NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 994

COLUMN STRENGTH OF EXTRUDED MAGNESIUM ALLOYS AM-C58S AND AM-C58S-T5

By J. R. Leary and Marshall Holt
Aluminum Company of America

Washington
December 1945

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 994

COLUMN STRENGTH OF EXTRUDED MAGNESIUM ALLOYS AM-C58S AND AM-C58S-T5

By J. R. Leary and Marshall Holt

INTRODUCTION

Tests have previously been made to determine the column strength of magnesium alloy AM-C58S-T5 extruded rod, but these few data were not considered a satisfactorily wide basis for establishing a general formula for the column strength of this alloy. It was therefore decided to make additional tests on a number of extruded sections of magnesium alloy AM-C58S-T5 with some tests on AM-C58S for comparison.

OBJECT

The object of this investigation was to provide a basis for establishing a general formula for the column strength of magnesium alloys AM-C58S and AM-C58S-T5 members that are not subject to local buckling or to torsional instability.

MATERIAL

The material used in this investigation was magnesium alloys AM-C58S and AM-C58S-T5. The -T5 temper was obtained by means of an aging treatment consisting in heating for 16 hours at 340° F ± 10° in the aging chamber in the Extrusion Division of New Kensington Works. The aging cycle was as follows:

Time for hot load-couple to reach 330° F, hr	2.8
Time for low load-couple to reach 330° F, hr	3.8
Time of soak after low load-couple reached 330° F, hr.	16.0
Total time in furnace, hr.	19.8

The mechanical properties of the material before and after artificial aging are shown in table I. The values for the unaged material are in reasonably good agreement with the typical values and exceed the specified minimum values given in tables 5 and 6, respectively, of reference 1. The values for the aged material are somewhat less than the typical values which are based on limited data obtained from tests on extruded rod.

The tensile tests were made on standard 1/2-inch-wide tensile specimens (see reference 2) of the full thickness of the material. In the compression tests the specimens were of the full cross section, and the stress-strain relations were obtained from the relative movement of the platens of the testing machine. It is recognized that this measured movement includes not only the strain in the specimen, but also certain strains and distortions of the platens. The data were therefore corrected so that the initial slope of the stress-deformation curves was equal to the nominal value of the modulus of elasticity 6,500,000 psi. The corrected stress-deformation curves are shown in figures 1 and 2.

SPECIMENS AND METHOD OF TEST

The column specimens are listed and described in tables II and III. The average area of each specimen was determined from its weight and length and the nominal specific gravity of the material (0.0654 lb per cu in.).

The ends of the specimens were finished flat and normal to the axis of the specimen by turning on an arbor in a lathe. The specimens were then tested as columns with flat ends, that is, with the platens of the testing machine fixed against tipping and turning during the loading of the specimen. Before loading the specimen, however, the platens were alined parallel within 0.0003 inch in 12 inches by means of special tapered leveling rings under the lower platen. By rotating the rings relative to one another or rotating the two of them relative to the platen, it is possible to tip the platen about any axis in the plane of the bearing surface. The load was applied uniformly and slowly until a maximum value was reached.

RESULTS AND ANALYSIS

The column strengths developed in these tests are given in tables II and III. Only in the case of specimen 83-5, which was from the $2\frac{1}{2}$- by $2\frac{1}{2}$- by 7/16-inch angle of the aged material, was there a material failure. In this case the final collapse occurred by a shearing type of failure that beveled each leg of the angle at one end along planes at about 45 degrees to the bearing surface. This shearing type of failure occurred at a strain of about 6.3 percent. The other angle specimens failed by sidewise bending. The failures of the shorter specimens of the T-section were accompanied by local buckling of the flanges and webs at strains of about 2 percent. Of course, the longer specimens failed by lateral bending at much smaller strains.

The relations between column strength and slenderness ratio are shown in figures 3 to 7. The dash-line curves shown with the data were obtained by means of the Engesser interpretation of the Euler column formula. The formula is:

$$\frac{P}{A} = \frac{\pi^2 \overline{E}}{\left(\frac{KL}{r}\right)^2} \qquad (1)$$

in which

P/A column strength, pounds per square inch

$\overline{E}$ effective modulus, pounds per square inch

L length of member, inches

r least radius of gyration, inches

and

K coefficient describing the end conditions; for round ends K equals unity, and for fixed ends K equals one-half

It follows then that the expression $\left(\frac{KL}{r}\right)$ is the effective slenderness ratio of the member. The results of a large number of tests on aluminum alloy columns indicate that with this method of testing the value of K can be taken as one-half.

The Euler equation was first developed on the basis of elastic action of the material, in which case the value of E is the elastic modulus. Engesser's interpretation considers E as an effective modulus which for stresses above the elastic-stress range varies with the stress and is less than the elastic modulus. A rather extensive experience with various materials, especially the aluminum alloys, indicates that when the compressive tangent modulus, or the slope of the compressive stress-strain curve, is used as the effective modulus the computed curve agrees very well with test results. As seen in figures 3 to 7, the tangent-modulus-column curves agree quite well with these test results.

The stress-tangent modulus relations obtained from the compressive stress-deformation curves are shown in figure 8. The differences in the shapes of these curves are reflections of the small differences in the shapes of the stress-strain curves.

Although the Engesser formula represents the test results very well, it is not suitable for general engineering use. The trend of the data, as well as that of data previously obtained in other tests on magnesium columns (references 3 and 4), suggests the use of a column formula of the Rankine type which is more convenient for general engineering use. Because of the nature of the formula it is necessary to limit the maximum value of column strength to the compressive yield strength of the material. The dot-dash curves shown in figures 3 to 7 are of this type and can be represented by an equation of the form

$$\frac{P}{A} = \frac{B}{1 + D\left(\frac{KL}{r}\right)^2} \quad \text{with a maximum value equal to the compressive yield strength of the material} \qquad (2)$$

in which

P/A column strength, pounds per square inch

KL/r effective slenderness ratio

and

B and D coefficients chosen to give good agreement with the test results

The equations of the curves shown with the data are,

for AM-C58S,

$$\frac{P}{A} = \frac{42900}{1 + 0.000659\left(\frac{KL}{r}\right)^2} \tag{3}$$

for AM-C58S-T5,

$$\frac{P}{A} = \frac{98200}{1 + 0.001520\left(\frac{KL}{r}\right)^2} \tag{4}$$

For the materials tested, the values of compressive yield strength which are to be taken as the maximum values of column strength are approximately:

	(psi)
AM-C58S	21,300
AM-C58S-T5.	30,000

These formulas are for use with axially loaded columns sturdy enough to fail by sidewise bending and not by local buckling or twisting. In problems of design suitable factors of safety must be used in connection with these formulas.

CONCLUSIONS

The following conclusions have been drawn from the test results on extruded shapes of AM-C58S and AM-C58S-T5 and the discussion presented in this report:

1. The mechanical properties of the AM-C58S material are in reasonably good agreement with the typical values and exceed the specified minimum values given in reference 1.

2. The mechanical properties for the AM-C58S-T5 material are somewhat less than the typical values given in reference 1 which are based on limited data obtained from tests on extruded rod.

3. For columns that fail by sidewise bending, the test results agree very well with the Engesser column formula when the compressive tangent modulus is used as the effective modulus. This formula, while very useful for analyzing data, is not well suited to general engineering use.

4. The trend of the column test results is represented very well by a formula of the Rankine type with a maximum value equal to the compressive yield strength. Column formulas of this type based on the test results given herein are as follows:

for AM-C58S,

$$\frac{P}{A} = \frac{42900}{1 + 0.000659\left(\frac{KL}{r}\right)^2}$$

with a maximum value equal to the compressive yield strength, 21,300 psi

for AM-C58S-T5,

$$\frac{P}{A} = \frac{98200}{1 + 0.001520\left(\frac{KL}{r}\right)^2}$$

with a maximum value equal to the compressive yield strength, 30,000 psi

These formulas are for use with axially loaded columns sturdy enough to fail by sidewise bending and not by local buckling or twisting. When determining allowable column strengths in problems of design, suitable factors of safety must be applied.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., February 8, 1945.

REFERENCES

1. Anon.: Designing with Magnesium. Am. Magnesium Corp., 1943.

2. Anon.: Standard Methods of Tension Testing of Metallic Materials (E8-42). 1942 Book of A.S.T.M. Standards, pt. I, p. 898, fig. 2.

3. Holt, M.: Column Strength of Magnesium Alloy AM-57S. NACA TN No. 899, 1943.

4. Winston, A. W.: Magnesium Alloys and Their Structural Application. A.S.C.E. Proc., vol. 62, Oct. 1936, pp. 1125-1340.

TABLE I

PROPERTIES OF MATERIAL USED IN COLUMN TESTS ON EXTRUDED MAGNESIUM ALLOYS AM-C58S AND AM-C58S-T5

Section	Dimensions, in.	Die No.	Tensile Strength, psi	Tensile Yield Strength (Offset=0.2%), psi	Elongation in 2 in. or 4D, per cent	Compressive Yield Strength (Offset=0.2%), psi
			AM-C58S as Extruded and Commercially Straightened			
I-Beam	2-1/2 x 2 x 1/8	XM-844	48 150	34 850	19.5	21 200
Angle	2-1/2 x 2-1/2 x 7/16	XM-840	47 650	35 150	17.8	21 300
			AM-C58S-T5			
I-Beam	2-1/2 x 2 x 1/8	XM-844	51 300	34 000	9.0	30 400
Angle	2-1/2 x 2-1/2 x 7/16	XM-840	49 800	32 400	6.5	30 200
Angle	4 x 4 x 1/2	XM-439	51 300	37 400	5.1	29 700
			Typical Properties*			
AM-C58S			(46 000 / 47 000)	(32 000 / 35 000)	12	22 000
AM-C58S-T5			53 000	36 000	7	33 000
			Specification Values†			
AM-C58S			42 000	27 000	8	

Tensile tests made on standard tension test specimens for sheet metals - Fig. 2 of "Standard Methods of Tension Testing of Metallic Materials (E8-42)," 1942 Book of A.S.T.M. Standards, Part I, p.898. Compressive tests made on a short length of the full cross section.

* From Table 5 of "Designing with Magnesium," American Magnesium Corporation, 1943.

† Loc. cit. Table 6.

TABLE II

DESCRIPTION OF SPECIMENS AND RESULTS OF TESTS
COLUMN STRENGTH OF EXTRUDED MAGNESIUM ALLOY AM-C58S

Specimens tested as columns with flat ends, K taken as 0.5.

Specimen No.	Length, L, in.	Weight, lb	Effective Slenderness Ratio, KL/r	Measured Crookedness, e, in.	Ratio L/e	Area, A, sq in.	Ultimate Load, P, lb	Column Strength, P/A, psi
I-Beam, Depth 2.5 in., Flange 2 in., Thickness 1/8 in., r = 0.452 in.								
3-5	4.58	0.241	5.1	--	--	0.805	17 900	22 240
3-9	9.05	0.475	10.0	0.003	3020	0.803	17 850	22 230
1-18	18.07	0.947	20.0	0.003	6020	0.801	16 950	21 160
2-27	27.20	1.435	30.1	0.003	9070	0.807	16 750	20 760
2-36	36.10	1.900	40.0	--	--	0.805	16 350	20 310
3-45	45.10	2.370	50.0	0.009	5010	0.804	12 300	15 300
3-56	56.40	2.960	62.5	--	--	0.803	8 900	11 080
2-68	67.80	3.562	75.0	0.003	2260	0.803	6 970	8 680
1-90	90.10	4.710	99.9	0.008	1130	0.799	4 680	5 860
Angle, 2-1/2 in. x 2-1/2 in. x 7/16 in., r = 0.484								
80-5	4.90	0.638	5.1	--	--	1.991	64 900	32 600
80-10	9.68	1.261	10.0	--	--	1.992	56 150	28 190
80-20	19.39	2.522	20.0	0.005	3880	1.989	43 100	21 670
80-29	29.00	3.783	30.0	0.007	4140	1.995	42 200	21 150
80-39	38.70	5.040	40.0	0.006	6530	1.992	42 100	21 130
82-48	48.40	6.260	50.0	0.015	3230	1.978	32 100	16 230
82-58	58.10	7.530	60.0	0.010	5810	1.982	27 630	13 940
81-78	71.90	9.370	74.2	--	--	1.993	19 030	9 550

TABLE III

DESCRIPTION OF SPECIMENS AND RESULTS OF TESTS
COLUMN STRENGTH OF EXTRUDED MAGNESIUM ALLOY AM-C58S-T5

Specimens tested as columns with flat ends, K taken as 0.5.

Specimen No.	Length, L, in.	Weight, lb	Effective Slenderness Ratio, KL/r	Measured Crookedness, e, in.	Ratio, L/e	Area, A, sq in.	Ultimate Load, P, lb	Column Strength, P/A, psi
I-Beam, Depth 2.5 in., Flange 2 in., Thickness 1/8 in., r = 0.452 in.								
11-5	4.60	0.242	5.1	--	--	0.805	25 000	31 060
11-9	9.09	0.480	10.1	--	--	0.807	25 500	31 600
10-18	18.00	0.937	19.9	0.002	9 000	0.796	23 900	30 020
11-27	27.40	1.440	30.3	--	--	0.804	23 800	29 610
10-36	36.40	1.870	40.3	0.009	4 040	0.787	23 000	29 220
11-45	45.00	2.368	49.8	0.005	9 000	0.805	17 000	21 120
11-56	56.60	2.970	62.7	0.018	3 140	0.802	11 850	14 780
10-68	68.80	3.568	76.1	0.046	1 495	0.793	8 100	10 210
9-90	89.90	4.730	99.5	0.013	6 900	0.805	4 750	5 900
Angle, 2-1/2 in. x 2-1/2 in. x 7/16 in., r = 0.484								
83-5	5.04	0.656	5.2	--	--	1.991	97 000	48 720
83-10	9.85	1.282	10.2	--	--	1.991	61 500	30 890
83-20	19.40	2.525	20.0	--	--	1.990	58 550	29 420
83-29	29.20	3.810	30.2	--	--	1.995	58 000	29 070
84-39	39.70	5.175	41.0	0.008	4 960	1.993	55 800	28 000
85-48	48.10	6.250	49.7	--	--	1.987	43 500	21 890
85-58	58.10	7.565	60.1	0.004	14 500	1.991	33 000	16 570
84-79	78.20	10.178	80.9	--	--	1.990	19 350	9 720
Angle, 4 in. x 4 in. x 1/2 in., r = 0.776 in.								
57-8	7.55	1.844	4.9	--	--	3.735	118 400	31 700
56-16	15.47	3.752	10.0	--	--	3.709	113 000	30 470
56-23	23.20	5.630	14.9	--	--	3.711	110 100	29 670
56-31	31.00	7.510	20.0	0.007	4 430	3.705	108 250	29 220
56-39	38.70	9.395	24.9	0.015	2 580	3.715	108 250	29 140
57-47	46.50	11.370	30.0	0.011	4 230	3.739	106 100	28 380

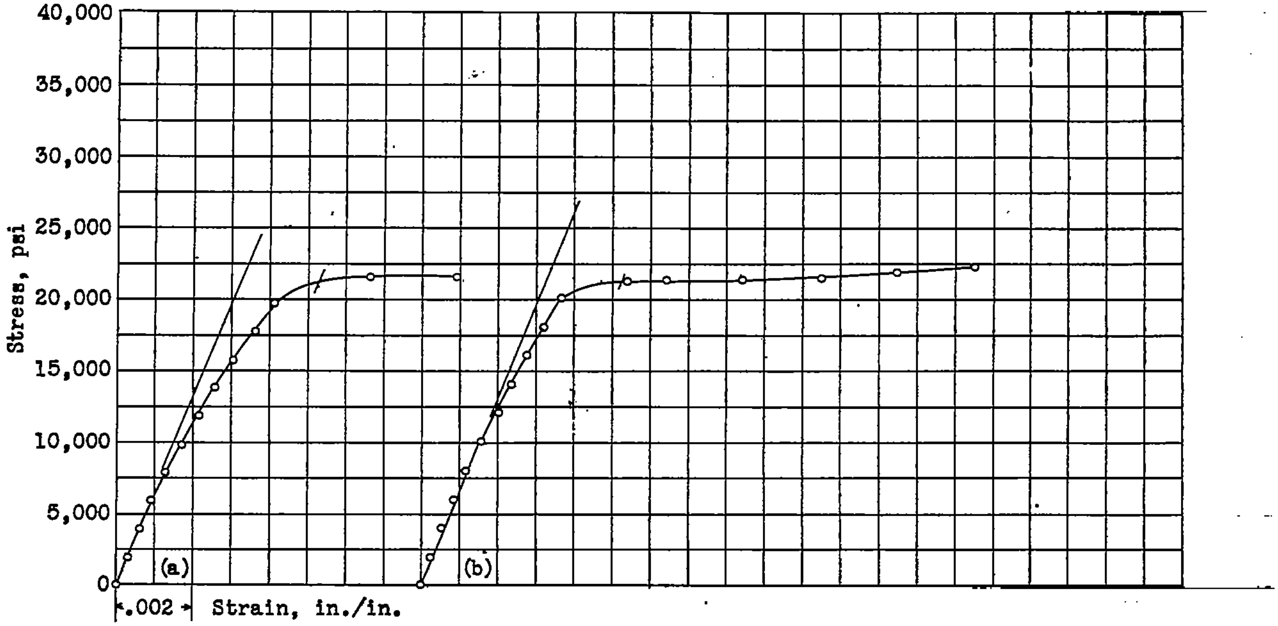

Figure 1.- Compressive stress-strain curves. (a) I-beam, die no. XM-844; web depth = 2.5 in.; flange width = 2 in.; thickness = 1/8 in.; (b) 2-1/2 × 2-1/2 × 7/16 in. angle. Metal, AM-C58S.

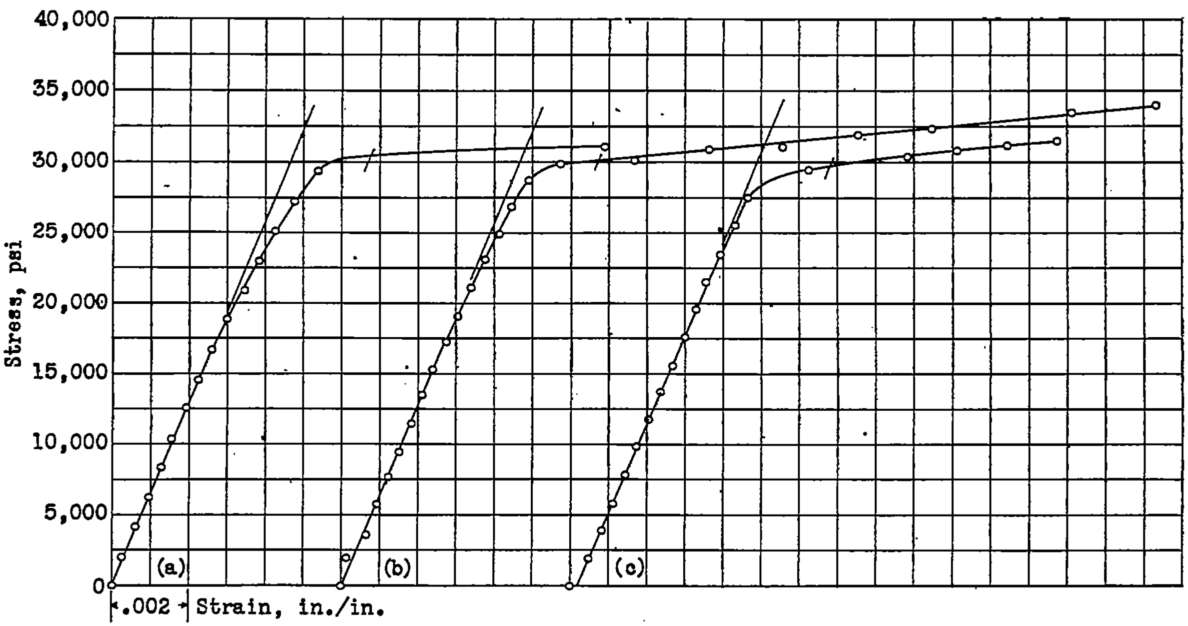

Figure 2.- Compressive stress-strain curves. (a) I-beam, die no. XM-844, web depth = 2.5 in., flange width = 2 in.; thickness = 1/8 in.; (b) 2-1/2 × 2-1/2 × 7/16 in. angle; (c) 4 × 4 × 1/2 in. angle. Metal, AM-C58S-T5.

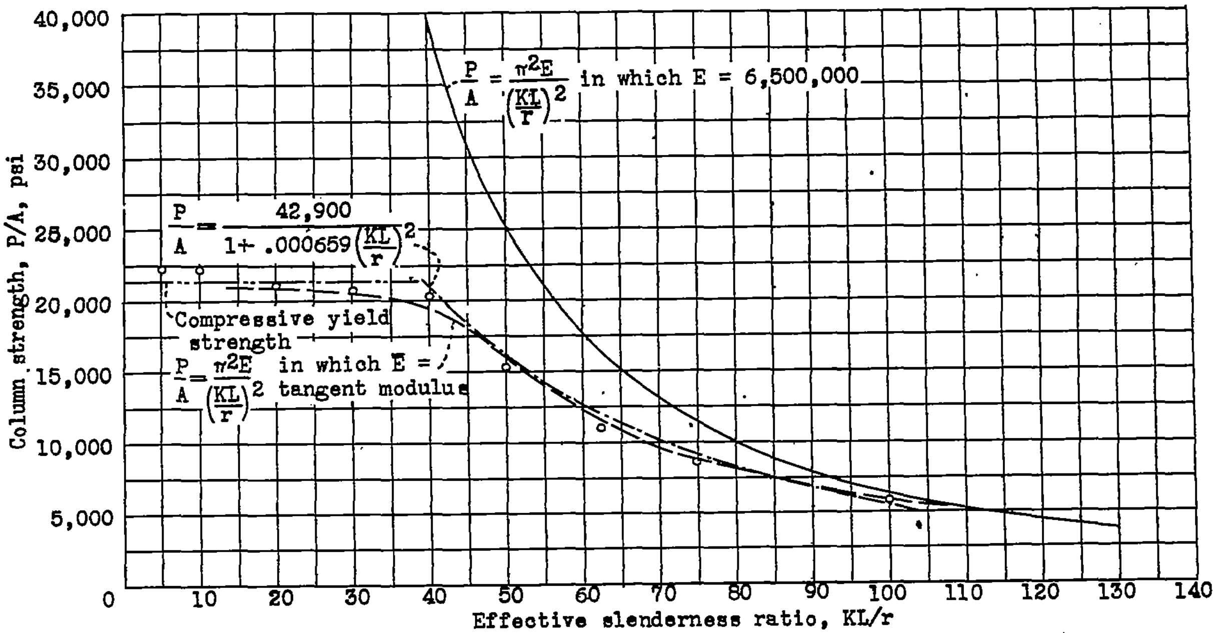

Figure 3.- Column strength of AM-C58S I-beam. Specimens tested at columns with flat ends K taken equal to .50. I-beam, die no. XM-844; web depth = 2.5 in.; flange width = 2 in.; thickness = 1/8 in.

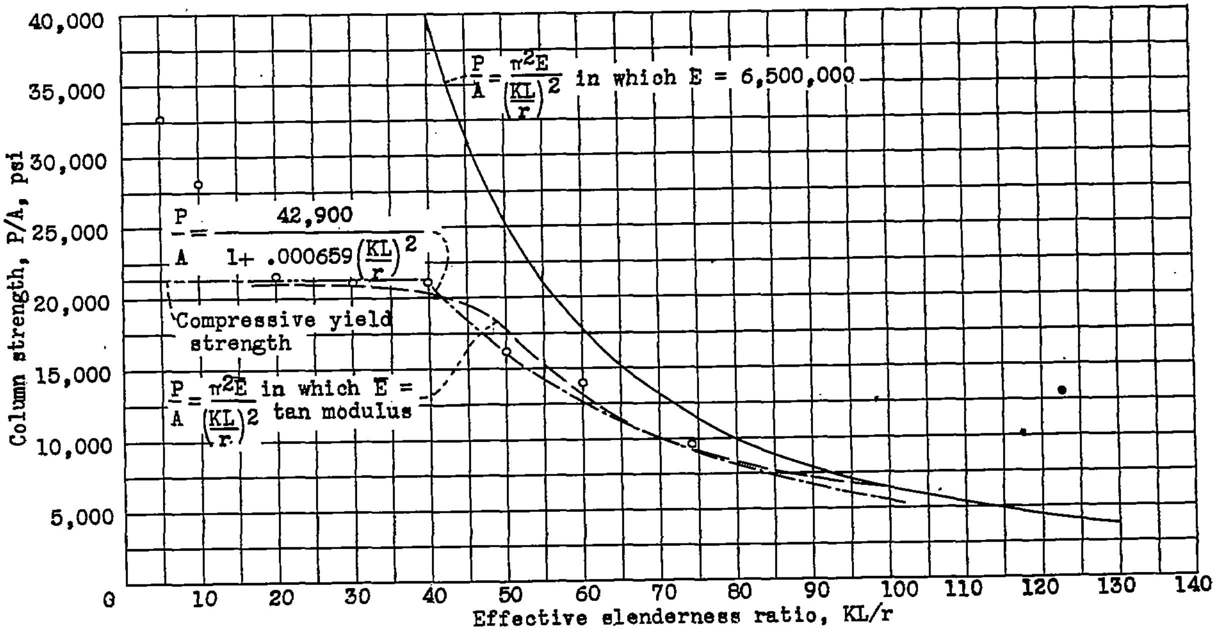

Figure 4.- Column strength of AM-C58S 2-1/2 × 2-1/2 × 7/16 in. angle. Specimens tested as columns with flat ends K taken equal to .50.

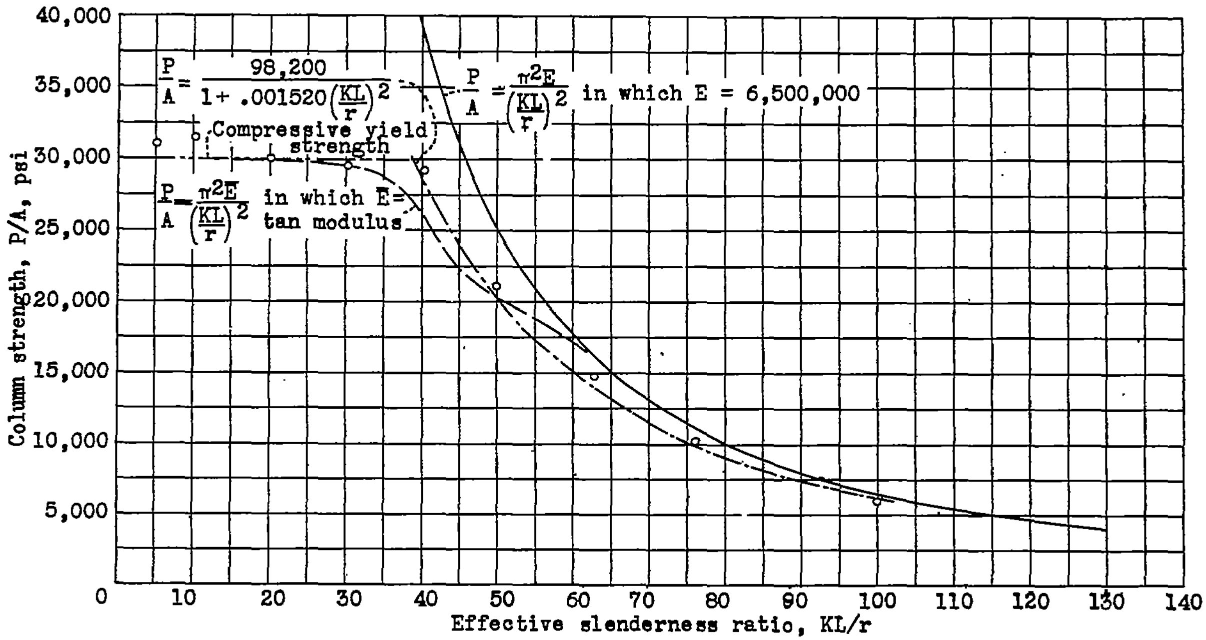

Figure 5.- Column strength of AM-C58S-T5 I-beam. Specimens tested as columns with flat ends. K taken equal to .50. I-beam, die no. XM-844; web depth = 2.5 in.; flange width = 2 in.; thickness = 1/8 in.

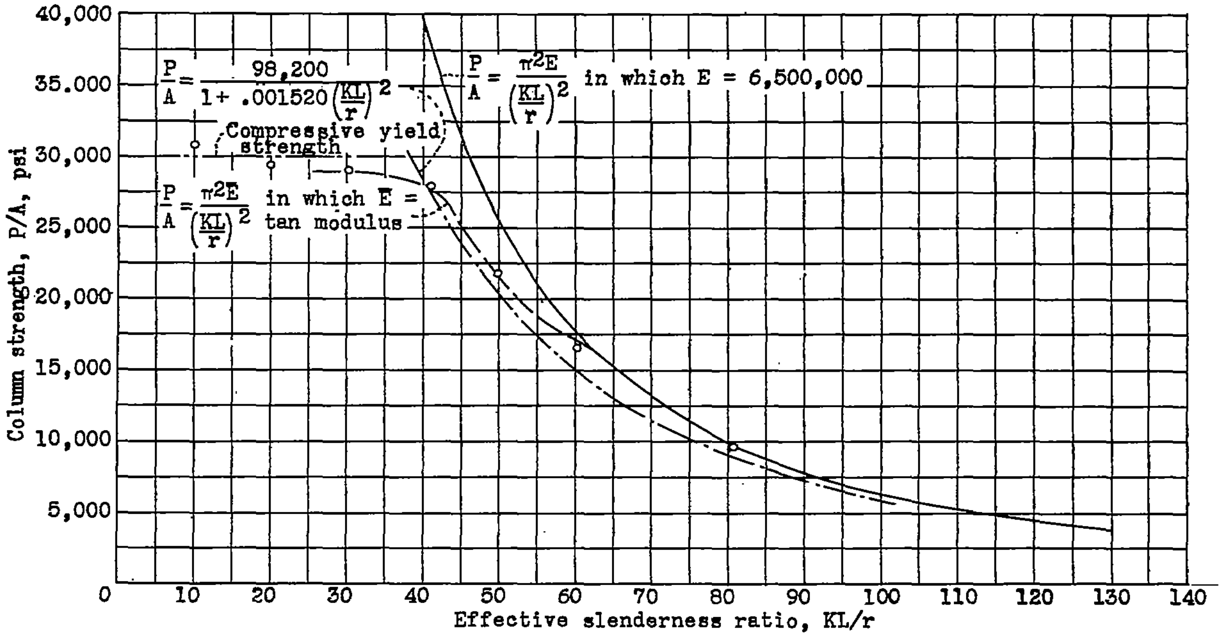

Figure 6.- Column strength of AM-C58S-T5 2-1/2 × 2-1/2 × 7/16 in. angle. Specimens tested as columns with flat ends. K taken equal to .50.

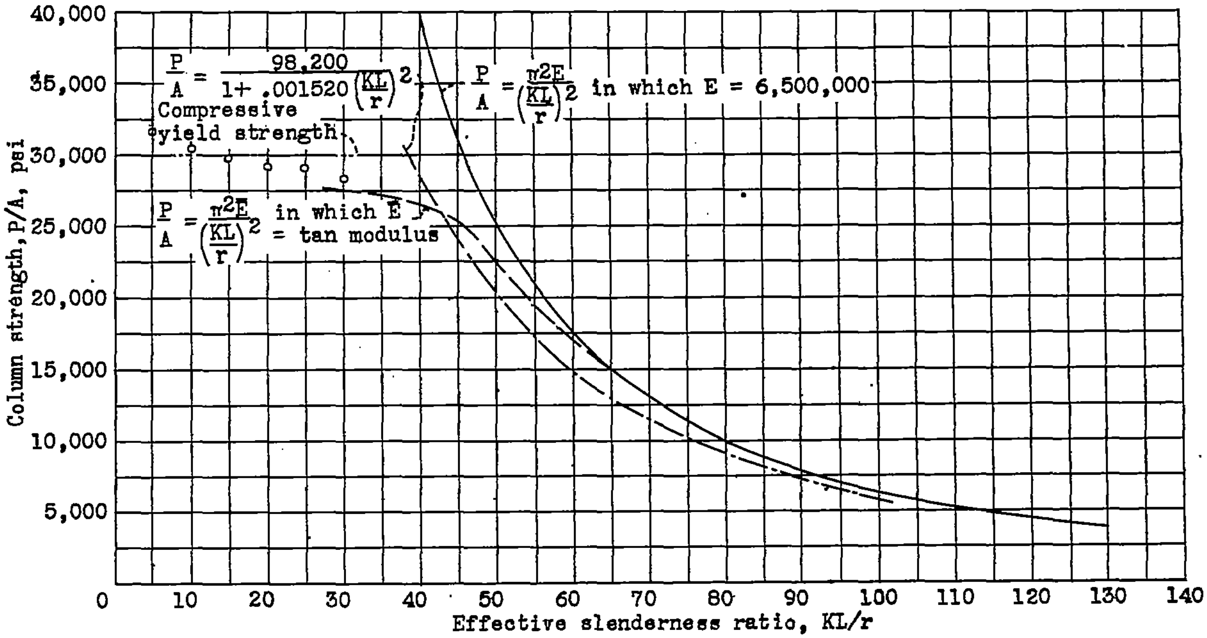

Figure 7.- Column strength of AM-C58S-T5 4 × 4 × 1/2 in. angle. Specimens tested as columns with flat ends. K taken equal to .50.

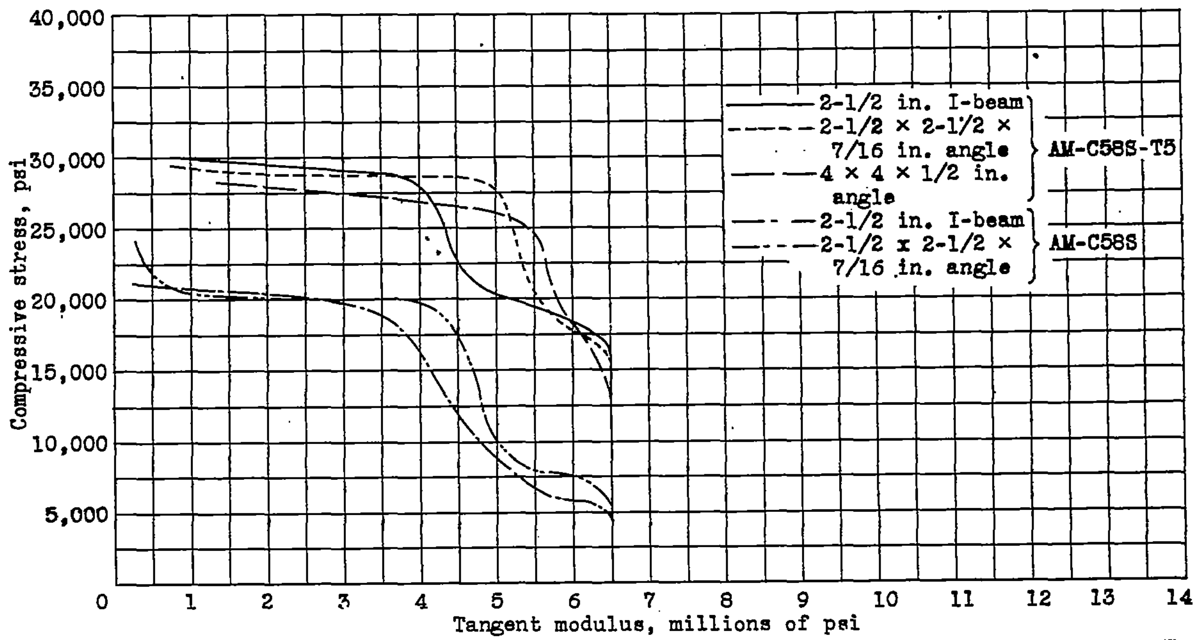

Figure 8.- Stress-tangent modulus curves.