EVALUATION OF VARNISH COATING PERFORMANCE FOR TWO SURFACING METHODS ON SUGAR MAPLE WOOD

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(Received July 2004)

ABSTRACT

The understanding of adhesion mechanisms on wood surfaces is essential in order to extend service life of film-forming coatings. Pull-off adhesion test and accelerated aging were used to assess adhesion and performance of a high-solids polyurethane coating on sugar maple wood. Two surfacing processes were employed prior to coating: peripheral knife planing and sanding. Planing produced surfaces and subsurfaces virtually free of damage, which provoked a higher coating penetration. However, this was not sufficient to promote good adhesion. Sanding offered better wetting properties of wood surface even though superficial crushing of cells hindered coating penetration. Wetting was facilitated in the direction of abrasive scratches. Stronger pull-off adhesion and better aging-resistance of films on sanded surfaces were mainly associated to the presence of torn-out micro-fibrils, which promoted a better mechanical anchorage and offered a greater actual surface available to coating and wood interactions. Surface roughness, wetting properties and film aging-resistance were significantly correlated with pull-off adhesion.

Keywords: Planing, sanding, wetting properties, roughness, varnishing, sugar maple.

INTRODUCTION AND BACKGROUND

The understanding of adhesion mechanisms on wood surfaces is essential in order to extend service life of transparent film-forming coatings, especially for exterior uses. One of the most common approaches to enhance film durability is changing the chemical composition of wood surfaces. However, the most efficient chemical treatments for wood surfaces are relatively expensive and hazardous. In this context, physical approaches to increase adhesion and performance may also be regarded as primarily important.

Good wetting is fundamental for good adhesion as it provides better mechanical interlocking, molecular-level interactions and secondary force interactions between the coating and the wood surface. For any type of coating, good wetting contributes to good film performance (Wulf et al. 1997). If a coating cures prior to complete wetting, a weak boundary layer of air bubbles will form in the interface (Gray 1965; Lewis and Forrestal 1969).

In general, wetting occurs when the surface tension of the liquid is inferior or equal to the solid surface energy. For good wetting, the solid surface energy must be as high as possible, whilst the liquid surface tension must be minimal (Gray 1965). Thus, if the surface tension of the liquid adhesive is higher than the surface energy of the substrate, the wetting process will be incomplete and adhesion will be poor.

The wettability may be evaluated by the contact angle measured between the horizontal surface of the solid and the surface of a droplet of a

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given liquid: lower contact angles indicate higher wettability. If the liquid doesn't spread completely, equilibrium is established in a point in simultaneous contact with the solid, liquid, and gas phases (Collett 1972). This equilibrium is explained by the classic Young equation:

$$\gamma_{sv} - \gamma_{sl} = \gamma_{lv} \cdot \cos\theta_w \quad (1)$$

where γ_{sv}, γ_{sl} and γ_{lv} represent, respectively, the solid surface energy, the liquid/solid interfacial energy, and the liquid surface tension. θ_w is the contact angle for an ideal, perfectly smooth surface.

The surface roughness affects the wetting characteristics of a solid. An increase in surface wettability is often associated to an increase in surface roughness (Wenzel 1936; Dolenko et al. 1974). Previous studies suggested that increasing roughness accelerates liquid spreading (Wenzel 1936; Lewis and Forrestal 1969).

Wood sanding produces a superficial layer of crushed cells with obstructed lumens, which precludes the coating penetration into the wood surface capillaries, principally through rays. Likewise, fine sanding may generate an accumulation of dust into lumens, also hindering penetration (de Meijer et al. 1998). However, crushed and raised cells produced by sanding or planing seem to improve the performance of stains, by avoiding the over-penetration in earlywood tissue and providing sufficient finish penetration in dense latewood zones. Owing to its crushing action, sanding homogenizes the surface and reduces the influence of wood anatomical characteristics on coating behavior. Thus, surface damage possibly contributes to a homogeneous spread and penetration of the stain (Richter et al. 1995). In this work, we hypothesize that this effect may also be observed for film-forming coatings.

Few researches have been made concerning the effects of machining on the wetting characteristics of wood surfaces. The main objective of this work is to evaluate the effects of two machining processes on wood surface characteristics and coating performance. The relationships between surface roughness, wettability, coating adhesion, and performance are studied. Sanding and planing were used to prepare surfaces prior to coating given that they produce surfaces with different characteristics.

MATERIALS AND METHODS

Testing materials

Sugar maple (*Acer saccharum* Marsh.) wood was selected for this study. This species is a diffuse-porous hardwood commonly used for indoor applications. Commercial air-dried flat-sawn sapwood boards were stored in a conditioning room at 20ºC and 40% relative humidity (RH) for two months, until they reached an 8% equilibrium moisture content (EMC). After conditioning, the boards were cut into fourteen 60-mm (T) by 612-mm (L) oriented-grain samples. These samples were freshly planed to a thickness of 19.8 mm (R) and cross-cut in two 305-mm (L) matched sections (Fig. 1). Each section underwent a surfacing treatment and was re-sectioned in order to prepare specimens for roughness (60 × 40 mm), wetting (60 × 10 mm), varnishing, accelerated aging and pull-off adhesion tests (60 × 250 mm) (Fig. 1). The average and standard deviation of basic density of the boards were 586 and 20 kg/m^3, respectively.

Machining treatments

The first group of sections was knife-planed using a conventional cabinet peripheral planer working at a feeding rate set to achieve 34 knife marks per 25 mm of length. A freshly sharpened non-rectified knife was installed in the cutterhead. The other two knives were kept in the cutterhead to avoid vibration but were disabled. A 15º rake angle was used as recommended for planing sugar maple wood (Cantin 1967). Planing was carried out parallel to the grain with a cutting depth of 0.40 mm.

The second group of sections was submitted to a 120- 180-grit sanding program. The two sanding steps were performed with open-coat paper-backed sandpapers. Both sandpapers were com-

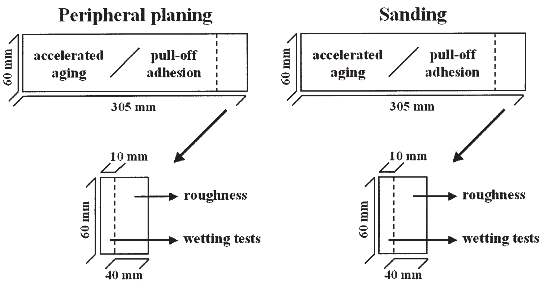

FIG. 1. Schema showing sample dimensions used for each test.

posed of aluminum oxide abrasive grains coated with anti-static zinc stearate. The drums of the sander had a 390-mm diameter and worked at a speed of 21 m/s. The 120-grit sandpaper was installed onto the drum having a toughness of DURO 68. The 180-grit sandpaper was mounted onto a DURO 44 drum. Sanding was carried out fiberwise and the total removal rate was 216 g/m² with a cutting depth of 0.37 mm.

Surface wettability tests

Wetting analyses were performed within 24 h after machining treatments with a Ramé-Hart imaging goniometer at room conditions of 23ºC and 50% RH. Small droplets (2 μl) of distilled water were added to the machined wood surfaces with an injection microsyringe. A frame grabber recorded the changes in droplet profile during wetting. Contact angles of droplets were measured at 1-s intervals until complete spreading. All measurements were carried out with a view parallel to the orientation of wood fibers. Two replicates were performed on each specimen for a total of 28 measurements for each machining treatment. Contact angle was calculated as an average of both sides of droplets to compensate for horizontality variations. The initial contact angles θ_i, recorded immediately after droplet deposition, were used to estimate the wood surface energies by the Berthelot's combining rule (Kwok and Neumann 2000). The surface tension of water was considered as being 72.8 dynes/cm (Wu 1982). In order to quantify the water spreading and penetration, the k-value proposed by Shi and Gardner (2001) was calculated for each machining condition. The time taken to complete surface wetting by water was also recorded.

Surface roughness measurements

Roughness measurements were carried out with a Hommel T1000 waveline-20 tester equipped with a TK300 pick-up. The pick-up travel length and cut-off length were set to 20 mm and 2.5 mm, respectively. Measurements were performed at 0.5 mm/s. Roughness parameters were calculated as an average of five consecutive cut-off lengths for each pick-up travel length. The roughness average (R_a), RMS roughness average (R_q) and total waviness depth (W_t) were determined, as well as skewness (R_{sk}) and kurtosis (R_{ku}) coefficients, according to ISO 4287-1 (1984). Kurtosis was calculated from the fourth moment of the amplitude distribution curve. The surface profile was assessed in the parallel and perpendicular directions to the grain. One pick-up travel length was performed on each direction for a total of 28 for each machining treatment.

Coating procedure

Samples were roll-coated immediately after machining treatments. The coating film consisted of 6 layers of sealer followed by 3 layers of varnish. All layers were composed of high-solids UV-curable polyurethane with a 80 KU viscosity. A light 280-grit sanding was performed before the last layer of varnish. The average film thickness was 77.5 μm. The coated specimens were stored in a conditioning room at 20ºC and 40% RH for two months prior to artificial aging and mechanical tests.

Accelerated aging

All specimens underwent an accelerated aging treatment in an Atlas xenon arc weatherometer. The treatment consisted of 50 cycles of 102 min of UV radiation followed by 18 min of UV radiation combined with distilled water spray, totalizing 100 h of aging. Specimens were exposed without any protection against water penetration.

The chamber during drying periods was about 52ºC and 40% RH. The conditions during humid periods were about 45ºC and 70% RH. After aging treatment, the specimens were conditioned at 20ºC and 40% RH for a month to reach their initial 8% EMC. All aged specimens were ranked by their coating conditions: grades varied from 1 (best) to 28 (worst). Aging-resistance was expressed in terms of the global ranking.

Adhesion tests

The adhesion of the aged films was evaluated by means of a pull-off test according to ASTM D 4541 (1995). A DeFelsko PosiTest AT-P pull-off tester with maximal capacity of 8 MPa and ±1% full-scale accuracy was employed. Small 20-mm-diameter dollies were glued on the film surface with Araldite 2011 two-part epoxy resin. After 24 h of curing at room conditions, the perimeters of the glued dollies were carefully incised in order to prevent propagation of failures out of the tested area. A cylindrical actuator connected to a hydraulic pump was placed over the dolly head. Vacuum was applied gradually into the actuator with a rate inferior to 1 MPa/s until separation of the dolly. The drag pointer of the pressure gage displayed the value of the maximal normal pull strength at the rupture. The pull-off tests were carried out at 20ºC and 40% RH room conditions.

Microscopic evaluation

Small blocks measuring 8 mm^2 on the tangential face were cut from the surfaced boards prior to coating for scanning electron microscopy (SEM) evaluation. After coating, other blocks with a coated surface were taken from each specimen for SEM examination. The latter blocks were prepared with a razor blade mounted onto a microtome, by carefully cutting one of the end-grain surfaces. All blocks were then desiccated with phosphorus pentoxide for two weeks, mounted onto standard aluminium stubs with silver paint and coated with gold/palladium in a sputter-coater. Electron micrographs were taken for three representative machined surfaces and for all coated subsurfaces. The coated blocks were assessed for film thickness, gaps at the interface, coating penetration, and cell damage at surface and subsurface. The mass of the film remaining above the machined surface was calculated based on a film density of 1.36 g/cm^3. Coating penetration was estimated as the difference between the total mass of applied varnish and the mass remaining above the machined surface.

RESULTS AND DISCUSSION

Surface topography

An analysis of the SEM micrographs showed that the sanded surfaces were rougher than planed surfaces (Figs. 2 and 3). Cell-wall fibrillation was observed in sanded surfaces due to the abrasive tearing action. Scratches produced by abrasive grains could be easily observed on sanded surfaces (Fig. 3). Sanding action obstructed lumens, mainly those from rays and fibers. Open vessels were seldom observed on sanded surfaces. Planing produced surfaces with relatively more open cells, particularly vessels (Fig. 2), which could give paths for coating penetration. However, lumens of fibers and rays were not frequently visible in planed surfaces, due to superficial crushing.

Results of the roughness and waviness evaluation are presented in Table 1. Significant differences in roughness (R_a and R_q) were only observed in measurements taken in the direction perpendicular to the grain. For this direction, sanded surfaces were rougher than planed surfaces. As expected, the roughness produced by sandpaper was more pronounced in the direction perpendicular to the movement of the abrasive grains (Fig. 3). Otherwise, waviness (W_t) differences were only detected along the grain. The higher waviness along the grain on sanded surfaces was probably associated to vibrations normal to the surface during sander feeding. These vibrations were more prominent than waves produced by peripheral planing. For planed surfaces, roughness was consistently similar in both directions of measurement.

The more negative skewness (R_{sk}) confirms that planed surfaces had a higher concentration of material near the top of the roughness profile, indicating a plateau-like surface (Fig. 2). Indeed,

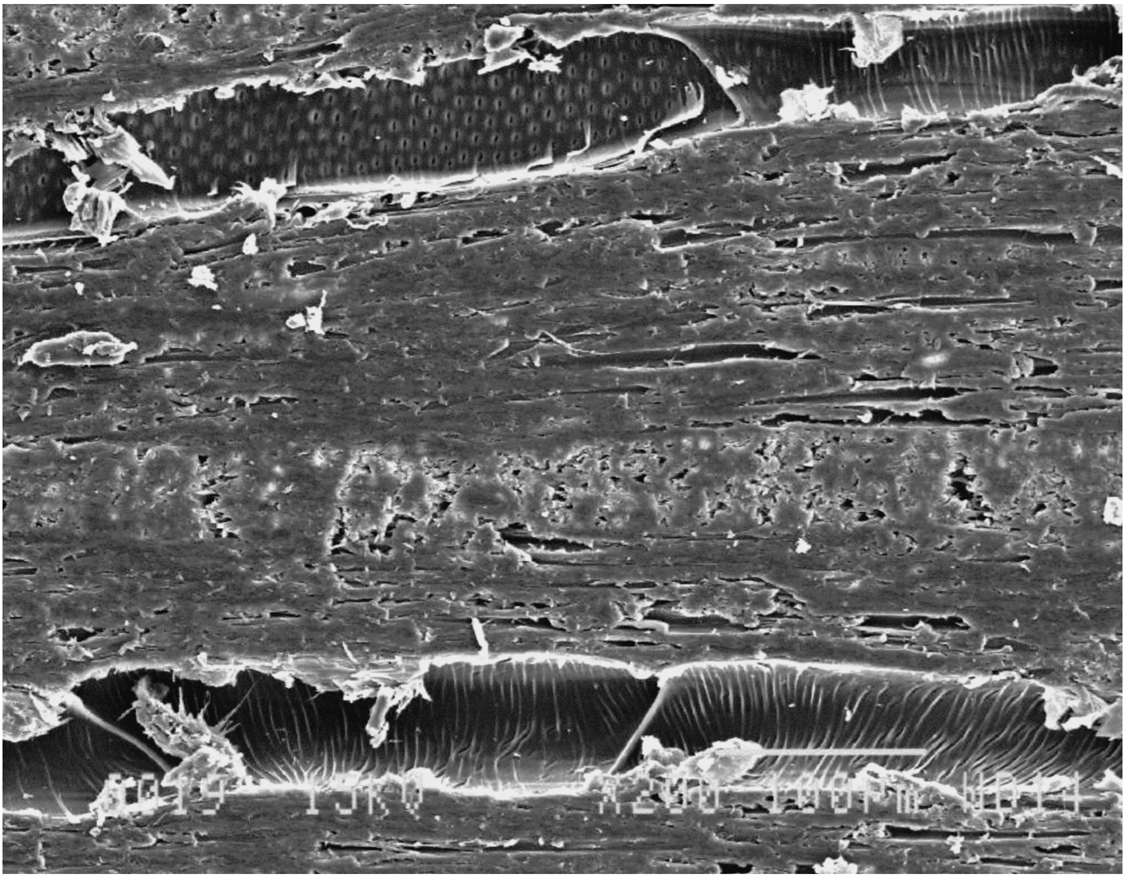

FIG. 2. Tangential surface of sugar maple wood peripherally planed with a freshly sharpened knife.

the scarce valleys on planed surfaces certainly corresponded to open lumens. On the other hand, sanded surfaces were characterized by smaller values of kurtosis (R_{ku}), which signify more numerous small and rounded peaks and valleys in the surface profile, corresponding to abrasive scratches.

Although planed surfaces provided more possibilities for coating penetration, it is noticeable that they offered a lower real surface for superficial mechanical anchorage than sanded surfaces did (Figs. 2 and 3).

Surface wettability

The results of wetting tests are summarized in Table 2. In general, water spreading was more pronounced along the grain, which confirms observations by Shi and Gardner (2001). Initial contact angles θ_i were higher on planed than on sanded surfaces. Sanded surfaces offered better conditions for water spreading, due to the fiberwise abrasive scratches (Fig. 3), which accelerated water conduction parallel to the grain. This effect was not observed for planed surfaces. The acceleration of liquid spreading by surface scratches has been reported in earlier studies (Garrett 1964; Wålinder 2000). As a result, the time required for complete wetting was considerably less on sanded surfaces than on planed surfaces (Table 2). The statistically significant higher k-values confirm that sanding facilitated spreading. A significant negative correlation was detected between initial contact angles and roughness average values, which corroborates the classi-

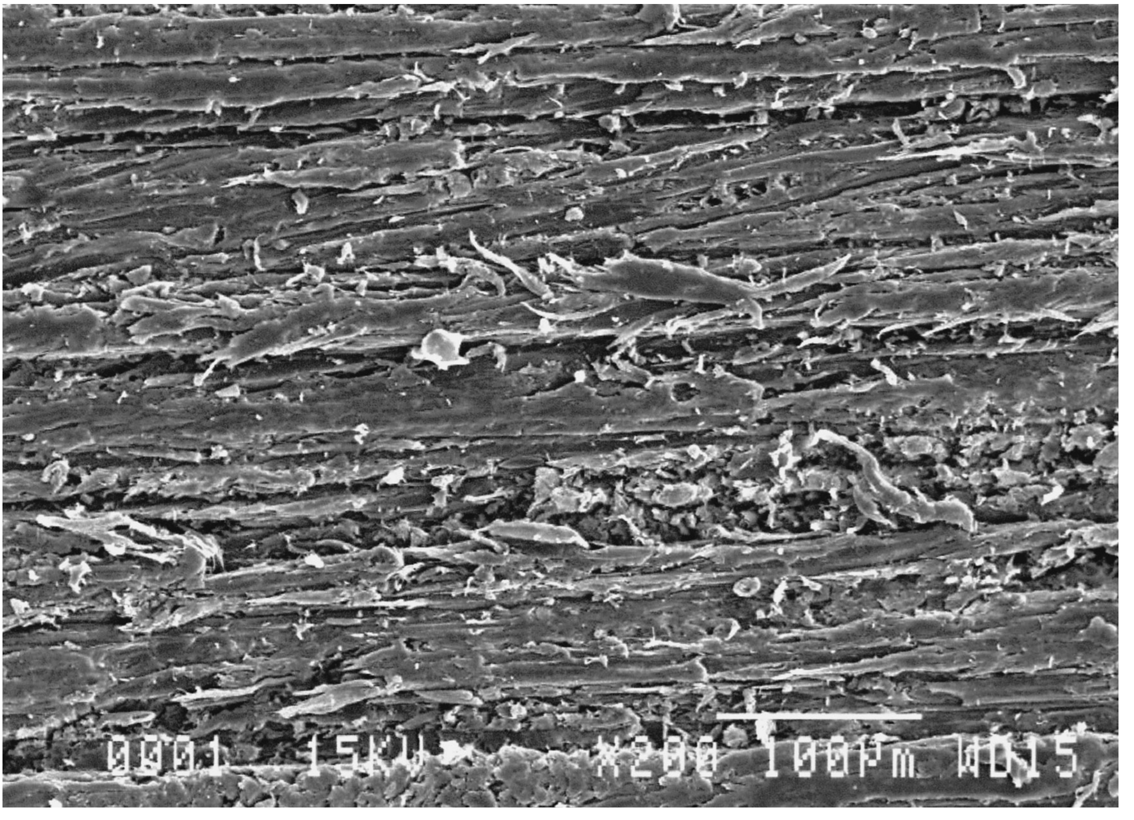

FIG. 3. Tangential surface of sugar maple wood sanded with a 120- 180-grit program.

TABLE 1. *Roughness parameters obtained for two surfacing methods applied to sugar maple sapwood*

	Perpendicular to grain[1]		Parallel to grain[1]	
Parameter	Planing	Sanding	Planing	Sanding
R_a (μm)	2.6 (0.1)[2] A[3] a	4.9 (0.2) B a	2.7 (0.3) A a	3.3 (0.2) A b
R_q (μm)	4.2 (0.2) A a	6.2 (0.3) B a	4.2 (0.5) A a	4.4 (0.2) A b
W_t (μm)	28.4 (6.2) A a	24.7 (5.2) A a	25.3 (3.5) A a	45.4 (3.9) B b
R_{sk}	–3.0 (0.2) A a	–0.7 (0.1) B a	–2.3 (0.3) A b	–0.4 (0.2) B a
R_{ku}	18.1 (1.5) A a	4.6 (0.6) B a	14.7 (2.5) A a	5.0 (0.6) B a

[1] Direction of measurement. Means of fourteen replicates.
[2] Standard error of the mean in parentheses.
[3] Means within a row followed by the same letter are not significantly different at the 5% probability level. Upper case letters are for machining comparison, for each roughness measurement direction separately. Lower case letters are for roughness measurement direction comparison, for each machining treatment separately.

TABLE 2. *Wetting properties obtained for two surfacing methods applied to sugar maple sapwood.*

Surfacing treatment	Contact angle θ_i[1] (°)	Wetting time[1] (s)	k-value[1]	Surface energy[1] (dynes/cm)
Planing	52.1 (2.8)[2] A[3]	120.4 (23.7) A	0.12 (0.01) A	47.3 (2.2) A
Sanding	39.7 (1.9) B	21.3 (5.3) B	0.44 (0.04) B	56.6 (1.4) B

[1] Means of twenty-eight replicates (two droplets for each specimen).
[2] Standard error of the mean in parentheses.
[3] Means within a column followed by a different letter are significantly different at the 5% probability level.

cal theory in that roughness tends to decrease contact angles lower than 90° (Table 3). Furthermore, roughness averages were negatively correlated with wetting times and positively correlated with k-values, indicating that roughness enhanced the wetting properties (Table 3). Other researchers have previously associated better wettability to higher surface roughness (Wenzel 1936; Dolenko et al. 1974).

The surface energies provided by the Berthelot's combining rule depend on the surface tension of the testing liquid. An accurate estimation of the surface energies would require the analysis of a series of liquids (Wu 1982). Therefore, values shown in Table 2 must be regarded as critical surface tensions for wetting by water. Sanding produced surfaces with significantly higher energies than those observed on planed surfaces. The oxidation of wood extractives could have been increased by the high temperatures produced by friction of abrasive grains on the surface. The increase of wood surface energy by means of oxidation has been previously reported (Gray 1964; Podgorski et al. 2000; Wålinder 2000).

Interfaces and coating films

Planing with a freshly sharpened unjointed knife produced surfaces and subsurfaces virtually free of damage, given that crushing occurred only in the most outward cell layers (Fig. 4). In contrast, sanding produced a deeper layer of crushed and collapsed cells (Fig. 5). Several authors have suggested that the severity of damage to the surface and subsurface is associated with the magnitude of normal cutting forces (Jokerst and Stewart 1976; Stewart and Crist 1982; Hernández and de Moura 2002). Normal cutting forces are higher in sanding than in planing, owing to the negative rake angle of abrasive grains (Stewart and Crist 1982). This fact explains the higher severity of damage observed on sanded surfaces.

The percent of coating penetration was higher in planed (8.8%) than in sanded surfaces (4.6%). The PU sealer penetrated mainly via vessels (Figs. 4 and 6), and sound cells opened up in the surface. The lack of totally opened vessels on the sanded surfaces has certainly contributed to the scarce coating penetration. The importance of vessels as paths for fluid penetration in wood has been previ-

TABLE 3. *Statistical correlations obtained among wetting properties, roughness, film characteristics and adhesion performances for sugar maple sapwood coated with a high-solids PU after two surfacing methods.*

Parameter	Wetting time (s)	k-value	Surface energy (dynes/cm)	Ra[3] (μm)	Global ranking (1 to 28)	Pull-off adhesion (MPa)
θ_i (°)	0.637[1] 0.001[2]	–0.555 0.001	n/a	–0.518 0.005	–0.085 0.668	–0.403 0.041
Wetting time (s)		–0.544 0.001	–0.640 0.001	–0.598 0.001	–0.294 0.129	–0.520 0.007
k-value			0.547 0.001	0.811 0.001	0.002 0.991	0.564 0.003
Surface energy (dynes/cm)				n/a	0.085 0.668	0.404 0.041
Ra[3] (μm)					–0.248 0.203	0.616 0.001
Global ranking (1 to 28)						–0.423 0.031

[1] Pearson correlation coefficient (r), for correlations between two continuous variables, and Spearman correlation coefficient (r), for correlations between Global ranking (ordinal variable) and any other variable.

[2] Prob. > |r| under H_o: $\rho = 0$.

[3] Roughness average measured perpendicular to the grain. Among the roughness parameters and measurement directions studied, the cross-grain R_a presented the highest correlation coefficients (r).

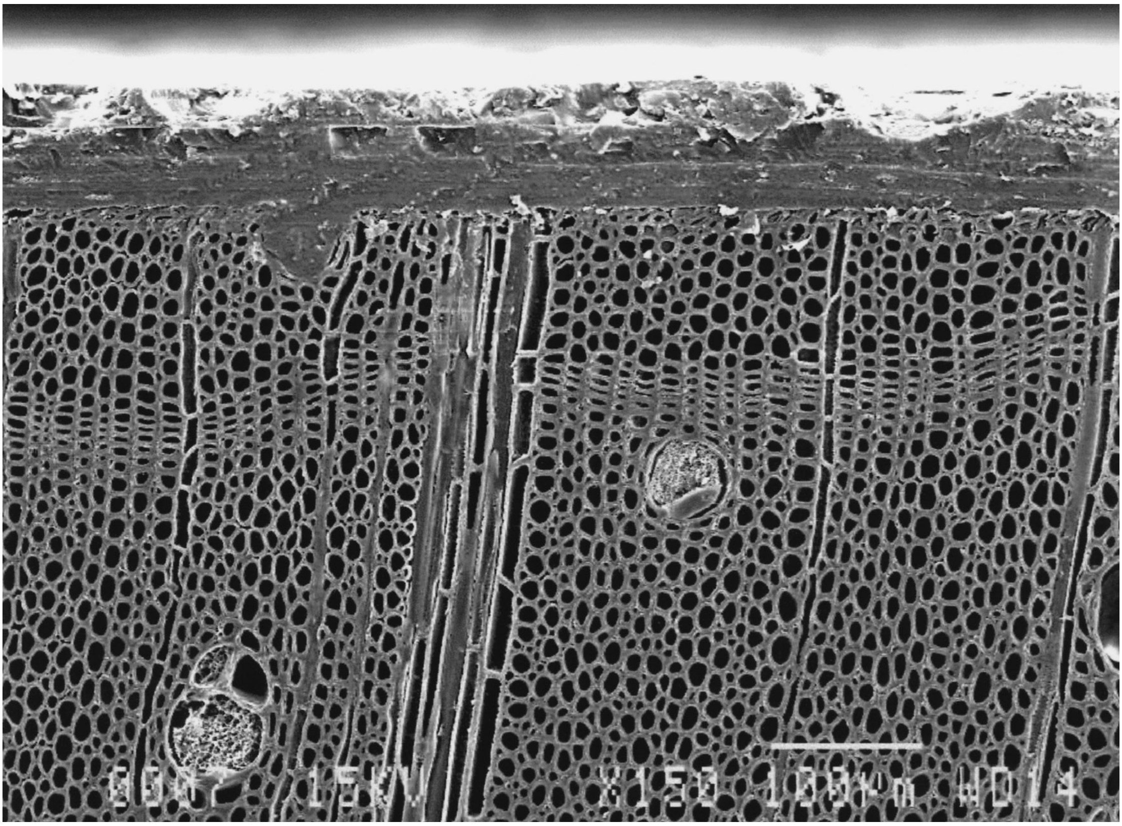

FIG. 4. Transverse SEM micrograph of a sugar maple surface peripheral planed with a freshly sharpened knife and coated with polyurethane.

ously reported (Vasishth et al. 1974; de Meijer et al. 1998). Ray cells have not shown to be important paths of penetration in the surfaces studied.

The presence of air bubbles in the coating film/substrate interface is a primary aspect of non-wetting systems. In this study, no air bubbles could be observed in the film/wood interfaces. This fact indicates that wetting was satisfactory for both types of surfaces. The pressure produced by rolls during coating application assured good wetting despite the relatively high PU sealer viscosity (Collett 1972).

Adhesion

The PU coating adhered better on sanded than on planed surfaces. Despite good wetting and penetration, adhesion was very weak between planed wood and the coating studied. For instance, most of the planed surfaces presented adhesive failures during microtome cutting for SEM observations (Fig. 6). These failures were not observed during preparation of sanded specimens. Vasishth et al. (1974) also observed that strongly adhered coatings did not separate from the wood surface even during sectioning for SEM observations.

After the accelerated aging treatment, the planed surfaces presented the most severe adhesive failures (Fig. 7). In general, coating failures and wood cracks occurred at the end edges of samples. Failures initiated predominantly near wood cracks whereby water infiltrated through the interface and formed hydrogen bonds with cellulose molecules, removing gradually the coating film from the surface (Lewis and Forre-

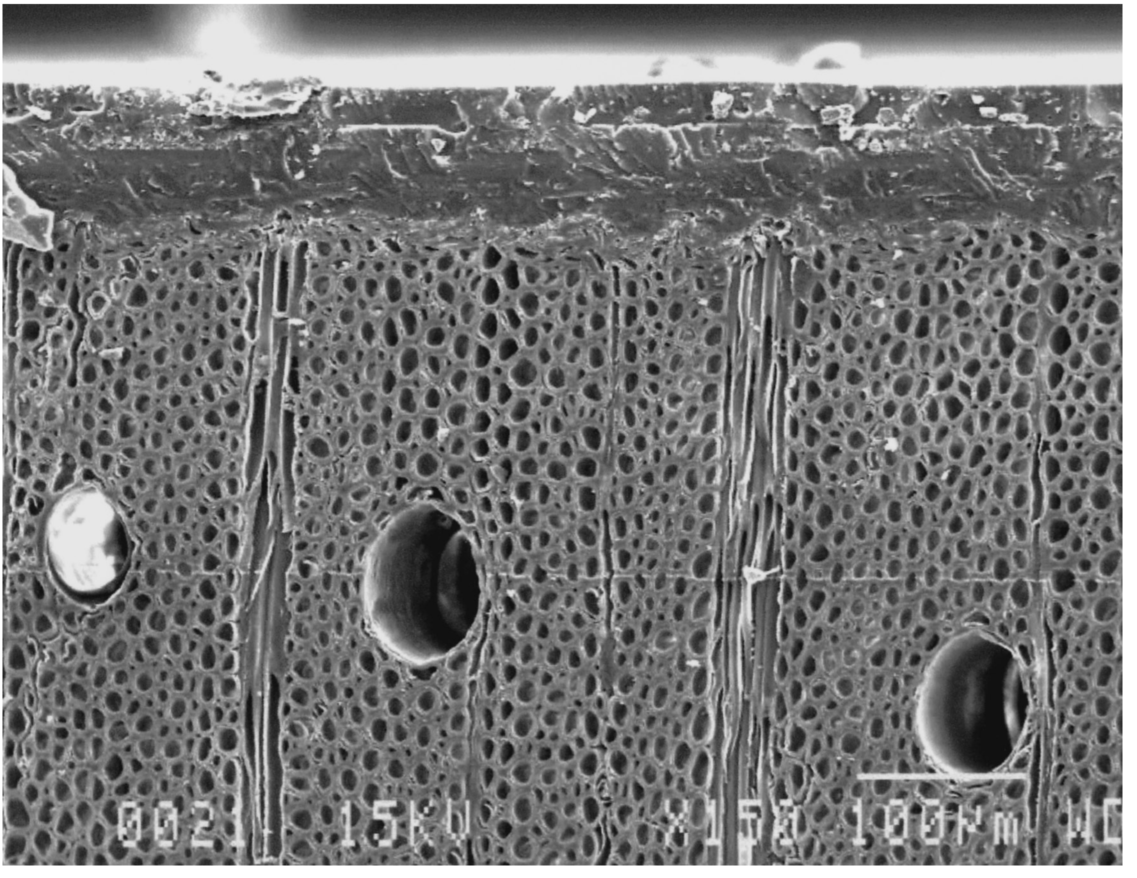

FIG. 5. Transverse SEM micrograph of a sugar maple surface sanded with a 120- 180-grit program and coated with polyurethane.

stal 1969; Yalinkiliç et al. 1999). This effect was less pronounced on sanded surfaces (Fig. 7). As a result, pull-off adhesion was significantly higher on sanded (7.1 MPa) than on planed surfaces (4.5 MPa). The correlations among wetting properties, roughness, film characteristics, and adhesion performances are presented in Table 3. A significant correlation was detected between the pull-off adhesion and the aging-resistance of films, as expressed by the global ranking. However, we observed that severely cracked specimens occasionally showed relatively good adhesion values, whereas the most aging-resistant films were necessarily related to high pull-off adhesion. In fact, the incidence of severe cracks in denser woods may not be an informative portrait of the actual loss of adhesion (Williams and Feist 1994).

There are no references available or direct evidences in this work indicating the presence of chemical linkages between wood and coatings. Hence, we could affirm that mechanical bonding was the major adhesion factor. The smooth zones of crushed fibers produced by peripheral planing couldn't contribute to good mechanical anchorage (Fig. 2). Therefore, mechanical bonding on planed surfaces was mainly associated to the coating penetration into opened vessels and sound cells. However, the amount of penetration was not sufficient to obtain a strong bond. As a result, pull-off failures occurred principally in the film/wood interface (Fig. 8).

The strongest adhesion on sanded surfaces may be explained by the presence of microfibrils torn out from cell walls by abrasive grains (Fig. 3). These fibrils have certainly diffused

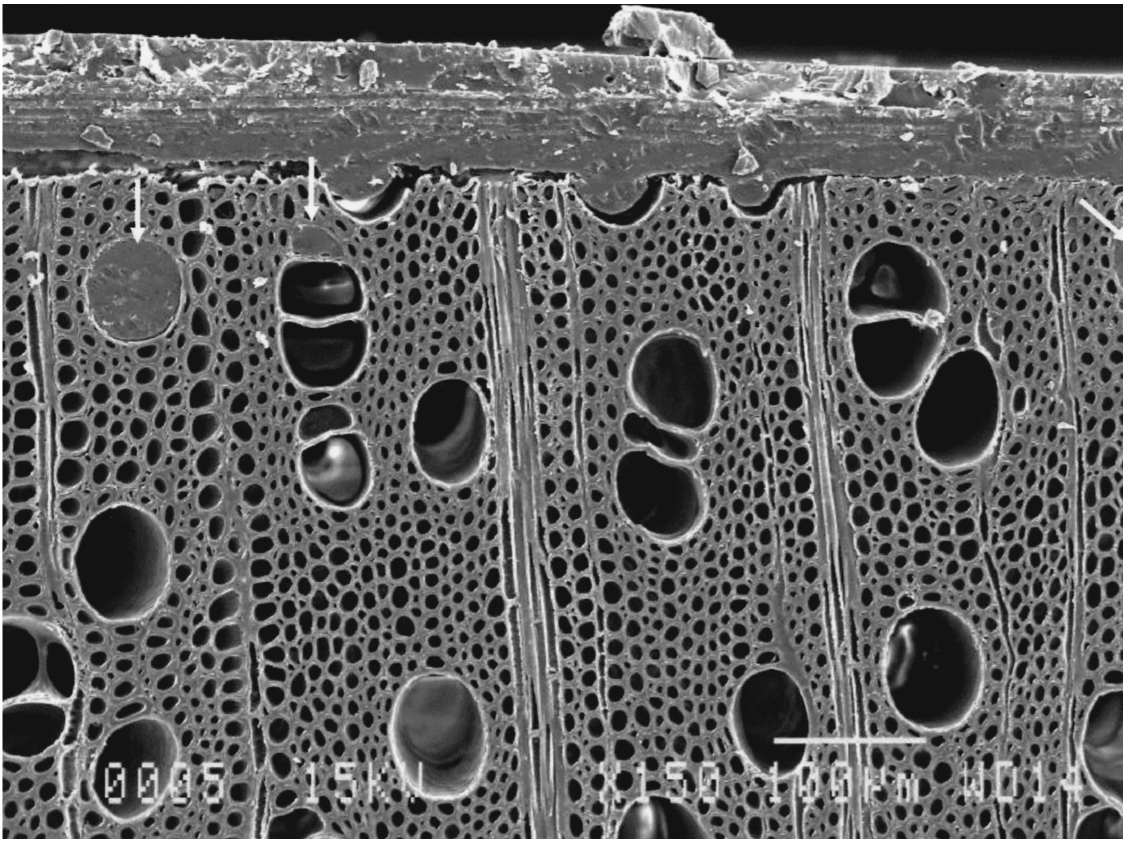

FIG. 6. Adhesive failure of PU coating caused by the razor blade during SEM preparation. Arrows indicate vessels filled with PU sealer. Apparently, the extent of penetration was not sufficient to obtain satisfactory adhesion.

through the liquid coating, so maintaining the film satisfactorily bound to the wood surface after curing. There are evidences that molecular entanglements (Lewis and Forrestal 1969) have occurred between the abrasive torn-out wood fibrils and the PU coating. This phenomenon is explained by the diffusion theory of adhesion, which may be regarded as a mechanical theory at a molecular level. According to Lewis and Forrestal (1969), diffusion may be an important adhesion mechanism on rough and porous surfaces. When diffusion occurs, adhesion takes place in a three-dimensional interface and is directly proportional to the length and number of molecules crossing the interface. In this case, a composite of polymer and wood is observed as a transition between wood and coating (Backman and Lindberg 2002). Owing to this interface characteristic, adhesive failures were rarely observed on sanded surfaces. Failures were predominantly cohesive and propagated through damaged cells at surface and subsurface, which behaved as a mechanical weak boundary layer. In fact, the test dollies pulled-off from sanded specimens showed a considerable amount of fibers pulled out from the surface (Fig. 8), which corroborates the effectiveness of the mechanical anchorage and the relative weakness of the crushed cell layers. Furthermore, increased roughness caused by torn-out micro-fibrils and abrasive scratches provided a greater actual surface available for other adhesion mechanisms. These facts are confirmed by the significant positive correlation detected between the surface roughness average, measured across the grain, and the pull-off adhesion of films (Table 3).

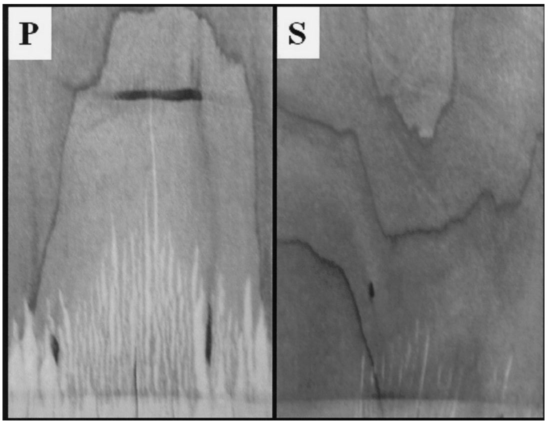

FIG. 7. Typical matched planed (P) and sanded (S) specimens showing different conditions after accelerated aging.

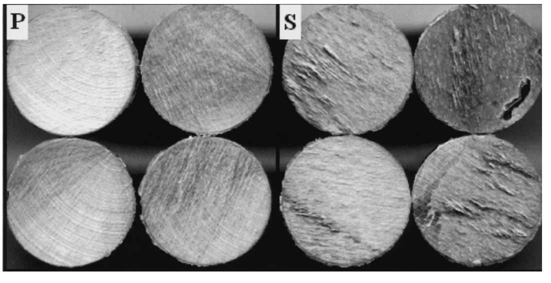

FIG. 8. Pull-off test dollies showing the coating interfaces holding fibers pulled out from the surface. At the left-hand side, four representative dollies pulled-off from planed surfaces (P); at the right-hand side, four dollies pulled-off from sanded surfaces (S).

All wetting parameters studied were significantly correlated with pull-off adhesion. Among these parameters, the k-value was the most significantly correlated with pull-off adhesion, followed by the wetting time and, finally, by the initial contact angle and the critical surface energy for wetting by water (Table 3). Wetting parameters showed, however, lower Pearson's correlations than those obtained by the roughness average. These results confirm the possibility of predicting the adhesion ability of a wood surface by the means of wetting and roughness analyses. Moreover, the aging-resistance of coating appeared to be directly related to pull-off adhesion.

CONCLUSIONS

Coating penetration was not sufficient for optimal adhesion on peripheral straight-knife planed surfaces. For these surfaces, further research on different coatings is required to enhance adhesion on smooth crushed zones. On the other hand, sanded surfaces showed a greater actual surface available to bonding. Good mechanical anchorage was guaranteed by the micro-fibrils torn out from cell walls by abrasive grains. Fibrillation is desirable for adhesion, but it has to be limited to an extent in that it cannot be considered as a machining defect, i.e., the fuzzy grain.

Further researches on surfacing methods producing different levels of fibrillation are needed. The effects of different types of abrasive minerals and their dimensions on the adhesion of coating films should also be studied. Furthermore, the effect of penetration cannot be ignored as a strategy of coating anchorage. Surfacing methods producing surfaces with a higher amount of opened cells could probably allow enough penetration. In this context, the development and optimization of alternative crushing-free surfacing methods would also be important.

Surface wetting properties and roughness were good criteria for evaluating coating adhesion as observed in previous works. Among the parameters studied, the time taken to complete wetting, the k-value and the roughness average (R_a) measured across the grain were the most correlated with coating adhesion. Pull-off adhesion, in turn, was a good index for distinguishing coating aging-resistances.

ACKNOWLEDGMENTS

The authors thank Alpha Barry, Robert Beauregard, Isabelle Duchesne, Manon Gignac, Richard Lepine, Bernard Riedl, and Jun Zheng for valuable assistance as well as Forintek Canada Corp. and Les Industries PG for technical support during tests. This research was supported by the National Scientific and Technological Development Council of Brazil and by the Natural Sciences and Engineering Research Council of Canada.

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