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LONG TERM DURABILITY OF LABORATORY-MADE DOUGLAS-FIR FLAKEBOARD

Abstract

Douglas-fir flakeboards containing different resin binders in varying amounts and having different densities were tested by exposure to the weather, to an accelerated aging exposure of the American Society for Testing and Materials (ASTM), and to four laboratory-controlled exposures. After exposure the flakeboards were tested to determine the amount of deterioration. Tests after 1, 2, 3, 4, and 8 years of exposure outdoors indicated that much of the deterioration of the specimens occurred during the first year. Deterioration continued at a lesser rate throughout the exposure period, with some specimens completely disintegrating.

Painted flakeboards were more durable than unpainted and showed little if any change in their mechanical and physical properties. After 8 years of outdoor exposure, boards with phenolic-resin binders proved to be considerably more durable than those with urea or melamine-urea binders. Test-fence exposure of 8 years was more severe than six cycles of the ASTM accelerated aging on phenolic-bonded flakeboards. The six-cycle ASTM test and the repeating cyclic exposure of 158° F. and 20 percent relative humidity followed by 80° F. and 90 percent relative humidity were the only controlled exposures that approached the severity of outdoor weathering.

LONG TERM DURABILITY OF LABORATORY-MADE DOUGLAS-FIR FLAKEBOARD

By

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Introduction

In 1958 the Forest Products Laboratory began a long term study of particleboard durability. Eight sets of flake-type Douglas-fir boards that varied in density and in type and in amount of binder were fabricated and exposed to outdoor and laboratory-controlled exposures. Matched specimens were also given the accelerated aging exposure of the American Society for Testing and Materials, ASTM D1037-60. In two previous papers results were analyzed after 2 years of laboratory-controlled exposure and after 3 years of exterior exposure.[2,3] In this paper results after 8 years of exposure are analyzed.

Fabrication and Exposture of Specimens

Because of the large number of possible variables that could affect board properties, it was decided to codine the study to one species and to limit other variables to board density and type and amount of binder. A description of the binder and of the fabricating variables employed in making the flakeboards is given in table 1. The variables were selected to provide a broad range of board types within limits of typical commercial boards being fabricated when this study began.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Hann, R. A., Black, J. M., and Blomquist, R. F. How durable is particleboard? Part II The effect of temperature and humidity. Forest Prod. J. 13(5):169–174. 1963.

[3] Hann, R. A., Black, J, M., and Blomquist, R. F. How durable is particleboard? Forest Prod. J. 12(12):577–584. 1962.

Table 1.--Binder and bonding variables and employed fabrication of flakeboards

Variable No.	Binder[1]			Wax[2]	Moisture content[3]	Closing time[4]	Cure temperature	Cure time[5]	Density[6]
	Type	Amount	Calculated spread on flake surfaces						
		Pct.	Lb. per 1,000 sq. ft.	Pct.	Pct.	Sec.	°F.	Min.	Lb. per cu. ft.
1	Urea	4	0.5	....	10	45	310	15	34
2	....do....	4	.5	....	10	55	310	15	42
3	....do....	4	.5	1	10	60	310	15	44
4	Urea-	2		....					
	Melamine	2	.5	....	10	45	310	15	33
5	Urea	8	1.0	....	10	45	310	15	37
6	Phenol	3	.38	....	13	45	350	15	33
7	....do....	3	.38	....	13	60	350	15	40
8	....do....	6	.76	....	13	45	350	15	35

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[1] Percent of binder solids based on weight of dry wood. American Cyanamid Calco Yellow B fluorescent dye (0.1 percent), based on weight of binder solids, was added to binder solution of urea resin. No dye was added to phenol-resin binder. Spread values are in pounds of dry binder per 1,000 square feet of flake surface area.

[2] Percent of wax solids based on the weight of dry wood. Wax employed was an emulsion type applied by spray after application of binder.

[3] Moisture content of flakes at press time; obtained by adding the required amount of water to the binder solution.

[4] Time between insertion of the panel in the press to closing of press to 0.5-inch-thick stops.

[5] Total time in press after closing to stops.

[6] Based on weight and volume at equilibrium at 80° F. and 65 percent relative humidity.

The choice of laboratoory-controlled exposures was based primarily on experience in evaluating conventionally used wood glues.[4] The four controlled exposures were as follows:

(1) Continuous exposure to 80° F. and 65 percent relative humidity.
(2) Continuous exposure to 80° F. and 90 percent relative humidity.
(3) Continuous exposure to 158° F. and 20 percent relative humidity.
(4) A repeating cyclic exposure of 1 week at 80° F. and 90 percent relative humidity followed by 1 week at 158° F. and 20 percent relative humidity.

The purpose of the controlled exposures was to isolate the effects of temperature and humidity without the confounding effects of sunlight, other radiation, rain, wind, and biological deterioration.

The outdoor, or test-fence, exposure consisted of placing specimens on vertical racks facing south. Sixty-four unpainted specimens and 24 painted specimens were placed on exposure. Tests were made after 1, 2, 3, 4, and 8 years on the unpainted specimens and after 2, 4, and 8 years on the painted specimens.

In addition to the specimens for the laboratory-controlled and the outdoor exposures, a set of specimens--one from each board type--was given the ASTM accelerated aging exposure. This test requires that the specimens complete six cycles of accelerated aging. Each cycle consists of the following: (1) Immersing specimens in water at 120° ±3° F, for 1 hour; (2) spraying with steam and water vapor at 200° ±5° F. for 3 hours; (3) storing at 10° ±5° F, for 20 hours; (4) heating at 210° ±3° F. in dry air for 3 hours; (5) spraying again with steam and water vapor at 200° ±5° F. for 3 hours: and (6) heating in dry ais at 210° F. for 18 hours.

The specimens for the ASTM and the test-fence exposure were 7-3/16 by 13 inches, and for the laboratory-controlled exposures were 2 by 13 inches. The flakeboard was not sanded before placing on exposure.

Measurements for Deterioration

After removal from exposue, all specimens were reconditioned to approximate equilibrium at 80° F. and 65 percent relative humidity before testing. The procedures used in the preparation and testing were the same as those specified

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[4] Forest Products Laboratory. Durability of water-resistant woodworking glues. U.S.D.A. Forest Service, Forest Products Lab. Rep. No. 1530, Madison, Wis., 1956.

in ASTM D1037-60. The following properties were tested: Percent of thickness swelling, internal bond strength, shear strength in the center of the board, modulus of elasticity, and modulus of rupture in bending.

To determine the approximate amount of deterioration place during the various exposures, the values obtained from the tests of physical and mechanical properties were compared with original, or control, valves. The control values were determined by measuring the physical and the mechanical properties of the particleboard after allowing it to age for 1 much after fabrication in constant conditions of 80° F. and 65 percent relative humidity (table 2).

Results

The effect of the laboratory-controlled exposure on the internal bond strength measured perpendicular to the surface of the eight board types is shown in figures 1 through 4. Of these exposures, the effect of the repeating cyclic 158° F. and 20 percent relative humidity for 1 week followed by 1 week at 80° F. and 90 percent relative humidity (fig. 1) was the most severe. The amount of deterioration that occurred during the 24 months of the exposure was similar to that which occurred during 8 years of test-fence exposure.

The continuous exposure of the flakeboard to 80° F. and 90 percent relative humidity (fig. 2) caused considerable loss in strength in all board types the first year. After the first year the boards with urea binders continued to lose strength, but at a lower rate. The specimens with a phenolic-resin binder leveled off and remained almost constant for the remaining 7 years.

The laboratory-controlled exposure of 158° F. and 20 percent relative humidity (fig. 3) caused only the boards withaurea binder to lose strength. This exposure did not appreciably affect the specimens with phenolic binders. In only this exposure was a noticeable decrease in strength not accompanied by an increase in thickness.

The controlled exposure of 80° F. and 65 percent relative humididty (fig. 4) did not cause any substantial change in the physical and the mechanical properties of the flakeboard. Figure 5 shows the reaction of the internal bond strength of the eight board types to outdoor exposure. The only unpainted specimens still intact after 8 years of exterior exposure were those with a phenolic kinder. All specimens with a urea-binder--regardless of the amount of binder, of the board density, of the addition of wax, or of the fortification with melamine--had

Table 2.--Physical and mechanical properties of unexposed flakeboards conditioned to equilibrium at 80° F. and 65 percent relative humidity

Board variable No.	Variables in board composition					Bending properties[1]		Strength in tension perpendicular to face[2]	Shear parallel to face[2]	Water absorption after 24-hour soak	Increase in thickness[2]		Strength in tension perpendicular to face[2]	
	Binder			Density	Thickness	Modulus of elasticity	Modulus of rupture				After 24-hour	After 24-hour soak and reconditioning	After 24-hour soak and reconditioning	Loss in strength after 24-hour soak and reconditioning
	Type	Amount	Spread											
		Pct.	Lb. per 1,000 sq. ft.	Lb. per cu. ft.	In.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	Pct.	Pct.	Pct.	P.s.i.	Pct.
1	Urea	4	0.5	34	0.496	493	2,620	27	259	92	20	12	14	48
2	....do....	4	.5	42	.492	707	4,396	37	391	62	27	17	25	33
3	....do.... Wax	4 1	.5	44	.492	713	4,926	107	465	15	12	7	97	9
4	Urea-Melamine	2 2	.5	33	.493	522	2,896	[3]26	292	87	15	8	[3]40	[3]0
5	Urea	8	1.0	37	.497	552	3,456	117	416	70	15	8	103	12
6	Phenol	3	.4	33	.494	519	2,670	22	108	71	15	7	10	54
7	....do....	3	.4	40	.490	734	4,150	55	310	68	22	13	30	46
8	....do....	6	.8	35	.493	615	3,723	51	184	76	14	6	47	8

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[1] Values are average of 3 specimens.

[2] Values are average of 4 specimens.

[3] Values after water soak are higher than values for unsoaked control specimens, which indicates that values for the unsoaked No. 4 variable specimens are too low; reason for this not known.

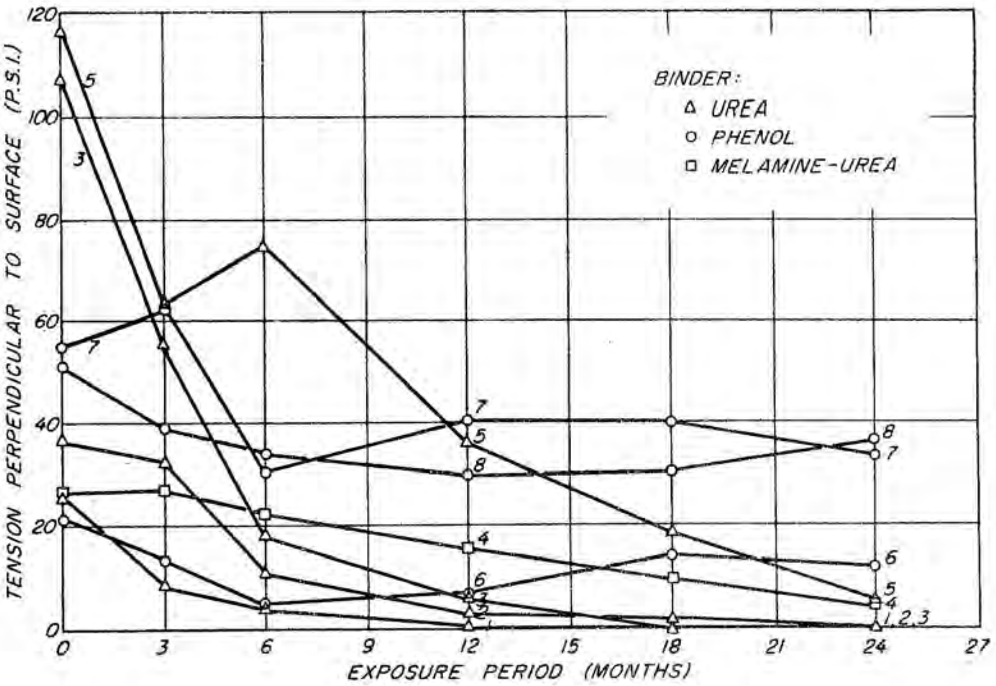

Figure 1.--Relation of deterioration in strength of Douglas-fir flakeboards to months of repeated cyclic exposure of 1 week at 158° F, and 20 percent relative humidity followed by 1 week at 80° F. and 90 percent relative humidity. Numbers are keyed to the eight variables In table 1. M 134 919

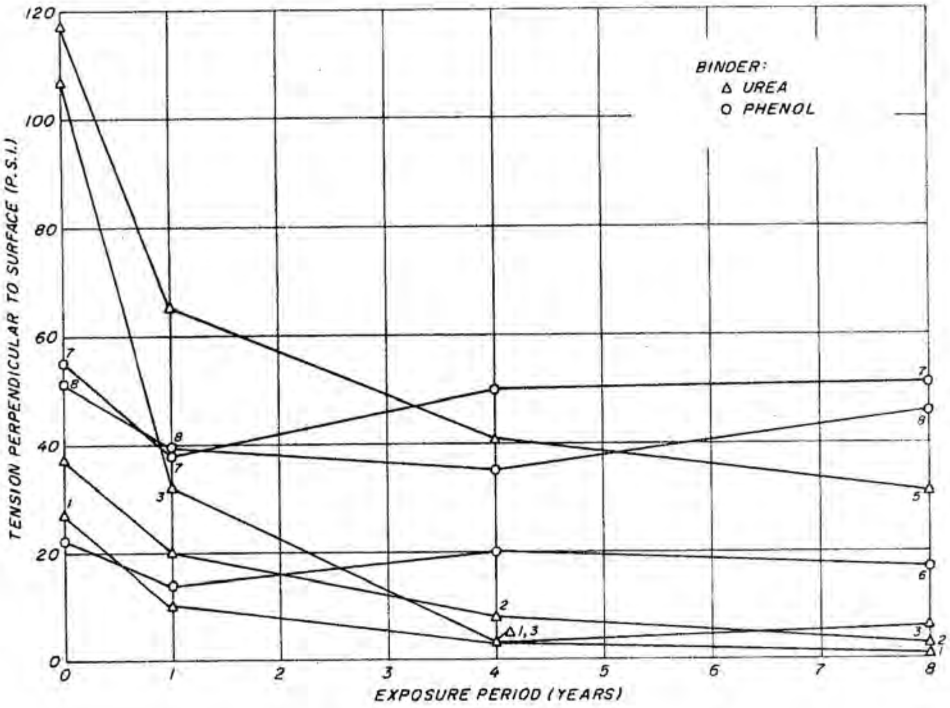

Figure 2.--Relation of deterloration in strength of Douglas-fir flakeboards to 8 years of continuous exposure at 80° F. and 90 percent relative humidity. Numbers are keyed to the eight variables in table 1. (Specimens for variable 4 were accidentally destroyed by water.)

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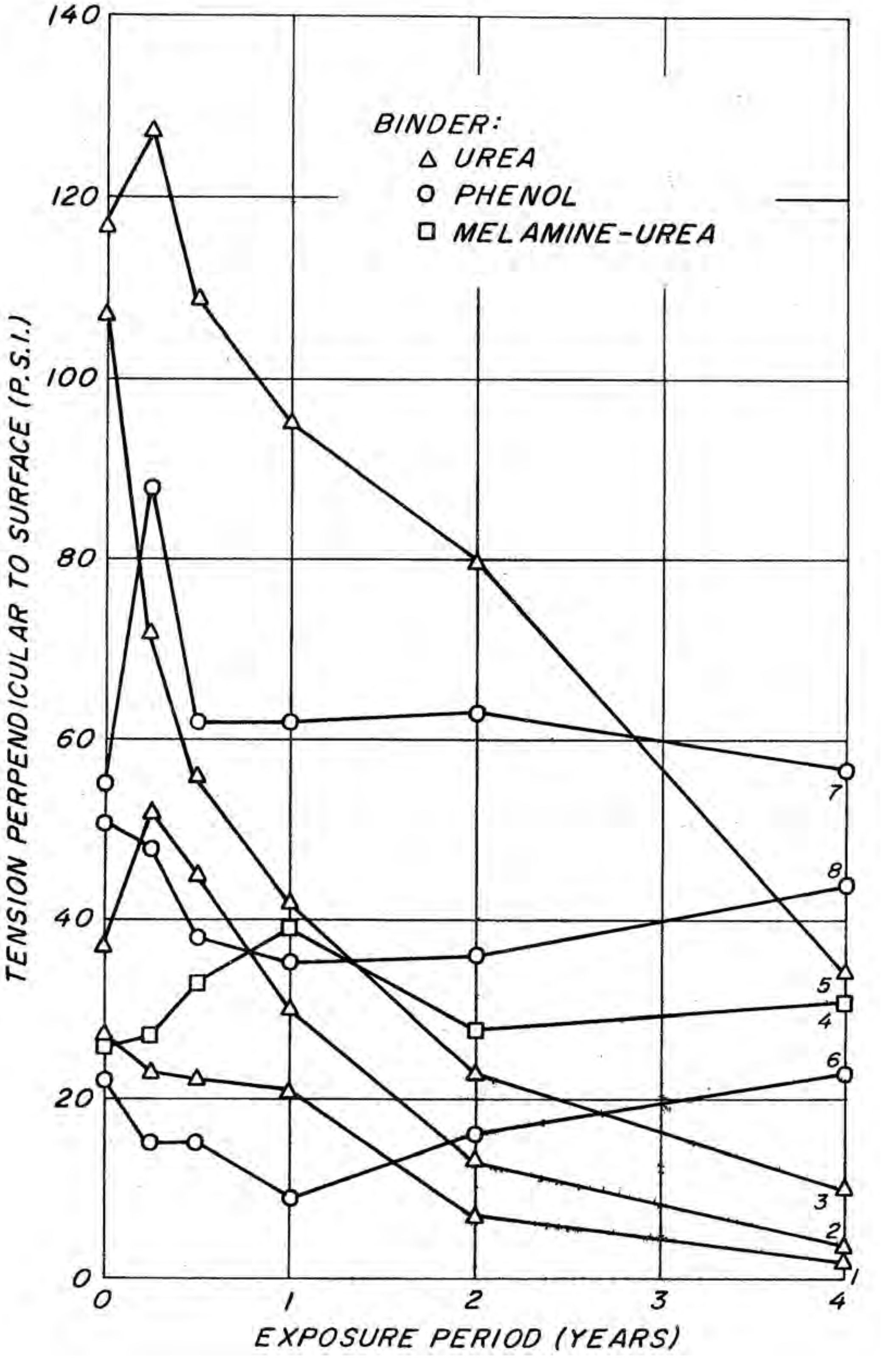

Figure 3.--Relation of deterioration in strength of Douglas-fir flakeboards to 4 years of continuous exposure at 158° F. and 20 percent relative humidity. Numbers are are keyed to eight variables in table 1.

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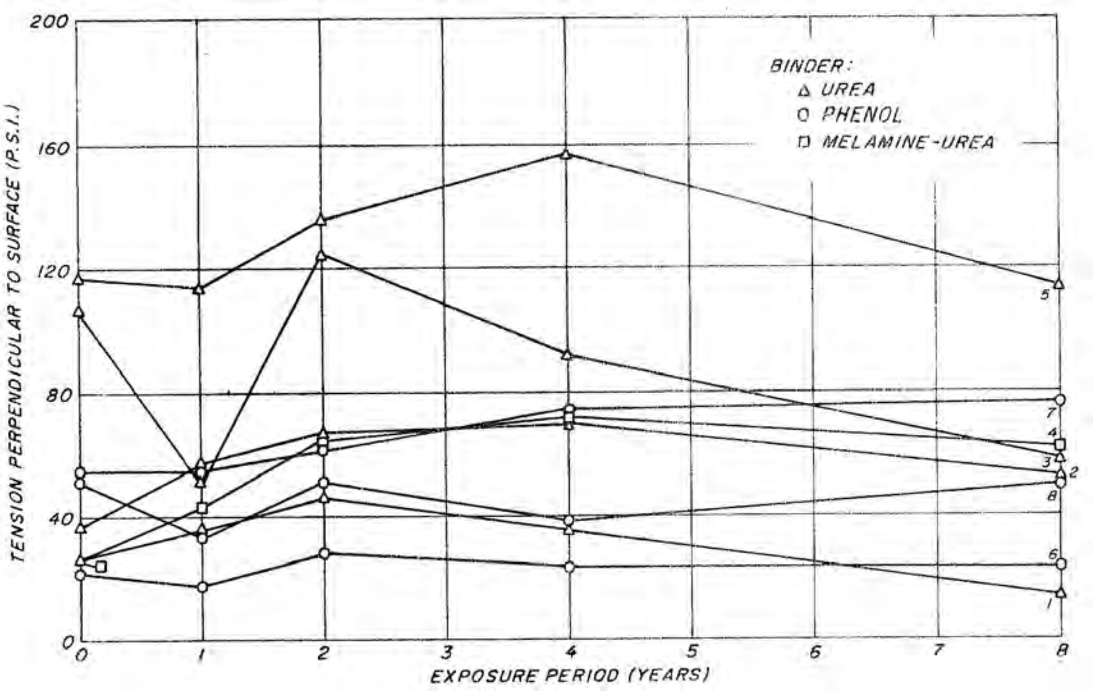

Figure 4.--Relation of deterioration in strength of Douglas-fir flakeboards to 8 years of continuous exoosure at 80° F. and 65 percent relative humidity. Numbers are keyed to the eight variables in table 1.

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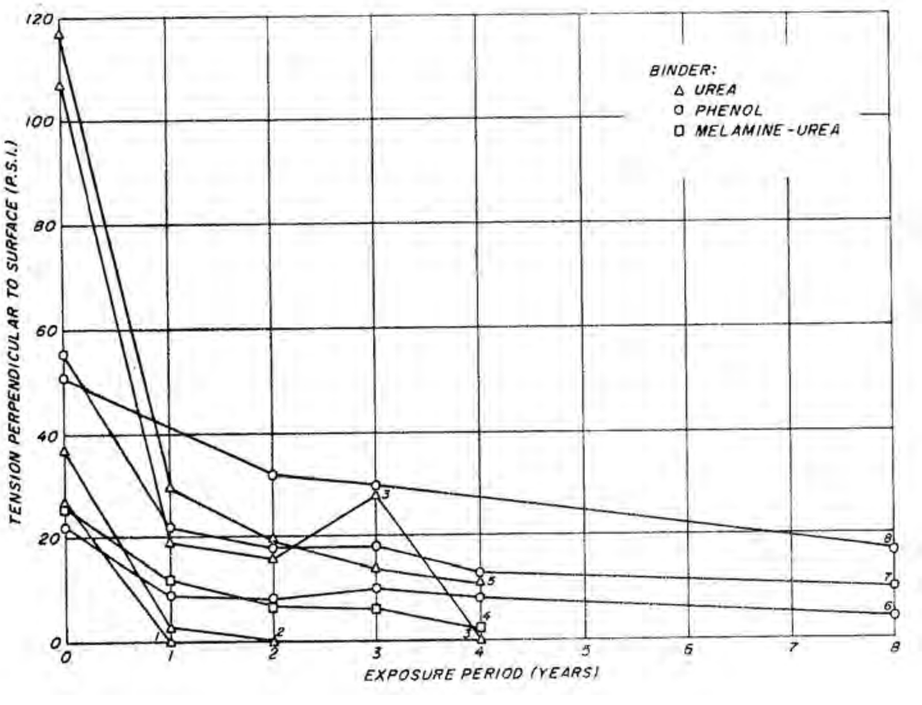

Figure 5.--Relation of deterioration in strength to 8 years of outdoor test-fence exposure for Douglas-fir flakeboards. Numbers are keyed to the eight variables in table 1.

M 134 280

deteriorated to the point of no longer being usable. After 8 years, the phenolic-bonded flakeboard specimens retained only 39 to 48 percent of their original modulus of rupture and 18 to 33 percent of their original strength in tension perpendicular to the face (tables 3 and 4).

Specimens of the phenolic-bonded flakeboard (variables 6, 7, and 8) retained 46 to 68 percent of their original modulus of rupture after 6 cycles of ASTM D1037-60 accelerated aging, and up to 61 percent of their original strength in tension perpendicular to the face of the board (table 5).

All painted specimens exposed on the test fence were still in excellent condition after 8 years, regardless of the binder used.

Discussion of Results

In the two papers published on the early results of this study, the physical reactions of the particleboard specimens to changes in moisture conditions were discussed in detail.[2,3] It was then concluded that particleboard deterioration took place because of the combined effects of springback from compression set, deterioration of the binder, and differential shrinkage of adjacent particles. Here discussion is concerned with the relative durability resulting from the different board variable combinations and with comparisons of the reactions of the test material on the test fence and in the four laboratory-controlled exposures.

The repeating cyclic exposure of 1 week at 158° F. and 20 percent relative humidity followed by 1 week at 80° F. and 90 percent relative humidity was the most severe of the laboratory-controlled exposures (fig. 1). However, 1 year of this exposure was not as degrading to the flakeboard as 1 year on the test fence. The repeating cyclic exposure did establish the relative durability of the eight types being studied. The repeating cyclic exposure also ranked the eight board types in the same order as the test-fence exposure. However, it is not possible at this time to equate a given number of cycles of exposure with a period of time in exterior exposure.

The continuous exposure of flakelboard to conditions of 80° F. and 90 percent relative humidity was the second most severe of the controlled exposures (fig, 2). This exposure caused a rapid drop in strength properties in all board

Table 3.--Modulus of rupture of laboratory-made flakeboards after exterior exposure

Board variable No.	Variables in board composition: Binder: Type	Binder: Amount	Density	0 (Control): Unpainted	0 (Control): Painted	1 year: Unpainted	1 year: Painted	2 years: Unpainted	2 years: Painted	3 years: Unpainted	3 years: Painted	4 years: Unpainted	4 years: Painted	8 years: Unpainted	8 years: Painted
		Pct.	Lb. per cu. ft.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
1	Urea	4	34	2,620	2,620	470	....	90	2,200	0	....	0	2,400	0	2,380
2	....do....	4	42	4,396	4,396	900	....	550	3,430	440	....	0	3,630	0	2,600
3	....do....	4	44	4,926	4,926	2,650	....	2,830	3,960	2,860	....	1,800	3,010	0	3,060
4	Wax Urea-Melamine	1 2 2	33	2,896	2,896	1,400	....	1,110	3,100	1,090	....	590	2,400	0	2,880
5	Urea	8	37	3,456	3,456	2,030	....	2,040	3,590	1,800	....	1,030	3,160	0	3,370
6	Phenol	3	33	2,670	2,670	1,740	....	1,300	2,200	1,640	....	1,760	2,520	1,050	2,730
7	....do....	3	40	4,150	4,150	2,800	....	2,550	4,710	2,370	....	2,760	4,270	1,670	4,430
8	....do....	6	35	3,723	3,723	1,950	....	2,630	2,980	2,350	....	2,230	3,160	1,795	3,280

Table 4.--Comparison of the strength in tension perpendicular to the face of flakeboards after exterior exposure

Board variable No.	Variables in board composition: Binder: Type	Binder: Amount	Density	0 (Control): Unpainted	0 (Control): Painted	1 year: Unpainted	1 year: Painted	2 years: Unpainted	2 years: Painted	3 years: Unpainted	3 years: Painted	4 years: Unpainted	4 years: Painted	8 years: Unpainted	8 years: Painted
		Pct.	Lb. per cu. ft.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
1	Urea	4	34	27	27	0	....	0	13	0	....	0	36	0	30
2	....do....	4	42	37	37	3	....	0	25	0	....	0	45	0	50
3	....do....	4	44	107	107	19	....	16	51	28	....	0	60	0	50
4	Wax Urea-Melamine	1 2 2	33	26	26	12	....	7	36	6	....	2	44	0	35
5	Urea	8	37	117	117	30	....	19	105	14	....	11	129	0	120
6	Phenol	3	33	22	22	9	....	8	12	10	....	8	14	4	15
7	....do....	3	40	55	55	22	....	18	48	18	....	13	67	10	65
8	....do....	6	35	51	51	24	....	32	44	30	....	76	54	17	55

Table 5.--Strength properties of various flakeboards after ASTM Accelerated Aging Exposure[1]

Board variable No.	Variables in board composition			Strength properties[2]			Amount of original strength retained[2]		
	Binder		Density	Modulus of rupture	Modulus of elasticity	Tension perpendicular to face	Modulus of rupture	Modulus of elasticity	Tension perpendicular to face
	Type	Amount							
		Pct.	Lb. per cu. ft.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Pct.	Pct.	Pct.
1	Urea	4	34	0	0	0	0	0	0
2	....do....	4	42	0	0	0	0	0	0
3	Urea	4							
	Wax	1	44	0	0	0	0	0	0
4	Urea-	2							
	Melamine	2	33	0	0	0	0	0	0
5	Urea	8	37	0	0	0	0	0	0
6	Phenol	3	33	1,230	231,000	1	46	45	5
7	....do....	3	40	2,680	430,000	1	65	59	2
8	....do....	6	35	2,510	381,000	31	68	62	61

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[1] Specimens from board variable Nos. 1, 2, 3, and 5 disintegrated after one cycle, whereas specimens from board variable No. 4 disintegrated after four cycles. Specimens were considered to be disintegrated when they could no longer be lifted by holding opposite corners.

[2] Flexural values are average of three specimens, and values for tension perpendicular to the face are average of four specimens.

variables the first year. After the first year the phenolic-bonded specimens stabilized, and the urea-bonded specimens continued to lose strength, but at a lower rate. A large portion of the decrease in strength during the first year of exposure was probably caused by recovery from compression set. The continued decrease in strength of the urea resin throughout the exposure is a reflection of this resin's lack of resistance to high-humidity conditions.

Board variable 3 contained 1 percent wax in combination with a 4 percent urea-resin binder. This particular combination resulted in exceptionally high initial strength properties, but had a very rapid decline in strength properties when exposed to conditions of fluctuating or high humidity (figs. 1 and 2).

The continuous exposure of 158° F, and 28 percent relative humidity did not affect the phenolic-bonded specimens, but caused considerable strength loss in the flakeboard with urea-resin binders (fig. 3). Only in this exposure was a loss in strength not accompanied by an increase in board thickness. Urea resins have been shown to be sensitive to these conditions.[4]

Exposure of a set of the test specimens to constant conditions of 80° F. and 65 percent relative humidity for 8 years did not cause any measurable change in the strength of the flakeboard. This was a mild exposure and not much change was expected (fig. 4). The variation within a board type is believed to have been caused by differences in temperature and pressure across the face of the press at the time the board was fabricated.

After 8 years of test-fence exposure the only unpainted specimens still in usable condition were those with a phenolic binder (fig, 5). All specimens with a urea or fortified-urea binder had deteriorated to the point of uselessness. Increasing the density of the board and increasing the percentagee of binder gave higher initial strength and also lengthened the service life.

In board variable 3, the addition of 1 percent wax to a 4 percent urea-resin board did increase the service life of the board over similar board without wax This increased life can be attributed to two factors: The wax greatly increased the initial strength properties; and the wax offered some protection against wetting by liquid water. However, wax does not prevent the movement of water vapor, which means that the board will move with the prevailing humidity conditions. The additional strength from the wax rapidly deteriorated and by the end of the fourth year of exposure the particleboard retained very little of its original strength.

Fortification of the urea with a melamine resin (variable 4) did little to improve durability. The binder in this instance was a 2 percent urea–2 percent melamine combination. Generally, melamine is considered more durable than urea in exterior exposures. Apparently in this case melamine was not present in sufficient quantity to maintain the integrity of the board after the urea deteriorated.

The painted specimens included in the test-fence exposure performed very well. None of the eight board types lost noticeable amounts of strength (tables 3 and 4). The painted specimens were given a water-repellent dip treatment and two coats of paint before being placed on the exposure racks, and were repainted after the fourth year of exposure. Because these results are highly dependent on the maintenance of a good coat of paint, they only indicate what might be expected where similar protection is provided.

Specimens from all eight board types (table 1) were given the ASTM accelerated-aging exposure (D1037-60). All flakeboard specimens with phenolic binders were intact after this six-cycle test. The melamine-urea-bonded specimens failed after four cycles, and all remaining specimens failed during the first cycle of the exposure.

After completing the six cycles, the three types of flakeboard with phenolic binders retained the following percentages of their original modulus of rupture in bending: 46 percent, variable 6; 65 percent, variable 7; and 68 percent, variable 8. The percentages retained of original internal bond strength (table 5) were as follows: 5 percent, variable 6; 2 percent, variable 7; and 61 percent, variable 8.

After 8 years on the test fence, the specimens retained the following percentages of their original modulus of rupture in bending 39 percent, variable 6; 48 percent, variable 7; and 48 percent, variable 8. The retention of original internal bond strengths were as follows: 18 percent, variable 6; 18 percent, variable 7; and 33 percent, variable 8.

The lower internal bond values for specimens of variables 6 and 7 may have been caused by shear failures induced when the modulus of rupture determinations were made. If this was the cause, then apparently 8 years of test-fence exposure was more degrading to the flakeboard than six cycles of the ASTM accelerated-aging test.

Conclusions

(1) The phenolic-bonded fakeboards far outperformed the urea-bonded boards in exterior exposures.

(2) Exposure of 8 years on the test fence was more severe than six cycles of the ASTM accelerated-aging exposure on phenolic-bonded flakeboard.

(3) Increasing board density, adding wax, and increasing the resin content of urea-bonded flakeboard increased initial strength, but did not materially retard rate of strength loss under severe exposures.

(4) The six-cycle ASTM test and the cyclic 158° F. and 20 percent relative humidity followed by 80° F, and 90 percent relative humidity were the only controlled exposures that approached the deterioration resulting from 8 years of test-fence exposure.

(5) The primary causes of deterioration of the flakeboard were springback from compression set, deterioration of the binder, and differential shrinkage of adjacent particles during moisture changes.

(6) A well-maintained coat of paint on the flakeboards in the test-fence exposure greatly improved durability.

combination. Generally, melamine is considered more durable than urea in exterior exposures. Apparently in this case melamine was not present in sufficient quantity to maintain the integrity of the board after the urea deteriorated.

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