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# COATING ADHESION AND WETTABILITY OF AGED AND PREWEATHERED FIR WOOD AND PINE WOOD SURFACES

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## ABSTRACT

Outdoor weathering of unprotected wood can cause severe surface degradation. This preweathering before finishing can lead to chemical and physical changes on the wood surface that can influence wood-coating interface. The change in wettability of wood surface with weathering and a change in adhesion strength of acrylic water based coating on preweathered fir wood (*Abies Alba Mill.)* and pine wood *(Pinus silvestris L.*) samples were evaluated. Wettability of fir wood and pine wood samples increased with time of weathering as shown by the decreasing contact angle. Adhesion of acrylic coating to fir wood significantly reduced after wood substrate had weathered for 2 to 6 weeks. The influence of preweathering on adhesion strength of acrylic coating on pine wood samples was not established.

KEY WORDS: adhesion of coating, wettability of wood, weathering, contact angle

## INTRODUCTION

Wood surfaces, especially wood sidings are often exposed to many weeks of weathering before being coated with different finishes. This weathering before finishing (preweathering) can lead to chemical and physical changes on the wood surface that can influence on wettability and adhesion properties. Numerous studies have shown the detrimental effects on adhesion between coatings and wood as a consequence of preweathering (Desai 1967, Underhaug et al. 1983, Boxall 1977, Kleive 1986). It has been established that exterior exposure of softwoods for little as four weeks prior to painting can reduce the adhesion and performance of some paints significantly (Williams et al. 1987, Williams et al. 1990, Williams and Feist 1994, Williams et al. 2002).

Kalnins and Knaebe (1992) reported that wettability of western redcedar increased with weathering and the wettability of southern pine, however, decreased to a minimum between 0 and 2 weeks of weathering and increased thereafter.

The objectives of this work were to determine the change in wettability of fir wood and pine wood during weathering and to evaluate the adhesion of waterborne coating applied to wood surfaces preweathered for 1, 2, 4 and 6 weeks before finishing.

## MATERIAL AND METHODS

### Wood materials

Vertical-grained fir (*Abies alba Mill.)* and pine (*Pinus silvestris L.*) panels 375 by 100 by 20 mm (longitudinal by radial by tangential) were used for the experiment. The panels were fine machined (planing) and stored at 23 ± 2°C and 50 ± 5 % RH before and after exposure to reach approximately 9% moisture content. The pine was all heartwood and the fir was all sapwood. The average density of pine wood was 490 kg/m$^3$ with the average value of ring width of 2, 3 mm and late wood proportion of 17,5%. The average density of fir wood panels was 410 kg/m$^3$ with the average value of ring width of 1,2 mm and late wood proportion of 11,95%. For each exposure time, three replicate panels were prepared. Nine control panels of each species were kept in a darkened conditioned room (23 ± 2°C and 50 ± 5 % RH). Three of them used as control specimens for measurements of contact angle and adhesion of coatings on unexposed samples (0 hours of weathering, but stored for two weeks in dark climate room) and six of them were freshly planed before contact angle measurements and before applying of coating in order to establish the influence of surface aging on wettability and adhesion.

### Natural weathering

Successive groups of panels were exposed outdoors at 45° facing south for 1, 2, 3, 4 and 6 weeks during June and July of 2005, started on June 1, 2005. The climate data were obtained from the National Meteorological and Hydrological Service and presented in Tab.1. Following weathering the wood panels were lightly washed with distilled water and conditioned to reach initial moisture content of 9% before contact angle measurements.

*Tab. 1: Climate data for period from June 1 to July 12, 2005*

| Week | Max temp | Min temp | Average temp in | Relative Humidity | Average wind speed | Average daily duration of sun shine | Precipitation |
|---|---|---|---|---|---|---|---|
| | °C | °C | °C | % | m/s | h | mm |
| 1 | 30 | 10,1 | 16,6 | 68 | 2 | 9 | 21 |
| 2 | 27,8 | 8,1 | 17,0 | 58 | 2 | 8 | 18 |
| 3 | 29 | 12,4 | 21,3 | 63 | 1 | 11 | 12 |
| 4 | 31,7 | 14,7 | 23,9 | 62 | 2 | 11 | 0 |
| 5 | 31 | 14,2 | 20,8 | 69 | 2 | 8 | 38 |
| 6 | 24,7 | 11,6 | 18,3 | 79 | 1 | 6 | 63 |

## Contact angle measurements

The wettability of the wood surface was expressed by contact angle. The three-phase contact angle was obtained by sessile drop method, using a *DataPhysics Instruments OCA 20* goniometer (optical microscope coupled to a CCD video camera with a resolution of 768 x 576 pixels and up to 50 images per second). Measurements were done at 23°C by using double distilled water (κ=1.3 μS/cm), drop volume was 5 μl. The contact angle has been determined 60 ms after the pendant drop has touched the surface. Average values of ten drops on different places on the same sample were taken along the longitudinal middle line of a specimen, regardless of whether these places were earlywood or latewood. The measurements were done one three replicate samples-panels.

## Coatings

After contact angle measurements the panels were finished with acrylic water-based lacquer. The lacquer was applied by spiral film applicator in wet film thickness of 100μm for the first coat. After drying for two hours under the ambient condition the second coat in wet film thickness of 60μm was applied, and after drying the third coat in wet film thickness of 60μm was applied. The panels were additionally conditioned for a week at a temperature of 23 ± 2°C and 50 ± 5 % RH before adhesion testing.

## Adhesion testing

Adhesion testing was performed according to ASTM D 4541-95 "pull-off "method using the PATTI-2A (pneumatic adhesion tensile testing instrument). The method consisted of gluing the cylindrical studs with the epoxy resin onto the surface of the film. After the curing of the adhesive for 24 hours a tensile force is applied to the loading fixture axis. The force is gradually increased until the coating is detached or specified force is reached. The failure occurs in the weakest layer of the system composed of the adhesive, test coating and substrate. The tensile strength of the film on the wood (adhesion of the film) was calculated from the ultimate force which led to the detachment of the stud from the surface (Jirouš-Rajković 2004.). Adhesion was measured at five places on every specimen.

## Statistical Analysis

Descriptive statistics were estimated for the analysed variables (represented by graphs). Differences in tensile strengths and contact angles between controls and specimens exposed for 1, 2, 3, 4 and 6 weeks were tested by analysis of variance. For all analysis type I error of 5% we considered statistically significant.

If a statistically significant ($p < 0.005$) difference in means occurred, then Tukey's post-hoc tests were done in order to determine specifically where the significance difference lies (McClave and Dietrich 1988). All analysis and graphics were performed using software package Statistica 7.0 (see ref . 22)

## RESULTS AND DISCUSSION

The influence of surface aging on wettability and adhesion results of unexposed samples can bee seen in Tab. 2.

*Tab. 2: Adhesive strength and contact angle of unexposed samples stored for two weeks before being coated and before measurement of contact angle (Control 1) and of unexposed samples freshly planed before contact angle measurement and before applying of coating (Control 2)*

| Sample code | Mean adhesive strength (kPa) and standard deviations of unexposed samples | Mean contact angle (°) and standard deviations of unexposed samples |
|---|---|---|
| Control 1- fir wood | 3557,9 ± 567,743 | 90,92 ± 6,231 |
| Control 2 – fir wood | 3654 ± 904,081 | 65,27 ± 8,299 |
| Control 1 – pine wood | 3795,1 ± 700,181 | 104,04 ± 9,283 |
| Control 2 – pine wood | 4635,9 ± 910,792 | 78,5 ± 7,26 |

It may be seen (Tab. 2) that the contact angle for pine is higher than for fir wood. It could be related with differences in chemical composition between fir sapwood samples and pine heartwood samples. Surfaces with high contents of lignin and extractives were found to have greater contact angles (Jaić et al. 1996, Gindl et al. 2001, Mantanis and Young 1997).

Control specimens who had been stored for two weeks in dark climate room exhibited worse adhesion and worse wettability (increased contact angle). This could be explained as a result of a natural surface inactivation process where low-molecular wood extractives - fatty and resin acids and their esters, terpenes, phenols etc. migrate to the surface (Back 1991). The inactivation of a surface may result in a drop in surface energy and thus a poorer liquid wettability and in reduction in adhesive bond strength (Chen 1970, Back 1991, Nussbaum 1999, Gindl et al. 2004).

A summary of the results of the contact angle measurements and adhesion testing on samples preweathered for 1, 2, 3, 4 and 6 weeks are presented in Figs. 1 to 4 and in Tabs. 3 and 4.

The wettability of fir wood and pine wood samples increased with longer period of weathering, as shown by the decreasing contact angle. The mean wettability values, expressed as contact angles are shown in Fig. 1 for the fir wood and in Fig. 2 for the pine wood. The change in wettability of fir wood samples shows the similar trend as change in wettability of pine wood samples (Figs. 1 and 2).

Results of analysis of variance (ANOVA) shows significant differences between contact angles mean values on fir wood samples ($F=55,26$; $df=5$; $p<0,0001$) and pine wood samples ($F=146,95$; $df=5$; $p<0,0001$) preweathered for 1, 2, 4 and 6 weeks. Tukey's post –hoc test showed significant differences between controls (0 weeks of exposure) and specimens exposed for 2, 4, and 6 weeks of exposure (Tab. 3). Differences between 3 and 4 weeks exposed and 3 and 6 weeks exposed fir and pine samples were not significant (at the 5% significance level).

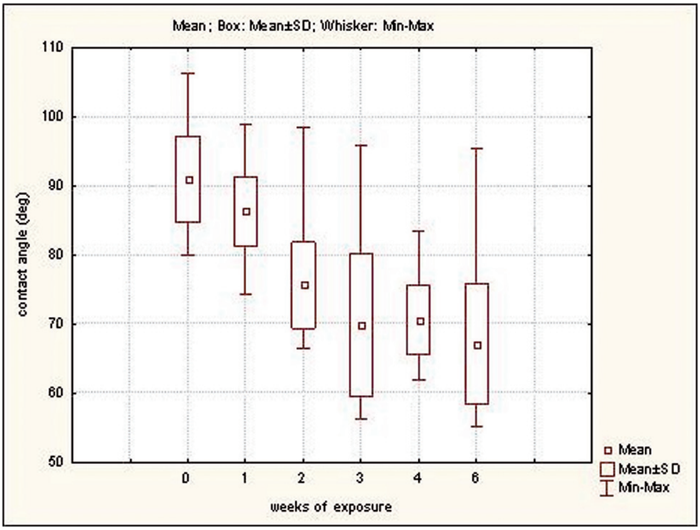


*Fig. 1: Change in wettability of fir wood with weathering*

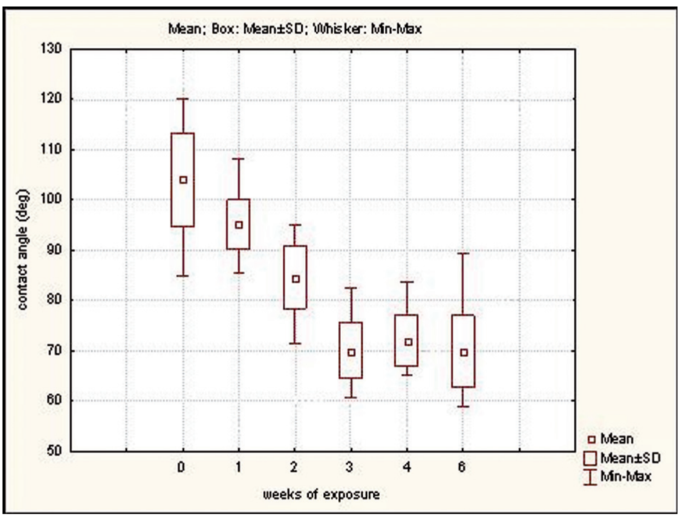


*Fig. 2: Change in wettability of pine wood with weathering*

*Tab. 3: Results of a Tukey HSD test on mean contact angle for fir wood (right side) and pine wood (left side) samples.*

| **Weeks of exposure** | **Tukey HSD test** | | | | | |
|---|---|---|---|---|---|---|
| **Fir / Pine** | **0** | **1** | **2** | **3** | **4** | **6** |
| **0** | | 0,124525 | **0,000020** | **0,000020** | **0,000020** | **0,000020** |
| **1** | **0,000022** | | **0,000020** | **0,000020** | **0,000020** | **0,000020** |
| **2** | **0,000022** | **0,000022** | | **0,023252** | 0,078110 | **0,000072** |
| **3** | **0,000022** | **0,000022** | **0,000022** | | 0,998312 | 0,651231 |
| **4** | **0,000022** | **0,000022** | **0,000022** | 0,861201 | | 0,376610 |
| **6** | **0,000022** | **0,000022** | **0,000022** | 0,999999 | 0,813777 | |

Increased wettability of fir and pine wood samples during early weathering could be explained as a consequence of weathering processes. Weathering, by the action of sunlight and water on wood, is known to produce volatile and water-soluble degradation products and to leave an eroded, leached surface layer that is high in cellulose content and has higher concentration of carbonyl, carboxyl, quinone, peroxide, and hydroperoxide groups (Kalnins and Knaebe 1992).

An increase in surface wettability is often associated to an increase in surface roughness (Moura and Hernandez 2005). Extractives, especially in softwoods, are known to impart some water repellency to wood, and they may be lost gradually during weathering (Kalnins and Knaebe 1992). We can only speculate which of these changes is responsable for improved wetting.

Much of the difficulty in evaluating adhesion values resulted from the variability in the data (see Figs. 3 and 4). This variability was probably attributed to the different failure modes for the three replicate samples after various prewethering period.

The change of the adhesion strength of acrylic coating on fir wood samples with weathering differed from that of pine wood samples. Results showed that adhesion of acrylic coating to fir wood was significantly reduced after the wood substrate had weathered for 2 or 6 weeks before coating.

Results of analysis of variance (ANOVA) showed no significant differences in mean tensile strength for pine wood specimens exposed to different preweathering periods (F=3,79; df=5; p = 0,24). Fir wood samples showed significant differences between controls and specimens exposed for 1, 2, 4 and 6 weeks (F=11, 33; df=5; p<0,0001). Tukey's post –hoc test showed significant differences in mean tensile strength between controls (0 weeks of exposure) and fir wood specimens exposed for 2,3, 4, and 6 weeks of exposure (Tab. 4).

*Tab. 4: Results of a Tukey HSD test on mean adhesive strength for fir wood samples*

| **Weeks of exposure** | **Tukey HSD test** | | | | | |
|---|---|---|---|---|---|---|
| **Fir wood** | **0** | **1** | **2** | **3** | **4** | **6** |
| **0** | | 0,194240 | **0,000172** | **0,034141** | **0,005192** | **0,000124** |
| **1** | | | 0,105141 | 0,977582 | 0,747578 | **0,000226** |
| **2** | | | | 0,419511 | 0,811105 | 0,309802 |
| **3** | | | | | 0,988191 | **0,002209** |
| **4** | | | | | | **0,016088** |
| **6** | | | | | | |

Examination of the specimens and pull-off test studs after adhesion testing revealed that type of failure had influence on adhesion results. On samples preweathered for more than 2 weeks cohesion failures of substrate were predominantly. The test studs pulled-off from specimens showed a considerable amount of fibers pulled out from the wood surface which indicate relative weakness of the surface layer of the wood substrate.

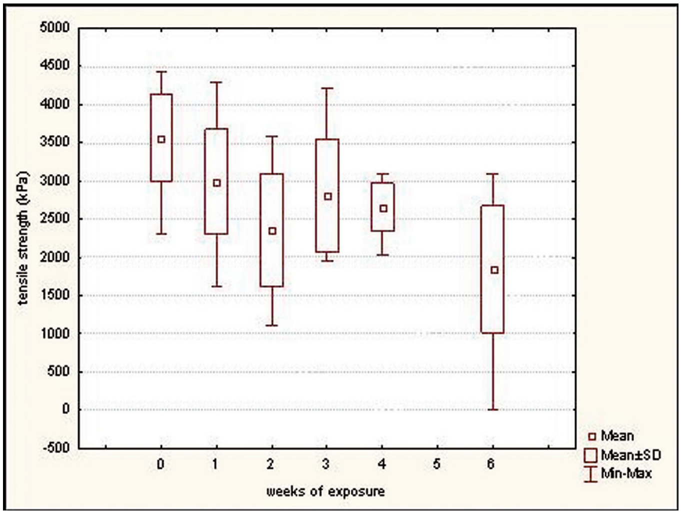


*Fig. 3: Change in adhesive strength of coating with preweathering of fir wood samples*

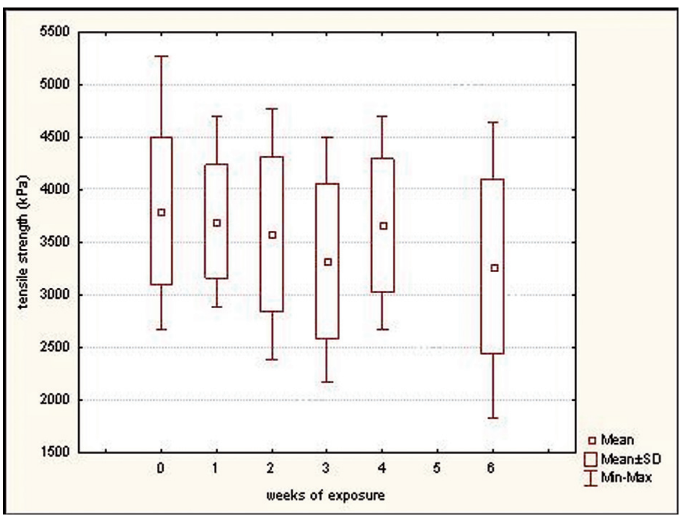


*Fig. 4: Change in adhesive strength of coating with preweathering of pine wood samples*

It has been established that natural weathering process results in physical deterioration of wood surface and in reduction in its surface integrity (Hon and Chang 1984, Derbyshire and Miller 1981). This reduction in strength and integrity of surface layer caused by weathering is probably cause for decreasing the adhesive strength with exposure for fir wood samples. Pine heartwood samples with higher density were probably more resistent to short term weathering and loss of coating adhesion on preweathered samples was not established. Hon and Chang 1984 showed that the middle lamella in wood fibers is destroyed by weathering action and that the cohesive strength of the wood tissue is lost, although the extent of the change may vary with with sample of wood used.

## CONCLUSIONS

- Control specimens with freshly planed surfaces exhibited better adhesion and better wettability (smaller contact angles) than specimens stored for two weeks in dark climated room before measuring contact angle and being coated with acrylic coating.
- The weattability of fir wood and pine wood samples increased with weathering.
- Adhesion of acrylic water based coating was significantly reduced after the fir wood substrate had weathered for 2 to 6 weeks before applying the coating.
- Short period od weathering had no influence on adhesion of acrylic coating on pine wood samples.

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