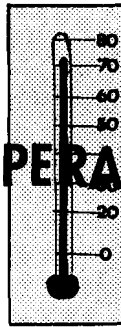


How Durable Is Particleboard?

Part II

The Effect of TEMPERATURE and Humidity



IN 1958, THE FOREST PRODUCTS Laboratory embarked upon a long-term study of particleboard durability. Eight sets of flake-type Douglas-fir boards that varied in density and type and amount of binder were fabricated at the Laboratory and matched specimens of each are being exposed to outdoor weather conditions and to various laboratory-controlled temperature and relative humidity conditions. Matched specimens were also given the ASTM Accelerated Aging Exposure (D1037-60T) the results of which were presented in a previous paper¹ along with the results of outdoor exposure after 3 years. In this paper, the results of exposure to the laboratory-controlled conditions after 2 years are presented.

It was recognized when this study was initiated that exterior exposure conditions include many factors that may cause deterioration of a wood-base panel product such as particleboard. Some of these factors are rain and dew, relative humidity, sunlight, wind, temperature variations from below zero to perhaps over 150° F. on the surface, decay and insect damage. It was also known that the ASTM Accelerated Aging Exposure, which is intended to rapidly approximate the effects of many years of exterior exposure, makes use of temperatures of 100° and 210° F. and may not accurately predict the long-term durability of all wood and wood-base products, especially products containing adhesives or binders that are adversely affected by temperatures of 200° to 210° F.

Therefore it was planned to isolate two factors the may cause exterior deterioration — temperature and humidity — and to study these factors

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

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Abstract

Specimens of Douglas-fir flakeboards of various densities and containing different types and amounts of binders were tested after exposure for varying periods of time to four different laboratory-controlled conditions. The results were compared with results of tests made on matching specimens that were exposed either outdoors for 3 years or to the ASTM Accelerated Aging Exposure. The mechanisms of deterioration are discussed.

separately within the limits of normal exterior exposure conditions without the confounding effects of sunlight and other radiation, rain, wind, and biological deterioration. Humidity and temperature effects consequently were studied by placing particleboard specimens in controlled constant and cyclic temperature and humidity conditions and determining the amount of deterioration that took place after appropriate intervals of time. In this paper, the deteriorations during laboratory-controlled exposures are examined and compared with the results from the outdoor exposures and the ASTM Accelerated Aging Exposure that were reported in the previous paper.²

Particleboards Used

A description of the binder and fabricating variables employed in making the eight sets of flake-type Douglas-fir particleboards at the Laboratory is given in table 1. The variables were selected to provide a broad range of board types that fall within the limits of boards being fabricated in typical commercial particleboard manufacturing operations. Details as to the actual fabrication processes used were given in the previous paper.²

The boards were not sanded. The size of the specimens used in the outdoor exposures and ASTM Accelerated Aging Exposure was 7-316 by 13 inches, while the size of the specimens used in the laboratory-controlled exposures was 2 by 13 inches.

Exposure Conditions

The choice of laboratory-controlled exposures was based largely on previous Laboratory experience with such exposures in the evaluation of conventional wood glues, particularly in plywood construction.³ These

³Significance of these various exposure conditions is given in Durability of Water-Resistant Woodworking Glues. Forest Products Laboratory Report No. 1530. 1956.

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;
- and (4) A repeating cyclic exposure for 1 week at 80° F. and 90 percent relative humidity; followed by 1 week at 158° F. and 20 percent relative humidity.

Exposure 4 was devised for the present study to combine the alternate effects of swelling and shrinking by high humidity and elevated temperature.

Using a table of random numbers, the 2- by 13-inch specimens were assigned to these four exposures. These were divided so that the amount of deterioration for each board variable could be determined on the basis of three specimens each for exposures 1 and 2 after periods of 1 and 2 years and for exposures 3 and 4 after periods of 3, 6, 12, 18, and 24 months.

Determination of Deterioration

After the specimens had been reconditioned to approximate equilibrium at 80° F., 65 percent relative humidity, the following physical and mechanical properties were evaluated: Percent of thickness swelling, internal

bond strength, shear strength in the center of the board, modulus of elasticity, and modulus of rupture in flexure. The procedures used in preparing and testing were those specified in ASTM D1037-60T, which were essentially the same as described in the previous paper.² The results were then compared with those obtained on control specimens, tested at the outset of the study. Three flexure tests and four shear and tension tests were made for each board variable.

Results Obtained

Figures 1 through 4 show the deterioration in the mechanical properties of each of the eight board variables after each of the four laboratory-controlled exposures. In Figure 5, these values are averaged for all of the eight board variables after each of the four exposures so that the general effect of time in the four exposures could be visualized. Figure 6 presents the percentage of thickness increase that occurred in the specimens during each of the four exposures.

The 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 caused much more thickness increase and strength loss than did constant exposure at either 80° F.

and 90 percent relative humidity or at 158° F. and 20 percent relative humidity (Figs. 5 and 6).

The continuous exposure at 158° F. and 20 percent relative humidity for 2 years had little effect on the strength and thickness swelling of the particleboards bonded with phenolic resin or melamine-fortified urea resin (Figs. 2 and 6). In the case of boards bonded with urea-resin binders, which are known to be quite sensitive to elevated temperatures, the continuous exposure to 158° F. and 20 percent relative humidity generally reduced the strengths of the specimens significantly but had no noticeable effect on the thickness.

During the continuous exposure at 80° F. and 90 percent relative humidity, all particleboards lost a significant amount of strength and increased in thickness during the first year of exposure (Figs. 3 and 6). Some additional strength loss and swelling occurred during the second year in boards bonded with 4 percent urea resin but did not occur in boards bonded with 8 percent urea resin, phenolic resin, or melamine-fortified urea resin.

During the continuous exposure at 80° F. and 65 percent relative humidity — the same conditions in which the specimens were equalized before

Table 1. - BINDER AND BONDING VARIABLES EMPLOYED IN FABRICATION OF VARIOUS PARTICLEBOARDS BEING USED IN DURABILITY STUDY AT U.S. FOREST PRODUCTS LABORATORY

Board No.	Type	Binder ¹		Wax ²	Moisture content ³	Closing time ⁴	Cure temperature	Cure time ⁵	Density ⁶
		Amount	Calculated spread on flake surfaces						
		Percent	Lb. per 1,000 sq. ft.	Percent	Percent	Sec.	°F.	Min.	Lb. per cu. ft.
1	Urea	4	0.5		10	45	310	15	34.3
2	do	4	.5		10	55	310	15	42.0
3	do	4	.5	1	10	60	310	15	42.8
4	Urea	2							
	melamine	2	.5		10	45	310	15	33.9
5	Urea	8	1.0		10	45	310	15	35.5
6	Phenolic	3	.38		13	45	350	15	34.1
7	do	3	.38		13	60	350	15	43.4
8	do	6	.76		13	45	350	15	34.8

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

²Percent of wax solids was based on the weight of dry wood. The wax employed was an emulsion type, which was applied by spray after the application of binder.

³Moisture content of the flakes at press time. This was obtained by adding the required amount of water to the binder solution.

⁴Closing time is the time between insertion of the panel in the press to closing of the press to 0.5-inch-thick stops.

⁵Total time in press after closing to stops.

⁶Density based on the weight and volume at equilibrium at a temperature of 80° F. and 65 percent relative humidity.

testing — no deterioration appeared to take place during the first 2 years (Figs. 4 and 6). This is not surprising because the conditions were relatively mild, no significant moisture content changes occurred after the control tests were made, and the exposure period was quite short.

Board variables 2, 3, and 7 were over 40 pounds per cubic foot in density, while board variables 1, 4, 5, 6, and 8 ranged from 33 to 37 pounds per cubic foot in density. Figures 1 through 6 show that; while density influenced the initial strength, density differences had little effect on the durability of the specimens in the laboratory-controlled exposures.

Board variable 3 contained 1 percent wax emulsion while board variable 2 contained no wax. The presence of the wax had no noticeable effect on the performance of the specimens in these exposures.

Discussion of Results

The results of major interest in these laboratory-controlled exposures are: (1) The repeating cyclic exposure was a very severe exposure; (2) the exposure to 90 percent relative humidity caused a significant loss in strength during the first year of exposure but little additional loss in strength during the second year of exposure; and (3) in specimens that were bonded with phenolic resin, the strength loss that occurred during exposure was always accompanied by an increase in thickness, but in specimens bonded with urea resin and exposed to 158° F. temperatures, the strength loss that took place was not associated with a thickness increase.

Three major factors and the interaction of these factors are believed to have caused the losses in strength and the thickness increases that occurred during the laboratory-controlled exposures — springback, deterioration of the adhesive, and failure due to shrinking and swelling stresses is a result of moisture content changes in the wood. These same factors were undoubtedly involved in the deterioration of the same particleboard being exposed outdoors.

Springback

A particleboard is essentially a series of small wood particles that are compressed and bonded together with a binder. When a particleboard is exposed to high relative humidity for the first time after pressing, the swelling in these wood particles that takes place is not only the normal swelling of the wood but also springback, defined in this paper as recovery from the compression set that

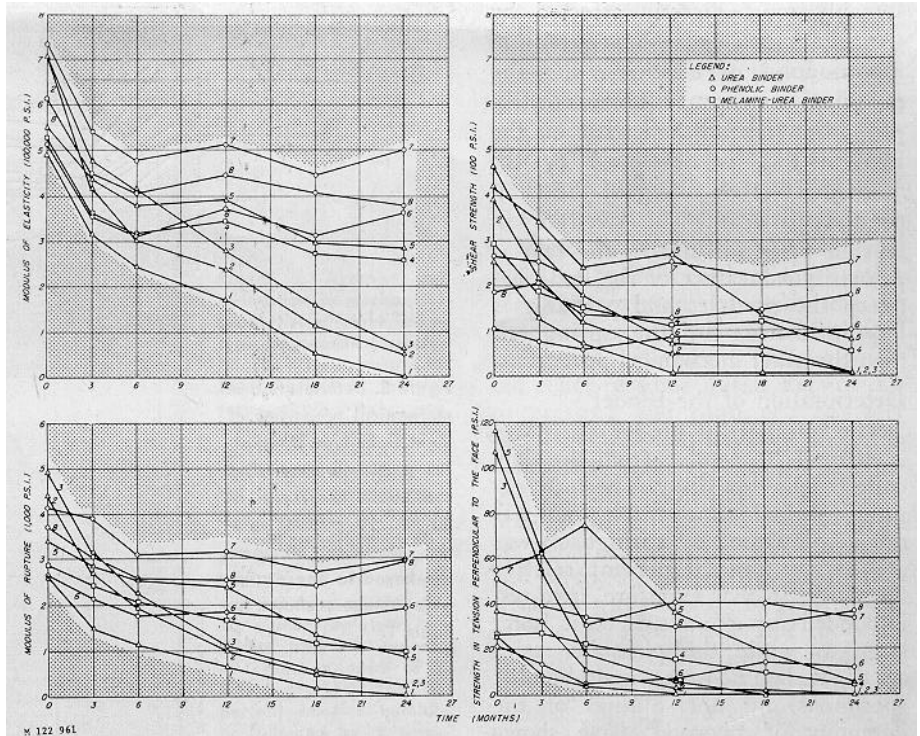


Figure 1. Deterioration in mechanical properties of eight flake-type Douglas-fir particleboards after repeated cyclic exposures of 1 week at 158° F., 20 percent relative humidity followed by 1 week at 80° F., 90 percent relative humidity. Numbers are keyed to board variable numbers shown in Table 1.

is induced during the pressing operation. The magnitude of this springback in excess of the normal swelling of the wood is undoubtedly related to both the amount of compression that is induced in the board during manufacture and to the pressing conditions. The amount and direction of swelling tendency in the individual particles in the board varies from

particle to particle due to differences in density, grain orientation, and nonuniform compression.

The springback that occurred in the specimens subjected to the different exposures very likely caused a reduction in strength because of a lowering of board density. The mechanical properties that were pre-

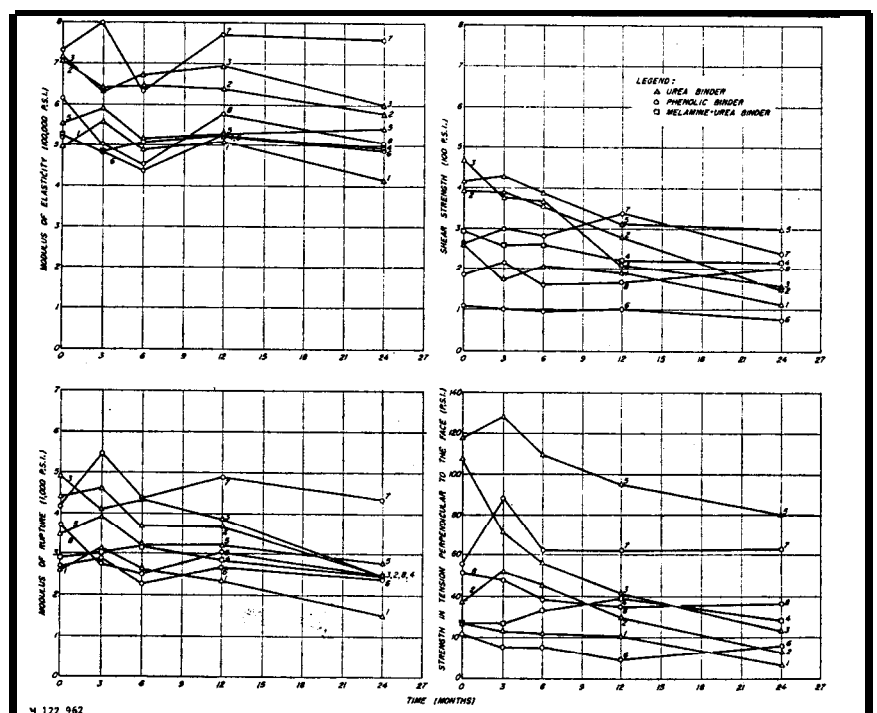


Figure 2. Deterioration in mechanical properties of eight flake-type particleboards after continuous exposure at 158° F., 20 percent relative humidity. Numbers are keyed to board variable numbers shown in Table 1.

sumably most directly affected by springback were the shear strength, the modulus of elasticity, and the modulus of rupture because these properties depend somewhat on the strength that is developed by the mechanical interlocking of the compressed particles. The strength in tension perpendicular to the face is primarily a measure of the bond between the particles and probably is less influenced by the springback than the other mechanical properties.

Deterioration of the Binder

The question of binder durability is difficult to resolve from the data collected in this study. The only exposure in which strength loss was not accompanied by springback was at 158° F. and 20 percent relative humidity. In that exposure, urea-resin-bonded specimens lost some strength while the phenolic resin-bonded specimens did not. Studies of the durability of plywood³ have shown that urea resins are sensitive to exposure to temperatures of 158° F. but that phenolic resins and melamine resins are not generally harmed by such temperatures. It appeared that the urea resin that is being used as a binder in this study also slowly deteriorated during exposure to moderately high temperatures. The possibility that this deterioration takes

Figure 3. Deterioration in mechanical properties of eight flake-type Douglas-fir particleboards after continuous exposure at 80° F., 90 percent relative humidity. Numbers are keyed to board variable numbers shown in Table 1.

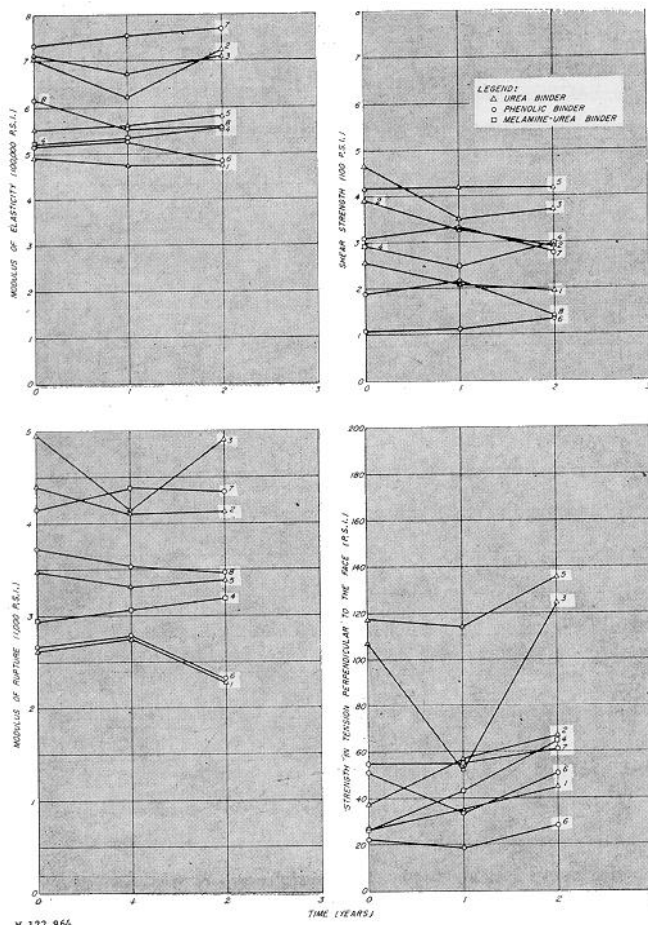
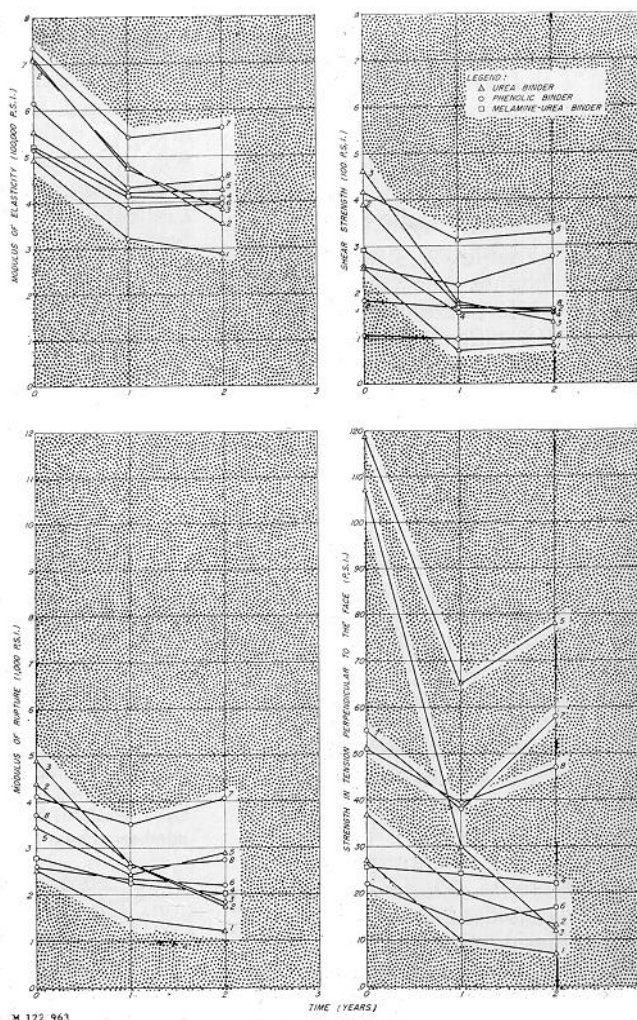


Figure 4. Deterioration in mechanical properties of eight flake-type Douglas-fir particleboards after continuous exposure to 80° F., 65 percent relative humidity. Numbers are keyed to board variable numbers shown in Table 1.

place during normal exterior exposure is discussed later.

Shrinking and Swelling Stresses

In cyclic exposures, during and after the time when springback is taking place, the constantly changing moisture content of the particleboard will create alternating shrinking and swelling stresses on the glue lines between adjacent particles as well as in the particles themselves. The magnitude of these stresses and their possible effects on the board depend on the ability of the binder to resist stresses and the ability of the wood to creep, thus reducing the magnitude of the stress on the binder through plastic flow. The weakening of the bonds between particles due to the normal swelling and shrinking stresses of the wood particles is presumably a long-term effect, which would diminish slowly with time. The rate at which the boards would deteriorate due to reversible stresses for any specific combination of binder, species, and particle type would depend on the number of cycles of moisture content change and the magnitude of the moisture-content changes.

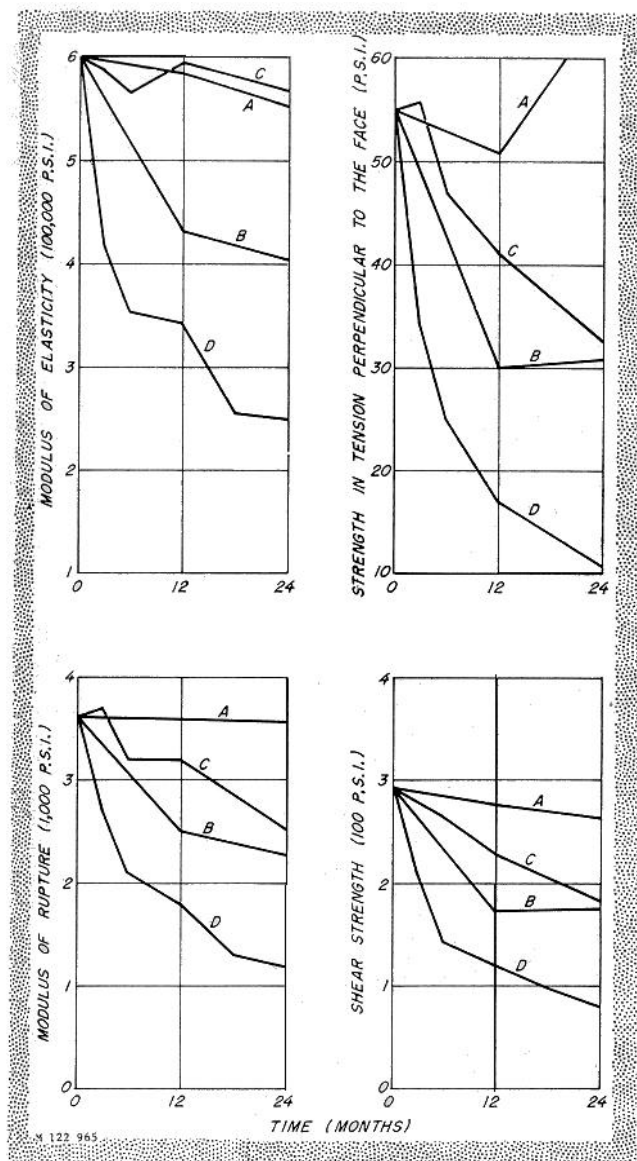


Figure 5. Average deterioration in mechanical properties of eight flake-type Douglas-fir particleboards after exposure to four different laboratory-controlled exposures which are coded on the curves as follows: A - continuous exoosure at 80° F., 65 percent relative humidity; B - continuous exposure to 80° F., 90 percent relative humidity; C - continuous exposure at 158° F., 20 percent relative humidity; and D - repeated cyclic exposure of 1 week at 158° F., 20 percent relative humidity followed by 1 week at 80° F., 90 percent relative humidity.

The data from the repeating cyclic exposure (Fig. 1) generally indicated that mechanical failure due to repeated stressing of the binder in the specimens that were bonded with phenolic resin was not a major factor because the repeated cycling of these specimens from low moisture content to high moisture content conditions did not cause any noticeable deterioration during the last 18 months of the 2-year exposure.

The continued deterioration of the urea-resin-bonded specimens in this cyclic exposure may have resulted from the inability of the urea resin to withstand these stresses, but a more likely explanation is that the urea resin deteriorated, and this was at least partially due to the temperature and humidity conditions that were involved in the exposure.

Interaction of Deteriorating Factors

In flake-type platen-pressed particleboards, such as are being used in this study, the swelling that is re-

lated to springback was primarily in the thickness direction. However, it is likely that swelling in the length and width of the panels was reduced somewhat because of the recovery from compression.

Thus in the first exposure to high humidity, the occurrence of springback in the thickness direction reduced the transverse swelling stresses on the glue line to a lower level than would have resulted without springback.

In the case of the continuous exposure to 80° F. and 90 percent relative humidity (Fig. 3), the board specimens were first conditioned to 65 percent relative humidity and then moved into the 90 percent relative humidity conditions. The moisture content undoubtedly increased, and both springback and normal swelling too place at the beginning of the exposure. This initial springback probably had detrimental effects on the quality of the particleboard. These effects were measured

after the first year of exposure. However, there were no increases in moisture content after the first year, and only slight deterioration occurred from the first to the second year. The deterioration during the second year was probably due to deterioration in the urea adhesive.

With the repeating cyclic exposure, the particle boards changed moisture content many times during the first and second year. This repeated change in moisture content permitted relief of some initial stresses due to pressing and continued recovery of the compression set (Fig. 6). After 6 months of the repeating cyclic exposure, the specimens that were bonded with phenolic resin remained relatively constant in thickness and strength, indicating that binder strength was adequate to resist stresses due to springback and moisture content change. The urea-resin-bonded particleboard continued to deteriorate during the entire 2-year repeating cyclic exposure period. This was probably due to the effect of heat and moisture on the urea resin, perhaps accelerated by the mechanical stressing.

A comparison of Figures 1 and 6 reveals that urea-resin-bonded specimens show much more total springback and strength loss than do phenolic-resin-bonded specimens of the same density and approximately the same resin content. Since the specimens were almost identical in particle geometry and fabrication detail, however, the springback and swelling stress potential in all specimens of the same binder content and density should be about equal. Therefore, the phenolic resin (board variable 6 with 3 percent resin) appears to be better able to resist stresses than is the urea resin (board variable 1 with 4 percent resin) probably because the urea resin deteriorated.

Figures 1 and 6 also show that the boards with higher percentages of binder — board variable 5, which has 8 percent urea-resin binder, and board variable 8, which has 6 percent phenolic-resin binder — had less total springback and strength loss in the repeating cyclic exposure than did boards of a similar density and binder type but which had less binder (board variables 1 and 7). This probably occurred because the additional binder increased the resistance of the board to springback and differential shrinkage stresses.

It appears that every particleboard of a given density had a fixed springback potential in the cyclic exposure. The binder tended to reduce the springback, and the amount of

this reduction depended on both the amount and durability of the binder. In the repeating cycle exposures, the springback of the articles continued until the magnitude of the swelling stress was reduced to a level where the binder could restrain the swelling. If the binder was durable, the springback stopped at some point below the maximum. However, if the binder deteriorated (such as the urea resin appeared to be doing in this study), the springback and deterioration of the binder continued until the particleboard reached its maximum springback thickness.

From a comparison of the results of these laboratory-controlled exposures with those of the exterior weathering and ASTM Accelerated Aging Exposure reported previously in the paper,² it would appear that

there was rather good agreement between 3 years of weathering and the 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. The ASTM Accelerated Aging Exposure test caused about the same amount of deterioration in the phenolic-bonded boards as did 3 years of weathering. The ASTM exposure was much more severe on the urea- and melamine-urea bonded boards, however, than was 3 years of weathering.

It is believed that the amount of springback, the durability of the binder, and the swelling and shrinking stresses that occurred during moisture content changes significantly influenced the relative performance of all the boards during the outdoor,

ASTM Accelerated Aging, and the laboratory-controlled exposures.

Addition of wax improved performance of boards to weathering, as did painting, primarily by reducing liquid water pickup that could result in excessive springback and swelling and shrinkage stresses.^{4,5} Such wax was ineffective under conditions where moisture vapor changes were involved.

Conclusions

Exposure of various laboratory-made particleboards in laboratory-controlled conditions showed that a 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 for 2 years caused much more deterioration than continuous exposure did at either of the above conditions.

It appears that the particleboard deterioration takes place because of the combined effects of springback from compression set, deterioration of the binder, and differential shrinkage of the adjacent particles during moisture content change. The phenolic resin-bonded boards were more durable than urea resin-bonded boards, apparently because the phenolic resin binder did not deteriorate in conditions of high temperature and high humidity as readily as did the urea resin binder that was used in this study.

Wax did not improve the performance of the specimens that were bonded with 4 percent urea resin in these laboratory-controlled conditions probably because wax is not effective as a water vapor repellent.

Increasing the resin content from 3 to 6 percent with phenolic resin and from 4 to 8 percent with urea resin definitely improved the performance of the specimens, apparently because the extra binder increased the resistance of the board to springback and differential shrinkage stresses.

⁴Olson, D. E. Studies to Improve the Dimensional Stability of Particle Board. Masters Thesis. University of Wisconsin, Dept. of Chemical Engineering. July 1960.

⁵Talbot, J. W., and Maloney, T. M. Forest Prod. Jour. Vol. VII. No. 10, p. 395. October 1957.

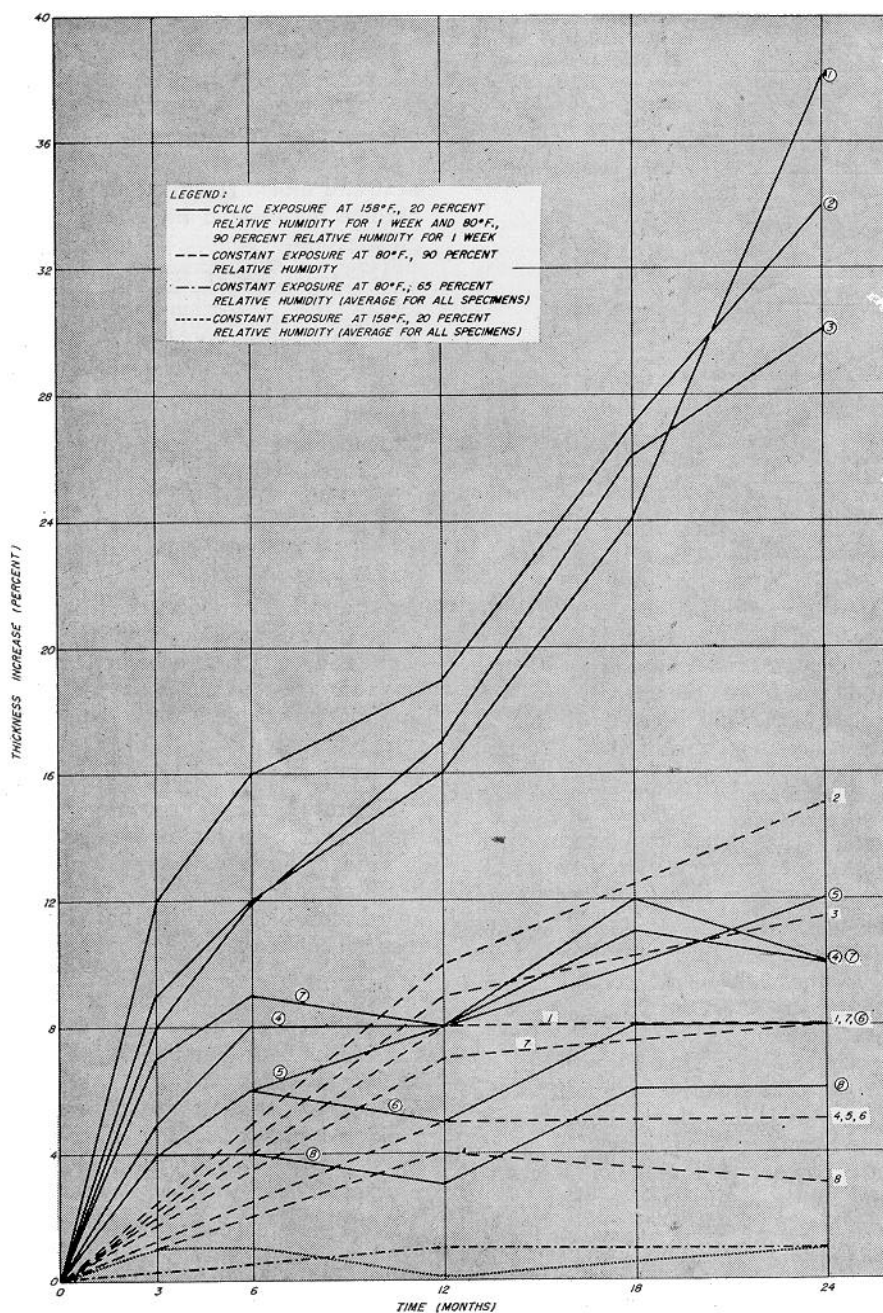


Figure 6. Thickness increases in eight flake type Douglas-fir particleboards after four different laboratory-controlled exposures. Numbers, both circled and not circled, are keyed to board variable numbers shown in Table 1 (1, 2, 3, and 5 being made with a urea binder, 4 with a melamine-urea binder, and 6, 7, and 8 with a phenolic binder).