EFFECT OF WOOD DENSITY AND CRACKS ON THE MOISTURE CONTENT OF COATED NORWAY SPRUCE (*PICEA ABIES* (L.) KARST.)

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Abstract. A protective coating is often used on the cladding of wooden facades to limit the absorption of moisture. Low wood moisture content (MC) is essential to obtain satisfactory durability performance. Wood density is known to influence the water sorption and crack formation of uncoated wood. However, the effect of density on the aforementioned behaviors of coated spruce is not yet fully understood. Six-years of data on the crack formation and the MC variation of outdoor exposed panels are analyzed in this article. The outdoor test was complemented by a subsequent laboratory experiment, wherein the MC variation was monitored at different depths on the board during artificial water spraying. The aim of this research was to increase the knowledge about how wood density and aging affect the water sorption of coated spruce through the crack formation. The results indicated that wood density had an impact on the overall sorption behavior of coated spruce. Low-density spruce contributed to faster water absorption and desorption processes than coated samples with higher density. However, the observed correlation to density was limited to a condition with an intact coating. High-density characteristics contributed to more crack formation, and the density–sorption relationship reversed with a cracked coating. A cracked coating caused a strong local increase in the MC of the wood at the location of the cracks. Weather-exposed replicates without cracks had a higher MC in the core of the board compared with the value beneath the coating. The higher MC is probably due to the water sorption of the uncoated backside of the panel. Such an occurrence raised awareness for future studies to account for multidimensional sorption behavior from all sides of the panel. The local difference in MC also raises awareness for future studies to investigate local MC variations (as opposed to the global average of the panel) in research on the durability of coated wood.

Keywords: Alkyd, acrylic, durability, moisture absorption, weathering.

INTRODUCTION

Wood is an attractive choice as a renewable resource material. However, it is imperative to maintain low moisture content (MC) to avoid natural degradation from microorganisms, such

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as bacteria and rot fungi (Eaton and Hale 1993). Constructions for outdoor purposes, such as house facades, are particularly exposed, and a coating is often used to limit the absorption of moisture. The moisture sorption behavior of coated wood has been studied extensively (Ahola et al 1999; Ekstedt 2002; Ekstedt 2003; Nejad and Cooper 2011; Van Meel et al 2011; Grüll et al 2013). However, studies on the subject are predominantly limited to the performance of the coating and do not address the relationship between coating performance and wood characteristics.

For Norway spruce (*Picea abies* (L.) Karst.), density is known to affect the water sorption across a wide range of aspects. For example, increasing wood density is associated with a reduced drying rate (Esping 1992), a reduced apparent diffusion coefficient (capillary and cell wall diffusion) (Sivertsen and Vestøl 2010), and a reduced maximum MC at full water saturation. Furthermore, both swelling and shrinkage increase with increasing wood density (Kollmann and Côté 1968). The main aspects behind the density-dependent water sorption behavior are the degree in porosity (ie tracheid lumina) of the wood and the degree in closure of the intercellular pits (Petty 1970). The higher porosity of low-density wood facilitates the water diffusion in the tracheid luminas. Furthermore, coatings do not change the equilibrium MC (EMC) of the wood source, but they affect the sorption rate (Williams et al 2000). EMC is the state where the wood is in equilibrium with the vapor pressure of the adjacent air—ie where the rate of water uptake and water release in the wood is equal. It is therefore assumed that the density-related behaviors of uncoated spruce will influence the behavior of coated wood in a similar way. In other words, density will affect the sorption process in the wood beneath the coating and, as a secondary effect, influence the swelling or shrinkage of the coated wood. The water sorption of coated wood is an interaction between the barrier properties of the coating and the sorption properties of the wood. Several factors influence this delicate interaction. For instance, cracks may affect the barrier property of the coating with increased water exposure. The properties of the coating itself are determined by the specific coating formula. Two coatings made with the same resin might behave very differently depending on other additives. The water-borne coatings are increasing its market because of health and environmental aspects, and two major resin categories for outdoor purposes are the alkyd and the acrylic resin.

The ability to resist crack formation in the coated wood depends on, among other things, moisture-induced volumetric variations (swelling and shrinkage) of the wood in interaction with the dimensional flexibility of the coating. Fatigue during extended weather exposure degrades the coating, and prolonged exposure often contributes to brittleness and crack formations in the coating (Grüll et al 2013).

Wetting the wood surface imposes moisture gradients on the wood, resulting in water diffusion from higher levels at the surface to lower levels in the core. MC is mainly gravimetrically determined, with the resulting value being a volume average of the specimen in question. However, the local MC can be subject to large variations, especially when exposed to cyclic wetting. As such, the global MC of the whole panel is not an ideal measure for assessing the risk of local degradation.

The influence of wood density on moisture sorption and crack formation of coated spruce is not well studied; even less studied is this relation during a natural aging process of coated wood. Therefore, the objective of this work was to monitor the long-term MC behavior of coated spruce during a natural aging process of the samples, with a focus on density effect and crack formation. Furthermore, an in-depth study was made to compare the MC beneath the surface with the core of the coated wood. The aim was to increase the knowledge about how wood density and crack formation affect the water sorption at a different depth of the board, and further improve the durability of coated spruce.

MATERIALS AND METHODS

Wood Material

The wood material used has previously been part of a study by Sjökvist and Blom (2016). Logs of Norway spruce (*P. abies* (L.) Karst.) were selected from two stands in the area of Växjö in southern Sweden, and the sapwood border was marked at the time of felling. After sawing, the planks were dried down in an industrial kiln at a maximum temperature of 70°C to an MC of approximately 17% by oven-dry weight basis. Planed samples free of dead knots, cracks, and resinous streaks were prepared from planks of varying densities, with dimensions of $(375 \pm 2) \times (100 \pm 2) \times (20 \pm 2)$ mm^3 (longitudinal × tangential × radial). Only sapwood material was selected, to prevent any interference of different heartwood and sapwood sorption behavior. After that, the wood material was acclimatized in a climate chamber at 65% RH and at 20°C before applying the coating. The oven-dry density of the replicates was calculated from the acclimatized mass and volume at 65% RH and at 20°C, with an estimated MC of 12%. Wood material was divided into two equal parts to be treated with two types of coating. Each part had 12 replicates (six low-density pieces and six high-density pieces). Table 1 presents low-density samples with an average oven-dry density of 369 (30) kg/m^3 (the standard deviation is in parentheses). Replicates of high-density samples had an average oven-dry density of 491 (48) kg/m^3. In this work, one sample comprised five individual replicates.

Coatings

Twelve replicates were painted with a coating made of acrylic resin (B), and the other 12 replicates were painted with a coating made of an alkyd resin (C). Both coating systems were water borne and pigmented in a red color with the color code S 5040-Y80R. The code is according to the Natural Color System, and the coatings were commercially available at the beginning of the study in 2009. The Swedish Paint and Adhesives Association selected the coatings as representative of the present systems in the Swedish market. The coating formulas were unknown, except for the type of solvent and resin. A brush was used to paint all sides of the wood panels, except for the tangential surface facing the pith of the log (the backside of a house facade panel is normally uncoated in Sweden). After painting, the replicates were stored in a climate chamber of 65% RH and 20°C until a stable mass was achieved. Because the study was carried out as a comparative study within each coating formulas, no uncoated samples were examined.

Methods

The crack formation was assessed once a year in June-August. The length of the cracks was measured with a steel ruler, and all cracks greater than 0.2 mm in thickness were counted. The crack thickness and depth were measured by a feeler gauge. The depth of the cracks was measured at the deepest location.

The MC of the panels was monitored by either mass or local-resistance measurements.

Mass measurements. Mass was gravimetrically determined with an accuracy of 0.1 g at a regular interval of approximately 2 mo at the test field. The MC of the replicate was then calculated relative to the oven-dry density. Each wood-coating combination consisted of five individual replicates, and the sample value was the average of the replicates. MC_m is the average MC defined according to Eq 1. n = the number of

Table 1. Sample information and crack development of the 6-yr, long-term measurements in Part 1.

Sample	Mean density (kg/m^3)	Resin	No. replicates	No. replicates with cracks in June 4, 2015	MC_m (%)	August 29, 2014		June 4, 2015	
						Crack length (mm)	Crack depth (mm)	Crack length (mm)	Crack depth (mm)
Low-dens. B	336 (9)	Acrylic	5	0	19.0 (0.9)	0	0	0	0
Low-dens. C	371 (44)	Alkyd	5	1	18.2 (1.2)	0	0	38 (85)	1.6 (3.6)
High-dens. B	488 (53)	Acrylic	5	2	17.4 (0.5)	26 (58)	1.4 (3.1)	38 (58)	2.6 (3.7)
High-dens. C	493 (53)	Alkyd	5	5	16.5 (0.7)	88 (121)	2.9 (4.1)	252 (148)	6.9 (3.4)

Dens, density; B, acrylic-based coating; C, alkyd-based coating. Standard deviation values in parentheses. MC_m = the mean value of the measurements of the period. Crack information was measured in the test field.

occasions with recorded MC over a subsequent period of time.

$$MC_m = \left(\sum_{1}^{n} MC_n\right)/n \qquad (1)$$

The difference in MC (MC_{diff}) between high-density and low-density samples at each measuring point was calculated according to Eq 2.

$$MC_{diff} = MC_{lowdens} - MC_{highdens} \qquad (2)$$

Local-resistance measurements. The local MC was calculated from the measured electric resistance in the wood. The electrical resistance was measured every 5 min by commercial resistance-type (OmniSense type S-16 sensors, OmniSense LLC, Ladys Island, SC). The custom electrodes were produced from stainless steel (A 304) threaded rods (M2, Ø = 2 mm) with sharp, pointed ends. The electrodes were partially insulated by nonconductive-glued shrink-tubing, leaving only 5 mm of the sharp/pointed end uninsulated. Holes were predrilled before inserting the electrodes, and silicone was applied inside and around the edge of the holes to prevent any water movement along the electrodes.

The electrodes were installed at two different depths, as shown in Fig 1. Two pairs of electrodes were inserted through the specimen's small side, thus creating a measuring depth of 10 ± 1 mm and 3 ± 1 mm. The embedded length of the electrode was about 30-40 mm; the exact length depended on where the desired measuring point was located. In specimens with cracks going in the direction of the fibers, the electrode length was adapted so as to minimize the distance between the bottom of the crack and the uninsulated tip of the electrode, ie the tip was located just below the crack in question. As a result, the sensor output represents a local measure of MC near the crack in question. Depending on the depth of the crack, it is possible for the electrodes to be in direct contact with water. The distance between the electrodes of each pair was set at 30 mm, according to the sensor default electrode configuration.

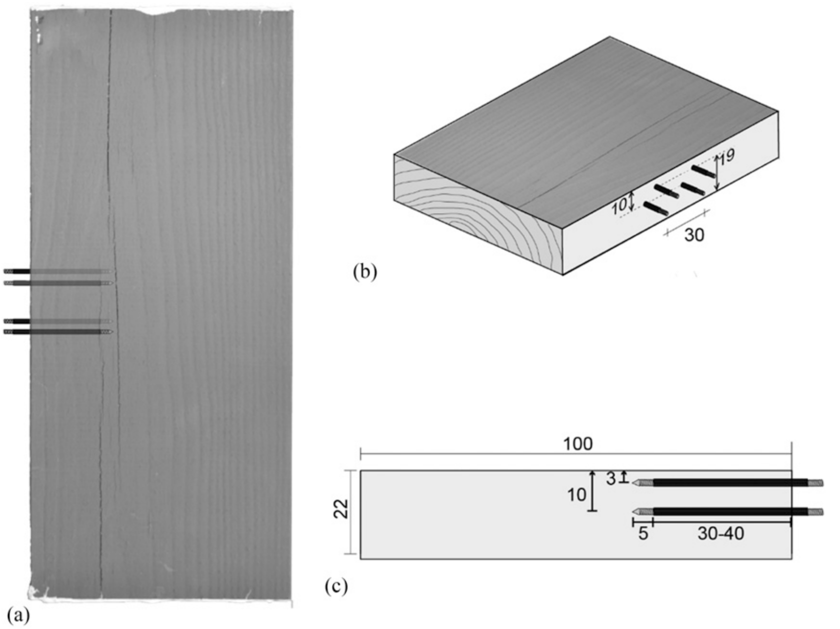

Figure 1. The electrode configuration on a weathered replicate with a larger crack. Top view (a), perspective view (b), and cross section (c). Units in (mm).

The resistance-type technique is relatively accurate below the FSP (Fredriksson et al 2013). FSP is the theoretical level of MC with water-saturated cell walls, although no free water is available in the cavities (Tiemann 1906). However, the FSP is today interpreted more as a range in MC with a transition in properties (Zelinka 2010). The fiber saturation range for Norway spruce is 30-52% MC, depending on the source of data (Kollmann and Côté 1968; Thygesen et al 2010; Telkki et al 2013). The reason for low precision above the range is related to lower moisture dependency on resistance compared with the hygroscopic range (Stamm 1929). As such, high precision and careful calibration are necessary to obtain accurate measurements above the fiber saturation (Brischke et al 2008; Fredriksson et al 2013; Otten et al 2017). Such a calibration was not performed as part of the present study, and measurements exceeding 25% MC should therefore be interpreted as being $\geq$25%, although changes occurring above this level still being indicative of whether the MC is increasing or decreasing. Finally, when using resistance-type sensors equipped with small pin-type electrodes, it is important to emphasize that the output is a measure of the *local* MC at the wood–electrode interfaces, with the MC of the wood volume *between* the electrodes being less decisive for the reading (Skaar 1988; Norberg 1999; Zelinka et al 2015).

In the present study, we used a calibration curve developed by Hjort (1996). A discussion of potential errors can be found in a previous publication by Niklewski et al (2018a), who used the same measuring system and calibration curve.

Measurement Series

This study started with a long-term monitoring of the mass and crack formation during a natural weathering process for 6 yr (Part 1). Part 1 was followed by a resistance-sensors observation in laboratory scale for 12 d (Part 2), with manual, induced, water exposure.

Natural weathering, mass measurements, and crack observation. One low-density and one high-density replicate from each coating system were stored in the climate chamber, hereafter called unexposed (x). The remaining 20 replicates were subjected to weather exposure from September 2009 to December 2015 at the Asa field research station, 40 km north of Växjö, Sweden. The replicates were part of a study by Sjökvist and Blom (2016). The replicates hung on racks at 45-degrees inclination, facing south, at approximately 60 cm above the ground (Fig 2). No additional roof or wall covered the replicates. The MC was calculated according to the aforementioned mass measurement method. Weather data during the period came from the weather station at the test field. The station is maintained by the Swedish Infrastructure for Ecosystem Science.

Laboratory scale, local-resistance measurements of the MC in the core and beneath the coating. Part 2 was performed with a selection of replicates from Part 1 together with the unexposed replicates (x). The replicates from Part 1 were selected in pairs from each wood-coating combination; when possible, one had cracks, and one did not. Table 2 presents the density and crack formation of the selected replicates. The replicates were mounted on inclined racks (30-degrees) inside a climate chamber (CTS C-40/1000, CTS Climate Test Systems AB, Sweden). The end grains of the replicates were sealed with silicone. The test setup and the climate sequence

Figure 2. The exposure racks at the test field.

Table 2. Replicate information for laboratory measurements in Part 2.

Sample	Replicate label	Density (kg/m^3)	Crack length (mm)	Crack depth (mm)
Low-density Acrylic (B)	307	366	0	0
	310	368	0	0
	x439	335	0	0
Low-density Alkyd (C)	313	363	0	0
	314	437	25	4
	x444	403	0	0
High-density Acrylic (B)	328	453	0	0
	327	465	130	7
	x438	392	0	0
High-density Alkyd (C)	331	460	195	7
	333	447	60	2
	x443	425	0	0

B, acrylic-based coating; C, alkyd-based coating. Replicate label starting with x = stored in climate chamber during test part 1. Data on cracks were measured indoors with acclimatized replicates at 18°C and 68% RH.

are shown in Fig 3. Two full-cone spray nozzles were used to simulate rain. The area of each replicate that was exposed to water from the spray nozzles had dimensions of (190 ± 2 × 60 ± 2) mm^2 (longitudinal × tangential); the rest of the area was covered with watertight tape. The nozzles gave a uniformly distributed pattern over the entire exposed area. A flow rate of 1.4 L/min was used, which translates to about 84 mm/h, with the exposed area being 1 m^2. The flow rate was selected so as to maintain a water film on the specimens during the entire spray sequence. The temperature of the water was kept constant at 20 ± 2°C. Each spray period was 1 h long; the periods involved began at times $t = 0$, 12, 24, 30, and 36 h. After the fifth spray session at 36 h, the panels were left for 114 h before a final spray sequence of 5.5 h was begun. Because of the high moisture load after each spray, the RH increased to full saturation before slowly reducing after each spray sequence. All surfaces of the replicates were exposed to the moist atmosphere. The front side—the coated tangential surface—was (as previously described) also exposed to spray water from the nozzles. The air circulation gave a velocity of 1.0-1.2 m/s measured at the wood surface.

RESULTS

Part 1: Natural Weathering, Mass Measurements, and Crack Observation

Figure 4 presents the average MC fluctuation of the replicates for each sample; Fig 5 describes the climate during the same period. The MC followed an annual cycle, with peaks during colder months (November-February) and valleys during warmer months. The measured MC ranged from 9 to 33% during the first years, with no pronounced differences between different coating types. The

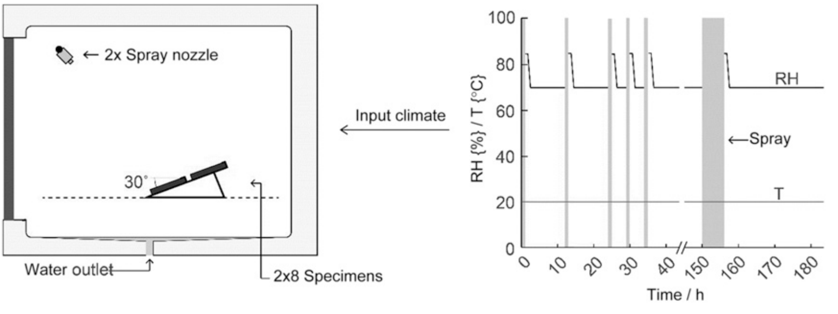

Figure 3. Side view of the climate chamber with a set of specimens organized in a 3 × 4 grid (left) and the climate sequence that was used serving as input (right).

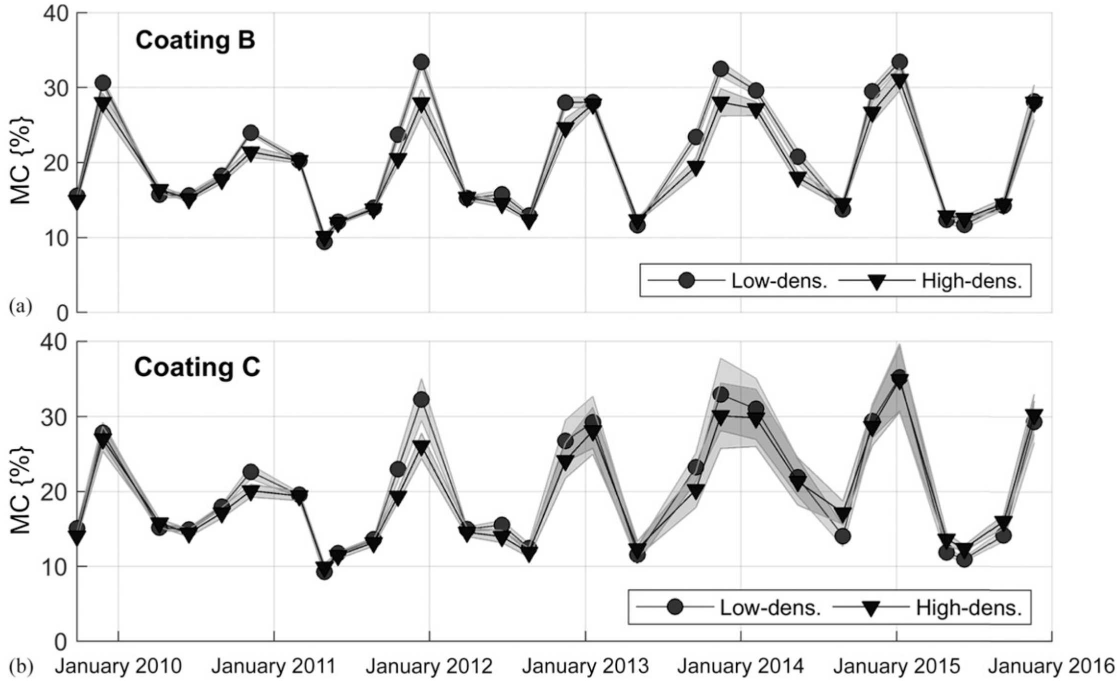

Figure 4. MC variations of high- and low-density samples during Part 1, a 6-yr natural weathering exposure. (a) samples with coating B, an acrylic-based coating. (b) samples with coating C, an alkyd-based coating. The standard deviation of MC with 2σ is presented as shaded areas.

largest differences between the density groups in MC were recorded at the annual peaks, where low-density samples had higher MC than high-density samples. This feature, of low density being associated with high MC, was equally pronounced for both coating systems during the first 4 yr.

However, around the summer of the fourth year (June 2013), the demonstrated effect from wood density on the MC changed between the coating systems.

Figure 6 illustrates the difference in MC (MC_{diff}) between the high-density and low-density samples

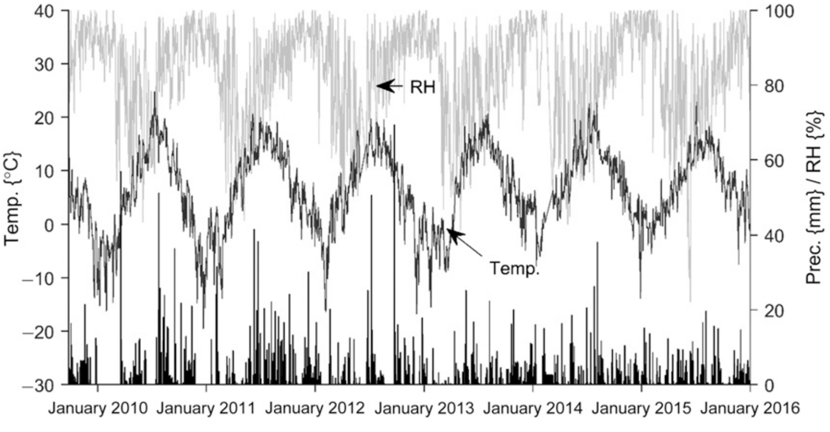

Figure 5. The variation in temperature, RH, and precipitation during exposure period Part 1 in Fig 4.

of the same coating. Positive MC_{diff} signifies that the low-density measured higher MC than the high-density ones. The difference in MC between a low-density and a high-density sample was at most six percent. As seen in Fig 6, MC_{diff} exhibits a regular seasonal variation, in addition to some short periods with negative values, during the first 4 yr. The magnitude and general variation of MC_{diff} were similar in the first year of exposure for both coating types. However, the trend changed around June 2013, when the MC_{diff} values started to diverge between the coating types. The samples coated with coating B, an acrylic resin, continued with similar fluctuations in MC_{diff} values as they had in previous years. The trend was broken with coating C, where MC_{diff} values became lower and even predominantly negative, with a reverse dependency relative to density. During the final 2 yr (2014 and 2015), the samples with coating C measured higher MC for high-density than low-density wood.

Table 1 presents the presence of cracks among the samples. Cracks were assessed every year, but it was only in the fifth year that any cracks appeared (2014), and only for high-density samples during the first year of appearance. At the end of the exposure time, the high-density samples had more cracks than the low-density samples in both coating types. However, the presence of cracks did not affect the average MC (MC_m) over the period for any of the samples. The combination of low density with coating B was the only set of replicates that was free from cracks. The replicates with the combination of high density with coating C had all developed cracks.

Part 2: Laboratory Measurements, Comparison of the MC in the Core and Beneath the Coating

Table 2 presents the density values and crack descriptions of the selected individual replicates from Part 1, together with the previously unexposed replicates. MC variation of the core and beneath the surface values is seen in Fig 7, with the weather-exposed replicates. A general trend of the replicates with cracks (independent of the choice in wood and the coating) was the pronounced increase in MC beneath the surface after each water spray occasion (replicates 314, 327, 331, and 333). A similar general increase in MC was not seen for replicates without cracks. The replicates with longer and deeper cracks (327 and 331) (see Fig 7) reached a stable peak MC directly after each of the first five spray occasions. The other two replicates (see Fig 7) with shorter and shallower cracks (314 and 333) had a gradually increasing maximum MC after each spray occasion. Some peaks also occurred in the measured MC signal for the beneath-surface

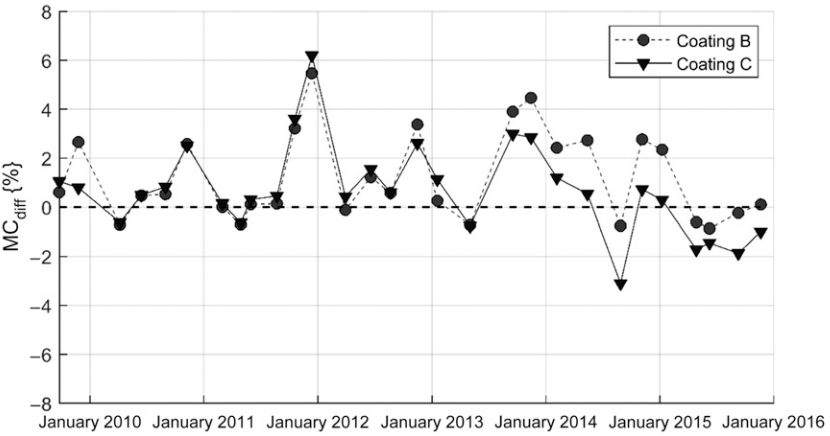

Figure 6. The difference in MC, with the value of low-density sample minus the value of high-density sample (MC_{diff}). Coating B, acrylic-based coating; coating C, alkyd-based coating.

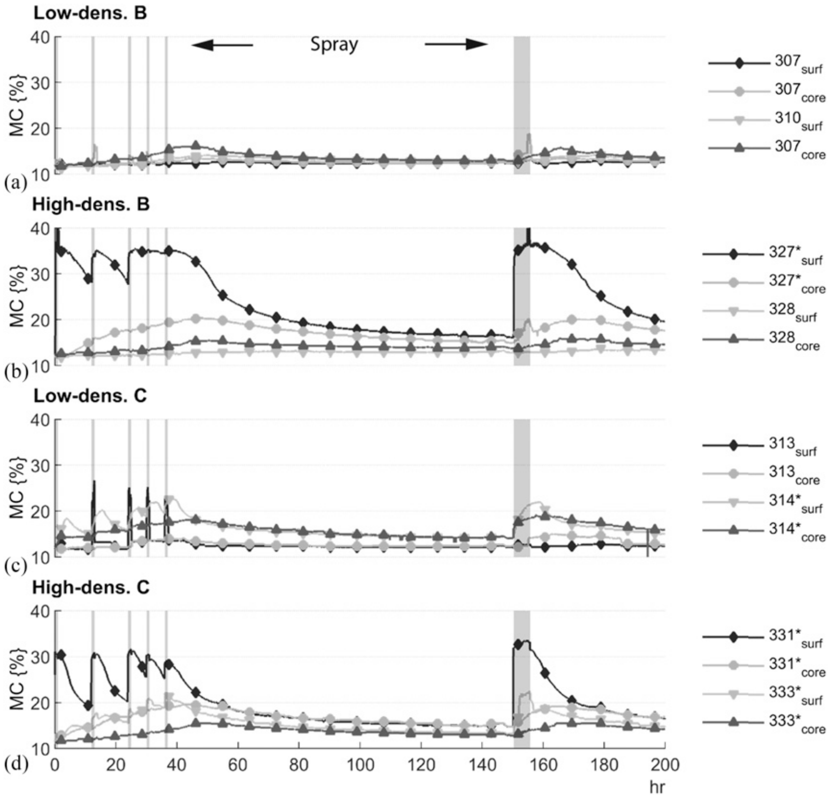

Figure 7. Moisture variations of the individual replicates during the laboratory scale resistance measurements in Part 2. dens, density; B, acrylic-based coating; C, alkyd-based coating. The asterisk indicate replicates with cracks; surf, beneath-surface value; core, center-located value.

value of replicate 313, which did not have any cracks.

Another general trend was the relationship between the core MC value and the beneath-the-surface value. The weather-exposed replicates with cracks had a higher MC beneath the surface than in the core. However, during prolonged water exposure, the weathered replicates without any cracks had a slightly higher MC in the core than beneath the surface (307, 310, 328, and 313). Replicate 313 had higher MC in the core only after the 6th spray occasion, at around 150 h of exposure time. The replicates that were not weather exposed during Part 1 in this study had a low, even MC at 13-14%, independent of the water spray occasions. Furthermore, in contrast to the weather-exposed samples without cracks, all the weather-unexposed samples had a lower MC in the core than beneath the surface.

DISCUSSION

Part 1: Natural Weathering, Mass Measurements, and Crack Observation

The long-term study revealed an interesting pattern, wherein the initial moisture sorption behavior changed with prolonged weathering exposure. Initially, the MC (Fig 4) for the two types of coatings exhibited similar behaviors, where the low-density samples in each coating group had a slightly higher MC than the high-density ones. This behavior was most pronounced at elevated MC. During the dry-out phase, the density groups converged to similar MC levels. The higher MC of low-density samples resembles the influence of density on uncoated spruce. High-density uncoated wood is less susceptible to moisture changes because the capillary water transport is lower in the smaller cell lumens as compared with the larger lumen size of low-density wood (Siau 1984). It can also be expected that the coating acts as a barrier toward water exposure and lowers the magnitude in MC fluctuations for coated wood in comparison with uncoated wood. However, the coated samples in this experiment had their rear surfaces uncoated. The uncoated backside allows the wood substrate to interact with the surrounding climate (absorb and release moisture) more easily than the front-side coated surface. Hence, the MC in the tested replicates had a partial influence in sorption properties by the uncoated wood. Low-density wood, with larger lumens and thinner cell walls, is related to a faster sorption process in the sample; therefore, is it quite likely that the MC differences in Fig 4 were influenced by the different sorption behaviors of high- and low-density wood.

The interesting results appeared after approximately 4 yr of weather exposure (around June 2013), when the relationship between high- and low-density coated wood (MC_{diff}) starts to change depending on the coating system. From this moment on, the samples coated with coating C (alkyd resin) began to have predominantly negative MC_{diff} values. High-density wood began exhibiting more rapid water sorption than low-density wood, as indicated by the negative MC_{diff} values in Fig 6. The observed change in water sorption behavior occurred at approximately the same time as the observed formation of cracks (Table 1), which implies a causal relationship between the two events.

There are some difficulties in elucidating the main cause behind crack formation; it seems to be an effect of moisture movement in the wood along with coating performance, since the first cracks appeared on high-density replicates. The shrinkage behavior of spruce wood is related to the wood density; ie increased density with a larger amount of cell wall material is positively related to increased volumetric shrinkage (Kollmann and Côté 1968; Boutelje 1973). Different coating formulas have individual degradation processes (Grüll et al 2013), which we can see on the different crack formations of the two coating systems. Therefore, the cause behind crack formation seems to be quite complex and related to a combined effect of wood density and coating performance. Formation of cracks also seems to have diminished the earlier differences in water sorption between different density groups. However, the number of samples is limited, and only two of many coating systems were evaluated, and thus the results should be analyzed with caution.

The findings in the long-term study were related to a global MC of the whole panel, with some very general MC variations. A deeper measurement method in the vicinity of the crack and the core of the panel could give some information on where the increased MC is located. Therefore, Part 2 in this study monitored the MC in the core and the close surface of the replicates.

Part 2: Laboratory Measurements, Comparison of the MC in the Core and Beneath the Coating

The panels with cracks exhibited considerable and rapid moisture increase during water exposure, in particular, near the surface of the replicates. These local measurements were taken in close vicinity to the cracks, and as such do not represent the global moisture balance, which is far less dramatic in fluctuation, as seen in the previous measurement of Part 1. The panels with an intact coating without any cracks did not show a major MC increase. This was expected, as the coating prevents rapid water sorption and the exposure periods are rather short. Thus, the amount of moisture absorbed through the coating is limited. The deviating peaks in MC increase in replicate 313 (see Fig 7) are therefore most likely due to measurement failure with the electrodes. One can also see the dependency between the crack formation and MC increase in Fig 7. Longer and deeper cracks contributed to an immediate MC increase and saturation to EMC, whereas replicates with shorter and shallower cracks showed slower moisture transport, with gradually increasing peaks in MC.

Further studies on the MC variation of different types of cracks could be of interest to future work on sorption models of the coated wood. The absolute values of MC in Fig 7 should be seen as indicative of the relationship between the replicates because the amount of water from the spray nozzles are far more than any normal amount of precipitation. See also the similar experimental setup in Niklewski et al (2018b), where previously weathered and newly planed surfaces were examined in a similar way with accelerated water spray. The water exposure per m^2 from the nozzles was 84 mm/h, whereas the precipitation at the Asa test field was measured to be on average 2 mm/d during the test period.

The MC curves of weathered replicates without cracks in Fig 7 had a surprising moisture gradient after a prolonged period of increased ambient humidity. The MC was slightly higher in the core than beneath the surface. The higher MC (approximately 2%) in the core was beyond any measurement errors and was probably caused by a moisture uptake from the uncoated backside of the replicates. The opposite was seen in the weather-unexposed replicates, with a lower MC in the core than beneath the surface. This peculiarity could possibly be related to water being absorbed from the backside of the sample, either as liquid water through condensation or as water vapor. The surface of weather-exposed wood is less hydrophobic than nonweathered wood (Kishino and Nakano 2004); as such, condensation would be more easily absorbed on the backside of weathered wood surfaces. Some research also suggests that the absorption of vapor could be higher with weathered wood surfaces (Kalnins and Feist 1993). The increased moisture sorption due to weathering could thus explain the higher MC in the core of the weathered replicates as compared with the unexposed ones.

The moisture gradient in the replicates, independent of the presence of cracks, highlighted a local MC variation that can substantially differ from the global MC of the whole replicate. The findings in this study raise attention similar to other work (Fredriksson et al 2016): the need to consider the local MC in durability studies of wood. Local MC could be especially important regarding crack formation, where the local surface MC can be higher than the core MC.

CONCLUSIONS

Wood density affected the overall sorption behavior of coated spruce. Low-density spruce contributed to faster sorption and desorption processes than high-density spruce; however, the effect of density was limited to an intact coating. The formation of cracks during prolonged weathering diminished the effect of wood substrate on the overall MC of the board. High-density wood characteristics contributed to more crack formation. In addition, the density–water sorption relationship reversed after crack formation, causing high-density replicates to absorb more water than low-density replicates. The cause behind crack formation seems to be complex and related to a combined effect of wood density and coating performance. Crack formations wider than 0.2 mm caused a clear local increase in MC at the vicinity of the crack. Furthermore, longer and deeper cracks contributed to an immediate MC increase and saturation to EMC, whereas replicates with shorter and shallower cracks showed slower moisture transport, with gradually increasing peaks in MC. However, the weather-exposed replicates without cracks had an opposite moisture profile, with higher MC in the core than beneath the surface. Moisture sorption from the uncoated backside of the panel probably caused the opposite profile. This behavior highlights the need to observe moisture sorption as a multidimensional process, from all moisture-exposed surfaces. The local difference in MC also raises awareness for future studies to investigate local MC variations in research on the durability of coated wood.

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