Performance of Finishes on Wood that is Chemically Modified by Acetylation

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Swelling and shrinkage of wood has a major effect on the performance of coatings applied to its surface. Altering the molecular structure of wood by a reaction with acetic anhydride is known to improve the dimensional stability of wood considerably. Such acetylation of wood was shown to have no effect on the drying characteristics and adhesion of applied coatings. Weathering performance of coatings was improved considerably. A color stabilizing effect was achieved with acetylated Scots pine with and without a clearcoating.

INTRODUCTION

Many properties of wood are a result of interactions with substances (e.g., water) or organisms in its immediate surroundings. The dimensions of wood change due to water absorption and desorption of the wood when the relative humidity of the surrounding air changes. Furthermore, wood is degraded by UV light. The durability of both opaque and transparent paints is largely influenced by the dimensional changes of wood. With transparent finishes, the UV degradation of the timber has an extra influence on its durability. The wood processing industry tries to minimize these effects of less favorable properties by using wood species, mainly tropical hardwoods, which have a high dimensional stability of their own.

In the past decade, increasing interest world-wide within wood science can be observed for chemical modification of wood.[1-9] By chemically modifying woods the molecular structure of the cell wall components is altered. Mainly involved in these processes are those parts of the cell wall components (hydroxyl groups) which are primarily involved in biodegradation processes and water absorption and desorption. By chemical modification of wood, material properties can be improved considerably. One of the aims of wood modification is to improve the dimensional stability of low quality timber species.

Of all treatments to modify wood, acetylation with uncatalyzed acetic anhydride has been studied the most and shown to be one of the most promising methods.[1,2] During the reaction of wood with acetic anhydride, hydroxyl groups of the cell wall polymers are converted into acetyl groups producing acetic acid as a by-product (*Figure* 1). Dimensional changes of wood can be reduced by up to 80% by acetylation compared to untreated wood.[10-12] This is thought to be a result of the lower moisture content of the wood because hydrophilic hydroxyl groups are substituted by more hydrophobic side groups of the cell wall polymers. Secondly, acetylation has a permanently ultrastructural bulking effect, also increasing dimensional stability.

Cell wall modification has been studied for its effectiveness in reducing the degradative effects of outdoor and accelerated weathering due to ultraviolet radiation and water. In accelerated weathering, southern pine modified with butylene oxide or methyl isocyanate gave no more protection than untreated controls.[13] A similar treatment, followed by lumen polymer fill with methyl methacrylate showed no surface erosion and was very effective in reducing the effects of ultraviolet and water degradation. A similar study was performed on acetylated wood.[14] Compared to that of untreated wood, the rate of moisture sorption of aspen acetylated to 18 weight percent gain (WPG) was greatly reduced as was the extent of swelling in liquid water. Erosion due to accelerated weathering was reduced 50%. A combined treatment of acetylation followed by methacrylate impregnation was the most effective in reducing the rate and extent of swelling and reducing erosion caused by accelerated weathering (85%).

The purpose of this research was to determine the effect of hydrophobation of Scots pine by acetylation on coating performance and color stability.

EXPERIMENTAL

Acetylation

For the adhesion tests, spruce (*Picea abies*) samples of 10 mm × 70 mm × 150 mm (radial × tangential × longitudinal)

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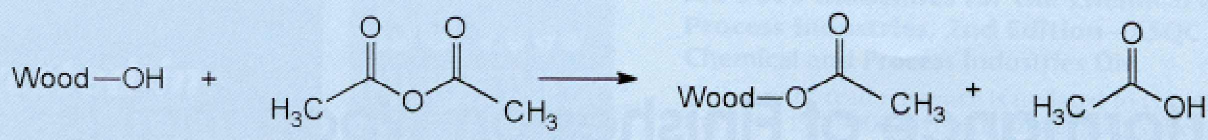

Figure 1—Acetylation of wood with acetic anhydride.

were acetylated using uncatalyzed acetic anhydride. Vacuum pressure impregnation was performed for 90 min followed by drainage of surplus anhydride and a reaction step of three hours at 120°C. After reaction a final vacuum was applied for two hours while an elevated temperature was maintained to remove nonreacted acetic anhydride and by-product acetic acid. Half of the acetylated samples were dried in an oven at 103°C to remove all residual acetic acid.

For weathering performance tests, Scots pine (*Pinus sylvestris*) sapwood samples of 12 mm × 80 mm × 1000 mm were acetylated using a somewhat different process. The test specimens were placed in a stainless steel reactor and impregnated under vacuum with acetic anhydride, which was preheated to 90°C. After one hour the vacuum was released and the anhydride was heated further to 120°C. After two hours the reactor was drained and a vacuum was applied to remove all unreacted acetic anhydride and formed acetic acid. Part of the acetylated samples were then placed in an oven at 103°C to remove all residual acetic acid.

Adhesion and Drying

Untreated and acetylated spruce samples, with and without residual acetic acid, were painted by brush with six different white primers. These products were two waterborne acrylic dispersions, two solventborne alkyd paints, a fast drying solventborne alkyd paint, and a waterborne alkyd emulsion. The amount of coating used on each board ranged between 110 and 130 g/m^2 per paint layer.

Each combination of paint and wood drying time on wood was compared to that on glass. Drying time was determined according to a modified DIN 53150. The dustfree time was determined by dropping a swatch of cotton wool from a height of 5 cm on the paint film. Dustfree time was recorded as the time at which the cotton did not stick to the paint film when the glass or wood panel was turned upside down. Subsequently a cotton swab was placed on the paint film and pressed for 10 sec with a weight of 1 kilo. Tack-free time was recorded as the time at which no cotton was found adhering to the paint film after removal of the weight.

The adhesion was determined according to the cross-hatch method (ASTM D 3359-Part A). The scale for evaluating the adhesion runs from 5 to 0. A value of 5 stands for a perfect adhesion, whereas a value of 0 represents a complete flaking of the paint. The difference in wood substrate is of minor influence on the intercoat adhesion, but was nevertheless recorded.

Accelerated Weathering

Xenon Weatherometer: Ten of the dried pine samples were cut into smaller sections of 10 mm × 70 mm × 147 mm. The edges of the front of these panels were rounded. Six types of finishes were applied to the front and edges, i.e., two solventborne alkyd paints (black and white), one solventborne alkyd stain (teak), two waterborne acrylic paints (black and white), and one waterborne acrylic stain (teak). All products are commercially available. Chemically modified panels, as well as untreated samples, were coated with a 120 μm thick dry film of stain or paint.

These panels were put in a Xenon weatherometer for 30 weeks. One-fifth of the panels were kept behind as a control. For this artificial weathering an Atlas weatherometer Ci 35 containing a Xenon lamp of 3000 W and a quartz-borosilicate filter combination was used. The light intensity was 0.35 W/m^2 by 340 nm with a total energy level of 450 W/m^2. Only the finished surface was sprayed with water.

Artificial weathering with test programs, which include a higher humidity level, generally show a more significant degradation compared to tests with a lower air humidity.[15] Artificial weathering was performed according to an aging cycle used previously by Van Acker et al.[16] and Bravery and Dickinson.[17] It is a combination of two cycles namely the Xenon-test of the

Table 1—Adhesion Test of Coatings on Untreated and Acetylated Spruce According to the Cross-hatch Method

Paint System	Untreated		Acetylated + AcOH		Acetylated	
	Coating-Substrate	Intercoat	Coating-Substrate	Intercoat	Coating-Substrate	Intercoat
Waterborne acrylic dispersion	4	3-4	2	2-3	3	4
Solventborne alkyd paint A	4	2	3	2-3	3	3
Solventborne alkyd paint B	2	2	3	2-3	3	3
Acrylic dispersion A	3	4-5	4	4-5	4	4
Acrylic dispersion B	4-5	5	3-4	5	4-5	5
Alkyd emulsion	2-3	3	3-4	3-4	3-4	3

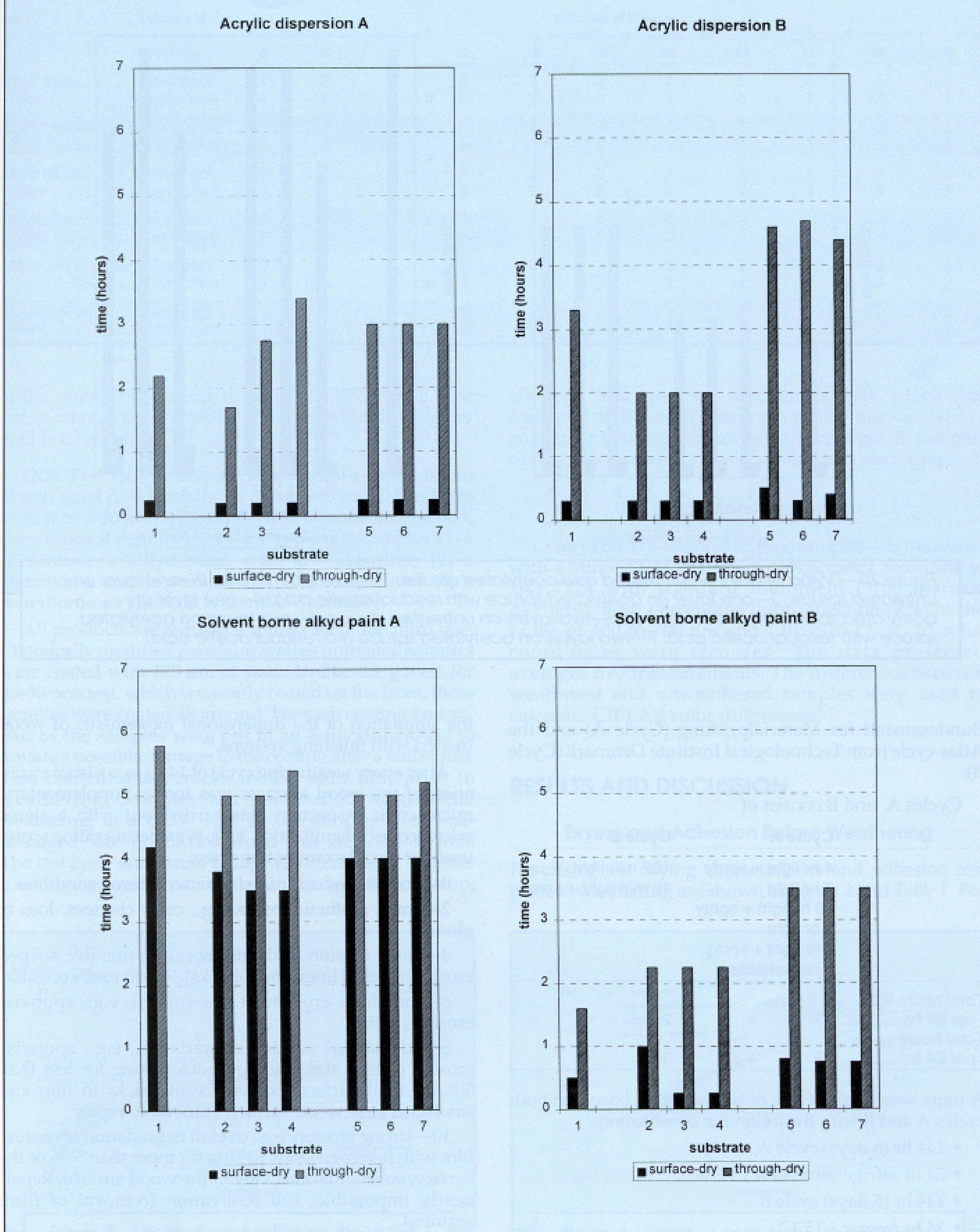

Figure 2a—Drying of paint on untreated and acetylated spruce.

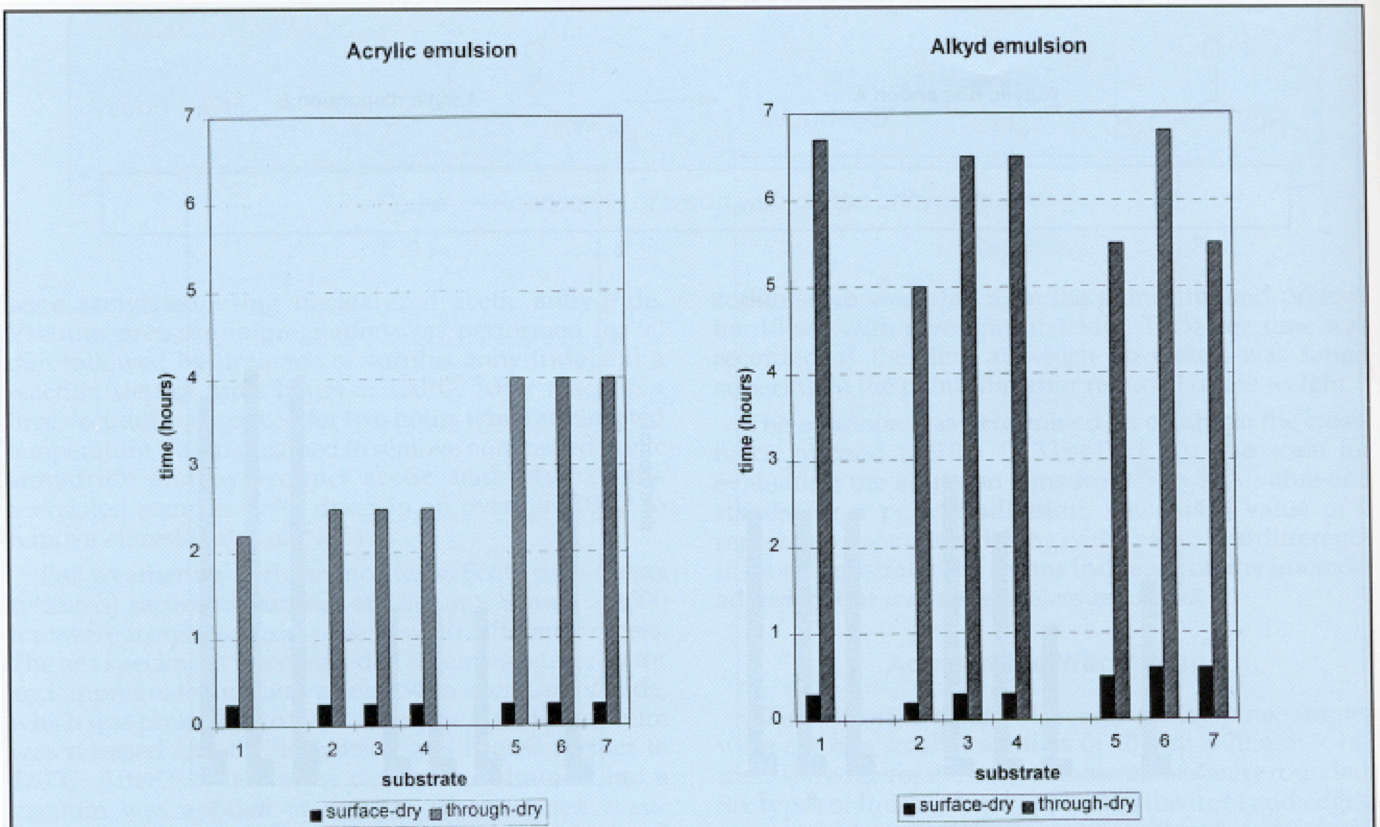

Figure 2b—Drying of paint on untreated and acetylated spruce. 1—glass 100 mm wet; 2—one layer on untreated spruce; 3—one layer on acetylated spruce with residual acetic acid; 4—one layer on acetylated spruce (no residual acid); 5—two layers on untreated spruce; 6—two layers on acetylated spruce with residual acetic acid; 7—two layers on acetylated spruce (no residual acetic acid)

Bundesanstalt für Materialprüfung (Cycle A) and the Atlas-cycle from Technological Institute Denmark (Cycle B).

Cycles A and B consist of :

	Cycle A	**Cycle B**
	4 hr light + spray 2 hr light 10 hr light + spray 2 hr light 5 hr light + spray 1 hr darkness	102 min light 18 min light + spray
Total hours light per 24 hr:	23	24
Total hours spray per 24 hr:	19	3.5

A unity weathering cycle of two weeks is based on both cycles A and B with the following constitution:

- 144 hr (6 days) cycle A
- 24 hr refrigerator (+4°C)
- 144 hr (6 days) cycle B
- 24 hr freezer (-15°C)

The combination of different conditions of humidity, light irradiance, and temperature seems to be essential for the simulation of the dimensional movements of wood treated with finishing systems.[16]

After every weathering cycle of 14 days, a visual evaluation of the wood surfaces was made. Supplementary, microscopic inspection was carried out with a stereo microscope (magnification 30X). Weathering rating scores used for visual examination were:

0—no changes compared to unweathered condition

2—small aesthetic losses, e.g., color changes, loss of gloss

4—small erosion of the surface, e.g., fine line shaped erosion in vessel lines (small cracks). Repair easily possible.

6—moderate erosion of the surface, e.g., spotwise erosion of film

8—substantial surface degradation, e.g., spotwise erosion of film and heterogeneous flaking for less than 50% of total surface; occurrence of cracks in film and small checks in wood surface. Difficult to repair.

10—strong erosion, e.g., overall degradation of coating film with heterogeneous flaking for more than 50% of the surface, substantial checking of the wood surface. Repair nearly impossible; full renovation (removal of film) required.

After 6, 8, 20, and 30 weeks, one of the samples was removed and used for an adhesion test. For this purpose two double crosscuts were made along the painted surface

Table 2—Performance of Untreated and Acetylated Pine Panels with Various Types of Wood Paints and Stains after Accelerated Weathering in a Xenon Weatherometer. Rating was Done on a Scale of 0 to 10 (0 = Unaffected; 10 = Heavily Degraded)

Paint	Treatment	Number of Weeks										
		6	8	10	12	18	20	22	24	26	28	30
Alkyd teak	Untreated	1	2	3	3	3	3	4	5	5	5	6
Stain	Acetylated	1	1	2	2	2	3	3	3	3	3	4
Acrylic teak	Untreated	1	2	3	3	3	3	4	5	5	5	5
Stain	Acetylated	0	2	3	3	3	3	3	3	3	3	3
Alkyd black	Untreated	3	3	3	3	3	3	3	4	4	4	5
Paint	Acetylated	1	2	2	2	2	2	2	2	3	3	3
Acrylic black	Untreated	2	3	4	4	4	4	4	4	5	5	5
Paint	Acetylated	2	2	2	2	2	2	2	3	3	3	3
Alkyd white	Untreated	2	2	2	2	2	2	2	2	2	2	3
Paint	Acetylated	1	1	1	1	1	2	2	2	2	2	2
Acrylic white	Untreated	1	1	2	2	2	2	2	2	2	2	2
Paint	Acetylated	1	1	2	2	2	2	2	2	2	2	2

of the samples according to ASTM D 3359-Part B. The rating represents an average of the individual rating per double crosscut.

***QUV Test*:** Acetylated pine samples and a same amount of untreated pine samples were cut into smaller sections of 12 mm × 80 mm × 285 mm. Next to unfinished wood, three types of clear finishes were applied to samples: (1) a solventborne alkyd stain with UV absorber; (2) a waterborne acrylic stain with UV absorber; and (3) a waterborne acrylic stain without UV absorber.

All products are industrial stains except the third one. Chemically modified panels, as well as untreated samples were coated with 120 µm of stain. Unlike the panels for the Xenon test, which were only coated on the front, these samples were coated all around. For each coating system, part of the samples were put in an artificial hail test to imitate a possible damage to the coating after a hail storm. This caused small cracks in the stain film prior to weathering. Samples were submitted to artificial weathering in a QUV. Half of the samples were hail-damaged, and unfinished wood was included as well. The test cycle and visual rating was identical to the ones used for the weatherometer test. Instead of a Xenon lamp, UV type A lamps were used in the QUV which was equipped with a water spray option allowing water spray and UV radiation simultaneously. Each week all samples of the QUV test were visually graded and photographed.

Color Measurements

Color of the UV-weathered pine samples was measured with a Minolta CM -500 spectrophotometer according to ISO 7724 with standard illuminent D 65 (natural daylight). Both percentage light reflection (R%) in the range of 400 to 700 nm and CIE 1976 L*, a*, b* color coordinates were recorded. The data presented averages five measurements. The differences between weathered and unweathered samples were used to calculate CIELAB color differences.

RESULTS AND DISCUSSION

Drying and Adhesion Before Weathering

Results of the drying characteristics and adhesion test prior to weathering are shown in *Figure* 2 and *Table* 1. For

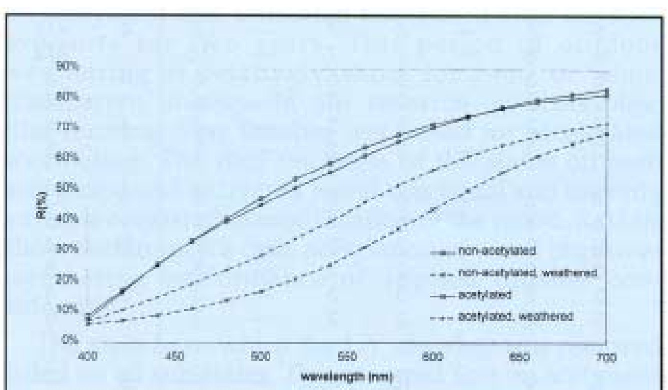

Figure 3—Effect of acetylation on the visible light reflection of pine sapwood with an alkyd clearcoat.

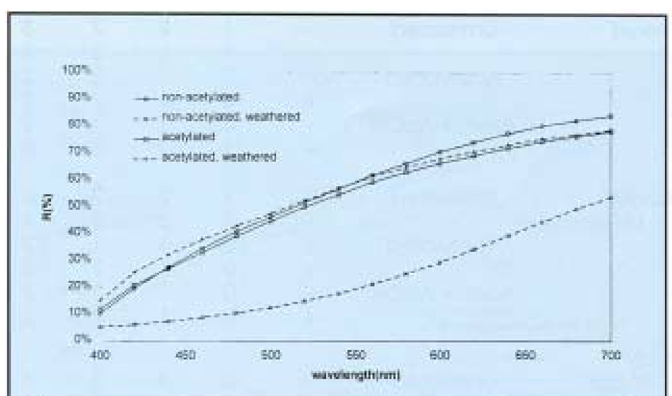

Figure 4—Effect of acetylation on the visible light reflection of pine sapwood with an acrylic clearcoat.

Table 3—Adhesion of Paint on Untreated and Acetylated Pine after Artificial Xenon Weathering

Paint	Treatment	Number of Weeks 0	8	20	30
Alkyd teak	Untreated	5	4	4	4
	Acetylated	5	4	4	4
Acrylic teak	Untreated	5	5	5	4
	Acetylated	5	5	5	5
Alkyd black	Untreated	4 1/2	4	4 1/2	4
	Acetylated	5	4	4 1/2	4
Acrylic black	Untreated	4	4	4	4
	Acetylated	4	4	4	4
Alkyd white	Untreated	5	5	-	5
	Acetylated	5	5	-	5
Acrylic white	Untreated	4	3 1/2	4	3 1/2
	Acetylated	4	4	4	4

drying time and adhesion, no significant difference could be observed between acetylated wood and untreated wood for most of the finishes applied. Surface dry time was considerably shorter for solventborne alkyd paint B on acetylated wood. Dry time of acrylic dispersion A was significantly influenced by acetylation. The dry time of this paint on acetylated wood was twice as long compared to untreated wood. An amount of residual acetic acid reduced this dry time to about one and a half times that on untreated wood. Dry time of the alkyd emulsion was also influenced by acetylation and extended from 5 to 6 1/2 hours, for both acetylated wood with and without residual acetic acid. Dry time of a second layer of alkyd emulsion was only extended on the acetylated wood with residual acetic acid. No problems with decreased wettability of the acetylated wood were observed. Pecina and Parzycki[19] showed that the wettability of acetylated wood was significantly different compared to untreated wood, but was lost after 30 sec of wetting.

Accelerated Weathering

Xenon Weatherometer Results: Results are presented in *Table* 2. Weathering performance proved to be better for the acetylated wood, especially for both teak pigmented stains and both black pigmented paints.

All panels were unfinished on the back. As a result, all untreated samples showed cracks in the wood after eight weeks of weathering. Growth rings of the wood used were nearly parallel to the finished surface. Usually a 45° angle is used to prevent this cracking. It is nearly impossible, though, to make samples of this size which consist completely of pine sapwood. Therefore, this failure of the wood was not included in the marking of the samples as mentioned in *Table* 2. The numbers mentioned represent the performance of the paint or stain itself. After 30 weeks of weathering most finishes were still reasonably intact and the highest rating was only a 6. Similar tests done in the past, most of which failed after 10 weeks, are mainly done with stains and usually have a lower film thickness. The samples used here had three layers of paint or stain with a total thickness of 120 µm.

Unfinished, untreated samples showed a clear darkening of their surface caused by degradation of lignin by UV light. The acetylated wood kept its original color. After a few weeks, the surface of the untreated wood was degraded, and loose white fibers were washed from the surface during spraying. The acetylated wood was

Table 4—Performance of Various Types of Wood Stains on Untreated and Acetylated Pine Panels after Accelerated Weathering in a QUV. Rating was Done on a Scale of 1 to 10. Rating of Adhesion was Done on a Scale of 5 to 0

Stain	Treatment	Art. Hail Damage	Number of Weeks Weathering and Cycle (A or B) 1 A	2 B	3 A	4 B	5 A	6 B	7 A	8 B	9 A	10 B	11 A	12 B	Adhesion After Week 0	12
Alkyd	Untreated	–	1	2	2	3	4	5	6	—	6	7	—	7	4	4/3
		+	1	3	3	4	5	6	6	—	7	7	—	10		4/2
	Acetylated	–	0	1	2	2	2	3	3	—	3	5	—	6	4	3
		+	0	1	2	2	2	2	2	—	2	3	—	4		4
	Acet. + AcOH	–	0	1	1	2	2	2	2	—	2	3	—	4	4	4
		+	1	2	3	3	3	3	3	—	3	3	—	5		3
Acrylic + UV-absorber	Untreated	–	1	2	2	3	4	4	6	—	6	7	—	8	5	4 1/2
		+	1	2	3	4	6	6	6	—	6	7	—	7		5
	Acetylated	–	0	1	1	2	2	2	2	—	2	2	—	2	5	4
		+	0	1	2	2	2	2	2	—	2	2	—	3		5
	Acet. + AcOH	–	0	1	2	3	2	2	2	—	3	3	—	3	5	4
		+	0	1	2	2	2	2	2	—	2	2	—	3		5
Acryl - UV abs.	Untreated	–	2	3	3	5	6	8	9	—	10	10	—	—	5	—
		+	2	4	4	6	7	8	9	—	10	10	—	—	—	—
	Acetylated	–	0	1	2	2	7	8	8	—	10	10	—	—	5	—
		+	1	3	8	8	8	9	9	—	10	10	—	—	—	—
	Acet. + AcOH	–	3	7	8	8	9	9	9	—	10	10	—	—	5	—
		+	3	4	8	8	10	10	10	—	10	10	—	—	—	—

Table 5—CIELAB Color Coordinates, Standard Deviations between Brackets

Coating	Treatment		L*	a*	b*	ΔE
Uncoated	Untreated	t_0	81.77 (0.40)	3.44 (0.21)	24.72 (0.66)	
		t_{12}	77.58 (0.64)	2.07 (0.30)	5.72 (0.34)	19.50
	Acetylated	t_0	82.64 (0.73)	1.88 (0.09)	22.23 (1.35)	
		t_{12}	85.28 (1.02)	1.54 (0.29)	8.79 (1.86)	13.70
Alkyd	Untreated	t_0	81.76 (0.53)	3.02 (0.14)	33.15 (0.84)	
clearcoat		t_{12}	62.95 (0.55)	15.55 (0.42)	40.20 (0.65)	23.67
	Acetylated	t_0	82.89 (0.06)	0.72 (0.10)	34.57 (0.36)	
		t_{12}	72.70 (0.57)	7.89 (0.45)	38.87 (0.33)	13.18
Acrylic	Untreated	t_0	82.01 (0.22)	2.84 (0.13)	31.18 (0.36)	
clearcoat		t_{12}	53.60 (2.34)	14.04 (0.55)	31.26 (1.07)	30.53
	Acetylated	t_0	80.48 (0.87)	1.69 (0.30)	29.81 (0.31)	
		t_{12}	81.66 (0.43)	1.99 (0.24)	25.66 (0.50)	4.33

degraded much later (loose white fibers) but after 30 weeks of exposure a thicker layer of the acetylated wood was degraded and washed away compared to the untreated wood.

The adhesion test of the weathered samples showed minimum differences between acetylated and untreated samples and between acrylic and alkyd paints (*Table* 3).

QUV Test: Results of the QUV weathering are presented in *Table* 4. Acetylation of wood considerably improves weathering performance of clear stains for both acrylic and alkyd systems. In general, weathering performance of the applied acrylic stain was better compared to the alkyd stain. Stain damage and graying of the wood on the sharp edges of the wood samples was especially less for the acrylic wood stain as compared to the alkyd wood stain. Even artificial hail damage had no significant effect on weathering performance of an alkyd or acrylic stain on acetylated wood. Feist et al.[20] found contrary results in their study on weathering and finish performance of acetylated aspen fiberboard. The penetrating finishes they used (semitransparent oil-based stains) performed better on untreated fiberboard as compared to acetylated fiberboard. Those stains could not penetrate the treated surface and were weathered with a three times higher spreading rate of the finish. Film-forming finishes (paints and solid-color stains) performed equally well on acetylated and untreated fiberboard after outdoor exposure for two years. This period of outdoor weathering is relatively short for non- or semi-transparent finishes. In our research on Scots pine, film-forming clear finishes were used for accelerated weathering. The film thickness of the stains on both acetylated and untreated wood was equal and the only variable consisted of modification of the wood. Results show that in such a case, acetylation of wood improves weathering performance of applied finishes considerably.

The stain from which the UV absorber was removed failed on all substrates. This occurred first on acetylated samples with some residual acetic acid left in the wood. After three weeks, blisters appeared in the film layer. The same occurred after six weeks of accelerated weathering to this stain on both the acetylated wood and untreated wood without residual acid. Removing the UV absorber obviously causes degradation of the polymers within the paint itself. This results in loss of adhesion of the paint to the wood irrespective to which type of wood it is applied.

Adhesion of the stain on the wood after artificial weathering was good and nearly the same for all stains applied.

The unfinished samples showed results which were comparable to those from the Xenon weathering. Erosion of the surface was not extensive, but weathering had only been done for 12 weeks instead of the 30 weeks of the weatherometer test.

Color Measurements

The color of the untreated wood was clearly affected by UV degradation. Both the acrylic and the alkyd stain could not prevent the wood from darkening considerably. Acetylating the wood, on the other hand, has a very good effect on the durability of the wood against UV degradation (see *Figure* 6). The samples with the acrylic stain and solventborne alkyd stain even became brighter after several weeks of weathering.

The L*, a*, b* values of the different samples and the color change ΔE are given in *Table* 5. Due to the acetylation, the color of the wooden substrate was slightly changed because of the lower degree of redness (a*-value) of the acetylated wood both with and without a transparent

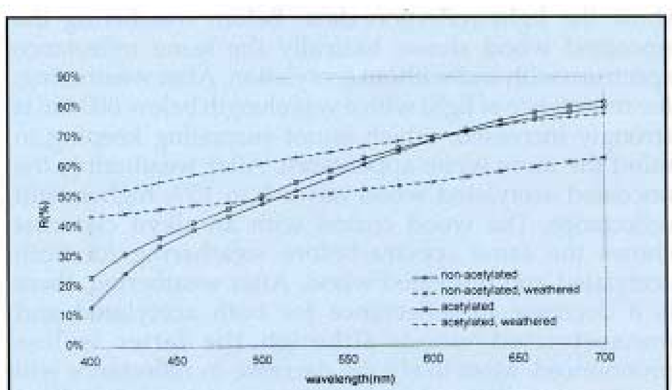

Figure 5—Effect of acetylation on the visible light reflection of uncoated pine sapwood.

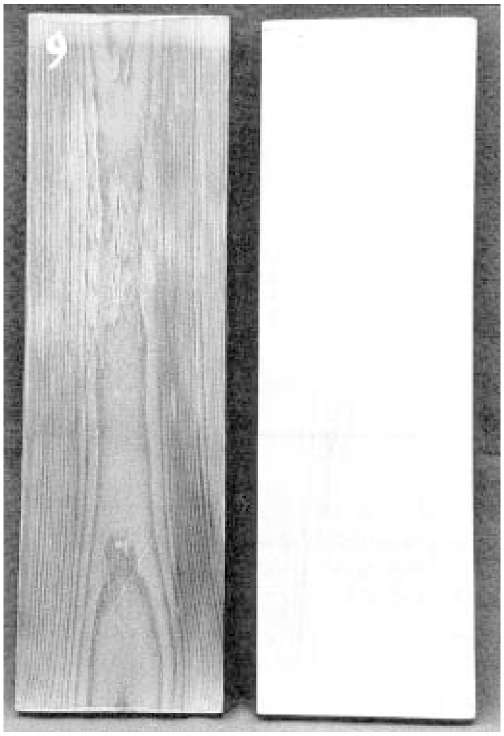

Figure 6—Untreated (left) and acetylated (right) pine sapwood after 12 weeks of UV weathering.

coating. Differences in either lightness or yellowness are negligible.

After weathering, the improvement in color retention of the coated acetylated wood is remarkably good. The typical darkening and yellowing of transparently coated wood is strongly reduced by acetylation. Uncoated acetylated wood still shows a strong color change because the top layer of the acetylated wood degrades under influence of the combination of UV light and water. This causes the development of a white to gray layer of cellulose fibers covering the wood surface. The layer directly underneath this layer, which contains both cellulose and the highly photochemical active lignin fractions, retains a more yellow color compared to the more brownish untreated wood.

More detailed information is given in *Figures* 3-5 which show the light reflection data. Before weathering the uncoated wood shows basically the same reflectance spectrum with and without acetylation. After weathering, the reflectance of light with a wavelength below 600 nm is strongly increased, which is not surprising keeping in mind the more white appearance. After weathering, the uncoated acetylated wood has a 5 to 15% higher light reflectance. The wood coated with an alkyd clearcoat shows the same spectra before weathering for both acetylated and untreated wood. After weathering, there is a decrease in reflectance for both acetylated and nonacetylated wood, although the latter is less pronounced. Most likely the decrease in reflectance will come mainly from the photodegradation of the alkyd resin itself.

The results of the combination of acetylated wood and an acrylic clearcoat are most striking since virtually no changes in reflectance are observed even after 1,728 hours of QUV weathering. This can be explained by a very good resistance of both coating and substrate against photodegradation. The nonacetylated wood still shows a strong decrease in reflectance because of the degradation of the wood itself.

The acetylation of wood in combination with the application of a fully transparent coating can prevent discoloration or failure of the coating even after severe artificial weathering. The best prevention against weathering is found in combination with the acrylic clearcoat. Discoloration can only be prevented by a combination of chemical modification of the wood and the application of a coating because of the synergistic effects of light and water in the wood weathering process. The initial photodegradation of lignin in the wood is initiated by light but subsequent leaching of the degradation products increases the rate of degradation.[21,22] The results of this study show that acetylation can prevent this degradation process as long as the surface is protected by a coating. The coating can protect the wood in two ways: first by preventing water to leach degradation products, and second, by filtering certain wavelengths from the UV spectrum. Why the coating is only effective in combination with acetylation is not clear yet. This will be studied in future work. Hon[23] stated that acetylation is not effective in long-term color stabilization. This idea is partly supported by our results as far as uncoated wood is concerned but seems not to hold for acetylated wood finished with a transparent coating. Acetylated wood gives new opportunities for finishing wood with clear unpigmented coatings since coating durability is strongly improved.

CONCLUSIONS

Within research on material properties of acetylated wood, several tests on coating performance were done. Acetylating spruce samples had no effect on adhesion and required drying time for paint applied to the wood. Performance of paints and stains was much better on acetylated pine compared to untreated samples. Acetylation of wood strongly reduces cracking and flaking of an applied coating when exposed to weathering. This is mainly caused by the improved dimensional stability of the wood by acetylation, which decreases the stresses applied to the coating that originate from the dimensional changes of the substrate. An artificial hail test had no effect on the appearance of a stain on acetylated wood, while similar damage to a stain on untreated wood caused the finish to crack and fail in an artificial weathering test. The UV resistance of acetylated wood was proven by an accelerated UV degradation of wood with transparent stains. It showed that acetylation improves the natural resistance of wood against UV degradation, particularly in combination with a transparent coating. The untreated wood discolored because of weathering while the acetylated wood kept its original color. Removal of the UV absorber from the stain caused degradation of the polymers within the paint itself and loss of adhesion of the paint from the wood.

ACKNOWLEDGMENTS

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References

(1) Rowell, R.M., “Chemical Modification of Wood,” *Forest Products Abstracts*, 6 (12): 363-382 (1983).
(2) Kumar, S., “Chemical Modification of Wood,” *Wood Fiber Sci.*, 26 (2): 270-280 (1994).
(3) Clemons, C., Young, R.A., and Rowell, R.M., “Moisture Sorption Properties of Composite Boards from Esterified Aspen Fiber,” *Wood Fiber Sci.*, 24 (3): 353-363 (1992).
(4) Goethals, P. and Stevens, M., “Dimensional Stability and Decay Resistance of Wood upon Modification with Some New Type Chemical Reactants,” International Research Group on Wood Preservation, Document No. IRG/WP/94-40028, 1994.
(5) Matsuda, H., “Preparation and Properties of Oligoesterified Wood Blocks Based on Anhydride and Epoxide,”*Wood Sci. Tech.*, 27: 23-34 (1993).
(6) Rowell, R.M., *Chemical Modification of Wood—Advantages and Disadvantages*, American Wood-Preservers’ Association, 1975.
(7) Rowell, R.M., “Nonconventional Wood Preservation Methods,” *Wood Technology: Chemical Aspects*, Chapter 4, page 47-56, 1977.
(8) Rowell, R.M. and Ellis, W.D., “Effects of Moisture on the Chemical Modification of Wood with Epoxides and Isocyanates,” *Wood Fiber Sci.*, 16(2): 257-267 (1984).
(9) Rowell, R.M. and Banks W.B., Water Repellency and Dimensional Stability of Wood, USDA Forest Products Laboratory. General Technical Report FPL-50, 1985.
(10) Beckers, E.P.J. and Militz, H., “Acetylation of Solid Wood—Initial Trials on Lab and Semi Industrial Scale,” Second Pacific Rim Bio-Based Composites Symposium, Vancouver, B.C., Canada, 1994.
(11) Goldstein, I.S., Jeroski, E.B., Lund, A.E., Nielson J.F., and Weaver, J.W., “Acetylation of Wood in Lumber Thickness,” *Forest Products J.*, 11(8):363-370 (1961).
(12) Rowell, R.M. and Plackett, D.V., “Dimensional Stability of Flakeboards Made from Acetylated *Pinus radiata* Heartwood or Sapwood Flakes,” *New Zealand J. Forestry Sci.*, 18(1): 124-131 (1988).
(13) Rowell, R.M., Feist, W.C., and Ellis, W.D., “Weathering of Chemically Modified Southern Pine,”*Wood Sci.*, 13(4): 202-208 (1981).
(14) Feist, W.C., Rowell, R.M., and Ellis, W.D., “Moisture Sorption and Accelerated Weathering of Acetylated and Methacrylated Aspen,”*Wood Fiber Sci.*, 23(1): 128-136 (1991).
(15) Arnold, M., and Sell, J., Künstliche Bewitterung von Holz und Holzanstrichen: Vergleich zweier Gerätetypen. *Holz als Roh- und Werkstoff* 48: 138-143 (1990).
(16) Acker Van, J., Stevens, M., and Nys, M., “Xenon Simulation of Natural Weathering of External Joinery Preserving—Finishing Systems,” International Research Group on Wood Preservation. Document No. IRG/WP/2412-92, 1992.
(17) Bravery, A.F. and Dickinson, D.J., “Artificial Weathering as an Aid to Assessing the Effectiveness of Chemicals for Preventing Blue Stain in Service—a Co-operative Study,” International Research Group on Wood Preservation, Document No. IRG/WP/2215, 1984.
(18) Sell, J. “Physikalische Vorgäge in Wetterbeanspruchten Holzbauteilen Fensterrahmen,” *Holz als Roh- und Werkstoff* 43: 259-267, 1985.
(19) Pecina, H., and Parzycki, O., “Untersuchungen über die Benetzbarkeit chemisch modifizierter Hölzer,”*Holz als Roh- und Werkstoff* 48: 61-65, 1990.
(20) Feist, W.C., Rowell, R.M., and Youngquist, J.A., “Weathering and Finish Performance of Acetylated Aspen Fiberboard,” *Wood Fiber Sci.*, 23(2): 260-272 (1991).
(21) MacLeod, I.T., Scully, A.D., Ghiggino, K.P., Ritchie, P.J.A., Paravagna, O.M., and Leary, B., “Photodegradation at the Wood-Clearcoat Interface,” *Wood Sci. Tech.*, 29: 183-189 (1993).
(22) Feist, W.C. and Hon, D.N.-S., “Chemistry of Weathering and Protection” in *The Chemistry of Solid Wood*, R.M. Rowell (Ed.), Advances in Chemistry Series, No. 207, American Chemical Society, Washington, D.C., Chapter 11, pp. 401-451, 1984.
(23) Hon, D.N.-S. “Stabilization of Wood Color: Is Acetylation Blocking Effective,” *Wood Fiber Sci.*, 27(4): 360-367 (1995).