WEATHERING AND FINISH PERFORMANCE OF ACETYLATED ASPEN FIBERBOARD[1]

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ABSTRACT

Unfinished and finished fiberboards prepared from untreated and acetylated (15 weight percent gain) aspen fibers were exposed to accelerated or outdoor weathering. Acetylated fiberboards swelled less than untreated fiberboards after weathering. Acetylated fiberboards were smoother than untreated ones after treatment, and acetylation helped retain surface smoothness of both finished and unfinished fiberboards after weathering. Finished and unfinished acetylated fiberboards also had less mildew growth after outdoor weathering compared to untreated fiberboards, demonstrating the greater biological resistance of the treated boards. A penetrating semitransparent oil-based stain did not perform as well on acetylated fiberboard as on untreated fiberboard because the finish could not penetrate the treated surface. Therefore, not as much material could be applied to the acetylated boards. Film-forming finishes (paints and solid-color stains) performed equally well on acetylated and untreated boards after 2 years of outdoor exposure.

Keywords: Acetylation, natural weathering, accelerated weathering, aspen, surface roughness, swelling, fiberboard, paints, stains.

INTRODUCTION

Wood composites used outdoors are subject to both dimensional instability and degradation by ultraviolet light (UV) radiation and water (Feist and Hon 1984; Rowell 1984; Rowell et al. 1989). The UV radiation causes photochemical degradation mainly in lignin polymers in cell walls. Water, in combination with UV radiation, plays a major role in weathering and the surface degradation of wood. As lignin is degraded, water washes away degradation products and subsequently loosens surface cellulose fibers, which causes the surface to deteriorate (erode). In earlier research, we found epoxide- and isocyanate-reacted solid wood

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(cell-wall modification) did not improve UV resistance to accelerated weathering (Rowell et al. 1981).

In a recent study, we evaluated wood cell-wall treatment with acetic anhydride, lumen fill with methyl methacrylate, and a combination of these treatments for their effectiveness in reducing the rate of moisture sorption and the resultant degradation during accelerated weathering (Feist et al., submitted for publication). Compared to untreated wood, the rate and amount of swelling in liquid water of aspen acetylated to 18 weight percent gain was greatly decreased, and erosion was reduced 50% after the boards were exposed to accelerated weathering. Methyl methacrylate treatment slightly decreased the rate of swelling in liquid water but did not reduce the amount of swelling. This treatment also reduced erosion about 40%. A dual treatment consisting of acetylation followed by methacrylate impregnation was the most effective in reducing the rate and amount of swelling and in reducing erosion caused by accelerated weathering (85%). Both acetylation and methacrylate treatments, or a combination of the two, reduced the loss of surface lignin as well as the erosion caused by accelerated weathering. Acetylation, especially at 18 weight percent gain, reduced the loss of xylans during accelerated weathering.

Dimensional instability, especially in the thickness direction, is a well-known problem in wood composites such as flakeboards, particleboards, and fiberboards. In addition to normal, reversible swelling, irreversible swelling occurs on the release of residual compressive stresses that develop during the pressing operation. Acetylation significantly improves dimensional stability and biological resistance of both solid wood and wood composites (Rowell 1984). Other studies show that thickness swelling in flakeboards and particleboards is reduced 80 to 90% by acetylation of the flakes and particles before board production (Rowell et al. 1986a, b).

The purpose of this research was to determine the effect of cell-wall chemical modification of aspen fibers using acetic anhydride on the weathering characteristics and finish performance of fiberboard.

EXPERIMENTAL

Chemical modification

Oven-dried aspen (*Populus tremuloides*) fibers were reacted with acetic anhydride at 120 C using a technique described earlier (Rowell et al. 1986a, b). Treatment conditions were chosen to obtain a 15 weight percent gain (WPG) based on the original oven-dry weight. Acetyl content was determined before and after weathering by a gas chromatographic method (Rowell et al. 1986b).

Fiberboard preparation

Aspen fiber was obtained from a commercial hardboard manufacturing plant. The fiber was produced from peeled wood that had been chipped, run through a double-disc pressurized refiner, and then flash dried. Both untreated and acetylated fiber were sprayed with a commercial phenol-formaldehyde resin to a level of 10% (based on oven-dry weight). The target thickness and specific gravity of the fiberboards for studies on millwork replacement materials were 3.8 cm and 0.75 g/cm^3, respectively. Each board was made from four layers of prepressed mats, each measuring 10.2 cm thick by 70 cm long by 71.1 cm wide. The four prepressed layers were stacked together, consolidated to a thickness of 3.8 cm, then hot pressed at 3.1 MPa for 40 min. The hot press was computer controlled and heated with oil at 190 C.

To measure bond quality, shear tests were conducted on 5.1-cm-diameter plugs cut from each board immediately after pressing. Three shear tests per plug were conducted at 0.6 cm, 1.9 cm, and 3.2 cm through the thickness. All boards not meeting minimum standards for this test were rejected and were not used in the experiment. Preliminary weathering tests indicated that thinner specimens would be suitable for all evaluations, and the top 0.95 cm of the boards was cut off using a fine-tooth saw. All exposed surfaces consisted of the original top surface of the fiberboards.

Accelerated weathering

Three replicates of finished and unfinished aspen fiberboard, each measuring 7.6 by 10.2 by 0.95 cm, were used to evaluate accelerated weathering and finish performance.

Accelerated weathering was conducted in a commercial chamber. The faces of all test specimens were exposed to a 6,500-W xenon arc light source (which closely approximates natural sunlight) in an enclosed chamber at 45 C to 50 C and 50% relative humidity (RH) (Feist and Rowell 1982). Each 24-h cycle of weathering consisted of 24 h of light with 4 h of distilled water spray. Exposure time is expressed as hours of exposure to light. Thickness measurements were made at 200-h intervals.

In addition to natural outdoor weathering, we used artificial weathering because it is reproducible and controllable. Moreover, it has good correlation with natural weathering of unfinished wood and wood finished with semitransparent stains (Black and Mraz 1974; Feist and Mraz 1978). With respect to erosion of an unfinished wood surface, 2,400 h of artificial weathering was equal to 4 to 5 years of natural weathering when specimens were exposed vertically on a wall facing south in Madison, Wisconsin (Feist and Mraz 1978).

Outdoor weathering

Finished and unfinished aspen fiberboard specimens (7.6 by 10.2 by 0.95 cm) (three replicates) were used to evaluate outdoor weathering and finish performance. After finishing, the specimens were assembled onto 40.6-cm-wide by 34.3-cm-long frames made from 0.64-cm exterior-grade plywood with 1.3-cm-wide by 2.5-cm-deep side rails (Feist 1987). The frames of these exposure panels were dip treated with a water-repellent preservative and edge coated with latex paint before substrates were attached to the frames with stainless steel bolts. The exposure panels were hung on vertical fences with southern exposure at Madison, Wisconsin, in May 1987.

Finishes

A variety of commercial finishes and one laboratory-prepared finish were selected for outdoor exposure tests (Table 1). The materials represent finishes currently available or recommended for application to wood in outdoor exposures.

TABLE 1. *Characteristics of finishes and pretreatments used for aspen fiberboard studies.*

Source	Finish	Color	Non-volatile content (percent)	Weight[a] (kg/liter)
Laboratory (Black et al. 1979)	Semitransparent oil-based stain	Brown	76	0.9 (7.9)
Commercial	Solid-color oil-based stain	Cream	60	1.1 (9.4)
	Solid-color latex stain	Cream	45	1.3 (10.5)
	Alkyd primer paint	White	78	1.4 (11.4)
	Latex primer paint	White	52	1.2 (9.8)
	Acrylic latex house paint A	White	52	1.4 (11.3)
	Acrylic latex house paint B	White	53	1.3 (10.9)

[a] Values in parentheses are expressed as pounds per gallon.

They are finishes of known durability on solid wood substrates as determined from experience or research (USDA 1987).

The fiberboard specimens were conditioned to 65% RH at 26.7 C before finishing. All surfaces were wiped with a soft cloth before finishing and between coats. No other special surface preparation was used. All finishes were brushed on clean, unweathered surfaces of fiberboards under ideal laboratory conditions, following applicable recommendations provided by the manufacturers. Finishes were applied with the specimens in a horizontal position. The top, side, and bottom edges were sealed as completely as possible with the finish itself.

Spreading rates for the finishes (Table 2) were those recommended by the manufacturer and were determined by direct weighing. The finished specimens were stored indoors at 60% RH at 21 C for 1 week before being installed on the exposure fences.

Swelling

Specimens were conditioned to equilibrium at 60% RH and 21 C before measurement. Fiberboard thickness was measured with a dial micrometer at four points on each specimen. Swelling is expressed as a percentage of the original thickness of the finished or unfinished specimen before accelerated or outdoor weathering (Table 3).

TABLE 2. *Spreading rates for finishes applied to aspen fiberboards.*

Finish	Spreading rate (m^2/liter)[a]			
	Control fiberboard		Acetylated fiberboard	
	1st coat	2d coat	1st coat	2d coat
Semitransparent oil-based stain	2.1 (85)	—	5.1 (210)	—
Solid-color oil-based stain	4.7 (190)	9.8 (400)	8.3 (340)	10.5 (430)
Solid-color latex stain	2.5 (100)	6.7 (275)	5.0 (205)	10.4 (425)
Alkyd primer paint plus acrylic latex house paint A	4.5 (185)	8.8 (360)	6.9 (280)	9.2 (375)
Latex primer paint plus acrylic latex house paint B	4.9 (200)	9.7 (395)	5.8 (235)	11.8 (480)

[a] Values in parentheses are expressed as square feet per gallon.

TABLE 3. *Swelling of aspen fiberboards after outdoor exposure.*[a]

Finish[b]	Swelling (percent)					
	6 months		14 months		24 months	
	Control	Acetylated	Control	Acetylated	Control	Acetylated
Unfinished	0.2	−1.7	1.8	−1.4	1.0	−1.8
ST stain	0.7	−1.0	1.6	−0.9	2.1	−0.9
SC oil stain	1.6	−1.1	1.1	−1.2	1.1	−1.2
SC latex stain	0.6	−1.7	1.4	−1.3	1.4	−1.3
Oil primer, latex topcoat	0.5	−2.0	0.5	−2.0	0.1	−2.3
Latex primer, latex topcoat	1.0	−2.2	−0.2	−1.8	−0.2	−2.1

[a] Average of 3 specimens.
[b] ST is semitransparent, SC solid-color.

Surface roughness

The surface roughness for finished and unfinished specimens was evaluated after accelerated and outdoor weathering. The techniques and equipment described by Oestman (1983) were used (Perthometer,[2] Type S6P, Feinpruef Corp., Charlotte, North Carolina).

The surface profiles of the specimens were measured with a fine stylus that moved along the specimen surface at a constant speed. The vertical movement of the stylus is registered so different surface roughness criteria can be calculated. For this study, we chose the following criteria (Figs. 1 and 2):

R_z = Average roughness depth (mean value) of individual roughness depths from five individual measuring lengths (l_e) measured in succession

R_a = Average roughness (arithmetic mean) of all values of the roughness profile within the measuring length (l_m).

The depth of the surface profile evaluates the maximum depth, including small microcracks detected by the fine stylus. The arithmetic mean deviation evaluates all depths along the surface (Oestman 1983).

RESULTS AND DISCUSSION

Aspen was chosen for these studies because of our interest in using a hardwood for determining the effects of chemical modification on wood composite properties (Rowell et al. 1986b). Because our previous work on the weathering resistance of modified woods involved softwoods, no information was available on the performance of modified hardwoods (Feist and Rowell 1982; Rowell et al. 1981).

Thickness swelling

Accelerated weathering

The extent of thickness swelling of aspen fiberboard after accelerated weathering is shown in Fig. 3. Swelling for fiberboard specimens made from acetylated fibers was essentially zero for those specimens finished with semitransparent stain. The

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

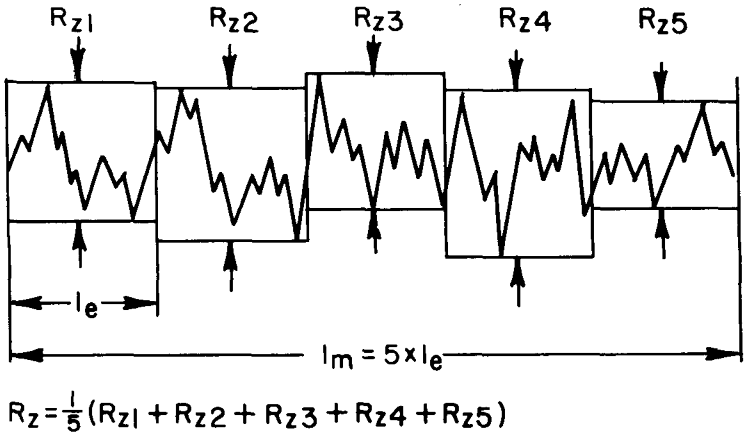

FIG. 1. Average roughness depth (R_z) in micrometers, calculated as mean depth for five lengths (l_e). (ML89 5886)

unfinished specimens showed a slight decrease in swelling (shrinkage) (Fig. 3). The reason for this slight shrinkage is probably a slow loss of surface fibers at a rate fairly close to that of untreated fiberboards. Reduced swelling of acetylated wood was demonstrated previously (Rowell 1984).

Fiberboard prepared from unfinished and untreated aspen swelled about 3.5% after 200 h of accelerated weathering. A slight increase in thickness swelling occurred after 400 h and then a slight decrease occurred over the next 600 h. This decrease with continued exposure was probably caused by the loss of surface fibers during the accelerated weathering process.

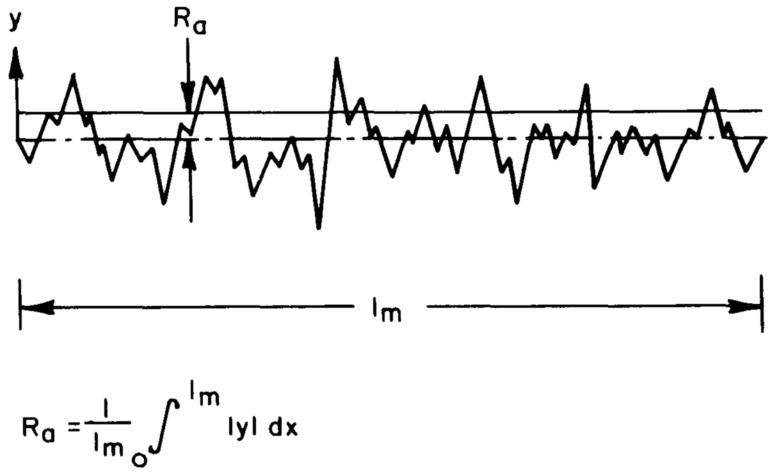

FIG. 2. Average roughness (R_a) in micrometers, calculated as the arithmetic mean within the measuring length (l_m). (ML89 5887)

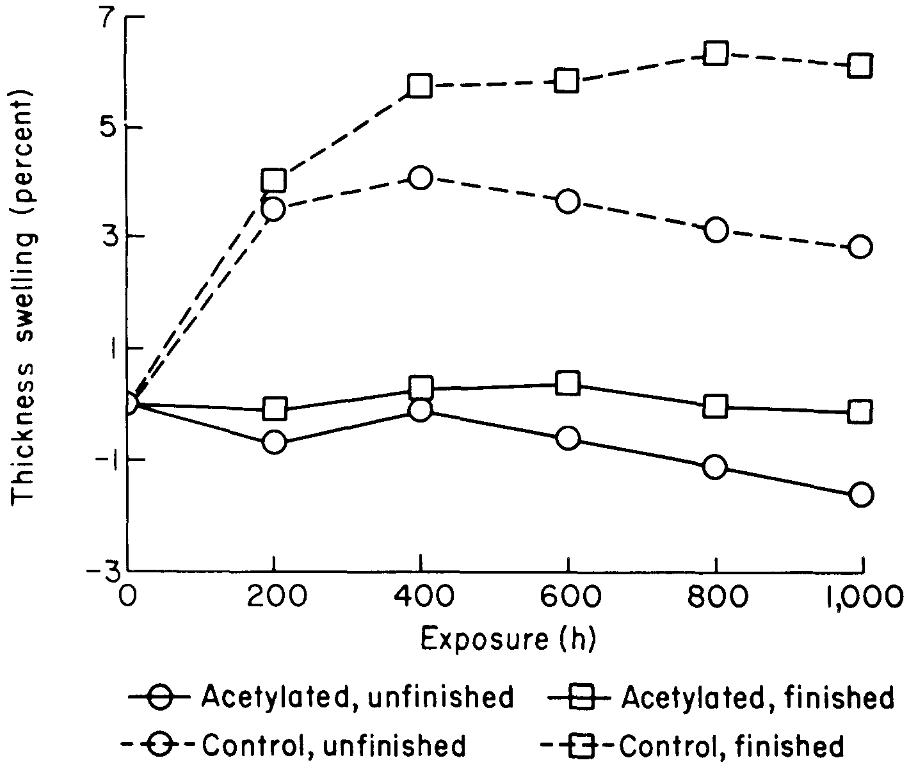

FIG. 3. Thickness swelling of aspen fiberboards after accelerated weathering.

When the untreated fiberboard was finished with a semitransparent stain (Black et al. 1979), swelling was nearly identical to that of the unfinished fiberboard after 200 h of exposure. After 400 h, however, swelling for the finished specimens was about 6% compared to about 4% for the unfinished specimens. This greater swelling shows that the finish prevented the loss of surface fibers during accelerated weathering but did not reduce swelling. This finish contains drying oils and a water repellent. A previous study had shown that semitransparent stain formulations containing water repellents reduce the rate and extent of weathering (Feist 1988).

Outdoor weathering

With regard to swelling, outdoor weathering after 24 months was not nearly as severe as accelerated weathering (Fig. 3, Table 3). In the untreated aspen fiberboard specimens, swelling was minimal but consistent, whether the specimens were finished or unfinished. No distinctive patterns of swelling were observed. The acetylated fiberboard specimens showed a slight shrinkage with exposure even for finished specimens. This result may be due to the measurement technique or to inadequate conditioning time before measurement. Somewhat smaller shrinkage values were observed in the accelerated weathering study (Fig. 3). Whatever the reasons for shrinkage, the difference between treated and untreated specimens is

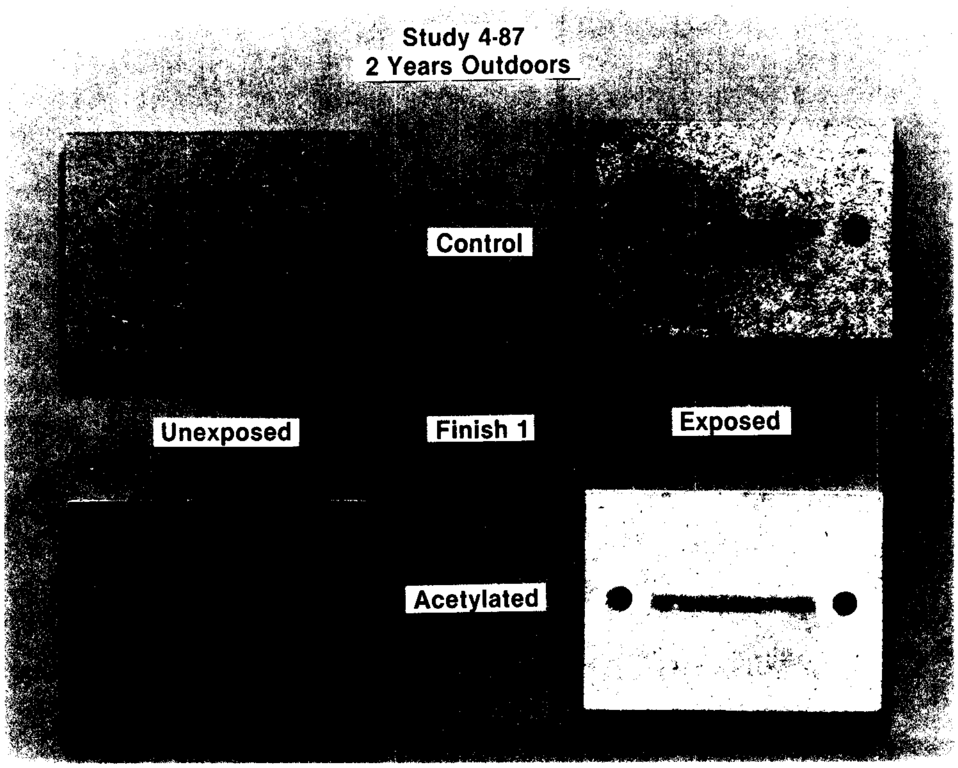

FIG. 4. Effect of outdoor weathering (2 years) on unfinished aspen fiberboards. Small area in center of exposed specimens was protected by a stainless-steel plate.

small; it reflects a slight tendency of untreated fiberboards to swell and of acetylated specimens to shrink.

Finish performance

Accelerated weathering

Unfinished specimens.—The unfinished fiberboard specimens were bleached during accelerated weathering. Except for differences in surface roughness, the untreated and acetylated fiberboards looked similar.

Finished specimens.—The only finish used in the accelerated weathering portion of the study was a semitransparent stain with a linseed oil base (Black et al. 1979). This is a penetrating-type finish, and its performance on the untreated aspen fiberboard was much better than that on the acetylated fiberboard. Finish erosion was evaluated on a 10 to 1 rating scale; 10 indicates perfect condition and 1 total failure of the surface. The finish had a value of 7 on untreated fiberboard surfaces and a value of 3 on acetylated ones. The poorer stain performance for the acetylated specimens resulted from less finish being spread on the specimen surface. The spreading rate was 5.2 m^2/liter (210 ft^2/gal) for the acetylated fiberboard and 2.1 m^2/liter (85 ft^2/gal) for the untreated fiberboard. Thus, nearly three times as much

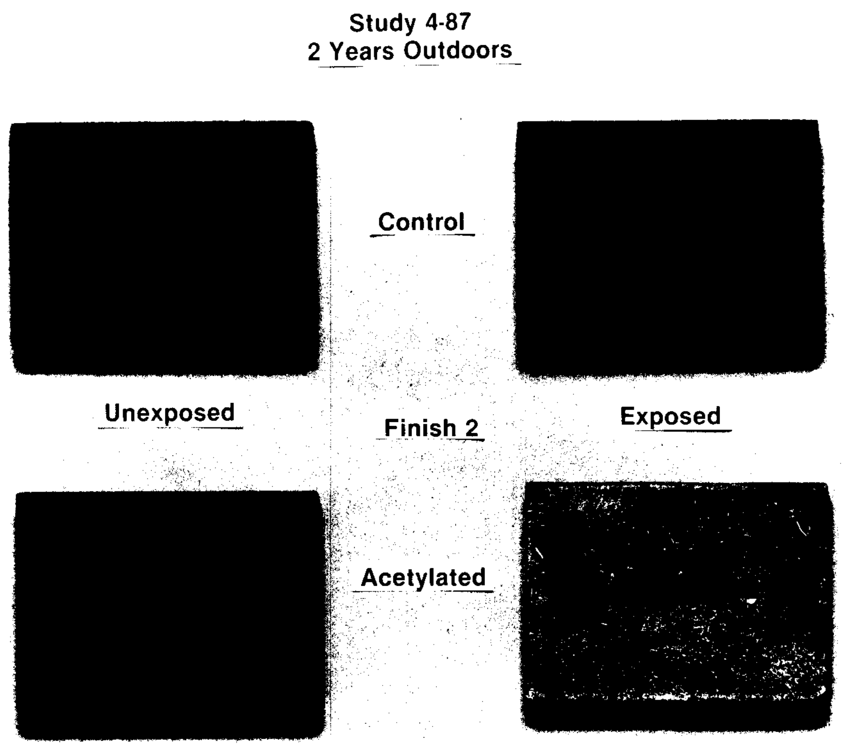

FIG. 5. Effect of outdoor weathering (2 years) on aspen fiberboards finished with a semitransparent oil-based stain. Small area in center of exposed specimens was protected by a stainless-steel plate.

stain was applied to the untreated fiberboard surface. The inability to apply more stain to the acetylated fibers is related to the reduced permeability of this modified material (Rowell et al. 1987) and is responsible for the poorer performance of the acetylated specimens. No additional finishes were included in the accelerated weathering portion of the study because correlation of film-forming finishes with outdoor weathering is very poor.

Outdoor weathering

Unfinished specimens.—The unfinished fiberboard specimens prepared from untreated aspen developed rough surfaces and mildew growth, whereas the specimens made from acetylated fibers retained their smoothness, were bleached, and had little mildew growth after weathering (Fig. 4). The reduced hygroscopicity and swelling of the acetylated fibers compared to untreated fibers explains the retention of smoothness after weathering. The biological resistance of acetylated wood was observed in a previous study (Rowell 1984).

Finished specimens.—The semitransparent penetrating stain finish performed well on the untreated aspen fiberboard; the erosion value was 9 after 2 years of exposure (Fig. 5). As we found in the accelerated weathering portion of the study, the stain did not perform well on the fiberboard prepared from acetylated fibers;

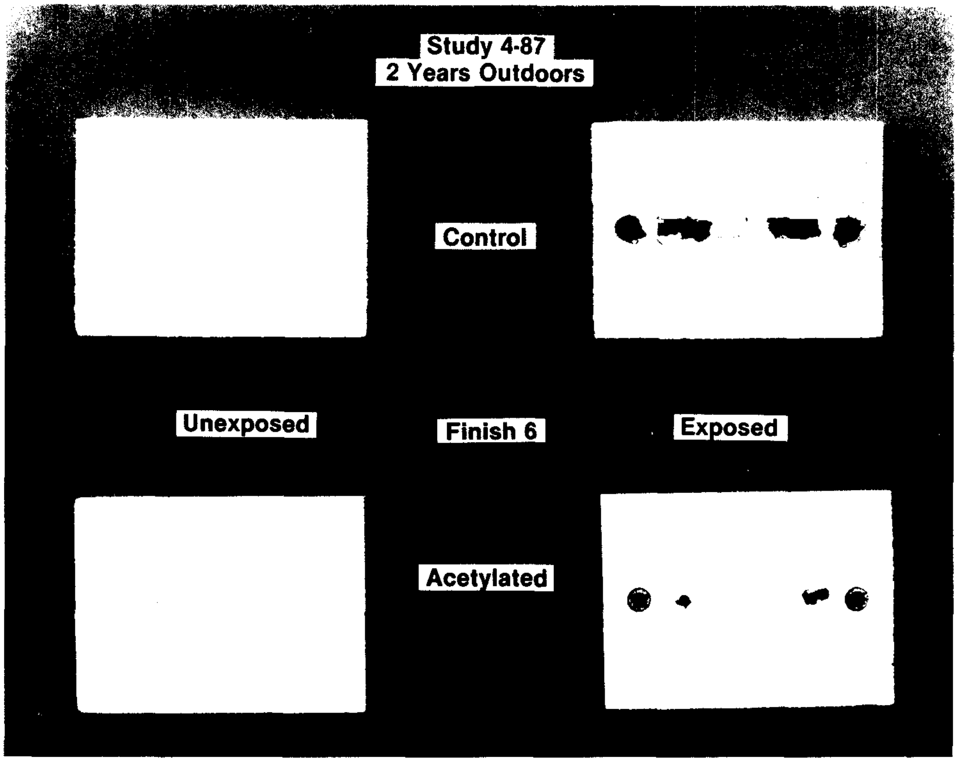

FIG. 6. Effect of outdoor weathering (2 years) on aspen fiberboards finished with an acrylic latex primer and topcoat paint system. Small area in center of exposed specimens was protected by a stainless-steel plate. Paint film was disrupted while the plate was removed from the untreated (control) specimen.

the stain erosion value was 2. As was indicated in our discussion of the effect of accelerated weathering on finished fiberboard, the spreading rate (Table 2) for the acetylated fiberboard was nearly three times higher than that of the untreated fiberboard (one-third less finish on the surface). This means the acetylated surface was less permeable to the stain.

The film-forming finishes (solid-color stains and paints) performed well on all specimens after 2 years of exposure. The finishes had a better appearance on the acetylated fiberboard than on the untreated fiberboard because mildew growth was reduced (Fig. 6). Thus, the acetylated fibers under the paints or solid-color stains help control mildew growth on the finished surface. With the exception of mildew discoloration, the film-forming finishes performed equally on untreated and treated fiberboards. No failures from cracking, peeling, or flaking were observed.

Surface roughness

The surface roughness of specimens before and after accelerated or outdoor weathering was measured with a fine stylus. Average roughness (arithmetic mean

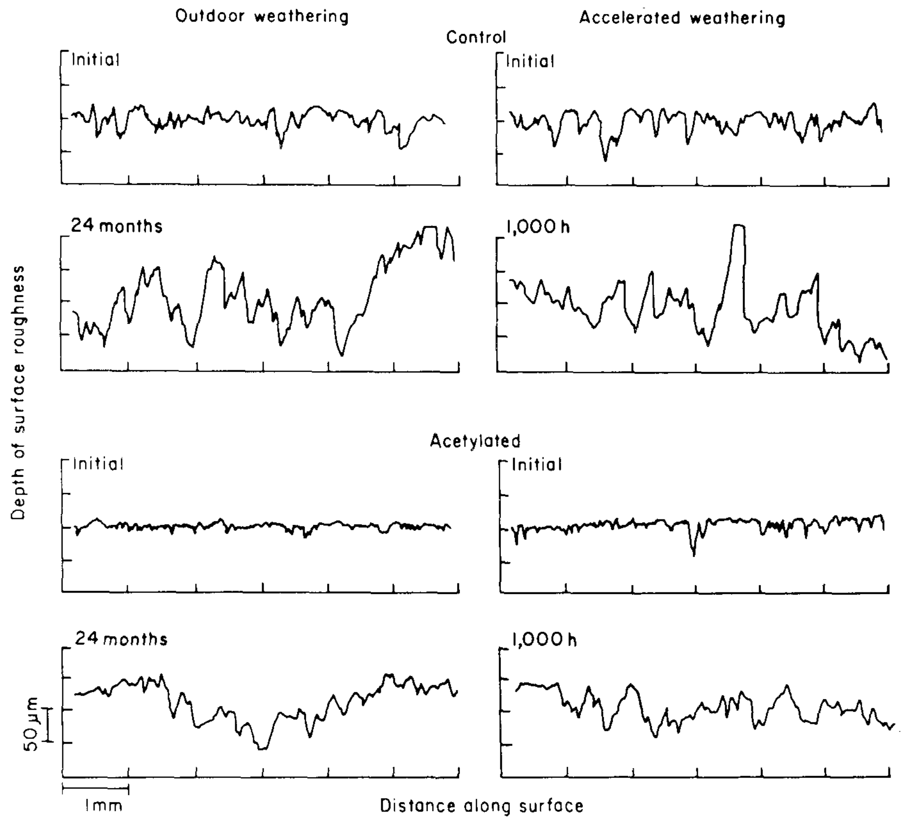

FIG. 7. Surface profiles of unfinished aspen fiberboard before and after outdoor or accelerated weathering.

deviation) and average roughness depth (mean of individual roughness depths) were used to evaluate surface roughness (Figs. 1 and 2).

Accelerated weathering

Accelerated weathering affected the surface roughness of both unfinished and stain-finished fiberboard specimens. The unfinished specimens were affected the most (Fig. 7, Table 4); the surfaces of untreated specimens were much rougher

TABLE 4. *Roughness measurement values for aspen fiberboards after 1,000 h of accelerated weathering.*[a]

	R_z (µm)				R_a (µm)			
	Control		Acetylated		Control		Acetylated	
Finish	0 h	1,000 h	0 h	1,000 h	0 h	1,000 h	0 h	1,000 h
Unfinished	55.6	120.0	33.0	53.3	10.0	23.1	5.0	11.7
ST stain[b]	44.8	63.4	25.6	36.7	7.9	11.9	4.7	6.7

[a] R_z is average roughness depth (mean value) of individual roughness depths from 5 lengths measured in succession; R_a is average roughness (arithmetic mean) of all values of the roughness profile within the measuring length.
[b] Semitransparent stain.

TABLE 5. *Roughness measurement values for aspen fiberboards after 24 months of outdoor weathering.*[a]

Finish[b]	R_z (μm)				R_a (μm)			
	Control		Acetylated		Control		Acetylated	
	0 mo	24 mo	0 mo	24 mo	0 mo	24 mo	0 mo	24 mo
Unfinished	44.5	88.2	20.6	52.1	7.8	19.3	3.4	9.5
ST stain	40.7	47.3	30.3	36.6	7.6	7.2	3.4	4.4
SC oil stain	21.7	20.3	19.8	20.0	3.9	3.8	3.3	3.1
SC latex stain	47.0	29.6	42.9	24.9	9.5	5.6	6.6	3.4
Oil primer, latex topcoat	21.8	27.6	16.7	18.2	4.4	5.7	3.7	4.0
Latex primer, latex topcoat	25.9	40.2	20.5	20.9	6.2	7.3	4.9	4.5

[a] R_z is average roughness depth (mean value) of individual roughness depths from 5 lengths measured in succession; R_a is average roughness (arithmetic mean) of all values of the roughness profile within the measuring length.
[b] ST is semitransparent, SC solid-color.

than those of specimens made from acetylated fibers. The surfaces of acetylated fiberboards were smoother than those of the untreated fiberboards before exposure and did not roughen as much as those of the untreated fiberboards after exposure. For the untreated fiberboards, the greatest surface change was in roughness depth (Table 4). The stain-finished surfaces were not as rough as the unfinished surfaces because the stain repelled more water more effectively.

Outdoor weathering

Outdoor weathering caused changes in surface roughness of unfinished fiberboard specimens, but these changes were less than those found during the more degradative accelerated weathering test (Fig. 7). As in the accelerated weathering test, the greatest change was in roughness depth (Table 5). Surface roughness changes on finished surfaces (semitransparent stain, solid-color stains, paints) were small compared to changes on unfinished surfaces. Surfaces finished with solid-color latex stain became smoother after outdoor weathering (Table 5).

CONCLUSIONS

This study shows that acetylation of aspen fibers prior to making a fiberboard reduces swelling of the fiberboard during exposure to accelerated and outdoor weathering. Acetylated fiberboards were smoother than untreated ones after treatment, and acetylation helped retain surface smoothness of both finished and unfinished fiberboard during weathering. Finished and unfinished acetylated fiberboard had less mildew growth after outdoor weathering than did untreated fiberboard, which demonstrates the greater biological resistance of acetylated fiberboards. Penetrating finishes like semitransparent oil-based stain performed better on untreated fiberboard compared to acetylated fiberboard because the finish could not penetrate the treated surface. Film-forming finishes (paints and solid-color stains) performed equally well on acetylated and untreated fiberboards after outdoor exposure.

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