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THE BONDING OF CERTAIN METALS WITH WOOD IN PLY CONSTRUCTION

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INTRODUCTION

Plymetal construction has been successful commercially in a limited sense since its inception some several years ago. However, the process is a trade secret and attempts to obtain any information concerning ingredients or techniques used in the bonding of metal to wood have been met with vague and evasive answers.

In an effort to learn the basis for successful bonding of metal to wood in ply construction, the writer has endeavored to use the information available on the gluing of wood to wood in correlation with the additional factors that present themselves when a metal is introduced. Writings on the subject of wood-metal bonding are non-existent except for commercial advertising. Perry (8) says, "A new field appears in which wood-fiber board and metal may be 'plied' together in various combinations. This will require a careful study of suitable glues and adhesives, but the opportunity is most promising."

Properties and Uses of Plymetal

Analysis of Plymetal Characteristics

Plying metal with wood results in a product of new and advantageous properties. The major property obtained is that of strength. The maximum tensile and compressive stresses in bending of a beam occur in the outermost fibers and these maximum stresses are given by the formula,

$$s = \frac{M c}{I}$$

where s is understood to be the normal stress parallel to the longitudinal axis of the beam, M is the bending moment in inch pounds, c is the distance in inches from the neutral axis to the outermost fiber, and I is the moment of inertia of the cross-sectional area about the neutral axis expressed in $inch^4$ units. In the case of a rectangular section, I is equal to the base times the heighth-cubed divided by 12. (9). This method of finding the stresses in a loaded beam is applicable to the problem of ascertaining the strength of a plied assembly, and its resistance to bending. From a study of the formula it is readily seen that the greater c is in a beam, assuming the material is homogeneous, the stronger is the beam in a direct proportion. Also, it is seen that those fibers farthest from the neutral axis support the greatest part of the load while those fibers progressively nearer the neutral plane do progressively less supporting. Two courses are then open to the construction of a beam scientifically; first, that material near the neutral axis may be partially removed (as is done in constructing I-beams), or, second, a material of greater strength than that of the beam may be affixed to the outer extremes of the beam to take the major part of the load. The latter is the principle utilized in the plying of metal to a wood core. This gives the property of strength together with light weight, a combination with definite advantages.

Uses of Plymetal

Plymetal finds use in aircraft construction, trailer-body construction, shipbuilding (for bulkheads, etc.), insulating work, kitchen furnishings, and as a general material of construction.

Approach to Problem

There is not, and is not likely to be, an adhesive of universal applicability, for the requirements within even a specialized industry using adhesives vary very greatly. (4) Likewise, there are several processes and techniques possible in the use of any one adhesive used to bond a given substance, or substances. In some cases, application by mechanical means is essential, in others application by hand brushing is necessary. The effect of slight changes in acidity or alkalinity on the materials being handled, the time which can be allowed for the formation of a strong dried joint, the pressures to be used, the temperatures best suited, the proper surface preparation before gluing, the cost of the adhesive solution, and the practicability of the process used are all factors which differ in varying degrees from one case to another. For each case there hundreds of possible combinations, but only one combination of conditions which gives the maximum results. Let us then not look upon this brief paper as a criteria, but rather a narrowing down of the possibilities evident in the bonding of metal to wood in ply construction.

Considerations Applicable to all Cases in Determining Procedure

There is one formula and technique best suited for giving maximum strength, one for giving maximum flexibility, one for giving maximum water-resistance, and so forth. In this work the ideal was taken as that process that would provide the best all-round resulting properties in the assembly. In arriving at a starting basis for each joint procedure, the major factors influencing joints in wood-to-wood were studied, and advice from authorities in the fields of chemistry, physics, and metallurgy was obtained both thru texts and personal interviews.

The major factors influencing the properties of a joint, using a given adhesive, were considered to be:

1. The species of wood used as cores
2. The moisture content of the wood used
3. The kind of metal used
4. The surface condition of the metal
   a. Degree of smoothness (in the case of the bare metal)
   b. Degree of corrosion or oxidation present (in the case of the bare metal)
   c. Chemical cleanliness of the surface of the bare metal
   d. The type of surface coating used, if any (See page 35)
5. Quantity of glue mixture per square foot of glued surface:
   a. Single spread:
      a to metal only
      b to wood only

   b. Double spread
   c. Thickness and number of layers of glue film used (resin film)

6. Time:
   a. Assembly time
   b. Pressure time

7. Pressure, as related to:
   a. Consistency (viscosity) of glue
   b. Strength of wood

8. Heat:
   a. Heat of polymeration of glue
   b. Thickness of metal and wood plies

9. Aging or conditioning:
   a. Temperature
   b. Moisture
   c. Time

Logic and reasoning formed the basis for both the considerations of the case as a whole and the considerations of the more minor influencing factors upon which no previous indicating data was obtainable.

Application of Condsiderations in Determining Procedure

Most of the data utilized in forming a basis for decisions made in the selection of a process was obtained from previous published works (6, 10) on the gluing of the wood-to-wood plys. Problems in procedure that arose for which no indicating data could be obtained were settled with a consensus of "horse sense" opinions.

The Species of Wood Used

The species of wood used throughout the tests was maple, straight grained and free from all defects visible to the unaided eye. It is probable that a softer, more porous wood would have altered the results in many cases and for several reasons.

The Moisture Content of the Wood Used

As the wood cores for the test assemblies were kept in a cabinet within a warm, steam heated building throughout the tests, they were quite constant at 5.70% moisture content. An increase in moisture content would give a probable fractional decrease in joint strength in most assemblies.

The Kind of Metal Used

The kind of metal used would influence the strength of the joint obtained, with a given adhesive, in that one metal may combine with the glue to form an oxide and thereby create a weaker joint than another metal that is not so affected. Also, the coefficient of thermal expansion of a metal used in a ply with a given adhesive may be greater than that of the wood to such an extent as to cause failure of the joint upon a rise in temperature of some several degrees. Copper, aluminum and annealed galvanized iron, whose trade name is "Galvaneal," all of 1/20 inch thickness, were used.

The Surface Condition of the Metal

a. Four of the manufacturers of the glues used (page 43) advised roughening the surface of the metal before applying their product. This is thought to enhance the mechanical adhesion, but the opposite has proved to be true with wood-to-wood construction (10, 13). It was found that roughening the surface by the use of emery cloth produced joint strengths inferior to those roughened by sandblasting.

The Forest Products Laboratory undertook some several years ago, a detailed study of factors that affect the strength of a glued joint. Two general principles were formulated as a result of these investigations: First, that glue adheres tenaciously to wood substance (author's note; specific adhesion) and that mechanical adhesion, such as exhibited by the holding power of nails, is of secondary importance. (3)

b. The degree of corrosion is an important factor and one to be reckoned with. In a letter from the head chemist of the Haskellite Manufacturing Company, makers of "Plymetl," the chemist states, "These metals, copper and aluminum, present greater than usual difficulties to one wishing to laminate them with wood. Copper, exposed to oxygen (air) and moisture develops the characteristic greenish-blue patina. This is a complex, quite insoluble salt, usually basic copper carbonate. Unfortunately, adhesives applied to freshly cleaned copper do not completely exclude air and moisture. The surface reaction progresses rapidly. The adhesive is soon found adhering to the corrosion product or patina, not to the copper. - - - The case of aluminum is much the same as that of copper. The corrosion product is a mixture of hydroxide and oxide, forms very quickly, is white in color. With aluminum, surface oxidation is so rapid that an oxide-free surface is almost impossible to maintain. Actually, a thin oxide film on aluminum is a protective coating, and one much to be desired."

An attempt to provide oxide-free surfaces was made by the simple action of placing the freshly sandblasted test blanks (metal) in an atmosphere of carbon dioxide.

c. Chemical cleanliness proved its importance in tests conducted. The cleansing agent used was carbon tetrachloride. The advantageous results are shown in the comparative strength values obtained using the bakelite resin film.

d. In an effort to provide a metal surface free from both present and future corrosion (1), several test plates were Bonderized, several Parkerized, and a few of both copper and aluminum were given a phosphate coating (page 35).

Quantity of Glue Mixture per Square Foot of Glued Surface

a. A single spread of glue to the surface was recommended by two of the manufacturers (page 43) whose advice was asked on the use of their glue base.

b. Double spreading was used for the most part, as a complete coating of glue to all parts of the glued area is assured and in that manner higher strength values are resultant. Browne (2) gives an interesting discourse on the quantity of glue to use per square foot of glued surface.

Time

a. Assembly time is in itself an important factor. (13) In this work the assembly time used in wood-to-wood gluing was duplicated.

b. Pressure time was determined from wood gluing data (10) and from manufacturer's specifications in the use of their glue.

Pressure

a. Pressure administered to the joint is directly related to the consistency (viscosity) of the glue when used (8, 13) and is too extensive a subject to do justice to here.

b. The crushing strength of the wood used in a study such as this is important in that higher joint strengths are obtained with some adhesives when higher pressures are allowed; thus would the crushing strength of the wood core used be of importance in the formulation of a process for any one glue. The highest pressure used in the tests made was 400 pounds per square inch, well under the crushing strength of maple wood. (5)

Heat

Heat, as applicable to cold press work has a minor, though definite, relation to the joint strengths obtained. (10) In hot press work, however, heat plays a major part in the bonding operation.

a. The heat of polymerization of a given resin adhesive has been determined by the manufacturers of that glue, and accompanies their product in the directions for use given the user. In the event a variation from the heat recommended is necessary, the manufacturers are both willing and able to provide graphs and charts showing temperature and time of polymerization relationships.

b. The heat necessary, and also the time required, to penetrate a given substance in a hot press has also been determined by manufacturers and users and is available from them. Merritt (6) has made tables of heat transfer which are invaluable in the determination of the length of time to be allowed for heat to penetrate a given thickness of material. Temperatures used with resin glues were chosen as 290° F, and with blood albumin glues 160° F.

A note at this time to show the correlation of pressure and heat is essential.

When, by the application of heat, a phenolic resin polymerizes and changes from its reactive state to its insoluble and infusible state, a multitude of small blisters is formed. in other words, the resin seems to bubble or boil. To prevent this and to secure a perfect bonding film between the plys, it is necessary to apply a combination of heat and pressure. Consequently, the hot plate press (page 38) must apply both uniformly. (6)

Hot pressing glues of the non-resin type, blood albumin, a mixture of casein and latex, or animal glue has proved both feasible and practical. (7)

Aging or Conditioning

Aging of glued joints permits a release of internal stresses and an evening of trapped moisture and gives a more uniform, and frequently, a stronger product.

a., c. The degree of temperature during the aging period is thought to have a direct bearing on the length of time necessary for complete release of internal stresses. Normal room temperatures and a one week period were used over the faster kilm method so as to provide a margin of safety.

b. Aging allows an evening of the moisture within the bonded assembly.

Preparing Glues for Use

Standard procedure was followed in preparing glues for use. This involves such details as the amount of water to be added, method of combining glue and water, and time of mixing. A standard procedure gives a more uniform mixture and avoids too much reliance on individuals who do the mixing. (10) Manufacturers' directions were followed carefully when available. When directions did not accompany the manufacturer's product, directions were obtained from either one of the many Forest Products Laboratory publications or from classroom notes taken in Course 172, Plywood and Laminated Construction, given at the School of Forestry and Conservation, University of Michigan, Ann Arbor, Mich. The correct proportions of glue and water vary for different kinds of glue, woods, types of joints, conditions under which the gluing is done, and conditions under which the finished product will be used. For most glues used in woodworking the proper amount of water varies from 1½ to 3 parts to 1 part dry glue by weight. With a given glue the amount of water used should be less where quick setting is desired. The amount of water used should also be less with porous woods, or where high joint strength is desired, than with non-porous woods or where high strength is not required. A glue mixture with a large proportion of water gives a large spread and is in satisfactory condition for pressing a long time after the spreading. (10) The preparation of the synthetic resin glues was done by manufacturers direction and from reference to joint-strength graphs furnished by the resin manufacturers

Formulas Used in the Preparation of Glues for Use

Animal

F-1 Franklin Liquid Hide Glue (M-5)*

Glue was used directly from container.

Casein

F-2 Casco Joint "L" glue base and Latex.

100 grams water

150 grams Casco Joint "L"

Add glue powder to water while mixing.

Mix five minutes.

Let stand 5 minutes.

Mix 5 minutes.

While mixer is running add 250 grams latex.

Mix 5 minutes.

Glue is now ready for use.

F-3 Perkins "Metal Veneer" (M-9)

Stir into 1¾ lbs. water 1 lb. Perkins "Metal Veneer".

Mix 15 to 20 minutes.

Use.

F-4 Monite Waterproof (M-7)

To 18 parts water add 10 parts "Monite Waterproof."

Mix thoroughly.

Let stand for thirty minutes.

Stir well.

Use.

This mix has a working life of 6 to 8 hours.

Vegetable Protein

F-5 Lauxite "7 - L" (13)

Weigh out 100 grams "Lauxite 7 - L" and 300 grams tap water.
Add glue base to water and stir for 3 minutes.

Weigh out 7 grams hydrated line and 25 grams tap water.
Add lime to water without stirring, allow to stand for 2 minutes, then stir.
Add milk of lime to glue base suspension.

Weigh out 7.5 grams caustic soda and 15 grams tapwater.
Dissolve caustic soda in tapwater by stirring.

Add caustic soda solution to glue mixture.

Add 25 grams sodium silicate to glue mixture and stir.
(1) Add 6 grams carbon disulfide and 4 grams carbon tetrachloride and mix.
Take 2.25 grams of (1) and add to glue.

Dilute with 30 grams tapwater, stirring for 10 min.

Glue is ready for use and has a working life of from 4 to 6 hours.

F-6 Blood Albumen (10, 13)

100 grams 90% soluble flaked Blood Albumen.

Mix and allow to stand for 2 hours without stirring.

Stir.

Add 4 grams ammonium hydroxide while stirring.

Add 3 grams hydrated lime as a thick water solution.

Stir well.
Glue is now ready for use.

Synthetic Resin

A. Phenol-formaldehyde (M-2)

F-7 Bakelite "X-C 3931" (Cold Press)

Add 3 grams Bakelite accelerator to 100 grams "X-C 3931."
Stir thoroughly.

Coat two surfaces.

Allow a few moments to air dry.

Press over night at 150 p. s. i.

Condition for 3 hours at 170° F.

F-8 Catabond "550" (Hot Press) (M-4)

To 100 grams Catabond "550" mix 3.5 grams Catabond accelerator.
Mix well at room temperature.

Use in hot press of 300° F temperature.

Polymerization time at 300° F is 6 minutes.

Mixed glue has life of 1 to 3 hours.

F-9 Resin Films (Hot Press) (13)

Both "Tego" and Bakelite films were used as removed from manufacturer's containers. One thickness of glue film was used at each glue line. Glue films kept at low temperatures have a long (years) life.

B. Urea-formaldehyde

F-10 Casco Resin No. 21 (Cold Press) (M-3)

To 100 grams Casco No. 21 add 16 grams C-4 Cold Hardener Powder.
Mix thoroughly.
Allow to stand 15 minutes.
Mixed glue has a working life of 2 to 3 hours.

* These reference numbers explain the source of the formula.

The Tests Conducted

The Glues Used

Of the glues and glue bases available to the writer, those were chosen for use that would give an indication of the test value of that class of glue. In event that a class of glue, i.e., Casein, Vegetable, Protein, Blood Albumen, etc., gave promise of good results, more than one glue in that class was tested. Those glues used, subheaded under their respective classes, are as follows:

Animal:

Franklin Liquid Hide Glue (M-5)

Casein:

Casco Joint "L" (M-3)

Perkins "Metal Veneer" (M-9)

Vegetable Protein:

Lauxite "7-L" (M-6)

Blood Albumen:

Armour, 90% soluble, flake (M-1)

Synthetic Resin:

A. Phenol-formaldehyde

Bakelite "X-C 3931" (M-2)

Catabond "550" (M-4)

"Tego Resin Film" (M-10)

"Bakelite Resin Film" (M-2)

B. Urea-formaldehyde

Casco Resin No. 21 (M-3)

Letters following glue name refer to manufacturer, see page 43 .

Procedure Followed in Each Case and Results Obtained

This phase of the work was discussed broadly in the section "Application of Considerations in Determination of Procedure," page 6 . In the following, the exact conditions chosen in each test conducted, and resultant strength figures for each of the five samples, together with the average of these figures, is given.

Animal Glue   Franklin Glue   (Cold Press)

Conditions 1A	Results (all in lbs.)	
Franklin Liquid Hide glue (F-1) Galvaneal Sandblasted surface	1. 485 2. 500	
Double spread	3. 490	
10 minute assembly	4. 450	Av. 490
150 pounds per square inch (p.s.i.)	5. 525	
Pressing time (p.t.), overnight		
1 week aging		

Casein   Casco "M" & Latex   (Cold Press)

Conditions A	Results	
Casco "M" - "Lotal" (F-2)	1.	Fell apart in sawing
Galvaneal	2.	

Conditions A	Results
Emeried surface	3. 30
Double spread	4. 160
Closed assembly	5. Fell apart while placing in test jaws
150 p.s.i.	
p.t., overnight	
1 weel age, cut, 1 week age.	

Conditions B	Results
Same as A except that copper was used.	No adhesion whatsoever No adhesion whatsoever

Conditions C	Results	
Same as A except that	1. 190	
aluminum was used	2. 210	
	3. 210	Av. 180 p.s.i.
	4. 110	
	5. 180	

Casein Perkins "Metal Veneer" (Cold Press)

Conditions D	Results	
Perkins "Metal Veneer"	1. 510	
Galvaneal	2. 600	
Sandblasted	3. 450	Av. 531 p.s.i.
Double spread	4. 535	
Closed assembly	5. 570	
150 p.s.i.		
p.t., overnight		
1 week aging		

Conditions	Results
Conditions E Same as conditions D except that aluminum was used	1. 410 2. 550 3. 420 4. 490 5. 410 Av. 470 p.s.i.
Conditions F Same as conditions D except that copper was used	1. Separated in sawing 2. Separated in sawing 3. 180 4. 120 5. Fell apart in handling.
Conditions G Same as conditions D except that a Bonderized surface coating on the metal was employed	1. 220 2. 280 3. 300 4. 180 5. 170 Av. 230 p.s.i.
Condition H Same as conditions E except that a phosphate coating on the metal was employed.	Assembly fell apart in handling

Casein "Monite Waterproof" (Cold Press)

Conditions I	Results	
"Monite Waterproof"	1. 400	
Galvaneal	2. 410	
Sandblasted	3. 300	Av. 379 p.s.i.
Double spread	4. 360	
Closed assembly	5. 425	
150 p.s.i.		
p.t., overnight		
6 days aging		

Vegetable Protein "Lauxite 7-L" (Hot Press)

Conditions J	Results	
"Lauxite 7-L"		
Galvaneal	1. 300	
Sandblasted surface	2. 220	
Double spread	3. 370	Av. 306 p.s.i.
Closed assembly	4. 310	
150 p.s.i.	5. 330	
p.t., overnight		
6 days aging		

Conditions K	Results
Same as conditions J except	No adhesion
that aluminum was used	Pulled apart in drying

Blood Albumen Armour's 90% Soluble Flake (Hot Press)

Conditions L	Results
Armour's 90% soluble flake Galvaneal Sandblasted Single spread Closed assembly 150 p.s.i. p.t., 8 minutes Temp. 160° F 1 week aging	Fell apart while sawing. (See comment in Conclusion concerning this assembly)

Conditions M	Results	
Same as conditions L except that aluminum with double spread was used.	1. 500	
	2. 490	
	3. 550	Av. 500
	4. 440	
	5. 520	

Synthetic Resin Glues

A. Phenol-formaldehyde Bakelite "X-C 3931" (Cold Press)

Conditions N	Results
Bakelite "X-C 3931" Galvaneal Sandblasted Double spread 5 minute open assembly 150 p.s.i. P.t., overnight 1 week aging	Assembly pulled apart upon handling after aging

Conditions O	Results
Same as conditions N except a Bonderized surface coating was employed on the Galvaneal	Assembly became separated in the sawing operation.

Conditions P	Results
Same as conditions N except that aluminum was used.	Assembly fell apart upon removal from press

Conditions Q	Results
Same as conditions N except that copper was used	Assembly fell apart upon removal from press.

Phenol-formaldehyde "Catabond 550" (Hot Press)

Conditions R	Results
"Catabond 550"	1. 340
Galvaneal	2. 260
Sandblasted	3. 326 Av. 309 p.s.i.
Double spread	4. 345
Closed assembly	5. 280
400 p.s.i.	(Some evidence of slight corrosion)
Temp. 300° F	
p.t., 7 min.	
1 week conditioning	

Conditions S	Results
Same as conditions R except that a Bonderized surface was employed on the Galvaneal	1. 320
	2. Fell apart upon being dropped
	3. 335
	4. 410 Av. 331 p.s.i.
	5. 260

Conditions T	Results
Same as conditions R except that copper was used.	1. 390
	2. 345 Av. 361 p.s.i.
	3. 220
	4. 300
	5. 430
	(Very brittle)

Conditions U	Results
Same as conditions R except that aluminum was used.	1. 335 (5% wood failure)
	2. 350
	3. 240
	4. 365 (5% wood failure)
	5. 360 Av. 330 p.s.i.

Conditions V	Results
Same as conditions T except that a phosphate coating was employed on the copper	Pulled apart in handling and sawing.

Phenol-formaldehyde "Tego" Resin Film (Hot Press)

Note:

In work with the resin films pressure time was standardized at 9 minutes, pressure was standardized at 400 p.s.i., film thicknesses used were one thickness, hot press temperature was standardized at 290° F, and the conditioning period was maintained at 1 week.

Conditions W	Results
"Tego" resin film	1. 550

Conditions W continued	Results	
Galvaneal	2. 540	
Sandblasted	3. 525	Av. 495 p.s.i.
	4. 460	
	5. 400	

Conditions X	Results	
"Tego"	1. 360	
Copper	2. 340	
Sandblasted	3. 420	Av. 367 p.s.i.
	4. 370	
	5. 345	

Conditions Y	Results	
"Tego" resin film	1. 360	
Aluminum	2. 340	
Sandblasted	3. Error	
	4. 525	Av. 408 p.s.i.
	5. 400	

Phenol-formaldehyde "Bakelite" Resin Film (Hot Press)

Conditions Z	Results	
"Bakelite" film	1. 235	
Galvaneal	2. 180	
Emeried surface	3. 215	Av. 210 p.s.i.
	4. 195	
	5. 225	

Conditions AA	Results	
"Bakelite" film	1. 635	
Galvaneal	2. 600	
Sandblasted surface	3. 485	Av. 532 p.s.i.
	4. 600	
	5. 550	

Conditions A B	Results	
"Bakelite" film	1. 560	
Galvaneal	2. 625	
Sandblasted	3. 610	Av. 586 p.s.i.
Washed surface	4. 575	
(carbon tetrachloride)	5. 560	

Conditions A C	Results	
"Bakelite" film	1. 215	
Galvaneal	2. 205	
Bonderized	3. 305	Av. 275 p.s.i.
	4. 300	
	5. 350	

Conditions A D	Results	
"Bakelite" film	1. 220	
Galvaneal	2. 265	
Parkerized	3. 300	Av. 265 p.s.i.
	4. 270	
	5. 270	

Conditions A E	Results		
"Bakelite" film	1.	570	
Aluminum	2.	560	Av. 551 p.s.i.
Sandblasted	3.	500	
Washed surface	4.	550	
	5.	575	

Conditions A F	Results		
"Bakelite" film	1.	265	
Aluminum	2.	150	
Phosphate coated	3.	170	Av. 188 p.s.i.
	4.	170	
	5.	Error	

Conditions A G	Results		
"Bakelite" film	1.	420	
Copper	2.	375	
Sandblasted	3.	510	Av. 460 p.s.i.
	4.	575	
	5.	380	

Conditions A H	Results
Bakelite film	
Copper	Fell apart in handling
Phosphate coated	

B. Urea-formaldehyde "Casco Resin No. 21" (Cold Press)

Conditions A I	Results
"Casco Resin No. 21 Galvaneal Sandblasted Double spread Closed assembly 150 p.s.i. p.t., overnight 6 days aging	Fell apart after aging.

In an effort to present the data obtained in a more comprehensive manner and to provide a means of analyzing and forecasting results of different combinations of considerations the table on page 30 is given. A study of this table gives an eye-picture of the results of the work done in that each metal is represented by its initial, and the average value of the tests conducted follows this initial. Hence, the first figure on the table, G 490, is easily interpreted as a Galvaneal assembly whose 5 test samples gave an average shear value of 490 lbs. per square inch; reading the column heading, further information is given in that the surface preparation of this assembly consisted of sandblasting, and a reference to the left hand Glue column informs the reader that the glue used was Franklin animal glue. Forecasting results of different combinations of considerations is quite feasible by the use of the table. For example, a Bakelite film using an emeried surface of Galvaneal gives a strength value of 210 p.s.i.; using a sandblasted surface the value jumps to 532 p.s.i.; continuing, washing the sandblasted surface with carbon tetrachloride will again raise the value, this time to 586; while using a Bonderized coating drops the value to 275; and further, to 265, by using a Parkerized coating. Then, by noting the strength figure, using the same process of gluing, of a different metal, say aluminum, one could easily estimate its strength figures, under conditions similar to those that the Galvaneal was tested, by direct proportion. Similarly, using reason and logic, and taking into mind the several variables, one could estimate several strength values for each of the other glues under the several conditions the table encompasses.

A study of the table indicates also the next steps to take in furthering this quest for the ideal bond between metal and wood in ply construction.

TABLE OF RESULTS

Glue	Condition of Surface				
	Emeried	Sandblasted	Bond.	Park.	Phos.Coat.
Animal Franklin		G 490			
Casein Casco "M"-Latex	C 180 Ax, Gx				
Perkin's Metal Veneer		G 531, A 470 Cx	G 230		Ax
Monite Waterproof		G 379			
Veg. Protein Lauxite 7-L		G 306, Ax			
Blood Albumen		Gx, A 500			
Synthetic resin Phenol-formaldehyde Bakelite X-C 3931		Gx, Ax Cx	Gx		
Catabond 550		G 309, C361 A 330	G 331		Cx
Phenol-formaldehyde Tego		G 495, C367 A 408			
Bakelite	G 210	G 532, A551 C 460	G 275	G 265	A 188, Cx
Bakelite washed (Carbon tetrachloride)		G 586			

Table of Results, Cont.

Glue	Condition of Surface				
	Emeried	Sandblasted	Bond.	Park.	Phos. Coat
Urea-formaldehyde					
Casco Resin No. 21		Gx			

Note:

Letters refer to metals; G, galvaneal; A, aluminum; and C, copper.

Numerals following the letters refer to average shearing strees in pounds per square inch.

The small letter **x** following a capital letter signifies a total absence of adhesion.

CONCLUSIONS

Because of the total absence of wood failure in the joint, (Conditions U excepted), when stressed to destruction, it is at once a question whether the author has yet touched upon the combination approximating the ideal. However, after consideration of the difficulties added to the construction of a ply by the introduction of a metal, and in the light of the strength values obtained with these difficulties present, it might be safe to say that there has been a definite step made and in the right direction by this work.

The tabulated results give a clear picture of the trends:

Sandblasting proved to be a better surface treatment than emerying.

Cleaning the sandblasted surface with a chemical agent (carbon tetrachloride was used), prior to gluing, increases the joint strength.

The oxidation preventive measures undergone, using an atmosphere of carbon dioxide for newly sandblasted test plates, proved of negligible value.

The phosphate coatings used proved of no worth and their use should be discouraged in future work.

There should be further work done with animal glues in the light of the surprising (to the writer) values obtained under conditions 1 A, using a liquid hide glue.

An attempt was made to use Casco "Waterproof" casein glue base, in formula F - 2, in the place of the prescribed Casco Joint "L" and with very poor results. Future work should, by all means, include a more comprehensive study of the casein-latex combinations.

Though the formulas including water were approached with apprehension, corrosion on the metal faces a seemingly inevitable resultant, strength figures obtained using Perkin's "Metal Veneer", formula F-3, and those obtained using Blood Albumen, formula F-6, were surprisingly high. Further aging would quite probably result in lower values due to the action of the moisture on the metal. This, however, should be investigated.

It should be mentioned here that the results obtained using the Blood Albumen mix are not to be construed as representative but rather, indicative of the possibilities present in this glue.

The other water-mix glue bases, "Monite Waterproof" and "Lauxite 7-L" gave relatively low values and it is probable that these should be discarded in further work.

Of the phenol-formaldehyde resins "Bakelite X-C 3931" fell down completely; "Catabond 550" gave relatively poor stress figures and made a very brittle assembly. However, the glue films "Tego" (Conditions W) and "Bakelite Glue Film" (Conditions A B) gave excellent results. These latter two present the top figures of the tests conducted and, because moisture is not present at the glue line during the bonding, it is quite probable that there would be no corrosion on the metal surface adjacent to the glue line. It is to be noted that the "Bakelite" film is slightly superior to the "Tego" film.

The one urea-formaldehyde glue tested, "Casco Resin No. 21" fell apart after aging. This is but one instance, it must be remembered, and rash conclusions must not be formed even though the indication is evident.

Mr. R. Casselmann of the Bakelite Corp., in a letter to the writer, sounds a warning against hasty conclusions from laboratory tests in this work; "It is fairly easy to prepare small samples of hot press bonded metal face plywood, but the results so obtained should not be confused with the results obtainable with larger panels"; continuing, "We have obtained figures in the neighborhood of 1000 p.s.i., but the load figures could just as well have been 500 or 2000. Very high load figures are obtained when the core is thin and the faces heavy and stiff. Conversely, very low figures are obtained when the core is very heavy, and the faces thin and flexible."

Continued work in this field, then, should include a further study of the possibilities of animal glues, casein-latex combinations, the Perkin's product, "Metal Veneer," Blood Albumen, and the phenol-formaldehyde films, together with new products as they present themselves on the market.

APPENDIX

Protective Phosphate Coatings for Metal

Bonderizing (12)

Bonderizing is a chemical process by which a protective coating is produced upon the surface of steel and iron.

The solution into which the cleaned metal is dipped consists of zinc phosphate and phosphoric acid with a trace (1 to 2 1/10,000 of 1%) of copper, and a nitrate. The solution is kept at 180° F. and the work is placed in it for from 8 to 10 minutes. The solution may be sprayed on and the job done in shorter time if this is required, but the cost is greater.

The phosphoric acid is neutralized by the iron forming a phosphate with less acid in it, and containing some of the metal from the treated surface.

The result is a smooth surface coating that makes the underlying metal resistant to corrosion and also provides an excellent base for paints. Bonderizing finds its major use as a base for automobile body painting.

Parkerizing (12)

Parkerizing is a process quite similar to Bonderizing. The coating is thicker and has more iron in it. In the Parkerizing process the solution is never sprayed on. The time the work is left in the solution is much longer. The solution contains no copper but uses nickle as a catylist.

Parkerizing leaves a spongy, matte surface which frequently is filled with oil, then centrifuged to remove the excess oil. This procedure of filling the phosphate layer with oil leaves the metal in a very protective state and a coating of paint is not necessary.

In gluing procedure a clean, grease-free, surface is desired and so there was no oil treatment given the test plates.

Phosphate Coating for Metals Other Than Iron (12)

To coat aluminum and copper a process similar to the two described above is used; however, coating aluminum and copper requires a process with many more complications in ingredients used and technique followed.

In all cases a phosphate combines chemically with the metal surface and produces a corrosion resistant coating which is an integral part of the metal itself.

The Plywood Joint Test (10, 13)

In the standard plywood joint tests used at the Forest Products Laboratory pieces of veneer are glued up into plywood of the size and arrangement shown in figure 1 . The arrangement of transverse grooves is such that when the samples are pulled apart in a Riehle tensile testing machine (see plate 2), the separation must come on either one or both of the glue lines, or in the short center piece of veneer core.

In this work the outer plys were of metal in sheets 1/20 of an inch thick and the core was of maple veneer 1/16 of an inch in thickness, the transverse grooves were cut in the same position as with wood specimens.

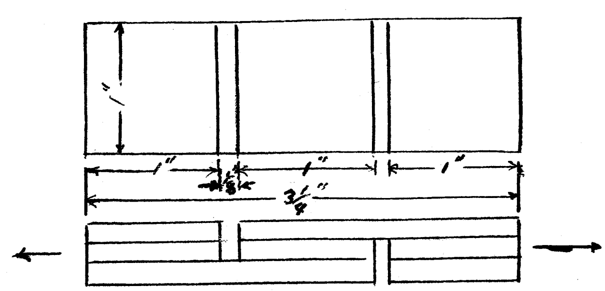
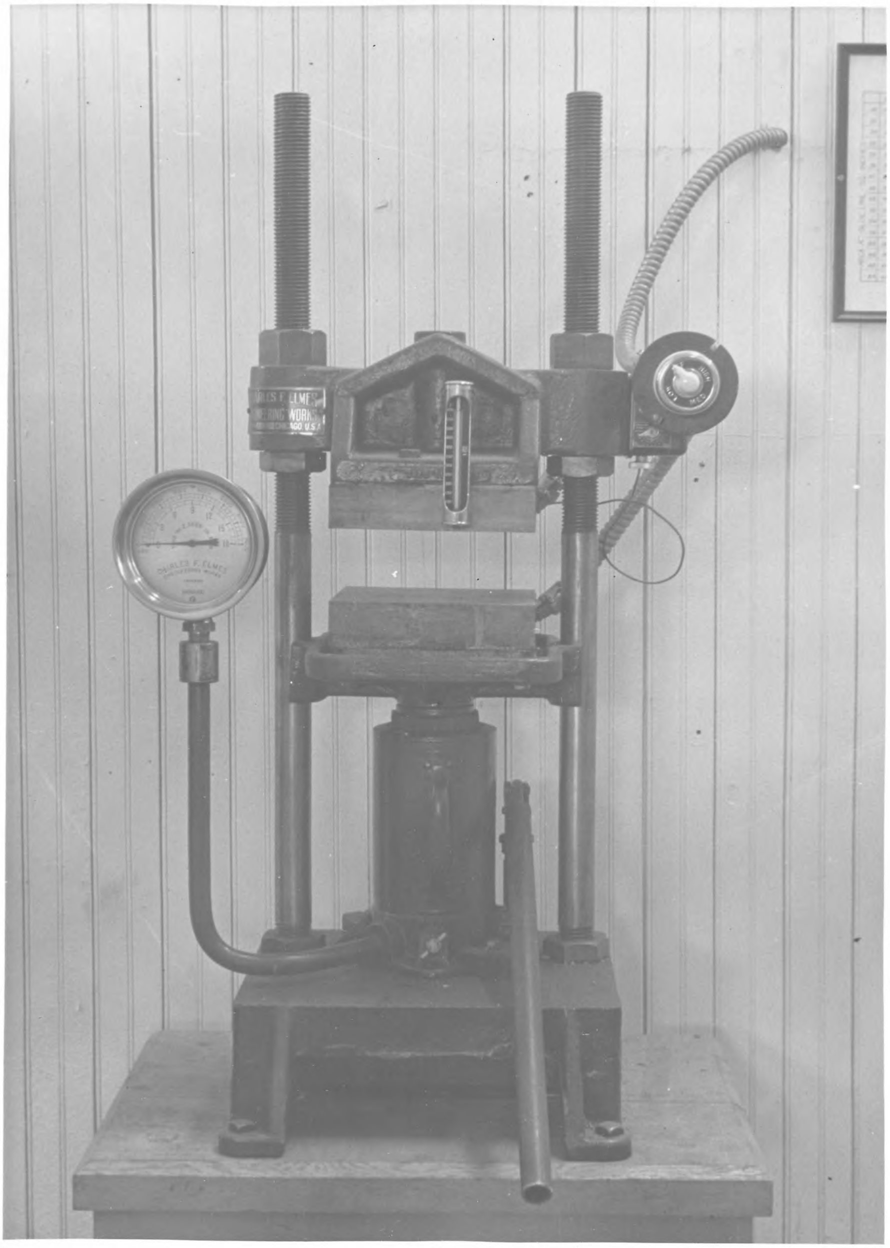


Figure 1

With proper care in selecting and making joints, the plywood shear tests will show fairly consistent differences between weak and strong glues and will enable the selection of a glue or glues satisfactory for a particular job. (11)

A metal-cutting bandsaw was used to cut test pieces to size and a hacksaw was utilized to cut the necessary transverse grooves in the individual test samples.

Plate 1

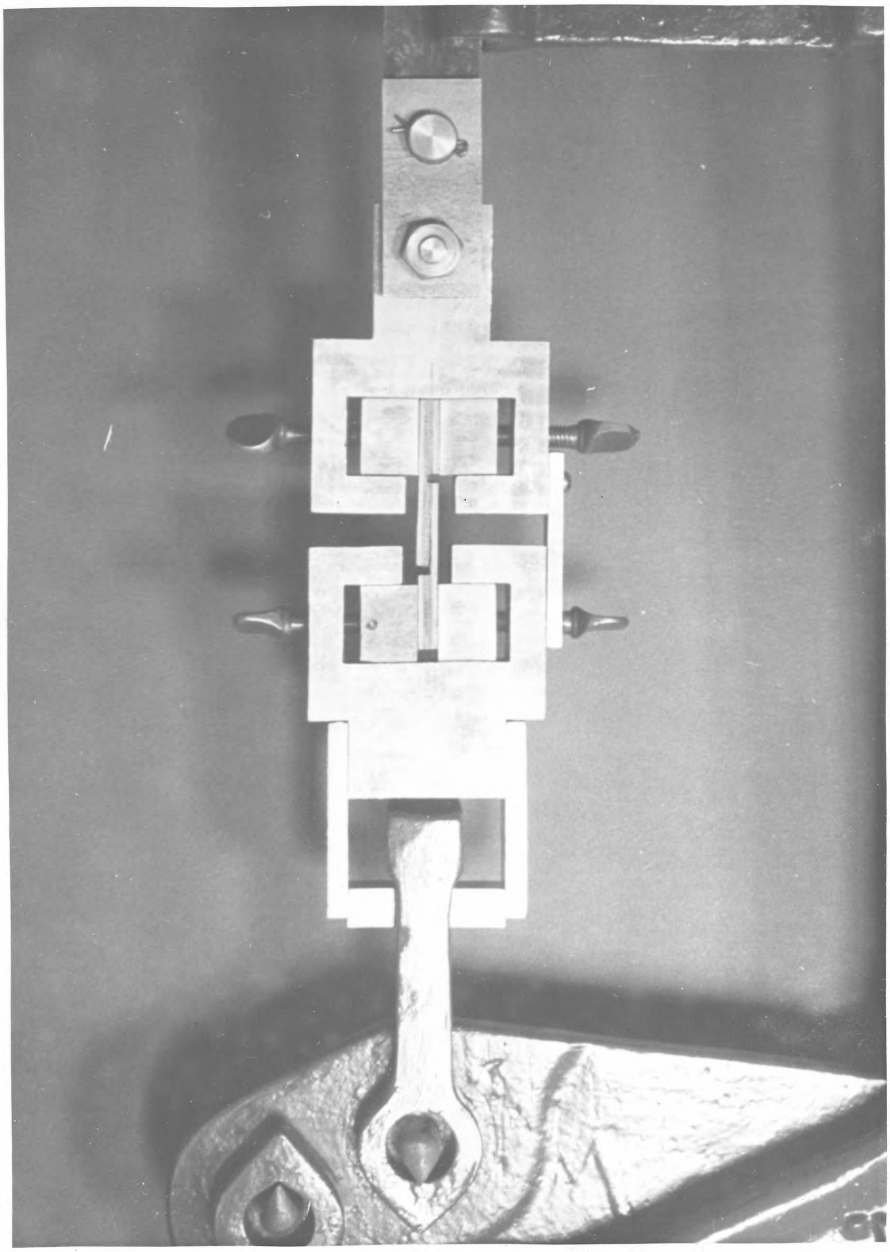


Hydraulic Hot Plate Press   18 Ton Capacity

Plate 2

Equipment Used for the Plywood-Joint Test

Plate 3



Detail of Grips Used in Making Plywood-Joint Tests

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Manufacturers of Glues Used

M-1 Armour Fertilizer Works
Union Stock Yards,
Chicago, Ill.

M-2 Bakelite Corporation,
Bloomfield, New York

M-3 Casein Mfr. Co., of America, Inc.
350 Madison Ave.,
New York City

M-4 Catalin Corp. of America,
Fords, New Jersey

M-5 Franklin Glue Co.,
Columbus, Ohio

M-6 I. F. Laucks, Inc.
Lockport, New York.

M-7 Monite Waterproof Glue Co.,
Minneapolis, Minn.

M-8 Naugatuck Chemical Co.,
Naugatuck, Conn.

M-9 Perkins Glue Co.,
Lansdale, Pa.

M-10 Resinous Products & Chemical Co., Inc.
W. Washington Square,
Philadelphia, Pa.

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