

SURFACE WETTING OF SELECTED WOOD SPECIES BY WATER DURING INITIAL STAGES OF WEATHERING

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ABSTRACT

Currently, the trend of using untreated wood elements in the exterior is becoming more progressive. The rainwater nevertheless needs to be recognized as an important factor increasing photo-degradation of wood and causing other damages as splits, cracks and deformations. The aim of this work is to determine the influence of initial stages of weathering on wetting properties of wood surfaces evaluated by the contact angle measurements using goniometer Krüss DSA 30E. Nine wood species were tested during 12 months of weathering: spruce, larch, pine, Douglas fir, oak, black locust, maple, alder and poplar. The lower decrease of the contact angle of water drop was observed on maple, alder and black locust surfaces, which predicts higher durability and slower degradation during weathering. On the contrary, the higher decrease of contact angle and higher hydrophilicity of wood surfaces was observed on all softwoods and oak and poplar as well.

KEYWORDS: Wood wettability, weathering, water, contact angle, sessile drop method.

INTRODUCTION

Already in the last century the trend of ecological building, which is closely connected with using sustainable materials (as wood), recyclability and reduction in utilization of chemicals, has begun (Gabriel 2011). As a result, the untreated wood cladding and decking have started to appear again. There are some obvious advantages as lower cost, maintenance and natural appearance. Untreated wood elements correspond to ecological trend, but they also bring some limitations connected with wood protection (precise constructional solution, suitable selection of wood species).

Wood exposed to exterior conditions is subjected to process called natural weathering (Williams 2010). Weathering, mainly through the action of sunlight and water, causes gradual degradation of a wood substance (Temiz et al. 2005), which affects the surface layers of the wood and is basically manifested by a change in the colour, followed by a loosening of wood fibres and

gradual erosion of the wood surface (Williams and Feist 1999). The rate of weathering effects is closely connected to the exposure site (weather, location, and altitude), wood species and structure and chemical composition of wood (Creemers et al. 2002). Lignin is one component responsible for the water repellency of wood (Rowell and Banks 1985). Wood extractives are also known to affect the wettability (Maldas and Kamden 1999). During the process of weathering, hydrophobic lignin is decomposed by the UV light and leached from the wood surface together with extractives by water (Williams 2010), which increases the wettability of wood. Cellulose, being more resistant to weathering effects, becomes more abundant on the weathered wood surface. This presumably increases the hydroxyl concentration on the wood surface. When a drop of water contacts the weathered wood, greater interaction between the hydroxyl groups of wood and water occurs (Kalnins and Feist 1993). The wettability is a term used to describe the interfacial phenomenon of a liquid contacting a solid surface (Baldan 2012). The degree of wettability is given by the value of contact angle. One of the most common techniques used for contact angle determination is the sessile drop method (Petrič and Oven 2015), mainly due to its speed, affordability and accuracy. The contact angle is an angle between the tangent line of the liquid and the solid material (Liptáková and Kúdela 1994, Yuan and Lee 2013). It can theoretically range from the 0° to 180° – the lower contact angle signifies greater wettability (Kalnins and Feist 1993). Leaching of the extractives from the surface of weathered wood reduces water repellency, while degradation of lignin results in a more hydrophilic surface (Rowell 2005). Carbohydrates (cellulose and hemicelluloses) are more resistant to UV light degradation, but they absorb and desorb moisture. The process of weathering significantly accelerates absorption and penetration of water to wood, consequently, it significantly reduces total wetting time (Huang et al. 2012). The determination of contact angle of water drops and weathered wood provides the information about the expected behaviour of rainwater after the contact with wood exposed to outdoor conditions. Rainwater drops can either flow down or be absorbed to the surface which depends on the wettability of material. In the case of absorption, they enhance the negative effect of biotic and abiotic degradation factors and reduce the service life of wood element.

There is a high diversity of contact angle data in the literature (Petrič and Oven 2015). The differences in the response of wettability to weathering are caused by the differences between wood species and the extractives content (Kalnins and Feist 1993). Decreasing contact angles, i.e. increasing wettability, with the time of outdoor weathering were reported for western redcedar from 77° to a minimum of about 51° after 4 weeks of weathering (Kalnins and Feist 1993), untreated beech wood from 70° to nearly 30° after 52 weeks of weathering and Scots pine from 80° to less than 30° after 52 weeks of weathering (Banks and Voulgaridis 1980). In another study, the wettability of Eucalypt woods increased as a function of time of outdoor exposure of untreated wood. The surface became fully wettable after 240 days of exposure caused by leaching the chemical compounds and an appearance of micro cracks on the wood surface (Gonzalez de Cademartori et al. 2015). In these studies, the highest decrease of the contact angle, i.e. increase of the wettability, was observed during the initial process of weathering. In the contrary in the study of Kalnins and Knaebe (1992) the contact angles for southern pine increased during the early period of weathering, but eventually the steady decrease of the values was reported after 12 weeks of weathering. Deeper knowledge of wetting phenomena on wood may add valuable fundamental information about the wood material itself and its complex nature (Wälinder 2000).

The aim of this study is to determine the wettability of nine wood species (larch, pine, spruce, Douglas fir, black locust, oak, poplar, maple, alder) and to monitor and compare the wettability changes of softwood and hardwood species during 12 months of exposure to natural weathering in Central Europe climate conditions (Prague, Czech Republic). This knowledge will

help to understand individual process of weathering of different untreated wood species exposed to exterior from the point of view of wettability as an important technological and economical factor strongly influencing the wood degradation.

MATERIAL AND METHODS

Material

The experiment was carried out using wood specimens of dimensions 375x78x20 mm (LxTxR), sanded by the sandpaper with grain 120, from the representatives of nine different wood species (Tab. 1).

Tab. 1: Tested wood species and their initial characteristics (natural durability against fungi, density and initial value of the contact angle with standard deviation).

Wood species	Latin name	Natural durability against fungi (EN 350-2)	Density (kg.m ⁻³) (ČSN 49 0108)	Contact angle (°)
Norway spruce	<i>Picea abies</i> L. Karst.	4	533	77 ± 9
Scots Pine	<i>Pinus sylvestris</i> L.	3-4	698	82 ± 6.5
Douglas fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco	3	605	83 ± 3
English oak	<i>Quercus robur</i> L.	2	710	60 ± 4.1
Black locust	<i>Robinia pseudoacacia</i> L.	1-2	827	56 ± 2.6
Poplar	<i>Populus</i> ssp.	5	413	51 ± 5.4
Sycamore maple	<i>Acer pseudoplatanus</i> L.	5	599	44 ± 2.8
Black alder	<i>Alnus g lutinosa</i> (L.) Gaertn.	5	534	55 ± 3.1
European larch	<i>Larix decidua</i> (Mill.)	3-4	559	48 ± 5.8

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.m⁻³ was determined according to ČSN 49 0108 (1993).

Natural weathering test

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 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). An overview of climatic conditions during 12 months of exposure can be seen in Tab. 2:

Tab. 2: An overview of average climatic conditions during 12 months of natural weathering.

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 RH (%)	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)	2745.5	10010.0	18601.5	19248.4	11143.7	3494.0

Contact angle measurements

The effect of outdoor exposure on the wettability by water was investigated. The contact angle was measured using goniometer Krüss DSA 30E (Krüss GmbH, Germany) on radial surfaces of wood samples. The sessile drop method was used, when the static contact angle (without external interference during the measurement) was carried out. Twelve measurements were done for each sample (three samples for each wood specie and period of weathering were used) with distilled water drops with a dosing volume of 10 μl to minimise the effects of structural and chemical variations of the wood samples. All samples were conditioned to the moisture content $12 \pm 2\%$ before measurement to reduce the effect of different moisture content on water contact angle on wooden surfaces (Kúdela et al. 2015). There are more methods how to measure water contact angle on wood surfaces (Kúdela 2014). The aim of this work was to compare nine wood species and changes of their wettability during weathering, so the simply sessile drop method was used. The contact angle measurements were done at 5 seconds after the deposition of the water drop on the surface as it was carried out in other studies (Wälinder and Johansson 2001, Bastani et al. 2015, Gonzalez de Cademartori et al. 2015). The phenomena of spreading and absorption of drops on the wood surface were investigated by the variation of the weathering time (before exposure and after 3, 6 and 12 months of natural weathering (Fig. 1).

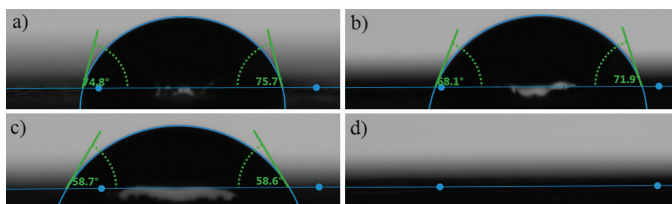


Fig. 1: Contact angle measurements at 5 seconds after the deposition of the drop; a) pine wood before the exposure to natural weathering, b) pine wood after 3 months of exposure, c) pine wood after 6 months of exposure, d) pine wood after 12 months of exposure – the contact angle was 0° .

Data analysis

The analyses of obtained data were carried out using the software STATISTICA 12 and MS EXCELL.

RESULTS AND DISCUSSION

Softwood species

A similar trend of the contact angle was observed for most softwood species during weathering (Fig. 2). The permanent decrease of this value to final total wetting (contact angle 0°) was observed only for spruce wood with lower density (from 77° in the beginning; to 42° after 3 months and 37° after 6 months of exposition), which shows faster degradation of surfaces. Other softwoods with heartwood fulfilled with a higher amount of extractives have shown different results. Pine wood has a relatively slow decrease of contact angle during 6 months of weathering (from 82° in the beginning; to 78° after 3 months and 73° after 6 months of exposition), which could be influenced by the high amount of resins with hydrophobic function and their slower degradation and leaching from the wood. An increase of contact angle was observed for larch (from 48° in the beginning; to 68° after 3 months of exposure) and Douglas fir (from 83° in the beginning; to 91° after 3 months of exposure), probably caused by better resistance against weathering in initial stadium of surface degradation.

Subsequently, a fast decrease of contact angle was shown during weathering period (to 39° for larch and to 49° for Douglas fir after 6 months of exposure). After 12 months of outdoor exposure, the contact angle 0°, which signifies full wettability, was measured for all the softwoods. Fully wettable surface caused by high degradation of surfaces, loosened cellulose fibres, increased roughness, an appearance of micro cracks, leached extractives and degraded lignin (Gonzalez de Cademartori et al. 2015) was determined for all the softwoods after 12 months of weathering. An interesting result was a relatively high value of contact angle of all softwoods before exposure except larch (Fig. 2). Possible explanation is the high amount of arabinogalactans in larch wood (Bučko et al. 1988), which differ the surface wetting characteristics in comparison with other softwoods. This fact could be also confirmed by problematic adhesion and durability of coatings applied on larch wood in practice (Truskaller et al. 2014).

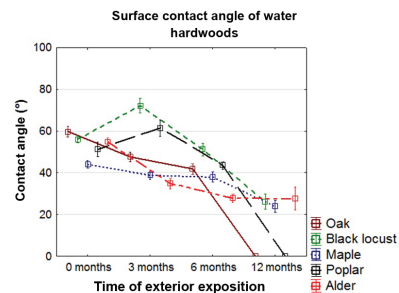
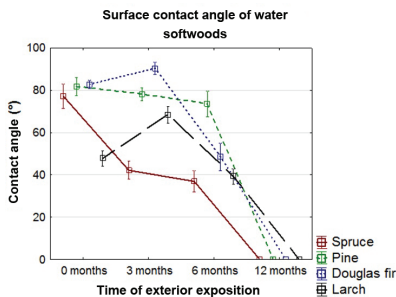


Fig. 2: The changes of contact angle of softwoods during exposure to weathering. Fig. 3: The changes of contact angle of hardwood species during exposure to weathering.

Hardwood species

Hardwoods have shown more variable results of contact angle measurements during weathering in comparison with softwoods (Fig. 3). Different results were influenced by the variability in density, microscopic structure and amount of extractives, as known from the literature (Kalnins and Feist 1993, Wälinder and Johansson 2001). Due to the higher density of diffuse-porous alder and maple samples, the contact angle after 12 months of weathering was measured (24° for maple and 28° for alder). Black locust achieved similar final results connected with increasing hydrophobicity during an initial stage of weathering (56° in the beginning; 72° and 51° after 3 and 6 months and 26° after 12 months of exposure). Only oak wood did not confirmed this trend (60° in the beginning; 48° after 3 months and 42° after 6 months), that can be explained by high influence of opened vessels on the wood surface (in the contrast with black locust wood) and faster soaking of water drop to the wood. This fact was confirmed also after 12 months of weathering when partly degraded surfaces caused that after 5 seconds of measurement the contact angle was 0° because all water soaked to the surface of the specimen. Poplar wood has shown some initial increase of contact angle (51° in the beginning; 61° after 3 months of exposure). But then degradation of surfaces and increase of wettability was very fast (37° after 6 months of exposure) due to its low density and after 12 months of weathering water contact angle was 0°.

In some cases (larch, Douglas fir, black locust and poplar), an increase of contact angle after 3 months of weathering was observed (Figs. 2 and 3). This fact is the most likely caused by an increasing hydrophobicity of surfaces with non-homogenous structure in nano-scale dimension (Lin and Junhui 2014). There is an extremely high variability of wood and diversity of contact

angle data, so the results have only a relative value even when measured within the same set of experiments (Petrić and Oven 2015) and it is often very difficult to find proper explanations for all observed cases. Nevertheless, an increment of wetting of wood surface is related to chemical changes after outdoor exposure. Degradation of hydrophobic lignin, leaching of extractives with water repellent effect and allowing cellulose to become more abundant on the wood surface increased the degree of surface hydrophilicity (Kalnins and Feist 1993, Rowell 2005). Furthermore, also an appearance of micro cracks increases the degree of wettability (Huang et al. 2012, Gonzalez de Cademartori et al. 2015). Further, the greater wettability of weathered wood is suggested as a contributing factor to the deterioration of wood structures (Kalnins and Feist 1993).

CONCLUSIONS

In this study, a high decrease of the contact angle of all the tested wood species during weathering, mainly between 6 and 12 months of exposure, was observed. Better surface wetting characteristics of pine, larch and Douglas fir during 6 months of weathering were probably influenced by their higher density and amount of extractives in their heartwood zones. In opposite, a faster decrease of the contact angle of spruce was determined already after 3 and 6 months of weathering. The very hydrophilic surface was obtained after 12 months of outdoor exposure, wherein wood surface presented full absorption of water drops (contact angle 0°).

More compact and integrated anatomical structure of black locust, maple and alder caused a lower decrease of contact angle and the possibility to measure its values after 12 months of weathering. In opposite, a lower density and faster degradation of poplar wood and large opened vessels of oak caused a higher decrease of contact angle, which was 0° after 12 months of outdoor exposure. From the point of view of a possible use of tested wood species as an untreated cladding, decking or other outdoor elements, presented results give some useful information about an impact of rain water on the quality and degradation of surfaces. Furthermore, also a proper constructional solution and natural durability of wood against fungi and insects (EN 350-2, 1994) must be considered. Considering these factors, the black locust, pine, larch and Douglas fir can be recommended for the application in the exterior conditions.

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