EXPERIMENTS TO DEVELOP A RAPID DURABILITY TEST FOR UREA-RESIN GLUES

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EXPERIMENTS TO DEVELOP A RAPID DURABILITY TEST FOR UREA-RESIN GLUES[1]

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Summary

Six experiments were conducted progressively for the purpose of developing a rapid durability test for urea-resin glues. The first four were unsuccessful, the fifth showed promise, and the sixth appears to present a workable test. The method found to be workable, according to the sixth experiment, will be tried with a variety of urea-resin glues, both cold-setting and hot-setting, to ascertain the variability of different urea-resin glues when tested by this method.

Introduction

Previous long-term durability tests made at various temperatures and relative humidity conditions have shown that wood-to-wood plywood joints made with urea-formaldehyde resin glues lose strength when exposed to elevated temperatures and that the rate of strength loss increases when the relative humidity increases. Accompanying these losses were indications that different urea resins may vary in their resistance to degradation by heat and moisture. From such experience it seemed likely that an investigation of the effects of heat and humidity upon urea-resin-glued joints might lead to a rapid means of distinguishing between urea resins of different durabilities.

In many applications where urea resins are used it is important that they have the highest degree of durability possible. Therefore an easy, rapid, and satisfactory means of estimating the durability of urea resins is desirable both for specification purposes and as an aid to glue manufacturers in formulating urea-resin glues of superior durability. For these reasons, a search for a suitable, rapid laboratory method of determining durability of urea-resin glues was begun at the Forest Products Laboratory.[2]

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[1] This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

[2] This investigation was discussed in July 1944, with members of a British Wood Aircraft Mission to the United States under the auspices of the Ministry of Aircraft Production, and parts of the experiments were outlined at that time.

General Experimental Technique

The glues used in this study were cold-setting urea-formaldehyde resin glues commercially produced in the United States. They were mixed and used in accordance with the manufacturers' instructions.

The plywood was three-ply, made of 1/16-inch rotary-cut yellow birch veneer, selected for straightness of grain and freedom from defects, cut to 5 by 12 inches in size, and conditioned to approximately 12 percent moisture content before gluing.

On each side of the core ply of each panel, approximately 10 grams of wet glue was spread. A closed assembly time of 10 to 15 minutes was allowed before pressure was applied. The pressure was approximately 150 pounds per square inch and was held 15 to 18 hours in a room at 24° C. (75° F.). After pressing, the panels were conditioned for at least 6 days in an atmosphere of 27° C. (80° F.) and 65 percent relative humidity, then cut into standard plywood shear-test specimens, 10 from each panel, of the type shown in figure 1, Specimen A.

The containers for exposing the shear-test specimens were 1-quart cylindrical tin cans, with wide mouths capable of being tightly closed with friction lids, and fruit jars with screw caps and rubber ring gaskets of pint and quart capacities. The specimens were placed vertically in these containers and rested on a wire screen 1/2 to 1 inch from the bottom. The specimens were held apart from each other and from the walls of the container by metal paper clips on both ends in order to allow circulation of air. Heating of the containers and their contents was in an electric oven that was thermostatically controlled.

For determining the effects of the exposure, the specimens were tested to failure in the conventional plywood shear-test machine. The grips in the test machine were approximately 1-1/4 inches apart, as shown in figure 2, and the load was applied at 600 to 800 pounds per minute. The failing loads were read in pounds and were expressed in pounds per square inch of shear area. The percentages of the shear area that broke in the wood were estimated by visual inspection.

Experiment I. Exploratory Tests on Urea-resin-glued Joints Exposed to Miscellaneous Conditions

Early in 1944, a number of miscellaneous exposure tests were made to get an estimation of the rate at which urea-resin-glued joints could be expected to decrease in strength under various conditions. The conditions and results of these experiments are listed in table 1.

The data of series A, table 1, show that some decrease in strength took place in the urea-resin joints heated in the dry atmosphere of an oven at 90° C. (194° F.), that the decrease varied with the particular glue, but

that the decrease in strength for most of the glues was not great, even after 96 hours in the oven. It is noteworthy that there was no significant change in wood failure in this series.

The data of series B, table 1, show that drying wet specimens in an oven at 90° C. (194° F.) reduced the joint strengths to some extent and that different glues seem to react differently to this treatment, but that it would take several repetitions of the soaking and drying to reduce the strengths greatly. The same is true for the data of series C. Series D, on the other hand, shows that a rapid degradation of joint strength was produced by maintaining a high moisture content in the specimens while they were being heated at 90° C., (194° F.) and that the several urea-resin glues performed differently. These results indicate that a steaming treatment, somewhat less drastic than that of series D, offers promise of a suitable test for distinguishing rapidly between the resistance of different urea-resin glues to heat and moisture.

Experiment II. Cyclic Exposure of Urea-resin-glued Plywood at 90° C. (194° F.) in a Vented Container[3]

The specimens were of about 13 percent moisture content at the start. The containers were 1-quart cylindrical tin cans with wide mouths capable of being tightly closed with a friction lid. To equalize air pressure inside and outside the cans, a 1-millimeter hole had been bored in the center of each lid. In each can, 10 specimens were placed and this number was held nearly constant except for the last exposure period, when only 5 remained. No water was added to these cans. The cans were covered with the lids, placed in an oven at 90° C. (194° F.), and allowed to remain there until the glue lines had been at this temperature ±1° C. (1.8° F.) for 3 hours, as ascertained by a thermocouple embedded between the plies of one of the specimens. The total time in the oven for each cycle was about 4 hours, after which the cans with their contents were moved to a room at 27° C. (80° F.) and 65 percent relative humidity, cooled, and allowed to stand without cover in this room for the remainder of 24 hours to complete the cycle. This cycle was repeated 15 times. Between cycles groups of five specimens were removed, weighed twice (once after the oven and again after the cool portion of the cycle), soaked in water for 24 hours, tested wet

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[3] The details of this experiment were agreed upon in collaboration with the British Wood Aircraft Mission. Exposure conditions were chosen that were thought to simulate fairly closely extreme conditions often encountered in wood parts of airplanes suffering rapid changes in temperature. Calculations indicated that, assuming no loss of moisture from the container by slow diffusion during the exposure, the moisture content of the wood would be reduced but very little by the increase in temperature, whereas the relative humidity of the ambient air within the container would be increased to a relatively high percentage. Under these conditions it was expected that urea-resin-glued joints would undergo, with sufficient rapidity to make the test both practical and convenient, the kind of deterioration that would occur in service.

for shear strength, and oven dried for moisture content determination. The data obtained are presented in table 2.

In this experiment the moisture content of the wood changed more than calculations had indicated. Some moisture undoubtedly escaped through the small vent hole as the can breathed with the temperature fluctuations within the oven. When the cans were opened an appreciable amount of water had condensed on the inside walls, the amount becoming less the greater the number of cycles. In the time that the specimens were in the cool portion of the cycle, approximately 20 hours, they never regained the original average moisture content level.

It is apparent from the data of table 2 that the joint strengths are caused to decrease very slowly by this cyclic exposure. A quicker method would be desirable for a specification test.

More rapid deterioration of the joint strengths than was achieved in this experiment could be expected with a higher initial moisture content of the specimens and with longer periods in the oven. This formed the basis for Experiment III.

Experiment III. Continuous Exposure of Urea-resin-glued Plywood Joints to 90° C. (194° F.) in a Vented Container

Birch plywood shear specimens bonded with urea-resin glue were conditioned by groups to five different values of moisture content within the range of 8 to 17 percent. For each moisture condition, 10 specimens were placed in a quart tin can provided with a friction lid with a 1-millimeter hole for venting. The cans were then placed in an oven at 90° C. (194° F.). For one group, water was added to the can to a depth of 1/8 inch; in the other groups, no free water was added. Periodically a can was moved from the oven to a room at 27° C. (80° F.) and 97 percent relative humidity, cooled, and opened. Five specimens were removed (being replaced by five new specimens of the original moisture content to maintain as nearly constant moisture conditions as possible during each cycle) were soaked in water 24 hours, and were tested wet for shear strength. Three of the five specimens were weighed immediately after removal from the can and, after being tested for shear strength, were oven-dried and reweighed for the moisture content determination. The data are presented in table 3.

From the data of this table it may be concluded that there is a progressive decline in strength during this exposure and that, in general, the greater the moisture content the more rapid the decline in strength. On the other hand, it may also be concluded that there is a progressive decrease in moisture content of the specimens exposed in a dry, vented can, and that, as the moisture content drops, the rate of deterioration slows down, so that, even when starting with a moisture content of 16.9 percent, it would require over 6 days of heating under these conditions to reduce the joint strength to 200 pounds per square inch.

The data in the last column of table 3 show that the deterioration is extremely rapid if the moisture content is maintained at a relatively high level. Following this indication, Experiment IV was carried out with the container not vented but connected with the outer atmosphere by a mercury seal through which moisture could not diffuse.

Experiment IV. Continuous Exposure of Veneer and Urea-resin-glued Plywood at 90° C. (194° F.) in a Container with Mercury Seal

Two sets of specimens of yellow birch plywood glued with a cold-setting urea-formaldehyde glue, one set conditioned to 12.4 percent moisture content, the other to 21.6 percent, were placed in dry, glass, quart fruit jars, one jar for each set, closed with a large rubber stopper fitted with a bent tube containing mercury to serve as a mercury seal. The jars so sealed were placed in an oven at 90° C. (194° F.). The quantity of mercury was such as to allow release of most of the pressure as the air in the jars became warm, but was adequate to prevent diffusion and loss of moisture by breathing of the container with temperature fluctuations in the oven. Periodically, each jar was removed from the oven to a room at 27° C. (80° F.) and 97 percent relative humidity, opened briefly without cooling, and five specimens quickly transferred to a weighing bottle for determination of weight and subsequent determination of shear strength and moisture content.

The moisture content measurements showed about the same loss of moisture from the plywood of approximately 12 percent moisture content as occurred in Experiment III with the vented tin can. When the jars were opened there was such a strong odor of formaldehyde as to suggest that much of the loss of weight might be due to decomposition of the urea-resin glue. Accordingly, a second experiment was run using yellow birch veneer instead of plywood. Again there was a falling off in weight of nearly the same magnitude. The data are given in table 4.

Experiment V. Continuous Exposure of Urea-resin-glued Plywood Joints in an Air-tight Glass Jar at 90° C. (194° F.)

The failure of the mercury seal to maintain the moisture content of wood in the exposed specimens indicated the need of a completely air-tight container for this exposure. To accomplish this, pint fruit jars with screw caps and rubber ring gaskets were utilized. Ten specimens were placed in each jar and the jars with their contents set in an oven at 90° C. (194° F.), with the caps loose for about 20 minutes to allow the glass and the air within to become warm, the caps were then screwed down tightly and the exposure in the oven was continued. Periodically a jar was removed from the oven, cooled and opened in a room at 27° C. (80° F.) and 97 percent relative humidity, five specimens were quickly transferred to a glass weighing bottle, five dummy specimens of the original moisture content were put into

the jar in place of those removed, and the heating process including the 20-minute warming period with loosely fitting caps was repeated. The specimens removed were tested for moisture content and shear strength without reconditioning. Each jar contained enough specimens for two test periods. If an appreciable suction was not noticed when each jar was opened, it was assumed that the seal had not been air-tight, and the contents of that jar were discarded.

The results of this experiment are shown in table 5. The moisture content values were maintained better in the air-tight jar than in the containers of the previous experiments. The differences in average moisture content before and after exposure were small in specimens starting with about 7 percent moisture but large in those specimens starting with about 22 percent moisture.

The data show further that the original moisture content values must be relatively high, probably 20 percent or above, for the test to be short enough for adequate convenience.

The moisture content results after exposure varied rather widely, probably because of uncontrolled loss of moisture during the period of warming, and the brief interval when the bottle was opened for removal of the first set of five specimens. Whatever the reason, the variation of moisture content of the specimens in the bottle was too great for the procedure to be an entirely suitable test method, for, undoubtedly, changes in moisture content would cause variations in the rate of deterioration of the joints.

Experiment VI. Continuous Exposure at Several Temperatures of Urea-resin-glued Plywood Joints Immersed in Water or Suspended Above a Layer of Water in a Vented Container

The next experiment was made in containers with a shallow layer of water in the bottom or with the specimens immersed in water. These exposures were made with the specimens in quart glass fruit jars with loosely fitting screw caps. In the total-immersion experiments, the water was brought to the desired temperature before the specimens were put in. Just before immersion the moisture content of the plywood specimens was brought rapidly up to 60 to 90 percent by drawing a vacuum for 10 minutes on the specimens in water at room temperature in a vacuum desiccator, and then releasing the vacuum with the specimens immersed.

In the experiments over water, the depth of water was about 1/8-inch and the specimens were supported vertically on a screen platform about 1 inch above the water. Prior to this exposure, the specimens had been divided into two groups and had been conditioned in constant humidity rooms to about 12 and 25 percent moisture content values. In one instance, the specimens were treated with water by the vacuum method to 86 percent moisture content and were then exposed.

Exploratory experiments (table 1) had indicated that exposure over water at 90° C. (194° F.) had rapid and drastic action on urea-resin glue joints. To lessen the severity of the action, tests were also made at lower temperatures down to 70° C. (158° F.). Periodically, specimens were removed, weighed in order to determine their moisture content, soaked for 24 hours in water at room temperature, tested wet for shear strength, then dried in an oven at 105° C. (221° F.), and reweighed.

The results of these experiments are presented in table 6. The greater deteriorating effects of increased temperature, time of exposure, and moisture content of the specimens are clearly revealed by the data. Specimens deteriorated faster when immersed in hot water than when exposed to saturated air of the same temperature.

The considerable difference in rate of deterioration of specimens above 25 percent moisture content, when exposed to temperatures of 75°, 80°, and 90° C. (167°, 176°, and 194° F.), (groups 4, 7, and 9 of table 6), indicates the importance of precise temperature control in the experiment.

The difference between the rate of deterioration at 75° C. (167° F.) of specimens beginning with 27.4 and with 68.1 percent moisture content is of importance and indicates the need for moisture content control even above the fiber-saturation point. Specimens containing about 25 percent moisture changed relatively little in moisture content value when heated in a container over water. Specimens starting with about 12 percent moisture content took up moisture; specimens starting with about 68 percent moisture content lost moisture.

General Results and Conclusions

Plywood glued with cold-setting urea-formaldehyde resin glues lost joint strength when heated at elevated temperatures, and the rate of loss of strength was greater the higher the moisture content of the wood.

Dry, urea-resin-glued, plywood specimens heated in an oven at 90° C. (194° F.) decreased in joint strength but at a rather slow rate. (Series A, table 1.)

Wet, urea-resin-glued specimens that were dried in an oven at 90° C. (194° F.) decreased in joint strength slightly more than the initially dry specimens heated at the same temperature, but repeated soaking and oven-drying would be required to reduce the strengths greatly. (Series B and C, table 1.)

Cyclic exposure of urea-resin-glued specimens in a dry, vented tin can, alternately to 3 hours at 90° C. (194° F.) and 20 hours at 27° C. (80° F.) reduced joint strength and wood failure very slowly. (Table 2.)

Continuous exposure to 90° C. (194° F.) of urea-resin-glued plywood specimens, in a dry, vented tin can, produced more rapid loss of joint strength than did the cyclic exposure, but the moisture content fell off

progressively during the exposure and more than 6 days were required to reduce the joint strength to 200 pounds per square inch. The use of a mercury seal on the container in place of a vent was not effective in maintaining the specimens at a constant moisture content. (Tables 3 and 4.)

Continuous heating of urea-resin-glued specimens at 90° C. (194° F.), in an air-tight container, degraded the joints faster than heating in a vented container, but under the conditions of the experiment, there was a gradual loss of moisture. It appears that the moisture content value should be about 20 percent or above to shorten the test to a few days. (Table 5.)

Continuous immersion of urea-resin-glued specimens in hot water of 70° to 90° C. (158° to 194° F.) temperature brought about very rapid loss of joint strength. With the particular glue employed, all strength was lost in about 6 hours at 90° C. (194° F.) or in about 48 hours at 70° C. (158° F.). (Table 6.)

Continuous exposure to hot saturated air above water in an enclosed space also brought about rapid lowering of joint strength, the rate depending on the temperature and the moisture content of the wood. By varying the temperature, moisture content, and time of exposure to hot water vapor, it would seem possible to obtain any desired rate of degradation. If this method of testing the resistance of urea-resin-glued joints to hot, moist air is acceptable, it would be necessary to choose only those conditions that are easily controlled and which provide a test period of convenient length. From these experiments it appears that 75° C. (167° F.) might be a suitable temperature and, since wood of about 27 percent moisture content changes little during the exposure, that a moisture content value between 25 and 30 percent might be most desirable. (Series D, tables 1 and 6.)

All the experiments performed in this study caused lowering of the joint strength. There was some advantage of certain experimental conditions over others in reproducibility but, so far as these experiments went, the effect of the different exposure conditions was in the speed of deterioration rather than in type of deterioration. Consequently, the choice of the particular exposure conditions for use as a test method would be largely a matter of personal preference. The choice of the Forest Products Laboratory at present is for the test in which yellow birch heartwood plywood specimens of approximately 30 percent moisture content are exposed over water at 75° C. (167° F.) in a vented container.

Table 1.—Average shear-test results on yellow birch plywood specimens, glued with cold-setting urea-resin glues, before and after exposure to various soaking and heating conditions[1]

Group	Conditions and hours of exposure to which specimens were subjected				Condition when tested	Shear strength and percentage of wood failure[2] in seven commercial urea-resin glues						
	Soaking in water at room temperature[3]	Drying in oven at 90° C.	Steaming over water in vented can	Soaking in water at room temperature[3]		Glue 1	Glue 2	Glue 3	Glue 4	Glue 5[4]	Glue 6	Glue 7
	Hours	Hours	Hours	Hours								
				Series A — Heated in oven at 90° C. (194° F.), soaked, and tested wet								
5[5]				48	wet	484-100	464-64	448-99	485-100	505-100	475-95	456-79
2		24		24	wet	465-99	417-89	456-100	444-100	349-100	411-99	364-72
3		48		24	wet	475-84	404-51	440-99	400-100	267-100	398-100	331-68
4		72		24	wet	476-95	404-76	422-100	414-100	333-100	421-100	349-80
5		96		24	wet	424-98	409-74	413-100	386-100	279-100	364-99	316-90
				Series B — Soaked, dried in oven at 90° C. (194° F.), and tested dry								
6[6]					dry[7]					403-22	412-86	394-41
7	24	1/2			dry[7]					398-15	420-100	353-5
8	24	2			dry[7]					385-3	363-78	318-10
9	24	24			dry[7]					294-12	412-76	351-35
10	1-1/2 (vacuum)[8]	2			dry[7]					287-21	398-78	355-18
11	1 (vacuum)	92			dry[7]					235-1	405-60	316-5
				Series C — Soaked, dried in oven at 90° C. (194° F.), soaked, and tested wet								
10[12]				48	wet					374-36	478-100	436-39
13	1-1/2 (vacuum)	2		48	wet					304-7	446-98	363-24
14	1 (vacuum)	112		48	wet					147-0	372-78	341-12
12[15]				48	wet	445-68	450-64	503-74			470-95	474-69
16	16 (pressure)[13]	1		16 (pressure)	wet	437-37	335-5	455-37			459-89	431-52
17	16 (pressure)	3		16 (pressure)	wet	422-25	358-14	455-64			443-84	383-15
18	16 (pressure)	4		16 (pressure)	wet	408-42	340-15	431-46			459-98	381-27
19	16 (pressure)	24		16 (pressure)	wet	332-6	295-2	389-21			413-97	330-8
20	16 (pressure)	48		16 (pressure)	wet	325-8	345-7	398-30			403-100	330-5
21	16 (pressure)	98		16 (pressure)	wet	323-7	367-31	382-44			420-74	325-4
				Series D — Soaked, heated over water at 90° C. (194° F.), soaked, and tested wet								
14[14]				48	wet	445-68	450-64	503-74			470-95	474-67
23	16 (pressure)		1	1 (vacuum), 16	wet	424-36	310-0	416-13			442-96	372-22
24	16 (pressure)		2	1 (vacuum), 16	wet	404-31	301-0	379-7			436-90	358-3
25	16 (pressure)		3	1 (vacuum), 16	wet	372-24	200-0	336-2			415-97	316-3
26	16 (pressure)		4	1 (vacuum), 16	wet	177-0	0-0	69-0			253-3	202-0
15[27]				48	wet	484-100	464-64	448-99	485-100	505-100	475-95	456-79
28	2 (vacuum)		1	48	wet	483-100	407-28	472-99	441-100	422-80	458-100	453-92
29	2 (vacuum)		2	48	wet	422-37	407-37	422-61	458-97	481-91	464-94	464-89
30	2 (vacuum)		3	48	wet	301-10	235-0	275-7	442-91	226-0	406-76	313-3
31	2 (vacuum)		4	48	wet	245-6	0-0	168-4	255-9	0-0	266-17	273-4

1 Control values are an average of 10 or 15 specimens; all others an average of 5 specimens.

2 First number is the average shear strength in pounds per square inch; the second number is the estimated percentage of wood failure.

3 Soaking was done at atmospheric pressure unless otherwise noted.

4 New formulation (film pH = 3.1) used in series A and D; old formulation (film pH = 1.6) used in series B and C.

5 Controls for groups 2, 3, 4, and 5.

6 Controls for groups 7, 8, 9, 10, and 11.

7 The moisture content at the time of testing was 3 to 5 percent.

8 Where vacuum is indicated, 25 to 30 inches were drawn for the period stated, then released while the specimens were immersed.

9 Then soaking and drying repeated 2 more times.

10 Controls for groups 13 and 14.

11 Repeated 2 more times followed by soaking 48 hours.

12 Controls for groups 16, 17, 18, 19, 20, and 21.

13 70 pounds air pressure on specimens during immersion.

14 Controls for groups 23, 24, 25, and 26.

15 Controls for groups 28, 29, 30, and 31.

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Table 2.--Average[1] shear-test results on yellow birch plywood specimens, glued with a cold-setting urea-resin glue,[2] tested wet before and after repeated cyclic exposure to 90° C. (194° F.) in a vented container for 3 hours and to 27° C. (80° F.), 65 percent relative humidity for 20 hours.

Number of cycles	Wet joint strength and wood failure[3]	Moisture content values		
		Original	After oven portion of cycle	After cool portion of cycle
		Percent	Percent	Percent
0-(Control)	436-84[4]	12.9		
1	421-44	12.9	12.0	12.6
2	408-56	13.1	11.0	11.6
3	426-40	13.3	10.7	11.4
4	442-68	13.1	10.2	11.0
5	405-69	12.9	9.7	10.4
6	382-56	13.3	10.1	10.7
7	366-66	12.9	9.8	10.5
8	348-60	13.0	9.5	10.2
9	401-38	13.2	9.6	10.1
11	383-12	13.6	10.1	10.5
13	370-10	13.0	8.3	9.5
15	317-30	13.2	7.8	8.8

[1] The control strength values are averages for 10 specimens; all other strength values are averages for 5 specimens. The moisture content values are averages for 5 specimens.

[2] Glue 7 of table 1.

[3] After exposure the specimens were immersed for 24 hours in water at room temperature before being tested.

[4] The first number is the average shear strength in pounds per square inch; the second number is the estimated percentage of wood failure.

Mimeo. No. 1533

Table 3.--Average[1] shear-test results on yellow birch plywood specimens, glued with a cold-setting urea-resin glue[2] and exposed for various periods in vented tin cans at 90° C. (194° F.)

Time in can at 90° C. (194° F.)[3]	Average shear strengths and wood failures on specimens tested wet after 24 hours immersion in water, and average moisture contents, before and after heating in vented can[4]					
						Over water[5]
0 hours (control)	446-63 (8.5%)	446-63 (11.4%)	446-63 (14.8%)	446-63 (15.9%)	446-63 (16.9%)	446-63 (11.4%)
3 hours						411-56 (16.7%)
5 hours						287-19 (18.5%)
24 hours		376-82 (8.6%)	414-51 (12.3%)	314-26	292-21 (10.2%)	0-0 (29.2%)
2 days		354-71 (7.2%)	370-30 (12.3%)	234-4 (8.6%)	229-7 (9.2%)	
3 days		391-62 (8.4%)		330-10 (11.0%)		
4 days	318-40 (6.1%)	340-32 (5.9%)	277-16 (10.8%)			
6 days	278-21 (6.2%)	254-10 (5.3%)	325-15 (6.6%)	211-1 (2.3%)	257-3 (6.6%)	
10 days	212-16 (2.9%)	138-6 (3.8%)	173-1 (3.4%)	55-0 (0.2%)	33-0 (2.3%)	

[1] The control strength values are an average of 10 specimens; all other strength values are an average of 5 specimens. The moisture content values are an average of 3 specimens.

[2] Glue 7 of table 1.

[3] The time indicated was the time the specimens were in the oven after having reached 86° C. (187° F.) in the glue line. The time to reach 86° C. (187° F.) from room temperature was approximately 1 hour.

[4] The first number is the average shear strength in pounds per square inch. The second number is the average estimated percentage of wood failure. The third number, in parentheses, is the moisture content of the wood based on oven-dry weight after the indicated period of exposure in the can.

[5] The data of this column were taken on specimens exposed in a vented can containing 1/8 inch of water.

Mimeo. No. 1533

Table 4.--Average[1] results with birch plywood, glued with urea-resin glue,[2] and veneer after exposure for various periods at 90° C. (194° F.) in a dry glass jar with mercury seal

Time in jar at 90° C. (194° F.)[3]	Moisture content of plywood[4]	Dry shear strength of plywood	Wood failure of plywood	Moisture content of veneer[4]
Hours	Percent	Pounds per square inch	Percent	Percent
0	12.4	452	98	10.5
18	9.6	388	5	9.7
42	8.4	310	5	7.5
70	7.9	365	10	7.7
94	6.1	350	5	.....
0	21.6	481	95	19.9
48	15.2	365	30	19.1
96	9.7	320	5	10.2
336	9.9	0	0	10.7

[1] The control values are an average of 10 specimens; all other values are an average of 5 specimens.

[2] Glue 1 of table 1.

[3] The times indicated are the hours the specimens were in the oven after having reached 86° C. (187° F.) in the glue line.

[4] Moisture content value after the designated period of exposure.

Mimeo. No. 1533

Table 5.--Average[1] moisture content and shear-test results on dry birch plywood specimens, glued with a cold-setting urea-formaldehyde glue,[2] before and after heating at 90° C. (194° F.) in air-tight, dry glass jars.

Time of exposure	Shear strength, wood failure, and moisture content values for plywood specimens at 4 initial moisture content values[3]			
	6.9 percent	12.4 percent	15.2 percent	21.6 percent
Days				
0	474-71 (6.9%)	505-94 (12.4%)	584-96 (15.2%)	571-84 (21.6%)
1				336-22 (15.5%)
2	352-14 (5.6%)	422-19 (10.1%)	428-29 (9.7%)	284-27 (14.4%)
3	328-8 (5.4%)			
4		351-36 (10.5%)	397-31 (7.7%)	125-1 (12.1%)
5	378-10 (5.1%)			125-0 (11.1%)
6			385-37 (10.1%)	80-0 (10.9%)
7	308-7 (6.6%)			54-0 (12.5%)
9		281-21 (6.3%)	327-9 (7.4%)	
11		326-19 (8.4%)		
12		291-11 (8.8%)	93-0 (10.6%)	
14		271-7 (10.0%)		

[1] The control strength values are averages of 10 specimens; all other values are averages of 5 specimens. The moisture content values are averages for 3 specimens.

[2] Glue 1 of table 1.

[3] The first number is the average shear strength in pounds per square inch. The second number is the average estimated wood failure in percent. The third number, in parentheses, is the moisture content determined after the period of exposure.

Mimeo. No. 1533

Table 6.—Average[1] moisture content and wet-shear-test results on yellow birch plywood specimens glued with a cold-setting urea-formaldehyde glue[2] before and after immersion in hot water and exposure to hot saturated air at different temperatures

Group No.	Condition of exposure	Temperature of oven	Wet joint strength, wood failure, and moisture content values after various periods of exposure[3]						
			Exposure periods[4]						
			0 hours	1 hour	3 hours	6 hours	24 hours	48 hours	72 hours
		° C.							
1	Over water in vented bottle in oven	70	[5] 452-37 (12.5%)	.....	.....	[5] 449-27 (15.4%)	[5] 337-0 (19.1%)	[5] 264-0 (24.7%)	[5] 268-0 (24.3%)
2	do	70	452-37 (25.1%)	.....	.....	307-8 (26.6%)	240-6 (27.0%)	235-5 (29.0%)	288-10 (28.4%)
3	do	75	497-92 (12.2%)	.....	505-51 (15.5%)	445-36 (18.8%)	443-25 (19.7%)	368-24 (22.7%)	401-11 (20.0%)
4	do	75	492-100 (27.4%)	376-12 (26.2%)	281-1 (26.2%)	301-5 (25.9%)	304-4 (25.4%)	227-0 (25.6%)	220-5 (26.9%)
5	do	75	[6] 498-98 (68.1%)	396-36	229-0 (65.9%)	167-0 (62.5%)	103-0 (62.9%)	.....	.....
6	do	80	452-37 (12.5%)	.....	.....	453-13 (16.4%)	378-4 (19.3%)	89-0 (25.0%)	0-0 (31.7%)
7	do	80	452-37 (25.1%)	225-0 (24.1%)	176-0 (23.8%)	0-0 (23.9%)	.....	.....	.....
8	do	90	452-37 (12.5%)	.....	411-56 (16.7%)	287-19 (18.2%)	0-0 (29.0%)	.....	.....
9	do	90	452-37 (25.1%)	168-0 (25.8%)	0-0 (26.1%)	.....	.....	.....	.....
10	Immersed in hot water in oven[7]	70	452-37 [6] (76.7%)	276-0	233-0	212-5	146-0	0-0	.....
11	do[7]	75	[6] 498-98 (68.2%)	239-2	226-0	170-0	0-0	.....	.....
12	do[7]	80	[6] 452-37 (70.1%)	213-0	135-0	54-0	0-0	.....	.....
13	do[7]	90	[6] 452-37 (68 to 70%)	246-1	167-0	0-0	.....	.....	.....

[1] The strength values of the controls (zero hours) are averages for 15 to 20 specimens; all other strength values are averages for 5 specimens. The moisture content values are the average of 3 specimens in each case.

[2] Glue 7 of table 1.

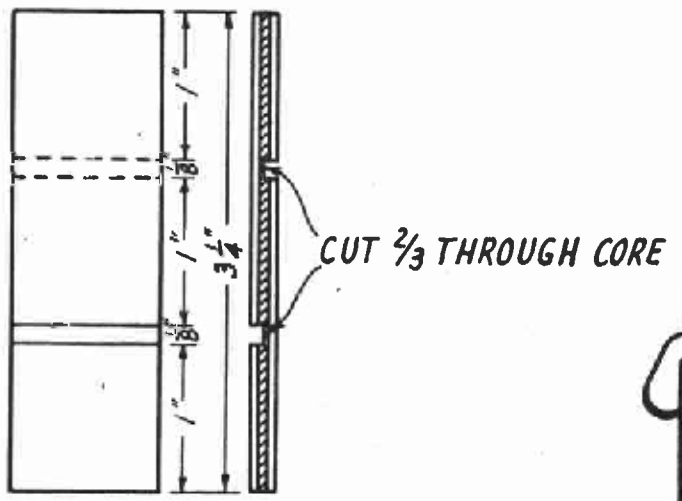
[3] After exposure to moist air the specimens were soaked 24 hours in water at room temperature before being tested.

[4] These periods are the total lengths of time the specimens were in the oven.

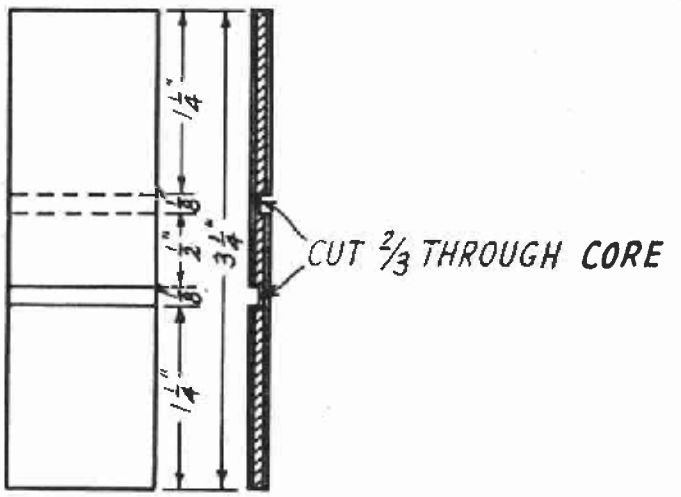
[5] The first number is the average shear strength in pounds per square inch. The second number is the estimated percentage of wood failure. The third number, in parentheses, is the determined moisture content immediately after the designated period of exposure.

[6] These specimens were immersed under a vacuum for 15 minutes.

[7] The water was brought to the temperature of the oven before the specimens were immersed.



SPECIMEN A



SPECIMEN B

FIGURE 1 - PLYWOOD GLUE SHEAR-TEST SPECIMENS

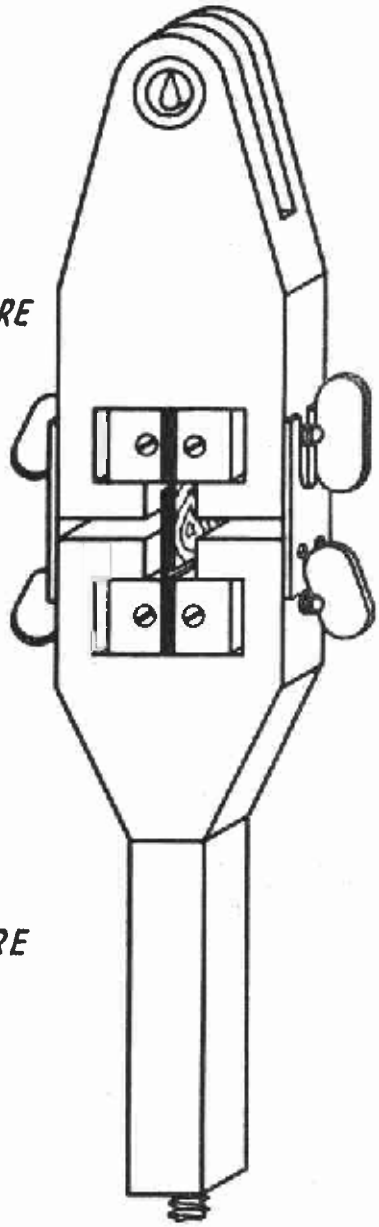


FIGURE 2 - TESTING GRIPS

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