

THE EFFECT OF NATURAL WEATHERING ON UNTREATED WOOD SURFACE

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ABSTRACT

As a result of contemporary ecological and sustainable movements, a number of constructions from wood, as the only renewable building material, is still increasing. In accordance with these trends, wood elements are often left untreated. The presented study is aimed to characterize and compare a surface degradation of untreated wood caused by weathering. Weathering characteristics of softwoods and hardwoods (spruce, pine, Douglas fir, larch, oak, black locust, maple, poplar and alder) during twelve months of exposure in the climatic conditions of Central Europe were determined. All the wood species were characterized by colour and gloss changes and increasing roughness. The lowest discoloration was observed for oak and the highest one for spruce wood, respectively. The lowest changes of roughness were observed for alder, the highest for spruce wood. The depth of colour changes was relatively similar among the softwoods. Regarding hardwoods, it varied more. The values of total colour changes had a significant correlation with the depth values of these colour changes. Maple, alder and poplar samples were characterized by the presence of mould and blue-stain fungi. Douglas fir wood was found to be the most liable for the formation of cracks.

Keywords: Central Europe, colour changes, natural weathering, surface roughness, untreated wood.

INTRODUCTION

Nowadays, the trend of ecological building is becoming more progressive. Wood as a renewable material is noted for some obvious advantages connected with its nature origin respecting the ecological and sustainable development. The amount of wood used both in the interior and exterior is increasing day by day. The wooden structures and elements are more often treated with natural-based surface treatments (Singh and Singh 2012) or even untreated.

When the wood is used in the exterior, there are some major issues which should be followed to reduce the effect of weathering on wood degradation. First, it is recommended to use wood materials with higher natural durability in accordance with EN 350-2 (1994). Second, a proper construction solution is required (optimal shape of wood element, covering the end parts, roof overlaps, ventilation, distance from the ground etc.). Third, the surface treatment can be used to prolong the service life of wood (Feist 1982, Brischke *et al.* 2006). In the case of respecting above mentioned steps, the

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degradation affects only the surface layers of wood (Reinprecht 2008), which is manifested by the change of colour (Williams and Feist 1999), followed by a formation of cracks and increased roughness of the samples (Feist 1990, Ozgenc *et al.* 2012). The most significant weathering factors influencing the rate of degradation are solar radiation and water, acting synergistically (Tolvaj and Faix 1995, Hon and Shiraishi 2001, Müller *et al.* 2003). However, there are other factors which contribute to surface degradation such as temperature, dust particles, acid rain and air flow (Feist 1990, Williams 2005, Evans 2008, Teacă *et al.* 2013). Mainly the UV light initiates photochemical reactions, which cause decomposition of lignin, extractives and partly even hemicellulose (Feist and Hon 1984, Pandey 2005, Reinprecht 2008). Degraded compounds are leached from the wood by water (Tolvaj and Faix 1995, Pandey 2005). As the result, wood changes colour, some species turns yellow or brown, eventually, they turn into grey, which is often caused by growth of fungi and moulds (Feist 1982) and by the dust particles in air which penetrate to the porous structure of wood (Hon and Chang 1984). After leaching of UV degradation products, underlying cell layers are exposed and further eroded (Feist 1982, Williams and Feist 1999, Reinprecht 2008). Erosion is more rapid in the less dense early-wood than in latewood, which leads to an uneven and rougher surface (Williams *et al.* 2001). Formation of checks, split and cracks caused by moisture and temperature changes also leads to tangible surface roughness (Feist 1990, Ozgenc *et al.* 2013).

A lot of studies were aimed at evaluating the properties of wood treated or modified with some protective compound after natural weathering (Kropf *et al.* 1994, Nzokou *et al.* 2011, Turkoglu *et al.* 2015) or accelerated weathering (Tolvaj and Faix 1995, Williams *et al.* 2001, Temiz *et al.* 2005, Ozgenc *et al.* 2012). In these studies, the surface became rougher and darker after weathering in comparison with the initial stages. Total colour change increased with increasing exposure times in natural weathering. Despite contemporary ecological trends, significantly less studies deal with the weathering characteristics of untreated wood (Hon and Feist 1986, Tolvaj and Faix 1995, Gonzalez de Cademartori *et al.* 2016). Untreated wood specimens exhibited higher colour changes in the shorter time than the treated specimens (Saei *et al.* 2015, Turkoglu *et al.* 2015). The colour changes were reported strictly as a surface phenomenon, they occurred to a depth of only 0,05-2,5 mm (Feist 1990, Reinprecht 2008). Measuring the surface roughness has been already used in several studies as a tool to analyse the effects of weathering on wood surfaces (Östman 1983, Xie *et al.* 2008, Nzokou *et al.* 2011). The trend of increasing roughness value was observed in these studies. The rate of degradation is usually related to the intensity of light (Kataoka *et al.* 2007) and its wavelengths (MacLeod *et al.* 1995, Kataoka *et al.* 2007), the time of irradiation (Tolvaj and Faix 1995, Hon and Shiraishi 2001), the wood species (Hon and Shiraishi 2001) and climatic factors occurring during exposure (Hon and Chang 1984). In addition, it must be considered that the weathering conditions in 45° south exposure are accelerated relative to vertically installed elements, e.g. claddings, and decelerated relative to horizontal surfaces, e.g. decking (Evans 1996).

This study is aimed on the evaluation and comparison of surface degradation of selected wood species during twelve months of natural weathering. The information about behaviour of untreated wood, both softwoods and hardwoods, exposed to outdoor climatic conditions is given. The change of colour, depth of these changes, change of gloss, roughness and formation of cracks and mould were investigated. The information about the depth of these changes could serve for those who is not satisfied with the grey shade of the wood and decides to sand the wood element to initial colour. Above mentioned information, important for a maintenance and service life of wood, must be provided for further effective use of wood in the exterior.

MATERIALS AND METHODS

Materials

The experiment was carried out using three samples, all of them with dimensions 375x78x20 mm (LxTxR), from nine wood species (Table 1). In the case of heartwood species, only the heartwood was tested. Test samples were sanded with the sandpaper grit of 120. Initial characteristics of wood samples before weathering are shown in Table 1.

Table 1. The mean values of density, colour parameters L^* , a^* and b^* , gloss and roughness parameter R_a of samples at the beginning of the weathering test.

Wood species (Latin name)	Nat. durability against fungi (EN 350-2)	Density [kg/m ³] (ČSN 49 0108)	Colour parameters (EN 927-3)			Gloss	Ra [μm] (ISO 4288)
			L^*	a^*	b^*		
Norway spruce (<i>Picea abies</i> L. Karst)	4	533	84,16 (0,16)	3,72 (0,08)	19,54 (0,20)	14,3 (2,0)	5,29 (0,73)
Scots Pine (<i>Pinus sylvestris</i> L.)	3-4	698	81,19 (0,23)	3,65 (0,95)	23,93 (1,57)	12,5 (2,5)	3,71 (0,86)
Douglas fir (<i>Pseudotsuga menziesii</i> (Mirb.) Franco)	3	605	71,82 (1,03)	11,78 (0,43)	21,68 (0,57)	10,0 (1,7)	4,43 (0,33)
English oak (<i>Quercus robur</i> L.)	2	710	72,86 (1,67)	10,44 (0,44)	22,55 (1,39)	7,9 (1,0)	7,23 (1,78)
Black locust (<i>Robinia pseudoacacia</i> L.)	1-2	827	66,40 (0,22)	6,28 (0,10)	20,45 (0,44)	8,1 (0,7)	4,39 (0,58)
Poplar (<i>Populus sp.</i>)	5	413	70,59 (1,06)	2,89 (0,14)	26,80 (0,36)	9,0 (1,6)	6,24 (0,40)
Sycamore maple (<i>Acer pseudoplatanus</i> L.)	5	599	78,85 (0,57)	5,11 (0,23)	16,69 (0,09)	10,3 (0,6)	4,17 (0,31)
Black alder (<i>Alnus glutinosa</i> (L.) Gaertn)	5	534	82,33 (0,19)	4,09 (0,07)	16,58 (0,24)	11,7 (1,2)	5,67 (0,91)
European larch (<i>Larix decidua</i> [Mill.]	3-4	559	71,63 (1,90)	10,95 (0,80)	21,71 (1,12)	6,6 (1,1)	5,01 (0,50)

Note: Mean values and Standard deviations (in parenthesis) were determined from 24 measurements of colour and gloss and from 12 measurements of roughness for each wood specie. The natural durability against fungi was determined according to 350-2 (1994), value 1-5, while 1 signifies the highest natural durability. The density (at the moisture content of 12%) in kg/m³ was determined according to ČSN 49 0108 (1993).

Natural Weathering Site

The natural weathering test was carried out at Suchdol, Prague (50°07'49,68"N; 14°22'13,87"E, elevation above sea level 285 m) and lasted 12 months from 15.12.2014 to 15.12.2015. The samples were exposed outdoors, at 45° inclination, facing south and placed approximately 1 m above the ground according to EN 927-3 (2006). The specimens were stabilized at 20±2 °C and 65% RH before the measurements. Overview of the climatic conditions during 12 months of weathering can be seen in Table 2.

Table 2. Overview of the climatic conditions at the test site during the exposure period.

Variable/month	0-2	2-4	4-6	6-8	8-10	10-12
Average temperature [°C]	2,0	5,2	14,1	21,2	14,4	6,7
Average rel. humidity [%]	77,3	67,1	61,5	55,2	67,8	80,6
Total precipitation [mm]	15,5	19,1	36,1	33,4	31,7	13,4
Average global solar rad. [kJ/m ²]	2746	10010	18602	19248	11144	3494

Note: based on data from Czech University of Life Sciences (2015)

Methods

The colour and gloss characteristics of the wood were measured using spectrophotometer 600d (Konica Minolta, Japan) according to CIE (1986). The equipment was configured to a D65 light source and observation angle of 10° (CIE L*a*b* standard). Parameters L*, a* and b* and gloss were measured at 8 points on each specimen (Figure 1) at the beginning of the experiment and after 1, 2, 3, 4, 6 and 12 months.



Figure 1. Measurement points for the analysis of the colour changes and their depths.

The total colour changes were calculated according to CIE (1986) using the following equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where: L* is the lightness from 100 (white) to 0 (black); a* is the chromaticity coordinate from -60 (green) to +60 (red); b* is the other chromaticity coordinate from -60 (blue) to +60 (yellow).

The depth of colour changes was determined after 3, 6 and 12 months of exposure. The samples were sanded at the measurement points until the colour change (measured continuously by Spectrophotometer Konica Minolta 600d) was in the range of interval where is non-visible by naked eye ($\Delta E^* < 3$) in comparison with initial state of wood colour before weathering. The depth of these changes was measured by electronic gauge (Mitutoyo, Japan) at the same initial points for each sample (Figure 1).

The surface roughness was determined according to EN ISO 4287 (1997) and EN ISO 4288 (1996) using a profilometer Talysurf Form Intra (Taylor-Hobson, UK). The measurement was carried out in four traversing lengths oriented perpendicularly to the length of the samples over the tangential surface. The parameters were set up according to EN ISO 4288 (1996).

Visual observation of samples with 10x magnifying glass was done during the period of natural weathering test to observe the formation of mould, cracks and other visual defects.

The statistical evaluation was carried out in the software Statistica 12 (Statsoft Ltd., USA) using mean values, standard deviations and linear correlations between the total colour changes and the depth of colour changes at the same measurement points (Figure 1).

RESULTS AND DISCUSSION

The total colour difference (ΔE^*) showed a systematic trend to increase values with longer duration of exposure (Table 3). The highest mean value of ΔE^* was determined for spruce, closely followed by poplar wood. The lowest ΔE^* was observed for oak wood. The visual appearance of the samples is given in Figure 6. The trend of gloss mean values did not show any systematic trend during exposure. Generally, the gently increase was observed for the most cases after 6 months and then large decrease after 12 months of natural weathering test (Table 3). The highest change of gloss was observed for pine, the lowest one for oak wood. The lightness (L^*) values decreased after 12 months of natural weathering for all the wood species (Figure 2). The highest mean value of ΔL^* after 12 months of weathering was determined both for poplar ($\Delta L^* = -30,9$) followed by spruce ($\Delta L^* = -30,4$), the lowest one for oak ($\Delta L^* = -16,1$). The redness (a^*) values decreased after 12 months of weathering (Figure 2). The highest mean value of Δa^* after 12 months of weathering was determined for Douglas fir ($\Delta a^* = -10,2$), the lowest one for black locust ($\Delta a^* = -1,4$). The yellowness (b^*) values also decreased after 12 months of weathering (Figure 2). The highest mean value of Δb^* was observed for black locust ($\Delta b^* = -20$), the lowest one for poplar ($\Delta b^* = -12,7$).

Table 3. Mean values of ΔE^* and gloss of tested wood surfaces during 12 months of weathering.

Wood Species	1 month		3 months		6 months		12 months	
	ΔE^*	gloss	ΔE^*	gloss	ΔE^*	gloss	ΔE^*	gloss
Spruce	11,4 (0,7)	12,9 (2,1)	13,9 (0,9)	12,7 (2,7)	18,3 (0,8)	16,3 (1,5)	34,1 (0,9)	9,3 (1,7)
Pine	8,3 (2,1)	8,5 (0,9)	10,8 (1,8)	9,4 (1,7)	15,8 (2,4)	14,3 (2,3)	28,9 (2,3)	9,5 (1,9)
Douglas fir	10,5 (0,8)	6,4 (0,8)	10,9 (1,4)	6,3 (1,0)	16,0 (1,3)	8,5 (1,3)	28,1 (1,6)	7,3 (1,2)
Larch	11,3 (2,9)	5,7 (1,2)	12,7 (3,8)	5,5 (1,5)	17,9 (2,7)	8,9 (2,4)	30,5 (2,6)	7,0 (1,6)
Oak	3,2 (0,7)	6,9 (0,7)	4,0 (1,5)	8,0 (1,4)	12,7 (1,5)	11,4 (2,0)	23,0 (1,2)	5,6 (0,8)
Black locust	8,4 (0,9)	6,9 (1,1)	12,5 (1,6)	7,0 (1,3)	16,0 (1,5)	9,0 (1,3)	29,6 (2,0)	6,3 (1,2)
Maple	5,2 (0,7)	10,4 (2,1)	2,9 (0,6)	11,9 (1,2)	11,7 (2,1)	15,8 (2,1)	28,5 (1,6)	9,3 (1,5)
Poplar	7,5 (1,3)	10,5 (0,8)	7,8 (2,8)	10,7 (1,1)	18,9 (5,9)	12,1 (2,1)	33,6 (2,5)	7,3 (1,5)
Alder	6,4 (2,5)	5,9 (1,2)	7,0 (2,5)	5,8 (1,9)	20,9 (2,5)	7,6 (2,2)	27,0 (2,8)	5,9 (2,1)

Note: Mean values and Standard deviations (in parenthesis) were determined from 24 measurements.

Hon *et al.* (1985) and Tolvaj and Papp (1999) mentioned that colour reflects the basic chemical composition of wood. If the wood contains a high amount of extractives, the chemical processes of the colour changes quickly take place. Regarding the wood species with low extractive content, the photo-degradation of lignin soon begins with slow but continuous colour change speed. This information is in line with obtained results of an increasing total colour difference ΔE^* . The values Δa^* and Δb^* followed a similar trend shown in previous studies (Ozgenç *et al.* 2012, Turkoglu *et al.* 2015), increased at the beginning of weathering and then decreased. The initial increase in b^* values indicates the degradation of lignin (Evans *et al.* 1992; Müller *et al.* 2003; Turkoglu *et al.* 2015). The final decrease of yellowness may be attributed to leaching of decomposed lignin and extractives by water (Turkoglu *et al.* 2015). The changes in a^* values are determined mainly by the changes of the chromophore groups in extractives. The results confirmed that in the early stages of weathering, dark wood trend to become light and light woods become dark or turn into the silver grey colour (Dawson *et al.* 2008, Saei *et al.* 2015).

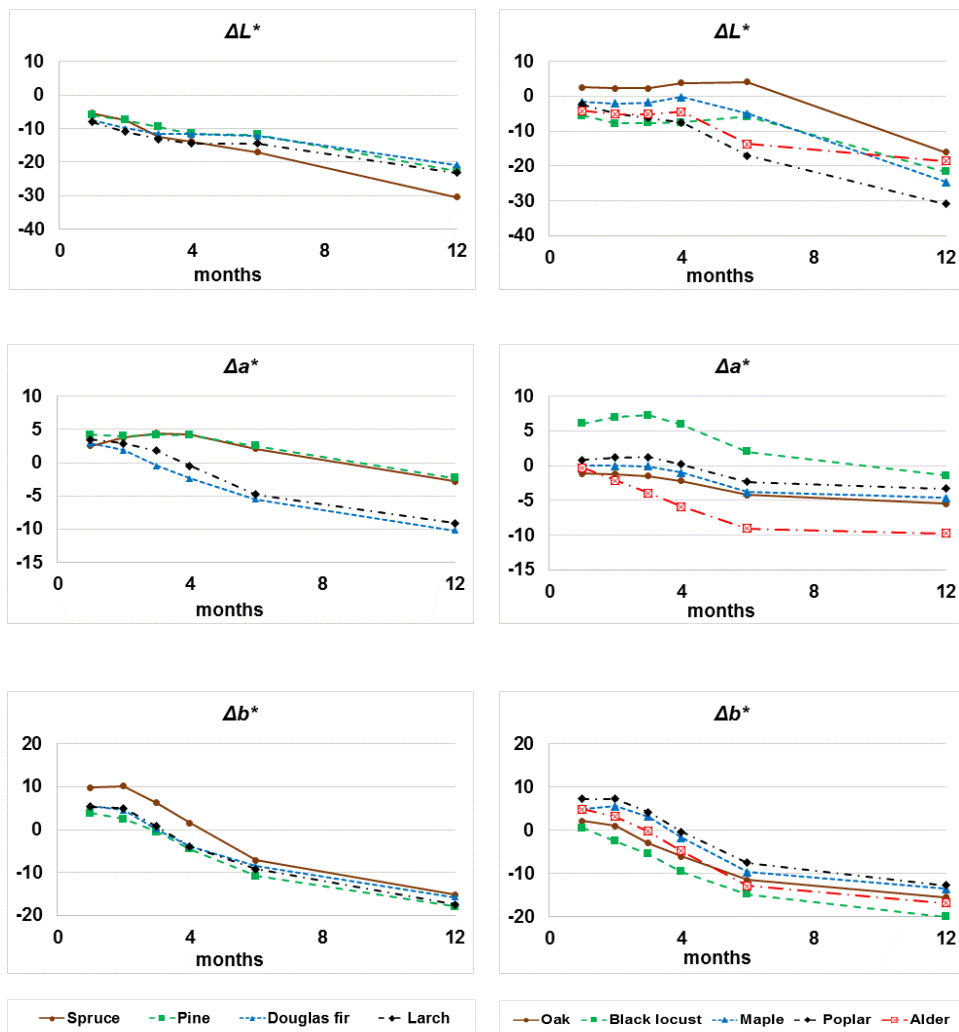


Figure 2. Colour changes of softwoods (left) and hardwoods (right) samples during 12 months of natural weathering.

The depth of colour change was relatively similar for softwood species. For hardwoods, it varied more (Figure 3). The highest value after 12 months of weathering was observed for larch (1,26 mm) and the lowest one for oak (0,50 mm). The values of the depth of the colour changes were found to be in high correlation with ΔE^* for all the wood species (Figure 4). The measurement after 6 months of exposure were done for all the samples, but after 12 months of exposure some samples cannot be measured (alder, poplar, maple) due to the presence of blue-stain fungi, which caused deeper degradation of wood and influenced the colour changes caused only by weathering. The graphs at Figure 4 show the correlation after 6 and 12 months of exposure to natural weathering. The colour changes depth values of all the wood species were in interval given by Feist (1990) and Reinprecht (2008) of 50 - 2500 μm and were found to be in high correlation with ΔE^* (Figure4). This fact confirms that during early stage of weathering the total colour change of wood surfaces is mainly caused by light decomposition of lignin which in consequence enables radical depolymerization to penetrate deeper into the wood mass. The depth of colour changes of some species (alder, poplar and maple) could not be measured after 12 months of exposure by chosen methodology due to the presence of blue-stain fungi growth in the volume of tested specimens. The penetration of UV radiation depends both on the wood

density and the wavelengths distribution, denser wood is penetrated less by UV radiation and shorter wavelengths also penetrate less (Rowell 2012).

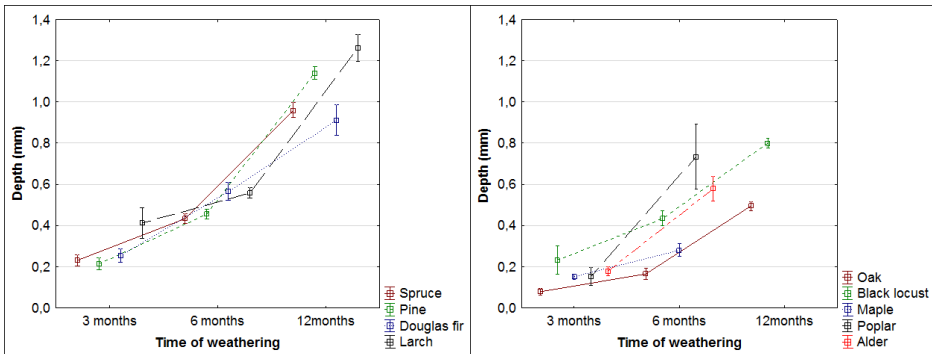


Figure 3. The depth of visible colour changes of softwoods (left) and hardwoods (right) during 12 months of weathering shown as 95% two sided confidence intervals.

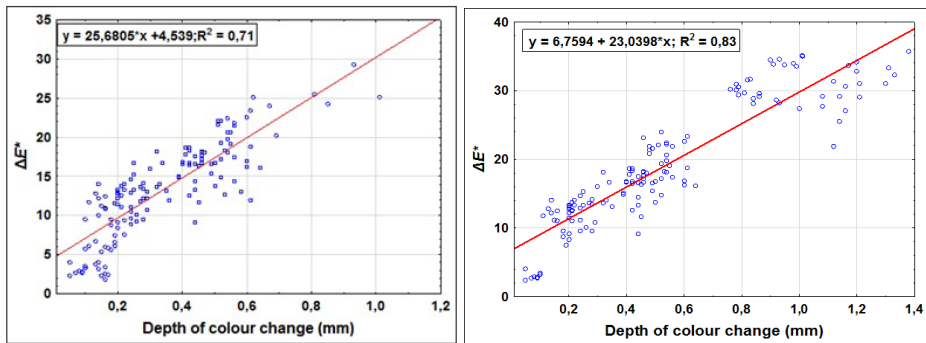


Figure 4. The correlation between total colour change and the depth of colour change during 6 months of natural weathering of nine wood species (left); and during 12 months of natural weathering of six wood species (right).

Note: The measurements were done at the same points before and after the weathering process (see Figure 1).

The roughness values (Ra^*) increased after 12 months of weathering for all the wood species as expected (Figure 5). The highest mean value of Ra^* after weathering was observed for spruce ($Ra = 25,21 \mu m$), while the lowest one for alder ($Ra = 7,70 \mu m$). The roughness measurements confirmed previous studies: value of wood roughness increases with the time of weathering (Nzokou *et al.* 2011, Tolvaj *et al.* 2014, Mohebbi and Saei 2015) because wood surfaces quickly erode (Williams *et al.* 2001). Any increased roughness can be related to natural weathering and degradation of the wood polymers (especially lignin) and removed degrading materials due to leaching after rain, mist or dew (Feist 1982). The relatively big differences in roughness values can be explained by the surface erosion occurring mainly in the early wood, due to its thin walled cells and low density (Williams *et al.* 2001). As the result, the early wood is more and faster degraded (Tolvaj *et al.* 2014) mainly for softwoods with lower density which was confirmed for spruce wood in presented study (Figure 5).

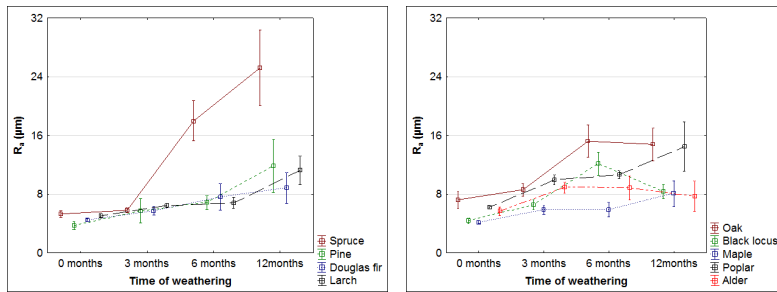


Figure 5. Changes of surface roughness of softwoods (left) and hardwoods (right) during 12 months of weathering shown as 95% two sided confidence intervals.

The mould growth was first observed at maple, poplar and alder samples after the fourth month of weathering. After 6 months of weathering, wood samples (mostly Douglas fir wood) showed formation of numerous cracks which basically ran in the direction of wood fibres. An appearance of the samples after 12 months of outdoor exposure is demonstrated in Figure 6. Mould and blue-stain fungi growth was observed in those species that are not durable against fungal attack (EN 350-2: 1994) such as maple, poplar and alder samples, especially after the fourth month of exposure. Faster attack of biotic factors was caused by higher mean temperature and the total precipitation after the fourth month of weathering (Table 2).

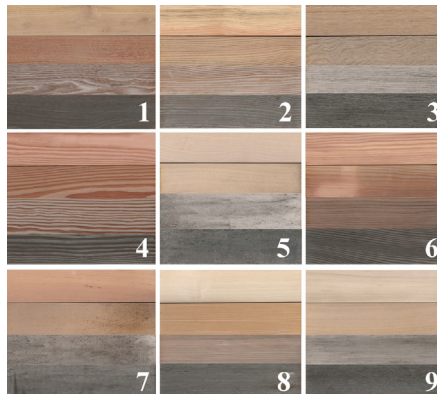


Figure 6. Colour changes of wood samples during 12 months of exposure (from up to down: reference sample, sample after 3, 6 and 12 months of exposure): 1 - locust; 2 - pine; 3 - oak; 4 - Douglas fir; 5 - maple; 6 - larch; 7 - alder; 8 - spruce; 9 - poplar

CONCLUSIONS

The results of this experiment describe surface degradation process of softwoods and hardwoods during 12 months natural weathering in the Czech Republic (Central Europe). It was confirmed that the surface properties of wood such as roughness, colour and formation of cracks are affected by the specific climatic conditions already during initial stage of weathering. But structural differences of wood are still the most important factors which affect weathering characteristics as concluded in the study of other authors. All the colour changes were fast and visible in a very short time about 1 month for all tested species. Also information about the depth of these colour changes of tested wood species,

which can occur during stocking or longer production time of untreated construction, is given.

A trend of discoloration based on the total colour changes (ΔE^*) was observed after very short time of outdoor exposure.

After 12 months of exposure, the lowest and the highest discoloration, according to ΔE^* values, was recorded for oak ($\Delta E^* = 23,0$) and for spruce ($\Delta E^* = 34,1$), respectively.

High correlation between ΔE^* and the depth of colour changes was determined after 6 months of weathering for all tested species ($R^2 = 0,71$) and after 12 months of weathering for all the softwoods and oak and black locust ($R^2 = 0,83$).

Δa^* and Δb^* values followed a similar trend: increased at the beginning and then decreased. The Δa^* change is determined mainly by the changes of the chromophore groups in extractives and the Δb^* change by the lignin degradation and later leaching.

The roughness values increased during outdoor exposure for all tested wood species, the highest was observed for spruce samples (high difference between density of early wood and late wood).

Mould and blue-stain fungi growth was observed in those wood species that are not durable against fungal attack (maple, alder and poplar). Douglas fir was determined as the most liable to formation of the cracks.

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