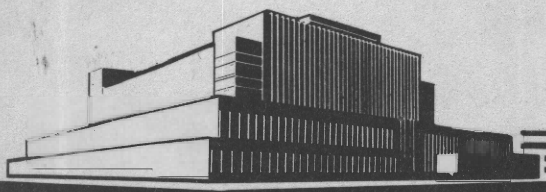
EFFECT OF HIGH AND LOW TEMPERATURES ON RESIN GLUE JOINTS IN BIRCH PLYWOOD

Information Reviewed and Reaffirmed

March 1956

No. 1345



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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

EFFECT OF HIGH AND LOW TEMPERATURES ON RESIN GLUE JOINTS IN BIRCH PLYWOOD[1]

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Considerable information is available on joint-strength values of plywood glued with synthetic resin glues and exposed to conditions of high humidity at room temperature or to alternate wetting and drying cycles[4, 5]. Practically none, however, has been obtained on the effects of extremely low or high temperatures, such as are encountered by aircraft in actual service. To learn more about the effects of these high and low temperatures, the present study was undertaken. Data were obtained from several groups of experiments which, though closely related, had been carried out under varying conditions. The results of each series of experiments are here considered separately.

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[1] This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available. Revised January 1944.

[2] This work was started by T. J. Martin, now of the Army Air Forces, and continued by the writer. Additional data have been provided by H. W. Eickner, A. E. Gabriel, and W. Z. Olson of the Forest Products Laboratory.

[3] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[4] Brouse, Don; "Contributions of Synthetic Resins to Improvement of Plywood Properties," Forest Products Laboratory Report R1212, 1939.

[5] "Wood Aircraft Fabrication Manual," prepared by the Forest Products Laboratory and issued by the Aeronautical Board, July 1942, pages 31-43.

First Study

This study consisted of exposing 3-ply birch shear specimens, glued with seven different glues, to several conditions of temperature, and periodically testing them in the dry condition for shear strength.

Selection of Veneer

Veneer of uniformly high quality was cut from a single birch log in such a way that each successive sheet was comparable to the previous one and each section in one sheet came from the same relative position in the log as the same section of the next sheet. In this way, five successive sheets were matched for faces, five for cores, and five for backs. Veneer was all 1/16 inch in thickness and was conditioned before use to the proper moisture content for each glue employed.

Glues and Gluing

On the basis of previous tests at the Laboratory, one glue of each of several types of synthetic-resin glues was chosen as representative of that type. Casein glue, Laboratory formula 4B, was included for comparison. The resin glues used in this first study were:

(1) A hot-setting phenolic resin -- Tego Glufilm

(2) A hot-setting urea resin -- Uformite 430 with hardener Y

(3) A cold-setting urea resin -- Plaskon 201-2 with hardener A

(4) A hot-setting phenolic resin (used in bag molding) -- Durez 11814

(5) A hot-setting fortified urea resin (used in bag molding) -- Plaskon 700-2

(6) A vinyl thermoplastic -- Butacite 4639

In gluing, the recommendations of the glue manufacturers were followed. All panels except those that were bag molded were 3-ply, 24 inches square. The latter were 12 by 24 inches in size so that they would fit on opposite sides of a flat mold in the autoclave. Five panels 24 inches square (or ten 12- by 24-inch half-panels for each bag molding glue) were prepared with each glue. Each panel was conditioned 1 week to approximately 12 percent moisture content, then cut into

plywood test specimens. A single 24- by 24-inch panel provided 120 test specimens. The test specimens for each glue were then divided into groups of 5, each of which included one specimen from each 24- by 24-inch panel or from each pair of 12- by 24-inch panels. Specimens from the same section of each large panel or each pair of small panels were subjected to every exposure condition.

Exposure Conditions

Two large insulated cabinets were equipped for storage of the specimens at two extreme conditions, namely, 158° F. and minus 67° F. The 158° F. cabinet was provided with electric resistance heaters operated automatically by means of a recording temperature regulator and the necessary relays. It was also provided with an automatic humidity regulator which controlled an electrically driven humidifier drum through relays. This equipment maintained a temperature of 158° F.[6], plus or minus 1° F., and a relative humidity of approximately 20 percent. A standard plywood testing machine was placed inside the cabinet when testing specimens at 158° F.

The other cabinet was placed in a refrigerated room kept at minus 25° F. or 0° F., as required. The interior of the box was cooled further with dry ice when required, to a temperature of minus 67° F., plus or minus about 3° F.[7] Inside this cabinet also a machine was placed to test specimens at minus 67° F.

Other specimens were stored at 80° F. and 65 percent relative humidity in a large room controlled at these conditions.

Control Tests

After the freshly glued panels had been conditioned for at least 1 week to a moisture content of about 12 percent, five specimens from each panel of each glue, a total of 25 specimens per glue, were tested dry

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[6] At the time these tests were started this temperature had been recommended as probably close to the maximum temperature to be expected in service. Experiments since that time have shown that temperatures above 200° F. are occasionally reached in an airplane wing exposed to the sun.

[7] After 12 months of tests, the use of dry ice was discontinued and the specimens exposed to low temperature were kept at minus 20° F. instead of minus 67° F.

at room temperature (75° F.). A like number of specimens was soaked for 48 hours in water at room temperature and tested while wet. Three other groups of specimens were kept in the storage cabinets for 24 hours at each of the following temperatures and then tested within the cabinets at these temperatures; 158° F., at 20 percent relative humidity; 0° F.; and minus 67° F. For the tests at 0° F., the low-temperature cabinet was used in the refrigerated room without the dry ice. No specimens were stored in the first study at these extreme temperatures for periods longer than 24 hours.

Cyclic Exposure Tests

The remaining specimens were divided into four groups, each made up of subgroups of 5 specimens (1 specimen from each panel) for each glue and subjected to a variety of cyclic exposure conditions.

One subgroup for each glue was tested at the end of 3, 9, 18, and 30 days, and at 2, 3, 4, 5, 6, 9, 12, and 15 months in each exposure. Each test came at the end of a cycle, after the specimens had been exposed to 80° F. and 65 percent relative humidity for 16 hours. All tests were made on dry specimens at room temperature. No wet tests were made in the cyclic tests of the first study.

The exposure conditions in this first study were:

Low-high Cycle -- One group was exposed to a 72-hour low-high cycle, as follows:

-67° F. for 8 hours[6]
+158° F. for 16 hours
+80° F. for 8 hours
-67° F. for 16 hours[6]
+158° F. for 8 hours
+80° F. for 16 hours and repeat.

The 80° F. interval was in a room at this temperature and at 65 percent relative humidity. This cycle allows both 8- and 16-hour periods at all three temperatures and gives complete jumps from low to high temperatures as well as half jumps from high to low temperatures with intermediate periods at room temperature.

Room-high Cycle -- A second group of specimens was exposed to a "room-high" cycle, a 24-hour period in which specimens were stored for 8 hours at 158° F. followed by 16 hours at 80° F. and the cycle repeated.

Room-low Cycle -- A third group of specimens was introduced into a "room-low" cycle, a 24-hour period in which specimens were stored for 8 hours at minus 67° F., followed by 16 hours at 80° F. and the cycle repeated.[6]

Storage at 80° F. -- A fourth group of specimens was kept continuously at 80° F. and 65 percent relative humidity, to bring out the effect of aging under normal atmospheric conditions. Specimens were tested at the same times as for the previous cycle tests.

Results -- The results obtained in all of the foregoing tests are shown in table 1. These cycle tests will eventually cover a period of 2 years.

Second Study

Because the original program of experiments did not include moisture resistance tests in the cycle tests and because only one glue of each type was included, a second group of specimens was prepared as part of another series of tests at the Laboratory. The specimens were subjected to a similar series of exposures and tested periodically both dry and after a 48-hour immersion in water at room temperature.

Preparation of Material

In these experiments, the veneer was also 1/16-inch birch but it was not all cut from one log. Thus it was impossible to match sheets as in the original program. The veneer used was all of good quality, however, and carefully selected from a large stock. Short, wavy, or cross-grain material was rejected.

Glues used in this second study included the following eight cold-setting, urea-resin glues: Plaskon 250-2, Perkins DC-246, LePage's Panite, Uformite CB-551, Bakelite 12772 (hardener 16229), Cascamite ANS, Lauxite 77X, and Cascamite 44-B. The last mentioned did not pass the pH requirement of Specification AN-G-8 but was included for comparison. The other cold-setting urea glues met the acidity requirement of the specification. Also included were three low-temperature phenolic-resin glues cured at 140° F. for 16 hours, (Cascophen LT-67, Bakelite 3931, and Durez 12041), two liquid hot-setting phenolic resins (Bakelite 7381 and Bakelite 13268), one hot-setting melamine resin (Melmac 400), one hot-setting urea-resin (Uformite 430 with hardener Y), two fortified urea-resins (Plaskon 700-2 and Bakelite 12772 with hardener 15287), one urea-melamine resin (Perkins M-411), one modified vinyl-resin glue (DuPont 4624), and two commercial casein glues (Lauxein 888 and Casco Aircraft

Joint A). The two casein glues were used both in the normal way and with 5 percent of pentachlorophenol preservative on the basis of the weight of the dry glue.

Panels made with cold-setting glues were 5 by 12 inches in size; those made with hot-setting glues and with the low-temperature phenolic glues were 12 by 12 inches in size. A total of 70 of the 5- by 12-inch panels and 24 of the 12- by 12-inch panels were prepared for each glue and specimens taken from each of the panels were used in this study. Thus a good distribution of representative specimens was possible for these tests. The 12- by 12-inch panels were first cut into three sections, each 4 by 12 inches in size and comparable to the 5- by 12-inch panels each of which furnished 10 test specimens. All of these 5- by 12-inch panels or 4- by 12-inch sections for a given glue were sorted into seven groups of 10 each so that the first group was made up of the first, eighth, fifteenth panel, etc., the second group was made up of the second, ninth, and sixteenth panels, etc. After cutting the panels into plywood shear specimens, the first specimens from each of the 10 panels were used for the control values for that group. Alternate specimens were used for the dry and wet control tests. The control values given in tables 2 and 3 thus represent the average of 5 specimens for the panels used for each particular exposure condition. There was some variation in the control values for a given glue in the five conditions studied because each value represents a different group of panels within the same large number of panels. Five of the seven groups of panels were used in this study.

Exposure Conditions and Testing

All the test specimens were first stored for 1 week at 80° F. and 65 percent relative humidity, after which the control values for each exposure group were determined. One group of specimens was then kept continuously at 80° F. and 65 percent relative humidity, to show the influence of aging at normal temperature. A second group was introduced into the "room-high" cycle and a third group into the "room-low" cycle, which had been previously described. A fourth group was exposed continuously at 158° F. and 20 percent relative humidity in the special cabinet used in the cycle tests. A fifth group was stored continuously at 158° F. plus or minus 5° F. and a relative humidity of 60 percent, plus or minus 5 percent, in an insulated cabinet which was similar to that used at 158° F., 20 percent relative humidity but without such precise control equipment. Continuous exposures at the last two conditions were not included in the original study.

After the exposure periods were started, specimens were tested at the end of 1 and 2 weeks; and 1, 2, 3, 6, 9, and 12 months in each exposure condition. After each test period and for each exposure condition, five specimens were tested dry and five after 48 hours' soaking in water at room temperature. No tests were made at the high or low temperatures after 24 hours' exposure as in the first study. Tests on specimens stored at 158° F. were made at room temperature after they had been allowed to remain at room conditions for at least 1 hour and not more than 2 hours.

Test values are now available for these glues over periods of 6, 9, or 12 months and the results to date are given in tables 2 and 3. Since the tests were not all started at the same time, test data are not yet available for some of the glues at the 9- and 12-month periods.

All the cycle tests and long-time continuous exposure tests in both studies are being continued and will eventually cover a period of 2 years of exposure.

Supplementary Studies

As part of another study at the Laboratory, several groups of 3-ply, 3/16-inch birch plywood specimens glued with 11 different synthetic resin glues were prepared and introduced into the "low-high" cycle described in the first study. Glues used in these tests included three cold-setting urea-resin glues: Plaskon 250-2, LePage's Plastic Resin, and Bakelite 12772 with hardener 14388, the last of which did not pass the pH requirement of Specification AN-G-8. Also included were two hot-setting, urea-resin glues (Bakelite 12772 with hardener 14282 and Plaskon 107-2 with hardener 7); two fortified urea-resin glues (Uformite 430 with Q-107 and Q-87 hardeners and Plaskon 700-2); one low-temperature, phenolic-resin glue (Durez 12041); one hot-setting, blood-phenolic-resin glue (Amberlite PR-23); one hot-setting, melamine-resin glue (Melmac S-77-V); and one thermoplastic resin glue (Butacite 4639).

Of these glues, two were used in the first study. Plaskon 700-2 was used as a bag-molding glue while in this supplementary experiment it was used as a hot-press glue. Butacite 4639 was used in both experiments although the gluing conditions used were somewhat different.

Specimens have been tested dry at room temperature at 5-week intervals after exposure in the low-high cycle up to 55 weeks. Test results are given in table 4. The tests are being continued and will eventually cover a period of 2 years.

In a second group of supplementary experiments, as part of another Laboratory study, 3-ply, 3/16-inch birch plywood specimens were prepared using seven different synthetic-resin glues and a casein glue. The glues used included a hot-setting, phenolic film glue (Tego Glufilm), a hot-setting, urea-resin glue (Bakelite 12772 with hardener 14282), a hot-setting, fortified urea-resin glue (Plaskon 700-2), three cold-setting, urea-resin glues (Plaskon 201-2 with hardener A, LePage's Plastic Resin, and Bakelite 12772 with hardener 14512, the last of which did not meet the pH requirement of Specification AN-G-8), a thermoplastic resin glue (Butacite 4639), and casein glue (Laboratory formula 4B). All gluing was done according to the manufacturers' directions.

For the purpose of these experiments, the plywood specimens were divided into three groups. One group was stored continuously at 80° F. and 65 percent relative humidity to serve as controls. The other two groups were exposed continuously at 158° F. and 20 percent relative humidity in the same cabinet used in the first study. Specimens from one of these groups were tested at room temperature immediately after removal from the heated storage cabinet. These specimens were warm when tested and were at a rather low moisture content. Specimens of the other group were conditioned at 80° F. and 65 percent relative humidity for 2 days after removal from the storage cabinet, after which time they were tested at room temperature. These specimens, therefore, were at a moisture content of about 12 percent at the time of test.

All tests in this second group were made after 1, 2, 3, 4, and 6 weeks' and 2, 3, 6, and 12 months' exposure. Results are given in table 5. These tests have been completed.

A third group of supplementary experiments was begun at a later date to study the effect of continuous exposure at 200° F. and 20 percent relative humidity. Such experiments seemed desirable in view of the fact that temperatures of this order have actually been measured in airplane wings exposed to the sun. For this purpose, another large insulated cabinet was equipped with electric resistance heaters and humidifier and provided with a thermostat and a humidistat operating through relays to maintain a temperature of 200° F., plus or minus 1° F., and a relative humidity of approximately 20 percent.

The specimens used for these tests were prepared at the same time as the specimens used in the second study. After gluing, they were kept for approximately 5 months at 80° F. and 65 percent relative humidity. Before the exposure tests were begun, representative specimens were tested dry and after 48 hours' immersion in water at room temperature and the averages used as the control values for the experiment. After starting the exposure at 200° F., specimens

were tested dry and after 48 hours' immersion in water at room temperature after 1 week, and 1, 2, 3, and 4 months. Test results are given in table 6.

A fourth group of supplementary experiments was begun as part of a larger series of tests in which 3-ply, 3/16-inch birch plywood specimens were prepared with each of 14 different resin glues of several types. These specimens were exposed at 200° F. and 20 percent relative humidity in the same cabinet used in the previous study. Specimens were tested at room temperature while dry and after 48 hours' immersion in water after 2 and 4 months of continuous exposure at these conditions. Test results are given in table 7. These tests will be continued to cover a period of 2 years or longer.

Discussion of Results

The joint strength results in these studies show some definite trends although, in some cases, the exposures thus far have been of relatively short duration.

In considering these results, it must be borne in mind that the precision possible with the method of testing joint strengths in plywood is not high. Appreciable variations in joint strength, therefore, may have no actual significance. This is particularly true when considering two successive values without relation to other values before and after. Likewise, the percentages of wood failure are rough estimates at best and have a relative value which is mainly useful to determine whether or not the wood failed before the glue, thus preventing an accurate estimate of the quality of the glue bond itself.

Effect of Different Exposure Conditions

Examination of the data in the several tables shows that for all glues in general the most damaging exposure condition used was continuous exposure to temperatures of 158° F. or above. Results of tests after exposure to 200° F. are very incomplete (tables 6 and 7) in that they cover only 4 months of exposure. There is some evidence that this is the most damaging condition for the majority of the glues tested, but these results must be considered as only tentative since the tests are of such short duration.

Deterioration of the urea-resin glues at 158° F., as shown in tables 2 and 3, was more rapid at 60 percent relative humidity than at 20 percent. The unfortified cold-setting, urea-resin glues particularly were seriously damaged by this temperature and relative humidity.

Under the same conditions, phenolic, melamine, and casein glues proved to be much more stable.

The next most damaging conditions were the "room-high" and the "low-high" cycles. Apparently the high-temperature part of the cycle did the damage in each case, for there was no significant indication that the low temperature in the "room-low" cycle caused any appreciable damage. In a few cases, particularly of the cold-setting, urea-resin glues, there was some indication that the joint strength did decrease slightly in the "room-low" cycle, but this was generally no greater than occurred during the exposure at 80° F. and 65 percent relative humidity.

Over a period of 9 to 12 months of continuous exposure at 80° F. and 65 percent relative humidity, certain individual glues, particularly some of the cold-setting, urea-resin glues, showed significant decreases in both wet and dry joint strength values as well as in percentages of wood failure. The amounts of such strength losses varied considerably for different glues of this type, but no glue meeting aircraft specification requirements reached a seriously low strength value.

In the supplementary studies (table 5) where specimens were tested both immediately upon removal from the 158° F. storage cabinet and after conditioning at 80° F. and 65 percent relative humidity for 2 days after removal, the joint strength values were usually not greatly different, but the thermoplastic resin glue always gave lower values when hot.

Comparison of Glues

Hot-press, phenolic-resin glues.--The three hot-press, phenolic glues exposed at 200° F. (tables 6 and 7) appeared to have lost strength significantly in 4 months, but it remains to be seen whether this strength loss is entirely in the glue or partly in the wood.

The joints made with the bag-molded phenolic glue, Durez 11814, showed what appear to be significant losses in the "room-high" and "low-high" cycles of table 1. Since the wood failures were always high, it is possible that something in the glue was harmful to the wood at elevated temperatures.

With the foregoing exceptions, the phenolic-resin glues showed no serious weakening. There are occasional indications in tables 1 to 5 that one or another of these glues has weakened seriously, but frequently the apparent trends are reversed in later tests and none of the apparent weakening indicated by occasional low results has been shown by subsequent tests to be significant.

Hot-press, melamine-resin glue.--There have been but slight decreases in dry and wet strength values with one glue of the hot-press, melamine-resin type when exposed to the "room-high" cycle and continuous exposure at 158° F. (tables 2 and 3) and the wood failure values were always high. Nearly all of the changes could be due to variations in the strength values of the wood in the test specimens. One of the melamine-resin glues has good durability after 4 months of exposure at 200° F. (table 7). The melamine resin film glue, however, has not shown as good durability under the same conditions. In table 4, the hot-press melamine glue has remained noticeably weaker than the original test value during most of the test period but recent values are again approaching the original.

Melamine-urea-resin glues.--One melamine-urea-resin glue showed appreciable loss in strength at 200° F. (table 6) but good durability at all other conditions except perhaps to continuous exposure to 158° F. and 60 percent relative humidity (tables 2 and 3), in which case both wet and dry test values were lower at the 6- and 9-month test periods. In these cases the percentages of wood failure remained high and it is still uncertain whether the glue has been damaged appreciably. One other glue of this type has shown good durability after 4 months' exposure at 200° F. (table 7). The 4-months' value for the wet strength was low but the wood failure was high and there is no evidence of serious damage to the glue.

Fortified urea-resin glues.--The fortified urea-resin glues showed indications of decreases in joint strength values after exposure at high temperatures. In table 1 the bag-molded urea resin (Plaskon 700-2), a fortified urea resin, showed decreases in strength and wood failure when tested dry after exposure in the "room-high" and "low-high" cycles. This same glue when used in the conventional hot-press method (tables 2, 3, 4, 5, and 6) showed similar decreases in both wet and dry strength values and in percentages of wood failure when exposed continuously at 158° F. The effect at 20 percent relative humidity, however, was much less than at 60 percent relative humidity at this temperature (tables 2 and 3). This glue was very seriously damaged within 3 months of continuous exposure at 200° F. The loss in strength in the "room-high" cycle was noticeable but was less than in the continuous exposures at 158° or 200° F. The magnitude of test values with this glue in the supplementary studies (table 5) was considerably lower than in the second study (tables 2 and 3).

The other fortified urea-resin glue (Bakelite 12772 with hardener 15287) showed much the same behavior under the same conditions of exposure (tables 2 and 3) as did Plaskon 700-2.

A third fortified urea-resin, Uformite 430 with Q hardener and catalyst, showed relatively good durability (table 4) when tested dry after

exposure in the "low-high" cycle, the only exposure condition to which this glue was subjected.

These fortified urea-resin glues generally showed no loss in strength and frequently showed increases in strength after periods of exposure at 80° F., 65 percent relative humidity and in the "room-low" cycle.

Hot-press, urea-resin glues.--Hot-press, urea-resin glues were also affected by exposures at high temperatures but, in general, there were no more significant differences between hot-press and fortified urea-resin glues than there were between individual glues of either type. Knowledge as to the presence or absence of fortifiers in the so-called hot-press, urea-resin glues is not accurate.

Low-temperature, phenolic-resin glues.--The alkaline-catalyzed glue (Cascophen LT-67) showed good joint strengths under all conditions. Some small decreases in joint strength values were indicated when specimens glued with this glue were tested dry after continuous exposures at both humidities at 158° F. and 200° F. and in the "room-high" cycle (table 2) but percentages of wood failure remained high. In the wet tests, however, (table 3) slight increases in strength were indicated. For this reason the changes in the dry strength values under these conditions may be insignificant and may indicate variations in the strength of the wood rather than of the glue joints. Two alkaline-catalyzed glues (Cascophen LT 67 and Resinox 230) showed some decreases in both wet and dry strength values when exposed continuously at 200° F. (table 7) but percentages of wood failure remained high and it is doubtful whether the glues have been damaged. In a number of tests the strength values and percentages of wood failure continued to increase above that of the controls. This was very likely due to the fact that the original curing conditions were not adequate for complete cure and that further curing took place, especially during the exposures to high temperatures.

The acid-catalyzed glues (Durez 12041 and Bakelite 3931) showed definite decreases in joint strength values, but with increases in the percentages of wood failure, when exposed continuously at 158° F. and in the "room-high" cycle, in both dry and wet tests (tables 2 and 3).

In one case (Durez 12041) this decrease in strength was much more noticeable at 60 percent relative humidity than at 20 percent, at 158° F. It seems likely that the acid catalyst in these glues is damaging the wood at the high temperature, and thus causing joints of low strength and with high percentages of wood failure. These joints fail at strength values considerably below the strength of the normal birch glued with a high-quality, nearly neutral resin glue. One acid-catalyzed glue (Textolite 2163), which had a film pH value of 2.4, has shown reasonably good durability at 200° F. (table 7).

The tests at this temperature have not run long enough to determine whether there is any acid damages to the wood under these conditions.

Resorcinol-resin glue.--The resorcinol-resin glue exposed at 200° F. (table 7) showed good durability over the short period of exposure studied. This type of glue has not been included in other tests thus far.

Casein glues.--Casein glues showed only slight decreases in both joint strength values and percentages of wood failure when exposed to high temperatures. The amounts of these decreases were much smaller than those for the cold-setting urea-resin glues exposed under the same conditions. It is worthy of note that, while the casein glues showed the characteristic lower wet strengths at the start of the tests, there was very little if any further decrease in the wet strengths after exposures to high temperatures for periods up through 9 months. This may be contrasted to the corresponding effects on the cold-setting, urea-resin glues where the wet strength values were originally high but showed rather rapid decreases in strength when exposed to 158° F., especially at the higher relative humidity. It should be noted that these wet tests involved a 48-hour immersion in water at room temperature after previous exposure of the dry specimens at some high temperature. No tests were made after continuous immersion in water throughout the entire test period.

No important difference in the durability of these casein glues with or without preservative is apparent at these exposure conditions but, of course, conditions favorable to growth of molds and bacteria were not employed in these tests.

Cold-setting, urea-resin glues.--Cold setting, urea-resin glues were seriously damaged by continuous exposure at 158° F., the 20 percent relative humidity being a less severe condition at this temperature than the 60 percent relative humidity, under which these glues lost all strength within 9 months. Incomplete data on five glues indicate that a more rapid deterioration takes place at 200° F. (tables 6 and 7). These glues are also seriously damaged in the "room-high" and "low-high" cycles but the rates of decrease in strength are less than those for continuous exposure at 158° F.

The cold-setting, urea-resin glues that did not pass the acidity requirement of Specification AN-G-8 were in general less durable than those which did and were broken down more rapidly at the elevated temperatures.

Thermoplastic glue.--The vinyl butyral thermoplastic (Butacite 4639) glue showed different trends in different parts of the tests. In the first study (table 1) the glue was seriously damaged in the "room-high"

and "low-high" cycles. In the supplementary studies, this glue showed very good durability in the "low-high" cycle (table 4). It was also tested in a third set of specimens after continuous exposure at 158° F. and 20 percent relative humidity (table 5) and showed a steady decrease in strength when specimens were tested immediately upon removal but showed much better results when the specimens were cooled and reconditioned before testing. Results on these latter tests were somewhat erratic.

Modified vinyl-resin glues.--The modified vinyl-resin glue (DuPont 4624) showed good durability. There was some decrease in dry and wet strength values after continuous exposure at 158° F. with both 20 and 60 percent relative humidity (tables 2 and 3) although the percentages of wood failure were consistently high. Under other conditions, this glue showed good performance.

Summary

In the tests thus far, the hot-press phenolic-resin, hot-press melamine-resin, modified vinyl-resin, and alkaline-catalyzed, low-temperature, phenolic-resin glues rank highest as a group in maintaining joint strength when exposed to high temperatures. The melamine-urea, fortified-urea, and hot-setting urea-resin glues are next. The acid-catalyzed, low-temperature, phenolic-resin glues show serious loss in joint strength when continuously exposed at high temperatures as well as in cycles including such temperatures. Casein glues have in general shown themselves to be definitely better than the cold-setting, urea-resin glues in resistance to high temperatures. The casein glues showed characteristic low wet strengths after 48 hours' immersion in water at the start of the tests but they showed very little further decrease in wet strength after continuous exposures at the high temperatures. The urea-resin glues as a class are damaged more by high temperatures than phenolic or melamine-resin glues, and the cold-setting, urea-resin glues have lost nearly all their strength within 9 months of continuous exposure at 158° F. and 60 percent relative humidity.

The thermoplastic glue did not give consistent results, but in the main portion of the tests it showed reasonable durability at high temperatures, especially after the specimens were allowed to condition at room temperature before the tests were made.

In general, none of the glues studied were appreciably affected by exposures at room temperature or at low temperatures. In some cases, strength values increased after exposure at room temperature, probably due to further curing; but in some cases, notably of the

cold-setting, urea-resin glues, there were some decreases in strength at this temperature.

Since these experiments are being continued over a 2-year period, final judgment is withheld on some glues until the results of further tests become available.

Table 1.--Joint strength values of birch plywood test specimens after exposure to the various temperature-time conditions indicated. All but one group of specimens tested dry.

Time of exposure	Dry joint strengths and percentages of wood failure[1]						
	Tego (hot phenolic)	Uformite 430-Y (hot urea-formalde-hyde)	Plaskon 201-2A (cold urea-formalde-hyde)	Butacite 4639 (thermo-plastic)	Casein 4B	Durez 11814 (bag phenolic)	Plaskon 700-2 (bag urea-formalde-hyde)
			Stored and tested at +158°F.[2]				
24 hours	360-21	386-100	303-7	136-0	340-14	374-93	332-46
			Stored and tested at +75°F.[2]				
24 hours	405-27	464-100	439-100	416-37	443-44	437-80	393-49
			Stored and tested at 0°F.[2]				
24 hours	383-40	421-100	363-84	442-61	410-24	387-72	397-76
			Stored and tested at -67°F.[2]				
24 hours	380-32	402-100	334-98	417-76	389-51	380-90	328-61
			Soaked in water at room temperature and tested wet[2]				
48 hours	382-5	395-100	438-100	180-0	201-0	436-43	414-89
			Exposed continuously at 80°F. and 65 percent relative humidity, tested at room temperature				
Control[4]	405-27	464-100	439-100	416-37	443-44	437-80	393-49
3 days	429-66	430-100	434-100	475-70	439-28	460-100	424-84
9 days	460-68	501-100	448-96	470-63	450-29	427-100	458-82
18 days	416-54	486-100	417-100	420-43	419-3	399-100	437-100
30 days	418-57	466-100	411-94	363-8	445-6	416-84	412-81
2 months	421-50	435-100	409-71	479-79	445-56	446-95	421-62
3 months	367-42	475-100	385-54	429-42	420-47	408-100	394-72
4 months	402-26	428-100	367-25	446-44	403-5	392-77	391-81
5 months	425-52	482-100	376-42	402-6	468-5	422-81	420-82
6 months	393-73	438-100	365-49	479-72	429-92	413-99	407-76
9 months	329-4	413-100	317-17	390-55	361-39	403-100	387-100
12 months	409-11	452-100	368-22	377-12	375-0	440-98	432-80
15 months	394-28	466-100	342-7	438-28	397-11	425-85	429-63
			Exposed to "room-high" cycle[3] and tested at room temperature				
Control[4]	405-27	464-100	439-100	416-37	443-44	437-80	393-49
3 days	418-54	405-98	345-50	382-8	411-40	383-84	340-41
9 days	392-74	444-100	352-19	236-3	377-16	383-100	424-79
18 days	419-54	414-100	343-13	244-0	376-3	400-100	387-70
30 days	395-79	415-100	316-6	207-1	422-18	378-100	349-48
2 months	406-39	403-95	299-5	149-2	381-49	358-98	266-18
3 months	374-54	380-96	306-2	154-2	370-14	328-100	314-39
4 months	353-52	375-100	258-5	139-1	328-5	278-100	285-7
5 months	386-68	355-52	301-2	148-1	360-10	330-100	319-9
6 months	372-54	363-82	311-3	123-3	360-78	337-100	242-2
9 months	325-7	370-90	272-0	108-0	328-0	285-100	268-10
12 months	368-32	370-35	261-0	76-1	338-6	294-100	282-4
15 months	336-36	336-51	270-1	104-17	314-1	270-100	238-22
			Exposed to "room-low" cycle[5] and tested at room temperature				
Control[4]	405-27	464-100	439-100	416-37	443-44	437-80	393-49
3 days	434-64	464-100	451-99	506-55	501-68	481-99	418-78
9 days	465-60	510-100	485-100	462-54	488-48	458-95	482-100
18 days	445-91	512-100	411-96	461-54	421-2	441-96	495-100
30 days	449-74	476-100	396-92	409-18	462-11	402-50	434-83
2 months	425-27	462-100	416-82	449-37	472-93	431-81	385-45
3 months	350-37	448-100	374-58	421-44	425-30	395-97	412-86
4 months	379-9	456-100	365-23	394-21	392-2	394-52	418-66
5 months	414-34	472-100	403-56	364-2	437-17	409-87	443-96
6 months	402-28	450-100	426-90	408-9	451-100	435-84	405-61
9 months	360-17	426-100	340-26	352-21	380-10	407-100	408-82
12 months	388-6	476-98	387-24	353-4	438-20	403-84	409-63
15 months	400-38	464-100	369-23	418-26	377-11	405-84	413-66
			Exposed to "low-high" cycle[6] and tested at room temperature				
Control[4]	405-27	464-100	439-100	416-37	443-44	437-80	393-49
3 days	392-83	417-100	353-86	352-7	380-50	400-100	388-81
9 days	405-72	455-100	320-12	264-6	409-24	417-100	392-74
18 days	434-60	452-100	323-5	222-3	407-3	357-100	374-64
30 days	405-69	404-100	324-5	163-2	390-5	367-100	356-58
2 months	367-50	351-100	276-4	157-3	373-83	313-100	281-2
3 months	339-44	371-100	245-6	82-3	352-13	293-100	304-28
4 months	331-19	392-100	281-0	110-1	346-0	317-100	294-8
5 months	406-49	383-85	277-2	62-0	351-4	326-100	298-6
6 months	357-76	356-90	252-67	144-4	343-84	287-100	263-1
9 months	306-6	335-72	251-0	95-0	338-15	266-100	246-29
12 months	319-7	309-46	228-0	0-0	288-0	243-100	245-2
15 months	347-35	313-35	240-0	118-20	337-12	293-99	265-2

[1] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2] Each of these control values is the average for 25 specimens.

[3] Eight hours at +158°F., 16 hours at 80°F., and repeat.

[4] The control value is the average for 25 specimens which were stored at 75°F. for 24 hours and tested at 75°F.

[5] Eight hours at -67°F., 16 hours at 80°F., and repeat.

[6] Cycle consists of: 8 hours at -67°F., 16 hours at 158°F., 8 hours at 80°F., 16 hours at -67°F., 8 hours at 158°F., 16 hours at 80°F., and repeat (3-day cycle).

Table 2.--Dry joint strength values of birch plywood test specimens after exposure to the various temperature-time conditions indicated. All specimens tested at room temperature.

Cold-setting glues

Time of exposure	Dry joint strengths and percentages of wood failure[1]											
	Cold-setting urea-formaldehyde resin glues								Casein glues			
									Without preservative		With 5 percent pentachlorphenol	
	Plaskon 250-2	Perkins DC-246	Bakelite 12772 (hardener 16229)	Cascamite 44B[2]	Le Page's Panite	Cascamite ANS	Uformite CB-551	Lauxite 77X	Lauxein 888	Casco Aircraft Joint A	Lauxein 888	Casco Aircraft Joint A
Exposed continuously at 80°F. and 65 percent relative humidity												
Control[3]	450-93	451-83	433-59	405-52	451-87	537-68	468-78	484-94	512-23	455-3	462-61	358-3
1 week	499-91	442-86	481-90	430-63	443-94	413-74	414-80	474-96	456-22	426-2	458-53	389-4
3 weeks	469-96	418-88	384-62	425-55	412-100	461-100	412-64	478-100	488-34	446-3	456-38	458-4
2 months	499-80	432-90	470-61	437-50	435-82	472-64	427-54	539-99	485-40	453-0	465-60	430-22
3 months	496-88	398-78	396-61	377-21	436-69	396-22	413-71	474-96	489-76	429-4	448-15	439-14
4 months	488-65	423-73	414-52	378-23	434-75	438-64	387-53	472-98	439-41	379-0	456-25	380-44
6 months	499-64	391-48	423-44	361-15	366-37	404-100	350-32	453-66	493-40	432-1	460-52	413-0
9 months	399-37	382-58	388-30	334-24	374-28	470-64	366-27	--	549-51	460-12	423-74	431-55
12 months	396-32	347-11	350-21	286-10	390-67	427-66	392-42	--	--	--	--	--
Exposed continuously at 158°F. and 20 percent relative humidity												
Control[3]	461-90	448-95	376-52	394-66	473-78	397-61	486-71	524-87	474-23	454-36	466-5	363-1
1 week	395-81	329-66	377-24	249-5	300-62	296-44	369-36	428-60	412-2	375-9	402-29	305-10
3 weeks	333-58	316-55	323-12	221-5	287-6	332-30	299-21	425-36	353-14	341-20	395-46	305-4
2 months	419-32	291-43	344-7	228-62	297-6	352-5	310-4	426-63	380-20	360-20	393-26	337-4
3 months	345-45	269-21	292-2	224-4	258-1	269-20	287-1	331-73	443-56	374-45	406-9	340-24
4 months	329-39	281-8	295-2	185-2	283-0	279-5	260-0	387-43	371-28	309-13	337-40	289-33
6 months	321-59	235-4	244-2	101-0	223-0	216-0	227-0	359-47	398-9	360-62	446-68	361-22
9 months	267-34	214-3	116-0	8-0	198-0	234-0	217-1	--	416-36	346-75	340-32	294-32
12 months	279-15	205-4	166-0	59-0	222-2	221-3	223-7	--	--	--	--	--
Exposed continuously at 158°F. and 60 percent relative humidity												
Control[3]	412-95	434-100	454-81	392-43	452-60	415-81	478-60	520-96	522-34	438-15	440-61	348-2
1 week	368-49	368-70	294-8	277-23	311-40	327-33	372-9	435-54	466-42	392-23	419-94	361-34
3 weeks	304-16	289-38	220-0	176-30	251-9	272-3	268-0	364-14	430-22	419-36	401-84	410-57
2 months	247-3	233-2	211-0	133-0	218-3	217-2	229-1	262-9	477-34	456-32	405-34	376-33
3 months	208-2	238-4	133-0	105-0	160-0	170-0	178-0	166-9	449-22	437-66	401-27	402-38
4 months	167-0	120-0	105-0	72-0	98-0	122-0	150-0	143-0	458-45	388-54	414-48	341-60
6 months	173-0	124-0	51-0	76-0	68-0	100-0	103-0	0-0	412-30	438-70	409-14	364-10
9 months	8-0	16-0	0-0	0-0	0-0	0-0	0-0	--	417-48	416-58	384-6	349-34
12 months	0-0	57-0	0-0	0-0	0-0	0-0	0-0	--	--	--	--	--
Exposed to "room-high" cycle[4]												
Control[3]	466-100	443-98	487-94	379-16	488-98	413-100	440-49	534-95	503-90	413-41	444-30	389-3
1 week	416-54	372-80	380-60	213-0	342-52	397-70	373-33	445-100	457-100	378-47	401-25	372-5
3 weeks	397-44	349-74	405-29	296-23	367-62	406-23	321-19	482-100	445-62	422-42	377-41	360-7
2 months	394-63	306-58	366-10	236-45	339-32	347-22	341-13	423-77	484-62	413-48	377-43	356-5
3 months	406-64	296-24	328-17	235-1	354-52	316-18	373-17	356-53	440-66	421-41	389-44	387-19
4 months	348-86	283-23	319-4	204-2	315-24	317-5	311-16	368-36	450-80	379-46	395-24	371-38
6 months	325-27	277-18	255-1	155-1	232-3	256-22	204-2	304-9	456-74	383-0	405-1	337-18
9 months	263-23	242-16	233-0	0-0	233-6	292-20	255-1	--	443-32	408-30	332-42	368-24
12 months	288-29	236-10	255-16	52-0	270-8	300-9	179-0	--	--	--	--	--
Exposed to "room-low" cycle[5]												
Control[3]	392-78	426-81	477-49	420-85	432-95	413-69	454-80	508-91	516-46	462-28	480-44	375-6
1 week	451-93	412-56	492-80	440-68	436-100	392-80	431-96	543-100	511-30	478-24	501-44	395-10
3 weeks	470-98	381-68	412-81	380-53	403-100	425-80	415-77	523-98	539-44	457-13	472-46	430-9
2 months	451-100	362-55	468-61	420-32	430-100	465-66	438-82	551-98	541-66	504-10	500-57	431-6
3 months	500-100	443-81	418-73	421-54	432-73	397-55	447-78	486-95	535-28	493-14	506-14	453-7
4 months	463-100	471-95	457-85	366-32	388-84	409-41	384-74	485-90	526-39	432-71	484-24	433-64
6 months	508-84	422-69	436-59	413-29	375-66	471-90	406-64	482-87	518-34	480-45	516-4	442-9
9 months	440-98	390-68	383-11	341-7	400-62	430-80	402-24	--	544-40	504-39	442-12	481-56
12 months	389-100	379-30	359-22	319-10	440-72	423-73	352-34	--	--	--	--	--

Note: Where no test values are given, the tests have not yet been made.

(Continued)

[1] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2] Did not pass the acidity requirement of Specification AN-G-8; all other cold-setting urea-resin glues did pass this requirement.

[3] Tested after 1 week storage at 80°F., 65 percent relative humidity.

[4] Eight hours at +158°F., 16 hours at 80°F., and repeat.

[5] Eight hours at -67°F., 16 hours at 80°F., and repeat.

Table 2. Dry joint strength values of birch plywood test specimens after exposure to the various temperature-time conditions indicated. All specimens tested at room temperature. (Continued)

Low-temperature and hot-setting resin-glues

Time of exposure	Dry joint strengths and percentages of wood failure[1]										
	Low temperature phenolic-resin glues[2]			Hot-setting phenolic-resin glues		Hot-setting urea-resin glue	Fortified urea-resin glues			Urea-melamine resin glue	Hot-setting melamine resin glue	Modified vinyl resin glue
	Cascophen LT67	Durez 12041	Bakelite 3931	Bakelite 7381	Bakelite 13268	Uformite 430 (hardener Y)	Plaskon 700-2	Bakelite 12772 (hardener 15287)		Perkins M-411	Melmac 400	du Pont 4624
Exposed continuously at 80°F. and 65 percent relative humidity												
Control[3]	442-67	404-100	313-12	405-61	419-24	393-100	508-79	498-94		473-81	456-71	578-81
1 week	413-52	448-90	379-26	406-44	519-61	403-100	540-81	505-90		496-84	491-80	457-80
3 weeks	483-71	481-95	375-13	413-31	401-25	371-100	539-84	573-100		507-97	475-98	564-87
2 months	469-68	464-100	370-18	342-24	444-22	417-100	538-79	565-100		452-70	519-100	602-100
3 months	464-72	482-100	409-22	407-21	455-34	410-100	575-80	523-100		471-100	517-96	546-100
4 months	474-82	443-90	365-31	389-22	433-56	361-100	573-64	533-96		484-100	512-100	587-100
6 months	518-91	431-81	396-41	389-3	376-20	378-100	613-100	626-98		471-99	463-100	601-100
9 months	443-70	408-84	372-28	378-64	518-44	366-98	533-66	518-100		432-96	470-92	501-98
12 months	504-97	404-99	395-63	411-62	--	--	--	--		--	470-100	--
Exposed continuously at 158°F. and 20 percent relative humidity												
Control[3]	423-46	431-84	366-24	398-93	376-39	424-98	504-74	466-82		462-96	454-100	527-100
1 week	415-85	366-100	338-64	390-94	401-65	364-59	464-55	436-74		404-100	457-100	517-98
3 weeks	401-98	378-82	338-64	395-100	387-36	340-27	470-27	479-81		428-90	438-100	504-91
2 months	424-98	301-99	372-79	390-45	421-36	314-42	429-42	445-50		432-74	324-100	515-100
3 months	370-100	339-100	393-74	422-52	450-40	329-27	447-36	444-62		416-96	395-100	449-100
4 months	362-95	219-100	233-88	394-81	391-44	340-39	433-26	424-36		401-100	444-100	450-100
6 months	367-100	224-100	241-100	323-94	408-53	318-8	417-40	507-2		454-82	400-90	451-100
9 months	311-100	295-96	250-100	353-74	451-74	281-28	348-8	371-7		422-96	381-86	464-100
12 months	374-100	261-100	242-90	431-65	--	--	--	--		--	399-100	--
Exposed continuously at 158°F. and 60 percent relative humidity												
Control[3]	398-50	387-55	331-12	383-78	395-56	435-100	582-81	514-100		451-91	452-100	647-100
1 week	445-88	369-97	329-29	299-52	424-48	405-86	505-85	520-76		479-98	492-99	545-99
3 weeks	425-100	295-88	355-66	373-32	404-29	371-94	471-58	497-52		493-90	425-81	544-97
2 months	362-99	272-100	333-92	390-43	427-8	386-80	420-60	416-50		461-63	407-46	504-100
3 months	447-100	291-100	321-81	431-58	441-35	366-64	421-62	442-61		449-88	433-99	420-100
4 months	409-100	196-100	278-81	405-42	342-38	323-22	417-25	405-26		414-48	425-86	425-100
6 months	430-100	191-100	302-99	435-50	415-7	291-4	298-1	376-5		386-30	440-75	425-100
9 months	382-100	198-100	274-86	370-60	417-21	263-12	281-5	253-2		364-64	376-87	343-100
12 months	346-100	212-100	243-97	409-91	--	--	--	--		--	426-95	--
Exposed to "room-high" cycle[4]												
Control[3]	432-57	383-66	320-35	403-47	411-28	398-100	543-100	513-99		414-76	455-100	646-100
1 week	406-82	376-98	326-64	391-42	484-58	375-98	508-92	491-93		442-82	485-100	589-100
3 weeks	407-99	368-93	341-30	375-52	395-35	361-87	485-26	500-98		434-96	454-100	571-96
2 months	389-97	336-100	392-15	380-75	431-49	328-70	501-79	525-100		432-94	439-96	556-100
3 months	426-100	383-100	326-43	359-60	427-60	381-56	476-80	475-100		418-100	421-100	519-100
4 months	415-100	293-100	293-82	364-61	416-33	348-94	397-26	485-63		432-86	426-100	491-100
6 months	389-100	260-100	280-72	427-50	457-27	367-34	431-57	583-74		391-99	412-100	522-100
9 months	386-80	252-100	345-80	391-84	437-33	334-27	448-28	480-57		452-91	394-100	458-100
12 months	371-85	275-100	286-84	441-96	--	--	--	--		--	447-100	--
Exposed to "room-low" cycle[5]												
Control[3]	439-77	397-66	301-0	365-48	421-60	387-84	561-82	475-100		469-100	438-80	664-100
1 week	445-51	433-63	303-2	405-41	554-56	389-97	581-100	528-65		496-100	497-100	680-100
3 weeks	446-51	464-99	316-0	451-32	516-37	385-98	636-96	554-100		485-87	474-100	612-91
2 months	443-61	433-62	384-11	436-22	516-38	356-100	567-81	526-100		480-82	479-100	611-100
3 months	494-83	475-78	308-0	483-47	493-14	368-100	537-90	547-100		517-100	500-100	606-100
4 months	435-25	427-81	363-6	441-50	461-13	399-100	603-80	540-100		510-90	479-100	583-100
6 months	436-51	424-100	313-3	454-50	463-19	422-98	569-100	665-93		524-88	516-100	560-100
9 months	444-46	461-100	365-4	355-20	476-56	403-98	544-74	586-98		494-85	460-100	552-100
12 months	490-82	421-90	367-5	463-71	--	--	--	--		--	515-100	--

Note: Where no test values are given, the tests have not yet been made.

[1] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2] These specimens were cured for 16 hours at 140°F.

[3] Tested after 1 week storage at 80°F.; 65 percent relative humidity.

[4] Eight hours at +158°F., 16 hours at 80°F., and repeat.

[5] Eight hours at -67°F., 16 hours at 80°F., and repeat.

Table 3.--Wet joint strength values of birch plywood test specimens after exposure to the various temperature-time conditions indicated. All specimens tested at room temperature. (Continued)

Low-temperature and hot-setting resin-glues

Time of exposure	Wet joint strengths and percentages of wood failure after immersion in water at room temperature for 48 hours[1]										
	Low-temperature phenolic-resin glues[2]			Hot-setting phenolic-resin glues		Hot-setting urea-resin glue	Fortified urea-resin glues		Urea-melamine resin glue	Hot-setting melamine-resin glue	Modified vinyl-resin glue
	Cascophen LT67	Durez 12041	Bakelite 3931	Bakelite 7381	Bakelite 13268	Uformite 430 (hardener Y)	Plaskon 700-2	Bakelite 12772 (hardener 15287)	Perkins M-411	Melmac 400	du Pont 4624
Exposed continuously at 80°F. and 65 percent relative humidity											
Control[3]	443-65	494-99	340-23	460-90	487-18	371-96	562-100	498-100	507-100	509-100	521-100
1 week	429-43	473-94	322-17	441-65	456-37	369-100	617-100	522-98	559-100	495-100	516-96
3 weeks	450-45	510-100	407-20	453-12	437-35	361-100	600-100	516-100	562-100	521-100	524-84
2 months	448-54	497-98	344-21	489-24	461-12	327-100	643-98	500-100	527-83	516-100	485-100
3 months	459-63	467-100	392-21	483-43	458-39	327-100	572-100	471-100	484-100	527-100	475-100
4 months	503-80	476-95	387-27	423-41	461-46	332-93	558-94	482-100	527-100	503-100	512-100
6 months	467-82	440-100	368-49	443-42	450-16	363-100	584-99	568-99	542-100	488-100	476-94
9 months	481-91	414-100	350-39	489-14	453-35	346-94	557-95	492-99	505-100	489-100	477-98
12 months	511-100	409-100	392-61	445-8	--	--	--	--	--	491-100	--
Exposed continuously at 158°F. and 20 percent relative humidity											
Control[3]	471-53	464-100	338-59	463-83	476-35	351-100	516-100	536-100	464-80	479-100	487-100
1 week	518-90	390-100	363-88	467-45	451-93	367-100	531-100	521-96	502-98	460-100	480-100
3 weeks	561-100	373-100	388-97	489-49	436-31	353-84	470-80	509-100	486-100	464-100	478-96
2 months	524-100	320-100	272-100	482-70	445-26	309-100	468-80	485-98	441-88	460-100	433-100
3 months	499-100	289-100	277-100	493-65	450-54	322-100	449-92	462-100	433-100	444-100	399-100
4 months	563-100	278-100	238-100	475-100	427-30	285-90	488-79	521-98	420-100	431-100	420-100
6 months	502-100	199-100	217-100	514-80	433-17	279-100	452-80	467-95	460-90	425-100	403-97
9 months	468-100	241-100	217-100	490-78	430-66	285-98	454-67	466-94	420-100	462-100	417-98
12 months	487-100	252-100	181-100	473-100	--	--	--	--	--	429-100	--
Exposed continuously at 158°F. and 60 percent relative humidity											
Control[3]	396-51	521-100	325-32	486-44	470-53	371-93	594-100	546-100	462-96	505-100	423-100
1 week	495-99	383-100	401-95	553-44	465-98	386-100	570-100	592-86	504-98	508-98	449-98
3 weeks	532-100	240-100	357-98	557-71	466-52	403-99	605-98	553-100	474-100	462-100	418-97
2 months	536-100	237-100	351-100	544-100	432-60	364-100	565-70	490-80	455-80	464-100	381-96
3 months	473-100	247-100	289-100	546-96	484-98	367-100	541-92	477-90	407-98	460-100	364-90
4 months	503-100	214-100	264-100	539-98	432-100	322-85	450-61	411-12	434-100	469-100	400-100
6 months	508-100	177-100	254-100	513-92	358-48	281-30	346-9	284-3	294-37	391-100	341-96
9 months	461-100	163-100	272-100	478-100	320-60	268-35	297-0	254-9	328-98	457-99	356-100
12 months	483-100	152-100	235-100	404-100	--	--	--	--	--	396-100	--
Exposed to "room-high" cycle[4]											
Control[3]	419-64	519-100	355-5	472-67	464-32	359-72	574-90	487-100	471-90	498-100	441-100
1 week	491-62	443-100	362-3	517-32	478-87	394-100	639-80	527-98	470-100	469-100	483-100
3 weeks	578-100	412-100	356-52	450-70	483-10	345-82	535-100	524-100	494-100	458-100	481-100
2 months	549-85	346-100	355-65	462-72	455-14	327-100	531-80	482-100	492-100	449-100	466-100
3 months	560-100	333-100	362-74	464-91	451-40	322-100	520-90	474-100	437-100	483-100	429-100
4 months	570-80	339-100	320-100	443-68	443-80	318-82	481-76	435-80	406-100	423-100	462-100
6 months	524-100	235-100	275-100	479-94	448-50	315-98	501-67	497-95	424-100	446-100	399-100
9 months	517-100	271-100	278-100	538-77	441-82	340-87	469-94	418-96	408-100	483-100	386-96
12 months	488-100	205-100	285-100	462-80	--	--	--	--	--	391-100	--
Exposed to "room-low" cycle[5]											
Control[3]	456-80	472-100	346-2	491-92	455-24	362-78	580-100	516-100	511-98	500-100	435-88
1 week	440-75	470-100	384-7	499-30	426-48	375-100	611-100	535-99	565-98	531-100	455-86
3 weeks	442-76	520-72	397-10	465-48	442-40	371-94	600-100	563-100	573-100	437-100	496-100
2 months	436-58	483-80	327-6	475-24	430-12	346-100	627-100	536-100	544-100	513-100	468-100
3 months	457-61	518-84	407-6	499-58	449-48	329-100	561-100	532-100	515-100	535-100	441-100
4 months	476-80	508-100	393-5	522-36	436-56	325-90	593-100	559-98	508-100	540-100	490-100
6 months	483-80	493-100	406-1	521-73	478-30	361-100	628-98	518-98	530-100	497-100	430-100
9 months	524-75	429-100	392-3	545-50	487-62	375-94	630-98	576-98	470-100	548-99	437-99
12 months	475-98	421-100	391-60	483-60	--	--	--	--	--	438-100	--

Note: Where no test values are given, the tests have not yet been made.

[1] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2] These specimens were cured for 16 hours at 140°F.

[3] Tested after 1 week storage at 80°F., 65 percent relative humidity.

[4] Eight hours at +158°F., 16 hours at 80°F., and repeat.

[5] Eight hours at -67°F., 16 hours at 80°F., and repeat.

Table 3.--Wet joint strength values of birch plywood test specimens after exposure to the various temperature-time conditions indicated. All specimens tested at room temperature

Cold-setting glues

Time of exposure	Wet joint strengths and percentages of wood failure after immersion in water at room temperature for 48 hours[1]											
	Cold-setting urea-formaldehyde resin glues							Casein glues				
								Without preservative			With 5 percent pentachlorphenol	
	Plaskon 250-2	Perkins DC-246	Bakelite 12772 (hardener 16229)	Cascamite 44-B[2]	Le Page's Panite	Cascamite ANS	Uformite CB-551	Lauxite 77-X	Lauxein 888	Casco Aircraft Joint A	Lauxein 888	Casco Aircraft Joint A
Exposed continuously at 80°F. and 65 percent relative humidity												
Control[3]	467-97	458-99	486-87	355-24	380-100	437-80	469-62	475-90	205-1	206-2	270-6	245-4
1 week	477-89	438-96	448-98	347-31	391-100	497-80	490-97	522-100	222-10	208-1	291-17	254-4
3 weeks	456-100	380-84	408-100	308-9	382-99	427-45	446-60	490-100	208-0	204-3	282-8	298-4
2 months	481-98	420-81	455-100	302-1	406-100	402-30	417-27	478-98	214-1	198-4	275-0	258-8
3 months	483-98	423-98	446-80	285-2	438-95	447-100	405-64	444-99	219-1	188-0	277-16	250-7
4 months	490-100	470-100	462-70	293-0	442-100	405-21	415-37	474-70	212-4	202-4	291-24	278-16
6 months	477-100	421-90	425-41	273-0	370-98	379-20	266-30	420-100	218-1	185-6	235-2	242-9
9 months	421-76	414-51	366-11	230-0	367-34	329-1	355-36	--	214-2	200-6	274-28	259-13
12 months	415-86	375-38	345-48	192-0	345-58	317-26	359-19	--	--	--	--	--
Exposed continuously at 158°F. and 20 percent relative humidity												
Control[3]	451-77	434-88	448-82	293-13	398-100	440-80	458-39	499-84	200-0	222-1	273-6	239-5
1 week	388-86	334-70	309-24	142-0	285-62	346-26	343-48	438-100	224-0	222-2	264-13	250-24
3 weeks	337-64	328-72	289-2	101-2	279-30	320-1	287-25	398-100	220-0	221-0	279-17	251-11
2 months	354-42	314-38	277-0	133-0	267-43	269-2	210-20	379-47	226-1	212-0	261-12	238-10
3 months	334-28	304-2	258-0	107-0	238-2	234-1	233-20	366-93	217-0	192-11	254-16	222-12
4 months	286-25	250-6	208-0	89-0	224-0	240-1	230-0	357-48	207-0	220-16	226-6	239-33
6 months	249-10	232-15	170-0	52-0	183-0	197-0	187-0	323-90	210-0	182-0	233-6	201-3
9 months	244-3	174-0	0-0	0-0	183-0	141-0	160-0		201-5	210-4	246-15	219-29
12 months	249-50	196-0	148-2	0-0	191-1	148-0	192-0	--	--	--	--	--
Exposed continuously at 158°F. and 60 percent relative humidity												
Control[3]	442-93	443-100	404-68	342-10	358-82	466-100	424-72	543-100	187-0	219-3	266-0	260-5
1 week	454-62	344-54	320-41	183-6	261-62	337-40	340-1	502-66	230-2	242-1	303-14	280-14
3 weeks	278-23	256-28	235-3	144-36	249-36	250-0	244-0	322-10	234-2	254-4	288-26	284-10
2 months	248-0	246-3	213-1	103-0	231-25	194-2	148-0	175-4	252-23	284-18	298-26	266-11
3 months	193-1	185-0	144-2	66-0	148-0	130-0	143-0	103-0	253-11	291-10	299-25	272-68
4 months	140-0	86-0	62-0	51-0	90-0	114-0	98-0	89-0	237-7	294-26	281-18	273-48
6 months	153-0	77-0	0-0	57-0	82-0	83-0	108-0	0-0	234-0	245-19	260-24	231-24
9 months	0-0	0-0	0-0	0-0	0-0	0-0	0-0	--	222-6	239-10	241-19	245-11
12 months	0-0	0-0	0-0	0-0	0-0	0-0	0-0	--	--	--	--	--
Exposed to "room-high" cycle[4]												
Control[3]	461-50	460-100	414-88	362-43	359-100	435-94	447-46	525-92	170-0	219-0	244-11	256-2
1 week	419-69	404-90	415-86	161-0	364-89	430-88	375-20	469-100	236-3	239-0	275-10	263-15
3 weeks	408-90	350-73	331-61	145-2	332-57	374-49	342-1	426-100	219-0	237-0	250-14	267-9
2 months	435-98	373-74	330-30	147-0	319-42	342-34	273-1	429-66	240-0	239-0	260-0	259-5
3 months	393-76	350-64	361-42	148-0	303-56	334-27	285-0	413-94	231-0	242-3	248-20	269-8
4 months	352-55	319-61	329-21	100-0	276-52	313-15	271-0	393-56	220-2	245-0	245-8	274-22
6 months	337-57	274-42	209-20	70-0	232-14	217-4	163-0	357-50	220-4	214-0	235-11	227-12
9 months	312-28	230-3	219-1	0-0	203-20	209-0	198-1	--	218-11	235-3	233-21	247-10
12 months	266-6	242-37	179-1	0-0	229-20	216-0	185-2	--	--	--	--	--
Exposed to "room-low" cycle[5]												
Control[3]	465-81	466-98	451-94	330-13	473-90	400-98	373-69	492-98	173-0	231-2	250-1	256-1
1 week	444-98	475-97	464-74	347-7	413-100	418-90	394-82	512-96	217-0	227-0	288-5	268-5
3 weeks	433-100	454-75	443-91	289-2	451-77	428-75	458-88	521-100	222-0	242-0	298-9	278-3
2 months	465-100	461-98	489-82	316-2	449-98	415-94	432-64	498-100	267-0	250-0	309-10	263-32
3 months	463-100	446-100	518-100	328-13	421-99	438-92	423-94	452-100	282-1	260-15	290-14	291-27
4 months	443-100	453-92	486-67	291-27	464-100	452-81	399-85	502-90	273-4	272-20	299-10	293-64
6 months	470-99	456-100	449-51	280-16	457-100	431-62	400-92	477-100	274-1	245-0	273-14	266-14
9 months	477-98	432-70	386-41	237-8	426-85	384-40	372-66	--	262-6	296-26	295-60	276-7
12 months	421-100	422-100	385-30	248-0	426-97	371-44	440-60	--	--	--	--	--

Note: Where no test values are given, the tests have not yet been made.

(Continued)

[1] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2] Did not pass the acidity requirement of Specification AN-G-8; all other cold-setting urea-resin glues tested did pass this requirement.

[3] Tested after 1 week storage at 80°F., 65 percent relative humidity.

[4] Eight hours at +158°F., 16 hours at 80°F., and repeat.

[5] Eight hours at -67°F., 16 hours at 80°F., and repeat.

Table 4.--Dry joint strength values of birch plywood test specimens after exposure to the "low-high" cycle. All specimens tested at room temperature.

Time of exposure	Dry joint strengths and percentages of wood failure[1]											
	Cold-setting urea-formaldehyde resin glues			Low-temperature phenolic resin	Hot-setting blood-phenolic resin	Fortified urea-formaldehyde resin glues		Hot-setting urea-formaldehyde resin glues		Hot-setting melamine	Thermoplastic
	Plaskon 250-2	LePage[2] Plastic Resin	Bakelite 12772[3] (Hardener 14388)	Durez 12041	Amberlite PR-23	Uformite 430-Q	Plaskon 700-2 (Hardener 700-B)	Bakelite 12772 (Hardener 14282)	Plaskon 107-2 (Hardener 7)	Melmac S-77-V	Butacite 4639
Control[4]	460-91	361-51	430-78	390-16	433-10	422-90	472-84	401-69	435-84	506-99	517-86
5 weeks	310-9	208-5	286-0	400-61	376-28	379-79	373-96	236-3	346-11	403-99	529-70
10 weeks	383-38	234-0	264-0	368-97	428-26	378-100	335-3	264-3	356-40	444-100	510-64
15 weeks	356-46	222-4	226-0	347-98	424-80	370-95	302-4	263-0	318-10	408-75	561-60
20 weeks	324-25	226-0	130-0	326-82	377-50	390-79	250-0	223-0	236-4	415-83	576-88
25 weeks	278-3	156-1	155-0	351-97	386-34	388-60	318-24	199-0	305-12	415-83	538-78
30 weeks	283-1	143-0	63-0	336-98	414-56	329-79	237-0	179-0	248-8	391-86	569-100
35 weeks	271-16	169-0	74-0	269-78	385-49	361-61	229-0	169-0	259-0	328-80	581-98
40 weeks	260-0	150-0	14-0	299-98	319-59	322-80	233-0	123-0	238-0		572-80
45 weeks	256-0	112-0	10-0	293-100	386-40	316-37	306-36	119-0	276-2	404-100	561-74
50 weeks	246-0	93-0	10-0	329-85	377-29	334-34	197-0	77-0	230-0	454-100	520-80
55 weeks	314-11	170-0	0-0	332-100	372-42	363-96	224-5	203-4	266-2	442-96	445-56

[1]The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2]This is not the same as LePage Panite in tables 2 and 3.

[3]Did not pass Specification AN-G-8. Other cold-setting urea-resin glues in this table did pass this specification as far as pH was concerned.

[4]Original dry strength after 1 week at 80°F., 65 percent relative humidity.

Table 5.--Dry joint strength values of birch plywood test specimens after exposure to the time-temperature conditions indicated. All tests were made at room temperature but, as indicated, some of the specimens were still hot at time of test.

Time of exposure	Dry joint strengths and percentages of wood failure[1]							
	Cold-setting urea-formaldehyde resin glues			Hot-setting phenolic-film	Fortified hot-setting urea resin	Hot-setting urea resin	Casein	Thermoplastic
	Plaskon 201-2A	LePage's[2] Plastic Resin	Bakelite 12772[3] (Hardener 14512)	Tego	Plaskon 700-2	Bakelite 12772 (Hardener 14282)	Casein 4B	Butacite 4639
Exposed continuously at 80° F., 65 percent relative humidity								
1 week	412-90	341-60	388-25	430-73	432-99	432-100	406-85	484-60
2 weeks	355-94	300-35	412-35	398-95	420-93	386-100	376-61	504-39
3 weeks	360-98	336-52	409-26	371-75	375-88	399-81	405-81	510-39
4 weeks	343-69	350-64	404-15	368-76	403-98	425-100	404-50	499-21
6 weeks	329-28	320-32	392-12	391-88	417-99	444-99	383-31	502-28
2 months	421-100	351-68	389-15	431-94	447-98	414-90	430-90	508-13
3 months	362-100	305-66	346-2	392-72	404-99	363-100	386-59	478-32
6 months	373-78	--	338-42	391-58	423-98	392-100	388-58	530-44
12 months	297-53	237-8	217-0	369-65	385-100	398-96	369-59	410-34
Exposed continuously at 158° F., 20 percent relative humidity. Tested hot immediately upon removal from exposure conditions.								
1 week	269-55	228-5	236-0	340-67	336-64	364-94	308-17	406-42
2 weeks	249-58	187-2	240-0	299-70	311-62	282-100	264-22	423-29
3 weeks	280-51	259-6	276-2	345-78	320-75	331-50	325-67	334-13
4 weeks	211-3	209-3	247-0	328-91	303-56	307-61	310-47	323-0
6 weeks	218-0	184-0	247-0	308-76	286-58	304-27	280-38	342-4
2 months	231-18	217-0	239-0	317-86	293-42	291-28	324-55	352-5
3 months	245-42	207-0	193-0	342-61	292-52	289-25	299-30	348-25
6 months	226-29	--	182-0	294-61	285-1	257-1	285-15	286-25
12 months	189-0	134-0	92-0	323-65	239-0	208-0	290-5	280-27
Exposed continuously at 158° F., 20 percent relative humidity, then stored at 80° F., 65 percent relative humidity for 48 hours before testing.								
1 week	318-63	232-3	314-12	420-91	375-85	409-83	346-51	466-50
2 weeks	301-48	274-2	319-5	407-90	402-73	426-84	381-49	488-26
3 weeks	299-49	264-4	313-14	392-64	372-62	426-88	399-75	369-12
4 weeks	238-2	282-2	381-22	393-71	382-92	392-99	373-35	386-10
6 weeks	234-0	199-1	270-0	408-100	353-84	395-64	346-34	380-13
2 months	312-54	211-0	256-0	372-83	347-52	302-50	359-35	390-12
3 months	280-62	218-0	250-0	369-75	323-45	342-76	325-26	513-33
6 months	291-18	--	228-0	367-55	298-45	325-20	313-29	511-30
12 months	177-0	162-0	83-0	308-63	271-7	216-0	284-8	349-74

[1] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure. Each value is the average for five specimens.

[2] This is the same glue as listed in table 4.

[3] Did not pass Specification AN-G-8. Other cold-setting urea-resin glues listed in this table did pass this specification as far as pH was concerned.

Note: Where no test values are given tests have not yet been made.

Table 6.--Dry and wet joint strength values of birch plywood test specimens after exposure at 200°F., 20 percent relative humidity[1]. All specimens tested at room temperature

Time of exposure	Casein glues				Cold-setting urea-resin glue	Hot-setting urea-resin glue	Fortified urea-resin glues		Urea-melamine resin glue	Hot-setting phenolic-resin glue	Modified vinyl resin-glue
	Without preservative		With 5 percent pentachlorphenol								
	Lauxein 888	Casco Aircraft Joint A	Lauxein 888	Casco Aircraft Joint A	Lauxite 77-X	Uformite 430 (hardener Y)	Plaskon 700-2	Bakelite 12772 (hardener 15287)	Perkins M-411	Bakelite 13268	du Pont 4624
Dry joint strengths and percentages of wood failure[2]											
Control[3]	495-59	490-22	553-92	436-22	491-98	372-100	495-82	460-100	516-100	470-50	540-100
1 week	412-72	333-26	340-73	289-5	329-27	325-56	430-10	418-83	464-96	382-22	584-100
1 month	390-39	315-20	352-31	421-79	269-2	259-9	271-0	292-27	305-7	377-44	458-76
2 months	312-29	248-25	289-37	257-8	193-1	224-0	259-0	281-15	309-54	355-12	334-92
3 months	249-23	241-0	236-64	281-63	67-2	152-5	144-0	190-20	232-14	235-40	312-100
4 months	237-6	244-0	253-24	287-43	64-0	145-0	159-0	176-1	222-3	275-22	302-100
Wet joint strengths and percentages of wood failure, after immersing in water at room temperature for 48 hours[2]											
Control[3]	223-(a)	268-37	285-18	287-21	480-(a)	360-(a)	558-(a)	483-(a)	500-(a)	442-(a)	447-(a)
1 week	217-9	254-15	258-12	263-27	379-62	321-98	504-92	436-100	472-96	451-21	434-90
1 month	185-2	224-1	230-16	220-15	199-2	263-81	371-44	369-92	417-100	401-29	380-100
2 months	189-15	209-4	217-3	219-22	153-9	233-67	303-10	297-43	417-98	400-42	379-100
3 months	158-3	177-5	230-11	209-17	81-0	161-6	184-2	239-11	333-95	381-51	361-100
4 months	149-1	164-3	202-11	328-98	0-0	129-0	142-1	210-13	191-29	320-56	349-100

(a) Through error, data on wood failure not obtained.

[1] These tests were run as preliminary experiments using test specimens which had been prepared for another study five months earlier and which had been stored during this period at 80°F., 65 percent relative humidity.

[2] The first value represents the joint strength in pounds per square inch; the second values represent the percentage of wood failure. Each value is the average for five specimens.

[3] Tested after all specimens had been stored for approximately 5 months at 80°F., 65 percent relative humidity before the tests began.

Table 7.--Dry and wet joint strength values of birch plywood specimens after exposure at 200° F., 20 percent relative humidity. All specimens tested at room temperature.

Time of exposure	Cold-setting urea-resin glues					Low-temperature phenolic-resin glues[1]			Resorcinol-resin glue[2]	Hot-setting phenolic-resin glues		Urea-melamine resin glue	Hot-setting melamine-resin glue	
	Bakelite 12772 Hardener 16229	Cascamite ANS	Plaskon 250-2	Uformite CB-551	Lauxite 77X	Cascophen LT 67	Resinox 230	G. E. Textolite 2163	Penacolite G-1124	Amberlite PR-14	Bakelite 16200	Lauxite MU-260	Resamine 840	Resamine 841 (film)
	Dry joint strengths and percentages of wood failure[3]													
Control[4]	430-77	440-45	428-99	380-60	395-55	452-91	417-96	454-90	559-86	527-88	363-26	567-99	557-100	472-56
2 months[5]	161-1	91-0	196-0	0-0	109-15	365-99	289-98	391-80	345-99	335-99	291-100	385-88	476-58	385-89
4 months[5]	90-0	0-0	118-4	10-0	85-3	273-89	243-100	235-75	284-100	323-98	258-100	370-74	388-96	318-68
	Wet joint strengths and percentages of wood failure, after immersion in water at room temperature for 48 hours[3]													
Control[4]	393-41	413-59	430-98	363-38	409-62	465-97	451-97	497-100	513-98	401-66	354-3	553-99	563-100	346-43
2 months[5]	0-0	35-0	138-5	0-0	35-0	413-100	321-100	343-100	410-100	403-100	383-100	450-100	390-100	291-88
4 months[5]	0-0	21-25	84-5	0-0	31-2	334-100	326-100	260-100	409-100	379-88	396-100	208-100	399-100	269-94

[1] These specimens were cured for 24 hours at 180° F.

[2] These specimens were cured for 24 hours under pressure at 80° F., followed by the usual conditioning period of at least one week at 80° F.

[3] The first value represents the joint strength in pounds per square inch; the second value represents the percentage of wood failure.

[4] Each control value is the average for 40 specimens.

[5] Each test value is the average for 5 specimens.

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