RP442

EFFECT OF ANTIMONY ON THE MECHANICAL PROPERTIES OF A BEARING BRONZE (CU 80 : SN 10 : PB 10)

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ABSTRACT

A study of was made the effect of additions of antimony (from 0 to 0.58 per cent)upon the Brinell hardness, the structure, the Izod impact value, the deformation under pounding, and the broaching properties of a bearing bronze containing 80 per cent copper, 10 per cent tin, and 10 per cent lead.

In general, increasing the antimony content from 0 to 0.58 per cent had no effect upon the broaching properties nor upon the distribution of the lead particles throughout the copper-tin matrix. There was a slight tendency toward an increased size of the areas of the hard delta constituent with the higher antimony content. Additions of antimony lowered the Izod impact value. The deformation under pounding was markedly lowered with the first addition of antimony, reaching a minimum at 0.2 per cent antimony. Higher antimony additions tended to increase the deformation. The addition of antimony up to about 0.2 per cent slightly increased the Brinell hardness of the alloy, but further additions of antimony, up to 0.58 per cent, caused little or no further change in hardness.

CONTENTS

I. INTRODUCTION

Previous studies of bearing bronzes reported from the Bureau of Standards have described the effect of variations in composition and in casting temperatures upon the properties of bronze bearing metals.[2 3 4 5] As a continuation of this work, the present paper reports a study of the effect of small additions of antimony upon some properties of a leaded bronze containing 80 per cent copper, 10 per cent tin, and 10 per cent lead.

The main object of the present investigation was to determine the effect of small additions of antimony (below 0.5 per cent) upon the machinability of this alloy when broached. This method of machining the cylindrical bearing surfaces is widely used in finishing the bore of bearings because it is less expensive than other methods. It was pointed out by manufacturers of bearing bronzes that many of

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[2] H. J. French, S. J. Rosenberg, W. LeC. Harbaugh, and H. C. Cross, Wear and Mechanical Properties of Railroad Bearing Bronzes at Different Temperatures, B. S. Jour. Research, vol. 1 (RP13), September, 1928.

[3] H. J. French and E. M. Staples, Bearing Bronzes With and Without Additions of Zinc, B. S. Jour. Research, vol. 2, (RP68), June, 1929.

[4] E. M. Staples, R. L. Dowdell, and C. E. Eggenschwiler, Bearing Bronzes With Additions of Zinc, Phosphorus, Nickel, and Antimony, B. S. Jour. Research, vol. 5 (RP205), August, 1930.

[5] C. E. Eggenschwiler, Effect of Casting Temperatures and of Additions of Iron on Bearing Bronze (Cu 80 : Sn 10 : Pb 10), B. S. Jour. Research, vol. 8 (RP401), January, 1932.

the failures observed during the broaching of bushing bearings, failures from fracture, or from scoring, checking, tearing, or other roughening of the bore often appeared to be attributable to an undesirable antimony content.

Varied opinions have been expressed as to the effect of antimony upon copper, brass, and bronze. The consensus of opinion seems to be that antimony causes brittleness of copper alloys. St. John has described several effects of antimony on copper and copper alloys [6] and Dews has given the results of some investigations on the effect of antimony on admiralty gun metal (88–10–2).[7] The latter author pointed out that antimony present in amounts over 0.5 per cent decreases both the tensile strength and the elongation of bronzes. A recent publication of the Bureau of Standards also shows that the addition of 1 per cent antimony to bronzes reduced the Izod value considerably.[8]

Although antimony is rarely added to bronzes intentionally, it is usually present to a small extent. It probably makes its way into bronze largely through the use of secondary lead and tin which contain antimony. Zinc and copper may also contain small amounts of antimony. The antimony content of bronze obviously may be increased considerably if unserviceable and "worn out" bronze bearings carrying either lead-base or tin-base babbitt metal are used as a portion of the furnace charge.

This investigation is a continuation of the study of bearing bronzes which has been in progress for the last four years in cooperation with the Bunting Brass & Bronze Co. under the research-associate plan.[9]

II. PREPARATION OF THE CASTINGS

Cylindrical castings for the broaching test specimens and plate castings for the impact, pounding, and hardness specimens were cast, with the dimensions and with the method of gating illustrated in Figure 1. In the present work on the effect of antimony only four cylinders were cast in a flask, instead of six as has been done in previous work on bearing bronzes and as illustrated in Figure 1. These castings were of relatively thin section and approximated the average thickness of castings used for bushing bearings in the automotive industry.

The following procedure was followed in the founding of the specimens: A stock alloy of copper and tin was first prepared and poured into small ingots. The furnace charge in making this stock alloy consisted of 96 pounds of electrolytic copper and 12 pounds of refined Straits tin. The copper was melted under a slag of glass, and tin was then added. Two such heats were prepared. The chemical composition of each is given in Table 1.

TABLE 1.—*Chemical composition of the stock copper-tin alloy*

Heat No.	Copper	Tin
	Per cent	*Per cent*
1	88.90	11.15
2	88.97	11.11

[6] H. M. St. John, The Influence of Impurities in Foundry Brasses and Bronzes, Metals & Alloys, vol. 2, p. 243, 1931.
[7] H. C. Dews, Metallurgy of Bronze, Sir Isaac Pitman & Sons, N. Y., pp. 86–91, 1930.
[8] See footnote 4, p. 363 of reference.
[9] B. S. Circular No. 296.

In the preparation of the castings, between 20 and 24 pounds of the stock alloy, together with the desired amounts of copper were melted under a slag of glass. After the charge had become molten, tin and refined lead were added in calculated amounts to bring the composition to 80 per cent copper, 10 per cent tin, and 10 per cent lead. The antimony was melted with a small amount of tin and was added prior to pouring the alloy. Metallic antimony could not be added directly to the molten metal without considerable spattering. The bearing bronze alloys were prepared in a graphite crucible heated in a gas-fired furnace and were poured into sand molds. No defects were noted in any of the castings.

Copper and lead in the castings were determined by the electrolytic method, tin gravimetrically and antimony volumetrically. All chemical analyses were carried out in accordance with American Society for Testing Materials standard methods for the analysis of bearing metals.[10] The chemical compositions of the alloys are given in Table 2.

TABLE 2.—*Chemical compositions and pouring temperatures of the bronzes*

Alloy No.	Casting temperature	Chemical composition			
		Copper	Tin [1]	Lead	Antimony [1]
	°*F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
27-A-10	2, 085	80. 10	9. 80	9. 90	0. 12
27-A-1	2, 100	80. 00	9. 90	10. 10	.19
27-A-25	2, 100	79. 74	10. 00	10. 00	.26
27-A-3	2, 085	79. 95	9. 90	9. 55	.33
27-A-45	2, 090	79. 50	9. 90	10. 00	.48
27-A-5	2, 100	79. 25	10. 30	9. 88	.58

[1] Since antimony and tin were both present in the bronze samples, a deduction was made in the gravimetric determination of tin for the antimony remaining with the ignited tin oxide.

Temperature measurements were made with a chromel-alumel thermocouple and a portable potentiometer. The thermocouple was incased in a glazed porcelain tube which, in turn, was inclosed in a graphite tube. This assembly was preheated before immersing in the molten metal. Casting temperatures were determined from readings taken in the crucible immediately before pouring.

III. METHODS OF TESTING

The tests applied to the bearing bronze alloys consisted of microscopic examination, resistance to deformation under pounding, resistance of notched specimens to single-blow impact, Brinell hardness, and machinability in broaching. As the effect of antimony upon the resistance to wear[11] and upon tensile properties[12] has been previously investigated, it was unnecessary to make wear resistance and tensile tests in the present work.

The procedure used in all of the above tests, except that of machinability in broaching, has been fully described in previously published work.[13]

[10] A. S. T. M. standards, 1930, Pt. I, Metals, pp. 852–863. Standard Methods of Chemical Analysis of Bronze Bearing Metals, B46-27.
[11] See footnote 4, p. 625.
[12] See footnote 7, p. 626.
[13] See footnote 4, p. 625.

The broaching tests were included for the purpose of correlating a practical machining test with the results of the laboratory tests. The broaching tests were made in the plant machine shop by the Bunting Brass & Bronze Co.

Three of the cast cylinders (fig. 1) from each heat were used for broaching tests. The three specimens from any one heat, representing a given content of antimony, were bored before broaching in order to eliminate variations in the inside surface of the cylinder and in order to prepare specimens of three different wall thicknesses. This latter object was accomplished by boring the No. 1 specimen of each heat to an inside diameter of 1.375 inches, the No. 2 specimen to 1.625 inches, and the No. 3 specimen to 1.750 inches. The original cast outside surface remained on all specimens and the outside diameter of all cylinders for broaching was, therefore, the original cast diameter of 2.167 inches.

The broaching tools used each had four cutting edges spaced one-half inch apart along the axis of the broach. These cutting edges made an angle of 90° with the axis of the broach. The four edges of each broach cut to a total depth of 0.045 inch. All broaching was at a tool speed of 70 feet per minute.

Broaching and Brinell hardness tests were conducted at room temperature. Impact and pounding tests were conducted at both room and elevated temperatures.

IV. EFFECTS OF ANTIMONY

1. MICROSTRUCTURE

A small section was cut from each of the plate castings, polished, etched, and examined visually for any differences in grain size that might indicate differences in casting temperatures. The grain size was similar in all the alloys and no serious defects were observed in any of the castings.

Microscopic examination of the bronzes containing antimony from 0.12 to 0.58 per cent disclosed no significant differences in either the structure or the distribution and size of the lead particles. The black areas in Figure 2 (*a*) and (*b*) which shows the bronzes containing 0.12 and 0.58 per cent antimony, the extremes of the range of antimony content used, are representative of the lead distribution in all the alloys prepared.

The structures revealed by etching these same specimens are shown in Figure 2 (*c*) and (*d*). Again these micrographs are typical of all the bronze specimens of the series. The hard delta constituent is shown in relief in the copper-tin solid solution. The delta constituent particles appeared slightly larger in the alloys of higher antimony content.

No separate constituent characteristic of the presence of antimony could be detected in the microstructure of the bronzes studied. Since antimony may be in solid solution in lead to the extent of 0.25 per cent,[14] in copper to about 7 per cent,[15] and in tin to about 9 per cent,[16] it is not surprising that, within the range of antimony content studied (0.12 to 0.58 per cent) this impurity should be in solid solution in the ternary alloy of copper-tin-lead.

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[14] National Metals Handbook, 1930 ed., American Society for Steel Treating, Cleveland, Ohio, p. 716.
[15] International Critical Tables, McGraw-Hill Book Co., New York, vol. 2, p. 434, 1927.
[16] National Metals Handbook, 1930 ed., American Society for Steel Treating, Cleveland, Ohio, p. 764.

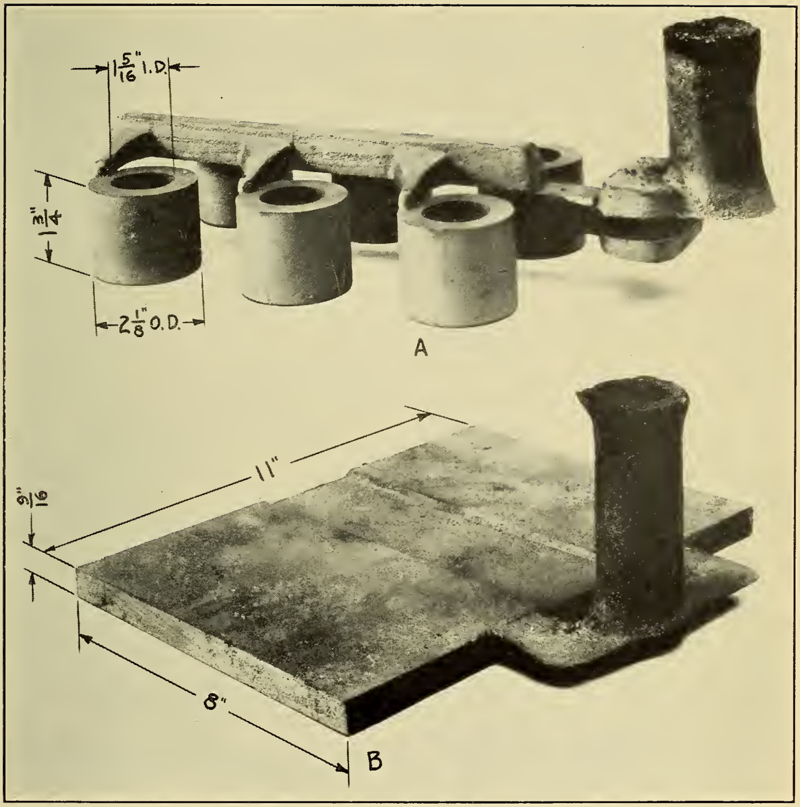

FIGURE 1.—*Test castings*

A, For broaching test specimens; *B*, for pounding, impact, and hardness tests.

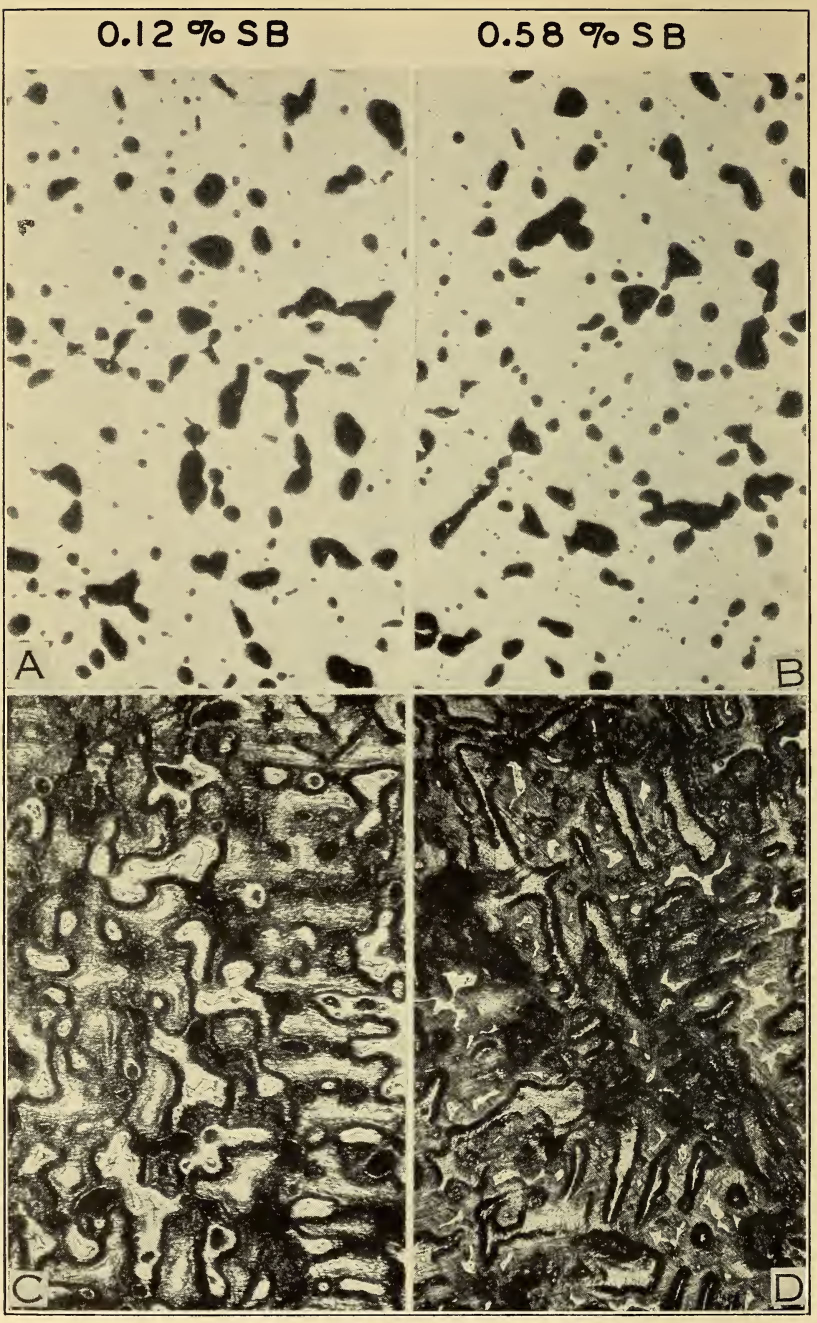

FIGURE 2.—*Distribution of the lead (A and B) and microstructure (C and D) of 80–10–10 bronze containing additions of antimony.* × *100*

C and *D*, etched with a solution of 3 parts of NH_4OH plus 1 part H_2O_2 followed by a solution of $FeCl_3$ (10 g $FeCl_3$ plus 30 ml concentrated HCl plus 120 ml H_2O).

2. RESISTANCE TO POUNDING

The results of the pounding tests at room temperature, 350° F., and 600° F. are shown in Figures 3, 4, 5, and 6. Since pounding produces work hardening of the bronze, the first application of blows resulted in a relatively higher rate of deformation, but as the number of blows increased the rate of deformation decreased rapidly.

In previous investigations of bearing bronzes either the number of blows necessary to produce 5 per cent deformation or curves similar to those of Figure 6 showing the number or the per cent deformation produced by a definite number of blows, have been used as the basis for comparison of the test results.[17] While these methods are quite adequate for comparative results, there are also given in the present

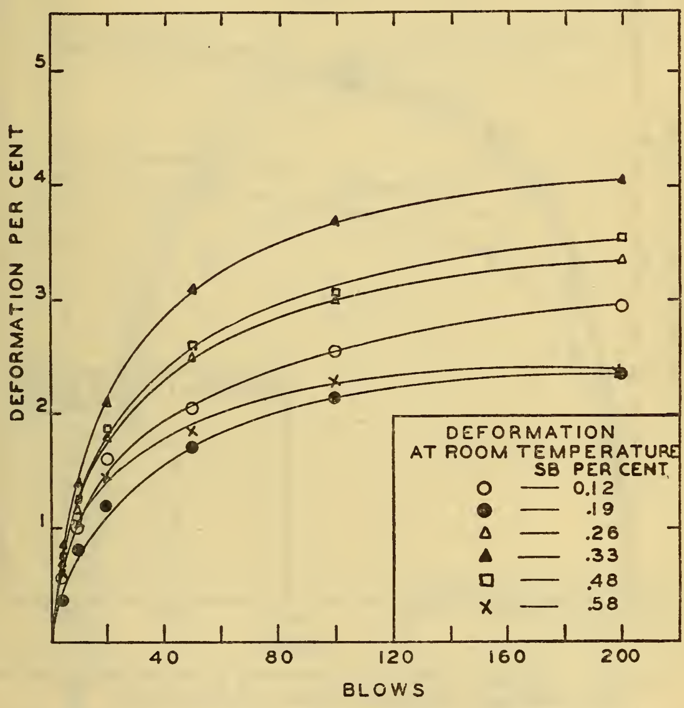

FIGURE 3.—*Effect of additions of antimony to 80–10–10 bronze on the resistance to deformation under pounding at room temperature*

report the rates of deformation of the various alloys studied. (Figs. 3, 4, and 5.) These latter figures give an approximate idea of the amount of deformation these alloys may undergo in service unless, as a part of the manufacturing process, they have been work hardened by plastic deformation. It will be observed that increasing the temperature of the specimen very noticeably increased the rate of deformation in the beginning of the test.

The data given in Figures 3, 4, and 5 are summarized in Figure 6. The alloys containing 0.2 and 0.6 per cent antimony deformed the least. There was a marked tendency for the alloys to show increased deformation when the antimony content increased from about 0.20

[17] See footnotes 2, 3, and 4, p. 625.

to about 0.40 per cent. It is noteworthy that the alloys containing no additions of antimony suffered a greater deformation at a given temperature than any of the bronzes containing antimony.

3. IMPACT VALUE

Previous work [18] has shown that additions of 1 per cent antimony to a number of bearing bronzes produced a quite noticeable decrease in the resistance to impact.

Figure 7 shows the effects of antimony upon the resistance to impact. Tests at room temperature and 350° F. indicated that antimony additions up to 0.25 per cent caused a marked decrease in the

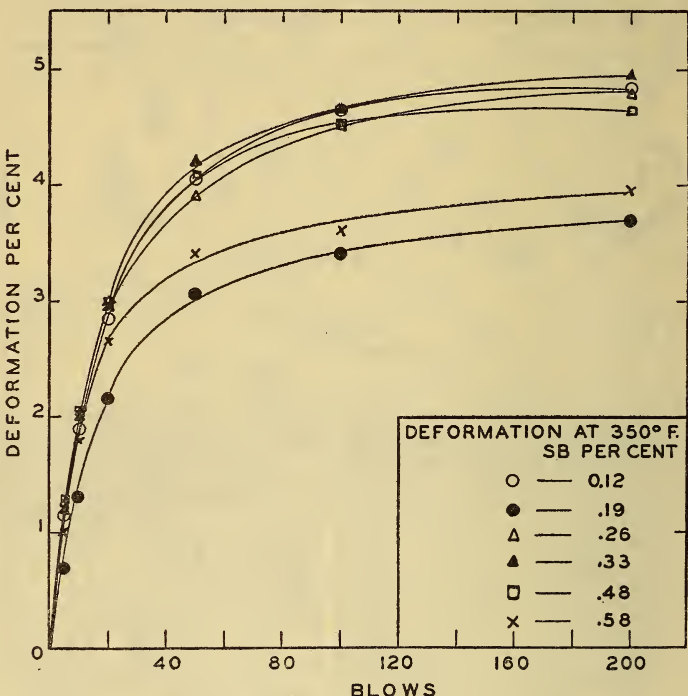

FIGURE 4.—*Effect of additions of antimony to 80–10–10 bronze on the resistance to deformation under pounding at 350° F.*

resistance to impact. The impact value decreased less rapidly with larger proportions of antimony in the alloy. At 600° F. very little effect on the impact resistance was observed as the antimony content was increased.

The effect of increasing the temperature from room temperature to 350° F. was a relatively small decrease in the resistance to impact, but increasing the temperature to 600° F., resulted in a very marked lowering of the impact resistance.

4. BROACHING PROPERTIES

The results obtained in the broaching tests, given in Table 3, indicated that all the specimens behaved satisfactorily in the broaching tests described in a preceding section of this report.

[18] See footnote 4, p. 363 of reference.

As a more searching test of the possible effect of the antimony present, an additional broaching operation was conducted. Specimens previously broached in test No. 1, that is, having the original "as cast" outside diameter of 2.167 inches and an inside diameter of 1.465 inches, were machined to an outside diameter of 1.875 inches and an inside diameter of 1.625 inches, thus leaving a wall thickness

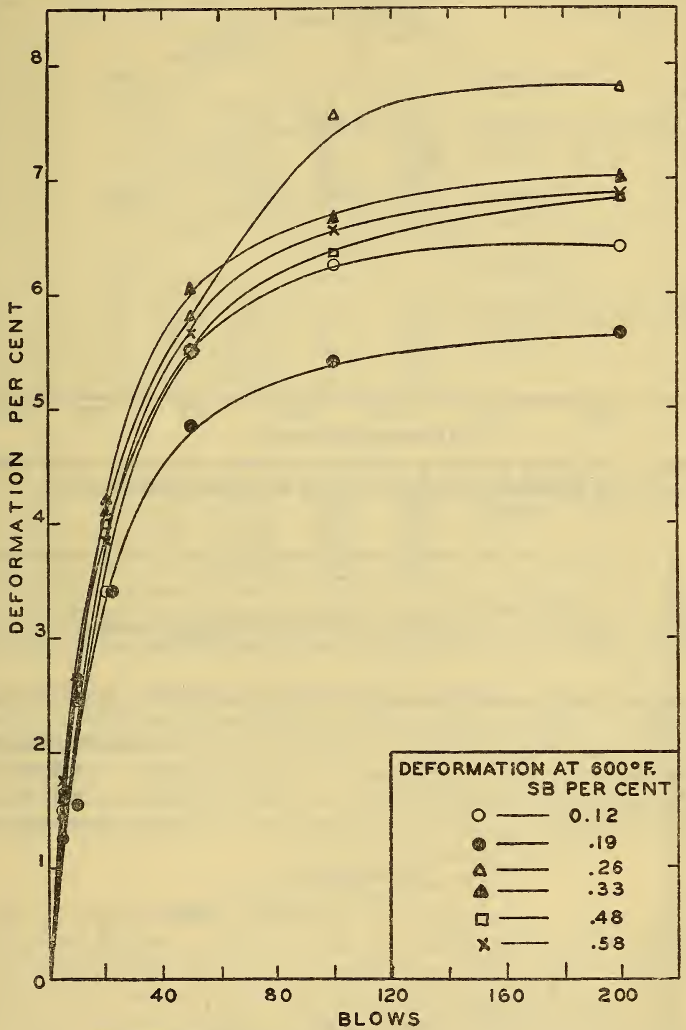

Figure 5.—*Effect of additions of antimony to 80–10–10 bronze on the resistance to deformation under pounding at 600° F.*

of 0.125 inch. They were then broached in the manner previously described. After this operation the outside surfaces of all specimens showed marked fracturing at the grain boundaries and the broached cylinders emitted a dull sound when tapped with a metal rod. There was no apparent difference in behavior under this test between the low antimony and the high antimony alloys.

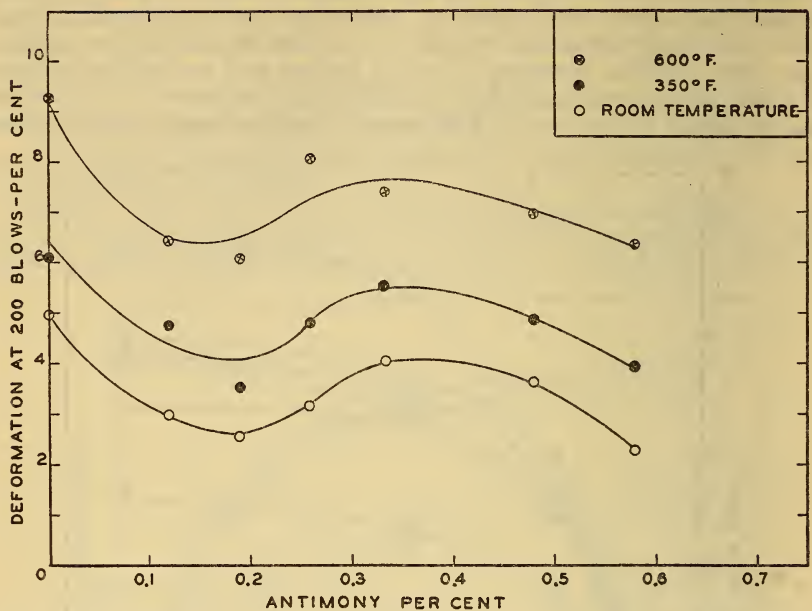

FIGURE 6.—*Effect of antimony additions to 80–10–10 bronze on the resistance to deformation under pounding at various temperatures*

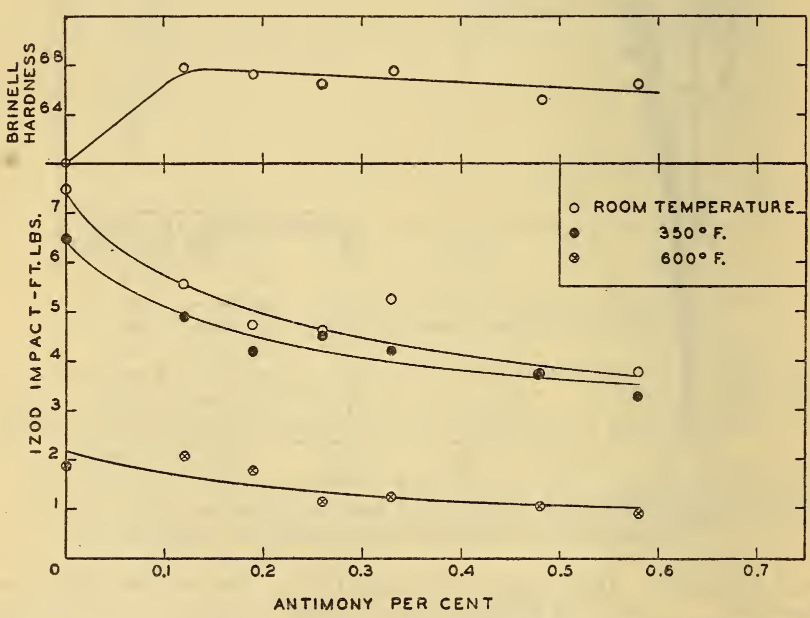

FIGURE 7.—*Brinell hardness and Izod impact tests at various temperatures on 80–10–10 bronze containing additions of antimony*

TABLE 3.—*Broaching tests of cylindrical bronze castings containing antimony*

[Depth of broaching throughout, 0.045 inch. Rough outside (as cast) diameter of all specimens, 2.167 inches]

TEST NO. 1

Alloy No.	Specimen No.	Antimony [1]	Inside diameter as machined preliminary to broaching	Wall thickness	Inside diameter after broaching	Remarks
		Per cent	*Inches*	*Inch*	*Inches*	
27-A-10	1	0.13	1.375	0.396	1.465	Fractures, none; scoring, none; checking, none; tearing, none; bore, smooth.
27-A-1	1	.18	1.375	.396	1.465	
27-A-25	1	.23	1.375	.396	1.465	
27-A-3	1	.28	1.375	.396	1.465	
27-A-45	1	.40	1.375	.396	1.465	
27-A-5	1	.53	1.375	.396	1.465	

TEST NO. 2

Alloy No.	Specimen No.	Antimony [1]	Inside diameter as machined preliminary to broaching	Wall thickness	Inside diameter after broaching	Remarks
27-A-10	2	0.13	1.625	0.271	1.715	Fractures, none; scoring, none; checking, none; tearing, none; bore, smooth.
27-A-1	2	.18	1.625	.271	1.715	
27-A-25	2	.23	1.625	.271	1.715	
27-A-3	2	.28	1.625	.271	1.715	
27-A-45	2	.40	1.625	.271	1.715	
27-A-5	2	.53	1.625	.271	1.715	

TEST NO. 3

Alloy No.	Specimen No.	Antimony [1]	Inside diameter as machined preliminary to broaching	Wall thickness	Inside diameter after broaching	Remarks
27-A-10	3	0.13	1.750	0.2085	1.840	Fractures, none; scoring, none; checking, none; tearing, none; bore, smooth.
27-A-1	3	.18	1.750	.2085	1.840	
27-A-25	3	.23	1.750	.2085	1.840	
27-A-3	3	.28	1.750	.2085	1.840	
27-A-45	3	.40	1.750	.2085	1.840	
27-A-5	3	.53	1.750	.2085	1.840	

[1] Analyses made by L. M. Long, of the Bunting Brass & Bronze Co. The antimony contents of these specimens differ slightly from those given in Table 2 due to the fact that the cylinders for broaching tests were from different castings than the specimens used for all other tests.

The broaching qualities of the bronzes, therefore, were not adversely affected by additions of antimony up to 0.53 per cent. It should be pointed out, however, that antimony was the only minor element or impurity added to these bronzes. If antimony does affect the broaching qualities of commercial bronzes it would appear that this influence may be dependent on the simultaneous presence of other impurities.

5. HARDNESS

It was found in some previous investigations [19] that antimony increased the hardness of bronze alloys. Most of these investigations indicated that while there is a hardening effect, this effect is not progressive with increasing additions of antimony.[20]

According to the results of the present investigation, given in Figure 7, the presence of 0.1 per cent antimony was sufficient to cause a perceptible increase in the Brinell hardness. However, larger amounts of antimony, up to 0.58 per cent, had slight effect upon the hardness at room temperature.

[19] See footnote 4, p. 363 of reference.

[20] See footnote 7, p. 89 of reference.

V. SUMMARY AND CONCLUSIONS

A study has been made of the effect of antimony (up to 0.58 per cent) on the deformation under pounding, the Izod impact value, microstructure, hardness, and broaching properties of a bearing bronze containing 80 per cent copper, 10 per cent tin, and 10 per cent lead. In addition to the tests made at room temperature, many tests were made at 350° and 600° F.

Increasing the antimony content decreased the Izod impact value; had no effect upon the size or distribution of lead particles in the structure of the bronze; produced a slight increase in the size of the hard (delta) constituent; had no effect upon the machinability under broaching; and decreased the deformation under pounding when the antimony content was present to the extent of 0.2 or 0.58 per cent. The Brinell hardness of the alloys was slightly increased by the addition of 0.2 per cent antimony; further additions of antimony produced no signficant change in hardness.

It may be concluded that the effect of additions of small amounts of antimony was seriously detrimental only to the notch toughness of the bronzes studied. It is to be kept in mind, however, that the above conclusions are applicable only to the type of test specimens and test castings employed, and to bronzes which do not contain, in addition to antimony, the other impurities usually present in similar commercial bronzes.

VI. ACKNOWLEDGMENTS

The author expresses his appreciation to L. M. Long and other members of the Bunting Brass & Bronze Co., for their cooperation in conducting the broaching tests and for their helpful comments and suggestions.

Acknowledgment is also made to Louis Jordan, for his supervision.

WASHINGTON, March 5, 1932.