DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON DIRECTOR

No. 188

SOME PROPERTIES OF WHITE METAL BEARING ALLOYS AT ELEVATED TEMPERATURES

BY

JOHN R. FREEMAN, Jr., Associate Physicist
R. W. WOODWARD, Physicist
Bureau of Standards

APRIL 5 , 1921

PRICE, 5 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

SOME PROPERTIES OF WHITE METAL BEARING ALLOYS AT ELEVATED TEMPERATURES

By John R. Freeman, Jr., and R. W. Woodward

ABSTRACT

An apparatus is described for determining the yield point and ultimate strength of white metal bearing alloys at temperatures up to 100° C. A new design of heating apparatus is described for determining the Brinell hardness of metals at temperatures up to 100° C.

The results of compression tests and Brinell hardness tests at temperatures up to 100° C are given for five typical white metal bearing alloys, including three tin-base alloys, one lead-base alloy, and one intermediate alloy, which show that the tin-base alloys maintain their properties better at elevated temperatures than the lead-containing alloys.

Results of tests are given which indicate that up to 5 per cent of lead in a high-grade babbitt does not affect the yield point or ultimate strength at 25 or 75° C.

The yield point of tin-base alloys is not affected by heating for six weeks at about 100° C, but the yield point is lowered in the lead-base alloy by heating for two weeks at about 100° C.

CONTENTS

		Page
I.	Introduction	4
II.	Preparation of alloys	5
	1. Metals used	5
	2. Alloying procedure	5
III.	Preparation of test specimens	6
IV.	Apparatus used for testing	6
	1. Compression tests	6
	2. Brinell hardness tests	8
V.	Preliminary tests	9
VI.	Elevated-temperature compression tests	10
VII.	Elevated-temperature Brinell tests	12
VIII.	Discussion of results	13
	1. Compression tests	13
	2. Brinell hardness tests	14
IX.	Effect of prolonged heating at 100° C	15
X.	Effect of small percentages of lead	15
XI.	Summary and conclusions	16

33333°—21

I. INTRODUCTION

The mechanical properties of white metal bearing alloys have been the subject of several investigations with the particular object of establishing the relations between the properties obtained in laboratory tests and the ultimate test of service. Practically all of these tests reported in the literature on white metal bearing alloys were conducted at room temperature, the Brinell hardness alone[1] having been determined for a few alloys under other conditions of temperature. While we therefore have considerable knowledge of the mechanical properties of these alloys at ordinary temperatures, our knowledge of their properties at elevated temperatures is very limited.

The importance of knowing the properties of bearing alloys at elevated temperatures is readily appreciated when one considers that the oil temperature in the crank case of an automobile engine may often reach 60° C, and that bearing temperatures of 100° C and higher have been measured in similar engines.

It is the purpose of this paper to present the design of new apparatus and the results of tests to determine the mechanical properties in compression and the Brinell hardness of some representative white metal bearing alloys at elevated temperatures.

The nonferrous metals division of the Society of Automotive Engineers is proposing as standard white metal bearing alloys the four compositions given in Table 1.

TABLE 1.—Specifications for White Metal Bearing Alloys Proposed by the Society of Automotive Engineers

Components	S. A. E. No. 10	S. A. E. No. 11	S. A. E. No. 12	S. A. E. No. 13
	Per cent	Per cent	Per cent	Per cent
Tin	90–92	86–89	Remainder	4.50– 5.50
Copper	4–5	5–6.50	2.25– 3.75	<0.50
Antimony	4–5	6–7.50	9.50–11.50	9.25–10 75
Lead	<0.35	<0.35	24–26	84–86

These four alloys and A. S. T. M. alloy No. 2[2] were selected as of representative composition suitable for this investigation. It will be noticed that A. S. T. M. alloy No. 2 (Table 2) is very similar

[1] Jesse L. Jones, Babbitt and babbitted bearings, A. I. M. M. E. Trans., 60, p. 458; 1919.

[2] "Tentative specifications for white metal bearing alloys," Proc. A. S. T. M., 19, pt. 1, p. 469.

to the S. A. E. alloy No. 11. The properties of these two alloys are compared here, as the A. S. T. M. alloy was considered by the S. A. E. committee as a little hard.

The results of chemical analyses[3] of the five alloys studied are given in Table 2.

TABLE 2.—Percentage Composition of Alloys Studied

Components	Bearing metal No. 1: S. A. E. No. 10; A. S. T. M. No. 1	Bearing metal No. 2: A. S. T. M. No. 2	Bearing metal No. 3: S. A. E. No. 11	Bearing metal No. 4: S. A. E. No. 12	Bearing metal No. 5; S. A. E. No. 13; A. S. T. M. No. 9
	Per cent	Per cent	Per cent	Per cent	Per cent
Copper	4.56	3.51	5.65	2.90	....
Antimony	4.52	7.57	6.90	10.50	10.03
Tin	Remainder	Remainder	Remainder	Remainder	Remainder
Lead	None	None	0.09	25.05	84.95
Iron	<0.05	<0.05	< .05	< .05	< .05

II. PREPARATION OF ALLOYS

1. METALS USED

Pure Banka tin and the best grade of "Star" antimony were used. Neither these metals nor the copper were analyzed, as the freedom of the alloys from impurities is proof of the purity of the metals used.

Analysis of the commercially pure lead used showed the following: Lead, 99.94 per cent; copper, 0.03 per cent; antimony, <0.03 per cent.

2. ALLOYING PROCEDURE

Alloys Nos. 1, 2, 3, and 4 were prepared by first melting the tin in a plumbago crucible in a gas furnace and then adding the requisite amounts of a 50 per cent Sn.-50 per cent Cu hardener and metallic antimony. After addition of the alloying elements the temperature of the bath was carried up to the melting point of antimony and stirred to insure a homogeneous alloy. The temperature of the melt was then allowed to drop to about 500° C with continual stirring of the metal, which was then poured into a cast-iron mold. The surface of the bath was always kept covered with charcoal to prevent excessive oxidation. The temperature was measured by means of a specially calibrated chromel-alumel thermocouple connected to a portable potentiometer.

[3] J. A. Scherrer, of the Bureau of Standards, made all chemical analyses reported in this paper.

The lead-base alloy No. 5 was similarly prepared, but in this case the lead was first melted and then the metallic tin and antimony were added.

The alloys were made up to meet the mean composition of the specifications, and the resultant compositions given indicate how close a desired composition may be obtained with the careful laboratory methods used.

III. PREPARATION OF TEST SPECIMENS

The compression test specimens used were small cylinders 1½ inches long by about ½ inch diameter (1.5 by 0.514 inch), this ratio of length to diameter being within the limits recommended by the A. S. T. M., and the cross section for these experiments being easily tested in a 10 000-pound testing machine. These specimens were turned in a lathe, with a hollow mill, from castings 2 inches long by ¾ inch diameter which were made by pouring the metal from the desired temperature into a split steel mold of the above dimensions.

The samples for Brinell testing were similar to those used by Lynch,[4] the metal being poured into an open steel mold 2 inches in diameter by ⅝ inch deep, but in this case the mold was not previously heated before pouring, always being at room temperature when the metal was first poured. Before making the impressions, the faces of the casting were turned off and the test then made on the bottom face. Three impressions were made on each casting at equidistant points on a circle one-half the radial distance from the center. The average of these three readings was taken as the Brinell hardness under the given conditions.

IV. APPARATUS USED FOR TESTING

1. COMPRESSION TESTS

The cylinders were compressed in a standard Reihle 10 000-pound testing machine.

The deformation per unit load was measured by a specially designed compressometer. A copy of a photograph of this instrument mounted on a specimen is shown in Fig. 1. The frame and uprights are made of aluminum. They are held to the specimen by three small steel screws, having conical points, set radially in the same plane, and spaced equidistantly around

---

[4] T. D. Lynch, "Study of bearing metals and methods of testing," A. S. T. M., **13**, p. 699; 1913.

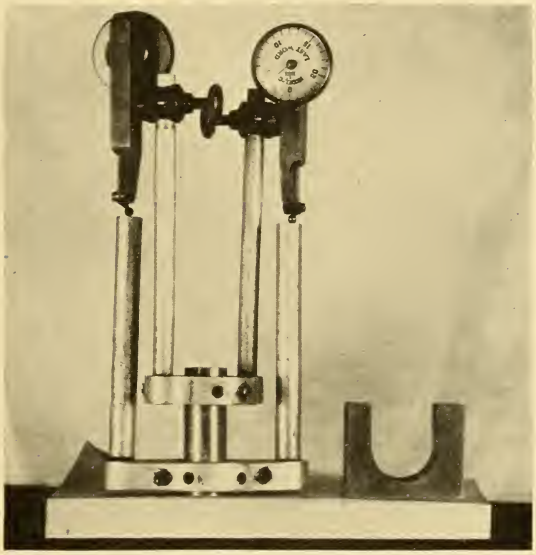

FIG. 1.—*Compressometer mounted on specimen*

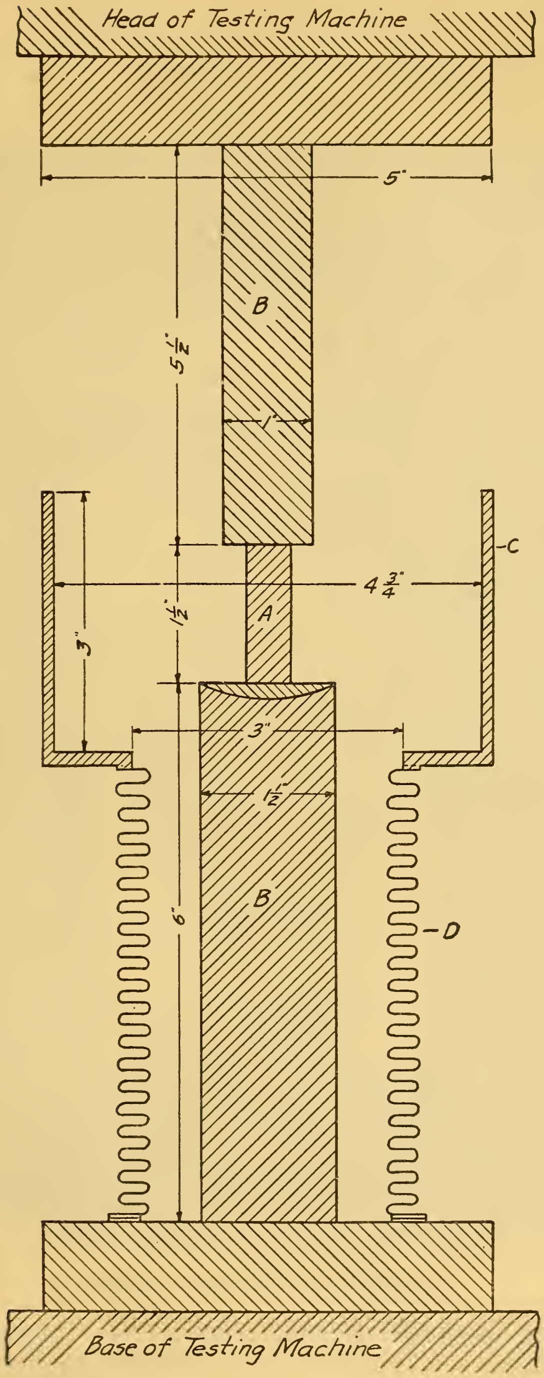

FIG. 2.—*Assembly drawing of a section of heating bath, showing original dimensions*

the specimen, as may be seen in the photograph. The small U-shaped block is a gage used for spacing the frames at the proper distance on the specimen. The gage length or the distance between the planes of the screws is 1 inch.

The "Last Word" dials used read to approximately thousandths of an inch (one division on dial = 0.00087 in.), and ten thousandths are readily estimated.

The assembly and important dimensions of the bath used for heating the specimen during tests are shown in Fig. 2, which is a section through the center. The specimen *A* is compressed between the steel posts *B B*. During test the specimen with compressometer attached is immersed in a heated liquid (glycerin was found very satisfactory) held in the container *C*. *D* is a Silphon diaphragm. This collapses like an accordion, permitting the top of the container *C* to drop below the level of the base of the specimen. This is a particularly convenient method for lowering the bath to place a specimen in position for testing, especially as it eliminates the need for any packed joints. A photograph of the entire apparatus with a specimen in position for testing is shown in Fig. 4.

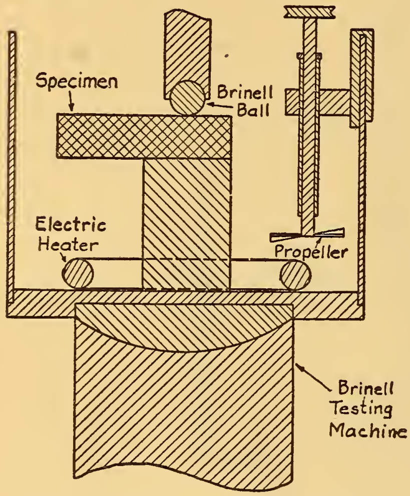

FIG. 3.—*Apparatus for Brinell hardness testing at elevated temperatures*

The bath is heated with a small size Hot-Point electric heater immersed in the glycerin. The glycerin was forced in a continuous stream over the heater by a small electric motor-driven propeller. This continuous stirring of the glycerin and the ready control of the heating current with a variable resistance provided excellent control of the temperature of the specimen during the test. In all cases the temperature of the bath and consequently the specimen did not vary by more than 2° C during a test.

2. BRINELL HARDNESS TESTS

The Brinell hardness tests were made with a standard Brinell machine using a 500 kg load on a 10 mm ball applied for 30 seconds. For the elevated temperature tests the apparatus shown in Fig. 3 was used. It is simply a suitable container for the heat-

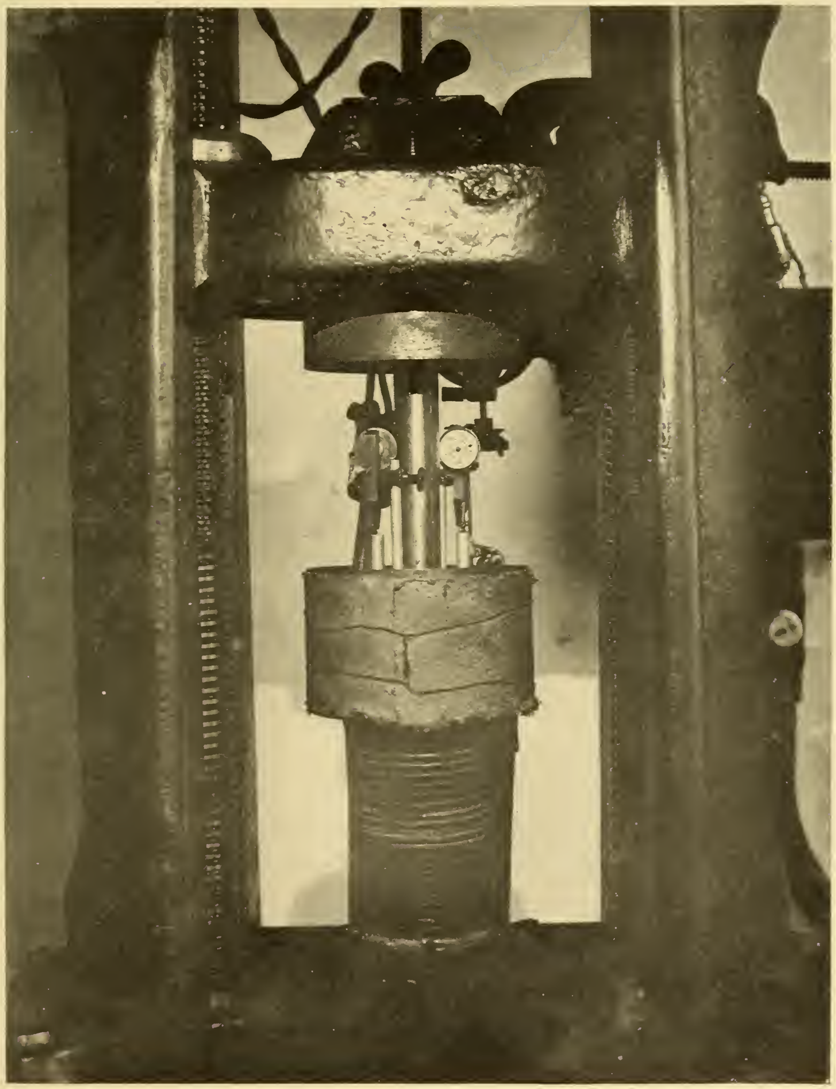

FIG. 4.—*Specimen with compressometer and heating bath assembled in testing machine*

ing liquid (glycerin was used) with a base made to fit on the spherical seat of the Brinell machine and a post on the inside to support the specimen away from the bottom and permit good circulation of the liquid around it. The bath was stirred with a small motor-driven propeller and was heated by a small resistor placed on the bottom of the container. During test the entire specimen was submerged, the Brinell ball also being completely immersed. Sufficient time was always allowed for the specimen to reach the temperature of the bath, this having been previously determined by inserting a thermocouple in a specimen and noting the time elapsed between the placing of the specimen in the bath and when the center reached the temperature of the bath.

V. PRELIMINARY TESTS

It is well known that the pouring temperature of a bearing metal, all other conditions being constant, has a marked influence on the mechanical properties. In view of this fact, preliminary to any test at elevated temperatures, the effect of pouring temperature on the compressive strength at room temperature was determined for alloys Nos. 1, 3, 4, and 5. The results obtained from compression tests are given in Table 3.

TABLE 3.—Effect of Pouring Temperatures on Yield Point and Ultimate Strength in Compression of Various Alloys

Alloy No.	Pouring temperature	Yield point	Ultimate strength
	° C	Lbs./in.²	Lbs./in.²
1	400	3750	12 940
	446	4000	12 855
	495	3500	13 500
3	390	3500	15 830
	445	4250	16 435
	500	4000	15 830
4	300	5000	14 015
	350	4250	13 685
	400	4750	13 635
5	300	3250	13 840
	356	3750	15 020
	404	3250	15 245

In results reported in this paper the yield point was adopted arbitrarily as at ⅛ of 1 per cent reduction of the gage length. The ultimate strength was arbitrarily chosen as the unit load necessary to produce a deformation of 25 per cent of the original length of the test specimen. The reasons for selecting these values will be discussed later.

From a comparison of the results of Table 3 and the pouring temperatures suggested in the tentative specifications of the A. S. T. M.[5] the following temperatures were used in casting test specimens for all further tests.

	Pouring temperature, °C
No. 1	440
No. 2	440
No. 3	440
No. 4	345
No. 5	325

VI. ELEVATED-TEMPERATURE COMPRESSION TESTS

Stress deformation curves were taken on all five alloys at room temperature (20–30° C), 50, 75, and 100° C. At least two specimens were tested under each condition to provide a check.

Representative stress-strain curves at the four temperatures of each alloy except No. 2 are given in Fig. 5. These show the type of stress-deformation curve obtained with the apparatus described in this paper and also show very clearly the marked change in the compressive strength of the alloys with increasing temperatures. On the plot a "dial unit" is equivalent to 0.00087 inch and is the algebraic mean of the total deformation shown by the individual dials for any given load.

A study of the curves shows that it is practically impossible to pick out a limit of proportionality as ordinarily determined by noting the departure of the stress-deformation curve from a straight line, and, further, we know that the finer the measurement the lower will be this point. An arbitrary yield point was therefore determined upon. After comparing the yield points indicated by several values of percentage reduction of gage length the value of ⅛ of 1 per cent of the gage length (0.00125 inch) was adopted for purposes of compaiison, as it generally seems to coincide with the first marked yielding of the specimens tested. This value 0.00125 inch) is practically equivalent to 1.5 division on the dial or "dial units" used on plot (Fig. 5).

When soft metals of this type and size of test specimens are compressed they do not eventually shear but continue to flatten

[5] See footnote 2.

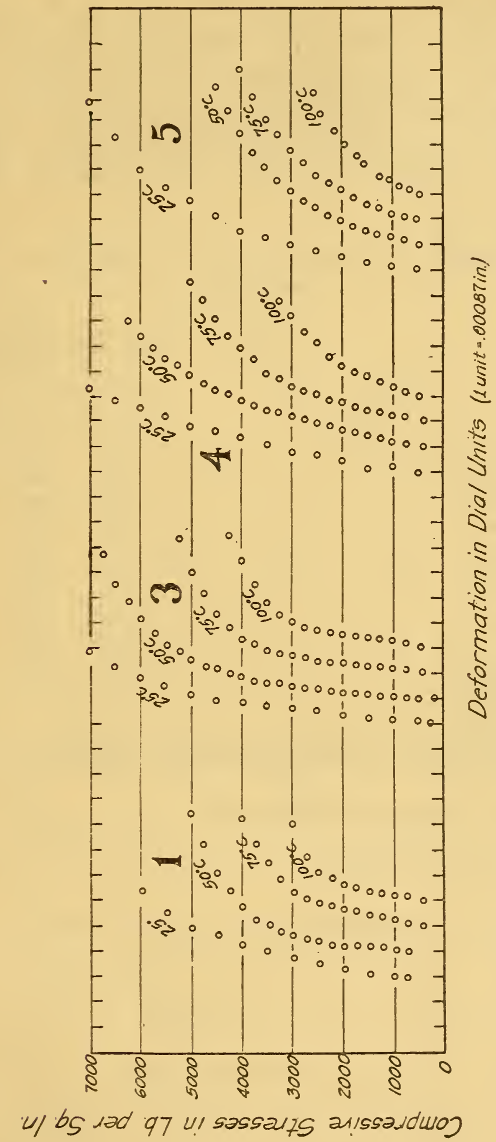

FIG. 5.—*Representative stress-strain curves of alloys Nos. 1, 3, 4, and 5 (see Table 2) at 25, 50, 75, and 100° C*

out with increasing loads, so it is necessary to adopt some arbitrary values for ultimate strength which will at least be comparable among themselves. A reduction of 25 per cent of length was chosen in this investigation as at this value in all cases the load had become nearly constant for increasing deformation. In the case of high lead alloys the load generally reached a maximum value and then fell off before the 25 per cent reduction was reached. In these cases the maximum load was recorded. The values of yield point and ultimate strength thus obtained are given in Table 4.

TABLE 4.—Yield Point and Ultimate Strength in Compression at Elevated Temperatures

Alloy No.	Property	Values in pounds per square inch at—			
		25° C	50° C	75° C	100° C
1	Yield point	4 400	3 800	3 150	2650
	Ultimate strength	12 850	10 400	8 450	6950
2	Yield point	6 250	4 850	4 000	2850
	Ultimate strength	15 175	11 850	9 400	6825
3	Yield point	5 750	5 000	4 250	3350
	Ultimate strength	16 425	12 175	10 100	7725
4	Yield point	4 700	3 650	2 900	2150
	Ultimate strength	13 685	10 035	7 845	6045
5	Yield point	3 750	2 650	2 250	1550
	Ultimate strength	15 020	11 275	7 920	4770

VII. ELEVATED TEMPERATURE BRINELL TESTS

The Brinell hardness of alloys Nos. 1, 3, 4, and 5 was determined at room temperature, 50, 75, and 100° C. The values obtained are given in Table 5.

TABLE 5.—Brinell Hardness at Elevated Temperatures

Alloy No.	Brinell hardness numeral at—			
	25° C	50° C	75° C	100° C
1	[a] 17.2 (28.6)	13.8	11.1	8.2 (12.8)
3	22.3	18.2	14.8	11.3
4	22.4	15.8	11.3	7.5
5	19.7 (19.5)	16.8	11.4	8.2 (8.6)
2	22.3 (28.3)	....	....	....

[a] A. S. T. M. specifications (see footnote 2) give the values shown in parentheses.

VIII. DISCUSSION OF RESULTS

1. COMPRESSION TESTS

For greater convenience of comparison the yield points of the four alloys are plotted against temperature in Fig. 6*b*.

As one would expect from the composition, the yield point of alloy No. 3 is considerably higher at all temperatures than the other alloys. The yield point of No. 3, however, falls off more

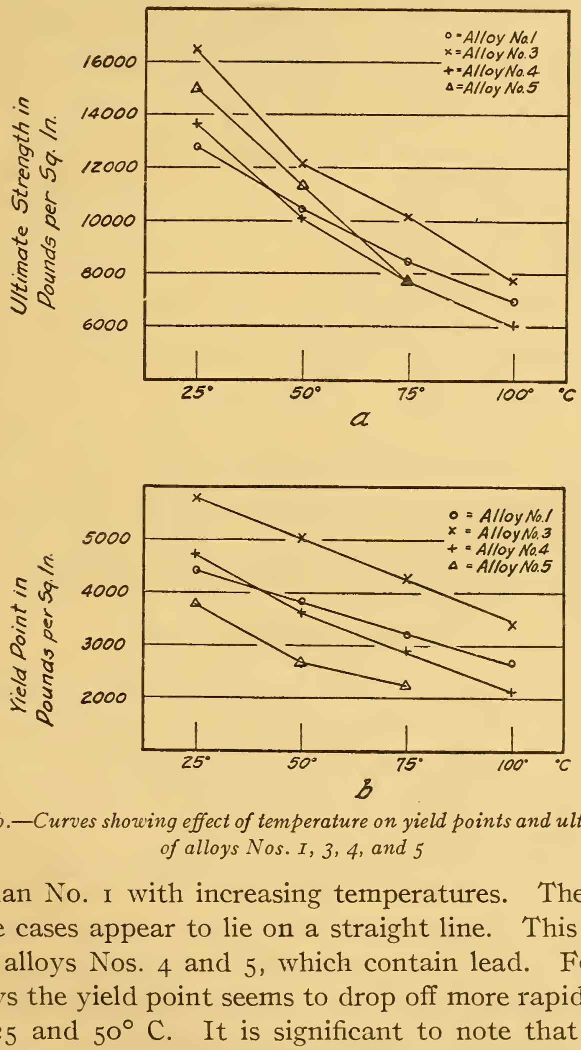

FIG. 6 *a* and *b*.—*Curves showing effect of temperature on yield points and ultimate strength of alloys Nos. 1, 3, 4, and 5*

rapidly than No. 1 with increasing temperatures. The points in both these cases appear to lie on a straight line. This is not the case with alloys Nos. 4 and 5, which contain lead. For both of these alloys the yield point seems to drop off more rapidly at first, between 25 and 50° C. It is significant to note that while the yield point of alloy No. 4 is higher than No. 1 at room temperature, it is lower at 50° C and decreases at a more rapid rate between 25 and 100° C than does No. 1, and that the yield point of tin-base alloys is higher at all temperatures above 50° C.

The yield point of alloy No. 2, curves of which are not given, is slightly higher at room temperature than that of No. 3, but at 50° C its yield point is slightly less than No. 3, and so, if the bearing heats to 50° C or over, any advantage gained by using No. 2 alloy in a bearing is lost in so far as the yield point is concerned.

There are given in Fig. 6*a* curves showing the variation of the ultimate strength with the temperature. Here, as with the yield point, alloy No. 3 has the maximum value throughout the temperature range, and alloys Nos. 1 and 3 maintain their strength better, having a higher ultimate strength at temperatures above 60° C than either alloys Nos. 4 or 5, which contain lead, even though the ultimate strength of No. 1 at room temperature is less than that of Nos. 4 or 5. The ultimate strengths of the four alloys at 100° C stand in the same relation to each other as their respective yield points.

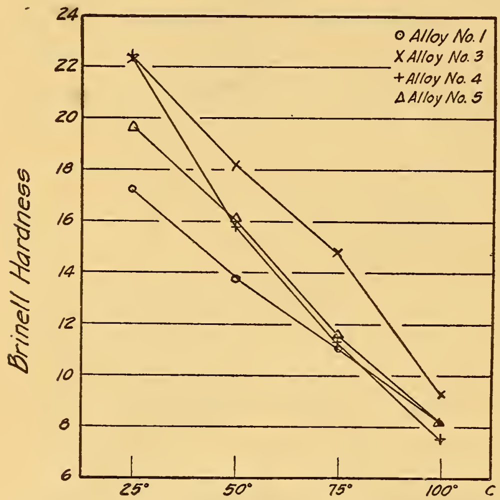

FIG. 7.—*Curves showing relation of Brinell hardness to temperature for alloys Nos. 1, 3, 4, and 5*

2. BRINELL HARDNESS TESTS

It is noted that the Brinell hardness values obtained for the tin-base alloys are considerably lower than those usually given. This difference may be due to the small percentage of impurities in the alloys used in this investigation as compared with similar alloys as ordinarily prepared.

Curves showing the variation of the Brinell hardness with temperature are given in Fig. 7. Here, again, alloy No. 3 has a maximum value throughout the temperature range. There is no evident relation between the relative magnitude of either the ultimate strength or yield point and the Brinell hardness.

The hardness of alloys Nos. 4 and 5, however, drops off very rapidly with increasing temperature, while Nos. 1 and 3 maintain their hardness, both having a greater hardness at 100° C than No. 4, and No. 1 having the same value as No. 5 at this temperature.

IX. EFFECT OF PROLONGED HEATING AT 100° C

Oftentimes a babbitted bearing which has given good service will foı no apparent reason gradually become soft and "wipe out." As a working hypothesis it was thought that this failure with age might be due to softening from prolonged heating causing an annealing action. In order to determine the validity of this tentative hypothesis, compression specimens of alloys Nos. 1, 3, 4, and 5 were heated in an oil bath for from one to six weeks at temperatures between 90 and 100° C. They were then tested at room temperature with the results given in the following table:

TABLE 6.—Effect of Prolonged Heating on the Yield Point in Compression

Days heating at 100° C	Yield points of the various alloys			
	Alloy No. 1	Alloy No. 3	Alloy No. 4	Alloy No. 5
	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²
0	4550	5750	4650	3750
7	4500	5500	....	3450
14	4600	5800	4250	3200
28	5025	5650	4750	[a] 2800
42	4900	5950	4850	3150

[a] One specimen only. All other values are the average of two specimens.

A study of the above table indicates that for alloys Nos. 1, 3, and 4, heating at 100° C for 42 days has no appreciable effect on the value of the yield point when the specimens are cast in the manner indicated. For alloy No. 5, however, there is a very evident decrease in the value of its yield point with the prolonged heating which, however, evidently takes place in the first two weeks of the heating.

X. EFFECT OF SMALL PERCENTAGES OF LEAD

The specifications for high-grade, tin-base alloys such as Nos. 1, 2, and 3 call for a low lead content generally not to exceed 0.35 per cent.

Many believe, and one investigator [6] has presented experimental evidence, that percentages of lead even up to 5 per cent are not harmful but possibly beneficial. The authors have therefore investigated the effect of small percentages of lead on the yield point and ultimate strength of No. 2 alloy at room temperature and at 75° C.

[6] Jesse L. Jones; see footnote 1.

The alloys were prepared by adding metallic lead to the No. 2 babbitt in amounts shown by the chemical analysis given, together with the yield points, in Table 7.

TABLE 7.—Effect of Lead on Compressive Strength

Percentage of lead	Yield point at—		Ultimate strength at—	
	25° C	75° C	25° C	75° C
	Lbs./in.^{2}	Lbs./in.^{2}	Lbs./in.^{2}	Lbs./in.^{2}
0.00	6150	4000	15 175	9 395
0.26	5850	3700	15 640	10 010
0.51	5750	3300	14 025	9 765
1.01	6300	....	....	....
1.25	6000	4100	16 380	10 600
5.04	5850	3850	15 330	9 725

The addition of amounts up to 5 per cent of lead to this babbitt seems to have no very appreciable effect on its mechanical properties in compression at room temperature or at 75° C under the conditions of test used. The authors think, however, that these tests should not lead to an increase in the lead content tolerance in tin-base bearing metal specifications until much more work is done along this line and particularly to determine the possible effect of small percentages of lead on the resistance to repeated impact.

XI. SUMMARY AND CONCLUSIONS

An apparatus is described for determining the yield point and ultimate strength of white metal bearing alloys at temperatures up to 100° C. A new design of heating apparatus is described for determining the Brinell hardness of metals at temperatures up to 100° C.

The results of compression tests and Brinell hardness tests at temperatures up to 100° C are given for five typical white metal bearing alloys, including three tin-base alloys, one lead-base alloy, and one intermediate alloy, which show that the tin-base alloys maintain their properties better at elevated temperatures than the lead-containing alloys.

Results of tests are given which indicate that the addition of amounts up to 5 per cent of lead in a high-grade babbitt does not affect the yield point or ultimate strength at 25 or 75° C.

The yield point of tin-base alloys is not affected by heating for six weeks at about 100° C, but the yield point is lowered in the lead-base alloy by heating for two weeks at about 100° C.

WASHINGTON, November 6, 1920.