Surface Preparation of Wood for Application of Waterborne Coatings

Véronic Landry
Pierre Blanchet

Abstract

Year after year, water-based coatings gain market share due to new regulations on volatile organic compound emissions and voluntary certification programs. Work still has to be done on wood surface preparation, however, for water-based finishes to become truly reliable. In this research, water-based and solvent-based coatings were applied to edge-glued panels of yellow birch (*Betula alleghaniensis* Brit.). Sandpaper grits from 150 to 280 were used to prepare wood surfaces prior to coating application. A first series of specimens was prepared with a wiping stain and a second series with a spray stain. Contact angle measurements showed that surface preparation—more precisely the sandpaper grit—strongly affects water wettability and hence coating adhesion. Adhesion was found to change with the contact angle of the water. It was found that using a 150-grit sandpaper leads to unfilled wood cavities, high contact angles, and poor coating adhesion. At the opposite end of the range, using a 180-grit sandpaper leads to good wetting and good adhesion. In our tests, surface preparation had no significant effect on the color of systems using a spray stain. With a wiping stain, however, the grit of the sandpaper was found to affect the color of the specimens.

There is a global trend to limit volatile organic compound (VOC) emissions caused by the use of organic solvents in many industries, including the coating industry. Worldwide, regulations on VOC emissions from paints and coatings are becoming more stringent. Year after year, new finishes with low VOC emissions score significant market share gains. UV-cured coatings, powder coatings, high solids coatings, and water-based coatings are the main alternatives to solvent-based coatings traditionally used in many industries such as metal, automotive, and wood (Turner and McCrillis 1996, Marshall and Fields 2000). Water-based techniques are among the most popular alternatives for the North American furniture and kitchen cabinet industries (Marshall and Fields 2000). Hydrodispersible or hydrosoluble resins, mostly acrylics or urethanes, are added to water and polar solvents at approximately 30 percent by weight (Anonymous 2007). The resulting coatings present a lower organic solvent content (VOC compliant) than the solvent-based systems and meet most regulations. These are not the only benefits of water-based technology. Reduced fire hazard leads to lower insurance premiums as well as lower risks to human health and the environment (Roux 2003). Water-based systems show good gloss retention and reduced yellowing. They can be applied with the same equipment as solvent-based coatings and emit virtually no odors. However, some issues still limit market penetration for water-based coatings. Higher product costs, a limited color range, and lower productivity due to slow drying are among the drawbacks of this technology. Moreover, they are still associated with poorer appearance as compared with solvent-based products. Two factors contribute to make water-based finished wood components less attractive. One is the lower transparency of water-based resins, which leads to a hazy or milky appearance (Charron 1998, Roux 2003). The other is wood grain raising.

Sanding is among the most commonly used surface preparation techniques in the furniture and kitchen cabinet industries (Lister 1948). The suppliers of water-based coatings suggest changes in wood sanding operations in order to improve final appearance, and the manufacturers must ensure that these changes lead to good adhesion of the coating to the substrate as well as a better appearance. If sanding is performed with very fine–grit sandpaper, adhesion problems may occur. It is well known that an increase in surface roughness enhances wettability and adhesion (Garrett 1964, Huntsberger 1964, Lewis and Forrestal 1969, Couvrat 1990, de Meijer and Militz 1998, de Meijer et al. 2001) as high roughness facilitates liquid spreading by capillarity. If, on the other hand, sanding is too coarse, adhesion problems may also occur (Lewis and

The authors are, respectively, Research Scientist and Research Leader, FPInnovations Secondary manufacturing, Québec City, Québec, Canada (veronic.landry@fpinnovations.ca [corresponding author], Pierre.blanchet@fpinnovations). This paper was received for publication in May 2010. Article no. 10-00011.

Forest Prod. J. 62(1):39–45.

Forrestal 1969). Hernandez and Cool (2008) studied the effect of three surface preparation methods, helical planing, face milling, and sanding, on the adhesion of water and solvent-based coatings. Their studies showed that sanding produced the lowest surface roughness, with wetting properties being lower than helical planning and higher than face milling. Sanded specimens also incurred more severe surface and subsurface damage (de Moura and Hernández 2006a, 2006b, 2006c, 2007).

Many studies have shown that penetration into the substrate as well as adhesion vary with the types of coating applied (Rodsrud and Sutcliffe 1994; Nussbaum et al. 1998; Rijckaert et al. 2001a, 2001b), so that benchmarking water-based systems against solvent-based ones, as tested in this study, should be done carefully. Molecular interactions between the wood surface and the coating are also important in achieving good adhesion, as are the resin used in the coating and the thinner (water or organic solvent; Zisman 1972).

Work remains to be done to meet market needs in terms of appearance and adhesion. The aim of this study was to determine optimal surface preparation for a water-based sealer and lacquer system on yellow birch (*Betula alleghaniensis* Brit.) wood, and to compare the resulting properties against a solvent-based system. Both of the systems selected for this work are commercially available to the furniture and kitchen cabinet industries.

Materials and Methods

Raw materials and specimen preparation

Solid wood panels, 30 by 30 cm, were manufactured from Select grade yellow birch lumber. The edge-glued panels were assembled with polyvinyl-acetate adhesive (Nacan Wood Lok 40-025A) as per adhesive manufacturer recommendations and paneling practice (Bandel 1995, Suchsland 2004). The panels were conditioned to constant weight at 20°C and 50 percent relative humidity to reach an equilibrium moisture content of 8 percent.

As shown in Table 1, two coating systems were used in this project, one water-based and the other solvent-based, both provided by AkzoNobel. For an assessment of optical properties, wiping and spray stains were used with both systems. The solid content (wt/wt) of the stains used were 12.3 percent (F15-0077), 4.7 percent (F19-0049), 20 percent (F15-0076), and 7.2 percent (F15-0075). The water-based stains contained different alcohols and glycols: dipropylene glycol monomethyl ether, 1-butoxy-2-propanol, isobutanol, 1-propoxy-2-butanol, 2-methyl-1,3-propanediol, 1-ethoxy-2-propanol, 1-methoxy-2-propanol, and 1,2-ethanodiol. The solvents used for the solvent-based stains were acetone, *n*-butyl acetate, xylenes, 2-butoxyethanol, 1-methoxy-2-propanol, toluene, naphta, isobutanol, 1,2,4-trimethylbenzene, butan-1-ol, and 4-hydroxy-4-methyl-2-pentanone.

The wood panels were sanded in a triple belt Costa sander with P100-, P120-, and P150-grit sandpaper. Each panel was then cut into 15 by 15-cm smaller panels, one for each stain and coating system. Further sanding steps were performed with a Sioux orbital sander at 12,000 RPM and an orbital of 3/32 inch. Table 2 summarizes the experimental program in terms of lacquer, stain, and grit selection.

The sealed specimens were lightly sanded with 320-grit sandpaper before topcoat application as performed in the industry to prevent raised grain. All applications were conducted with the support of the coating system manufacturer (AkzoNobel).

Surface analysis

Contact angle measurements served to assess specimen wettability for every surface preparation. The contact angle of water was measured 15 seconds after contact with the wood. The demineralized water used for these experiments was taken from the Nanopure Diamond system. This water was filtrated with a 0.2-μm filter. The total organic carbon value was lower than 10 ppb. Water droplets were 4 μL in volume. Fifteen replications were considered, and the apparatus used was an FTA 200 from First Ten Angstroms. The specimens were tested within 24 hours after the surface preparation.

Wood surface morphology was assessed by scanning electron microscopy (SEM). All specimens coated with a water-based system and surface prepared with 150- and 280-grit sandpaper, the two extreme conditions in this study, were observed by SEM. All specimens coated with solvent-based products were also observed by SEM (sanding grit 180). Samples were metalized with a thin gold layer (10 to

Table 2.—Surface preparation for the different coating systems.

Coating solvent	Type of stain	Orbital sanding sandpaper grit
Water based	Wiping stain	150
		180
		220
		180-240
		180-220-280
	Spray stain	150
		180
		220
		180-240
		180-220-280
Solvent based	Wiping stain	180
	Spray stain	180

Table 1.—Description of coating systems used in this study.

	Water-based systems		Solvent-based systems	
	Wiping stain	Spray stain	Wiping stain	Spray stain
Stain	Aquawipe Cognac F15-0077	W/B Stain F19-0049	Cognac Stain F15-0076	S/S Cognac F15-0075
	Film build-up		Film build-up	
Sealer	Aqualac II 423-44XX (acrylic lacquer)		Plastiseal Low VOC 53-8003 (precatalyzed sealer)	
Lacquer	W/B 2K Topcoat 680-40L5W-743 (acrylic-urethane lacquer)		Chemglide N.Y. U4 26 432-3625 (catalyzed lacquer)	
Identification	EW	EP	SW	SP
Thinner	Water		Solvent	

15 nm). Images were recorded at 30 kV. SEM observations were performed on a JEOL 6360.

Coating adhesion performance was assessed as per American Society for Testing and Materials (ASTM) Standard D4541 (ASTM 1995). Instead of a portable adhesion tester, a universal testing machine from Instron was used, the constant pulling speed being 50 mm/min. Three measurements were performed per specimen on 10 replications (for a total of 30 measurements).

Optical analysis

The aesthetics of wood products are of primary importance, especially in furniture and kitchen cabinets. This section presents the methods used to assess the appearance of the systems tested.

Color assessments to compare the different coating systems were conducted with a colorimeter (color-guide 45/0 BYK-Gardner) using CIELab coordinates (Commission Internationale de l'éclairage), i.e., the L*, a*, and b* color components. The spectral range of this equipment is 400 to 700 nm with a resolution of 20 nm. The illuminant used for these experiments was the D65. Four measurements were performed per specimen on 10 replicates for every surface preparation and system (water-based or solvent-based).

For all the parameters studied, a Waller-Duncan multiple comparison test was performed on the data when applicable.

Results

Contact angle and wettability

The wettability of yellow birch surfaces sanded with 150- to 280-grit sandpaper was assessed through contact angle measurements. It was assumed that a lower contact angle indicated superior wettability and hence better spreading of the finishing material and better adhesion.

Sanding a wood surface generally leads to good wettability due to the scratching effect of the sandpaper. Water tends to follow these scratches, rapidly spreading over the surface and wetting it (de Moura and Hernández 2005, Hernandez and Cool 2008). Sanding also leaves many lumens open, so that the coating can penetrate into the surface and generate good mechanical interlocking.

Figure 1 presents a curve showing the variation of contact angle as a function of time for a surface prepared with 150-grit sandpaper. Similar curves were obtained for the other sandpaper grits studied. As can be observed on this graph, contact angles were large at the beginning of the test (around 70°), and they decreased rapidly. Garrett (1964) and Walinder (2000) reported better wettability (low contact angle) with coarser grit (increasing roughness), but different results were observed in this study. Figure 2 compares water contact angles after 15 seconds for the different surface preparations. The specimen prepared with 150-grit sandpaper showed the lowest wettability. Couvrat (1990) mentioned that excessive roughness could harm the wetting process because the coating may not be able to completely cover the wood surface and unfilled cavities may lead to weaknesses in terms of coating adhesion. Moreover, wood grain raising can be observed when water-based coatings are used, which could explain the excessive roughness and lack of adhesion. In fact, observation of the roughness of a wood sample by SEM showed that some surface cavities were not filled by the coating, as illustrated in Figure 3. Entrapped air was also observed at the interface by Lewis and Forrestal (1969). On the other hand, the specimen prepared with 180-grit sandpaper and a water-based coating showed the best

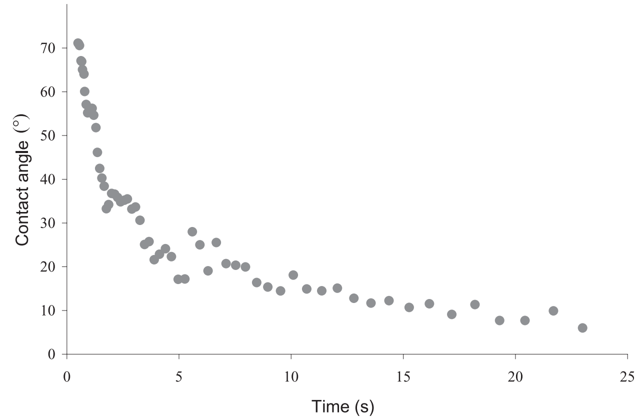

Figure 1.—Contact angle as a function of time for wood surfaces sanded with 150-grit sandpaper—typical curve.

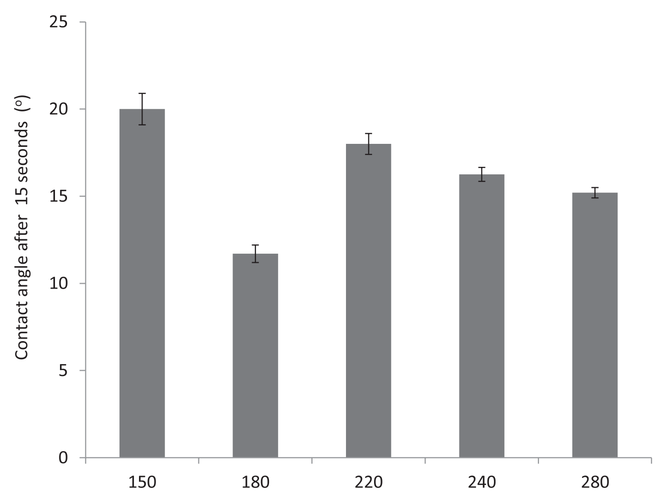

Figure 2.—Contact angle after 15 seconds as a function of sandpaper grit.

Figure 3.—Scanning electron microscopy image of wood cavities unfilled with coating.

wetting performance (lowest contact angle). With this preparation, the coating was able to follow the sandpaper scratches without the problems involved in wetting deeper scratches such as those caused by 150-grit sandpaper.

Adhesion

Adhesion of a coating to the substrate is critical performance criterion for coating systems. The technique used is described in the ASTM D4541 test method. Adhesion is related to wettability, so the better the wettability, the better the coating spread. The literature suggests that water-based coatings achieve better adhesion that solvent-based coatings (Hernandez and Cool 2008). Figure 4 indicates average perpendicular strengths for spray stain coating systems. The highest strength was observed with the water-based coating and a P180 sandpaper preparation. This correlates with the contact angle observations previously presented. A multiple comparison statistical test (Duncan grouping) demonstrated that P240 and P280 sandpaper preparations led to statistically comparable adhesion values at a probability level of $\alpha = 0.05$. Fine sandpaper preparation may lead to weak mechanical anchorage, but such was not the case in this study, as indicated in the SEM micrograph shown in Figure 5. In this figure, mechanical anchorage can be seen, with coating penetrating into the lumens.

The solvent-based coating with P180 sandpaper preparation and the water-based coating with P220 sandpaper preparation yielded lower adhesion than water-based coatings with P180, P240, and P280 preparation. Solvent-based coatings do not cause wood fibers to swell and open up the grain of the wood, which explains why mechanical anchorage may be expected to be lower.

The P150 surface preparation generated the highest contact angle and therefore poorer wetting than with the other surface preparation processes. It also yielded the lowest coating adhesion observed with the water-based systems. This can be explained by the fact that the coating was unable to cover the greatly increased surface area of the wood, which weakened the coating films.

Figure 6 displays average perpendicular strengths for systems prepared with a wiping stain. These differ from the results reported above for systems using a spray stain. The solvent-based system produced the best adhesion performance according to the Duncan grouping. With the water-based systems, the 280 sandpaper preparation (EW280) led to the lowest adhesion. In this last case, SEM observation

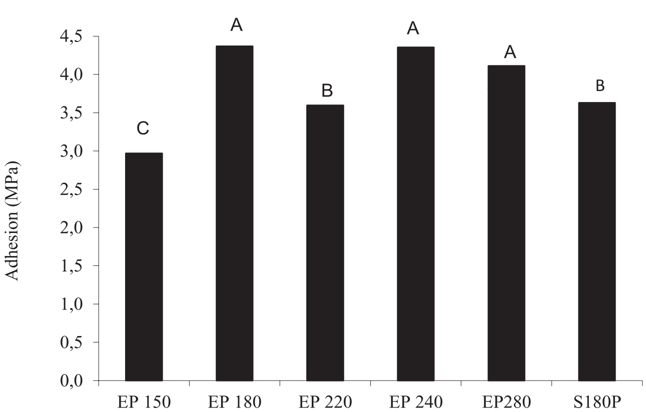

Figure 4.—Perpendicular adhesion strength for systems using spray stain in relation to surface preparation (same letter means that the adhesion is not significantly different according to Duncan grouping).

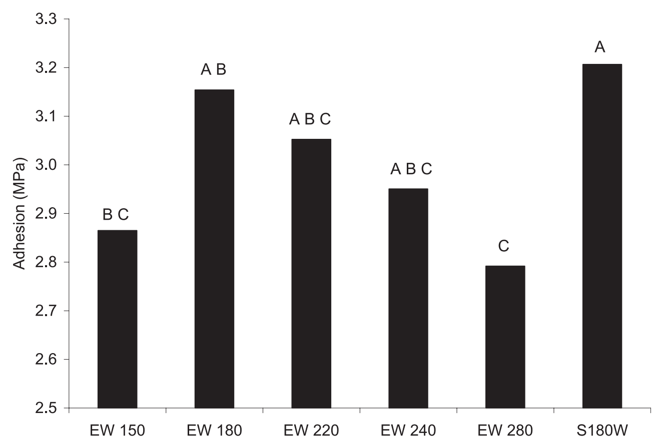

Figure 6.—Perpendicular adhesion strength for systems using wiping stain in relation to surface preparation (same letter means that the adhesion is not significantly different according to Duncan grouping).

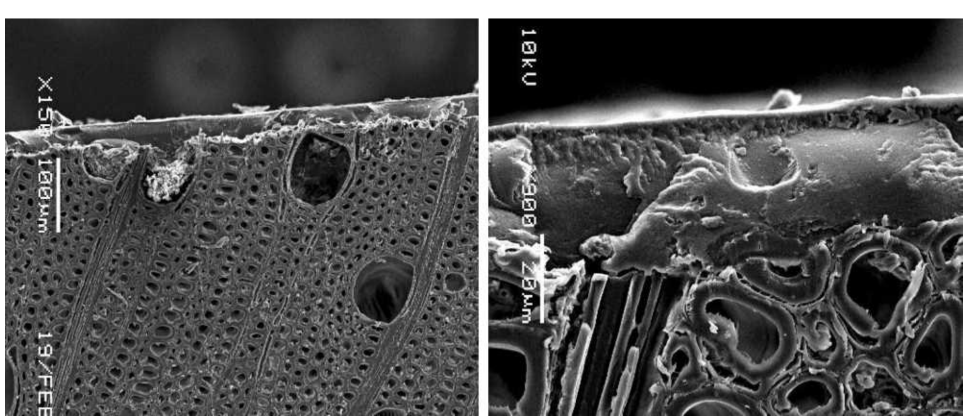

Figure 5.—Scanning electron microscopy photographs showing limited mechanical anchorage of the coating system when sanded with fine sandpaper (×150 and ×900).

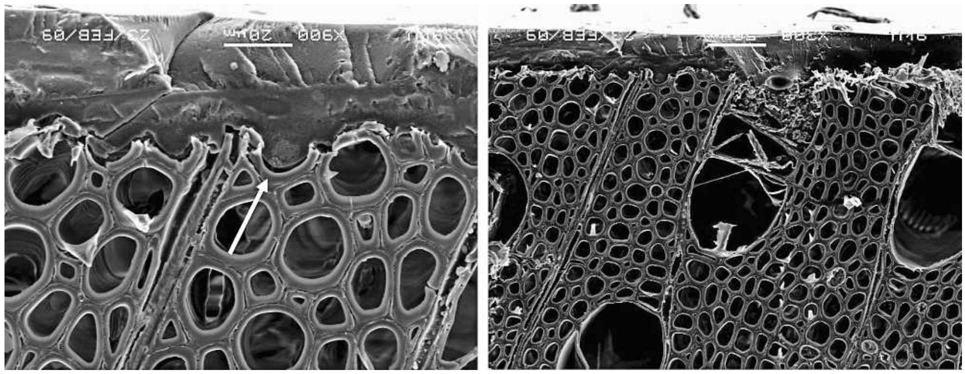

Figure 7.—Scanning electron microscopy photographs showing poor coating-to-wood bond when surface is prepared with fine sandpaper.

revealed areas where the coating was not bonded to the wood (Figure 7). Furthermore, the surface available for mechanical anchoring is lower in the case of the P280 preparation (EW280), which is consistent with lower adhesion strength.

Optical characterization

The color of the final product is a particularly critical issue to manufacturers considering a switch from solvent-based to water-based coatings. Adjustments to the surface preparation are one avenue for preserving acceptable aesthetic properties, and color is a good tool to assess performance.

Spray stain system.—Figure 8 presents the color components, L*, a*, and b* as a function of surface preparation. Since L* appeared to be the most widely variable color component, a Duncan multiple comparison test was performed to characterize significant differences. The results of this test are presented in Table 3. The only water-based system yielding the same lightness as the solvent-based finish was the one obtained with a 220-grit sandpaper (EP220). Other surface preparations produced darker colors. Specimens EP180, EP280, and EP150 yielded similar results. EP150 and EP240 also produced comparable, albeit darker, lightness measurements. In the absence of any trends between finish lightness and sandpaper grit, it is difficult to ascribe variations to surface preparation or to wood lightness differences. More work should be performed to confirm these results. Spray stains leave a film on the wood surface so that the color differences should be more difficult to measure for these surfaces compared with the systems prepared with a wiping stain.

Table 3.—Duncan test on the effect of surface preparation on color lightness with a spray stain.

Surface preparation[a]	L*	Duncan[b]
SP180	32.88	A
EP220	32.36	A
EP180	30.37	B
EP280	30.18	B
EP150	29.34	BC
EP240	29.03	C

[a] SP = solvent-based spray stain; EP = water-based spray stain.
[b] The same letter indicates no significant difference.

Wiping stain systems.—Figure 9 presents the color components as a function of surface preparation. For the specimens prepared with the wiping stain, wood grain proved very critical for final appearance. Table 4 summarizes the results obtained for the lightness component L* following a Duncan statistical test. None of the surface

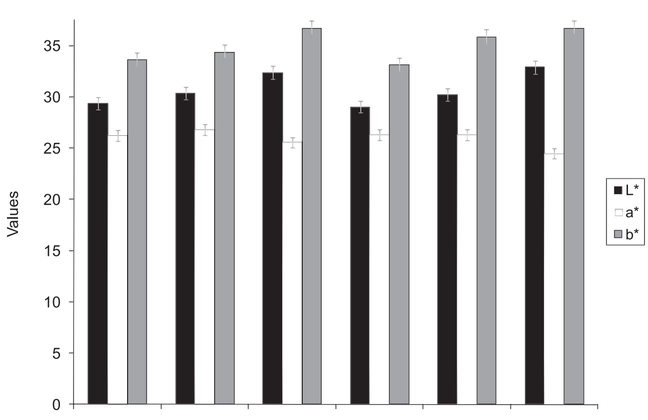

Figure 8.—CIELab color component in relation to surface preparation (spray stain).

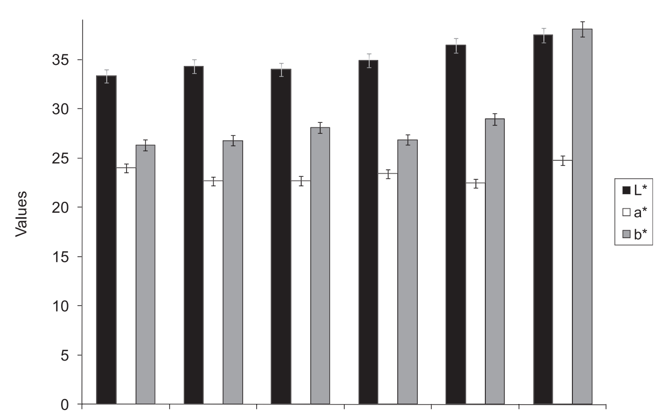

Figure 9.—CIELab color component in relation to surface preparation (wiping stain).

Table 4.—Duncan test on the effect of surface preparation on color lightness with a wiping stain.

Surface preparation[a]	L*	Duncan[b]
SW180	37.47	A
EW280	36.43	B
EW240	34.86	C
EW180	34.29	CD
EW220	33.99	DE
EW150	33.32	E

[a] SW = solvent-based wiping stain; EW = water-based wiping stain.
[b] The same letter indicates no significant difference.

preparations used with water-based systems proved comparable to the solvent-based system (SW180). EW280 came closest but remained statistically different. It may be of interest to note that a trend could be observed between finish lightness and sandpaper grit; the coarser the grit, the darker the finish. These results show that in order to achieve similar wood color when using water-based and solvent-based finishes, it is necessary to do a series of tests on wood with the proper wood surface

Conclusions

Water-based coatings are gaining market share in wood product finishing. Stricter regulations on VOCs have convinced the furniture and kitchen cabinet industries to move in the same direction. Water-based lacquers are expected to generate the same aesthetic quality as solvent-based lacquers. The aim of this study was to determine the optimum wood surface preparation process for water-based lacquers and compare it with a solvent-based system.

The best (i.e., lowest) contact angle was obtained with 180-grit sandpaper for water-based coatings. With a rougher surface (150-grit), wetting problems were observed. Poor wetting was attributed to unfilled wood cavities. When using products of solvent-based finishes, sanding with a 150-grit sandpaper is a common industry practice. However, it was found in this study that a finer sanding is necessary when using water-based finishes. A 180-grit sandpaper preparation has also led to the highest perpendicular adhesion strength for spray coating systems. This confirmed the efficiency of the wetting with this surface preparation, which produced the best results for water-based wiping stain systems but performed at a lower level than the reference solvent-based system.

Surface preparations leading to good coating adhesion tended to affect the aesthetic quality of the finish. With spray stain systems, only the 220-grit sandpaper treatment yielded a lightness level similar to that of the solvent-based coating. With wiping stains, none of the preparation treatments were able to yield a lightness level similar to that of the solvent-based wiping stain system. With wiping stains, all surface preparations led to a darker appearance.

As a final conclusion, it would appear difficult to switch from a solvent-based to a water-based system without some sort of a compromise. Good wettability and adhesion strength with a water-based system (sprayed or wiped) may not be achievable without some loss in coating lightness.

It is generally accepted that a ΔE, which is the total color difference between two samples or two points, of one or lower is undetectable by the human eye. ΔE found for the different samples were all around one, which is close to the limit to detect color differences between samples.

Acknowledgments

The authors thank FPInnovations and its industry members for their financial support. Special thanks to AkzoNobel and SIA abrasives for material and technical support.

Literature Cited

American Society for Testing and Materials (ASTM). 1995. Standard test method for pull-off strength of coatings using portable adhesion testers. ASTM D4541. ASTM, Philadelphia.

Anonymous. 2007. Guide de recommandations: les finitions aqueuses en ameublement. Centre Technique du Bois et de l'Ameublement, Paris.

Bandel, A. 1995. Gluing Wood. CATAS. 301 pp.

Charron, A. 1998. Water-Based Finishes. Taunton Press, Newtown, Connecticut. 155 pp.

Couvrat, P. 1990. Le collage moderne. Hermès, Paris. 63 pp.

de Meijer, M. and H. Militz. 1998. Wet adhesion measurements of wood coatings. *Holz Roh- Werkst*. 56(5):306.

de Meijer, M., K. Thurich, and H. Militz. 2001. Quantitative measurements of capillary coating penetration in relation to wood and coating properties. *Holz Roh- Werkst*. 59(1/2):35–45.

de Moura, L. F. and R. E. Hernández. 2005. Evaluation of varnish coating performance for two surfacing methods on sugar maple wood. *Wood Fiber Sci*. 37(2):355–366.

de Moura, L. F. and R. E. Hernández. 2006a. Characteristics of sugar maple wood surfaces produced by helical planing. *Wood Fiber Sci*. 38(1):166–178.

de Moura, L. F. and R. E. Hernández. 2006b. Effects of abrasive mineral, grit size and feed speed on the quality of sanded surfaces of sugar maple wood. *Wood Sci. Technol*. 40(6):517–530.

de Moura, L. F. and R. E. Hernández. 2006c. Evaluation of varnish coating performance for three surfacing methods on sugar maple wood. *Forest Prod. J*. 56(11/12):130–136.

de Moura, L. F. and R. E. Hernández. 2007. Characteristics of sugar maple wood surfaces machined with the fixed-oblique-knife pressure-bar cutting system. *Wood Sci. Technol*. 41(1):17–29.

Garrett, H. E. 1964. Contact angles and their significance for adhesion. *In:* Proceedings of the Conference Held at Northampton College of Advanced Technology, EC1, D. J. Alner (Ed.), March 23–24, 1964, Northampton, England. pp. 18–41.

Hernandez, R. E. and J. Cool. 2008. Evaluation of three surfacing methods on paper birch wood in relation to water- and solvent-borne coatings performance. *Wood Fiber Sci*. 40(3):459–469.

Huntsberger, J. R. 1964. The relationship between wetting and adhesion. *Adv. Chem*. 43:180–188.

Lewis, A. F. and L. J. Forrestal. 1969. Adhesion of coatings. *In:* Treatise on Coatings. Characterization of Coatings: Physical Techniques. Vol. 2. Marcel Dekker, New York. pp. 57–98.

Lister, S. 1948. Sanders and Sanding. Lomax, Erskine & Co., London. 76 pp.

Marshall, A. M. and J. L. Fields. 2000. Case Studies: Low-VOC/HAP Wood Furniture Coatings. US Environmental Protection Agency, Washington, D.C.

Nussbaum, R. M., E. J. Sutcliffe, and A. C. Hellgren. 1998. Microautoradiographic studies of the penetration of alkyd, alkyd emulsion and linseed oil coatings into wood. *J. Coat. Technol*. 70(878):49–57.

Rijckaert, V., M. Stevens, and J. Van Acker. 2001a. Effect of some formulation parameters on the penetration and adhesion of water-borne primers into wood. *Holz Roh- Werkst*. 59(5):344–350.

Rijckaert, V., M. Stevens, J. Van Acker, M. de Meijer, and H. Militz.

2001b. Quantitative assessment of the penetration of water-borne and solvent-borne wood coatings in Scots pine sapwood. *Holz Roh-Werkst*. 59(4):278–287.
Rodsrud, G. and E. J. Sutcliffe. 1994. Alkyd emulsions—Properties and application. Results from comparative investigations of penetration and ageing of alkyds, alkyd emulsions and acrylic dispersions. *Surf. Coat. Int*. 77(1):7–16.
Roux, M.-L. 2003. The impact of the European VOC directive on the coating process of the furniture industry. *In:* RadTech Europe Conference and Exhibition, November 3–5, 2003, Berlin.
Suchsland, O. 2004. The Swelling and Shrinking of Wood—A Practical Technology Primer. Forest Product Society, Madison, Wisconsin. 189 pp.
Turner, S. L. and R. C. McCrillis. 1996. Evaluation of Alternative Chemical Strippers on Wood Furniture Coatings. US Environmental Protection Agency, Research Triangle Park, North Carolina. 68 pp.
Walinder, M. E. P. 2000. Wetting phenomena on wood—Factors influencing measurements of wood wettability. Doctoral thesis. KYH-Royal Institute of Technology, Stockholm.
Zisman, W. A. 1972. Surface energetics of wetting, spreading, and adhesion. *J. Paint. Technol*. 44(564):41–57.