly resistant for *P. placenta*, and highly resistant to *G. trabeum*. It should also be emphasized that the test method used did not include leaching, weathering, or detoxification prior to exposure to decay fungi.

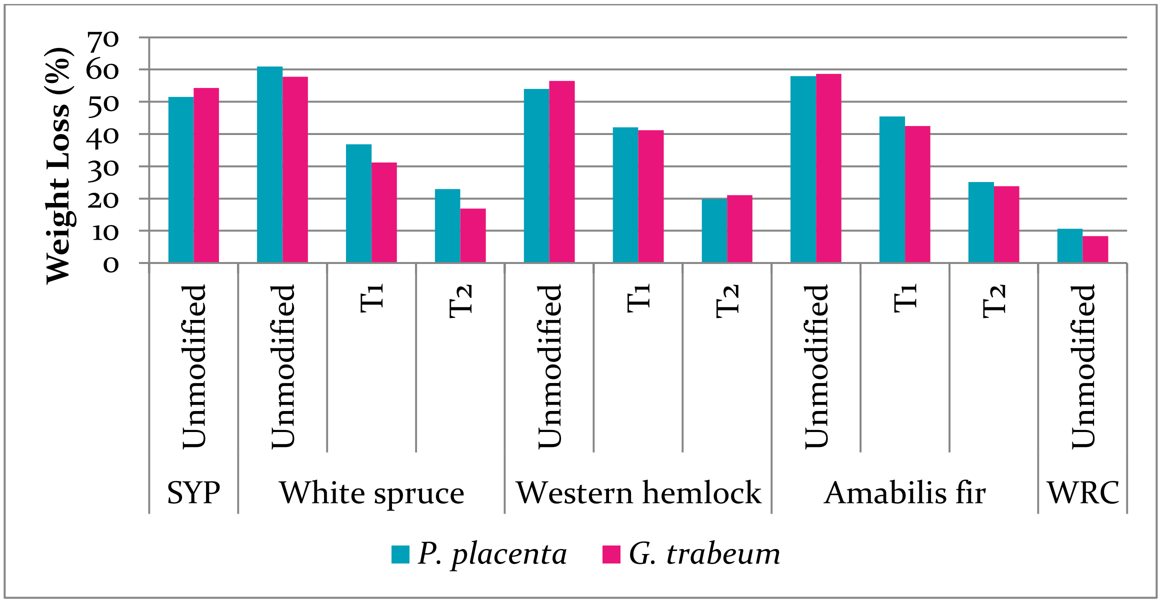

Figure 1: Weight loss in thermally modified samples exposed to two brown-rot fungi

3.2 Accelerated Field Simulation Test

Overall, little decay was observed in samples exposed in the AFS without mycelial inoculation after 5 years (Figure 2). Moderate levels of decay were observed in unmodified spruce and Pacific silver fir, and decay was confirmed in at least one sample from every treatment group, except WRC. WRC extractives have been shown to inhibit basidiospore germination (Stirling *et al.* 2016), which may explain the high resistance of the material in this test where there is no weathering to break down extractives on the wood surface. A recent decking decay test using Pacific silver fir found average decay ratings of 9.3 after five years (Stirling and Wong 2018). In this AFS test Pacific silver fir was substantially more decayed after five years, indicating a considerable acceleration of the rate of decay.

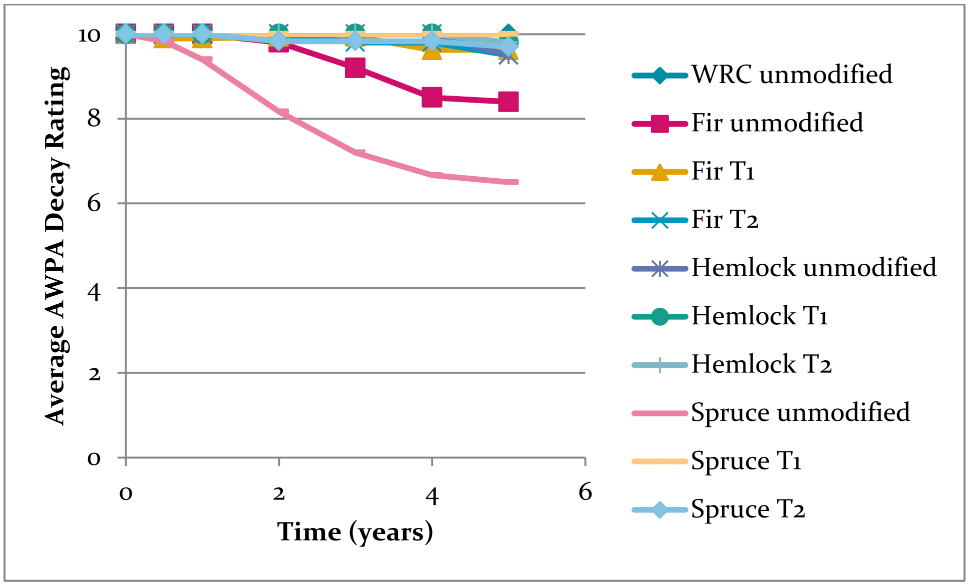

Figure 2: Average AWPA Decay Ratings of Materials Exposed in the Accelerated Field Simulator with only Spore Inoculum

Decay was much more rapid in samples exposed to mycelial inoculum (Figure 3). After five years of exposure, substantial decay, including several failures, was observed in unmodified Pacific silver fir. Unmodified hemlock and spruce had the next highest extent of decay, followed by the T1 modifications, the T2 modifications, and the WRC reference. The lowest decay rating observed in WRC was a 9, indicating the presence of small pockets of decay. In contrast, ratings of 8 or lower were observed in some of the T2 modified samples of each species. These data show that thermal modification improves decay resistance in these species under the conditions of this test; however, WRC was still more resistant to decay.

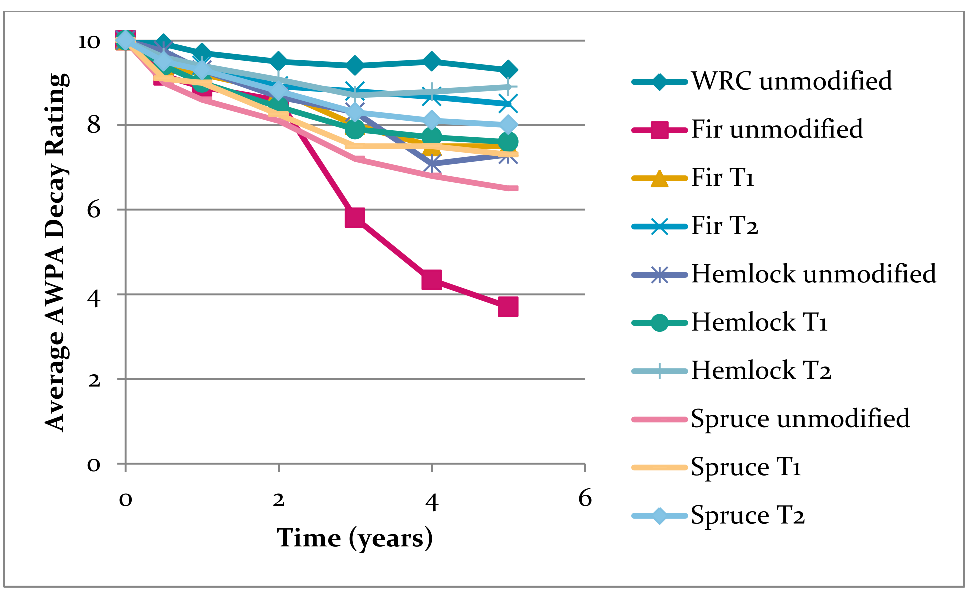

Figure 3: Average AWPA Decay Ratings of Materials Exposed in the Accelerated Field Simulator with Mycelial and Spore Inoculum

3.3 L-Joint Test

The extent of decay in the L-joint test was similar to that observed in the AFS test with mycelial inoculation (Figure 4). However, a greater species effect was observed in this test. Hemlock and Pacific silver fir were more heavily decayed than spruce, regardless of whether the material was modified or not. The fluctuating moisture conditions of this field test would have made the sorption properties of the materials more determinate of decay performance. Consequently the unmodified hem-fir, which likely would have been wetter for longer, was more decayed. There was no evidence of decay in any of the WRC samples, which is also known for its low equilibrium moisture content (Stirling and Morris 2006).

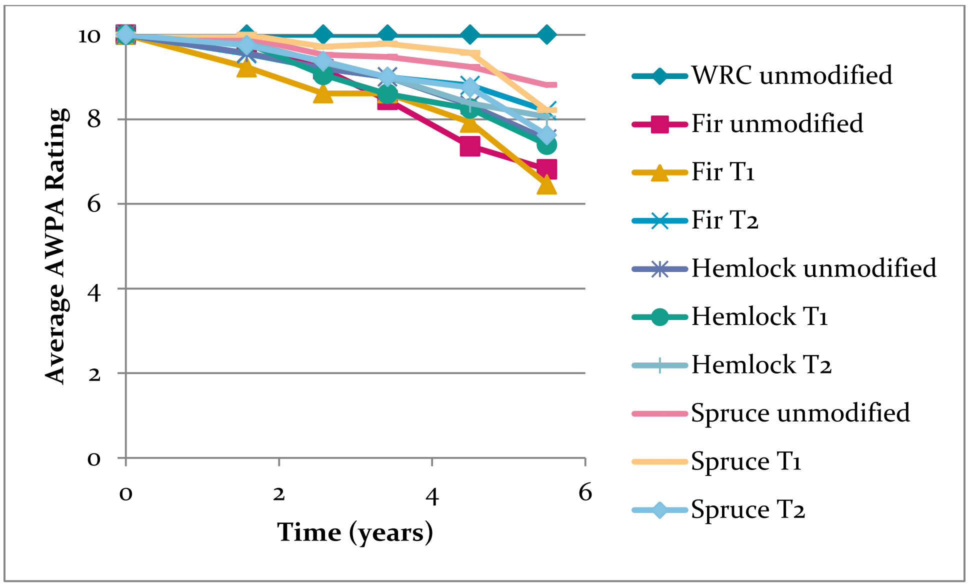

Figure 4: Average AWPA Decay Ratings of Materials Exposed in AWPA E9 L-Joint Test

3.4 Ground Contact Stake Test

Thermally modified wood is generally not recommended for use in ground contact. Nevertheless, it was evaluated in a stake test to gain a fuller understanding of its decay resistance (Figure 5). After five years in test, decay was advanced in most samples. Hemlock modified at the higher temperature, spruce modified at both temperatures, and WRC were among the best performing groups, however the average AWPA ratings were 7 or less. In contrast, wood treated with ACQ and CA-B to CSA O80 standards and exposed at the same site at the same time were largely sound after 5 years (Morris *et al.* 2016).

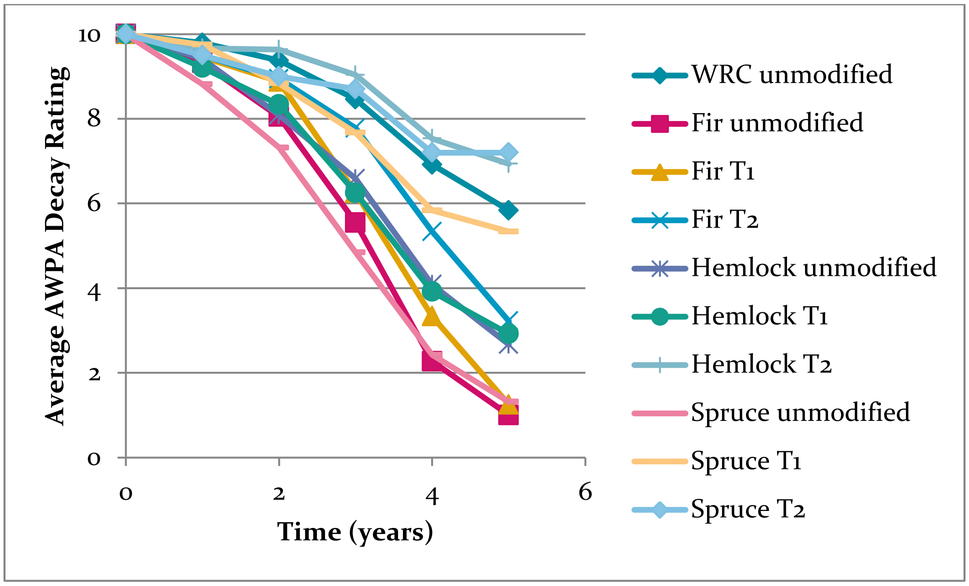

Figure 5: Average AWPA Decay Ratings of Materials Exposed in AWPA E7 Stake Test

4. Conclusions

Thermal modification can improve the decay resistance of western hemlock, Pacific silver fir, and white spruce, with higher temperature modifications providing greater decay resistance. However, in above- ground applications it was not as decay resistant as WRC. In ground contact, thermally modified spruce and hemlock performed similarly to WRC.

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