

**TENSILE STRENGTH AT ELEVATED  
TEMPERATURE OF GLUED JOINTS  
BETWEEN ALUMINUM AND  
END-GRAIN BALSA**

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TENSILE STRENGTH AT ELEVATED TEMPERATURE OF GLUED JOINTS

BETWEEN ALUMINUM AND END-GRAIN Balsa<sup>1</sup>

By

HERBERT W. EICKNER, Engineer

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Aluminum alloy sheets glued to a core of end-grain balsa wood comprise a form of sandwich panel being investigated for aircraft construction. Several adhesives produce bonds between the aluminum and balsa that have tensile strengths as great at room temperature as that of the end-grain balsa or are sufficiently strong to prevent glue-joint delamination in buckling tests of the panels. There is evidence, however, that some of these glues will soften at elevated temperatures. It is, therefore, important to know how well glued wood-to-metal joints maintain their strength at temperatures that might prevail in aircraft standing in the heat of sunshine. To determine the extent to which glue joints made with several adhesive processes between aluminum alloy and end-grain balsa may change in tensile strength under such exposures, test specimens were heated to temperatures as high as 190° F.

Preparation of Specimens

The type of specimen used throughout this study is shown in figure 1. Two 1-inch cubes of 17 S-T aluminum alloy, with holes 1/4 inch in diameter as shown, were bonded to each side of a piece of end-grain balsa 1/2 inch thick. Table 1 gives the gluing processes and probable types of the commercial glues tested.

Aluminum bar stock 1 inch thick was cut into 1-inch lengths with a milling machine cut-off saw or on a metal cutting bandsaw, and the holes drilled and reamed. The face of the cube to be glued was lightly milled, then cleaned and etched. The surfaces of the aluminum cubes to which Glue C (table 1) was to be applied were washed with acetone and then immersed for 3 to 5 minutes at 160° to 185° F. in a solution having the formulation:

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<sup>1</sup>This mimeograph 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.

Sodium metasilicate, anhydrous	3.6 ounces <sup>2</sup>
Alkyl aryl sodium sulphonate	.4 ounce
Water	1.0 gallon

The cubes were rinsed with cold water to remove the cleaning solution, then immersed for about 20 minutes at 140° to 150° F. in a solution composed of the following ingredients:

Sodium dichromate	1 part by weight
Sulfuric acid (conc.)	10 parts by weight
Water	30 parts by weight

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

The aluminum cubes which were to be bonded by adhesives other than Glue C were washed with acetone, immersed for 20 minutes in the solution of sodium dichromate and sulfuric acid, washed in cold water, then in hot water, and air dried.

The balsa used in these specimens ranged in density from 6 to 9 pounds per cubic foot at 12 percent moisture content. Most of it weighed between 6 and 7 pounds per cubic foot. All balsa with areas of rot, pith, or checks was rejected, but no selection was made to eliminate short-fiber balsa.

The ends of the balsa planks were cut off in thicknesses of 1/2 inch on a table saw and edge glued together with urea resin into squares 6 by 6 inches in size. These balsa squares were conditioned for at least 1 week at 80° F. and 30 percent relative humidity, then assembled for gluing in the jig shown in figure 2.

The procedure in assembling specimens in these jigs was to place aluminum cubes with glue on their upper faces in the lower alining holes, lay the balsa core spread with glue on both sides, place the alining frame on top of the core, and insert in the upper holes of the frame cubes with glue on their lower faces. This assembly was pressed at 100 pounds per square inch in a hot or cold press according to the requirements of the glue, using soft cauls to equalize the pressure. When the glue was cured in a hot press, with its platens at 310° to 325° F., approximately 20 minutes was required for the glue lines to reach the platen temperature. The jig was always taken from the press without prior cooling. The glued assembly was cut into individual specimens (fig. 1), from which excess glue and core were removed by cutting and sanding.

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<sup>2</sup>The use of this metasilicate cleaning bath preceding an acid cleaning bath is recommended by the manufacturer of the Glue C.

Thirty-two specimens were prepared with each of the six gluing processes. In a few instances, reruns were made to check results. Conditions<sup>3</sup> peculiar to each process were as follows:

Gluing Process 1. Two medium coats of this commercially formulated wood-to-metal glue, A, thinned with an equal volume of ethyl acetate, were applied with a brush to the etched metal surfaces and the balsa core. One-half hour of air drying was allowed between coats and an open assembly period of 16 hours after the second coat. The glue in the assembly was precured in the hot press without pressure for the 20 minutes required to bring the temperature of the glue line up to the platen temperature of 325° F., after which the pressure of 100 pounds per square inch was applied for 15 minutes.

Gluing Process 2. Four coats of the metal-priming adhesive, B<sub>1</sub>, thinned with 2 volumes of a thinner distributed by its manufacturer, were sprayed on the etched metal. Following 16 hours of air drying, the glue was cured for 30 minutes in an oven at 310° F. The dry-film thickness was about 0.003 inch. The cured film was lightly sanded with No. 1/2 emery cloth. A medium spread of the resorcinol resin glue, B<sub>2</sub>, was applied to both the balsa and the sanded priming coat on the metal surfaces, and an open assembly period of 10 minutes and a closed assembly period of 5 minutes were allowed before applying the pressure. The assembly was pressed over night in a room at 80° F.

Gluing Process 3. Six spray coats (two passes each) of the commercial wood-to-metal brush glue, C, thinned with 0.8 volume of the manufacturer's recommended solvent to 1 of the glue, were applied to both metal and balsa so as to obtain a film on each surface 0.003 inch in thickness when dry. A 5-minute flash-off period was allowed between coats and 16 hours of air drying after the final coat. The glue film on both aluminum and balsa was precured for 45 minutes in an oven at 180° F. to remove residual solvent before assembling the specimens in the jig. The assembly was cured and pressed for 40 minutes in a hot press with a platen temperature of 325° F.

Gluing Process 4. Glue D<sub>1</sub>, identical to Glue C, was applied to the metal in the same manner as for the specimens glued directly with the adhesive in Process 3. After air drying for 16 hours, the glue was cured for 20 minutes at 325° F. The cured film of glue was sanded with No. 320 Grit sandpaper to remove surface irregularities. Both surfaces of the balsa core were coated by spraying with 3 grams per square foot of a commercial sizing resin. A medium spread of Glue D<sub>2</sub> prepared with one-half the normal amount of acid catalyst was applied to the primed metal surface. After this glue had been allowed to stand in open assembly for 2 hours and the sizing resin for at least 24 hours, the cubes and core were assembled and pressed for 2 hours at a platen temperature of 220° F.

Gluing Process 5. This commercial wood-to-metal glue, E<sub>1</sub>, was sprayed on the metal surface in 10 coats to build up a dry-film thickness of about 0.003 inch. Three to 5 minutes of air drying was allowed between coats and

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<sup>3</sup>These gluing processes are essentially those recommended by the respective manufacturers.

16 hours after the final coat, before assembly. Two thin brush coats of glue E<sub>2</sub>, supplied by the same manufacturer, were also applied to each side of the balsa core, allowing 10 minutes air drying between coats and 20 minutes after the second coat. The assembly was pressed for 45 minutes at a platen temperature of 325° F.

Gluing Process 6. This commercial wood-to-metal glue, F, is furnished in two parts by the manufacturer, a liquid resin and a powder. A coat of liquid resin was applied to the etched metal faces by brushing and the powder immediately sprinkled over it. A coat of liquid was also applied to the balsa core, but no powder was sprinkled over it. After an open assembly period of 4 hours, the aluminum and balsa were assembled and pressed for 35 minutes at a platen temperature of 325° F.

### Test Procedure

Following a conditioning period of at least 1 week at 80° F. and 30 percent relative humidity, the glue-joint specimens were tested in tension.

The testing apparatus consisted of a set of specially designed testing grips (fig. 1) with a universal joint to eliminate effects of misalignment, an insulated cabinet with temperature control (fig. 3), and a universal testing machine. The testing grips were inside the cabinet and attached to the heads of the machine. The test specimen was held in the testing grips by 1/4-inch diameter pins through both grips and aluminum cubes. The two pins were orientated at right angles (figs. 1, 3) to distribute the stresses more uniformly over the area of the joint under test. The temperature of the insulated cabinet was controlled so that the joints could be tested at various temperatures from 80° to 190° F. For each of 5 processes, 8 specimens were tested at 80° F. and 6 at each of the following temperatures: 120°, 145°, 170°, and 190° F. For process 2, twice this number were tested. It had been found that about 40 minutes were required for the glue-joint area of a tension specimen to come to temperature equilibrium with the cabinet at 190° F. and all specimens were held in the cabinet for 60 minutes before they were tested.

Each specimen was loaded to failure in a hydraulic testing machine operated at a uniform head movement of 0.05 inch per minute. Maximum load at the instant of failure was recorded, together with the nature of the failure.

### Results of Tests

The average tensile strengths and estimated percentages of balsa failure for the joints made by the different gluing processes and tested at the several temperatures are given in table 2. The average strength values are plotted in figure 4, with broken lines to indicate the standard deviation limits.

The glues differed appreciably in their general level of joint strength and the rate at which they lost strength with increase in temperature. Although the joints glued by gluing process 1 were the strongest at room temperature, they were affected most by heat. The change in the strength of joints in the temperature range between 145° and 190° F. appeared to be negligible for the joints made by gluing processes 2, 4, and 5, and, although there was some decrease in strength of the joints prepared by process 3, it is doubtful if it is statistically significant. There was a considerable reduction of strength within this temperature range for joints made by gluing processes 1 and 6, and also a reduction in the amount of failure in the balsa.

As indicated by the broken lines in figure 4, the variability in strength between duplicate specimens was greatest for joints made by gluing process 6 and least for processes 4 and 5. The balsa failure for the joints glued with process 6, however, was relatively high at the lower temperatures and much of their observed variability may have been caused by nonuniformity of the balsa.

Caution is advised in extrapolating the last segment of the graph beyond 190° F. without giving due regard to the possibility of the point at 190° being relatively too high or too low within the limits of the standard deviation due to experimental error.

Of the six gluing processes investigated, process 1 was the easiest to use. Process 2, however, gave the best over-all performance in these tests, with high joint strength at room temperature and least change in strength with increase in temperature up to 190° F.

Table 1.--Types of glues or combinations of glues included in the six gluing processes tested for tensile strength in wood-to-metal glue joints at elevated temperatures

Gluing process	Glue symbol	Probable type
1	A	Hot-setting modified thermoplastic resin.
2	B <sub>1</sub>	Hot-setting thermoplastic resin modified with thermosetting resin and pigment;
	B <sub>2</sub>	Room-temperature-setting resorcinol resin.
3	C	Hot-setting mixture of thermosetting resin and synthetic rubber.
4	D <sub>1</sub>	Hot-setting mixture of thermosetting resin and synthetic rubber;
	D <sub>2</sub>	Intermediate-temperature-setting acid-catalyzed phenol resin.
5	E <sub>1</sub>	Thermosetting combination of synthetic rubber and plastics;
	E <sub>2</sub>	Modified low pressure thermoplastic resin.
6	F	Hot-setting two component adhesive of liquid thermosetting resin and thermoplastic powder.



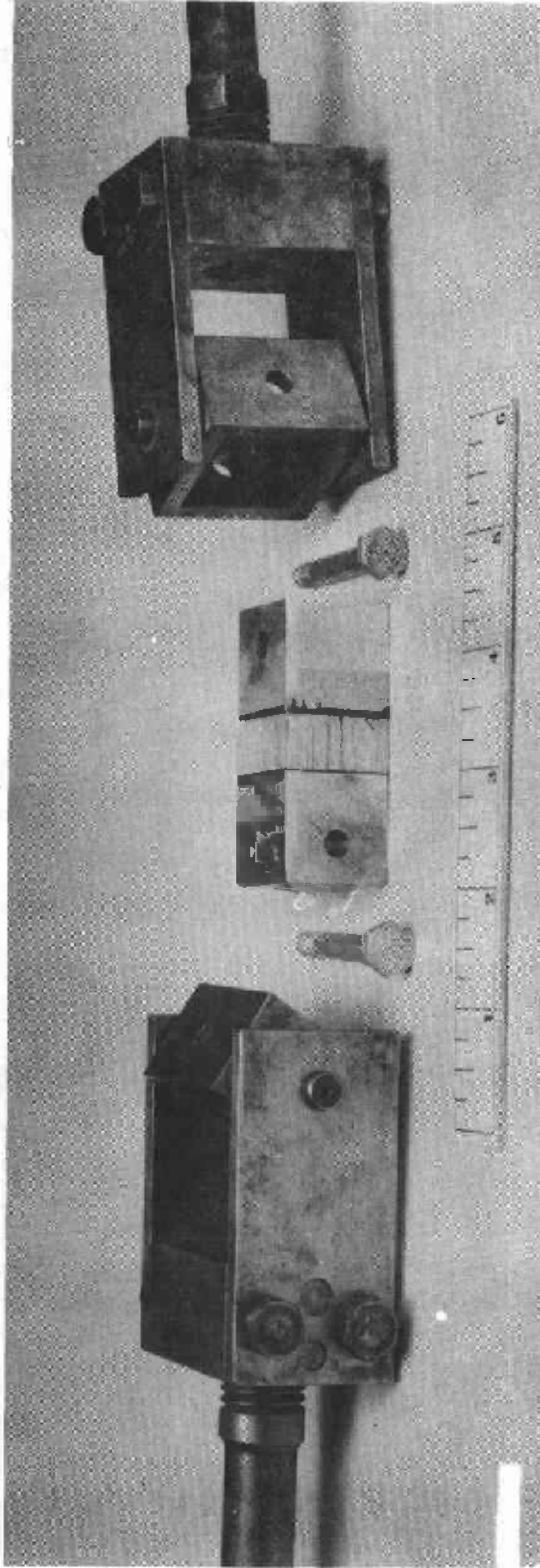


Figure 1.--Specimen (aluminum cubes glued to end-grained balsa) and fittings for tensile test of aluminum-to-balsa sandwich joints.

Z X 87038 F

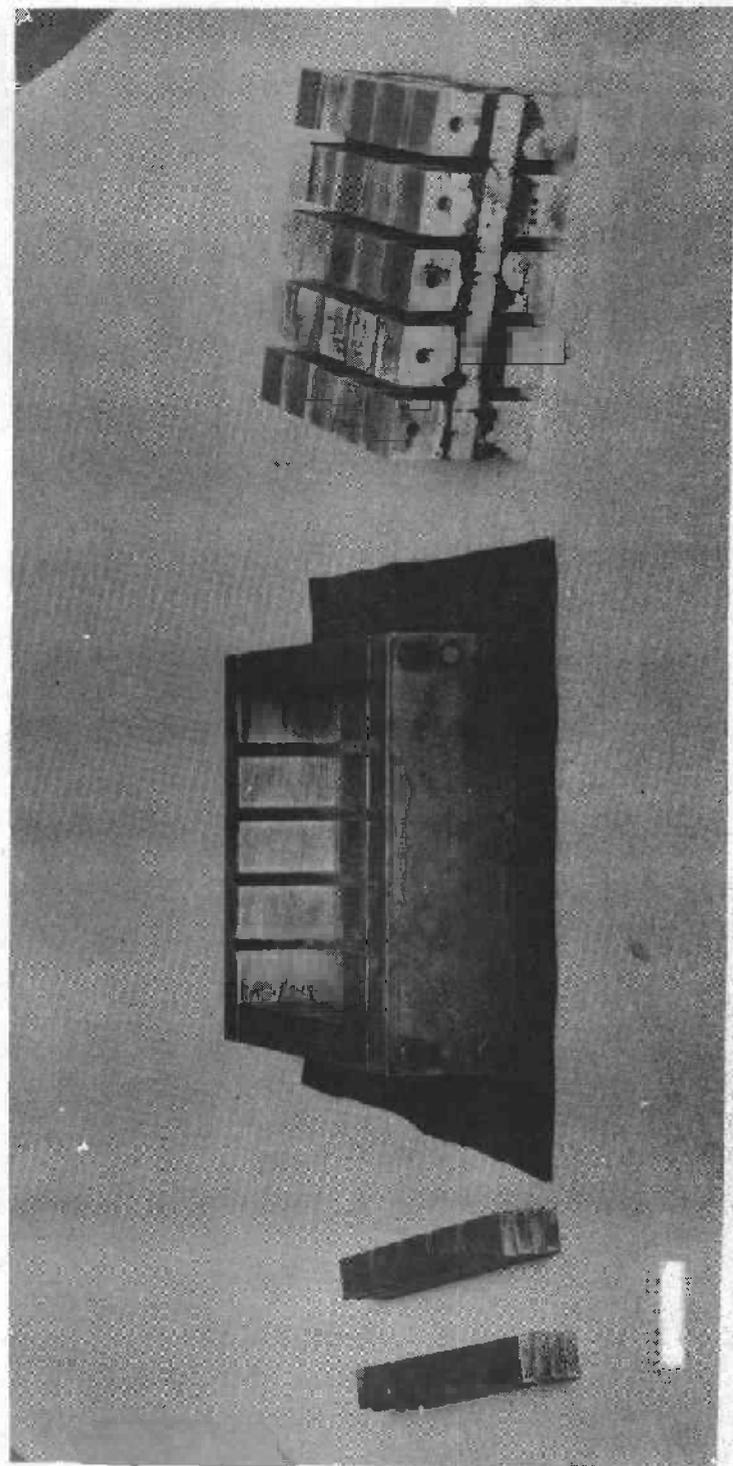


Figure 2.--Aligning jig used in the preparation of tensile test specimens in which aluminum cubes are glued to end-grain balsa.

Z X 68793 F

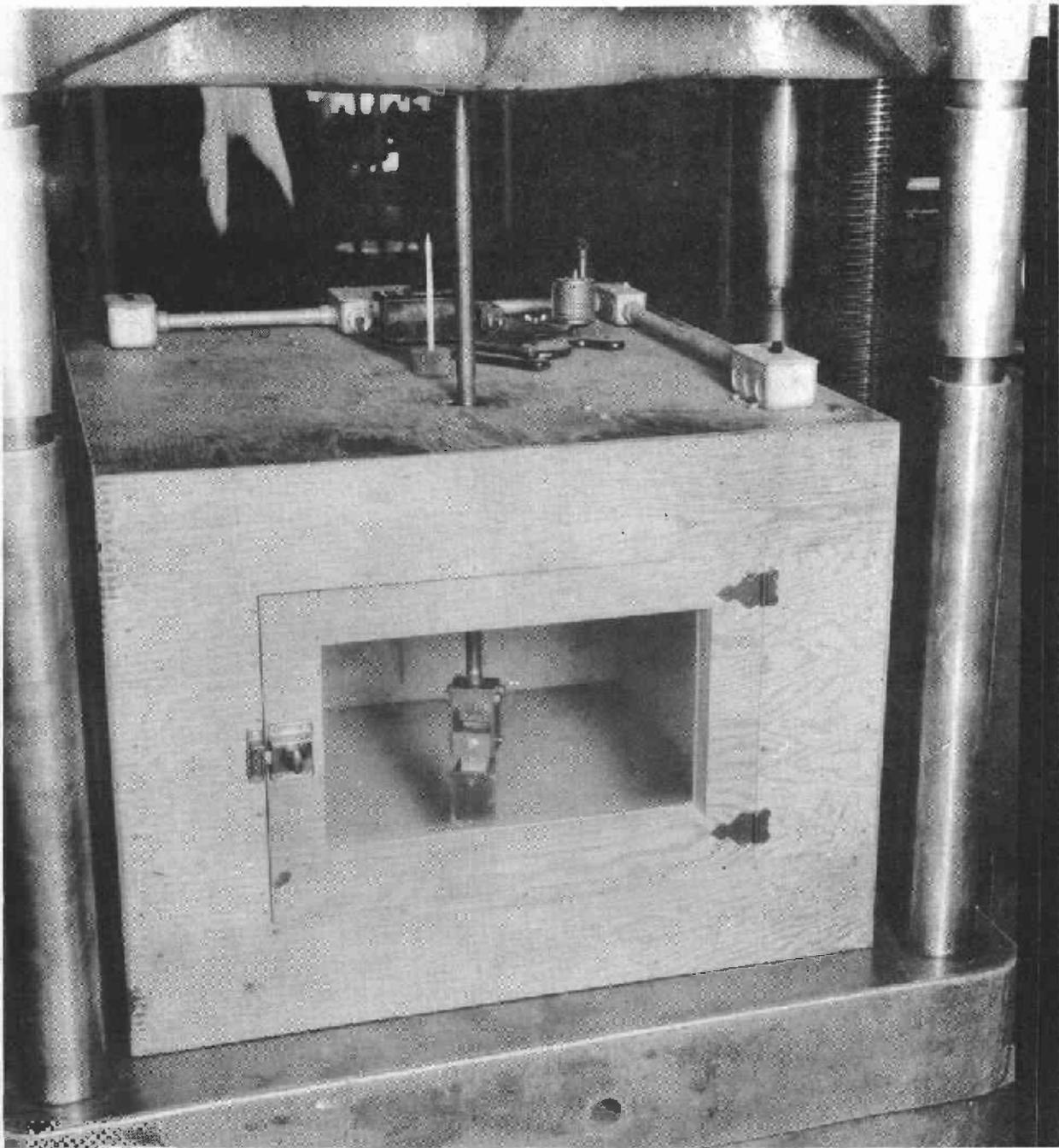


Figure 3.--Insulated heated cabinet in which glued joints were tested in tension at controlled elevated temperatures.

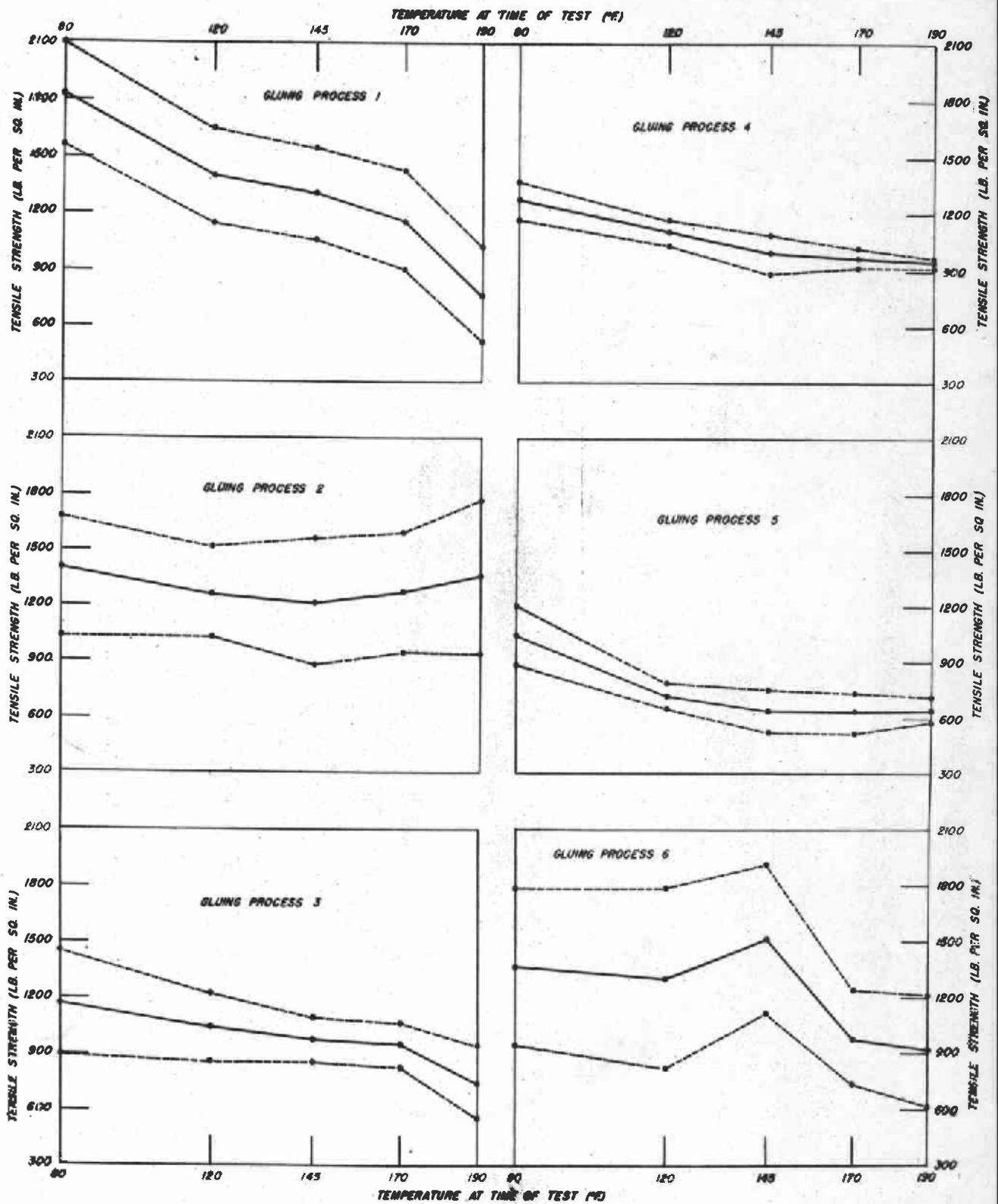


Figure 4.--Average results of tensile tests at elevated temperatures of glued joints between aluminum and end-grain balsa. Broken lines indicate standard deviation limits.