Wood surface protection by wood modification systems and their resistance to mould and blue stain fungi

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ABSTRACT

The development of staining fungi and mould on wooden surfaces is of great economic importance due to loss of surface quality and a negative perception of wood. The aim of this study was therefore to investigate the resistance of modified wood surfaces to mould and blue stain fungi under different climatic conditions; outdoors and in a controlled environment, and furthermore study the fungal behaviour by modelling the accumulation of fungal growth and identify the effects of exposure time, wood treatment, cardinal direction and location. Thermally modified Scots pine, acetylated Scots pine and dimethyloldihydroxyethyleneurea treated Scots pine (DMDHEU), two references substrates (CCA and Cu preservative treated Scots pine) and untreated Scots pine were exposed outdoors in identical test setup in Göttingen, Germany, and Ås, Norway, and in a controlled laboratory environment. The laboratory fungal test was carried out according to BS 3900 Part G6. The outdoor test period was 10 months; July 2012 to May 2013, and the mould growth was evaluated according to EN 16492. The results showed that there were clear differences between the laboratory test and the outdoor test; acetylated wood had the best resistance to fungal growth of the modification systems in the laboratory test, but the results was opposite for the outdoor tests. The fungal discoloration went faster in Ås than in Göttingen. Ordinal logistic regression was used to fit the data, and the full model predicting the mold rating was a function of the explanatory variables; wood substrate, cardinal direction, location and exposure time. The model also included interaction effects. All factors contributed significantly and wood substrate, exposure time and location contributed the most.

INTRODUCTION

Different wood modification methods, partly available on the market nowadays, have been in the focus of scientific research the last years. Research has proved that modified wood becomes considerably more resistant against degrading fungi (basidiomycetes, soft rots) and a better dimensional stability. However, modified wood still seems to be degraded by UV-light and by surface moulds and stains. The development of staining fungi and mould on wooden surfaces is of great economic importance due to loss of surface quality and a negative perception of wood.

Fungi causing discoloration of wood are generally described as staining fungi, and those growing superficially on wood are called moulds (Eaton and Hale 1993). The discoloration is often caused by the production of fungal melanin (Butler and Day 1998). Staining fungi live on nutrients in the parenchyma cells of the sapwood. They do not cause any cell wall degradation, therefore the strength properties are not influenced (Liese and Schmid 1961, Grosser 1985, Zink and Fengel 1988, Eaton and Hale 1993). Staining fungi and moulds are able to grow in wide temperature and moisture ranges. High relative humidity (RH), uptake of rainwater and sorption of moisture under outdoor weathering conditions are the main risk factors for an infestation of blue stain fungi and surface moulds.

Research has shown that modified wood does not necessarily perform better than unmodified wood regarding surface mould growth (Wakeling *et al*. 1992, Beckers *et al*. 1994, Jämsä *et al*. 2000, Ahola *et al*. 2002, Nienhuis *et al*. 2003, Gobakken and Westin 2008, Gobakken and Lebow 2009). There are several indications that acetylated wood does not resist colonisation and growth of staining fungi better than non-acetylated wood (Beckers *et al*. 1994, Wakeling *et al*. 1992). Acetylated wood has even in some studies been found to be more susceptible to staining and mould fungi (Gobakken and Lebow 2010, Gobakken *et al*. 2010) than other comparable wood substrates. Pfeffer *et al*. (2011) reported that DMDHEU reduced, but did not prevent, fungal growth in an eight weeks laboratory test with the blue stain fungus *Aureobasidium pullulans*. Also previous work has indicated that treatments with DMDHEU and siloxanes may restrict but not prevent an infestation of blue stain during outside weathering (Xie *et al*. 2005, Donath 2004). Thermally treated wood is generally believed to be equally susceptible to surface moulds and blue stain fungi as untreated wood (Boonstra 2007, Jämsä *et al*. 2000, Ahola *et al*. 2002), but in some studies thermally treated wood have been reported to perform better than untreated wood (Rep *et al*. 2010).

Even if several studies on modified wood, moulds and blue stain fungi have been performed, more knowledge is needed to identify the main influencing factors causing the biological growth on the various substrates. The aim of this study was therefor to investigate the resistance of modified wood surfaces to mould and blue stain fungi under different climatic conditions; outdoors and in a controlled environment. Furthermore, we wanted to study the fungal behaviour by modelling the accumulation of mould and blue stain fungi on the surfaces, and thereby identify the effects of exposure time, wood treatment, cardinal direction and location.

EXPERIMENTAL

Materials

Table 1: Wood substrates

	Description	**Treatment**	**Producer**	**Label**
References	Untreated			Un
	Preservative treated with copper chromium arsenate	Retention level 5 kg/m³	NFLI*	CCA
	Preservative treated with a copper based material	Retention level 12 kg/m³	NFLI*	Cu
Modified wood	Thermally modified wood	Thermo D	Scandinavian Fine Wood	TM
	Acetylated wood	WPG 21%	Titan wood	AC
	DMDHEU treated wood	1.3M concentration	UniGö**	DMDHEU

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The same material was used for both the laboratory test and the outdoor tests. The specimens were made of Scots pine sapwood (*Pinus sylvestris* L.) and were modified or treated as described in Table 1. The specimens were produced from nine trees and all trees were from the same stand representing dominate, co-dominant and supressed trees.

Laboratory test – controlled environment

The laboratory fungal test to assess the resistance against mould and staining fungi was carried out according to BS 3900 Part G6 (1989). The specimens had a size of 100 x 50 x 10mm (long x radial x tangential). The test specimens were named, scanned, drilled a hole in and conditioned at 20 °C and 65 % RH for 7 days before sprayed with the mixed spore suspension. All specimens were inoculated with a mixed spore suspension of *Aspergillus versicolor, Aureobasidium pullulans, Cladosporium cladosporioides, Penicillium purpurogenum, Phoma violaceae, Rhodotorula rubra, Stachybotrys chartarum, Sudowia polyspora* and *Ulociadium atrum*. Afterwards the samples were stored in the test tank. The bottom of the tank was covered with water (50 mm high) and the test panels were hanging vertically from the ceiling with a distance of approximately 25 mm. The temperature inside the test tank was above 25 °C during the whole test period. After 14 days test duration, the specimens were visually evaluated according to the rating scale described in Table 2. After 28 days of incubation were the test specimens finally evaluated.

Table 2: Classification of fungal growth

Classification	Description
0	No fungal growth
1	< 20 % fungal growth on the surface
2	20-50 % fungal growth on the surface
3	50-75 % fungal growth on the surface
4	> 75 % fungal growth on the surface

Outdoor testing – two locations

The specimens were exposed vertically towards the north and the south, and horizontally in identical test setup in Göttingen, Germany, and Ås, Norway (Figure 1 and 2). The test period was 10 months; July 2012 to May 2013. The specimens had a size of 200 x 50 x 10mm (longitudinal x tangential x radial). The mould growth was evaluated according to the A3 scale defined in the standard prEN 16492 (2012) going from 0 to 4 (where 0=no growth, 4=more than 50% up to 100% growth), and this make the response value ordinal. The mould growth was evaluated twice; September 2012 and May 2013.

Figure 1: Test set up, vertically exposed samples

Figure 2: Test set up, horizontally exposed samples

Statistical methods and modelling

The specimens were exposed over a period of time and measured at time intervals with counts at each time interval indicating performance over the life of the experiment. Ordinal responses can be modelled by fitting a series of logistic curves to cumulative probabilities. When the response variable is ordinal, it is possible to fit the cumulative response probabilities to a logistic function of a linear model using maximum likelihood. Ordinal logistic regression was used to fit the data and the model development was carried out where mould rating was a function of wood substrate (*wsub*), exposure time (*ext*), cardinal direction (*cardir*) and location (*loc*):

$$Probability\ (mould\ rating\ 0-5) = \frac{1}{1+e^{-(\beta_0+\beta_1 wsub\ +\beta_2 ext+\beta_3 cardir\ +\beta_4 loc)}}$$

where:

wsub = wood substrate (U, CCA, CU, TM, AC, DMDHEU)
ext = exposure time (months; 3 and 10)
cardir = cardinal direction (south, north, horizontally)
loc = location (Göttingen and Ås)

The models were based on a total of 360 observations performed on 180 samples. The statistical analyses were conducted with JMP, version 10.0 (SAS Institute Inc. 2012).

RESULTS AND DISCUSSION

Laboratory test – controlled environment

All specimens were evaluated after 14 and 28 days test duration. The development of fungal growth is shown in Table 3.

Table 3: Development of fungal growth (averages)

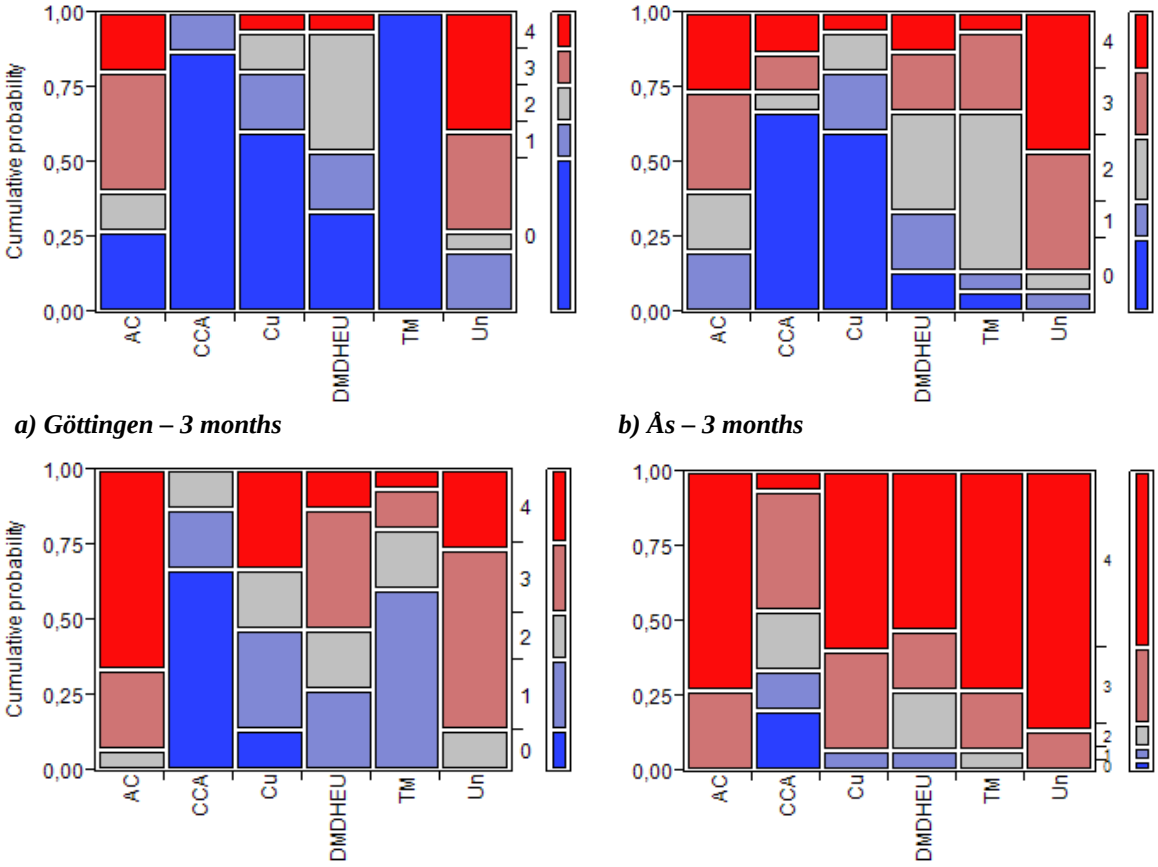
Specimens	Evaluation of fungal growth	
	After 14 days	After 28 days
Un	1.2	3.8
CCA	0.0	0.2
Cu	0.8	1.0
TM	1.2	4.0
AC	0.3	2.5
DMDHEU	1.0	3.3

The results show that the preservative treated specimens were most resistant against mould and staining fungi. The modified wood specimens varied largely in fungal resistance depending on modification system. Thermal modified wood had a poor resistance to fungal growth. DMDHEU treated wood had a somewhat better resistance to fungal growth, but still had quite poor resistance. AC treated wood had the best resistance to fungal growth, comparing modification systems.

Outdoor testing - two locations

As expected, higher mould ratings were recorded after 10 months exposure compared to 3 months exposure, and all substrates had higher probability of reaching mould rating 4 with increasing time (Figure 3). When comparing wood substrates after 3 and 10 months, highest mould ratings were found on acetylated and untreated wood for both locations. Acetylated wood has also often in other outdoor tests showed to have more mould growth that other substrates (Beckers *et al*. 1994, Gobakken and Lebow 2010, Gobakken *et al*. 2010, Wakeling *et al*. 1992). After 10 months exposure, CCA treated

wood had the lowest mould rating at both locations – and show that chromated copper arsenate is an effective fungicide. Of the modified wood substrates TM showed the lowest mould rating in Göttingen after 10 months and DMDHEU had the lowest mould rating in Ås. The fungal discoloration went faster in Ås than in Göttingen.



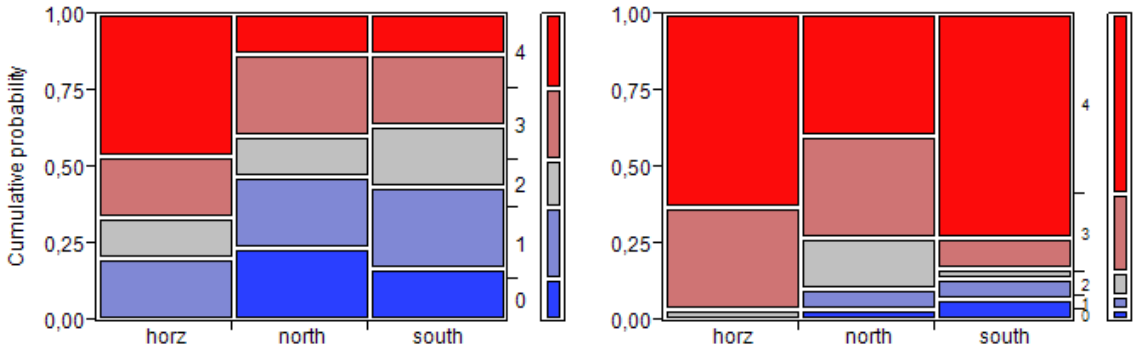
a) Göttingen – 3 months

b) Ås – 3 months

c) Göttingen – 10 months

d) Ås – 10 months

Figure 3: Contingency table showing cumulative probability for mould ratings for the tested wood substrates at 3 and 10 months exposure; Göttingen and Ås.



a) Göttingen – 10 months

b) Ås – 10 months

Figure 4: Contingency tables showing cumulative probability for mould ratings for each of the cardinal directions after 10 months: Göttingen and Ås.
horz=horizontally, north=vertically displayed against north, south=vertically displayed against south

Highest mould ratings were recorded on samples exposed in Ås at both 3 and 10 months. The speed of colonisation was also clearly higher on samples exposed in Ås. In

Göttingen, the horizontally exposed samples had the highest mould ratings after 10 months. In Ås, the samples exposed horizontally together with the samples exposed vertically against the south had slightly higher mould rating than those exposed against north (Figure 4).
Ordinal logistic regression was used to fit the data with the following independent variables; wood substrate (*wsub*; TM, AC, DMDHEU, CCA, Cu and Un), cardinal direction (*cardir*; south – vertically, north – vertically and horizontally), location (*loc*; Göttingen and Ås) and exposure time (exp; 3 months and 10 months). The model also included the following interaction effects; Wood substrate*Exposure time, Wood substrate*Cardinal direction, Wood substrate*Location and Wood substrate*Cardinal direction*Location. The model yielded an R^2 of 0.36. See the test statistics found in table 3.

Table 3: Test statistics for the factors included in the model

Source	Nparm	DF	L-R ChiSquare	p-value
Wsub	5	5	147.502929	<0.0001*
Cardir	2	2	57.1311641	<0.0001*
Loc	1	1	90.654567	<0.0001*
Ext	1	1	136.288584	<0.0001*
wsub x *cardir*	10	10	30.3506835	0.0008*
wsub x *loc*	5	5	40.026893	<0.0001*
wsub x *ext*	5	5	32.5320696	<0.0001*
wsub x *cardir* x *loc*	10	10	29.7482097	0.0009*

* significant p-value

The interactions between the factors cause the internal ranking of the wood substrates to change from location to location and between cardinal directions.
Acetylated wood has in several studies shown not to be resistant against mould and blue stain fungi. This is similar to what we found in the outdoor test. On the other hand we got a complete opposite result in the laboratory test. It is therfore important to compare results from laboratory tests with results from outdoor tests to see if laboratory tests are able to produce realistic performance data. The outdoor test had a longer duration and fluctuations in the climatic factors. This probably caused the complete different ranking of tested substrates compared to the laboratory test.
Acetylated wood, thermally treated wood and DMDHEU treated wood are all susceptible to mould and blue stain fungi – and will outdoors be colonised by fungi and appear with a weather grey surface color. The time until an even weather grey color is achieved will vary due to location, the climate (fluctuation in the climatic factors) and the type of modified substrate. Generally modified wood have better durability (against decay fungi) and dimensional stability than unmodified wood – two very important properties. Further, studies by Xie (2005) and Pfeffer *et al*. (2012) have shown, that the depth of discoloration by staining fungi is much less and superficial in some modified wood. Mould and blue stain fungi on surfaces will probably have to be accepted on uncoated modified wood when used outdoors.

CONCLUSIONS

In the laboratory test acetylated wood had the least growth of mould and staining fungi of the modified wood substrates, but the opposite was recorded for the outdoor test. Thermally treated and DMDHEU treated wood had more or less the same ranking in both studies. The differences between the laboratory test and the outdoor test showed the importance of also testing the application outside, not only in a laboratory. All

factors in the model contributed significantly to the development and growth of moulds and blue stain fungi, but wood substrate, exposure time and location contributed the most. Mould and blue stain fungi will give modified wood substrates a weathered grey surface, and speed of this process is determined by location, climatic factors, type of wood substrate and the interactions between these factors.

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