# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE

## No. 1513

# STRESS-STRAIN AND ELONGATION GRAPHS FOR ALCLAD ALUMINUM-ALLOY 24S-T81 SHEET

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# STRESS-STRAIN AND ELONGATION GRAPHS FOR ALCLAD ALUMINUM-ALLOY 24S-T81 SHEET

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## SUMMARY

Results of tests on duplicate longitudinal and transverse specimens of Alclad aluminum-alloy 24S-T81 sheets with nominal thicknesses of 0.032, 0.064, and 0.125 inch are presented in the following form:

Tensile and compressive stress-strain graphs and stress-deviation graphs to a strain of about 1 percent

Graphs of tangent modulus and of reduced modulus for a rectangular section against stress, in compression

Stress-strain graphs for tensile specimens tested to failure

Graphs of local elongation and elongation against gage length for tensile specimens tested to fracture

The stress-strain, stress-deviation, tangent modulus, and reduced modulus graphs are plotted on a dimensionless basis to make them applicable to material with yield strengths which differ from those of the test specimens.

## INTRODUCTION

This report is the fourth of a series presenting data on high-strength aluminum-alloy sheet. The data are in the form of tables and graphs similar to those in the first report of the series on aluminum-alloy R301 sheet (reference 1) as modified in the preceding report of the series on Alclad 24S-T sheet (reference 2). The graphs are presented in dimensionless form to make them applicable to sheets of these materials with yield strengths which differ from those of the test specimens. All data are given for duplicate specimens.

The report gives the results of tests on Alclad aluminum-alloy 24S-T81 sheet in thicknesses of 0.032, 0.064, and 0.125 inch, obtained by artificially aging for 10 hours at 375° ± 7° F Alclad 24S-T sheet furnished by the Aluminum Company of America.

The author expresses his appreciation to Mr. P. L. Peach and Mrs. P. V. Jacobs, who assisted in the testing and in the preparation of the graphs.

This investigation was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

## MATERIAL

The sheets, as received from the manufacturer, were of Alclad aluminum alloy 24S in the "T" condition. Average values of yield strength (offset = 0.2 percent), tensile strength, and elongation for this material are given in table 1; the stress-strain and elongation graphs were shown in reference 2. Part of each sheet was aged at $375^\circ \pm 7^\circ$ F for 10 hours to furnish specimens for the present report. The nominal thickness of the cladding on each side was 5 percent of the sheet thickness for the 0.032-inch sheet and 2.5 percent of the sheet thickness for the other two sheets.

## DIMENSIONLESS DATA

### Test Procedure

Tensile tests were made on two longitudinal (in direction of rolling) specimens and on two transverse (across direction of rolling) specimens from a sheet of each thickness. The specimens corresponded to specimens of type 5 described in reference 3. The specimens were tested in a beam-and-poise, screw-type, machine of 50-kip capacity by using the 5-kip range. They were held in Templin grips. The strain was measured with a pair of 1-inch Tuckerman optical strain gages attached to opposite sheet faces of the reduced section. The rate of loading was about 2 ksi per minute.

Compressive tests were made on two longitudinal and two transverse specimens from each sheet. The specimens were rectangular strips 0.50 inch wide by 2.25 inches long. The compressive specimens were tested between hardened-steel bearing blocks in the subpress described in reference 4. The loads were applied by the testing machine that was used for the tensile tests. Lateral support against premature buckling was furnished by lubricated solid guides, as described in reference 5. The strain was measured with a pair of 1-inch Tuckerman optical strain gages attached to opposite edge faces of the specimen. The rate of loading was about 2 ksi per minute.

## Test Results

The results of the tensile and compressive tests are given in table 2. Each value of Young's modulus in the table was taken as the slope of a least-square straight line fitted to the stress-strain curve at stresses below the point where the cladding started to yield. The modulus was based on from four to eight times the number of points shown on the graphs for that portion of the curves. The yield strengths determined by the offset method were obtained from the stress-strain curves and the experimental values of Young's modulus. The yield strengths determined by the secant method were obtained from the stress-strain curves and values of secant modulus 0.7 and 0.85 times the experimental values of Young's modulus.

## Stress-Strain Graphs

The stress-strain graphs are plotted in dimensionless form in figures 1 to 6. The coordinates $\sigma$, $\epsilon$ in these graphs are defined by

$$\sigma = \frac{s}{s_1} \qquad \epsilon = \frac{Ee}{s_1}$$

where

$s$ stress corresponding to strain $e$

$s_1$ secant yield strength (0.7E)

$E$ Young's modulus

Composite dimensionless stress-strain graphs which show the bands within which lie the data for tests of a given kind and a given direction in the sheet are shown in figures 7 and 8. The maximum width of band in terms of $\sigma$ is 0.02 in tension and 0.025 in compression. Each band represents data for six specimens; the widths might have been greater if tests had been made on a larger number of specimens. A part of the deviation of the curves from affinity may be attributed to experimental variation in the values of Young's modulus which were obtained from a relatively small region of each curve and a part to differences in the percentage of cladding of the 0.032-inch sheet and of the other two sheets.

## Stress-Deviation Graphs

Dimensionless stress-deviation graphs are shown in figures 9 to 14. The ordinates are the same as those used for the stress-strain graphs. The abscissas are the corresponding values of $\delta = \epsilon - \sigma$. All the curves intersect at the point $\sigma = 1$, $\delta = \frac{3}{7}$, which corresponds to the secant yield strength (0.7E). This point is indicated on the graphs by a short vertical line.

The graphs were plotted on logarithmic paper to indicate that portion of the stress-strain curves which can be represented by the analytical expression given in reference 6

$$e = \frac{s}{E} + K\left(\frac{s}{E}\right)^n$$

This expression holds (see reference 6) when the plot of deviation against stress on logarithmic paper follows a straight line. Actually each graph has a pronounced knee. This is caused, in part, by the large deviations at low stresses due to the yielding of the cladding material. It follows that the stress-strain graphs of the sheets cannot be accurately represented by a single analytical expression of the foregoing type. The graphs for longitudinal compression, except for a rather large transition region, can be approximated by two straight lines represented by two equations of the foregoing type with different sets of constants. Only the graphs for longitudinal compression show good agreement with a straight line for values of $s/s_1 > s_2/s_1$, where $s_2$ is the secant yield strength (0.85E); values of $s_2/s_1$ are shown in each figure. Table 2 gives values of $s_1/s_2$ for all specimens to indicate the sharpness of the knee of the stress-strain curve and to aid in obtaining an average value of the parameter $n$ from figure 10 of reference 6.

## Tangent Modulus Graphs

Dimensionless graphs of tangent modulus against stress for the compressive specimens are shown in figures 15 to 20. The ordinates are the ratios of tangent modulus $E_t$ to Young's modulus. Each value of tangent modulus was taken as the ratio of a stress increment to its strain increment for the successive pairs of points shown in the stress-strain graphs. The abscissas are the mean values of $\sigma$ for the stress increments.

Most of the graphs do not show a well-defined region of constant "secondary" modulus such as might be expected after yielding of the soft cladding material. Nearly all the points above the knee of the curve are above the nominal values of secondary modulus based on the nominal percentage of core material in the sheet. These nominal values correspond to a value of 0.90 for $E_t/E$ for the 0.032-inch sheet and 0.95 for the 0.064- and 0.125-inch sheets.

The limits within which the tangent modulus curves fell are shown in figure 21. The maximum spread in values of $E_t/E$ is 0.065. Much of this spread can be attributed to the differences in percentage of cladding thickness of the 0.032-inch sheet and of the other sheets. An example of the use of these graphs is given in reference 7.

### Reduced Modulus Graphs

Dimensionless graphs of reduced modulus against stress are shown in figures 22 to 24. The ordinates are the ratios of reduced modulus for a rectangular cross section $E_r$ to Young's modulus, and the abscissas are the corresponding values of $\sigma$. The curves were derived from the corresponding curves of tangent modulus against stress by using the formula:

$$\frac{E_r}{E} = \frac{4E_t/E}{\left(1 + \sqrt{E_t/E}\right)^2}$$

The limits of the dimensionless graphs of reduced modulus against stress are shown in figure 25. The maximum spread in values of $E_r/E$ was 0.035.

## TENSILE STRESS-STRAIN TESTS TO FAILURE

### Procedure

Tensile tests to failure were made on two longitudinal and two transverse specimens from a sheet of each thickness. The specimens corresponded to specimens of type 5 described in reference 3. The tests were made in fluid-support, Bourdon-tube, hydraulic testing machines having Tate-Emery load indicators. The specimens were held in Templin grips. They were tested at a cross-head speed of about 0.1 inch per minute. Autographic load-extension curves were obtained with a Templin type stress-strain recorder by using a Peters averaging total-elongation extensometer with a 2-inch gage length and a magnification factor of 25. Stresses based on the original cross section and corresponding strains based on the original gage length were determined from these curves. The data for the portion at and beyond the knee of each curve were combined with stress-strain data on duplicate specimens on which strain up to the knee of the curve had been measured with Tuckerman optical strain gages.

### Stress-Strain Graphs

The resulting stress-strain curves are shown in figures 26 to 28. Values of tensile strength and elongation in 2 inches are given in the tables in each figure. The values of elongation usually corresponded to a strain of about 0.006 less than the maximum recorded strain under load.

## LOCAL-ELONGATION TESTS

### Procedure

Photogrid measurements (reference 8) were made on two longitudinal and two transverse tensile specimens from a sheet of each thickness. The specimens corresponded to specimens of type 5 described in reference 3. The photogrid negative was made from the master grid described in reference 1. The specimens were coated with cold top enamel. This has been found to be less critical with respect to exposure time than the photoengraving glue mentioned in reference 8. The prints were also usually easier to measure near the fracture. The specimens were held in Templin grips and were fractured in a testing machine at a cross-head speed of about 0.1 inch per minute. Measurements of grid spacing were made by the technique described in reference 1, except that the magnification was about 100 diameters.

### Graphs

The local elongations in percent of the original spacing, plotted against the distance before test from one end of the gage length, are shown in figures 29 to 34. The fracture in each case occurred in the grid spacing in which the greatest elongation took place.

The elongations in percent of the original gage length were computed for various gage lengths from the local-elongation data. These values are plotted against gage length in figures 35 to 40. The gage lengths were plotted to a logarithmic scale to present a large range of values on a single graph.

National Bureau of Standards
Washington, D.C., June 23, 1947

## REFERENCES


1. Miller, James A.: Stress-Strain and Elongation Graphs for Aluminum Alloy R301 Sheet. NACA TN No. 1010, 1946.

2. Miller, James A.: Stress-Strain and Elongation Graphs for Alclad Aluminum-Alloy 24S-T Sheet. NACA TN No. 1512, 1948.

3. Anon: General Specification for Inspection of Metals. Federal Specification QQ-M-151a, Federal Standard Stock Catalog, sec. IV, pt. 5, Nov. 27, 1936.

4. Aitchison, C. S., and Miller, James A.: A Subpress for Compressive Tests. NACA TN No. 912, 1943.

5. Miller, James A.: A Fixture for Compressive Tests of Thin Sheet Metal between Lubricated Steel Guides. NACA TN No. 1022, 1946.

6. Ramberg, Walter, and Osgood, William R.: Description of Stress-Strain Curves by Three Parameters. NACA TN No. 902, 1943.

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8. Brewer, Given A., and Glassco, Robert B.: Determination of Strain Distribution by the Photo-Grid Process. Jour. Aero. Sci., vol. 9, no. 1, Nov. 1941, pp. 1-7.

TABLE 1.– RESULTS OF TENSILE AND COMPRESSIVE TESTS ON ALCLAD

ALUMINUM-ALLOY 24S-T SHEET, AS RECEIVED

| Nominal thickness (in.) | Test | Direction | Yield strength (offset = 0.2 percent) (ksi) | Tensile strength (ksi) | Elongation in 2 in. (percent) |
|---|---|---|---|---|---|
| 0.032 | Tensile | Longitudinal | 51.4 | 68.2 | 18.2 |
| .032 | Tensile | Transverse | 44.7 | 66.0 | 18.0 |
| .032 | Compressive | Longitudinal | 43.1 | ---- | ---- |
| .032 | Compressive | Transverse | 47.8 | ---- | ---- |
| .064 | Tensile | Longitudinal | 48.6 | 69.0 | 21.0 |
| .064 | Tensile | Transverse | 43.1 | 66.7 | 19.0 |
| .064 | Compressive | Longitudinal | 41.4 | ---- | ---- |
| .064 | Compressive | Transverse | 46.4 | ---- | ---- |
| .125 | Tensile | Longitudinal | 55.4 | 71.8 | 19.2 |
| .125 | Tensile | Transverse | 47.1 | 69.4 | 19.5 |
| .125 | Compressive | Longitudinal | 45.0 | ---- | ---- |
| .125 | Compressive | Transverse | 50.8 | ---- | ---- |

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TABLE 2.– RESULTS OF TENSILE AND COMPRESSIVE TESTS ON ALCLAD ALUMINUM-ALLOY 24S-T81 SHEET

| Specimen | Test | Direction | Thickness (in.) | Young's modulus, E (ksi) | Yield strength: Offset method (offset = 0.2 percent) (ksi) | Yield strength: Secant method $s_1$ (0.7E) (ksi) | Yield strength: Secant method $s_2$ (0.85E) (ksi) | $s_1/s_2$ | Tensile strength (ksi) | Elongation in 2 in. (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| 032-T1L | Tensile | Longitudinal | 0.0325 | 10,750 | 61.7 | 62.0 | 59.3 | 1.046 | 67.9 | 6.5 |
| 032-T2L | ----do---- | ----do---- | .0324 | 10,610 | 61.3 | 61.7 | 59.1 | 1.043 | 68.0 | 6.0 |
| 032-T1T | ----do---- | Transverse | .0324 | 10,560 | 60.2 | 60.8 | 57.1 | 1.066 | 67.3 | 6.0 |
| 032-T2T | ----do---- | ----do---- | .0325 | 10,720 | 60.0 | 60.5 | 56.5 | 1.069 | 66.9 | 5.5 |
| 032-C1L | Compressive | Longitudinal | .0324 | 10,750 | 60.4 | 61.2 | 57.0 | 1.074 | ---- | --- |
| 032-C2L | ----do---- | ----do---- | .0324 | 10,710 | 60.7 | 61.5 | 57.4 | 1.072 | ---- | --- |
| 032-C1T | ----do---- | Transverse | .0324 | 10,670 | 61.4 | 62.0 | 59.0 | 1.050 | ---- | --- |
| 032-C2T | ----do---- | ----do---- | .0324 | 10,760 | 61.6 | 62.2 | 59.1 | 1.054 | ---- | --- |
| 064-T1L | Tensile | Longitudinal | .0649 | 10,660 | 58.7 | 58.9 | 56.8 | 1.038 | 66.5 | 7.5 |
| 064-T2L | ----do---- | ----do---- | .0650 | 10,700 | 58.6 | 58.8 | 56.6 | 1.039 | 66.4 | 7.5 |
| 064-T1T | ----do---- | Transverse | .0649 | 10,680 | 57.7 | 58.0 | 55.1 | 1.053 | 65.8 | 6.5 |
| 064-T2T | ----do---- | ----do---- | .0650 | 10,660 | 57.4 | 57.8 | 54.9 | 1.053 | 65.4 | 6.5 |
| 064-C1L | Compressive | Longitudinal | .0650 | 10,770 | 58.4 | 58.9 | 55.8 | 1.054 | ---- | --- |
| 064-C2L | ----do---- | ----do---- | .0649 | 10,780 | 58.6 | 59.1 | 56.0 | 1.055 | ---- | --- |
| 064-C1T | ----do---- | Transverse | .0649 | 10,770 | 58.3 | 58.7 | 56.3 | 1.043 | ---- | --- |
| 064-C2T | ----do---- | ----do---- | .0649 | 10,700 | 58.5 | 58.9 | 56.5 | 1.043 | ---- | --- |
| 125-T1L | Tensile | Longitudinal | .1236 | 10,740 | 64.9 | 65.3 | 63.0 | 1.036 | 71.6 | 7.5 |
| 125-T2L | ----do---- | ----do---- | .1237 | 10,760 | 65.2 | 65.6 | 63.4 | 1.035 | 71.8 | 7.5 |
| 125-T1T | ----do---- | Transverse | .1240 | 10,650 | 62.9 | 63.6 | 59.9 | 1.062 | 70.5 | 7.5 |
| 125-T2T | ----do---- | ----do---- | .1234 | 10,650 | 63.4 | 64.0 | 60.5 | 1.058 | 70.6 | 7.0 |
| 125-C1L | Compressive | Longitudinal | .1239 | 10,760 | 64.0 | 64.9 | 61.4 | 1.058 | ---- | --- |
| 125-C2L | ----do---- | ----do---- | .1235 | 10,780 | 64.0 | 64.9 | 61.3 | 1.059 | ---- | --- |
| 125-C1T | ----do---- | Transverse | .1240 | 10,730 | 65.1 | 65.8 | 63.0 | 1.045 | ---- | --- |
| 125-C2T | ----do---- | ----do---- | .1237 | 10,770 | 65.3 | 66.0 | 63.2 | 1.045 | ---- | --- |

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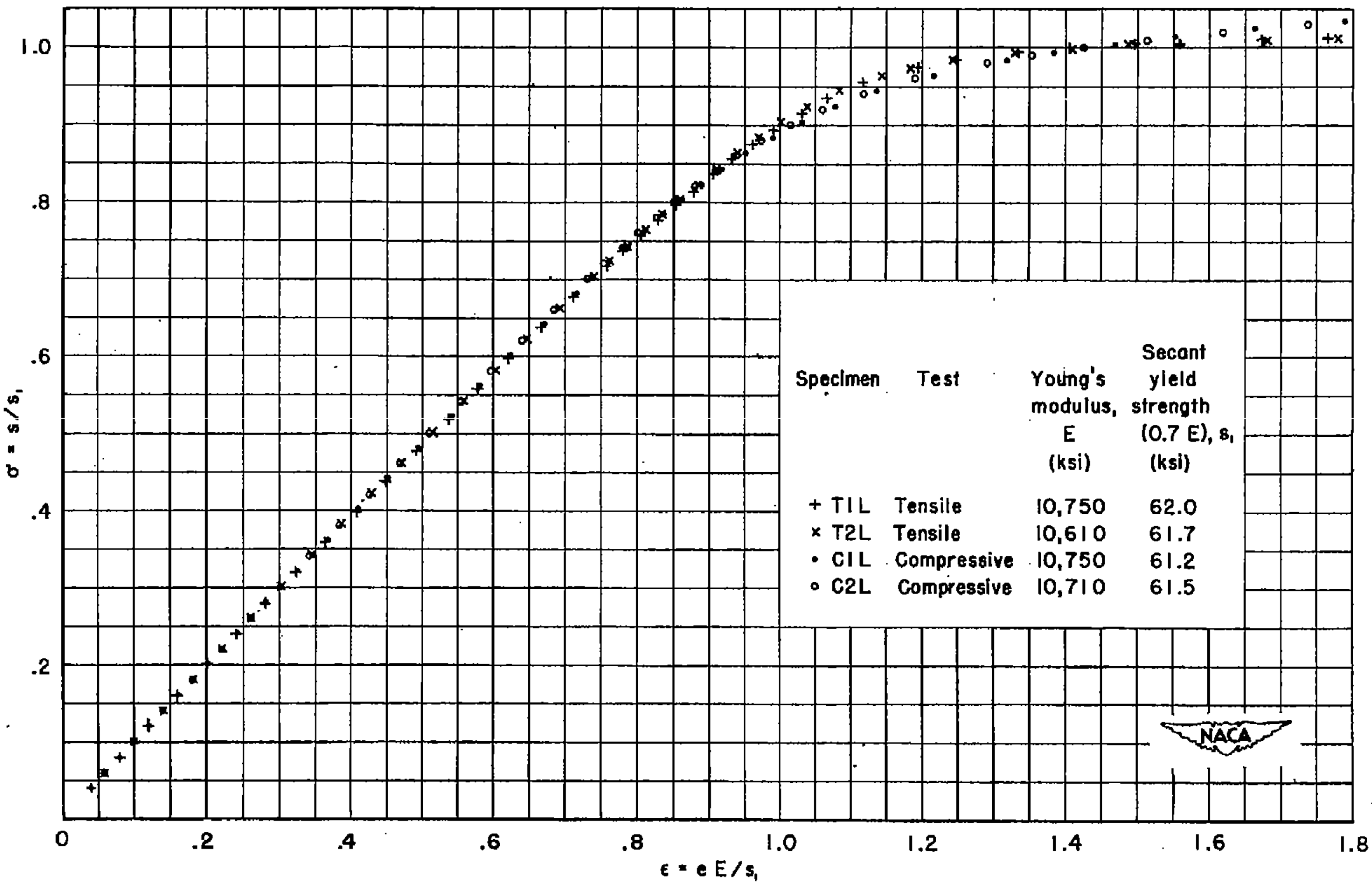


Figure 1.- Dimensionless stress-strain graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.032 inch thick.

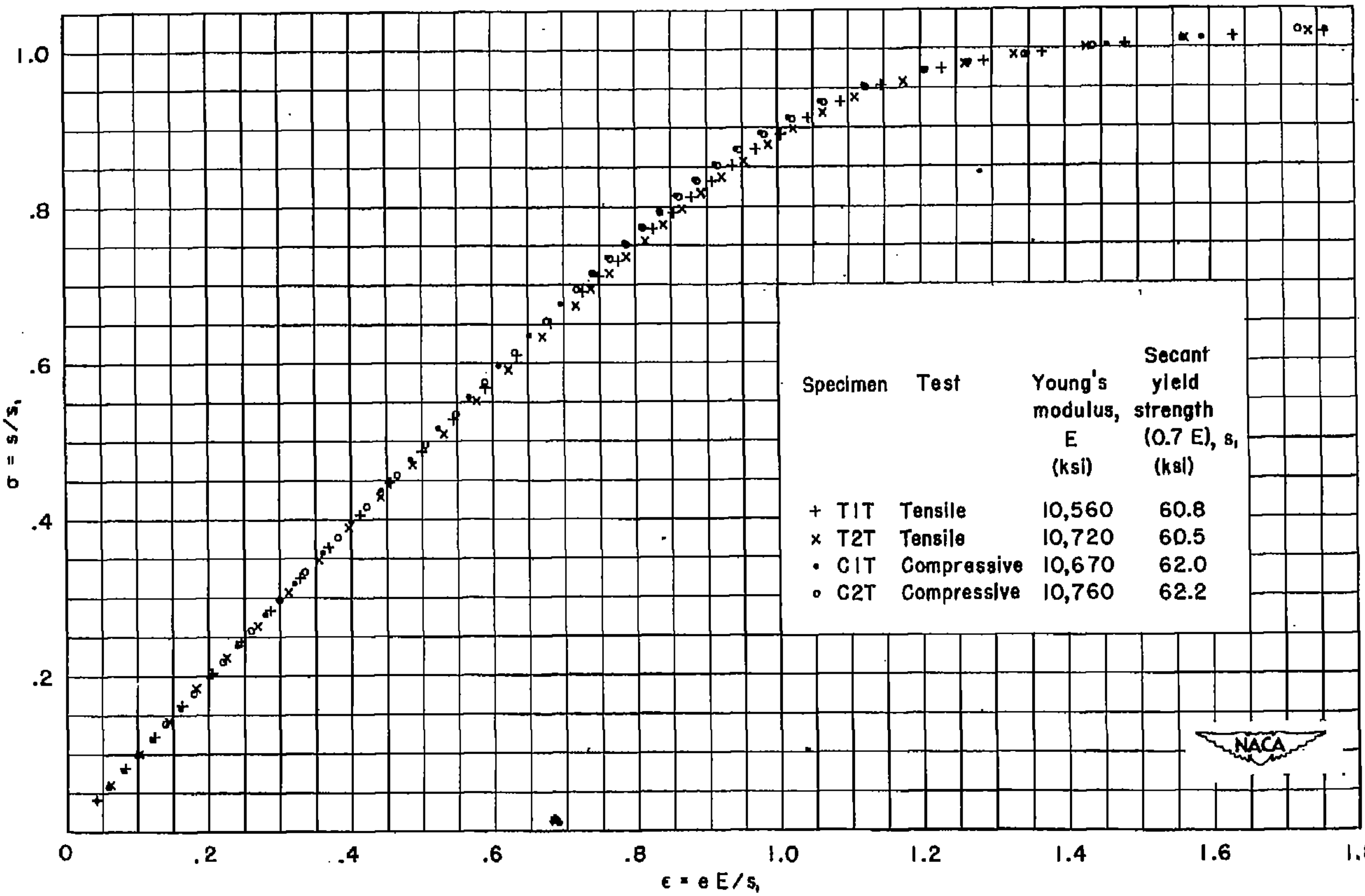


Figure 2.- Dimensionless stress-strain graphs. Alclad 24S-T81 sheet, transverse specimens 0.032 inch thick.

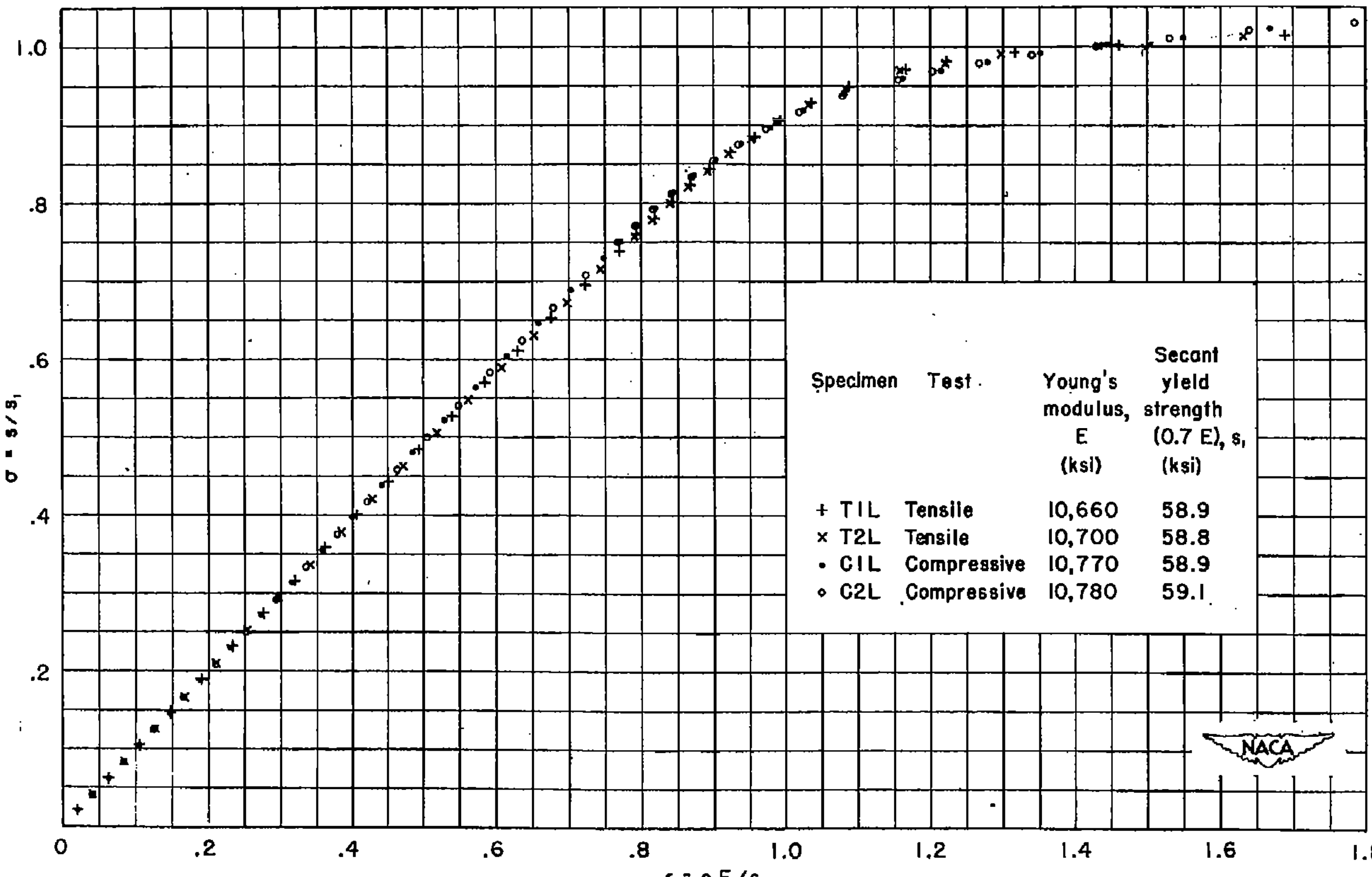


Figure 3.- Dimensionless stress-strain graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.064 inch thick.

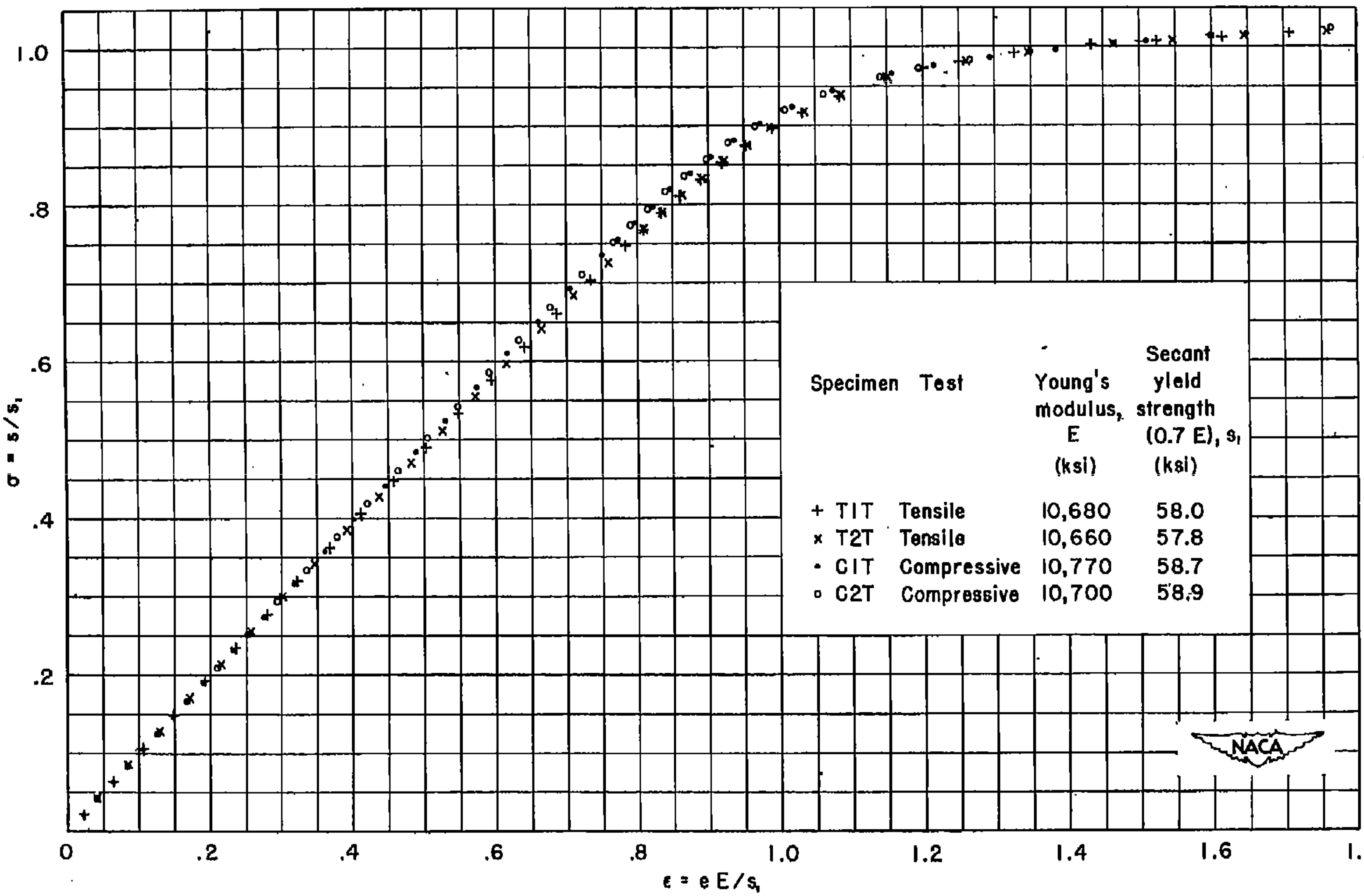


Figure 4.- Dimensionless stress-strain graphs. Alclad 24S-T81 sheet, transverse specimens 0.064 inch thick.

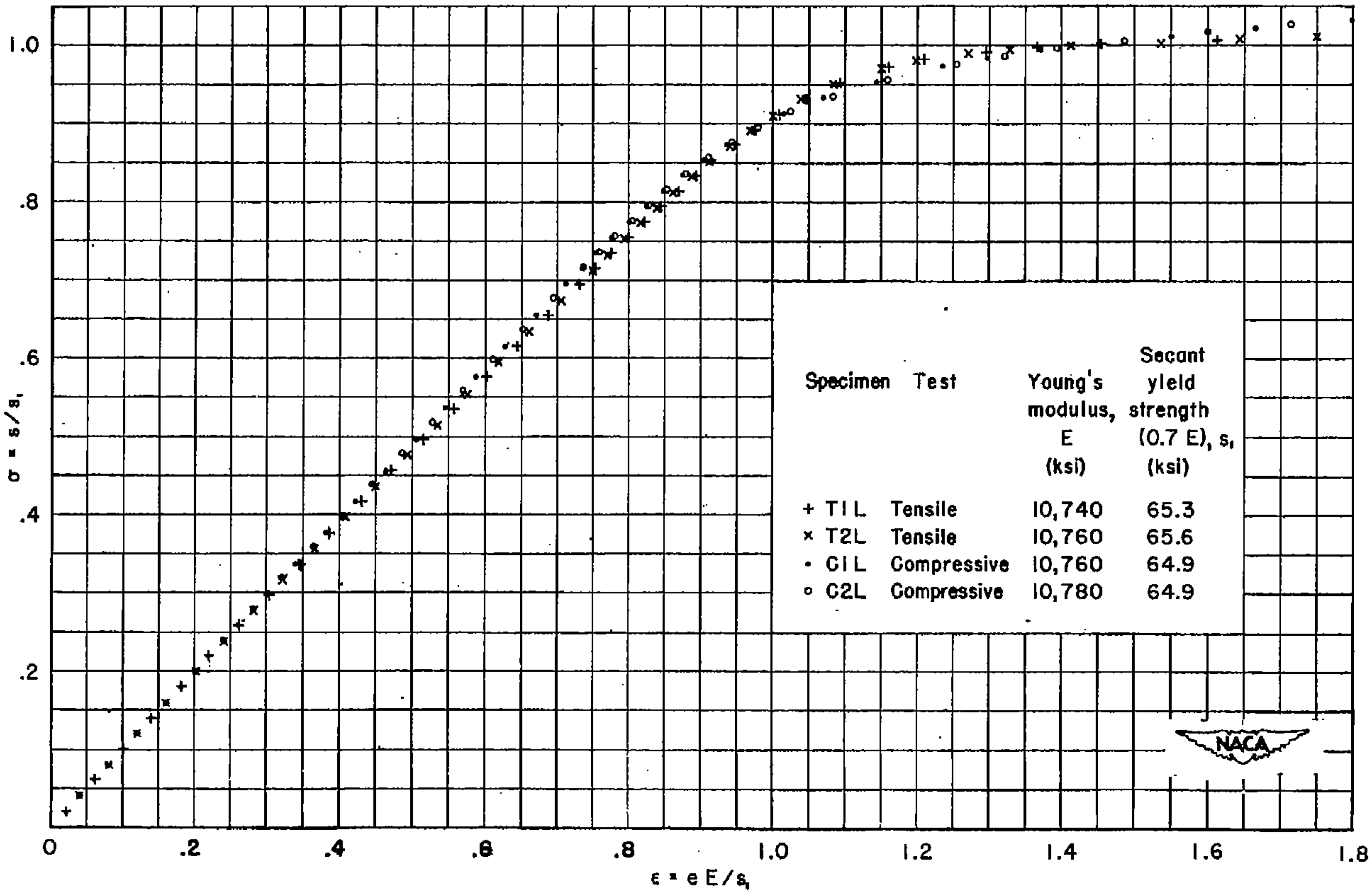


Figure 5.- Dimensionless stress-strain graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.125 inch thick.

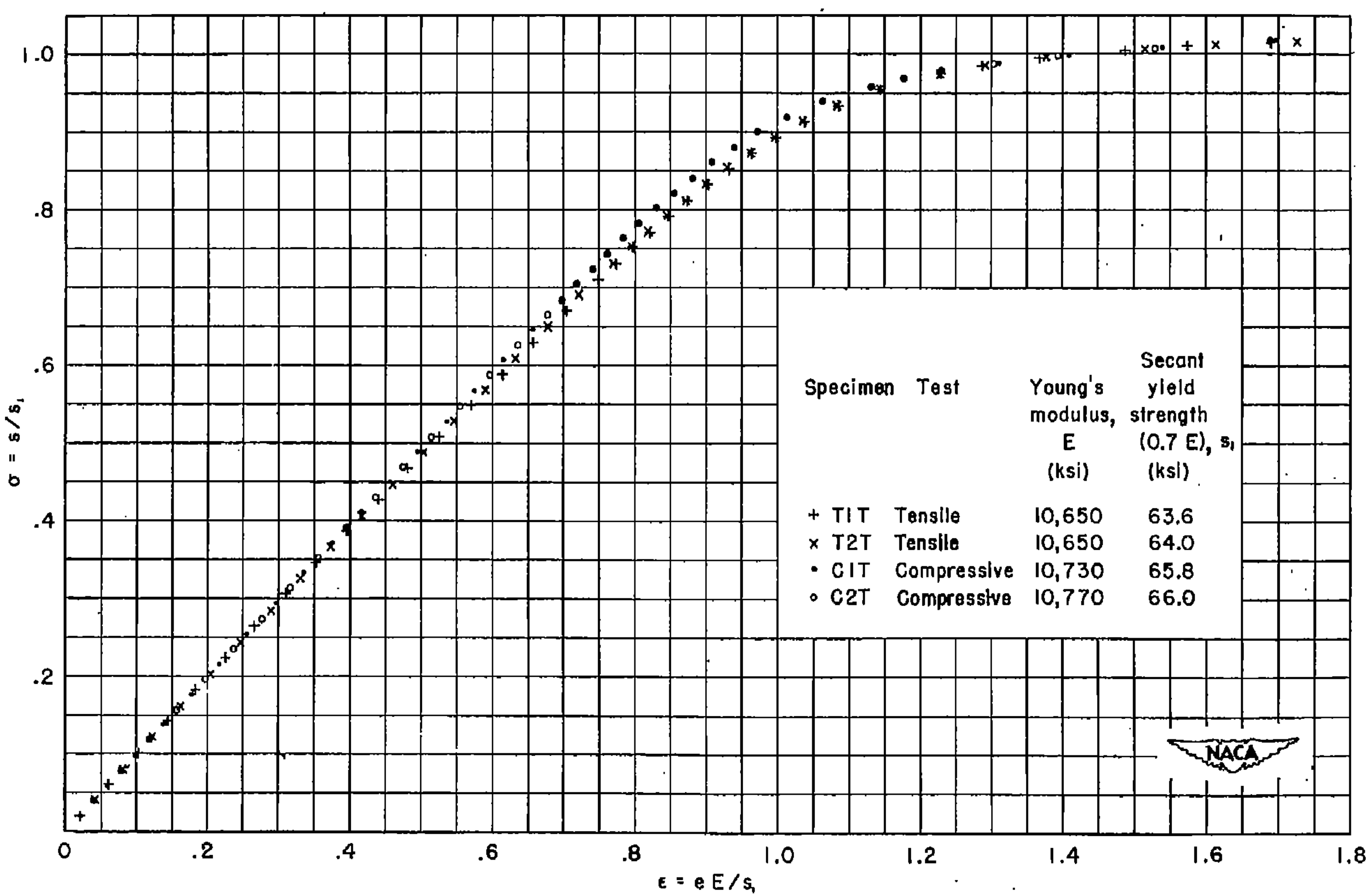


Figure 6.- Dimensionless stress-strain graphs. Alclad 24S-T81 sheet, transverse specimens 0.125 inch thick.

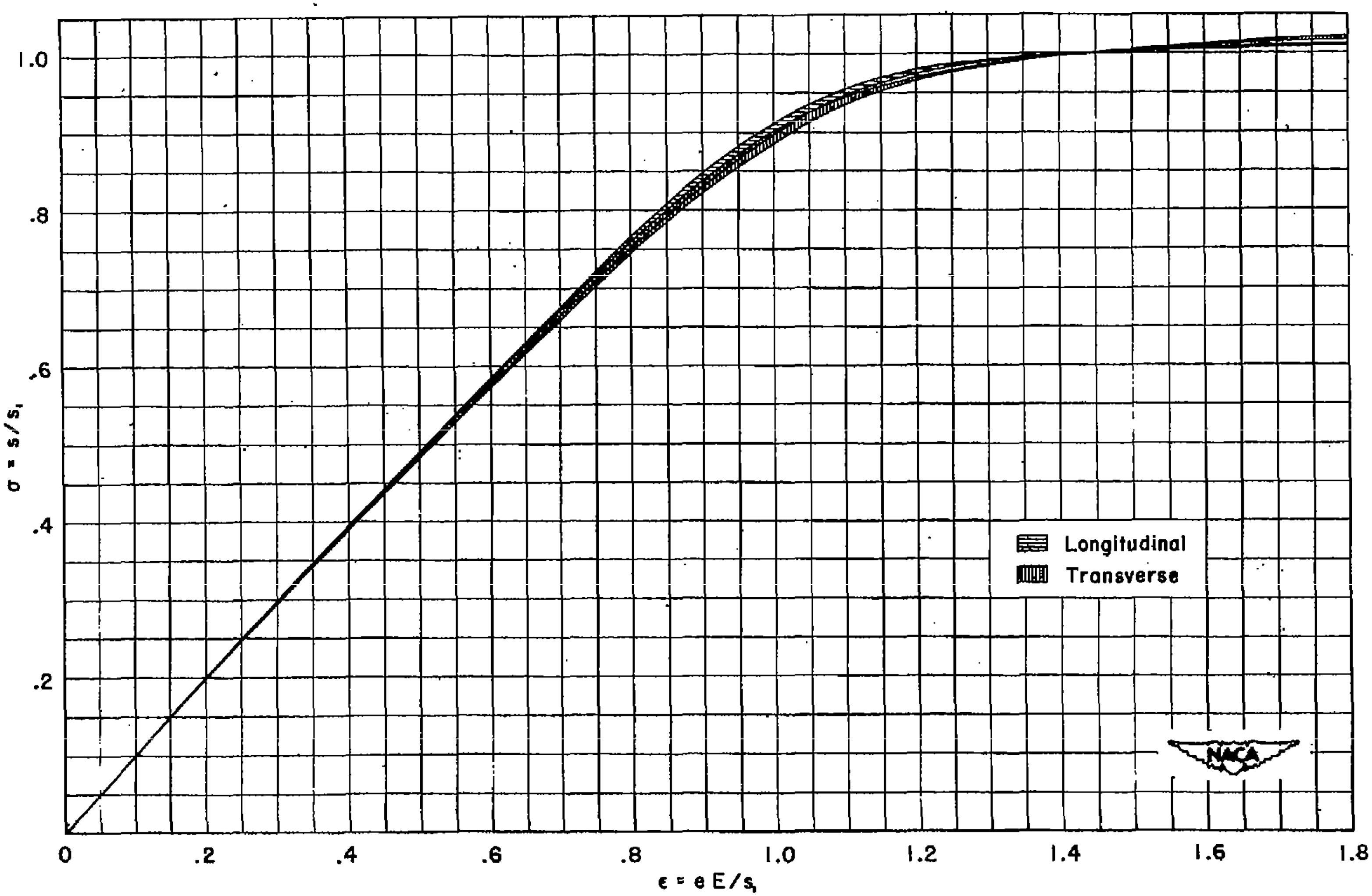


Figure 7.- Limits of dimensionless tensile stress-strain graphs. Alclad 24S-T81 sheets 0.032, 0.064, and 0.125 inch thick.

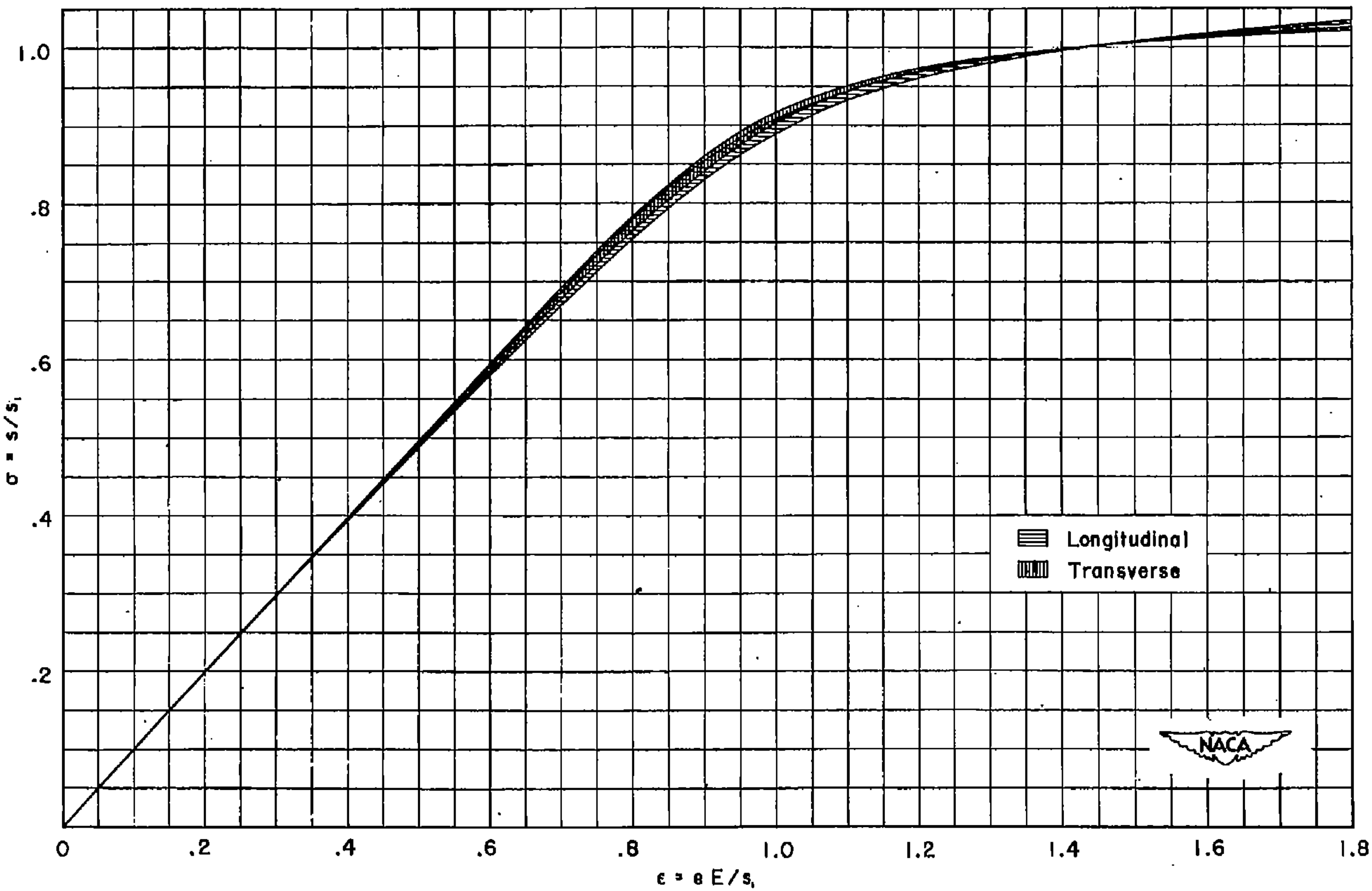


Figure 8.- Limits of dimensionless compressive stress-strain graphs. Alclad 24S-T81 sheets 0.032, 0.064, and 0.125 inch thick.

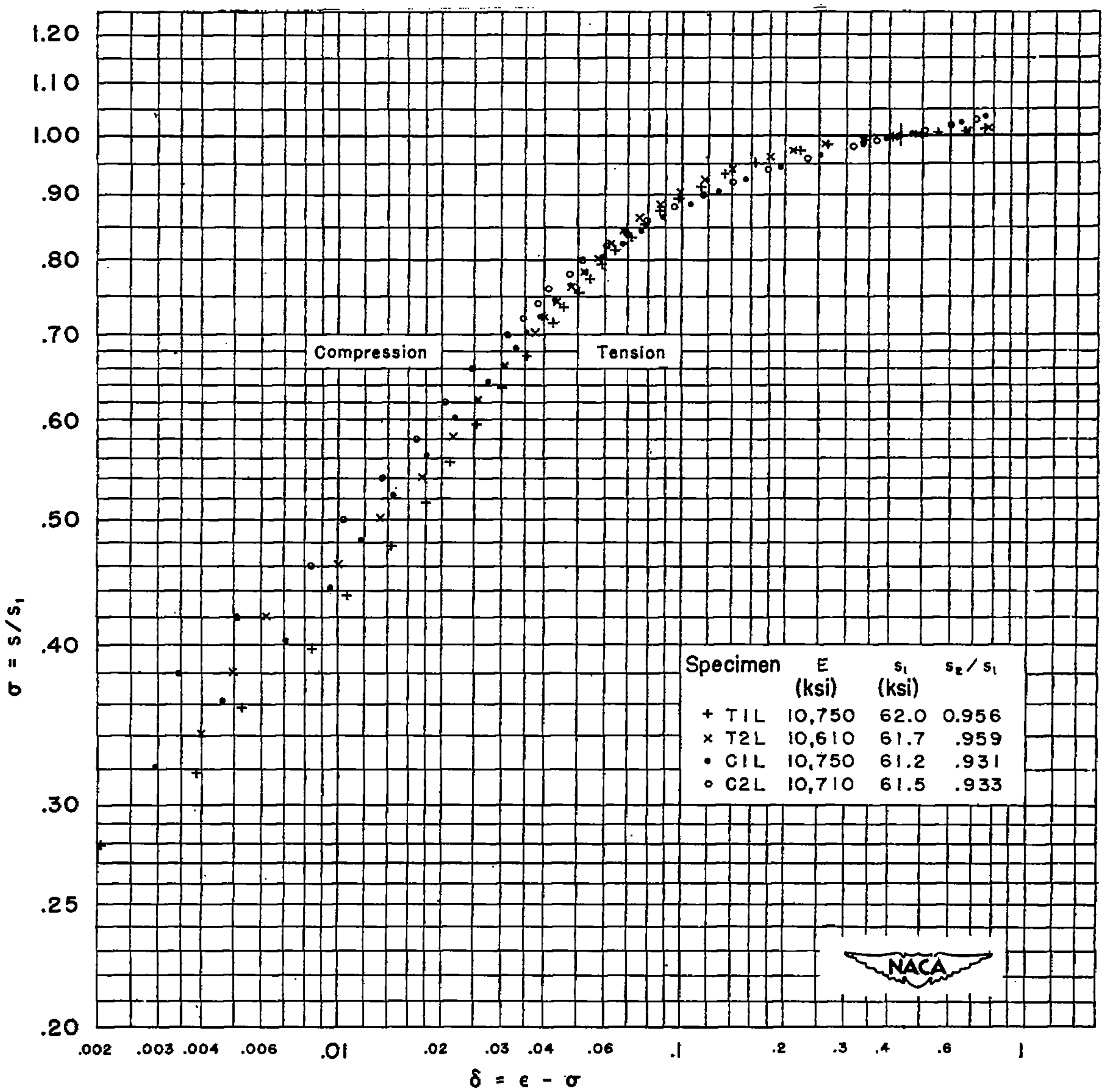


Figure 9.– Dimensionless stress-deviation graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.032 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7 E); $s_2$, secant yield strength (0.85 E).

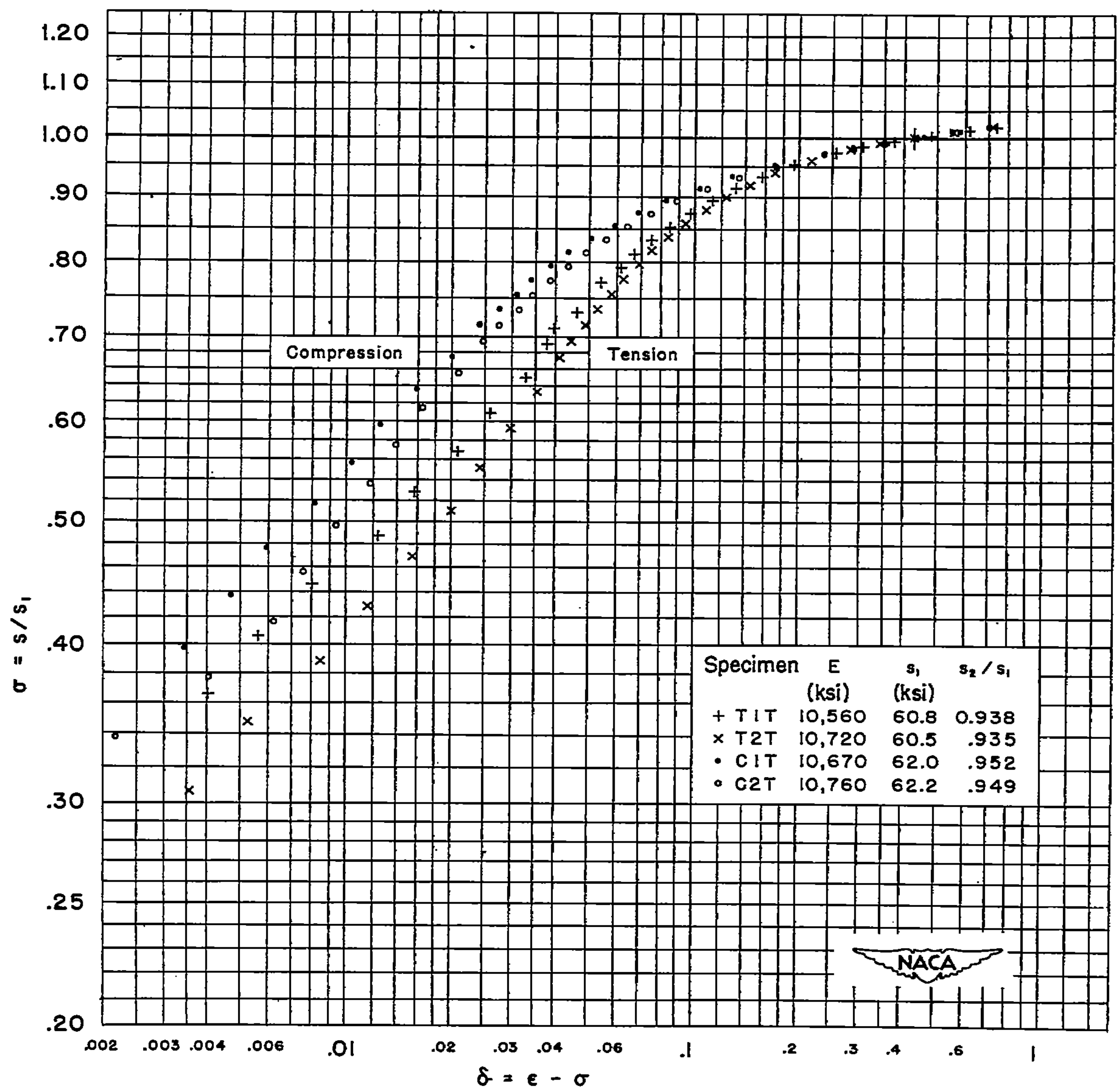


Figure 10.— Dimensionless stress-deviation graphs. Alclad 24S−T81 sheet, transverse specimens 0.032 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7 E); $s_2$, secant yield strength (0.85 E).

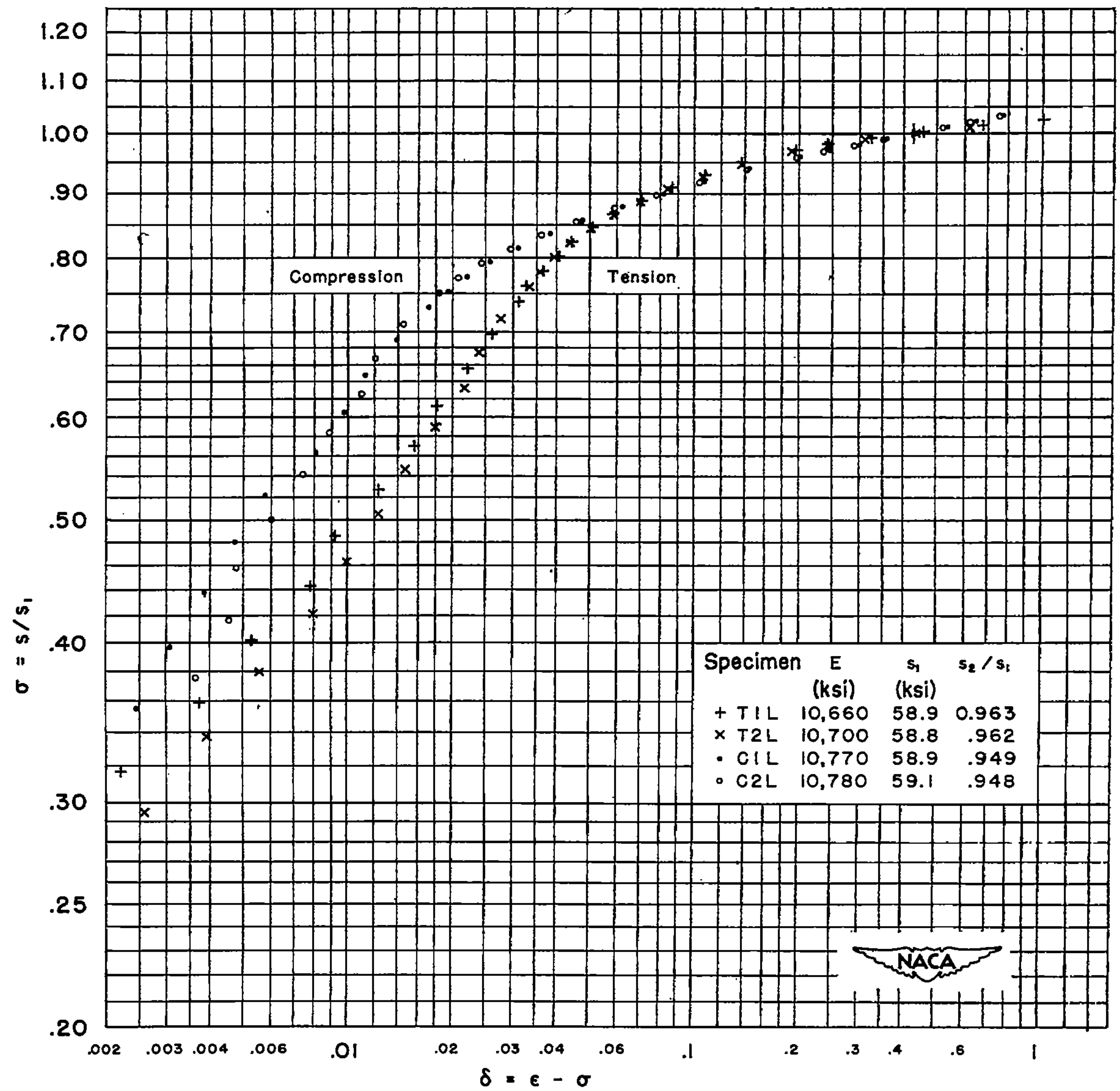


Figure 11.— Dimensionless stress-deviation graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.064 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7 E); $s_2$, secant yield strength (0.85 E).

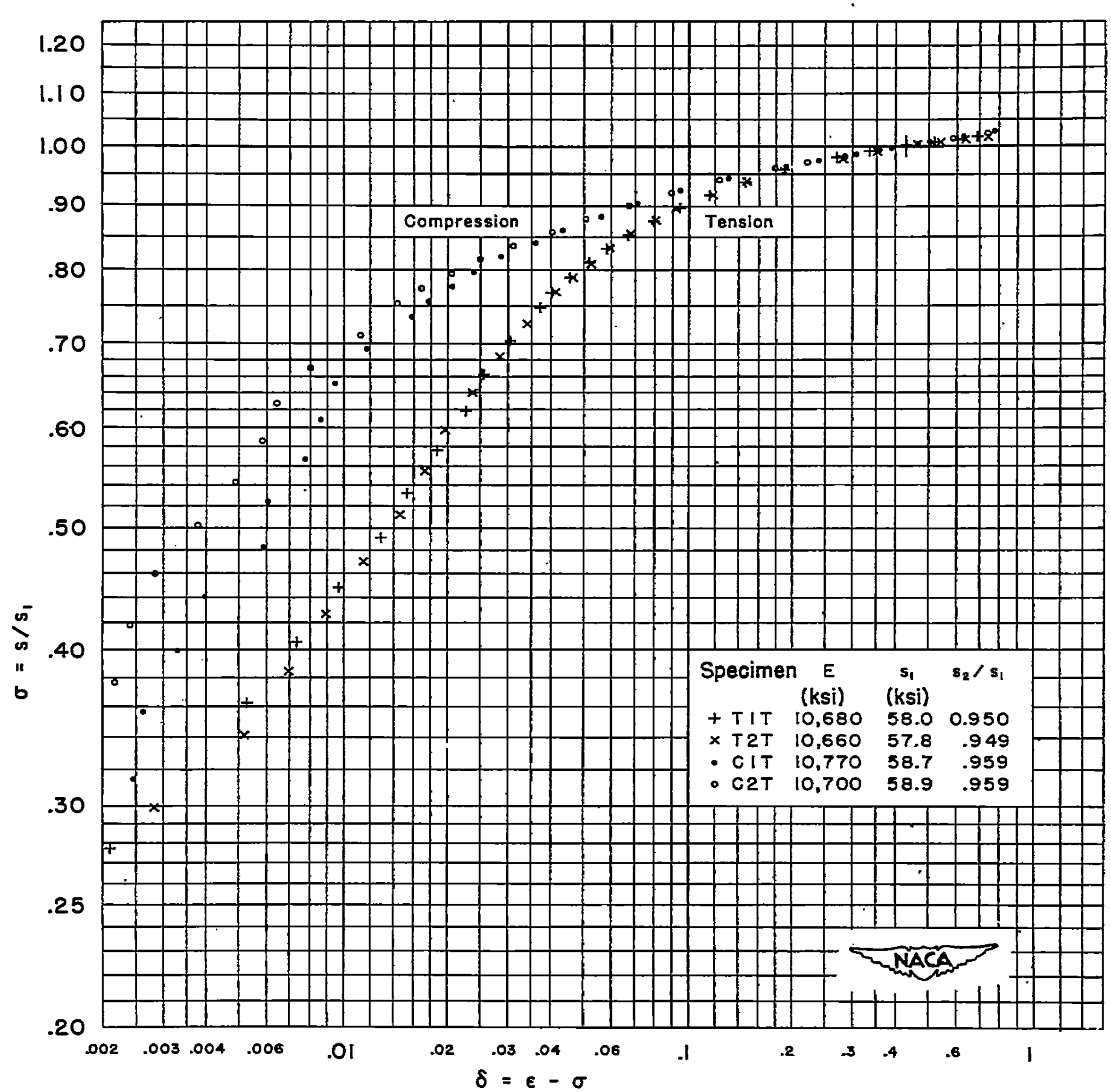


Figure 12.- Dimensionless stress-deviation graphs. Alclad 24S-T81 sheet, transverse specimens 0.064 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7 E); $s_2$, secant yield strength (0.85 E).

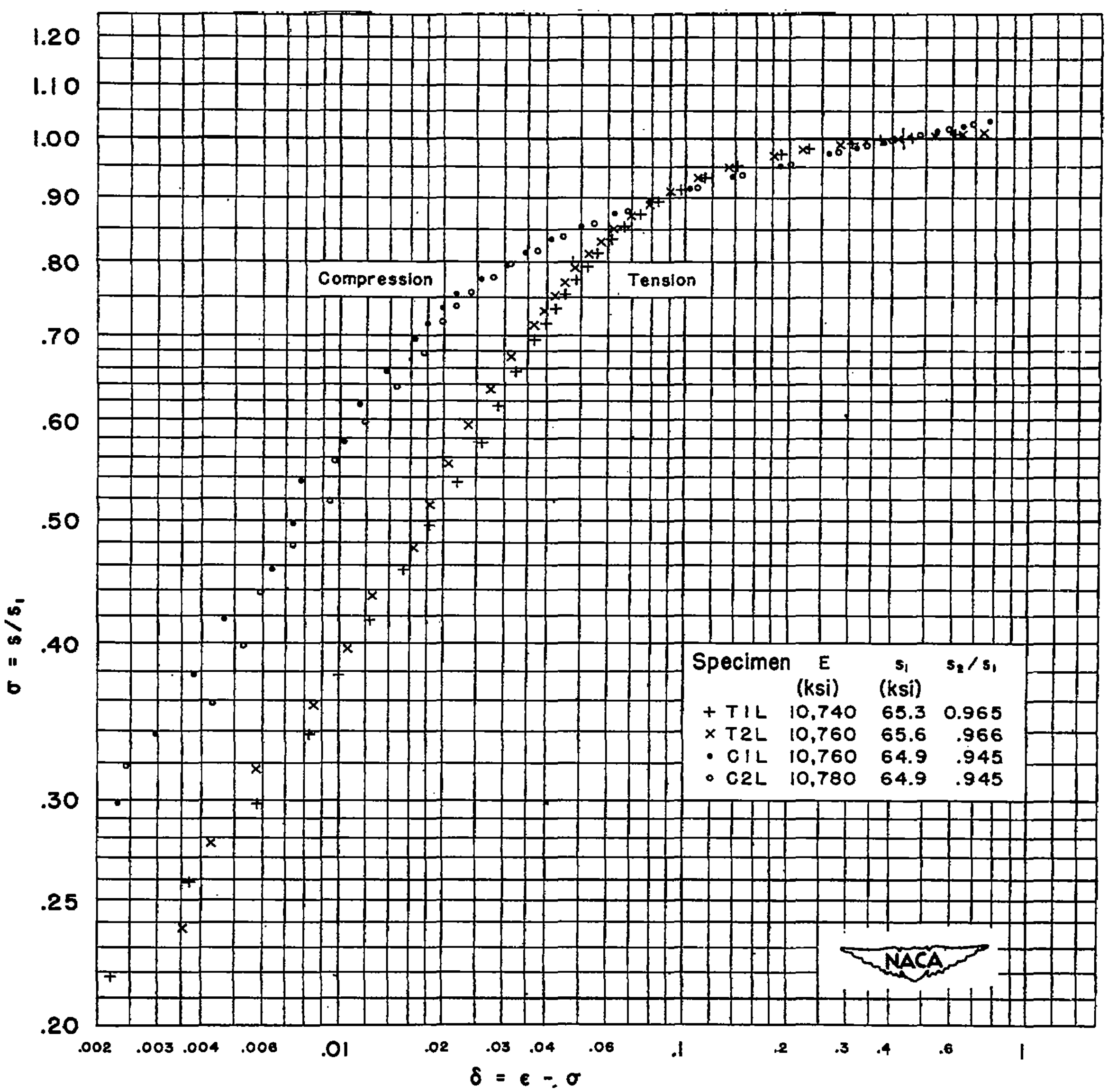


Figure 13.- Dimensionless stress-deviation graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.125 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7 E); $s_2$, secant yield strength (0.85 E).

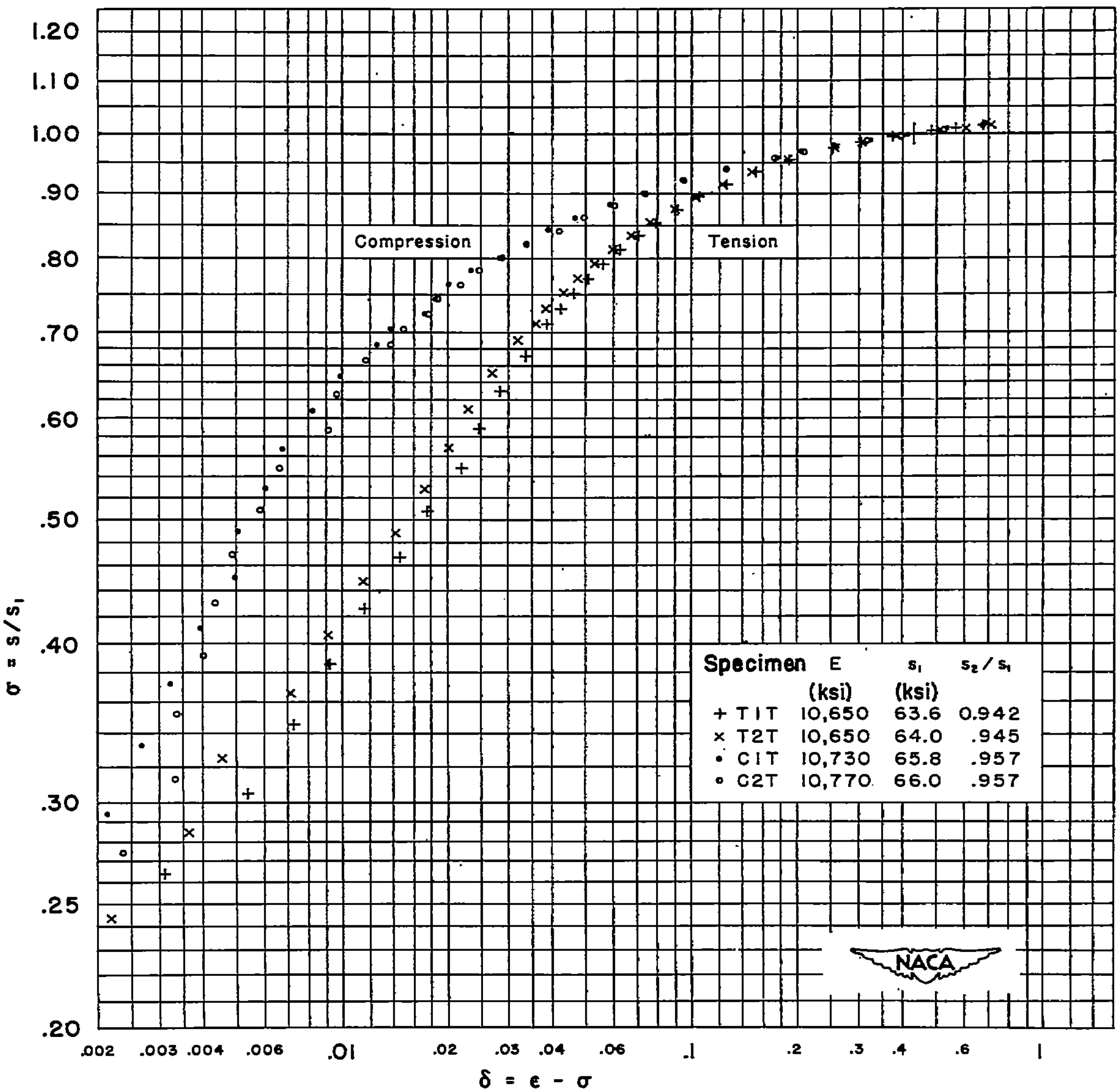


Figure 14.- Dimensionless stress-deviation graphs. Alclad 24S-T81 sheet, transverse specimens 0.125 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7 E); $s_2$, secant yield strength (0.85 E).

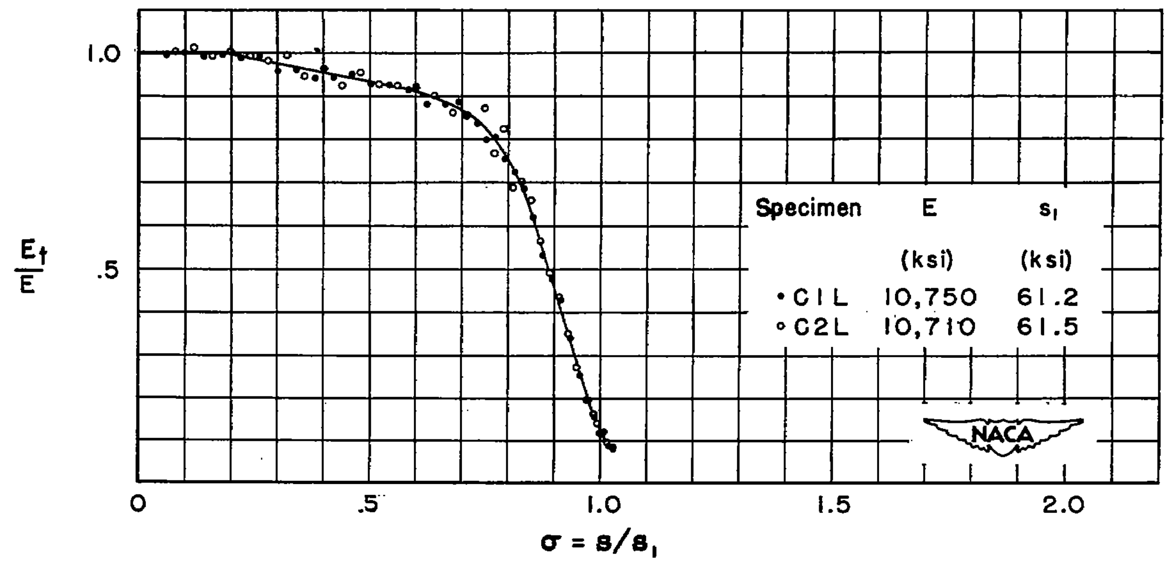


Figure 15.- Dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.032 inch thick.

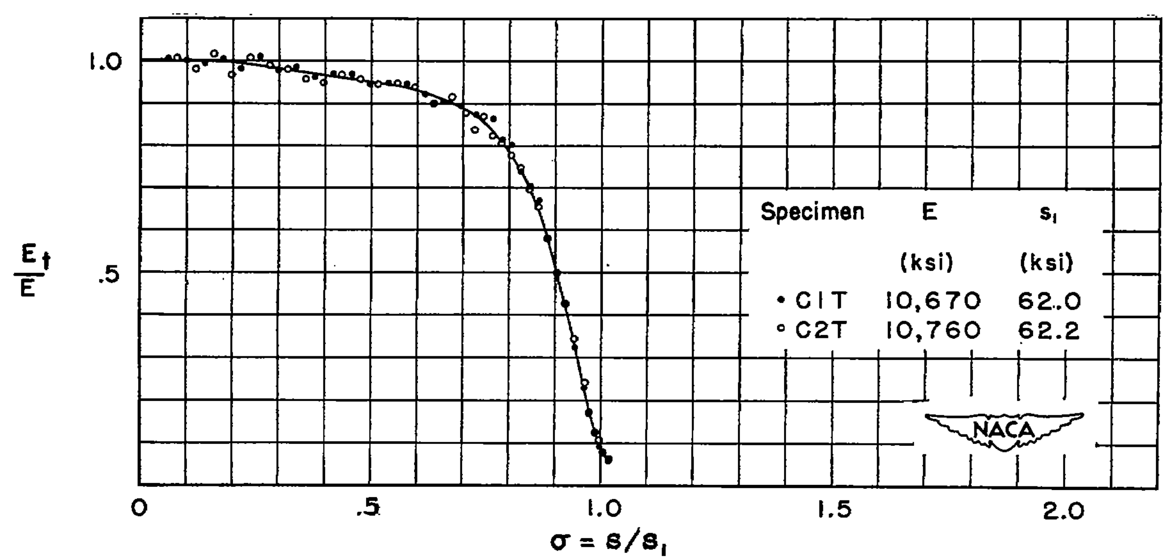


Figure 16.- Dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheet, transverse specimens 0.032 inch thick.

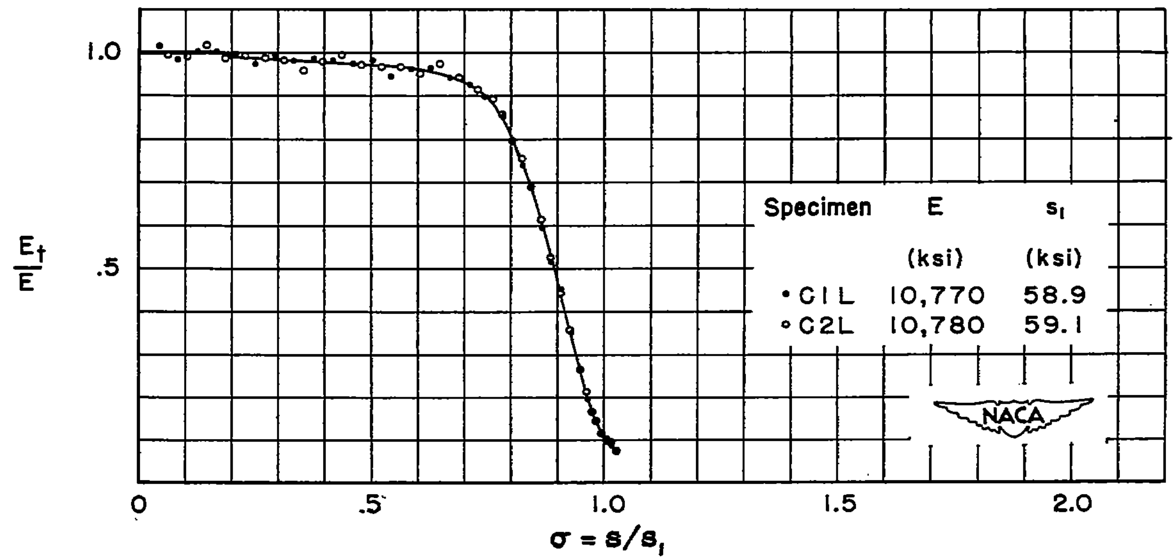


Figure 17.- Dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.064 inch thick.

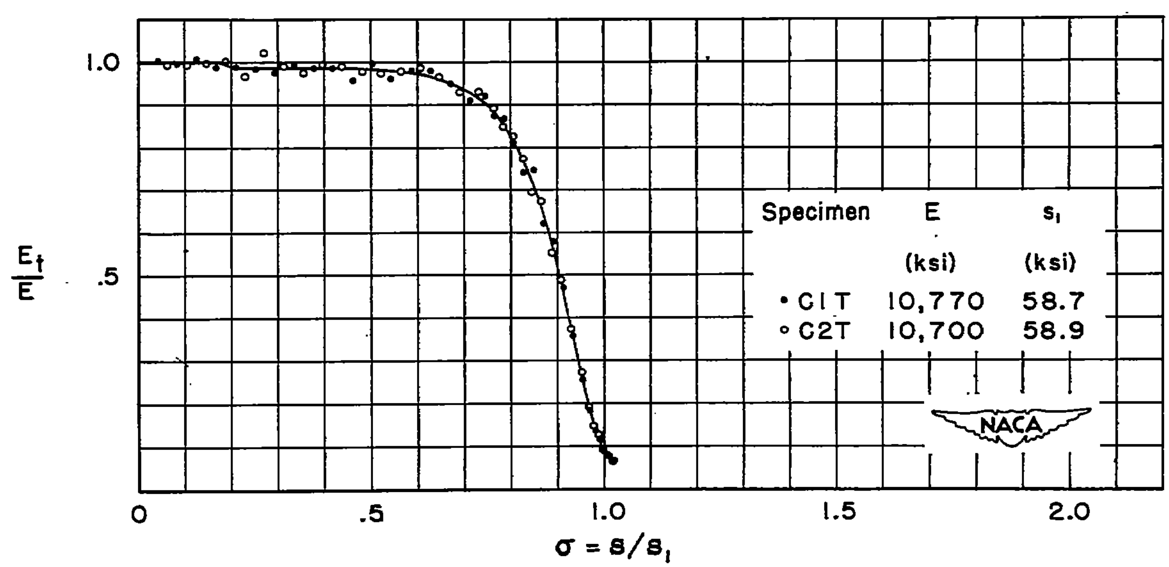


Figure 18.- Dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheet, transverse specimens 0.064 inch thick.

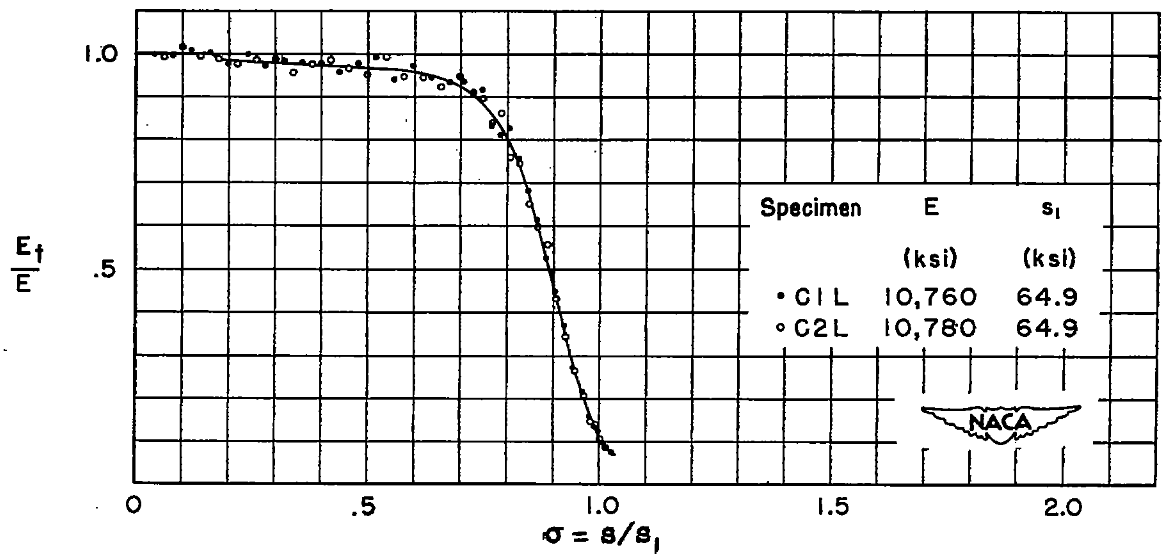


Figure 19.- Dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheet, longitudinal specimens 0.125 inch thick.

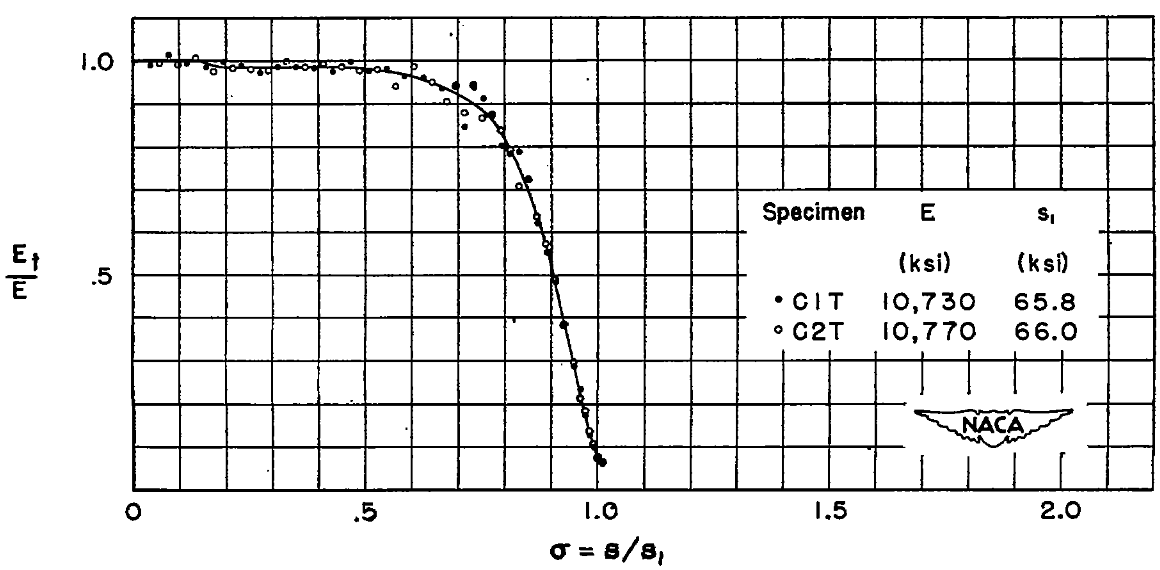


Figure 20.- Dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheet, transverse specimens 0.125 inch thick.

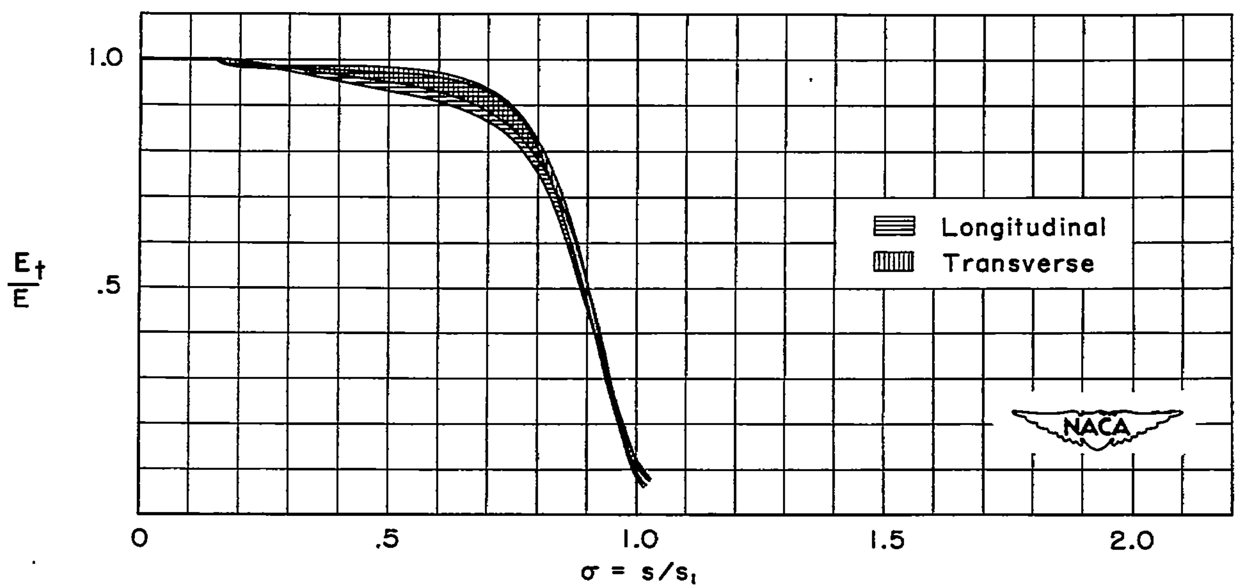


Figure 21.- Limits of dimensionless compressive tangent modulus graphs. Alclad 24S-T81 sheets 0.032, 0.064, and 0.125 inch thick.

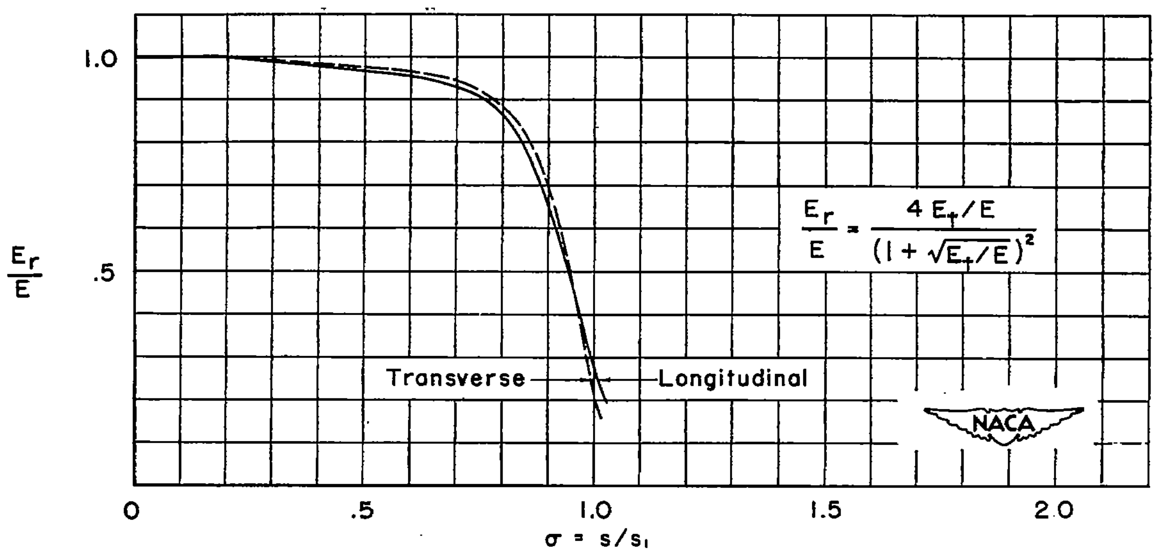


Figure 22.- Dimensionless compressive reduced modulus graphs, rectangular sections. Alclad 24S-T81 sheet 0.032 inch thick.

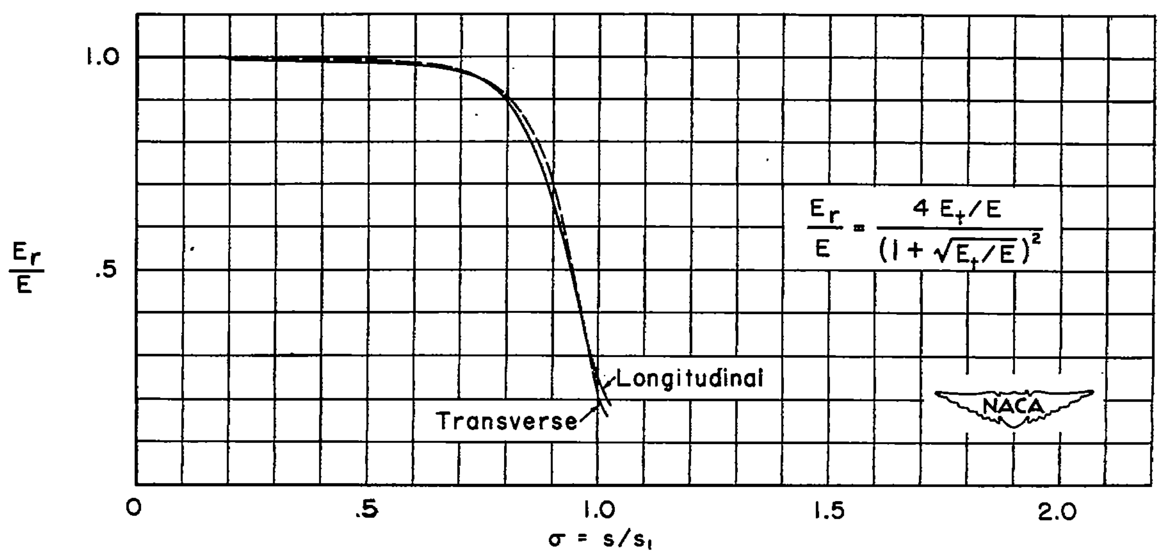


Figure 23.- Dimensionless compressive reduced modulus graphs, rectangular sections. Alclad 24S-T81 sheet 0.064 inch thick.

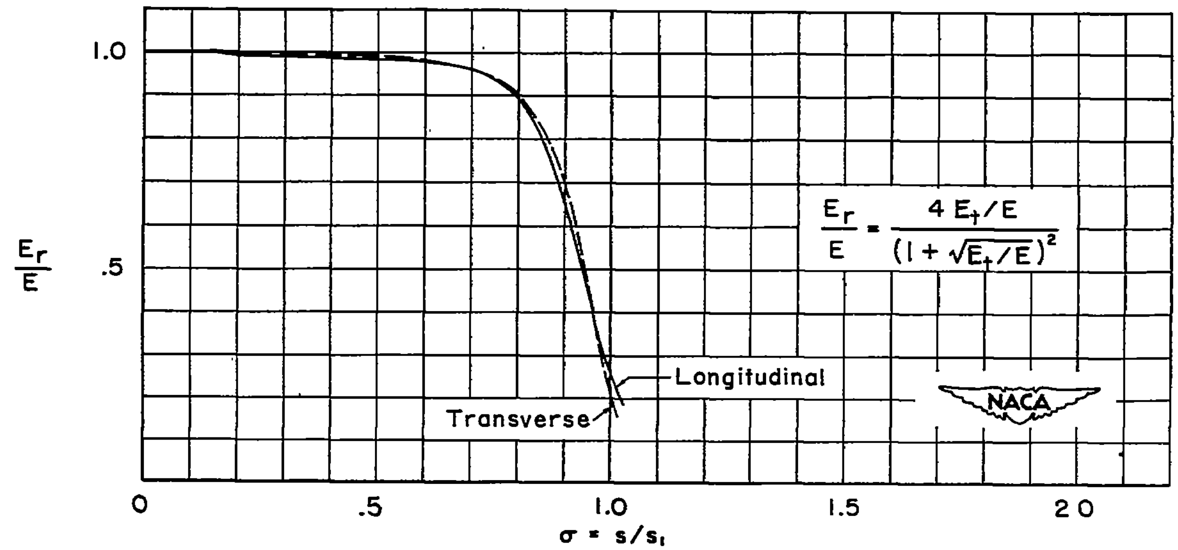


Figure 24.- Dimensionless compressive reduced modulus graphs, rectangular sections. Alclad 24S-T81 sheet 0.125 inch thick.

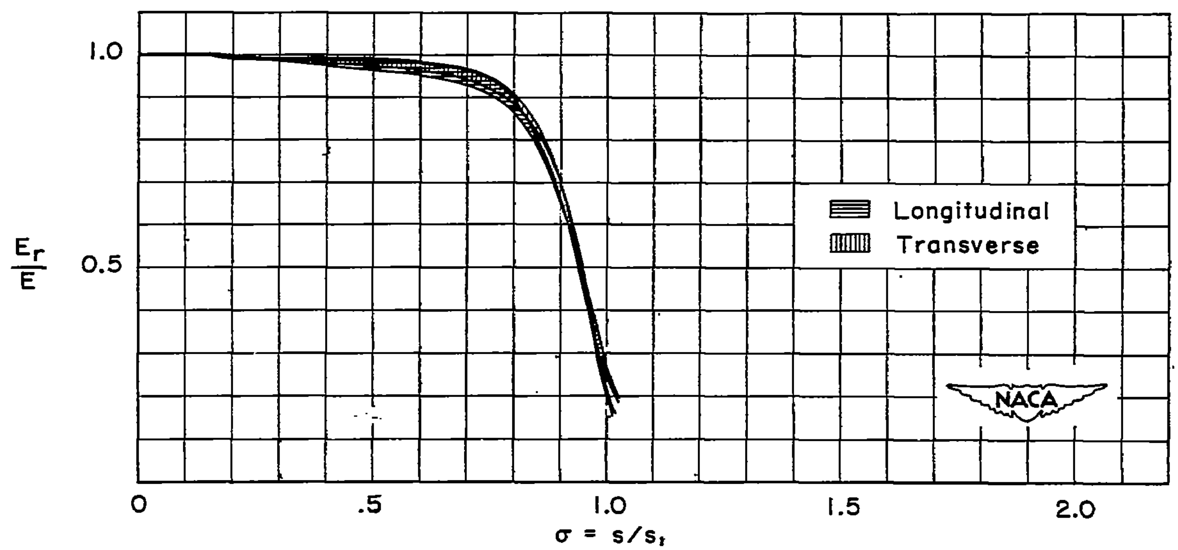


Figure 25.- Limits of dimensionless reduced modulus graphs for rectangular sections. Alclad 24S-T81 sheets 0.032, 0.064, and 0.125 inch thick.

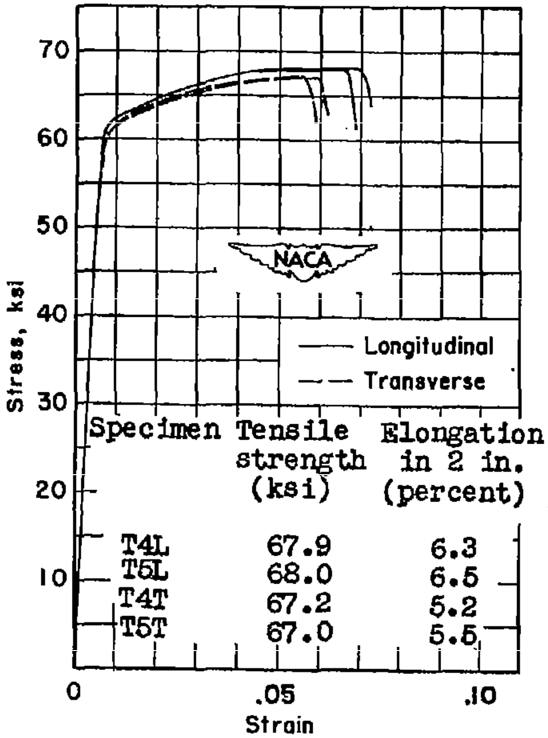


Figure 26.- Curves of tensile stress-strain tests to failure. Alclad 24S-T81 sheet 0.032 inch thick.

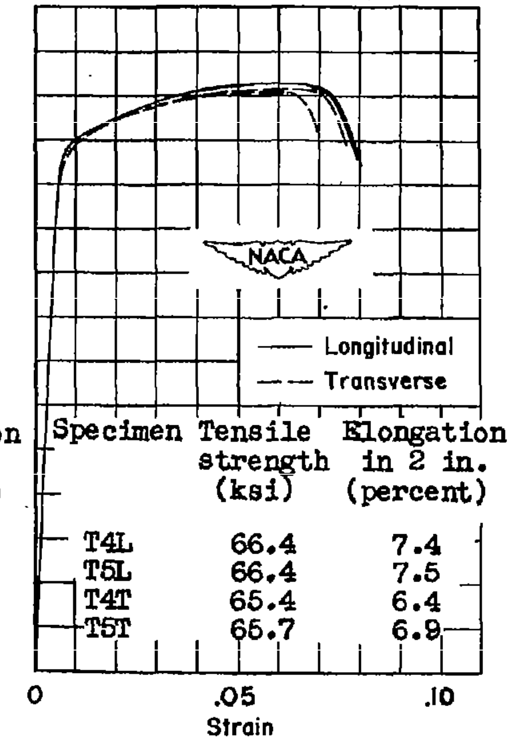


Figure 27.- Curves of tensile stress-strain tests to failure. Alclad 24S-T81 sheet 0.064 inch thick.

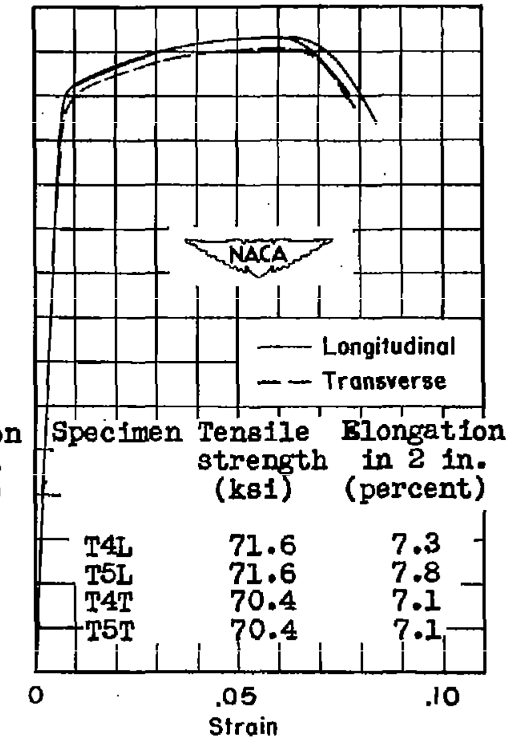


Figure 28.- Curves of tensile stress-strain tests to failure. Alclad 24S-T81 sheet 0.125 inch thick.

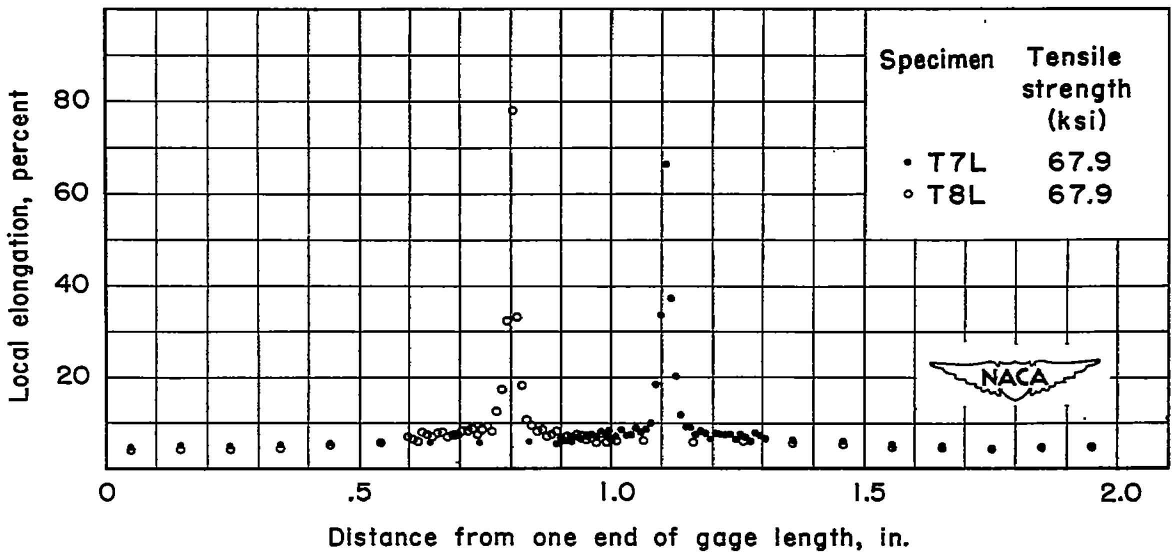


Figure 29. Local elongation. Alclad 24S-T81 sheet, longitudinal specimens 0.032 inch thick.

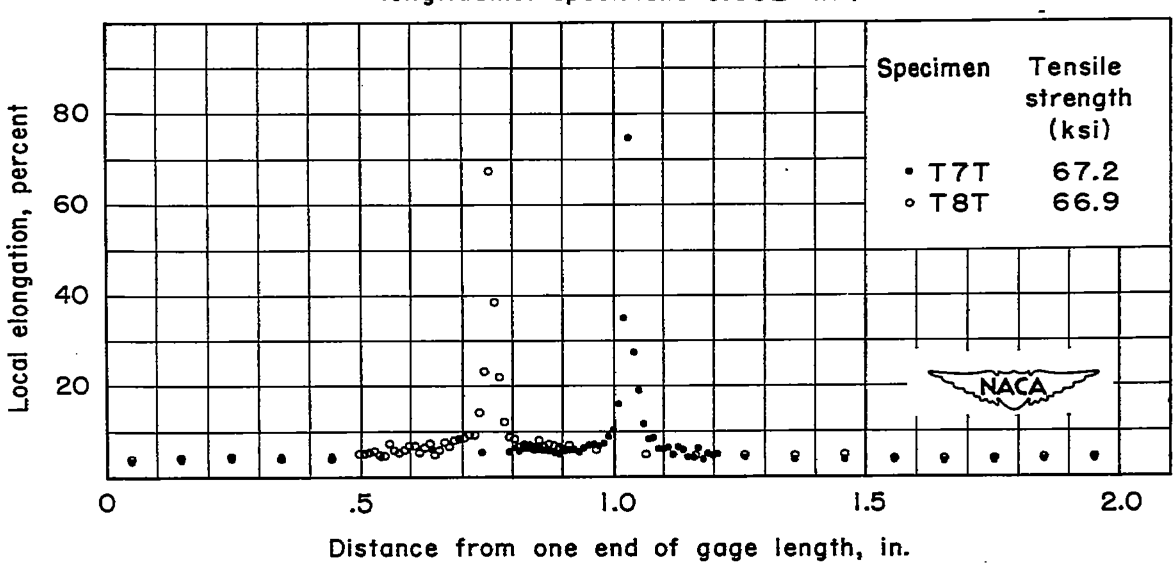


Figure 30.- Local elongation. Alclad 24S-T81 sheet, transverse specimens 0.032 inch thick.

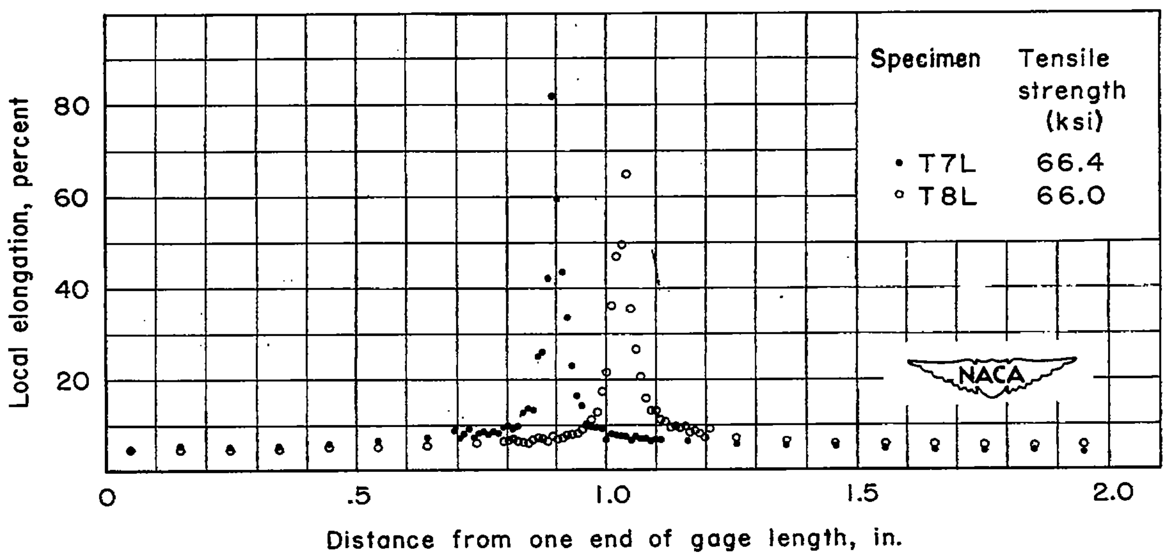


Figure 31.- Local elongation. Alclad 24S-T81 sheet, longitudinal specimens 0.064 inch thick.

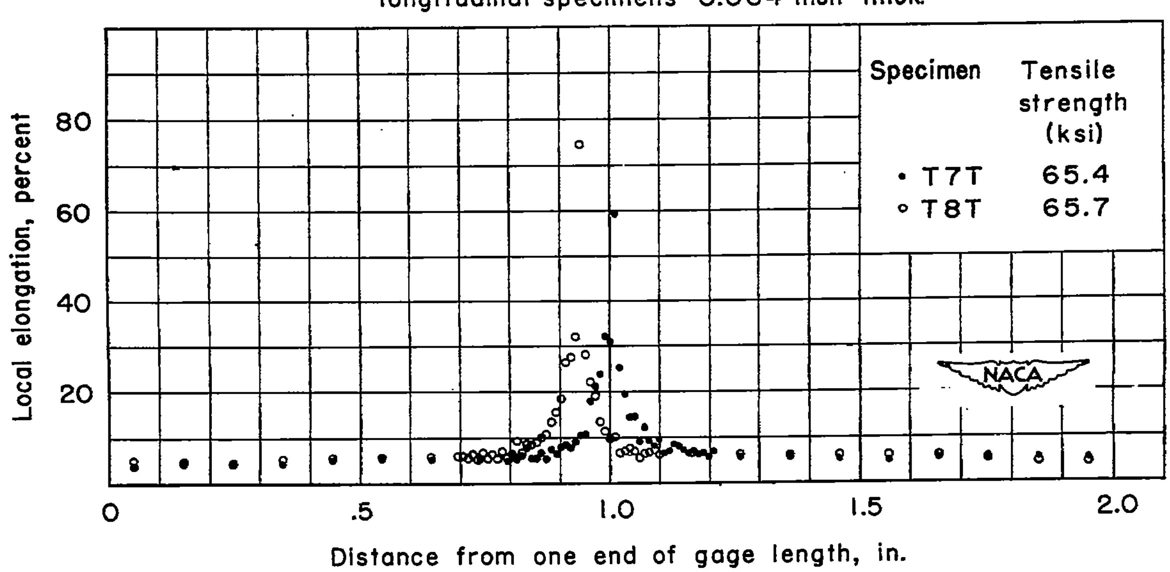


Figure 32.- Local elongation. Alclad 24S-T81 sheet, transverse specimens 0.064 inch thick.

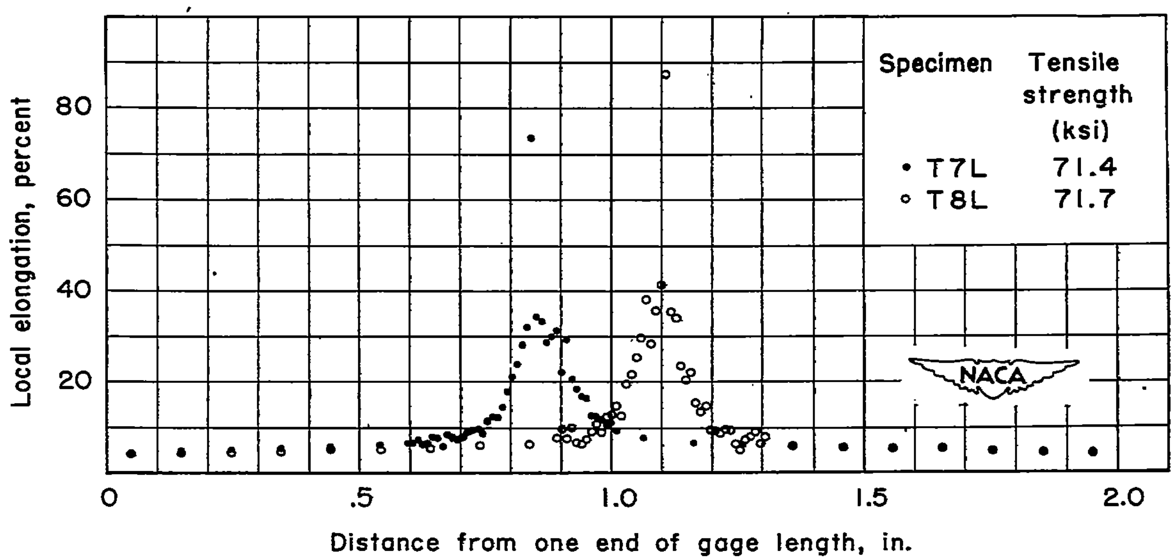


Figure 33.- Local elongation. Alclad 24S-T81 sheet, longitudinal specimens 0.125 inch thick.

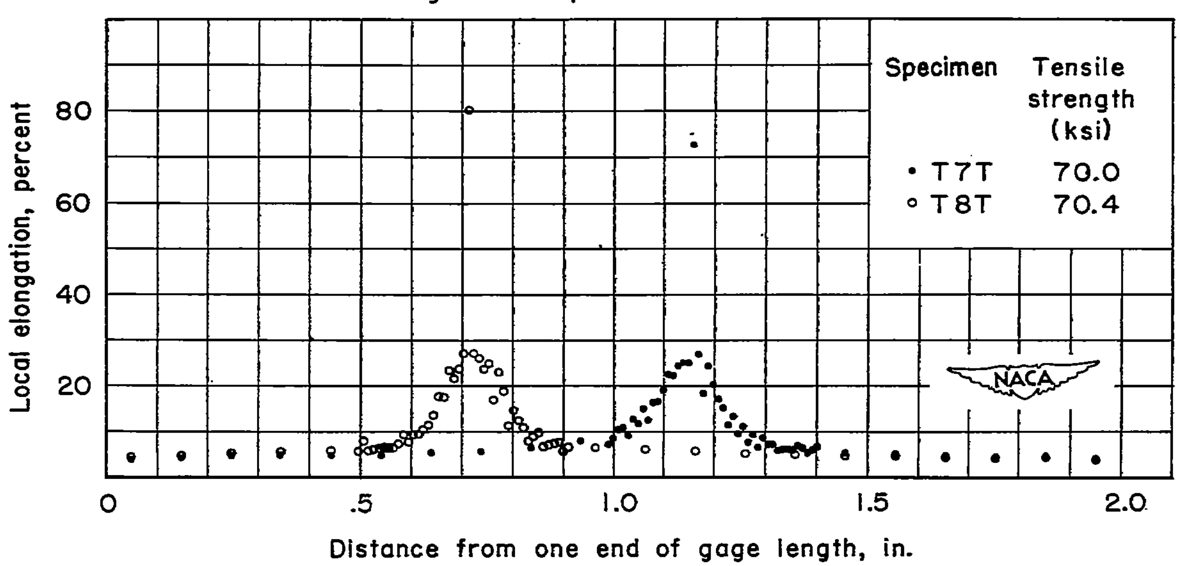


Figure 34.- Local elongation. Alclad 24S-T81 sheet, transverse specimens 0.125 inch thick.

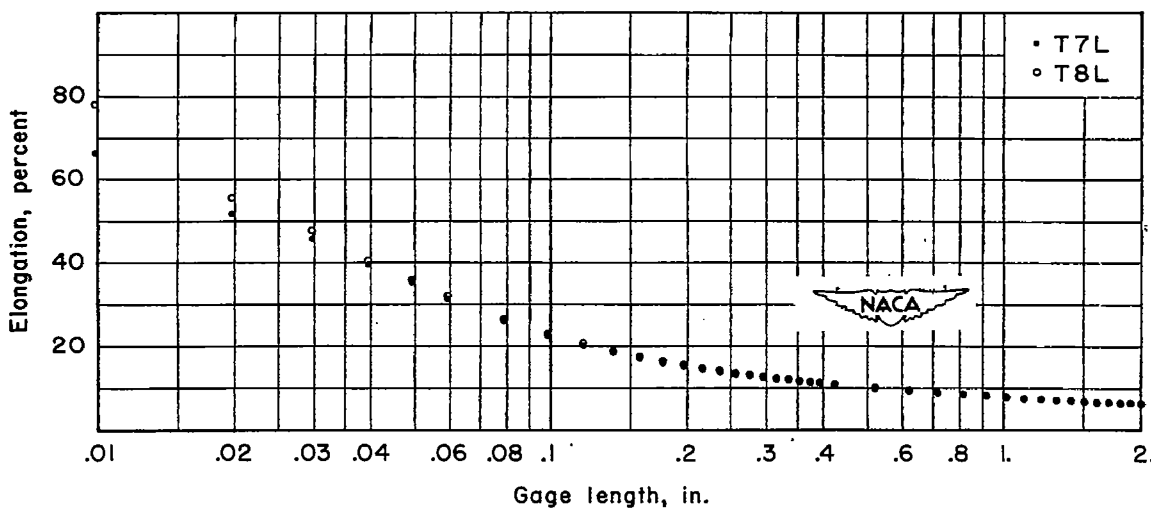


Figure 35.- Graphs of elongation against gage length. Alclad 24S-T81 sheet, longitudinal specimens 0.032 inch thick.

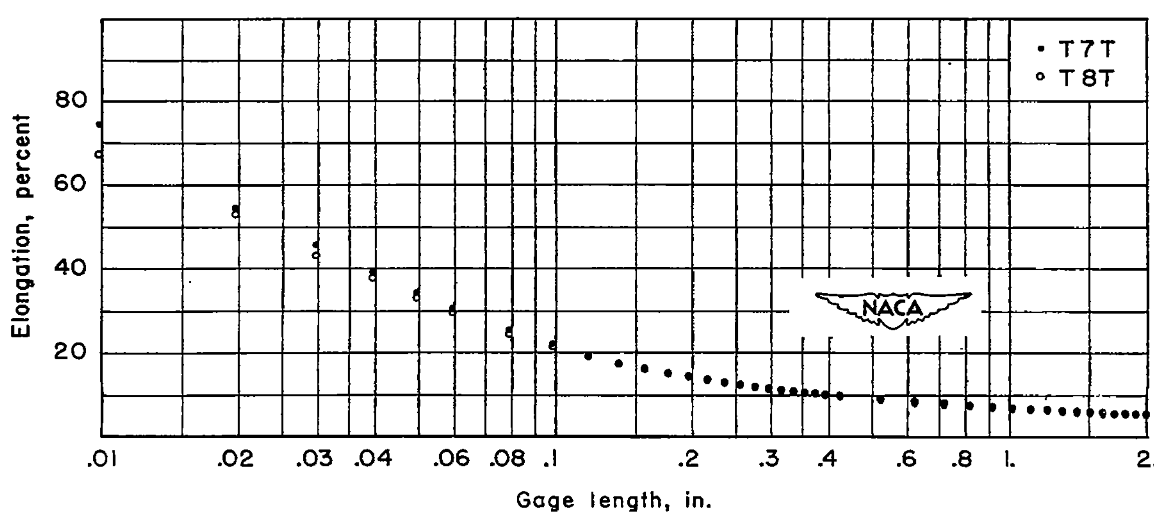


Figure 36.- Graphs of elongation against gage length. Alclad 24S-T81 sheet, transverse specimens 0.032 inch thick.

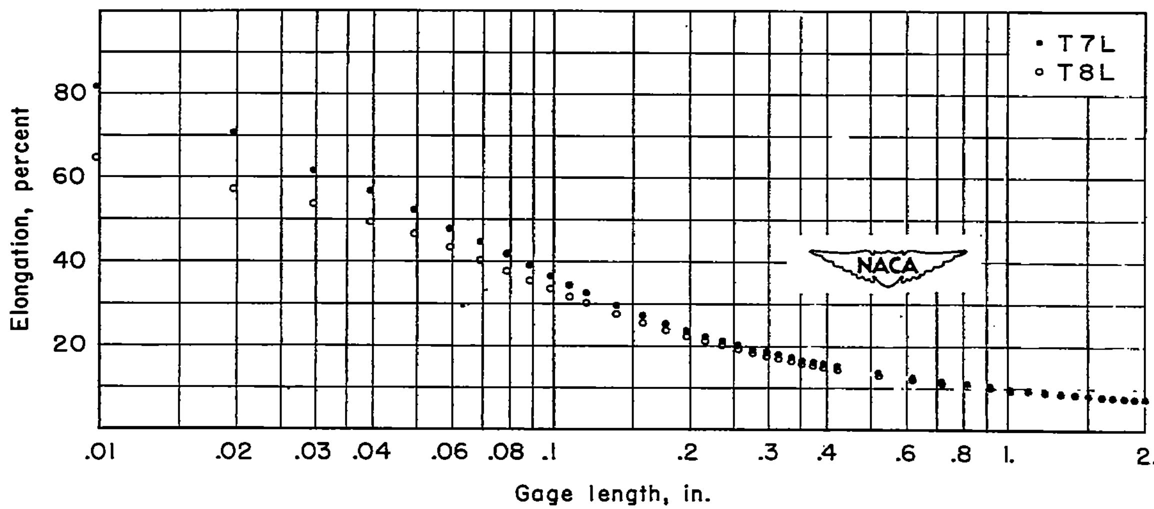


Figure 37.- Graphs of elongation against gage length. Alclad 24S-T81 sheet, longitudinal specimens 0.064 inch thick.

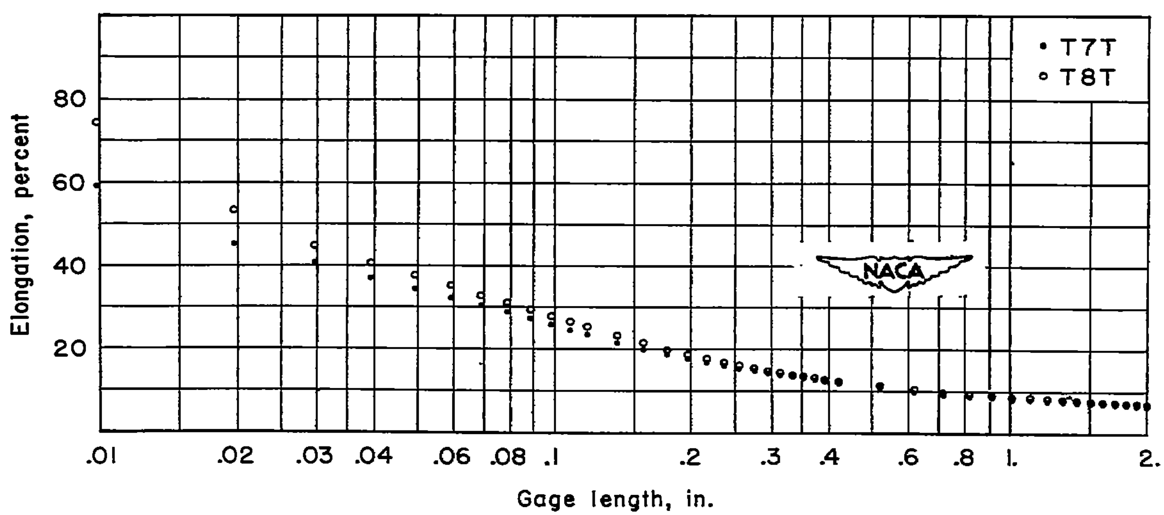


Figure 38.- Graphs of elongation against gage length. Alclad 24S-T81 sheet, transverse specimens 0.064 inch thick.

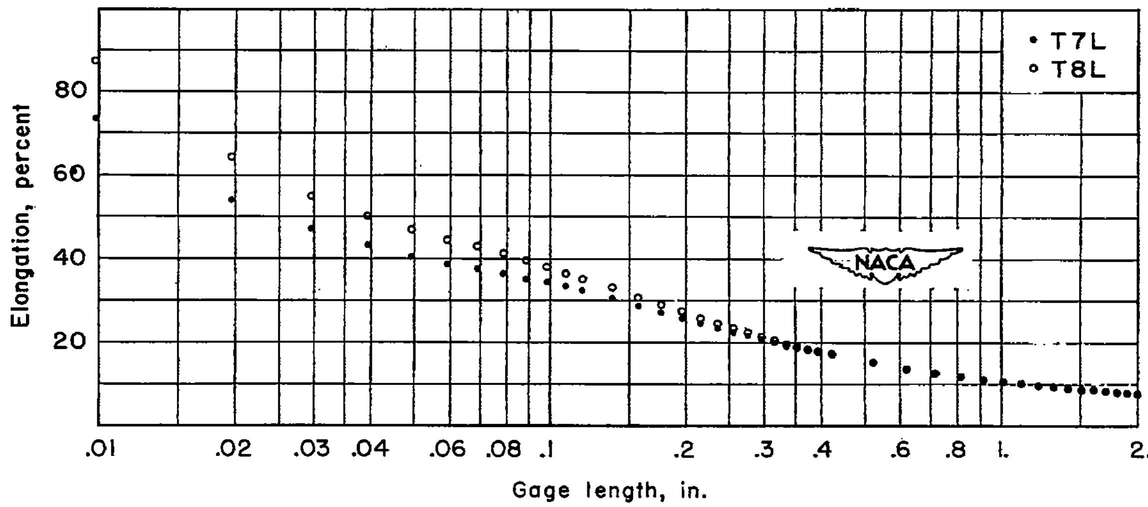


Figure 39.- Graphs of elongation against gage length. Alclad 24S-T81 sheet, longitudinal specimens 0.125 inch thick.

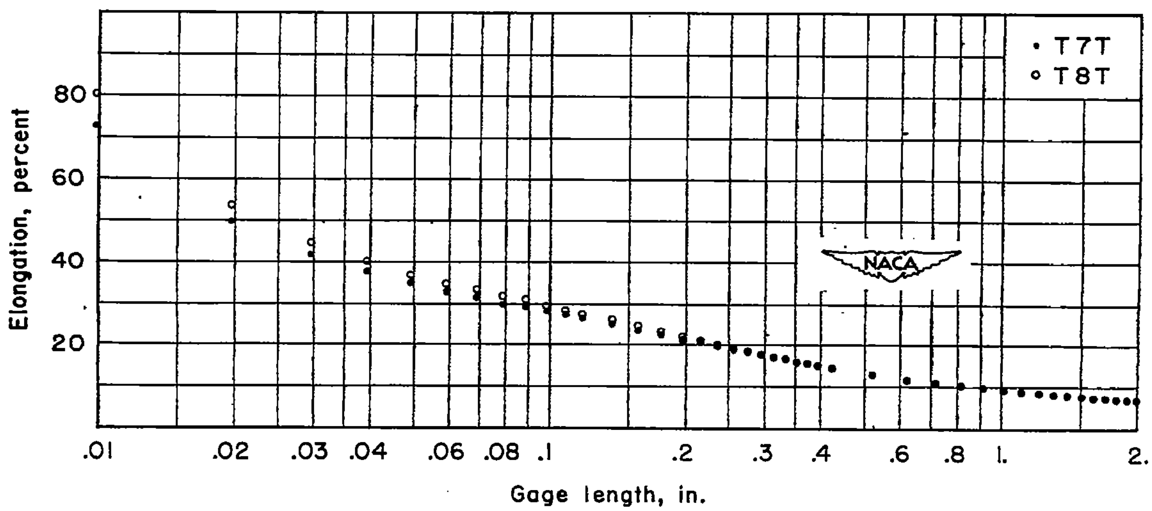


Figure 40.- Graphs of elongation against gage length. Alclad 24S-T81 sheet, transverse specimens 0.125 inch thick.