

# DURABILITY OF GLUED JOINTS BETWEEN ALUMINUM AND END-GRAIN BALSAM

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# DURABILITY OF GLUED JOINTS BETWEEN ALUMINUM AND END-GRAIN BALSAS<sup>1</sup>

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## Summary

Tension-type specimens of aluminum cubes bonded to end-grain balsa with each of three typical two-stage bonding processes were subjected to different exposure conditions and tested after periods of 32 to 52 weeks.

Joints in specimens bonded by using one metal primer and a resorcinol-resin glue decreased in strength after immersion in isopropyl alcohol. Joints in specimens bonded by using another metal primer and a resorcinol-resin glue decreased in strength after continuous exposure to high humidity, alternate exposure to high and low humidity, and immersion in gasoline and ethylene glycol. Specimens glued by using a metal primer and an intermediate-temperature-setting phenol-resin glue, showed a partial loss of strength after immersion in water for 2 weeks but little or no further change thereafter.

## Introduction

Aluminum alloy sheets glued to a core of end-grain balsa comprise a form of sandwich construction that has been investigated for use in aircraft. Before this type of sandwich construction can be widely used in aircraft, however, the durability of the glued joints when exposed for prolonged periods to high and low humidities, to high and low temperatures, and to soaking in water and aircraft fluids must be known. A previous study<sup>2</sup> was made by the Forest Products Laboratory on the durability, under these types of exposure, of joints between metal and wood made with a number of gluing processes; but in that study tests were made only on lap-joint shear specimens of aluminum and steel glued to flat-grained yellow birch, fabricated, for the most part, by direct-bonding processes. It was the purpose of this study, therefore, to make similar tests on three

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<sup>1</sup>This 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.

<sup>2</sup>"Durability of Glued Wood-to-Metal Joints," Forest Products Laboratory Report No. 1570.

two-step gluing processes (designated as gluing processes 1, 2, and 3) with tensile-type specimens made of aluminum facings glued to end-grain balsa cores to determine the durability of the glue joints in this type of sandwich construction.

### Preparation of Specimens

The type of specimen (fig. 1) used throughout this study consisted of two 1-inch cubes of 17 ST aluminum alloy bonded to a 1/2-inch thick section of end-grain balsa. Holes, 1/4 inch in diameter, in each aluminum cube were used for attaching a universal-joint loading apparatus to the specimen.

#### Preparation of Aluminum Cubes

Aluminum bar stock, 1 inch square, was cut into 1-inch lengths on a metal-cutting bandsaw, and the holes were drilled and reamed. After the face of the cube was lightly milled, it was cleaned and etched.

Cubes to be glued by gluing process 1 were cleaned by washing them with acetone, and then immersing them for about 20 minutes at 140° to 150° F. in an etching solution composed of the following ingredients (by weight):

Sodium dichromate	1	part
Sulphuric acid (conc.)	10	parts
Water	30	parts

The cubes were washed in cold and warm water to remove the etching solution and then air dried.

Cubes to be glued by gluing process 2 were cleaned in a similar manner, except that before the acid etching the grease was removed from them by washing them with acetone and then immersing them for 3 to 5 minutes at 160° to 185° F. in a solution formulated as follows:

Sodium metasilicate, anhydrous	3.6	ounces
Alkyl aryl sodium sulphonate	0.4	ounces
Water	1	gallon

The cubes were thoroughly washed in cold and warm water to remove the metasilicate solution before they were placed in the sodium dichromate-sulphuric acid etching solution.

Cubes to be glued by gluing process 3 were cleaned first with acetone and then with metasilicate and washed in the same manner as those glued with gluing process 2. Etching of the cubes was then done by

immersing them for 1 to 3 minutes at 140° to 150° F. in a solution of the following composition (by weight):

Chromic acid	5 parts
Water	95 parts

The cubes were washed in cold and warm water to remove the etching solution and then air dried.

### Preparation of Balsa Sections

The balsa planks used in the preparation of the specimens ranged in density from 6 to 9 pounds per cubic foot at 12 percent moisture content. Sections, 1/2-inch thick, were cut from the ends of the balsa planks on a table saw. Selection was made from among these pieces so as to obtain balsa free from rot, pith, and checks, and having a density of about 7 pounds per cubic foot, but no selection was made to eliminate the inclusion of balsa having short fibers.

Balsa for use with gluing processes 1 and 2 was selected at the same time to insure uniformity in general quality. Balsa sections for use with gluing process 3 were selected at a different time, and there is a possibility that this balsa might have been of slightly different quality than was used with the other two gluing processes.

The balsa pieces were bonded together with urea-resin glue into 6- by 6-inch sections, 1/2-inch thick. The square balsa sections were conditioned for at least 1 week at 80° F. and 30 percent relative humidity before they were glued into specimens.

### Fabrication of Specimens

Four different commercial glues (designated as glues A, B, P, and R) and one sizing agent (H) were used in the preparation of the specimens.

Specimens were prepared in groups of 25 by using the alining jig as shown in figure 2. Twenty-five aluminum cubes to which the primer had previously been applied were placed in the bottom section of the jig. The secondary adhesive was applied to the primed surface of these cubes and also to the 25 cubes for the top of the assembly. With two of the processes, secondary adhesive was also applied to both sides of the core. After suitable assembly period, the core was placed on top of the cubes in the alining box, additional alining spacers were placed on top of the core, and the upper set of cubes was placed between the spacers on top of the core. The assembly was pressed at 100 pounds per square inch in a cold or hot press depending upon the type of secondary glue used. A soft caul was used to equalize the pressure. Following the curing of the secondary glue, the jig was disassembled, and the core with cubes bonded to it was cut into the individual test specimens.

Eight hundred individual tension specimens were prepared with each of gluing processes 1 and 2 and 450 with gluing process 3. The gluing conditions used with each process were as follows:

Gluing Process 1. Metal-priming adhesive A was thinned with two volumes of a solvent distributed by the glue manufacturer to one volume of adhesive, and four successive coats were sprayed on the cleaned and etched faces of the aluminum cubes. After 16 hours of air drying, the glue film was cured for 30 minutes at 310° F. The glue-film thickness was about 0.003 inch. The cured film was lightly sanded with No. 1/2 emery cloth. A medium spread of resorcinol-resin glue R was applied by brushing to both the balsa core and to the sanded priming coat on the metal cubes. An open assembly period of approximately 10 minutes and a closed assembly period of 5 minutes elapsed before the assembly was pressed for 16 hours at 100 pounds per square inch in a room at 75° to 80° F.

Gluing Process 2. Six spray coats (two passes each) of metal-priming adhesive B, thinned with 0.8 volumes of the manufacturer's solvent to one volume of glue, were applied to the cleaned aluminum cube surface. A five-minute flash-off period was allowed between coats and 16 hours of air drying after the final coat. The primer film was cured for 20 minutes at 320° F. The film thickness was about 0,003 inch. The film was lightly sanded with No. 1/2 emery cloth. A medium spread of resorcinol-resin adhesive R was applied by brushing to both balsa and primed metal, and then an open assembly of 10 minutes and a closed assembly of 5 minutes elapsed before the assembly was placed under a pressure of 100 pounds per square inch for 16 hours at 75° to 80° F.

Gluing Process 3. Metal-priming adhesive B was applied and cured on the face of the cube in the same manner as used in gluing process 2. The balsa was sized, by spraying with sizing agent H at a rate of approximately 1 gram per square foot of surface. The sizing coat was then allowed to air dry at 75° to 80° F. for at least 24 hours before secondary gluing to the primed aluminum cubes. A medium spread of an acid-catalyzed, intermediate-temperature-setting phenol-resin glue P was applied by brushing only on the primed aluminum surface. After an open assembly period of 3 to 5 hours, the cubes and core were assembled and pressed for 1 hour at 220° to 230° F. and 100 pounds per square inch,

#### Test Procedure

Following a conditioning period of about 1 week at 80° F. and 30 percent relative humidity, the specimens were sorted into groups for exposure and testing. Thirty specimens made by each gluing process were selected for test as control specimens. The remaining specimens (770 with gluing processes 1 and 2 and 420 with gluing process 3) were divided into groups of 70 specimens. The selection of these specimens and also of the specimens for control tests was made so that each group consisted,

as far as possible, of the same number of specimens from all jig loads made with a given gluing process. The 11 groups of specimens made with gluing processes 1 and 2 were subjected to all of the following 11 exposure conditions, and the 6 groups of specimens made with gluing process 3 to the first 6 of the following exposures:

1. Continuous exposure to air at 80° F., and 30 percent relative humidity .
2. Continuous exposure to air at 80° F. and 97 percent relative humidity.
3. A repeating cycle consisting of 2 weeks at 80° F. and 97 percent relative humidity, followed by 2 weeks at 80° F. and 30 percent relative humidity.
4. Continuous exposure to air at 158° F. and 20 percent relative humidity. The specimens were teated following a conditioning period of 1 week at 80° F, and 30 percent relative humidity.
5. A repeating cycle consisting of 1 day at 158° F. and 20 percent relative humidity followed by 1 day at -67° F. in a cabinet cooled with solid carbon dioxide. The specimens were tested following a conditioning period of 1 week at 80° F. and 30 percent relative humidity,
6. Continuous soaking at room temperatures in tap water.
7. Continuous soaking at outdoor temperatures in 100-octane gasoline.
8. Continuous soaking at outdoor temperatures in 73-octane gasoline.
9. Continuous soaking at outdoor temperatures in ethylene glycol.
10. Continuous soaking at outdoor temperatures in isopropyl alcohol de-icer fluid.
11. Continuous soaking at outdoor temperatures in aircraft lubricating oil,

The specimens for exposures 7 through 11 were immersed in sealed containers of the fluids indicated and allowed to stand outside the Laboratory with no protection against temperature changes.

Ten specimens from conditions 1, 2, 3, 4, and 5 were removed for testing after 4, 8, 16, 24, 32, and 52 weeks of exposure; from condition 6 after 2, 4, 6, 7, 8, 16, and 24 weeks of exposure; and from conditions 7, 8, 9, 10, and 11 after 2, 4, 6, 8, 12, 24, and 52 weeks of exposure. Specimens were also to be removed from conditions 1, 2, 3, 4, and 5 after 104 weeks of exposure. The selection of the specimens from the various

exposure conditions to be tested at any one test period was always made SO that a representative sampling was obtained including approximately equal numbers of specimens from each jig load.

All specimens were tested to failure in tension by the use of the testing fixture (fig. 1) and universal testing machine loading with uniform head movement of 0.05 inch per minute. A record was made of the failing load and estimates as to the percentages of balsa failure, of secondary glue to wood, of primary glue to metal, and failures in the primary glue or between the primary glue and the secondary glue.

## Results

Tables 1 and 2 present the average results of these tension tests on the groups of specimens following the several exposures.

The control tests on the specimens bonded with gluing processes 1 and 2 averaged 1,183 and 1,143 pounds per square inch, respectively, with average failures in the balsa of 50 and 65 percent, respectively. The control tests on the Joints bonded with gluing process 3 averaged somewhat lower, with a tensile strength of 1,027 pounds per square inch, but the failure was 53 percent in the balsa. These values may be considered to be equal to or somewhat higher than those usually obtained in unpublished work at this Laboratory with a number of adhesives in this type of construction, and consequently may be regarded as satisfactory joints,

In some instances, the test results following exposure showed that the exposure affected decidedly the quality of the glued joint and balsa core,

### Results of Gluing Process 1

With gluing process 1, a decided decrease in the quality Of the glued joint or of the balsa core was observed in only 2 of the 11 exposure conditions during 52 weeks of exposure. These two conditions were continuous exposure to 97 percent relative humidity at 80° F, and continuous immersion in isopropyl alcohol. In exposure to the high humidity, 8-weeks test results showed a decrease in the average tensile strength of about 20 percent from the dry control strength, and there was a continual decrease with exposure until, when the specimens were tested after 52 weeks of exposure, the strength was less than 50 percent of the dry control strength. Since a high percentage of failures occurred in the balsa, this loss in strength might be attributed in part to the deterioration of the balsa in this exposure condition. When the specimens were soaked

continuously in isopropyl alcohol, a decided decrease<sup>3</sup> in Joint quality was shown in the tests made after 24 weeks, and evidence of decreasing strength appeared in the tests made after 4 weeks. After 52 weeks of exposure there was a further decrease in joint quality, as the average tensile strength was only 33 percent of the dry control strength with failures of only 20 percent in the balsa. This loss in joint strength could be attributed to the effect on the glue itself,

## Results of Gluing Process 2

With gluing process 2, 7 of the 11 exposure conditions caused a significant decrease in the quality of the glued joint or of the balsa core during 52 weeks of exposure. Continuous exposure to 97 percent relative humidity at 80° F. and exposure alternately to 97 and to 30 percent relative humidity at 80° F., were the two tests conditions that had the greatest effect on joint specimens glued by this process. In the continuous high humidity exposure, tests made after 4 weeks of exposure showed an average strength of only 64 percent of the dry-control strength with 39 percent failure in the balsa. After 52 weeks of exposure the joint strengths had continued to decrease until the average strength was only 27 percent of the dry-control strength and the failure was only 17 percent in the balsa. In the alternating high and low humidity exposure, test results after 16 to 52 weeks of exposure showed strengths that continued to decrease from 70 down to 25 percent Of the dry-control strength, and the average failures decreased from 40 to 19 percent in the wood. With both exposure conditions, the specimens tested after the longer exposure periods had a large percentage of adhesion failure of the primer coat from the metal. Continuous exposure to 158° F. at 20 percent relative humidity and exposure alternately to 158° F. at 20 percent relative humidity and to -67° F., materially reduced the strength of joint specimens glued by gluing process 2 in 32 and 52 weeks of exposure. These losses of strength under continuous exposure to 158° F. could be attributed in part to deterioration of the balsa, since the observed failures were mainly in the balsa. For joints glued with gluing process 2, there was a deterioration of the joints soaked in 73-octane gasoline, 100-octane gasoline, and ethylene glycol. In the tests made following 2 to 12 weeks of soaking in gasoline, the Joint quality remained approximately constant, but the level of strength was generally slightly below that of the dry control specimens. The joint quality progressively decreased after 24 weeks of soaking, and after 52 weeks the average strengths were about 50 percent of the dry-control strength and the failure was less than 20 percent in the balsa. No decided decrease in the quality of the joints soaked in ethylene glycol

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<sup>3</sup>This decrease in joint quality is somewhat contradictory to the results obtained in the durability study of lap-type specimens of aluminum to wood (footnote 2). It was observed that the priming coat on these tensile specimens seemed to be somewhat more porous than it was on the lap specimens, which might have affected the results, although application of the primer was done in the same way.

was noted until the tests made after 62 weeks. As this last test furnished the only evidence of deterioration in quality of joints when soaked in ethylene glycol, no positive conclusions can be drawn until additional data are available.

### Results of Gluing Process 3

While the average strengths of the bonds obtained by the use of gluing process 3, were slightly lower than those obtained by the other two gluing processes, a decided change in joint quality occurred in only one of the six exposure conditions used. Two weeks of soaking in water decreased the joint quality by reducing the strength of the joint and the percentage of failure in the balsa. Thereafter, however, the joints maintained an average of about 70 percent of the dry-control strength, with about 30 percent failure in the balsa, through the 24th week. Joints bonded by the other two processes also showed some decrease in strength when tested after soaking in water, but the major portion of these decreases can be attributed to normal decrease in wood strength with higher moisture content.

Table 1.—Average results of lesion tests made on joints of aluminum glued to end-grain balsa after exposure to five conditions of humidity and temperature.

Exposure period	Continuous 80° F. and 30 percent relative humidity					Continuous 80° F. and 97 percent relative humidity					Alternating 2 weeks at 80° F. and 30 percent relative humidity and 2 weeks at 80° F. and 97 percent relative humidity					Continuous 158° F. and 20 percent relative humidity					Alternating 1 day at 158° F. and 20 percent relative humidity and 1 day at -67° F.					
	Tensile strength	Balsa failure	Wood adhesion	Metal adhesion	Primer adhesion	Tensile strength	Balsa failure	Wood adhesion	Metal adhesion	Primer adhesion	Tensile strength	Balsa failure	Wood adhesion	Metal adhesion	Primer adhesion	Tensile strength	Balsa failure	Wood adhesion	Metal adhesion	Primer adhesion	Tensile strength	Balsa failure	Wood adhesion	Metal adhesion	Primer adhesion	
Weeks	P.s.i.	Percent	Percent	Percent	Percent	P.s.i.	Percent	Percent	Percent	Percent	P.s.i.	Percent	Percent	Percent	Percent	P.s.i.	Percent	Percent	Percent	Percent	P.s.i.	Percent	Percent	Percent	Percent	
<u>Gluing Process 1 - Primer A and Resorcinol Resin B</u>																										
0 (control)	1183	50	4	2	44																					
4	1350	61	0	2	37	1197	74	0	6	20	1225	73	2	6	19	1484	70	9	0	21	1393	80	5	1	14	
8	1349	61	9	1	29	942	73	7	6	14	1025	58	5	14	23	1399	83	12	1	4	1282	81	6	4	9	
16	1144	67	13	0	20	793	74	6	14	6	929	59	10	13	18	1267	86	7	1	6	1056	76	7	4	13	
24	1253	70	7	1	22	678	63	10	21	6	910	60	16	19	5	1449	91	5	1	3	1387	75	13	2	10	
32	1467	82	14	1	33	690	59	3	19	19	1185	67	9	7	17	1475	88	0	0	12	1152	70	6	3	21	
52	1217	73	0	0	27	560	75	0	12	13	1127	59	5	16	20	1769	81	7	2	10	1129	82	8	3	7	
<u>Gluing Process 2 - Primer B and Resorcinol Resin B</u>																										
0 (control)	1143	65	15	2	18																					
4	1396	66	24	0	10	733	39	16	25	16	1044	61	22	10	7	1223	85	6	0	9	1446	55	41	4	0	
8	1258	79	8	0	13	742	43	15	24	15	897	61	5	33	1	1266	70	22	1	7	1385	69	22	2	7	
16	1161	77	6	1	16	422	17	7	67	9	794	40	5	38	19	1232	72	7	2	19	976	85	0	4	11	
24	1275	68	18	0	14	454	35	14	49	2	691	22	4	69	5	1110	80	1	1	18	1093	80	1	3	16	
32	1244	67	4	2	27	424	47	2	48	3	580	16	12	50	22	686	77	2	17	4	877	71	1	9	19	
52	1287	64	0	1	15	310	17	7	67	9	282	19	0	73	8	532	70	0	10	20	391	34	0	47	19	
<u>Gluing Process 3 - Primer B and Phenol-Resin B</u>																										
0 (control)	1027	53	27	9	11																					
4	1069	40	44	6	10	956	30	45	16	9	1170	22	56	5	17	1110	85	34	13	6	932	46	39	3	12	
8	850	61	27	3	9	802	30	35	28	7	1088	42	43	0	15	1053	50	34	6	10	988	43	45	5	9	
16	1011	55	37	6	3	824	30	42	18	10	1046	24	55	19	2	1158	36	58	3	3	939	52	45	2	1	
24	1106	58	39	2	1	715	25	42	27	6	1078	48	46	3	1	1109	52	40	2	6	905	62	33	1	4	
32	945	57	40	2	1	989	63	28	8	1	913	38	41	16	5	956	51	38	11	0	1033	59	40	1	0	

<sup>1</sup>Each value for the control tests is the average of 30 specimens and each value for all other tests is the average of 10 specimens.

<sup>2</sup>Failure between the secondary glue and the end-grain balsa.

<sup>3</sup>Failure between the primary glue and the metal.

<sup>4</sup>Failure between the secondary and primary glues, and cohesion failure in the primary glue.

Table 2.—Average results of tension tests made on joints of aluminum glued to end-grain balsa after they were soaked in various fluids

Specimen no.	Tap water				100 octane gasoline				75 octane gasoline				Ethylene glycol				Isopropyl alcohol (de-aer fluid)				Aircraft lubricating oil							
	Tensile strength	Failure period	Failure mode	Failure location	Tensile strength	Failure period	Failure mode	Failure location	Tensile strength	Failure period	Failure mode	Failure location	Tensile strength	Failure period	Failure mode	Failure location	Tensile strength	Failure period	Failure mode	Failure location	Tensile strength	Failure period	Failure mode	Failure location				
2	1050	22	4	0	61	0	0	0	1386	21	0	0	0	1000	69	0	0	0	1174	61	0	6	26	1119	50	2	2	45
4	1076	26	12	10	66	2	4	0	1205	21	0	0	0	976	50	0	0	0	1048	65	4	16	25	1195	36	5	4	58
6	986	24	17	10	68	7	0	10	1265	37	12	7	44	1036	49	0	1	30	1032	50	0	3	38	1068	53	6	2	27
7	1038	24	17	10	68	7	0	10	1265	37	12	7	44	1036	49	0	1	30	1032	50	0	3	38	1068	53	6	2	27
12	1227	26	17	11	67	13	0	0	1259	35	3	0	34	1071	58	9	1	32	945	60	4	2	34	1260	48	6	1	45
24	1045	20	17	11	67	13	0	0	1259	35	3	0	34	1071	58	9	1	32	945	60	4	2	34	1260	48	6	1	45
52	1004	22	4	0	61	0	0	0	1386	21	0	0	0	1000	69	0	0	0	1174	61	0	6	26	1119	50	2	2	45
2	927	21	30	9	62	4	1	35	1047	36	13	4	43	1029	72	4	1	19	1132	71	13	1	22	1227	40	1	1	18
4	1003	28	27	6	69	0	0	0	1000	46	12	6	34	1047	63	22	0	15	1265	71	12	0	17	1269	64	25	0	11
6	950	21	17	10	68	7	0	10	1265	37	12	7	44	1036	49	0	1	30	1032	50	0	3	38	1068	53	6	2	27
12	789	41	17	11	67	13	0	0	1259	35	3	0	34	1071	58	9	1	32	945	60	4	2	34	1260	48	6	1	45
16	915	20	17	11	67	13	0	0	1259	35	3	0	34	1071	58	9	1	32	945	60	4	2	34	1260	48	6	1	45
24	1004	22	4	0	61	0	0	0	1386	21	0	0	0	1000	69	0	0	0	1174	61	0	6	26	1119	50	2	2	45
52	927	21	30	9	62	4	1	35	1047	36	13	4	43	1029	72	4	1	19	1132	71	13	1	22	1227	40	1	1	18
2	563	49	27	14	10	0	0	0	870	32	11	0	0	1257	63	10	0	0	1148	77	11	1	21	1123	66	2	1	9
4	908	23	17	10	66	2	0	0	1205	37	12	7	44	1036	49	0	1	30	1032	50	0	3	38	1068	53	6	2	27
6	630	23	22	21	7	0	0	0	1000	46	12	6	34	1047	63	22	0	15	1265	71	12	0	17	1269	64	25	0	11
8	628	24	20	21	15	0	0	0	853	32	11	0	0	1165	61	5	3	21	1166	66	11	2	19	1154	60	7	0	13
16	672	18	49	33	0	0	0	0	823	31	0	6	35	1194	65	9	1	19	1009	86	15	20	23	1270	69	0	0	23
24	835	40	45	15	0	0	0	0	599	31	1	41	46	686	42	8	18	42	625	49	0	25	28	1059	34	1	0	23

Each value is the average for 10 specimens.  
 1 Failure between the secondary glue and the end-grain balsa.  
 2 Failure between the primary glue and the metal.  
 3 Failure between the secondary and primary glues, and cohesion failure in the primary glues.

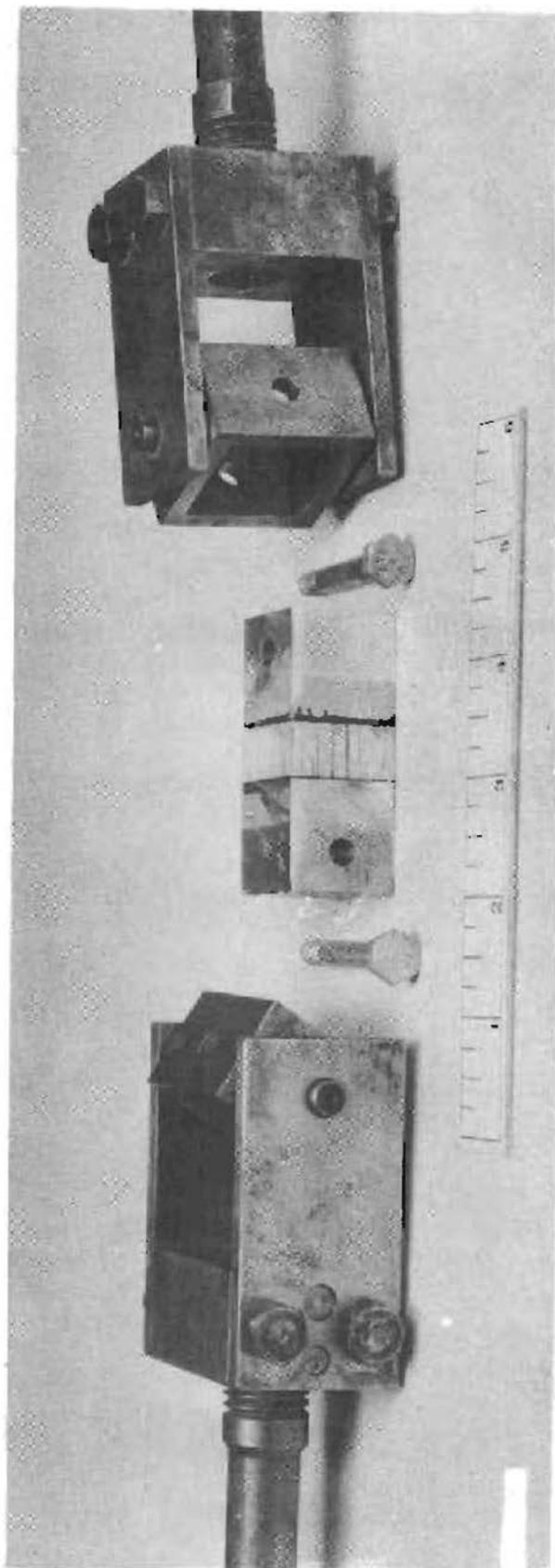


Figure 1.--Specimen (aluminum cubes glued to end-grained balsa) and fittings for tensile test of aluminum-to-balsa sandwich joints.

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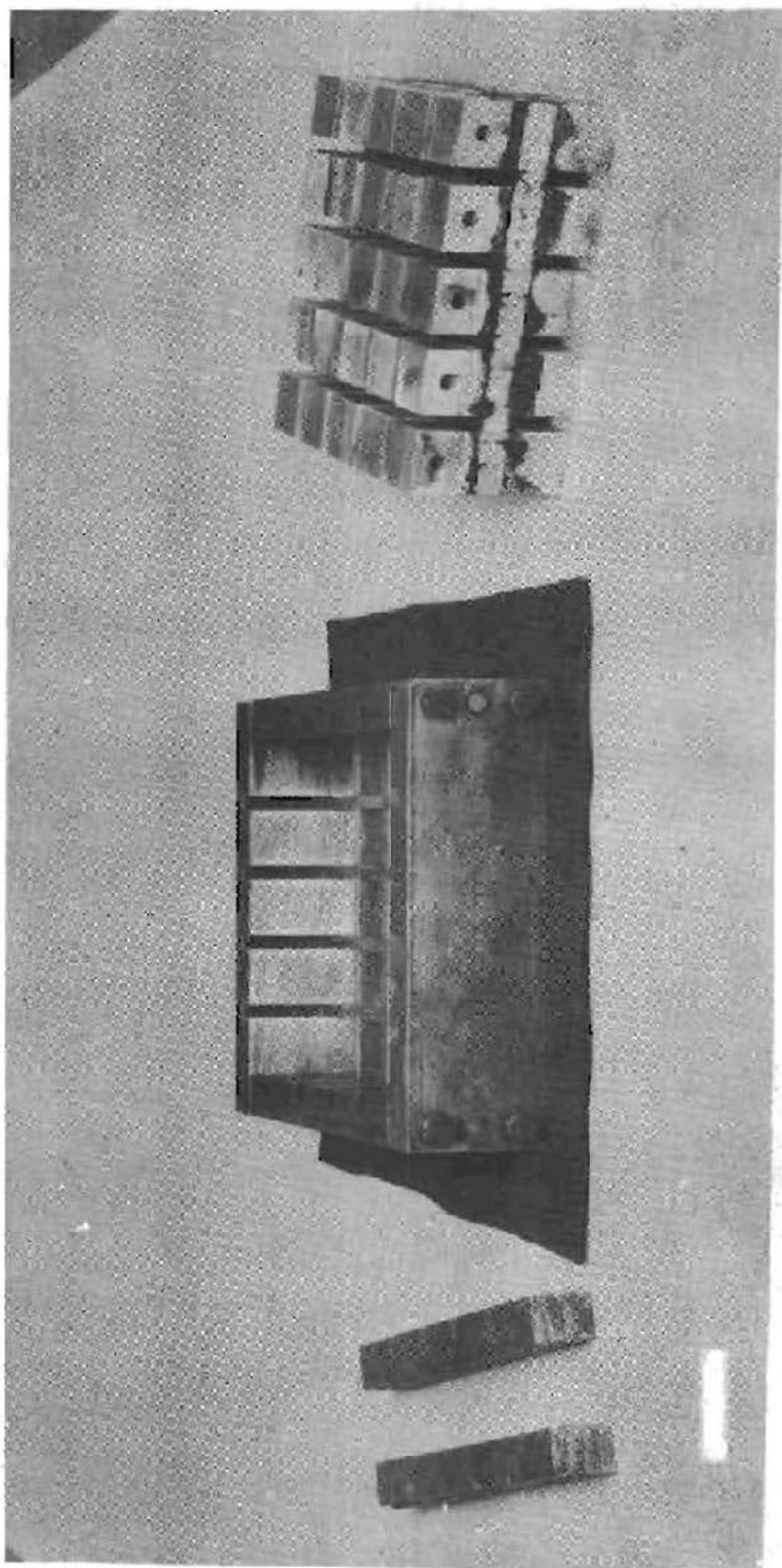


Figure 2.--Alining jig used in the preparation of tensile test specimens in which aluminum cubes are glued to end-grain balsa.