Adhesion of Waterborne Paints to Wood

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Using a modified torque technique, statistically significant differences in adhesion values were detected for waterborne model paints on wood as a function of moisture content, waterborne preservative, and after fungal inoculation. Change in a paint constituent sometimes resulted in a significant change in the adhesion value. The adhesion values of the alkyd emulsion paints tested decreased after inoculation with a blue stain fungus. On the contrary, the adhesion values of the acrylic dispersion paints tested became significantly higher after inoculation.

INTRODUCTION

The adhesion of surface coatings to wood is important for its long-term performance and is a subject of great interest to scientists and to the paint industry. Adhesion is an interfacial phenomenon where physical and chemical forces operate.[1] The degree of success achieved in forming a coating with good adhesion depends not only on the nature of the paint but also on the way the surface was prepared.[2-6] Painted wood has been described as a three-component system consisting of paint, wood, and the paint/wood interface. According to Brown and Garnishe[7] and Williams et al.,[8] the critical factor for maintaining long-term paint performance is the interface.

Holloway and Walker[9] developed a technique for measuring the adhesion force between a paint film and wood that has been broadly accepted and used (torque method). The technique was modified by Ahola[10] for measuring the adhesion between paint and a machine planed wood substrate. Low percentages of adhesion failure at the fracture zone have been previously reported when measuring adhesion of paint to wood.[8,11-13] Mechanical anchoring is probably very important for the adhesion of paints to wood, as has been shown for coated paper.[14] The mechanical adhesion due to penetration of paint into wood has also been suggested as an important factor.[15] However, the interlocking of surfaces caused by surface roughness of wood prepared by mechanical means is complex and not easy to define.[16] For a painted sawn wooden surface, high percentages of wood and cohesive paint failures as opposed to adhesion failures may be closely related to a strong mechanical anchoring at the surface.

Blue stain fungi are known to colonize wood and wood surface coatings,[17-18] and to penetrate into the paint/wood interface.[20] Blue stain fungi are also considered to be an important cause of deterioration of paint films.[18,20] The adhesion of paint films to wood has been shown to decrease with increasing moisture levels.[21]

Preservative treated wood has been considered to be a good substrate for coating.[22-26] If a specific wood preservative which provides efficient protection against microorganisms also could increase the adhesion between paint and wood, the long-term performance of the painted preservative treated wood should improve.

The objective of this investigation was to study the adhesion of different well-specified waterborne paints on hand planed wood. The use of hand planed wood was expected to result in reduced mechanical anchoring of paint films to the wood surface. The effects of moisture, waterborne wood preservatives, or infection by a blue stain fungus on the adhesion of paints were also studied.

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EXPERIMENTAL

Painted Wood Samples

Rectangular wood samples of Norway spruce (*Picea abies*) sapwood were cut tangentially to the growth rings. The outer flat surface of the samples was hand planed with a sharp surgical knife. The samples were 1 to 2 mm thick and of variable size, and were planed just before painting to ensure a fresh surface. Samples were painted twice with a brush with a drying period of two days in between.

Table 1—Some Characteristics of the Paints Tested

Paints	Characteristics
Alkyd emulsion paints	
E1	Anionic surfactant (Elfan NS242)
E2	Nonionic surfactant (Berol 542) 5%
E3	Nonionic surfactant (Berol 542) 10%
Acrylic dispersion paints	
L1	Particle size 0.1 μm
L2	Particle size 0.4 μm

Waterborne Paints

Three alkyd emulsion paints and two acrylic dispersion paints of known composition were made by The Institute of Surface Chemistry (YKI), Stockholm, Sweden, in collaboration with the paint manufacturers. All paints contained TiO_2. The pigment volume concentration (PVC) was 20%.

The model alkyd emulsion paints were made with a resin based on the alkyd S78/70N, consisting of 73% tall oil fatty acids and 19% isophthalic acid. One paint was made using the anionic surfactant sodium laurylmyristylether (2) sulphate C12/C14 from Akzo (Elfan NS242). Two other paints were made using the nonionic surfactant ethoxylated fatty alcohol C11/C12 (Berol 542): one with 5% surfactant and the other with 10%. Some important characteristics of the alkyd emulsion paints are given in *Table* 1.

The two model acrylic paints contained an acrylic binder made of a copolymer of butylacrylate-methylmethacrylate-methacrylic acid (49% - 49% - 2%). The anionic surfactant sodium dodecylsulphate (1.2%) was used for dispersion. The solid content was 40.3%. Both dispersions were comparable to the commercial dispersion Multilobe 200 but varied with regard to particle size (*Table* 1).

Inoculation with a Blue Stain Fungus

A set of painted samples was exposed to the blue stain fungus *Sclerophoma pityophila* (Corda) v. Höhnel. Pure cultures of *S. pityophila* were grown on solid nutrient medium (1.5% w/v malt extract - 2.5% w/v agar) in petri dishes for 15 days. The painted samples were immersed in deionized water for one minute for uptake of moisture and placed in the petri dishes on top of the fungal cultures. The petri dishes were sealed with a plastic film (Parafilm "M" - American National Can) and incubated at 23 (±2) °C for five weeks.

Table 2—Some Characteristics of the Basic Composition of the Wood Preservatives Tested

Preservatives	Characteristics
P1	Copper and quaternary ammonium compounds
P2	bis-(N-Cyclohexyldiazeniumdioxid)-copper (Cu-HDO)
P3	Triazol
P4	Copper and Triazol
P5	Copper-, chrome- and arsenic (CCA)

Preservative Treated Samples

A set of samples was impregnated with five waterborne preservatives approved by the Nordic Wood Preservation Council (NWPC) for above ground use in Sweden (*Table* 2). The samples were left to soak in the preservative solutions for two days. After the soaking period 90% vacuum (10 kPa) was applied for 30 min followed by a pressure period of 30 min with a pressure of 10 bar (1 MPa). The samples were allowed to dry at room temperature for one week prior to painting with the alkyd emulsion paint E3 containing 10% nonionic surfactant. The samples were 1 to 2 mm thick and were hand planed, as described, just before painting to ensure a fresh surface.

Measurement of Adhesion

The adhesion between the paint film and the hand planed wood surface was determined by means of a torque method modified from Holloway and Walker[9] as described by Ahola.[10] In this shear technique, studs were glued on the painted samples using a solvent-free dual-component epoxy glue. After the glue was dried, a slot was drilled in the paint film around the studs until the wood surface was reached. The stubs were then removed using a recording torque wrench. The failure load was noted and the type of failure (glue, adhesion, wood failures, and cohesive paint failure) estimated visually as a percentage of the total area covered by the stud. Measurements for which glue failure exceeded 10% were rejected. The shear stress (adhesion value) was calculated using the equation $T = (16I)/(\pi d^3)$ where I is the measured torque (Nm), and d is the diameter of the stud (12.5 mm). A minimum of six replicate values was used for the calculation of each mean adhesion value. Adhesion values are given in MNm^{-2}.

The painted samples were conditioned at 65% RH for two weeks prior to the adhesion test. The samples were tested in two modes:

Dry: Taken directly from the conditioning room (65% RH)

Wet: Taken from the conditioning room and immersed in deionized water at 20°C for 25 min before testing.

Further Assessment of the Samples

After completion of the adhesion test, samples were taken from the failed surfaces, dried, mounted on studs, coated with gold, and examined using a Cambridge S150 scanning electron microscope.

Computerized image analysis was used to determine the percentage of adhesion failure of the paints on preservative treated wood samples. The software used was Image-Pro Plus for Windows™, Version 1.0A, purchased from Media Cybernetics.

A *t*-test was used for statistical evaluation of the significance of the results.

Table 3—Adhesion Values of the Paints Tested at 65% RH and after Immersion in Water for 25 Minutes

Paints	Adhesion Values					
	Dry Mode			*Wet* Mode		
	Mean (MNm^{-2})	S.D.	n	Mean (MNm^{-2})	S.D.	n
Non-Infected Samples						
E1	5.0	1.0	13	3.1	0.7	15
E2	3.5	1.1	8	1.4	0.5	19
E3	2.8	0.3	14	1.9	0.5	14
L1	9.0	1.0	15	3.3	0.8	15
L2	6.6	1.1	12	3.0	0.6	16
Blue Stain Infected Samples						
E1	3.9	1.4	11	3.0	1.2	12
E2	1.6	0.4	9	0.7	0.3	9
E3	2.8	0.5	8	1.7	0.6	10
L1	11.7	1.7	8	9.7	2.3	7
L2	—	—	—	6.8	3.0	7

S.D. = Standard deviation; n = number of replicates.

RESULTS

The adhesion values of the paints tested varied depending on the type of paint and moisture conditions. Results are summarized in *Table* 3. The number of determinations used for the calculation of a mean value varied from 7 to 19. In the *dry* mode the acrylic dispersion paints tested showed the highest values. The acrylic paint L1, with 0.1 µm particle size, showed the highest adhesion value, 9.0 MNm^{-2}. Paint E3, the alkyd emulsion paint with 10% nonionic surfactant showed the lowest value, 2.8 MNm^{-2}. In the *wet* mode the adhesion values of the alkyd emulsion paints and of the acrylic dispersion paint L2 decreased with almost 50%, and for the acrylic dispersion paint L1 with 70%. The statistical significance of the results is shown in *Table* 4. The mean values of the type of failure are summarized in *Table* 5. In the *dry* mode the predominant type of failure for the acrylic dispersion paints and for the alkyd emulsion paints containing an anionic surfactant was adhesion failure. The alkyd emulsion paints with nonionic surfactant showed predominance of cohesive paint failure. All paints showed increased adhesion failure in the *wet* mode with only 1% cohesive paint failure for the alkyd emulsion paint E1, and the acrylic dispersion paints L1 and L2.

After exposure of the samples to cultures of *S. pityophila* the adhesion values of the alkyd emulsion paints decreased (*Table* 3). In contrast, the acrylic dispersion paints showed increased adhesion values. After fungal infection the acrylic paint with a particle size of 0.1 µm showed the highest adhesion value in the *dry* mode, 11.7 MNm^{-2}. No data is available for paint L2 with particle size 0.4 µm due to high percentage of glue failure resulting from the cuping and twisting of samples after conditioning at 65% RH. The alkyd emulsion paint containing five percent nonionic surfactant showed the lowest adhesion value. The adhesion values of the alkyd emulsion paints with nonionic surfactants were even lower in the *wet* mode. The adhesion values of the acrylic dispersion paints increased after infection. Very fine hyphae were seen growing from the wood substrate towards the paint film at the wood-paint interface (*Figure* 1a). Hyphae were also seen emerging from the walls of wood tracheids (*Figure* 1b), and growing within the paint film (*Figure* 1c). The film structure of the acrylic dispersion paints L1 and L2 is illustrated in two SEM micrographs (*Figures* 2a and 2b). Hyphae were also seen growing vigorously at the wood-paint interface of samples painted with the alkyd emulsion paints E1, E2, and E3 (*Figure* 1d). No hyphae penetrating or growing within these paint films were detected. Sporulating hyphae were seen at the interface zone of samples painted with paint E2.

The types of failure of inoculated samples are summarized in *Table* 6. The acrylic dispersion paint with particle size 0.1 µm showed predominance of wood failure both in the *dry* mode and in the *wet* mode. The acrylic dispersion paint with particle size 0.4 µm showed predominance of adhesion failure in the *wet* mode. No data concerning the *dry* mode is available for this paint. The alkyd emulsion paints showed predominance of adhesion failure both in the *dry* and *wet* mode, with exception of paint E3 which showed high percentage of cohesive paint failure in the *dry* mode.

Table 4—Statistical Analysis of the Variance of the Adhesion Values Obtained for the Paints Tested Assuming Unequivalence of Results

Analysis of Variance

Modes	Paints				
	E1	E2	E3	L1	L2
Dry and Wet	***	***	***	***	***
Dry inf. and Wet inf.	**	***	**	ns	NT[a]
Dry and Dry inf.	ns	***	*	*	NT[a]
Wet and Wet inf.	ns	**	ns	***	*

Significance levels: $P < 0.05$ = * ; $P < 0.01$ = ** ; $P < 0.001$ = *** ; Non-significant = ns; NT = Not Tested

(a) No data is available for paint L2 with particle size 0.4 µm due to the high percentage of glue failure resulting from the cuping and twisting of samples after conditioning at 65% RH.

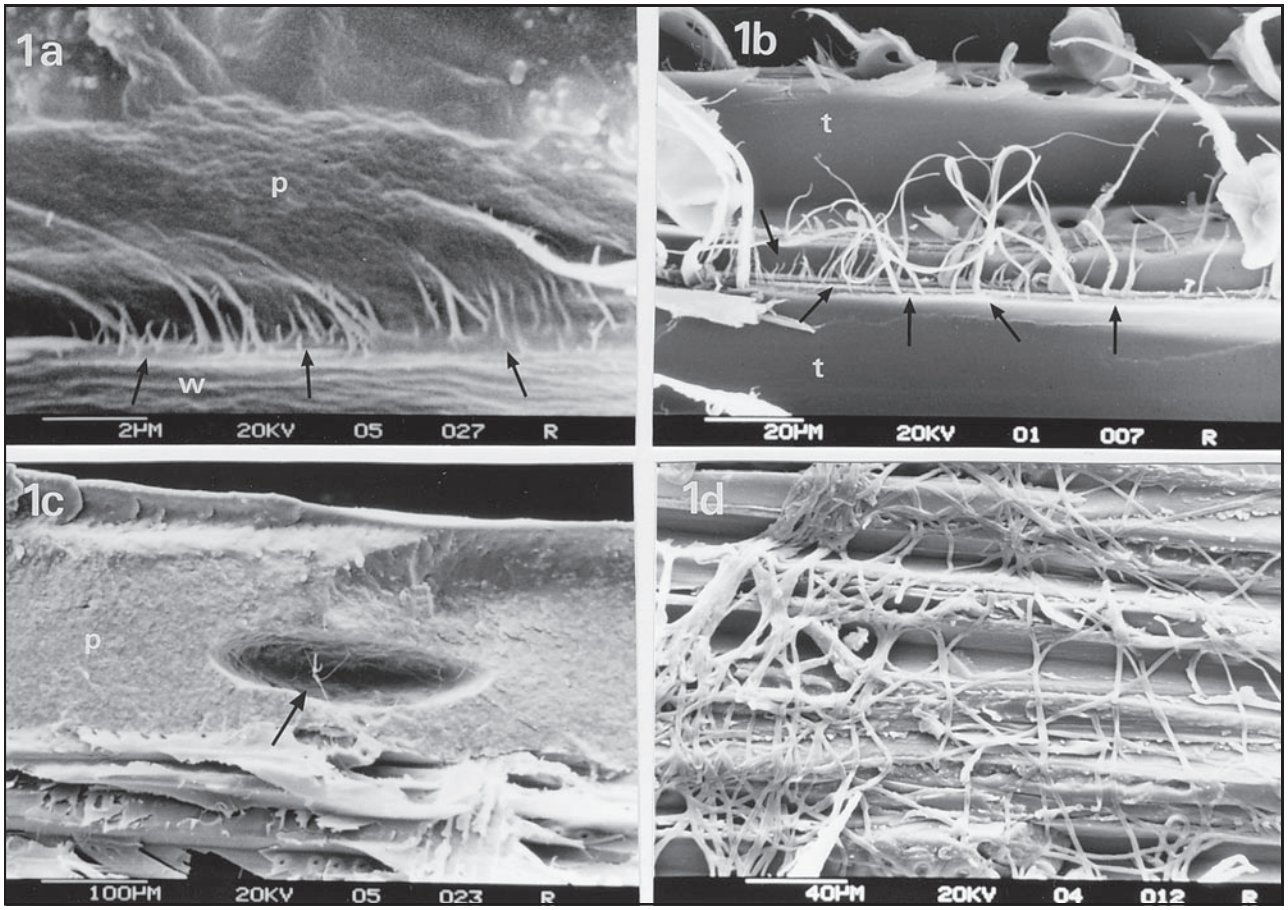

Figure 1—SEM views of samples infected with Sclerophoma pityophila: (a)—transversal cryo-fracture of a sample painted with the acrylic dispersion paint with particle size 0.1μm. The arrows point to fine hyphae growing from the wood substrate (w) into the paint film (p); (b)—surface of wood painted with the acrylic dispersion paint with particle size 0.1μm after detachment of the paint film. The arrows point to hyphae emerging from the cell walls of the wood tracheids (t); (c)—transversal section of a sample painted with the acrylic dispersion paint with particle size 0.1μm. The arrow points to hyphae growing in a cavity within the paint film (p); (d)—surface of wood after detachment of a paint film of an alkyd emulsion paint with anionic surfactant. Hyphae can be seen growing at the paint/wood interface.

The adhesion values obtained from the preservative treated samples painted with the alkyd emulsion paint E3 were similar to the adhesion values obtained for paint E3 painted on non-preservative treated wood samples (*Table* 7). The number of accepted replications giving a mean value varied from 14 to 23.

Types of failure results for the painted preservative-treated wood samples are summarized in *Table* 8. Cohesive paint failure was the predominant type of failure among the samples in the *dry* mode. In the *wet* mode, adhesion failure increased for all painted preservative treated samples with the exception of the samples treated

Table 5—Visual Evaluation of the Types of Failure Produced During the Measurement of Adhesion Value Between Paint and Wood

	Dry Mode Type of Failure (%)			*Wet* Mode Type of Failure (%)		
Paints	Adhesion	Paint	Wood	Adhesion	Paint	Wood
Alkyd Emulsions						
E1	82	11	4	99	0	0
E2	13	79	7	91	8	0
E3	0	98	0	22	70	0
Acrylic Dispersions						
L1	99	0	1	99	0	1
L2	77	0	18	99	0	0

Table 6—Visual Evaluation of the Types of Failure Produced on Blue Stain Infected Samples During the Measurement of Adhesion Value Between Paint and Wood

	Infected Samples					
	Dry mode Type of failure (%)			*Wet* mode Type of failure (%)		
Paints	Adhesion	Paint	Wood	Adhesion	Paint	Wood
Alkyd Emulsions						
E1	80	6	0	96	2	0
E2	86	13	0	67	33	0
E3	24	72	0	62	36	0
Acrylic Dispersions						
L1	29	3	64	31	1	68
L2	—	—	—	76	3	14

with preservative P1 (copper and quaternary ammonium compounds). The percentages of adhesion failure were determined by means of computerized image analysis (*Table* 9). Similar values were determined visually (*Table* 8).

Some interesting features of the preservative treated samples were observed with SEM. Parts of the tracheid cell walls of the samples treated with P4 (Cu + Triazol) remained adherent to the surface of the paint film after detachment (*Figure* 3a). *Figure* 3b shows imprints of the wood structure left on the surface of the paint film of samples treated with P1 (copper and quaternary ammonium compounds).

By examining the samples with SEM after detachment of the paint films with the torque method, damages on the tracheid cell walls of samples painted with the two acrylic dispersion paints L1 and L2 were observed. Influence of the twisting motion of the torque method was revealed (*Figures* 4a and 4b). Sparse mechanical anchoring of the paint film was observed on the samples painted with the alkyd emulsion paints tested (*Figure* 4c).

DISCUSSION

Adhesion of paint films to wood has been evaluated by different methods including peeling, pull-off, and shear tests.[8,9,12,21,27-30] Some of these methods evaluate differences in the adhesion strength over a painted surface. The torque method used in this study is one of the methods that measures the force needed to detach a paint film from a wooden surface, which can be expressed in MNm^{-2}.

The main aim of the present study was to measure differences in the adhesion strength of five model paints as a function of moisture content and paint composition. In order to decrease the contribution of mechanical anchoring, hand planed wood surfaces were used.

Typical adhesion values obtained from earlier studied alkyd emulsion paints and acrylic dispersion paints applied on machine planed wooden panels were 13 MNm^{-2} and 14 MNm^{-2} respectively at 65% RH, and 10 MNm^{-2} and 11 MNm^{-2} respectively at 90% RH.[21] The adhesion values obtained in this study for painted hand planed samples equilibrated at 65% RH were 5 MNm^{-2} or less for the three alkyd emulsion paints, and 9 MNm^{-2} or less for the two acrylic dispersion paints tested. Although these results are not really comparable because of differences in panel preparation, the lower adhesion values obtained in this study could be due to the smoother wood surface produced by careful hand planing. For coated paper, up to 80% of the adhesion value has been shown to depend on mechanical anchoring.[14] It is likely that mechanical anchoring due to surface roughness of wood might also be important for the adhesion of paints to wood. However, by using a smooth hand planed surface, it was thought that other components that influence adhesion could be studied. The results in this study accordingly showed higher percentages of adhesion failure.

Table 7—Adhesion Values for Preservative Treated Wood Painted with Alkyd Emulsion Paint E3

	Dry Mode			*Wet* Mode		
Preservatives	Mean (MNm^{-2})	S.D.	n	Mean (MNm^{-2})	S.D.	n
P1	1.8	0.4	16	2.0	0.6	15
P2	2.5	0.5	16	2.9	0.6	15
P3	2.4	0.4	23	1.8	0.5	20
P4	3.1	0.9	18	2.6	0.7	19
P5	2.8	0.9	18	2.7	0.6	21
Paint E3 on Untreated Wood	2.8	0.3	14	1.9	0.5	14

S.D. = Standard deviation; n = number of replicates.

Table 8—Visual Evaluation of the Types of Failure Produced During the Measurement of Adhesion Value Between Paint and Wood on Preservative Treated Samples Painted with Alkyd Emulsion Paint E3

	Dry mode Type of failure (%)			*Wet* mode Type of failure (%)		
Preservatives	Adhesion	Paint	Wood	Adhesion	Paint	Wood
P1	2	96	0	2	96	0
P2	7	87	1	44	54	2
P3	14	84	1	58	47	0
P4	4	93	0	18	76	3
P5	14	69	3	33	58	1
Painted E3 on Untreated Wood	0	98	0	22	70	0

The alkyd emulsion paints have lower adhesion values than the acrylic dispersion paints. The adhesion values obtained for the alkyd emulsion paints with the same basic composition but with different type and quantities of surfactant also differed. The use of the anionic surfactant sodium laurylmyristylether (2) sulphate C12/C14 from Akzo (Elfan NS242) resulted in higher adhesion values compared to the adhesion values of a paint with the same basic composition but containing the nonionic surfactant ethoxylated fatty alcohol C11/C12 (Berol 542). The most common type of failure for the paints with the nonionic surfactant was cohesive paint failure. These results indicate that the type of surfactant could influence the adhesion between coats or the intermolecular forces within the paint film. Adhesion between coats is known to be influenced by bulk and surface properties of the paint.[2]

After infection with *Sclerophoma pityophila* the adhesion values of the alkyd emulsion paints decreased, which is in accordance with the previous notion that fungal infection by blue stain fungi could cause paint disfigurement.[15,16,19,31] SEM observations showed hyphae growing vigorously at the paint/wood interface of the samples painted with the alkyd emulsion paints. This could be due to the weak adhesion of the paint films to the wood surface, which was confirmed by the adhesion measurements, thereby allowing hyphae to grow freely at the paint/wood interface. The initial moisture uptake prior to the exposure of the samples to *S. pityophila*, and the subsequent growth of the fungus might cause an increase in moisture content at the paint/wood interface which weakens the bond between the paint film and the wood surface.

The adhesion values of the two acrylic dispersion paints tested, which had the same basic chemical composition, were much higher than the adhesion values for the alkyd emulsion paints regardless of the particle size. Damage to the tracheid cell walls was visible with SEM after applying the torque method to wood painted with these paints. However, immersing samples painted with these two acrylic dispersion paints in water before testing resulted in lower adhesion values. These values are comparable to the adhesion values obtained from samples painted with the alkyd emulsion paint with anionic surfactant. The paint with particle size 0.1 µm gave an adhesion value of 9.0 MNm^{-2} and the paint with particle size 0.4 µm gave 6.6 MNm^{-2} at 65% RH. It thus seems that the particle size influences the adhesion of these acrylic paints. SEM micrographs of the internal structure of the paint films showed that the internal structure varied significantly depending on particle size. The structural differences between the acrylic dispersion

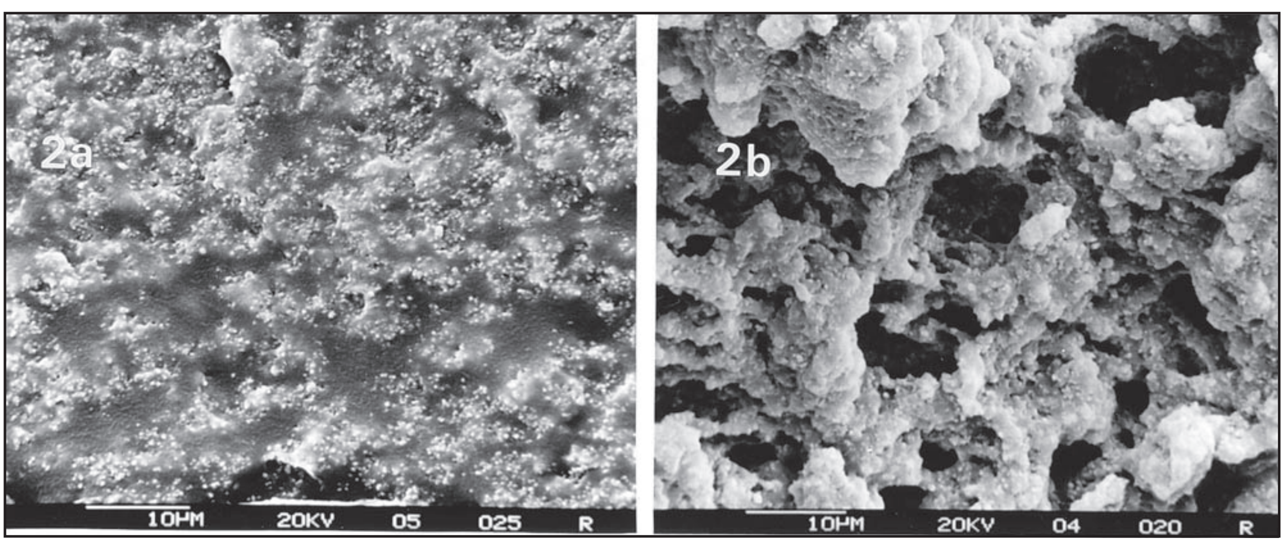

Figure 2—SEM views of cryo-fractures of an acrylic dispersion paint with particle size 0.1µm (a), and of an acrylic dispersion paint with particle size 0.4 µm (b).

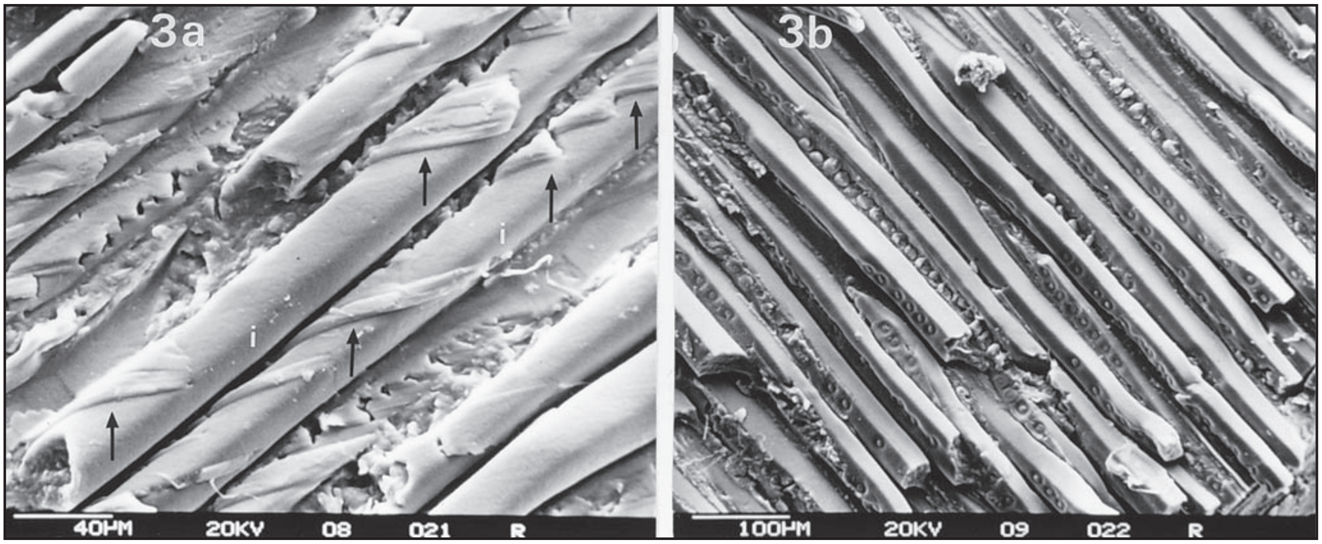

Figure 3—SEM views of the surface of paint films that have been in contact with preservative treated wood surfaces: (a)—Paint film detached from a sample pre-treated with the preservative containing copper and Triazol. The arrows point to parts of the tracheid cell walls that still adhere to the wood imprints (i) left on the paint film after detachment with the Torque method; (b)—Imprints of the wood structure left on the surface of the paint film of sample treated with the preservative containing copper and quaternary ammonium compounds.

paints with particle size 0.1 and 0.4 µm also might explain in part the differences in growth of discoloring fungi on these two paints and the differences in their moisture dynamic characteristics.[32,33] Somewhat surprisingly, the adhesion values of the two acrylic dispersion paints increased after infection with *S. pityophila*. This might be due to fungal growth from the wood into the paint films which could give an additional mechanical anchoring or due to interaction of paint film, wood, and substances produced by the fungus. As a consequence of the resulting decrease in adhesion failure, and of a possible effect of the fungus on the wood strength, a higher percentage of wood failure was recorded.

The differences in adhesion value for the acrylic paints with particle size 0.1 and 0.4 µm might be explained by differences in penetration and/or structure of the paints. However, the importance of surface coatings penetration into wood for the adhesion of paints is a matter of some controversy. Most scientists have considered penetration of surface coatings into wood to be of less importance for adhesion only causing unnecessary depletion of valuable binder.[3,18,34,35] On the other hand, some scientists have considered deep penetration to be useful because it enables the binder to interact with a larger contact area that should be beneficial to adhesion.[15,18]

The pretreatment of wood samples with waterborne wood preservatives prior to painting with the alkyd emulsion paint with 10% nonionic surfactant did not increase the adhesion value between paint and wood at 65% RH when compared to samples painted without pretreatment. Unfortunately, this paint showed low adhesion values when painted on untreated wood specimens if compared with the other test paints. The results could have been different if a paint with better adhesion properties had been used. However, some influence on the type of failure was observed with the preservative containing copper and quaternary ammonium compounds (P2). The pretreatment of samples with this preservative resulted in high percentages of cohesive paint failure which remained unaffected by the change in moisture level. This could be an effect of dimensional stabilization of the wood surface by the preservative.[21] The good quality of the imprints of the wood structure left on the surface of the paint film of samples treated with this preservative, as revealed by SEM, also indicates that the wettability of the paint on the treated wood might have been high during the formation of the paint film. These results imply that valuable information could be obtained by conducting a careful analysis of the type of failure, and surface conditions at the fracture zone, with the aid of SEM. Formulations containing copper and quaternary ammonium compounds have also resulted in improved paint performance in lap joint trials.[36] A preservative containing a combination of Cu and Triazol resulted in sporadic but strong adhesion sites between the paint film and the tracheid cell walls, as was clearly indicated by portions of the tracheid cell walls adhering to the paint film after the adhesion test. The results in this study indicate that wood preservatives may play a role in stabilizing the adhesion between paint and wood. If a specific wood preservative, which provides efficient protection against micro-organisms, also could increase the adhesion between paint and wood, particularly when subjected to moisture, the long-term performance of painted preservative treated wood would be expected to improve.

CONCLUSIONS

The results in this study revealed differences in the adhesion values of model waterborne paints to wood which were related to paint composition, moisture conditions,

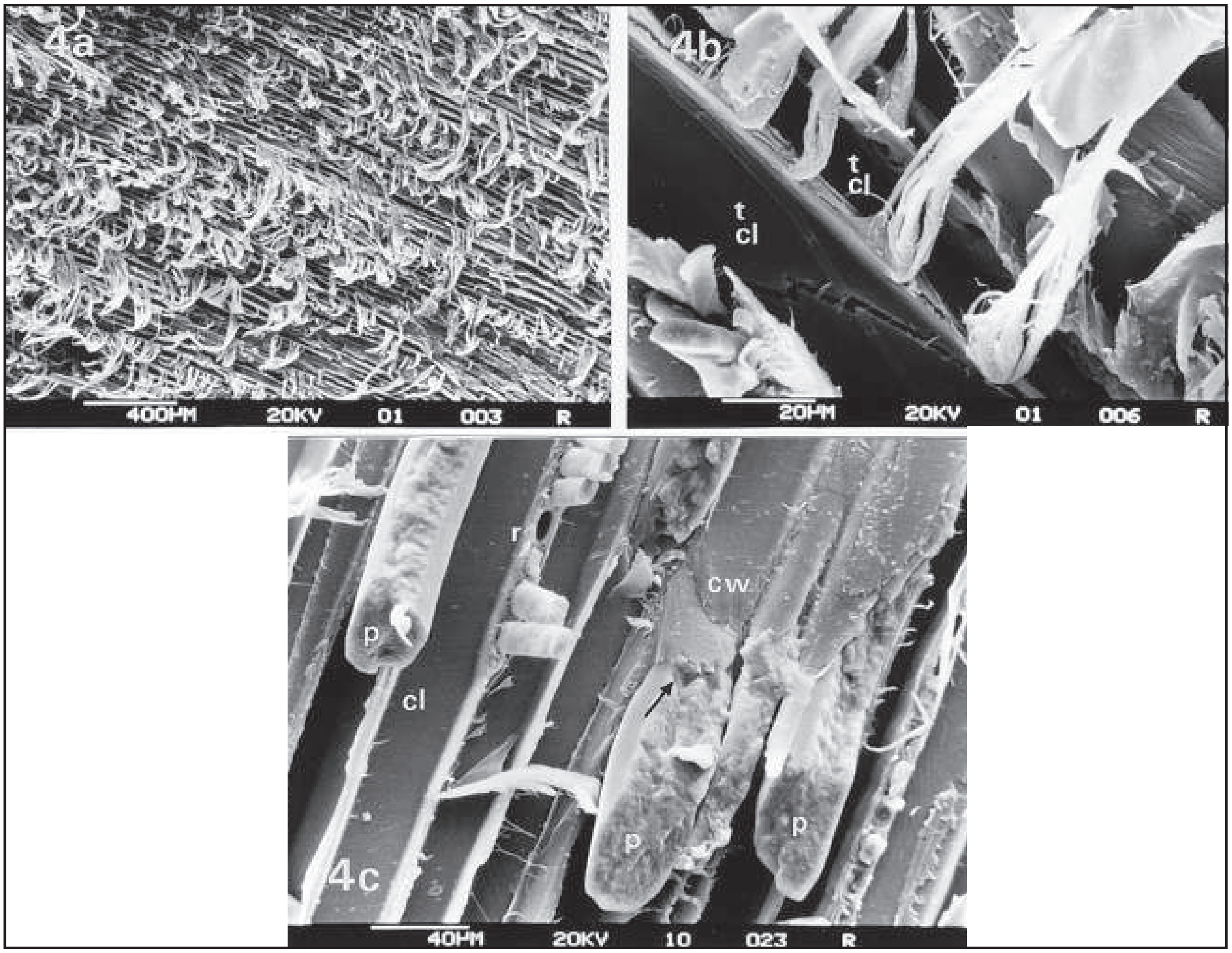

Figure 4 —SEM views of the wood surface of samples after detachment of the paint films with the torque method: (a)—Damages to the tracheids cell walls as an influence of the twisting motion of the torque method of samples painted with the acrylic dispersion paint with particle size 0.1µm infected with S. pityophila; (b)—Detail of the damages to the tracheid (t) cell walls of the sample viewed in Figure 4a. Cell lumen (cl); (c)—View of sparse mechanical anchoring of the paint film of the alkyd emulsion paint with 10% non-ion surfactant after detachment. Paint fragments (p) are seen emerging from the cell lumen (cl) of tracheids. Paint is also seen emerging from a ray (r). The arrow (central part of figure) points to the anchoring induced by the still remaining tracheid cell wall (cw).

and pretreatment with waterborne preservatives. In order to decrease the influence of mechanical anchoring, hand planed wood was used. Valuable information could be gained by characterizing the type of failure with SEM following the adhesion test. According to the results the adhesion values of the alkyd emulsion paints were much lower than the adhesion values of the acrylic dispersion paints under dry conditions. The presence of the anionic surfactant improved the adhesion of an alkyd emulsion paint. The adhesion values were higher for a small particle acrylic dispersion paint than for another with the same chemical composition but with larger particles. This might be related to improved penetration of the small particle paint into wood and/or to an increased contact area between this paint film and the wood substrate due to a more ideal packing of the particles. Under high moisture conditions the adhesion values of the acrylic dispersion paints decreased to a high extent. When painted wood was colonized by a blue stain fungus the adhesion values of the acrylic dispersion paints increased,

Table 9—Computerized Evaluation of Percentages of Adhesion Failure Produced During the Measurement of Adhesion Value Between Paint and Wood on Preservative Treated Samples Painted with Alkyd Emulsion Paint E3

Image Analysis

	Adhesion Failure (%)	
Preservatives	***Dry* mode**	***Wet* mode**
P1	2	2
P2	11	48
P3	16	58
P4	5	17
P5	13	33
Paint E3 on untreated wood	0	21

particularly under wet conditions, while the adhesion values of the alkyd emulsion paints decreased. Among the waterborne preservatives tested a preservative containing copper and quaternary ammonium compounds improved the adhesion between a paint film and wood resulting in high frequency of cohesive paint failure after the adhesion test under wet conditions.

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