REPORT No. 649

THE PACK METHOD FOR COMPRESSIVE TESTS OF THIN SPECIMENS OF MATERIALS USED IN THIN-WALL STRUCTURES

By C. S. Aitchison and L. B. Tuckerman

SUMMARY

The strength of modern lightweight thin-wall structures is generally limited by the strength of the compression members. An adequate design of these members requires a knowledge of the compressive stress-strain graph of the thin-wall material. The "pack" method was developed at the National Bureau of Standards with the support of the National Advisory Committee for Aeronautics to make possible a determination of compressive stress-strain graphs for such material.

In the pack test an odd number of specimens are assembled into a relatively stable pack, like a "pack of cards." Additional lateral stability is obtained from lateral supports between the external sheet faces of the pack and outside reactions. Studies have been made of the reproducibility of the test results by testing packs taken from sheets of aluminum alloy 17ST and steel. The largest spread in yield strength was about 2 percent. Tests were also made to determine whether the results from packs were like those obtained from compact solid specimens. The results indicated that the method of transverse support had no appreciable effect on the yield strength. The largest difference between a pack and a solid specimen was 1.60 percent. Experience gathered in developing the test emphasized the fact that, while the method seemed to furnish results within the same order of accuracy as was usually obtained from other mechanical tests, such as the tensile test, it must be simplified before it can be used economically for inspection testing. The test seems adequate, however, for many problems in structural research.

INTRODUCTION

During recent years a remarkable expansion has taken place in the use of thin sheet and thin-wall material in lightweight structures such as airplane wings, and airplane fuselages. The strength of these structures is generally limited by the strength of certain members carrying compressive loads. These members have frequently been designed on the basis of the tensile properties of the material. This is convenient as the tensile test is relatively simple and is widely used. However, it may lead to an unsafe structure, on the one hand, or an uneconomical structure, on the other hand, if the compressive properties of the material differ from the tensile properties. There is an urgent need for a method which makes possible a direct determination of compressive stress-strain graphs for thin-wall material. In recognition of this need an investigation has been undertaken by the National Bureau of Standards with the financial support of the National Advisory Committee for Aeronautics.

Specimens of thin sheet usually fail through instability before the yield strength is reached. Some methods have been reported for overcoming this difficulty by assembling the material under consideration into a compact unit similar to a compact solid By these methods failures through instability occur at higher compressive loads.

E. B. Wolff and L. J. G. Van Ewijk (reference) made compressive tests on carefully selected wood and compared the results from "massive" bars with those from bars built up by gluing together lamellae taken from the same wood. They reported that the elastic properties for both kinds of specimens were the same.

A. Robertson (reference 2), in his investigation of the strength of subular struts, gives compressive results on various tubes which were made from strips of wood, about 0.025 inch thick, "* * * by wrapping the necessary number of strips round a mandril having first spread a fine coating of glue on all the faces that were to come together." He adds that "* * * the collapsing stress is uniform and practically that of the solid specimen for all values of * * *" ratios of thickness of the wall to radius of the tube greater than 0.08. In his report Robertson suggests, also, the possibility of combining sheet metal into compact units. He made some experiments on high tensile steel strip, about 0.015 inch thick. He states that "It is very difficult to get a good compression test of the material when in the form of such thin strips. An attempt was made to make a test piece by soldering together a large number of pieces and then machining the resulting block to a square section. The result, however, was not satisfactory."

PACK TEST

The successful results for tests where pieces of wood are combined into compact units suggest that the compressive properties can be obtained when there is sufficient lateral stability so that the yield strength is reached before the unit buckles.

With this approach a number of methods were tried at this Bureau to develop an adequate technique for compressive tests of thin-wall material. A compressive test (reference 3), which has become known as the pack test, has resulted from this preliminary work. The pack test is described in detail in the following pages. The details are given very fully because minor deviations from these details have, in some cases, produced unsatisfactory results and the necessary time has not been available to investigate just which of these are essential and which are unessential to the success of the test. The method was developed at this Bureau in 1933 and has given satisfactory results in all those cases in which the detail procedure, given below, was closely followed.

The pack test involves the use of external support supplied by a number of transverse members between outside reactions and the external sheet faces of a "pack" of specimens. The test was intended to simulate a block compressive test on a compact solid specimen of the kind described (reference 4), in a tentative specification of the American Society for Testing Materials as a "medium-length" specimen to determine the "general compressive strength properties of metallic materials." It was not intended, however, to determine the modulus of elasticity for which the "long" specimen described in this specification would be preferable.

The pack was composed of an odd number of rectangular specimens taken from the same material. These were assembled with sheet faces in contact to form a compact unit. The strains were measured on the middle specimen of the pack which, therefore, acted as a compression specimen supported on both faces by the remaining specimens of the pack. The specimens were machined using procedures similar to those normally employed for tensile specimens. This avoids other operations, such as forming, riveting, or welding, which are frequently used to stiffen structures and which might change the properties of the specimens.

The lateral supports of the pack were designed to give adequate support against buckling combined with a minimum resistance to displacements parallel to the load. Emphasis was placed on this requirement in order to assure that the method of support would not alter the stress distribution in the compression specimen.

THE PACK

MIDDLE SPECIMEN

The middle specimen M of a pack composed of 9 specimens taken from a piece of steel tubing is shown in fig. 1. The middle specimen is also shown in fig. 2 in a pack of 13 specimens taken from aluminum alloy sheet.

The compressive load P was applied parallel to the length of the pack and was distributed over the ends E of the pack. The lateral edge faces were nominally parallel to the load axis. These faces were left clear so that gages to measure the strain could be attached to the specimen. Stability in the direction of the width was obtained by making the specimen sufficiently wide in comparison to the length. The width h was about $^{23}/_{32}$ inch. The length L was twice the width plus one inch or about $2^{7}/_{16}$ inches.

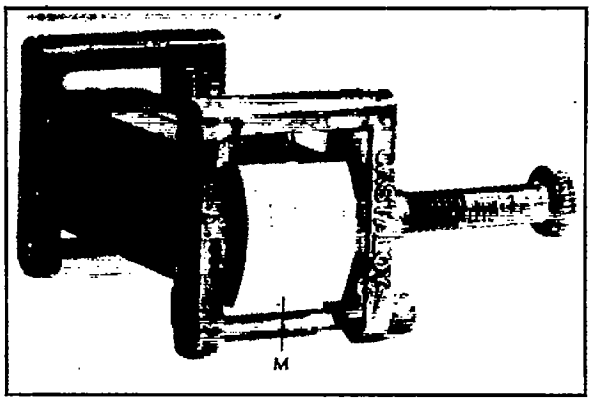

FIGURE 1.—Pack taken from tubing.

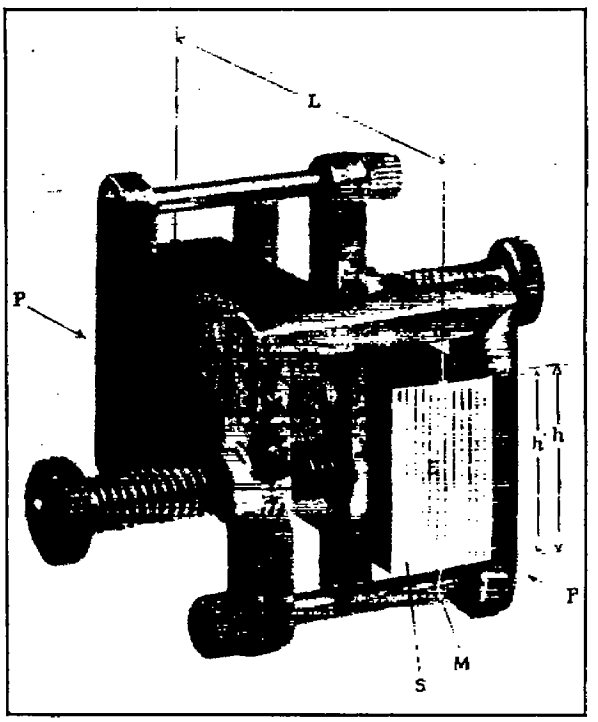

FIGURE 2.—Pack taken from sheet.

SUPPORTING SPECIMENS

All of the specimens in the pack were subjected to the axial load. For this reason the supporting specimens S (fig. 2) were made the same length as the middle specimen. In order that they would not interfere

with the seating of the strain gages, their width h' was made 0.02 to 0.05 inch less than the middle specimen.

In practice the specimens were usually slightly warped, bowed, or irregular on the surface. The effect of these deviations from a plane surface was minimized by assembling the supporting specimens, whenever possible, so that they bowed toward the middle specimen. The number of supporting specimens was kept as small as possible consistent with obtaining sufficient stability with the transverse support employed. This was done to limit the sample from the piece, so that specimens would be taken from like material and to obtain packs where only a small amount of material was available. This, also, reduced the cost of machining.

MACHINING PROCEDURE

The specimens were finished to width using a series of light cuts in order that the underlying material

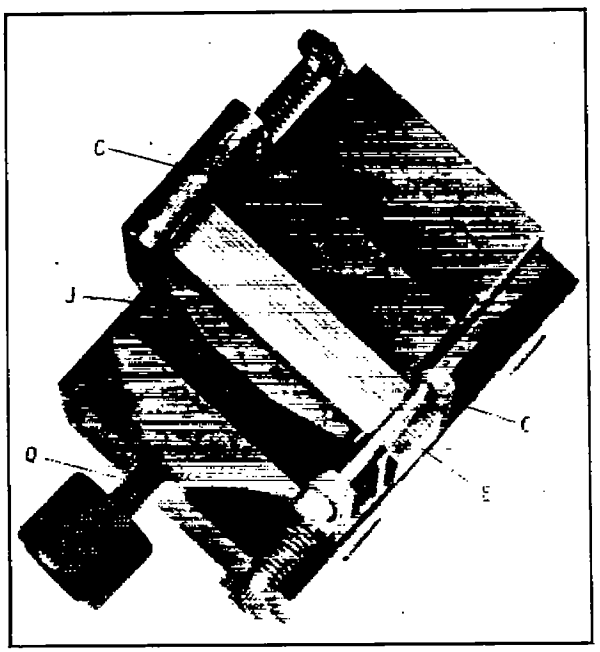

FIGURE 3.—Machining jig.

would be disturbed as little as possible. The lateral edges were finished smooth and the burrs were removed.

The specimens were finished to length after they were assembled in the pack. The machining jig, shown in fig. 3, was used to hold the specimens while they were being machined. This jig was a small vise. The contact surfaces of the jaws were $1\frac{11}{16}$ inches long and ½ inch wide. They were plane and smooth. The movable jaw J pivoted at the end of the screw Q. The surfaces of the body of the vise were planes parallel and perpendicular to the stationary jaw K so that the pack could be readily aligned with the machine tool.

A small clamp C was attached at each end of the pack before the ends were machined to hold the specimens in position after the pack was removed from the jig.

The specimens were sawed in a milling machine about $\frac{1}{32}$ inch longer than the finished length. The ends E were then finished in a surface grinder using a Norton alundum grinding wheel, number 1936:G and kerosene as a lubricant. No attempt was made, however, to make them more than nominally parallel and perpendicular to the axis of the pack. The edges were neither rounded nor marred, appreciably, when the burrs were removed.

TRANSVERSE SUPPORT

Transverse support was supplied as shown in fig. 4 by thirty steel pins A on each side of the pack. The pins were in three columns and ten rows. They were ⅛ inch in diameter and about two inches long. One end G was hardened and ground to a conical point. The other end H was machined to a hemisphere. The pointed end touched the external sheet face of the pack. The hemispherical end rested in a conical seat in the end of a size 8 machine screw Y, one inch long. The screws were threaded through the webs of two pieces of three inch structural steel channel R and were spaced on ¼-inch centers.

The channels were bolted at the bottom to the rectangular steel block B and were prevented from spreading at the top by a heavy yoke clamp, not shown in the figure.

TEST PROCEDURE

TESTING MACHINE

The packs were tested in a vertical, fluid-support, Bourdon-tube hydraulic type of testing machine of 100 kips capacity, using the 10 kip dial and the 50 kip dial to indicate the load. The testing machine is shown in fig. 5.

BEARING BLOCKS

The surfaces of bearing blocks which transfer the load from the heads of the testing machine to the pack were flat. They were inspected frequently for dirt or mars. A paper shim D, shown in fig. 4, was used between the $5\frac{1}{16}$ by 3 by 1¾ inch block B and the surface of the lower head of the testing machine. The bearing block F was a disk of hardened steel $1\frac{15}{16}$ inches in diameter and $\frac{11}{16}$ inch thick with top and bottom surfaces smooth-ground.

The bearing block U was attached to the upper head of the testing machine through the $8\frac{1}{16}$ by $5\frac{9}{16}$ by $1\frac{13}{16}$ inch plate I. The upper contact surface of the bearing block was 3½ inches in diameter and the lower contact surface was $1\frac{15}{16}$ inches in diameter.

Slight deviations from parallelism of the bearing blocks, the heads of the testing machine, and the ends of the pack which are within the limits of good machine shop practice, may appreciably affect the results of compressive tests. To eliminate these effects and to equalize the load on the specimen a cap-block V and a plaster of paris shim N were used, as shown in fig. 4.

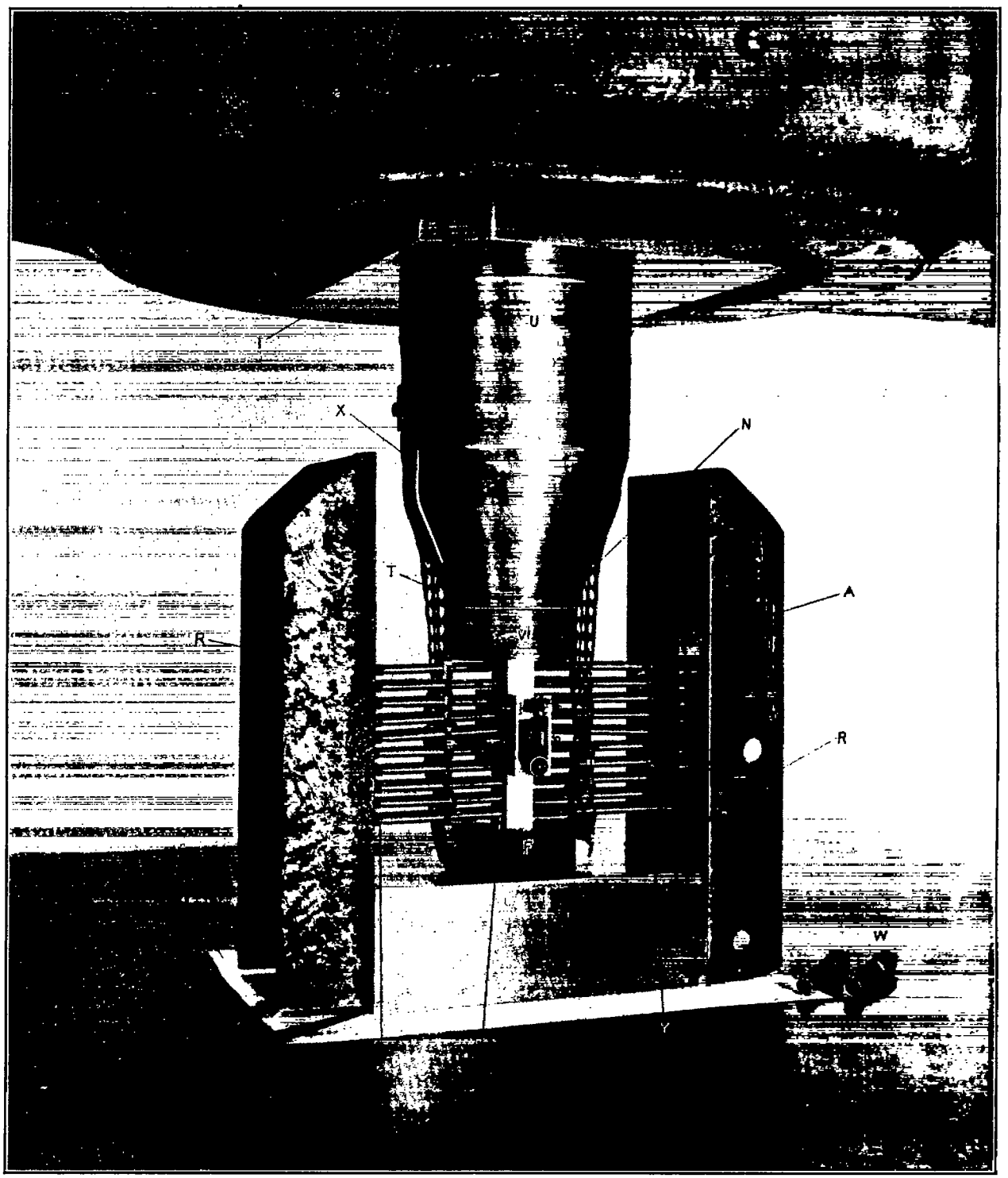

FIGURE 4.—Pack ready for test.

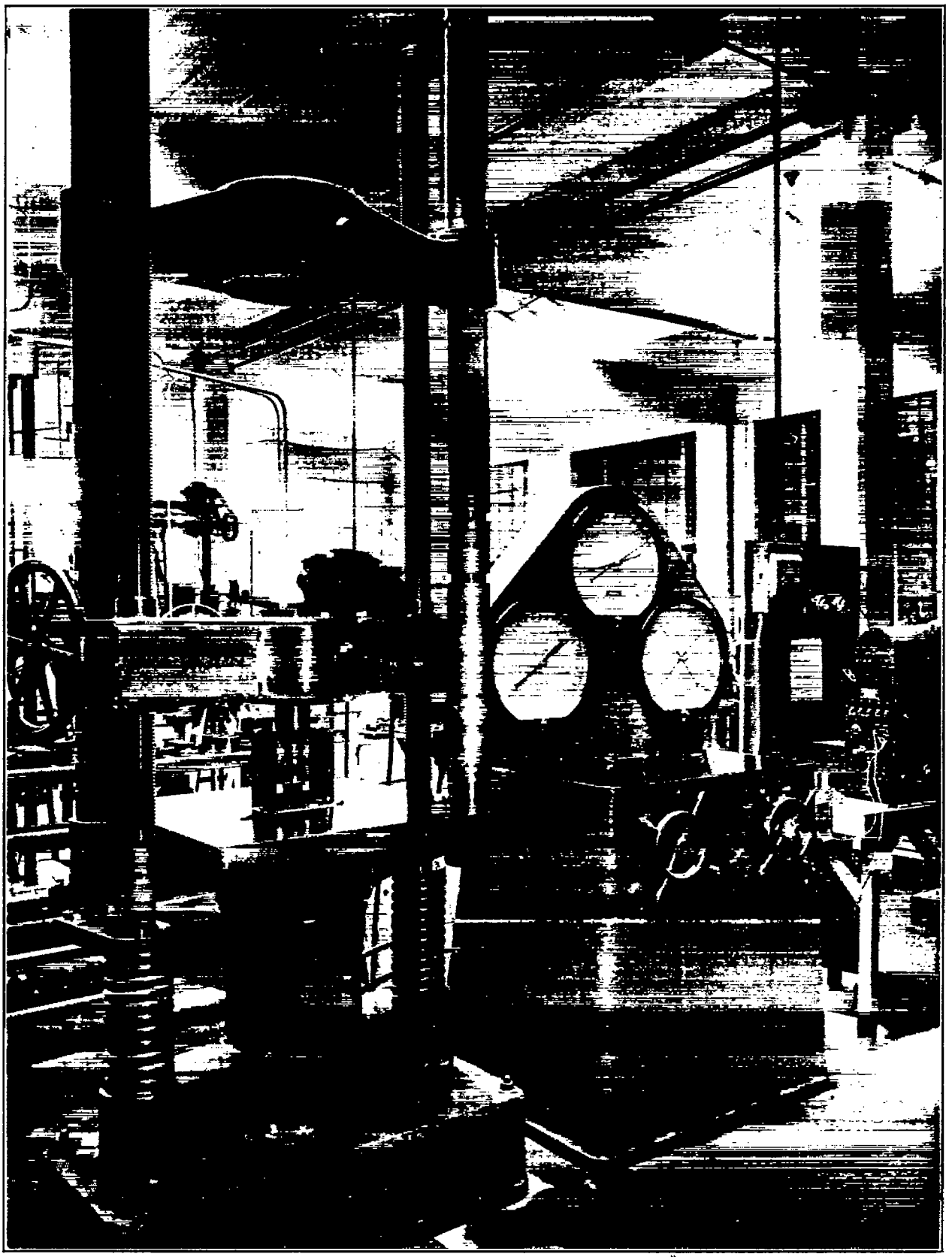

FIGURE 5.—Testing machine.

The cap-block was a disk of hardened steel $1\frac{15}{16}$ inches in diameter and $\frac{3}{4}$ inch thick. Its lower surface, which was smooth-ground, made direct contact with the upper end of the pack. The plaster of paris shim did not exceed 0.1 inch in thickness. It was cast, under an initial load of about one kip, between bearing block U and the upper surface of the cap-block V. The plaster was allowed to harden about 10 minutes before the pins were placed in position.

ASSEMBLING PINS

The pins providing transverse support were located by a definite procedure. They were first positioned, using the tweezers Z to guide the pins to their proper location and the small wrenches W to turn the screws. The perforated strips of tracing cloth T were used to support the pins in approximately the right position. The screws in the same locations on opposite sides of the pack were then tightened simultaneously and progressively until the points of the pins were slightly embedded in the surface of the pack.

It was considered important to locate the pins in a definite order. Satisfactory results were obtained by using the following sequence. Numbering the pins in rows from 1 to 10 beginning at the top, the pins in rows 5 and 6 of the middle column were located first. Next, those in rows 3, 4, 7, and 8 of the middle column, and then those in rows 3 to 8, inclusive, of the outside columns were located. The clamp at the upper end was then removed and the end of the strip of tracing cloth T placed under the clamp X. The pins in rows 1 and 2 were then located. The clamp at the lower end of the pack was removed and pins in rows 9 and 10 located. All screws were then systematically tried with the wrenches to insure that the ends of all the pins were bearing against the pack.

STRAIN GAGES

The strain was measured by a pair of Tuckerman 1-inch optical strain gages (reference 5). These gages were attached on each side of the pack to the edge of the middle specimen.

CROSS-SECTIONAL AREA

The cross-sectional area of a pack was computed by dividing the weight of the pack by its length and the density of the material.

LIMITATIONS

The limitations of this method of test have not been thoroughly explored. When preliminary results were obtained which apparently furnished satisfactory information for some of the materials generally used in aircraft, tests on a greater number of materials were desired. This has limited the time available for a thorough investigation into the capacity and accuracy of the method under various conditions.

Experience from tests, however, has shown that packs taken from aluminum alloy sheet composed of 13, 7, and 5 specimens of 0.032, 0.064, and 0.081 inch material, respectively, sustained compressive stresses in excess of 60 kips/in.^{2} before the packs failed through major instability. Packs composed of five specimens taken from heat-treated chromium-molybdenum steel sheet, 0.05 inch, were subjected to compressive stresses up to 180 kips/in.^{2} without failure through major instability. Within these limitations the pack test appears to give the compressive properties of a material within the same order of accuracy as is usually obtained in other mechanical tests, such as the tensile test.

TESTS ON BARS

PURPOSE

The pack test is based on the assumption that it will give compressive results like those obtained from block compressive tests. A number of comparative tests on packs and on compact solid specimens taken from metal bars were made to see whether or not this assumption was justified.

MATERIALS

The following materials were used in making these tests:

a. Carbon steel bar.
- Condition, cold rolled.
- Shape, round.
- Size, one-inch diameter.

b. Brass bar.
- Condition, rolled.
- Shape, square.
- Size, one-inch on side.

c. Aluminum alloy.
- Condition, rolled.
- Shape, round.
- Size, one-inch diameter.

SPECIMENS AND PACKS

Compact solid specimens and packs were obtained from alternate locations along each bar. The compact solid specimens were cut with symmetry to the axis of the bar to a size of $\frac{23}{32}$ by $\frac{23}{32}$ by $2\frac{7}{16}$ inch.

The pack specimens were obtained from the same location in the cross section of the bar as the compact solid specimens. The pack was composed of five specimens, 0.1 inch thick. These specimens were prepared by machining with light cuts so that the underlying material was deformed as little as possible. The finished surfaces were smooth and the burrs were removed from the edges.

PROCEDURE

The packs were tested using the procedure for pack tests as previously outlined in the section on Test Procedure (p. 3).

One compact solid specimen of each material was tested using pins for transverse support. The remaining compact solid specimens were tested without transverse support. The yield strengths, offset = 0.2 percent, were obtained from the stress-strain graphs in accordance with American Society for Testing Materials' tentative specification E9–33T (reference 4) method 2 (a).

RESULTS

The stress-strain graphs for these tests are shown in figs. 6, 7, and 8.

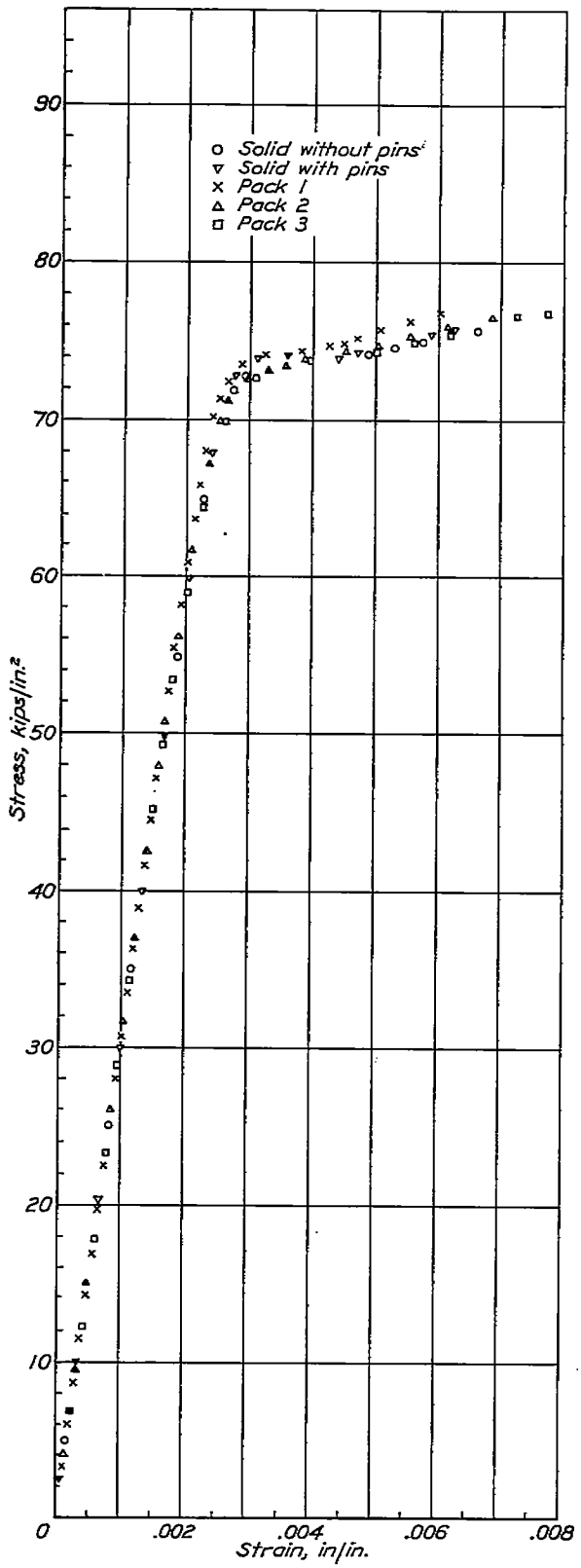

FIGURE 6.—Compressive tests on steel. Packs and compact solid specimens taken from one-inch round bar.

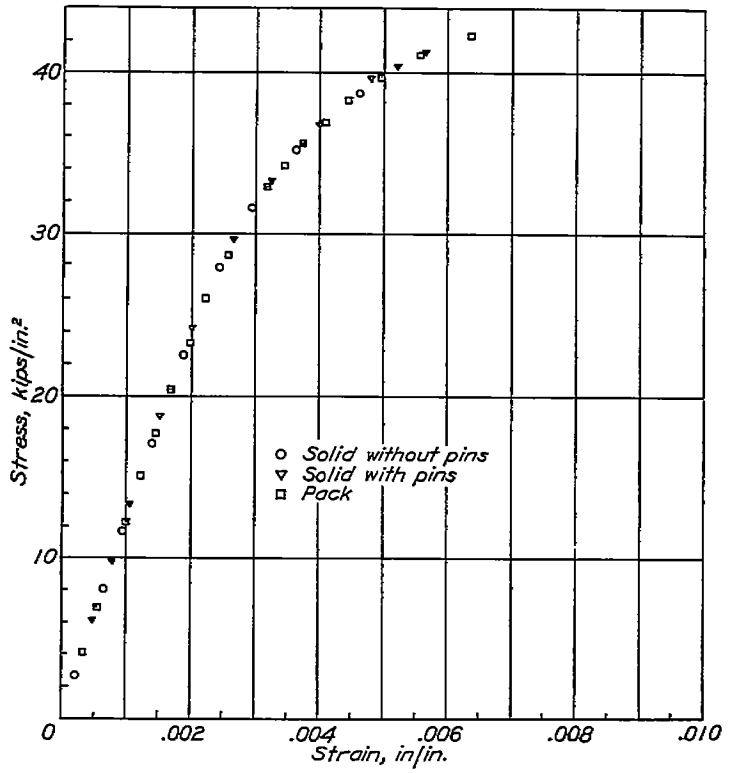

FIGURE 7.—Compressive tests on brass. Pack and compact solid specimens taken from one-inch square bar.

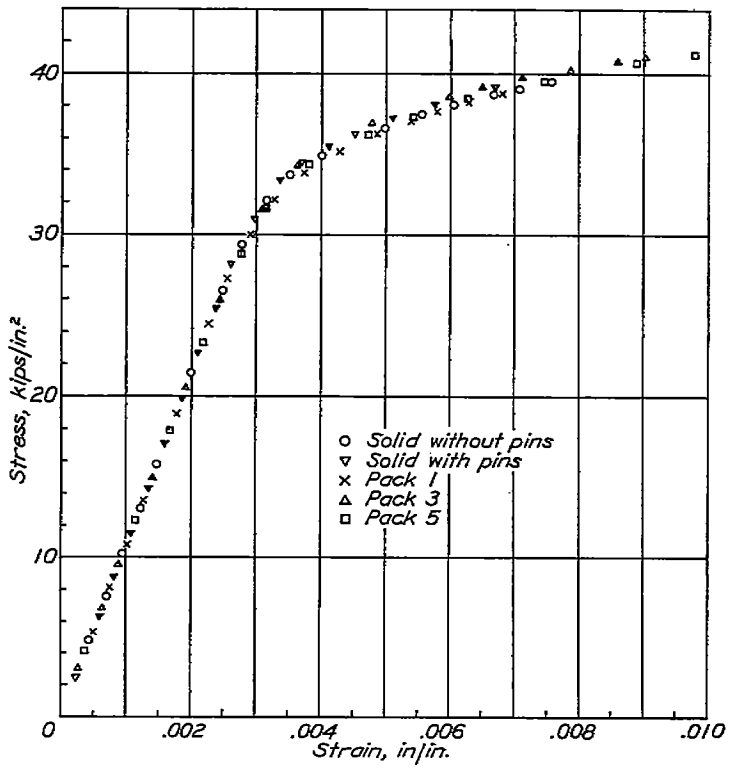

FIGURE 8.—Compressive tests on aluminum alloy. Packs and compact solid specimens taken from one-inch round bar.

The values for yield strength are given in table 1. The last two columns of this table list the difference in yield strength for each specimen from the compact solid specimen, without pins, expressed in kips/in.^{2} and in percent.

DISCUSSION

The results of these tests indicate that the pins when used as transverse supports on specimens of steel, brass, and aluminum alloy have no appreciable effect on the value of yield strength. The largest differences between a pack and a solid were 1.22 percent for steel, 0.25 percent for brass, and 1.60 percent for aluminum alloy. These differences are of the same order of magnitude as the spread in yield strengths for successive pack tests on the same material.

TESTS ON SHEET

PURPOSE

Some "pack" compressive tests were made on sheet metal of several materials and several thicknesses. The sheets were from 12 to 18 inches wide and in lengths not less than three feet. The results of these tests were used to obtain information on the effectiveness of the external support and the reproducibility of test results. They were confined to obtaining data for primitive stress-strain graphs from packs of specimens cut parallel to the long dimension of the sheet, which were called longitudinal packs, and to packs of specimens cut parallel to the short direction of the sheet which were called transverse packs. The tests were not intended to represent a study of present types of sheet metal.

TABLE 1.—YIELD STRENGTH OF PACKS AND COMPACT SOLID SPECIMENS

Material	Specimen number	Transverse support	Yield strength, offset = 0.2 percent	Difference from compact solid specimen, without pins	
			kips/in.^{2}	*kips/in.*^{2}	*Percent*
Steel	Compact solid	None	74.0		
	Compact solid	30 pins/side	74.0	0.0	0.00
	Pack #1	30 pins/side	74.9	+0.9	+1.22
	Pack #2	30 pins/side	74.2	+0.2	+0.27
	Pack #3	30 pins/side	73.9	−0.1	−0.14
Brass	Compact solid	None	40.5		
	Compact solid	30 pins/side	40.4	−0.1	−0.25
	Pack	30 pins/side	40.5	0.0	0.00
Aluminum alloy	Compact solid	None	37.5		
	Compact solid	30 pins/side	37.9	+0.4	+1.07
	Pack #1	30 pins/side	37.4	−0.1	−0.27
	Pack #3	30 pins/side	38.1	+0.6	+1.60
	Pack #5	30 pins/side	37.6	+0.1	+0.27

MATERIALS

The following materials were used in making these tests:

a. Aluminum alloy, 17ST.
- Condition, heat treated.
- Number of sheets, two.
- Thickness, 0.032 and 0.051 inch.
- Width of sheets, 16 inches.
- Received at this laboratory, early in 1932.

b. Mild-carbon steel (SAE number 1025).
- Condition, cold-finished, quarter-hard.
- Number of sheets, two.
- Thickness, 0.054 and 0.120 inch.
- Width of sheets, 12 inches.
- Received at this laboratory, late in 1930.

c. Chromium-molybdenum steel.
- Condition, annealed.
- Number of sheets, one.
- Thickness of sheet, 0.053 inch.
- Width of sheet, 18 inches.
- Received at this laboratory, late in 1928.

SPECIMENS AND PACKS

Longitudinal and transverse specimens were taken from adjacent locations in the sheet. The number of specimens used in each pack is given in table 2, which summarizes the results of the tests. The packs were assembled and machined according to the procedure outlined in the section describing the pack (p. 2).

PROCEDURE

The packs were tested in compression according to the procedure outlined in the section on Test Procedure (p. 3). The initial loads and the cross-sectional areas of each pack are given in table 2.

TABLE 2.—RESULTS OF PACK COMPRESSIVE TESTS ON SHEET

Material	Thickness	Direction in sheet	Specimen number	Cross-sectional area	Number of specimens in pack	Initial load	Yield strength, offset = 0.2 percent	Spread	
	inches			*in.*^{2}		*kips*	*kips/in.*^{2}	*kips/in.*^{2}	*Percent*
Aluminum alloy 17ST	0.032	Longitudinal	C-2-L	0.295	13	1.1	33.3	0.0	0.00
			C-3-L	.296	13	1.0	33.3		
		Transverse	C-2-T	.297	13	1.1	37.4	0.1	0.27
			C-3-T	.297	13	1.0	37.3		
	0.051	Longitudinal	C-2-L	.189	5	1.1	35.0	0.2	0.53
			C-3-L	.257	7	1.0	35.4		
		Transverse	C-2-T	.187	5	1.1	39.6	0.3	0.76
			C-3-T	.187	5	1.1	39.6		
			C-4-T	.258	7	1.0	39.3		
Chromium-molybdenum steel	0.053	Longitudinal	C-1-L	.195	5	1.0	65.5	1.3	2.00
			C-2-L	.195	5	1.0	64.2		
		Transverse	C-1-T	.197	5	1.1	71.0	0.6	0.84
			C-2-T	.196	5	1.0	71.6		
Mild-carbon steel	0.054	Longitudinal	C-1-L	.196	5	1.1	59.2	0.6	1.01
			C-2-L	.195	5	1.0	59.8		
		Transverse	C-1-T	.194	5	1.1	63.6	0.2	0.31
			C-2-T	.194	5	0.5	63.4		
	0.120	Longitudinal	C-1-L	.429	5	1.1	52.0	0.8	1.53
			C-2-L	.430	5	1.0	52.8		
		Transverse	C-1-T	.426	5	1.1	55.9	0.3	0.53
			C-2-T	.426	5	1.0	56.2		

RESULTS

The stress-strain graphs for these tests are shown in figs. 9, 10, 11, and 12.

The values for yield strength are given in table 2. The last two columns of this table list the spread in yield strength, expressed in kips/in.^{2} and in percent for specimens of the same kind.

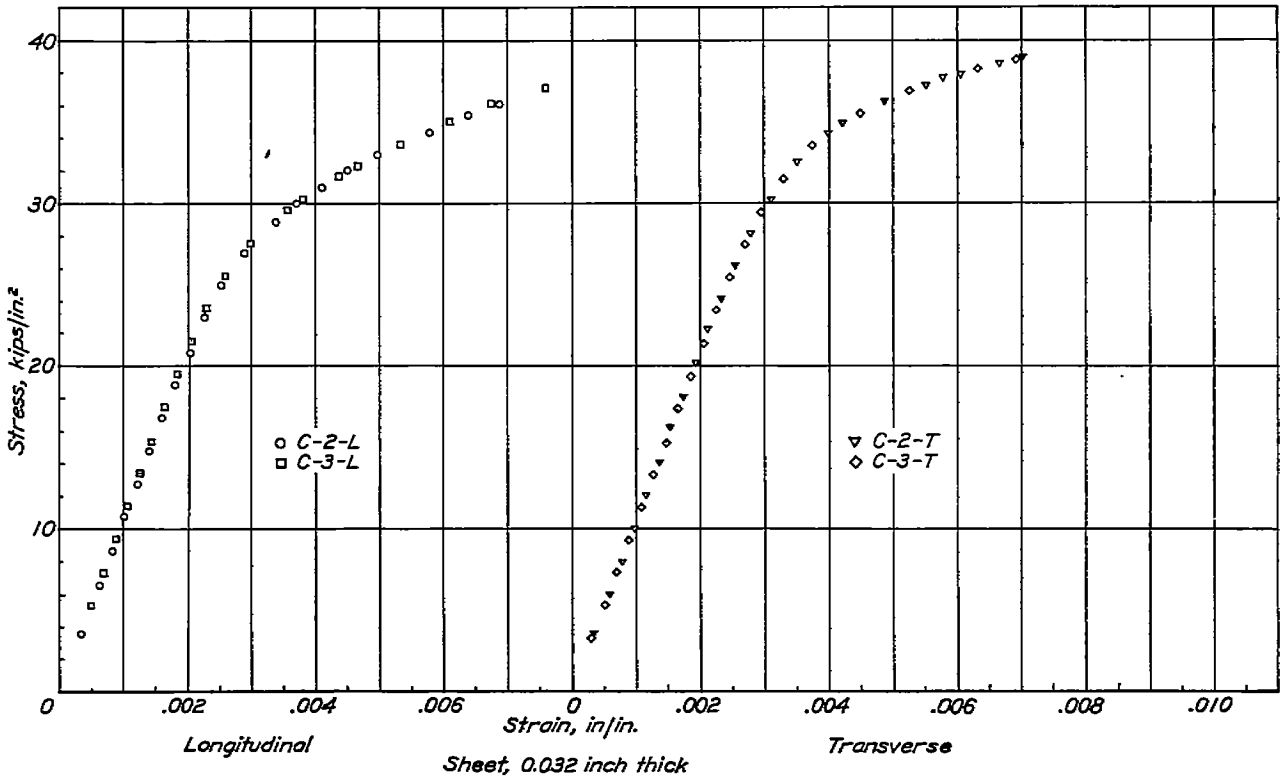

FIGURE 9.—Pack compressive tests on aluminum alloy 17ST sheet.

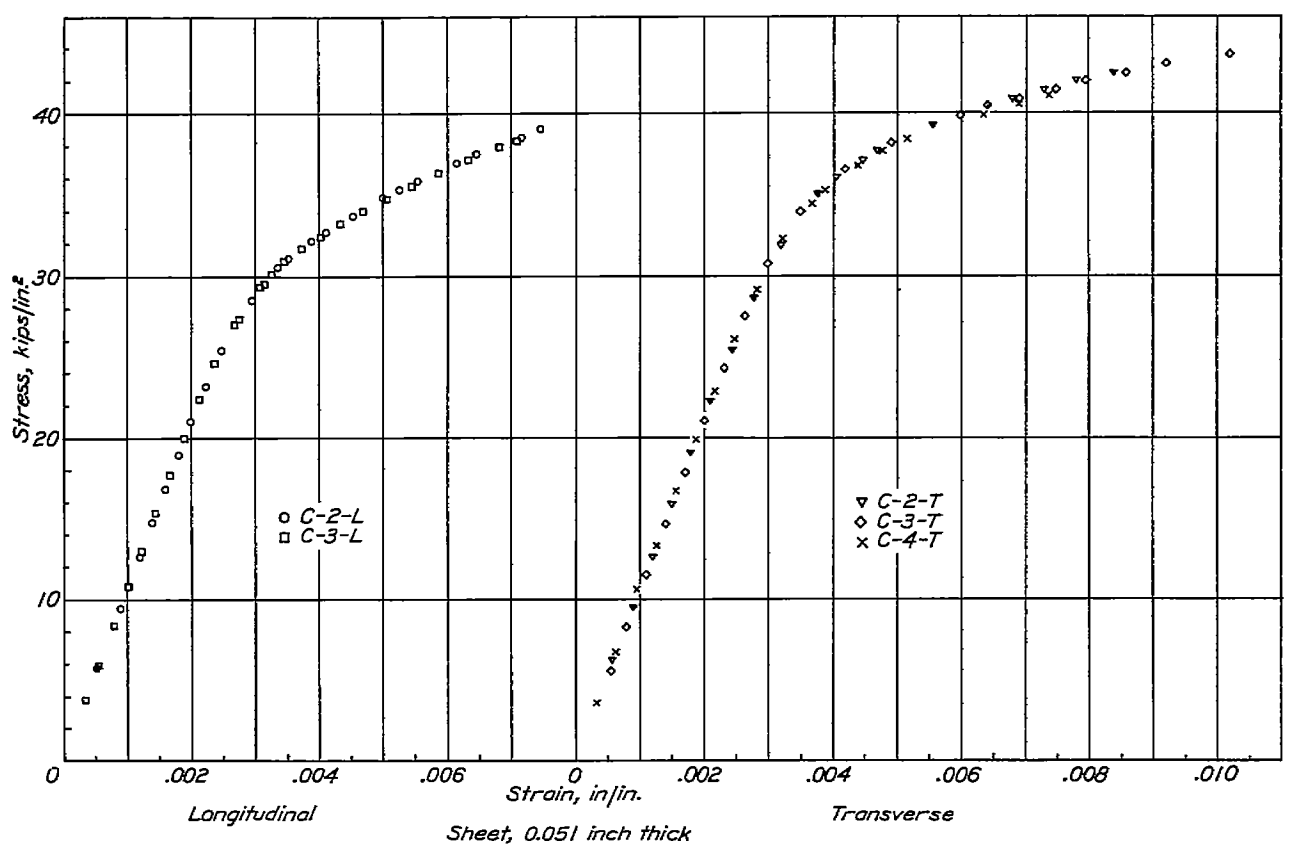

FIGURE 10.—Pack compressive tests on aluminum alloy 17ST sheet.

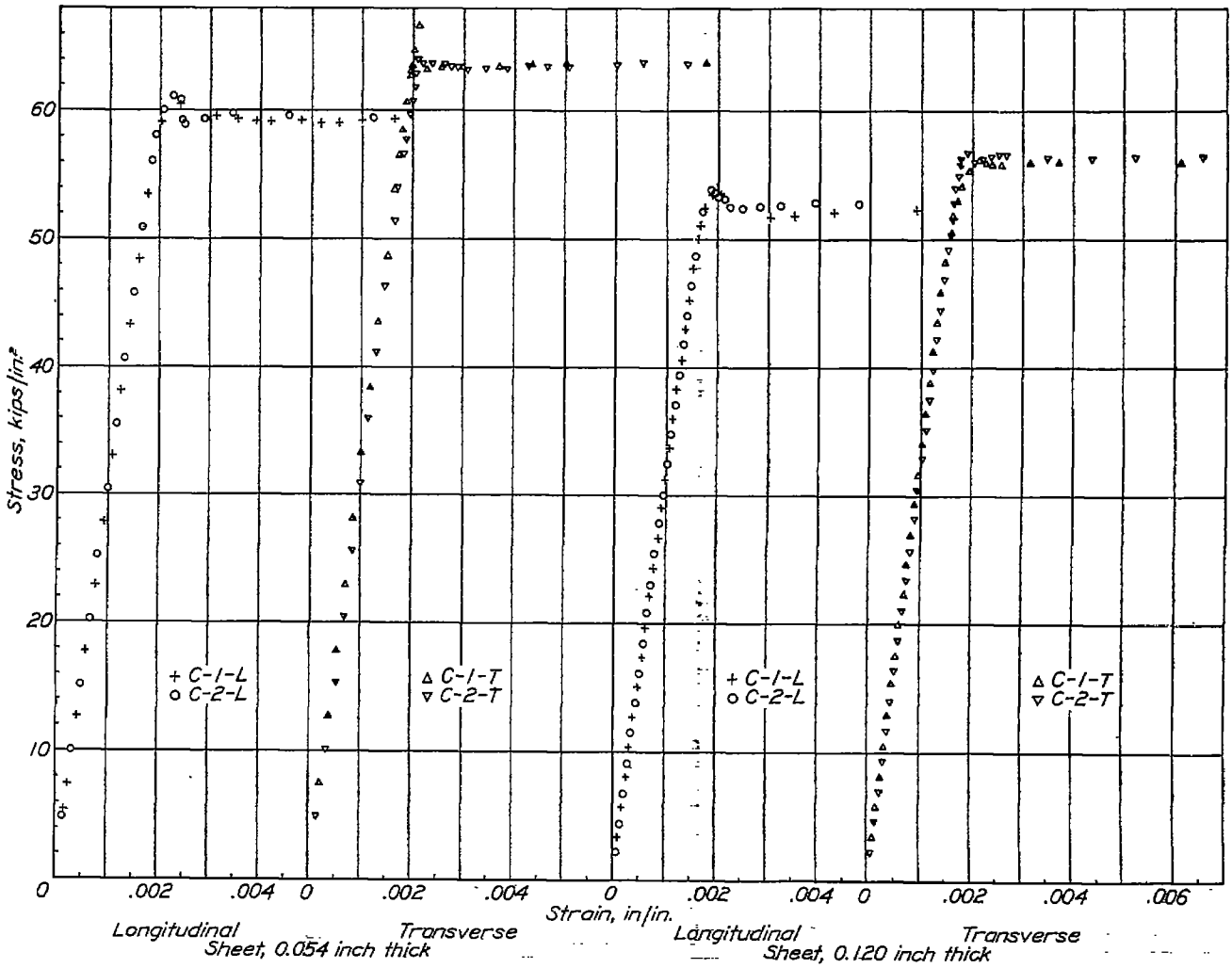

FIGURE 11.—Pack compressive tests on mild-carbon steel sheets (SAE 1025), cold-finished, quarter-hard.

DISCUSSION

The pack tests of sheet metal, 0.032 to 0.120 inch thick, include 10 groups of packs with at least 2 packs for each group. With one exception, that of the longitudinal packs for chromium-molybdenum steel 0.053 inch thick, tests in each group were made at different times, a number of months apart. The largest spread in yield strength was about 2 percent. The relatively small spread in yield strengths and the close correspondence of the stress-strain graphs for each group indicate that the test procedure is reproducible within this range of thicknesses of sheet. As metals with markedly different elastic properties were included in the tests the results suggest that the method is suitable for the determination of yield strength for many of the thin materials used in present construction.

CONCLUSIONS

Compressive tests on ductile materials with markedly different elastic constants indicate that the compressive stress-strain graphs obtained by the "pack" test agree with those obtained from block compressive tests and that they can be reproduced within an order of accuracy usually attributed to other mechanical tests, such as the tensile test.

The experience gathered at this laboratory in developing the pack test indicates that the test is adequate for many problems in structural research. It emphasizes, however, the need for simplifying the test procedure before it can be used satisfactorily for inspection testing.

In order to expedite the development of a compressive test of this kind, the details of the apparatus for pack tests have been shown and explained and the test has been demonstrated to representatives of other laboratories. As a result the Aluminum Research Laboratories of the Aluminum Company of America have made pack tests on aluminum alloy sheet using apparatus and test procedures duplicating as nearly as convenient the apparatus and procedure given in this report. A report entitled "Preliminary Compressive Tests on Thin Sheet using 'Pack' Compression Testing Apparatus" by C. F. Babilon and F. M. Howell was issued by the Aluminum Research Laboratories as "P. T. Report No. 38-17" on April 1, 1938.

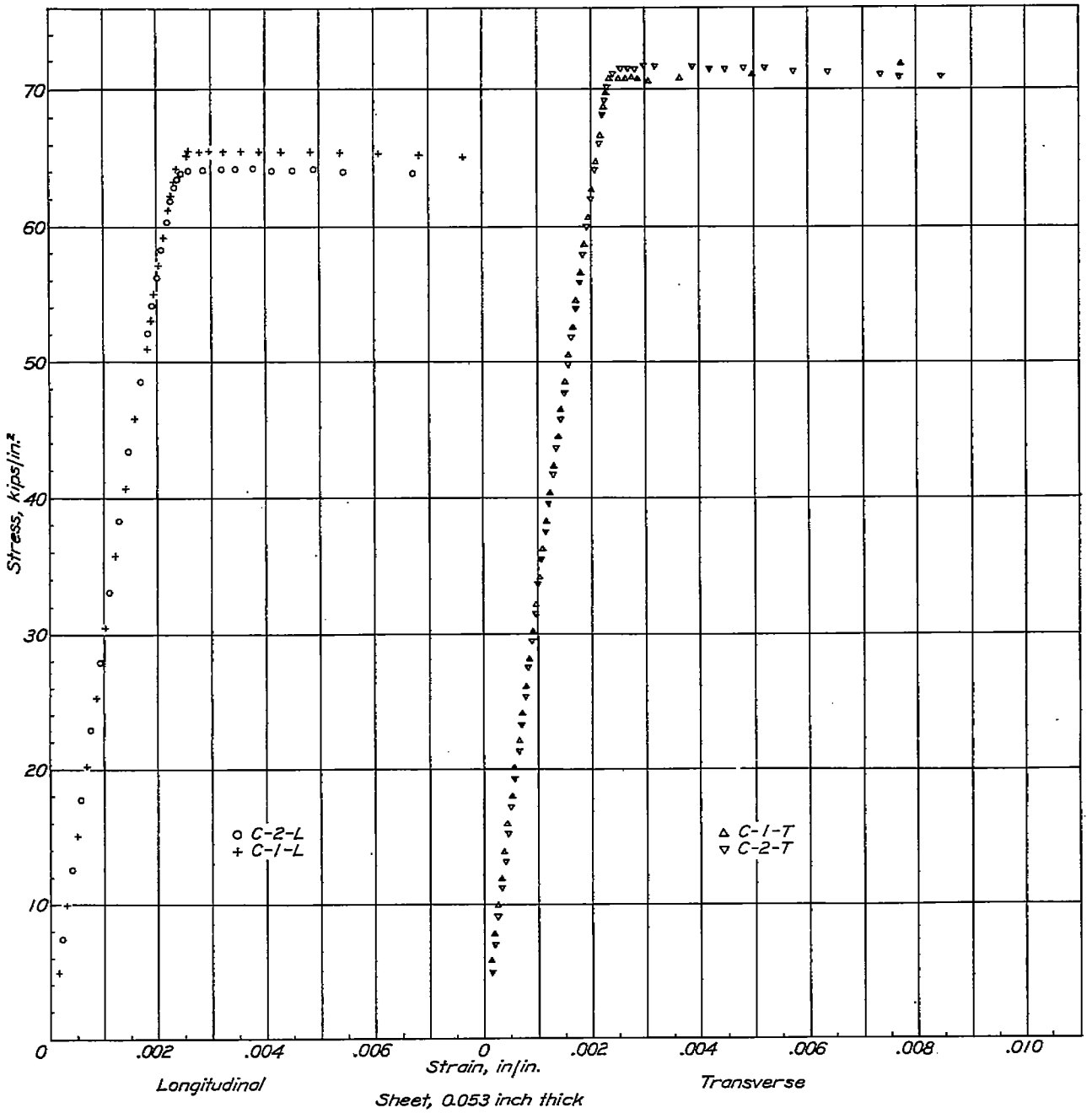

FIGURE 12.—Pack compressive tests on chromium-molybdenum steel sheet, annealed.

ACKNOWLEDGMENTS

The authors are indebted to their associates in the Engineering Mechanics Section for assistance in the tests and for suggestions concerning test procedures, and to Mr. A. Altman of the machine shop for his suggestions concerning machining procedures. They are indebted to the Bureau of Aeronautics, Navy Department, for sustained interest and cooperation.

NATIONAL BUREAU OF STANDARDS,
WASHINGTON, D. C., *August 23, 1938.*

REFERENCES

1. Wolff, E. B., and Van Ewijk, L. J. G.: On Some Elastic Properties of Laminated Wood for Constructional Purposes. International Congress for Testing Materials, Amsterdam, September 12–17, 1927; vol. 2, 1928, pp. 551–566.
2. Robertson, A.: The Strength of Tubular Struts. Proc. Roy. Soc. (London), Series A, vol. 121, 1928, pp. 558–585.
3. National Advisory Committee for Aeronautics Nineteenth Annual Report, 1933, pp. 23–26. Report of Subcommittee on Aircraft Structures.
4. American Society for Testing Materials—Tentative Methods of Compression Testing of Metallic Materials (E9-33T). Tentative Standards, 1936, pp. 1272–1279.
5. Tuckerman, L. B.: Optical Strain Gages and Extensometers. Proc. Am. Soc. for Testing Materials, vol. 23, Part II, 1923, pp. 602–610.