OUTDOOR AGING OF WOOD-BASED PANELS AND CORRELATION WITH LABORATORY AGING: PART 2

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ABSTRACT

The performance of four commercially manufactured structural wood-based panels and three ply woods was determined in accelerated laboratory-aging treatments and outdoor exposure. The wood-based panels met the ANSI/A208. 1-1989 standards for modulus of rupture (MOR) of 2-M-2 particleboard. Performance of the wood-based panels was severely decreased by accelerated laboratory-aging treatments, including the cyclic boil-dry treatment and the ASTM D 1037 accelerated-aging treatment. Wood-based panels did not meet the ANSI A208. 1 bond durability requirement for MOR after undergoing ASTM D 1037 accelerated-aging treatment. Performance of the wood-based panels after aging was considerably below that of two lower ranking wood-based panels from a previous study. Outdoor aging for 1 year reduced MOR and modulus of elasticity of wood-based panels by 38 to 59 percent. Internal bond strength decreased 34 to 60 percent; panel thickness increased 11 to 18 percent after 1 year of outdoor exposure. Performance of the three plywoods was comparable to that of the exterior marine plywood tested previously. A relationship was developed between the MOR after 1 year of outdoor exposure and after five boil-dry cycles. This relationship was compared with a similar relationship developed previously for a broad range of exterior-type panel materials. The new relationship appears to coincide and strengthen the relationship developed in the previous study.

A durability database for exterior phenolic-bonded panels was established at the USDA Forest Service, Forest Products Laboratory (FPL), by Baker and Gillespie (5) in the 1970s. In that study, they determined modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) strength, and thickness swelling (TS) of seven commercial and four FPL wood-based panels and compared them with a plywood and two solid woods. These properties were compared before and after exposure of specimens of each material to several different accelerated-aging tests. Several years later, River et al. (7) reported similar data acquired from testing four phenolic-bonded commercial hardboard panels. That report also compared and added the hardboard data to the data obtained from the original study.

Specimens from each material tested in both studies were also exposed at an outdoor weathering site near Madison, Wis. Groups of specimens were exposed and tested for five different exposure times between 1 and 10 years or more. Finally, the effects of outdoor and laboratory aging on these materials were compared and correlations were developed (6).

The main objectives of this study were to 1) expand the existing durability database of phenolic-bonded panels with test data from contemporary commercial panels; 2) compare the new and old panels; and 3) test correlations between outdoor and accelerated laboratory aging developed previously.

EXPERIMENTAL PROCEDURE

MATERIALS

In this and the previous report (6), flakeboard, strandboard, particleboard, and similar materials are referred to as wood-based panels. The term panel refers to all materials, whether wood-based or plywood.

Three different phenolic-bonded plywoods and four wood-based panels were investigated in this study. The three plywoods included nominal 12.7-mm-thick, four-ply Douglas-fir (DF) and southern pine (SP) and five-ply aspen (AS) plywood. The wood-based panels included nominal 12.7- and 11. l-mm-thick oriented strandboards (OSB) (identified as AA, AB, DA, and DB) that were manufactured by two different companies. All panels selected for testing were purchased in Madison, Wis.

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TABLE 1. — Initial strength and thickness of nine commercial phenolic-bonded oriented strandboard, waferboard, and plywood panels.

Board	Species and board type	Property MOR	MOE	IB	Thickness
		(MPa)			(mm)
AA	Aspen OSB	27.3	4070	0.35	13.0
AB	Aspen OSB	27.7	4856	0.46	11.4
DA	Aspen OSB	25.8	4636	0.37	12.8
DB	Aspen OSB	27.4	4884	0.44	12.6
AS	Aspen plywood	45.7	6406	1.31	13.4
SP	Southern pine plywood	67.3	9921	1.50	11.4
DF	Douglas-fir plywood	49.4	7552	1.29	11.6
C[a]	Aspen waferboard	18.3	3503	0.48	13.5
P[b]	Douglas-fir plywood	45.9	6654	0.88	12.2

[a] Waferboard tested in original study (5).
[b] Plywood tested in original study (5).

TABLE 2. — TS and percentage of ori strength properties retained after ASTM D accelerated-aging exposure.

Board	Property MOR	MOE	IB	T
	(%)			
AA	18.7	15.6	0	46
AB	23.5	21.0	3.0	37
DA	21.0	16.5	0	41
DB	26.9	20.8	7.5	34
AS	77.1	78.6	90.8	2
SP	59.3	60.4	51.5	3
DF	74.7	74.7	78.3	3

SPECIMEN PREPARATION AND AGING

Each of the seven panels were cut into 51- by 305-mm bending specimens. The OSB specimens were cut so that the predominant orientation of the strands in the faces was parallel to the specimen's length. Plywood test specimens were cut so that the longitudinal grain of outer ply was parallel with the specimen's length. When plywood specimens were cut, no attempt was made to eliminate knots. This was unlike Baker and Gillespie's study, in which the specimens were cut from knot-free marine plywood (5). Standard ASTM D 1037 (4) IB specimens were cut from one end of each bending specimen after the bending test.

Groups of five specimens of each material were subjected to 1,5, 10,20, and 40 cycles in both the boil-dry (BD) and vacuum-pressure-soak-dry (VPSD) treatments. A given group of five specimens was removed from a given treatment and tested after a given number of cycles. Five specimens of each material were also treated by the ASTM D 1037 accelerated-aging treatment. These treatments are fully described in previous reports (5,7).

Twenty-five specimens of each material were also placed on an outdoor fence near Madison, Wis. This exposure was the same as used previously (5,7).

Five specimens of each material have now been tested after 1 year of exposure. Four additional groups of specimens are still under exposure and will be tested after 2,3,7, and 10 years.

TESTING AND DATA ACQUISITION

Unaged and aged specimens were conditioned to equilibrium moisture content in a room controlled at 27°C and 65 percent relative humidity in preparation for the bending and IB tests.

After bending specimens had reached moisture content equilibrium and before mechanical testing, their thickness was measured. Thickness was determined as the average of three measurements taken at the midpoint and 25 mm from each end of each specimen.

Bending specimens were tested following the modified ASTM D 1037 method described in the previous reports (5,7). The MOR and MOE values of the specimens were calculated using aged thickness and data collected in the bending test. The IB specimens were cut from the undamaged ends of the tested bending specimens, reconditioned to moisture equilibrium, and tested according to ASTM D 1037.

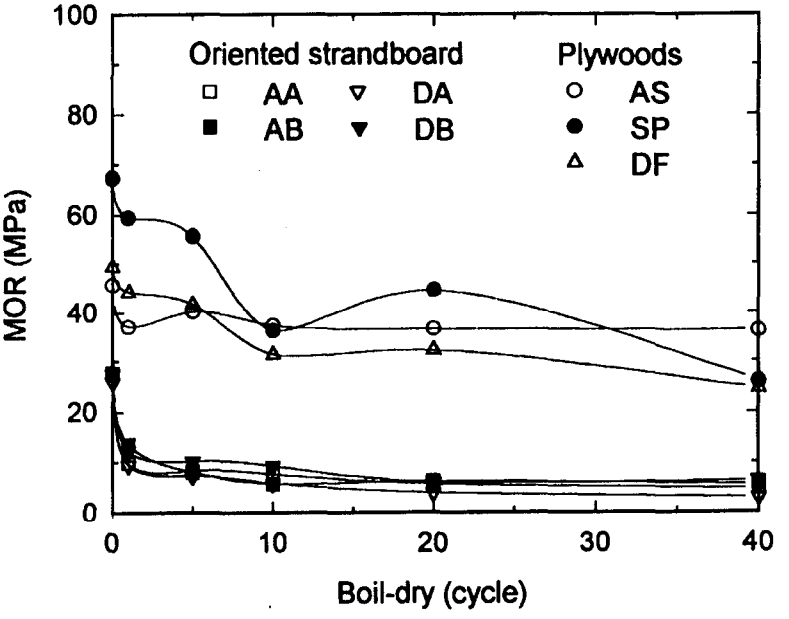

Figure 1. — MOR based on aged thickness for seven panels after laboratory BD cycles.

RESULTS AND DISCUSSION

NEW PANELS

When this study was initiated, the only standard for nonveneer wood-based panels in the United States was CS 236-66 for mat-formed particleboard issued by the Department of Commerce (8). The CS 236-66 required minimum values of MOR, MOE, and IB strength for unaged exterior, phenolic-bonded, grade 2-M-2 (exterior glue) particleboard of 17.2,3,103, and 0.41 MPa, respectively. It also required that the panel retain at least 50 percent of its original bending strength (based on original thickness) after undergoing the ASTM D 1037 accelerated-aging treatment (4). The CS 236-66 was revised and reissued in 1989 as American National Standard ANSI/A208.1-1989 (2). The product

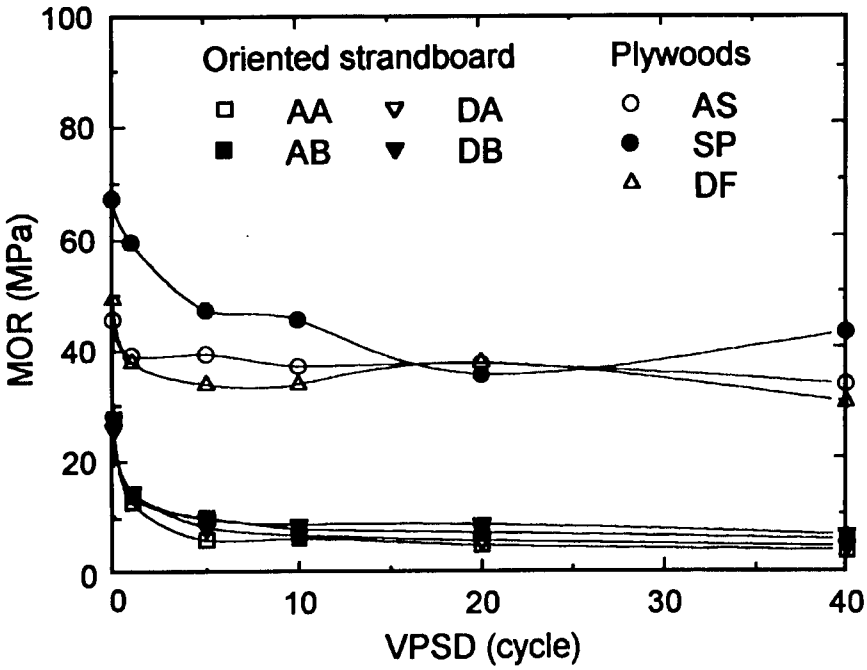

Figure 2. — MOR based on aged thickness for seven panels after laboratory VPSD cycle.

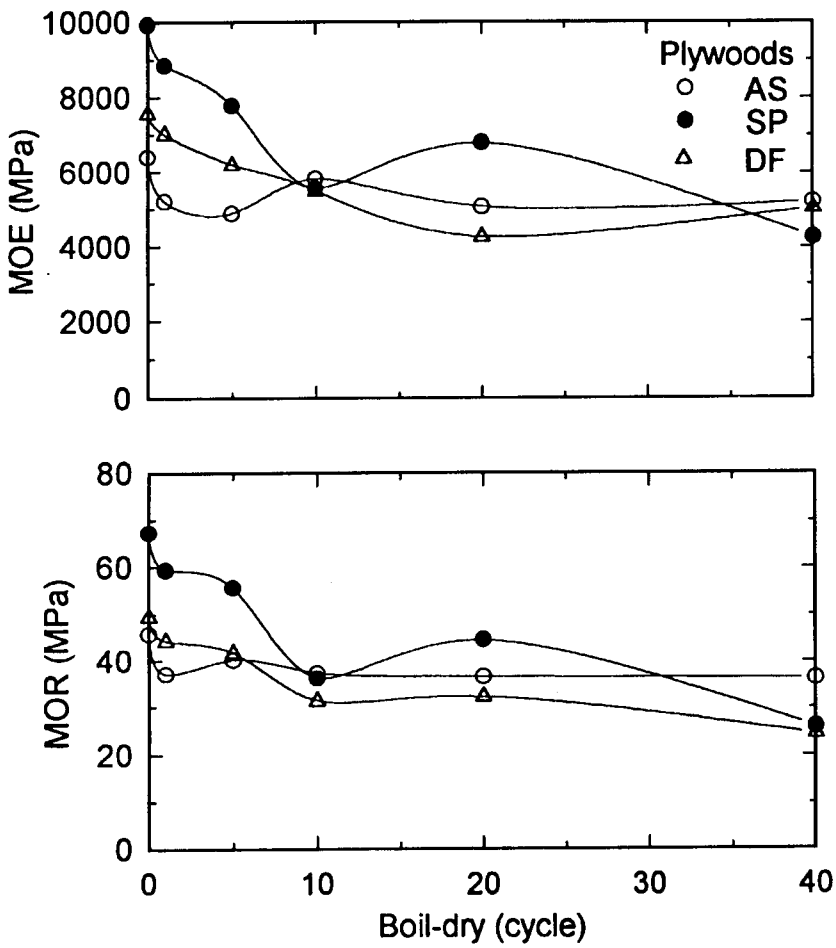

Figure 3. — Similarity between MOR and MOE after laboratory BD cycling of plywood specimens.

designation was changed to M-2 (exterior glue), and the performance requirements were changed to 14.5, 2,250, and 0.45 MPa for MOR, MOE, and IB, respectively, in the most recent revision of the ANSI/A208.1 (3).

The ANSI/A208 remained as the only standard for exterior-type, nonveneer wood-based panels until the American Plywood Association published APA PRP-108 (1) in 1986. The PRP-108 quickly became the accepted standard for structural nonveneer panels, including many wood-based materials used in this and the original study. In 1992, PRP-108 was revised and issued as Voluntary Product Standard PS 2-92 by the Department of Commerce (9). Standards PRP-108 and PS 2-92 use large-sized panels for mechanical property determinations in contrast to the small-sized bending specimens specified by ANSI/A208 and used in our previous studies. The PS 2-92 standard does use a small bending specimen for determining bond durability with the requirement that it retain 50 percent of its initial bending strength after a cyclic swell-shrink treatment. The main differences in PS 2-92 are that the load is applied to the edge of the specimen (edge of panel) instead of the face. We have continued to use the ANSI standard rather than the PS 2-92 standard, simply to maintain the continuity of our database.

All four wood-based panels tested satisfied the ANSI/A208 standard for MOR and MOE **(Table 1),** with panel DA having the lowest MOR (25.8 MPa). Panel AA had the lowest unaged MOE (4,070 MPa). Two of the four wood-based panels (AB and DB) met the 1989 ANSI standard for unaged IB strength; however, only panel AB met the higher 1993 ANSI standard of 0.45 MPa. Panels AA and DA, the thicker flakeboards, had the lowest IB strength of 0.35 and 0.37 MPa, respectively.

None of the OSB panels tested met the 50 percent bending strength retention requirement of CS 236 and ANSI/A208. 1 **(Table 2).** MOR (based on thickness at test) decreased to 19 to 27 percent of that before treatment.

The performance of wood-based panels expressed as the change in MOR or MOE with increasing BD or VPSD cycles was similar **(Figs. 1** and **2).** The change in the MOR and MOE of a given plywood was similar for a given aging

TABLE 3. — Comparison of MOR and MOE retained after five different BD cycles and 1 year of outdoor exposure.

Board type	1 cycle		5 cycle		10 cycle		20 cycle		40 cycle		1-yr. outdoor exposure	
	MOR	MOE	MOR	MOE	MOR	MOE	MOR	MOE	MOR	MOE	MOR	MOE
	(%)											
AA	36	33	30	24	28	21	21	16	18	13	44	41
AB	49	40	29	25	21	16	23	17	20	39	48	43
DA	37	28	28	20	23	17	15	10	12	9	48	42
DB	45	39	37	28	34	23	22	18	24	16	62	55
AS	81	81	88	76	82	91	80	79	79	82	78	81
SP	88	89	83	78	54	56	66	69	39	43	72	78
DF	90	93	84	82	64	73	65	56	50	67	83	88

TABLE 4. — IB strength retained after BD and VPSD cycling and outdoor exposure.

Board type	1 cycle		5 cycle		10 cycle		20 cycle		40 cycle		1-yr. outdoor exposure
	BD	VPSD	BD	VPSD	BD	VPSD	BD	VPSD	BD	VPSD	
	(%)										
AA	23	116	90	9	31	4	3	0	3	0	40
AB	29	43	53	27	30	12	5	8	3	0	41
DA	16	61	92	79	5	5	0	0	0	0	46
DB	37	47	79	14	121	10	6	6	3	0	66
AS	93	90	109	79	103	87	91	85	85	95	72
SP	87	98	80	70	66	76	75	60	56	32	58
DF	91	95	92	97	119	94	121	91	95	64	105

TABLE 5. — TS after BD and VPSD cycles and 1 year of outdoor exposure.

Board type	1 cycle		5 cycle		10 cycle		20 cycle		40 cycle		1-yr. outdoor exposure
	BD	VPSD	BD	VPSD	BD	VPSD	BD	VPSD	BD	VPSD	
	(%)										
AA	34	26	41	36	40	39	42	41	42	50	18
AB	29	19	39	30	46	36	41	38	45	41	18
DA	26	19	39	30	37	35	45	41	48	39	16
DB	23	18	35	29	37	34	33	44	38	37	11
AS	3	2	2	2	2	2	3	1	1	1	1
SP	2	2	2	2	3	3	3	3	3	3	3
DF	2	3	2	2	1	3	2	3	2	3	2

process **(Fig. 3);** however, BD and VPSD treatments had somewhat different effects on plywood MOR and MOE (data not shown).

The MOR and MOE of wood-based panels decreased to 28 to 49 percent of initial values after 1 cycle of BD treatment and 9 to 39 percent after 40 cycles **(Table 3).** One year of outdoor exposure reduced MOR and MOE to about 40 to 60 percent of the initial values. The SP and DF plywoods retained about 90 percent of the initial MOR or MOE after 1 BD cycle and about 40 to 70 percent after 40 BD cycles **(Table 3).** Interestingly, MOR and MOE in the AS plywood were quite constant at about 80 percent of the initial values from 1 to 40 cycles of BD treatment. One year of outdoor exposure reduced MOR and MOE in all plywoods to about 70 to 90 percent of the initial values.

Percentages of IB strength retained after BD, VPSD cycling, and outdoor weathering were varied **(Table 4).** Wood-based panels lost almost all IB strength after 20 BD or VPSD cycles. Panel DA lost all but 5 percent of its initial IB strength after 10 BD or VPSD cycles, and panel AA lost all but 4 percent of its initial IB strength after 10 VPSD cycles. These panels retained 40 to 66 percent of their original IB strength after 1 year of outdoor exposure.

The AS and DF plywoods performed well through 40 BD or VPSD cycles, retaining 64 to 95 percent of their original IB strength. The SP plywood steadily lost IB strength, with 56 percent retained after 40 BD cycles and 32 percent retained after 40 VPSD cycles. Plywoods had greater IB strength levels than the OSB panels but also greater variability, which accounts for the apparent retention levels greater than 100 percent in some cases (6).

In most tests, BD treatment caused more TS in wood-based panels than did VPSD treatment **(Table 5).** One cycle of BD treatment caused 23 to 34 percent swelling, and one cycle of VPSD treatment caused 18 to26 percent swelling. The difference between BD and VPSD treatments changed little during 40 cycles asTS increased to about 37 to 50 percent. In comparison, 1 year of outdoor exposure caused 11 to 18 percent TS in wood-based panels. Thickness of the plywood panels was only slightly affected by either the BD or VPSD treatments or the outdoor exposure as shown in **Table 5.**

NEW AND OLD PANEL COMPARISON

Figure 4 compares the MOR of panel C (aspen waferboard), which was one of the weaker wood-based panels in the original study (5), with the average MOR of the four wood-based panels in this study after BD treatment. The average MOR of the four new panels was used for this comparison because of the similarity in their performance, as shown

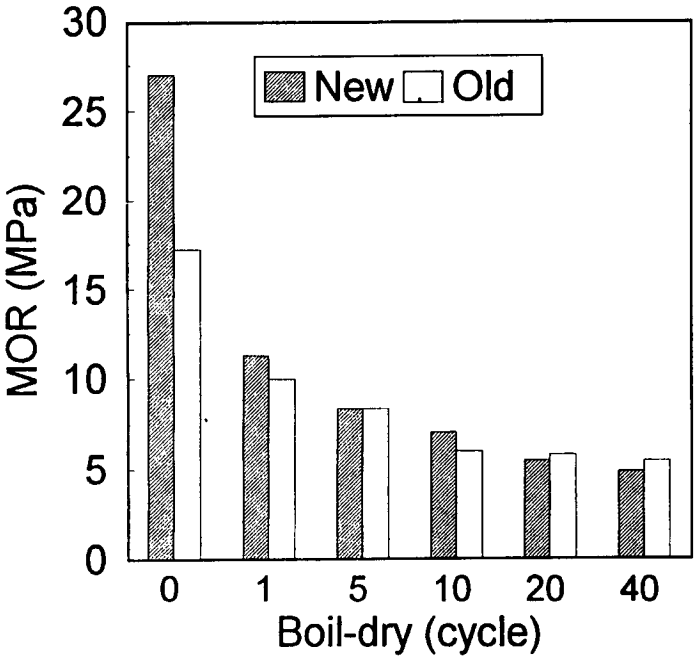

Figure 4. — Comparison of average MOR of the four OSB tested in this study (new) and panel C (waferboard) from old study (5) after laboratory BD cycle.

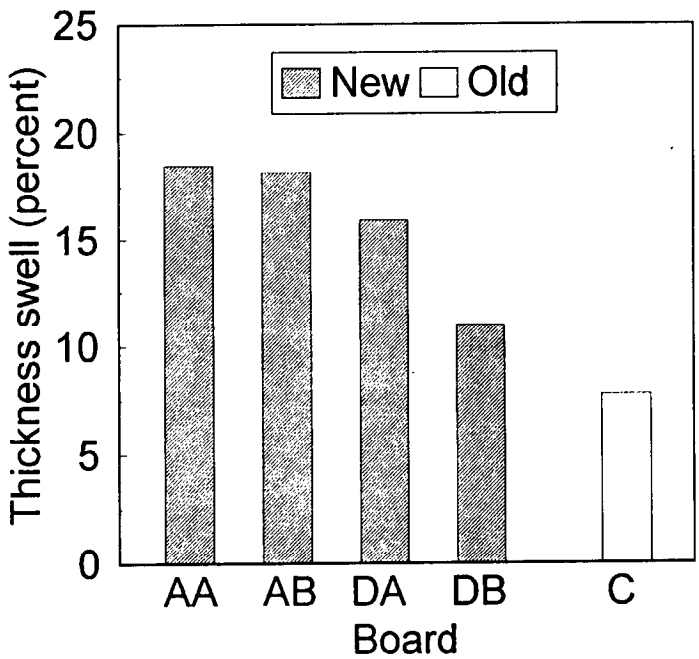

Figure 5. — Comparison of TS of the four OSB tested in this study (new) and panel C (aspen waferboard) from old study (5) after 1 year of outdoor exposure.

in Figure 1. The initial MOR of the new panels (AA, AB, DA, and DB) was greater than that of panel C. This was probably due to the oriented-strand construction of the new panels compared with the random-flake construction of panel C. However, after one BD cycle, the new wood-based panels retained only about 42 percent of their original strength. After one or more BD cycles, the bending strength levels of panel C and the new panels were similar. In fact, panel C retained slightly greater strength after 40 BD cycles than did the new panels. The greater relative loss of the new panels from the original strength compared with the relative loss of panel C was remarkable (Fig. 4). This difference can be explained directly by differences in TS and indirectly by factors such as furnish geometry, panel construction, resin content, and the aging conditions.

Panels with similar oriented-strand construction were tested in the original study (5). However, at least in the case of laboratory-made panels (A, B, L, and O), it is known that the resin content of those panels was high (5% to 6% of furnish dry weight).

TS for new oriented strandboards varied from 11 to 18 percent after 1 year of outdoor exposure **(Fig. 5).** This was much greater than the 8 percent recorded for panel C in Baker and Gillespie's original study (5). The greater TS in the new panels could be caused by several factors. One factor could be the occurrence of more severe weather (e.g., heat, moisture, freezing) during the year of exposure in the new study. This would cause additional severe swelling and shrinking stresses. The other possible factors are suspected lower resin contents in the new panels compared to panel C and differences in the geometry and stiffness of the particles of wood. These last factors seem to be the most logical because the large difference in TS between the new panels and panel C also occurred under controlled laboratory-aging conditions.

Plywood from the original study (5) also could not be directly compared with the plywoods tested in this study because of the difference in wood species or the number of plies. However, the initial MOR of the old five-ply Douglas-fir, marine-grade plywood (P) was not much greater than that of the new four-ply Douglas-fir and five-ply aspen plywoods (Fig. 6). The new four-ply Douglas-fir plywood compared well with the old five-ply Douglas-fir plywood through 1 and 5 BD cycles but then its MOR decreased more rapidly through 10,20, and 40 cycles. The new five-ply aspen plywood retained 81 percent of its initial MOR after one BD cycle, which was somewhat more than the five-ply Douglas-fir plywood from the original study. But the strength of the aspen plywood was essentially unchanged by continued BD treatment. After 40 BD cycles, the aspen still maintained 79 percent of its initial strength **(Table 3).** Furthermore, after 40 cycles, aspen plywood

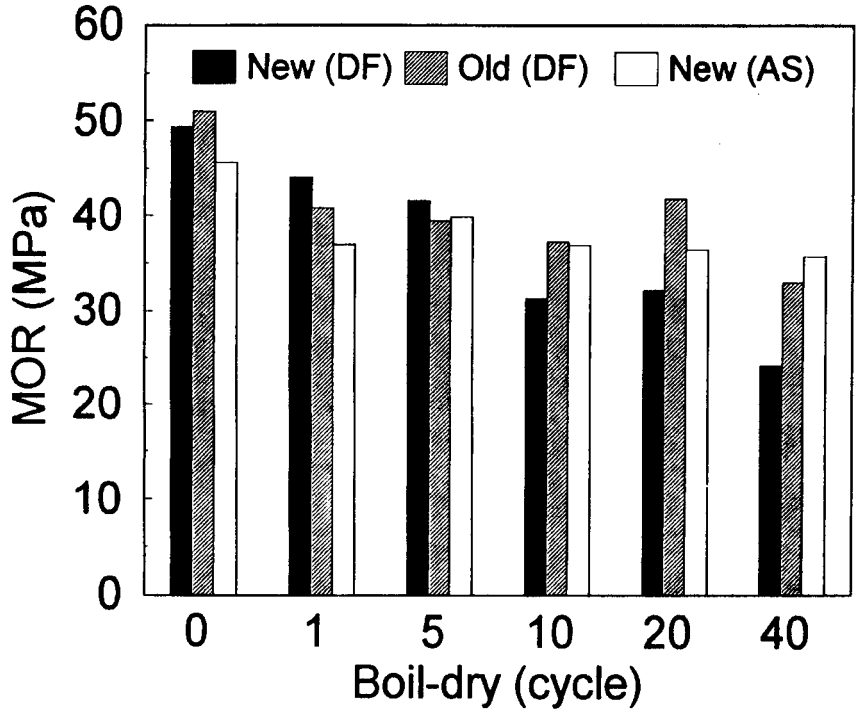

Figure 6. — Comparison of MOR of four-ply Douglas-fir and five-ply aspen plywood (new) and five-ply Douglas-fir marine plywood (old) after laboratory BD cycling.

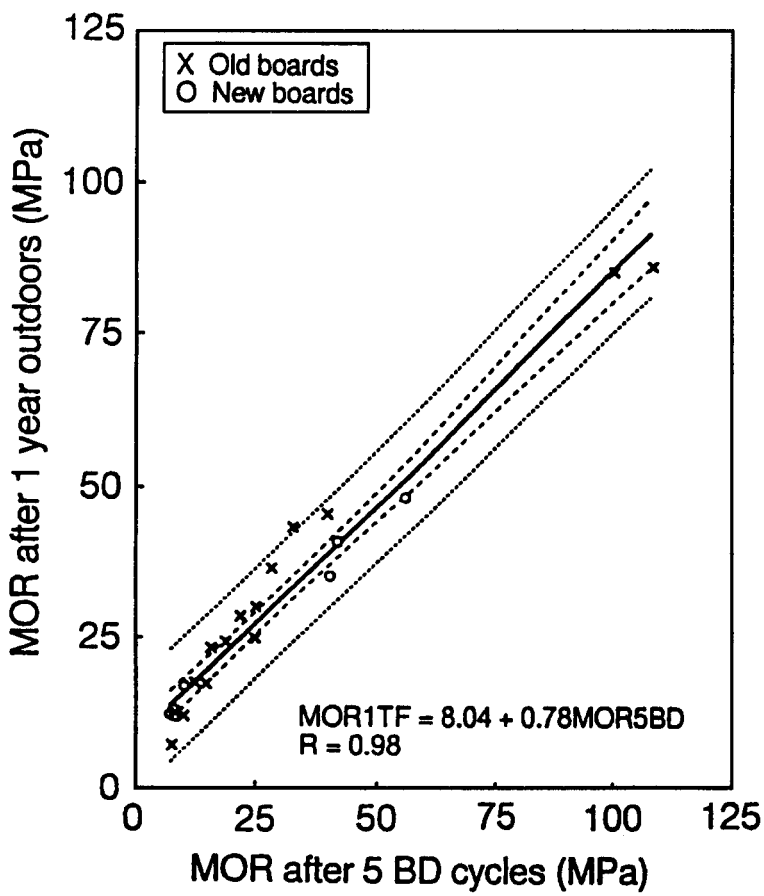

Figure 7. — Correlation between MOR data after 1 year of outdoor weathering and MOR data after five BD cycles for all boards (from old (6) and this study).

(AS) had a greater MOR than did the old five-ply Douglas-fir plywood (P). as shown in Figure 6.

EVALUATION OF OUTDOOR AND ACCELERATED-AGING CORRELATIONS

As in the previous report (6), we chose to focus this comparison on the behavior of the MOR of the materials to simplify the discussion. The MOE behavior was quite similar but with lower correlation coefficients than MOR. Similarly, BD and ASTM D 1037 treatments generally produced a greater correlation coefficient than did the VPSD treatment.

Two of the best predictive equations for outdoor weathering performance based on accelerated laboratory-aging performance from River (6) were chosen for evaluation. These equations are based on correlations between the MOR of 5 specimens alter 1 year of outdoor exposure and the MOR of 5 specimens of 17 different materials after laboratory aging. In this case, the laboratory aging was either five BD cycles or the ASTM D 1037 accelerated-aging treatment. The predictive equations are the following:

$$\text{MOR1TF} = 8.78 + 0.78\ \text{MOR5BD}$$
with r equal to 0.984

$$\text{MOR1TF} = 9.85 + 0.84\ \text{MORASTM}$$
with r equal to 0.975

where:

MOR1TF = MOR of five specimens after 1 year of outdoor exposure at Madison, Wis.

MOR5BD = MOR of five specimens after 5 BD cycles

MORASTM = MOR of five specimens after the six-cycle ASTM D 1037 accelerated-aging treatment

The MOR values obtained from specimens of the new panels were added to the data from River (6). All new panels were well within the 95 percent confidence limit fortheptedicted means (outer-lines). New data points tit the relationship established by River **(Figs. 7** and **8).** Adding new data to the old caused slight changes in the predictive equations. The following

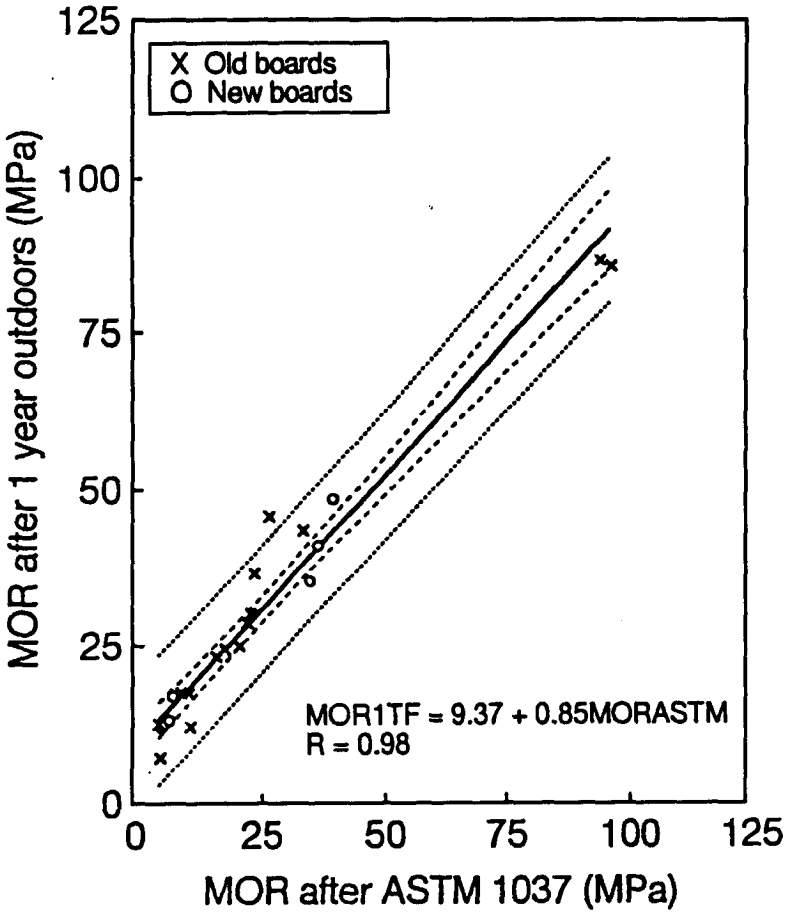

Figure 8. — Correlation between MOR data after 1 year of outdoor weathering and MOR after ASTM D 1037 exposure data for all boards (from old (6) and this study).

regression equations are based on the combined new and old data:

$$MOR1TF = 8.04 + 0.78\ MOR5BD$$
with R equal to 0.98

$$MOR1TF = 9.37 + 0.85\ MORASTM$$
with R equal to 0.98

The correlation coefficients were unchanged.

Conclusions

Wood-based panels lost between 51 to 72 percent of their initial bending strength and stiffness after one BD cycle. IB strength retained was erratic, but 20 cycles of either a BD or a VPSD treatment reduced strength more than 90 percent. One cycle of VPSD increased panel thickness 18 to 26 percent, and one BD cycle increased thickness 23 to 34 percent.

One year of outdoor exposure reduced strength and stiffness of wood-based panels 38 to 59 percent. IB strength decreased 34 to 60 percent; thickness increased 11 to 18 percent.

The average initial MOR of the wood-based panels was much greater than that of the lowest performing panel from the 1978 study (5); however, it was about the same after accelerated laboratory aging.

Aspen and Douglas-fir plywoods compared favorably with five-ply marine exterior grade Douglas-fir plywood from the 1978 study (5) through 40 BD cycles. Southern pine plywood did as well through five BD cycles, but its strength and stiffness decreased quickly after five cycles.

Data for the materials tested in this study fit witbin the boundaries of predictive equations for outdoor performance, based on performance after accelerated laboratory aging.

The addition of data from the present study did not greatly alter the predictive equations based on the 1978 and 1981 data.

Literature Cited

1. APA. 1986. Performance standards and policies for structural panels. American Plywood Association, PRP-1 08. Tacoma, Wash.
2. ANSI. 1989. American national standard-wood particleboard. ANSI/A208. 1-1989. American National Standard Institute. Published by National Particleboard Assoc., Gaithersburg, Md.
3. _____ 1993. American national standard-wood particleboard. ANSI/A208.1-1993. American National Standard Inst. Published by National Particleboard Assoc., Gaithersburg, Md.
4, ASTM. 1987. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM Designation D-1037. Annual book of ASTM standards. American Soc. For Testing And Materials, West Conshohocken, Pa.
5. Baker, A.J., and R.H. Gillespie. 1978. Accelerated aging of phenolic-bonded flakeboard. *In:* Proc., Structural Flakeboard From Forest Residue. Gen. Tech. Rept. WO-5. USDA Forest Serv., Washington, D.C.
6. River, B.H. 1994. Outdoor aging of wood-based panels and correlation with laboratory aging. Forest Prod. J. 44(11/12): 55-65.
7. _____, A.J. Baker, and R.H. Gillespie. 1981. Accelerated aging of phenolic-bonded hardboard and flakeboard. FPL-RP-393. USDA Forest Serv., Forest Prod, Lab., Madison, Wis.
8. U.S. Department of Commerce. 1966. Mat-formed wood particleboard. Commercial Standard CS 236-66. National Bureau of Standards, Washington, D.C.
9. _____.1992. Performance standard for wood-based structural-use panels. Voluntary Product Standard PS 2-92. National Inst. of Standards and Technology (formerly, National Bureau of Standards), Washington, D.C.

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