EFFECT OF AGING ON THE MECHANICAL PROPERTIES OF PARTICLEBOARD DECKING[1]

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ABSTRACT

Southern pine particleboard, bonded with urea and phenolic-formaldehyde resins, manufactured for modular home decks was evaluated for the effect of weathering on its mechanical behavior. Aging reduced the static bending, internal bond, and hardness more for urea than for phenolic-bonded particleboard. The reduction in tension and compression strength in the plane of the board due to weathering was not as severe as observed for static bending properties. Load-carrying stiffness was also reduced by all weathering treatments. All weathered boards failed to meet the minimum requirement of concentrated-load capacity for this material.

Keywords: Aging, particleboard, urea, phenolic-formaldehyde, weathering, southern pine.

INTRODUCTION

Several investigators have evaluated the basic mechanical properties of particleboard (Gatchell et al. 1966; Geimer et al. 1973; Lehmann 1974; McNatt 1973). However, little information is available on the effects of weathering on strength properties of particleboard decking for factory-built housing. Also, there is a dearth of information on service tests, such as concentrated loading, and on the behavior of this material when exposed to adverse environmental conditions. Hall and Haygreen (1975), reporting on impact strength of weathered particleboard, concluded that strength loss at the construction site due to weathering was negligible. Other investigators (Lehmann 1978; Sell 1978; Shen 1977; Okuma 1976) have all reported adverse strength losses for particleboard exposed to various accelerated weathering regimes.

The purpose of this paper is to evaluate the effects of weathering on the mechanical behavior of phenolic-bonded particleboard decking and urea-bonded particleboard manufactured from a similar furnish.

MATERIALS AND METHODS

Fifty sanded commercial southern pine particleboard panels, 4 by 8 feet by ⅝ inch thick, bonded with urea- and phenol-formaldehyde resins, were randomly selected for evaluation. The phenolic-bonded panels conformed to the requirements of commercial standard CS236-66 for Type 2B2 board and carried the National Particleboard Association 2-72 grademark (NPA 1972). The urea-bonded panels conformed to the Type 1B2 board requirements in CS236-66 (U.S. Department of Commerce 1966) and carried the NPA grademark for such boards.

Twenty-one Type 2B2 and 16 Type 1B2 panels were placed virtually unrestrained on a vertical exterior test fence facing east. After one year, four weath-

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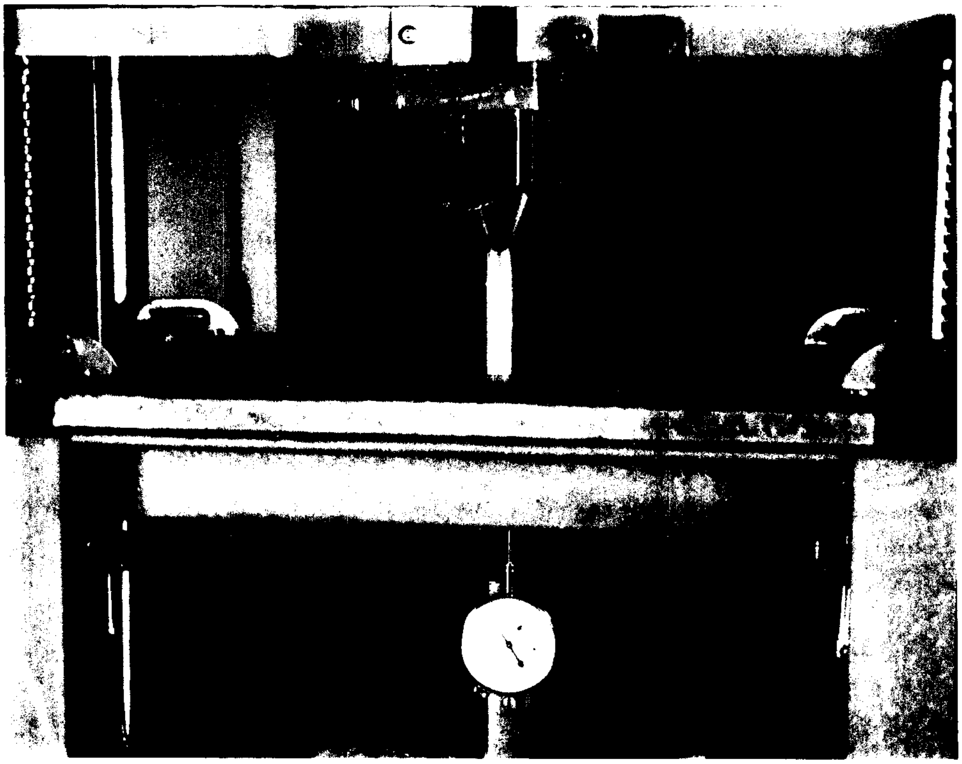

FIG. 1. Test apparatus for concentrated loading. (Note: The front and rear C-clamps have been removed for photographic purposes.)

ered panels per resin type, six unweathered phenolic panels (2B2), and four unweathered urea panels (1B2) were randomly selected for evaluation. All panels were cut to obtain standard test samples based on the cutting diagram for factory-built housing decking given in the NPA Standards (NPA 1971). All tests were performed according to ASTM D-1037-64 (1969) or NPA (1971) standards. Tests included static bending, internal bond, concentrated loading, hardness (modified Janka ball method), and compression and tension parallel to surface. Specimens for the last two tests were cut from large panel remnants.

Bending tests were also performed on samples that had been either accelerated aged (2B2 only), or soaked (1B2 and 2B2). Accelerated aging of unweathered Type 2B2 bending samples was performed according to ASTM D-1037-64 (1969). Samples designated as soaked were immersed in water (22 C) for 24 h prior to testing. All properties were based on the actual sample dimensions at the time of testing.

From a randomly selected unweathered panel per resin type, bending samples were obtained. These samples were divided into groups of ten, and each group was conditioned to a different moisture content to determine the effect of moisture content on bending properties.

All tests, except internal bond, were run using a Tinius Olsen universal testing

TABLE 1. *Static bending test results for aged and unaged urea- and phenolic-bonded particleboard.*[a]

		MOR			FSPL			MOE/1000			Work to prop. limit		
Board type/ treatment	Reps.	Mean, psi	Std. Dev. psi	PSR[b] %	Mean, psi	Std. Dev. psi	PSR %	Mean, psi	Std. Dev. psi	PSR %	Mean, in-lb/ cu-in	Std. Dev. in-lb/ cu-in	PSR %
Phenolic/ unaged	35	2,810	475	—	1340	343	—	507	88.2	—	0.200	0.078	—
Urea/unaged	40	2,400	350	—	970	204	—	462	71.5	—	0.117A	0.042	—
Phenolic/ soaked	24	1,580A	409	44	480A	146	64	249AB	55.1	51	0.052C	0.022	74
Urea/soaked	15	1,700A	435	29	402A	183	59	280A	69.3	39	0.037C	0.030	68
Phenolic/ accelerated aged	21	1,270B	347	55	621	185	54	218BC	63.7	57	0.109AB	0.054	46
Phenolic/ weathered	56	1,240B	360	56	724	190	46	189C	52.1	63	0.157	0.048	22
Urea/ weathered	56	810	200	66	429A	112	56	112	32.4	76	0.095B	0.034	19

[a] Means not followed by a common letter differ significantly one from another at the 0.05 probability level based on Duncan's Multiple Range Test.

[b] PSR—Percent strength based on original strength values.

machine equipped with a deflectometer and chart recorder for automatically recording load and deflection. Internal bond (IB) strength samples were tested on an Instron testing machine equipped with an automatic chart recorder for measuring load and crosshead movement. The concentrated test employed the Tinius Olsen machine augmented with a dial indicator for deflection determination (Fig. 1).

The data were analyzed using analysis of variance. Means were compared at the 5% probability level using the Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

Bending

Static properties.—Unaged phenolic board was superior to urea board in modulus of rupture (MOR), fiber stress at proportional limit (FSPL), modulus of elasticity (MOE), and work to proportional limit (WPL) as shown in Table 1. Soaking the boards for 24 h prior to testing significantly reduced all bending properties for both board types. Also, a larger reduction occurred in bending properties for the phenolic board than for the urea board, i.e. 44% vs 29% in MOR and 51% vs 39% in MOE. With the larger reduction in the initially higher phenolic board properties, no statistical difference between board properties resulted after soaking. Presumably, this larger property reduction was due to the fact that the phenolic board contained no wax to retard moisture adsorption for the short soaking cycle.

Although weathering significantly reduced the bending properties for both board types, the urea-bonded panel was affected the most. In fact, the more durable phenolic panel was 53% stronger and 69% stiffer than the less durable urea panel. The reduction in WPL due to weathering was much less than other bending properties, and averaged 20% for both board types combined. Statistical

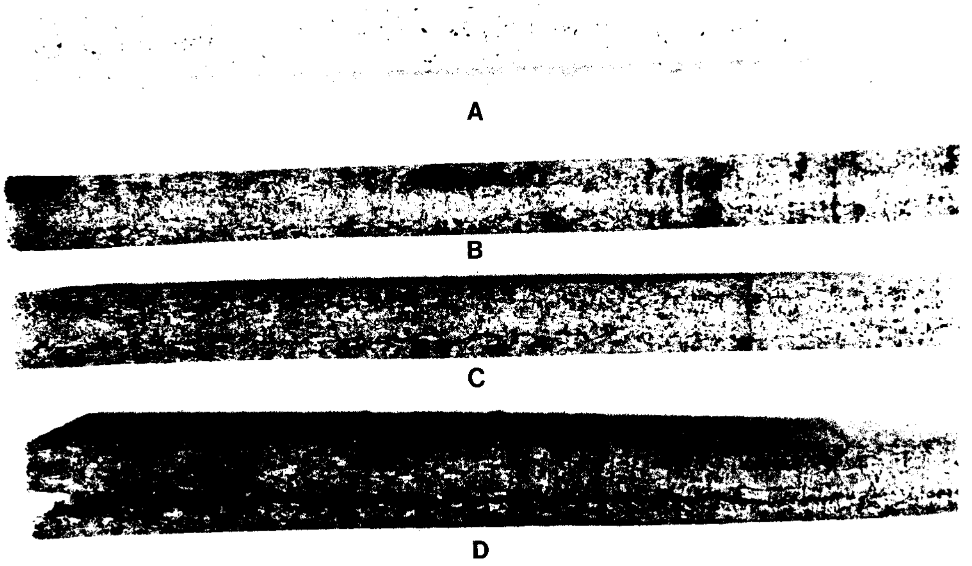

FIG. 2. Typical accelerated-aged phenolic particleboard decking showing (A) unaged, (B) slightly degraded, (C) severely degraded, and (D) very severely degraded samples.

comparison of weathered and accelerated aged phenolic boards indicates they had equivalent MOR and MOE. Therefore, accelerated aging reduces board properties the same as one year exterior exposure. Since the accelerated test can be accomplished quickly, it may prove a reliable barometer for determining the exterior performance of particleboard decking. The effect of accelerated aging on phenolic board is shown in Fig. 2.

Effect of moisture content

For the specimens conditioned to various moisture contents, the sample density and bending properties were obtained. The data were fitted to the model:

$$\hat{Y} = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2 ,$$

where: $\hat{Y}$ = the bending property (MOR or MOE),
x_1 = specimen density, pcf,
x_2 = specimen moisture content, %, and
$b_0 \ldots b_3$ are determined coefficients.

The determined coefficients are given in Table 2.

At constant density, MOR decreased with increasing moisture content (Fig. 3). At densities greater than 50 pcf, the effect of moisture content on MOR was similar for both board types, as shown by the similarity of slopes. At the low density, 44 pcf, moisture content affected the phenolic board properties less than the properties of urea boards.

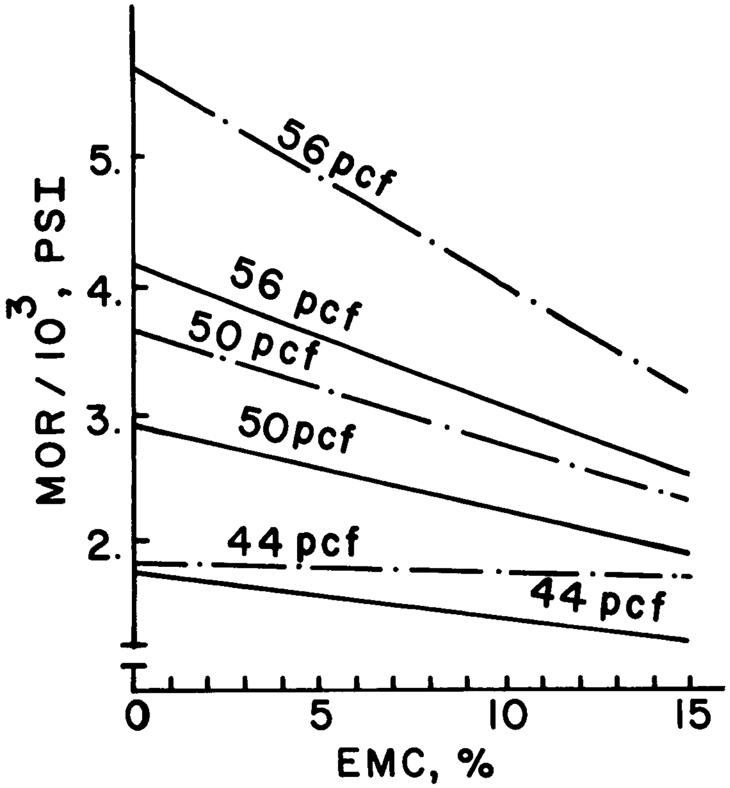

FIG. 3. Modulus of rupture (MOR) versus moisture content (EMC) and density for phenolic (—·—) and urea (—) particleboard decking.

MOE also decreased with increasing moisture content for both board types (Fig. 4). The effect of moisture content on MOE was greater than the corresponding effect on MOR because of the plasticizing effect of water.

The usefulness of the above data comes when one considers the end use of the particleboard decking. As decking, these panels can be subjected to extremes in moisture conditions, especially when poor construction techniques are used. In modular homes constructed with an unheated crawl space, the moisture content can be 20% or higher if insulation and vapor barriers are omitted.

TABLE 2. *Calculated regression coefficients for equation relating bending properties to moisture content and density.*

	2B2		1B2	
Coefficient	MOR	MOE	MOR	MOE
b_0	−13,047.3	−2,582,226.	−7,715.8	−1,539,537.
b_1	334.5	66,173.	212.1	43,053.
b_2	607.0	167,841.	303.6	104,298.
b_3	−13.9	−3,834.	−7.4	−2,461.
r	0.86	0.93	0.74	0.77

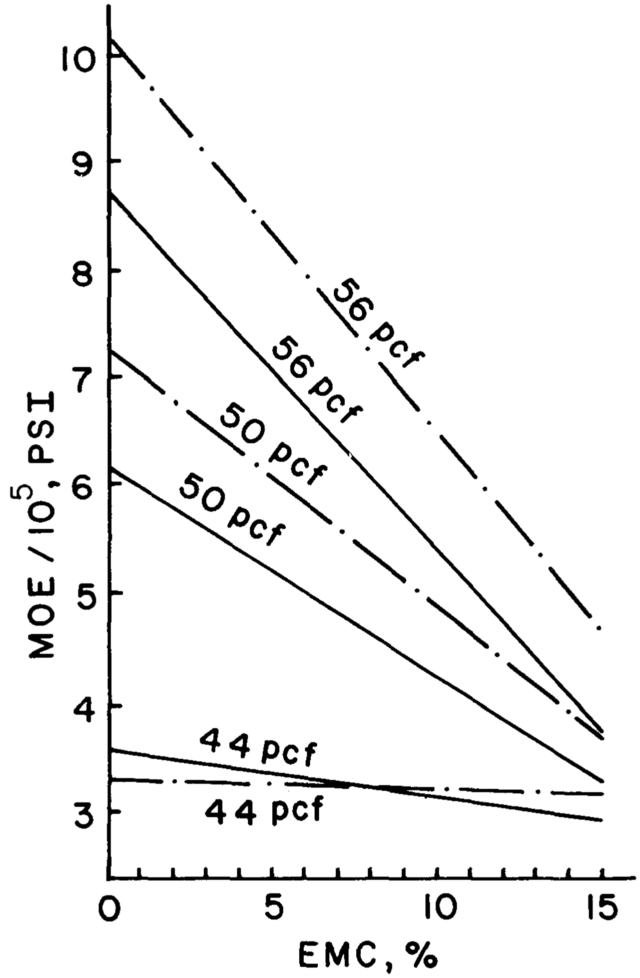

FIG. 4. Modulus of elasticity (MOE) versus moisture content (EMC) and density for phenolic (— · —) and urea (—) particleboard decking.

If the MOR and MOE values from soaked boards are taken as the limiting values (Table 1), the corresponding reductions in static strength might well be encountered in actual use.

Effect of aging and moisture content on engineering properties

The effects of the treatments (soaked, accelerated aged, and weathered) and relative humidity levels on engineering properties are summarized in Table 3. Load-carrying capacity (maximum load) and bending stiffness (EI) are expressed as a percentage of the unaged 50% RH conditioned specimens. Figure 5 presents the data graphically as a function of the conditioning exposures.

In engineering design both load-carrying capacity and bending stiffness must be considered. Assuming that the material has sufficient strength and elastic properties, then the engineering properties become important when design specifications are considered.

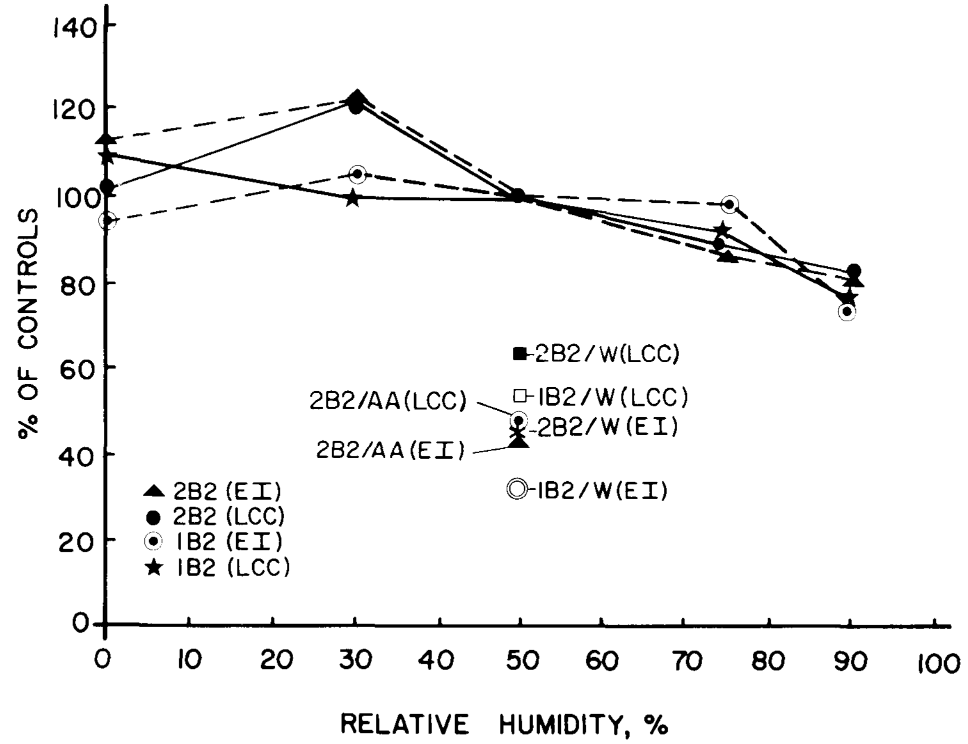

FIG. 5. Load-carrying capacity (LCC) and bending stiffness (EI) expressed as a percentage of the test value at 50% relative humidity for various exposure conditions. (Points for weathered board (W) and accelerated aged board (AA) are included for comparison.)

Load-carrying capacity and bending stiffness were not severely affected below 50% relative humidity. For phenolic board the effect of relative humidity on bending stiffness and load-carrying capacity was linear above 50% relative humidity. Urea board was more severely affected at 90% relative humidity. This is thought to be due to the breakdown in the protection afforded by the wax that was included in this board. The result would be a loss of glue bond quality through loss of hydrogen bonding between the resin and wood, and, to a much lesser extent, bond breakdown through hydrolytic action. Changes in load-carrying capacity and bending stiffness in the 0 to 50% range are of little value in engineering design, since most particleboard will be in the range from 6 to 10% moisture content when installed in a structure. This corresponds to a relative humidity of up to 75%. At higher relative humidities, adjustments to design data will be necessary to offset the decrease in engineering properties. In the present study, reductions in load-carrying capacity of 17% and 24% for phenolic and urea board, respectively, were observed for board conditioned at 90% relative humidity. The corresponding reductions for soaked board were 58% and 54% (Table 3).

The reduction in load-carrying capacity and bending stiffness due to weathering for both board types was greater than those found at the high relative humidity condition for unaged board. Weathered phenolic decking had only 62% of the

TABLE 3. *Effect of conditioning on load carrying capacity (LOC) lbs, and bending stiffness (EI) in²-lbs, expressed as a percent of the controls. (Values for the maximum load and EI are in parentheses.)*

Board type/ treatment[a]	0% RH		30% RH		50% RH		75% RH		90% RH	
	LCC	EI	LCC	EI	LCC	EI	LCC	EI	LCC	EI
Phenolic/ unaged	102 (70)	112 (33,900)	122 (83)	122 (36,900)	100 (68)	100 (30,200)	89 (61)	109 (33,000)	83 (57)	92 (27,800)
Urea/ unaged	109 (57)	95 (27,900)	101 (52)	105 (31,000)	100 (52)	100 (29,500)	92 (48)	105 (31,000)	76 (40)	75 (22,200)
Phenolic/ soaked[a]					42 (29)	62 (18,800)				
Urea/ soaked					46 (24)	69 (20,700)				
Phenolic/ accelerated aged					47 (32)	43 (13,100)				
Phenolic/ weathered					62 (43)	46 (13,900)				
Urea/ weathered					54 (28)	32 (9,600)				

[a] Soaked values based on MC at test rather than EMC at 50% RH.

load-carrying capacity and 46% of the bending stiffness of unaged board. Accelerated aging of phenolic board caused a reduction in bending stiffness very near that caused by weathering. Load-carrying capacity was less severely affected by accelerated aging.

Internal bond (IB) strength

Internal bond values of unaged phenolic and urea boards were equivalent (Table 4). Weathering caused a significant reduction in IB strength for both board types, 65% for the phenolic board and 82% for the urea board. The value for weathered urea board was well under the minimum property value (60 psi), while the phenolic board had 85% of the minimum. Also, urea boards had approximately half the IB strength of phenolic board after weathering. These results are consistent with what is known about the long-term durability of these resins.

TABLE 4. *Internal bond and hardness properties for weathered and unweathered phenolic and urea-bonded particleboard.*[a]

	Internal bond				Hardness			
Board type/ treatment	Reps.	Strength psi	Std. Dev. psi	Reduction %	Reps.	Strength lbs.	Std. Dev. lbs.	Reduction %
Phenolic	30	144A	27	—	30	1,584A	220	—
Phenolic/ weathered	18	51	29	65	20	1,125	208	29
Urea	20	146A	23	—	20	1,569A	141	—
Urea/ weathered	20	27	23	82	20	998	187	36

[a] Means not followed by a common letter differ significantly from one another at the 0.05 probability level.

TABLE 5. *Compression and tension parallel to surface properties for weathered and unweathered urea- and phenolic-bonded particleboard.*

Board type/ treatment	Reps.	Maximum strength[a] psi	Std. Dev. psi	PSR[b] %	FSPL[a] psi	Std. Dev. psi	PSR[b] %	MOE[a] psi	Std. Dev. psi	PSR[b] %
					Compression					
Phenolic	16	2,350A	350	—	1070 A	256	—	732,500	456,700	—
Phenolic/ weathered	16	1,750B	250	26	940 A	300	12*[c]	274,600A	153,900	63
Urea	15	2,220A	200	—	960 A	320	—	344,800A	169,100	—
Urea/ weathered	16	1,680B	180	24	730	230	24	269,600A	141,600	22*
					Tension					
Phenolic	16	1,570	320	—	600 A	220	—	610,700A	233,200	—
Phenolic/ weathered	16	1,150A	280	28	560 AB	130	7*	245,500B	66,700	60
Urea	16	1,240A	140	—	510 AB	140	—	568,200A	280,600	—
Urea/ weathered	16	870	160	33	450 B	110	11*	325,300B	138,700	43

[a] Means not followed by a common letter differ significantly at the 0.05 probability level.
[b] PSR—Percent strength reduction based on original strength values.
[c] * Not a significant reduction.

Hardness

Hardness, a measure of the resistance to indentation, is important in decking products to be used as combination subfloor/underlayment in modular and mobile homes. It is doubtful that, in such uses, particleboard will be subjected to the adverse exterior weathering conditions used here. However, condensation problems could lead to some of the same effects, namely a reduction in board integrity due to abnormal thickness swelling.

The same trends due to weathering that were found for IB strength were found for hardness values. Reductions of 36% and 29% for urea and phenolic board, respectively, were observed (Table 5). Both weathered boards met the optional hardness requirement (500 pounds), as specified in the standard (U.S. Department of Commerce 1966).

Tension and compression parallel to surface

Maximum strength, FSPL, and MOE in tension and compression parallel to the surface of the board are summarized for both board types in Table 5. Maximum strength was significantly reduced ($P = 0.05$) because of weathering by similar amounts for both board types, averaging 25% in compression and 28% in tension. Thus, the reduction in maximum tension and compression strength is only half the 66% reduction observed for MOR in bending. The explanation is partly due to the density variation through the board thickness. The low density surfaces of weathered board, particularly for Type 1B2, result in a severe reduction in MOR. This effect is not as detrimental to tests in the plane of the board where the intensity of stress is more uniform through the board thickness.

Fiber stress at proportional limit was less affected by weathering than ultimate strength. The reduction was only significant for Type 1B2 in compression. Many

TABLE 6. *Concentrated load properties for weathered and unweathered urea- and phenolic particleboard.*

Board type	Reps.	Deflection[a] @ 200#, in.	Std. Dev.	Max. load[a] lbs.	Std. Dev.	% Reduction
Phenolic	6	0.045A	.005	893	56	—
Phenolic/ weathered	4	0.122	.025	445A	69	50.2
Urea	4	0.052A	.004	792	53	—
Urea/ weathered	4	0.157	.012	401A	30	49.4

[a] Means not followed by a common letter differ significantly one from another at the 0.05 probability level.

of the compression specimens exhibited a nonlinear behavior, particularly for weathered boards. For this reason, the reported FSPL and MOE in compression should be regarded as estimated values. The 21.8% reduction in MOE for weathered urea boards was not significant due to large variations in the data. The percent reduction in MOE in tension, 59.8 for phenolic and 42.7 for urea boards, were both significant.

Concentrated loading

Both unweathered board types met the minimum requirements for maximum concentrated load-carrying capacity (600 pounds) and 200 pounds deflection limitation (0.06 inches), as specified in NPA 2-72 (1972). Statistically, the deflections at 200 pounds were the same for the unaged boards (average of 0.05 inches) and not equal after weathering (Table 6). The maximum load results were the opposite, i.e., unequal before weathering but equivalent after weathering. In all cases, the phenolic board had a higher average load and lower average deflection than the urea board.

After weathering, both board types failed to meet the standards.

SUMMARY AND CONCLUSIONS

The relationships between weathering and certain mechanical properties of phenolic and urea particleboard decking are summarized in the following statements.

(1) Weathering reduced the bending properties (MOR, FSPL, and MOE) more for urea than for phenolic board.

(2) Wax appears to have only a short-term protective effect on board durability.

(3) Accelerated aging yielded bending results similar to those found with one year's exterior exposure of phenolic board, thus indicating its potential use for measuring exterior durability.

(4) In terms of engineering design, corrections to design criteria should be applied to account for reductions in MOR, MOE, load-carrying capacity, and bending stiffness at relative humidities greater than 75%.

(5) Weathering significantly reduced IB strength and hardness for both board types with urea board being more severely affected. This reduction appeared to be due to change in thickness swelling and loss of gluebond quality.

(6) Tension and compression strength in the plane of the board were not as severely affected by weathering as bending strength. Stress at the proportional

limit in tension was only slightly reduced by weathering. Stress-strain diagrams from compression tests of weathered boards were nonlinear.

(7) Weathering caused reductions in deflection at 200 pounds and maximum concentrated load for both board types. Weathered boards failed to meet the minimum concentrated load property requirements outlined in the standards (U.S. Department of Commerce 1966).

By combining the information herein with information on load duration, etc., reasonable design criteria can be developed for particleboard decking. This study does point out that the consequence of exposure to adverse environments is important when structural applications are being considered.

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