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Tensile Behavior of Boron/Epoxy-Reinforced 7075-T6 Aluminum Alloy at Elevated Temperatures

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Tensile Behavior of Boron/Epoxy-Reinforced 7075-T6 Aluminum Alloy at Elevated Temperatures

Daniel J. Chwirut

and

George F. Sushinsky

Mechanics Division
Institute for Basic Standards
National Bureau of Standards
Washington, D.C. 20234

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TENSILE BEHAVIOR OF BORON/EPOXY-REINFORCED 7075-T6 ALUMINUM ALLOY AT ELEVATED TEMPERATURES

Daniel J. Chwirut and George F. Sushinsky

Static tensile tests were performed on specimens of 7075-T6 aluminum alloy, 0° unidirectional boron/epoxy, and 7075-T6 aluminum alloy reinforced on the surface with 0° unidirectional boron/epoxy laminate, at four temperatures up to 300 °F (149 °C). Analytical load-strain curves are formulated for the reinforced-metal specimens using the rule of mixtures, assuming that the longitudinal strains in the composite and the metal remain equal, and taking account of the residual stresses caused by the fabrication process. Two analytical curves are plotted for each reinforced-metal specimen, one based on the measured ply thickness of the composite, and one based on a nominal 0.005-in (0.13-mm) ply thickness. In general, the experimental load-strain curves fall between the two analytical curves for each specimen.

Key words: Aluminum alloy; boron/epoxy; co-cure; composite materials; fabrication process; load-deformation characteristics; residual stress; rule of mixtures; sandwich specimen; stress-strain curves; tensile properties.

1. INTRODUCTION

One philosophy of structural design with advanced composite materials involves the selective reinforcement of metallic components with fiber-reinforced composite materials. The advantages of this philosophy include large weight savings, minimal composite usage, and retention of current joining and fastening technology. Several experimental investigations of the benefits to be expected from using composite materials in this way have been made [1-4]*.

*Figures in brackets indicate literature reference on page 10.

Because of the difference in coefficients of thermal expansion for the metal and composite, residual stresses are introduced in the components if the structure is used at a temperature other than the temperature at which the structure is fabricated. Two commonly used techniques for fabricating composite-reinforced metal structures are the co-curing technique, by which the composite is cured and resin-bonded to the metal in the same process, and the secondary bond process, by which the composite laminate is first cured and then bonded to the metal using another adhesive. For room temperature applications, significant residual stresses can be introduced in the components fabricated by the co-curing technique, whereas structures can be fabricated with essentially no residual stresses if the secondary bond process is used with a room temperature curing adhesive. For higher temperature applications, the co-curing process may be preferable since the residual stresses are relieved as the temperature approaches the curing temperature for the composite. Several studies of the effects of these residual stresses on the static and creep strengths of boron/epoxy-reinforced metals have been made [5-7].

The investigation reported herein was undertaken to experimentally determine the elevated temperature load-strain behavior of boron/epoxy-reinforced 7075-T6 aluminum alloy fabricated by the co-curing process, and to determine if this behavior can be predicted by a rule-of-mixtures approach. Residual stresses resulting from fabrication are included in the analysis, and various composite-to-metal volume ratios are considered. This investigation was performed in the Engineering Mechanics Section of the National Bureau of Standards. Part of this work was carried out under the sponsorship and with the financial assistance of the National Aeronautics and Space Administration, Langley Research Center.

2. ANALYSIS

The basic assumption of this analysis is that the total external load applied to a composite-reinforced metal is distributed between the component materials such that the strains in the direction of the applied load are the same in both components. Using this assumption, predictions of load-strain behavior and tensile moduli for composite-reinforced metal specimens can be made if the stress-strain behaviors of the component materials are known. Residual stresses resulting from fabrication are accounted for by displacing the initial points on the component material stress-strain curves an amount corresponding to the component residual stresses.

The residual strains in the components were calculated using thermal expansion coefficients of $2.8 \times 10^{-6}/°F$** and $13.6 \times 10^{-6}/°F$ ($5.0 \times 10^{-6}/°C$ and $24.5 \times 10^{-6}/°C$) for the boron/epoxy and aluminum alloy, respectively. Assuming that the residual strains are elastic, it can be shown that the residual strain in the aluminum alloy at any temperature T is given by

$$\varepsilon_a = \frac{(\alpha_a - \alpha_b)(T_\circ - T)}{1 + \frac{E_a A_a}{E_b A_b}}$$

where the α's are thermal expansion coefficients, the E's are the tensile moduli in the direction of the residual strains, the A's are cross-sectional areas, and subscripts a and b denote aluminum alloy and boron/epoxy, respectively. $T_\circ$ is the stress-free temperature, which was taken to be 350 °F (177 °C), the maximum temperature in the cure cycle. In order to develop the load-strain curve for a reinforced-metal specimen, the increases in stresses for an incremental increase in strain were determined for each component from the stress-strain curve for that component. The starting point on the aluminum-alloy curve was taken to be the point corresponding to the calculated value of the residual strain for that specimen. For the boron/epoxy, this correction was unnecessary since the stress-strain curves for this material are essentially linear (see figures 6-9). The component stresses for successive strain increments were multiplied by the respective cross-sectional areas, added, and are plotted as a load-strain diagram. Strain increments of 500×10^{-6} were used.

Using the scheme described above, two load-strain curves were calculated for each specimen. One was based on the actual measured cross-sectional areas of the composite and the metal, and one was based on a nominal 0.005-in (0.13-mm) ply thickness for the composite laminate. This was done in order to eliminate variations in the elastic modulus caused by slight variations in the fiber volume fraction of the composite. In 0° unidirectional boron/epoxy, the load-carrying capability (force) and the stiffness (force per unit deformation or strain) are essentially unaffected by slight variations in volume fraction caused by bleeding out different amounts of resin during

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**Units for physical quantities in this paper are given in both the U. S. Customary Units and the International System Units (SI). Conversion factors pertinent to the present investigation are presented in the Appendix.

the curing process, since the resin carries only a small percentage of the total load. However, because of the area terms, the ultimate strength (stress) and the elastic modulus (stress per unit strain) are affected. For small variations in volume fraction, the load-carrying capability of a metal reinforced with 0° unidirectional boron/epoxy is determined principally by the cross-sectional area of the metal and the number of fibers. Therefore, it was felt that more consistent results would be obtained if a normalized cross-sectional area based on a nominal ply thickness were used.

3. TEST SPECIMENS

The geometric configurations of the specimens tested in this investigation are shown in figure 1.

3.1 Boron/Epoxy Specimens

The composite specimens were unidirectional boron/epoxy with the filaments alined along the axis of loading. The material was purchased as continuous prepreg tape and cured by the platen-press technique using pressures and temperatures recommended by the manufacturer. The material contained approximately 212 0.004-in (0.10-mm) diameter filaments per inch (83 filaments per cm) of tape width. The material was supplied with a glass scrim backing, 0.001 in (0.03 mm) thick. The filament volume fractions of these specimens, as measured by the point-counting technique, were between 54 and 58 percent.

3.2 Aluminum Alloy Specimens

Aluminum alloy specimens were cut from a single sheet of 0.032-in (0.8-mm) thick 7075-T6 aluminum alloy. All specimens were cut so that the longitudinal axis of the specimen was in the direction of rolling of the sheet. The specimen geometry was the standard flat tensile specimen (fig. 6 of ASTM Designation E8-69, Tension Testing of Metallic Materials), with a reduced section approximately 7 in (18 cm) long. All specimens were preconditioned by a thermal treatment of one hour at 325 °F (163 °C) and five hours at 350 °F (177 °C) prior to testing. This simulated the thermal treatment experienced by the aluminum alloy during the co-cure processing of the sandwich specimens which is discussed below.

3.3 Sandwich Specimens

Sandwich specimens consisting of 2, 4, 8, 10 or 12 plies of boron/epoxy between two sheets of 0.032-in (0.8-mm) thick 7075-T6 aluminum alloy were tested. The specimens were fabricated by curing the composite and resin-bonding it to the aluminum alloy in the same operation without a supplementary adhesive. Good adhesion between composite and aluminum alloy was achieved for test temperatures up to 300 °F (149 °C). Volume fractions for these specimens were not measured, but based on specimen thicknesses the composite was judged to be approximately 40 percent filaments and 60 percent epoxy.

4. TEST EQUIPMENT

4.1 Testing Machine

The test program was conducted in a screw-powered universal testing machine. The calibration of this machine was verified in accordance with ASTM Designation E4-64, Standard Methods of Verification of Testing Machines. Errors in applied loads were less than one percent. Specimen alinement was enhanced by the use of spherical seats in the load train.

4.2 Heating System

The test furnace is composed of two semi-cylindrical sections hinged along one side. The walls of the furnace were fabricated from 0.5-in (1-cm) thick asbestos cement pipe, while the upper and lower cover plates are of 1-in (2-cm) thick asbestos cement sheet.

Heat is supplied by three semi-cylindrical radiant heating units in each half of the furnace. The annular space between the heating units and the outer shell is packed with glass fiber insulation. The heaters are wired in pairs, and the power to each pair is regulated separately. Temperature was measured with two thermocouples taped to opposite sides of the specimen equally spaced above and below the mid-height of the specimen. Temperature was controlled and recorded by a time-proportioning, recording controller.

4.3 Strain Measurement

Each specimen was instrumented with two electrical resistance strain gages mounted back-to-back, and alined along the longitudinal axis. The gages were connected in series to record the average strain.

5. TEST PROCEDURE

The same procedures were followed for tests on all three types of specimens. The specimen was cleaned with acetone to remove dirt and oil. Strain gages were bonded to the specimen using an epoxy adhesive, and thermocouples were taped to the specimen, which was then mounted in the testing machine.

The specimen was heated to the test temperature in approximately 20 minutes. Adjustments were made to the temperature controller and power regulators to reduce the temperature variations to an acceptable level. A difference of 3° F (2 °C) or less between thermocouples and a time variation of 2 °F (1 °C) over the duration of the test were considered acceptable. The specimen was maintained at this condition for 30 minutes prior to the application of the load.

Strain readings were taken at discrete load levels up to specimen failure, while temperature was continuously recorded for the duration of the test.

6. EXPERIMENTAL RESULTS

6.1 Single Component Specimens

Tensile tests at four temperatures were performed on boron/epoxy specimens and on aluminum alloy specimens to obtain stress-strain curves. Initial tangent tensile moduli were determined in accordance with the procedure outlined in ASTM Designation E231-69, Static Determination of Young's Modulus of Metals at Low and Elevated Temperatures, except that resistance strain gages were used instead of extensometers. The moduli determined from these tests are given in table 1. Stress-strain curves for the aluminum alloy were faired through the data from two tests at each temperature. These curves are given in figures 2 through 5. Stress-strain curves for the boron/epoxy specimens, based on actual measured area and based on a nominal 0.005-in (0.13-mm) ply thickness, are given in figures 6 through 9.

6.2 Sandwich Specimens

Tensile tests on sandwich specimens with four plies of boron/epoxy between two sheets of 7075-T6 aluminum alloy were performed at four temperatures. The test conditions and results are given in table 2.

Tensile tests on sandwich specimens with 2, 4, 8, 10, and 12 plies of boron/epoxy were performed at 150 °F (66 °C) to determine the effect of composite-to-metal volume ratio. Tests conditions and results of these tests are given in table 3.

Load-strain curves for the 4 - ply specimens are shown in figures 10 through 17 while the family of curves for the 2, 4, 8, 10, and 12 ply specimens is shown in figure 18.

The experimental and the calculated initial tangent tensile moduli for each specimen were determined graphically from the experimental and calculated load-strain curves for that specimen. These moduli are given in tables 2 and 3. The experimental elastic moduli for specimens with different amounts of boron/epoxy reinforcement are shown as a function of specimen volume fraction in figure 19.

Most tests resulted in failure of the boron/epoxy in the grips, followed by aluminum failure or gross debonding. Therefore, no meaningful ultimate strength data were obtained.

7. DISCUSSION

7.1 Load-Strain Behavior of Composite-Reinforced Metal

The load-strain curves for the boron/epoxy-reinforced 7075-T6 aluminum alloy specimens tested in this investigation are generally nonlinear from zero load, with the amount of nonlinearity decreasing with increasing temperature. This nonlinearity is expected since these curves are combinations of the essentially linear, boron/epoxy stress-strain curves (figs. 6-9) and the nonlinear aluminum alloy stress-strain curves (figs. 2-5). Herakovich [5, 6] has reported the load-strain curves for boron/epoxy-reinforced aluminum and titanium to be basically bilinear at room temperature. His stress-strain curves appear to be strictly linear for boron/epoxy and bilinear for aluminum and titanium (see [6], fig. 6). The differences between the stress-strain behaviors of the aluminum alloy specimens reported by Herakovich and those tested in this investigation may by due to differences in the thermal preconditioning prior to testing.

7.2 Correlation Between Experiment and Analysis

For tests run at the three lowest temperatures, the experimental load-strain curves generally fall between the two analytical curves (figs. 10-15). For both tests at 300 °F (149 °C) the experimental curves fell below both analytical curves (figs. 16-17). This trend also occurs in the moduli data (table 2). The differences between the calculated moduli and the experimentally determined moduli range from 0 to 20 percent of the experimental moduli.

Two factors contributing to these discrepancies are differences in the volume fractions of the boron/epoxy between component specimens and sandwich specimens, and uncertainty in the values of residual stress in the specimen. The influence of the first factor may be removed by using the normalized ply thickness. Although this did not remove the discrepancies completely, the normalized-thickness curves are somewhat closer to the experimental curves than the curves based on the actual measured areas. It appears then that uncertainty in the residual stress is the prominent factor. An earlier investigation at this laboratory [7] indicated a large scatter in the values of residual stress measured in specimens fabricated using the co-cure method. If the exact value of residual stress were determined for each specimen, analytical results more consistent with the experimental results might have been obtained.

7.3 Effects of Specimen Volume Fraction

With no residual stresses, the tensile modulus of the reinforced-metal specimens would be expected to increase linearly with increased reinforcement (see dashed line, fig. 19), based on a simple rule-of-mixtures combination of the tensile moduli of the two component materials. When residual stresses are considered, the effective tensile modulus of the metal is reduced, and the modulus of the reinforced metal is somewhat below the linear relationship. The overall effect of the reduction in metal modulus is lessened as the volume fraction of metal in a reinforced-metal specimen is reduced. The limiting value is the modulus of the composite at 100 percent composite volume fraction. This trend is followed closely by the experimental data as shown in figure 19.

8. CONCLUSIONS

Based on the experiments and analysis covered by this report, the following conclusions are drawn:

1. Load-strain curves for 7075-T6 aluminum alloy reinforced with 0° unidirectional boron/epoxy at temperatures up to 300 °F (149 °C) can be formulated with reasonable accuracy from stress-strain data on the component materials. The analysis, which is based on an empirical rule-of-mixtures approach, includes a prediction of the effect of the fabrication residual stresses in the component materials.

2. If a normalized area, based on a nominal 0.005-in (0.13-mm) ply thickness, is used for the composite, the resulting analytical load-strain curves are generally closer to the experimental curves than the curves based on actual measured cross-sectional areas. This normalization removes the effect of small changes in the amount of epoxy matrix in the system which add negligible strength or stiffness to a composite-reinforced metal.

3. The discrepancies between the analytical and the experimental load-strain curves probably result from inaccuracies in the values of residual stress

used in the calculations.

4. The elastic modulus of boron/epoxy-reinforced 7075-T6 aluminum alloy fabricated by co-curing increases nonlinearly with increased amounts of reinforcement. This nonlinearity results from the fabrication residual stresses, which reduce the effective modulus of the metal component.

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Table 1 - Results of Tension Tests on Single Component Specimens.

Test temperature		Specimen number		Cross-sectional area		Fiber volume fraction	Elastic Modulus based on actual area	
		Boron/ epoxy	Aluminum alloy					
°F	°C			in^2	cm^2	percent	lbf/in^2	N/m^2
75	24	-	A-1	0.0158	0.102	-	9.74×10^6	6.71×10^{10}
75	24	-	A-2	0.0158	0.102	-	9.84	6.78
150	66	-	A-3	0.0161	0.104	-	9.77	6.74
150	66	-	A-4	0.0161	0.104	-	9.68	6.67
225	107	-	A-5	0.0159	0.103	-	9.60	6.62
225	107	-	A-6	0.0159	0.103	-	9.37	6.46
300	149	-	A-46	0.0158	0.102	-	9.68	6.67
75	24	B-42	-	0.0097	0.063	54	33.6×10^6	2.31×10^{11}
75	24	B-45	-	0.0117	0.075	54	26.8	1.85
150	66	B-47	-	0.0123	0.079	58	27.7	1.91
150	66	B-48	-	0.0123	0.079	58	27.7	1.91
225	107	B-41	-	0.0097	0.063	54	35.0	2.41
225	107	B-43	-	0.0098	0.063	54	32.6	2.25
300	149	B-7	-	0.0167	0.108	54	28.1	1.94
300	149	B-8	-	0.0167	0.108	54	29.4	2.02

Table 2 - Results of Static Tensile Tests on 7075-T6 Aluminum Alloy Reinforced with 4 Plies of Boron/Epoxy.

Test temperature		Specimen number	Cross-sectional area				Composite volume fraction	Experimental elastic modulus		Calculated elastic modulus based on actual area		Calculated elastic modulus based on 0.005-in ply thickness	
			Metal		Composite								
°F	°C		in^2	cm^2	in^2	cm^2	percent	lbf/in^2	N/m^2	lbf/in^2	N/m^2	lbf/in^2	N/m^2
75	24	BA-1	0.0315	0.203	0.0126	0.081	28.6	14.3×10^6	9.8×10^{10}	15.3×10^6	10.5×10^{10}	14.3×10^6	9.8×10^{10}
75	24	BA-2	0.0315	0.203	0.0135	0.087	30.0	14.2	9.8	15.9	11.0	13.6	9.4
150	66	BA-4	0.0315	0.203	0.0135	0.087	30.0	14.2	9.8	14.7	10.1	13.8	9.5
150	66	BA-11	0.0315	0.203	0.0140	0.090	30.8	14.4	9.9	14.8	10.2	12.8	8.8
225	107	BA-5	0.0315	0.203	0.0120	0.077	27.6	14.4	9.9	16.8	11.6	14.3	9.8
225	107	BA-6	0.0315	0.203	0.0125	0.081	28.4	15.0	10.3	17.1	11.8	13.8	9.5
300	149	BA-7	0.0315	0.203	0.0135	0.087	30.0	13.1	9.0	15.3	10.5	14.0	9.6
300	149	BA-8	0.0315	0.203	0.0128	0.082	28.9	13.2	9.1	15.8	10.9	15.2	10.5

Table 3 - Results of Static Tensile Tests at 150 °F (66 °C) on 7075-T6 Aluminum Alloy Reinforced with Various Amounts of Boron/Epoxy.

Specimen number	Plies of boron/epoxy	Cross-sectional area: Metal		Cross-sectional area: Composite		Composite volume fraction	Experimental elastic modulus		Calculated elastic modulus based on actual area		Calculated elastic modulus based on 0.005-in ply thickness	
		in^2	cm^2	in^2	cm^2	percent	lbf/in^2	N/m^2	lbf/in^2	N/m^2	lbf/in^2	N/m^2
BA-10	2	0.0315	0.203	0.0062	0.040	16.4	12.1×10^6	8.3×10^{10}	11.7×10^6	8.1×10^{10}	11.7×10^6	8.1×10^{10}
BA-4	4	0.0315	0.203	0.0135	0.087	30.0	14.2	9.8	14.7	10.1	13.8	9.5
BA-11	4	0.0315	0.203	0.0140	0.090	30.8	14.4	9.9	14.8	10.2	12.8	8.8
BA-12	8	0.0315	0.203	0.0249	0.161	44.1	17.0	11.7	17.3	11.9	17.0	11.7
BA-13	10	0.0315	0.203	0.0321	0.207	50.5	17.6	12.1	18.3	12.6	17.6	12.1
BA-9	12	0.0315	0.203	0.0326	0.210	50.9	18.8	13.0	20.0	13.8	18.4	12.7

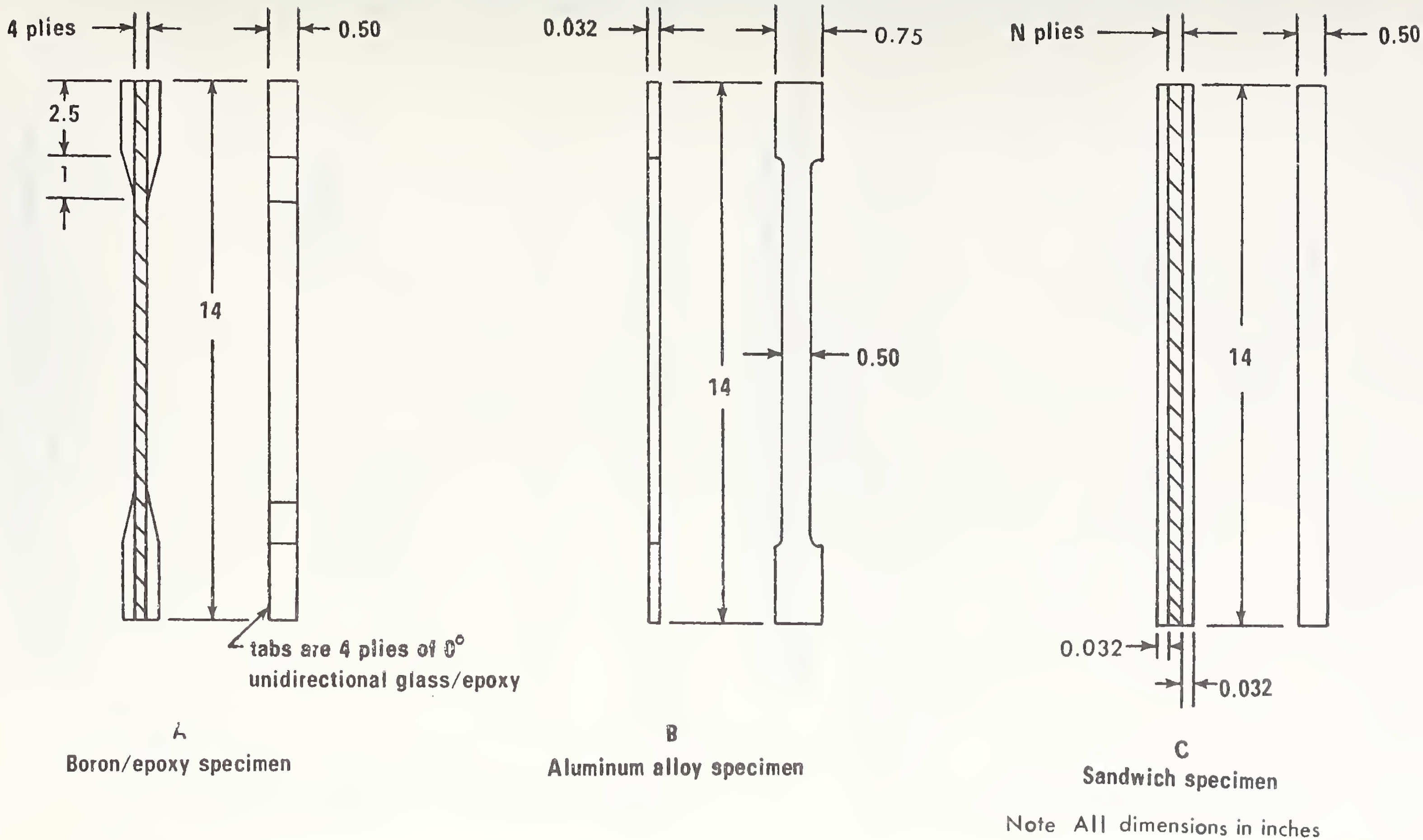


FIGURE 1. SPECIMEN GEOMETRIES.

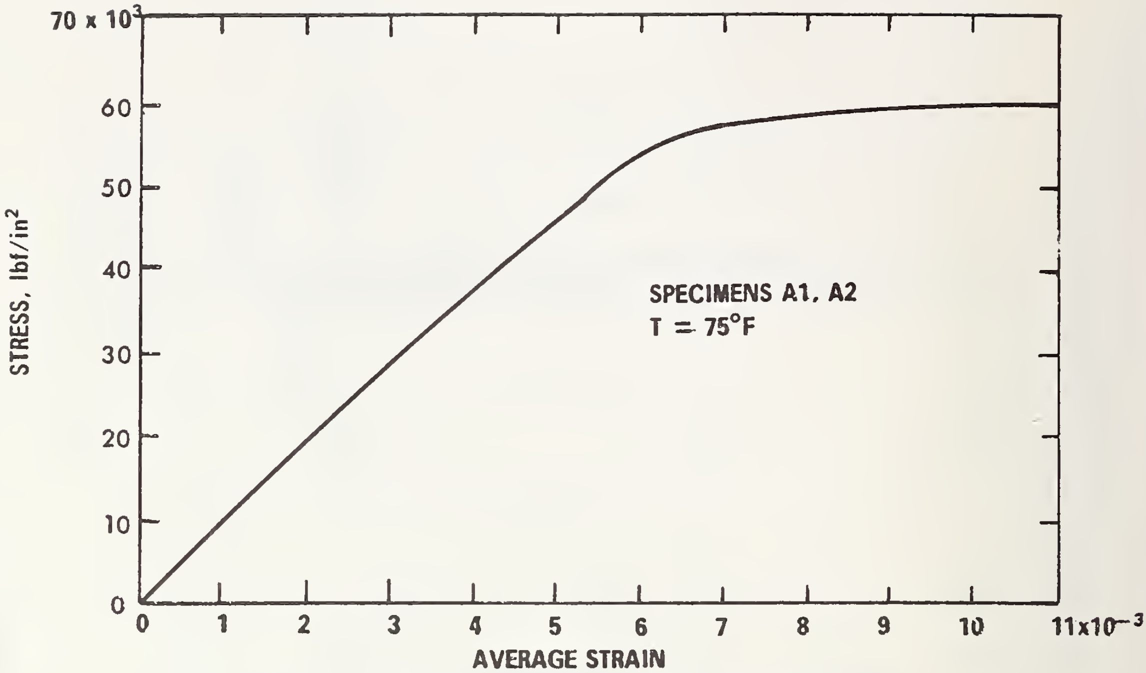


FIGURE 2. STRESS–STRAIN CURVE FOR PRECONDITIONED 7075–T6 ALUMINUM ALLOY AT 75°F(24°C)

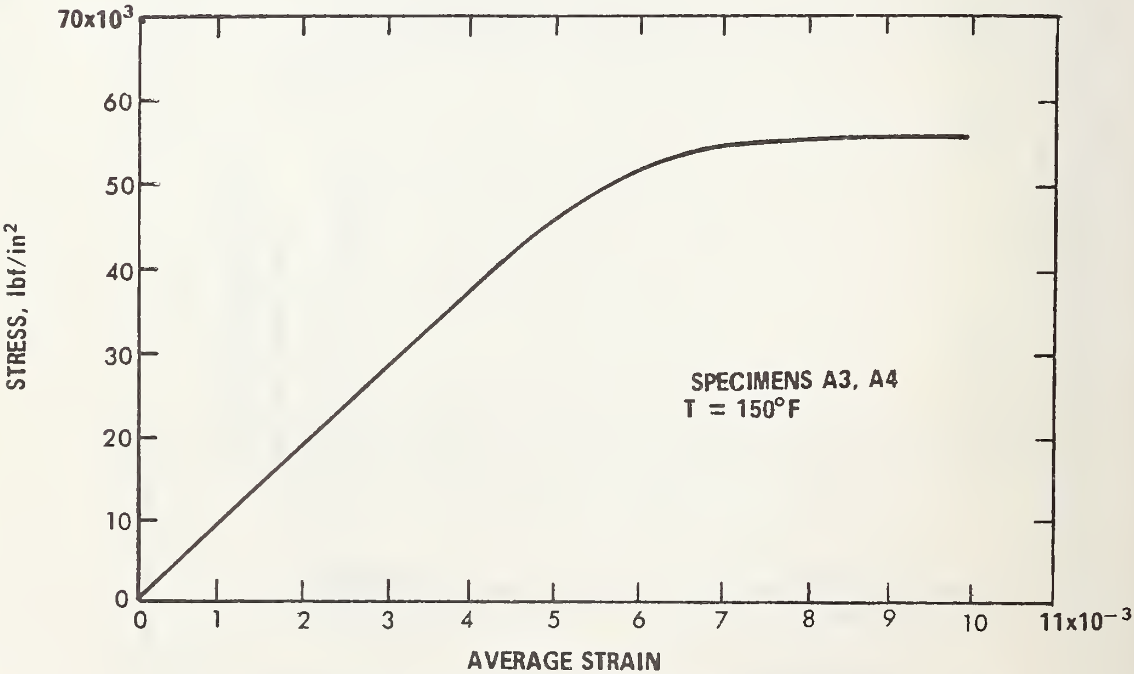


FIGURE 3. STRESS–STRAIN CURVE FOR PRECONDITIONED 7075–T6 ALUMINUM ALLOY AT 150°F(66°C)

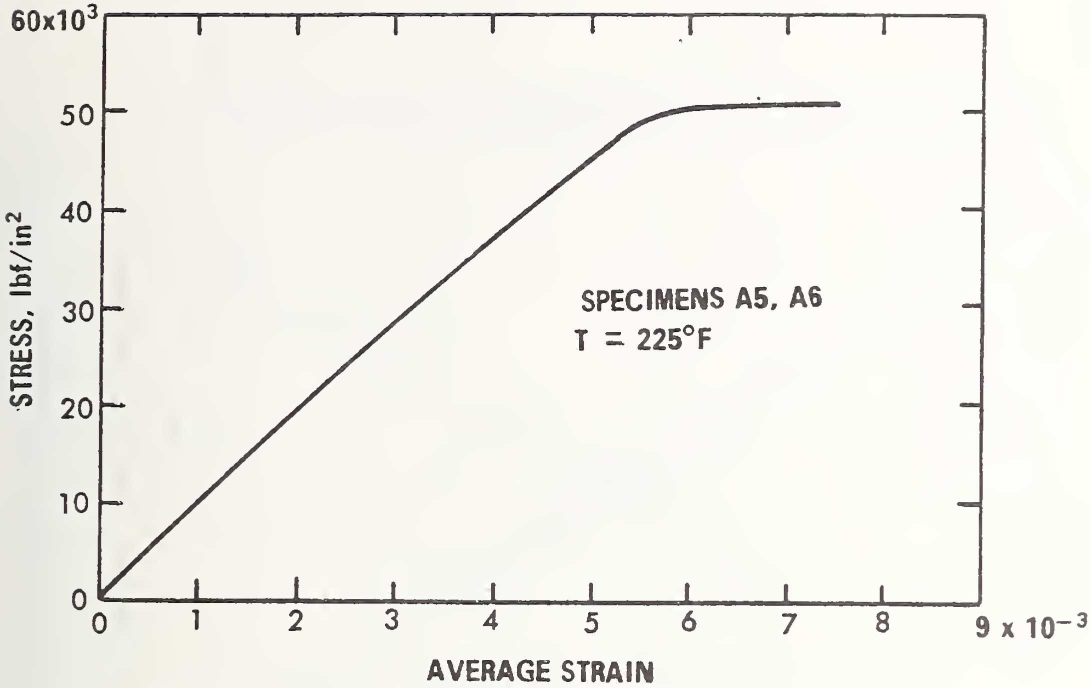


FIGURE 4. STRESS–STRAIN CURVE FOR PRECONDITIONED 7075–T6 ALUMINUM ALLOY AT 225°F(107°C)

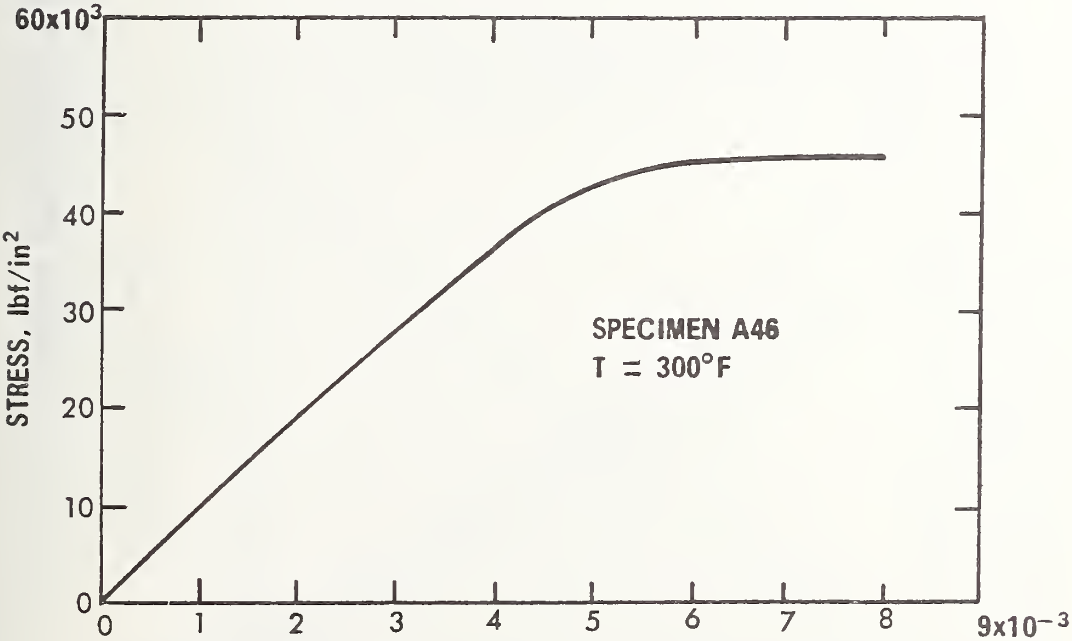
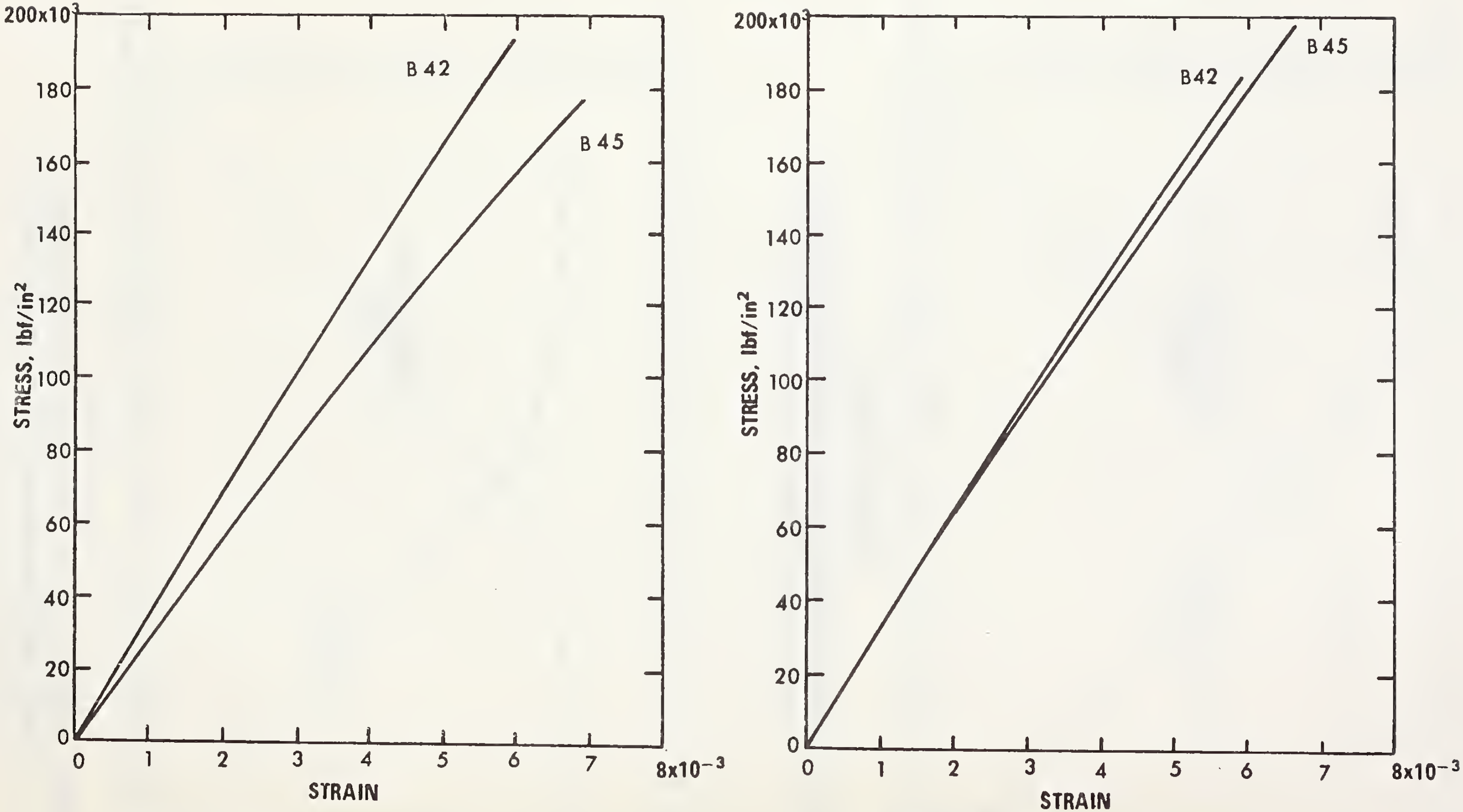


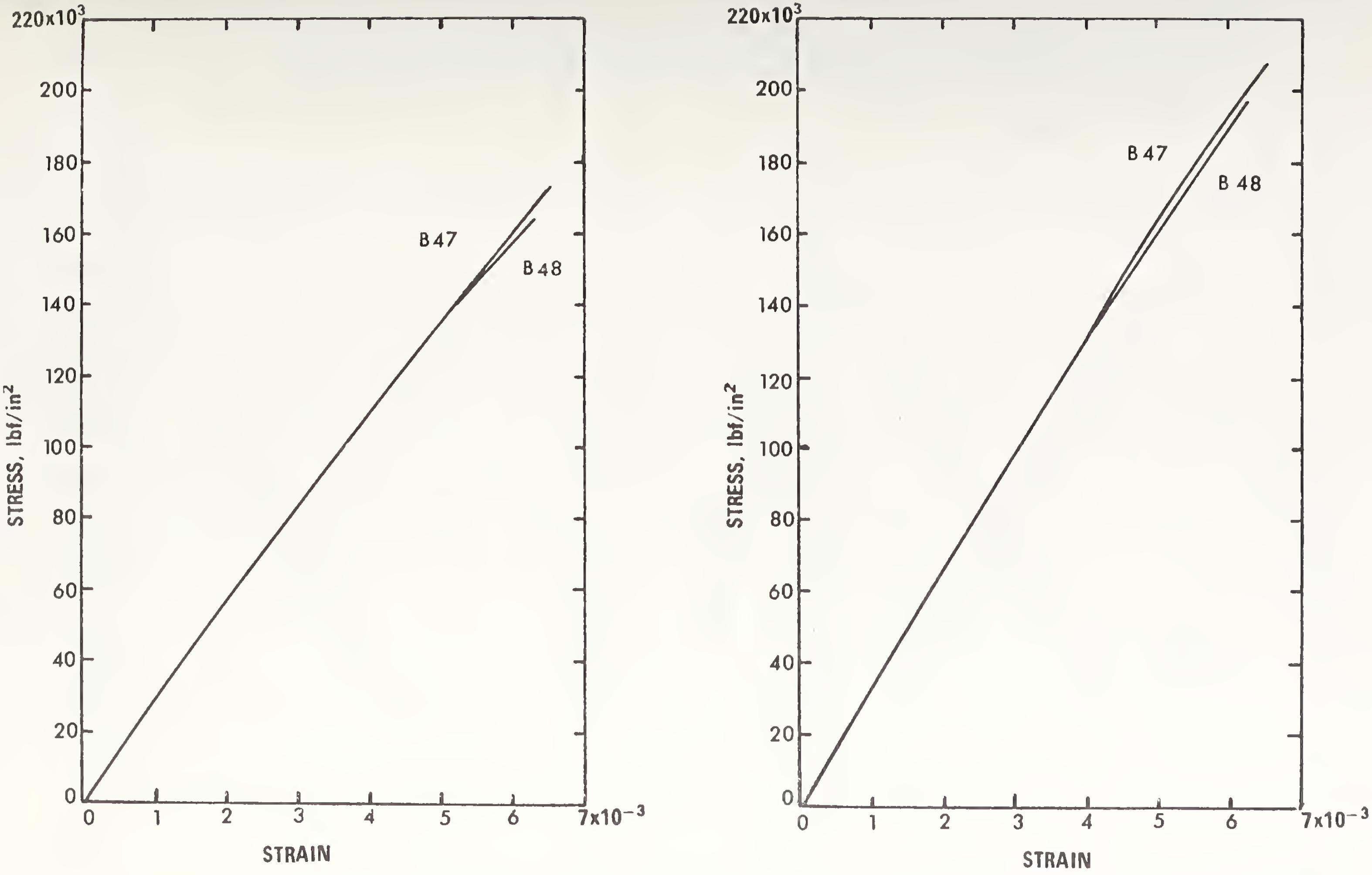
FIGURE 5. STRESS–STRAIN CURVE FOR PRECONDITIONED 7075–T6 ALUMINUM ALLOY AT 300°F(149°C)



a) BASED ON ACTUAL AREA.

b) BASED ON 0.005 in/PLY THICKNESS

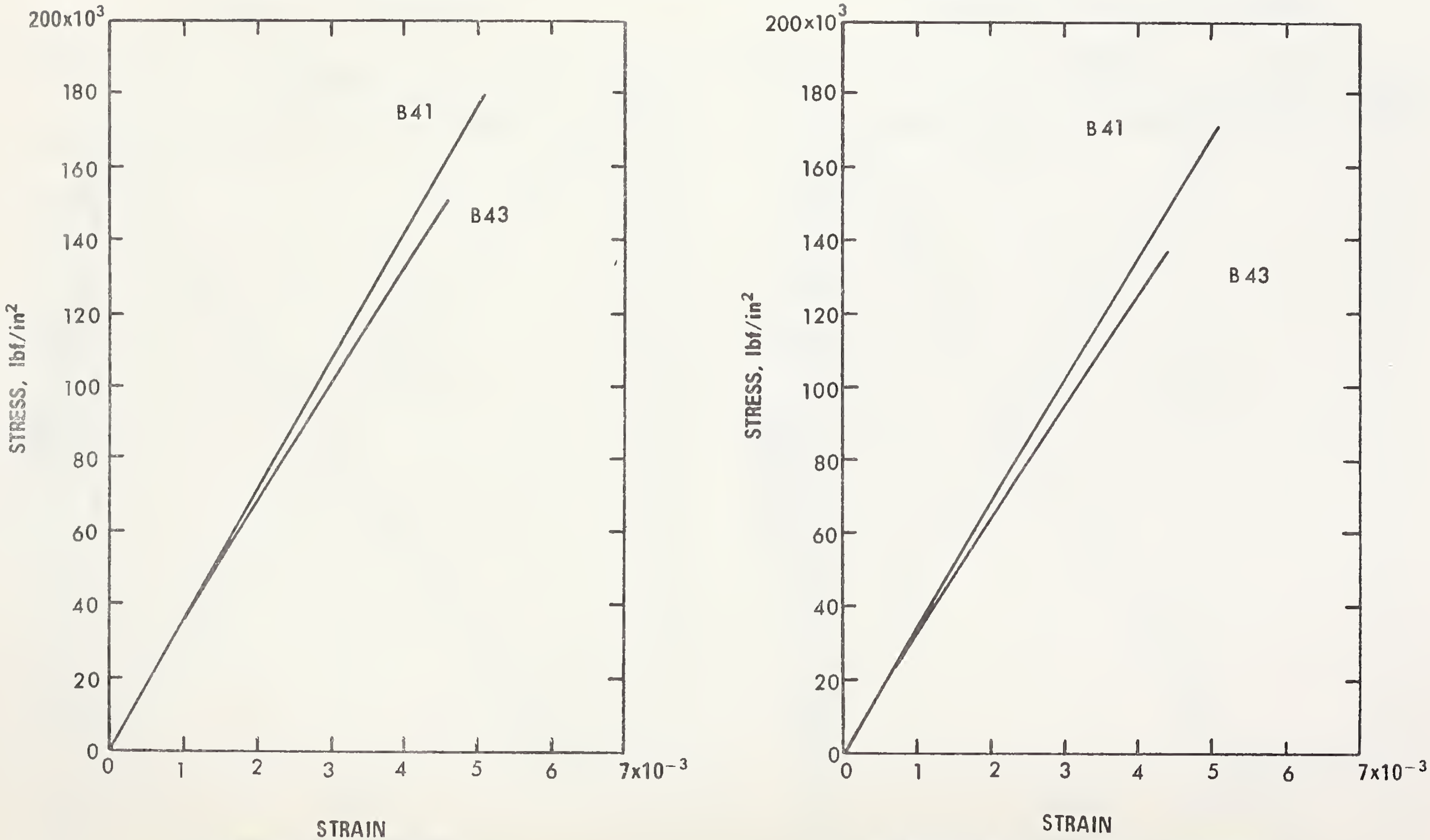
FIGURE 6. STRESS–STRAIN CURVES FOR BORON/EPOXY SPECIMENTS AT 75°F(24°C)



a) BASED ON ACTUAL AREA

b) BASED ON 0.005 in/PLY THICKNESS

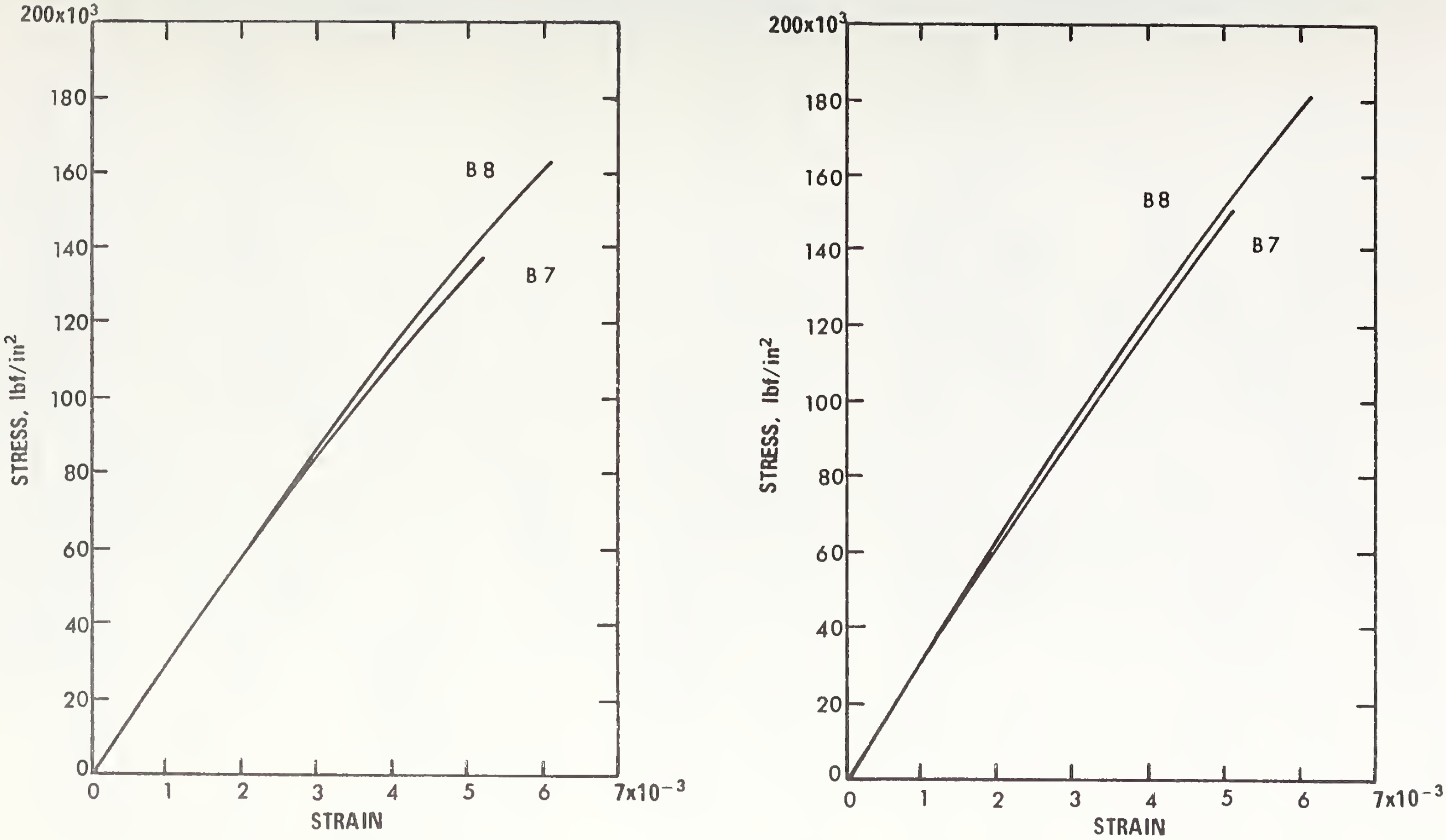
FIGURE 7. STRESS–STRAIN CURVES FOR BORON/EPOXY SPECIMENS AT 150°F(66°C)



a) BASED ON ACTUAL AREA

b) BASED ON 0.005 in/PLY THICKNESS

FIGURE 8. STRESS–STRAIN CURVES FOR BORON/EPOXY SPECIMENS AT 225°F(107°C)



a) BASED ON ACTUAL AREA

b) BASED ON 0.005 in/PLY THICKNESS

FIGURE 9. STRESS–STRAIN CURVES FOR BORON/EPOXY SPECIMENS AT 300°F(149°C)

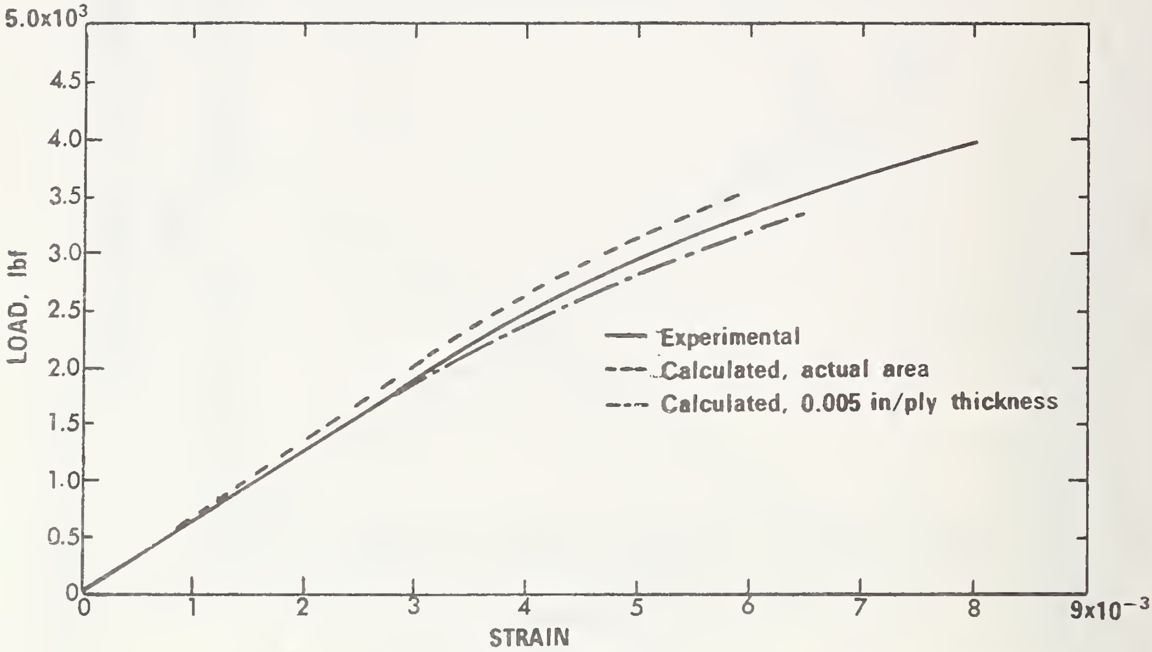


FIGURE 10. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–1 (T = 75°F, 24°C)

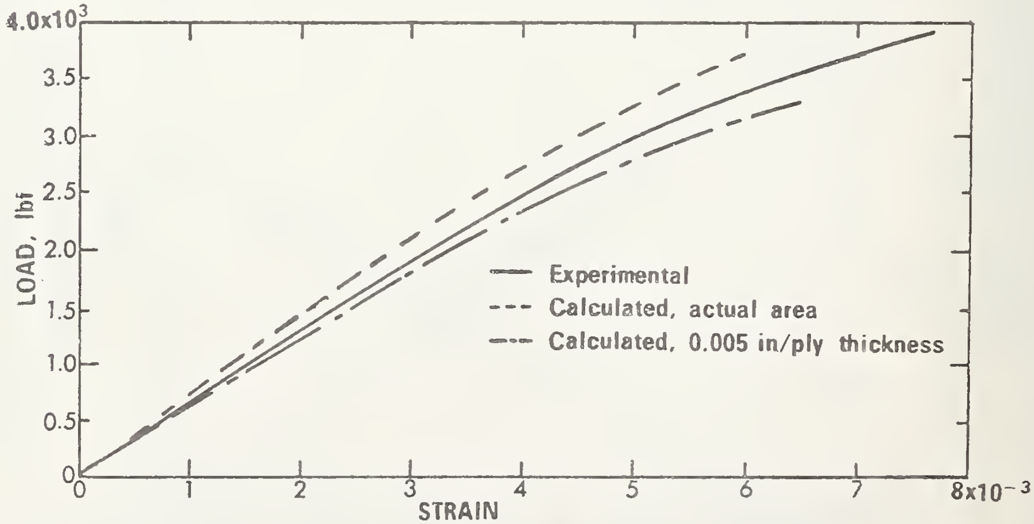


FIGURE 11. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–2 (T = 75°F, 24°C)

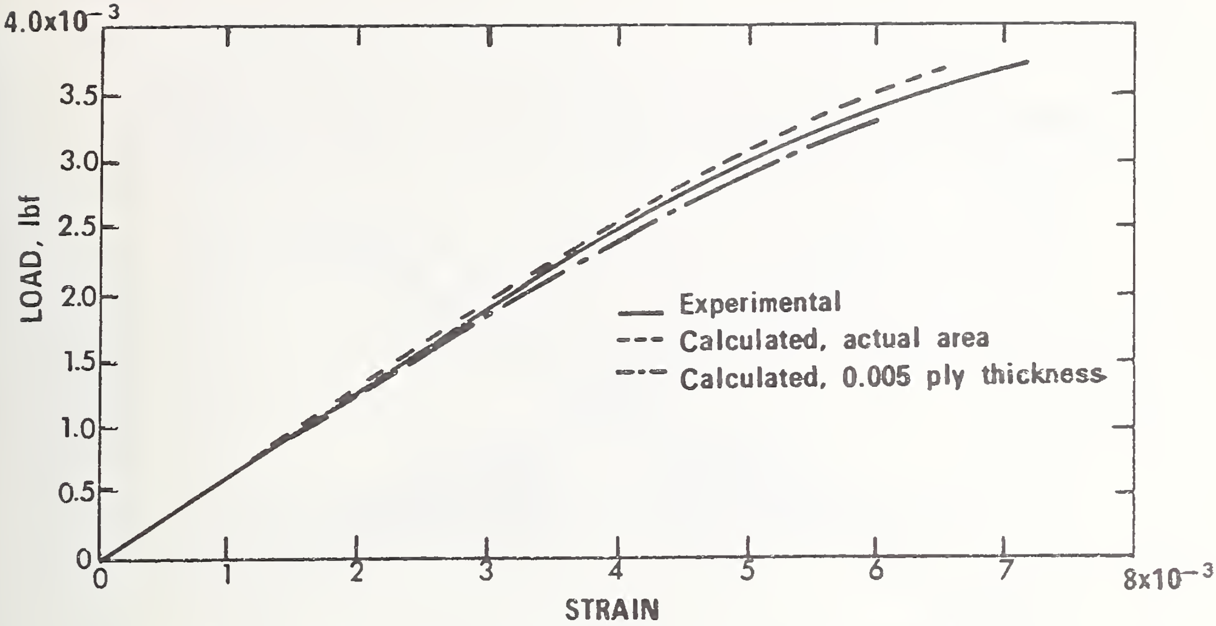


FIGURE 12. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–4 (T ≃ 150°F, 66°C)

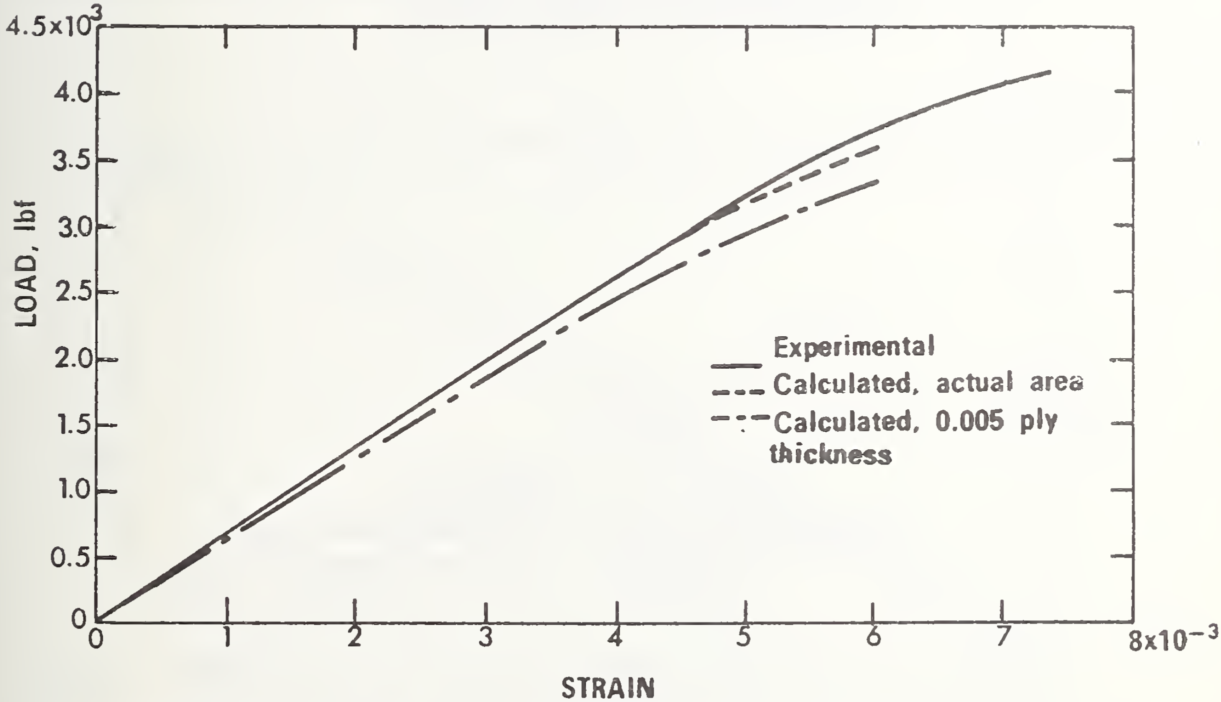


FIGURE 13. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–11 (T = 150°F, 66°C)

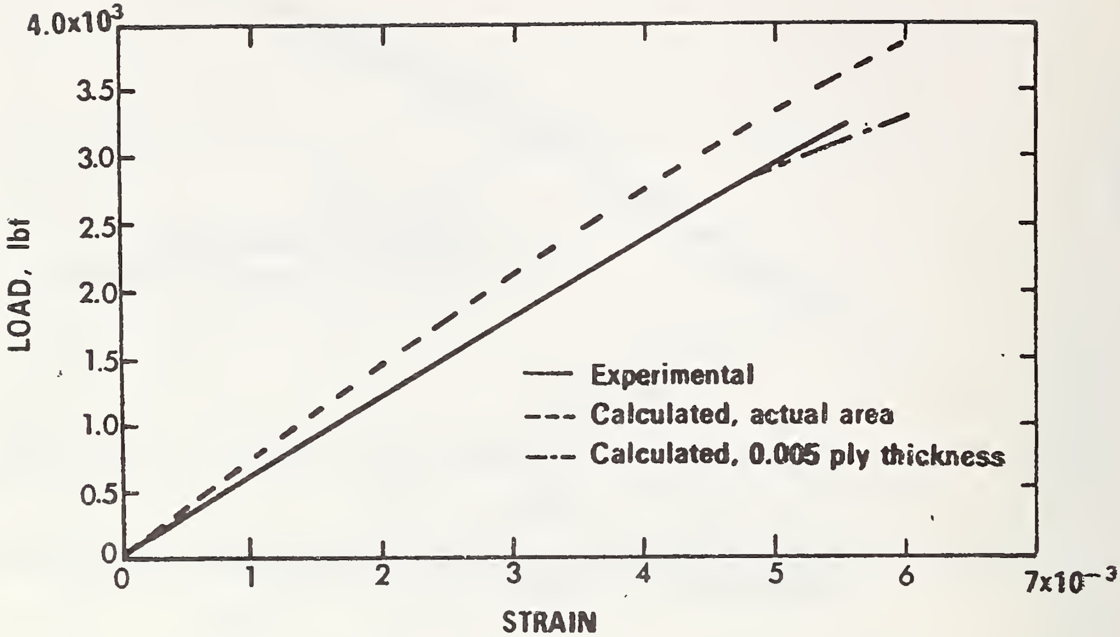


FIGURE 14. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–5 (T = 225°F, 107°C)

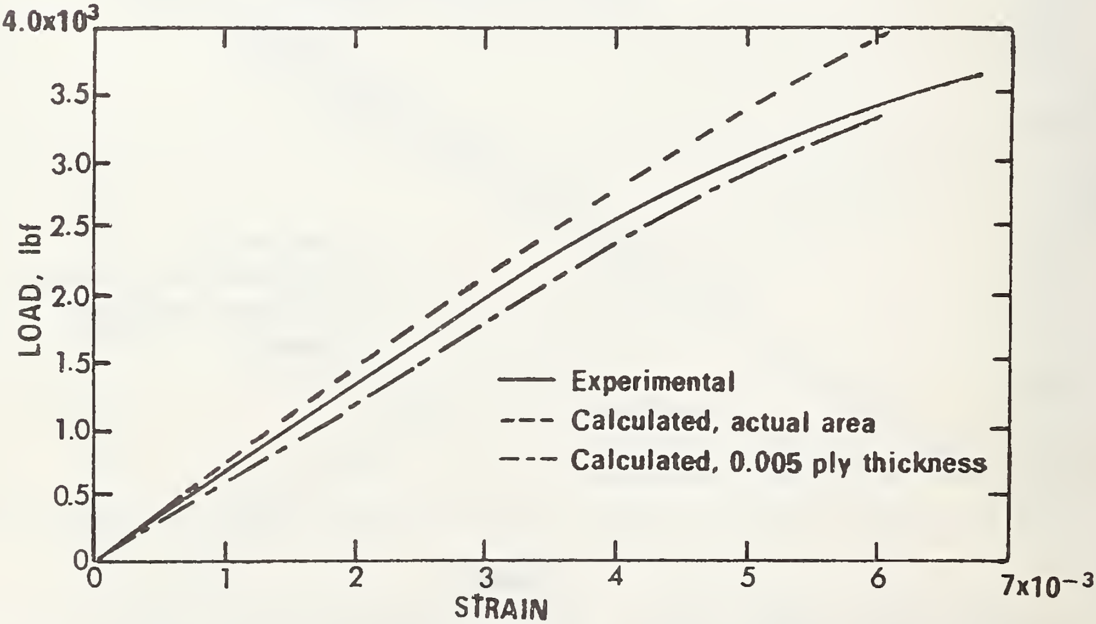


FIGURE 15. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–6 (T = 225°F, 107°C)

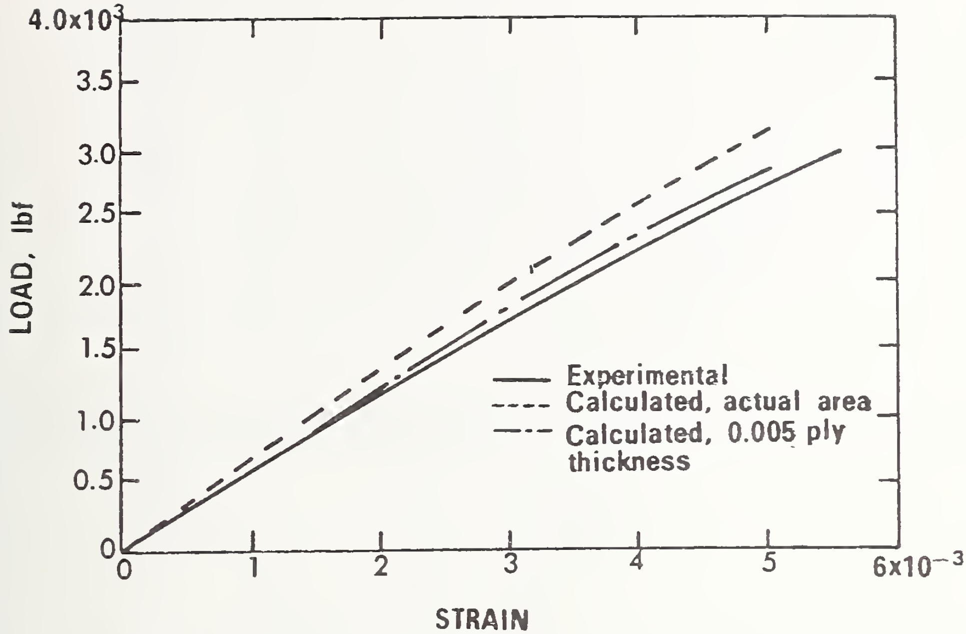


FIGURE 16. EXPERIMENTAL AND CALCULATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–7 (T = 300°F, 149°C)

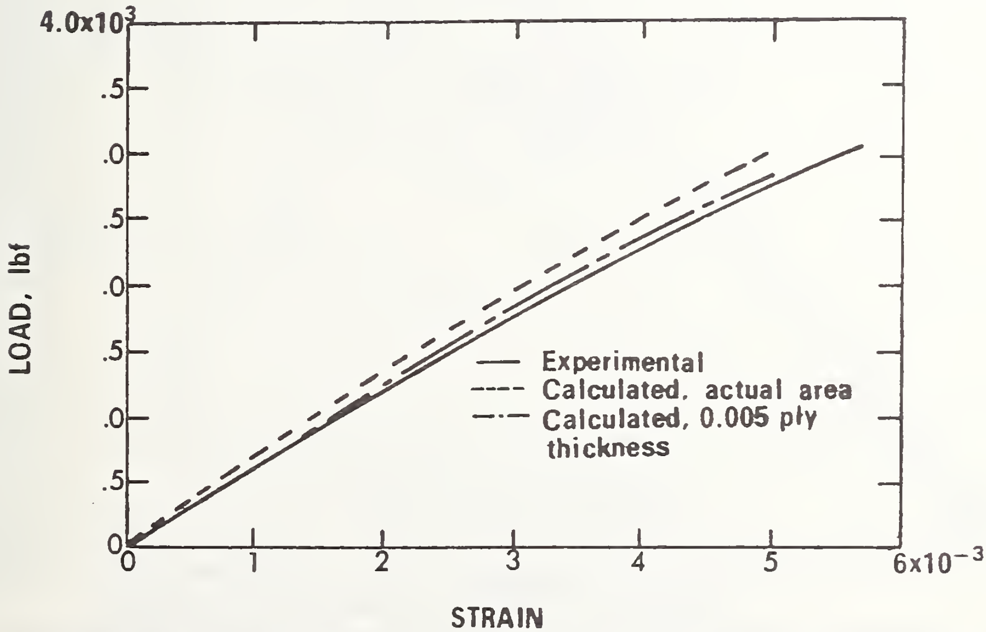


FIGURE 17. EXPERIMENTAL AND CALUCLATED LOAD–STRAIN RELATIONS FOR SPECIMEN BA–8 (T = 300°F, 149°C)

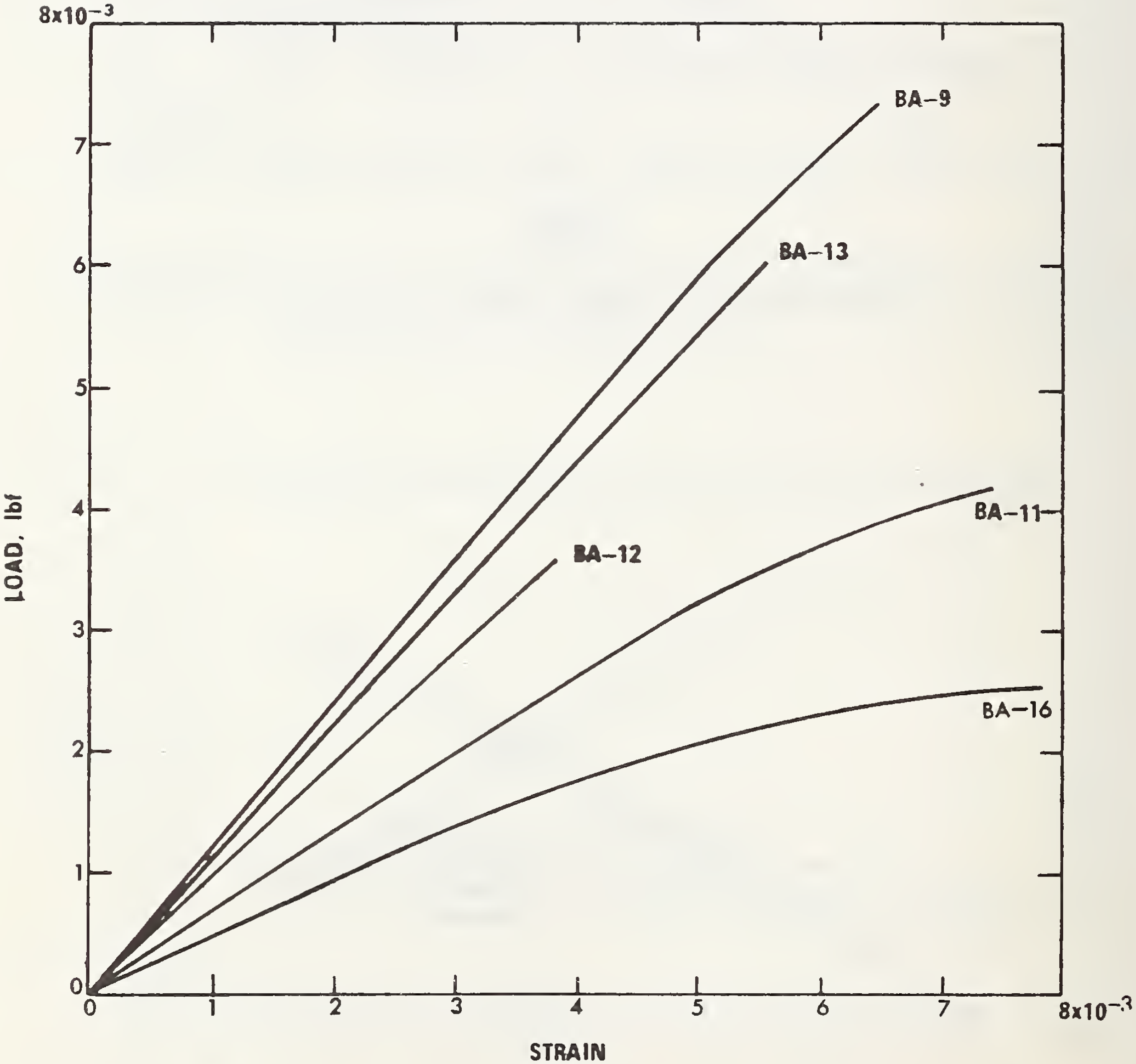


FIGURE 18. EXPERIMENTAL LOAD-STRAIN CURVES FOR BORON/EPOXY REINFORCED PRECONDITIONED 7075-T6 ALUMINUM ALLOY WITH DIFFERENT VOLUME FRACTIONS AT 150°F(66°C)

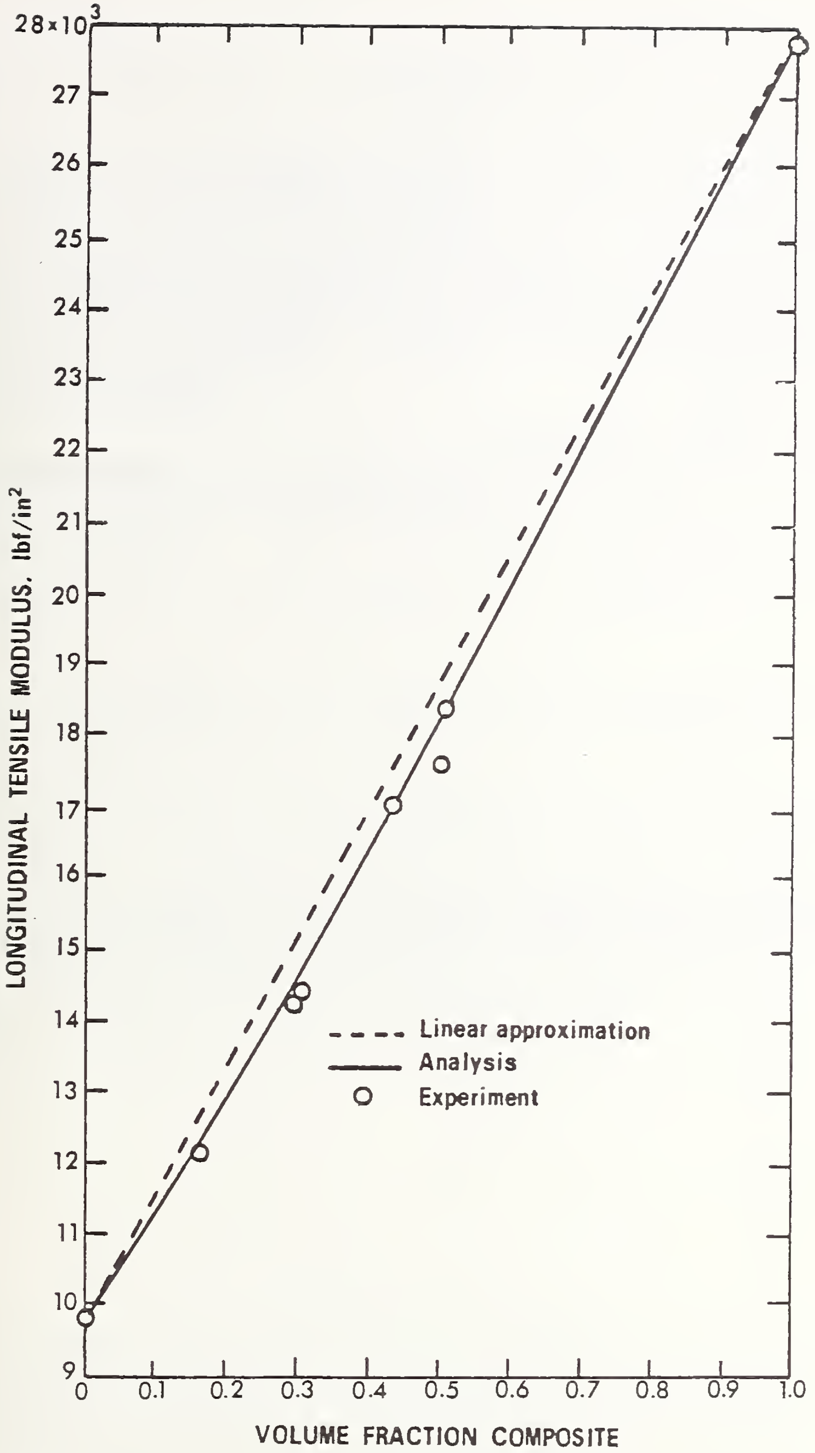


FIGURE 19. TENSILE MODULUS AT 150°F(66°C) FOR RECONDITIONED 7075–T6 ALUMINUM ALLOY REINFORCED WITH VARIOUS AMOUNTS OF BORON/EPOXY

APPENDIX

Conversion of U. S. Customary Units to SI Units

For simplicity, only U. S. customary units have been used in the figures of this report. It should be noted that the U.S.A. is a signatory to the General Conference of Weights and Measures which gave official status to the metric SI system of units in 1960. Conversion factors for units used in this paper are given in the following table:

Physical quantity	U. S. customary unit	SI unit	Conversion factor
Force	pound-force (lbf)	newton (N)	1 lbf = 4.448 N
Length	inch (in)	metre (m)	1 in = 0.0254 m
Area	in^2	m^2	1 in^2 = 6.4516×10^{-4} m^2
Stress	lbf/in^2	N/m^2	1 lbf/in^2 = 6895 N/m^2
Temperature	°F	°C	°C = 0.556 (°F - 32)

Other conversion factors can be found in ASTM Standard Metric Practice Guide, ASTM Designation E380-72 (available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103).

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Static tensile tests were performed on specimens of 7075-T6 aluminum alloy, 0° unidirectional boron/epoxy, and 7075-T6 aluminum alloy reinforced on the surface with 0° unidirectional boron/epoxy laminate, at four temperatures up to 300 °F (149 °C). Analytical load-strain curves are formulated for the reinforced-metal specimens using the rule of mixtures, assuming that the longitudinal strains in the composite and the metal remain equal, and taking account of the residual stresses caused by the fabrication process. Two analytical curves are plotted for each reinforced-metal specimen, one based on the measured ply thickness of the composite, and one based on a nominal 0.005-in (0.13-mm) ply thickness. In general, the experimental load-strain curves fall between the two analytical curves for each specimen.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Aluminum alloy; boron/epoxy; co-cure; composite materials; fabrication process; load-deformation characteristics; residual stress, rule of mixtures; sandwich specimen; stress-strain curves; tensile properties.

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