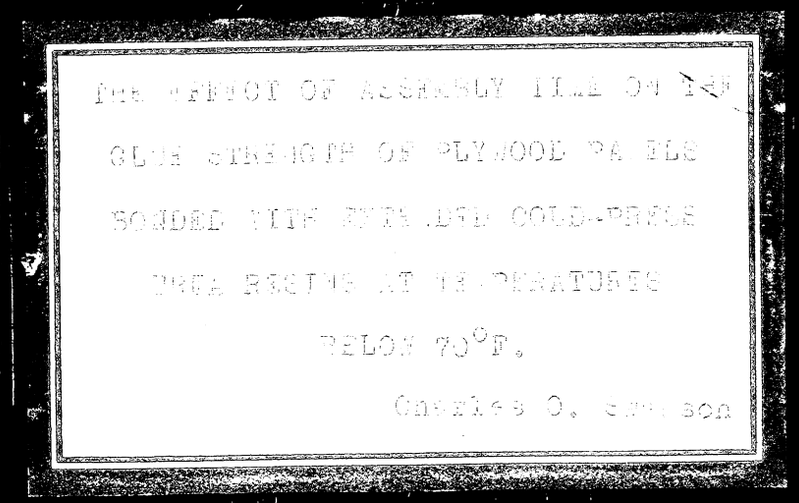

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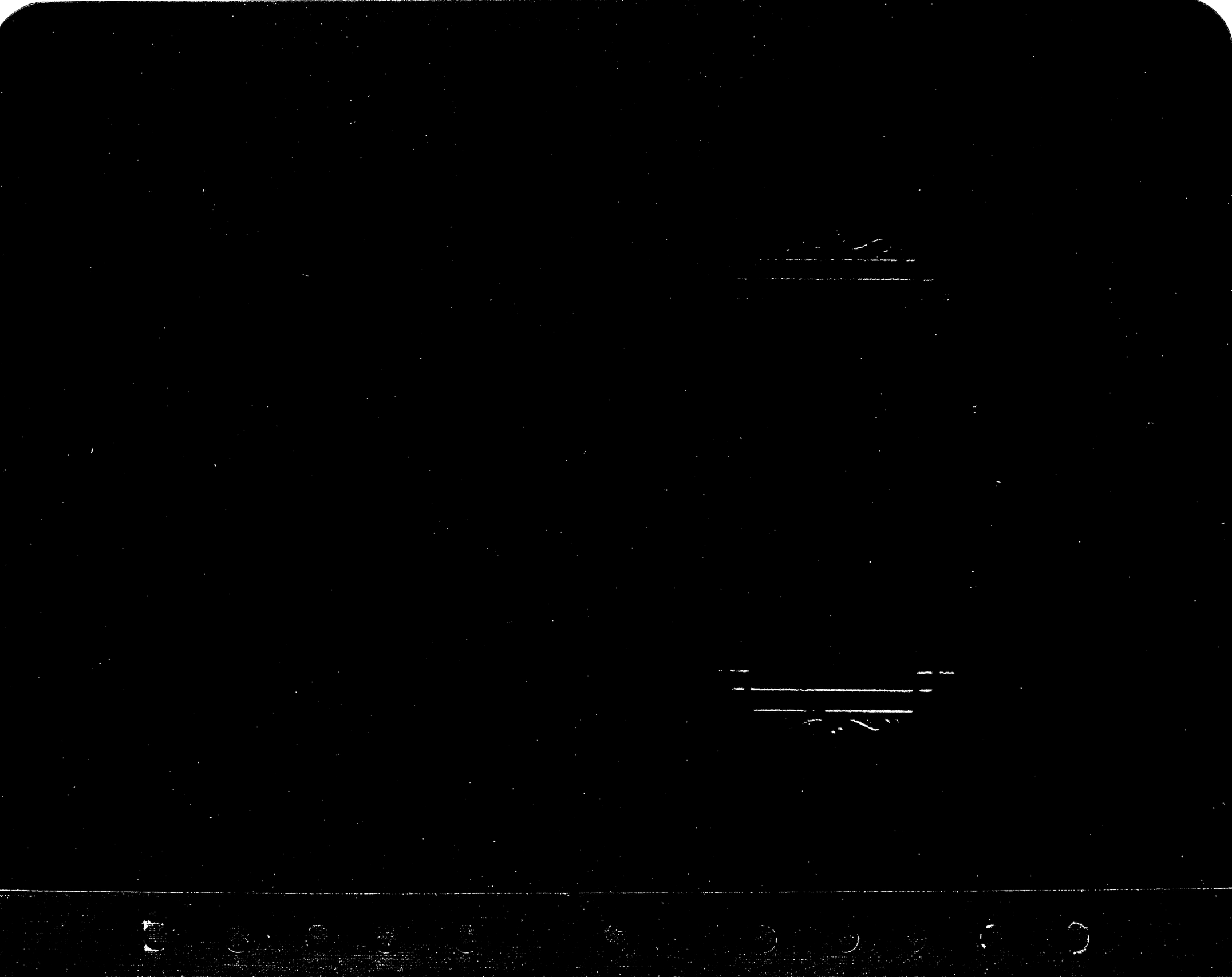

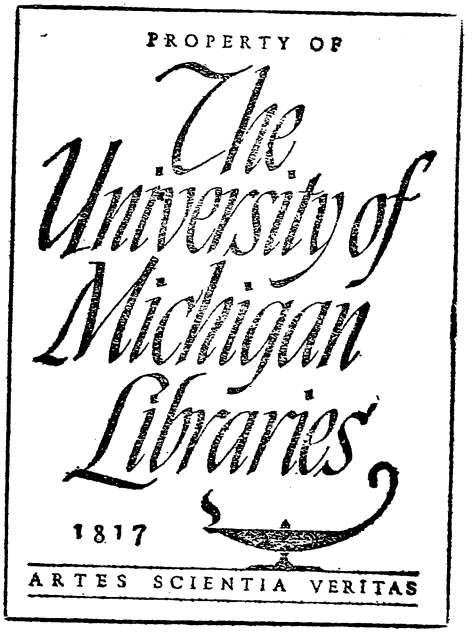
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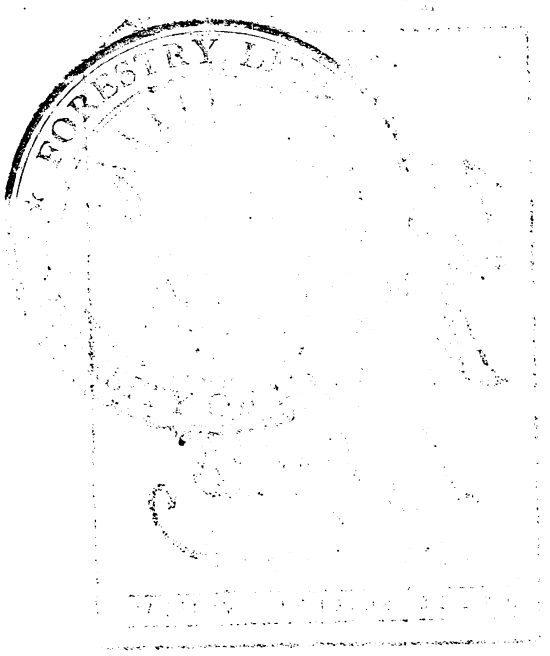

THE EFFECT OF ASSEMBLY TIME ON THE GLUE STRENGTH OF PLYWOOD PANELS BONDED WITH EXTENDED COLD-PRESS UREA RESINS AT TEMPERATURES BELOW 70°F.

This report is submitted as partial fulfillment in candidacy for the degree of Master of Wood Technology.

Charles O. Swanson, B.S.Wood Tech.
Ann Arbor, Michigan, 1948

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The author is grateful to Professor Patronsky for his interest and aid in carrying out this project. His ready and able assistance was called upon many times to solve problems pertinent to this work.

The author is also indebted to several furniture manufacturers for their cooperation. Mr. C.M. Kindel of the Kindel Furniture Company in Grand Rapids, Michigan, furnished corestock panels needed in this work and Mr. Bert Baker of the Grand Rapids Chair Company, also of Grand Rapids, furnished a glue catalyst and a formula used by his organization.

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INTRODUCTION

The urea-formaldehyde resin glues were introduced about 1937 as a low cost resin adhesive which would be more durable under humid conditions than the conventional glues. They would cure at lower temperatures than the phenol-formaldehyde resin film formerly employed and would be compatible with extenders thus reducing costs substantially.(1) Both room temperature setting and hot press types were developed, were universally used, and grew in popularity over the years. As the use of this type of glue expanded, so did the problems connected with it. Although many of the difficulties have been overcome, there are still problems confronting manufacturers using this resin glue especially in the extended form. As evidence that furniture manufacturers recognize these problems as among their foremost, the following is an excerpt from a recent bulletin of the National Association of Furniture Manufacturers. It concerns the research program to be installed at the University of Michigan under their sponsorship.

"Special Reference to Urea-resin Glues"

> "The NAFM-sponsored research program is to give special attention to the use of urea resin glues, with which many manufacturers are having trouble. Has the core been properly dried? Perhaps it has been dried too much. Is the right kind of press being used and the right timing? These are some of the questions for which answers will be sought,

(1) Refers to item of the same number in the Bibliography.

not answers "By guess and by golly" but scientifically-sound answers."*

One of the problems confronting manufacturers using resin glues is the control of conditions; a problem not as serious when using natural glues. For satisfactory results the temperature of the glue room and stock must be watched carefully. The moisture content of the wood must be controlled accurately so as to keep it within the critical limits. The pot life of the glue varies with the temperature so must be checked. Fresh mixtures must be made up instead of adding to the old. All rules of cleanliness must be observed. Maintaining satisfactory temperature of the wood, adhesive and glue room is very difficult unless the plant has been constructed with this factor in mind.

Room temperature setting urea resins are most practical for a company that wishes to change from natural glues to synthetic resin glues because additional equipment is not necessary. Manufacturers of this type of glue state in their bulletins and instructions that neither the adhesive nor the wood should be below 70°F. at the time of gluing for best results. The room temperature should also be 70°F. or above. These manufacturers say that at temperatures below 70°F. the resins will not polymerize fast enough for commercial work and that full strength will not

* Bulletin No. 48-4, National Association of Furniture Manufacturers, Chicago, Illinois, January, 1948

be developed. Gluing at 70°F. or above is not always practical, especially in the winter months. When the factories cool down at night, stock gets cold and it takes some time to bring all the materials and the air up to the required minimum. Because it is not practical it often times isn't done and the gluing is begun the first thing in the morning regardless of the temperature.

Panels that are to be cold pressed are laid up in stacks and then clamped into bales. In order to reduce the time required for curing, these bales are placed in a heated storage room. Nevertheless while the panels are being glued at less than the minimum required temperature the wood absorbs some of the moisture from the adhesive. Also after the panels are clamped into bales and moved to the curing room, the temperature in the center of the bale remains low for some time because the heat is not transmitted through the wood and glue line rapidly. Meanwhile the wood is still absorbing moisture from the glue thus changing the composition of the adhesive although the resin is not polymerizing appreciably. Will this absorbing of the moisture by the wood affect the glue bond? The aim of this project is to investigate this question.

Before delving farther into this work a few facts

about resin adhesives should be reviewed. Unlike natural adhesives, resin glues cure by means of a chemical reaction involving heat. Increasing the temperature will shorten the polymerization time. Because it is a chemical reaction the addition of a catalyst speeds up the curing. On the other hand, natural glues"harden" or "set" largely by the evaporation of the glue solvent. This difference in the two types of glue should be kept in mind the better to understand the work undertaken.

The problem was to learn if the absorption of moisture from the glue, before it began curing to any extent, had an appreciable effect on the glue bond. It was decided to test the bonds made at various temperatures below 70°F. and with different closed assembly times at each temperature. The temperatures selected for the gluing were 40°F., 50°F., and 60°F. The closed assembly times chosen were one hour, twenty minutes, and ten minutes. Because most gluing difficulties had developed with lumber core furniture panels, 5 ply panels were made up using 5/8" corestock. Yellow poplar(Liriodendron tulipifera) and red gum(Liquidambar styraciflua) cores were used because both species are widely used in industry. Rotary cut yellow birch(Betula lutea) was used for the face veneer and sliced yellow poplar for the crossbanding.

Good gluing procedure was followed as closely as possible in carrying out this work. The moisture contents of the cores and veneers were within the satisfactory limits set by manufacturers. The pressure applied during curing was in accord with present accepted industry practice according to manufacturers' instructions. The length of curing time was adequate in all cases. The temperature of the wood and the room temperature at which it was glued are the only factors that differed from those specified in the glue manufacturers instructions.

The standard plywood shear test was employed as a means of comparing the strength of the panels glued at the three assembly periods. Because of the variations among the panels as to corestock, temperature, and curing conditions it was only possible to compare those panels that were glued at the same time under the same conditions, with the assembly time being the only variable.

PROCEDURE

Preparation of Panels.

In order to make this work as similar to manufacturing practice as possible the plywood shear specimens were made from 7/8" - 5 ply panels consisting of a 5/8" core with 1/16" crossbanding and face veneer. Commercial corestock panels of red gum and yellow poplar were used. The crossbanding in all cases was 1/16" sliced yellow poplar veneer and the face veneer was 1/16" rotary cut yellow birch. The cores and veneers were conditioned to 7 - 11% moisture content and were left for 12 hours at the temperature at which they were to be glued. In most instances six panels made up a set. Each set differed from all other sets either in type of glue used, temperature at which glued, or kind of corestock. Within a set two panels were made at each assembly period. Both sides of the panels were used to furnish the plywood shear specimens for testing.

Glues Used.

Two fresh samples of commercial urea resin glues of the room temperature setting type, designated in this report by the letters A and B, were used. They were mixed according to directions supplied by the glue manufacturers to two furniture manufacturers. Glue A was extended 40% and glue

B 50% with wheat flour. In production usage it is essential that glues be extended for economical reasons. This addition of wheat flour changes some of the properties of the unadulterated resin so in this research work the author believes that it is appropriate to study the adhesives in the form in which they will be used. That is why formulas as supplied to furniture manufacturers were used in this work. With both glues low temperature catalysts were used. The various constituents of the adhesives were allowed to stand for at least 12 hours at the temperature at which they were to be mixed. The glue was mixed immediately preceding the assembling of the first panel. The temperature of the mixture was determined before spreading was begun.

Moisture Content.

Manufacturers of resin glues recommend that the wood and veneer moisture contents be between 7 and 12% for best results. In this work the moisture content of the veneers and corestock varied from 7 - 12% in the different sets of panels but never more than 3% in any one set of panels. A Hart Moisture Meter was used to obtain the moisture content readings and a thermometer was used to determine the temperatures of the wood.

Glue Spreading.

Twenty grams of liquid glue per square foot of glue line was applied to the crossbanding. This was done by weighing the piece of crossbanding and then spreading eight grams of adhesive on each side with a rubber roller. The area of the panels was approximately 60 square inches so eight grams over this area is the equivalent of forty-four pounds per thousand square feet of glue line.*

Closed Assembly Periods.

Three closed assembly periods of one hour, twenty minutes, and ten minutes were used for the set of panels glued at each temperature. These assembly periods were only approximate because two panels were glued up at each assembly time and it took several minutes to weigh out the adhesive and spread it over the crossbanding. Therefore the second panel in each case would be slightly short of the maximum assembly time. During these closed assembly periods only enough pressure was exerted to keep the veneers flat on the corestock. Plywood cauls were used between each set of two panels.

Curing of Panels.

When the assembly period for the last panel was

* "Service Bulletin No. 30", Casein Company of America, March 1946.

completed the set was placed in a press under a pressure of 200 pounds per square inch. If the curing conditions called for elevated temperatures, infra-red lamps were used as the heat source. Otherwise the room temperature of approximately 80°F. was used. The curing times varied from a few hours at a high temperature to twenty hours at a lower temperature. Several curing conditions were used and they varied from severe (high heat and low humidity) to mild. It must be remembered that the purpose of this work was to compare the three assembly times within each set of panels and not the sets with each other. In order to compare the results of different curing conditions the sets were cured in various ways. The internal temperature of the stacks of panels was determined by using a thermocouple. In all cases the time that the panels were under pressure was sufficient to develop 50% of the glue's ultimate strength.

After removal from the press some sets were placed in a constant temperature and humidity room for several hours where 80°F. and 78% relative humidity prevailed. Eventually all panels reached an equilibrium by being stored in a room of approximately 80°F. and 15% relative humidity until being cut into the plywood shear specimens.

Preparation of Specimens.

After curing, the panels were trimmed and made into plywood shear specimens by ripping down the center of the corelumber leaving only 1/16" of corestock against the poplar crossbanding and then cutting the two 3 ply sections into one inch strips. Each of these strips made two specimens which were notched so as to give a shearing area of one square inch. The specimens were divided into groups that were representative of each of the panels and then were ready for conditioning. A point that should be mentioned here is that the corestock in each of the sets came from the same larger corestock panel so there should be a minimum of variation as a result of the properties of the corelumber.

Conditioning.

Some of the panels furnished so few specimens suitable for testing that they were divided into two groups, one was conditioned at 80°F. and 78% relative humidity, the second at 80°F. and 15% relative humidity. This first condition was the dampest, and the second was the dryest obtainable in the building without resorting to soaking. The high humidity approximated a moisture content of 15% and the low, 4%. The plywood shear specimens were left

to condition under the prescribed relative humidity and temperature until they reached a state of equilibrium. This was determined by weighing the specimens and noting when they neither gained nor lost weight. From the panels that furnished ample specimens, a third group was soaked for twenty-four hours at room temperature.

Testing.

Delamination was evident in many of the specimens so it was necessary to set up some criterion as to which specimens would be discarded before testing. It was decided that all specimens that could be pulled apart easily by hand would not be tested.

The specimens were tested by the standard plywood shear test on a two-thousand pound Riehle Testing Machine loading at eight-hundred pounds per minute. Because the machine is not accurate on very small loads, it was found necessary to give defective specimens that broke almost as soon as the load was applied a minimum reading of fifty pounds per square inch. If these tests were for any other purpose than to compare panels within each set, it would not have been possible to use defective specimens. However their use seems legitimate in establishing a comparison such as this.

The amount of wood failure on each specimen was noted, but almost without exception it varied from 0-3%. It was only when the crossbanding sheared because of not being straight grained that there was wood failure of any consequence. The amount of wood failure, being so insignificant, is not recorded in this report.

EXPLANATION OF RESULTS

On the following pages the results of the plywood shear tests are tabulated. At the top of each page the information pertinent to that set of panels is stated.

All shear strength values listed are in pounds per square inch.

The headings above the columns state the temperature and humidity at which the specimens listed were conditioned.

Each horizontal line gives the shear strength of the specimens from one side of a panel.

Each number given is an average. The figure following in parenthesis indicates the number of test specimens included in the average.

TABLE I

Temperature of adhesive and wood: 60-63°F.

Air temperature and relative humidity: 57°F. and 40% R.H.

Corestock: Red gum.

Glue used: Type A.

Moisture content of corestock: 8-10%.

Moisture content of veneers: 8-10%.

Curing conditions: While under pressure of 200 lbs./sq. inch, the internal temperature of the panels was raised to 115°F. by the use of infra-red lamps. After 3 hours the lamps were removed but the panels were left under pressure for 24 more hours.

80°F. and 78% R.H.	80°F. and 15% R.H.
60 Minute Assembly Time	
89.2 (5)	133.8 (4)
243.8 (4)	211.0 (5)
172.5 (4)	133.3 (3)
115.0 (2)	97.5 (2)
Av. 155.1	Av. 143.9
20 Minute Assembly Time	
130.0 (3)	55.0 (4)
160.0 (3)	133.8 (4)
160.0 (5)	151.4 (7)
Delaminated	Delaminated
Av. 150.0	Av. 113.4
10 Minute Assembly Time	
104.0 (5)	100.8 (6)
100.0 (2)	70.0 (4)
104.0 (5)	99.0 (5)
128.0 (4)	148.0 (5)
Av. 109.2	Av. 104.5

TABLE II

Temperature of adhesive and wood: 43-44°F.

Air temperature and relative humidity: 40°F. and 70% R.H.

Corestock: Red gum

Glue used: Type A

Moisture content of corestock: 9-12%

Moisture content of veneers: 9-12%

Curing conditions: While the panels were kept under a pressure of 200 lbs./sq. inch, the air surrounding them was held at 120°F. by the use of infra-red lamps. This heat was kept on for 4 hours and the internal temperature of the panels reached 110°F. The panels were kept under pressure for 18 more hours before being removed.

80°F. and 78% R.H.		80°F. and 15% R.H.	
60 Minute Assembly Time			
148.0	(5)	158.3	(6)
214.0	(5)	178.0	(5)
85.0	(4)	89.0	(5)
125.0	(2)	80.0	(1)
Av. 143.0		Av. 126.3	
20 Minute Assembly Time			
137.5	(6)	51.7	(6)
105.0	(4)	60.0	(2)
130.0	(4)	62.5	(4)
130.0	(4)	83.8	(1)
Av. 125.6		Av. 64.5	
10 Minute Assembly Time			
170.0	(4)	76.7	(3)
117.5	(2)	103.3	(3)
196.0	(5)	133.3	(3)
108.3	(3)	82.5	(4)
Av. 148.0		Av. 99.0	

TABLE III

Temperature of adhesive and wood: 46-49°F.

Air temperature and relative humidity: 51°F. and 40% R.H.

Corestock: Red gum

Glue used: Type A

Moisture content of corestock: 7-9%

Moisture content of veneers: 8-11%

Curing conditions: For 2 hours the stack of panels was under pressure of 200 lbs./sq. inch and heated by infra-red lamps. During this time the internal temperature reached 110°F. Then the panels were removed and placed in a room of 80°F. and 78% R.H. for 20 hours.

80°F. and 78% R.H.		80°F. and 15% R.H.	
60 Minute Assembly Time			
70.0	(4)	76.3	(4)
96.3	(4)	72.5	(4)
90.0	(3)	53.3	(3)
56.3	(4)	56.0	(5)
Av. 78.2		Av. 64.5	
20 Minute Assembly Time			
60.0	(3)	50.0	(4)
53.8	(4)	70.0	(4)
97.5	(4)	67.0	(5)
73.3	(3)	50.0	(3)
Av. 71.2		Av. 59.3	
10 Minute Assembly Time			
92.5	(4)	83.0	(5)
53.3	(3)	50.0	(4)
116.0	(5)	109.0	(5)
60.0	(4)	63.8	(4)
Av. 80.5		Av. 76.5	

TABLE IV

Temperature of adhesive and wood: 59-60°F.

Air temperature and relative humidity: 58°F. and 42% R.H.

Corestock: Red gum.

Glue used: Type B.

Moisture content of corestock: 8-10%.

Moisture content of veneers: 8-10%.

Curing conditions: Cured 18 hours at approximately 80°F. and 15% relative humidity under a pressure of 200 lbs./sq. inch.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
60 Minute Assembly Time		
195.0 (5)	182.0 (5)	118.8 (4)
197.0 (5)	194.0 (5)	136.3 (4)
294.0 (5)	217.0 (5)	173.7 (4)
215.0 (4)	174.0 (5)	107.5 (4)
Av. 225.3	Av. 191.8	Av. 134.1
20 Minute Assembly Time		
193.8 (4)	158.0 (5)	103.8 (4)
237.0 (5)	184.0 (5)	103.8 (4)
250.0 (5)	233.0 (5)	126.3 (4)
235.0 (5)	169.0 (5)	98.8 (4)
Av. 229.0	Av. 186.0	Av. 106.0
10 Minute Assembly Time		
250.0 (5)	211.3 (4)	125.0 (4)
226.0 (5)	148.0 (5)	95.0 (3)
192.5 (4)	73.8 (4)	----
216.3 (4)	182.5 (4)	105.0 (3)
Av. 221.2	Av. 153.9	Av. 108.3

TABLE V

Temperature of adhesive and wood: 40-42°F.

Air temperature and relative humidity: 40°F. and 36% R.H.

Corestock: Red gum

Glue used: Type B

Moisture content of corestock: 8%

Moisture content of veneers: 8-9%

Curing conditions: Cured under infra-red lamps and 200 lbs./sq. inch pressure for 2 hours. The internal temperature of the panels reached 95°F. Then heat and pressure were removed and the panels were placed in a room of 80°F. and 78% R.H. for 18 hours.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
60 Minute Assembly Time		
197.0 (5)	165.0 (5)	76.3 (4)
215.0 (5)	136.3 (4)	120.0 (3)
218.0 (5)	156.0 (5)	96.3 (4)
230.0 (5)	180.0 (5)	111.3 (4)
Av. 215.0	Av. 159.3	Av. 101.0
20 Minute Assembly Time		
213.8 (4)	99.0 (5)	92.5 (2)
152.0 (5)	112.5 (5)	86.6 (3)
205.0 (5)	176.3 (4)	96.7 (3)
189.0 (5)	156.0 (5)	97.5 (2)
Av. 190.0	Av. 136.0	Av. 93.3
10 Minute Assembly Time		
163.0 (5)	89.0 (5)	50.0 (1)
213.0 (5)	121.0 (5)	105.0 (3)
153.8 (4)	101.6 (3)	60.0 (1)
99.0 (5)	72.5 (4)	---
Av. 157.2	Av. 96.0	Av. 71.7

TABLE VI

Temperature of adhesive and wood: 47-48°F.

Air temperature and relative humidity: 49°F. and 49% R. H.

Corestock: Red gum

Glue used: Type B

Moisture content of corestock: 7-9%.

Moisture content of veneers: 7-10%.

Curing conditions: Under pressure of 200 lbs./sq. inch internal temperature was raised to 105°F. in 2 hours by use of infra-red lamps. Lamps were then removed but the panels were left in the press another hour before being put in a constant temperature and humidity room of 80°F. and 78% R.H. Panels remained there 24 hours before being stored.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
60 Minute Assembly Time		
223.0 (5)	220.0 (5)	193.8 (4)
260.0 (4)	170.0 (5)	153.8 (4)
392.0 (4)	227.0 (4)	143.8 (4)
382.0 (4)	237.5 (4)	160.0 (4)
Av. 314.3	Av. 213.6	Av. 162.9
20 Minute Assembly Time		
247.0 (5)	194.0 (5)	133.8 (4)
234.0 (5)	192.0 (5)	108.3 (3)
253.8 (4)	182.5 (4)	95.0 (3)
270.0 (4)	213.8 (4)	150.0 (4)
Av. 251.0	Av. 195.6	Av. 121.8
10 Minute Assembly Time		
250.0 (5)	198.0 (5)	123.8 (4)
228.0 (5)	116.0 (5)	110.0 (1)
260.0 (5)	119.0 (5)	127.5 (4)
215.0 (4)	124.0 (5)	140.0 (1)
Av. 238.3	Av. 159.3	Av. 125.3

TABLE VII

Temperature of adhesive and wood: 55°F.

Air temperature and relative humidity: 55°F. and 34% R.H.

Corestock: Yellow poplar.

Glue used: Type A.

Moisture content of corestock: 8-10%.

Moisture content of veneers: 8-10%.

Curing conditions: Panels were cured at a temperature of 85°F. for 18 hours under a pressure of 200 lbs./sq. inch.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
60 Minute Assembly Time		
80.0 (4)	52.5 (2)	---
162.0 (5)	161.0 (5)	60.0 (3)
223.7 (4)	230.0 (4)	70.0 (2)
128.8 (4)	98.8 (4)	---
Av. 148.6	Av. 135.6	Av. 65.0
20 Minute Assembly Time		
141.3 (4)	102.5 (4)	50.0 (1)
107.5 (4)	53.8 (4)	50.0 (1)
232.0 (5)	212.0 (5)	62.5 (4)
195.0 (5)	146.0 (5)	75.0 (2)
Av. 169.0	Av. 128.6	Av. 59.4
10 Minute Assembly Time		
176.3 (4)	107.5 (4)	---
212.5 (4)	176.7 (3)	50.0 (3)
194.0 (5)	205.0 (5)	62.5 (4)
201.0 (5)	176.0 (5)	50.0 (3)
Av. 196.0	Av. 166.3	Av. 54.2

TABLE VIII

Temperature of adhesive and wood: 34-36°F.

Air temperature and relative humidity: 34°F. and 80% R.H.

Corestock: Yellow poplar.

Glue used: Type A.

Moisture content of corestock: 8-10%.

Moisture content of veneers: 8-10%.

Curing conditions: Panels were cured at 85°F. under 200 lbs./sq. inch pressure for 18 hours.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
	60 Minute Assembly Time	
196.0 (5)	147.0 (5)	Delaminated
122.5 (4)	68.3 (3)	"
168.8 (4)	58.8 (4)	"
167.5 (4)	71.3 (4)	"
Av. 163.7	Av. 86.4	
	20 Minute Assembly Time	
147.5 (4)	100.0 (5)	Delaminated
152.5 (4)	123.0 (5)	"
170.0 (4)	108.0 (5)	"
134.0 (5)	102.0 (5)	"
Av. 151.0	Av. 108.3	
	10 Minute Assembly Time	
185.0 (5)	129.0 (5)	Delaminated
219.0 (5)	176.0 (5)	"
124.0 (5)	78.0 (5)	"
128.7 (4)	105.0 (5)	"
Av. 164.2	Av. 122.0	

TABLE IX

Temperature of adhesive and wood: 59-60°F.

Air temperature and relative humidity: 58°F. and 42% R.H.

Corestock: Yellow poplar.

Glue used: Type B.

Moisture content of corestock: 9-10%.

Moisture content of veneers: 7-10%.

Curing conditions: Cured at 80°F. and under pressure of 200 lbs./sq. inch for 18 hours.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
60 Minute Assembly Time		
272.0 (5)	243.8 (4)	143.8 (4)
246.0 (5)	220.0 (5)	135.0 (4)
250.0 (4)	218.0 (5)	130.0 (4)
242.5 (4)	225.0 (5)	113.8 (4)
Av. 252.6	Av. 226.7	Av. 130.7
20 Minute Assembly Time		
266.0 (5)	221.3 (4)	111.3 (4)
273.0 (5)	237.0 (5)	113.8 (4)
299.0 (5)	232.0 (5)	137.5 (4)
300.0 (5)	225.0 (5)	151.3 (4)
Av. 284.5	Av. 228.8	Av. 128.5
10 Minute Assembly Time		
278.0 (5)	242.0 (5)	88.3 (3)
257.0 (5)	221.0 (5)	103.8 (4)
Av. 267.5	Av. 231.5	Av. 96.1

TABLE X

Temperature of adhesive and wood: 48-50°F.

Air temperature and relative humidity: 49°F. and 48% R.H.

Corestock: Yellow poplar.

Glue used: Type B.

Moisture content of corestock: 8-10%.

Moisture content of veneers: 8-10%.

Curing conditions: Cured for 18 hours under a pressure of 200 lbs./sq. inch and a temperature of 83°F.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
	60 Minute Assembly Time	
229.0 (5)	162.0 (5)	107.5 (4)
222.0 (5)	185.0 (5)	101.3 (4)
208.0 (5)	164.0 (5)	97.5 (4)
224.0 (5)	179.0 (5)	141.3 (4)
Av. 220.8	Av. 172.5	Av. 111.9
	20 Minute Assembly Time	
172.0 (5)	160.0 (4)	67.5 (4)
196.0 (5)	155.0 (5)	80.0 (4)
182.0 (5)	142.0 (5)	81.3 (4)
218.0 (5)	178.0 (5)	111.3 (4)
Av. 192.0	Av. 158.8	Av. 85.0
	10 Minute Assembly Time	
213.0 (5)	191.3 (4)	92.5 (2)
227.0 (5)	167.0 (5)	127.5 (2)
189.0 (5)	131.0 (5)	120.0 (2)
204.0 (5)	164.0 (5)	83.8 (4)
Av. 208.3	Av. 163.3	Av. 106.0

TABLE XI

Temperature of adhesive and wood: 40-42°F.

Air temperature and relative humidity: 43°F. and 49% R.H.

Corestock: Yellow poplar.

Glue used: Type B.

Moisture content of corestock: 7-8%.

Moisture content of veneers: 8-10%.

Curing conditions: Cured under infra-red lamps and a pressure of 200 lbs./sq. inch. After 2 hours the lamps were removed but the pressure was maintained for an additional 1½ hours. The internal temperature reached 120°F. After the panels were removed from the press they were placed in a room of 80°F. and 78% R.H. for 24 hours.

80°F. and 78% R.H.	80°F. and 15% R.H.	24 Hour Soak
60 Minute Assembly Time		
282.5 (4)	207.5 (4)	137.5 (4)
245.0 (4)	182.5 (4)	102.5 (4)
274.0 (5)	245.0 (4)	131.3 (4)
271.3 (4)	186.3 (4)	143.3 (3)
Av. 268.1	Av. 205.3	Av. 128.7
20 Minute Assembly Time		
243.8 (4)	200.0 (3)	110.0 (4)
260.0 (4)	182.5 (4)	100.0 (3)
280.0 (5)	197.0 (5)	97.5 (4)
246.3 (4)	182.5 (4)	115.0 (4)
Av. 257.5	Av. 190.5	Av. 105.6
10 Minute Assembly Time		
245.0 (5)	185.0 (5)	85.0 (3)
252.5 (4)	156.3 (4)	130.0 (2)
255.0 (4)	207.5 (4)	102.5 (4)
256.3 (4)	162.5 (4)	101.3 (4)
Av. 252.2	Av. 177.8	Av. 104.7

GRAPHS OF TEST RESULTS

Table I

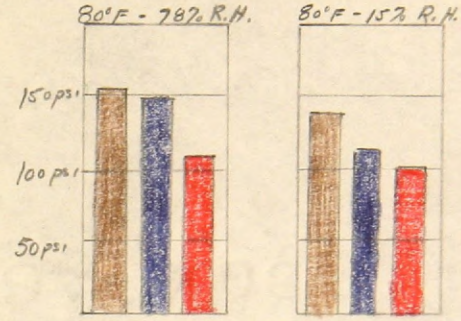


Table II

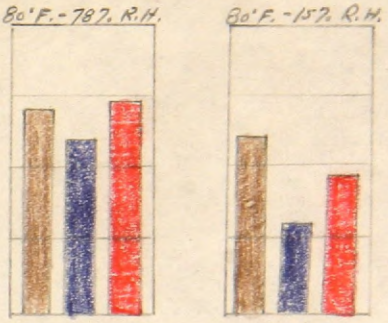


Table III

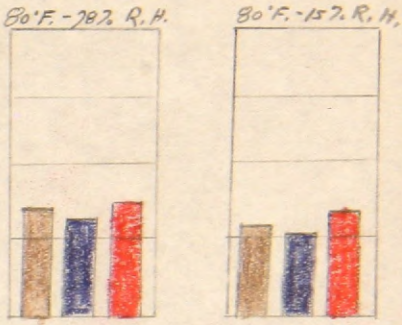


Table IV

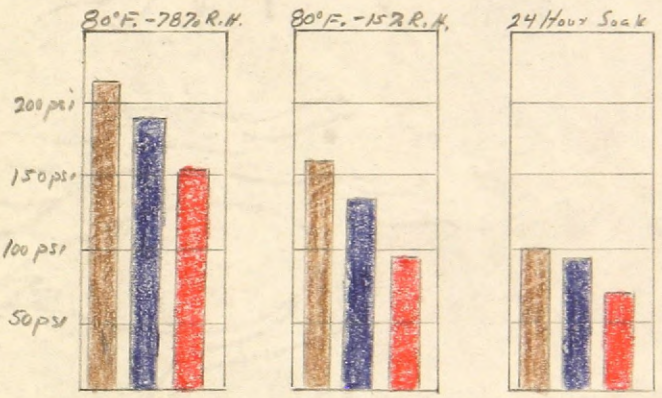


Table V

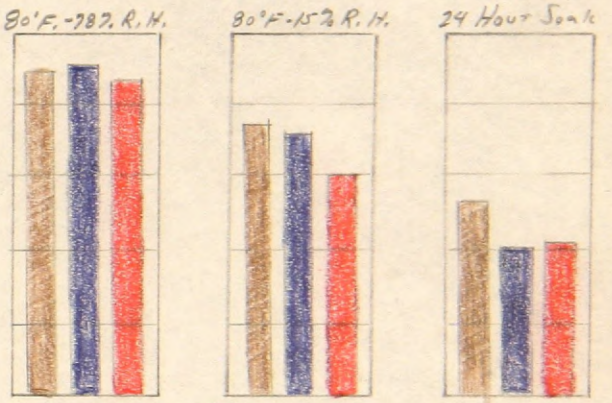


Table VI

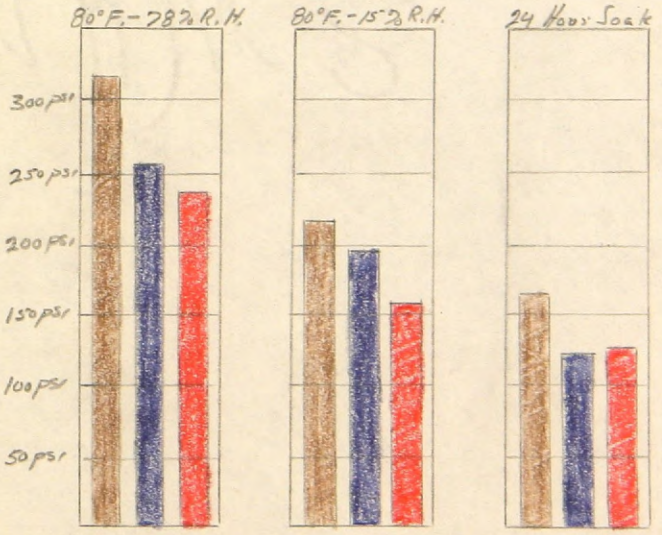
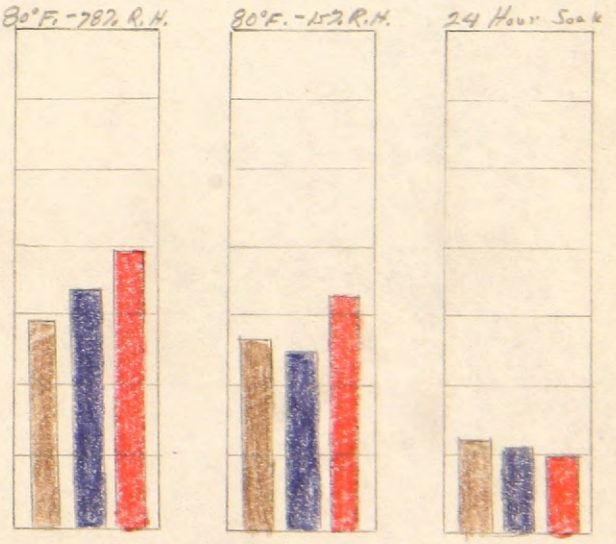


Table VII



60 minute assembly 20 minute assembly 10 minute assembly

Table VIII

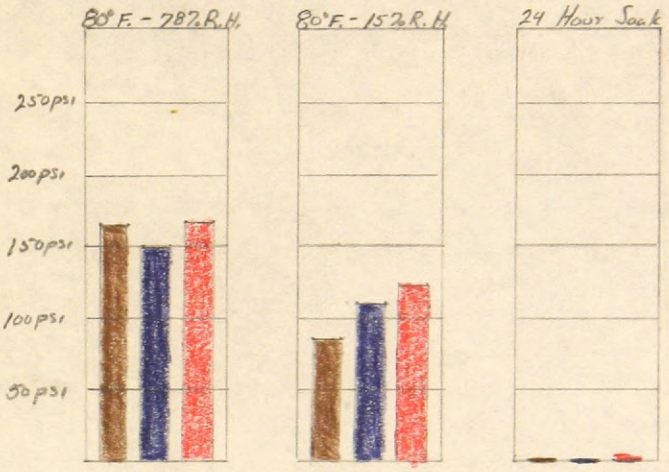


Table IX

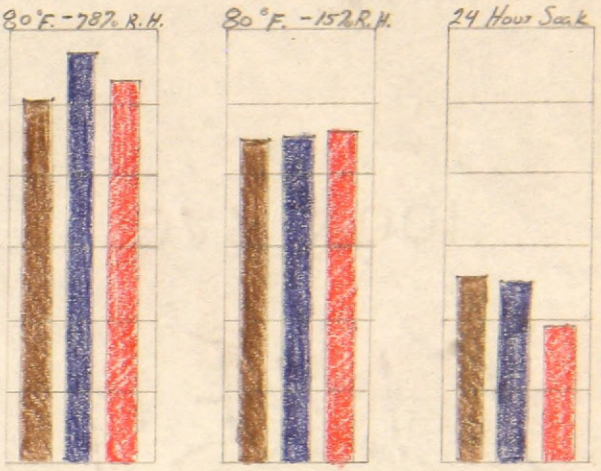


Table X

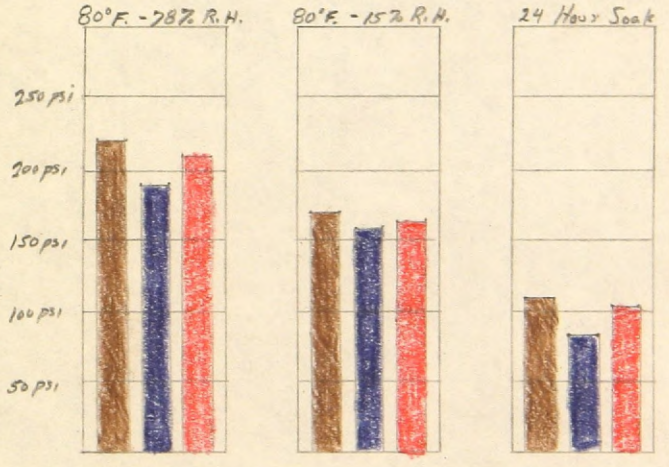
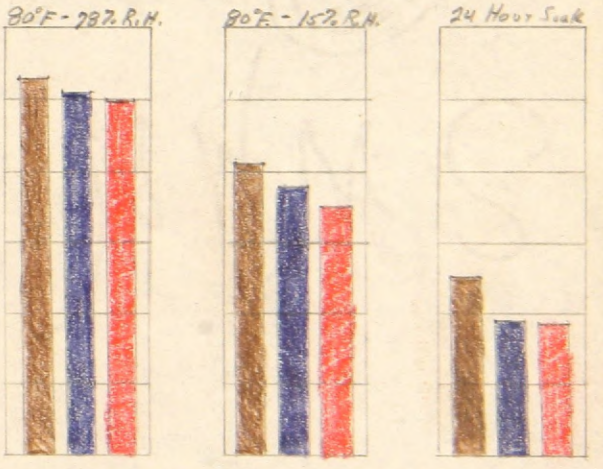


Table XI



60 minute assembly 20 minute assembly 10 minute assembly

DISCUSSION OF RESULTS

It is apparent after studying the preceding test results that there is no direct correlation between 10, 20 and 60 minute assembly times below 70°F. and the strength of the glue bond. A tabulation of the results will further demonstrate this fact.

	80°F. & 78% R.H.	80°F. & 15% R.H.	24 Hour Soak
	60 Minute Assembly Time		
No. of times strongest	5	7	7
" " " intermediate	4	2	0
" " " weakest	2	2	0
	20 Minute Assembly Time		
No. of times strongest	2	0	0
" " " intermediate	5	7	4
" " " weakest	4	4	3
	10 Minute Assembly Time		
No. of times strongest	4	4	0
" " " intermediate	2	2	3
" " " weakest	5	5	4

Many times the averages will show only a slight difference in strengths between the panels. For example in Table III under the column headed 80°F. and 78% R.H.

panels with 60 minute and 10 minute assembly periods differ by only 2.3 pounds per square inch. In Table IX under the column headed 80°F. and 15% R.H. the difference between the strongest and the weakest panels is only 4.8 pounds per square inch. In any statistical work involving the human element such small variations as shown in the preceding tables cannot be significant. If the results were consistent, that is if one panel consistently tested stronger than the others, and there was only a small difference between the results it might be permissable to reach a conclusion based on the figures. However, such was not the case here. Because the assembly times of the panels with 20 minute and 10 minute assembly periods are nearer equal, it can be easily understood how they can have near equal shear strengths. However, it is more difficult to explain the results of the tests on the panels with 60 minute assembly periods in the light of the theory proposed in this work. In fact, it may definitely be said that this project shows no relationship between 10, 20 and 60 minute assembly periods below 70°F. and the strength of the resulting bond.

One theory that might help explain the results of the tests on the panels with a 60 minute assembly period is the mechanical theory of adhesion. According to this theory

the glue becomes thoroughly anchored into the fibers of the wood during the closed assembly period. That is, it soaks into the wood before curing and then, when polymerization takes place after heat is applied, the glue hardens.(6) The result is a glue line that is firmly attached to the wood on both sides.

Another theory is that the resulting bond is based on the amount of adhesive left to cure at each glue line. When pressing the sets of panels it was observed that there was little or no "squeeze out" on the panels with a 60 minute assembly period. The panels with a 10 minute assembly period furnished the most. Therefore if 8 grams of glue were spread on each glue line and some of the panels retained all of this adhesive while other panels lost some of it, when pressure was applied, it seems logical that this might account for the difference in strengths.

The theory that was proposed in the introduction to this report concerning the absorption of moisture from the adhesive into the wood may be true. However other factors, such as those stated above, enter into the picture and the result that is obtained is the product of all.

Although it was not the purpose of this report to study the effect of flour extension on room temperature setting urea resins, a few observations were made. It is

to be expected when the amount of extension is as great as it was in this work that the shearing strength will be much less than with non-extended glue of the same type. There are great differences in strength not only among the panels in each set but even among the specimens in one panel. The Forest Products Laboratory is now investigating the effect of extending room temperature setting urea resin glues on working properties. Here is what they say about extended mixtures.

> "Somewhat erratic results may be expected when extended mixtures are used to glue wood containing more than about 9% moisture. As the extension was increased, joint strengths decreased more rapidly when the wood contained more than 9% moisture than when the moisture content of the wood was 9% and below."(2)

This may partially explain the irregularities shown in the results given here, because in almost all of the panels the moisture content of the corestock or the veneer was within the range considered ideal by glue manufacturers.

Another fact that seems to contradict all published material on this subject is that almost invariably those specimens that were conditioned at 80°F. and 78% relative humidity gave better test results than those conditioned at 80°F. and 15% relative humidity. In other words, if the specimens from any one panel were divided into two groups representative of the panel and one group subjected to comparatively high humidity and the other group to low

humidity, the group conditioned at the high humidity would have the greater shear strength. In bulletin No. 1345, the Forest Products Laboratory shows how the urea resin glues are damaged more by high temperatures than other classes of glue and that high humidity is more destructive to the glue than low humidity.(5) The results given in this report can be successfully defended because, as was stated in the procedure, the specimens were not conditioned at the various humidities for any length of time. They were kept under the prescribed treatment only until they reached a state of equilibrium regarding moisture content. This was a matter of only a few days as the specimens were stickered and the air circulation was good. If the conditioning period had extended over several months, as was the case at the Forest Products Laboratory, the final results might have been in agreement with those of the Forest Products Laboratory. Another point to be mentioned is that the moisture content of the wood when glued is not stated in their bulletin. It merely says that the requirements of the manufacturer were met regarding the moisture content of the veneer. It has been noticed in work at the Wood Utilization Laboratory of the University of Michigan that plywood made up at a low moisture content

delaminates when placed under high humidity conditions. In this work it has been found that the converse of the above statement is also true. That is, when plywood is made up of wood at a relatively high moisture content it will delaminate upon being subjected to low humidity conditions. If this situation exists it is important that panels be made of corestock and veneers conditioned to the desired moisture content of the finished panel.

Because the resin glues require such critical limits as to the moisture content of the wood, they can only be used successfully when the moisture content can be controlled accurately. For this reason manufacturers doing production gluing often find it more practical to use natural glues not requiring this accurate control of moisture content than to attempt to control plant conditions to such an extent. The ideal glue would be one that would not require any more control of conditions than natural glues do and still have the durability and be in the same price range as urea resin glues.

Since the assembly time below 70°F. does not seem to affect the resulting bond of urea resin glues it is the opinion of the author that gluing below 70°F. is permissable as long as sufficient heat is supplied in the curing to polymerize the glue. However, glue manufacturers do not

endorse this policy and have designated 70°F. as the temperature below which urea resin glues should not be used. Tests with resorcinal resin glue have shown that good glue bonds are entirely possible, even if the gluing is done below 70°F., as long as sufficient heat is used to cure the glue. This same reasoning seems to follow for urea resin glues.

The shear test results obtained in this work were far from satisfactory. A good bond should give a shear test result of at least 400 pounds per square inch. This figure was never reached in this project. Therefore it may be that urea resin glues cannot be extended to such an extent and withstand any appreciable changes in the moisture content of the panels.

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