Durability of Hardboard Siding

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ABSTRACT

In response to concerns about hardboard siding failures, a study was performed to assess if performance in a current hardboard industry quality assurance test procedure correlated with in-service performance and how well this performance might be predicted by use of alternative or additional test procedures. A variety of laboratory tests were performed on a large number of specimens, and the in-service performance of matched specimens was periodically evaluated over 38 months of outdoor exposure. Siding specimens were installed on two test fences that were sprayed with water for one hour each day during summer. Commercially available siding was included as well as siding that was specially produced for the study. A total of 13 different hardboards were tested.

It was found that the properties and performance of commercial hardboard siding vary appreciably from mill to mill, as well as within samples of board from the same mill. Performance in the industry standard test procedure for residual edge swell proved to be an imperfect, but nonetheless useful, indicator of some performance characteristics on the test fences. With appropriate pass-fail criteria, the standard test for residual edge swell may be used to limit the likelihood of in-service failures, in particular, edge welting, surface mildew, and cracking of the paint on the drip edge. The authors also believe that the standard would be more meaningful if it included statistically based procedures that would ensure, at a specific level of confidence, that a product would meet the standard's performance requirements.

INTRODUCTION

In the 1980s and 1990s many cases of failure of hardboard siding were reported in the United States, leading to class action law suits and substantial damage claims. Although failure of hardboard siding often occurs due to improper installation or detailing (Keplinger and Waldman 1988; HUD 1992), there was some reason to believe that stricter test requirements than stated in U.S. industry standard ANSI/AHA A135.6-1998 (AHA 1998) would have lowered the incidence of performance problems. The research literature is, however, largely devoid of meaningful performance data for hardboard siding in service, and, to date, it does not address how well the current minimum test requirements in the ANSI/AHA standard correlate with satisfactory performance in service.

Accelerated aging tests have long been used as a method to screen products for durability, but it is difficult to correlate results of accelerated exposure with exposure to natural weathering (Ruffin 1960). The U.S. hardboard industry currently uses a number of tests (e.g., ANSI/AHA A135.6-1998) to evaluate hardboard siding, and it has formulated minimum test criteria. Keplinger and Waldman (1988) and Baldwin (1988) suggest that when durability problems with hardboard siding occur, irreversible ("residual") thickness swell is frequently a contributing factor to, or a cause of, problems. We therefore postulated that results from the ANSI/AHA A135.6 test procedure for "weatherability of substrate" would be a reasonably good predictor of durability in service. This procedure prescribes six consecutive cycles of wetting, drying, and freezing of the hardboard and requires the measurement of the permanent increase in the

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thickness of the drip edge (residual thickness swell, RTS). Standard ANSI/AHA A135.6-1998 allows a maximum RTS of 20%.

Permanent thickness swell in response to wetting and drying cycles is an important way in which composite wood materials are different from solid wood. Wood swells when wetted and returns to virtually its original thickness when dried. Wood composite materials, on the other hand, because of interleaving of the wood elements (particles, flakes, or fibers) in the mat prior to pressing and because of compaction under high pressure during pressing, contain internal residual stresses that may relax during wetting-drying cycles. Hardboard siding generally shows less RTS than other commercial wood composition materials bonded with similar adhesive systems, in particular those made from wood particles or flakes (River 1994). However, hardboard siding can exhibit significant levels of RTS (Biblis 1989, 1991; River 1994). If swelling is extreme, paint may crack, caulking may fail, and nail heads may be pulled through the paint surface, providing pathways for water entry into the board. Although there is no published evidence of a direct link between residual swell and siding degradation, Kelly et al. (1984) showed that hardboard siding with RTS can absorb water much more easily than does hardboard without residual swelling. The extent of RTS of individual hardboard products depends on chemical additives or heat treatments, raw materials, prevention of buildup or relief of residual stresses during manufacturing, amount of adhesives used, and sizing additives (Carll 1996).

The objectives of our study were to examine to what extent RTS ratings, determined with the current ANSI/AHA standard test procedures, correlate with siding performance in use and to see if any changes in the standard could lead to improved siding performance in-service. We therefore conducted laboratory RTS tests on a variety of hardboard sidings, and related the results to observations from field exposure tests of the same hardboards.

We performed several other laboratory tests for this study, such as vapor sorption and a water absorption test, but the results of these tests are not reported here. Results of these tests, along with more detailed information on methodology and performance during exposure, can be found in the full report for this study (Carll and TenWolde 2004).

HARDBOARD SIDING SPECIMENS

Materials for this study included six classes of noncommercial hardboard sidings, which we selected from different batches of board specially produced for this study, and seven commercial hardboard sidings. All U.S. hardboard manufacturing plants that produced hardboard siding in 1996 and1997 are represented in this study. We did not retain any information on the origin of the commercial boards. A commercial oriented strandboard (OSB) siding was also included in the study, but its performance is not discussed in this paper because OSB is not subject to hardboard industry standards.

Noncommercial Siding

Three separate lots of dry-process hardboard siding were specifically produced for this study at a U.S. hardboard plant at lower than usual steam pressures and shorter press times to provide test materials with a wide range of properties. An additional batch was produced at normal temperatures and press times. These we received unprimed and unpainted in 4 ft by 8 ft (1.2 m by 2.4 m) sheets. We cut the sheets into 8 ft by 8 in. (2.4 m by 0.2 m) wide strips of lap siding; these siding strips, therefore, did not have shaped drip edges. Strips from each lot were segregated and were marked as cut to retain a record of the sheet and position within the sheet from which the strips were cut. After preliminary RTS tests, we found that selecting strips from different lots and positions within the sheet yielded six separate classes of lap siding with a wide range of RTS values. Of the noncommercial siding, the boards produced with normal temperatures and press times had the lowest RTS, and these were assigned to class 1. The RTS properties of the other material varied widely with location in the sheet; material from near the edges produced the highest RTS. Classes 2, 3, and 4 were assigned to boards from the center of the sheets, which had low to medium RTS values. Classes 5 and 6 were assigned to boards cut from the edge of the sheet, and the average RTS of this material did not meet the industry minimum standard of 20%. Thus, classes 1 through 6 represented a wide range in RTS values.

Commercial Siding

Seven commercial hardboards were delivered as 8 ft (2.4 m) long pieces of factory-primed 8 in. (0.2 m) wide lap siding. All the commercial lap siding had beveled or slightly rounded drip edges, which had been shaped prior to priming. Classes 7 through 14 were randomly assigned to boards from each mill, with the exception of class 9, which was assigned to the OSB siding (not discussed in this report). Unlike the ordering of the six classes for the noncommercial boards, which reflect relative performance in the substrate weatherability test, the class numbers for commercial boards are not indicative of any performance ranking. Boards in class 12 contained press blows (steam pressure-induced, within-board delaminations that occur during the later stages of board pressing), but these defects were so inconspicuous that we did not notice them until we observed unusual on-fence behavior of these boards.

Specimen Selection

From each board class, twenty 8 ft (2.4 m) pieces were selected to provide specimens. From each piece, three specimens were cut for outdoor exposure tests, four specimens for weatherability of substrate (RTS) tests, and one specimen for water absorption testing (Figure 1). The ends of the 8 ft pieces were not used for specimens for the laboratory tests because those specimens needed to represent the properties of the specimens for outdoor exposure as closely as possible. Two of the three specimens for outdoor exposure were installed on two test.fences; the third specimen was installed on a building at the

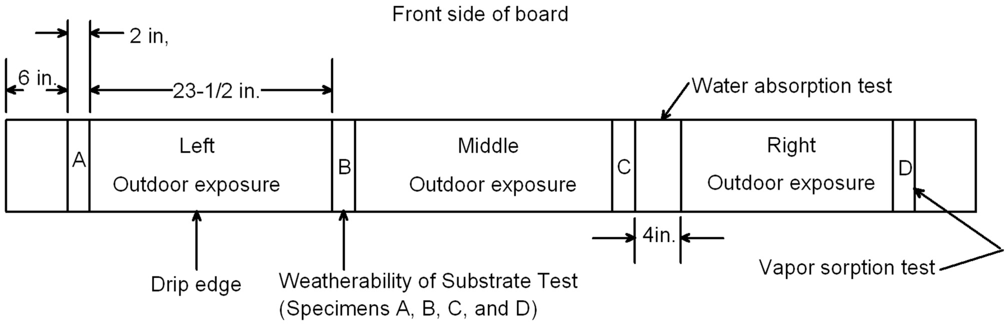

Figure 1 *Diagram for cutting specimens from 8 ft (2.4 m) pieces.*

same test site, We are still collecting data on the building specimens and so do not report on their performance in this article.

Specimens for exterior exposure were brush-painted with two thin coats of satin exterior latex paint. On the commercial hardboards, the latex paint was applied over the factory primer. On the noncommercial hardboards, which were not factory-primed, the latex paint was applied over brush-applied alkyd primer. The alkyd primer was compatible with the topcoat and was recommended by the paint manufacturer for use on hardboard that had not been factory-primed. Average spread rate for the combined two coats of latex paint was 387 ft^2/gal (9.5 m^2/L). The boards were painted by brush in a conditioned laboratory. Specimen end-cuts were left bare.

RESIDUAL THICKNESS SWELL MEASUREMENTS

We performed residual thickness swell (RTS) tests on 80 samples of each siding class according to section 4.1, “Weatherability of Substrate,” of standard ANSI/AHA A135.6-1998 (AHA998). Specimen edges were unprimed. Four specimens were cut from each of the 20 siding boards as shown in Figure 1. The drip edge on each specimen was cut off and left bare.

Specimens were first conditioned for many months at 70°F (18°C), 50% relative humidity (RH). Next, thickness was measured at the center of the edge to be submerged. The specimens were then exposed to six 24-hour cycles, each cycle consisting of the following steps:

1. Suspension in 100°F (38°C) deionized water for 18½ hours. Specimens were suspended vertically and immersed to a depth of 1 in. (25 mm).
2. Heating in 220°F (104°C) oven for 30 minutes.
3. Cooling in freezer at 0°F (−18°C) for two hours. This was slightly colder than the temperature specified in ANSI/AHA A135.6-1998 (5°F, –14°C).
4. Heating in oven for another 30 minutes.

Steps 3 and 4 were repeated to complete a 24-hour cycle. Fresh deionized water was used for each cycle. After the sixth cycle, the specimens were reconditioned for several weeks at 70°F (18°C), 50% RH, after which the edge thickness was again measured to determine RTS.

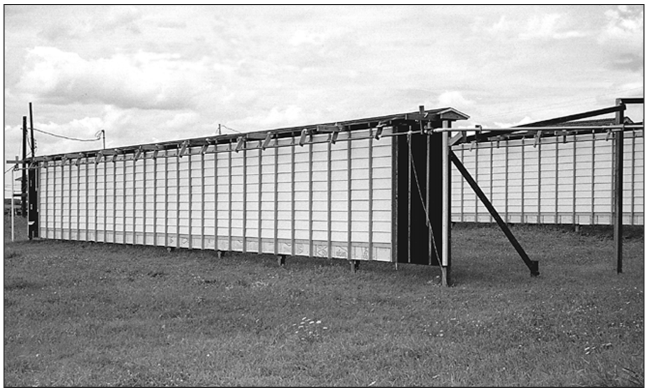

Figure 2 *Test fences at the Valley View test site.*

TEST FENCES

Siding specimens were installed on two test fences located west of Madison, Wisconsin. Boards on the fences faced south and were exposed for 38 months. Boards were mounted on 0.75 in. (19 mm) thick foam sheathing to simulate exposure on an insulated wall. On each fence, boards were installed in 28 columns. Each column had ten lap-siding courses, and each course had 6.625 in. (0.17 m) exposure. Column width was 22.5 in. (0.57 m). Plastic-wood composite lumber, which was fastened to the plywood sheathing, separated adjacent columns. There was a gap of roughly 0.25 in. (6 mm) between each board end and the column separator. These gaps simulated open (uncaulked) joints between siding and corner trim. Boards were installed on the fences in July and August 1997 and removed on October 12 and 13, 2000. Figure 2 shows both test fences immediately after board installation.

The two test fences were identical, with one exception: on fence 1 all drip edges were cut and left bare, whereas on fence 2 the painted drip edges were left intact. End cuts were left bare on both fences.

Each column of siding on the test fences was individually sprayed for one hour each day from May through late November. During the winter the siding was exposed to the weather without

Table 1. Residual Thickness Swell (RTS) of Noncommercial Boards

Class	Average RTS (%)*	Standard Deviation (%)	Percent of Specimens Exceeding 20% RTS
1	5.9	1.8	0%
2	6.7	1.3	0%
3	8.9	2.0	0%
4	12.0	2.5	0%
5	22.7	3.2	80%
6	30.1	5.6	99%

* Average residual thickness swell of 80 samples

Table 2. Residual Thickness Swell (RTS) of Commercial Boards

Class	Average RTS (%)*	Standard Deviation (%)	Percent of Specimens Exceeding 20% RTS
7	11.5	1.2	0
8	15.0	4.4	14%
10	4.9	1.0	0%
11	7.5	2.9	0%
12	9.1	3.7	0%
13	12.4	1.4	0%
14	11.0	2.0	0%

* Average residual thickness swell of 80 samples

additional spray. Spraying started mid-August 1997. The water spray hit above the top board, and water ran down each column of siding. Column separators prevented water movement between neighboring columns. The water was drawn from a well on the test site. To verify that each column received comparable amounts of spray water, we measured the water spray rate of each spray nozzle in July 1997 and again in June 1998. We found that, although the spray rate varied with water pressure, the average flow rate was about 0.23 gal/min (15 mL/s), with maximum variations between nozzles of about 10%.

Specimen placement was identical on both test fences. The 20 boards of each board class (13 classes of hardboard siding and an OSB siding) were placed randomly over the 28 columns on each fence. Because the water was sprayed at the top of the wall, we felt it appropriate that all classes be represented equally in the top four positions. Thus, the top four courses and the remaining courses were randomized separately.

INSPECTIONS OF THE TEST FENCES

Two or three inspections were conducted each year from May through November, always by the same person. The inspection protocol evolved over time, but it did not change after November 1998. Each board was inspected for edge welt, paint condition, evidence of decay, and mildew discoloration. As mildew was found, we did not attempt to immediately identify mildew species, although a mycologist identified mildew species on a few board specimens after the final inspection. We did not expect to observe buckling in these short (0.57 m long) specimens, installed with end gaps, and we observed no noticeable buckling during our inspections. The first inspection took place in late September 1997 and the last between September 26 and October 4, 2000.

RESULTS OF RTS MEASUREMENTS

Results of the weatherability tests for the noncommercial boards (classes 1 through 6) are shown in Table 1. As we intended, the RTS of the noncommercial classes covered a broad range. Classes 1 and 2 exhibited very little RTS, whereas most boards in classes 5 and 6 did not meet the minimum industry RTS standard of 20%.

The RTS results for the commercial boards (Table 2) show considerable variation between classes, and sometimes within a class. On average, all classes meet the industry minimum standard, but 14% of the test specimens in class 8 failed to meet the maximum allowable RTS in the ANSI/AHA A135.6-1998 standard.

RESULTS OF INSPECTIONS

Paint performance on all test specimens was generally good. After 38 months of exposure on the test fences, no paint peeling, flaking, or erosion was observed. We observed localized paint cracking only near nail heads and on some drip edges, which was largely associated with in-service substrate swelling. Our observation of good paint performance on hardboard siding agrees with previous research results (Feist 1982, 1990). There was no visual evidence of decay in any of the boards on either fence, and we saw only minor amounts of mildew on some of the boards.

Edge Welt

"Edge welt" is a term sometimes used in the hardboard siding industry to describe localized swelling along panel edges (Baldwin 1988). The swollen area projects beyond the normal panel surface, and the surface within the swollen area is irregular, that is, not flat (Figure 3). Some degree of fiber raising can be expected in welted areas.

Some degree of edge welting at the horizontal drip edges developed in all 13 classes of hardboard siding. We recorded the approximate area and severity of edge welt. The edge welt severity rating was a visual estimate. A rating of 10 indicates no perceptible welt; 9.5, welt could be perceived when the surface was viewed at an oblique angle; and 9, welt was perceptible when the surface was viewed from a position normal to the board surface. Ratings lower than 9 indicate progressively more noticeable welt.

We combined area and severity into a single edge welt index I as follows:

$$I = A \cdot (10\text{-}S) \tag{1}$$

where
A = area of welt and
S = severity of welt (10 to 0).

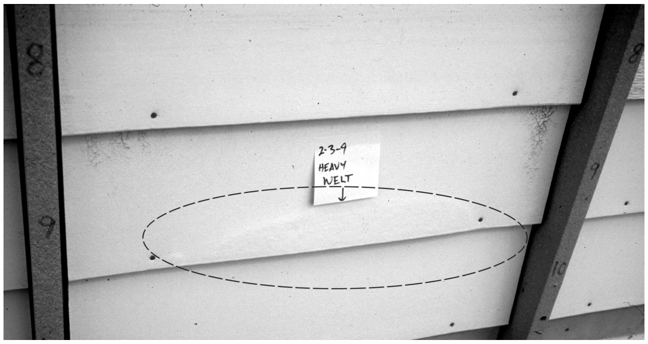

Figure 3 *Example of edge welt on Fence #2 (drip edges intact). Note: Photo was taken on August 30, 1999. Five days earlier (August 25), specimen had been rated with a welt severity of 9.0 and a welt area of 21 in.2 (0.014 m2) (edge welt index =21).*

Thus, the edge welt index reflects both the extent and severity of edge welt.

The results in Table 3 show that all classes showed some welting, but some classes (11, 12, and 13) consistently had considerably less welting than other classes. Classes 2 and 10 experienced very little welting when the drip edge was intact (Fence 2), but fared less well with the drip edges removed (Fence 1).

Light conditions influenced the degree to which a welt was perceivable. We therefore ensured that light conditions were similar at all welt inspections. Welt inspection was performed on sunny days, preferably when some degree of upper level cloudiness or haze was present. On days when sun exposure was judged to be too direct or intense, moveable translucent shading was used to limit the light intensity, and the west edge of the shading device was placed approximately even with the left (west) edge of the column of specimens being inspected. When movable shading was used, the location of its edge varied with sun intensity and time of day. Welt inspections were always performed between 10:30 a.m. and 4:00 p.m.

Time trends in edge welt development on both fences are shown in Figures 4 and 5, for all classes combined. Edge welt generally worsened over time, although at some intermediate inspections, welt was less perceivable than it had been in the

Table 3. Severity of Drip Edge Welt and Welt Index, by Class, as Measured September 26-October 4, 2000[*]

	Fence 1				**Fence 2**			
	Severity (10-0)[†]		**Edge Welt Index**		**Severity (10-0)**[†]		**Edge Welt Index**	
Class	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
1	8.3	0.5	48.2	17.1	9.5	0.7	4.6	8.4
2	7.9	0.6	30.4	14.8	9.8	0.3	0.5	1.1
3	7.9	0.4	64.8	17.2	8.8	0.6	13.3	11.6
4	7.7	0.3	66.6	14.5	8.8	0.8	12.2	14.2
5	7.8	0.2	71.1	12.8	7.6	0.4	51.0	13.5
6	7.6	0.5	72.6	21.6	8.0	0.6	32.9	12.6
7	7.6	0.5	51.3	17.0	9.4	0.6	3.3	7.2
8	8.0	0.4	50.8	13.1	8.5	0.5	23.6	12.8
10	7.8	0.5	23.1	10.7	9.7	0.5	0.2	0.4
11	8.2	0.4	9.8	4.0	9.6	0.6	0.3	0.8
12	8.6	0.5	13.9	7.1	9.0	0.3	5.9	4.1
13	8.8	0.4	4.7	3.8	9.4	0.5	2.1	3.3
14	8.7	0.6	44.9	54.2	9.1	0.6	24.9	40.6
Average	8.1	0.6	42.5	30.1	9.0	0.8	13.5	20.4

[*] Does not include welting along vertical edges
[†] Lower numbers indicate greater severity of welting

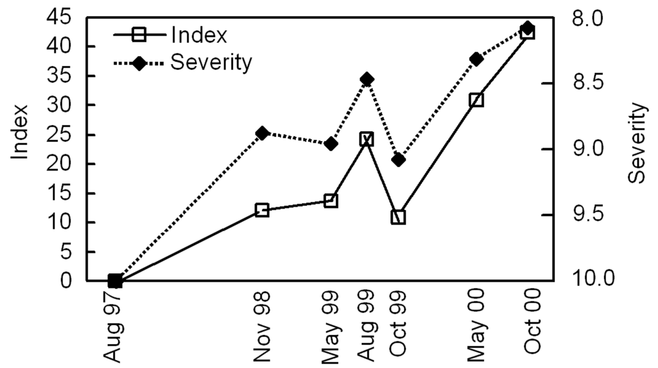

Figure 4 *Edge welt behavior over time, fence 1 (drip edges cut).*

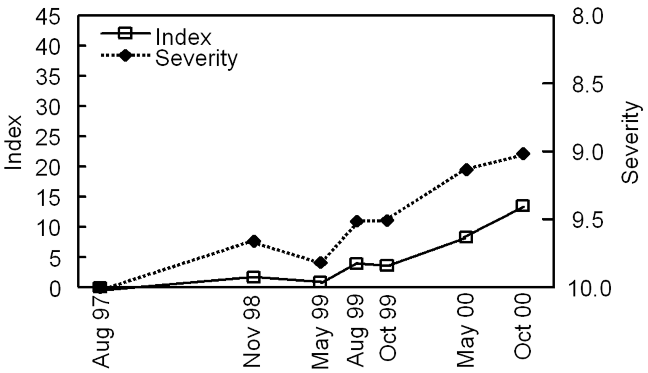

Figure 5 *Edge welt behavior over time, fence 2 (drip edges intact).*

preceding inspection. These reversals occurred following winter, when spraying did not occur, or following a period of intermittent failure of the spray system. From November 1998 through the final inspection in September/October 2000, the rate at which edge welting increased apparently accelerated. On both test fences, the greatest increase in welting occurred during the last year of exposure. As Table 3 and Figures 4 and 5 indicate, a painted drip edge (Fence 2) significantly retarded the development of edge welting.

Mildew

The fungus identified as causing discoloration of painted hardboard surfaces was *Aureobasidium pullulans*. The paint and coatings industry generally categorizes *A. pullulans* as a mildew fungus (Bussjaeger et al. 1999; Zabel and Morrell 1992).[1] We recorded mildew in a similar manner as edge welt (area and severity) and calculated a mildew index with Equation 1. The results for the last inspection during the fall of 2000 are listed in Table 4. Mildew was more common on the noncommercial boards, perhaps because they were hand-primed with an alkyd primer.[2] More mildew growth occurred on boards in class 5 than on boards in any of the other classes.

Mildew growth on specimen surfaces was concentrated in distinct areas. Even on specimens that had intense patches of mildew growth, appreciable areas were devoid of mildew. We therefore characterized mildew growth by measuring the surface area within which mildew was observed and assigning an intensity rating within that area. We used an adaptation of ASTM Standard D 3274, *Standard Test Method for Evaluating Degree of Surface Disfigurement of Paint Films by Microbial (Fungal or Algal) Growth or Soil and Dirt Accumulations* (ASTM 2001) for judging the intensity rating within face areas containing mildew. While D 3274 appears to have been developed for surfaces on which mildew distribution is more uniform than it was on our specimens, we used the same approach to judge severity where mildew was present. Mildew growth was more pronounced on drip edges than on face surfaces, but we did not rate mildew on drip edges because it was difficult to do so with consistency. Difficulties of rating drip edge mildew are discussed in Carll and TenWolde (2004).

Paint Cracks

We documented the occurrence of paint cracks on the drip edge of specimens on fence 2. Cracking was rated according to severity:

0	no cracks
0.5	minor cracking, visible with a 10x hand lens
1	significant cracking, visible without magnification at about 15 in. (0.4 m) from the drip edge
2	severe cracking, visible without magnification at roughly 3 ft (1 m) from the drip edge

Table 5 summarizes the results from the final inspection (September-October 2000) by siding class.

Differences in degree of drip edge cracking between classes were substantial; some classes showed very little cracking, and others, namely, classes 5, 6, 8, and 12, showed significant or severe drip edge cracking. Given our evaluation criteria, boards in these four classes received the same drip edge crack rating, but the nature of drip edge paint cracking observed in class 12 boards differed substantially from that in the other three classes. Drip edge paint cracks in class 12 boards were substantially fewer in number but generally extended for longer distances along the drip edge. Boards in classes 5, 6, and 8 showed significant edge welting as well as drip edge paint cracking, whereas boards in class 12 showed modest levels of edge welting (Table 3). A close inspection of spare unexposed boards of class 12 revealed inconspicuous press blows in the boards as shipped from the manufacturer. The press blows evidently opened when boards were exposed on the fence and showed up as cracks in the drip edge paint film.

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[1] Also see sidebar "What is mildew?" in Forintek (2003).

[2] The alkyd primer contained soya alkyd resin, which is significantly more resistant to mildew growth than are unmodified plant-derived oils, such as linseed oil. However, alkyd resins are generally viewed as having lower resistance to mildew growth than acrylic resins. The commercial boards were factory-primed with thermosetting primer, in which the paint resins were likely acrylic. Field application of acrylic emulsion paints is sometimes accompanied by problems stemming from their surfactants, but such problems would not be anticipated in factory-applied thermosetting emulsion paints, which are formulated for baking.

Table 4. Severity of Mildew and Mildew Index, by Class, as Measured September 26-October 4, 2000

	Fence 1				Fence 2			
	Severity (10-0)*		Mildew Index		Severity (10-0)*		Mildew Index	
Class	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
1	9.0	1.8	2.6	5.0	9.8	0.9	0.4	1.8
2	9.4	0.8	0.7	1.6	9.9	0.4	0.3	1.5
3	7.8	1.8	4.3	4.4	8.6	1.6	2.9	7.1
4	8.2	1.6	4.5	6.1	8.7	1.9	3.0	6.1
5	7.1	2.2	11.3	14.1	6.1	1.5	16.6	14.7
6	7.9	1.3	4.0	4.2	6.9	2.1	7.6	8.5
7	9.6	0.6	0.5	1.0	10.0	0	0	0
8	8.7	1.0	4.1	5.4	9.5	0.8	0.9	1.4
10	9.0	0.7	1.5	1.7	10.0	0	0	0
11	9.8	0.5	0.1	0.3	10.0	0	0	0
12	10.0	0	0	0	10.0	0	0	0
13	10.0	0	0	0	10.0	0	0	0
14	10.0	0	0	0	10.0	0	0	0

* Lower numbers mean greater severity.

Table 5. Paint Cracks at the Drip Edge, Averaged by Class, as Recorded September 26-October 4, 2000

	Drip Edge Cracks	
Class	Average*	Standard Deviation
1	0.33	0.44
2	0.08	0.18
3	0.88	0.28
4	0.60	0.45
5	1.60	0.50
6	1.56	0.51
7	0.03	0.11
8	1.15	0.49
10	0.55	0.32
11	0.28	0.38
12	1.40	0.50
13	0.60	0.38
14	0.82	0.30

* Values range from 0 (no cracks) to 2 (most severe).

CORRELATIONS BETWEEN RTS AND INSPECTION RESULTS

We related selected performance characteristics on the two fences to the results of the weatherability of substrate tests, i.e., residual thickness swell (RTS) on a board-by-board basis. Each specimen on the fence was associated with two adjacent RTS specimens (see Figure 1), and in our anaylses we compared performance values of individual test fence specimens with the average RTS value of those two RTS specimens. Direct data plotting over the full data range showed modest degrees of correlation between RTS and several performance characteristics, such as edge welt and drip edge paint cracking, but there was usually appreciable scatter in the data. This data scatter prevented us from establishing simple relationships that would allow us to quantify the potential effect of changes in the performance criteria in the ANSI/AHA standard. We therefore analyzed the data in terms of frequency (or probability) of occurrence of a failure or failure severity level within ranges of RTS values (RTS bins). This allowed us to determine the change in probability of occurrence of a certain value or value range for welt, mildew, etc., as a function of RTS. It also revealed in which RTS range the change in performance characteristics was the most rapid. To have a sufficient number of data points in each bin, we selected bins with an RTS range of 6%. For instance, the 15% RTS bin contains data for boards with an RTS between 12% and 18%. Table 6 shows the number of specimens in each of the RTS bins. The number of specimens per RTS bin reaches

Table 6. Number of Specimens in Each of the RTS Bins

RTS Bin		Number of Specimens per Bin					
		All Boards		Noncommercial		Commercial	
Center	Range	Fence 1	Fence 2	Fence 1	Fence 2	Fence 1	Fence 2
5%	2%-8%	88	81	43	37	45	44
6%	3%-9%	103	102	52	49	51	53
7%	4%-10%	111	119	58	60	53	59
8%	5%-11%	114	119	54	55	60	64
9%	6%-12%	118	116	50	50	68	66
10%	7%-13%	118	120	47	43	71	77
11%	8%-14%	111	115	35	39	76	76
12%	9%-15%	103	102	26	31	77	71
13%	10%-16%	98	88	22	19	76	69
14%	11%-17%	76	69	15	15	61	54
15%	12%-18%	51	49	10	9	41	40
16%	13%-19%	34	32	5	7	29	25
17%	14%-20%	22	26	5	8	17	18
18%	15%-21%	21	19	11	4	10	15
19%	16%-22%	19	14	12	7	7	7
20%	17%-23%	21	18	16	12	5	6
21%	18%-24%	21	22	18	18	3	4
22%	19%-25%	22	20	20	18	2	2
23%	20%-26%	23	18	21	16	2	2
24%	21%-27%	21	22	19	21	2	1
25%	22%-28%	17	22	16	21	1	1
26%	23%-29%	13	19	13	18	–	1
27%	24%-30%	12	14	12	14	–	–
28%	25%-31%	11	15	11	15	–	–
29%	26%-32%	9	16	9	16	–	–
30%	27%-33%	6	11	6	11	–	–
31%	28%-34%	7	8	7	8	–	–
32%	29%-35%	8	7	8	7	–	–
33%	30%-36%	7	6	7	6	–	–
34%	31%-37%	5	3	5	3	–	–
35%	32%-38%	5	3	5	3	–	–
36%	33%-39%	5	4	5	4	–	–
37%	34%-40%	4	4	4	4	–	–
38%	35%-41%	3	3	3	3	–	–
39%	36%-42%	2	2	2	2	–	–
40%	37%-43%	2	2	2	2	–	–
41%	38%-44%	2	1	2	1	–	–
42%	39%-45%	1	–	1	–	–	–
43%	40%-46%	1	–	1	–	–	–

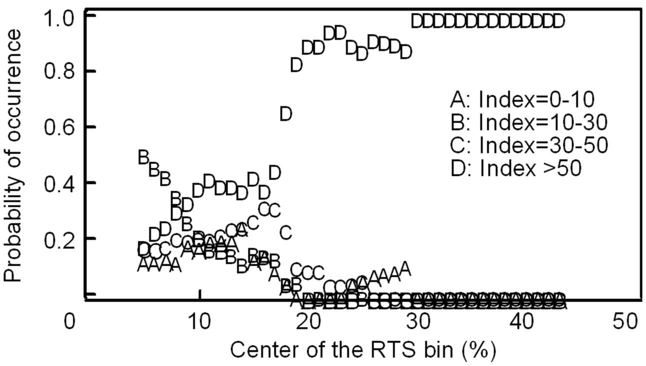

Figure 6 *Edge welt index as a function of residual thickness swell (RTS), fence 1, all hardboard classes. Note: Lower index means less welt.*

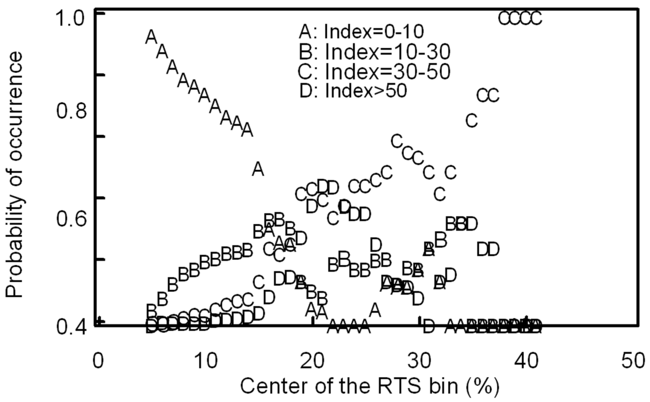

Figure 7 *Edge welt index as a function of residual thickness swell (RTS), fence 2, all hardboard classes.*

a maximum at around 10% bin midpoint value and thereafter declines with increasing RTS. The number eventually becomes too small for meaningful data analysis.

Edge Welt Versus Residual Thickness Swell

Figure 6 shows the probability of occurrence of various levels of edge welt as a function of RTS for fence 1 at final inspection. The frequency of an edge welt index of over 50 (category D) increases steadily between the 5% and 11% RTS bins (2%-14% RTS) and steeply increases in the 18% and 19% RTS bins (15%-22% RTS). Figure 6 further shows that the frequency of a category C index value (30<I<50) steadily increases from the 13% to 18% RTS bins, where category D begins to take over. The 30% RTS bin and the bins beyond (RTS > 27%) contain only boards with a welt index over 50.

On fence 2, where severe welting was less common than on fence 1, frequency of boards with the lowest edge welt index A (I = 0-10) steadily drops, with RTS between the 5% and 14% RTS bins, and then drops more rapidly in the 15% and 16% RTS bins (Figure 7). Higher edge welt index categories (C and D) begin to increase markedly at the 16% RTS bin. No strong relationship seems to exist at RTS levels beyond 25%, except that the number of boards with an edge welt index between 30 and 50 (C) gradually increases with RTS.

Another way of viewing the results is to graph the probability of a board showing any edge welt as a function of its RTS rating. Figure 8 shows the results of this analysis for fence 2. The occurrence of boards with edge welt increases with RTS for boards in RTS bins below 19%, with the steepest increase between the 5% and 9% RTS bins, and a more gradual increase in the 10% through 18% bins. Above 16% RTS (19% RTS bin), all boards have edge welts.

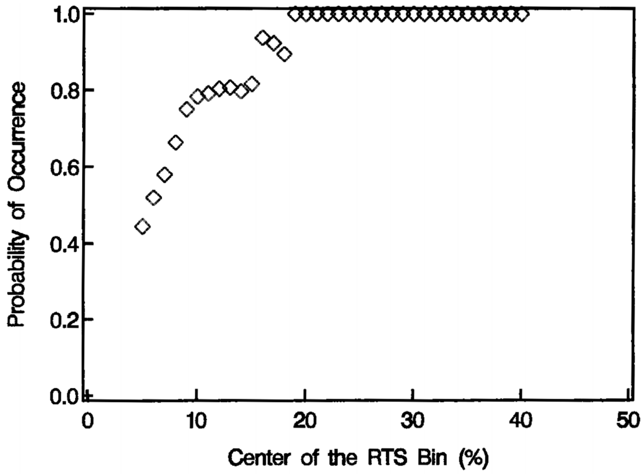

Figure 8 *Probability of boards developing edge welt as a function of RTS, fence 2, all hardboard classes.*

In summary, the data indicate that the current 20% RTS criterion in the ANSI/AHA standard does exclude boards that are prone to serious edge welting but that the incidence and severity of edge welting may be further reduced, and to a significant degree, if the RTS criterion were lowered from 20% to around 16% or 17%. Even further reduction in the probability of welt incidence and severity would be expected if the level were reduced still more.

Mildew Versus Residual Thickness Swell

Figure 9 shows the probability of occurrence of mildew on fence 1 as a function of RTS rating. The data show a sharp increase in the occurrence of mildew after the 16% RTS bin (13%-19% RTS) and mildew on all boards with an RTS rating of 27% or greater (30% RTS bin and higher bins).

The data for fence 2 (drip edges intact, Figure 10) gave us somewhat different results. The likelihood that boards had mildew rapidly increases after the 13% RTS bin (10%-16% RTS), but after the 20 RTS bin (17%-23% RTS) there appears

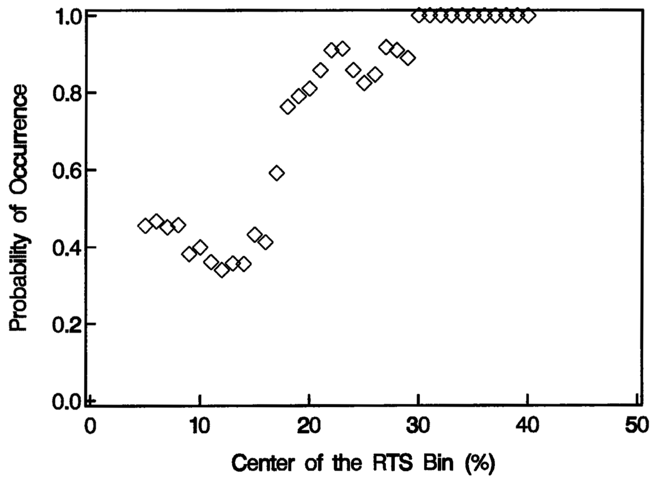

Figure 9 *Probability of boards developing mildew as a function of RTS, fence 1, all hardboard classes.*

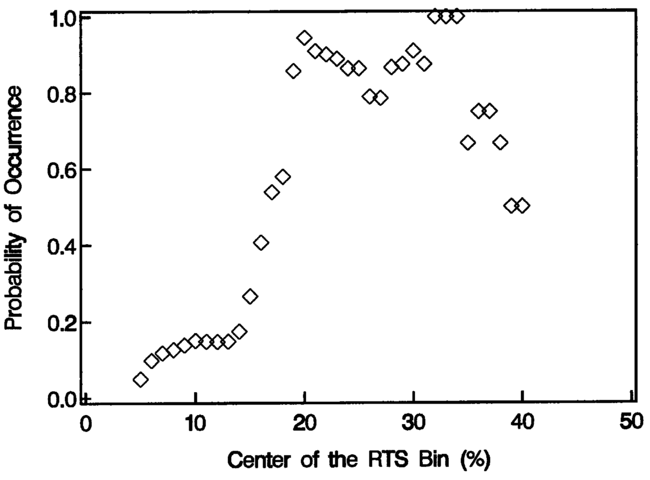

Figure 10 *Probability of boards developing mildew as a function of RTS, fence 2, all hardboard classes.*

to be no clear correlation. The 34% RTS and higher bins contain only four or fewer specimens, and the apparent trend reversal at those very high RTS values is, therefore, unduly influenced by the lack of mildew on one specimen.

The mildew index did not correlate as well with RTS as did the edge welt index, but it was nevertheless a reasonably good indicator of the likelihood of mildew growth. The data suggest that the incidence of mildew growth may be reduced by lowering the RTS requirement in the ANSI/AHA standard from 20% to 16% or 17%. The data do not suggest that further significant improvement can be expected by dropping the criterion below 16% RTS.

We cannot state with great confidence a precise deterministic reason for the empirical relationship that we found between laboratory-measured RTS level and the probability of mildew growth on the test fences. However, we postulate that RTS level was in some way related to moisture content of the boards on the fences. The most prevalent mildew growth was observed on boards of classes 5 and 6 (Table 4). Among commercial boards, mildew growth was most prevalent on boards of class 8. Boards in classes 5, 6, and 8, all of which showed high RTS values in laboratory testing, also showed more extensive back-surface staining than did boards of other classes (Carll and TenWolde 2004), as well as higher moisture contents at time of removal from the test fences than most if not all boards in their respective groups (commercial or noncommercial).

Drip Edge Paint Cracks Versus Residual Thickness Swell

Figure 11 shows the relationship between the probability of occurrence of various drip edge crack ratings and RTS. The data show that RTS is an effective indicator of the likelihood of development of drip edge cracks. The frequency of boards without drip edge cracks steadily declines with increasing RTS until, at 16% RTS and above (19% and higher RTS bins), there are no board specimens without drip edge cracks. At 32% RTS and above (35% and higher RTS bins) all the cracking is severe, but the number of specimens in those bins is very small (four or less). The data suggest that significantly lowering the RTS requirement from 20% RTS is likely to yield substantial improvement in drip edge performance.

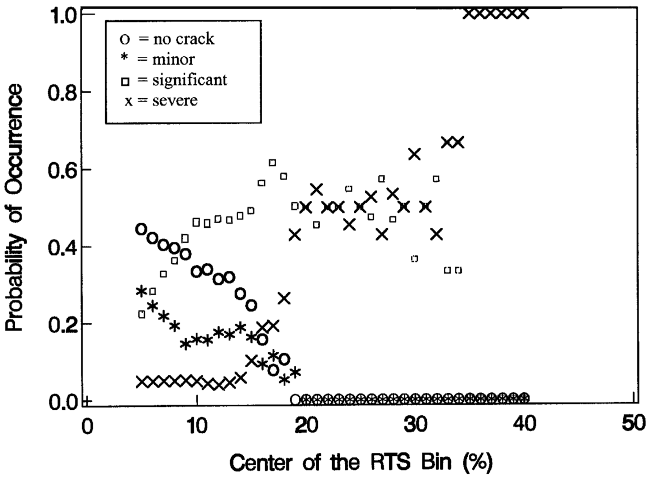

Figure 11 *Occurrence of cracks on the drip edge as a function of residual thickness swell, fence 2, all hardboard classes.*

ISSUES RELATED TO STANDARD ANSI/AHA 135.6

Besides pass/fail criteria, other issues related to the weatherability of substrate test procedures in the ANSI/AHA A135.6-1998 standard are worth noting. The standard does not specify any statistically based procedures that would ensure, at a specific level of confidence, that a product meets the standard's performance requirements. Instead, it implies that all specimens (in a sample selected for purposes of certification testing) must meet the test criteria. No mention is made of sample size, frequency of sampling, or specimen selection. It appears that in practice sample size for certification testing is sometimes very small (see Table 1 of Carll et al. [2000]).

In this study, we found that a significant minority of specimens of one class of commercial board failed to meet ANSI/AHA requirements, even though the board was grade-stamped as conforming to the standard. Biblis (1989) had a similar experience. The 100% passage rate requirement implied in the ANSI/AHA standard for specimens in the certification sample does not guarantee that all boards in the population associated with that sample also meet test criteria requirements.

We believe that the standard would be more meaningful if it specified a statistical confidence level with which the product can be expected to meet the standard's RTS requirement. If the sample size were 10 randomly selected specimens, and we assume a normal distribution, a 95% confidence level for the board population that the sample is supposed to represent would translate to the following pass/fail criterion:

$$\textit{Average} + 1.8 \times \textit{standard deviation} < \textit{maximum RTS requirement}$$

where *standard deviation* is the standard deviation of the measurements. If the required number of samples were lowered, the multiplier value for the standard deviation value would need to be raised to maintain the same confidence level. A similar approach could be followed for all the other test requirements (e.g., linear expansion, water absorption) in the standard.

By themselves, these measures address only variability in the sample population, not variations in the product over time. Variability over time can only be addressed by an effective in-plant quality control program and/or frequent random sampling and testing.

CONCLUSIONS AND RECOMMENDATIONS

- Commercial hardboards varied substantially in performance, both in laboratory testing and in accelerated field testing.
- A painted drip edge noticeably inhibited development of edge welting in accelerated field testing.
- Direct correlation between performance in laboratory RTS testing and any given measurement of field performance was rarely strong; there was usually substantial scatter in the data. Laboratory RTS testing was nevertheless useful in predicting some performance characteristics during field exposure:
- RTS proved to be a good predictor of the likelihood of edge welting. The data suggest that lowering the test criterion in AHA/ANSI Standard A135.6 to around 16% or 17%, would noticeably lower the incidence of edge welting in service. Lowering the criterion still further would have additional benefits.
- Although we found only minor amounts of mildew on the painted surfaces of some boards, RTS proved to be a reasonably good predictor of the likelihood of mildew growth on painted surfaces. The data suggest that lowering the RTS criterion in the standard to 16% or 17% is likely to reduce the incidence of mildew growth in service, but the data do not suggest that further lowering of the criterion would yield additional benefits.
- RTS proved to be a good predictor of the likelihood of paint cracking on drip edges. The data suggest that lowering the RTS criterion in the standard to 18% would noticeably lower the incidence of paint cracking on drip edges and that further reductions would yield additional benefits.

Based on our conclusions and on observations concerning ANSI/AHA Standard A135.6, we make the following recommendations:

- ANSI/AHA Standard A135.6 should be made more meaningful by including statistically based procedures that would ensure, at a specific level of confidence, that the population of product associated with a certification sample meets the standard's performance requirements.
- The RTS pass/fail criterion in the standard should be lowered to 17% or lower.

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