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RISK ASSESSMENT OF MOULD GROWTH ON SPRUCE WOOD DURING TRANSPORT IN AN INTERMODAL CONTAINER

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ABSTRACT

Microclimatic conditions (relative humidity and temperature) were monitored in a shipment of Norway spruce (*Picea abies*) wood inside an intermodal container on its 66-day transport from Slovenia to Japan. In parallel, the susceptibility of Norway spruce wood to moulding fungi was determined and a dynamic vapour sorption analysis was performed. Considerable moulding developed on specimens that were exposed to a climate with relative humidity above 93%. The results of the laboratory assessment correlated with the observations of mould development in the container. The relative humidity in the container was below 93%, so there was no mould growth on the transported Norway spruce wood.

Keywords: *Aspergilus sp*., *Penicilium sp*., *Picea abies*, relative humidity, temperature, vapour sorption analysis.

INTRODUCTION

Wood is one of the most important materials and, as such, part of global trade. For example, forest products, as a group, the 8th most valuable transported goods, following fuels, transport equipment, office and telecom equipment, chemicals, iron and steel, and clothing (FAO 2007), what clearly indicates the importance of the wood trade. Wood, as bulk material, is frequently transported by ship, either in containers or in the hold of a general cargo vessel. Even more, it is one of the most transported materials. Conditions in containers and in a ship's hold can be favourable for the development of moulds (Baecker *et al.* 1995, Welling and Lambertz 2008). Up to our best knowledge, we were not able to find published data available on microclimatic conditions in containers during long shipments.

There are quite some information available concerning favourable conditions for the development of mould fungi on various materials (Zabel and Morell 1992; Eaton and Hale 1993). Growth of the moulds was studied on growth on stored and blocked wood, on piled wood chips, within buildings, on wallpapers, silicone in bathrooms … Generally, moulding is favoured by high substrate moisture (water activity 0,9 – 1,0), high air humidity around 95%, warmth and insufficient ventilation (Schmidt 2006). Critical relative humidity for the development of moulds on Scots pine sapwood as well as spruce wood is between 75% and 80% (Viitanen and Ritschkoff 1991, Johansson *et al.* 2012). However, critical

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relative humidity depends on temperature and environment, as well as wood species.

Since favourable conditions for mould growth during transport of wood are hard to avoid, wood is frequently protected with biocides based on boric acid, quaternary ammonium compounds, IPBC and/or fenpropimorph, among other. (Unger *et al.* 2001). These active ingredients are used in the global timber trade and are key constituents in the anti-sapstain products on the market. However, some end users require wood free of biocides and do not allow dipping and similar biocidal treatments. The aim of this short study was to elucidate whether microclimatic conditions in containers are favourable for the development of mould fungi on spruce wood and to determine favourable conditions for moulding on technically dry Norway spruce in laboratory.

MATERIALS AND METHODS

The moulding experiment in laboratory was performed on spruce wood (*Picea abies*). All specimens were made from the single oven dry plank. Wood was technically dry with initial MC of 12%. Five parallel specimens (6,5 cm × 2,5 cm × 0,5 cm) that were positioned in a polyethylene container (V = 1 L), so there was 50 specimens used for moulding experiment. Half of the volume in the container was occupied by a glass jar filled with a saturated salt aqueous solution that produce a target relative humidity (RH) (Palumbo *et al.* 2016). The solutions used to achieve each target RH were: NaCl (75% RH), NH_4Cl (80% RH), KCl (85%), Na_2CO_3 (92% RH) or distilled water (98% RH) (Table 1). Theoretical RH values in the containers were verified with RH sensors. The values reported in Table 1 are the actual, measured RH values. It should be considered, that the containers were not completely sealed, what enables oxygen diffusion. Prior to the exposure, the samples were not sterilised but they were exposed to natural climate for three weeks, so the samples were naturally infested with the spores form the environment. It should be considered that the respective laboratories are located quite close to the forest what ensures presence of spores in the air. The containers were placed in climate chambers maintained at 20 °C or 25 °C. Moulds development was monitored for ten weeks on a weekly basis. Ten weeks represents the duration of transport between Mediterranean European and nortern Japanese ports. The percentage of the wood surface overgrown by mould growth was estimated weekly on all surfaces. Intensity of the moulding was not determined.

Moisture content (MC) of spruce wood at respective RH, was determined with dynamic vapour sorption (DVS) analysis on Intrinsic 2 DVS analyser (Surface Measurement Systems). DVS analysis was performed on parallel specimens (5,0 mm × 5,0 mm × 2,5 mm). Adsorption and desorption curves were determined at 5% intervals from 70 to 95% RH on an Due to technical limitations, we were not able to determine MC at 98% RH. Experiment was repeated three times. The respective analysis was performed to obtain as accurate information regarding the moisture performance of actual material.

A Scanntronik Thermofox data logger, equipped with RH and temperature sensors (Thermo - Hygro - Sensor) was placed in a ship container between the spruce wood specimens. Wood was technically dry, with initial moisture content of 12%. Two sensors recorded the temperature and RH every hour. The container travelled from the port of Koper (Slovenia, 29. 12. 2016) to Tomakomai (Japan, 28. 2. 2017). Travelled times was 66 days, which correspond to the 10 weeks of the moulding experiment performed in laboratory.

RESULTS AND DISCUSSION

Moulding can be an important aesthetic and health problem. RH, wood moisture content, temperature, ventilation, wood species and spore of mould species locally present in the environment, have a considerable effect on the occurrence of mould. However, several results indicate that similar fungal species colonize buildings all over the globe (Khan and Karuppayil 2012). The majority of mould studies have been performed on pine sapwood, which is considered to be one of the most susceptible wood species to fungal infestation reference. Since spruce wood has different performance against moulding than pine wood, our moulding experiment was performed on spruce wood to obtain data that are more reliable. There was no sign of discoloration during the first three weeks of exposure (data not displayed). As expected, moulding increased with increasing RH. Moulding was characterised by presence of fungal hyphae and presence of spores. Visual and microscopy inspection indicates, that the fungi predominately belongs to the species belonging to *Aspergilus* and *Penicilium* species. Only limited mould developed on the specimens exposed in chambers with RH below 83%, regardless of the temperature. Approximately 5% of the surface of the samples that were in containers with 93% RH were covered with mould at both temperatures investigated. Those low values may be due to the low moisture content obtained by 93% – 98% RH (Figure 1). Furthermore, the samples had not been infected artificially. Therefore, the infection power was rather low. The observed mould growth could only come from spores which already infected the wood during sample preparation or from the unsterile containers or salt solutions. Experiments with moist and artificially infected lignocelluloses such as palm wood resulted in 100% surface covering (Bahmani *et al.* 2016). As expected, the strongest moulding developed on samples exposed to RH above 98%. More prominent fungal growth was present on specimens incubated at 20°C than those at 25°C.

Table 1: Influence of temperature and RH on the development of mould on the surface of wood samples incubated for 3 to 10 weeks.

T (°C)	Actual RH (%)	Weeks of exposure							
		3	4	5	6	7	8	9	10
		Percentage of surface covered with mould fungi (%)							
25	75	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5
	79	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	83	0,0	0,0	0,0	0,0	0,0	1,0	1,0	0,5
	93	0,0	0,0	0,0	0,0	2,0	2,5	3,5	4,5
	98	1,0	5,6	5,8	6,4	8,9	11,8	12,7	14,3
20	74	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	82	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	85	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	93	0,0	0,0	0,0	0,0	0,0	2,5	2,5	3,0
	98	9,5	23,0	26,5	37,5	40,2	58,0	72,5	75,5

Figure 1 shows that the Moisture content (MC) of the wood specimens is strongly influenced by the RH. MC, at RH 95% was 21,5% at 90 % RH the MC was 18,3% at RH 85% the MC was 15,8%, at RH 80% the MC was 14,0% and at RH 75% the MC reached 12,5%. These values are in line with literature data (Simón *et al.* 2017).

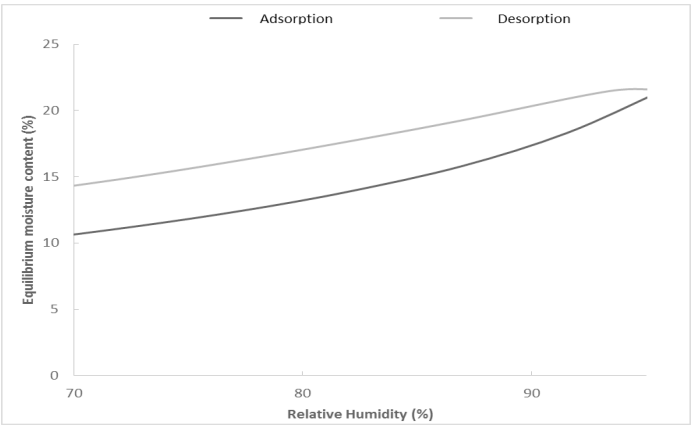

Figure 1: Adsorption and desorption isotherms for spruce wood.

Table 2: Number and percentage of measurements when the relative humidity (RH) or temperature (t) were above a specific threshold in a cargo container driven from port Koper (Slovenia) to Tomakomai (Japan) over the time of 66 days.

RH (%)	No. of RH measurements above the threshold [a]	Percentage of RH measurements above the threshold (%)	t (°C)	No. of temperature measurements above the threshold [a]	Temperature measurements above the threshold (%)
75	882	56	**10**	905	57
79	581	37	**15**	685	43
83	128	8	**20**	469	30
93	1	0	**25**	144	9
98	0	0	**30**	0	0

[a] Based upon 1584 measurements.

The RH and temperature measurements in the container during transport clearly observed that the container travelled from a colder climate to a warmer one and then back to the colder north (Table 2, Figure 2). The lowest temperature (-4,5 °C) was measured at the beginning of the journey. While the highest temperature (25,8 °C) was recorded on the 37th day of the transport. Temperatures were above 10 °C for 57% of the time, and exceeded 20 °C for 30 % of the travel time. In contrast to temperature, RH steadily increased during the transport. For example, RH during the first third of the transport was 70,5%, during the second third 76,9% and in the third period, RH reached 80,5%. Since the container was filled with technically dry timber, with an initial MC around 12%, the dry wood could have acted as a water vapour buffer and absorbed excess water. MC of the wood increased from the initial 12 % to as much as 14% at the end of the transport. Fortunately, these values were still fairly low and no mould was noted.

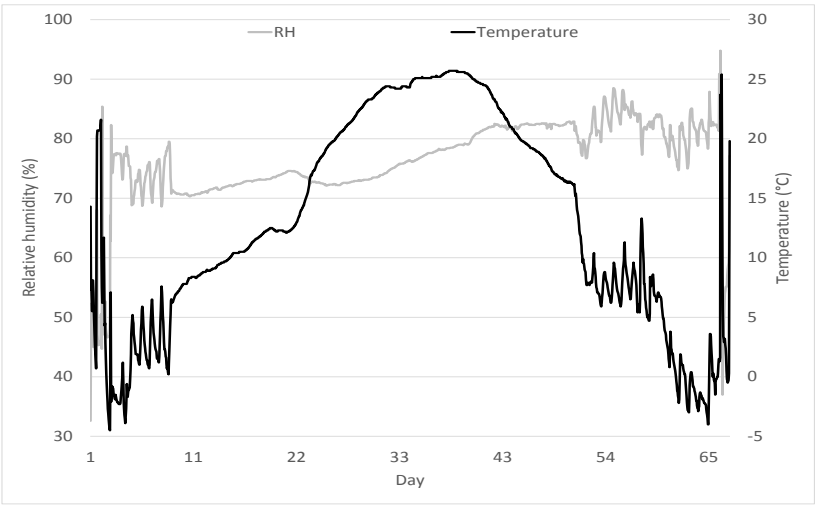

Figure 2: Changes of the temperature and RH in container with wood during transport between Slovenia and Japan.

CONCLUSIONS

Microclimatic conditions (RH and temperature) in a container traveling from Slovenia to Japan were unfavourable for the moulds development on spruce wood. RH was below 83% for 91% of the transport time. But if did RH in the container increased over time; it is likely that a longer transport time would result in moulding. Further test on containers over longer transport periods, during warmer seasons should be performed in the future.

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