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Wettability of weathered wood

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Abstract–No single technique has been universally satisfactory for determining the wettability of wood. The objective of this study was to determine the change in wettability of weathered wood using a videotape technique for determining contact angles. Contact angles of water on western redcedar and southern pine panels were determined alter 0 – 12 weeks of outdoor weathering. Contact angles were calculated by computer on 'frozen' images of drops displayed from videotape recordings. Wettability of western redcedar increased with time of weathering, as shown by progressively decreasing contact angles. Contact angles increased during the early portion of weathering of southern pine, but decreased steadily thereafter. The conservative Tukey test was used to show which values are significantly different.

Keywords: Wettability; western redcedar; southern pine; weathering, contact angle.

1. INTRODUCTION

Previous studies on the wettability of wood have primarily focused on three areas: (1) elucidation of basic material properties of wood. (2) study of changes in basic material properties of wood, and (3) improvement or adaptation of experimental methods for tests on wood.

Wood is a complex material, and its wettability (expressed as contact angle or its cosine) depends on many factors; e.g. wood species, type of wood (sapwood or heartwood), previous history (such as exposure to water, light, weathering, or biological attacks, and method of drying), grain orientation, and aging of exposed surface [1-4]. Surface free energies for wood have been estimated from cosines of contact angles measured using liquids with different surface tensions [4–8]. Using the methods of Good [9] and Becher [10], an interaction parameter of wood has also been estimated [4]. Other studies have addressed more practical concerns. Surface energy, wettability, and strength of adhesive bonds have been discussed in general by Mittal [11]. Effective wetting of wood by adhesives has been correlated with the strength of adhesive bonds [1, 12–16]. Studies have also addressed water repellency, essential in wood used outdoors [3, 17–22]. The affinity of wood for water is attributed to two hydroxyl-containing components, cellulose and hemicellulose [23]. Extractives, on the other hand, can provide some water repellency, especially in softwoods.

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Several methods have been tried for determining the wettability of wood [1, 4, 7, 8, 15, 24, 25], but no single technique has been satisfactory for all applications. We have adapted two procedures. We have found that a modified Wilhelmy procedure is effective for small sticks of wood [1]. For larger surfaces (panels or boards), we developed it videotape technique [24] used in the study reported here to determine contact angles.

Previous work in our laboratories showed that weathering of wood prior to painting resulted in decreased adhesion of the paint film [26, 27]. In a preliminary study, we noted an increase in wettability of cedar panels following weathering: such an effect had been reported in beech and scotch pine [3]. The subject of wettability and water repellency of wood is currently being reviewed (Kalnins, in preparation).

The objectives of the work described here were twofold: (1) to determine the change in wettability of western redcedar and southern pine as a result of weathering, and (2) to improve our videotape procedure for determining contact angles on wood.

2. EXPERIMENTAL PROCEDURES

Panels. 1.3 × 7.6 × 40.6 cm, were planed and cut from three beveled western redredar *(Thuja plicata)* siding boards; 1.9 × 13.7 × 40.6 cm panels were planed and cut from three southern pine *(Pinus* sp.) boards. The cedar panels were cut mostly in the radial direction, so that the annual ring lines ran parallel to the longer dimension of the panels on the study surfaces. The southern pine panels were cut radially or tangentially; when cut tangetitially, wide summerwood (latewood) and springwood (earlywood) zones were exposed. The cedar was all heartwood; the wood was obtained from old growth trees with small annual growth increments. The southern pine was all sapwood. The panels were stored at 26.6°C and 65% relative humidity before and after exposure to reach approximately 12% moisture content, the level suggested for wood in construction. The panels were exposed to outdoor weathering in July near Madison, Wisconsin. Successive groups of four panels each of cedar and pine were exposed outdoors at intervals, for weathering times of 1, 2, 4, 8 and 12 weeks.

In the wettability determinations. previously described by Kalnins *et al.* [241, we used a Gilson* Pipetman 100 automatic micropipette to place 25-μl drops of distilled water on the wood panel surface. The drops were placed (1) on one planed face of the panel, (2) in a row along the long axis of the panel, and (3) along both longitudinal edges. On radially sawn panels, drops contacted both springwood and summerwood. On tangentially sawn panels, drops were placed alternately on springwood and summerwood. Generally both springwood and summerwood were contacted by each drop on the cedar panels.

The profile of the drop was recorded on videotape with fiber optic illumination, using a Sony DXC-325 video camera, 135-mm Nikon lens, and bellows attachment to obtain a 4× magnification. Drop size variation in this size range

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was previously found to have little effect on the value of the contact angle. Both the left and the right sides of the drop were used to determine the contact angles. The number of determinations ranged from 160 to 92 (4 panels × 2 edges × 10 drops × 2 sides = 160). The lower number is the result of an inability to measure some angles. usually because one side of the drop moved off the screen.

The previously described method [24] was improved by eliminating the manual measurement of the contact angle on the computer monitor screen. A special video board (Videomail VMC-1 live motion video controller board with Dosview), which accepted a videocassette recorder (VCR) image and converted it to VGA computer format, as installed in the computer. This board intercepted the computer video image, overlaid it with the VCR image and sent the combined signal to the computer monitor. The image of the water drop was 'frozen' on the screen 0.4 s after deposition. A computer-assisted design (CAD) program was used to determine the contact angle of the drop. It was more convenient first to define the are made by the drop and then to select the tangent to the arc at its intersection with the plane of the wood surface. The tangent forms one side of the angle; the other side is a line along the wood surface. The computer automatically calculates and displays the contact angle (Fig. 1).

3. RESULTS AND DISCUSSION

The wettability of cedar increased with longer periods of weathering. The mean wettability values. expressed as contact angles, are shown in Fig. 2 as plus signs. From 0–4 weeks of weathering, the contact angles showed a linear decrease. The box plot shows the distribution of values; 75% fall within the dotted lines. The hatched lines below the points are Tukey groupings that indicate which points are not significantly different. The height of the hatched areas has no meaning and is used for clarity. The contact angles of about 45 and 35° after 8 and 12 weeks of weathering. respectively, were higher than expected. This can be explained by our inability to measure small angles, as the drop moved off one edge of the screen. Such was the case with nearly half the drops at 12 weeks of

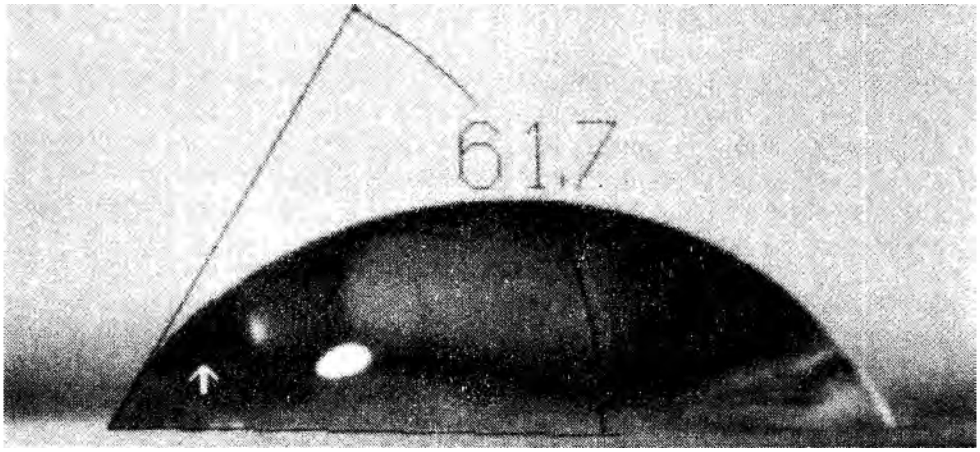

Figure 1. Photograph of computer monitor showing automatically calculated contact angle of water on western redcedar before weather-ins.

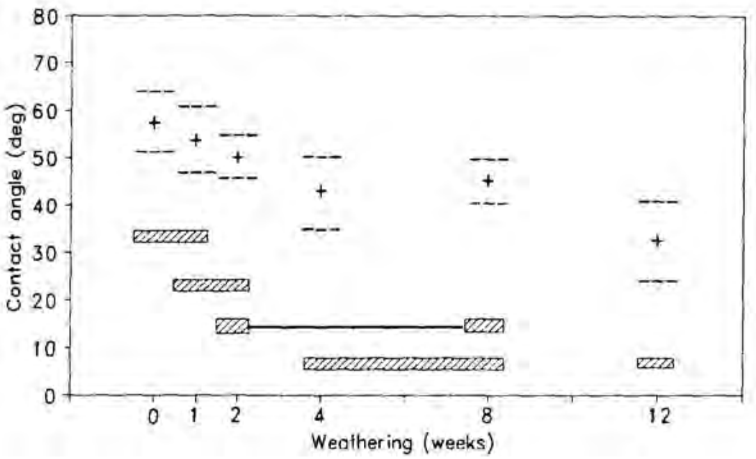

Figure 2. Change in wettability of cedar with weathering; mean, 75% box plots, and Tukey groupings (hatched lines).

weathering. The missing values were most often smaller than the 35° average. and in some cases, the values approached zero.

The determination of contact angles for cedar weathered for 8 or 12 weeks is also questionable on theoretical grounds. The assumption of a condition approaching an equilibrium is justified for the controls and the panels exposed to only 1 or 2 weeks of weathering. For highly absorptive wood surfaces, a method [28] that compares areas under the curve from a plot of contact angles as a function of time (until disappearance of the drop) has some advantages. This could be done easily with the videotape technique.

The explanation of increasing wettability of cedar during early weathering is largely speculative at this time. 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 a higher concentration of carbonyl, carboxyl, quinone, peroxide, and hydroperoxide groups [29–32]. It is not known which of these changes is directly responsible for improved wetting and to what extent. Research has suggested, however, that lignin is responsible for the water repellency of wood [23], and loss of aromatic components during photodegradation has been described [29]. Extractives, especially in softwoods, are known to impart some water repellency to wood, and they may be lost gradually during weathering.

The wettability of southern pine differed from that of cedar. After a week of weathering, the contact angle showed an increase, followed by a decrease (Fig. 3). After about 8 weeks, the contact angle was comparable to the angle before exposure to weathering. The curve is similar to one depicting adhesion of paint film to southern pine wood exposed to increasing weathering periods [26, 27]. For southern pine exposed to weathering, we suggest that wettability is related to the strength of the adhesive bond.

One possible explanation for the initial increase in contact angles for pine is the migration of fatty acids to the surface when the wood is exposed to the sun. Self-sizing or air-sizing has been studied in paper and paper products [33]. The

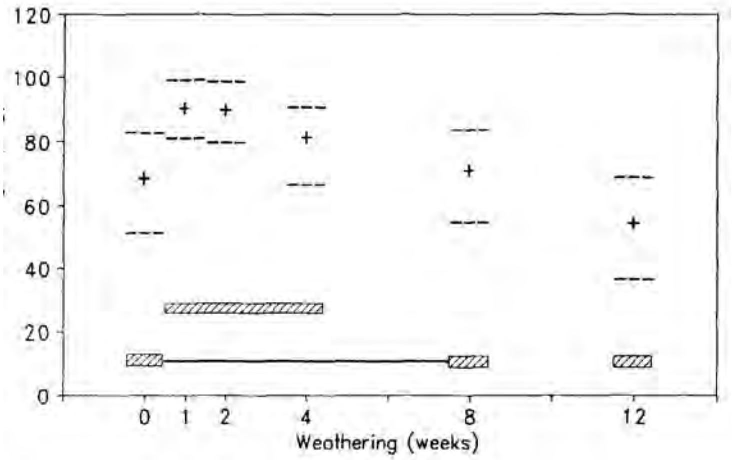

Figure 3. Change in wettability of southern pine with weathering; mean, 75% box plots, and Tukey groupings.

authors cited poor wetting with printing inks. water resistance in paper intended to be absorbent, and poor adhesion during the manufacture of corrugated board; they demonstrated vapor phase deposition of extractives and stearic acid.

Our results show the rate at which wettability of southern pine and western redcedar changes during short periods of exposure to weathering. These changes may affect long-term durability of finishes applied over wood weathered for a short period before finishing. Our technique for determining contact angles of water on wood may be useful for other materials, especially when there appears to be a period of stability similar to an equilibrium between the solid surface and the drop for a number of seconds. but the change in the contact angle accelerates thereafter.

4. CONCLUSION

The wettability of western redcedar increased with weathering, as shown by the decreasing contact angle. The wettability of southern pine. however, decreased to a minimum between 0 and 2 weeks of weathering and increased thereafter. The videotape technique used in this study is useful for nondestructive determination of contact angles on large specimens and is made considerably faster by computer analysis.

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