- 1943

RESTRICTED

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Metals - Magn. alloys

No. 899

COLUMN STRENGTH OF MAGNESIUM ALLOY AM-57S

By M. Holt
Aluminum Company of America

Washington
July 1943

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 899

COLUMN STRENGTH OF MAGNESIUM ALLOY AM-57S

By M. Holt

SUMMARY

Tests were made to determine the column strength
of extruded magnesium alloy AM-57S. Column specimens
were tested with round ends and with flat ends. It
was found that the compressive properties should be
used in computations for column strengths rather than
the tensile properties because the compressive yield
strength was approximately one-half the tensile yield
strength. A formula for the column strength of magne-
sium alloy AM-57S, based on the test results, is given
herein.

INTRODUCTION

Inquiries have been received for information on
the column strength of magnesium alloys, particularly
that of AM-57S. Since there were no test data avail-
able for verifying the computed curves of column
strength for the various alloys, the investigation de-
scribed herein was undertaken in order to determine
the column strength of extruded magnesium alloy AM-57S.

MATERIAL AND SPECIMENS

The material used in this investigation was magne-
sium alloy AM-57S having the following nominal chemical
composition:

	percent
Aluminum	6.5
Manganese	.2 minimum
Zinc	.8 maximum
Magnesium	rest

The material was furnished in the form of extruded
angle ($2\frac{1}{2}$ by $2\frac{1}{2}$ by 1/4 in.) in the "as-extruded" condi-
tion. The seven pieces furnished were cut into speci-
mens as indicated in figure 1. The letter in the speci-
men number indicates the type of test to be made on the
piece. The letter C designates a compressive specimen
used to determine the compressive properties of the
material. The specimen is a short piece of the full sec-
tion with the length such that the slenderness ratio of
the specimen is 10. The letter T designates a tensile
specimen used to determine the tensile properties of the
material. Standard flat tensile specimens (reference 1,
fig. 2) 1/2 inch wide were cut from one leg of the angle.
The letter R indicates a column specimen tested with
the condition of round ends, and the letter F indicates
a column specimen tested with the condition of flat ends.
All the column specimens were lengths of the full section.

The tensile properties of the material as determined
by the standard tensile test are given in table I. These
values are a little less than those considered typical
(see reference 2) for this material and indicate a range
of about 10 percent in the values of yield strength (off-
set = 0.2 percent). The stress-strain relations were ob-
tained with a Templin autographic extensometer (reference 3).

The compressive yield strengths (offset = 0.2 percent)
of the various pieces of material as determined by testing
the compressive specimens between the fixed heads of the
testing machine are also shown in table I. These values
are considerably lower than those considered typical for
the material. The relations between stress and strain
from which these values of yield strength were determined
were obtained by measuring the relative movement of the
heads of the testing machine with dial gages at the four
corners of the bearing heads. The yielding of the ma-
terial at stresses near the yield strength occurred by
short quick jerks accompanied by chattering sounds. It
is known that stress-strain relations determined in this
way do not give accurate stress-strain curves, but the
curves have the same characteristics as the correct stress-
strain curves; that is, they indicate correctly the yield
strength and the general shape of the curve. This type
of curve has been found satisfactory for use with alumi-
num alloys and, in view of the very flat curve obtained
for magnesium alloy AM-57S in the region of the permanent
set used to define the yield strength, this type of curve
should be as satisfactory for determining the yield strengths

as more precise stress—strain relations. Figure 2 shows
the stress—shortening curve for specimen 3C, which is
typical of the curves for the group of C specimens. The
measured strains were multiplied by a common factor so
that the initial slope would equal the generally accepted
value of the modulus of elasticity, 6,500,000 pounds per
square inch.

The stress—strain curves for both tension and com-
pression indicate rather low values of proportional limit,
between 4000 and 6000 pounds per square inch. The com-
pressive yield strengths are only about one—half as great
as the tensile yield strengths. Tensile stress—strain
curves are not included.

The ends of the column specimens were finished flat
and parallel by turning the specimens on an arbor in a
lathe. The specimens are further described in table II.
The areas were calculated from the weight and length of
the specimens and the nominal specific gravity of the
material, which is 0.0647 pound per cubic inch. The
crookedness was measured by inserting thickness gages be-
tween the specimen and a surface plate. Specimen 8F showed
the greatest crookedness, with a ratio of length L to
crookedness e of 1360:1.

It should be pointed out in connection with this in-
vestigation using AM—57S alloy that this alloy has been
found under some conditions to be susceptible to stress—
corrosion cracking. If this alloy is exposed to a corro-
sive medium under conditions in which the exposed surfaces
are subjected to steady tensile stresses greater than about
one—quarter of the yield strength, fracture may occur in
a time short enough to render the metal structurally un-
satisfactory. Protection by painting will prolong the
life of the metal but will not entirely prevent cracking
where conditions are severe.

High steady residual tensile stresses left by weld-
ing, severe cold—forming operations, faulty assembly of
misalined parts, or pressed—in bushings appear to be the
most serious in producing stress—corrosion cracking. The
lower stresses produced by normal service loads, particu-
larly by intermittent service loadings, do not appear to
have any appreciable influence on the occurrence of stress—
corrosion cracking, especially where the corrosive condi-
tions are not severe. Therefore, alloy AM—57S will probably

be entirely satisfactory for applications where "locked-up"
stresses are not present or are held to a value less than
about one-quarter of the yield strength. Experience has
shown that this alloy has been satisfactory in many appli-
cations.

METHOD OF COLUMN TESTING

The specimens marked "R" were tested as columns with
round ends. The special ball-bearing spherical heads
were used with the 30,000 pound setup of an Amsler test-
ing machine of 300,000-pound capacity. These heads are
known to have a low resistance to tipping. The specimens
were placed on the heads as centrally as possible. The
relative vertical movement of the heads was measured at
the four corners; and, unless the four movements were
practically the same for the first few increments of load,
the specimen was shifted on the heads until equal move-
ments were obtained. This procedure insured an axial ap-
plication of the load. The load was applied in increments
and the stress-shortening curve determined.

The specimens marked "F" were tested between the
fixed heads of the testing machine. This set of heads
does not necessarily fix the ends of the specimens since,
under large deflections, the specimens could tip on the
heads. The stress-shortening relations were also deter-
mined for these specimens by measuring the relative move-
ment of the heads.

RESULTS AND DISCUSSION

The stress—shortening relations of the column speci-
mens are shown in figures 3 and 4. The initial slopes
of the curves are all practically equal. Specimen 2R
was accidentally loaded to a stress of about 12,000
pounds per square inch before the test. It will be no-
ticed in figure 3 that the stress—shortening curve for
this specimen does not indicate a proportional limit as
the curves for the other specimens do. The effect of
this accidental load was studied during the test of speci-
men 3R. This specimen was loaded to a stress of 12,000
pounds per square inch and the load—shortening curve de-
termined. The load was then removed and the test repeated.
On the second loading, the stress—shortening relation is
represented by a straight line parallel to the original
slope of the curve from the first loading. The load was
again removed and reapplied. The stress—shortening rela-
tion for the third loading coincides with that determined
for the second loading. The indication is that the pro-
portional limit can be raised by this method of working
the metal. The effect on the tensile properties was not
determined.

In studying the relation between the properties of
the material and the column strength, the stress—strain
relations were given consideration. From the stress—
deformation data obtained with the dial gages, the rela-
tion between the stress and the tangent modulus of elas-
ticity was plotted as shown in figure 5. The values of
tangent modulus of elasticity plotted are merely the in-
crements of stress divided by the increments of strain
measured by the dial gages and so adjusted that the
initial slope of the stress—strain curve was 6,500,000
pounds per square inch.

The stress—modulus relations show a great deal of
scatter; it should therefore be appreciated that there
would be considerable scatter between the column—test
results and a single column curve derived from these data.
This scatter is shown in figure 6, in which the column
curve was obtained by taking pairs of values of stress
and tangent modulus of elasticity from the curve of fig-
ure 5 and computing the corresponding values of slender-
ness ratio from Euler's equation for column strengths

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

where

$\dfrac{P}{A}$ average stress, pounds per square inch

E modulus of elasticity, pounds per square inch

$\dfrac{L}{r}$ slenderness ratio

K coefficient describing end conditions, taken as
      1.00 for round ends and 0.50 for fixed ends

The agreement between the computed column strengths and
the actual test values is as good as could be expected
from a study of figure 5. For a group of specimens with
more nearly uniform stress—modulus relations, the agree—
ment between the test results and the column curve would
undoubtedly be better.

Figure 6 shows two other curves also, namely:
(1) the curve of equation (1) using a constant value of
modulus of elasticity, and (2) the curve of the equation
for the column strength of magnesium alloys given in ref—
erence 4. The latter equation is a modified Rankine—
Ritter formula as follows:

$$\frac{P}{A} = \frac{Y}{1 + Q\left(\dfrac{L}{R}\right)^2} + \frac{80000}{\left(\dfrac{L}{r}\right)} \qquad (2)$$

where

$\dfrac{P}{A}$ column strength, pounds per square inch

Y yield strength, pounds per square inch

Q Ritter's constant $\left(\dfrac{Y}{C\pi^2 E}\right)$

C fixation coefficient $\left(\dfrac{1}{K^2}\right)$ and the other quantities
      are as defined in equation (1)

In these equations, the value of modulus of elasticity
has been taken equal to the nominal value, 6,500,000
pounds per square inch. It will be seen that, for very
long columns, the agreement between the test data and
the Euler curve is fair and, for short columns for which
the stresses exceed the elastic limit of the material,
the discrepancies are on the unsafe side. Equation (2)
gives a curve that crosses the trend of the test data.
The computed values in the range of intermediate slender-
ness ratios are too low while the computed values in the
range of long columns are too high.

     With the great difference between the properties in
tension and compression, it would seem important to base
computations for column strengths on the compressive
properties of the material.

TENTATIVE COLUMN FORMULA FOR AM-57S

     A study of figure 6 indicates that each of the three
column formulas plotted with the data has some disadvan-
tages for general use in design. The Euler curve in which
E is a constant and equal to the nominal modulus of elas-
ticity (E = 6,500,000 lb/sq. in.) tends to give values
consistently too high in the range of slenderness ratios
(50 to 100) most common in structures. The modified Euler
curve in which E has a changing value equal to the tangent
modulus taken from the average stress-modulus diagram is
fairly satisfactory and safe but is not convenient for
ordinary engineering design purposes. The Rankine-Ritter
formula as modified is too conservative in the range of
slenderness ratios most frequently used and is unsafe
for long columns.

     The data from the column tests indicate, however,
that a curve of the Rankine-Ritter type with a limiting
maximum stress about 95 percent of the compressive yield
strength of the material seems to be a satisfactory
column curve for AM-57S. In figure 7 the test results
have been plotted with a curve of this type in which the
values of the constants have been arbitrarily chosen to
give a good agreement with the test results. The result-
ing column formula for AM-57S may be written as follows:

$$\frac{P}{A} = \frac{48000}{1 + 0.00075 \left(\frac{KL}{r}\right)^2} \tag{3}$$

where

P   ultimate column load, pounds

A   cross-sectional area, square inches

$\frac{L}{r}$ and K   are defined in equation (1), and the value
         of P/A has a maximum value equal to 95
         percent of the compressive yield strength of
         the material

    This formula agrees reasonably well with the test
results, is fairly conservative, and has the advantage
of being very simple to apply. A suitable factor of
safety, of course, must be applied when determining the
allowable column stress in design.

    It should be appreciated in using equation (3) that
it is based on results of tests which are restricted to
one lot of magnesium alloy AM-57S. There is no evidence
to indicate how generally this formula may be applied to
other alloys. For aluminum alloys, it has been found
that a single basic type of column formula can be ap-
plied with reasonable accuracy to all the various alloys
simply by so changing the constants that they bear a
certain relation to the compressive yield strength of
the material. It is reasonable to believe that this
same condition might hold in the case of magnesium alloys.

    Equation (3) can be written in the general form

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

where

B   original ordinate of the curve, pounds per
         square inch

D $\frac{B}{\pi^2 E}$, $\frac{P}{A}$ has a maximum value equal to x percent

      of the yield strength

and the other terms are as previously defined. Undoubted-
ly, a relation exists between the compressive yield strength

and the values of B and X which might be established
from test data on additional magnesium alloys

CONCLUSIONS

The following conclusions concerning magnesium
alloy AM–57S seem justified by the foregoing data and
discussion:

1. The compressive yield strength of the lot of
material tested is approximately one–half the tensile
yield strength; therefore, the compressive properties
rather than the tensile properties should be used in
computations for column strengths.

2. The compressive yield strength can be satisfac-
torily obtained from the stress–shortening curve de-
termined by measuring the relative movement of the heads
of the testing machine. This conclusion agrees with re-
sults of previous work on aluminum alloys.

3. The use of the tangent modulus in the Euler
column formula gives a curve that agrees fairly well
with the column strengths developed.

4. A tentative column formula for magnesium alloy
AM–57S, based on the test results given herein, is as
follows:

$$\frac{P}{A} = \frac{48000}{1 + 0.00075\left(\frac{KL}{r}\right)^2} \tag{3}$$

where

P   ultimate column load, pounds

A   cross–sectional area, square inches

$\frac{L}{r}$ slenderness ratio

K   coefficient describing end conditions, taken as
       1.00 for round ends and as 0.50 for flat ends

and P/A has a maximum value equal to 95 percent of the
compressive yield strength of the material. This formula
fits the test results closely enough that it may be con-
sidered satisfactory for ordinary engineering purposes.
A suitable factor of safety must be applied to this
formula when determining allowable column stresses in
design.

Aluminum Research Laboratories,
     Aluminum Company of America,
          New Kensington, Pa., February 4, 1943.

REFERENCES

1. Anon.: Tentative Methods of Tension Testing of
     Metallic Materials. 1940 Supplement to A.S.T.M.
     Standards, pt. I, Metals. (E 8-40T). A.S.T.M.
     (Philadelphia), pp. 454-463.

2. Anon.: Properties of Mazlo Magnesium Products.
     Am. Magnesium Corp., 1941.

3. Templin, R. L.: An Automatic Autographic Extensometer
     for Use in Tension Tests of Materials. A.S.T.M.
     Proc., vol. 32, pt. II, 1932, pp. 783-792.

4. Winston, A. W.: Magnesium Alloys and Their Structural
     Application. Structural Application of Steel and
     Light-Weight Alloys, Symposium. A.S.C.E. Proc.,
     vol. 62, pt. 1, nos. 8 and 10, Oct. 1936, pp.
     1125-1340.

TABLE I.— MECHANICAL PROPERTIES OF MAGNESIUM ALLOY AM—57S

[Extruded angle, $2\frac{1}{2}$ by $2\frac{1}{2}$ by 1/4 in.]

Specimen	Tensile strength (lb/sq in.)	Tensile yield strength (offset = 0.2 percent) (lb/sq in.)	Elongation in 2 in. (percent)	Compressive yield strength (offset = 0.2 percent) (lb/sq in.)
1	42,700	31,700	12.5	16,000
2	41,290	28,100	[a]12.0	14,300
3	42,550	29,700	12.0	15,000
4	42,180	29,800	11.0	15,300
5	42,620	28,500	[a]12.0	15,600
6	42,090	28,300	11.5	15,100
7	43,200	30,600	15.0	15,300
[b]Typical	44,000	30,000	14.0	20,000

[a]Broke outside middle third.
[b]See reference 2.

TABLE II.— DESCRIPTION OF COLUMN SPECIMENS OF MAGNESIUM ALLOY AM-57S AND RESULTS OF TESTS

[Extruded angle, $2\frac{1}{2}$ by $2\frac{1}{2}$ by 1/4 in.]

Specimen (1)	Length, L (in.)	Slenderness ratio	Crookedness e (in.) (2)	Initial curvature	Weight (lb)	Area, A (sq in.) (3)	Max. load, P (lb)	Column strength, $\frac{P}{A}$ (lb/sq in.)
1R	9.93	20	0	Straight	0.776	1.21	17,450	14,420
2R	19.65	40	.004	C-curve	1.536	1.21	17,750	14,670
3R	29.20	60	.004	C-curve	2.266	1.20	16,800	14,000
4R	39.30	80	.026	C-curve	3.063	1.21	10,150	8,390
5R	49.05	100	.011	C-curve	3.827	1.21	7,550	6,240
6R	58.95	120	.006	C-curve	4.600	1.21	5,890	4,870
7R	78.55	160	.006	S-curve	6.108	1.20	3,000	2,500
1F	9.92	20	0	Straight	0.777	1.21	18,250	15,080
2F	19.65	40	0	Straight	1.529	1.20	17,460	14,550
3F	29.50	60	.003	C-curve	2.293	1.20	18,170	15,140
4F	39.30	80	.006	C-curve	3.052	1.20	17,350	14,460
5F	49.05	100	.009	C-curve	3.818	1.20	18,260	15,220
6F	58.95	120	.012	S-curve	4.580	1.20	14,900	12,420
7F	78.55	160	.033	C-curve	6.110	1.20	9,120	7,600
8F	98.10	200	.072	C-curve	7.628	1.20	5,850	4,875
9F	126.1	257	.010	C-curve	9.730	1.19	3,580	3,010

[1] R designates specimens tested as columns with round ends (ball-bearing spherical seats); F, specimens tested as columns with flat ends (fixed heads).

[2] Crookedness as measured by inserting thickness gages between specimen and a surface plate.

[3] Calculated from weight and length of specimen and nominal specific gravity of material (0.0647 lb/cu in.).

Fig. 1.
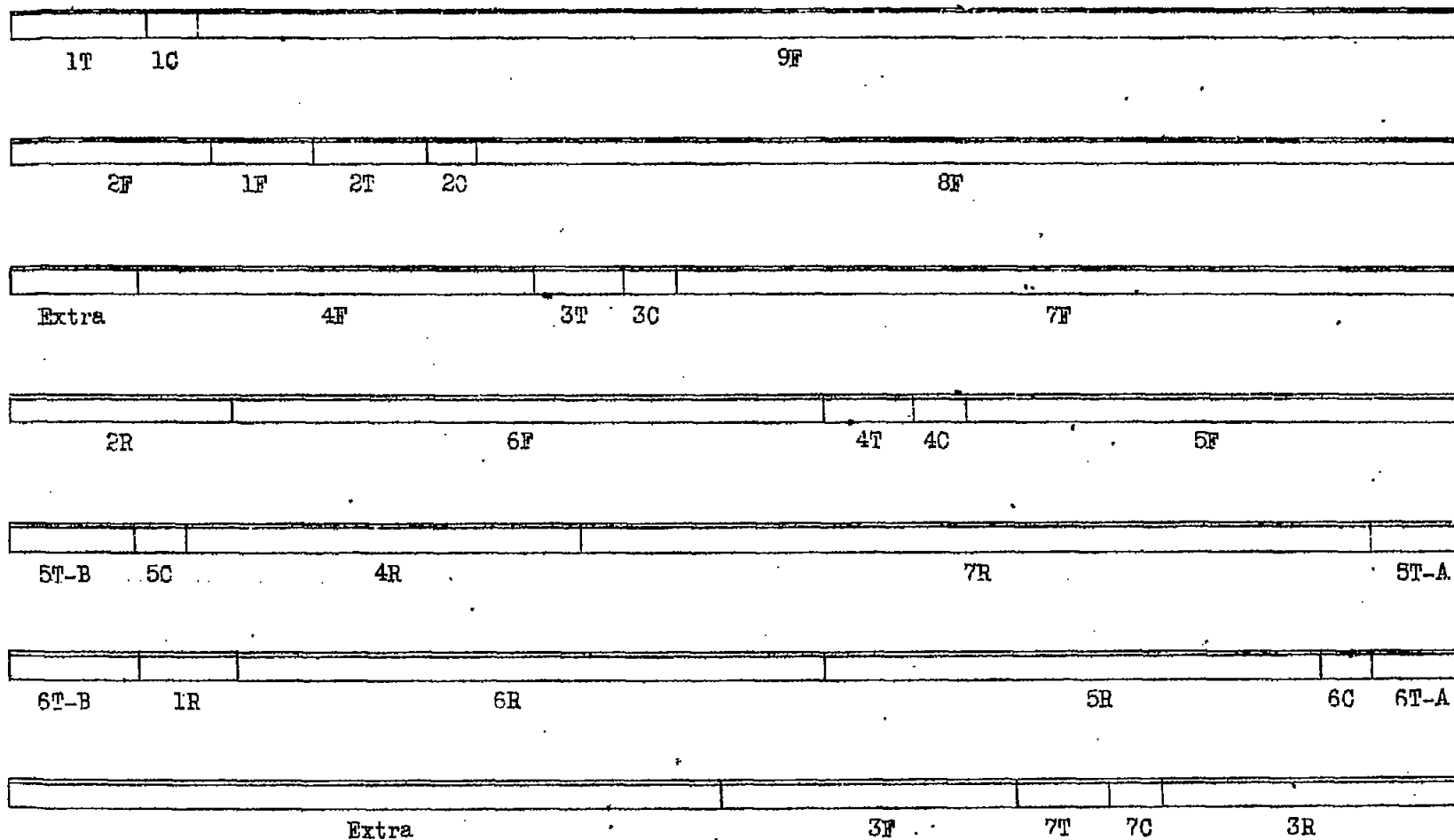
T   tensile specimen   R   column specimen tested with round ends
C   compressive specimen   F   column specimen tested with flat ends

Figure 1.- Locations of specimens in pieces of material furnished. Magnesium alloy AM-57S;
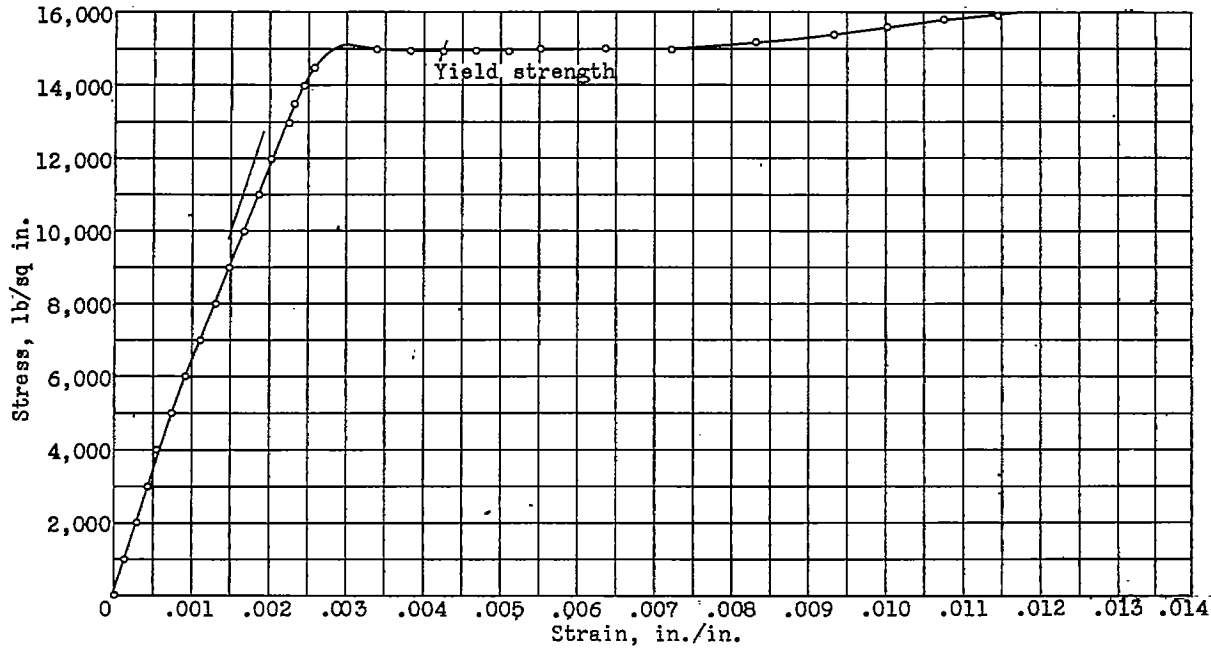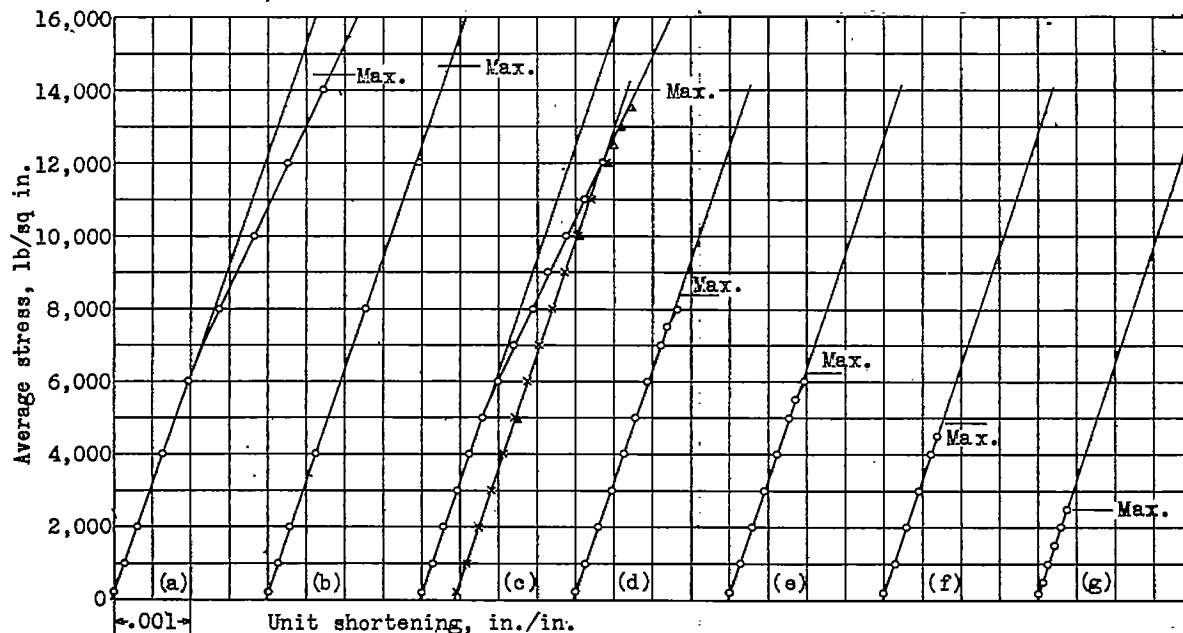extruded angle, 2-1/2 by 2-1/2 by 1/4 inches.

Figure 2.- Compressive stress-strain curve for specimen 3C. Length of specimen, 5.0
            inches; area, 1.20 square inches; L/r, 10. Relative movement of heads of
testing machine interpreted as strains.

(a) Specimen 1R; L, 9.93 inches; L/r, 20.   (b) Specimen 2R, which was accidentally
loaded to about 12,000 pounds per square inch before testing; L, 19.65 inches; L/r, 40.
(c) Specimen 3R; L, 29.20 inches; L/r, 60. (Loading: o first; × second; △ third.)
(d) Specimen 4R; L, 39.30 inches; L/r, 80. (e) Specimen 5R; L, 49.05 inches; L/r, 100.
(f) Specimen 6R; L, 58.95 inches; L/r, 120. (g) Specimen 7R; L, 78.55 inches; L/r, 160.

Figure 3.- Compressive stress-shortening curves for specimens tested as columns with
           round ends. Shortening determined by measuring the relative vertical move-
ment of the heads of the testing machine.

Figure 4.- Compressive stress-shortening curves for specimens tested as columns with flat
　　　ends. Shortening determined by measuring the relative vertical movement of the
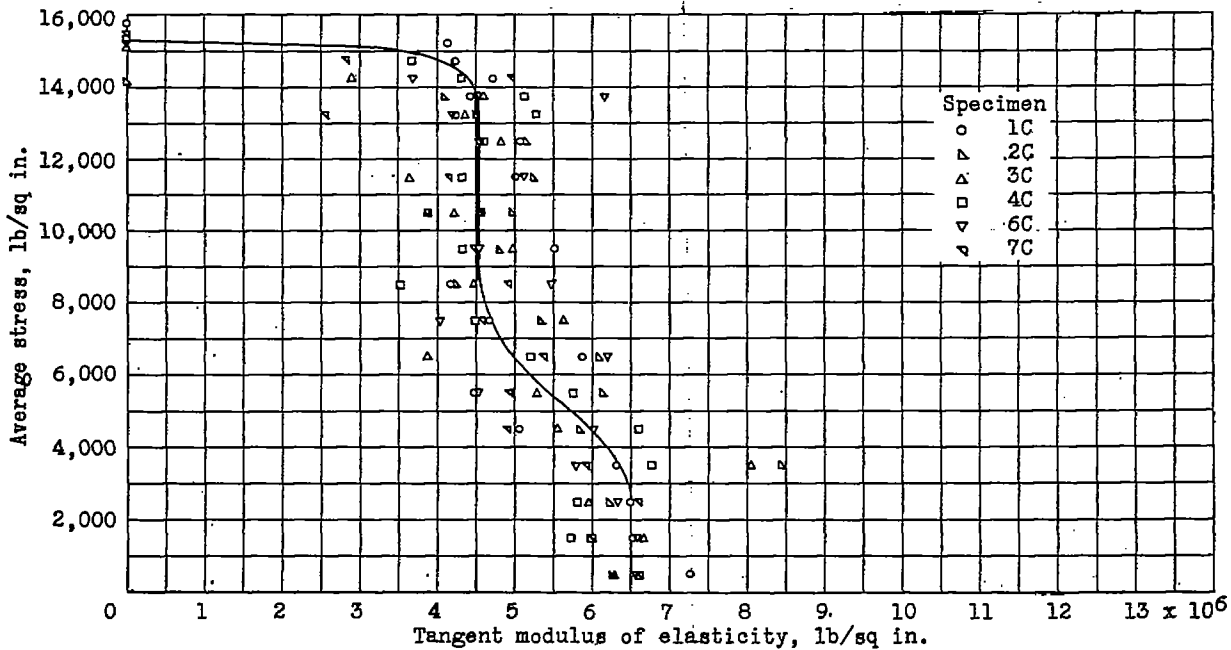heads of the testing machine.
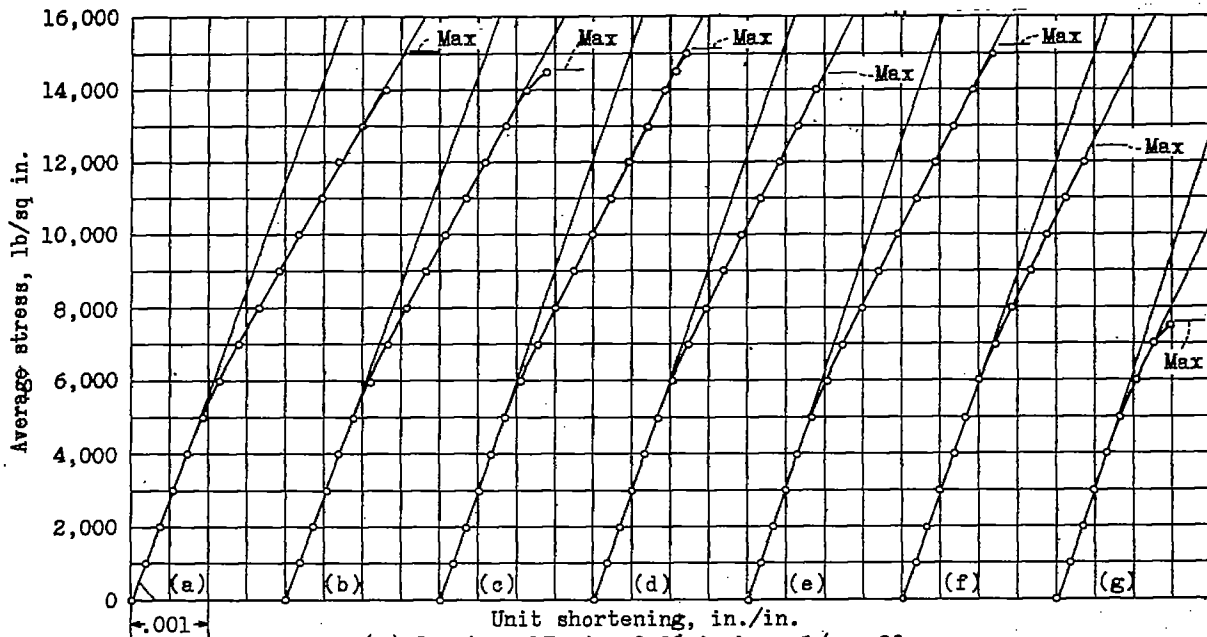
(a) Specimen 1F; L, 9.92 inches; L/r, 20.
(b) Specimen 2F; L, 19.65 inches; L/r, 40.
(c) Specimen 3F; L, 29.50 inches; L/r, 60.
(d) Specimen 4F; L, 39.30 inches; L/r, 80.
(e) Specimen 5F; L, 49.05 inches; L/r, 100.
(f) Specimen 6F; L, 58.95 inches; L/r, 120.
(g) Specimen 7F; L, 78.55 inches; L/r, 160.

Figure 5.- Stress against tangent modulus of elasticity, obtained as the increment of
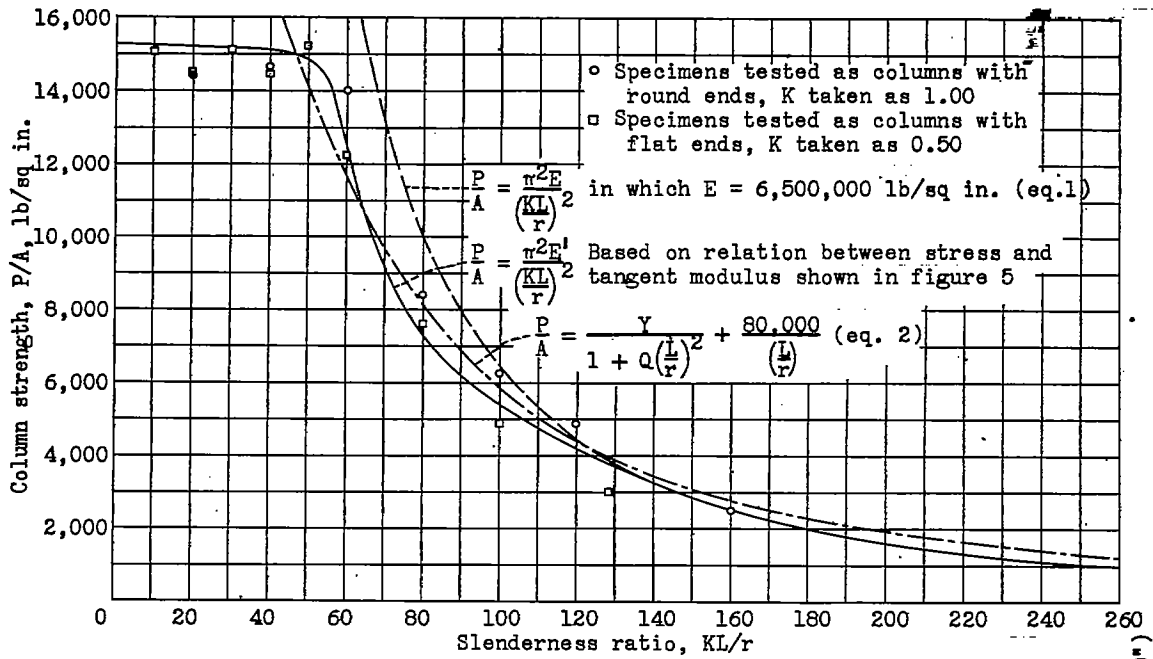　　　stress divided by the increment of strain. Length of specimen, 5.0 inches;
L/r, 10.

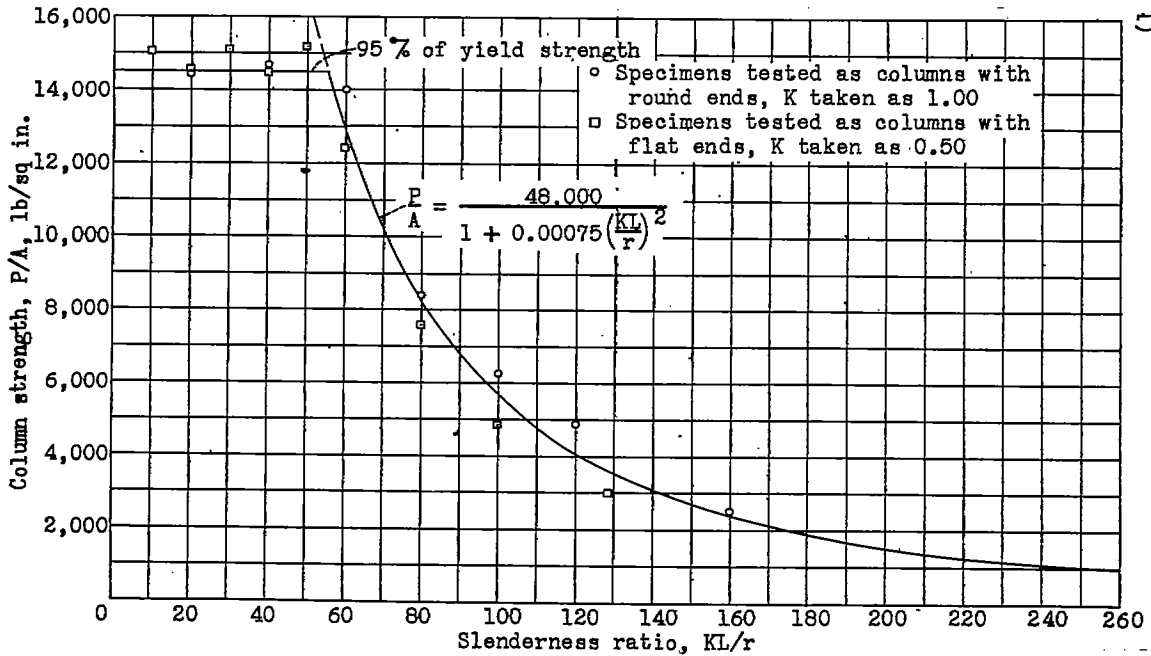Figure 6.- Column strength of magnesium alloy AM-57S.

Figure 7.- Column strength of magnesium alloy AM-57S.