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**EFFECT OF MOISTURE CONTENT OF WOOD ON JOINT  
STRENGTH IN GLUING BIRCH VENEER AND MAPLE  
LUMBER WITH ROOM-TEMPERATURE-SETTING AND  
INTERMEDIATE-TEMPERATURE-SETTING PHENOL,  
RESORCINOL, AND MELAMINE GLUES**

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**UNITED STATES DEPARTMENT OF AGRICULTURE  
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EFFECT OF MOISTURE CONTENT OF WOOD ON JOINT STRENGTH IN GLUING BIRCH  
VENEER AND MAPLE LUMBER WITH ROOM-TEMPERATURE-SETTING AND  
INTERMEDIATE-TEMPERATURE-SETTING PHENOL, RESORCINOL, AND MELAMINE GLUES<sup>1,2</sup>

By

W. Z. OLSON, Technologist

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Introduction

This report is part of an investigation being made at the Forest Products Laboratory to determine satisfactory gluing conditions for room-temperature-setting and intermediate-temperature-setting phenol, resorcinol, and melamine resin glues. It deals specifically with the effect of the moisture content of the wood at the time of gluing on the quality of glue joints.

Thirteen glues, representative of the phenol, resorcinol, and melamine room- and intermediate-temperature-setting types, were included in this study.

The moisture content of the wood glued varied from 2 to 25 percent.

Procedure

The glues were mixed in accordance with the manufacturers' instructions.

Plywood Joints

Yellow birch veneer 1/16-inch in thickness selected for straightness of grain and freedom from defects was cut into 8- by 8-inch squares and conditioned to approximately 2, 6, 11, 17, 21, or 25 percent moisture content in constant temperature and humidity chambers. The conditioned sheets

<sup>1</sup>This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the nation's war effort. The results here reported are preliminary and may be revised as additional data become available.

<sup>2</sup>This work was done partly with funds provided by the ANC Committee on Wood Aircraft Structures and partly by the Bureau of Ships of the Navy Department.

of veneer were spread with glue, assembled into three-ply panels, and clamped in portable presses under a pressure of 150 pounds per square inch. The assembly times employed were within the limits recommended by the manufacturers. One resorcinol glue was cured in a constant-temperature room at 75° F.; all the other glues were cured at higher temperatures in a kiln in which the temperature and humidity were controlled to hold the moisture content of the wood constant. Details of the gluing conditions are given in table 1.

After removal from the curing chamber, all panels were conditioned to a moisture content of approximately 11 percent, cut into standard plywood-joint specimens, and tested for shear strength in a plywood testing machine with the load applied at a rate of approximately 750 pounds per minute.

Five panels were prepared with each glue for each of the moisture content values. Each panel was cut into 12 specimens, 4 of which were tested dry, 4 tested wet after 48 hours' soaking in water at room temperature, and 4 tested wet after 3 hours' immersion in boiling water.

### Block Joints

Hard maple blocks, 7/8 by 2-1/2 by 12 inches in size, were selected for straightness of grain, freedom from defects, and specific gravity of 0.63 to 0.71, based on weight and volume when oven dry. These blocks were conditioned to approximately 6, 11, 17, or 21 percent moisture content, surfaced to 3/4 inch in thickness, and glued together in stacks of four laminations. All laminations in any one stack were of the same moisture content. Pressure of 200 pounds per square inch was applied by means of pressure-equalizing rocker-head clamps. The joints were cured in a kiln in which the humidity conditions were such as to maintain throughout the curing period the moisture content of the wood at the time of gluing. Other gluing details are summarized in table 2.

After removal from the kiln, the assemblies were conditioned for 2 to 3 weeks to a moisture content of 10 to 12 percent and cut into step-type block-shear test specimens.

Two assemblies, each composed of four laminations, were prepared with each glue at each moisture content. Five step-type specimens, each having three test joints, were obtained from each assembly. The specimens were tested in shear in a universal testing machine with shearing head moving at a rate of approximately 0.015 inch per minute.

## Results

The averaged results of the tests on the birch plywood joints are given in table 1 and those on the hard maple block joints in table 2. Following are summarized conclusions drawn from the data for which it was arbitrarily assumed that a shear strength of 400 pounds per square inch or better indicated an acceptable joint for the plywood and a shear strength of 2,800 pounds per square inch or better indicated an acceptable joint strength for the maple blocks.

On this basis, acceptable plywood joints were obtained with all but one of the intermediate-temperature-setting phenol glues tested on veneer throughout the moisture content range of 2 to 25 percent inclusive. The exception, glue B, gave acceptable results in the range from 2 to 11 percent inclusive in the wet and dry tests but only at 6 percent in the boil test with the boiled specimens from 2- and 11-percent veneer averaging slightly less than 400 pounds per square inch. Glue B is a solution of relatively low nonvolatile content of a highly alkaline, very water soluble, phenol resin. All the other phenol glues in this study were of high nonvolatile content dissolved in a mixture of alcohol and water.

Acceptable joint strengths were obtained with maple block joints made with the intermediate-temperature-setting phenol glues in the range of 6 to 21 percent inclusive, except for glue B, which gave satisfactory block joints only at 6 and 11 percent.

None of the melamine glues gave acceptable joint strengths on 2 percent veneer. Glue H formed acceptable joints in veneer of all moisture contents except 2 percent. The same was true of glue F, except for the boil tests on specimens made of veneer of 6 and 25 percent moisture content, and also of glue G, except for the dry tests on specimens made of veneer of 21 and 25 percent moisture content.

All three melamine glues gave acceptable joint tests on maple blocks in the moisture content range of 6 to 21 percent inclusive.

The resorcinol glues all produced acceptable joints in birch plywood in the range of 2 to 25 percent inclusive, except glue J, which gave joints that had a shear strength of less than 400 pounds per square inch on veneer of 2 percent moisture content.

Acceptable joints were obtained with all resorcinol glues studied in maple blocks glued at 6 to 21 percent moisture inclusive.

## Conclusions

Considering both shear strength and wood failure, it appears from the data that, with two possible exceptions, all of the glues studied could be used on birch or maple in the moisture content range of 6 to 21 percent inclusive with reasonable assurance that, with good gluing conditions, strong joints would be obtained. The exceptions are glue B on wood of 17 and 21 percent moisture content, and glue G on wood of 21 percent moisture content.

The phenol glues and most of the resorcinol glues produced satisfactory joints in birch plywood at 2 percent moisture content, but in general the melamine glues did not perform satisfactorily on wood at 2 percent moisture.

Acceptable joints were made from birch veneer of 25 percent moisture content with glue H, a melamine glue, with all resorcinol glues studied, and with all phenol glues studied, except glue B.

## Note

✓ { Although strong joints were obtained in this study with many of the resin glues on wood of rather high moisture content, it should not be inferred from this report that such high moisture content values are to be recommended. Other contingencies such as blistering in hot pressing and the desirability of having the final moisture content of the glued product at the approximate moisture content attained in service are important reasons for placing closer limits on permissible moisture contents.

Table 1.--Results of joint tests on birch plywood glued at several moisture-content values with room- and intermediate-temperature-setting resin glues.

Glue code symbol and type	Gluing conditions				Average results of plywood joint tests <sup>1</sup>		
	Approximate moisture content of veneer	Spread <sup>2</sup>	Assembly time (closed)	Curing temper- ature <sup>3</sup>	Tested dry	Tested wet after 48-hour immersion in water	Tested wet after 3-hour immersion in boiling water
	Percent	Grams	Minutes	° F.			
A (phenol)	2	24	26 - 30	160	443-100	455-78	434-100
	6	25	26 - 30	160	442-99	583-99	543-99
	11	25	26 - 30	160	457-100	519-100	482-100
	17	24	26 - 30	160	486-100	510-99	482-99
	21	20	21 - 25	160	511-100	567-98	524-93
	25	22	16 - 20	160	480-99	490-99	463-100
B (highly alkaline, water soluble, phenol)	2	24	23 - 30	190	468-74	410-80	392-75
	6	28	21 - 28	190	549-61	460-100	432-95
	11	26	26 - 30	190	515-76	420-100	391-92
	17	24	18 - 30	190	$\frac{4}{3}362-15$	$\frac{4}{3}350-25$	$\frac{4}{3}348-23$
	21	24	17 - 29	190	$\frac{4}{1}161-0$	$\frac{4}{1}157-0$	$\frac{4}{1}158-0$
	25	24	16 - 30	190	$\frac{4}{1}136-0$	$\frac{4}{1}163-0$	$\frac{4}{1}136-0$
C (phenol)	2	23	26 - 30	180	559-93	514-99	488-100
	6	24	21 - 25	180	501-100	580-100	519-100
	11	25	26 - 30	180	501-100	527-100	510-100
	17	24	26 - 30	180	541-96	617-96	565-99
	21	25	21 - 25	180	468-74	533-62	495-89
	25	24	16 - 20	180	501-74	571-78	504-95
D (phenol)	2	22	36 - 40	160	494-91	556-100	514-100
	6	24	36 - 40	160	439-66	530-97	528-100
	11	26	36 - 40	160	448-98	502-98	462-99
	17	24	36 - 40	160	468-86	531-100	517-100
	21	26	36 - 40	160	513-91	483-99	484-100
	25	24	36 - 40	160	474-86	529-89	494-100
E (phenol)	2	25	26 - 30	140	436-75	511-94	473-100
	6	28	21 - 25	140	475-99	563-97	529-100
	11	28	26 - 30	140	492-89	613-98	535-100
	17	24	26 - 30	140	471-70	538-85	471-85
	21	23	21 - 25	140	438-69	504-79	514-99
	25	23	16 - 20	140	466-69	580-98	553-94

(Continued)

Table 1.--Results of joint tests on birch plywood glued at several moisture-content values with room- and intermediate-temperature-setting resin glues (continued)

Glue code symbol and type	Gluing conditions				Average results of plywood joint tests <sup>1</sup>		
	Approximate moisture content of veneer	Spread <sup>2</sup>	Assembly time (closed)	Curing temper- ature <sup>3</sup>	Tested dry	Tested wet after: 48-hour immersion in water	Tested wet after: 3-hour immersion in boiling water
	Percent	Grams	Minutes	° F.			
F (melamine)	2	27	26 - 30	120	252-27	233-20	195-130
	6	28	26 - 30	120	418-95	409-100	379-93
	11	24	26 - 30	120	454-96	454-100	408-99
	17	27	26 - 30	120	436-64	508-91	466-74
	21	26	26 - 30	120	436-70	493-93	422-69
	25	27	26 - 30	120	413-39	449-92	394-57
G (melamine)	2	21	22 - 30	180	347-34	347-57	271-29
	6	22	21 - 29	180	449-100	445-100	462-100
	11	25	22 - 30	180	478-97	501-98	514-100
	17	19	22 - 30	180	486-69	531-100	520-98
	21	18	21 - 29	180	342-9	424-73	443-72
	25	24	22 - 30	180	364-11	444-54	450-54
H (melamine)	2	20	22 - 30	180	261-24	218-31	164-28
	6	23	21 - 29	180	470-99	445-99	417-97
	11	24	22 - 30	180	513-96	512-100	513-97
	17	15	22 - 30	180	531-100	501-100	511-100
	21	17	21 - 29	180	502-91	477-99	509-99
	25	19	22 - 30	180	433-100	444-100	486-99
I (resorcinol)	2	24	23 - 30	140	565-91	548-97	538-92
	6	28	21 - 28	140	547-90	548-93	501-81
	11	25	26 - 30	140	563-69	595-91	554-89
	17	23	18 - 30	140	567-95	579-88	549-90
	21	23	17 - 29	140	569-96	561-82	524-88
	25	23	16 - 28	140	598-87	565-65	540-76
J (resorcinol)	2	24	22 - 30	140	358-67	336-69	396-92
	6	23	21 - 29	140	406-92	412-93	410-98
	11	24	22 - 30	140	491-99	455-92	432-99
	17	23	18 - 30	140	534-99	570-97	523-100
	21	23	17 - 29	140	533-98	531-100	506-100
	25	25	16 - 28	140	520-80	530-93	502-100

(continued)

Table 1.--Results of joint tests on birch plywood glued at several moisture-content values with room- and intermediate-temperature-setting resin glues (continued)

Glue code symbol and type	Gluing conditions				Average results of plywood joint tests <sup>1</sup>		
	Approximate moisture content of veneer	Spread <sup>2</sup>	Assembly time (closed)	Curing temper- ature <sup>3</sup>	Tested dry	Tested wet after 48-hour immersion in water	Tested wet after 3-hour immersion in boiling water
	Percent	Grams	Minutes	° F.			
K (resorcinol)	2	20	18 - 30	140	414-73	424-68	469-85
	6	20	17 - 29	140	486-90	492-84	506-80
	11	19	16 - 23	140	471-99	502-96	511-93
	17	23	18 - 30	140	534-98	529-99	487-98
	21	24	17 - 29	140	551-94	560-96	535-96
L (resorcinol)	25	22	16 - 28	140	517-92	549-98	515-98
	2	22	14 - 16	75	567-84	512-90	497-100
	6	24	14 - 16	75	601-83	542-97	519-100
	11	24	14 - 16	75	500-88	516-98	522-99
	17	24	14 - 16	75	519-93	519-94	500-99
M (resorcinol)	21	23	14 - 16	75	529-83	531-95	522-98
	25	24	14 - 16	75	518-81	486-92	481-100
	2	23	26 - 30	140	460-95	464-97	434-100
	6	23	21 - 25	140	462-95	512-100	471-100
	11	23	26 - 30	140	455-97	540-100	469-99
	17	24	26 - 30	140	533-83	544-100	493-100
	21	23	21 - 25	140	504-100	525-100	506-100
	25	24	16 - 20	140	469-76	473-86	457-95

<sup>1</sup>Plywood conditioned to about 11 percent moisture content before testing. The first value is the joint strength in pounds per square inch; the second value is wood failure in percent. Each value is the average for 20 joint tests except for those bearing footnote <sup>4</sup>.

<sup>2</sup>Number of grams of wet glue per square foot of single glue line.

<sup>3</sup>Plywood cured for 24 hours at the temperature noted.

<sup>4</sup>Average of 40 joint tests.



Table 2.--Results of shear tests on maple blocks glued at several  
moisture-content values with room- and intermediate-  
temperature-setting resin glues

Glue designation and type	Gluing conditions				Average results of joint tests <sup>1</sup>	
	Approximate moisture content of wood	Spread <sup>2</sup>	Assembly time (closed)	Curing temperature <sup>3</sup>	Shear strength	Wood failure
	Percent	Grams	Minutes	° F.	Pounds per square inch	Percent
A (phenol)	6	38	29 - 30	160	3,531	31
	11	43	29 - 30	160	3,330	87
	17	45	29 - 30	160	2,858	96
	21	43	27 - 28	160	2,892	82
B (highly alkaline, water soluble, phenol)	6	38	28 - 30	190	3,422	79
	11	38	28 - 30	190	3,702	96
	17	48	28 - 30	190	2,162	22
	21	46	25 - 27	190	1,346	4
C (phenol)	6	48	28 - 30	180	3,210	70
	11	40	28 - 30	180	3,358	82
	17	38	28 - 30	180	3,292	84
	21	36	24 - 26	180	2,961	61
D (phenol)	6	44	29 - 30	160	3,467	79
	11	38	27 - 28	160	3,125	68
	17	41	29 - 30	160	3,029	81
	21	40	27 - 28	160	2,885	82
E (phenol)	6	42	29 - 30	140	2,804	36
	11	43	29 - 30	140	3,155	70
	17	50	29 - 30	140	2,832	76
	21	50	27 - 28	140	2,882	67
F (melamine)	6	40	28 - 30	120	2,920	52
	11	37	29 - 30	120	2,980	80
	17	40	26 - 30	120	2,984	87
	21	42	24 - 26	120	2,843	70
G (melamine)	6	40	26 - 30	180	3,251	96
	11	45	26 - 30	180	3,296	94
	17	34	26 - 30	180	2,947	88
	21	33	26 - 30	180	2,825	76

(continued)

Table 2.--Results of shear tests on maple blocks glued at several moisture-content values with room- and intermediate-temperature-setting resin glues (continued)

Glue designation and type	Gluing conditions				Average results of joint tests <sup>1</sup>	
	Approximate moisture content of wood	Spread <sup>2</sup>	Assembly time (closed)	Curing temperature <sup>3</sup>	Shear strength	Wood failure
	Percent	Grams	Minutes	° F.	Pounds per square inch	Percent
H (melamine)	6	36	26 - 30	180	3,089	79
	11	36	26 - 30	180	3,192	88
	17	34	26 - 30	180	2,948	98
	21	30	26 - 30	180	2,867	83
I (resorcinol)	6	36	28 - 30	140	3,718	62
	11	37	28 - 30	140	3,380	72
	17	31	28 - 30	140	2,937	84
	21	30	24 - 26	140	2,901	81
J (resorcinol)	6	42	29 - 30	140	3,004	31
	11	36	29 - 30	140	3,153	80
	17	42	28 - 30	140	2,982	83
	21	39	27 - 28	140	3,141	79
K (resorcinol)	6	37	28 - 30	140	3,256	84
	11	34	24 - 26	140	3,185	72
	17	35	28 - 30	140	3,154	66
	21	39	24 - 26	140	2,940	52
M (resorcinol)	6	39	29 - 30	140	3,277	91
	11	40	27 - 28	140	3,169	91
	17	44	25 - 26	140	3,054	76
	21	38	23 - 24	140	2,829	62

<sup>1</sup>Block joints conditioned to 10 to 12 percent moisture content before testing. Each value is the average for 30 joint tests.

<sup>2</sup>Number of grams of wet glue per square foot of single glue line, double spread.

<sup>3</sup>Block joints cured for 24 hours in a kiln at the temperature stated.