DEVELOPMENT OF JOINT STRENGTH IN BIRCH PLYWOOD GLUED WITH PHENOL-, RESORCINOL-, AND MELAMINE-RESIN GLUES CURED AT SEVERAL TEMPERATURES

Information Reviewed and Reaffirmed

August 1960

No. 1531
DEVELOPMENT OF JOINT STRENGTH IN BIRCH PLYWOOD GLUED WITH PHENOL-, RESORCINOL-, AND MELAMINE-RESIN GLUES CURED AT SEVERAL TEMPERATURES

By
H. D. BRUCE, Chemist
W. Z. OLSON, Technologist
J. M. BLACK, Chemist
and
A. H. RAUCH, Technologist
Forest Products Laboratory, Forest Service
U. S. Department of Agriculture

Introduction

To obtain information about the curing characteristics of certain commercial intermediate- and room-temperature glues, plywood was made with them by pressing at several temperatures for various lengths of time and the strength of the joints so made was ascertained by shear tests. The joints increased in strength with increased temperature and time of heating until the glue became sufficiently cured to develop the full strength of the wood. Differences between glues in rate of development of joint strength were taken as indicative of diverse curing characteristics.

Curing and Testing Procedures

Each glue was mixed according to the manufacturer's instructions in the proportion shown in table 1 and spread on selected straight-grained 1/16-inch yellow birch veneer at a moisture content in equilibrium with 80°F and 65 percent relative humidity. The veneer was assembled into 3-ply plywood panels and pressed at 150 pounds per square inch. The length of time under pressure and the temperature of curing were varied independently. Curing temperatures from 75° to 220°F were investigated. Panels cured at 75°, 90°, and

---

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

Report No. 1531
110° F. were prepared in a screw press in a room held at these temperatures; panels cured at 120°, 140°, 160°, 180°, and 200° F. were pressed in a large hydraulic press between platens heated with hot water; and panels cured at 220° F. were pressed between electrically heated metal plates.

In all gluing, temperatures at the glue line were measured throughout the heating period by thermocouples inserted in one of the glue lines. In the presses with electrically heated and hot-water heated platens, approximately 5 minutes were required for the glue lines to come to the desired temperature. In the rooms at 75°, 90°, and 110° F. the mixed glue and the wood were at the room temperature at the time of gluing.

Immediately after removal from the presses, the panels were chilled in a room held at -20° F. It had previously been found that, at this temperature, no appreciable further cure took place in a limited time in partially cured resin glues. After chilling, the panels were cut as rapidly as possible into standard plywood-joint-test specimens. Some of the specimens were immediately tested dry, some were put to soak in water at room temperature for 48 hours before testing, and some were immersed in boiling water for 3 hours, cooled in water, and tested wet.

**Time-temperature Curing Data**

For most of the glues investigated, only the wet-strength data taken after 48 hours of immersion are presented in this report. The dry-test data usually paralleled the wet-strength data closely, but were more erratic and less amenable to analysis. The results on specimens boiled for 3 hours provided little additional evidence as to the stage of cure for the glues after various periods of heating. If the degree of cure was slight, such that the dry plywood specimens tested below 150 pounds per square inch in shear, boiling usually lowered the joint strength and sometimes produced delamination. With moderate degrees of cure and dry-joint-strength values above 150 pounds per square inch, boiling increased the strength, usually to the maximum attainable with failure entirely in the wood.

The original joint-strength data are not given, but, for the sake of simplicity of interpretation and facility of use, the graphs shown in figures 1 through 16 are smoothed curves prepared from the original test data.

Figures 1 through 12 show the wet-joint-strength values that may be expected in straight-grained yellow birch plywood glued with the adhesives in question after pressing for the stated intervals of time.
at the temperatures given, and soaking in water at room temperature for 48 hours. The wet-strength values shown in figures 1 through 12 do not necessarily indicate the strength values of the joints upon removal from the press, since some further curing may have taken place during the 48-hour soaking period. A comparison of the dry- and wet-strength data shows that, in general, they agree with each other rather closely. Certain consistent differences, however, were observed and these differences are presented in table 2.

For the intermediate-temperature phenolic and melamine glues at low degrees of cure, the dry-joint-strength values were somewhat greater than the wet-joint-strength values. With these glues at higher degrees of cure, except for Lauxite 252, there was little observable difference between wet- and dry-joint-strength values. Presumably, in phenolic and melamine glues, if the cure was not beyond critical minimum values, soaking in water damaged the glue and lowered the joint strength. Above these minimum values, these glues were not weakened by soaking for 48 hours nor, with the exception of Lauxite 252, was there any evidence of further development of joint strength during the soaking period.

In the three resorcinol glues, the wet-joint-strength values were consistently higher than the dry-joint-strength values up to about 450 to 525 pounds per square inch, indicating that further curing of the glue with increase in joint strength had taken place in the 48-hour immersion period. The intermediate-temperature melamine glue, Lauxite 252, also showed evidence of curing at room temperature, for within the range of dry-joint-strength values of 200 to 525 pounds per square inch, the wet-joint-strength values were slightly but definitely the greater. For relatively high degrees of cure there was no significant difference between the wet- and dry-joint-strength values for any of the 12 glues studied.

For the four glues in which dry-joint-strength values were lower than the wet-joint-strength values in some ranges, the dry-joint-strength data were also analyzed graphically and are shown as functions of the time and temperature of curing in figures 13 through 16. These graphs should be more useful for estimation of pressing time for these particular glues than the graphs of figures 6, 10, 11, and 12.

The curves in figures 1 through 16 were terminated at a maximum of 545 pounds per square inch because this value was the average strength of the yellow birch veneer used in this study when joint failure was entirely in the wood. It is unlikely, however, that 545 pounds per square inch is the maximum strength that glue joints made with these glues are capable of developing. From the shape of the curves, it seems likely that all these resin glues are capable of developing considerably higher strength values on stronger woods with further curing.
For specimens that tested above about 500 pounds per square inch in shear strength, the failure was almost entirely in the wood. Hence, above this value the slopes of the curves for shear strength versus time of heating are dependent not so much on the properties of the glue as on the quality of the wood. For this reason it is advisable to neglect the portions of the curves above the 500 pounds per square inch line in comparing one glue with another.

The durability of partially set intermediate- and room-temperature resin glues is being studied. It has been shown in studies with white oak timbers made with 3/4-inch laminations, that phenolic resin glues must be nearly completely cured to resist delamination when subjected to alternate soaking and drying. Under less severe stressing, as in continuous soaking, or alternate exposure to high and low humidity, full cure is not necessarily required to prevent delamination. A study of the durability of partially cured phenolic glues is under way.\(^2\)

**NOTES**

These strength data were measured upon yellow birch plywood. Since these data were obtained, there is evidence that resin glues do not cure at the same rate upon all species of wood. Accordingly, similar time-temperature studies are being made upon other species. From data now available, it appears that resorcinol glues cure at a somewhat similar rate upon birch, maple, sweetgum, noble fir, and Western hemlock, but more slowly upon Douglas-fir and white oak; the melamine glues cure at a similar rate upon birch and sweetgum, but more rapidly upon Douglas-fir; but that the difference between the effect of species are not pronounced for the intermediate-temperature-setting phenol glues.

The data for this report were obtained in 1944-45, at which time the glues tested were commercially available. Although some of the glues are no longer manufactured under the trade names shown, the data may be considered useful for similar types of glues which are still available.

\(^2\) Forest Products Laboratory Report No. 1537, "Durability of room-temperature-setting and intermediate-setting resin glues cured to different degrees in yellow birch plywood."
<table>
<thead>
<tr>
<th>Designation of glue</th>
<th>Type of glue</th>
<th>Designation of hardener</th>
<th>Mixing proportions, parts by weight</th>
<th>Other ingredients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amberlite PR-75B</td>
<td>Phenolic</td>
<td>P-79</td>
<td>90 : 13.5 : 10, alcohol</td>
<td></td>
</tr>
<tr>
<td>Cascophen LT-67</td>
<td>Phenolic</td>
<td>M-18</td>
<td>100 : 8</td>
<td></td>
</tr>
<tr>
<td>Durez 12041</td>
<td>Phenolic</td>
<td>#7422</td>
<td>100 : 12</td>
<td></td>
</tr>
<tr>
<td>Durez 12533-12534B</td>
<td>Phenolic</td>
<td></td>
<td>12533, 100 : 20, walnut</td>
<td>12534B, 100 : shell flour</td>
</tr>
<tr>
<td>Durez 12688</td>
<td>Resorcinol</td>
<td>12689</td>
<td>100 : 20</td>
<td></td>
</tr>
<tr>
<td>Lauxite 252</td>
<td>Melamine</td>
<td>252-B</td>
<td>160 : 19 : 88, water</td>
<td></td>
</tr>
<tr>
<td>Melmac 401</td>
<td>Melamine</td>
<td></td>
<td>100 : 50 : 88, water</td>
<td></td>
</tr>
<tr>
<td>Penacolite G-1124</td>
<td>Resorcinol</td>
<td>G-1124B</td>
<td>100 : 25</td>
<td></td>
</tr>
<tr>
<td>Penacolite G-1131</td>
<td>Resorcinol</td>
<td>G-1131B</td>
<td>100 : 20</td>
<td></td>
</tr>
<tr>
<td>Perkins M-411</td>
<td>Melamine-urea</td>
<td></td>
<td>100 : 60 : 60, water</td>
<td></td>
</tr>
<tr>
<td>Resinox 230</td>
<td>Phenolic</td>
<td>230-B</td>
<td>100 : 22</td>
<td></td>
</tr>
<tr>
<td>Resinox 840</td>
<td>Melamine</td>
<td></td>
<td>70 : 30 : 30, water</td>
<td></td>
</tr>
</tbody>
</table>

Report No. 1531
Table 2.--A comparison of the dry- and wet-joint-strength data for several low-temperature glues at various stages of cure in 3-ply, 3/16-inch plywood

<table>
<thead>
<tr>
<th>Glue</th>
<th>Type of glue</th>
<th>Approximate range of wet joint strengths in which dry strengths exceed wet strengths: There is little difference between wet strengths and dry strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
<tr>
<td>Amberlite PR-75B</td>
<td>Phenolic: 0 - 200</td>
<td>200 - 545</td>
</tr>
<tr>
<td>Cascophen LT-67</td>
<td>Phenolic: 0 - 450</td>
<td>450 - 545</td>
</tr>
<tr>
<td>Durez 12041</td>
<td>Phenolic: 0 - 250</td>
<td>250 - 545</td>
</tr>
<tr>
<td>Durez 12533-12534B</td>
<td>Phenolic: 0 - 200</td>
<td>200 - 545</td>
</tr>
<tr>
<td>Durez 12688</td>
<td>Resorcinol: 0 - 450: 450 - 545</td>
<td>450 - 545</td>
</tr>
<tr>
<td>Lauxite 252</td>
<td>Melamine: 0 - 200: 200 - 525: 525 - 545</td>
<td>525 - 545</td>
</tr>
<tr>
<td>Melmac 401</td>
<td>Melamine: 0 - 200</td>
<td>200 - 545</td>
</tr>
<tr>
<td>Penacolite G-1124</td>
<td>Resorcinol: 0 - 500</td>
<td>500 - 545</td>
</tr>
<tr>
<td>Penacolite G-1131</td>
<td>Resorcinol: 0 - 525</td>
<td>525 - 545</td>
</tr>
<tr>
<td>Perkins M-411</td>
<td>Melamine-urea: 0 - 250</td>
<td>250 - 545</td>
</tr>
<tr>
<td>Resinox 230</td>
<td>Phenolic: 0 - 300</td>
<td>300 - 545</td>
</tr>
<tr>
<td>Resinox 840²</td>
<td>Melamine: 0 - 300</td>
<td>300 - 545</td>
</tr>
</tbody>
</table>

¹Example: If birch plywood be glued with Cascophen LT-67 under conditions to produce a wet-joint-strength of 300 pounds per square inch, since this value falls within the 0 - 450 range, the dry strength of the same plywood will average higher than 300 pounds per square inch, but not above 450 pounds per square inch. If the glue be cured to a wet-joint-strength of 500 pounds per square inch, the dry strength will also be about 500 pounds per square inch.

²Resinox 840 is no longer being marketed.

Report No. 1531
Figure 1.—Wet joint strengths of 3 ply, 3/16-inch yellow birch plywood glued with Amberlite PR-75B, low-temperature phenolic, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 2.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Cascophen LT-67, low-temperature phenolic, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 3.--Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Durez 12041, low-temperature phenolic, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 4.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Durez 12533-12534B, low-temperature phenolic, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 5.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Resinox 230, low-temperature phenolic, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 6.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Lauxite 252, low-temperature melamine, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 7.--Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Melmac 401, low-temperature melamine, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 8.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Perkins M-411, low-temperature melamine-urea, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 9.--Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Resinox 840, low-temperature melamine, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 10.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Durez 12688, low-temperature resorcinol, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 11.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Penacolite G-1124, low-temperature resorcinol, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 12.—Wet joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Penacolite G-1131, low-temperature resorcinol, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested wet after soaking 48 hours at room temperature.
Figure 13.—Dry joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Durez 12688, 
low-temperature resorcinol, for various lengths of time at several glue line temperatures. 
Specimens cooled and tested dry soon after removal from the press.
Figure 14.—Dry joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Penacolite G-1124, low-temperature resorcinol, for various lengths of time at several glue line temperatures. Specimens cooled and tested dry soon after removal from the press.
Figure 15.—Dry joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Penacolite G-1131, low-temperature resorcinol, for various lengths of time at several glue line temperatures. Specimens cooled and tested dry soon after removal from the press.
Figure 16.—Dry joint strengths of 3-ply, 3/16-inch yellow birch plywood glued with Lauxite 252, low-temperature melamine, for various lengths of time at several glue line temperatures. Specimens cooled and tested dry soon after removal from the press.
APPENDIX

ADDITIONAL RESIN GLUES

A study of time-temperature curing requirements has been completed on two more resin glues, Amberlite PR-245 and Cascophen RS-216, employing the same technique as used for the 12 glues covered in the main body of the report.

The glues were mixed and used according to the manufacturers' instructions with a closed assembly time of 30 minutes for the Amberlite PR-245 and 10 minutes for the Cascophen RS-216. The mixing proportions are given in table 3.

<table>
<thead>
<tr>
<th>Designation of glue</th>
<th>Mixing proportions, parts by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amberlite PR-245</td>
<td>Q-108 : 100 : 3.5 : 152</td>
</tr>
<tr>
<td>phenolic</td>
<td></td>
</tr>
<tr>
<td>Cascophen RS-216</td>
<td>FM-60 : 100 : 15 : 0</td>
</tr>
<tr>
<td>resorcinol</td>
<td></td>
</tr>
</tbody>
</table>

The results of this study are presented in the graphs of figures 17, 18, 19, and 20 showing smoothed curves obtained from the original data by crossplotting. Graphs for both dry and wet strength data are given.
Figure 17.—Dry joint-strength of three-ply, 3/16-inch yellow birch plywood glued with Amberlite PR-245, intermediate-temperature-setting phenol, for various lengths of time at several glue line temperatures. Specimens cooled and tested dry soon after removal from the press.
Figure 18.—Wet joint strengths of three-ply, 3/16-inch yellow birch plywood glued with Amberlite PR-245, intermediate-temperature-setting phenol, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested after soaking 48 hours at room temperature.
Figure 19.—Dry joint-strength of three-ply, 3/16-inch yellow birch plywood glued with Cascophen RS-216, room-temperature-setting resorcinol, for various lengths of time at several glue line temperatures. Specimens cooled and tested dry soon after removal from the press.
Figure 20.—Wet joint strengths of three-ply, 3/16-inch yellow birch plywood glued with Cascophen RS-216, room-temperature-setting resorcinol, for various lengths of time at several glue line temperatures. Specimens immersed in water soon after removal from the press and tested after soaking 48 hours at room temperature.
SUBJECT LISTS OF PUBLICATIONS ISSUED BY THE
FOREST PRODUCTS LABORATORY

The following are obtainable free on request from the Director, Forest Products Laboratory, Madison 5, Wisconsin:

List of publications on
Box and Crate Construction and Packaging Data

List of publications on
Chemistry of Wood and Derived Products

List of publications on
Fungus Defects in Forest Products and Decay in Trees

List of publications on
Glue, Glued Products and Veneer

List of publications on
Growth, Structure, and Identification of Wood

List of publications on
Mechanical Properties and Structural Uses of Wood and Wood Products

Partial list of publications for Architects, Builders, Engineers, and Retail Lumbermen

List of publications on
Fire Protection

List of publications on
Logging, Milling, and Utilization of Timber Products

List of publications on
Pulp and Paper

List of publications on
Seasoning of Wood

List of publications on
Structural Sandwich, Plastic Laminates, and Wood-Base Aircraft Components

List of publications on
Wood Finishing

List of publications on
Wood Preservation

Partial list of publications for Furniture Manufacturers, Woodworkers and Teachers of Woodshop Practice

Note: Since Forest Products Laboratory publications are so varied in subject no single list is issued. Instead a list is made up for each Laboratory division. Twice a year, December 31 and June 30, a list is made up showing new reports for the previous six months. This is the only item sent regularly to the Laboratory's mailing list. Anyone who has asked for and received the proper subject lists and who has had his name placed on the mailing list can keep up to date on Forest Products Laboratory publications. Each subject list carries descriptions of all other subject lists.