NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3204

AN INVESTIGATION OF THE CREEP LIFETIME OF 75S-T6 ALUMINUM-ALLOY COLUMNS

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SUMMARY

The results of short-time elevated-temperature creep tests of 75S-T6 aluminum-alloy columns are presented and examined with the objective of obtaining procedures for predicting column lifetime. Semiempirical lifetime curves are obtained with the aid of a previously published column creep theory and are used for deriving column curves. The semiempirical lifetime curves are also used to study the effect of varying applied stress and out-of-straightness. In the range considered, small variations in out-of-straightness are found to be of little practical significance; whereas, small stress variations change the column lifetime considerably. For the range of out-of-straightness encountered in the tests, the data can be presented in plots that do not explicitly include out-of-straightness, and plots of this type should be satisfactory for predicting column lifetime for design purposes.

INTRODUCTION

Considerable knowledge of the creep behavior of materials has been obtained from many theoretical and experimental studies during the past fifty years, but only recently, as a result of increased use of structures at elevated temperatures, has much attention been directed toward an understanding of the creep behavior of structural elements and composite structures. Supersonic aircraft and missiles represent one of the more recent and important uses of structures at elevated temperatures. At high speeds, the members of these structures may creep, and the distortions that result may be sufficiently large to affect the aerodynamic characteristics or to initiate complete failure of the structure.

The problem now confronting the designer is to determine, from the present knowledge of the creep behavior of the material, methods for predicting the magnitude of structural distortions and the time that the composite structure will support a given load at elevated temperatures. The column is the simplest of the fundamental structural elements whose behavior should be understood in order to bridge the gap between the behavior of the composite structure in compression and the behavior of the material.

Although several theories have been proposed for analyzing the creep behavior of columns (for example, refs. 1 to 5), few attempts have been made to correlate theory and actual column tests. In comparing experiment and theory, difficulties arise because of the idealizations employed in the theories and the scarcity of test data. A great deal of experimental work is required before sound procedures can be established for the design of columns which may be subjected to creep.

In the present paper, the results of static-strength and creep tests of 75S-T6 aluminum-alloy columns are presented. The creep test results are examined with the objective of obtaining procedures for predicting column lifetime. The data are plotted in terms of the parameters given by the column creep theory of reference 1, and semiempirical lifetime curves are obtained from the plots. The semiempirical lifetime curves are used to study the effects of variations in applied stress and out-of-straightness on the lifetime of the column. The column creep data are also plotted in forms that are used in the study of material creep data and do not explicitly include out-of-straightness. Procedures are discussed for obtaining column curves that may be satisfactory for predicting column lifetime.

SYMBOLS

A, B, K	material creep constants
b	column thickness, in.
d	lateral deflection of column at midheight including initial out-of-straightness, in.
d_o	initial out-of-straightness of column at midheight, in.
e	natural logarithmic base
E	Young's modulus, psi
L	column length, in.
t	time, hr
t_{cr}	lifetime of column subjected to creep, hr
T	temperature, $^{\circ}$F
T_R	absolute temperature, $^{\circ}$R

ϵ	strain, in./in.
ρ	minimum radius of gyration, in.
σ	stress, psi
$\bar{\sigma}$	average stress, psi
σ_E	stress corresponding to Euler load at a given temperature, psi
σ_T	stress corresponding to tangent-modulus load at a given temperature, psi

SPECIMENS, EQUIPMENT, AND PROCEDURES

Test specimens.- The column test specimens with a nominal cross section of 3/8 inch by 1/2 inch were machined from a 3/8-inch-thick 75S-T6 aluminum-alloy plate. The magnitude of the out-of-straightness at the midheight was measured for each specimen by a dial gage reading to 0.0001 inch. These specimens were used for determining the static strength as well as the creep strength of columns at elevated temperatures.

Compressive stress-strain specimens were machined from the same 3/8-inch-thick 75S-T6 aluminum-alloy plate. The compressive stress-strain specimens were 1.000 inch wide and 2.560 inches long.

Test equipment.- The equipment used for the column tests is shown in figures 1 and 2. The column was placed in fixtures supported on knife edges arranged so that the axes of rotation of the fixtures coincided with the ends of the specimen (fig. 3). The same equipment was used to support the specimen in both the static and the creep tests; however, for determining the static strength, load was applied by the hydraulic testing machine, and for determining creep behavior, a dead-weight apparatus was used to apply constant load.

The temperature control panel, shown in figure 1, permitted individual control of the electrical power supplied to each of the three horizontal banks of strip heaters in the furnace, as well as individual control of the power supplied to the heaters built into each end fixture. An automatic control device permitted the temperature of the columns to be maintained within ±3° F at the test temperatures. The specimen temperature was obtained with the aid of an automatic temperature recorder and iron-constantan thermocouples that were fastened by spring clips at the midheight and near each end of the columns.

The magnitude of the midheight lateral deflection of the column was measured by a rod and lever assembly which actuated a linear variable differential transformer (fig. 2). For the static tests, the deflection was autographically recorded against load; for the creep tests, against time.

Column alinement procedure.- Alinement of the ends of the column to insure concentric axial load application was accomplished at room temperature as follows: A column specimen with relatively large out-of-straightness and an intermediate value of slenderness ratio was placed in the end fixtures, the end of the column fitting into a slotted plate as shown in figure 3. A hydraulic testing machine was used to apply end load on the column, and a curve of load against midheight deflection was obtained.

The maximum load applied was always less than the load that would produce permanent deformation in the column. Upon removal of the load, the column was rotated 180° about its longitudinal axis, another load was applied, and another curve of load against midheight deflection was obtained. Adjustments in the alinement screws were made until the two deflection curves were symmetrical about the load axis. Final adjustments were made by using a column with small out-of-straightness and repeating the above procedure. The slotted plates at the ends of the column were then locked in place. The alinement procedure was not repeated for each test; however, periodic checks of the alinement were made between tests.

Test procedures.- For all tests the furnace and fixtures were initially stabilized at the test temperatures. The specimens were then placed in the fixtures and exposed to the test temperature for 30 minutes prior to application of load.

For both the compressive stress-strain and static tests of the columns, load was applied by a hydraulic testing machine at a rate of average strain of 0.002 per minute.

Results of the static tests and the compressive stress-strain tests were used as a basis for selecting the magnitude of the fixed load to be applied in the column creep tests. After the column creep specimen had been exposed to the test temperature, the fixed load was applied on the specimen at a rate requiring approximately 20 seconds for the total load to bear. The load was maintained on the specimen until collapse occurred, and the lifetime was measured from the beginning of loading and ranged, in general, from several minutes to a few hours. The specimen data and test results are given in table I.

RESULTS AND DISCUSSION

Stress-Strain and Static Tests

Figure 4 presents compressive stress-strain curves for the 75S-T6 aluminum-alloy plate at room temperature and at 300°, 400°, 500°, and 600° F, with 30-minute exposure at the elevated temperatures. Each curve represents an average obtained from the results of several tests. The material shows substantial decreases in compressive strength and stiffness with increasing temperature.

Results of static tests of the columns are shown in figure 5 for 300°, 400°, 500°, and 600° F and are compared with the tangent-modulus and Euler stresses determined from the stress-strain test results. The test points in general show good agreement with the tangent-modulus and Euler stresses for pin-ended columns. In particular, the tangent-modulus stress is a good approximation for the maximum column stress for the inelastic or short columns at elevated temperatures. The scatter that appears in the test results at a fixed slenderness ratio is probably accounted for in part by differences in the initial out-of-straightness of the columns as shown, for example, in reference 6.

Creep Tests

Figure 6 shows typical deflection results obtained in the column creep tests for columns having slenderness ratios of approximately 30 and 100. The total midheight deflection expressed as a fraction of the column thickness is plotted against time. For the short column, collapse occurred when the midheight deflection was less than 10 percent of the column thickness, and for the long columns, collapse occurred when the midheight deflection was less than 75 percent of the column thickness. Since these results are representative of all the tests, it appears that the use of small-deflection theory for analysis of column deflections due to creep is reasonable and, in most cases, not subject to any appreciable error up to the beginning of collapse of the column. In addition, figure 6 shows that failure or collapse of the column occurs rather suddenly after a critical value of deflection is reached.

The most significant information obtained from these plots is the column lifetime. The lifetimes obtained in all the creep tests are given in table I and the corresponding stress ratios $\bar{\sigma}/\sigma_E$ and $\bar{\sigma}/\sigma_T$ are included. An examination of table I reveals that for short-time creep tests the low stress ratios $\bar{\sigma}/\sigma_E$ are associated with the short or inelastic columns and high stress ratios with long or elastic columns. In the present paper, the tangent-modulus stress is assumed to be the maximum stress that the short or inelastic column can support. In the long- or elastic-column range, the Euler stress σ_E and the tangent-modulus stress σ_T are identical and are assumed to be the maximum or failing stress. Application of the maximum stress in either case implies zero column lifetime.

Correlation of Data With Column Creep Theory

Theoretical column creep parameters.- The theoretical analysis of reference 1 provides three parameters that may be used for presenting creep test results of columns of a given material at a specified temperature. These parameters are a stress parameter $\bar{\sigma}/\sigma_E$, a lifetime parameter $t_{cr}e^{B\bar{\sigma}/K}$, and an out-of-straightness parameter $\bar{\sigma}\frac{d_o}{b}$ and are derived in reference 1 by employing the assumed material creep relation

$$\epsilon = \frac{\sigma}{E} + Ae^{B\sigma}t^K$$

where A, B, and K are material constants. This relation, originally proposed in reference 7 and there shown to describe the creep behavior of 75S-T6 aluminum alloy at 600° F, is assumed in the present paper to approximate satisfactorily the creep behavior of the material at other temperatures. The approximate values of A, B, and K, determined from data for 211°, 300°, and 375° F in reference 8 and given for 600° F in reference 7, were used to determine the curves in figure 7. In addition, the variation of the elastic modulus with temperature, determined from the stress-strain curves reproduced in figure 4, is presented in figure 7.

Comparison of theory with test results.- The creep behavior of a column is expressed in reference 1 by a partial-differential equation that is difficult to evaluate for a particular case. An approximate solution of this equation can be obtained in closed forms which can be readily evaluated from tables of functions by following the procedure outlined in reference 1 (pp. 14 and 15). An example of this approximate solution is given in figure 8 for 400° F where stress-ratio curves, obtained with the aid of the material constants of figure 7, are plotted in terms of the lifetime and out-of-straightness parameters. Test data are also shown in figure 8 and the value of stress ratio $\bar{\sigma}/\sigma_E$ is given at each point. A comparison of the test data with the approximate theoretical solution indicates that the theory will, in general, predict lifetimes that are smaller than those obtained in the tests.

The fact that the theoretical lifetimes are smaller than the experimental lifetimes is not the result of the approximations made in the solution of the partial-differential equation, because the more detailed solution gives even smaller lifetimes. (See, for example, fig. 7 of ref. 1.) The discrepancy must be due to the assumptions made in the theoretical analysis regarding material and column behavior. For example, it was assumed that stresses and deflections of the column existing immediately upon load application are obtainable from an elastic analysis, an assumption usually violated for short or inelastic columns. This assumption of elastic behavior yields stresses and resulting creep strains on the concave side of the column that are greater than the actual values. Since the magnitude of the creep strain on the concave side is used as a criterion for column lifetime in the theoretical analysis, the predicted lifetime will be less than the experimental lifetime, and the discrepancy will be greatest for short or inelastic columns, as indicated in figure 8. In addition, use of the previously stated material creep relation to approximate material behavior for all conditions of stress and temperature may contribute to the discrepancy.

Despite the fact that disagreement exists between the theoretical and experimental lifetimes, empirical corrections of the theoretical solution made on the basis of tests will produce results that are useful for predicting column lifetime.

Semiempirical lifetime curves.- In figure 9, the results of the creep tests are plotted in terms of the theoretical parameters, and lines of constant stress ratio have been fitted to the data. The general shape of the curves was assumed to be similar to that of the curves given by the approximate theoretical solutions, but the actual location of the lines of constant stress ratio is determined from the test data. In general, the curves of constant stress ratio on the experimental plot of figure 9 have been shifted vertically relative to the stress-ratio curves of the theoretical plots in figure 8. Column lifetime may be predicted from the empirical plots in figure 9 for values of stress and out-of-straightness not encountered in the tests.

An examination of figure 9 indicates the possibility that like stress-ratio curves for different temperatures may coincide, in particular for the lower stress-ratio curves. However, the theory of reference 1 does not predict this behavior, and on the basis of the limited number of tests and the approximate evaluation of the material creep constants, presentation of the data in this manner is not at present warranted.

Column curves.- The column lifetime curves presented in figure 10 for the four test temperatures, several lifetimes, and a fixed value of dimensionless out-of-straightness were derived from figure 9. The dimensionless value of out-of-straightness of 0.01 was selected as representative of the value encountered in the tests. The lifetime curves of 0.1 and 1 hour can be verified by the test data. However, the curves for 10 and 100 hours are extrapolations that become possible when the test data are plotted in terms of the parameters of reference 1; these extrapolations have not been verified by tests of that duration. The tangent-modulus and Euler stresses obtained by appropriate use of the material stress-strain curves are also shown in figure 10 and are assumed to be the maximum static stresses for the columns at each temperature.

Effect of Variations in Stress and Out-of-Straightness

The relative variations that occur in column lifetime due to changes in applied stress or out-of-straightness are illustrated in figure 11, which is reproduced from the 400° F plot of figure 9. In addition to the curves of constant stress ratio $\bar{\sigma}/\sigma_E$ that appear in figure 9, two families of lines, constant column geometry and lifetime, have been added to aid in the study of the significance of these variations. The curves of constant column geometry $\sigma_E \frac{d_o}{b}$ and constant stress ratio $\bar{\sigma}/\sigma_E$ are general in nature because many combinations of applied stress $\bar{\sigma}$, slenderness ratio L/ρ, and dimensionless out-of-straightness d_o/b will apply. The lifetime curves of 1 and 10 hours are shown for three specific values of out-of-straightness and cannot be generalized. The 1-hour lifetime curves for all given values of out-of-straightness intersect the vertical axis at a value of the lifetime parameter of unity. Similarly, the 10-hour lifetime curves intersect the vertical axis at a value of 10. In addition, all time lines for a given out-of-straightness are parallel.

The changes in column lifetime that result from variations in applied stress with the out-of-straightness constant are shown by the appropriate $\sigma_E \frac{d_o}{b}$ curve. In like manner, the changes in column lifetime that result from constant stress and variations in out-of-straightness are indicated by the appropriate $\bar{\sigma}/\sigma_E$ curve.

As a specific example of the effects of stress and out-of-straightness variations on a particular column, consider a column having an Euler stress σ_E of 40,000 psi (or $L/\rho \approx 46$) and an out-of-straightness d_o/b of 0.01. If the lifetime is chosen to be 1 hour, the time line intersects the column-geometry curve $\sigma_E \frac{d_o}{b}$ at a stress ratio $\bar{\sigma}/\sigma_E$ of 0.5, or $\bar{\sigma} = 20{,}000$ psi and $\bar{\sigma}d_o/b = 200$. Reducing the applied stress $\bar{\sigma}$ by 15 percent, or from 20,000 to 17,000 psi, changes $\bar{\sigma}d_o/b$ to 170, and at this value of the abscissa the column-geometry curve $\sigma_E d_o/b = 400$ intersects the time line of 10 hours. Thus the column lifetime has been increased by a factor of 10 for this change in applied stress.

In contrast, if the column dimensionless out-of-straightness is changed by the same percentage as the stress, or from 0.01 to 0.0085, and the applied stress remains fixed, the change in column lifetime can be determined by proceeding along the curve $\bar{\sigma}/\sigma_E = 0.5$ to the value of 170 defined by the abscissa. The new lifetime will now be calculated from the magnitude of the ordinate because time lines are not shown in figure 10 for this particular out-of-straightness. The calculated lifetime of 1.2 hours is very close to the original 1-hour lifetime; the difference between the two values is within the scatter to be expected in column creep test data. In order to increase the column lifetime from 1 to 10 hours (the result of lowering the stress 15 percent), the out-of-straightness must be decreased to less than 1/20 of the initial value 0.01.

In order that numerical comparisons can be made of the relative importance of stress and out-of-straightness changes, figure 12 was prepared to show the effects of these changes on column lifetime. Stress and out-of-straightness values that will produce column failure in 1 hour at 400° F are tabulated in the figure for three slenderness ratios.

The result of a given stress variation is to change the column lifetime considerably; whereas, a similar percentage change in out-of-straightness has a very small effect on the lifetime. In addition, the lifetime of a long or elastic column ($L/\rho = 70$) is influenced to a greater extent by stress changes than is the lifetime of a short or inelastic column ($L/\rho = 30$). Out-of-straightness variations in long columns similarly have a larger effect on column lifetime than in short columns. Figure 12 shows why small variations in applied stress may materially affect column lifetime in an experimental investigation and also shows why it is difficult to determine experimentally the changes in column lifetime that are the result of small variations in out-of-straightness.

Additional Methods for Correlating Column Creep Data

Inasmuch as small variations in out-of-straightness produce relatively small changes in lifetime, it is feasible to present the test data in forms which do not explicitly include the effects of out-of-straightness. Two such forms, frequently used in the analysis of material creep data, are stress-lifetime and stress-temperature-lifetime plots.

Stress-lifetime plots.- In figure 13, the results of the column creep tests are presented in terms of stress plotted against lifetime on a logarithmic scale - a method similar to that used in analyzing material creep or fatigue data. Over the range of lifetime covered by the test results, the curves are assumed to be straight lines. The symbols on the vertical axis indicate the magnitude of the tangent-modulus stresses, and, as previously mentioned, application of the tangent-modulus stress is assumed to imply that the column lifetime is zero. It is evident from the grouping of the limited amount of test data that a plot of this nature permits a reasonable prediction of the column lifetime. Figure 13 also indicates that a small variation in stress produces a greater change in the lifetime of long columns than of short columns.

Stress-temperature-time plots.- A disadvantage of the plots shown in figure 13 is that the effects of temperature changes on the column lifetime are not shown directly. Time-temperature parameters that have been developed for analyzing material creep data may be helpful in overcoming this disadvantage. The column creep test data are plotted in figure 14 in terms of a time-temperature parameter given in reference 9. The time-temperature parameter $T_R(C + \log t_{cr})$ contains a constant C which must be empirically determined. The value of $C = 20$ was determined from a limited amount of available data from creep tests of 75S-T6 aluminum alloy (ref. 7) and in the present paper is used for short-time creep tests of rectangular-cross-section columns of the same material. It is possible that the constant may assume a different value for columns of other cross section or for long-time creep tests.

An examination of the time-temperature parameter indicates that for a fixed temperature the test data of figure 14 are in the same form as in figure 13 except for a scale factor in the abscissa. In addition to making it possible to show creep results for all temperatures on one figure, the plot of figure 14 is of value for predicting lifetime at any stress level for temperatures other than the test temperatures, provided the predicted lifetime is of the order of magnitude of the test lifetimes.

Design Recommendations

Figures 9, 13, and 14 present plots of creep test results from which column curves may be determined; for example, the column curves of figure 10 were obtained from figure 9. The selection of one of these types of plots for predicting column lifetime depends upon the particular problem encountered. If a column lifetime is desired for an out-of-straightness that is considerably different from the test values, the type of plot shown in figure 9 is recommended because extrapolations to out-of-straightness values outside the test range are possible. However, in most cases the out-of-straightness is not known or not considered, and the use of the type of plot such as figure 14, which does not explicitly include the effect of out-of-straightness, should be satisfactory for predicting lifetime for design purposes.

CONCLUDING REMARKS

Static tests of 75S-T6 aluminum-alloy columns that were made in conjunction with the column creep tests indicate that the tangent-modulus stress is a good approximation for the maximum stress of short, or inelastic, columns at elevated temperatures, as has been previously shown to be true at room temperature.

A comparison of experimental lifetimes with those obtained from a previous theoretical analysis of column creep indicates that the theory predicts lifetimes that are less than the experimental values. In order to obtain a procedure for predicting lifetimes based on the significant parameters of this theory, the limited amount of test data is used to make empirical adjustments to the theoretical lifetimes, and column curves are then obtained for a fixed out-of-straightness from the semiempirical lifetime curves.

A study of the semiempirical lifetime curves shows that small variations in applied stress produce considerable change in column lifetime, whereas the same percentage of variation in out-of-straightness produces a relatively insignificant change in lifetime. The study also reveals that variations in applied stress or out-of-straightness have a greater effect on the lifetime of long columns than of short columns.

Because of the small effect of variations in out-of-straightness on column lifetime for the range of random out-of-straightness encountered in the tests, procedures for predicting column lifetime can be obtained by presenting the data in the form of plots that do not explicitly include out-of-straightness. One such plot shows applied stress in terms of a time-temperature parameter, and, on the basis of limited test data, this type of plot appears to be satisfactory for predicting column lifetime for design purposes.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 22, 1954.

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TABLE I.- SPECIMEN DATA AND CREEP TEST RESULTS FOR

75S-T6 ALUMINUM-ALLOY COLUMNS

Column	T, $^{\circ}$F	L/ρ	d_o/b	$\bar{\sigma}$, psi	$\bar{\sigma}/\sigma_E$	$\bar{\sigma}/\sigma_T$	t_{cr}, hr
1	300	29.4	0.0029	45,100	0.42	0.94	0.56
2	300	29.5	.0084	39,700	.38	.83	3.83
3	300	40.3	.0029	33,700	.60	.79	6.74
4	300	40.5	.0078	31,600	.56	.74	.66
5	300	50.1	.0026	29,100	.79	.82	3.37
6	300	50.0	.0042	28,950	.79	.82	.89
7	300	58.5	.0057	23,450	.87	.87	.52
8	300	63.2	.0073	19,190	.83	.83	1.90
9	300	63.1	.0116	19,540	.85	.85	1.30
10	300	72.7	.0032	16,620	.95	.95	.88
11	300	71.9	.0212	15,780	.88	.88	1.58
12	300	98.6	.0391	8,510	.89	.89	4.02
13	400	29.2	.0018	29,900	.30	.90	.28
14	400	29.2	.0049	28,700	.29	.87	.94
15	400	29.9	.0093	28,500	.30	.87	.22
16	400	38.3	.0080	24,820	.43	.81	.22
17	400	38.2	.0082	23,740	.43	.78	.45
18	400	40.4	.0028	23,450	.45	.78	.87
19	400	49.3	.0134	17,340	.50	.65	2.18
20	400	58.7	.0047	15,600	.63	.69	1.77
21	400	67.8	.0045	15,300	.83	.83	.11
22	400	72.2	.0039	12,400	.77	.77	4.83
23	400	72.7	.0168	10,940	.68	.68	4.45
24	400	89.9	.0060	9,130	.87	.87	.46
25	400	98.8	.0067	7,630	.89	.89	1.28
26	400	100.4	.0332	6,940	.82	.82	2.27
27	500	30.0	.0043	13,040	.17	.86	.69
28	500	29.2	.0083	12,250	.15	.80	1.53
29	500	29.4	.0120	10,360	.13	.68	1.90
30	500	40.6	.0050	10,810	.26	.77	.69
31	500	40.7	.0107	9,880	.24	.70	1.08
32	500	40.5	.0135	8,860	.21	.63	1.93
33	500	49.8	.0063	9,390	.34	.73	1.05
34	500	49.9	.0118	8,990	.33	.70	1.79
35	500	49.3	.0148	8,180	.29	.63	1.66
36	500	58.5	.0065	9,490	.47	.80	.50
37	500	58.4	.0096	8,840	.44	.75	1.10
38	500	72.3	.0140	6,810	.52	.68	1.59
39	500	99.2	.0078	5,830	.84	.84	.29
40	500	99.2	.0159	4,900	.70	.71	1.32
41	600	29.4	.0034	5,930	.10	.85	.98
42	600	29.2	.0119	5,660	.10	.81	1.41
43	600	29.2	.0182	5,160	.09	.74	1.41
44	600	40.7	.0042	5,610	.18	.85	.34
45	600	41.0	.0121	4,540	.15	.70	2.00
46	600	50.2	.0032	4,180	.18	.68	2.00
47	600	58.6	.0060	4,540	.30	.78	.50
48	600	58.8	.0102	4,270	.29	.74	1.16
49	600	58.6	.0180	3,570	.24	.62	3.77
50	600	73.2	.0055	4,150	.44	.80	1.10
51	600	72.1	.0125	3,750	.38	.72	.99
52	600	99.2	.0078	3,130	.60	.77	.93
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54	600	110.3	.0038	3,080	.73	.84	.35

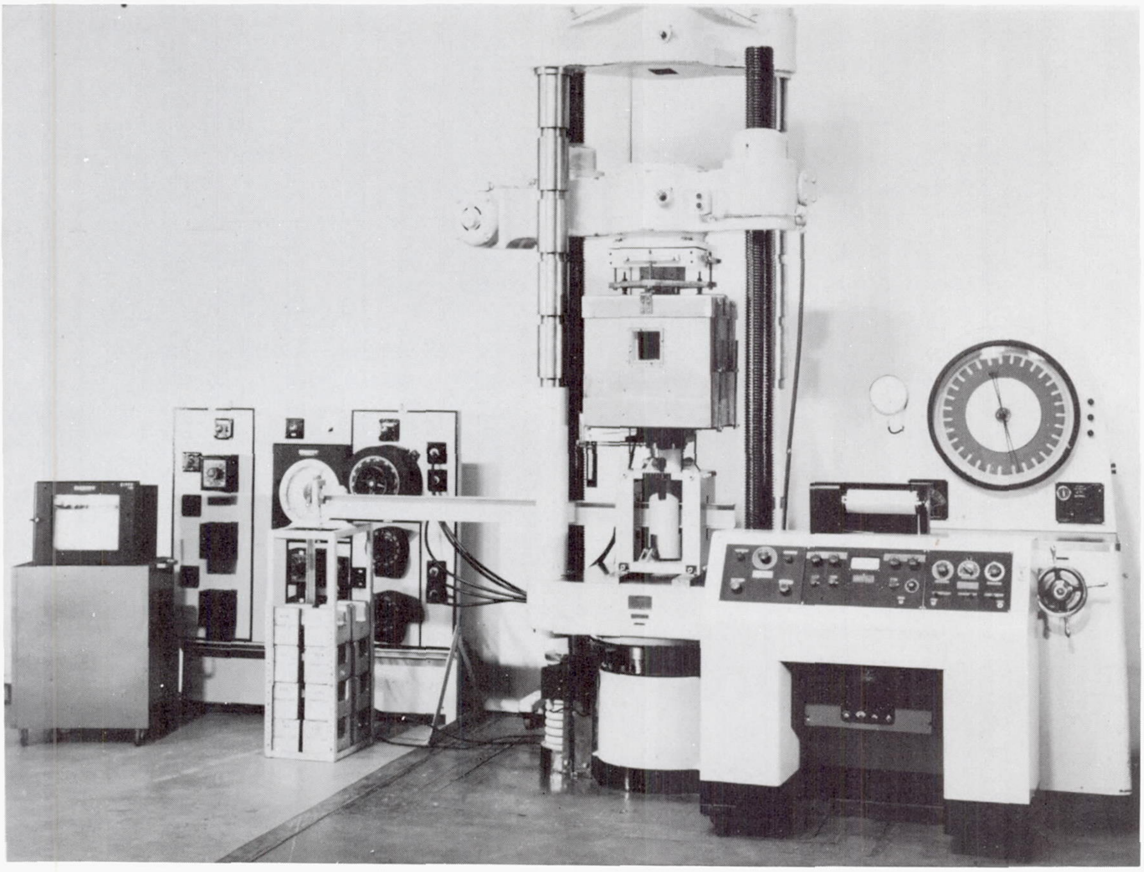

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Figure 1.- Test equipment.

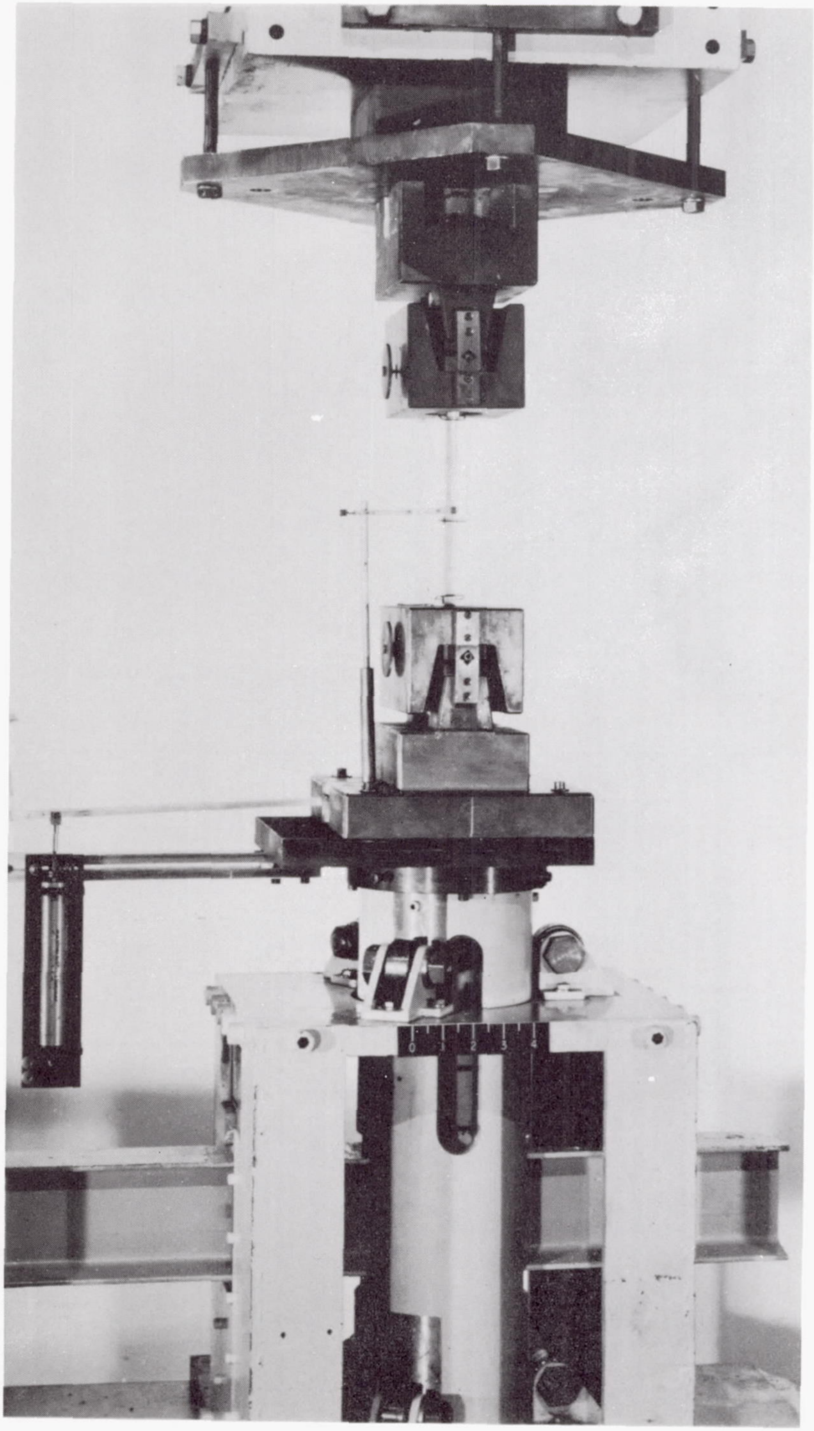

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Figure 2.- Column end fixtures and apparatus for measuring midheight deflection.

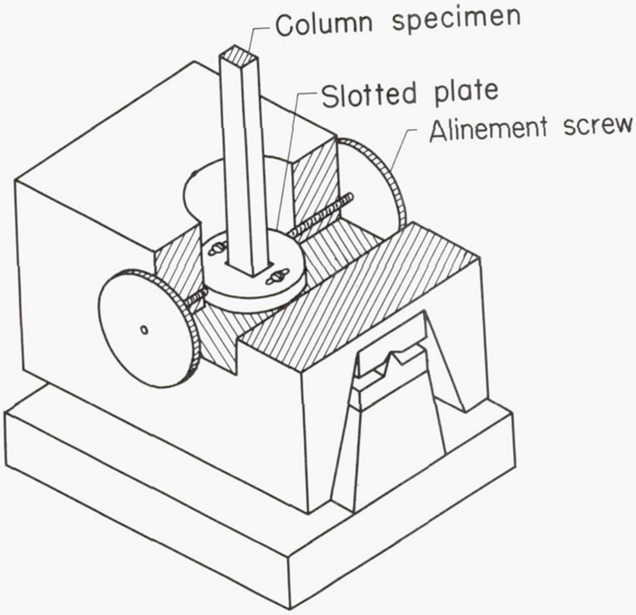


Figure 3.- Sectional view of column fixture.

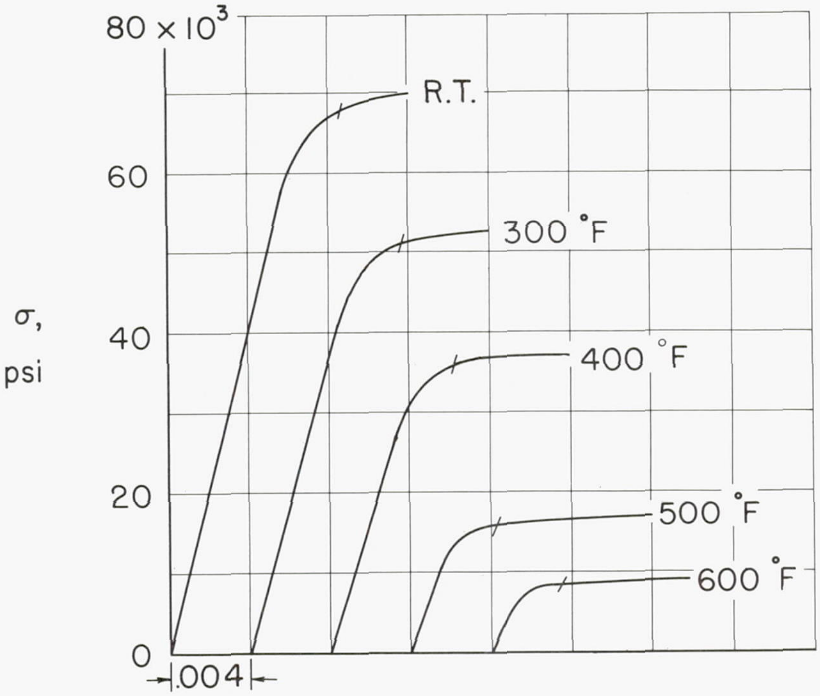


Figure 4.- Compressive stress-strain results for 75S-T6 aluminum-alloy plate. Plate thickness, 3/8 inch; exposure time, 30 minutes; strain rate, 0.002 per minute.

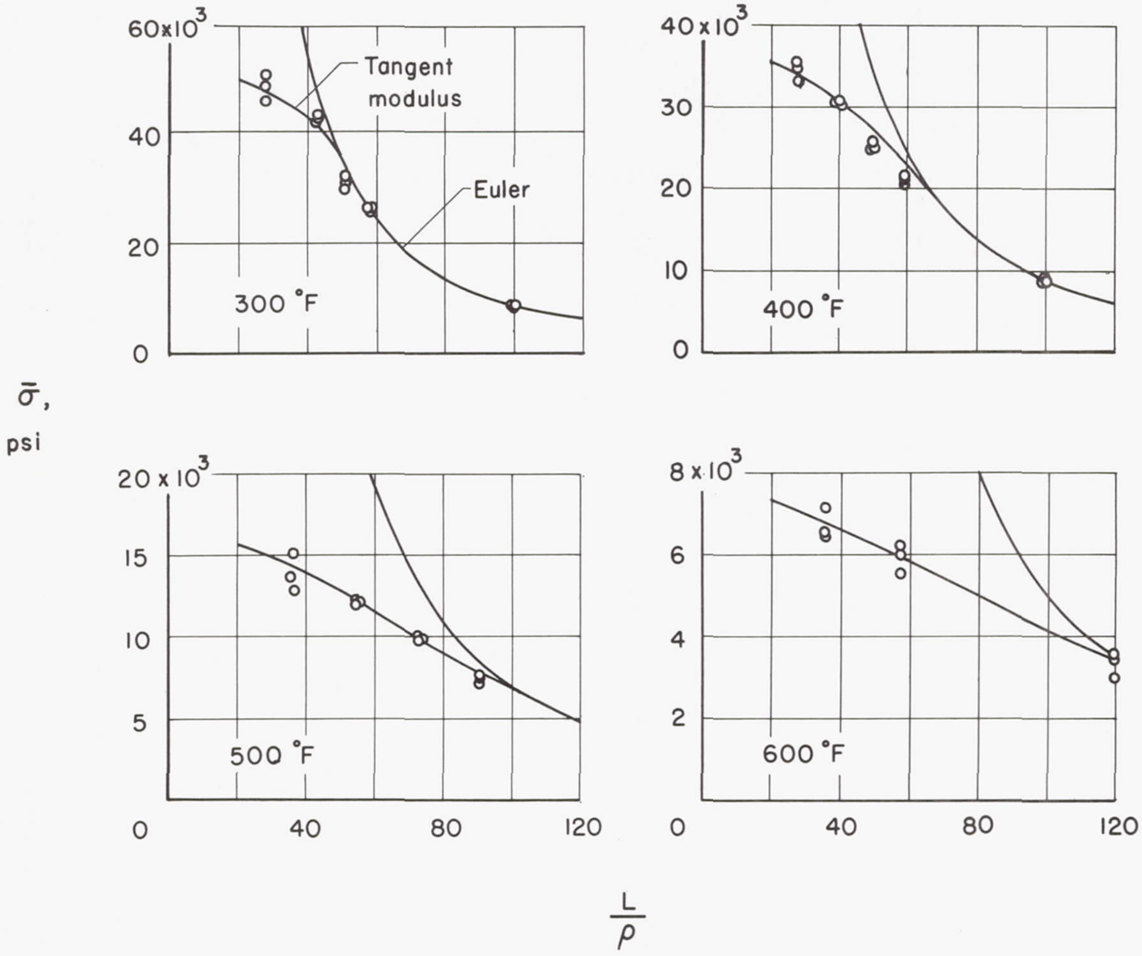


Figure 5.- Static-strength test results for 75S-T6 aluminum-alloy columns. Nominal cross section, 3/8 inch by 1/2 inch.

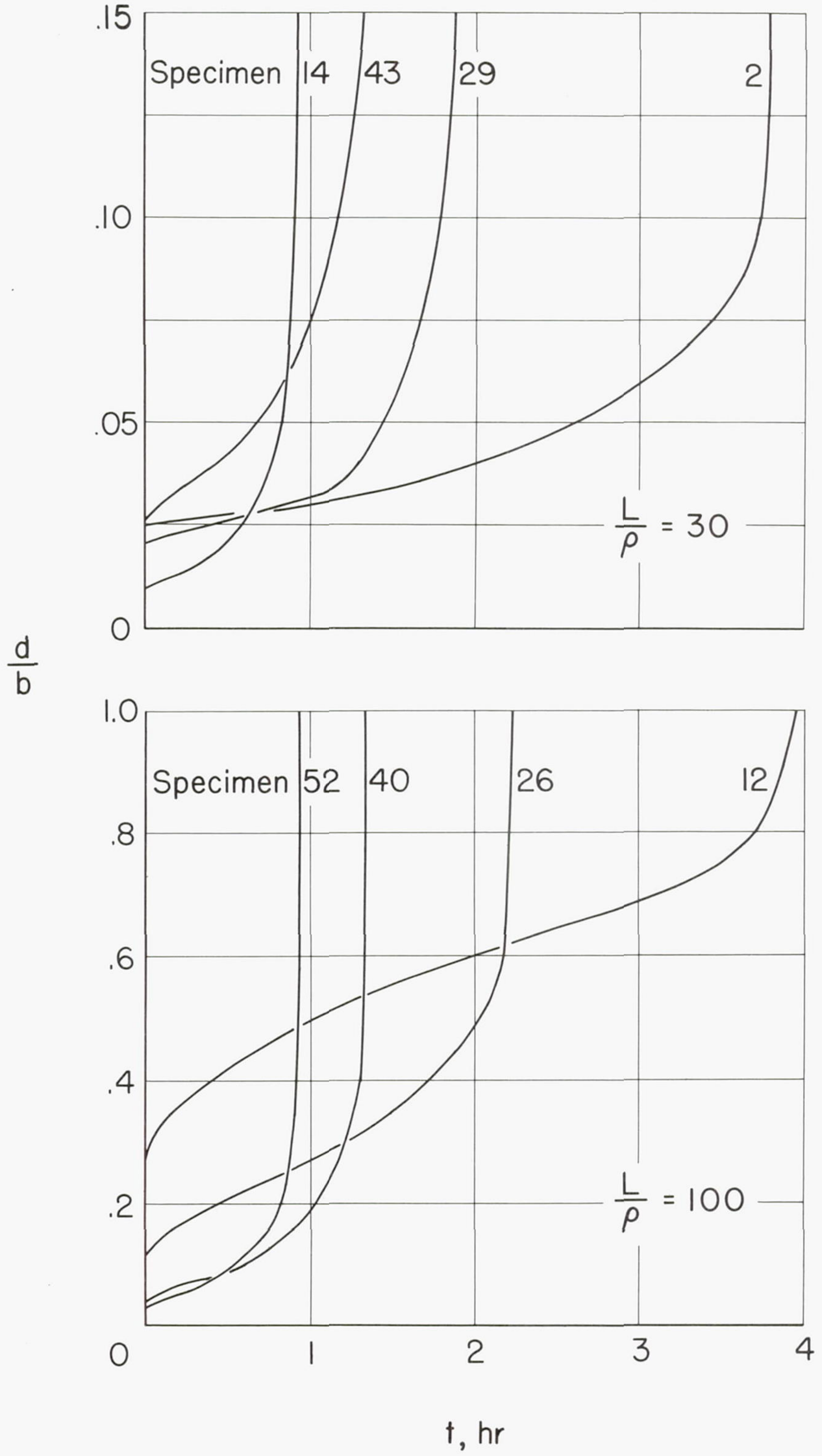


Figure 6.- Typical deflection curves from creep tests of 75S-T6 aluminum-alloy columns.

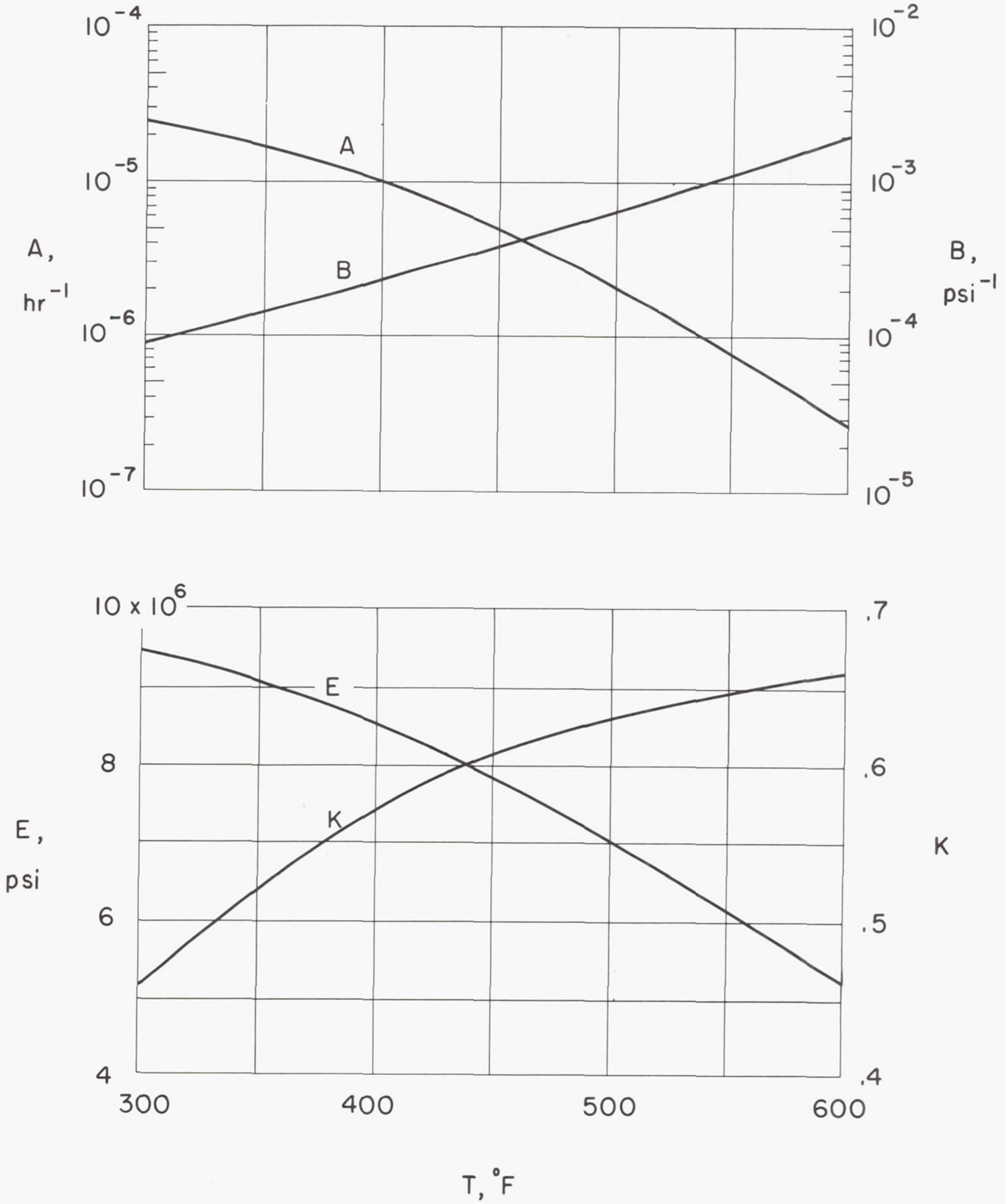


Figure 7.- Material creep constants of 75S-T6 aluminum alloy for the creep relation $\epsilon = \frac{\sigma}{E} + Ae^{B\sigma}t^{K}$.

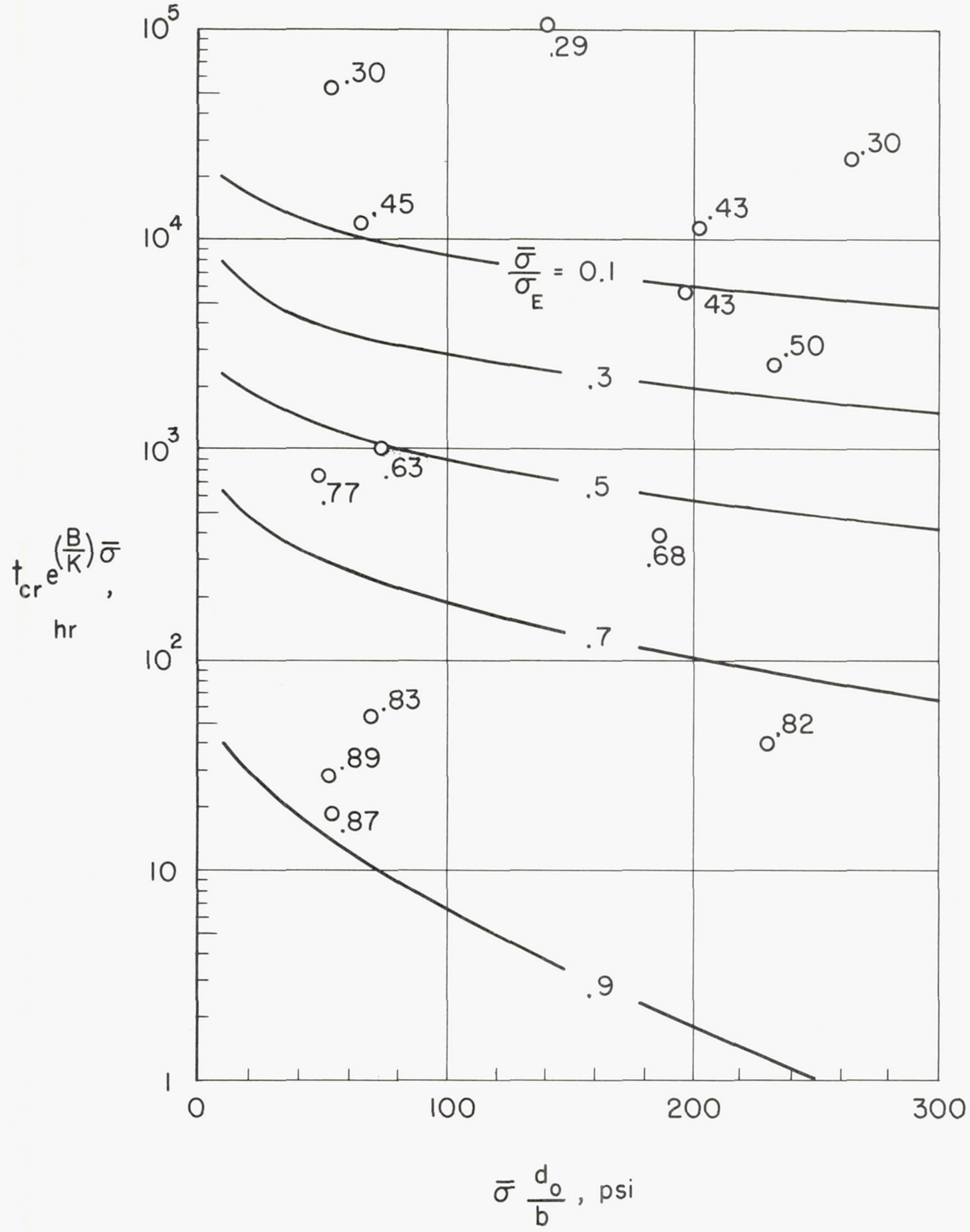
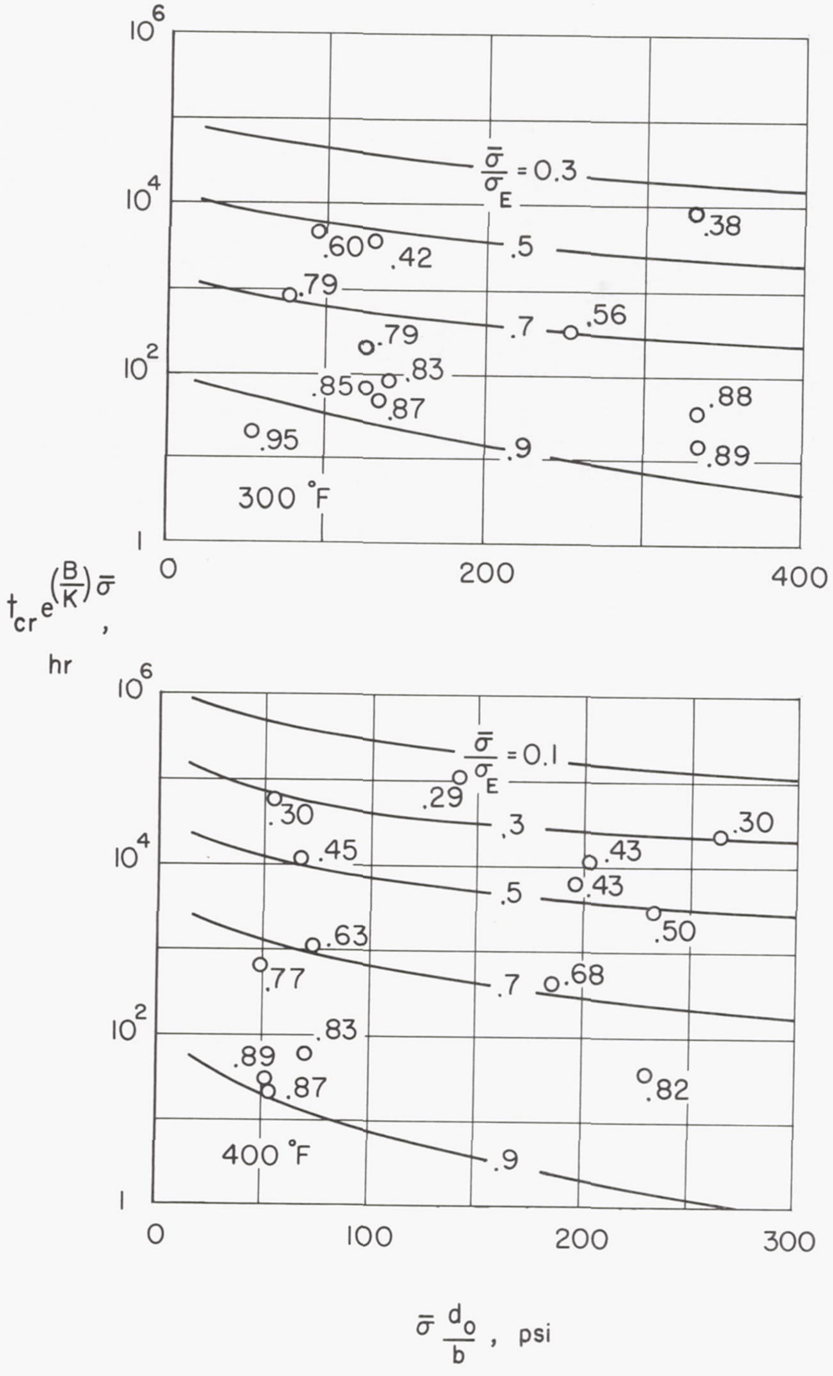
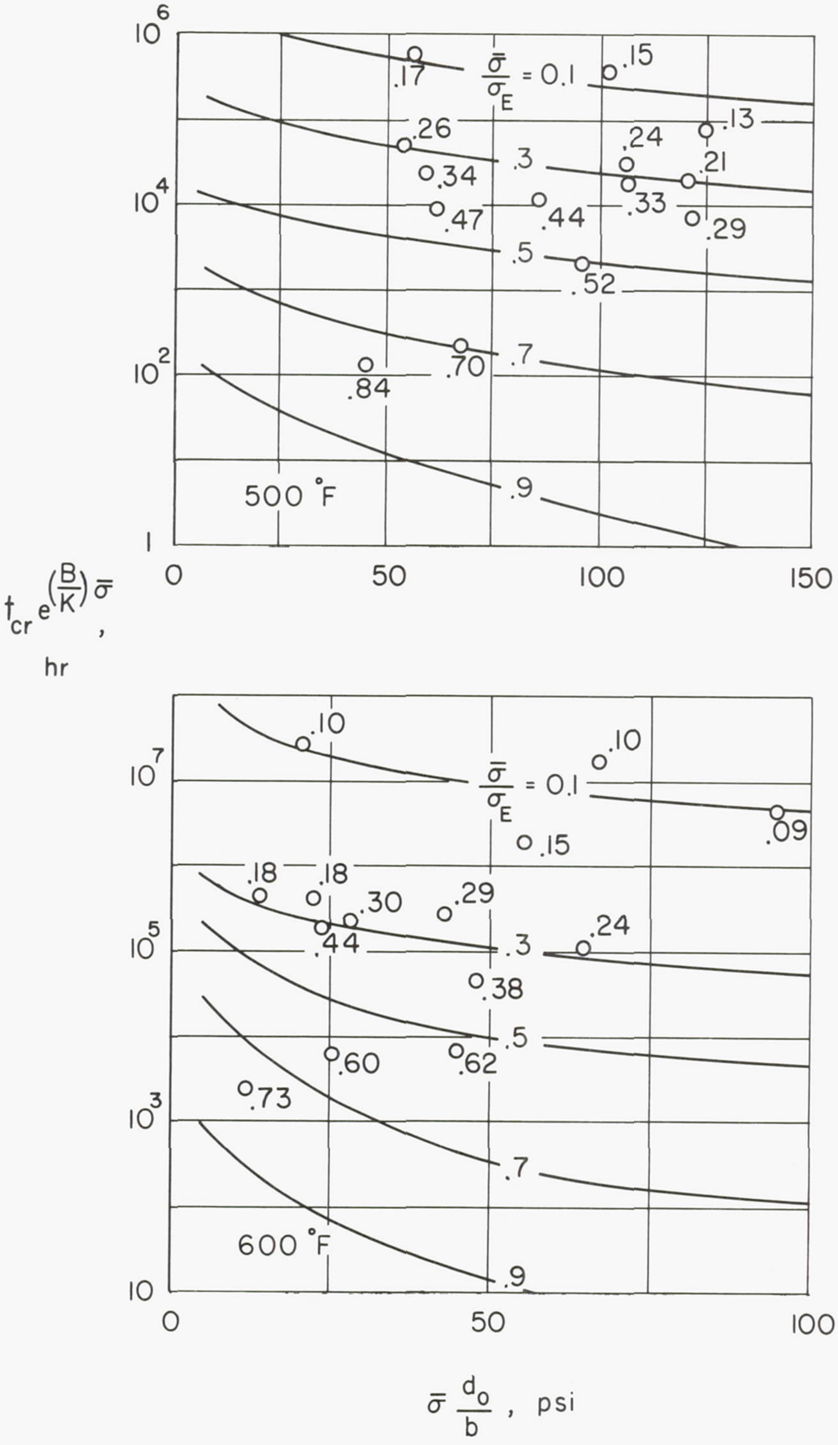


Figure 8.- Comparison of column lifetime obtained from theoretical solution suggested in reference 1 (pp. 14 and 15) and test data $\left(\frac{\bar{\sigma}}{\sigma_E}\right.$ indicated at each test point$\left.\right)$. T = 400° F; $\frac{B}{K} = 4.07 \times 10^{-4}$.



(a) $\frac{B}{K} = 1.95 \times 10^{-4}$ for $T = 300^\circ$ F; $\frac{B}{K} = 4.07 \times 10^{-4}$ for $T = 400^\circ$ F.

Figure 9.- Creep test results for 75S-T6 aluminum-alloy columns plotted in terms of stress, lifetime, and out-of-straightness parameters. $\bar{\sigma}/\sigma_E$ indicated at each test point.



(b) $\frac{B}{K} = 1.04 \times 10^{-3}$ for T = 500° F; $\frac{B}{K} = 2.91 \times 10^{-3}$ for T = 600° F.

Figure 9.- Concluded.

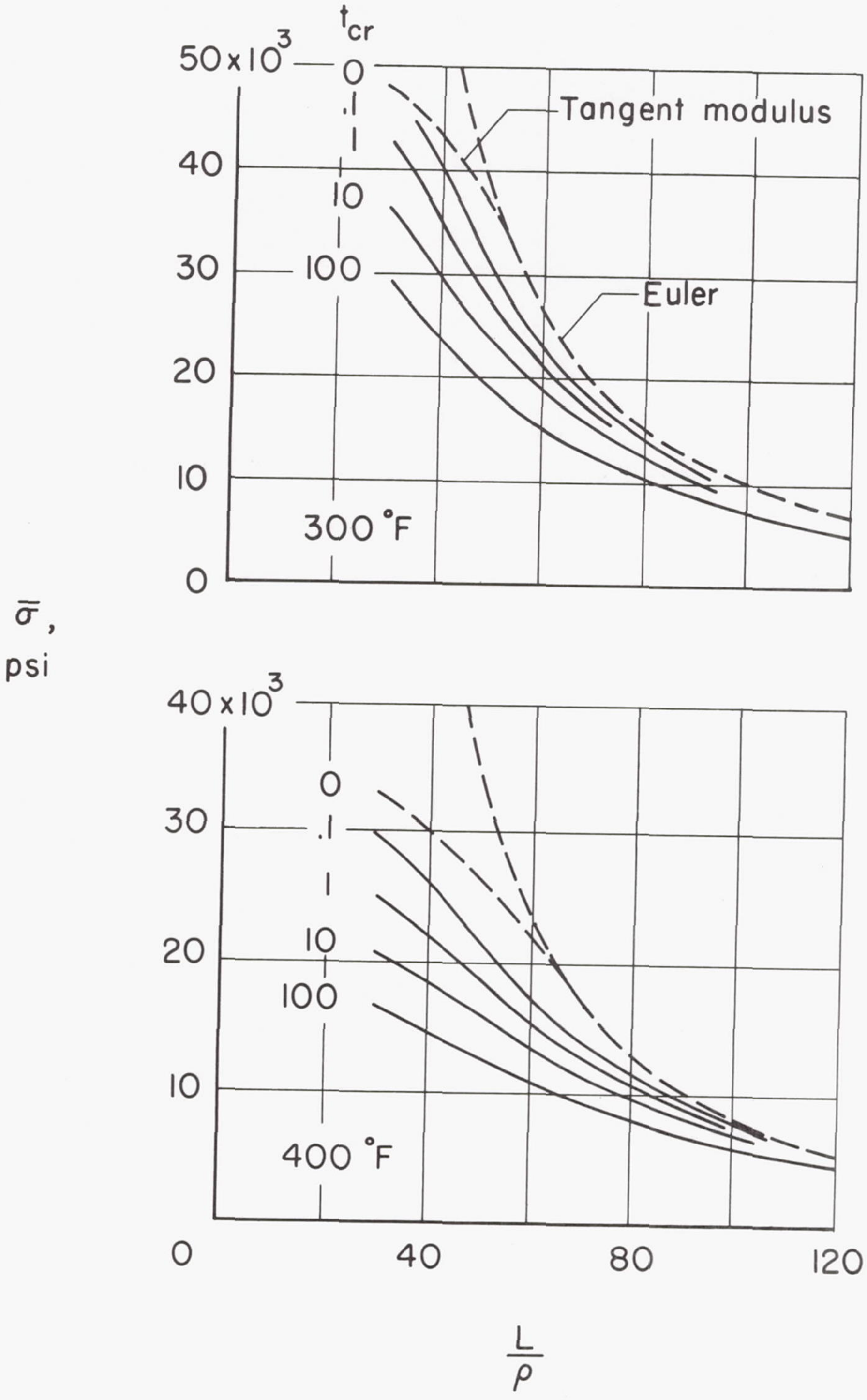


Figure 10.- Column curves showing lifetimes for 75S-T6 aluminum-alloy columns. $\frac{d_o}{b} = 0.01$.

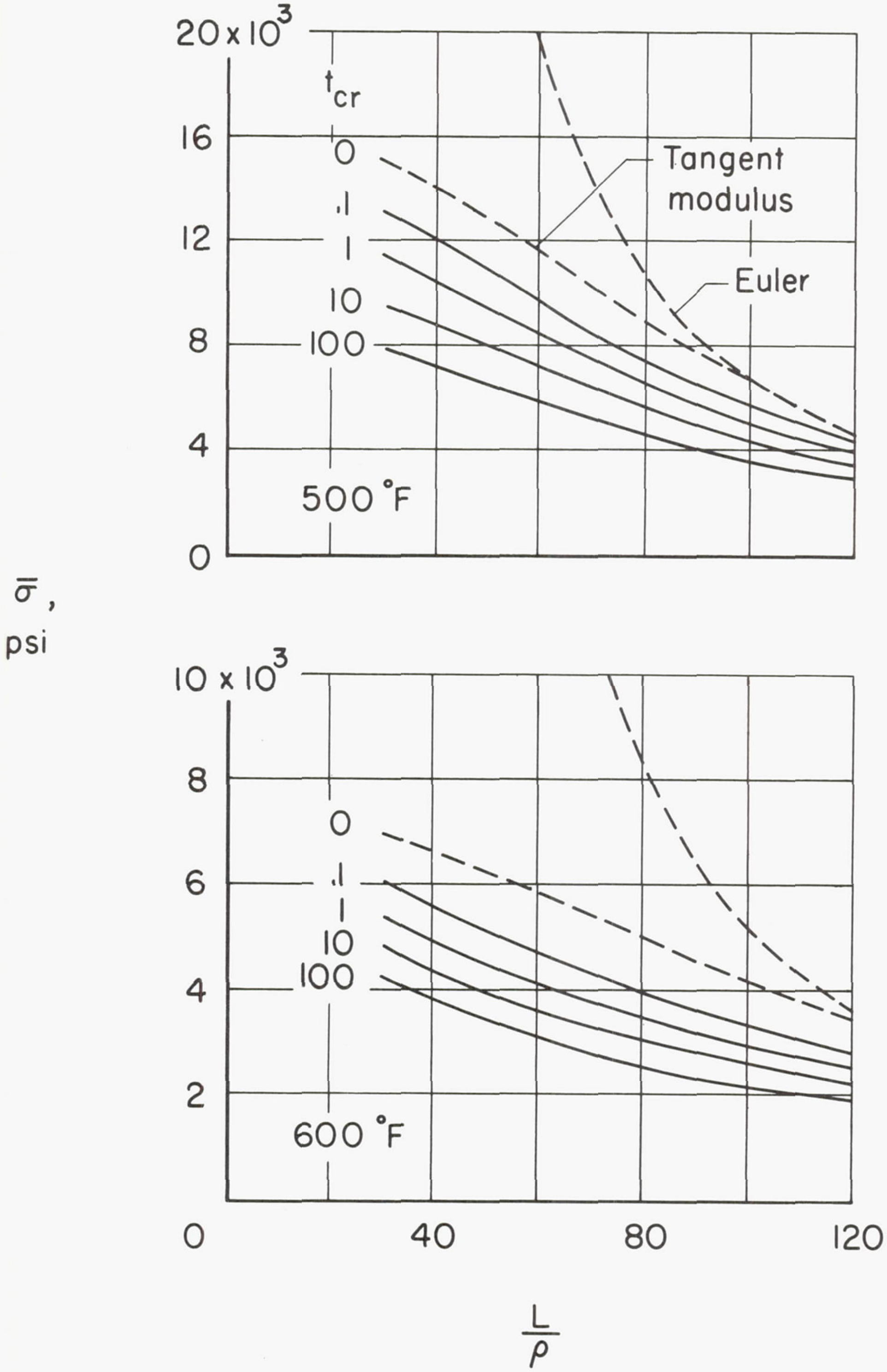


Figure 10.- Concluded.

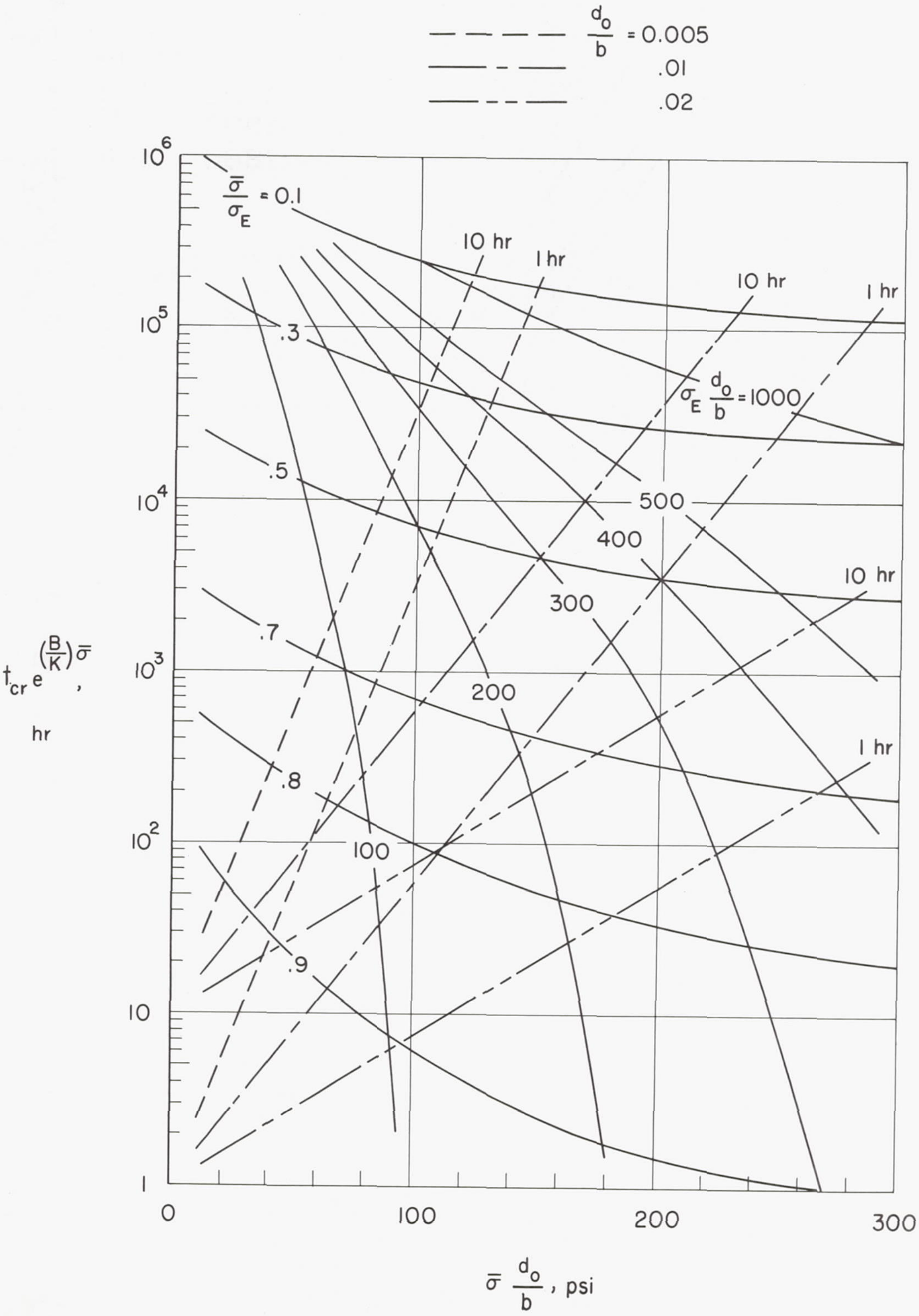


Figure 11.- Lines of constant column geometry and lifetime added to 400° F plot of figure 9.

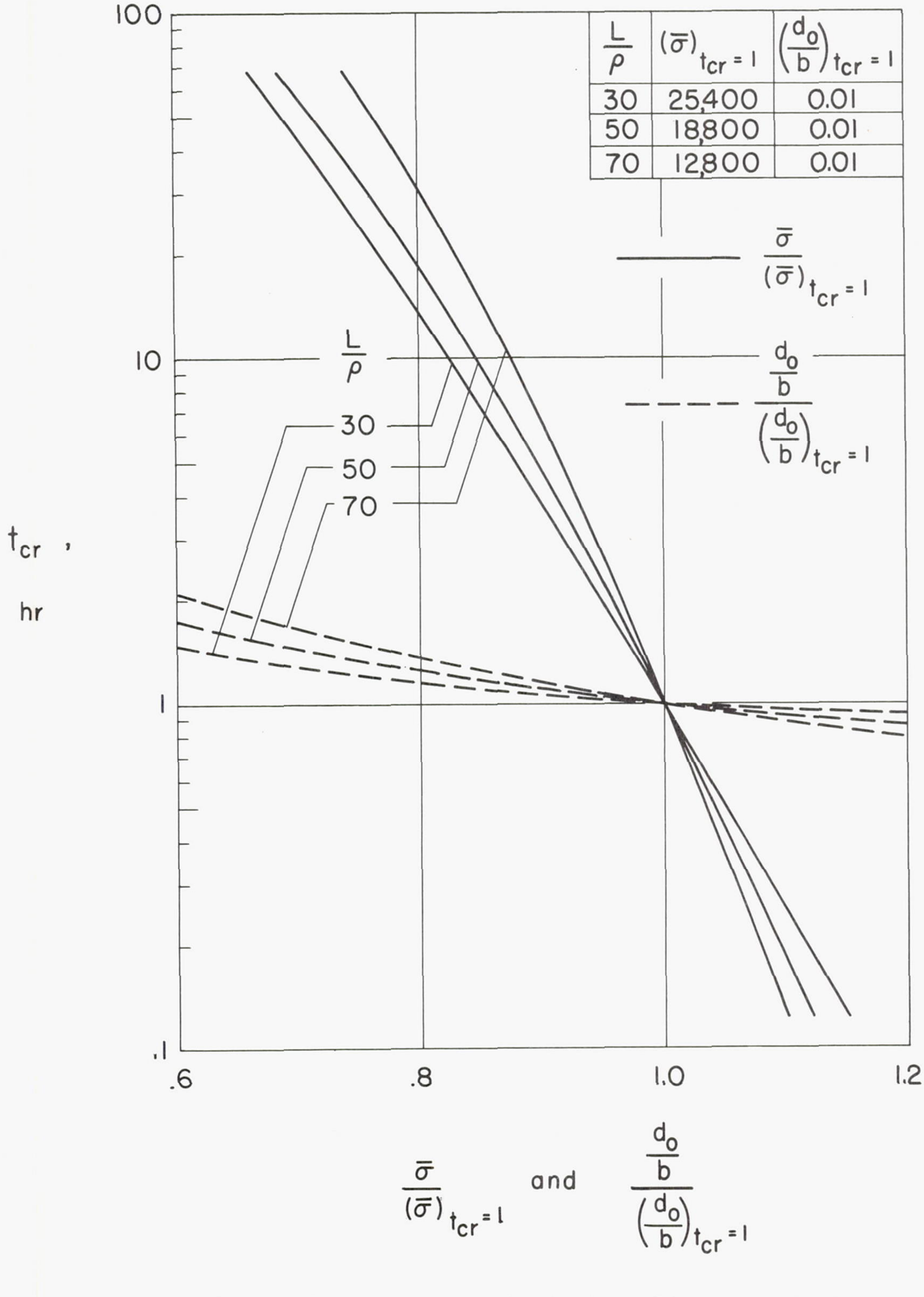


Figure 12.- The effect of stress and out-of-straightness variations on column lifetime. $T = 400^\circ$ F.

Test data

Symbol	○	□	△	◇	▽	◺	◿
L/ρ	30	40	50	60	70	90	100

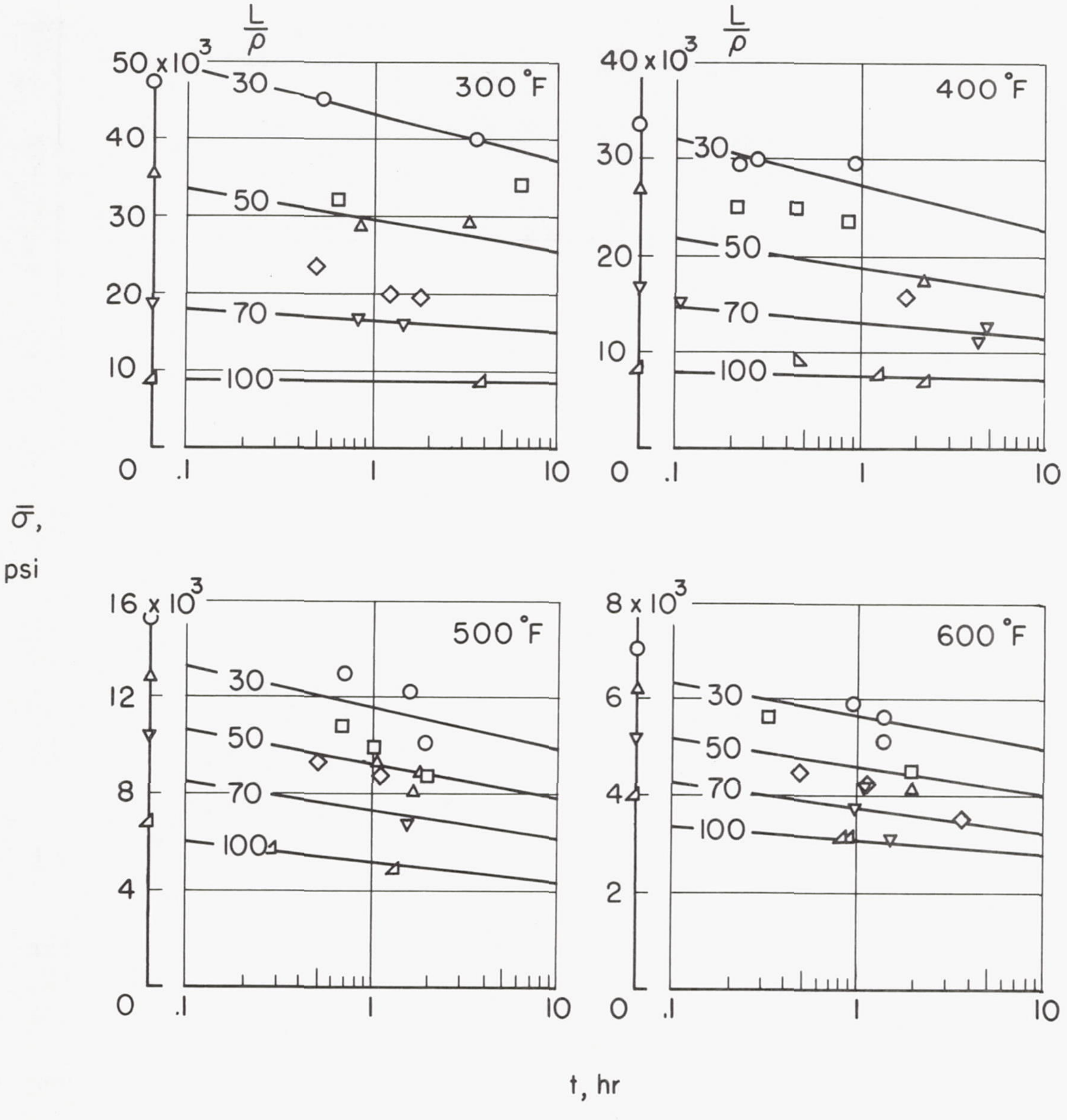


Figure 13.- Lifetime curves for 75S-T6 aluminum-alloy columns.

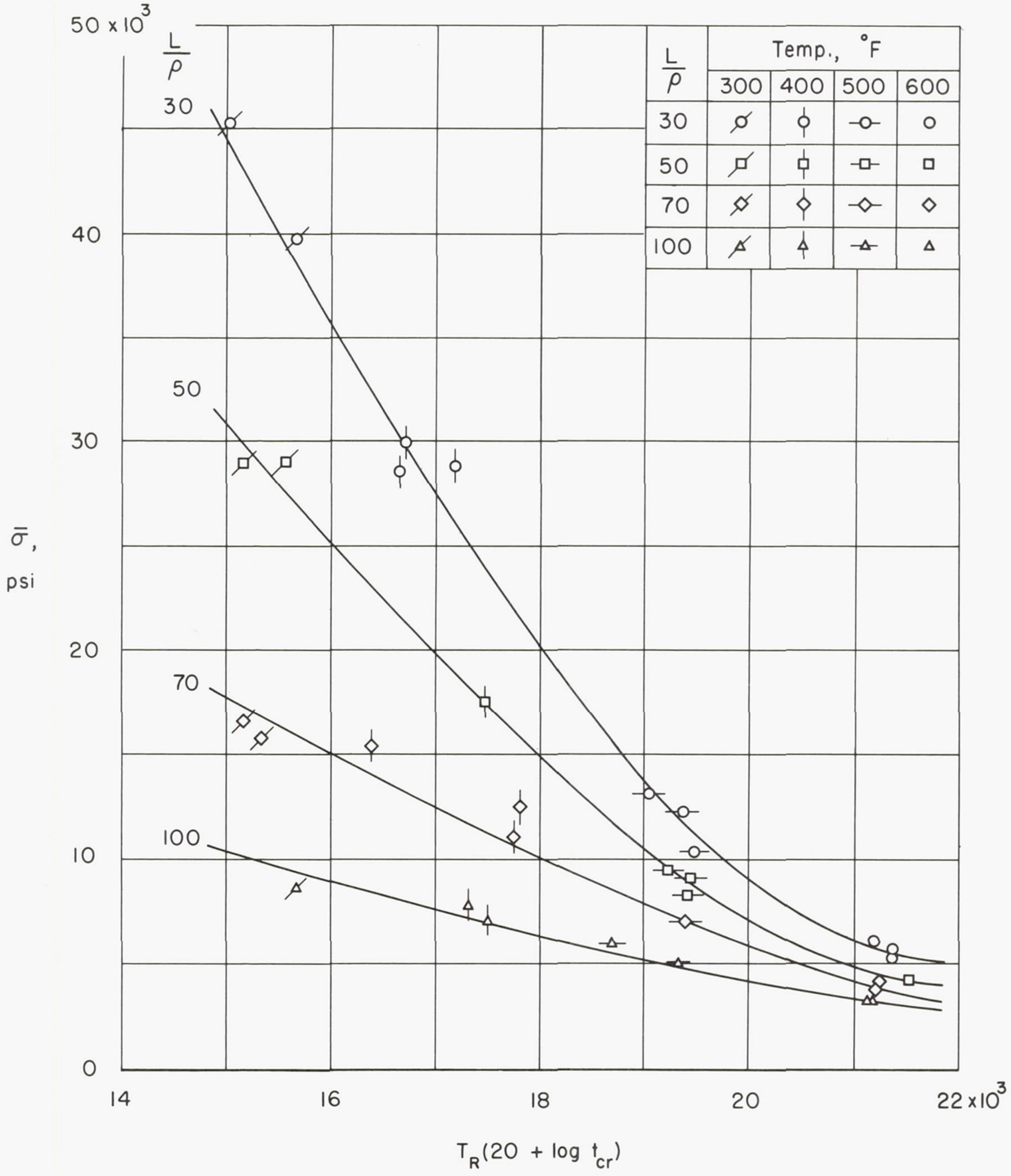


Figure 14.- Column creep test data plotted in terms of a material creep parameter.

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