RATE OF SETTING OF COLD-SETTING, UREA-RESIN GLUE JOINTS

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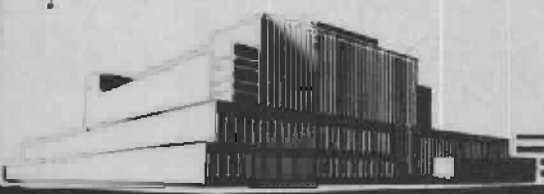

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

RATE OF SETTING OF COLD-SETTING, UREA-RESIN GLUE JOINTS[1]

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This study was made to determine the rate of increase in the shear strength of joints made with cold-setting, urea-resin glues. Its results offer a guide in determining the minimum time that joints made with this type of glue should remain under pressure, and how long they should be conditioned after removal from the press, before being subjected to stresses, to obtain maximum strength of the joints. These results can be compared to similar work which has been done previously with animal and casein glues.[3]

Method of Procedure

Selection of Wood

In making this rate-of-setting study, sugar maple and Sitka spruce lumber and 1/16-inch yellow birch veneer were selected to demonstrate the effects of species and thickness of material on the rate of setting.

The minimum specific gravity[4] of the material used was 0.62 for the sugar maple, and 0.32 for the Sitka spruce. A small portion of the material was discarded because of rapid growth, sharply sloped grain, and bird's eye, but a degree of leniency was allowed in making these discards.

The plies of birch veneer used in the faces of the plywood were carefully selected to avoid cross grain that might cause them to fail in tension while being tested. It was necessary to use veneer cut from several logs, and for this reason the quality of the material varied slightly.

The stock was allowed to reach approximate equilibrium conditions in a room where the relative humidity was 65 percent at 80° F. The wood thus attained a moisture content between 11 and 12 percent.

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[1] Report originally issued August 18, 1942.

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

[3] Truax, T. R., "The Gluing of Wood," U. S. Dept. Agr. Bul. No. 1500.

[4] Specific gravity used throughout this report is based on oven-dry weight and volume at approximately 12 percent moisture content.

Just before gluing, the sugar maple and Sitka spruce blocks were surfaced and cut to a size of 7/8 by 2-1/2 by 12 inches, and the yellow birch veneer was cut into pieces 5 by 12 inches in size. The blocks were weighed and those of approximately equal weight were paired. Two joints each of sugar maple and Sitka spruce were glued for each test period shown in table 2. For each species, blocks were selected to give each set about the same average specific gravity (Sitka spruce 0.36-0.37, sugar maple 0.64-0.65) as that for all the material glued. The average specific gravity of the blocks glued for each conditions, therefore, was about the same, and variations in test results due to differences in specific gravity were thereby reduced.

Glues and Gluing

Three commercial cold-setting urea-resin glues were used. They varied slightly in their composition and characteristics, as indicated in table 1.

Each glue was mixed as directed by the manufacturer, and spread on the blocks and veneer by a mechanical spreader which was adjusted to give a spread of 20 to 25 grams per square foot. Gluing was done at two room-temperature conditions, 75° F. and 90° F. with both wood and glue at approximately room temperature.

An assembly period (time between spreading and pressing) of 10 minutes was allowed before applying a pressure of 150 pounds per square inch. In order to obtain comparative data on the effect of different pressure periods and periods of aging after removal from the press, the joints were pressed and aged for the various periods indicated in table 2.

Testing

Three panels (three plies of 1/16-inch yellow birch) and two block joints of each species were glued for each condition of temperature, pressure period, and aging time. In some instances, duplicate runs were made and, if the values were similar, they were averaged with the original results. The panels and blocks were cut into shear specimens of conventional design.[2] One-half of the plywood specimens were tested dry and the remainder after soaking for 48 hours in water at room temperature. All the shear blocks were tested dry. In each average plywood test value, therefore, at least 15 specimens are included and in each average block shear value at least 10 specimens are included.

Results and Discussion

Effect of Pressure Period and Aging on Block Joint Shear Strength

The results of the block shear tests on Sitka spruce and sugar maple glued with the three cold-setting, urea-resin glues are summarized in tables 3 and 4 and

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[2] Described in U. S. Dept. Agr. Bull. No. 1500 and in Army, Navy, and Federal glue specifications.

figures 1, 2, 3, and 4. The average strength for the joints produced with the three glues is shown on the graphs as a heavy line.

The rate of increase in the joint shear strength of the Sitka spruce blocks during the first 24 hours under pressure is shown in table 3 and figures 1 and 2. The strength of joints glued at 75° F. was low during the first hour, and there was no wood failure. At 2 hours, there was some wood failure and an average shear strength of about 570 pounds per square inch. This rate of increase in strength continued (figure 1) during the first 4 hours and then became slower until the seventh hour, when the average shear strength was about 1,260 pounds per square inch and the wood failure uniformly high. The average joint shear strength increased but little for pressing periods of longer than 7 hours because the average shear strength of the joints was then very close that of the wood.

When gluing at 90° F., the average shear strength at the end of 2 hours was nearly 780 pounds per square inch (table 3). During the next 2 hours there was a further increase in strength to about 1,190 pounds per square inch and more than 95 percent wood failure. The average maximum strength at 90° F. was somewhat lower than that at 75° F., but since the wood failures are well above 90 percent in all but the early tests, it is improbable that the difference is significant.

Table 3 also shows the strength of the Sitka spruce joints which had been under pressure for various periods of time and then allowed to condition 14 days before testing. Joints which were pressed 1 hour at 90° F. or 2 hours at 75° F., followed by 14 days of conditioning, had an average wood failure of greater than 90 percent. This indicates that a pressure period of at least 2 hours, followed by conditioning, would be the minimum that could be recommended for the gluing of Sitka spruce with cold-setting, urea-resin glues at normal room temperatures.

In table 4 is shown the strength at various intervals throughout the conditioning period of Sitka spruce joints under pressure for 2 and 16 hours. The joints which were pressed only 2 hours showed a great increase in strength during the first day of conditioning, and attained the approximate strength of the wood during that period. No consistent increase in shear strength is shown by the Sitka spruce data after the first day of aging.

In table 3 and figures 3 and 4 is shown the rate of increase in joint shear strength of the sugar maple blocks during the first 24 hours under pressure. At 75° F., a 2-hour pressing time was required to obtain an average shear strength of about 400 pounds per square inch. There was a consistent increase in strength to about 3,000 pounds per square inch at the end of the 24-hour pressing period for two of the glues. The joints made with glue No. 3 did not average as strong after 24 hours as they did at 16 hours, but this reversal is not confirmed by other data. Wood failure occurred in the joints after 7 hours pressing, at which time the average shear strength for the 3 glues was about 1,750 pounds per square inch.

When gluing at 90° F., the increase in joint strength was more rapid than at 75° F., and during the first 4 hours of the pressing period an average strength of about 2,360 pounds per square inch was obtained. The shear strength increased to nearly 3,100 pounds per square inch at 16 hours pressing time. As this joint strength is approximately equal to the strength of the wood, no significant increase in strength was obtained for the longer pressing period.

The effect of aging the joints for 14 days is shown in table 3. At 75° F., 2 hours pressing time followed by 14 days of conditioning produced joints with wood failure of 75 percent or more, with the exception of the joints made with glue No. 3, which required 4 hours at 75° F. At 90° F., 75 percent wood failure or better was produced when using two of the glues with 1 hour of pressure followed by the conditioning period. The joints made with the other glue gained strength slowly during the shorter pressing periods.

Table 4 shows the effect of the conditioning period on the shear strength of maple joints under pressure for 2 and 16 hours. The joints glued at 75° F. showed a great increase in strength during the first day of conditioning and some additional increase during the second day. The joints glued at 90° F. gained nearly all of their strength during the first day of conditioning.

The joints made with the slowest setting glue, when pressed for 2 hours at 75° F., did not reach the strength of a good joint even after 14 days of conditioning. There was a gradual increase in the strength of these joints during the aging period. When these joints were pressed for 16 hours, or at the higher temperature, their strengths were equal to those obtained with the other glues.

Comparison of Glues and Species

The sugar maple joints glued with glue No. 3 had lower strength than those glued with the other two glues during the first two hours at 75° F. or one hour at 90° F., but after this period the rate of setting was similar to that obtained with the other two glues. In the gluing of Sitka spruce, and of sugar maple after the initial period of lag, the rate of setting of these glue joints was slightly faster than that of those glued with the other two glues.

The joints of both species increased in strength at approximately the same rate until most of the wood strength of the Sitka spruce had been reached. The sugar maple joints then continued to gain strength while the Sitka spruce joints acquired very little additional.

Comparison of the Rate of Setting of Urea-resin, Animal, and Casein Glue Joints

The data in table 5 show that the rate at which the resin glue joints gained their strength at 75° F. was only slightly different from the results that were previously obtained[1] with animal and casein glue joints at 70° F. In the gluing of maple, the casein and animal glue joints had a faster rate of setting between the first and fourth hour of the pressure period, but after the fourth hour the resin glue joints gained their strength at a faster rate, and joints of equal strength were obtained at the end of 8 hours pressing time.

Effect of Pressure Period and Aging on the Strength of Plywood Glued with Cold-setting, Urea-resin Glues

The results of the wet and dry joint tests on the yellow birch plywood specimens are summarized in tables 6 and 7 and figures 5 and 6.

When gluing at 75° F. (table 6) a pressure period of 1 hour gave low dry-test values with no wood failure. From then on, the increase was steady until the seventh hour, when wood failure occurred in the joints and the average dry test was about 430 pounds per square inch. The average dry strength then increased slowly to about 460 pounds per square inch at about 9 hours (figure 5) and remained fairly constant for the remainder of the 24-hour pressing period. The average wood failure showed a gradual increase throughout the 24 hours.

The wet strengths at 75° F. developed more slowly and at 24 hours averaged only 313 pounds per square inch. The joints made with glues Nos. 1 and 3 averaged a little over 350 pounds at 24 hours, which was satisfactory; but the joints made with glue No. 2 reached only 236 pounds, with 1 percent wood failure, in the 24-hour period.

The rate of setting was much faster at 90° F., and wood failure was obtained in some of the joints tested after 1 hour of pressing. At this temperature the average dry shear strength for the 3 glues was over 400 pounds per square inch after 1 hour. The average strength increased slowly thereafter to about 490 pounds per square inch at 7 hours and did not change significantly during the remainder of the 24-hour pressing period.

Increasing the gluing temperature to 90° F. effected a greater improvement in the rate of increase of the wet strength than it did on that of the dry strength. The average wet strength was nearly 400 pounds per square inch at 7 hours pressing, and reached a strength approximately equal to the dry strength at 16 hours.

Table 6 also shows the results of aging the joints for 14 days after removal from the press. Joints made with glues Nos. 1 and 2, pressed 2 hours at 75° F. or 1 hour at 90° F., and aged for 14 days, were sufficiently well glued to have more than 80 percent of wood failure in the wet and dry tests, with the exception of the panels glued with glue No. 2, which were pressed only 1 hour at 90° F. These panels required a pressing period of 2 hours to attain more than 80 percent of wood failure.

The change of joint strength during the conditioning period of plywood joints which have been pressed for 2 hours and 16 hours is shown in table 7. Most of the dry strength was obtained during the first day of conditioning. The dry strengths remained fairly constant for the remainder of the conditioning period with the exception of the joints made with glue No. 3. These joints appeared in general to become somewhat weaker and to have lower wood failure with the longer aging periods. The wet strengths were slower in developing, and joints made with one of the glues at 75° F. did not reach maximum wet strength until the second day of conditioning.

Summary

Joints of sugar maple lumber made with cold-setting, urea-resin glues reached their average maximum strength after a pressing period of 24 hours at 75° F. or 16 hours at 90° F. The average maximum strength of the joints made on Sitka spruce lumber was obtained after a pressing period of 7 hours at 75° F. or 4 hours at 90° F. The yellow birch plywood required a pressure period of 7 hours at 90° F. and less than 16 hours at 75° F. to obtain its maximum dry strength. These results showed that increasing the temperature greatly decreased the time that the joints required in the press. The thickness of the section being glued had very little effect on the rate of setting when all the material was heated to the pressing temperature before gluing.

Much of the strength was gained during the early part of the pressure period. When the material was glued at 75° F., more than one-half of the final strength was obtained for the Sitka spruce joints in 3 hours, for the birch plywood in 4 hours, and for the sugar maple joints in 6 hours. Where maximum speed of production is important, pressing times of 1 to 2 hours at 90° F. or 2 to 4 hours at 75° F., with the longer periods being used with the higher density species or in heavier constructions, will produce well glued joints if the joints are then allowed to condition adequately before being made before using them as the glue used and conditioning of the material will affect this lower limit. Most of the strength of the joints was obtained during the first day of the conditioning period.

The wet strength of the plywood increased at a much slower rate than did the dry strength. A conditioning period of 2 days was needed to obtain the average maximum wet strength when gluing at 75° F.; at 90° F., this strength was obtained during the first 24 hours.

The three urea-resin glues used produced joints which had a generally similar rate of setting, although there were some "local" variations. The joints produced with glue No. 3 on the sugar maple blocks were slower in developing their initial strength, and when a glue of this composition is used on sugar maple the joint should be in the press for at least 4 hours. The plywood joints glued with this glue were weaker than those glued with the two other glues, and the joint strengths decreased slightly in the 14 days of aging.

The species (Sitka spruce, sugar maple, and yellow birch plywood) had no effect on the rate of setting with two of the three urea-resin glues used. The joints made with the other glue on maple gained very little strength during the first hour under pressure, but after this period the rate of setting was slightly faster than those of the other glues. This glue also showed slightly faster setting on the yellow birch plywood and Sitka spruce lumber.

The rate of increase in the strength of urea-resin glue joints at 75° F. was found to vary slightly from the results previously obtained with animal and casein glue joints at 70° F. At 70° F., the urea-resin joints would gain their strength at a slower rate.

Table 1.--Characteristics of the urea-resin glues studied

Glue No.	Filler	pH of glue mix	Working life at 75° F.
Glue 1[1]	Insoluble	Over 2.5	5.0 hours
Glue 2	Soluble	Over 2.5	4.0 hours
Glue 3	Unextended	Under 2.5	1.5 hours

[1] Glue 1 is the only one of the three glues used in this study which will pass all of the requirements of Army-Navy Specification AN-G-S for cold-setting resin glues, dated April 25, 1942.

Table 2.--Pressing and aging schedule

Pressure period	Age of joint at time of test[1]					
	Tested upon removal from press	1 day	2 days	4 days	7 days	14 days
30 min.	X					X
1 hr.	X					X
2 hrs.	X	X	X	X	X	X
4 hrs.	X					X
7 hrs.	X					X
16 hrs.	X	X	X	X	X	X
24 hrs.	X					X

[1] Joint age includes time in the press.

Table 3.--Effect of aging on the shear strength of cold-setting, urea-resin glued joints[1]

Pressure period	Glue 1				Glue 2				Glue 3				Average for the three glues[2]			
	Gluing temperature				Gluing temperature				Gluing temperature				Gluing temperature			
	75° F.		90° F.		75° F.		90° F.		75° F.		90° F.		75° F.		90° F.	
	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure
	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Material - Sitka spruce blocks																
Joint age - 0-24 hours[3]																
30 minutes	0	0	0	0	0	0	0	0	0	0	40	0	0	0	13	0
1 hour	21	0	112	0	20	0	200	0	20	0	730	40	20	0	347	0
2 hours	608	10	688	5	467	4	527	2	646	20	1,121	92	574	11	778	33
4 hours	1,011	59	1,248	95	1,058	63	1,144	98	1,270	97	1,162	98	1,113	73	1,194	97
7 hours	1,180	98	1,181	95	1,289	99	1,150	99	1,331	100	1,158	100	1,266	98	1,163	99
16 hours	1,123	92	1,204	100	1,208	100	1,156	90	1,327	92	1,173	94	1,219	95	1,177	95
24 hours	1,332	90	1,236	89	1,234	100	1,253	88	1,250	95	1,209	96	1,272	95	1,233	91
Joint age - 14 days																
30 minutes	358	23	427	35	141	20	719	72	557	45	728	75	352	29	625	61
1 hour	644	36	1,244	93	417	45	1,151	99	614	60	1,084	88	558	47	1,159	93
2 hours	1,225	100	1,298	88	1,255	94	1,219	100	1,433	99	1,032	95	1,304	98	1,183	94
4 hours	1,253	92	1,279	97	1,288	96	1,222	98	1,370	94	1,218	93	1,304	94	1,239	96
7 hours	1,336	95	1,213	98	1,259	91	1,232	100	1,365	96	1,144	94	1,320	94	1,196	97
16 hours	1,453	99	1,311	99	1,305	99	1,179	99	1,358	95	1,028	100	1,372	98	1,173	99
24 hours	1,244	84	1,279	90	1,273	98	1,263	100	1,368	99	1,094	98	1,295	94	1,212	96
Material - Sugar maple blocks																
Joint age - 0-24 hours[3]																
30 minutes	15	0	47	0	37	0	50	0	5	0	0	0	29	0	32	0
1 hour	77	0	596	0	222	0	619	0	10	0	150	0	103	0	455	0
2 hours	477	0	1,313	0	645	0	1,115	0	67	0	912	2	396	0	1,113	1
4 hours	1,230	0	2,413	55	1,326	0	2,136	52	748	0	2,539	75	1,101	0	2,363	61
7 hours	1,582	4	2,782	100	1,952	6	2,714	94	1,714	10	2,803	92	1,749	6	2,766	95
16 hours	2,619	94	3,308	100	2,690	70	2,970	89	3,013	100	2,974	96	2,774	88	3,084	95
24 hours	3,000	80	3,148	99	3,017	87	2,990	94	2,697	98	3,203	100	2,905	89	3,113	98
Joint age - 14 days																
30 minutes	180	5	674	18	922	29	456	11	438	18	323	5	513	17	451	11
1 hour	741	29	2,020	78	2,227	72	2,319	80	623	15	322	10	1,197	37	1,554	56
2 hours	2,589	90	2,931	100	3,058	75	2,593	98	1,508	40	2,786	95	2,385	68	2,770	98
4 hours	2,978	96	2,991	100	3,184	91	2,599	93	2,520	96	3,002	98	2,894	94	2,864	97
7 hours	2,950	99	2,926	97	3,191	97	3,063	97	3,040	100	3,290	100	3,037	98	3,093	98
16 hours	2,690	94	2,984	100	3,391	81	2,837	98	2,912	100	3,162	95	2,998	92	2,994	98
24 hours	2,831	97	2,921	99	3,003	93	3,052	99	2,768	94	3,080	97	2,867	95	3,017	98

[1] Gluing conditions - moisture content 12 percent; spread 20-25 gm. per sq. ft.; assembly period 10 minutes; pressure 150 lb. per sq. in.

[2] The grand average is for 30 or more shear test specimens; the individual averages are for 10 or more specimens.

[3] Specimens were cut and tested upon removal from press. About 20 minutes were required to prepare specimens for test after removal from press.

Table 4.--Effect of aging on the shear strength of cold-setting, urea-resin glued joints[1]

Joint age	Glue 1				Glue 2				Glue 3				Average for the three glues[2]			
	Gluing temperature				Gluing temperature				Gluing temperature				Gluing temperature			
	75° F.		90° F.		75° F.		90° F.		75° F.		90° F.		75° F.		90° F.	
	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure
	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Material - Sitka spruce blocks																
Pressure period - 2 hours																
2 hours[3]	508	10	688	5	467	4	527	2	646	20	1,121	92	540	11	778	33
1 day	1,236	97	1,244	100	1,207	95	1,202	97	1,243	92	1,394	99	1,229	95	1,280	99
2 days	1,440	95	1,199	95	1,126	95	1,192	95	1,277	100	1,146	92	1,314	96	1,172	94
4 days	1,224	95	1,309	95	1,133	94	1,301	99	1,249	86	1,070	95	1,202	92	1,226	96
7 days	1,345	96	1,261	98	1,238	91	1,121	99	1,190	98	1,174	100	1,257	95	1,185	99
14 days	1,225	100	1,298	88	1,255	94	1,219	100	1,433	99	1,032	95	1,304	98	1,183	94
Pressure period - 16 hours																
16 hours[3]	1,123	92	1,204	100	1,208	100	1,156	90	1,327	92	1,173	94	1,219	95	1,177	95
1 day	1,228	83	1,250	100	1,217	100	1,299	90	1,332	98	1,176	98	1,259	94	1,242	96
2 days	1,080	98	1,231	98	1,208	99	1,125	92	1,233	83	1,230	96	1,174	93	1,195	95
4 days	1,363	96	1,273	100	1,328	100	1,323	99	1,424	100	1,190	93	1,372	98	1,263	97
7 days	1,274	88	1,363	98	1,200	100	1,202	99	1,225	99	1,119	97	1,233	96	1,228	98
14 days	1,453	99	1,311	99	1,305	99	1,179	99	1,358	95	1,028	100	1,372	98	1,173	99
Material - Sugar maple blocks																
Pressure period - 2 hours																
2 hours[3]	477	0	1,313	0	645	0	1,115	0	67	0	912	2	396	0	1,113	1
1 day	3,065	70	3,273	100	2,771	90	2,710	91	673	28	2,762	93	2,169	63	2,915	95
2 days	2,718	92	2,850	94	2,958	92	2,844	97	822	24	2,808	88	2,166	69	2,834	93
4 days	2,719	96	3,075	98	2,834	91	2,951	93	1,210	34	2,726	88	2,254	74	2,914	92
7 days	2,735	92	3,103	99	2,752	89	2,752	92	1,511	58	2,874	97	2,333	80	2,909	96
14 days	2,589	90	2,931	100	3,058	75	2,593	98	1,508	40	2,786	95	2,385	68	2,770	98
Pressure period - 16 hours																
16 hours[3]	2,619	94	3,308	100	2,690	70	2,970	89	3,013	100	2,974	96	2,774	88	3,084	95
1 day	2,620	82	3,000	100	2,760	90	2,785	95	2,857	100	3,058	100	2,744	91	2,948	98
2 days	3,241	98	3,439	100	2,864	87	3,064	100	3,095	99	2,901	92	3,066	95	3,134	97
4 days	3,005	95	3,092	93	3,382	100	2,761	96	3,423	98	3,282	100	3,270	98	3,045	96
7 days	3,088	99	2,839	90	3,357	95	2,924	87	2,951	99	2,969	99	3,132	98	2,911	92
14 days	2,690	94	2,984	100	3,391	81	2,837	98	2,912	100	3,162	95	2,998	92	2,994	98

[1]Gluing conditions - moisture content 12 percent; spread 20-25 gm. per sq. ft.; assembly period 10 minutes; pressure 150 lb. per sq. in.

[2]The grand average is for 30 or more shear test specimens; the individual averages are for 10 or more specimens.

[3]About 20 minutes were required to prepare specimens for test after removal from press.

Table 5.--Average rate of setting of glued sugar maple joints

Pressure period	Urea-resin at 75° F.[1]	Casein and animal at 70° F.[2]
	Approximate shear strength	Approximate shear strength
Hours	Lb. per sq. in.	Lb. per sq. in.
1	100	390
2	400	920
3	1,100	1,580
7	1,750	1,890
8	1,920	1,920

[1] Data from average curve, figure 3.

[2] Data from U. S. Dept. Agr. Bull. No. 1500.

Table 6.--Effect of aging on the shear strength of 3-ply, 3/16-inch, yellow birch plywood glued with urea-resin glue[1]

Pressure period	Glue 1				Glue 2				Glue 3				Average for the three glues[2]			
	Gluing temperature				Gluing temperature				Gluing temperature				Gluing temperature			
	75° F.		90° F.		75° F.		90° F.		75° F.		90° F.		75° F.		90° F.	
	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure
	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Dry shear tests																
Joint age - 0-24 hours[3]																
30 minutes	0	0	178	0	0	0	0	0	0	0	0	0	0	0	59	0
1 hour	16	0	352	6	15	0	393	0	117	0	482	25	49	0	409	10
2 hours	148	0	417	13	199	0	415	22	166	0	519	95	171	0	450	43
4 hours	264	0	476	53	230	0	468	65	285	0	472	95	276	0	472	71
7 hours	384	3	465	64	441	25	529	81	463	59	471	96	429	29	488	80
16 hours	446	24	495	81	449	79	553	85	497	93	463	88	464	65	504	85
24 hours	471	68	424	89	436	75	487	81	449	95	492	100	452	79	468	90
Joint age - 14 days																
30 minutes	219	17	453	95	86	0	0	0	188	4	52-	0	164	7	168	31
1 hour	304	49	428	94	351	19	481	85	330	0	333	17	328	23	414	65
2 hours	431	89	438	83	516	89	486	66	365	22	365	27	437	66	429	58
4 hours	400	83	456	77	492	96	508	91	360	30	438	61	417	69	467	76
7 hours	403	77	408	81	456	83	477	92	390	27	452	68	416	62	446	80
16 hours	393	90	463	93	522	97	474	82	436	32	410	33	450	73	449	69
24 hours	365	85	471	87	520	87	522	86	448	49	427	47	444	74	473	73
Wet shear tests																
Joint age - 0-24 hours[3]																
30 minutes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 hour	0	0	0	0	0	0	0	0	73	1	362	28	24	1	121	9
2 hours	0	0	54	1	0	0	111	0	144	13	436	80	48	4	200	27
4 hours	0	0	186	8	0	0	352	24	260	28	434	71	86	9	324	34
7 hours	0	0	296	23	57	1	407	27	288	35	473	91	126	12	392	47
16 hours	71	0	505	94	154	1	512	86	330	23	486	93	185	8	501	91
24 hours	357	70	403	98	236	1	456	88	347	90	473	93	313	50	444	93
Joint age - 14 days																
30 minutes	239	31	432	96	52	2	0	0	173	6	21-	0	154	13	151	32
1 hour	331	73	447	99	303	17	367	22	320	4	365	47	318	31	393	56
2 hours	443	88	471	90	507	83	474	84	354	41	374	36	439	71	445	70
4 hours	441	95	483	88	437	97	439	82	345	48	444	81	408	80	455	84
7 hours	403	97	434	99	440	81	438	74	367	47	378	49	403	75	418	74
16 hours	444	90	464	89	511	95	427	82	425	20	405	20	460	68	432	64
24 hours	373	91	468	95	496	75	468	94	423	38	354	56	431	68	436	82

[1]Gluing conditions - moisture content 12 percent; spread 20-25 gm. per sq. ft.; assembly period 10 minutes; pressure 150 lb. per sq. in.

[2]The grand average is for 45 or more plywood shear test specimens, the individual averages are for 15 or more specimens.

[3]Specimens were cut and tested upon removal from press. About 20 minutes were required to prepare specimens for test after removal from press.

Table 7.--Effect of aging on the shear strength of 3-ply, 3/16-inch, yellow birch plywood glued with urea-resin glue[1]

Joint age	Glue 1				Glue 2				Glue 3				Average for the three glues[2]			
	Gluing temperature				Gluing temperature				Gluing temperature				Gluing temperature			
	75° F.		90° F.		75° F.		90° F.		75° F.		90° F.		75° F.		90° F.	
	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure	Average shear strength	Average wood failure
	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Dry shear tests																
Pressure period - 2 hours																
2 hours[3]	148	0	417	13	199	0	415	22	166	0	519	95	171	0	450	43
1 day	432	96	457	67	563	83	526	100	441	57	489	97	478	78	491	88
2 days	441	94	376	72	564	77	511	97	437	75	470	57	481	82	452	75
4 days	433	88	401	55	534	91	526	78	372	36	468	65	446	72	465	66
7 days	398	87	423	98	506	92	464	90	367	25	383	80	424	68	423	89
14 days	431	89	438	83	516	89	486	66	365	22	365	27	437	66	429	58
Pressure period - 16 hours																
16 hours[3]	446	24	495	81	449	79	553	85	497	93	463	88	464	65	504	85
1 day	488	100	476	60	485	89	512	85	476	78	462	74	483	89	483	73
2 days	443	94	482	99	504	81	513	79	462	67	416	46	469	81	470	75
4 days	475	88	467	74	484	87	520	87	412	51	479	80	457	75	488	80
7 days	424	85	427	94	545	96	466	92	374	43	449	62	448	75	447	83
14 days	393	90	463	93	522	97	474	82	436	32	410	33	450	73	449	69
Wet shear tests																
Pressure period - 2 hours																
2 hours[3]	0	0	54	1	0	0	111	0	144	13	436	80	48	4	200	27
1 day	476	88	476	93	398	49	444	82	407	62	376	79	427	66	432	85
2 days	400	94	379	80	472	83	435	91	378	47	430	71	416	75	415	81
4 days	430	94	415	95	500	91	443	71	387	47	416	83	439	77	425	83
7 days	382	91	470	81	451	67	421	82	387	33	391	83	396	64	427	82
14 days	443	88	471	90	507	83	474	84	354	41	374	36	439	71	445	70
Pressure period - 16 hours																
16 hours[3]	71	0	505	94	154	1	512	86	330	23	486	93	185	8	501	91
1 day	474	91	449	89	360	54	433	78	368	43	430	45	401	63	437	71
2 days	424	95	539	100	431	70	416	86	435	75	428	62	430	80	461	83
4 days	424	95	502	100	443	75	476	98	404	70	461	100	424	80	480	99
7 days	396	90	466	100	523	93	469	96	367	39	420	84	428	74	452	93
14 days	444	90	464	89	511	95	427	82	425	20	405	20	460	68	432	64

[1]Gluing conditions - moisture content 12 percent; spread 20-25 gm. per sq. ft.; assembly period 10 minutes; pressure 150 lb. per sq. in.

[2]The grand average is for 45 or more plywood shear test specimens, the individual averages are for 15 or more specimens.

[3]About 20 minutes were required to prepare specimens for test after removal from press.

Z M 44339 F

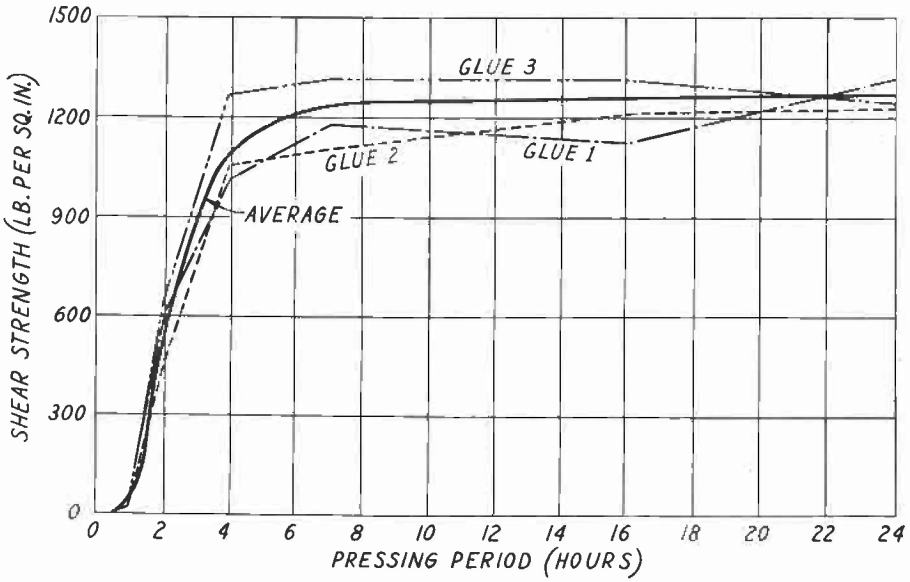

FIG. 1
EFFECT OF PRESSURE PERIOD ON THE SHEAR STRENGTH
OF COLD-SETTING, UREA-RESIN GLUE JOINTS ON SITKA SPRUCE.
GLUING TEMPERATURE - 75°F.

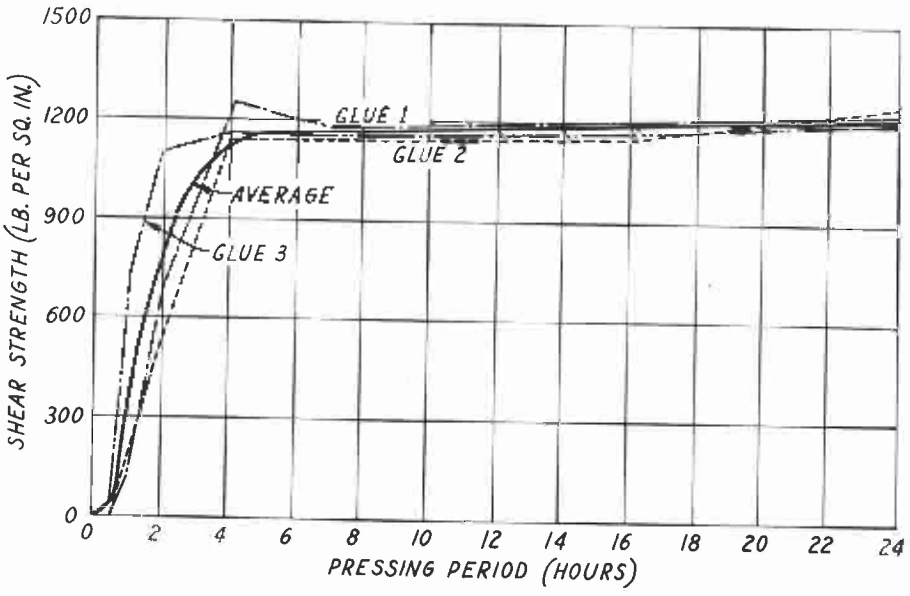

FIG. 2
EFFECT OF PRESSURE PERIOD ON THE SHEAR STRENGTH
OF COLD-SETTING, UREA-RESIN GLUE JOINTS ON SITKA SPRUCE.
GLUING TEMPERATURE - 90°F.

Z M 44133 F

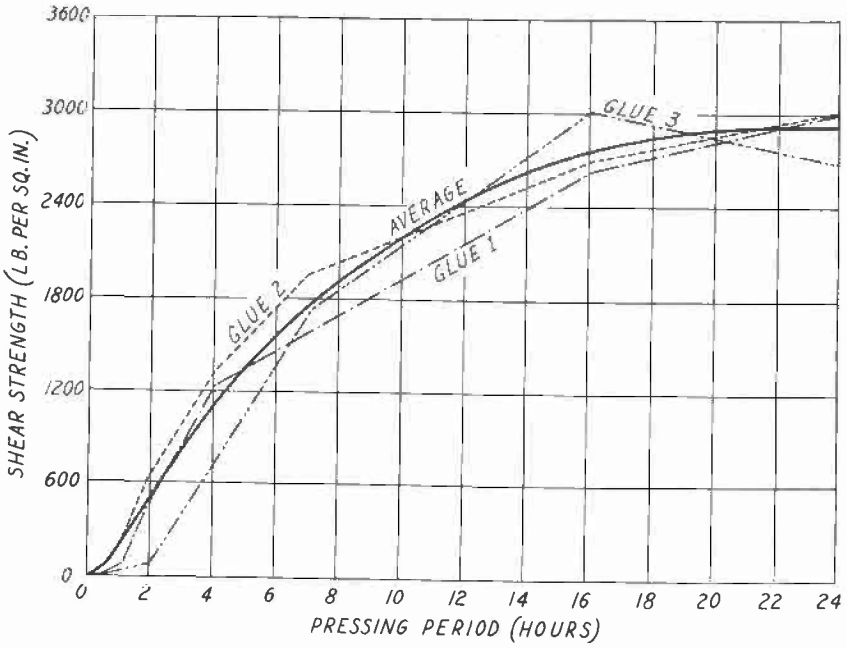

FIG. 3
EFFECT OF PRESSURE PERIOD ON THE SHEAR STRENGTH
OF COLD-SETTING, UREA-RESIN GLUE JOINTS ON SUGAR MAPLE.
GLUING TEMPERATURE-75°F.

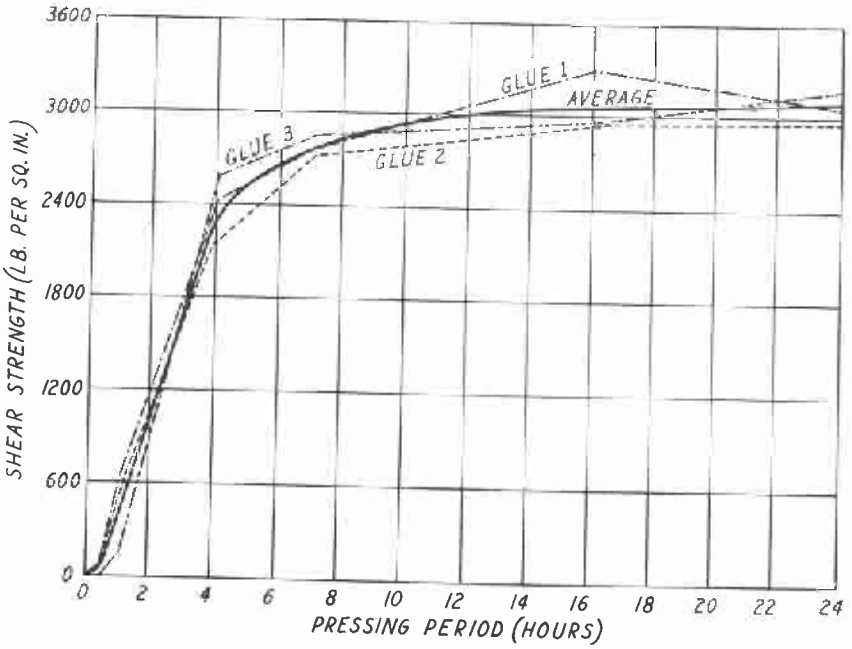

FIG. 4
EFFECT OF PRESSURE PERIOD ON THE SHEAR STRENGTH
OF COLD-SETTING, UREA-RESIN GLUE JOINTS ON SUGAR MAPLE.
GLUING TEMPERATURE-90°F.

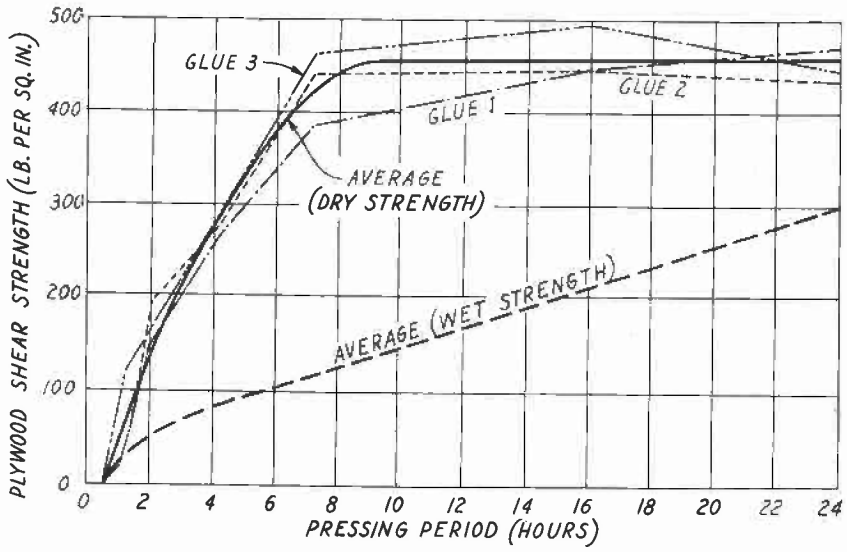

FIG. 5
EFFECT OF PRESSURE PERIOD ON THE SHEAR STRENGTH
OF 3 PLY, $\frac{3}{16}$ INCH, YELLOW BIRCH PLYWOOD
GLUED WITH COLD-SETTING, UREA-RESIN GLUES.
GLUING TEMPERATURE - 75°F.

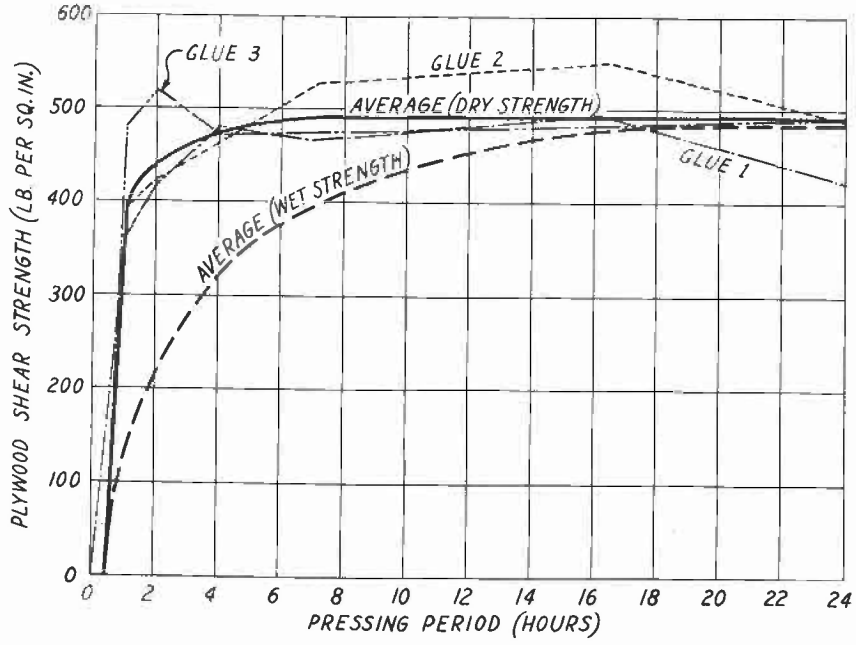

FIG. 6
EFFECT OF PRESSURE PERIOD ON THE SHEAR STRENGTH
OF 3 PLY $\frac{3}{16}$ INCH, YELLOW BIRCH PLYWOOD
GLUED WITH COLD-SETTING, UREA-RESIN GLUES
GLUING TEMPERATURE - 90°F.

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