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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 819

COMPARISON OF STRESS-STRAIN CURVES OBTAINED BY SINGLE-THICKNESS AND PACK METHODS

By D. A. Paul, F. M. Howell, and H. E. Grieshaber
Aluminum Company of America

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SUMMARY

An apparatus for supporting a single thickness of sheet against buckling so that its compressive yield strength can be determined by the single-thickness method is described. The results obtained with the apparatus are compared with those obtained on the same material by the pack method, and the results obtained in compression by the single-thickness and pack methods are compared with those obtained on large solid specimens of such dimensions that they did not require lateral restraint.

The results showed that the compressive yield strength of thin sheet metals could be determined within acceptable limits by the single-thickness method. The apparatus, which was designed and used by the Aluminum Company of America, is suitable for determining yield strengths of aluminum-alloy sheet 0.020 inch and greater in thickness.

INTRODUCTION

Since its development in 1933 at the National Bureau of Standards the "pack" method has been satisfactorily used for determining the compressive yield strength of thin metallic materials. (See reference 1.) The main disadvantages of this method are the high cost of machining the specimens and the length of time required to set up the specimen in the testing machine because of the large number of steel pins that must be individually adjusted to restrain the specimen laterally during a test. In order to eliminate some of the disadvantages of the pack method Mr. W. P. Montgomery of the Vought-Sikorsky Aircraft Corporation proposed a scheme for testing a single thickness of sheet. Following Mr. Montgomery's suggestion,

the Aluminum Research Laboratories designed and constructed a slightly modified device for supporting a single thickness of sheet against buckling so that its compressive yield strength could be determined.

Both the pack and the single-thickness methods are based on the supposition that they will give a compressive yield strength the same as that obtained from a solid compact specimen of such dimensions that it need not be reinforced against lateral buckling. In the original investigation of the pack test at the National Bureau of Standards it was shown, by tests of steel, brass, and an aluminum alloy, to give compressive yield strengths comparable with those obtained on solid specimens. Such a comparison is also desirable in the case of the single-thickness test.

This report describes the apparatus and compares the results obtained in compression on single-thickness specimens, using the single-thickness method, with those obtained by the pack method and with those obtained on large solid specimens with no lateral restraint.

MATERIAL

The specimens used in these tests were taken from 24S-T aluminum alloy flat sheet 0.020 inch and 0.040 inch thick and from 17S-T aluminum alloy plate 5/8 inch thick. The tensile properties of the sheet, as determined by the New Kensington Works laboratory (P.T. no. K101440-C) were as follows:

Lot [1]	Nominal thickness (in.)	Tensile strength (lb/sq in.)	Yield strength (offset=0.2 percent) (lb/sq in.)	Elongation in 2 in. (percent)
9431-W	0.020	73,120	63,100	14.5
9431-X	.020	72,810	55,800	15.0
3573-W	.040	71,130	52,300	17.5
3573-X	.040	69,210	46,100	21.0

[1] W, specimen cut with grain; X, cut across grain.

Results of tensile tests of the plate are given in table I.

The sheet was tested to compare the results obtained with the single-thickness and the pack methods; the plate was tested, primarily, to compare the results obtained, using single-thickness and pack specimens with results obtained on large solid specimens from the same material. These tests also provided additional comparisons between the single-thickness and the pack methods.

METHOD OF TEST

The compressive yield strength of each sheet sample was determined with and across grain, using both the pack and the single-thickness methods. Repeat tests were made with the single-thickness method. The pack specimens were composed of 21 pieces in the case of the sheet 0.020 inch thick and 11 pieces in the case of the sheet 0.040 inch thick. The single-thickness specimen is nominally 5/8 inch wide and 2 5/8 inches long. A group of such specimens can be machined together in the same manner as one pack specimen.

A total of seven specimens was cut from the plate, as shown by the sketch (fig. 1). Specimens T1 and T2 were tensile specimens and specimens C1 to C5 were compressive specimens. Specimens C1 and C2 were large compact specimens to be tested without lateral restraint and having a slenderness ratio (L/r) of 12. Specimen C3 was a pack specimen composed of 11 pieces, each 0.040 inch thick; specimens C4 and C5 were thin specimens 0.040 inch and 0.020 inch thick, respectively, to be tested with the single-thickness specimen apparatus. It may be noted from the sketch that specimens T1 and C1 were round and that the others were either square or rectangular. All these specimens were cut so that their longitudinal axes were parallel to the direction of rolling. The round specimens were the only ones from which the original surface was machined. Otherwise, the specimens were of the full thickness of the plate. The following tabulation shows the dimensions of the specimens cut from the 17S-T plate:

Specimen	Type of test	Type of specimen	Dimensions (in.)
T1	Tension	Rectangular ends, round reduced section	0.615 diameter (reduced section)
T2	--do--	Rectangular ends, rectangular reduced section	5/8 x 1/2 (reduced section)
C1	Compression	Round[1]	5/8 diam. by 1 7/8 long
C2	----do----	Square[1]	5/8 x 5/8 x 2.16
C3	----do----	Pack - 11 pieces each	0.040 x 5/8 x 2 1/4
C4	----do----	Single-thickness	0.040 x 5/8 x 2 5/8
C5	----do----	Single-thickness	0.020 x 5/8 x 2 5/8

[1]Slenderness ratio (L/r) = 12

Figures 2, 3, and 4 are photographs showing the apparatus for holding a single-thickness specimen for a compression test. Figure 2 shows the various parts of which the apparatus is composed. These parts are the steel holder 1; the steel blocks 2 that support the spring clips 3, which in turn support the steel rollers 4; and one of the aluminum rods 5 that are placed in the adjustable eyebars 6 to clamp the tensometers against the edges of the specimen.

Figure 3 shows the various parts assembled for a test. In the assembly of the apparatus the holder is placed on a smooth flat surface and the steel blocks supporting the rollers are placed in the holder. The specimen is placed in the holder and alined vertically. The holder, the steel blocks, and the specimen all rest on the smooth flat surface. The rollers are clamped firmly against the specimen, using the screws 7. The rollers then contact the specimen directly opposite one another on the two sides of the sheet and also bear against the steel blocks. The rollers are 0.093 inch in diameter and 7/16 inch long, with conical ends which are guided by the flexible brass spring clips 3.

As the rollers move during a test the spring clips move outward on the conical bearing so that they do not restrain the downward movement of the rollers. Each steel block supports 25 rollers spaced 0.10 inch center to center. Calculations show that with this spacing aluminum-alloy specimens with a minimum thickness of about 0.020 inch can be loaded to the compressive yield strength without lateral buckling.

The specimen, with Huggenberger tensometers clamped on each edge, is shown in the testing machine ready for test in figure 4. Increments of stress are applied and corresponding strains are measured until the compressive yield strength of the material is exceeded.

Huggenberger tensometers were used on a 1/2-inch gage length for measuring strains in the compression tests. All the compression tests were made in the same testing machine and with the same pair of tensometers. The large compact compression specimens were tested in a subpress placed between the heads of the testing machine.

DISCUSSION

Table II is a summary of the test results for the specimens cut from the 24S-T flat sheet and shows a comparison of values of compressive yield strength as determined on a single thickness and as determined on a pack made up of a number of thicknesses. The maximum variation of the yield-strength values determined in repeat tests by the single-thickness method was only about 2 percent from the average values. In all but one case the average compressive yield strength determined for the single-thickness specimens is slightly less than that obtained on a pack specimen. The average difference is about 1.3 percent. Compressive stress-strain curves have been plotted for the specimens cut from the sheet samples and are shown in figures 5 and 6. An examination of these curves reveals no significant differences in the shapes of the curves for the two types of specimen.

The compressive yield strengths obtained on the various specimens cut from the 17S-T plate are summarized in table I. The stress-strain curves from which the yield strength values were selected are shown by figure 7. The

maximum variation from the average of any of these values is only about 0.6 percent, and, because of this uniformity, it seems permissible to conclude that the single-thickness and pack methods give compressive-yield-strength values the same as those obtained on large solid specimens.

In the pack test the specimen on which strains are measured is restrained against lateral expansion by pressure of the adjoining specimens against its entire flat surface; whereas, in the single-thickness test the specimen is restrained against lateral expansion only at the line contact with the rollers. By the use of the pack apparatus, lateral pressure is effected by some 30 screws that are individually tightened; with the single-thickness apparatus, only two screws are used to provide lateral restraint. Even though these two screws are tightened with considerable torque, the total pressure exerted is undoubtedly less than that exerted by the large number of individulally tightened screws in the pack test. It was thought that this difference between the two methods might have some effect upon the shape of the stress-strain curves or upon the modulus-of-elasticity values and that deviation curves for the stress-strain diagrams might indicate such effects.

The data obtained on the 17S-T plate have been considered in this manner, and figure 8 shows the deviation curves corresponding to each of the stress-strain curves shown by figure 7. Modulus-of-elasticity values have been calculated, using the slopes of these curves to correct the trial modulus, and the greatest variation from the average is 1.2 percent. These values and the proportional limits indicated by the deviation curves are summarized in table I. It is apparent that these data and the deviation curves do not indicate any differences resulting from differences between the two types of tests. In other words, the pins used in the pack test and the rollers used in the single-thickness test provide adequate support against lateral buckling, but they do not restrain the specimen to such an extent that the lateral force applied affects the stress-strain properties. It is especially interesting to note that the modulus of elasticity and the proportional-limit values obtained on the single specimen 0.020 inch thick (specimen C5) compare favorably with those obtained on the larger compression specimens.

Among the factors that contribute to the high cost of making a pack compression test are the following:

1. The relatively large amount of material required, for some thin sheet as many as 21 pieces each about 5/8 inch by 2 1/4 inches

2. The time required to machine a pack on two edges and two ends with sufficient accuracy to produce good results

3. The time required to set up the specimen ready for test

4. The time required to obtain the stress-strain data

5. The time required to plot the stress-strain data

The single-thickness compression test offers considerable saving in the first three factors, but, of course, the time required to obtain the stress-strain data and to plot the data is unchanged. The cost of making a compression test of thin sheet metal, using either of the two methods considered, is very much greater than the cost of making the commercial routine inspection, laboratory tension test. In spite of this fact, however, the single-thickness method provides a very useful means of investigating the properties of thin sheet metals.

CONCLUSIONS

The results of this investigation may be summarized as follows:

1. The compressive yield strength of thin sheet metals can be determined within acceptable limits by the single-thickness method. The apparatus used in this investigation is suitable for determining yield strengths of aluminum-alloy sheet 0.020 inch and greater in thickness.

2. Because of substantial savings in the cost of preparing and testing the specimens, the single-thickness method would appear to have a definite advantage over the pack method.

3. Although the single-thickness specimen method described in this report is very useful for investigating

the compressive properties of thin sheet metals, its present cost would appear to preclude its use as a routine commercial inspection test.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Penna., May 27, 1941.

REFERENCE

1. Aitchison, C. S., and Tuckerman, L. B.: The "Pack" Method for Compressive Tests of Thin Specimens of Materials Used in Thin-Wall Structures. Rep. No. 649, NACA, 1939.

TABLE I

SUMMARY OF COMPRESSIVE AND TENSILE PROPERTIES OF SPECIMENS CUT FROM 5/8-THICK 17S-T PLATE

[Longitudinal axis of all specimens parallel to direction of rolling]

Specimen	Type of specimen[1]	Compressive properties			Tensile Properties			
		Yield strength (offset = 0.2 percent) (lb/sq in.)	Proportional limit (lb/sq in.)	Modulus of elasticity (lb/sq in.)	Tensile strength (lb/sq in.)	Yield strength (offset = 0.2 percent) (lb/sq in.)	Elongation (percent)	
							4D	2 in.
T1	Round				61,930	42,800	17.1	
T2	Rectangular				61,200	43,000		20.0
C1	Round	41,100	24,200	10,350,000				
C2	Square	40,800	22,200	10,540,000				
C3	Pack	41,200	22,300	10,470,000				
C4	Single-thickness	41,000	20,600	10,540,000				
C5	Single-thickness	41,100	22,200	10,500,000				

[1]See fig. 1.

TABLE II

RESULTS OF COMPRESSIVE YIELD STRENGTH DETERMINATIONS ON 24S-T ALUMINUM-ALLOY SHEET

(P.T. no. 101740-C)

Direction	Nominal thickness, (in.)	Specimen	Compressive yield strength (offset = 0.2 percent)			Variation of compressive yield strength obtained by single-thickness method from that obtained by pack method (percent)
			Single-thickness method		Pack method	
			(lb/sq in.)	Variation from average (percent)	(lb/sq in.)	
Longitudinal	0.020	A	51,500	+2.1		
		B	49,400	-2.1		
		Average	50,450		50,400	+0.1
Transverse	.020	A	55,500	-1.1		
		B	56,700	+1.1		
		Average	56,100		57,400	-2.3
Longitudinal	.040	A	43,900	+1.4		
		B	42,700	-1.4		
		Average	43,300		44,000	-1.6
Transverse	.040	A	48,000	-0.2		
		B	48,200	+0.2		
		Average	48,100		48,700	-1.2
					Average difference	-1.3

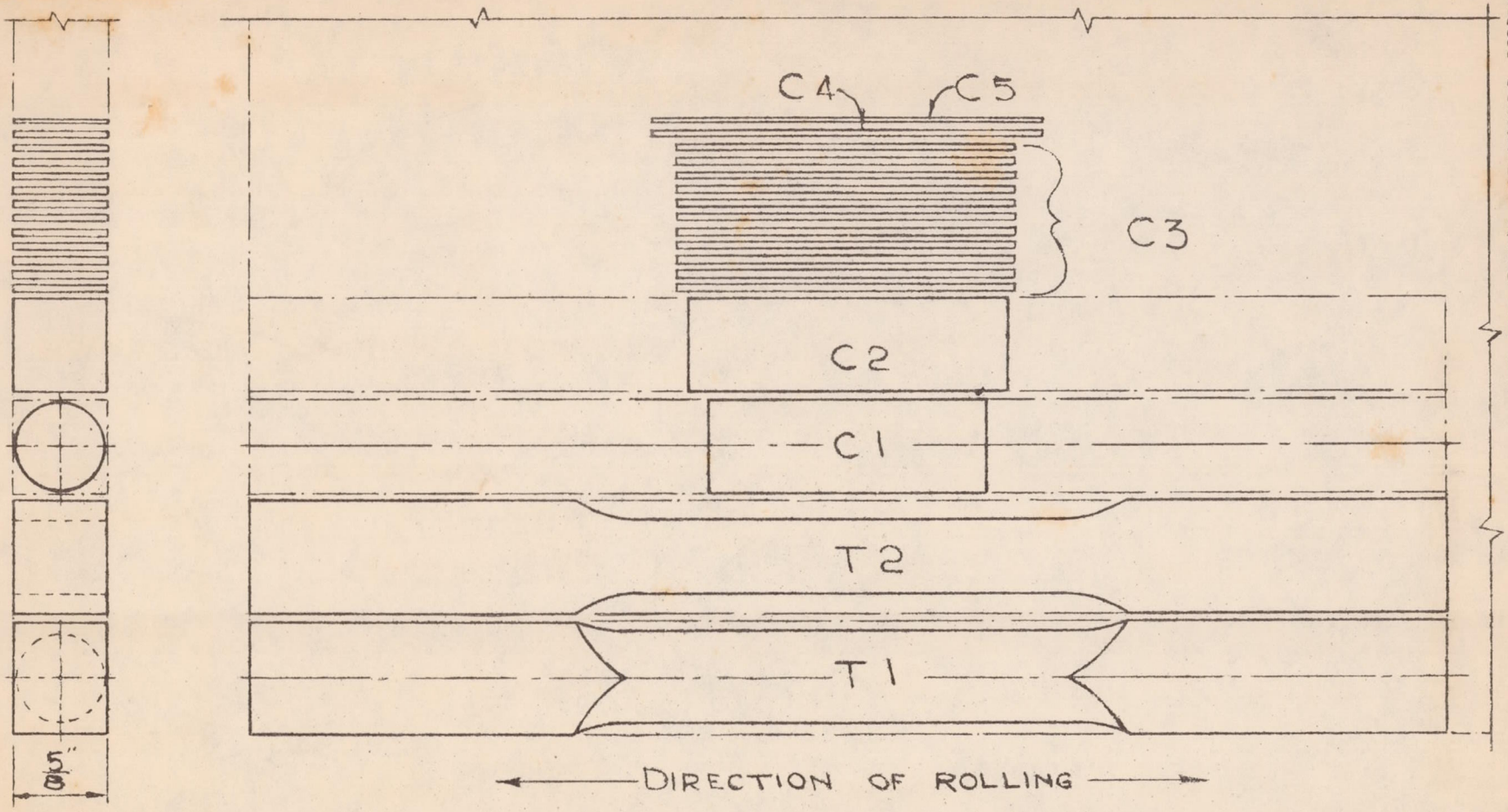

FIGURE 1.-SKETCH SHOWING LOCATION OF SPECIMENS CUT FROM $\frac{5}{8}$" THICK 17S-T PLATE.

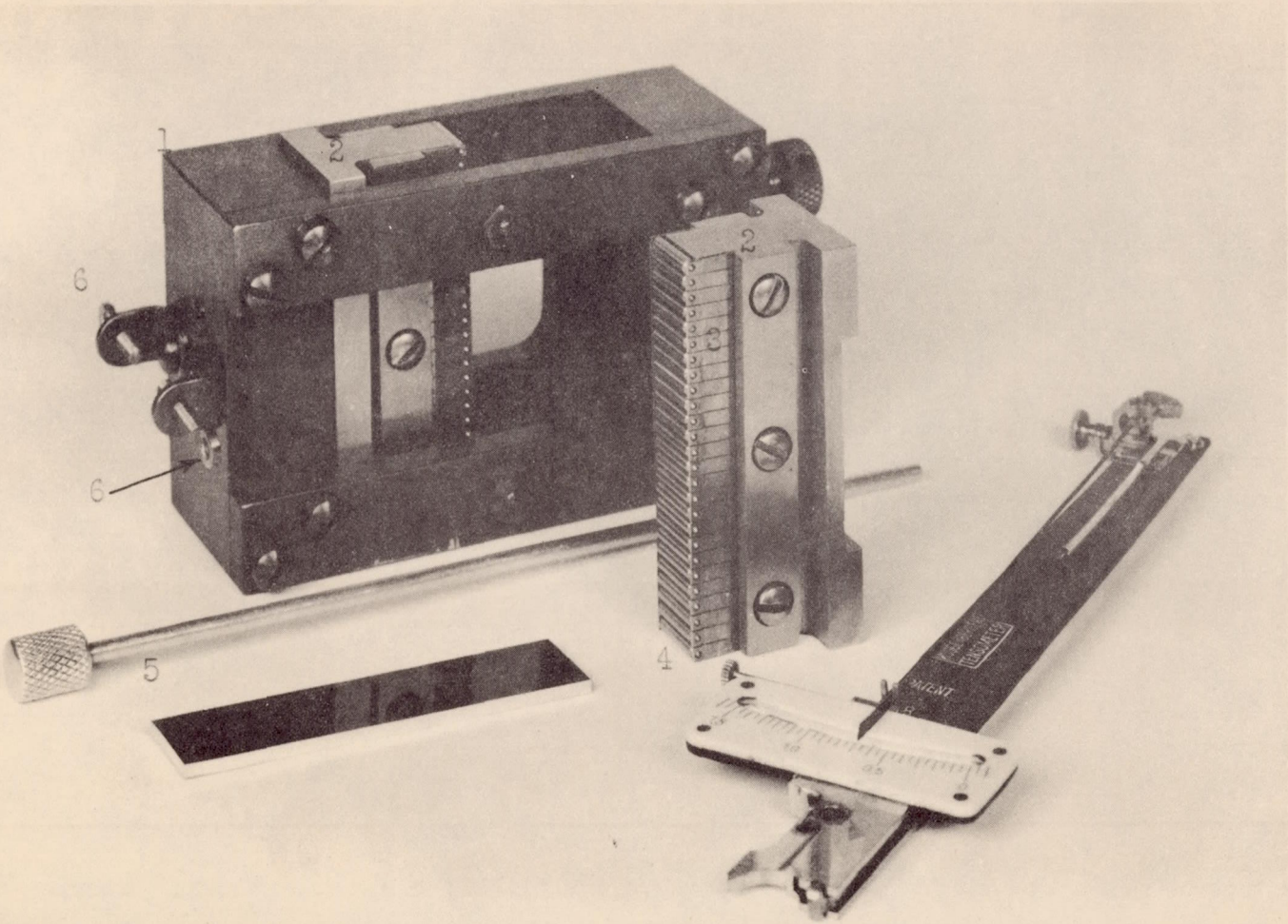

Figure 2.- Parts of device for making compression tests of single thicknesses of sheet metals.
(After Mr. W. P. Montgomery, Vought-Sikorsky Aircraft Corp.).

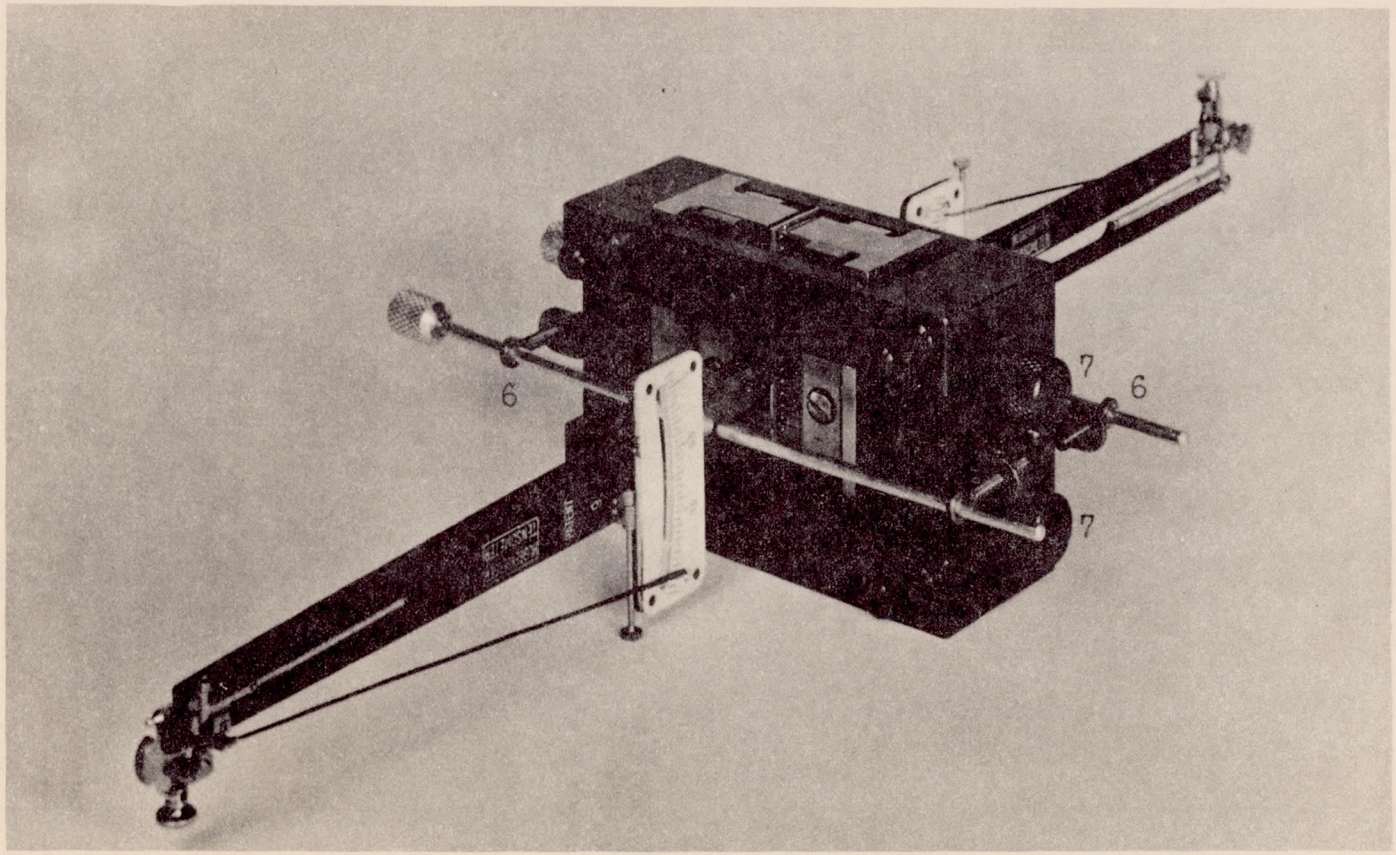

Figure 3.- Device for making compression tests of single thicknesses of sheet metals

Dimensions of specimen { length-----2.63 in.
width -----0.62 in.
thickness--0.020 in. or more.

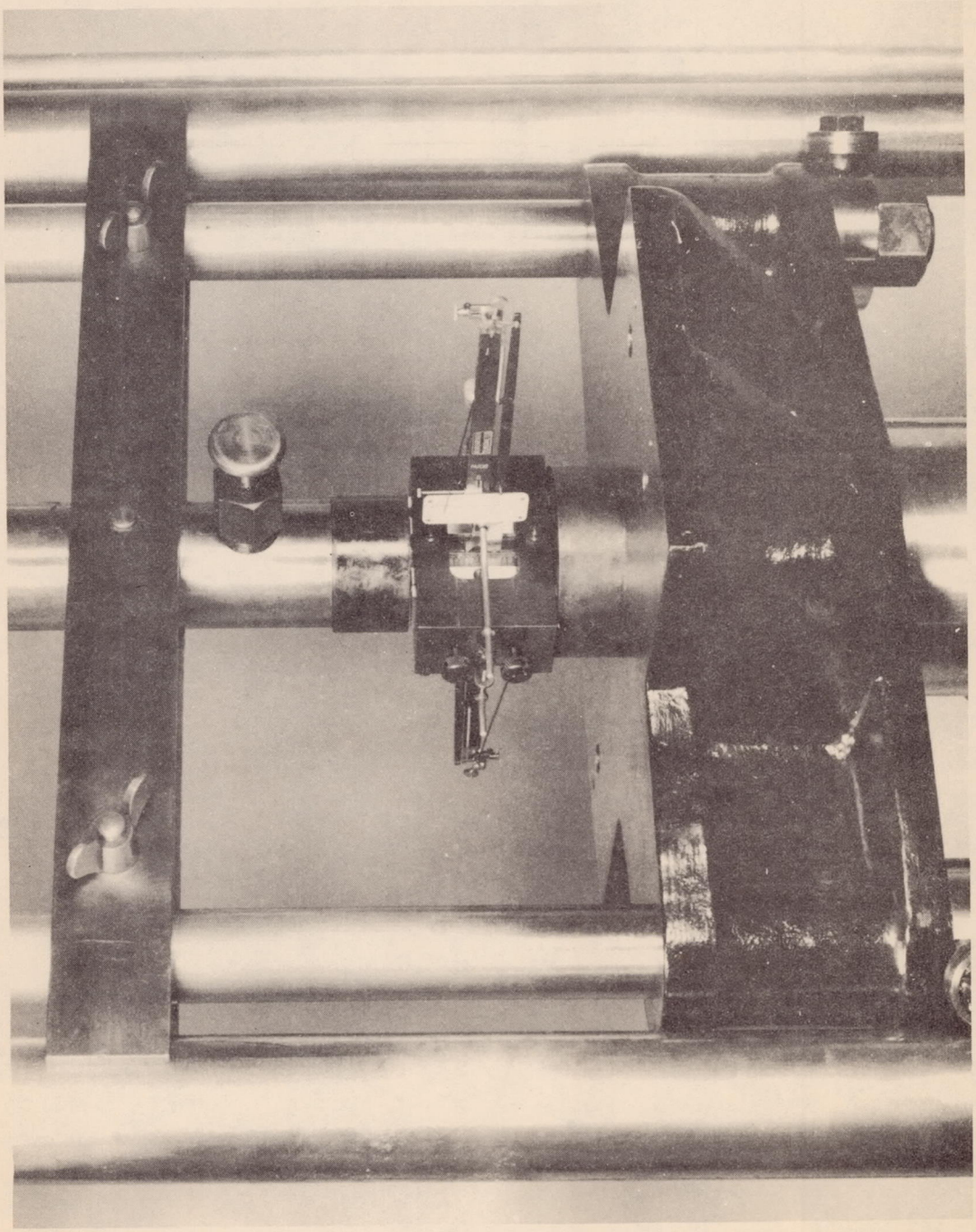

Figure 4.- Set-up for testing single thicknesses of sheet metals in compression.

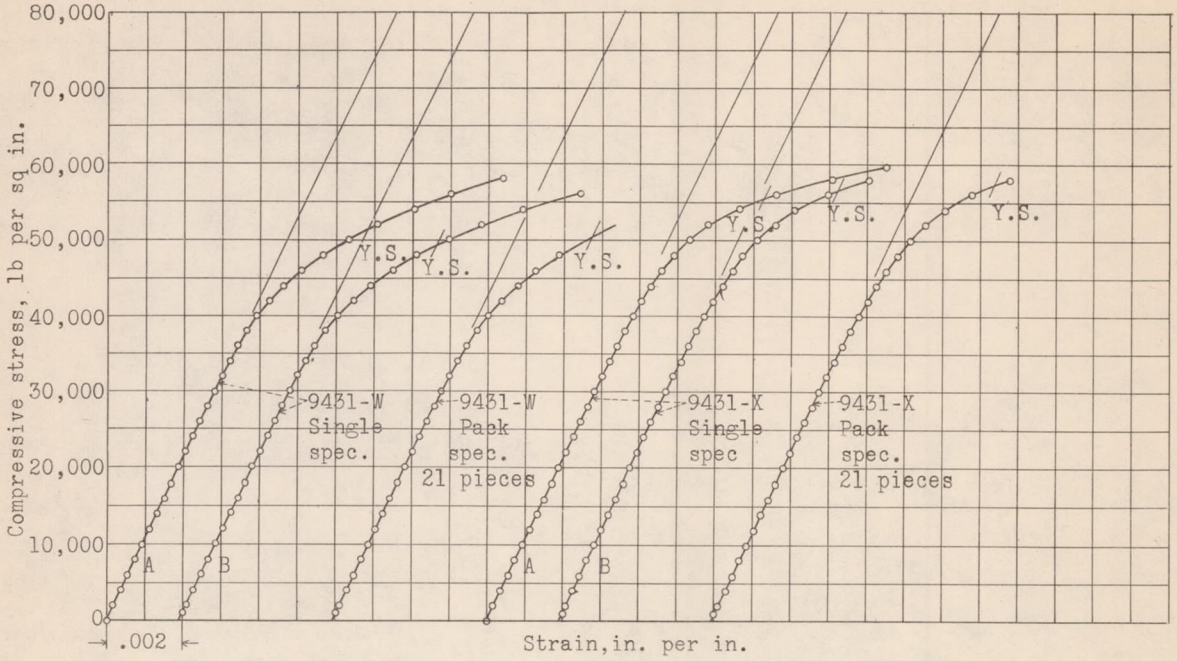

Figure 5.- Compressive stress-strain curves for 24S-T aluminum-alloy sheet. Nominal thickness;0.020 inch.

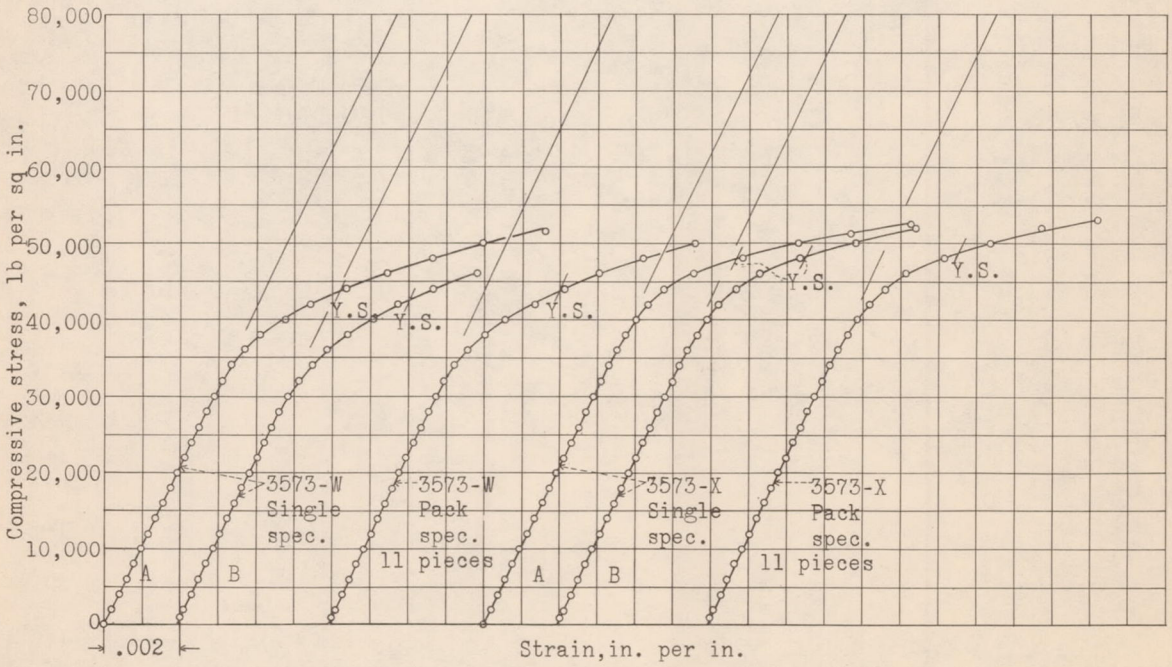

Figure 6.- Compressive stress-strain curves for 24S-T aluminum-alloy sheet. Nominal thickness;0.040 inch.

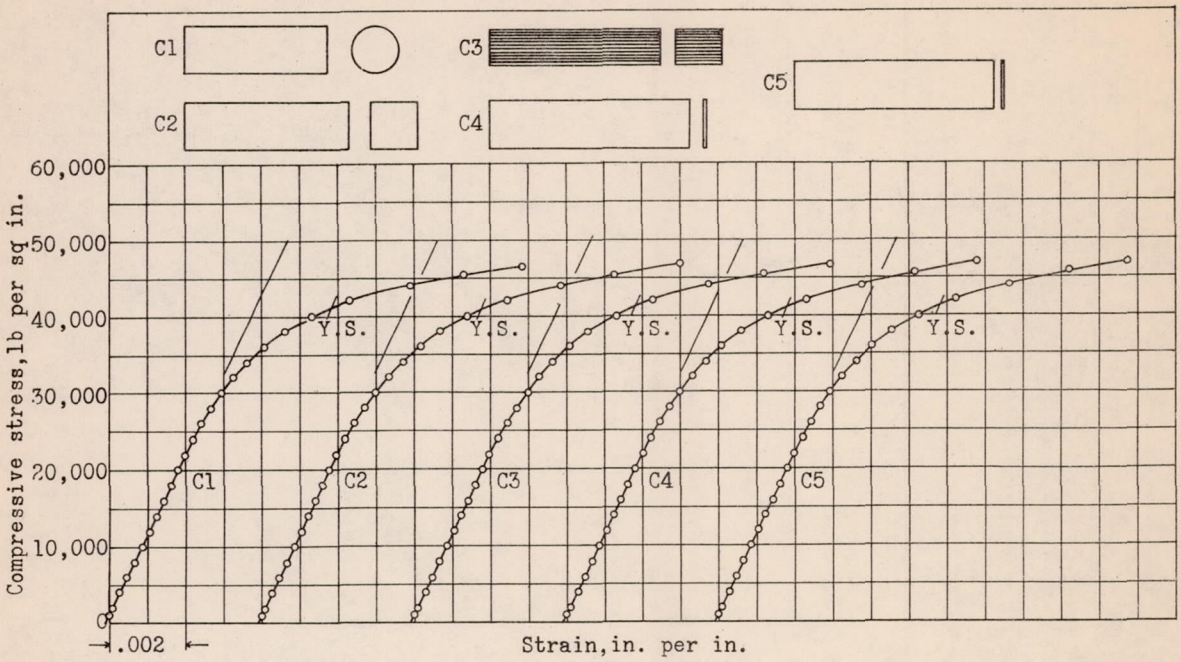

Figure 7.- Compressive stress-strain curves for 17S-T aluminum-alloy plate.

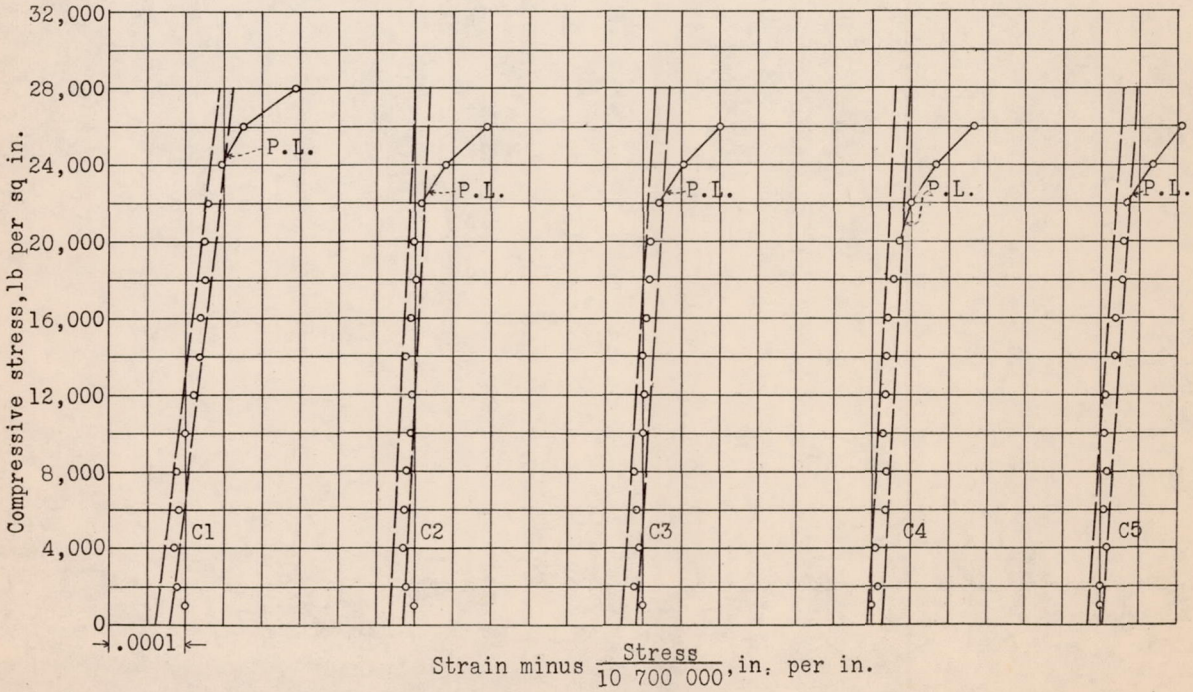

Figure 8.- Differences between observed and computed strains in 17S-T aluminum-alloy plate.