SERVICEABILITY OF GLUE JOINTS

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin
April 1938
SERVICABILITY OF GLUE JOINTS

Exposure tests give data on animal, vegetable, casein, and blood types

By

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Introduction

Tests have demonstrated that among the more important causes of failure of well-made glue joints in service are the following: (a) chemical hydrolysis of the glue, (b) destruction of glue by microorganisms, and (c) mechanical stresses developed on the glue joint as the wood changes dimensions under the effect of changes in moisture content. The relative importance of these different factors varies largely, depending on the type of glued construction, the variety of glue, and service conditions.

The significance of hydrolysis and its relation to composition has been developed for casein glues (1) and the general principles are believed to apply to other protein glues. Under conditions favorable to decay the destructive effect of microorganisms on glues of compositions that serve as food has been shown to be rapid and drastic. The effect, however, may be greatly reduced by incorporating toxic materials in the glue or by adequate treatment of the entire glued member with toxic preservatives (2). The effect of microorganisms on the glue joint and deterioration due to hydrolysis may, of course, be eliminated by the selection of adhesives that are not subject to attack by molds and that do not hydrolyze.

The effect of mechanical action, however, cannot be greatly retarded by minor changes in formulation although these changes might have a marked effect on the rate of hydrolysis. Nor will the mechanical effects be changed to any significant degree by adding toxic materials to the glue or by treating the glued members with chemicals commonly used for the preservation of wood. The primary requirement, if the glue joints are to maintain their strength under repeated changes in moisture conditions, appears to be a glue that is strong enough either in a wet or dry condition to withstand the stresses developed under severe conditions of service.

1. Published in Mechanical Engineering, April 1938.

2. Numbers in parentheses refer to the Bibliography at the end of the paper.
Failure of well-made glue joints under stresses developed by changes in moisture content may be thought of as depending first, on the magnitude of the stresses developed, and second, upon the degree to which the glue softens and weakens when it becomes moist. The magnitude of the mechanical stresses developed depends on the extent of the moisture changes and how far the extremes of moisture content depart from the moisture content of the stock at the time the glue sets; also upon the density and shrinkage characteristics of the species used, and the thickness of the laminations. The resistance that the glue line offers to these stresses may be thought of as depending on the amount of water absorbed by the glue line, and the degree to which the glue softens and loses its strength when this absorption occurs. Glues that are water resistant will withstand exposure to higher humidities than glues that are lacking in this property.

Tests were conducted at the Forest Products Laboratory to determine the relative resistance of some of the commonly used woodworking adhesives to service conditions involving successive exposures to alternating conditions of moisture that would develop mechanical stresses of increasing magnitude on the glue joint. The purpose was, further, to define if possible the conditions of service under which glue joints could be expected to remain permanently durable and the conditions under which either prompt or ultimate failure could be expected.

In these tests the complications of species characteristics and thickness combinations were eliminated by the use of a single species and a single thickness combination throughout, although it is recognized that these factors must be considered when general applications of the results are made. Further, the tests do not include the more recently developed synthetic resin adhesives. Other tests, however, have indicated that joints made with hot-pressed synthetic resins are highly resistant to conditions favoring mold attack and hydrolysis and that they retain a high percentage of their dry strength when saturated with water or exposed to high humidities.

Test Procedure

Seventeen panels, each of which was 12 in. square and composed of three plies of selected 1/16-in. yellow birch veneer, were glued with each of seven glues. They were (a) sodium-silicate-lime-casein glue mixed according to formula 4-B of the Forest Products Laboratory, (b) and (c) two sodium-hydroxide-lime-casein glues, (d) high-grade animal glue having a jelly strength of 303 g and a viscosity of 103 millipoises, (e) low-grade animal glue having a jelly strength of 190 g and a viscosity of 55 millipoises, (f) commercial vegetable or starch glue and (g) hot-press blood glue mixed according to the paraformaldehyde formula of the Forest Products Laboratory. In Table I, which gives the composition of these glues on a parts-by-weight basis, the individual glues are designated by the letters used in the preceding sentence.
Table 1.—Composition of glues used in tests

<table>
<thead>
<tr>
<th>Constituents</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
<th>(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium hydroxide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Animal glue</td>
<td></td>
<td></td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood albumin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casein</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td>28</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraformaldehyde</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>&quot;Processed&quot; starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Sodium hydroxide</td>
<td></td>
<td>12</td>
<td>4</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Sodium silicate</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>330</td>
<td>240</td>
<td>380</td>
<td>225</td>
<td>195</td>
<td>225</td>
<td>190</td>
</tr>
</tbody>
</table>

The veneer was conditioned to approximate equilibrium with 30 percent relative humidity before gluing, which brought it to a moisture content of about 6-1/2 percent. The gluing conditions were adjusted to fall within limits favorable to the production of good joints (3) with each glue. The gluing operations with animal, casein, and vegetable glues were carried out in the conventional way. The panels glued with blood albumin were spread and pressed at room temperatures, allowed to remain under pressure overnight, and hot-pressed the following morning for about 10 minutes at 260° F. and under a pressure of 200 pounds per square inch.

After gluing, the panels were again conditioned to approximate equilibrium with 30 percent relative humidity and then cut into standard plywood test specimens (3). Each of the 17 panels yielded 30 test specimens, giving a total of 510 for each glue. Five specimens from each panel were tested dry, and any panels that gave low or erratic test values were discarded.

Specimens from the remaining panels of each glue were then mixed together to insure random sampling and divided into 6 groups of 60 each, one group for each of the tests listed in Table 2. Air temperatures were maintained at approximately 80° F., while the soaking water temperatures of test No. 6 varied with those of the laboratory. Five specimens were withdrawn from each group and tested on a plywood-testing machine of conventional design (3) at intervals of 4, 8, 12, 16, 20, 40, 60, 80, 120, and 160 weeks. Specimens were unprotected, and their dimensions were small enough to permit the wood to attain approximate equilibrium with atmospheric conditions at each period of the exposure cycle.
Table 2.—Data on exposure tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Type of exposure cycle</th>
<th>First stage</th>
<th>Second stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Time, days</td>
<td>Relative humidity, percent</td>
</tr>
<tr>
<td>1</td>
<td>Continuous*</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Alternating</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Alternating</td>
<td>14</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>Alternating</td>
<td>14</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>Alternating</td>
<td>14</td>
<td>97b</td>
</tr>
<tr>
<td>6</td>
<td>Alternating</td>
<td>2b</td>
<td>97b</td>
</tr>
</tbody>
</table>

*Used as controls.

Soaked in water at room temperature.

In analyzing the data from the tests, the average test value of each group that remained in 30 percent relative humidity was considered a "control" average and other test values of specimens glued with the same glue were expressed as percentages of this. As the different exposures were continued and test values were obtained at different intervals, these were converted into percentages and plotted. After plotting, the points were joined by straight lines to illustrate general trends in strength changes. No attempt has been made to draw curves of mathematical exactness because the number of specimens tested at each period was not sufficient to justify such treatment. The tests have extended over a sufficient period of time, however, to permit confidence in the general tendencies illustrated.

Animal and Vegetable or Starch Glues

Both animal and vegetable or starch glues are lacking in water resistance, and the durability of joints made with them and exposed to water or to damp atmospheres is so similar that the results were averaged together and shown on the same curves, Figs. 1 and 2. When exposed to test No. 6, a soaking-drying cycle, all joints made with either animal or vegetable glue separated completely either in the first soaking period or in the drying that immediately followed (Fig. 2). This behavior is to be expected of glues that are not water-resistant.

Specimens, glued with animal or vegetable glue, exposed to test No. 5 did not separate immediately, but at the first test period, the end of the first complete cycle, the average joint strength was less than 40 percent of the original. All specimens had failed before the end of the fourth cycle, or in somewhat less than 16 weeks. This test does not
involve exposure to free water, but a relative humidity of 97 percent is sufficiently high to permit development of molds and to bring the moisture content of the wood to about 28 percent during the "wet half" of the cycle. Specimens exposed to test No. 4 failed less rapidly than those exposed to test No. 5. They had decreased in strength, however, by some 50 percent by the end of the first test cycle, and all specimens had failed by the end of 36 weeks. Moisture content of the wood during the "wet half" of this cycle probably reached about 22 percent (Fig. 1).

In test No. 3, more than 20 weeks of exposure were required before the average test values had fallen to 50 percent of the original. By the end of the eighty-first week, however, all specimens had failed indicating that animal- and vegetable-glued joints cannot be depended upon to remain permanently durable when exposed to conditions where the wood may at times exceed about 17 percent moisture content, which is approximately the equilibrium condition for 30 percent relative humidity (Fig. 1). These results may appear contrary to experience, for furniture glued with starch and animal glues often serves satisfactorily in spite of occasional exposures to relative humidities in excess of 50 percent. In those cases, however, the protection afforded by the finish may prevent the wood reaching the equilibrium moisture content of 17 percent, particularly if the exposure to dampness is not prolonged.

In tests Nos. 1 and 2, no evidence of significant loss in strength could be detected during the 160 weeks that the tests were in progress. Test No. 2 approximates the changes in moisture content that can be expected in interior woodwork in normal use in heated buildings in the northern part of the United States (4). In this type of service, properly designed and well-made joints of animal or vegetable glue should prove permanently durable, and experimental evidence, other than these tests, supports that belief (5).

Casein and Blood Glues

When exposed to conditions that cause alternating changes in the moisture content of wood, the casein glues used in these experiments displayed no great differences among themselves in durability of joint. Results from the three casein glues have been averaged together, therefore, and are shown in a single set of curves as Fig. 3. They are believed to be typical of the general tendencies that would develop when any of the better grades of casein glues are subjected to similar tests.

Results of test No. 6 illustrate that joints made with casein glue cannot be termed waterproof. In this series of soaking-drying tests, all specimens glued with casein glue had failed by the end of 15 weeks. In other similar tests (6), similar results have been obtained. While the time of total failure has varied from 3 to 15 months, an early weakening of the joints was apparent in all similar tests.

Exposure to 97 percent relative humidity followed by drying, test No. 5, also causes rapid weakening of unprotected casein-glue joints
with total failure occurring in these tests at about 48 weeks or 12 complete cycles. Even the cycle of 2 weeks in 90 percent relative humidity followed by 2 weeks drying in 30 percent relative humidity, test No. 4, was severe enough to cause ultimate failure of unprotected casein-glue joints. The rate of failure is slower than that displayed by joints of vegetable or animal glue exposed to the same conditions, but at the end of some 81 weeks, 20 complete cycles, all casein joints had failed.

In test No. 3, however, no evidence of significant weakening of joint strength was disclosed during the 160 weeks that the tests were in progress. The difference in resistance between casein and animal or vegetable glues is demonstrated in this test. Well-made casein-glue joints are apparently able to withstand repeated exposures to 80 percent relative humidity while joints made with starch or animal glues ultimately fail in this exposure. Tests Nos. 1 and 2 failed to disclose any weakening of well-made casein-glue joints while the tests were in progress and none would be expected, regardless of the length of time that the tests might be extended.

Until the development of artificial-resin glues, the "hot-press" paraformaldehyde blood glue was one of the most water-resistant of woodworking adhesives. In test No. 6, specimens held together for nearly 2-1/2 years (Fig. 4) before total failure, and, in other similar tests, specimens have withstood the cycle for as long as 3 years. Even this resistant glue, however, cannot be classified as waterproof, for severe moisture changes repeated over a long time will cause failure in the joint.

At the end of 160 weeks, blood-glue joints exposed to test No. 5 had lost approximately 50 percent of their original strength. From the downward trend in joint strength illustrated in Fig. 4, total failure might be expected somewhere between 4 and 5 years. In other similar tests, however, blood-glue joints have withstood this exposure for as long as 6 years and, at the end of that time, the joints retained some 40 percent of their original strength. By that time, the wood which had been exposed to the cycle of 97 percent relative humidity followed by 30 percent was beginning to show some evidence of decay.

From the trend illustrated in Fig. 4, ultimate failure might be expected in blood-glue joints exposed to test No. 4. In view of the long resistance to the more severe test No. 5, however, it appears reasonably safe to assume that these joints might, on more extensive tests, prove permanently durable as long as the moisture content of the wood did not exceed approximately 22 percent (Fig. 1). These tests produced no evidence that well-made blood-glue joints will fail when subjected to tests Nos. 1, 2, or 3.

Destructive humidities appear to be between 60 and 80 percent relative humidity, corresponding to a maximum equilibrium moisture content in wood of about 17 percent, for animal and vegetable or starch glues; between 20 and 90 percent relative humidity, corresponding to a
maximum equilibrium moisture content in wood of about 22 percent, for casein glue; and between 90 and 97 percent relative humidity, corresponding to a maximum equilibrium moisture content in wood of about 27 percent, for blood glue.

Bibliography


Figure 1.—Relation between the moisture content of wood, relative humidity of the surrounding atmosphere at 70°F, and destructive conditions for different glues.
Figure 2. Rate of deterioration of animal and vegetable glue joints in plywood under varying conditions of exposure.
Figure 3.—Rate of deterioration of casein glue joints in plywood under varying conditions of exposure.