RATE OF DEVELOPMENT OF JOINT STRENGTH BY FOUR RESIN GLUES ON EIGHT SPECIES OF WOOD

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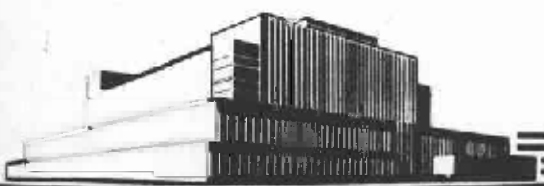

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

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

RATE OF DEVELOPMENT OF JOINT STRENGTH BY FOUR RESIN GLUES ON EIGHT SPECIES OF WOOD[1]

By

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In using resorcinol- and phenol-resin glues in the fabrication of wood aircraft the question arises as to whether these glues cure at the same rate on different species of wood. In an attempt to answer this question, joints were made with three room-temperature-setting glues and one intermediate-temperature-setting glue on eight species, cured for various lengths of time at two temperatures and tested in shear to follow the rate of development of the joint strength in the various species.

It was anticipated that the results would follow one of the three idealized patterns sketched in figure 1. If pattern (A) was found to be the case, in which the curves are coincident below the points where they depart from one another by virtue of differences in the strength of the woods, it could be concluded that there was no effect of species on the rate of curing. In the case of (B) and (C), on the other hand, a species effect could be inferred.

The glues employed were commercial glues and mixed according to the manufacturers' directions. The glues were designated as follows:

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[1] This report 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.

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

Designation	Type
A	Room-temperature-setting resorcinol
B	Room-temperature-setting resorcinol
C	Room-temperature-setting resorcinol
D	Intermediate-temperature-setting phenol

The eight species of wood employed were: yellow birch, Douglas-fir, noble fir, sweetgum, Western hemlock, mahogany, sugar maple, and Sitka spruce. Most of these woods are in common use in aircraft, and as a group provide a wide range in density and strength as well as the characteristic differences between softwoods and hardwoods. The maple, birch, and sweetgum were in the form of rotary-cut veneer and the other species as quarter-sliced veneer.

Procedure

All veneer had a nominal thickness of one-sixteenth inch, but each sheet was calipered and only those measuring 0.061 inch to 0.063 inch, inclusive, were selected for use. The selected veneer was cut into small slips 1 by 2-1/8 inches in size, with the grain running lengthwise.

In preparing the joints, the slips were clamped in a special frame (not shown) so that the glue could be applied quickly by brush to each surface area to be glued. The slips were then laid together in pairs with a 1-inch overlap in a special metal jig (fig. 2). After 15 minutes of closed assembly, a rubber caul was laid over the jig, and the specimens were subjected to a pressure of 150 pounds per square inch. The jig accommodated 32 lap joints, which made it possible to press one joint of each species with each of the 4 glues at the same time. Four sets were made at each gluing condition, and the results of these were averaged.

The joints for this study were cured at 80° F. and at 120° F. For curing at 80° F., the jig loaded with specimens and under pressure was kept for the curing period desired in a room maintained at 80° F. For curing at 120° F., the jig with specimens was pressed for the curing period desired between platens heated to 120° F. with hot water. At this higher temperature, approximately 3 minutes were required for the temperature in the

glue line to rise to within 5° F. of the platen temperature. Measurement of the time of heating was begun after this initial heating interval.

Immediately after the desired curing period, at both 80° F. and 120° F., pressure was released, and the individual specimens were removed from the jig and dropped into a beaker of cold water to lower their temperature and inhibit further cure of the glue. The beaker with immersed specimens was set in a vacuum desiccator and a vacuum was drawn for 30 minutes, then released. The moisture content of the specimens wet in this way was from 100 to 300 percent, and the wood of all species appeared to become wet through to the glue line. After wetting, the specimens were tested at once in a standard plywood-joint-testing machine loading at a rate of about 750 pounds per minute.

Results

The averaged results of the shear tests on the joints are given in tables 1 and 2.

Any effect of species on the rate of curing of the glue could be expected to be revealed more clearly in the initial stages of the curing in which the joints break without wood failure and the shear values are less dependent on the strength of the wood. To analyze the data for the effect of species, therefore, the joint strengths given in tables 1 and 2 for those curing periods at which the wood failure percentages were usually low have been plotted in figures 3 to 6. To avoid confusion of lines, points have been connected for selected species only. In the figures it may be seen that the glues did not develop joint strength at the same rate on all species but that the curves for the several species fan out early, more like (B) and (C) of figure 1 than like figure 1 (A). From these observations it may be concluded that, aside from any effect of density and strength of the wood on the shear strengths of the joints there is an effect of the species of the wood on the rate at which these resin glues harden.

The effect of species on the development of joint strength is revealed in the data for both the phenol and the resorcinol glues. In general, the curves for the several species are in about the same order for each of the three resorcinol glues but not in the same order for the phenol glue. The resorcinol glues built up strength more slowly on Douglas-fir than on maple, whereas the reverse was true for the phenol glue. The

influence of species was seen at both the 80° F. and 120° F. curing temperatures. The order of the curves was roughly the same at both temperatures.

The difference between the 'slowest' and the 'fastest' species may be enough to be of considerable practical importance. For example (fig. 5), glue C took about 3 hours longer at 80° F. to develop 200 pounds per square inch joint strength in Douglas-fir than it did on sugar maple. Glue A (fig. 3) required about 10 minutes more heating at 120° F. to develop 300 pounds per square inch strength on Douglas-fir than it did on sugar maple. These are, however, extreme examples and most of the species tested did not vary as widely in their effect on the curing of the glue.

The data of tables 1 and 2 were plotted in the form of graphs (not shown), and smooth curves drawn to fit as closely as possible the points for each species. From these smooth curves the estimated time for the joints to reach particular shear-strength levels has been tabulated in tables 3 and 4. The differences in the lengths of time shown in column 3 for a glue to reach 200 pounds per square inch are presumably due to the effects of the species on the rate of curing. The differences in the lengths of time to reach high joint strengths are due not only to the influence of the wood on the curing but also to differences in the strength of the wood of the different species.

No attempt was made herein to explain why a resin glue may not cure as rapidly on one species of wood as on another; instead it is the purpose of this report merely to point out that such differences do exist and that they may be great enough to be of practical importance in commercial gluing operations.

Table 1.—Averaged results[1] of shear tests on wet two-ply lap-joint specimens made with eight species and four resin glues cured for various periods of time at 80° F.

Species	Curing period at 80° F. (hours)												
	2	2-1/2	3	4	5	6	7	8	10	12	16	24	48	60
Glue A														
Noble fir	0-0	158-0	235-10	304-56	355-50	371-88	360-100	361-89	371-81	346-98	319-100	328-100	395-100	415-100
Western hemlock	0-0	103-0	189-16	236-46	322-82	411-66	422-68	365-79	345-79	428-79	404-100	414-100	390-100	459-100
Sitka spruce	0-0	110-0	188-2	252-21	335-18	366-30	389-46	380-64	359-78	370-95	386-100	394-100	388-100	432-100
Douglas-fir	0-0	15-0	183-2	222-3	280-5	321-60	366-79	370-92	380-85	372-90	381-81	368-100	379-100	320-100
Mahogany	26-0	138-0	282-8	303-6	362-19	479-64	496-74	480-38	495-74	510-95	528-100	509-100	508-100	495-100
Sweetgum	0-0	205-0	330-20	371-33	390-15	450-13	479-26	467-45	398-31	465-73	444-100	441-100	484-100	579-99
Yellow birch	0-0	122-0	256-1	406-0	468-5	555-29	608-44	599-61	558-41	676-71	661-99	670-100	634-100	764-100
Hard maple	41-0	172-0	225-0	486-1	553-8	568-26	592-35	590-29	600-53	673-69	658-46	676-100	693-100	705-99
Glue B														
Noble fir	0-0		77-0	177-0	222-4	318-21	341-33	373-56	386-75	386-84	350-95	350-100	353-100	380-100
Western hemlock	0-0		109-0	135-1	195-2	264-19	368-31	365-75	368-63	376-80	378-100	394-88	368-100	378-100
Sitka spruce	0-0		134-1	169-1	215-2	274-3	301-15	290-25	334-26	354-60	409-78	436-100	423-100	449-100
Douglas-fir	0-0		91-0	107-0	124-0	175-0	198-27	246-5	291-28	349-66	379-86	391-100	404-100	365-100
Mahogany	0-0		135-0	175-0	224-0	280-0	334-5	350-8	391-13	468-71	494-91	516-81	539-100	529-100
Sweetgum	0-0		110-0	216-0	289-0	343-13	345-35	390-20	419-4	431-3	464-65	535-58	538-100	574-100
Yellow birch	0-0		95-0	197-0	270-0	391-3	490-1	510-21	563-6	581-15	690-78	646-75	668-100	755-100
Hard maple	0-0		116-0	167-0	269-0	362-0	443-0	481-0	543-8	517-5	646-35	710-86	695-95	766-100
Glue C														
Noble fir	70-0		271-28	302-8	381-21	384-90	361-89	328-86	334-90	440-91	311-100	424-100	504-100	440-94
Western hemlock	60-0		254-6	281-5	399-52	409-73	394-78	414-70	406-85	419-79	329-100	351-100	348-100	371-100
Sitka spruce	40-0		161-0	190-0	232-0	293-40	270-9	319-34	378-38	365-54	349-40	373-100	379-100	475-100
Douglas-fir	35-0		134-1	148-0	162-2	225-11	231-9	231-18	275-65	296-71	323-31	436-89	434-90	298-100
Mahogany	55-0		178-2	190-0	194-0	253-6	348-8	338-1	376-24	355-16	406-23	433-19	400-89	484-100
Sweetgum	120-0		285-2	318-12	366-6	356-15	410-10	409-10	436-11	416-33	384-55	515-48	541-66	560-100
Yellow birch	79-0		288-1	344-0	480-6	563-29	605-41	562-16	595-45	608-83	626-69	693-85	633-100	496-89
Hard maple	102-0		313-0	354-0	436-0	454-18	535-8	532-7	498-15	505-15	641-13	651-21	613-48	698-95
Glue D														
Noble fir	0-0		28-0	58-0	56-0	80-0	160-1	171-4	230-3	274-10	340-16	381-70	428-100	390-100
Western hemlock	0-0		26-0	34-0	46-0	55-0	102-5	141-0	164-26	231-15	288-29	286-91	330-93	366-90
Sitka spruce	0-0		42-0	86-0	72-0	84-0	119-0	141-4	186-3	200-6	301-3	353-51	420-66	406-100
Douglas-fir	0-0		70-0	69-0	85-0	93-0	128-1	164-0	206-3	205-6	280-8	353-38	431-95	370-100
Mahogany	0-0		39-0	81-0	96-0	80-0	160-0	169-0	173-1	246-0	300-4	368-6	416-71	518-48
Sweetgum	0-0		24-0	25-0	49-0	51-0	133-1	168-0	200-0	260-4	310-24	444-38	480-41	430-98
Yellow birch	0-0		32-0	75-0	50-0	66-0	126-0	128-0	179-0	200-0	263-1	380-1	405-26	428-5
Hard maple	0-0		44-0	40-0	49-0	59-0	94-0	113-0	155-0	227-0	338-0	433-6	491-6	465-0

[1] The value before the dash is averaged shear strength in pounds per square inch; the value after the dash is averaged wood failure in percent. Each value is the average of four tests.

Table 2.—Averaged results[1] of shear tests on wet two-ply lap-joint specimens made with eight species and four resin glues cured for various periods of time at 120° F.

Species	Curing period at 120° F. (minutes)									
	5	10	15	20	25	35	45	60	75	90	180
Glue A											
Noble fir	25-0	174-0	265-5	322-58	395-20	368-96	376-100	361-100	339-100	358-100	489-100
Western hemlock	15-0	156-5	300-2	313-10	400-45	395-100	354-100	350-100	378-100	401-100	536-100
Sitka spruce	21-0	142-0	257-0	328-8	330-65	363-73	418-100	454-100	445-100	431-100	541-100
Douglas-fir	0-0	80-0	180-0	259-33	315-91	330-43	335-100	398-100	414-100	464-100	448-100
Mahogany	0-0	126-0	303-4	325-9	419-20	508-99	553-100	540-100	575-100	525-100	453-100
Sweetgum	21-0	172-0	277-0	291-10	330-5	481-14	525-46	538-89	553-100	571-100	608-100
Yellow birch	0-0	174-0	325-0	433-3	528-11	543-10	672-80	780-90	777-100	738-95	750-100
Hard maple	0-0	154-0	371-0	514-11	596-16	595-5	685-65	760-80	765-100	715-100	753-100
Glue B											
Noble fir	0-0	119-0	160-0	219-3	229-4	329-33	384-70	365-100	340-100	355-100	344-100
Western hemlock	0-0	91-0	130-0	172-5	220-0	334-24	348-61	380-100	320-100	348-100	535-100
Sitka spruce	0-0	98-0	120-0	196-2	258-0	290-1	350-49	378-60	404-100	445-100	408-100
Douglas-fir	0-0	0-0	60-0	169-0	215-0	252-19	284-48	293-100	340-100	380-100	407-100
Mahogany	0-0	111-0	140-0	209-0	306-1	358-14	451-44	500-94	529-100	536-100	561-100
Sweetgum	0-0	111-0	130-0	245-0	318-0	385-8	466-43	485-24	500-85	555-100	618-100
Yellow birch	0-0	120-0	159-0	268-0	319-0	455-3	546-31	685-31	678-58	726-100	788-100
Hard maple	0-0	93-0	155-0	234-0	320-0	399-0	543-10	586-26	710-65	696-98	865-100
Glue C											
Noble fir	69-0	165-0	201-5	225-10	379-10	368-53	375-100	410-100	378-96	410-100	401-100
Western hemlock	60-0	140-0	199-4	216-9	262-6	334-36	364-100	420-100	418-100	381-100	376-100
Sitka spruce	55-0	120-0	134-0	166-2	178-3	229-1	268-11	285-20	330-53	341-16	408-100
Douglas-fir	16-0	99-0	105-0	118-0	155-0	145-0	223-1	266-9	311-64	320-24	330-100
Mahogany	20-0	116-0	143-0	200-1	219-4	243-3	324-8	386-13	431-26	395-31	515-100
Sweetgum	79-0	196-0	228-0	335-9	368-6	382-15	438-50	465-49	536-95	531-74	608-100
Yellow birch	45-0	200-0	206-0	297-1	354-5	499-5	615-29	701-33	723-78	691-95	800-100
Hard maple	63-0	198-0	249-0	328-2	454-4	516-5	528-15	644-25	598-48	635-66	709-100
Glue D											
Noble fir	0-0	49-0	85-0	131-0	156-0	196-4	305-9	351-59	341-100	386-71	381-100
Western hemlock	0-0	0-0	44-0	115-0	140-0	171-0	288-34	340-18	358-100	271-100	270-100
Sitka spruce	0-0	0-0	86-0	110-0	160-0	170-0	196-0	288-40	324-14	382-23	453-100
Douglas-fir	0-0	0-0	48-0	105-0	120-0	179-0	223-0	298-28	361-47	406-55	418-100
Mahogany	0-0	49-0	94-0	149-0	168-0	199-0	259-0	346-21	370-47	483-56	543-100
Sweetgum	0-0	0-0	0-0	83-0	79-0	75-0	188-0	283-0	298-8	319-3	461-100
Yellow birch	0-0	0-0	48-0	80-0	110-0	184-0	194-0	323-0	308-2	465-11	656-100
Hard maple	0-0	0-0	0-0	70-0	73-0	139-0	200-0	284-0	318-1	425-2	574-64

[1] The value before the dash is averaged shear strength in pounds per square inch; the value after the dash is averaged wood failure in percent. Each value is the average of four tests.

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Table 3.—Estimated curing periods at 80° F. to develop shear strength of several levels in lap-joints of 1/16-inch veneer of eight species glued with four resin glues

Species	Approximate ultimate shear strength	Curing period required to develop shear strength of:											
		200 p.s.i.		300 p.s.i.		400 p.s.i.		500 p.s.i.		600 p.s.i.			
	P.s.i.	Hours	Minutes	Hours	Minutes	Hours	Minutes	Hours	Minutes	Hours	Minutes		
Glue A: Room-temperature-setting resorcinol formaldehyde													
Noble fir	380	2	45	3	55								
Western hemlock	385	3	10	4	30								
Sitka spruce	425	3	10	4	25								
Douglas-fir	380	3	40	5	30								
Mahogany	535	2	50	3	40	5	5	8	25				
Sweetgum	545	2	30	3	5	4	30	8					
Yellow birch	720	2	45	3	15	4		5	15	7	20		
Hard maple	725	2	35	3		3	35	4	25	7			
Glue B: Room-temperature-setting resorcinol formaldehyde													
Noble fir	380	4	20	5	40								
Western hemlock	385	4	45	6	45								
Sitka spruce	425	4	35	8	9								
Douglas-fir	380	6	30	10	30								
Mahogany	535	4	15	6	25	10		17					
Sweetgum	545	3	45	5	15	8	30	20					
Yellow birch	720	4	25	5		6		7	50	14			
Hard maple	725	4	20	5	15	6	20	8	20	16			
Glue C: Room-temperature-setting resorcinol formaldehyde													
Noble fir	380	2	40	3	50								
Western hemlock	385	2	40	3	50								
Sitka spruce	425	4	5	7	5								
Douglas-fir	380	5	45	12	15								
Mahogany	535	4	25	7	15	13							
Sweetgum	545	2	25	3	30	6	45						
Yellow birch	720	2	30	3		3	55	5	15	11	30		
Hard maple	725	2	40	3	15	4	20	9		20			
Glue D: Intermediate-temperature-setting phenol formaldehyde													
Noble fir	380	8	42	13	25								
Western hemlock	385	10	40	16	25								
Sitka spruce	425	11		17	10								
Douglas-fir	380	10	25	16	30								
Mahogany	535	9	55	15	40	38							
Sweetgum	545	9	50	15	10	21							
Yellow birch	720	11	30	19		33							
Hard maple	725	10	50	16	20	22							

Table 4.—Estimated curing periods at 120° F. to develop shear strengths of several levels in lap-joints of 1/16-inch veneer of eight species glued with four resin glues

Species	Approximate ultimate shear strength	Curing period required to develop shear strength level of:				
		200 p.s.i.	300 p.s.i.	400 p.s.i.	500 p.s.i.	600 p.s.i.
	P.s.i.	Minutes	Minutes	Minutes	Minutes	Minutes
Glue A: Room-temperature-setting resorcinol resin						
Noble fir	380	11	19			
Western hemlock	385	12	19			
Sitka spruce	425	11	20	47		
Douglas-fir	380	15	26			
Mahogany	535	12	16	22	32	
Sweetgum	545	11	16	25	38	
Yellow birch	720	11	14	19	26	38
Hard maple	725	11	13	17	22	31
Glue B: Room-temperature-setting resorcinol resin						
Noble fir	380	18	30			
Western hemlock	385	22	36			
Sitka spruce	425	20	34	39		
Douglas-fir	380	24	39			
Mahogany	535	18	26	37	60	
Sweetgum	545	16	24	35	56	
Yellow birch	720	16	22	30	40	51
Hard maple	725	17	25	34	44	56
Glue C: Room-temperature-setting resorcinol resin						
Noble fir	380	15	28			
Western hemlock	385	16	30			
Sitka spruce	425	27	52	130		
Douglas-fir	380	38	75			
Mahogany	535	21	38	65		
Sweetgum	545	11	20	34	60	
Yellow birch	720	13	20	27	35	44
Hard maple	725	11	19	27	37	48
Glue D: Intermediate-temperature-setting phenol resin						
Noble fir	380	31	46			
Western hemlock	385	35	49			
Sitka spruce	425	42	67	110		
Douglas-fir	380	39	60			
Mahogany	535	36	52	73	118	
Sweetgum	545	47	76	122	186	
Yellow birch	720	42	60	80	108	150
Hard maple	725	46	64	88	130	200

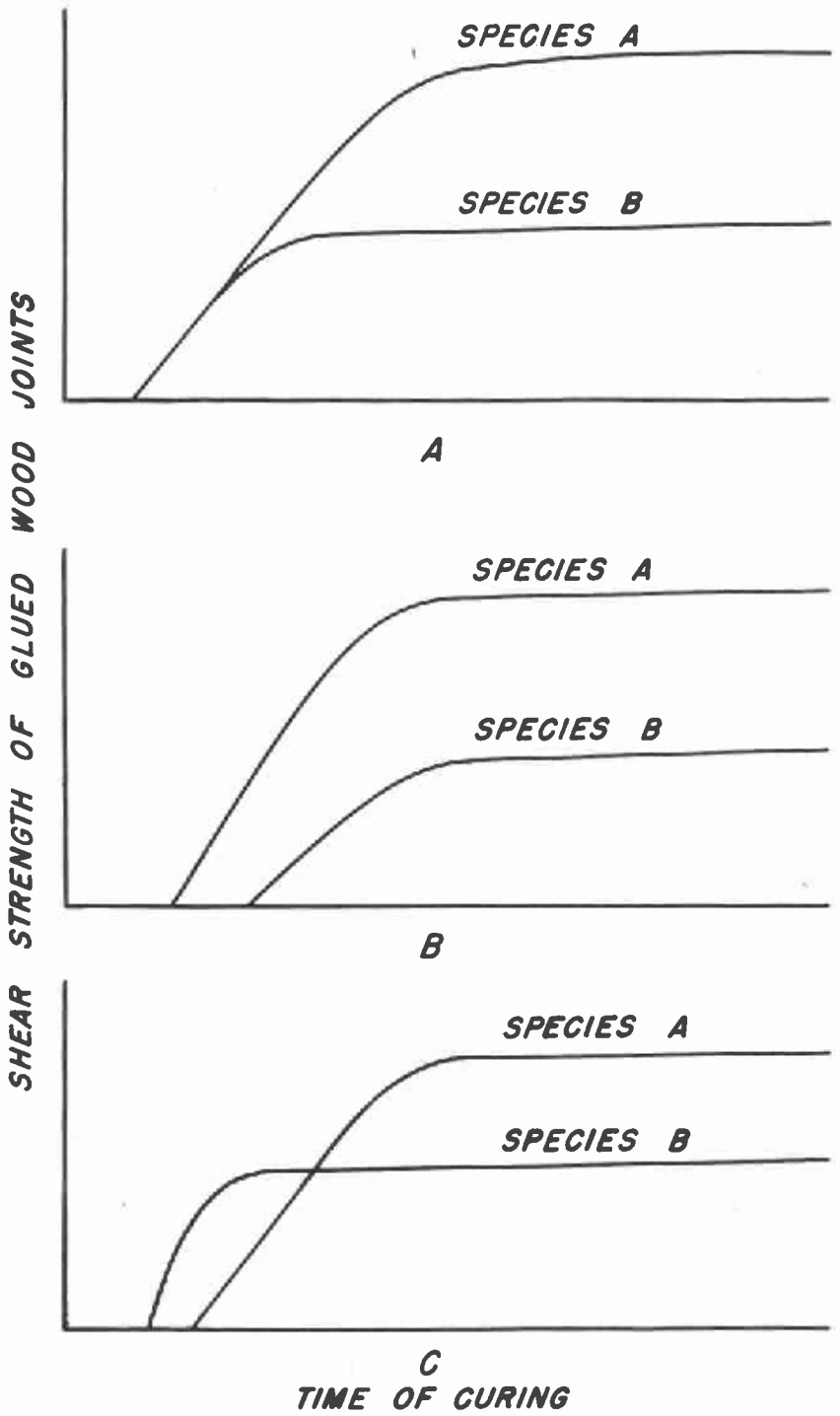

Figure 1.--Idealized rate of development of joint strength by a resin glue in two species of wood: (A) without, and (B) and (C) with species effect on the rate of curing of the glue.

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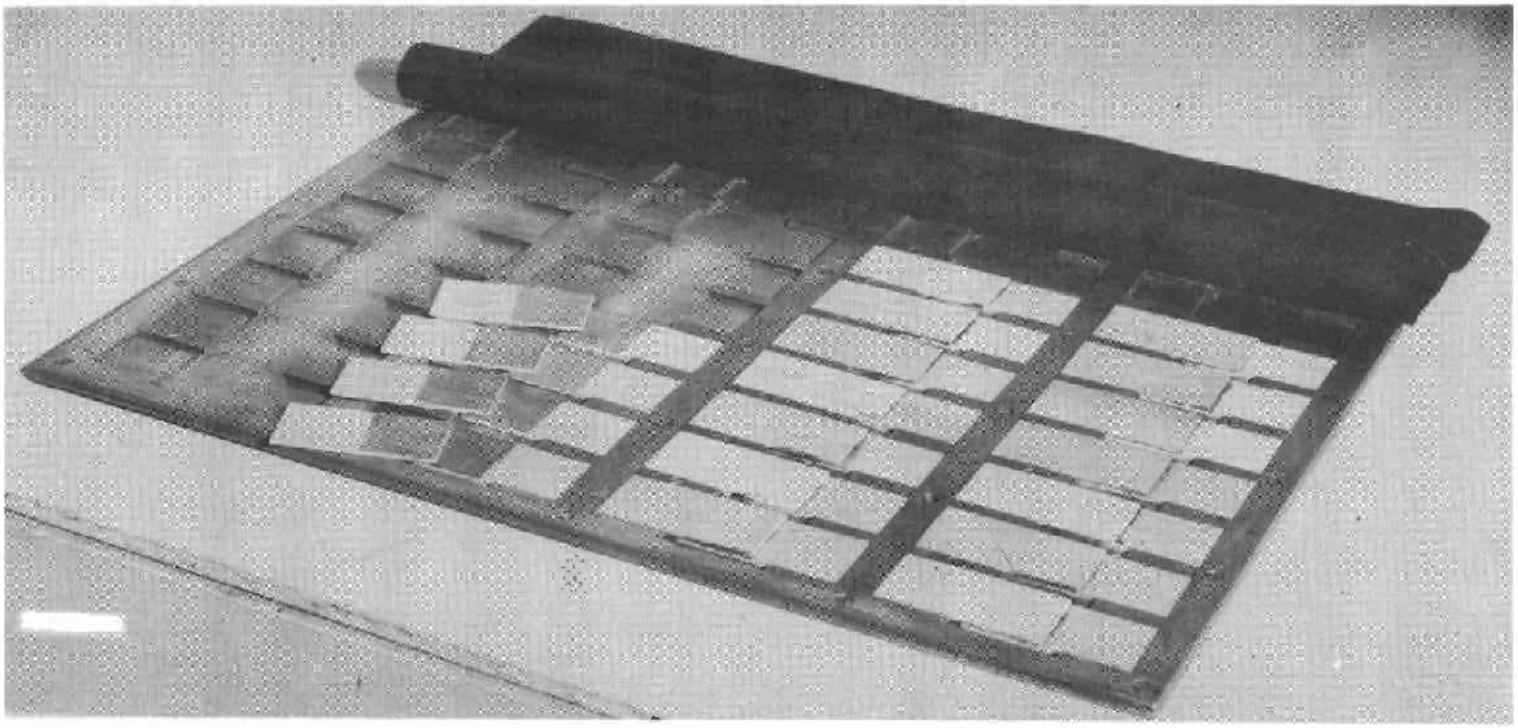

Figure 2.--Metal jig, with rubber caul, in which lap-joint specimens were prepared, 32 at a time.

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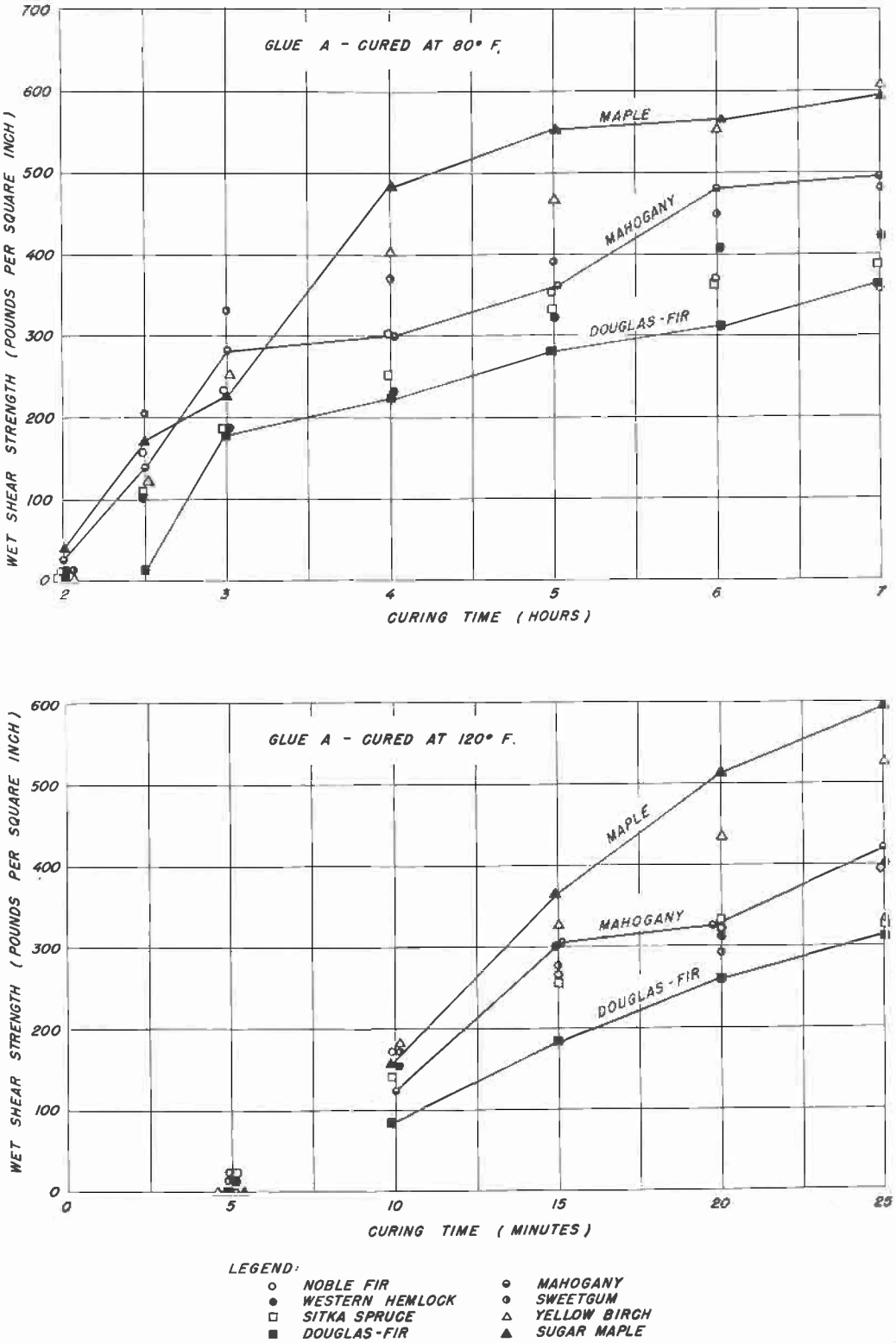

Figure 3.--Shear strength of two-ply lap-joints of eight species of wood glued with room-temperature-setting resorcinol-resin Glue A at 80° F. and 120° F.

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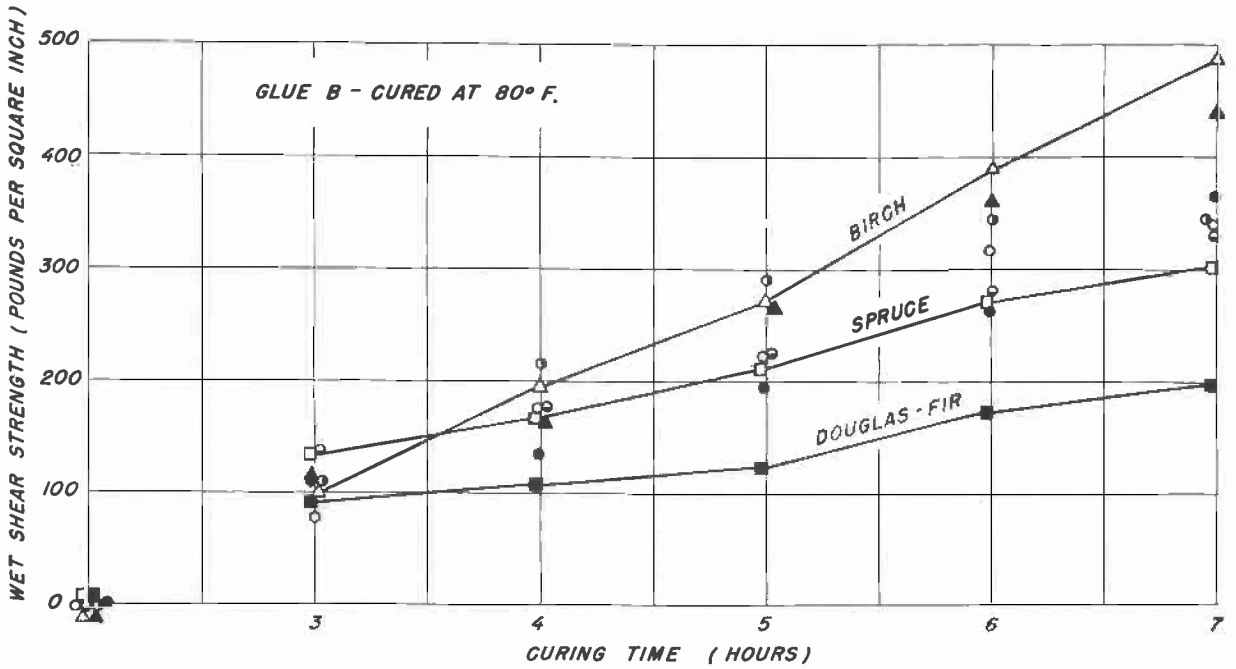

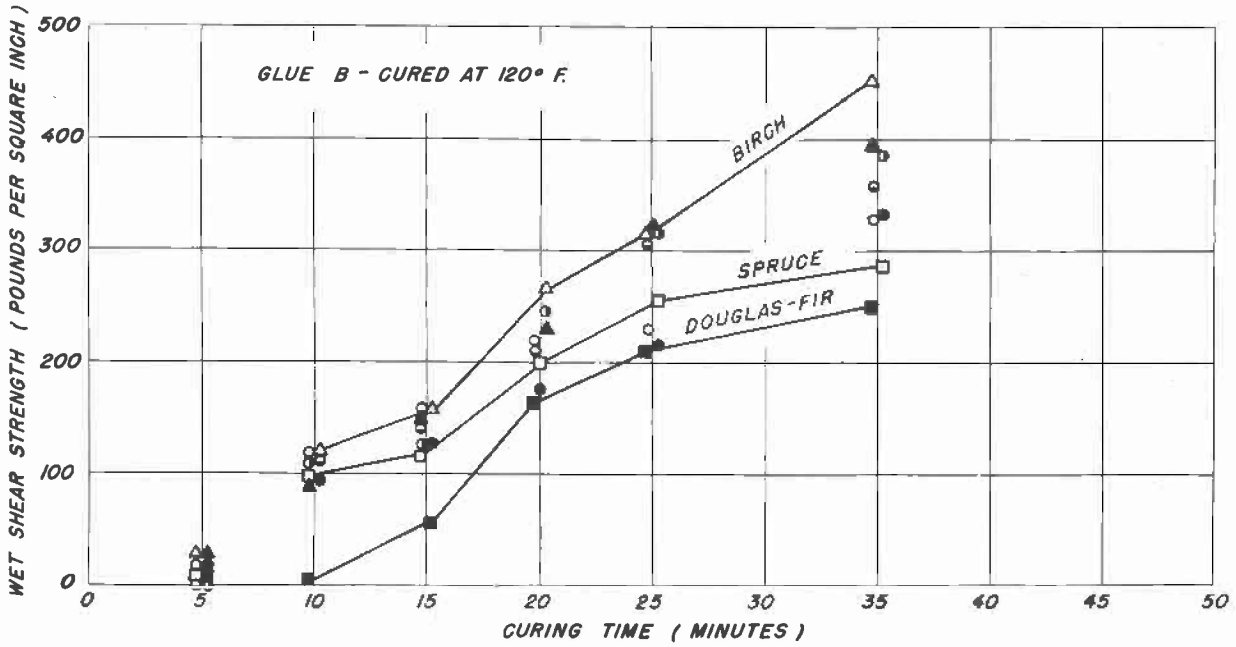

LEGEND:

○ NOBLE FIR	● MAHOGANY
● WESTERN HEMLOCK	● SWEETGUM
□ SITKA SPRUCE	△ YELLOW BIRCH
■ DOUGLAS-FIR	▲ SUGAR MAPLE

Figure 4.--Shear strength of two-ply lap-joints of eight species of wood glued with room-temperature-setting resorcinol-resin Glue B at 80° F. and 120° F.

Z M 68844 F

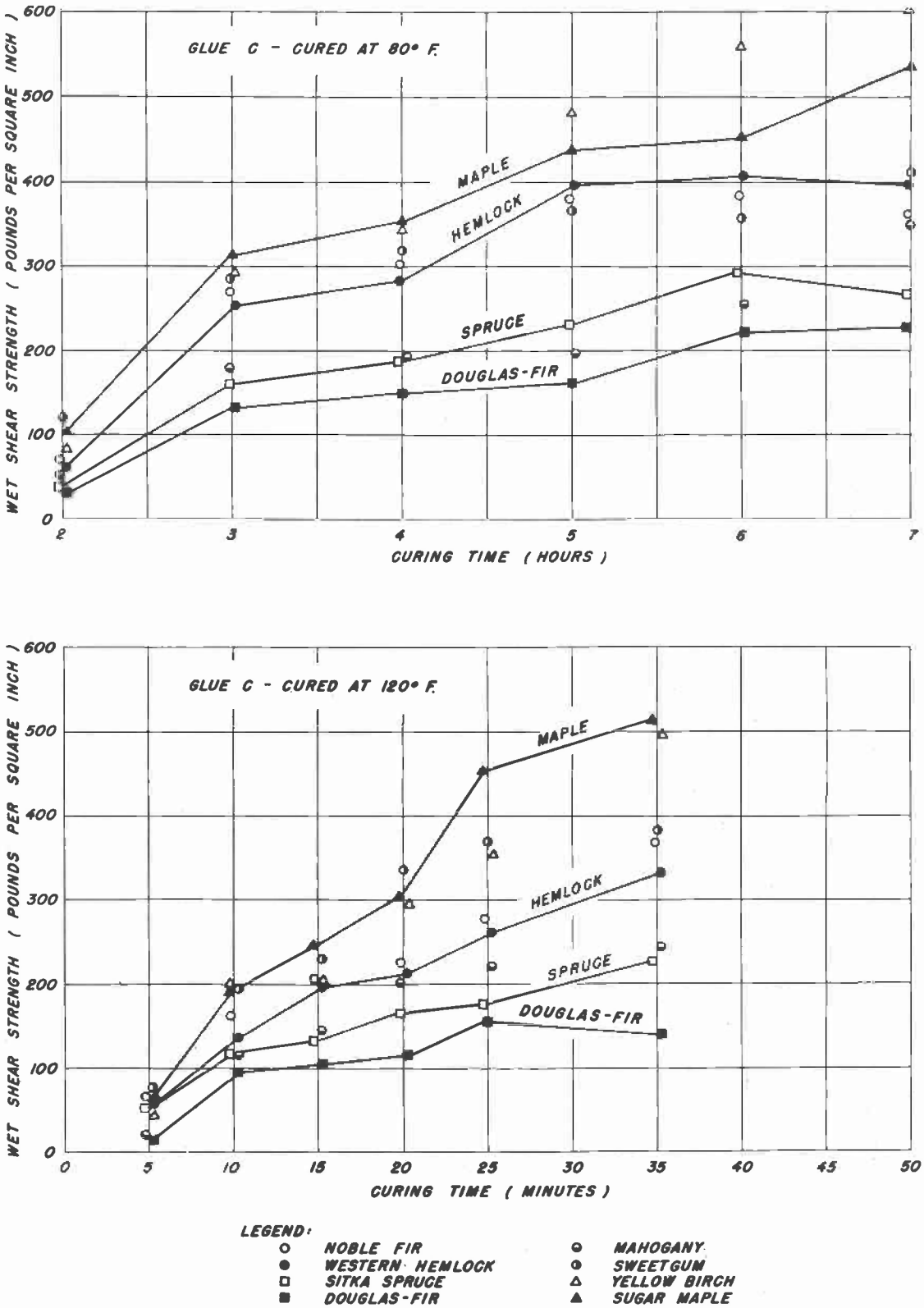

Figure 5.--Shear strength of two-ply lap-joints of eight species of wood glued with room-temperature-setting resorcinol-resin Glue C at 80° F. and 120° F.

Z M 68845 F

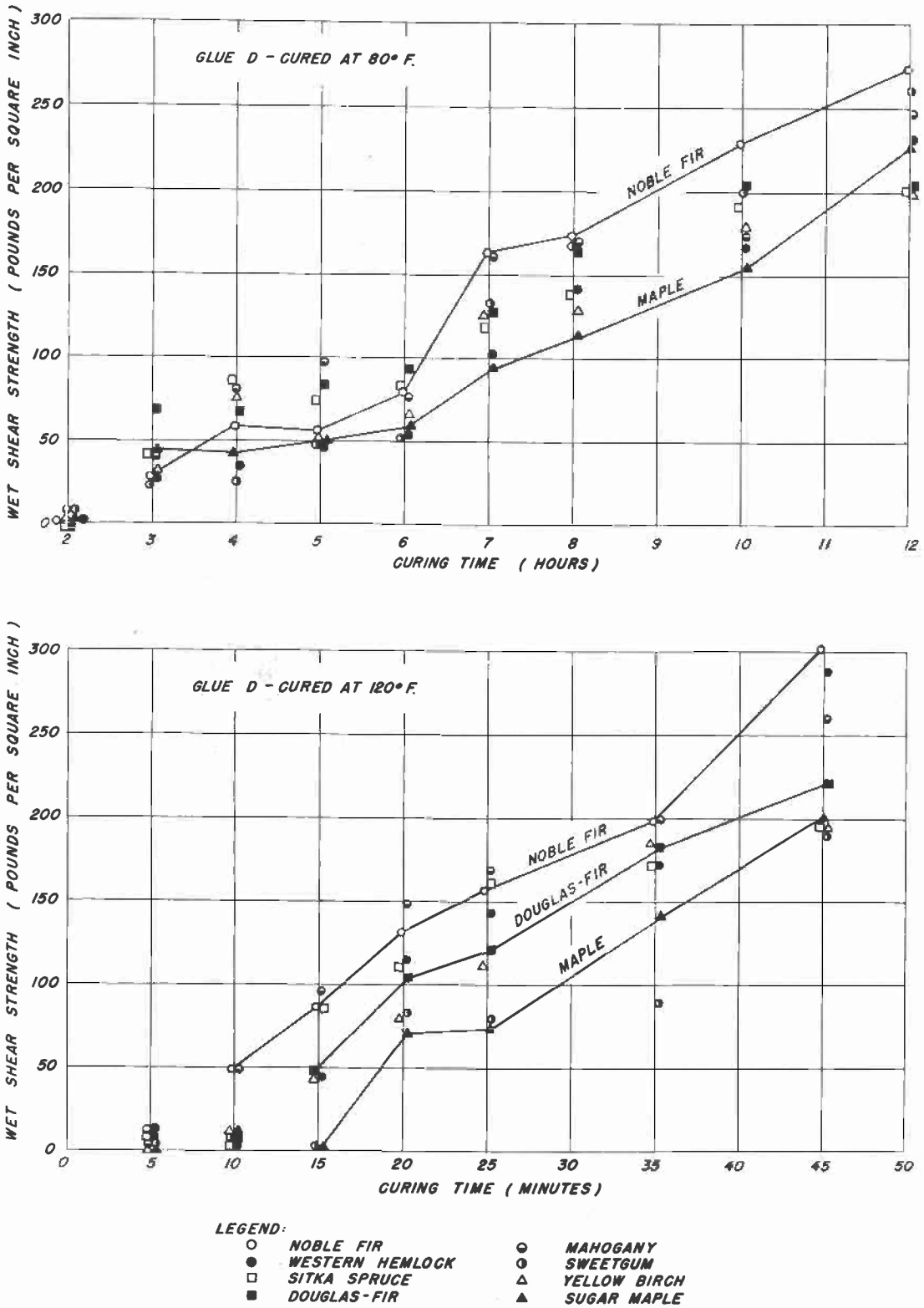

Figure 6.--Shear strength of two-ply lap-joints of eight species of wood glued with intermediate-temperature-setting phenol-resin Glue D at 80° F. and 120° F.

Z M 68846 F