Retarding Dimensional Changes of Particle Boards

by

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ABSTRACT

A survey of pertinent literature was made and interviews with manufacturers of particle board and hardboard were conducted to review methods of improving dimensional stability of composition boards. Particle board was selected for study. The following procedures were treated as variables in the study: preparing normally with and without sizing; increasing resin contents; pressing at high temperatures; use of impregnating phenolic resin; heating chips before pressing; treating with polyethylene glycol; treating with formaldehyde vapor; treating with tempering oil; controlling pH with phenol-bound boards; and extending urea binder with blood.

Panels were made with urea or phenolic binders following ordinary commercial pressing conditions as far as possible. Specimens were tested for strength and dimensional stability; least significant differences were determined for the most important results. Specimens from each combination meeting selected specifications were exposed on a rack outside. These will be tested periodically for stability and strength.

Every treatment contained some experimental combination of variable factors that produced boards meeting minimal specifications. Several treatments were significantly as good (by statistical analysis) as normal treatment. In almost every test, however, only boards with high contents of resin were significantly better than the norm. Those boards pressed at high temperature were as good as, or slightly better than, normal boards, although not significantly so.

ACKNOWLEDGMENTS

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INTRODUCTION

In attempt to improve the dimensional stability of particle board, variations and innovations in manufacturing variables were studied.

Because particle boards are composed mainly of wood, they react as wood does with changes in moisture content. Unlike wood, however, practically every phase of manufacturing affects final stability of the product. Some of the most influential factors are size and shape of particles, amounts and efficiency of additives, moisture content, and time, temperature, and pressure in the hot-pressing cycle.

Interviews with producers of composition board, research organizations, and manufacturers of adhesives and a survey of pertinent literature indicated the following methods had showed promise in imparting stability to wood or wood products: coating the structure with water-repellent chemicals; depositing bulking agents within the cell wall; chemically modifying at least one of the wood components; forming cross-links between the structural units; and other methods such as control of pH, changing the resin content, and use of modified resins.

There appeared to be three approaches to the study of dimensional instability:

1. Attempt to determine the exact nature of dimensional change.
2. Investigate means of reducing dimensional change.
3. Correlate laboratory testing methods for dimensional stability with conditions of outside exposure or in-use situations.

Based on the surveys, decision was to focus this study on the two latter approaches; results from long-continued outside exposure will be reported when available. Treatments selected for the study were those that could be applied either to the particles before spraying the resin binder, or to the mat of particles during the hot-pressing cycle, while reserving methods of post-treating completed boards for possible research later.
EXPERIMENTAL PROCEDURE

Particle board was produced in the laboratory under controlled conditions involving different experimental combinations of treatments. The products were tested for dimensional stability and strength according to treatment.

The experiment was designed for statistical analysis, so that any treatment could be compared with another. There were 44 different combinations of treatments (Table 1), and 3 replications were made for each combination, resulting in a total sample of 132 boards.

The first batch of particles from Douglas-fir planer shavings had been hammer-milled, screened, and dried at the mill. The second batch, obtained later, was of similar shavings that had been prepared undried to allow maximal penetration of the chemical in the treatment with polyethylene glycol (19).*

To insure uniformity, each batch was spread on the laboratory floor and mixed thoroughly. Proportions of various sizes of particles were similar in the two batches, as verified by screening.

Moisture contents of the two batches were maintained in storage. The undried shavings were stored at 35 F in polyethylene bags to deter growth of fungi.

Preparing the Boards

The following outline shows factors that were held as constant as possible in each treatment for dimensional stabilization:

1. Usual commercial pressing conditions for urea- or phenol-bound boards were maintained, except for slight changes when necessary in some treatments to produce a satisfactory board. Exceptions will be noted.

   Urea-formaldehyde resin (Pacific Resins and Chemicals, Inc., 7504) was applied at two rates—6 or 12 percent solids based on oven-dry weight of particles; urea-bound boards were pressed at 310 F for 9 minutes with pressure released slowly during the last 15 to 30 seconds, then boards were stickered and cooled.

   Phenol-formaldehyde resin (Monsanto Chemical Co., PF891M) also was applied at two rates—4 or 8 percent

*Numbers in parentheses refer to similarly numbered references.
solids based on oven-dry weight of particles; phenol-bound boards were pressed at 350 F for 12 minutes, then boards were hot-stacked at 160 F overnight.

2. Particles were Douglas fir, hammer-milled planer shavings.

3. Specific gravity was 0.65 (40 pounds a cubic foot).

4. Boards were 18 by 18 inches, with thickness controlled by stops to 3/4 inch, then sanded to 5/8 inch.

5. Moisture content at pressing was 10-12 percent.

6. Press closing time averaged 2.7 minutes. A few pretreatments required adjustment of closing time to avoid soft cores.

7. Conditions for spraying resin were air pressure of 80 psi, fluid pressure of 50 psi, and 20 grams of resin solids a minute at 70 F.

8. Wax and resin were mixed and sprayed together.

9. Wax sizing (Hercules Powder Co., Paracol 404 N) was applied at 0.75 percent solids content, based on oven-dry weight of particles.

All ten series of experimental combinations studied are outlined in Table 1. The boards were produced in as near random order as possible without excessive loss of time.

The following discussion describes the various treatments and any necessary deviations from ordinary commercial pressing conditions:

**The norm**

The normal series consisted of laboratory boards with usual contents of resin and wax prepared under ordinary commercial conditions for urea- and phenol-bound boards.

Inclusion of wax sizing in particle boards has been discussed in several publications (1, 2, 3, 7, 9, 11). Another series of boards was prepared under ordinary pressing conditions, but omitting wax sizing.

In addition, samples of commercial boards were selected randomly from the mill that furnished shavings for laboratory-made boards and were tested for comparison of properties. Commercial boards selected were slightly different in levels of binder and density from the normal series of boards pressed in the laboratory.

**Increasing resin content**

Because previous research (26) had indicated the value of increasing resin content, a series was prepared to evaluate improvement.
### Table 1. Outline of Treatments.

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>Level of treatment</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Normal resin content</td>
<td></td>
</tr>
<tr>
<td>Commercial, UF$^2$</td>
<td>6%+sizing</td>
</tr>
<tr>
<td>Commercial, PF$^3$</td>
<td>4 1/2%+sizing</td>
</tr>
<tr>
<td>Laboratory, UF</td>
<td>6%+sizing</td>
</tr>
<tr>
<td>Laboratory, PF</td>
<td>4%+sizing$^1$</td>
</tr>
<tr>
<td>High resin content</td>
<td></td>
</tr>
<tr>
<td>Laboratory, UF</td>
<td>12%+sizing</td>
</tr>
<tr>
<td>Laboratory, PF</td>
<td>8%+sizing</td>
</tr>
<tr>
<td>High press temperatures</td>
<td></td>
</tr>
<tr>
<td>Laboratory, UF</td>
<td>380 F</td>
</tr>
<tr>
<td>Laboratory, PF</td>
<td>400 F</td>
</tr>
<tr>
<td>Impregnating phenol binder</td>
<td>4%+sizing</td>
</tr>
<tr>
<td>Heated particles</td>
<td></td>
</tr>
<tr>
<td>UF+sizing</td>
<td>15 min at 400 F</td>
</tr>
<tr>
<td>PF+sizing</td>
<td>15 min at 400 F</td>
</tr>
<tr>
<td>Polyethylene glycol</td>
<td></td>
</tr>
<tr>
<td>UF-sizing</td>
<td>5%</td>
</tr>
<tr>
<td>PF-sizing</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>UF-sizing</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td><strong>Formaldehyde vapor</strong></td>
<td>30 min at 220 F</td>
</tr>
<tr>
<td></td>
<td>120 min at 220 F</td>
</tr>
<tr>
<td><strong>Tempering oil</strong></td>
<td>30 min at 220 F</td>
</tr>
<tr>
<td></td>
<td>120 min at 220 F</td>
</tr>
<tr>
<td><strong>UF-sizing</strong></td>
<td>5%</td>
</tr>
<tr>
<td><strong>PF-sizing</strong></td>
<td>5%</td>
</tr>
<tr>
<td><strong>Control of pH</strong></td>
<td>pH=4.0</td>
</tr>
<tr>
<td><strong>PF-sizing</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Extension of binder with blood</strong></td>
<td>5% blood</td>
</tr>
<tr>
<td><strong>UF-sizing</strong></td>
<td></td>
</tr>
</tbody>
</table>

1. Normal boards for each resin.
2. UF=urea-formaldehyde resin
3. PF=phenol-formaldehyde resin
obtained by adding more resin than usual. Again, as in the normal series, two groups of boards were prepared, one with wax sizing and another without.

**High pressing temperature**

Possible improvements in increased dimensional stability were indicated by using high press temperatures (3, 13, 16). This series consisted of pressing ordinary mats at two temperatures higher than common in commercial production.

**Use of impregnating phenolic binder**

Various degrees of success had been obtained with impregnating resins in earlier studies (1, 13, 20).

Boards were made containing low and high amounts of resin, and with and without wax sizing. Spraying the sizing separately was necessary before adding the resin because the two would not mix. Although normal pressing time for the phenol binder was 12 minutes, time had to be increased to 15 minutes to prepare boards in this series. The resin was Monsanto Chemical Company's PF 594.

**Heating particles**

Added dimensional stability attained by heating wood has been the subject of several studies (1, 8, 10, 11, 15, 17, 18, 20).

Particles were heated to 400 F for periods of 15, 30, and 45 minutes. After heating, particles were removed from the oven and spread on the floor for reconditioning to the desired 5 percent moisture content.

**Adding polyethylene glycol**

Polyethylene glycol added as a bulking agent to reduce dimensional change in wood and paper is well-known (1, 4, 19, 20, 21).

Boards in this series were produced by spraying undried particles with polyethylene glycol (Dow Chemical Co., E-1000) mixed with an equal weight of water. Spray was applied in concentrations of 5, 10, and 20 percent solids content, based on oven-dry weight of the wood. The material then was dried to the desired moisture content and stored in polyethylene bags.

During manufacture of the boards, closing pressure was reduced to maintain the desired rate of closure and to avoid soft cores possible with increasing amounts of polyethylene glycol. Also, in the phenol-bound series, press time was increased to 24 minutes to cure the binder.
Treatings with formaldehyde vapor

Formaldehyde cross-linking is another treatment that imparts added dimensional stability to wood and paper (1, 13, 18, 20, 22, 23, 24).

This treatment consisted of applying 1 percent zinc chloride, based on oven-dry weight of the particles, as a catalyst, and then placing the particles in an excess of formaldehyde vapor for periods of 30, 60, and 120 minutes at 220°F in an electrically heated oven.

The following tabulation shows the amount of chemical used in each treatment:

<table>
<thead>
<tr>
<th>Length of Treatment</th>
<th>Amount of Paraformaldehyde</th>
<th>Moisture Content after Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minutes</td>
<td>Percent*</td>
<td>Percent</td>
</tr>
<tr>
<td>30</td>
<td>0.35</td>
<td>3.3</td>
</tr>
<tr>
<td>60</td>
<td>0.58</td>
<td>1.7</td>
</tr>
<tr>
<td>120</td>
<td>1.48</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Based on weight of wood.

After removing particles from the oven, they were reconditioned and stored. No changes were made in pressing conditions during manufacture.

Adding tempering oil

In the hardboard industry, tempering oil is applied routinely to increase resistance to water (8, 14).

The treatment consisted of adding tempering oil at rates of 5 and 10 percent solids content, based on oven-dry weight of the chips, by spraying it on the particles before applying the resin binder. The oil, a commercial product, was heated to 175°F, and sprayed at air pressure of 30 psi. Ordinary pressing conditions were followed, except the closing pressure was reduced slightly to avoid soft cores.

Controlling pH

Products with added dimensional stability have been produced by controlling pH during manufacturing (6).

Control of pH was obtained by spraying either 0.45 gram or 1 gram of a solution of equal amounts of 1N sulfuric acid and 1N alum on
each 10 grams of particles. These additions reduced pH with phenolic binder from 5.1 with no control, to pH of 4 and 3.

**Extending urea binder with blood**

Adding soluble blood to urea-formaldehyde resin will impart resistance to moisture to the glue bonds of plywood (25).

Treatment in this series consisted of spraying particles with urea binder that had been extended with 5 and 10 percent soluble blood, based on oven-dry weight of solids in urea. The blood-urea resin did not spray so well as did unextended resin, but no special precautions were needed during pressing.

**Testing the Boards**

The procedure for testing the various specimens closely followed that of American Society for Testing and Materials, D1037-60T, Tests for Evaluating Building Fiberboards (5), wherever possible.

After manufacture, all boards were trimmed to 16 by 16 inches and stored for at least 2 weeks at 70°F and 65 percent relative humidity. Then they were sanded to a thickness of 5/8 inch and stored another week.

Five 5/8- by 3- by 16-inch specimens were cut from the boards for tests of dimensional stability and strength (Figure 1). Specimens

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**Figure 1. Plan of cutting specimens for testing.**
for dimensional tests were conditioned for 3 weeks at 90 F and 30 percent relative humidity. The specimens to be tested for strength were kept at 70 F and 65 percent relative humidity until tested.

**Strength and related properties**

Specimens prepared for tests of strength were tested over a 15-inch span at a headspeed of 0.3 inch a minute. Maximum load and load at deflection of 0.1 inch were recorded for determination of moduli of rupture and elasticity.

Specific gravity based on undried volume and oven-dry weight, and moisture content at time of testing were determined from a 1-by 3-inch coupon cut from this test specimen (Figure 1).

The 2-by 2-inch coupon cut adjacent to the coupon for test of specific gravity (Figure 1) was tested for internal bond at headspeed of 0.05 inch a minute.

**Dimensional properties**

Linear expansion, thickness swelling, and water absorption were measured in both water-soaking and humidification tests. In the water-soak test, initial measurements of weight, length, and thickness were taken. Specimens then were placed horizontally under 1 inch of water at 67 F. Weight, length, and thickness were measured after the pieces had soaked 1/2, 1, 2, 4, 7, and 14 days.

Specimens for the test by exposure to high humidity were removed from conditions of 90 F and 30 percent relative humidity, and initial measurements were taken. Specimens were stickered at 90 F and 90 percent relative humidity. Weight, length, and thickness were determined after exposure of 1/2, 1, 2, 4, 7, 14, 28, and 56 days. Specimens then were returned to 90 F and 30 percent relative humidity and reconditioned for 56 days. Additional measurements were taken to determine permanent increase in thickness. Specimens were oven-dried to determine moisture content at beginning of test.

Specimens for testing linear expansion were exposed for 56 days. Since practical equilibrium had been reached at some time between 14 and 28 days of exposure, however, the analysis of least significant difference was performed on the results of 14-days' exposure.

A rack on which specimens could be tested by exposure to weather was built so the specimens would be facing south at an angle of 45 degrees to the horizontal (Figure 2).

Initial results of tests in laboratory were compared with minimal specifications set by Commercial Standard CS 236-61 (12) to select experimental boards for exposure. Because of a combination of low
strength and poor dimensional characteristics, boards from 15 of the 44 experimental combinations were omitted from the tests of outside exposure as follows:

1. All four combinations using impregnating phenolic binder.
2. Particles heated for periods of 30 and 45 minutes with both types of binder.
3. Addition of 20 percent polyethylene glycol, with urea binder.
4. Treatment with formaldehyde vapor for 60 and 120 minutes with phenolic binder.
5. All four combinations containing tempering oil.

From the remaining combinations, four of each set of six specimens were selected and initial weight, length, and thickness were measured. These pieces were cut 3 by 16 inches so that strength could be tested conveniently. Measurements were taken after exposures of 3 and 6 months and 1 and 2 years.

Duplicate specimens were tested for strength at the end of 1 year. Testing procedures were the same as in initial tests, except for the test of internal bond. In this test, because of roughness of the specimens and accompanying difficulty of attaching glue blocks, a modified
procedure* was followed (Figure 3). A correlation factor was applied to correct values to those obtained in the usual test. Retention of strength was calculated for each test.

Analysis of data

Statistical analysis consisted of calculating least significant differences for only those treatments that were exposed on the test fence. The remainder were omitted because of their poor showings in tests.

*A technical note is being prepared outlining this test in detail.

Figure 3. Test for internal bond of specimens exposed outside on fence was modified. Cutting a groove slightly deeper than the center in each side of the piece with ring saws of two diameters provided a circular section which would separate when pressure was applied to center and outside areas from opposite sides of the piece.
RESULTS AND DISCUSSION

Usually there was a relationship between strength and dimensional stability; a treatment resulting in favorable strength properties ordinarily achieved favorable dimensional properties also.

Since effects of each treatment were similar in most instances in tests for both stability and strength, results will be discussed by treatment. Normal boards containing usual amounts of resin and wax sizing were a basis for all statistical comparisons. Effects of all treatments on various properties are presented for phenol-bound series only (Figures 4, 5, 6, 18, 19, and 20), as effects usually were comparable in urea-bound series.*

Specific gravity was determined from coupons taken from the strip used in the strength test and averaged 0.652, with a pooled standard deviation of 0.017.

Moisture content at time of testing was determined from the same coupons measured for specific gravity and averaged 9 percent for urea-bound boards and 8 percent for phenol-bound boards.

Normal preparation

Most of the best boards were made under normal conditions or by the treatment with added resin (Figures 4, 5, 6, 18, 19, and 20). A summary of those combinations that were significantly better than the norm in stability is given in Table 3.

Effects of various treatments on linear expansion after 14 days' exposure to high humidity are compared with the norm in Figure 4. No experimental combinations were significantly better in linear expansion than was the normal treatment.

In the urea-bound series, boards with wax sizing and high content of resin swelled in thickness significantly less than did normal boards (Figure 5). In the phenol-bound series, both the treatment including high content of resin and wax sizing and the treatment with high pressing temperature of 450 F were significantly better than the normal treatment (Tables 2, 3).

Comparing treatments containing wax sizing with those without sizing, especially in the normal series and the one with added resin, showed that boards without wax sizing swelled more rapidly and also to a greater extent in most tests (Figures 7 and 8). This difference usually occurred even in boards exposed to high humidity, although to a much

*A table compiling most important test results for all experimental combinations is available upon request.
Figure 4. Effect of treatments on linear expansion of phenol-bound boards exposed for 14 days to 90°F and 90 percent relative humidity. PF refers to phenol-formaldehyde resin and W represents wax sizing.

lesser extent than in those that were soaked. At the end of the 14-day period of water-soaking, however, degree of swelling in those boards with wax sizing was approaching that in those without wax. This finding indicated that sizing was effective only for short periods of immersion (Figures 7 and 8).

Effects of treatments on water absorption are summarized in Figure 6. No treatments analyzed were significantly better than the norm in tests of water absorption. Again, however, the difference between combinations with and without wax sizing was apparent. All combinations without sizing were significantly greater than normal boards in percentage of water absorption.

During the first year of outside exposure, boards made according to seven experimental combinations of variables became badly de-
Figure 5. Effect of treatments on swelling in thickness of phenol-bound boards water-soaked for 24 hours.

teriorated and were removed from the test. These combinations were as follows:

1. Heating particles for 15 minutes, using urea binder.

2. Combinations containing polyethylene glycol (5 and 10 percent), with urea binder.

3. Treatments of 30, 60, and 120 minutes with formaldehyde, using urea-formaldehyde, and 30 minutes with phenol-formaldehyde.

Results of 2 years' outside exposure are presented for comparison of dimensional stability in Figures 11, 12, and 13. The top line of each bar represents the maximum amount of linear expansion, thickness swelling, or water absorption measured in wet winter weather during the 2-year interval. The lower line of each bar represents the minimum measurement of change occurring during exposure in dry summer weather. The dotted lines on the bars representing specimens containing polyethylene glycol (Figures 11 and 12), and on the bar representing the
Figure 6. Effects of treatments on water absorption in phenol-bound boards water-soaked for 24 hours.

phenolic specimens made with 8 percent resin content without sizing (Figure 12), indicate the last measurement made on the boards.

Presence of wax sizing was definitely an important factor in retaining both stability and strength in boards during exposure.

Results of tests for retention of strength after 1 year's exposure are presented in Figures 14, 15, and 16. Each bar represents loss in strength from original conditions. The top of the bar represents degree of strength under original conditions; the lower line on the bar shows strength of specimens after outside exposure of 1 year. A composite of retention of strength as a percentage of original strength is shown in Figure 17.

Boards with urea binder prepared under normal conditions retained less than 50 percent of their strength in most tests after 1 year's exposure, but normal boards with phenolic binder and wax sizing were one of the six combinations retaining at least 50 percent of their strength in all tests.
Results of tests for modulus of rupture and modulus of elasticity on boards with phenolic binder are summarized in Figures 18 and 19. The deteriorating effects of the more severe treatments are apparent. The treatments significantly better than the normal one were those with added resin content with and without wax sizing.

In these tests of bending strength the only treatment in the urea-bound group that was significantly better than normal was the one with both added resin and wax sizing.

Figure 7. Effect of water-soak or exposure to high humidity on swelling in thickness of urea-bound boards with and without sizing.

Figure 8. Effect of water-soak or exposure to high humidity on swelling in thickness of phenol-bound boards with and without sizing.
There was a large spread of values in the test of internal bond (Figures 16 and 20); normal boards with urea binder were twice as strong as normal boards with phenol binder. Only the two treatments with high resin content were significantly better than normal treatment in the urea-bound group. In the phenol-bound group, however, the following treatments were significantly better: normal boards without wax sizing, all boards containing polyethylene glycol, and boards containing increased amounts of resin with and without wax sizing.
Figure 11. Effect of treatments on linear expansion in boards exposed outdoors for 2 years. Each bar represents maximal and minimal measurements during 2-year interval. Horizontal dotted lines represent measurements made last, indicating leaching in boards containing polyethylene glycol.

Figure 12. Effect of treatments on swelling in thickness of boards exposed outdoors for 2 years. Top of bar represents maximal, and lower limit of bar represents minimal measurements during 2-year interval. Horizontal dotted lines represent measurements made last, indicating leaching in some phenol-bound boards.
Figure 13. Effect of treatments with and without sizing, high pressing temperatures, and treatments containing polyethylene glycol on absorption of water by boards exposed outdoors for 2 years. Each bar represents maximal and minimal measurements during 2-year interval.

Treating with high resin content

The beneficial effects of high content of resin plus wax sizing in maintaining dimensional stability were evident in several tests. In tests of swelling in thickness, boards with added resin and wax sizing were significantly better than normal boards, regardless of type of binder (Figure 5).

In tests of bending strength, the only treatment in the urea-bound group that was significantly better than the norm was the one with both added resin and wax sizing. In the phenol-bound group, the significantly better treatments were those with added resin with and without wax sizing (Figures 18 and 19).

In tests of internal bond, only the two treatments with increased amounts of resin were significantly better than the normal treatment for boards with urea binder. Both treatments were significantly better than the norm for phenol-bound boards also, but so were several other treatments (Figure 20).

With urea binder, the treatment with high content of resin plus wax sizing was one of only two combinations producing boards that retained over 50 percent of their strength in all tests after 1 year's exposure (Figure 17).
Boards with phenol binder made by treatments containing added resin with and without wax sizing also retained over 50 percent of their strength in all tests (Figure 17).

The general superiority of normal boards and those made with added resin indicates the difficulty of improving this type of particle board now being produced commercially without increasing resin content. Since there was general improvement in properties with increasing resin content, the hypothesis might be suggested that the most important qualification for good particle board would be quality and quantity of resin-wood bonds. The possibility that improved boards might be produced from the promising treatments in this study by adjusting various manufacturing conditions could be confirmed only by further research.

Boards prepared under normal conditions and boards made by adding more resin were compared statistically to determine effects of adding wax sizing or leaving it out. Whether the board containing sizing was better or poorer than the comparable board without sizing is indicated in Table 2.

Tests of boards exposed outdoors or soaked in water showed statistically significant differences in every instance, the better board be-
Fig. 15. Effect of treatments on elasticity of boards after 1 year's outside exposure.

Figure 16. Effect of treatments on internal bond of boards after 1 year's outside exposure.
Table 2. Effect of Wax Sizing and Resin Content on Stability and Strength.

<table>
<thead>
<tr>
<th>Test</th>
<th>Urea-formaldehyde resin</th>
<th>Phenol-formaldehyde resin</th>
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<tbody>
<tr>
<td></td>
<td>6% (+sizing)</td>
<td>-sizing</td>
</tr>
<tr>
<td>Linear expansion, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(14 days' high relative humidity)</td>
<td>0.32</td>
<td>0.35</td>
</tr>
<tr>
<td>Thickness swelling, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(24-hour water-soak)</td>
<td>8.5*</td>
<td>17.3</td>
</tr>
<tr>
<td>Water absorption, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(24-hour water-soak)</td>
<td>13.6*</td>
<td>63.2</td>
</tr>
<tr>
<td>Rupture, psi</td>
<td>2710</td>
<td>2460</td>
</tr>
<tr>
<td>Elasticity, M psi</td>
<td>450</td>
<td>420</td>
</tr>
<tr>
<td>Internal bond, psi</td>
<td>178</td>
<td>190</td>
</tr>
</tbody>
</table>

*Significant difference at 5 percent level.
Figure 17. Effect of treatments on percentage of retention of strength in boards exposed outside for 1 year.

The reason why the inclusion of sizing resulted in increase in strength in some instances and decreases in other instances is not known. Small variations in techniques of manufacturing have been checked for possible effects, but these factors were not consistent as a possible explanation.

Treating with high pressing temperatures

Test results from treating with high pressing temperatures were comparable to the normal boards (Figures 11 through 16) and were significantly better in one instance (Table 3). The phenol-bound boards appeared to suffer no ill effects from high temperatures, but the urea-bound boards were discolored noticeably on the surface. Sanding re-
Table 3. Treatments Statistically Better\(^1\) Than the Norm.

<table>
<thead>
<tr>
<th>Test</th>
<th>Urea binder</th>
<th>Phenol binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear expansion</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Thickness swelling</td>
<td>12%+sizing</td>
<td>8%+sizing, high temperature, 450 F</td>
</tr>
<tr>
<td>Water absorption</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Bending strength</td>
<td>12%+sizing</td>
<td>8%-sizing, 5% polyglycol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8%+sizing, 10% polyglycol, Commercial</td>
</tr>
<tr>
<td>Elasticity</td>
<td>12%+sizing</td>
<td>8%-sizing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8%-sizing</td>
</tr>
<tr>
<td>Internal bond</td>
<td>12%-sizing</td>
<td>Commercial, 10% polyglycol</td>
</tr>
<tr>
<td></td>
<td>12%+sizing</td>
<td>8%-sizing, 5% polyglycol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8%+sizing, 20% polyglycol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4%-sizing</td>
</tr>
</tbody>
</table>

\(^1\)At 5-percent level of significance.

moved most of the discoloration, however, and apparently removed the damaged fiber and resin also, as indicated by favorable results in tests.

Beneficial effects of high press temperatures together with those resulting from increased resin content were evident in nearly all tests of stability and strength (Figures 4, 5, 6, 11 through 16). In fact, treatment with high pressing temperatures probably was the most promising treatment in this study. Increasing press temperatures may make shorter press times possible without appreciably lowering properties of the boards.

Improved durability in both stability and strength was gained by using high pressing temperatures for boards containing phenol binder. The one instance where this treatment resulted in boards significantly better than the norm was in the phenol-bound series with high pressing temperature of 450 F in the test of thickness swelling. Effects of high press temperature on thickness swelling are shown in Figure 9.

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Figure 18. Effect of treatments on bending strength of phenol-bound boards.

With urea binder, the pressing temperature of 450 F was one of the two treatments making boards that retained over 50 percent of their strength in all tests after 1 year's exposure. With phenol-bound boards, both pressing temperatures of 400 F and 450 F were among the six combinations making boards that retained at least 50 percent of their strength in all tests.

Use of impregnating phenolic resin
Boards containing impregnating phenolic resin binder had very poor properties in several tests (Figures, 4, 5, 6, 18, 19, and 20). This treatment yielded low-quality boards in all tests of dimensional stability, whether water-soak or exposure to high relative humidity, except for thickness swelling and water absorption when the boards contained 8 percent impregnating resin, plus wax.

An explanation may be advanced as to why these poor results occurred, since good results were obtained with this resin in a previous study (3). Since this resin is designed primarily for a product with high
density or high resin content, perhaps the resin penetrated too much to form good bonds between adjacent particles at the usual density and resin content of commercial particle board.

**Heating particles**

When the chips were heated, a definite darkening occurred, as length of treatment increased. Detrimental effects of the heating treatment on linear expansion after 14 days' exposure to high humidity are shown in Figure 4. Although there may have been a small degree of stabilization imparted to the particles by heating (Figures 5 and 6), this effect was counterbalanced by definite reductions in strength (Figures 18, 19, and 20). Other researchers (11, 17, 18) also have reported this same general result from heating.

**Adding polyethylene glycol**

The treatment with polyethylene glycol required extended pressing time for the phenol-bound series. Although urea-bound boards from the press appeared normal, extended pressing time also may have been advantageous for this series.

Phenol-bound boards with 10 and 20 percent polyethylene glycol added were as good as normal boards in linear expansion (Figure 4).

![Figure 19. Effect of treatments on elasticity of phenol-bound boards.](image-url)
Addition of the chemical in tests of extended water-soaking and exposure to high humidity resulted in a reversal of effects on thickness swelling. Specimens with 5 percent polyethylene glycol were lowest in percentage of thickness swelling in test of high humidity and highest in the water-soak test (Figure 10). All boards with polyethylene glycol showed a level of stability better than normal in the water-soak test after the sixth day.

Phenol-bound boards containing polyethylene glycol had a considerable bow during dry periods in the early portion of the exposure test. This bowing was caused by leaching of the chemical to the lower half of the specimens. At the end of 2 years, no bowing remained. The boards also had decreased in length and thickness, indicating that leaching had occurred. This series of boards retained smoothness well, with only slight roughening occurring.

All phenol-bound boards with polyethylene glycol were significantly superior to normal boards in internal bond (Figure 20, Table 3). Boards with 5 and 10 percent polyethylene glycol also were significantly better than the norm in the test of bending strength (Figure 18, Table 3).
Urea-bound boards with the same chemical added tested less favorably in both tests. In this series, polyethylene glycol interfered with bonding; a similar effect was noted by other researchers working with paper (21).

The greater strength in the phenol-bound boards resulted from increased pressing time. Also, polyethylene glycol may have aided bonding action by decreasing compressive strength of the particles, thus allowing more intimate contact between particles. Probably near-normal stability in linear expansion and increased stability in thickness swelling in the water-soak test was caused by the bulking effect of polyethylene glycol. The chemical, however, is subject to leaching, as indicated in the outside exposure. Any beneficial effects would be temporary if water were encountered.

**Treating with formaldehyde vapor**

When placing the particles in an excess of formaldehyde vapor for periods of 30, 60, and 120 minutes at 220 F, the most harmful results came from adding the catalyst of 1 percent zinc chloride. The same degrading effect caused by action of the acidic zinc chloride and heat upon the particles had occurred during treatment of paper or wood specimens by other researchers (18, 22, 24). There was a marked decrease in quality of stability and strength of boards made from particles exposed 30 minutes to formaldehyde vapor, followed by a gentle decline in quality for the two longer periods of exposure (Figures 4, 5, 6, 18, 19, and 20). Apparently no added stability resulted from this treatment. In fact, the treatment yielded poor boards in both the water-soaking test and the test by exposure to high humidity.

**Adding tempering oil**

Addition of tempering oil proved to be another of the poorer treatments. Characteristics of low strength and stability probably resulted from interference of the tempering oil with formation of glue bonds (Figure 4, 5, 6, 18, 19, 20). One urea-bound board, which was manufactured almost immediately after application of the oil, had properties comparable to the norm, but no better. This treatment might be more satisfactory as a post-treatment of the completed board.

**Controlling pH of phenol-bound boards**

Although control of pH is important in production of paper and wet-process hardboard, pH had little effect on particle boards in the range studied. Generally, properties of boards with controlled pH were only slightly lower than those for normal boards. The differences were not significant, except in the test of bending strength at pH of 3.0, where a significant reduction in strength occurred (Figures 4, 5, 6, 18, 19, and 20).
Extending urea binder with blood

In the range studied, extension of urea binder with soluble blood had no significant effects, except for a lower modulus of rupture in those boards sprayed with urea resin that had been extended 10 percent with blood.

Commercial boards

Boards produced under commercial conditions varied considerably (Figures 14, 15, and 16). This variation may be explained partially by the fact that specific gravities of commercial boards compared to those of laboratory boards were lower in the urea-bound series (0.59 compared to 0.66), and higher in the phenol-bound series (0.72 compared to 0.65). The same situation was true with content of resin; the level of urea binder in commercial boards was 5 3/4 percent compared to 6 percent, and the level of phenolic binder ranged from 4 1/2 to 5 percent compared to 4 percent.

With phenol binder, commercial boards retained the highest percentage of their strength in all tests after 1 year's exposure (Figure 17) of any of the combinations.

The commercial board with higher density was one of the best in the study, indicating that density was associated with quality.
CONCLUSIONS

For the methods followed and in the experimental range studied in the project, the following conclusions are proposed:

1. No treatment contained boards that were significantly better than the norm in every test.

2. At normal conditions, only treatments with high resin contents produced particle boards with some dimensional and strength properties that were significantly better statistically than normal boards.

3. At other than normal conditions, only treatments with high pressing temperature or containing polyethylene glycol produced boards significantly better than the norm in some tests in either strength or stability.

4. In general, wax sizing had no significant effect in tests of strength or long-term exposure to high humidity. It did have a definite effect whenever water was encountered for short periods, as in the 24-hour water-soaking test, or as rain in outside conditions of exposure. In all conditions of high humidity, those treatments containing wax usually had slightly better stability than those without wax sizing.

5. Perhaps the most important conclusion of this study is realizing the difficulty of improving dimensional stability in particle board without upsetting an economic balance between cost of production and selling price. At the outset of the project, the most promising treatments were selected with the hope of increasing dimensional stability even slightly. Results indicate both the difficulty of improving dimensional qualities at economical levels, and the need for further research on this problem.
LITERATURE CITED


The Forest Research Laboratory is part of the Forest Research Division of the Agricultural Experiment Station, Oregon State University. The industry-supported program of the Laboratory is aimed at improving and expanding values from timberlands of the State.

A team of forest scientists is investigating problems in forestry research of growing and protecting the crop, while wood scientists engaged in forest products research endeavor to make the most of the timber produced.

The current report stems from studies of forest products.

**Purpose**

Fully utilize the resource by:

- developing more by-products from mill and logging residues to use the material burned or left in the woods.
- expanding markets for forest products through advanced treatments, improved drying, and new designs.
- directing the prospective user's attention to available wood and bark supplies, and to species as yet not fully utilized.
- creating new jobs and additional dollar returns by suggesting an increased variety of salable products. New products and growing values can offset rising costs.

Further the interests of forestry and forest products industries within the State.

**Program**

Identify and develop uses for chemicals in wood and bark to provide markets for residues.

- Improve pulping of residue materials.
- Develop manufacturing techniques to improve products of wood industries.
- Extend service life of wood products by improved preserving methods.
- Develop and improve methods of seasoning wood to raise quality of wood products.
- Create new uses and products for wood.
- Evaluate mechanical properties of wood and wood-based materials and structures to increase and improve use of wood.
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