Effect of Flakeboard Manufacturing Variables on Composite Properties: Part 1. Effect of Resin Content, Wax Content, Pressing Conditions, and Edge Treatments on Paint Performance

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ABSTRACT

Over the last several decades, oriented strandboard (OSB) and similar composite materials (flakeboard) have been successfully used to sheath residential, and to some extent, commercial structures. However, when used as exterior siding, they have often failed, often even if they were painted. The performance of OSB and flakeboard has not been consistent when used outdoors. Little is known of how manufacturing parameters, such as the amount of adhesive (resin), water repellent (wax and similar products), pressing conditions, and other factors, such as geographic area and paint, affect performance. We report the effect of these parameters on painted flakeboard exposed at the Forest Products Laboratory outdoor exposure sites near Madison, Wisconsin, and Gulfport, Mississippi. The study also evaluated the effect of a bevel and edge sealing on the drip edge . We found that a single coat of paint failed within a year because of dimensional change and debonding of flakes, particularly the areas of the boards having large flakes. Statistically significant effects were noted for exposure location, resin content, and edge sealing. The amount of wax had a positive effect only for flakeboard having low resin content. Those boards having 3.5% isocyanate resin performed better than those having 2.0% isocyanate res n and edge sealing generally decreased thickness-swell.

INTRODUCTION

Background

Over the last several decades, oriented strandboard (OSB) panels have performed quite well as sheathing for residential structures when protected from the weather; however, when used as exterior siding (*i.e.,* cladding), OSB panels often performed poorly, particularly if not overlaid with resin-impregnated paper. When used as siding, either as a panel product or cut into strips to give lap siding, edges of these products tended to delaminate, absorb moisture, and swell. Paint often failed by cracking and flaking. These failures relate to poor understanding of various OSB components (such as type of wood, resin, and wax), processing variables, drip-edge configuration, and finishes used on these products (edge seals and paint). Performance of painted OSB relies on an interaction between two completely different materials and the industries manufacturing these materials — the wood industry (OSB) and paint industry (edge sealers and finishes). These industries rarely cooperate in joint research to understand the complex nature of the interactions of these different materials as they age during outdoor exposure, nor does industry take into account the different climates where their products are used. Researchers in the Performance-Engineered Composites and Performance Enhanced Biopolymers Research Work Units at the Forest Products Laboratory (FPL) investigated this complex combination of materials.

Several previous studies reported interactions of finishes with flakeboard or OSB, but manufacturers in the United States no longer make these finishes. Hann et al. (1962) made flakeboard from Douglas-fir (*Pseudotsuga menziesii*) furnish using several blends of phenolic- and urea-based resins. They evaluated the effects of temperature and moisture under static and cyclic conditions in laboratory tests and compared the laboratory results with specimens exposed outdoors for 3 years. Some of the specimens exposed outdoors were painted. The face was painted with one coat of exterior under-coat and one top-coat of white-gloss house paint and the edges with several coats of paint. Some specimens were not painted. Details on the type of paint were not reported, but they were probably oil-alkyd paints, as water-borne latex paints were seldom used in exterior applications in 1962. Unpainted panels degraded markedly; however,

the painted ones were in good condition after 3 years. Jokerst (1968) also reported the performance of painted and unpainted Douglas-fir flakeboard. The resin systems appear to be the same as those in the study by Hann et al. (1962). It appears that the two reports reflect results from the same study taken 6 years apart (Hann et al. 1962, Jokerst 1968). Jokerst (1968) reported on the performance of the panels following 8 years of outdoor exposure. For unpainted specimens, only the phenolics-based panels were intact after 8 years. He reported, "The primary causes of deterioration of the flakeboard were springback from compression set, deterioration of the binder, and differential shrinkage c f adjacent particles during moisture changes." However, if painted, the panels having urea-based resins also were in good condition. Panels were repainted after four years.

Grozdits and Bibal (1983) prepared flakeboard from white fir (possibly *Abies concolor* (botanical name not give in publication)) using 1) phenol formaldehyde (PF) adhesive or 2) surface activation of particles by nitric acid in combination with a cross-linking agent (mixture of furfural alcohol, ammonium lignosulfonate, and maleic anhydride). They used a carbon-arc weathering chamber (18-min water spray/102-min ultraviolet light cycle). The study objective was to evaluate two adhesive systems; however, two paint systems (an oven-cured water-borne acrylic and an ambient-temperature-cured water-borne latex paint) were also evaluated for their compatibility with the flakeboard Panels were edge sealed with six coats of an aluminum-pigmented paint. Grozdits and Bibal reported that paint performance was improved by including additional fines in the surface layer of the furnish. Severe paint cracking occurred on specimens weathered for 1,024 hours.

Biblis (1990) and Grigoriou and Biblis (1995) reported paint performance on OSB overlaid with resin-impregnated paper. Overlaid surfaces and edges of panels were painted with several types of oil-based primers, latex top-coats, or epoxy paint. Results were obtained from a 21-d continuous water spray of panels. The most serious degradation for this short exposure was telegraphing (swelling of the underlying flakes giving an uneven surface).

He et al. (2000) tested the water repellency of five paints on OSB using a 24-h water soak. Coatings were applied to panels to seal them against water absorption: 1) top and bottom; 2) all edges; 3) top, bottom, and edges parallel to the flake direction; 4) top, bottom, and edges perpendicular to the flake direction; 5) top only; or 6) no coating (control). They applied five coats of phenol formaldehyde resin, two-part polyurethane, acrylics, or phenol formaldehyde resin containing gypsum or Portland cement. Water absorption was determined from thickness swell and the least swelling occurred with panels having coatings on top, bottom, and edges perpendicular to the fiber direction (Treatment No. 4). The two-part polyurethane coating gave the best waterproofing.

Only one study reported the interaction of manufacturing parameters and finish performance over long-term outdoor exposure, but this study used paints that are no longer available. (Hann et al. 1962) All architectural finishes were reformulated in the early 1990s to conform to regulations resulting from clean air legislation. None of the other studies evaluated the interaction of flakeboard manufacturing parameters on the performance of finishes. None of the studies evaluated contemporary finishes manufactured in the United States.

Objective

Our objective in this study is to identify and quantify the critical material properties and composite processing variables that relate the long-term field performance of exterior paints applied to flakeboard composite materials.

EXPERIMENTAL

Flakeboard panel preparation

In commercial OSB manufacture, individual flakes on panel faces are orientated parallel to the long-panel direction. Lap siding cut from the panels maintains this parallel orientation in the longitudinal direction. Parallel orientation of surface flakes minimizes differential dimensional changes among the flakes, thereby minimizing stress on paint films. However, this orientation is not always parallel; therefore, to obtain information for the worst-case scenario, panels were prepared with random orientation of flakes. This orientation maximizes the differential movement among flakes as they shrink and swell with changes in moisture content (MC).

Panels (610 by 610 mm (24 by 24 inches)) with a 10-mm (0.4-inch) target thickness were made from a single layer mat having random orientation using a laboratory press. Southern pine (*Pinus* spp.) The OSB flakes having nominal thickness of 0.7 mm (0.028 inches) with ~ $\leq$10–30% fines were used. Flakeboard-processing variables were two concentrations or resin (2.0 or 3.5%)[1] and wax (0.75 or 1.5%)[2] and two press conditions (continuous closure or two-step closure). For each combination of resin, wax, press control, and exposure location, three replicate panels were made.

Two levels of press-control were used. One level was a constant closing to target thickness to create a vertical density profile having dense faces and a lower density core. The other level was a two-step press closure to 80% of target thickness, a 30 s hold, and then closure to target thickness to create a more uniform vertical density profile.

After pressing panels and conditioning them to approximately 12% MC, about 100 mm (4 inches) were trimmed from the edges, and three 140 by 403 mm (5½ by 15 7/8 inches) boards were cut from the panel. Board F (flat-edge) had a drip edge 90° to the surface (*i.e.,* no beveled drip edge). Board B (bevel-edge) had a reverse beveled drip edge (~30°). The bevel-edge boards (B) and flat-edged boards (F) were finished and placed outdoors. Board T (test) yielded specimens for evaluating physical and mechanical properties (vertical density profile, 24-h thickness swell, water-absorption, bending strength, stiffness, and internal bond strength). We will report physical and mechanical test results our next report.

Preparation of boards for finishing evaluations
Edge-Seal

Half the length of the drip edge of all boards was painted with an edge-seal. Each 140- by 403-mm (5 ½- by 15 7/8-inch) board was marked (but not cut) into four 140- by 101-mm (approximately 5 ½- by 4-inch) paint-exposure zones designated as 1, 2, 3, and 4 when viewed from left to right along the 403-mm (15 7/8-inch) length of the board **(Figure 1).** Each of the two boards per flakeboard panel intended for finishing and subsequent outdoor exposure was edge-sealed with a commercial OSB edge seal on both side edges, the top edge and one-half of the bottom edge (Sections 3 and 4). The remaining two sections (1 and 2) were not edge-sealed along the bottom edge.
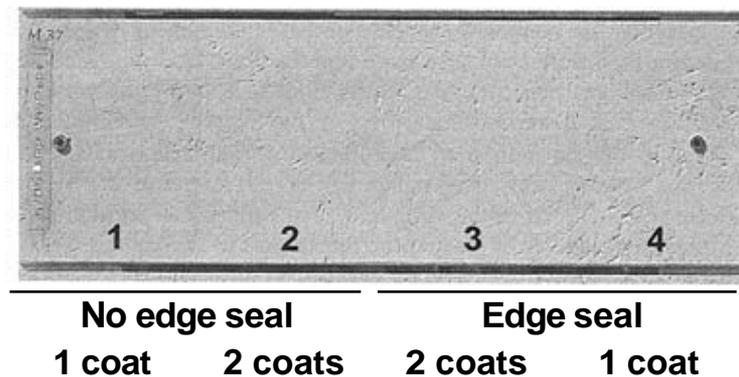

Figure 1. Single board showing four sections: 1. One coat of paint, no edge seal; 2. Two coats of paint, no edge seal; 3. Two coats of paint, edge seal; 4. One coat of paint, edge seal.

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[1] The resin MDI (diphenylmethane diisocyanate) was "Ruminate 1840," Huntsman, Inc., Twin Falls, ID.

[2] Wax was "Microlube N," Hercules, Inc., Wilmington, DE. 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.

Paint and Primer Finishing

The middle half of each board (Sections 2 and 3) was finished with a latex primer and after 24 hours, the entire board (Sections S1-S4) was finished with a single top-coat of a high-quality latex paint. The back side of all boards was finished with a single coat of latex-based primer. After a week of drying, boards were stickered, bundled, and placed in the 30% RH/80°F (27°C) room for conditioning before installation at the two test sites (Madison, WI, and Gulfport, MS).

Field Exposure

Painted specimens were placed on test racks vertically facing south at the FPL outdoor test sites located 5 km southwest of Madison, Wisconsin, **(Figure 2)** and 15 km north of Gulfport, Mississippi. The photograph was taken shortly after the boards were placed on the test fence.
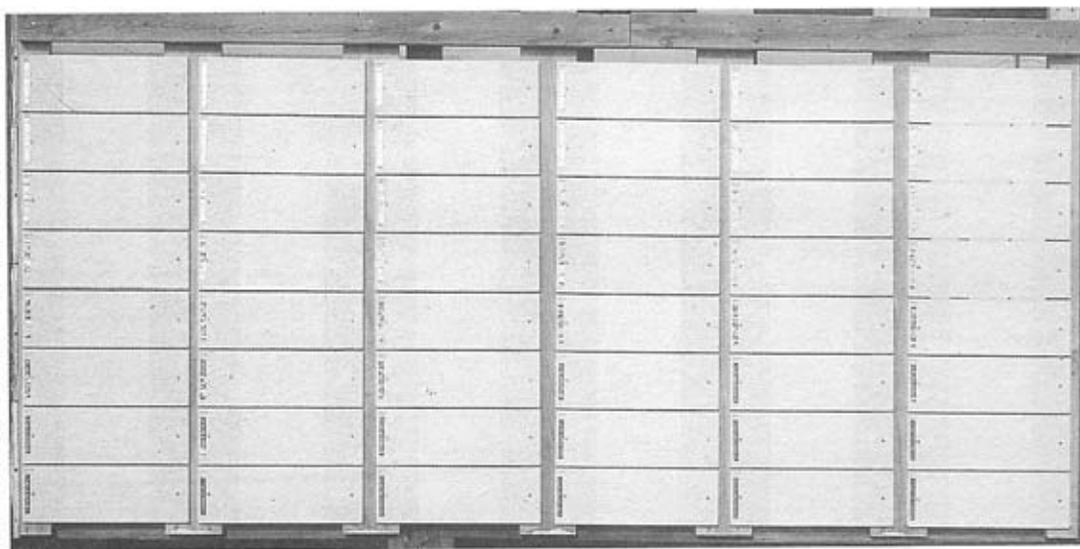

Figure 2. Painted boards mounted on test fence facing south, Madison, Wisconsin, soon after installation.

Finish evaluations for cracking, flaking, and general appearance were in accordance with D 661-93, D 772-86, and D 3274-95, respectively (ASTM International 2005). Substrate checking was also evaluated. A rating of 10 indicates no degradation, and 1 indicates total failure of the coatings system. A rating of 5 indicates a condition at which the coating should be refinished without having to do excessive surface preparation (in other words, the approximate service life).

Thickness-swell

After 3 years, we measured thickness of the edges and center for the four sections (1-4) of all boards exposed near Madison. Five random measurements were taken along the edge and at the center of each of the four sections of the boards.

RESULTS AND DISCUSSION

Visual evaluation of paint performance

Figures 3 and 4 show the change in specimens exposed for 3 years near Madison, Wisconsin. The boards are typical of the other boards exposed at this site. Inspection of the painted flakeboard boards after 3 years exposure clearly shows a difference in performance of the one- and two-coat paint systems. Each of the boards has four sections (Sections 1-4 (labeled left to right), **Figure 1).** Ends of boards 1 and 4 have one coat (latex top-coat), and the center (Sections 2 and 3) has two coats of paint (latex primer and top-coat). The drip edge of the left half (Sections 1 and 2) has no edge sealer and the right half (Sections 3 and 4) has an edge sealer. Other than the obvious difference in performance of the one- and two-coat paint system, there appears to be little difference in performance between the edge sealed and non-edge sealed **(Figure 4)** specimens. The single coat of paint failed and there was considerable debonding of flakes. The dimensional change of surface flakes often telegraphed through the two-coat paint system.
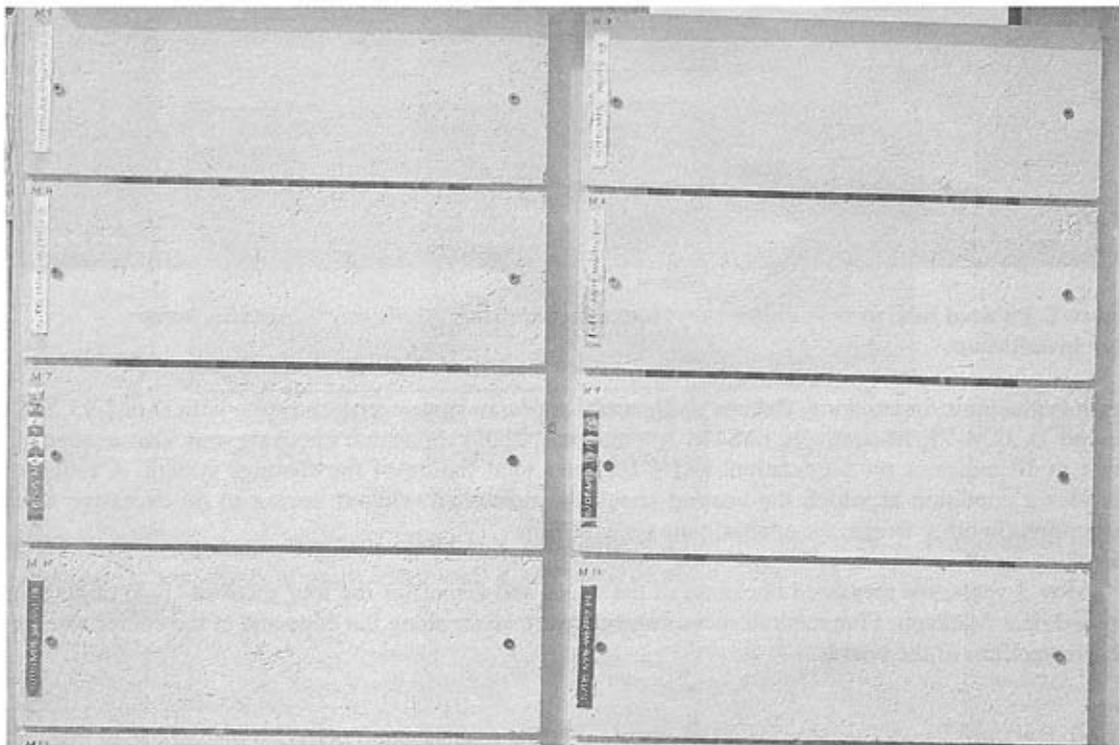

Figure 3. Close-up of several boards just after installation on the test fence near Madison, Wisconsin.
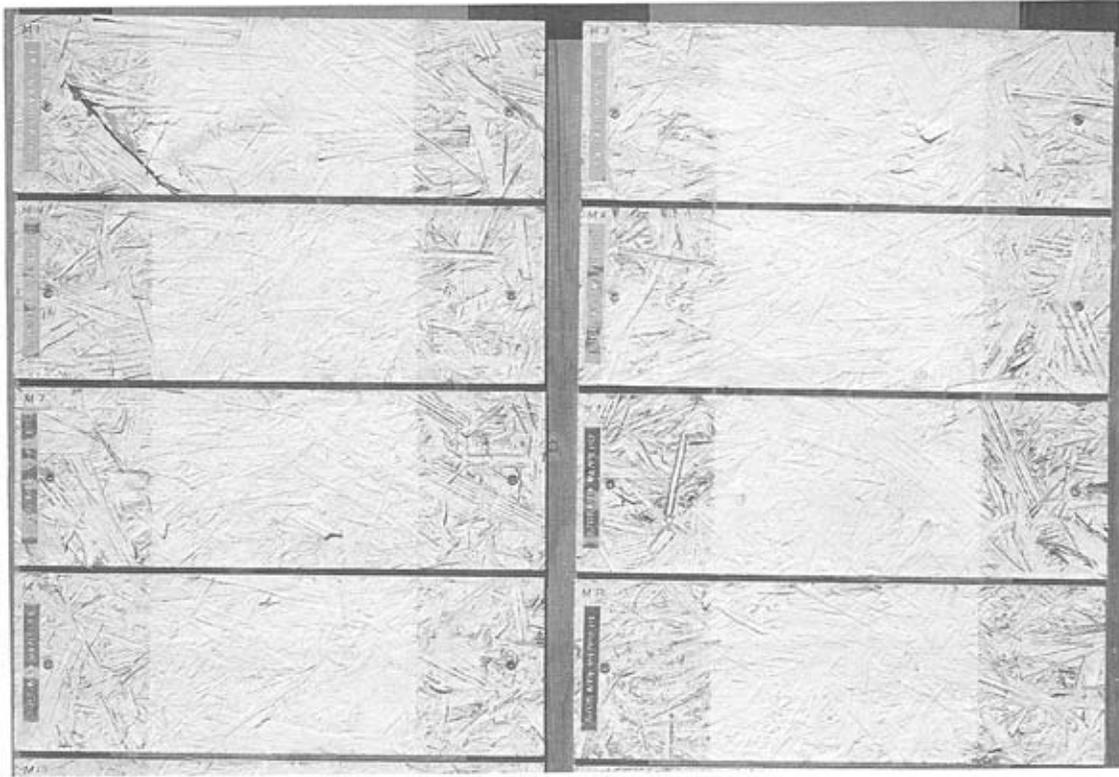
Figure 4. Close-up of the same boards as shown in Figure 3 after 3 years on the test fence near Madison, Wisconsin.

We evaluated substrate condition (S) for checking, flake curling, and debonding and the paint for paint cracking (C), flaking (F), discoloration (D), and general appearance (G). Large flakes near the surface of the painted boards were generally problematic, as they tended to curl and debond **(Figure 5a and b).** The random orientation is quite apparent in this close-up. As mentioned previously, single-layer mat formation with random flake orientation presents the worst-case scenario for moisture-induced surface movement with few fines in the outer surfaces. Grozdits and Bibal (1983) reported that fines on the surface decreased surface degradation. In our study, this surface movement was more serious under a single coat of paint for the edge-sealed and non-edge-sealed sections of the boards than for the two-coat paint system. In some cases, debonding extended into the two-coat portion of the board **(Figure 5a).**
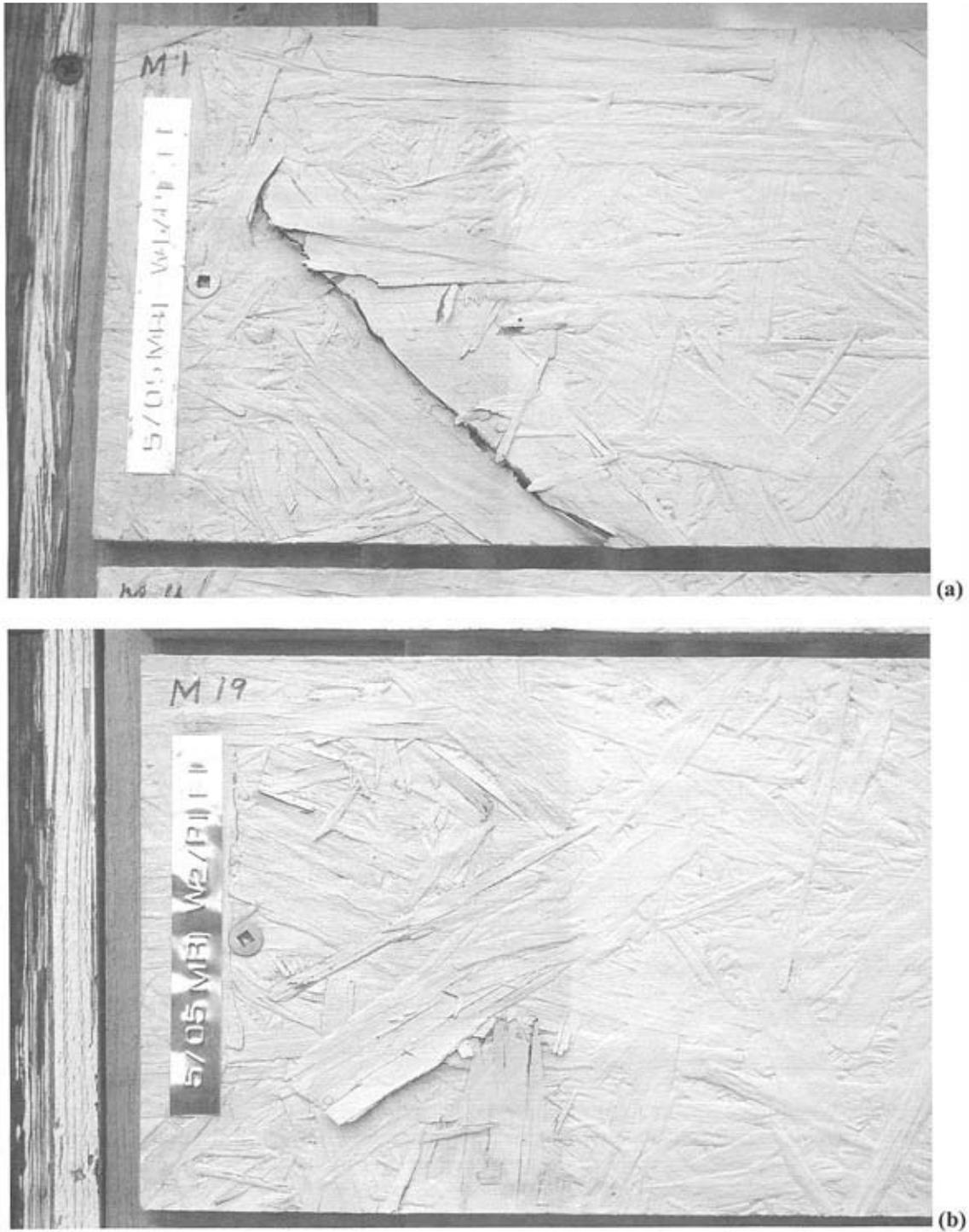
Figure 5. Close-up of boards on the test fence near Madison, Wisconsin, showing deterioration at the edges of large surface flakes.

Figure 6a and b are typical of the change in the boards at the Gulfport test site. As with boards exposed near Madison, the boards having a single coat of paint had failed. In our subjective judgment, telegraphing of the two-coat paint system was slightly worse near Gulfport than near Madison. In general, boards having one coat of paint had severely cracked paint with the flakes debonding. This debonding was more pronounced with larger flakes **(Figure 5).**
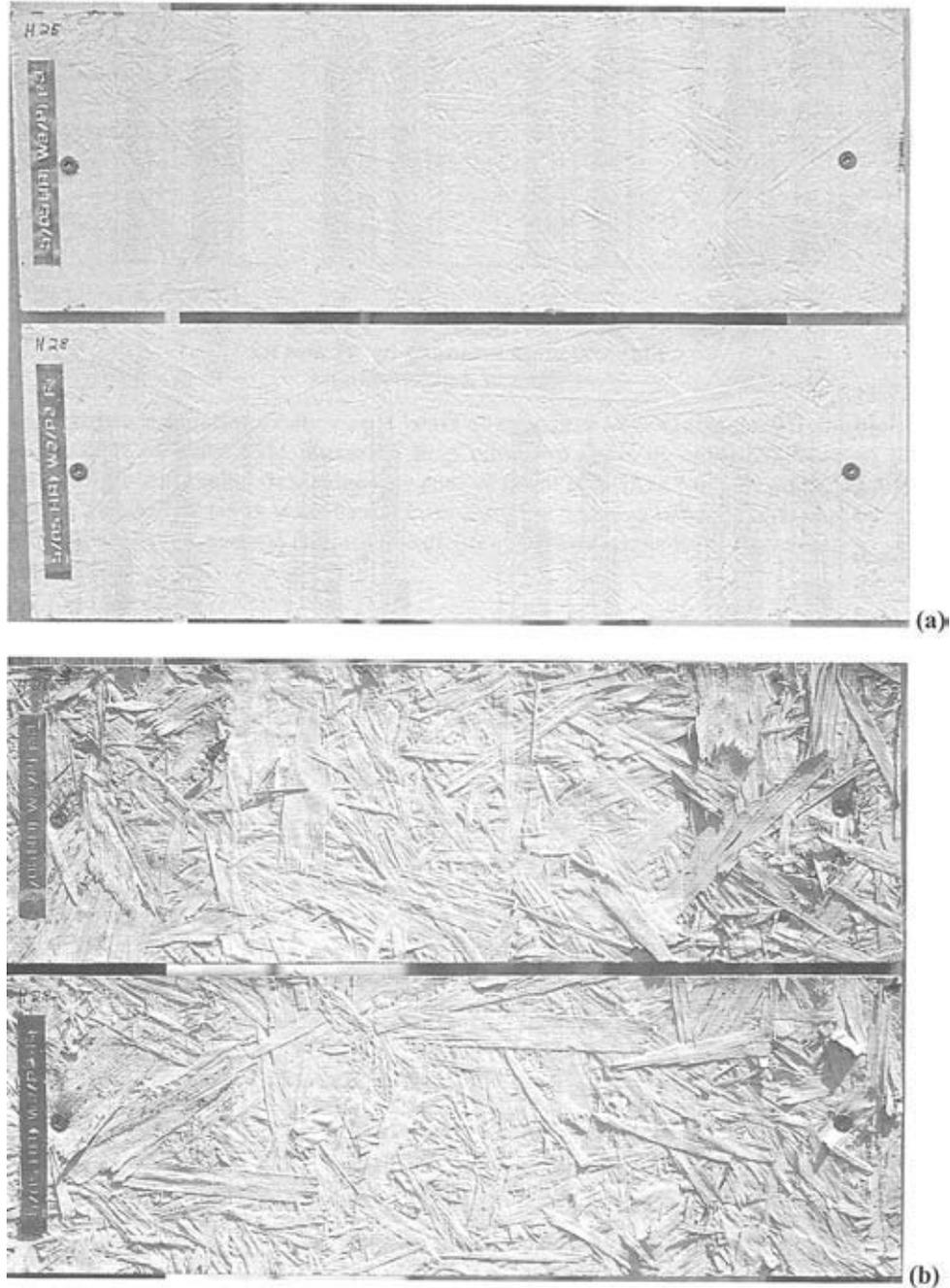

Figure 6. Close up of two boards just after installation (a) on the test fence near Gulfport, Mississippi, and following 3 years of exposure (b).

We evaluated the data for the effect of edge-seal, bevel- or flat-drip edge, and manufacturing parameters (resin, wax, and press closure) for boards exposed near Madison and Gulfport. Location had the largest effect and amount of resin had the second largest effect on board performance (Figure 7). Figure 7 shows the condition of the substrate (S evaluation) for non-edge sealed (S1 and S2) and edge sealed (S3 and S4) for flat-drip edges for boards exposed near Madison. Bars are first standard deviation of averages of three observations. The most notable effect is for the one- and two-coat paint systems.

Madison: Substrate – 3 years
Flat drip edge arranged by R1 and R2
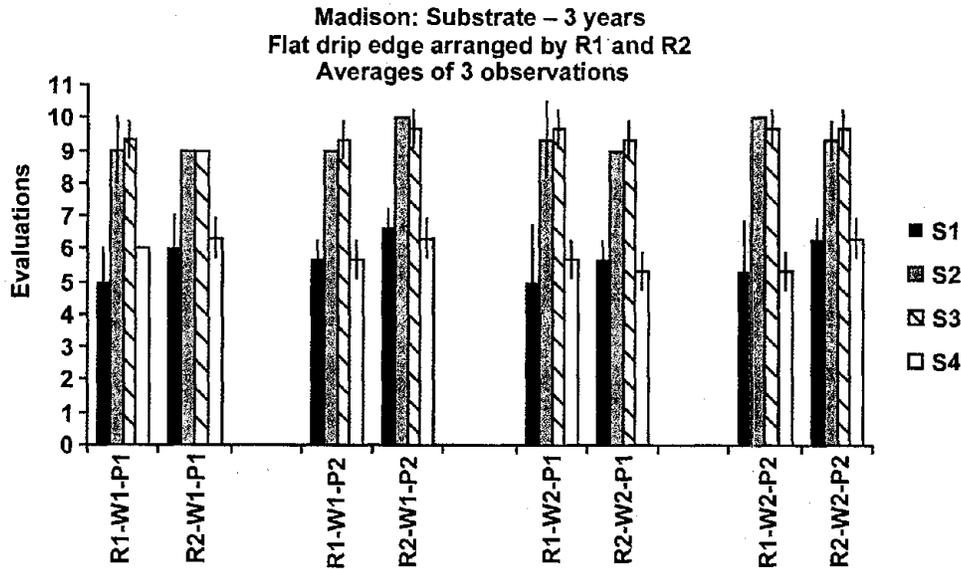**Averages of 3 observations**

Figure 7. Substrate evaluations following 3 years of exposure near Madison., Wisconsin, for unsealed drip edge/one coat of paint (S1); unsealed drip edge/two coats of paint (S2); sealed drip edge/two coats of paint (S3); and sealed drip edge/one coat of paint (S4). R1 is 2.0% resin, R2 is 3.5% resin, W1 is 0.75% wax, and W2 is 1.5% wax. Error bars indicate ± one standard deviation from mean. Lack of a line indicating first standard deviation indicates all evaluations were the same.

The next effect is for resin content; higher resin content improved performance. Boards exposed near Gulfport were similar **(Figure 8)**. The paint cracking evaluations for Madison and Gulfport show similar trends **(Figures 9 and 10)**.
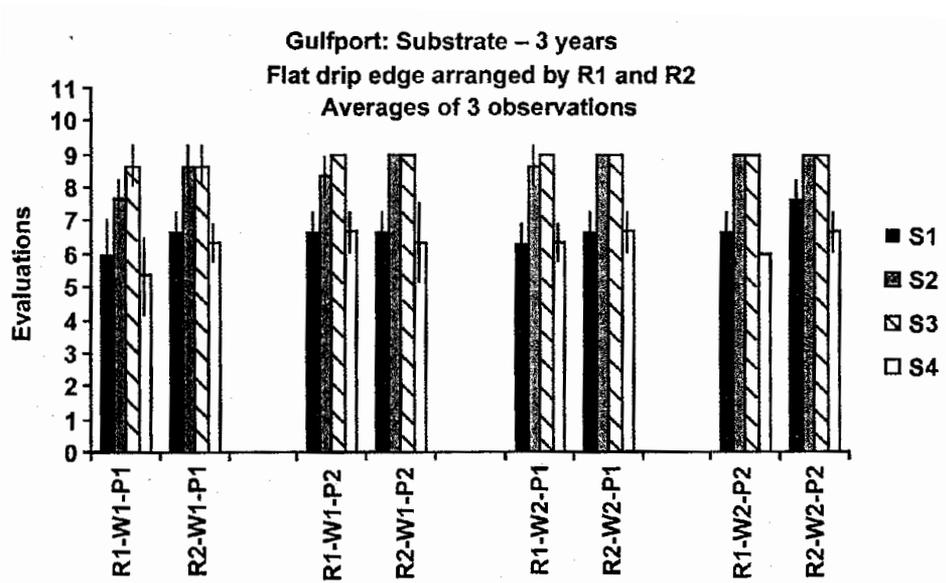
Figure 8. Substrate evaluations following 3 years of exposure near Gulfport, Mississippi, for unsealed drip edge/one coat of paint (S1); unsealed drip edge/two coats of paint (S2); sealed drip edge/two coats of paint (S3); and sealed drip edge/one coat of paint (S4 R1 is 2.0% resin, R2 is 3.5% resin, W1 is 0.75% wax, and W2 is 1.5% wax. Error bars indicate ± one standard deviation from mean. Lack of a line indicating first standard deviation indicates all evaluations were the same.
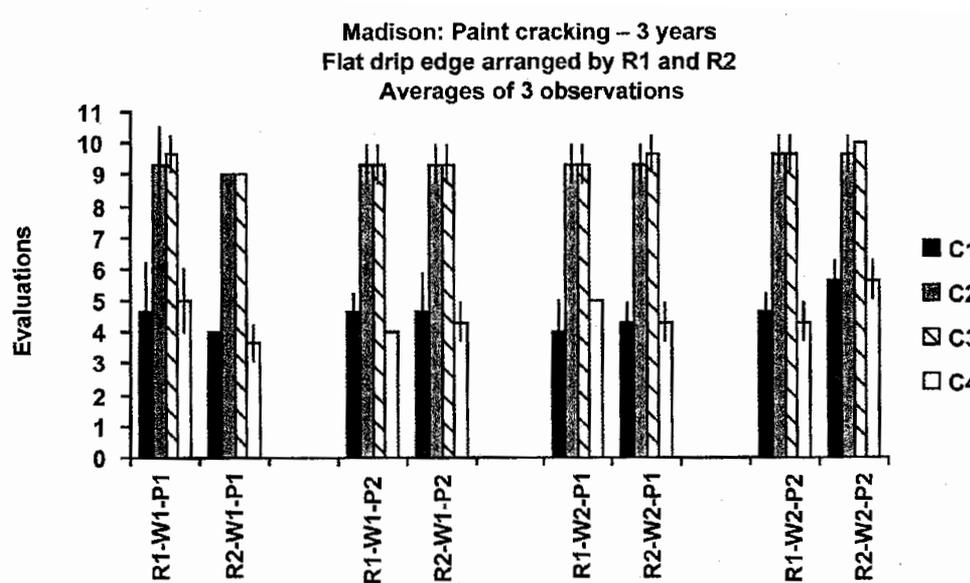

Figure 9. Paint cracking evaluations following 3 years of exposure near Madison, Wisconsin, for unsealed drip edge/one coat of paint (C1); unsealed drip edge/two coats of paint (C2); sealed drip edge/two coats of paint (C3); and sealed drip edge/one coat of paint (C4). R1 is 2.0% resin, R2 is 3.5% resin, W1 is 0.75% wax, and W2 is 1.5% wax. Error bars indicate ± one standard deviation from mean. Lack of a line indicating first standard deviation indicates all evaluations were the same.
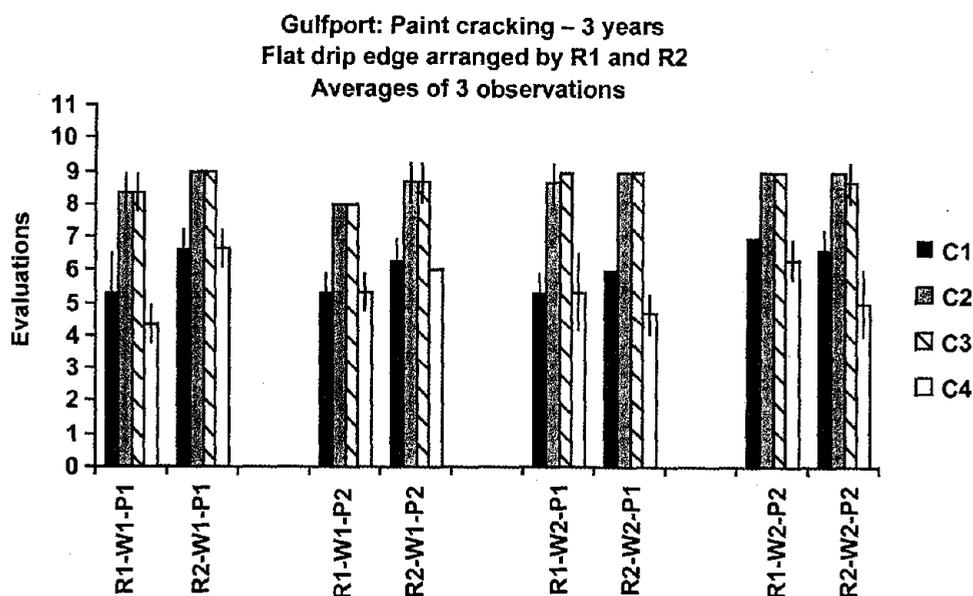
Figure 10. Paint cracking evaluations following 3 years of exposure near Gulfport, Mississippi, for unsealed drip edge/one coat of paint (C1); unsealed drip edge/two coats of paint (C2); sealed drip edge/two coats of paint (C3); and sealed drip edge/one coat of paint (C4). R1 is 2.0% resin, R2 is 3.5% resin, W1 is 0.75% wax, and W2 is 1.5% wax. Error bars indicate 5 one standard deviation from mean. Lack of a line indicating first standard deviation indicates all evaluations were the same.

We evaluated boards for discoloration and general appearance. For both evaluations, mildew growth caused a similar change. Boards exposed near Gulfport tended to have more mildew, but this was not consistent from year to year.

Two coats of paint and 3.5 percent resin in the boards improved paint performance, but the paint evaluation data revealed few other differences among experimental parameters **(Figures 7 and 10).** Statistical analysis provided a clearer picture of significant differences for the composite manufacturing parameters. The data were analyzed for edge-sealed compared with non-edge-sealed, bevel- compared with flat-edge, location, and manufacturing parameters (resin and wax content and press closure). There was no obvious effect for edge sealing or the type edge (bevel compared with flat). For statistical analysis, both the variability and the level of experimental redundancy affected the actual limits of significance. For this experiment, the limiting differences in means at the $p = 0.05$ and $p = 0.10$ levels of significance would be $0.58 \times SD$ and $0.49 \times SD$, respectively.

Significant substrate and finish-cracking effects for location, resin, wax, and press closure for the flat- and bevel-edge boards are shown in **Table 1.** The significant effects listed in Table 1 can be compared with the results in the various figures. For example, the difference between R1 and R2 can clearly be seen in Figures 7–10.

Table 1. Summary of significant effects for location, resin, and wax content, and press closure.															
	Flat-edge								Bevel-edge							
	S1[a]	S2	S3	S4	C1	C2	C3	C4	S1	S2	S3	S4	C1	C2	C3	C4
Location	G[b]	M	M	G	G	M	M	G	G	M	M	G	G	M	M	G
Resin	2	—	—	2	—	—	—	—	2	2	2	2	—	2	2	—
Wax	—	—	2	—	—	2	2	—	2	2	2	—	—	—	2	2
Press	2	2	2	—	2	—	—	—	—	—	—	—	—	—	—	—

[a] The letter or number indicates significantly greater value. For example, a single coat of paint having no edge seal (S1) was significantly better ($p < 0.05$) for Gulfport than Madison, higher resin content (2), and uniform panel desnity (press closure 2).
[b] G, Gulfport; M, Madison; S, substrate evaluation; C, paint cracking evaluation.

In all cases of significance, the increase in resin and wax improved performance of the flat- and bevel-edge boards. In all cases, the single coat of paint performed better in Gulfport than Madison, but the two-coat paint system was better in Madison. We cannot explain this inconsistency, except to comment that the single coat was badly degraded after 3 years, whereas the two-coat system was in good condition. It was difficult to see much difference in performance for the two-coat paint system at either location. Greater mildew growth on the panels at the Gulfport site may have biased the evaluations for the substrate and cracking evaluations.

Different climates at the two exposure sites had quite different effects on the painted boards. The field site near Gulfport is approximately 15 km from the Gulf of Mexico coast in an open area surrounded by southern pine forest that is predominately loblolly pine (*Pinus taeda*). The climate is almost sub-tropical with hot humid summers and mild winters. The test site near Madison is approximately 5 km west of Madison in a predominately agricultural area with some encroachment of housing. The climate is temperate with a few weeks of hot humid weather during the summer; it is usually dry in the autumn and cold in the winter. Winter temperatures usually reach $-30°$C in January. Boards exposed near Gulfport were subjected to high relative humidity (RH) throughout the year and seldom froze, whereas those boards exposed near Madison were subjected to drastic changes in RH and temperature. Thus, different climates gave different modes of degradation. Near Gulfport, mildew growth and telegraphing were more severe than near Madison. Delamination of surface flakes and paint cracking was common in boards exposed near Madison.

Thickness-swell evaluation

The original intent of the study was to assess paint performance. However, as the study progressed, it became apparent that substantial substrate degradation was occurring, particularly on the portions of the boards having one coat of paint. One method for quantifying the substrate degradation in a nondestructive manner is to measure thickness-swell. The results for the difference in thickness between the drip edge of the boards (measured approximately 3–5 mm from the drip edge) and the approximate center of boards showed substantial differences for the various experiment parameters **(Figure 11)**. The most striking feature of this figure is the negative values for zones with two coats of paint over an edge-sealer. Edge seal decreased the thickness-swell for all paired comparisons (4<1, 3<2). The edges swelled less than the center of the board. In all cases, two coats of paint performed better than one coat (2<1, 3<4). The effects of resin content (R1/R2), wax content (W1/W2), press closure (P1/P2), and bevel- compared with flat-edge on thickness swell are similar to the results for the visually assessed paint performance (R2<R1, and W2<W1). We expected to observe a decrease in edge thickness-swell with an increase in resin and wax content, and our measurements confirmed this.
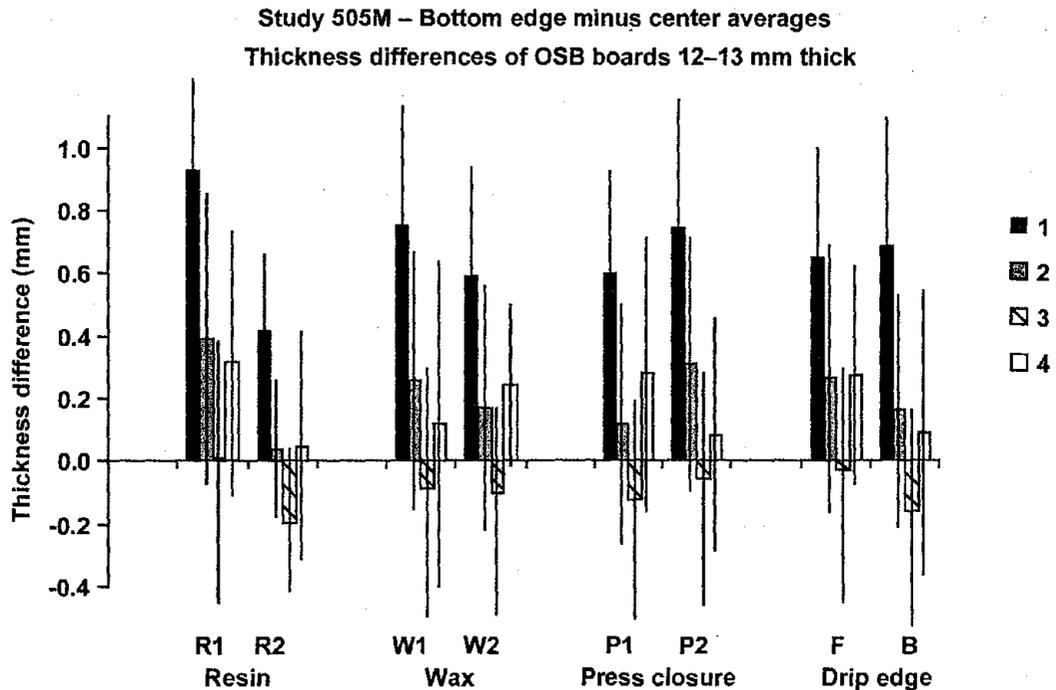
Figure 11. Thickness-swell difference between drip edge and center of board for: unsealed drip edge/one coat of paint (1); unsealed drip edge/ two coats of paint (2); sealed drip edge/two coats of paint (3); and sealed drip edge/one coat of paint (4). Lack of a line indicating first standard deviation indicates all evaluations were the same. R1 is 2.0% resin, R2 is 3.5% resin, W1 is 0.75% wax, and W2 is 1.5% wax. P1 is continuous press closure, P2 is two-stage press closure, F is flat edge, and B is bevel edge.

To analyze the unsealed compared with sealed effect, we considered the thickness difference between the edge and center for two sets of paired comparisons (1-4 and 2-3).For example, 1 and 4 are paired by being measured on the same strip from the same panel; both have one coat of paint (number 1 is not edge sealed whereas number 4 is edge sealed). In the other paired comparison (2 compared with 3), both have two coats of paint (number 2 is not edge sealed whereas number 3 is edge sealed). There are a total of eight [2 resins, 2 waxes, 2 presses], 3 replicates, 2 bevel-, flat-edge] = 48 measurements for 1 compared with 4 if we pool the bevel- and flat-edge measurements. The results for the pooled, bevel-, and flat-edge cases are presented in Table 2. The differences can clearly be seen in Figure 11.

Table 2. Unsealed minus sealed: all data, flat-edge case, and bevel-edge case			
Data	Effect	Mean	p-value[a]
All data	1–4	0.492	0.0001
All data	2–3	0.308	0.0001
Flat-edge	1–4	0.381	0.0002
Flat-edge	2–3	0.295	0.0001
Bevel-edge	1–4	0.603	0.0001
Bevel-edge	2–3	0.320	0.0002
[a] From the signed rank test in the SAS univariate procedure (SAS Institute, Inc. 2004).			

Statistical analysis of the flat- compared with bevel-edge flakeboard showed moderately significant ($p =$ 0.10) differences. We originally considered the bevel-edge to shed water more efficiently than the flat-edge and found some evidence for this; however, in general there was not much difference. The increase in surface area resulting from the bevel-edge probably increased the water absorption, thus counteracting the greater efficiency of the beveled drip edge.

The resin/wax/press closure effects were analyzed as described previously except that an eight parameter estimate was obtained. There was no factor for location. We then created a normal probability plot of these eight estimates. Significant effects should stand out from the relatively straight line of points in the normal probability plot. We used these two techniques to identify reduced models (models with fewer than 8 parameters) that could be fit to the eight data points. The normal probability plots did not identify press as a significant factor; therefore, we fit a model that just included resin, wax, and a resin/wax interaction. We obtained a four-parameter model with four degrees of freedom to estimate the variability. This permitted us to test whether the remaining parameters were statistically significant. In most cases, we found the same pattern. There was decreased thickness swell as resin content increased. The amount of wax significantly decreased thickness-swell only for the boards containing 2 percent resin. Higher wax concentration seemed to have little noticeable decrease in thickness swell for boards having 3.5 percent resin.

CONCLUSIONS

After 3 years of outdoor exposure, the two-coat paint system is performing reasonably well, whereas the single coat had failed within a year at both test locations. Paint performed better on those flakeboard formulations with higher resin content (3.5% compared with 2.0 % MDI). For boards having lower resin concentration, the amount of wax in the flakeboard improved the paint performance, whereas it had little positive effect at the higher resin level. The climate at the exposure site had a highly significant effect on the surface of the flakeboard on paint degradation; visual evaluation of the flakeboard and paint showed that the one-coat paint system cracked more at Madison than Gulfport whereas the two-coat paint systems degraded more at Gulfport than Madison. When bevel-edge siding was compared with flat-edge siding, there was no significant edge effect. Edge sealer was highly effective for decreasing thickness-swell at the drip edges of bevel-edge and flat-edge boards.

ACKNOWLEDGEMENTS

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PROCEEDINGS

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