Enclosure 12 to TN E-29128

Tietz, T. E., “Determination of the Mechanical Properties of a
High Purity Lead and a 0.058 % Copper-Lead Alloy,” WADC
Technical Report 57-695, ASTIA Document No. 151165,
Stanford Research Institute, Menlo Park, CA, April, 1958,
associated with RAIs 2-14 and 2-24

WADC TECHNICAL REPORT 57-695
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DETERMINATION OF THE MECHANICAL PROPERTIES OF A HIGH PURITY LEAD AND A 0.058 % COPPER-LEAD ALLOY

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WRIGHT AIR DEVELOPMENT CENTER

NOTICES

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MATERIALS LABORATORY
CONTRACT No. AF 33(616)-3785
PROJECT No. 2134

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
700 — May 1958

FOREWORD

This report was prepared by Stanford Research Institute under USAF Contract No. AF 33(616)-3785. This contract was initiated under Project No. 2134, "Shielding Subsystems," Task No. 73070, "Shielding Materials." The work was administered under the direction of the Materials Laboratory, Directorate of Laboratories, Wright Air Development Center, with Mr. R. F. Klinger acting as project engineer.

This report covers work conducted from July 1956 to September 1957.

This report was prepared by T. E. Tietz of the Department of Metallurgy of Stanford Research Institute, acting as Project Leader, under the supervision of R. H. Thielemann, Chairman of the Metallurgy Department. Acknowledgment is made to Mr. A. Ruotola for his assistance throughout the testing phase of this program.

ABSTRACT

The mechanical properties of a high purity lead and a 0.058% copper-lead alloy were determined at test temperatures of 100, 175, 250, and 325°F.

Tensile properties evaluated included the ultimate strength, elongation, modulus of elasticity, proportional limit, and yield strength. Compression properties evaluated were the modulus of elasticity, proportional limit, and yield strength. Ultimate shear strength and the bearing yield strength and ultimate bearing strength were determined. Stress-creep time curves were obtained for total strain values of 0.2, 0.5, 1.0, and 2.0%, for creep times of from 1 hour to 500 hours.

The data obtained are summarized in graphical and tabular form, in the Experimental Results section of this report.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Richard R Kennedy

RICHARD R. KENNEDY
Chief, Metals Branch
Materials Laboratory

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DETERMINATION OF THE MECHANICAL PROPERTIES OF A HIGH PURITY LEAD AND A 0.058% COPPER-LEAD ALLOY

I Introduction

The properties of lead make it the most practical shielding material presently available. In the design and development of nuclear-powered aircraft, the structural problem of providing effective over-all shielding with the lowest possible weight is most important, and requires that the mechanical properties of lead be sufficiently known. However, because of its low strength even at room temperature, lead has not been seriously considered as a structural material and its mechanical properties have not been adequately determined. In addition, the few studies which have been conducted on the mechanical properties of lead have been at or near room temperature.

The objective of this program was to determine the tensile, compression, shear, bearing, and creep properties of a commercially pure lead and a lead alloy, at four test temperatures up to 325°F.

II Test Material

The two materials evaluated in this program were a high purity lead (Doe Run Brand refined lead, 99.995% Pb) and a copperized lead (Copperized Doe Run Brand refined lead, 0.058% Cu), supplied by the St. Joseph Lead Company. The eutectic point in the lead-copper system occurs at approximately 0.06% copper. The chemical composition of the two test materials is given in Table I. In the case of the coppperized lead, bars extruded from lot I were used for the tensile, shear, and creep specimens, and from lot II for the compression and bearing specimens. The analyses are, for all practical purposes, identical for the two lots of copperized lead.

Manuscript released by author 3 January 1958 for publication as a WADC Technical Report.

Table I

CHEMICAL COMPOSITION OF TEST MATERIALS

Element	High Purity Lead	Copperized Lead Lot I	Copperized Lead Lot II
Pb	99.9951	99.9398	99.9404
Cu	.0001	.0577	.0577
As, Sb, Sn	.0004	.0006	.0004
Fe	.0001	.0001	.0001
Zn	.0002	.0001	.0001
Cd	.0029	.0006	.0005
Ni, Co	.0000	.0000	.0000
Bi	.0006	.0007	.0005
Ag	.0006	.0004	.0003

The lead was extruded by Morris P. Kirk and Sons, Los Angeles, into bar forms having the following cross-sections:

Type of Test	Extruded Cross Section
Tensile and Creep	1/2 x 1-1/4 inches
Compression	1/2 x 1/2 inches
Shear	1/2 inch round
Bearing	1/2 x 4 inches

The extrusion slugs were cast at 900-950°F. The slugs were 12 inches long by 4-1/2 inches in diameter, after cropping, with the exception of the bars for the bearing specimens which were extruded from a single slug, using a different extrusion press. The extrusion was done at room temperature.

III Test Specimens

The dimensions of the four types of test specimens used in this program are given in Figure 1. All test specimens were machined with their axes parallel to the extrusion direction.

All test specimens were given an annealing treatment of 2 hours in an oven at 400°F after machining and prior to testing, in order to remove any cold-work within the specimens due to machining and handling. The grain sizes of the two materials were considerably different, both in the as-received, and in the annealed conditions; the copper addition acted as a grain size refiner. The average annealed grain size of the high purity lead was about 0.55 grains per millimeter and that of the copperized lead about 18 grains per millimeter.

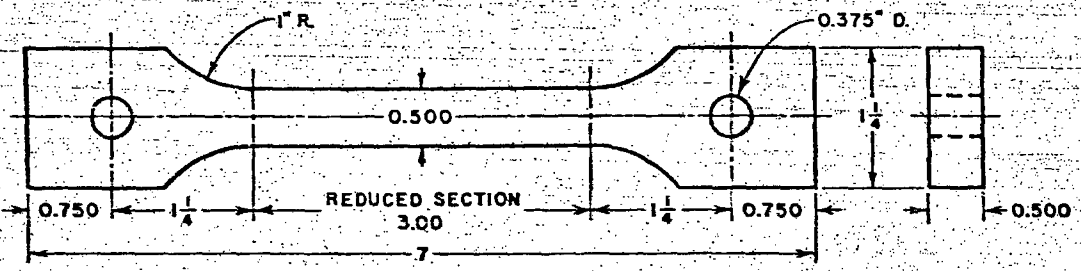
IV Experimental Apparatus and Procedures

The tensile, compression, shear, and bearing tests were conducted with a Baldwin Universal hydraulic testing machine, using a 600-pound full-scale load range. This machine, with a forced air convection furnace, is shown in Figure 2. Figure 2 also shows a dial gage mounted on the movable cross-head which was used to measure and control the cross-head travel rate during testing, and, resting on the table, a Baldwin deflectometer which was used to record the cross-head travel for tests in which cross-head travel was used as the strain measurement. The specimen was placed in the furnace approximately one hour before loading to permit the specimen to attain the test temperature. A thermocouple was attached directly to the test specimen during each test, and the test temperatures were maintained within ± 2°F.

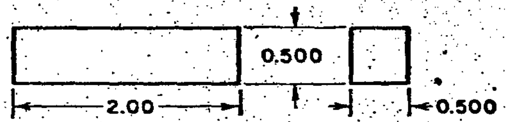
A. Tensile Tests

The tensile test specimens had a reduced cross-section of 1/2 inch x 1/2 inch x 3 inches. Figure 3 shows a tensile specimen with a Baldwin microformer extensometer in place. In this case the central 2 inches served as the gage length. This extensometer was used to evaluate the elastic properties in tension and the tensile stress-strain curve to 2% strain, at a cross-head rate of 0.015 in./min for a strain rate of 0.005 in./in./min.

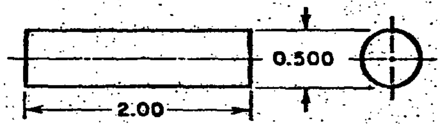
For determining the entire stress-strain curve, the strain was determined by using the deflectometer to measure cross-head travel, and in this case the entire 3-inch reduced section served as the gage length. For these tests, the cross-head rate was maintained at 0.150 in./min for a strain rate of 0.05 in./in./min.



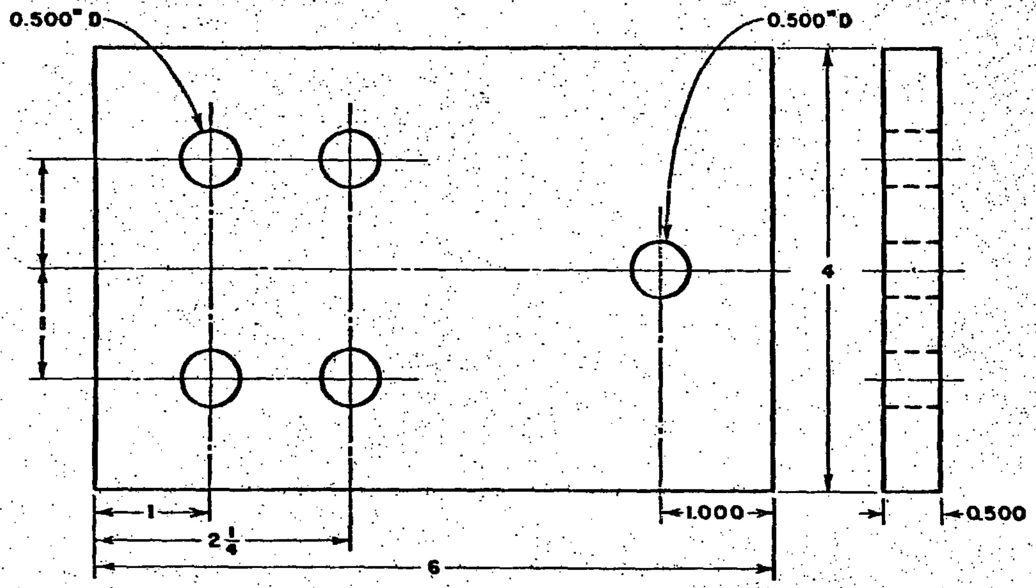
TENSILE AND CREEP SPECIMEN



COMPRESSION SPECIMEN



SHEAR SPECIMEN



BEARING SPECIMEN

B-185-F-26

FIG. 1

DIMENSIONS OF TEST SPECIMENS

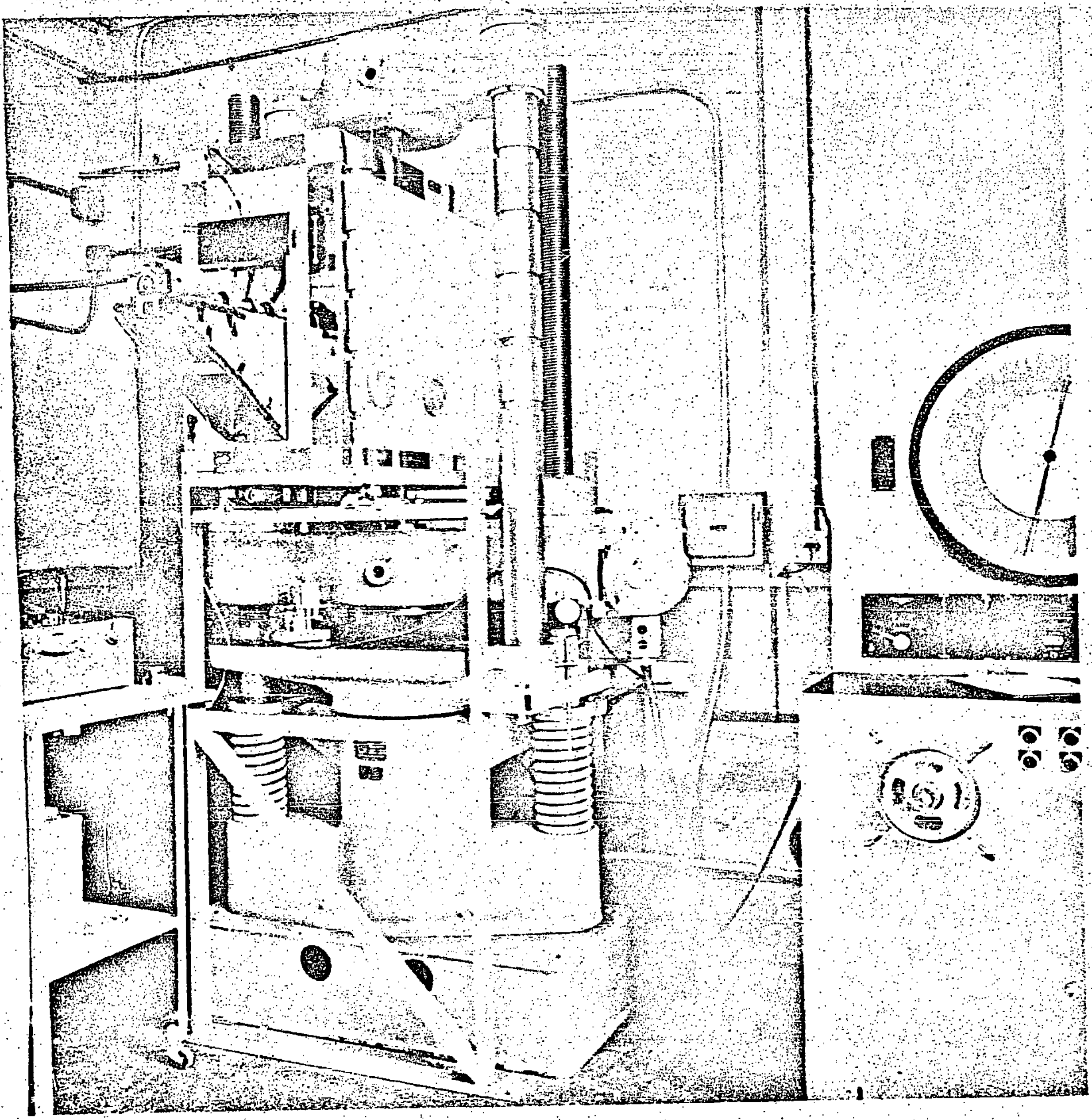


FIG. 2

UNIVERSAL TESTING MACHINE

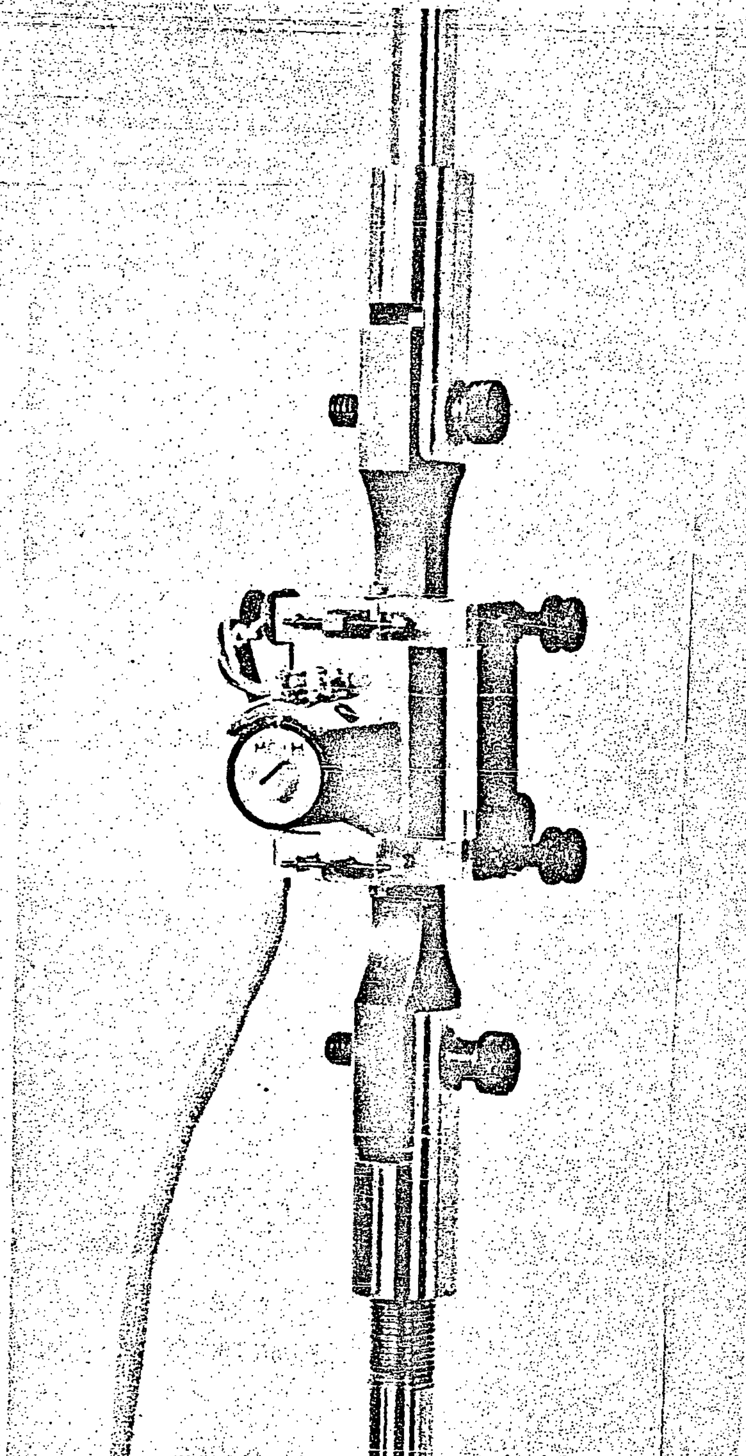


FIG. 3

TENSILE TEST ASSEMBLY

In both cases the stress-strain curves were obtained with a Baldwin stress-strain recorder.

B. Compression Tests

The compression tests were conducted on 1/2 inch x 1/2 inch x 2 inch specimens, at a cross-head travel rate of 0.010 in./min, for a strain rate of 0.005 in./in./min. Figure 4 shows the compression test specimen with a Baldwin microformer compressometer. The central 1 inch served as the gage length. This compressometer was used to evaluate the elastic properties in compression and the compression stress-strain curve to 5% strain.

Initial compression tests were conducted with a compression sub-press. At the elevated test temperatures, difficulty was encountered as a result of binding of the press. For this reason, all the compression tests were conducted without a sub-press, as indicated in Figure 4. The compressometer was also counter-balanced, with a lead block resting on a pair of support rods as indicated in the figure. A flat-ground bearing plate was placed on top of the specimen during the test.

C. Shear Tests

The shear test specimens, 1/2 inch in diameter by 2 inches long, were tested in double shear, using the fixture shown in Figure 5. A constant cross-head travel rate of 0.005 in./min was used for these tests.

D. Bearing Tests

The bearing test specimen consisted of a flat 4 inch by 6 inch by 1/2 inch plate with a 1/2-inch-diameter bearing hole whose center was 1 inch from the edge of the plate. A 1/2-inch steel pin was inserted in this hole and pulled at a constant cross-head rate of 0.005 in./min.

The yield strength, defined as 2% offset of the hole diameter, was determined by means of a small dial gage, which measured the relative pin movement and was mounted directly on the bearing test fixture, shown in Figure 6.

The stress-deformation curve to fracture was determined by measuring the cross-head movement and recording the load and deformation, using the Baldwin recorder.

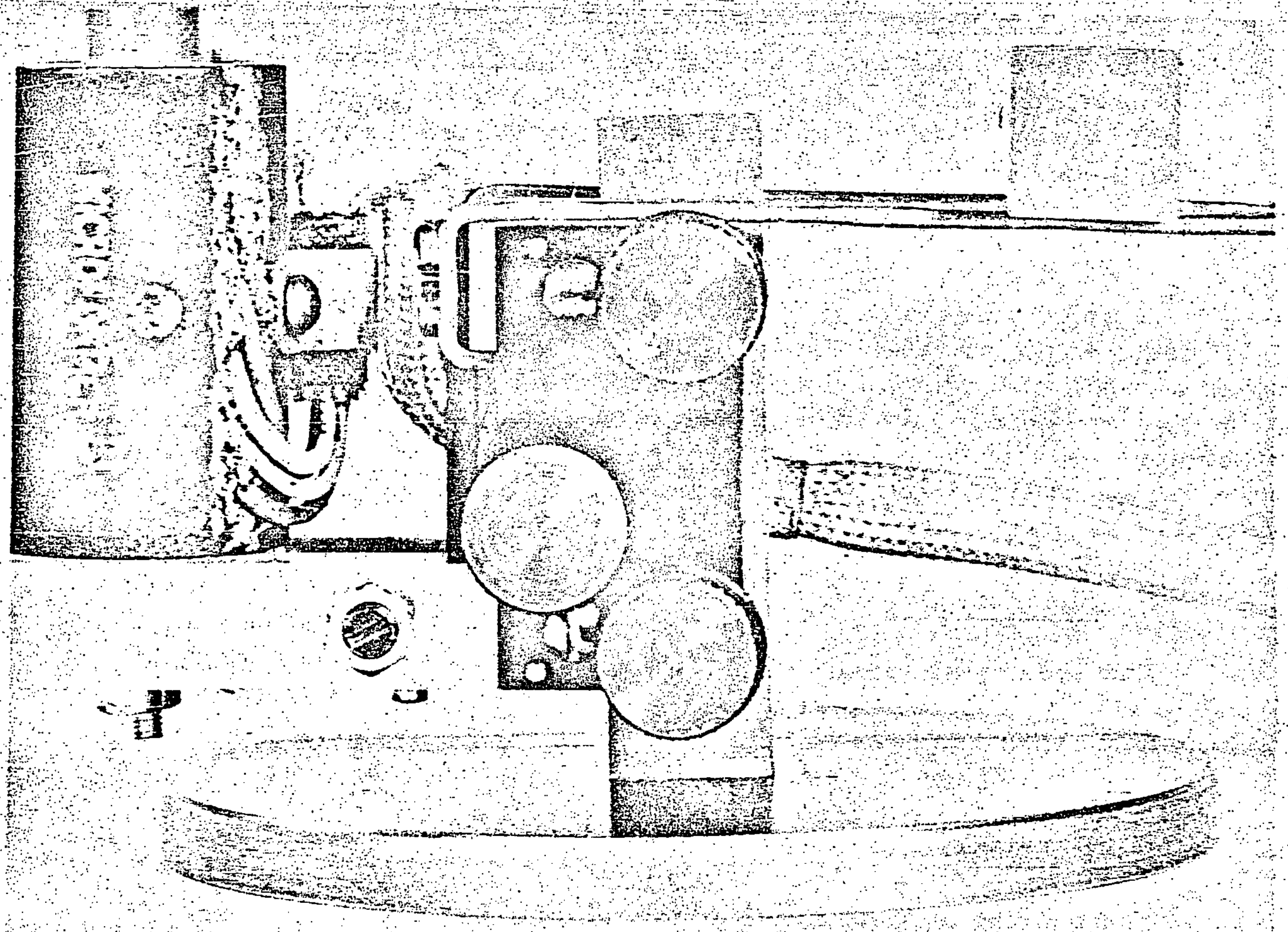


FIG. 4

COMPRESSION TEST SPECIMEN WITH COMPRESSOMETER

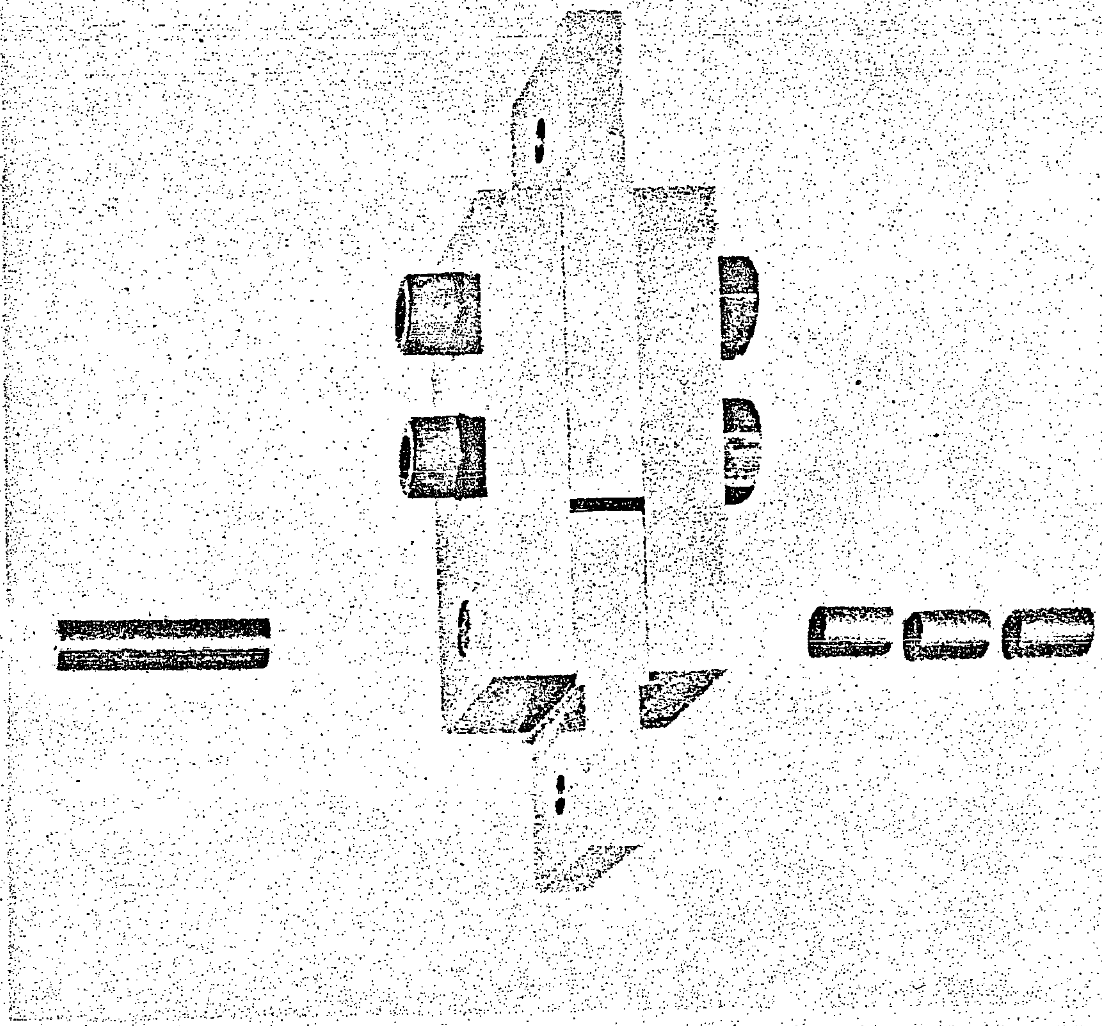


FIG. 5
SHEAR TEST FIXTURE

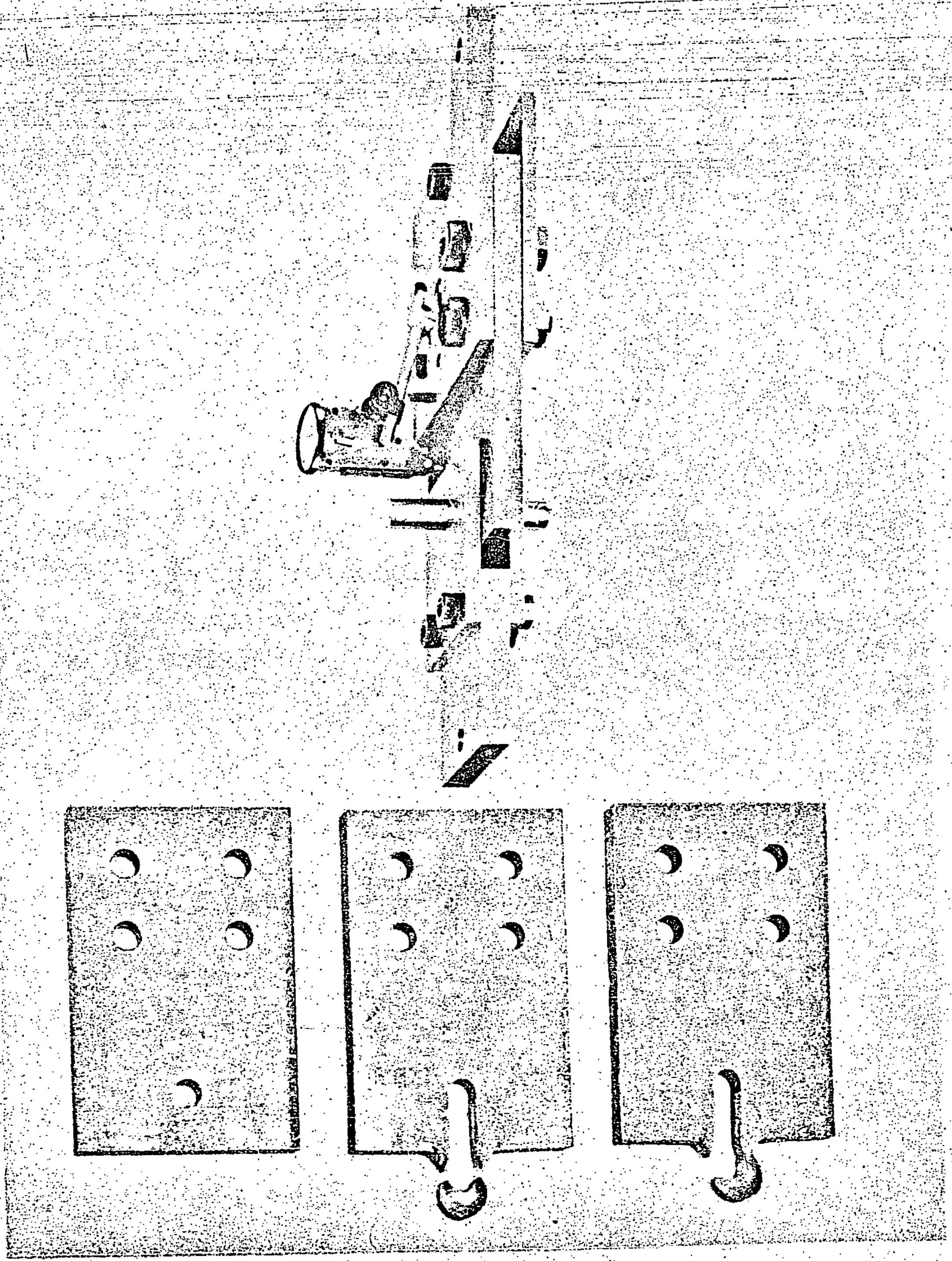


FIG. 6

BEARING TEST FIXTURE

E. Creep Tests

1. Equipment

The creep test units used for this program are shown in Figure 7. One creep unit was used for each test temperature. The furnaces for maintaining constant test temperatures consisted of cylindrical tanks 10 inches in diameter and 24 inches long, with a vertical, 2-inch-I.D. tube passing through the center of each tank. The specimens were heated and tested in an air atmosphere within the tubes. Suitable packing was used at the tube ends to prevent air convection through the tubes.

The specimens were loaded through 5 to 1 lever-arm systems in the case of the lower two test temperatures, and by dead-weight loading in the case of the upper two temperatures. The test temperatures of 100 and 175°F were maintained constant within ± 2°F by water and thermostatic control; the test temperatures of 250 and 325°F were maintained constant within ± 1°F by boiling glycol-water solutions and condenser systems.

An assembly of a creep specimen, pulling bars, and extensometer is shown in Figure 8. The central 2 inches of the specimen served as the gage length. The gage blocks were attached to the specimen by means of four hardened, conical points pressed into the specimen and held in place by coil springs. The relative movement of the gage blocks was transferred through two pairs of extension rods to a 0.0001-inch least-count dial gage outside the furnace. The upper guide blocks had polished surfaces which were free to move along the axis of the polished pulling bar.

2. Test Procedure

The test specimen was carefully assembled, using a special mounting board for aligning the pulling bars and extensometer. A thermocouple for temperature checks during test was tied directly to the specimen at the center of the 2-inch gage length.

A set of chromel-alumel thermocouples were calibrated, using a boiling distilled water bath which gave a calibration point midway between the four test temperatures. Four thermocouples were selected for uniformity, and one thermocouple was used for all creep tests at one test temperature.

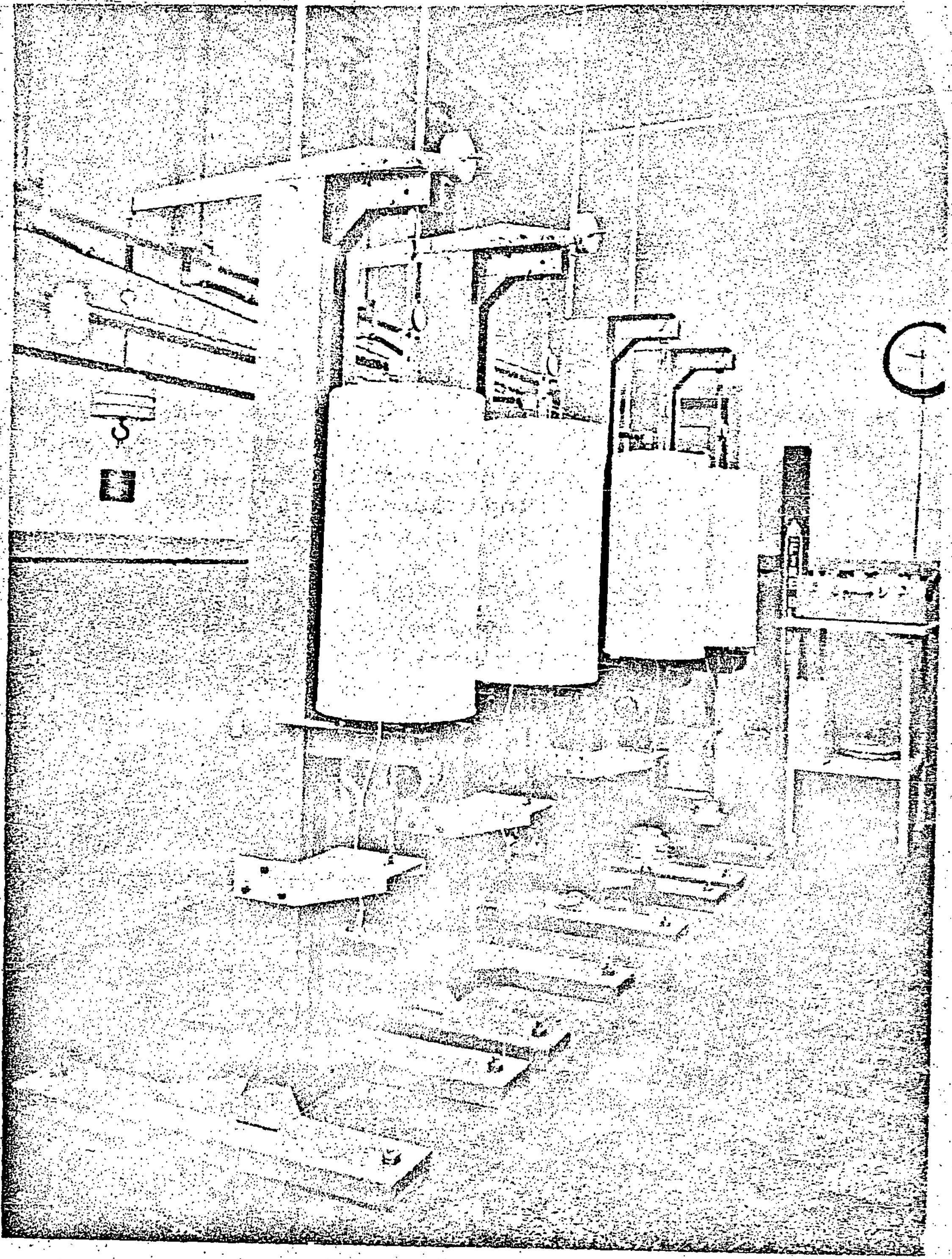


FIG. 7
CREEP TEST UNITS

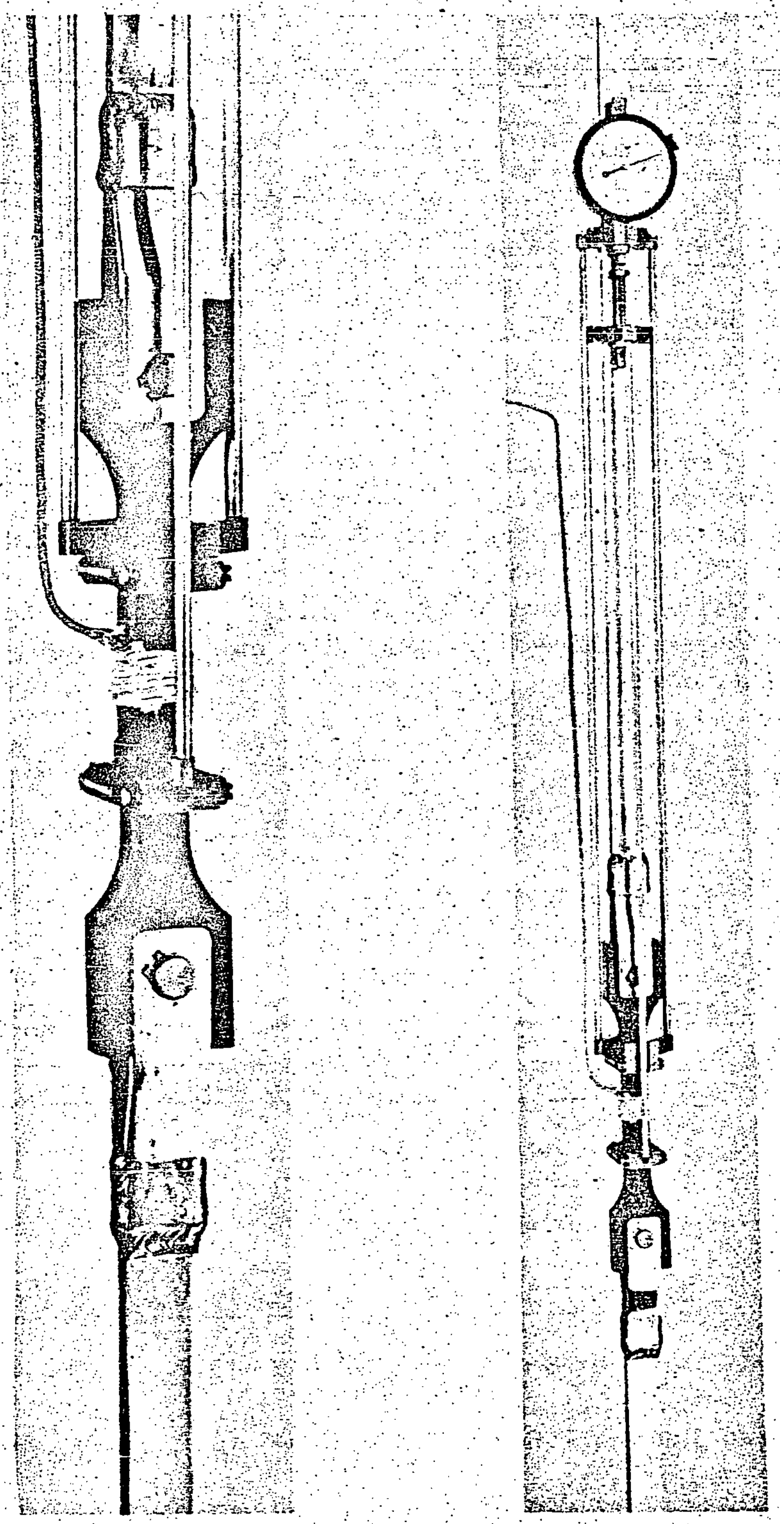


FIG. 8
CREEP SPECIMEN ASSEMBLY

The specimen assembly was inserted into the furnace two hours prior to application of the load in order to permit the specimen to attain the test temperature. The load was then gradually applied by hand over a period of about half a minute; zero time was taken when the full load was on the specimen.

V Experimental Results

A. Tensile Tests

1. Stress-Strain Curves to Failure

The stress-strain curves to failure are presented in Figure 9 for the two test materials. The tests were conducted in triplicate at each of the test temperatures: 100, 175, 250, and 325°F, and at a strain rate of 0.05 in./in./min. Data on the ultimate tensile strength and elongation are summarized in Table II. The elongation values given in the table were obtained by using gage marks originally 3.00 inches apart on the specimen.

Table II

TENSILE TEST RESULTS

Ultimate Tensile Strength (psi) and Elongation (%)
at a Strain Rate of 0.05 in./in./min

Test Material	Test Temperature, °F							
	100		175		250		325	
	UTS	Elong.	UTS	Elong.	UTS	Elong.	UTS	Elong.
High Purity Lead 1	1828	46.0	1240	57.3	788	64.0	498	77.6
2	1920	44.6	1196	42.6	798	50.6	488	72.0
3	1852	40.0	1204	36.0	768	68.3	492	83.3
Average	1867	43.5	1213	45.3	785	61.0	493	77.6
Copperized Lead 1	1580	53.6	1164	46.0	826	42.6	636	46.6
2	1604	46.3	1148	47.0	846	50.6	638	56.0
3	1570	53.0	1162	47.7	844	48.3	642	42.7
Average	1585	51.0	1158	46.9	839	47.2	639	48.4

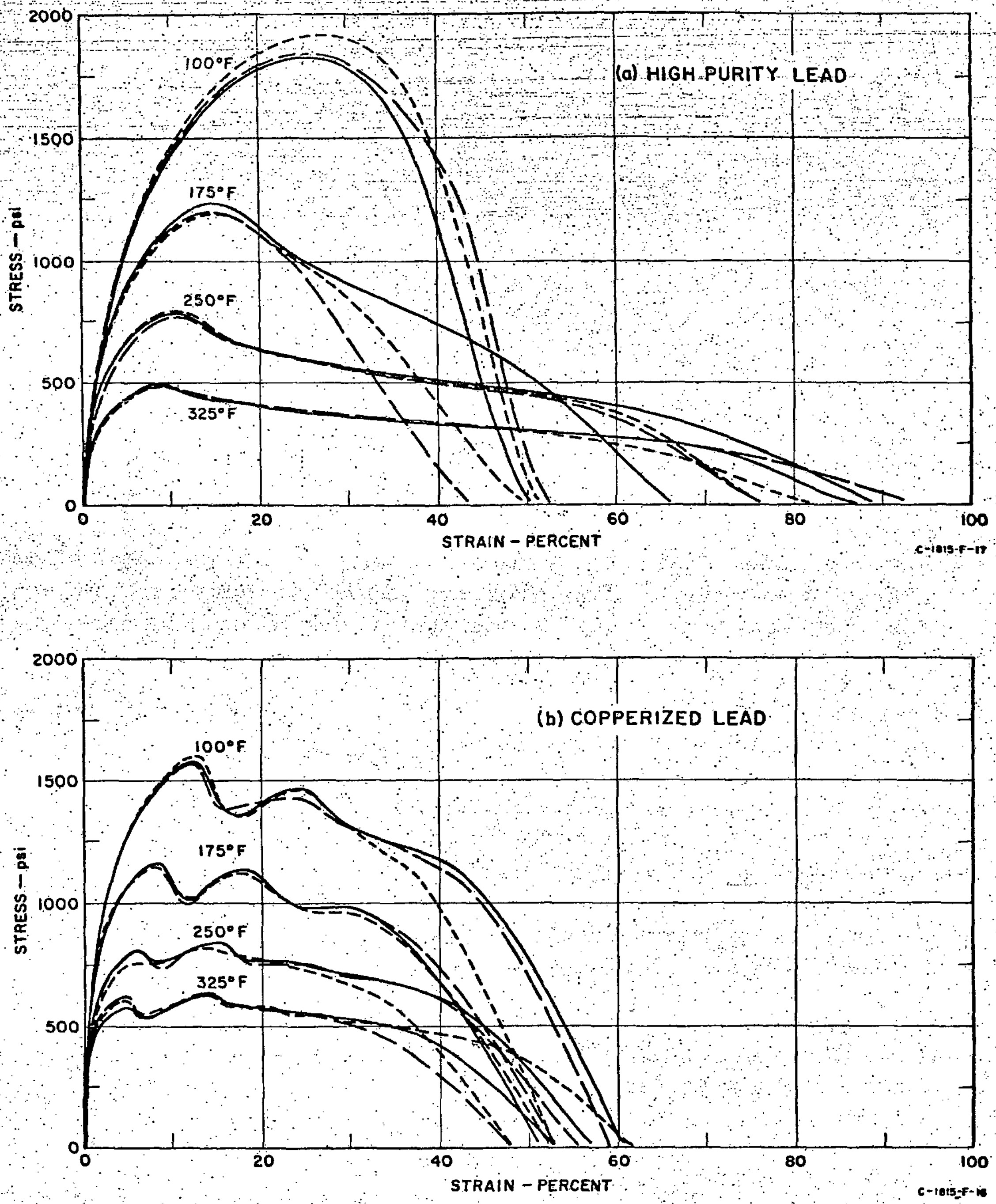


FIG. 9

TENSILE STRESS-STRAIN CURVES TO FAILURE
AT A STRAIN RATE OF 0.05 IN./IN./MIN

The triplicate tests under the same test conditions gave very similar stress-strain curves up to the point of necking. Beyond this point the curves differed considerably, due to differences in necking conditions, probably influenced by variations in grain size and grain orientation within the different specimens. The fracture strength was very nearly zero for all tests, as is indicated by the curves on Figure 9.

The stress-strain curves for the high purity lead were quite typical, each exhibiting one maximum, whereas the curves for the copperized lead all had two or more maxima. In the latter case, necking did not occur at the first maximum in the stress-strain curves; this effect was possibly associated with recrystallization of the finer-grain-size copperized lead during test.

The total elongation values shown in Figure 9 include some elongation of the specimen bearing holes, which in extreme cases amounted to about 1/16-inch per hole, whereas in most cases it was less than 1/32-inch per hole. Some elongation also occurred in the fillet areas outside the 3-inch reduced section, with the result that the indicated strain values are larger than actual. This problem was not encountered in the other tensile or compression tests, as the strain measurements were made directly on the specimen gage length.

Figure 10 presents the average values of the ultimate tensile strength and elongation as a function of test temperature. The high purity lead had a higher tensile strength at 100 and 175°F than the copperized lead and a lower value at the higher test temperatures of 250 and 325°F. It should be noted that at any one test temperature the rate of strain hardening of the copperized lead is greater than that for the high purity lead almost up to the point of the first maximum. If only the maximum associated with necking had occurred, these tests undoubtedly would have exhibited higher ultimate tensile strength values.

The percent elongation for the copperized lead was approximately constant at about 50% at all test temperatures, whereas the average elongation of the high purity lead increased from 43% to 77% over the temperature range from 100 to 325°F.

2. Elastic Properties

A second set of 24 tensile specimens was used to evaluate the elastic properties and the stress-strain curve to 2% strain. A crosshead travel rate of 0.015 in./min was used for these tests, for a strain rate of 0.005 in./in./min. The results of these tests are shown in Figure 11 for the two test materials tested at the four test temperatures. The triplicate tests at any one temperature are in good agreement. In order to show more clearly the effect of temperature, the data of Figure 11 were plotted as stress vs test temperature for constant values of total strain and are presented in Figure 12.

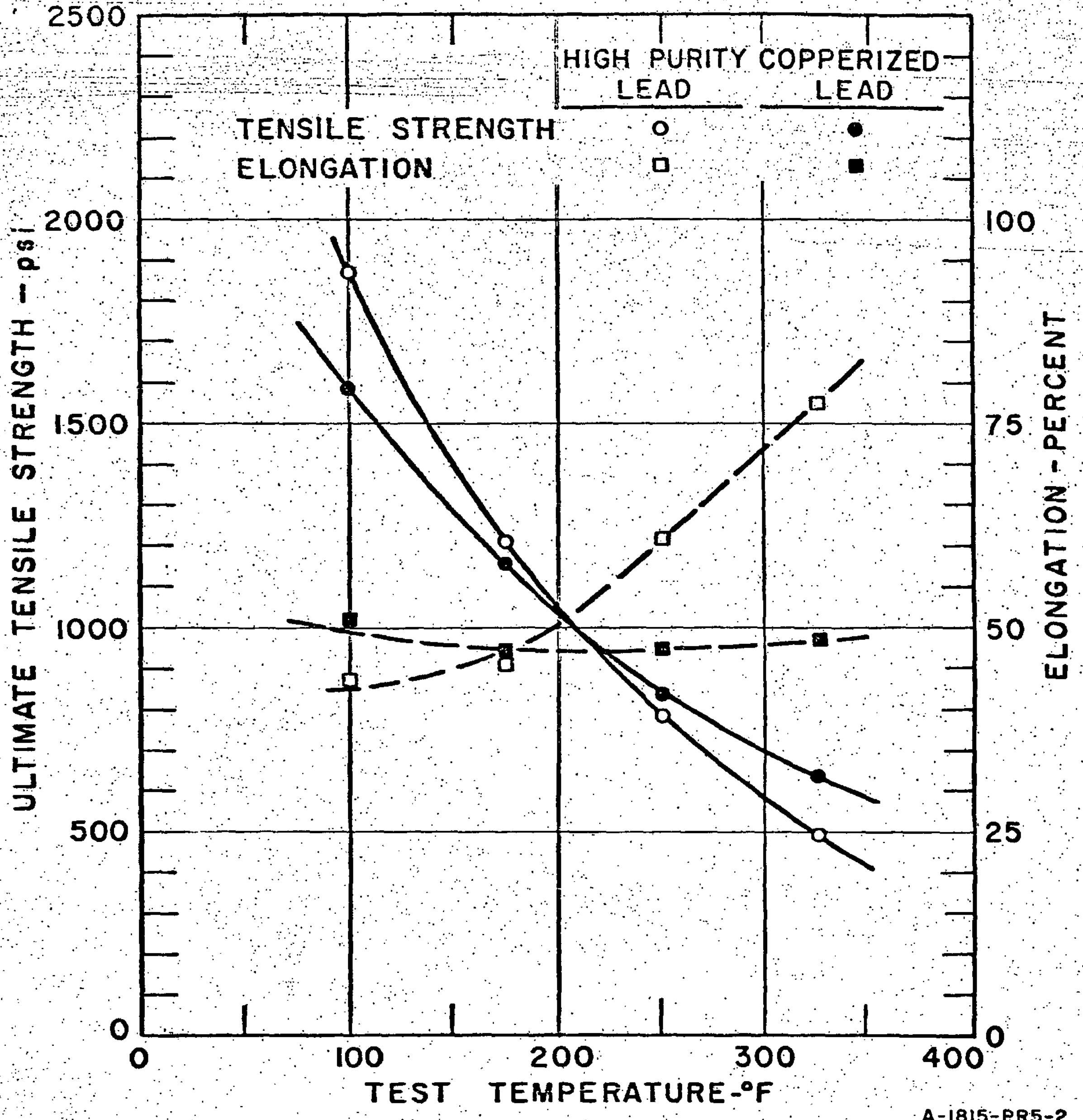


FIG. 10

TENSILE STRENGTH AND ELONGATION AS A FUNCTION OF TEST TEMPERATURE AT A STRAIN RATE OF 0.05 IN./IN./MIN

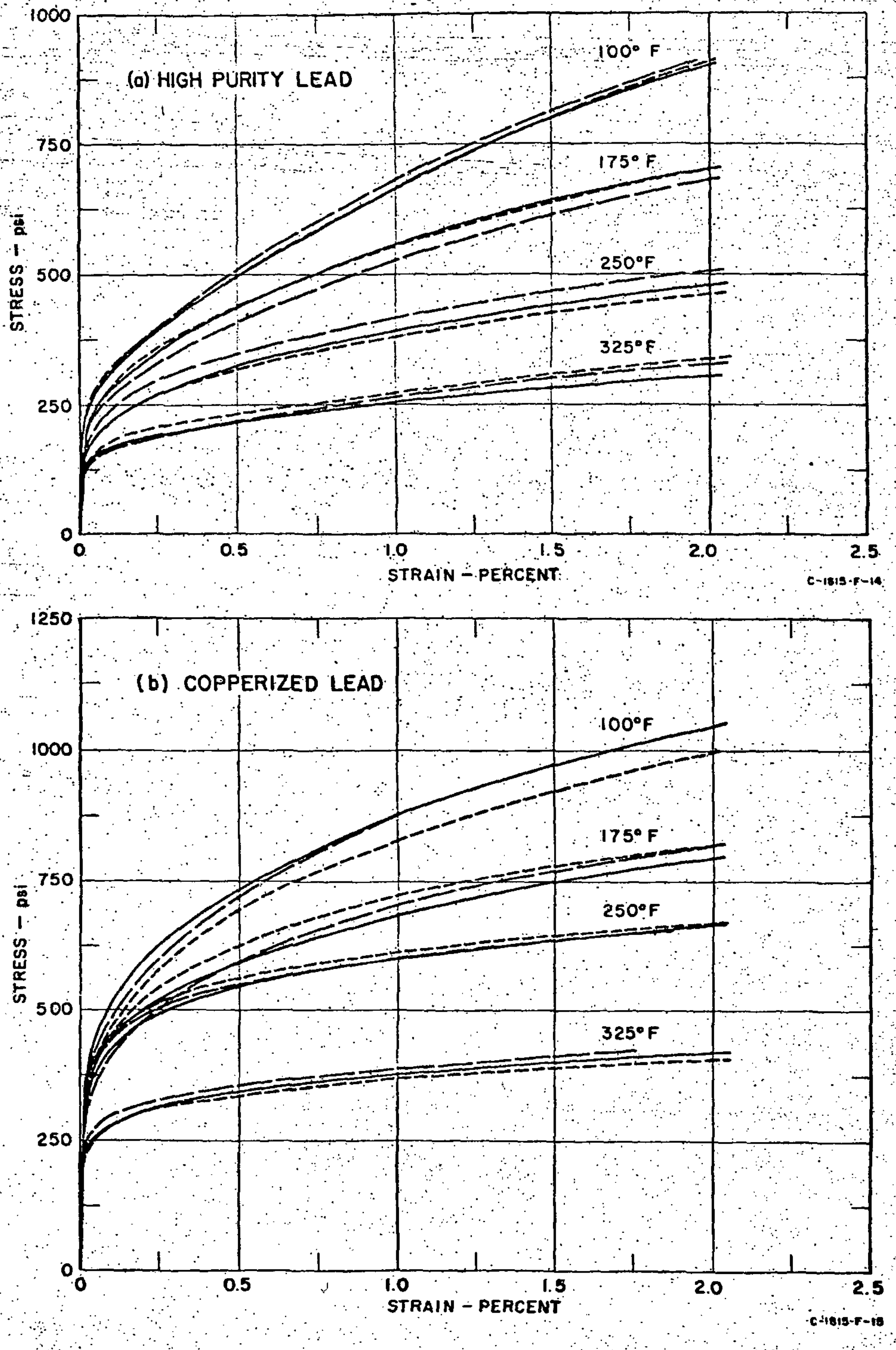


FIG. 11

TENSILE STRESS-STRAIN CURVES TO 2% STRAIN AT A STRAIN RATE OF 0.005 IN./IN./MIN

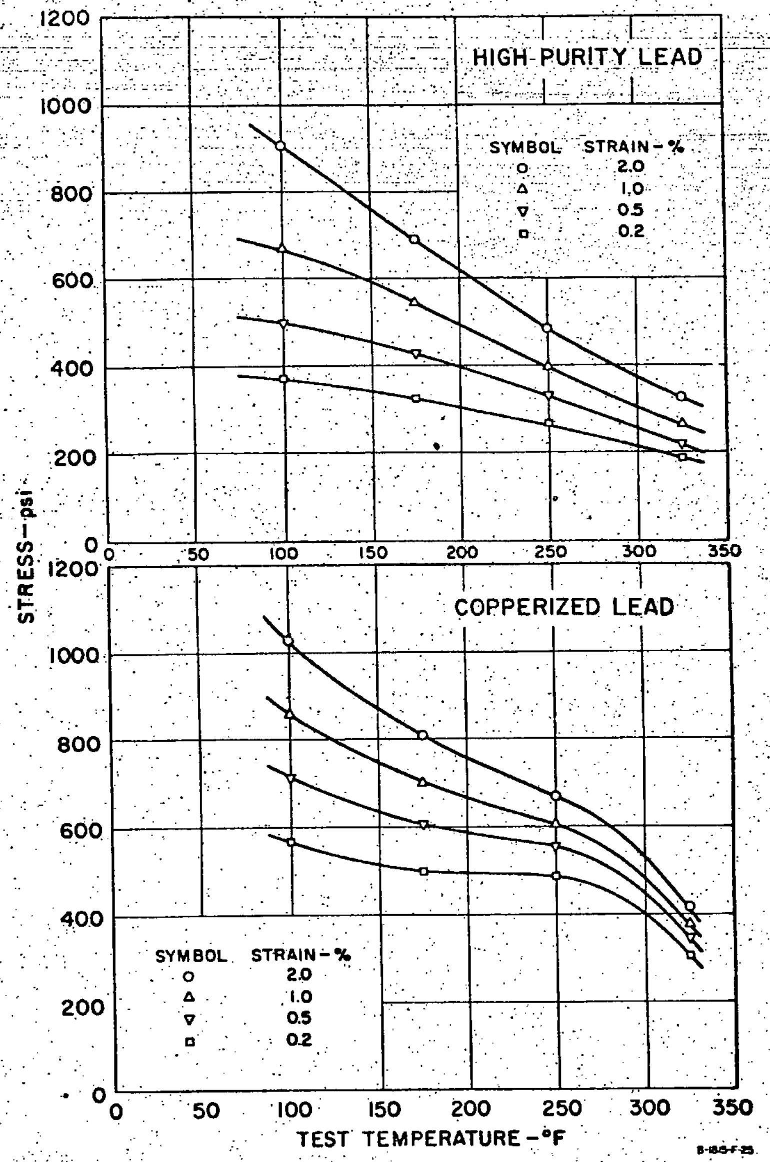


FIG. 12

TENSILE FLOW STRESS VS TEST TEMPERATURE FOR GIVEN VALUES OF STRAIN AT A STRAIN RATE OF 0.005 IN./IN./MIN

The elastic properties were evaluated from the recorded load-deformation charts by initially using a high strain magnification to a strain of 0.3%, 1 inch of chart being equal to 0.05% strain. The test was then completed by using a low magnification, 1 inch of chart equal to 0.2% strain, to a total strain of 2.0%. At this point the specimen was unloaded and reloaded three times, using the high strain magnification, the loading curves being used to evaluate the elastic modulus. This procedure was used to evaluate the modulus because the initial yield point was too low in most cases to make evaluation possible.

Tensile data for the modulus of elasticity, proportional limit, and yield strength are summarized in Table III. The tabulated values of the modulus of elasticity have been calculated on the basis of the reduced cross-sectional area at 2% strain. For the high purity lead, the average value of the modulus was 2.7×10^6 psi, with no apparent decrease from 100 to 250°F. Values at 325°F could not be evaluated with sufficient accuracy. The proportional limit and yield strength both show a decrease of about 50% with test temperature from 100 to 325°F. For the copperized lead the average value of the modulus was 2.2×10^6 psi with about a 10% decrease at 325°F; the proportional limit and yield strength remained practically constant from 100 to 250°F and then decreased about 35% at 325°F.

3. Effect of Strain Rate

The effect of strain on the stress-strain curve was evaluated at 100 and 250°F, for both test materials. Figure 13 presents tests conducted at a strain rate of 0.005 in./in./min, along with previous tests conducted at a rate of 0.05 in./in./min. For the high purity lead, a decrease in the strain rate from 0.05 to 0.005 in./in./min resulted in a decrease in the ultimate tensile strength of about 30% at both test temperatures, and also in a decrease in strain at the ultimate and in the total strain to fracture. For the copperized lead, the same decrease in strain rate resulted in a 15% decrease in the ultimate and a slight decrease in the elongation to fracture.

B. Compression Tests

The results of stress-strain tests in compression to 5% strain are given in Figure 14. Triplicate tests were conducted at each test temperature for both materials, using a cross-head travel rate of 0.010 in./min for a strain rate of 0.005 in./in./min. There is some overlapping in the curves for the high purity lead at small values of strain for the different test temperatures. This is most likely due to small sampling differences which initially existed from specimen to specimen. After 1% strain the curves at any one test temperature are in close agreement.

Table III

TENSILE DATA--MODULUS OF ELASTICITY PROPORTIONAL LIMIT, AND YIELD STRENGTH

at a Strain Rate of 0.005 in./in./min

	Test Temperature, °F	Modulus of Elasticity, psi x 10^{-6} E_1	E_2	E_3	$E_{avg.}$	Proportional Limit, psi	Yield Strength, 0.2% Offset, psi
High Purity Lead	100	3.0	3.0	3.1	3.0	190.	372.
	100	2.6	2.6	2.7	2.6	170.	380.
	100	2.6	2.6	2.6	2.6	180.	384.
	Average				2.7	180.	379.
	175	---	---	---	---	150.	332.
	175	2.6	2.6	2.5	2.6	150.	312.
	175	2.7	2.5	2.5	2.6	---	---
	175	2.6	2.6	2.6	2.6	103.	347.
	Average				2.6	134.	330.
	250	2.4	2.9	2.4	2.6	130.	260.
	250	2.2	2.5	2.6	2.4	140.	288.
	250	3.1	2.8	3.0	3.0	130.	260.
	Average				2.7	133.	269.
	325	---	---	---	---	90.	188.
	325	---	---	---	---	72.	180.
	325	---	---	---	---	90.	200.
	Average					84.	189.
Copperized Lead	100	2.5	2.5	2.4	2.5	328.	612.
	100	2.2	2.2	2.4	2.3	200.	580.
	100	2.3	2.2	2.1	2.2	300.	560.
	Average				2.3	276.	584.
	175	1.9	2.4	2.0	2.1	350.	512.
	175	2.2	2.2	2.3	2.2	260.	488.
	175	2.4	2.3	---	2.3	270.	528.
	Average				2.2	293.	509.
	250	---	2.3	2.3	2.3	260.	488.
	250	1.8	1.8	1.9	1.8	260.	500.
	250	2.9	2.6	---	2.7	312.	504.
	Average				2.3	277.	498.
	325	2.1	2.1	2.0	2.1	200.	308.
	325	---	---	---	---	208.	320.
	325	2.0	2.0	1.9	2.0	160.	304.
	Average				2.0	189.	311.

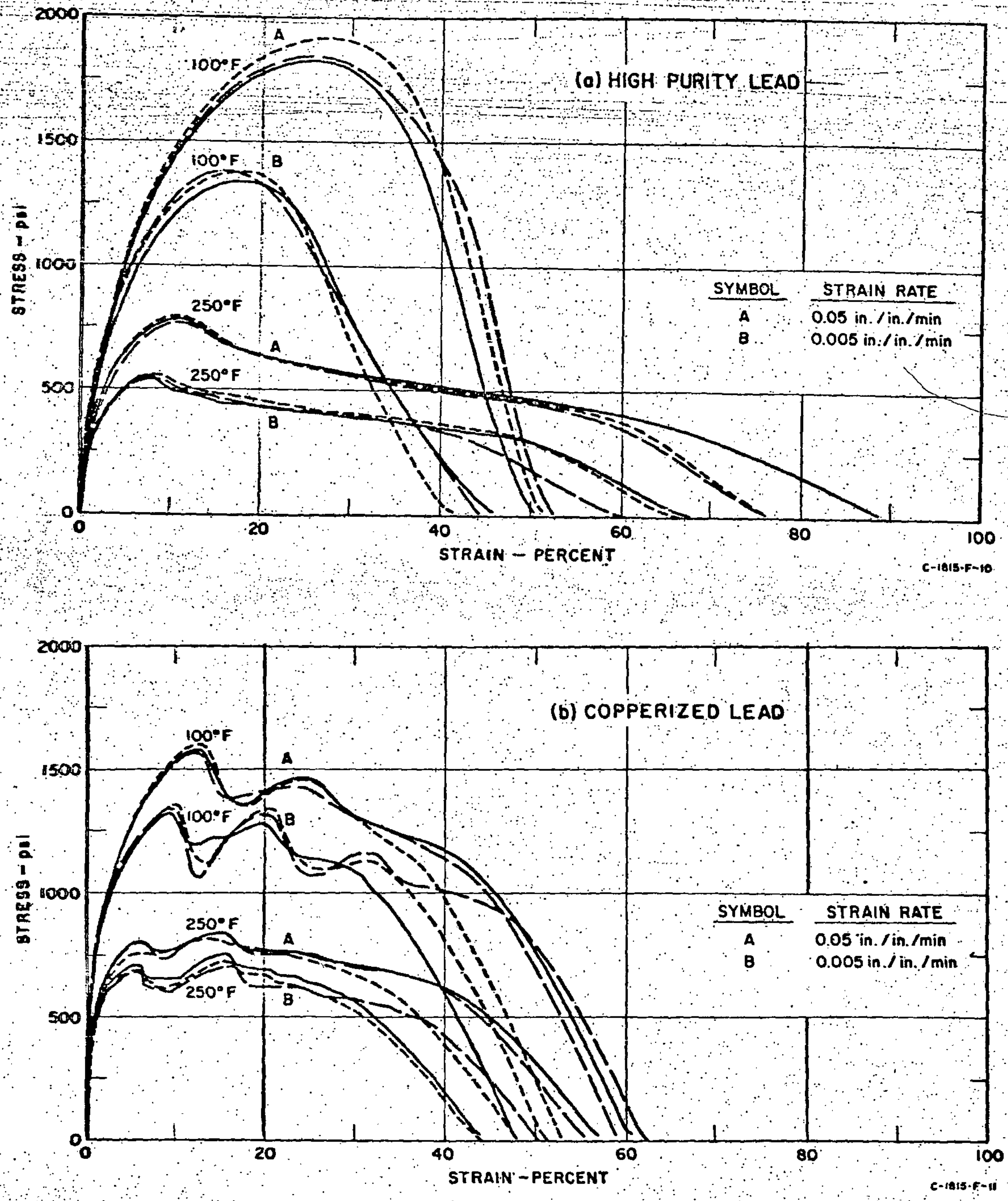


FIG. 13

EFFECT OF STRAIN RATE ON THE TENSILE STRESS-STRAIN CURVES AT 100 AND 250°F

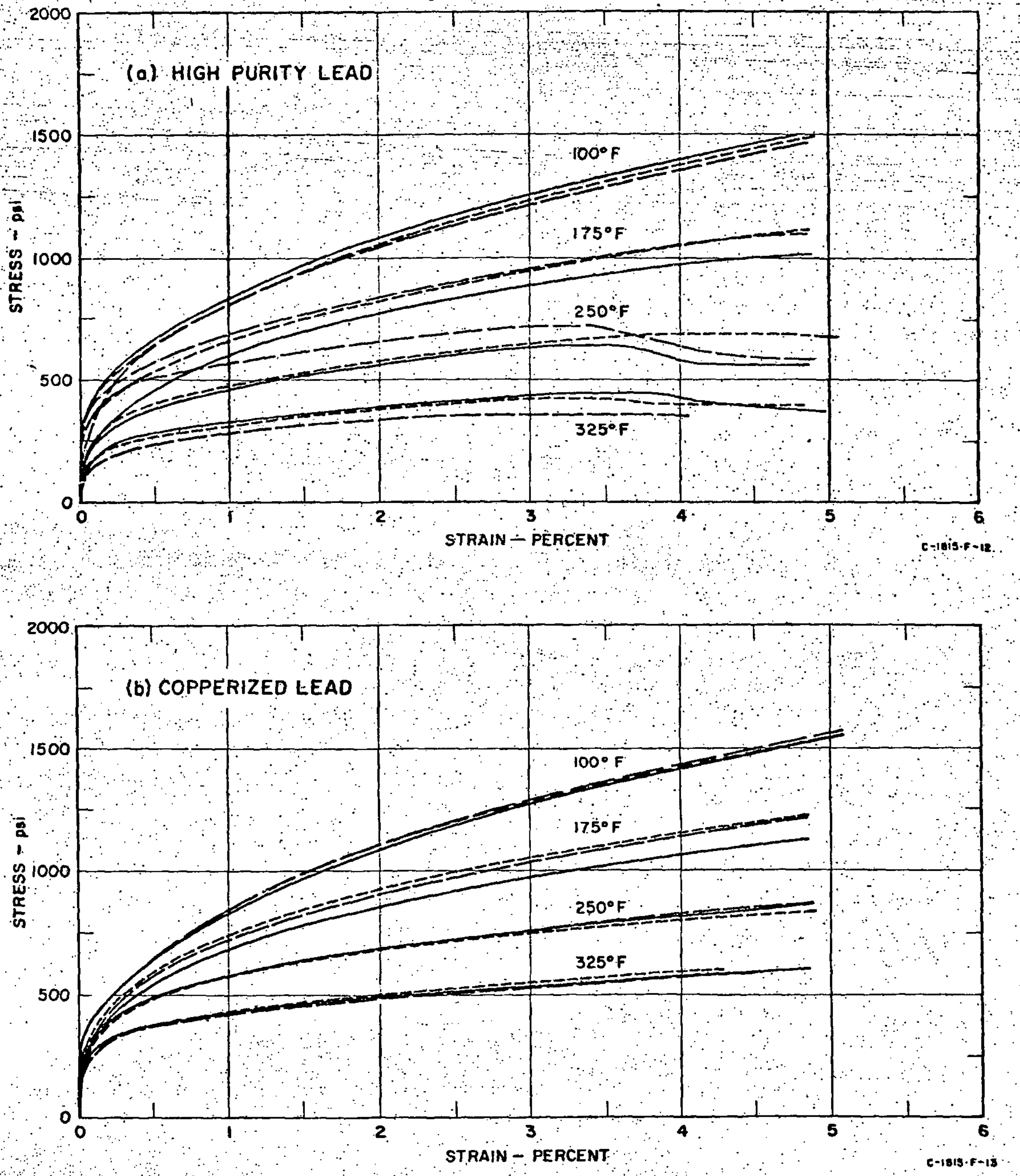


FIG. 14

COMPRESSION STRESS-STRAIN CURVES TO 5% STRAIN
AT A STRAIN RATE OF 0.005 IN./IN./MIN

For the high purity lead at 250 and 325°F, in some cases a decrease in the stress-strain curve occurred after 3% strain. In these cases no unusual condition was observed during test; a possible explanation is that recrystallization took place at these higher test temperatures under the particular test conditions.

The compression data are shown in Figure 15 as stress vs test temperature for various values of total strain. At the lower test temperatures the stress values for the copperized lead are only slightly higher than those for the high purity lead. At 325°F this difference becomes larger, the curves for the high purity lead decreasing more rapidly above 250°F than those for the copperized lead.

The elastic properties in compression were evaluated from the recorded load deformation charts in a manner similar to that used for the tensile tests. A high strain magnification, 1 inch of chart equal to 0.10% strain, was used to a strain of 0.3%. The test was completed at a low magnification, 1 inch of chart equal to 0.4% strain, to a strain of 5%. At this point the specimen was unloaded and reloaded three times, using the high strain magnification, the loading curves being used to evaluate the elastic modulus.

The modulus of elasticity, proportional limit, and yield strength data in compression are summarized in Table IV. The tabulated values of the modulus of elasticity have been calculated on the basis of the increased cross-sectional area at 5% strain.

The average value of the modulus was 2.6×10^6 psi for both materials, and decreased from 2.8×10^6 psi at 100°F to about 2.4×10^6 psi at 325°F. The proportional limit and yield strength values were about the same for the two leads at each of the three lower test temperatures; at 325°F the values for the copperized lead were about 50% higher than those for the high purity lead.

C. Shear Tests

The shear test results are summarized in Table V, and are presented in Figure 16 as ultimate shear strength vs test temperature. These tests were conducted by testing pins 1/2 inch in diameter by 2 inches long in double shear, using a constant cross-head travel rate of 0.005 in./min.

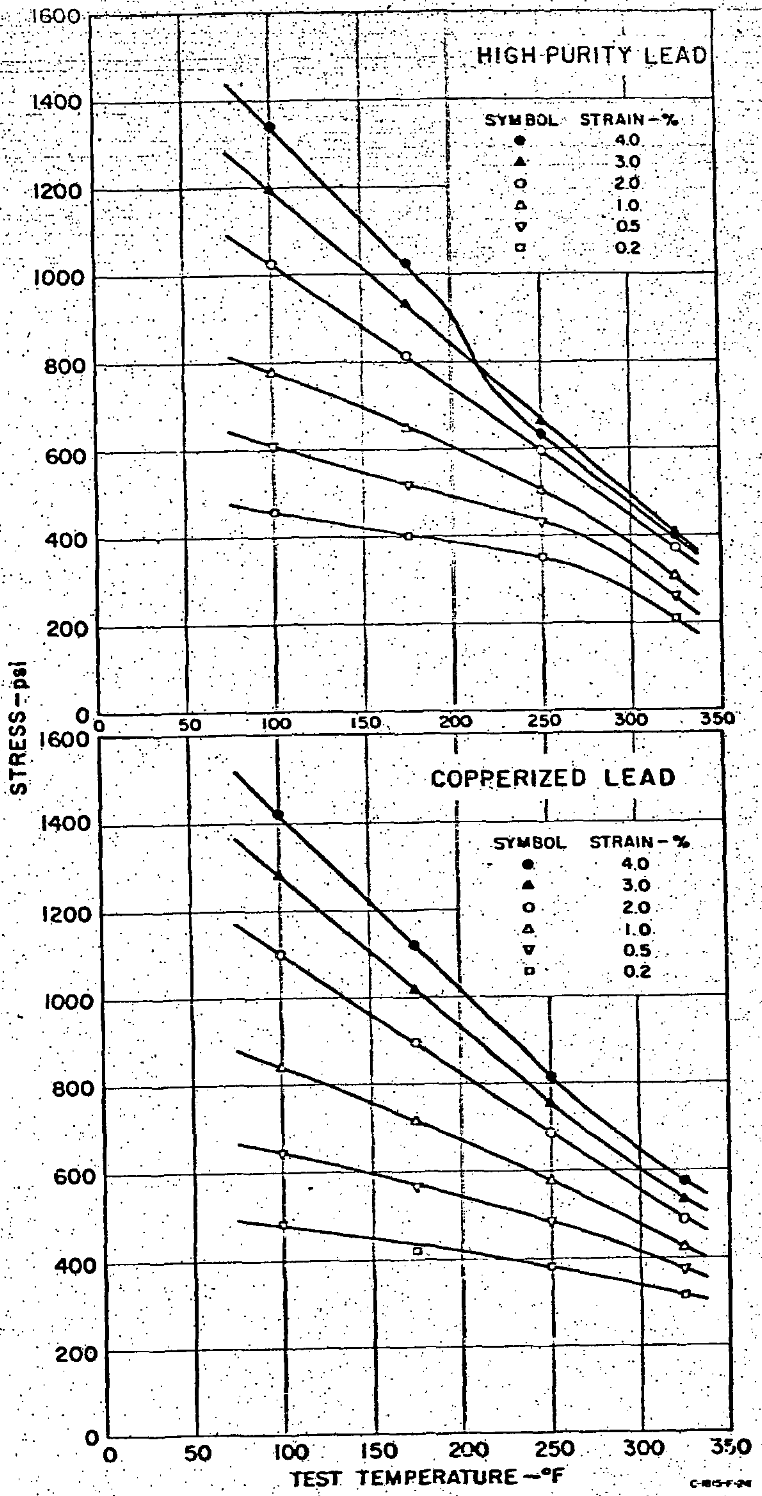


FIG. 15

COMPRESSION FLOW STRESS VS TEST TEMPERATURE
FOR GIVEN VALUES OF STRAIN
AT A STRAIN RATE OF 0.005 IN./IN./MIN

Table IV

COMPRESSION DATA--MODULUS OF ELASTICITY, PROPORTIONAL LIMIT, AND YIELD STRENGTH

at a Strain Rate of 0.005 in./in./min

	Test Temperature, °F	Modulus of Elasticity, psi x 10^{-6}				Proportional Limit, psi	Yield Strength, 0.2% Offset, psi
		E_1	E_2	E_3	$E_{avg.}$		
High Purity Lead	100	2.8	2.8	2.8	2.8	282.	500.
	100	---	2.6	2.6	2.6	81.	440.
	100	---	3.1	3.0	3.1	202.	472.
	Average				2.8	188.	471.
	175	---	2.5	2.7	2.6	100.	328.
	175	2.8	2.3	2.6	2.6	262.	472.
	175	2.6	2.3	2.5	2.5	202.	427.
	Average				2.6	188.	409.
	250	---	3.2	2.3	2.8	80.	292.
	250	2.5	---	2.3	2.4	181.	440.
	250	2.7	---	2.1	2.4	60.	322.
	Average				2.5	107.	351.
	325	2.5	---	---	2.5	50.	228.
	325	---	---	---	---	50.	180.
	325	---	---	---	---	80.	212.
	Average				2.5	60.	207.
Copperized Lead	100	---	2.9	3.0	2.9	222.	492.
	100	2.9	2.9	---	2.9	222.	492.
	100	2.5	2.6	---	2.6	201.	487.
	Average				2.8	215.	490.
	175	2.8	2.8	2.6	2.7	80.	408.
	175	---	2.8	---	2.8	120.	432.
	175	3.1	3.2	3.1	3.1	120.	444.
	Average				2.9	107.	428.
	250	2.4	---	2.5	2.5	120.	396.
	250	---	2.6	2.6	2.6	120.	396.
	250	2.4	2.4	---	2.4	80.	380.
	Average				2.5	107.	391.
	325	2.4	---	---	2.4	80.	320.
	325	---	---	---	---	80.	312.
	325	---	---	---	---	120.	328.
	Average				2.4	93.	320.

Table V

SHEAR TEST RESULTS

Ultimate Shear Strength, psi
at a Cross-head Rate of 0.005 in./min

Test Material	Test Number	Test Temperature, °F 100	175	250	325
High Purity Lead	1	1167	640	415	294
	2	1130	640	412	272
	3	1107	638	415	264
	Average	1135	639	414	277
Copperized Lead	1	1012	675	513	378
	2	908	690	513	383
	3	948	660	502	385
	Average	956	675	509	382

The data points in Figure 16 represent the average values for each set of triplicate tests. At 100°F the ultimate shear strength of the high purity lead was higher than that for the lead containing 0.058% copper. However, the shear strength of the high purity lead decreased more rapidly with test temperature than that of the copperized lead and was lower at temperatures above 160°F.

The shear tests on the copperized lead behaved in a similar manner to the tensile tests on the copperized lead, in that two maxima in the load occurred during each test.

D. Bearing Tests

The bearing tests were conducted at a cross-head travel rate of 0.005 in./min, and the stress-deformation curves to failure are given in Figure 17. For this purpose the stress is defined as the load divided by the bearing area, which is taken as the diameter of the bearing hole times the bearing plate thickness.

The bearing test results are given in Table VI in terms of yield strength, defined as 2% offset of the hole diameter, and ultimate bearing strength. The yield strength and ultimate strength are presented in Figure 18 as a function of temperature.

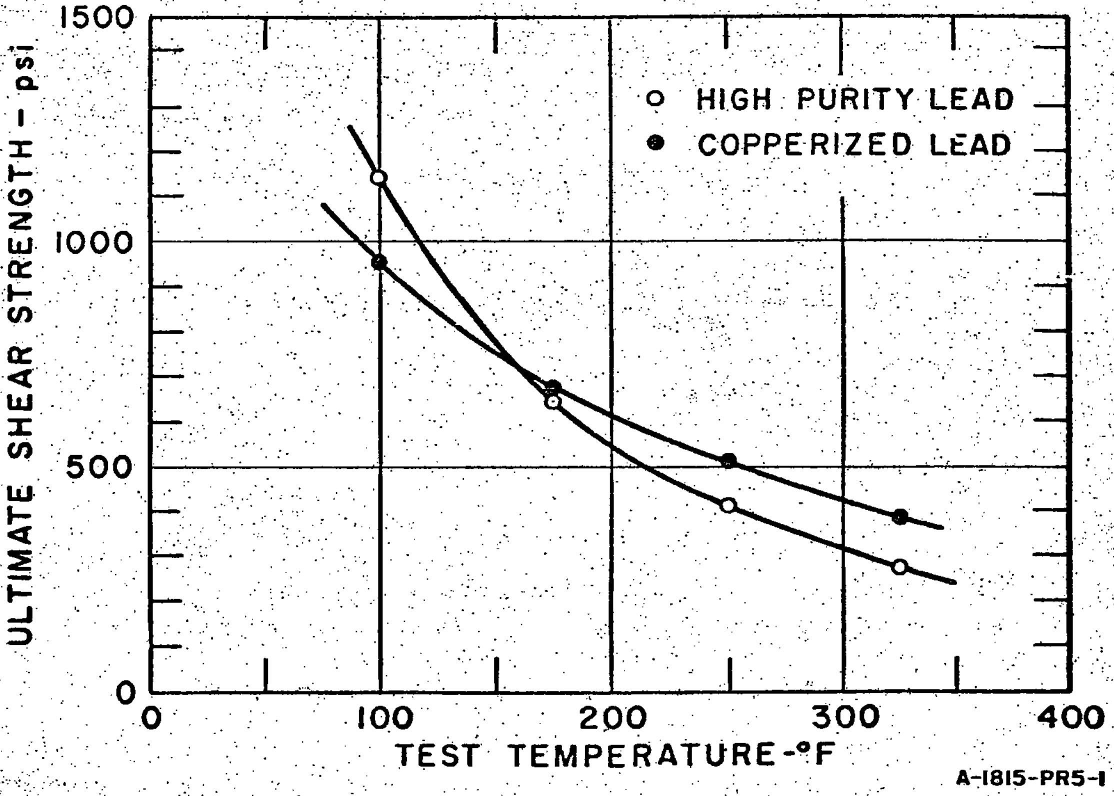


FIG. 16

SHEAR STRENGTH VS TEST TEMPERATURE AT A CROSS-HEAD RATE OF 0.005 IN./MIN

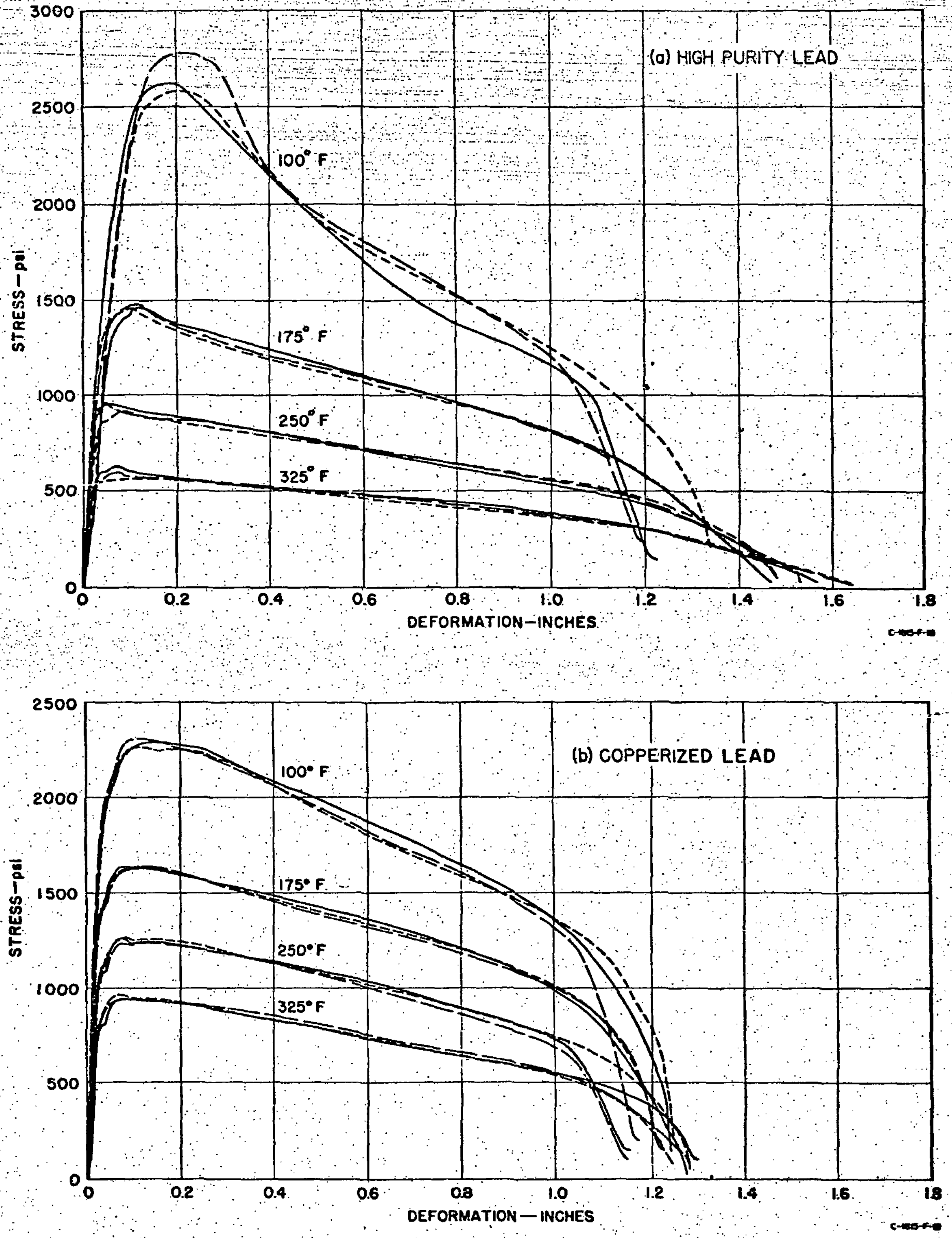


FIG. 17

BEARING STRESS-DEFORMATION CURVES TO FAILURE
AT A CROSS-HEAD RATE OF 0.005 IN./MIN

Table VI

BEARING TEST RESULTS

Yield Strength and Ultimate Bearing Strength
at a Cross-head Rate of 0.005 in./min

	Temperature, °F		Yield Strength, psi	Ultimate Strength, psi
High Purity Lead	100		1000.	2620.
	100		1060.	2780.
	100		1070.	2580.
		Average	1040.	2660.
	175		681.	1460.
	175		774.	1480.
	175		750.	1460.
		Average	740.	1470.
	250		629.	952.
	250		649.	963.
	250		605.	919.
		Average	630.	940.
	325		435.	629.
	325		443.	600.
	325		451.	564.
		Average	440.	600.
Copperized Lead	100		1090.	2280.
	100		1370.	2310.
	100		1150.	2260.
		Average	1200.	2280.
	175		1110.	1640.
	175		1120.	1640.
	175		1070.	1630.
		Average	1100.	1640.
	250		907.	1260.
	250		795.	1230.
	250		863.	1270.
		Average	860.	1250.
	325		710.	944.
	325		738.	947.
	325		685.	960.
		Average	710.	950.

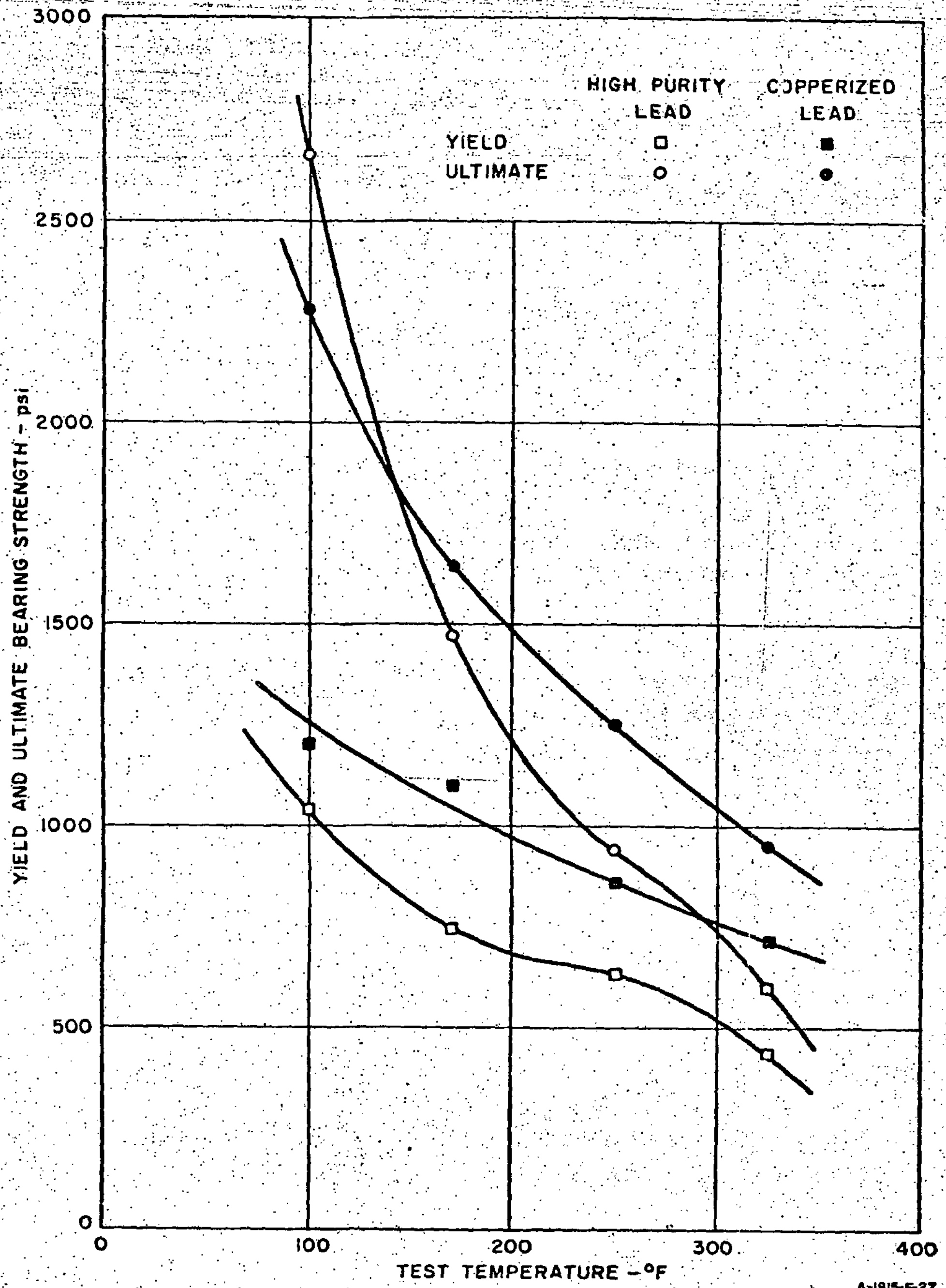


FIG. 18

BEARING YIELD STRENGTH AND ULTIMATE STRENGTH VS TEST TEMPERATURE AT A CROSS-HEAD RATE OF 0.005 IN./MIN

The bearing yield strength for the copperized lead is higher than that for the high purity lead at all test temperatures. The ultimate bearing strength for the high purity lead at 100°F is higher than that for the copperized, but becomes lower at temperatures above about 140°F. Inspection of the stress-deformation curves for the copperized lead shows that they exhibit a definite decrease in the rate of strain hardening, then an increase prior to the ultimate.

E. Creep Tests

The original creep data are presented as total strain vs creep time in Figure 19 for the high purity lead and in Figure 20 for the copperized lead.

Some crossing of the strain-time curves occurred at very low strain values of less than 0.0004 in./in. No fundamental significance is given to this behavior which is probably due to one or a combination of the following factors: sampling differences, slight variations in loading conditions, and possible initial lag in extensometer movement.

Greenwood and Worner,* studying the creep of lead, demonstrated that a rapid increase in the creep rate occurred when recrystallization took place during test. The longer time and higher temperature creep tests of the current study were plotted on regular coordinate paper as strain against time. All these curves showed a continually decreasing creep rate with time indicating that no recrystallization took place under the given test conditions. This was not confirmed, however, by microstructure studies.

In Figure 21 and 22 the creep results are summarized as stress-creep time curves for total strain values of 0.2, 0.5, 1.0, and 2.0% for the two test materials.

The high purity lead is less creep resistant than the copperized lead for the shorter creep times. However, for the longer creep times the high purity lead is more creep resistant than the copperized lead. This is especially true at the higher test temperatures.

It should be repeated here that these results are for the test materials in the as-received condition, annealed prior to testing only to remove any work hardening due to machining and handling. The materials were-

---

*Greenwood, J. Neill, and H. K. Worner, "Types of Creep Curves Obtained with Lead and Its Dilute Alloys." Jour. Inst. of Metals (1939) 64, No. 1, 135 tested in this condition in order to obtain the properties of these two materials as normally received. The grain sizes of the two materials as reported earlier were considerably different, both in the as-received and in the annealed conditions.

Several studies on the effect of grain size on the creep of metals have shown that, for any one material, a fine grain size material is in general less creep resistant than a coarser grain size material. This is attributed to the fact that the finer grain size material is generally less stable structurally.

Thus, the copperized lead, with a very fine grain size, has less creep resistance at the higher temperatures and longer creep times than it would with a coarse grain size. Under the present test conditions, this grain size effect is apparently great enough to more than counteract the alloy strengthening effect of the copper addition.

The grain size is an important factor in the creep of metals, and should be evaluated for the creep of lead at the contemplated service temperatures.

VI Summary

The tensile, compression, shear, bearing, and creep properties of a high purity lead and a 0.058% copper-lead alloy were evaluated at test temperatures of 100, 175, 250, and 325°F.

The data are summarized in graphical and tabular form in the Experimental Results section of the report.

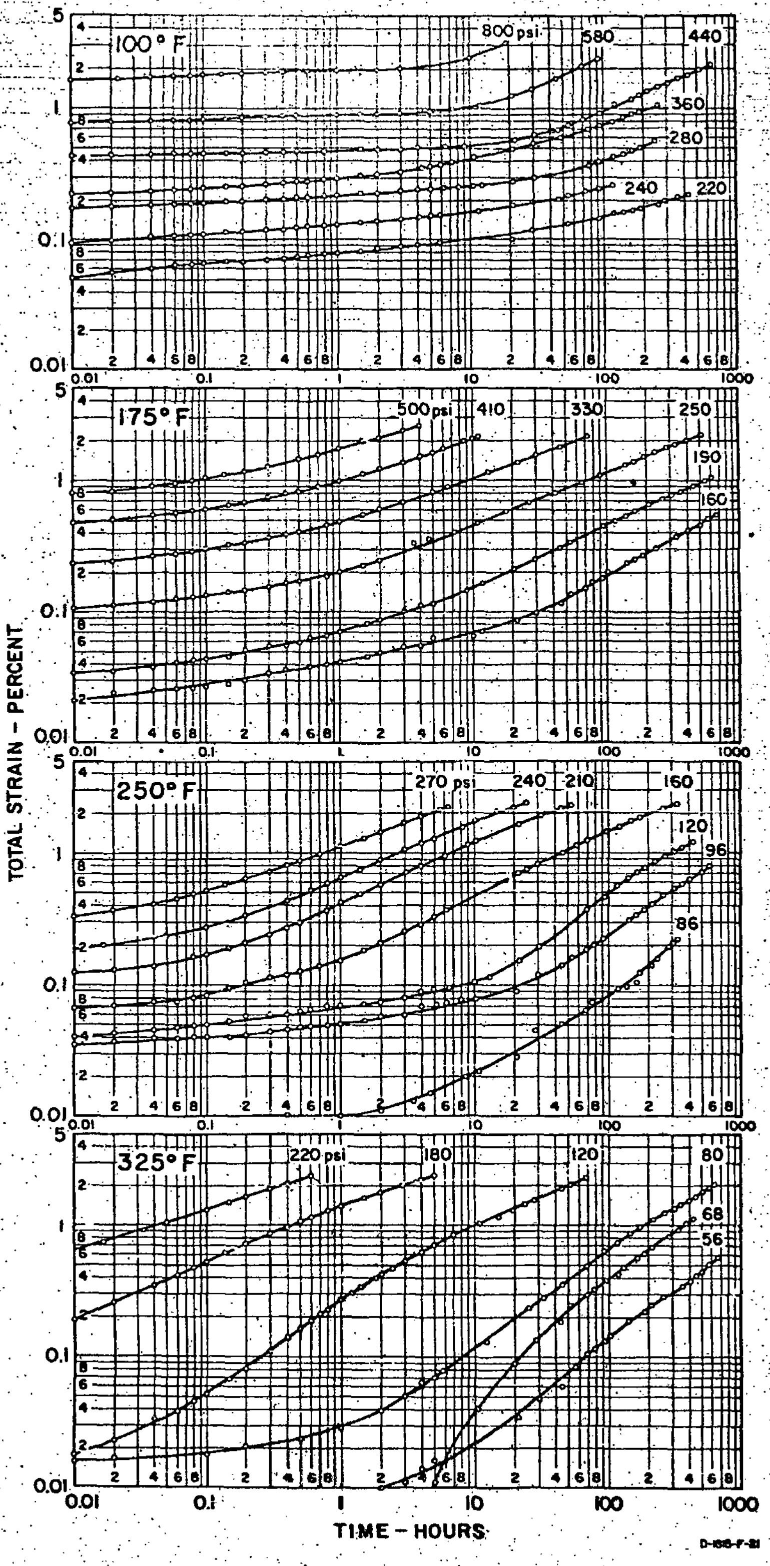


FIG. 19

TOTAL STRAIN VS CREEP TIME FOR HIGH PURITY LEAD

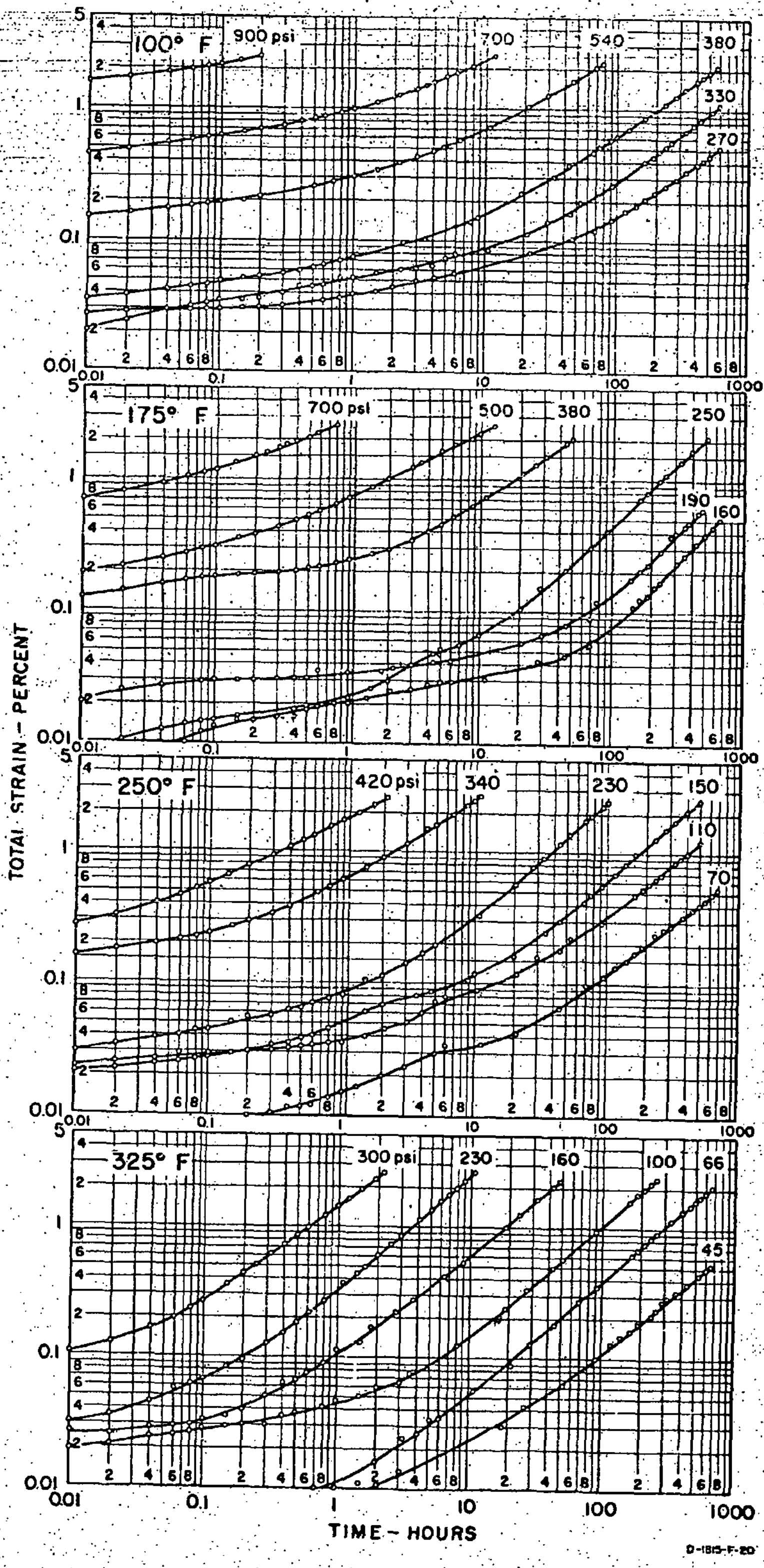


FIG. 20

TOTAL STRAIN VS CREEP TIME FOR COPPERIZED LEAD

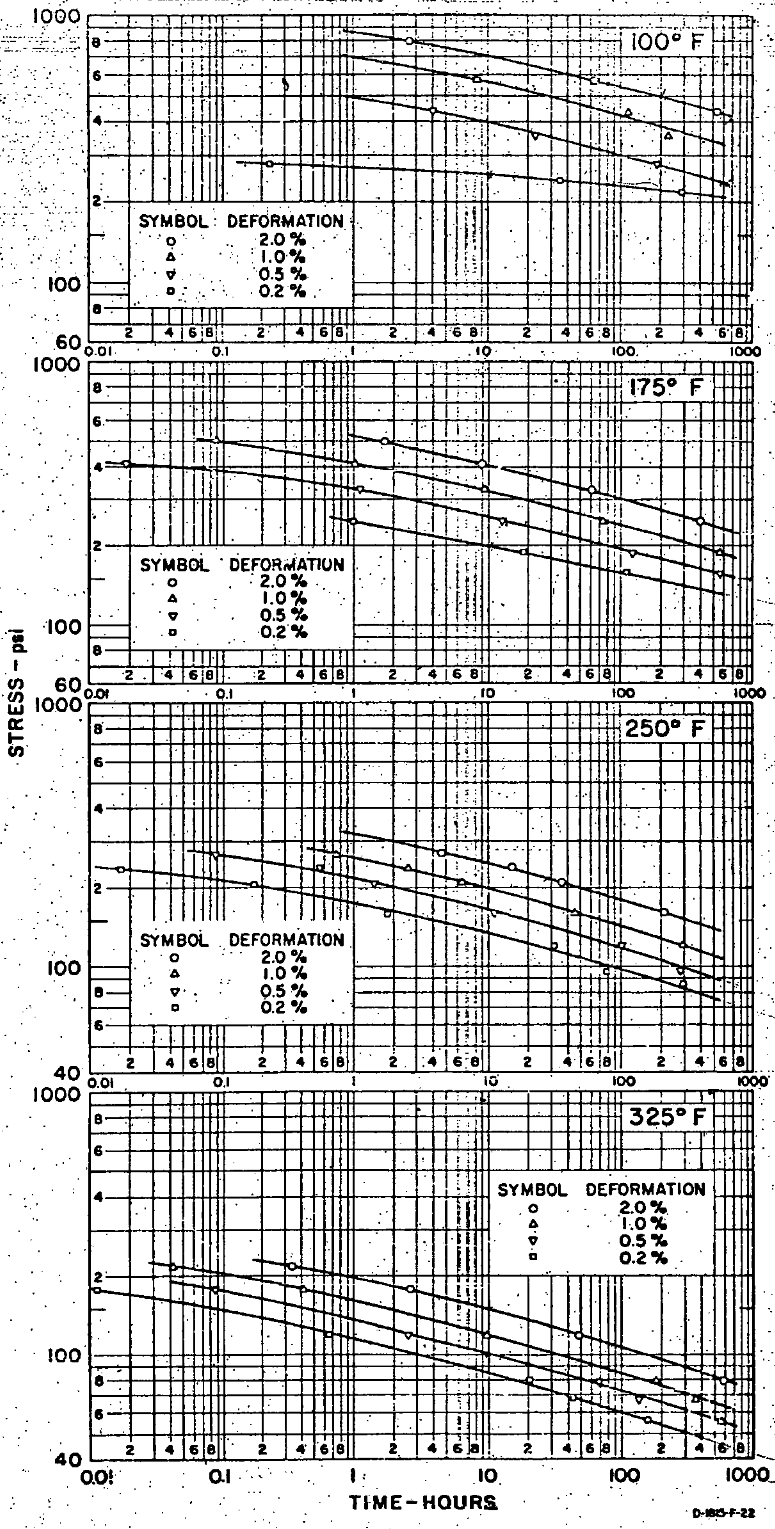


FIG. 21

STRESS VS CREEP TIME AT CONSTANT STRAIN VALUES OF 0.2, 0.5, 1.0, AND 2.0% FOR HIGH PURITY LEAD

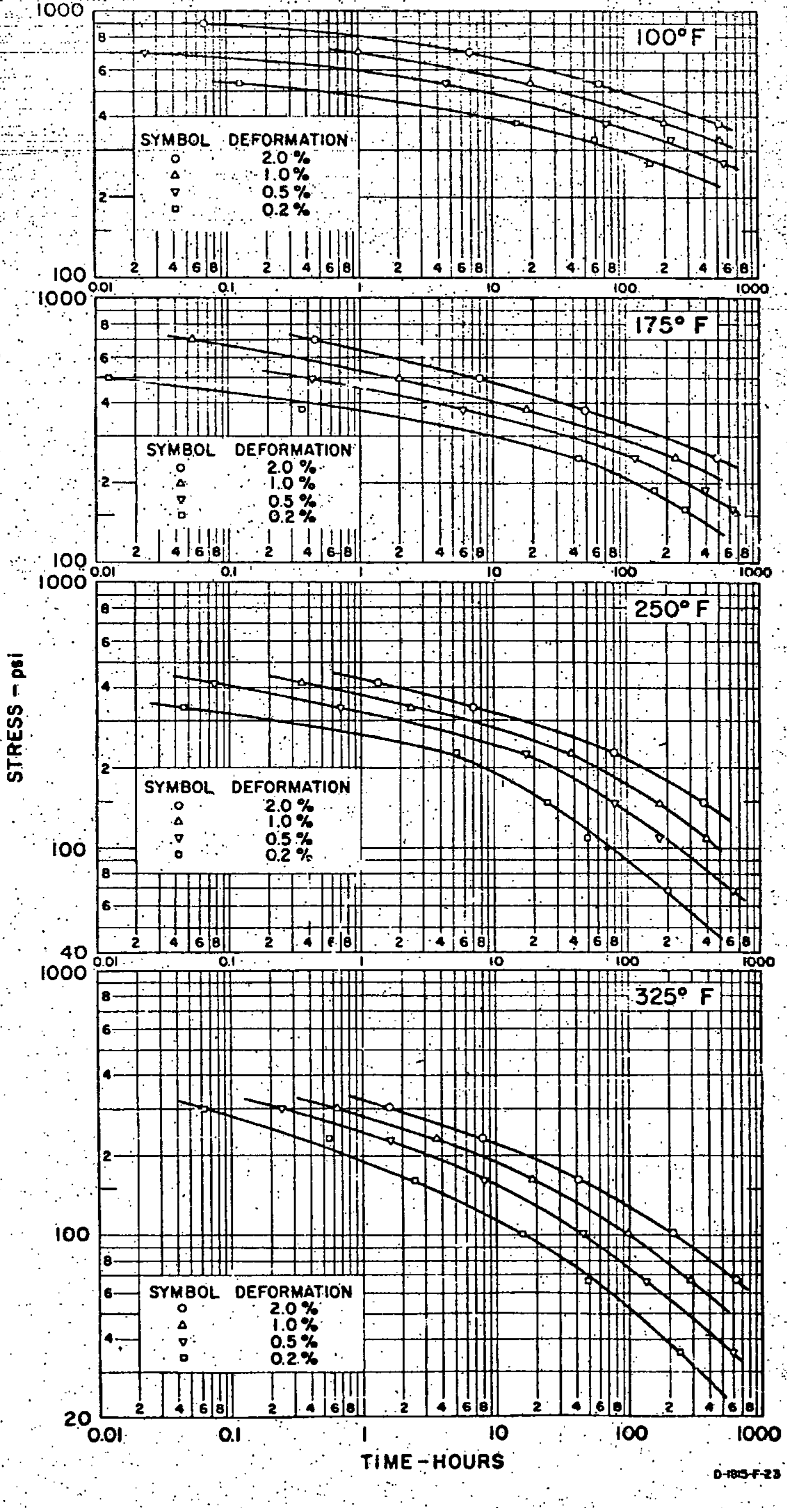


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FIG. 22

STRESS VS CREEP TIME AT CONSTANT STRAIN VALUES OF 0.2, 0.5, 1.0, AND 2.0% FOR COPPERIZED LEAD

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An Assessment of Stress-Strain Data Suitable for Finite-Element Elastic-Plastic Analysis of Shipping Containers

Henry J. Rack, Gerald A. Knorovsky

Sandia Laboratories

SF 2900 Q(7-73)

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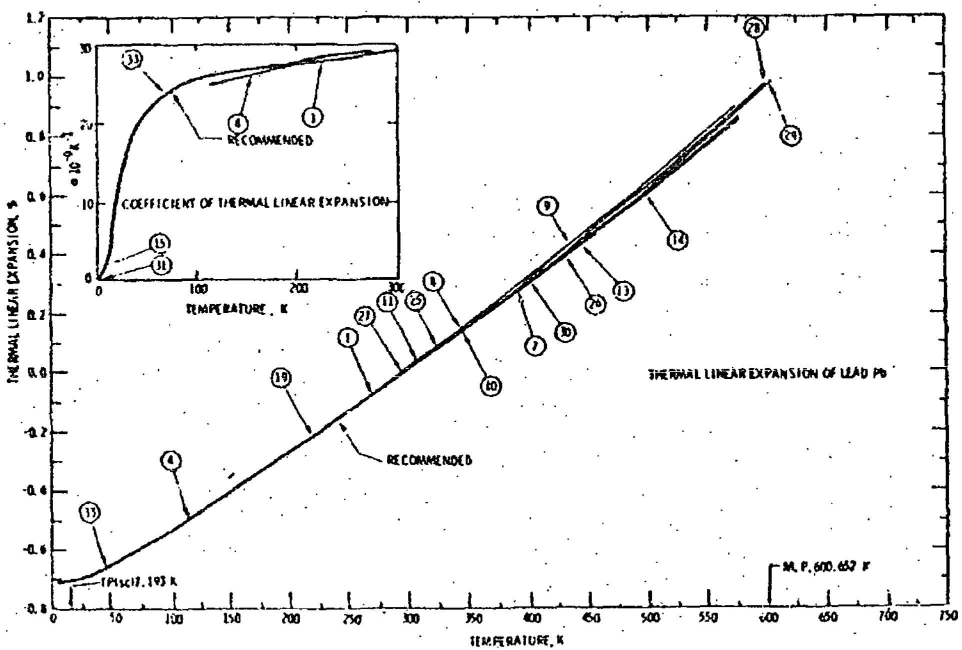

Figure A-3. Thermal expansion behavior of lead, curve reference numbers given by Touloukian et al. [57].

with the recommended values being

Temperature (K)	$\Delta L/L_o$(%)	$\alpha \times 10^6 (K^{-1})$
100	-0.526	25.6
200	-0.261	27.5
293	0.000	28.9
400	0.317	30.6
500	0.638	33.3
600	0.988	36.7

where

$$\alpha = (1/L_{293})dL/dT$$

values were obtained from specifically oriented uranium single crystals [63]. These results show that, whereas the modulus of non-textured polycrystalline uranium at 298 K is 29 x 10^6 psi, it can be as high as 41.5 x 10^6 psi or as low as 21.4 x 10^6 psi for a textured sample.

Finally, the authors were unable to obtain any reliable data on the influence of dilute alloy additions (e.g., 2 weight percent Mo) on the elastic properties of uranium.

Lead

The influence of temperature on the Young's modulus of cast high purity lead is shown in Figure B-8. Again, increasing temperature results in a gradual decrease in modulus. Attempts to locate more complete information, including values of the shear modulus and Poisson's ratio, have been unsuccessful to date.

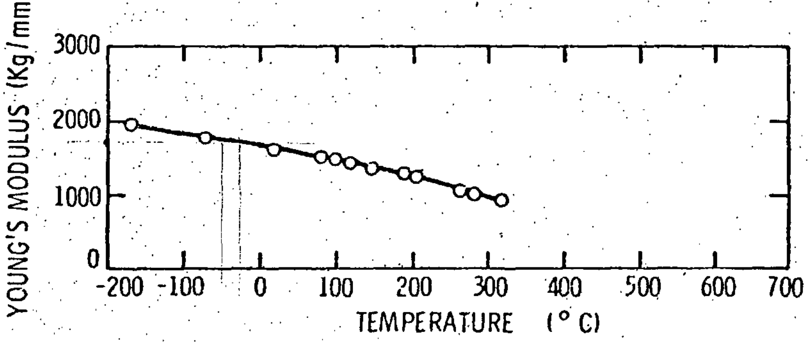

Figure B-8. Young's modulus of lead [65].

Enclosure 14 to TN E-29128

Cover Page and Page 3-110 from "Handbook of Heat Transfer Fundamentals," Second Edition, Warren M. Rohsenhow, James P. Hartnett, Ejup N. Ganic, McGraw-Hill Book Company, associated with RAI 2-14

Handbook of Heat Transfer Fundamentals

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TABLE 64 Density of Metallic Elements (*Continued*)

Temp., K	Symbol									
	Ho	In*	Ir	Fe	La*	Pb	Li	Lu*	Mg	Mo
50	8820	7460	22,600	7910	6203	11,570	547	9830	1765	10,260
100	8815	7430	22,580	7900	6200	11,520	546	9840	1762	10,260
150	8810	7400	22,560	7890	6196	11,470	543	9840	1757	10,250
200	8800	7370	22,540	7880	6193	11,430	541	9850	1752	10,250
250	8790	7340	22,520	7870	6190	11,380	537	9840	1746	10,250
300	8780	7310	22,500	7860	6187	11,330	533	9830	1740	10,240
400	8755	7230	22,450	7830	6180	11,230	526	9800	1736	10,220
500	8730	6980	22,410	7800	6160	11,130	492	9770	1731	10,210
600	8700	6810	22,360	7760	6170	11,010	482	9740	1726	10,190
800	8650		22,250	7690	6140	10,430	462	9660	1715	10,160
1000	8600		22,140	7650	6160	10,190	442	9580	1517	10,120
1200			22,030	7620		9,940	442	9500	1409	10,080
1400			21,920	7520			402			10,040
1600	—		21,790	7420			381			10,000
1800			21,660	7320			361	—		9,950
2000			21,510	7030			341			9,900

Temp., K	Symbol							
	Ni	Nb	Os	Pd	Pt	Pu	K	Pa*
50	8960	8610	22,550	12,110	21,570	20,270	905	
100	8960	8600	22,540	12,100	21,550	20,170	898	
150	8940	8590	22,520	12,090	21,530	20,080	890	
200	8930	8580	22,510	12,070	21,500	19,990	882	
250	8910	8570	22,490	12,050	21,470	19,860	873	
300	8900	8570	22,480	12,030	21,450	19,730	863	15,370
400	8860	8550	22,450	11,980	21,380	17,720	814	15,320
500	8820	8530	22,420	11,940	21,330	17,920	790	15,280
600	8780	8510	22,390	11,890	21,270	15,300	767	15,230
800	8690	8470	22,320	11,790	21,140	16,370	720	15,150
1000	8610	8430	22,250	11,680	21,010		672	15,050
1200	8510	8380		11,570	20,870		623	14,910
1400	8410	8340			20,720		574	—
1600	8320	8290			20,570		527	
1800	7690	8250		—	20,400			
2000	7450	8200	—		20,220			

TABLE 34 Thermodynamic Properties of Saturated Water Substance (English Units)