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ORIGINAL ARTICLE

## Durability of thermally modified Norway spruce and Scots pine in above-ground conditions

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### Abstract

One of the main objectives of thermal modification is to increase the biological durability of wood. In this study the fungal resistance of Norway spruce and Scots pine, thermally modified at 195°C and 210°C, was studied with a lap-joint field test. Untreated pine and spruce and pine impregnated with tributyl tin oxide (TBTO) and copper, chromium and arsenic (CCA) were selected as reference materials. The evaluations were carried out after 1, 2 and 9 years of exposure. After 1 and 2 years of exposure mainly discoloration was detected. Only the untreated pine was slightly affected by decay fungi. There were significant differences in the decay ratings of untreated and thermally modified wood materials after 9 years in the field. While the untreated wood materials were severely attacked by decay fungi or reached failure rating, only small areas of incipient decay were detected in the thermally modified samples. Thermally modified pine was slightly more decayed than thermally modified spruce. The only wood material without any signs of decay was CCA-treated pine, since some of the TBTO-treated pine samples were also moderately attacked by fungal decay. The results of the lap-joint test had a good correlation with mass losses in a laboratory test with brown-rot fungi.

**Keywords:** *Biological durability, brown rot, decay, discoloration, Norway spruce, Scots pine, thermal modification.*

### Introduction

One of the main objectives of thermal modification is to increase the biological durability and dimensional stability of wood. Thermal modification changes the chemical composition of wood, thereby altering the appearance and the physical and biological properties of the wood. In the past two decades, the biological durability of thermally modified wood has been widely studied, mainly in laboratory conditions, and some methods based on elevated temperatures have been found to be quite effective in increasing the durability of wood against biological decay. For instance, Tjeerdsma *et al.* (2000) investigated the resistance of radiata pine, Scots pine, Douglas fir and spruce treated with the PLATO process at 160–190°C against two Basidiomycetes and soft-rot fungi and bacteria in a laboratory test and found a considerable improvement in durability compared with untreated wood materials. The degree of improvement varied between wood

species. The PLATO process principally consists of two stages, hydrothermolysis and dry heat treatment, with an intermediate drying operation. There are also several publications about the improved durability of wood that has been thermally modified according to the principles of the retification process under a nitrogen atmosphere (Hakkou *et al.*, 2006; Mburu *et al.*, 2006, 2007; Lekounougou *et al.*, 2009; Šušteršič *et al.*, 2010) and with the oil–heat treatment (OHT) process in an oil bath (Sailer *et al.*, 2000). Previous studies assessed the decay resistance of the sapwood and heartwood of Scots pine and Norway spruce that have been thermally modified at 170–230°C using the ThermoWood® method against soft and brown rot fungi, and found a good correlation between the thermal modification temperature and decay resistance (Metsä-Kortelainen & Viitanen, 2009). The ThermoWood® method is based on heating the wood material for a few hours at high temperatures above 180°C under normal pressure while protecting it with water vapour. The

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Table I. Decay rating.

Rating	Description	Definition
0	Sound	No softening or weakening of the wood
1	Moderate attack	Small areas of decay (softened, weakened wood); typically not more than 3 cm <sup>2</sup>
2	Severe attack	Marked softening and weakening of the wood typical of fungal decay; distinctly more than 3 cm <sup>2</sup> affected
3	Failure	Very severe and extensive rot; joint member(s) often capable of being easily broken

positive effects of different types of thermal modification on the biological resistance of several wood species in laboratory conditions are also reported in Viitanen *et al.* (1994), Viitaniemi (1997), Tjeerdsma *et al.* (1998), Kamdem *et al.* (2002), Gosselink *et al.* (2004), Boonstra *et al.* (2007) and Welzbacher *et al.* (2007). As concluded, the improvement in biological durability definitely depends on wood species, wood part (sapwood/heartwood), decay fungus, thermal modification method used and especially the intensity of thermal modification, which usually depends on the thermal modification temperature and time.

The biological durability of thermally modified wood has been assessed in many investigations using laboratory tests. However, the fungal resistance of thermally modified wood in ground contact and especially in above-ground contact field tests has been less studied. Welzbacher and Rapp (2005, 2007) investigated the biological durability of thermally modified wood industrially produced by different European suppliers with an EN 252 test in ground contact. They found that thermal modification improved natural durability in ground contact compared with untreated Scots pine sapwood; however, the rate of decay of the differently modified materials started to increase significantly after 3 years of exposure and the samples were attacked predominantly by white rot. Thermally modified samples were classified after 5.5 years of exposure only into the natural durability classes slightly durable (DC 4) or not durable (DC 5), and the authors concluded that thermally modified wood appears to be unsuitable for ground contact applications. In the same research, the durability of thermally modified wood above ground was evaluated by means of a double-layer test, in which some visible signs of decay were found only from one thermally modified material after 5.5 years of exposure (Welzbacher & Rapp, 2007). Edlund and Jermer (2004) also tested

thermally modified Scots pine and Norway spruce with an EN 252 and a ground proximity multiple layer test and after 2 years no visible signs of decay were detected. In the multiple-layer test, thermally modified wood seemed to be less susceptible to discolouring organisms than untreated wood.

Therefore, thermally modified wood is not recommended for use in ground contact. It is used extensively in applications without ground contact, such as in the decking and claddings of buildings. For this reason, in this study, the fungal resistance of thermally modified Norway spruce and Scots pine was investigated with a lap-joint test in the field. The wood material was thermally modified at temperatures corresponding to those used in the industrial production of thermally modified wood. The results were compared with those for untreated spruce and pine samples and impregnated wood materials.

## Materials and methods

For the horizontal lap-joint experiments carried out according to ENV 12037 (CEN, 1996), kiln-dried Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) planks produced in south-eastern Finland were selected. The surfaces of the planks were sawn and their dimensions were 50 × 100 mm<sup>2</sup>. The selection criteria were small variation in the width of the year rings and good quality of the sawn timber and, in addition, that the planks had not been floated, water stored, or chemically treated or steamed. Part of the planks was selected for the thermal modifications, which were carried out under accurate conditions under steam at YTI Research Centre in Mikkeli, Finland. Two thermal modifications were carried out at 195°C and 210°C using the ThermoWood® method developed at VTT. The duration of thermal modification at the target temperature was 3 h in both test runs. The

Table II. Discoloration rating.

Rating	Description	Definition
0	No discoloration	No evidence of discoloration caused by micro-organisms
1	Slight discoloration	Slight discoloration and/or some individual blue-stained spots
2	Distinct discoloration	Distinct discoloration, in groups of spots, streaks and/or patches of continuous staining
3	Total discoloration	Dark discoloration of entire surface area

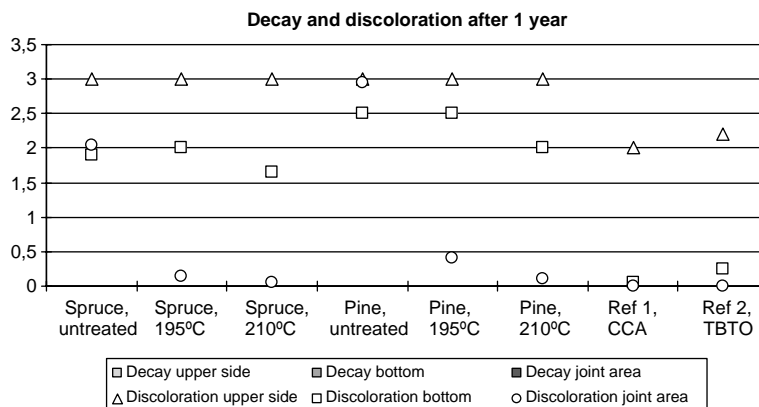


Figure 1. Decay and discoloration of the samples after 1 year of exposure. CCA = copper, chromium and arsenic; TBTO = tributyl tin oxide.

remainder of the spruce and pine planks was left untreated for use as reference material. In addition, Scots pine impregnated according to ENV 12037 (CEN, 1996) with tributyl tin oxide (TBTO) and copper, chromium and arsenic (CCA, class AB) was selected for the experiments.

Ten replicate specimens were prepared from each test material. The test covered eight different wood materials; therefore, the total number of test specimens was 80. The height of the specimens was 38 mm and the width 85 mm, and the length of specimen pairs was 300 mm with an overlapping close-fitting part at mid-length of 60 mm. The end grain surfaces of the specimens were sealed with weatherproof polyurethane sealant and the two joint members were fixed together with two cable straps. The specimens were then installed horizontally on purpose-designed exposure racks located approximately 1 m above ground level with the pith face downwards, at the test field of Otaniemi in southern Finland. The exposure started in November 2001 and the discoloration and decay of the specimens

were inspected separately after 1, 2 and 9 years, in accordance with the grading system presented in Tables I and II. The grading system was adapted from rating schemes in ENV 12037 (CEN, 1996) and EN 152 (CEN, 1984). Discoloration was evaluated visually and decay was inspected with a knife to reveal softened areas in the grading. In addition to investigating the differences between the selected materials, attention was paid to the suitability of the test method for modified wood, because the lap-joint method was originally developed for determining the relative protective effectiveness of wood preservatives.

## Results and discussion

Lap-joint specimens were inspected in November 2002, October 2003 and May 2010. The results for the development of discoloration and decay after different exposure times are presented in Figures 1–3. The results for the upper sides, bottom sides and joint areas of the specimens are presented separately.

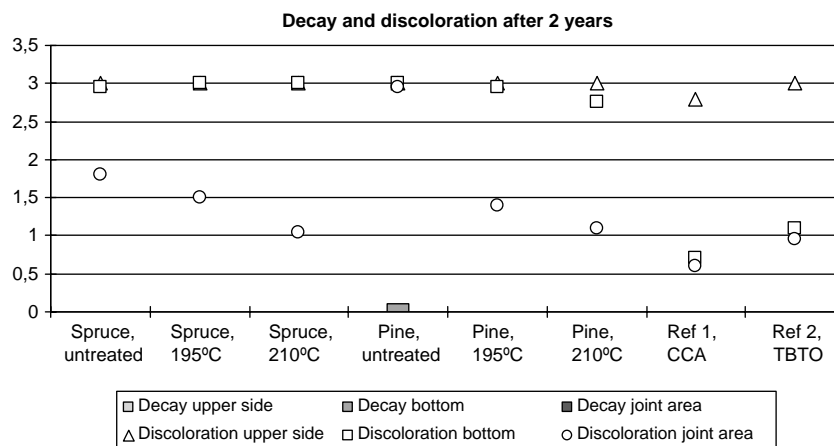


Figure 2. Decay and discoloration of the samples after 2 years of exposure. CCA = copper, chromium and arsenic; TBTO = tributyl tin oxide.

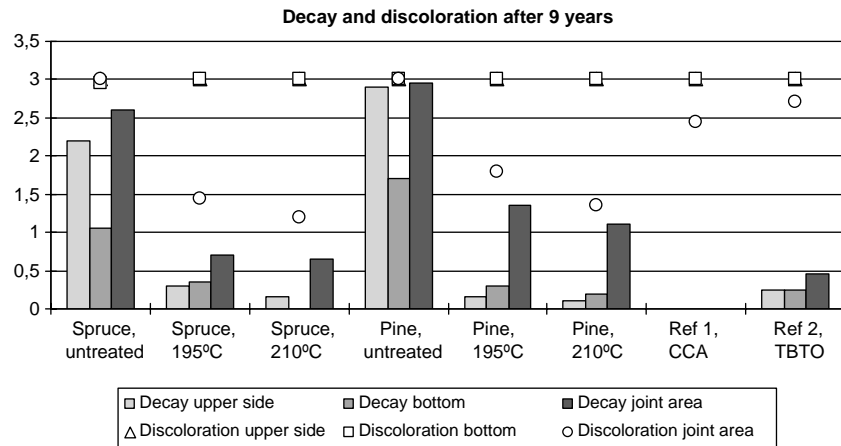


Figure 3. Decay and discoloration of the samples after 9 years of exposure. CCA = copper, chromium and arsenic; TBTO = tributyl tin oxide.

In general, the upper sides of the specimens were full of discoloration after 1 year in the field (Figure 1). Only the upper sides of the specimens treated with wood preservatives were not fully discolored. The bottom sides and joint areas were less discolored than the upper sides in all of the cases after the first evaluation. Thermal modification decreased the discoloration in the bottom sides and especially in joint areas. After 2 years of exposure, the difference between the discoloration of the upper sides and bottom sides was no longer significant, with the exception of impregnated samples (Figure 2). The joint area of untreated pine was also full of discoloration. All of the upper sides and bottom sides of the specimens were entirely discolored after 9 years in the field (Figure 3). In addition, the joint areas of the untreated spruce and pine were full of discoloration, as were the pressure-treated reference samples in practice. Thermal modification significantly decreased the discoloration of both wood species in the joint areas, which is in agreement with Edlund and Jermer (2004).

The first minor signs of decay were detected in untreated pine after 2 years of exposure in the field. Blom and Bergström (2006) ended up with the same type of results after testing Scots pine and Norway spruce in the field in above-ground conditions during 2 years: it seems that a longer period of exposure is needed to detect any decay damages in the wood material. After 9 years of exposure, highly significant differences in decay rating were discovered (Figure 3). In general, the joint areas of the specimens were mostly decayed. In addition, the upper sides and the bottom sides of the untreated spruce and pine samples were severely attacked by fungal decay. Both brown and white rot were detected. Most of these untreated wood samples and especially the pine samples reached failure rating and were full of decay and easily broken with gentle touching. As concluded, thermal modification improved substantially the fungal durability of both wood species. Thermally modified pine samples were somewhat more decayed than the comparable spruce samples. Thermal modification at 210°C

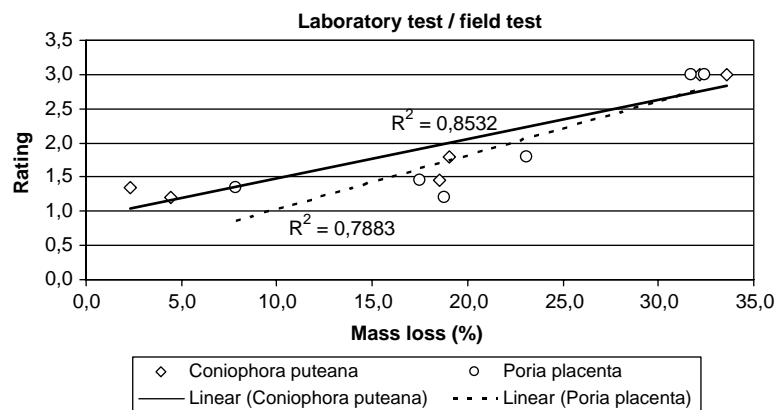


Figure 4. Correlation between mass loss in the laboratory test and rating of decay in joint areas in the field test. (Laboratory test data from Metsä-Kortelainen and Viitanen, 2009.)



Figure 5. Spruce samples (from the left: untreated, thermally modified at 210°C and 195°C) after 9 years of exposure. The upper and bottom sides of the specimens are at the bottom and top of the figure, respectively.

increased decay resistance slightly more than thermal modification at a lower temperature of 195°C. The only wood material without any signs of decay was CCA-treated pine, since some of the TBTO-treated pine samples were moderately attacked by fungal decay.

There has been discussion about the suitability of the present standard tests for evaluating the natural durability of wood and modified wood above ground and in ground contact. Råberg *et al.* (2005) concluded that accelerated tests should be used to



Figure 6. Pine samples (from the left: untreated, thermally modified at 210°C and 195°C) after 9 years of exposure. The upper and bottom sides of the specimens are at the bottom and top of the figure, respectively.



Figure 7. Pine samples [from the left: untreated, tributyl tin oxide (TBTO) and copper, chromium and arsenic (CCA) treated] after 9 years of exposure. The upper and bottom sides of the specimens are at the bottom and top of the figure, respectively.

complement long-term field tests and that laboratory tests are good as screening tests to obtain a first opinion about a new species or treatment. Thermally modified wood as well as acetylated or furfurylated wood should be regarded as a new wood species with improved natural durability (Jones *et al.*, 2003). However, to determine the performance of modified wood, the standards and techniques currently used for assessing the preservative-treated wood are used, especially in the field. In our earlier study, the resistance of thermally modified Norway spruce and Scots pine against brown-rot fungi *Coniophora puteana* and *Poria placenta* were investigated with a mini-decay test (Bravery, 1979; Metsä-Kortelainen & Viitanen, 2009). The results were classified into durability classes according to CEN/TS 15083-1 (CEN, 2005). After 10 weeks of incubation, all of the sapwood samples of untreated spruce and pine were classified into the durability class not durable (DC 5), while the samples thermally modified at temperatures of 190°C and 210°C were classified in almost all cases into the classes moderately durable or slightly durable (DC 3–4) and very durable or durable (DC 1–2), respectively. The correlations between the mass losses after 10 weeks of incubation in the earlier laboratory test and the decay rating of the joint areas after 9 years of exposure in the lap-joint test of this study of untreated and thermally modified (at 190–195°C and 210°C) sapwood of spruce and pine are presented in Figure 4, where the samples thermally modified at 190°C and 195°C are regarded as having been treated at the same thermal modification temperature. The correlation is quite

high, especially with the results of the laboratory test with *C. puteana*. This indicates that a simple and quick laboratory test may give preliminary results concerning fungal durability in above-ground or use class 2–3 conditions. However, the laboratory tests only measure the decay damage in the wood, compared with field tests where the effect of the weather (rain, sunlight) on the performance of the wood can also be evaluated.

As a general discussion, it has to be mentioned that the discoloration of wood is partly a natural phenomenon as a consequence of ultraviolet light and it cannot be directly classified as a defect. However, in this test, the presence of blue stain was confirmed and green algae, lichen, *Ditiola radicata* and *Dacrymyces stillatus* fungi were also detected, particularly on the surfaces of the untreated and thermally modified samples. The bottom sides of the TBTO-treated samples were covered in mould. Most of the wooden samples were also full of cracks after 9 years of exposure; therefore, the strength and visual appearance of the samples decreased too (Figures 5–7). Both thermally modified and untreated wood rapidly turned grey as a result of exposure to sunlight. This is in agreement with Jämsä et al. (2000), who studied coated thermally modified wood in the field. Jämsä et al. (2000) concluded that the cracking of the thermally modified wood without a coating was at the same level as that of untreated wood despite the lower moisture content of the thermally modified wood. The weather resistance of thermally modified wood can be improved with commercial coatings.

In conclusion, the upper and bottom sides of both thermally modified wood and untreated wood discolored after a short exposure of 1–2 years in the field. Part of this discoloration was a consequence of blue stain, while part of it was due to the natural greying of wood. The bottom sides and joint areas of impregnated wood materials were not discolored until an exposure duration of 9 years. Thermal modification significantly decreased the discoloration of the joint areas, which were not exposed to direct sunlight. The samples that had been thermally modified at a higher temperature of 210°C were less discolored than samples modified at 195°C. Pine samples became discolored slightly more quickly than spruce samples.

The first signs of decay were detected in untreated pine after 2 years in the field, and after 9 years most of these samples reached failure rating. In addition, the untreated spruce samples were severely attacked by decay after 9 years of exposure. Thermal modification increased the biological durability of both wood species. In general, spruce was less attacked by decay than pine. The only wood material without

any signs of decay was CCA-treated pine, since some of the TBTO-treated pine samples were moderately attacked by fungal decay. The results of the lap-joint test correlated well with mass losses in a laboratory test with brown-rot fungi.

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