RP401

EFFECT OF CASTING TEMPERATURES AND OF ADDITIONS OF IRON ON BEARING BRONZE (Cu 80:Sn 10:Pb 10)

By C. E. Eggenschwiler [1]

ABSTRACT

A study was made of the effect of different casting temperatures (1,850° to 2,120° F.) and of additions of iron (from 0 to 1.0 per cent) upon the hardness, the structure, and resistance to wear, to pounding, and to single-blow impact of a bearing bronze containing 80 per cent copper, 10 per cent tin, and 10 per cent lead.

In general, increasing the casting temperature from 1,850° to 2,120° F. increased the resistance to wear, increased the grain size with only a slight effect on the distribution of the lead, and slightly decreased the Brinell hardness. The resistance to pounding was increased within the casting range of 1,900° to 2,000° F. and the notch toughness decreased on the bronzes cast close to 2,000° F.

Additions of iron exceeding 0.3 per cent proved detrimental. Smaller additions of iron decreased the resistance to wear and increased the Rockwell and Brinell hardness. Additions of iron up to 1.0 per cent increased the resistance to pounding. Increasing the iron content above 0.3 per cent produced segregation of the lead particles, decreased the grain size, and decreased the notch toughness

CONTENTS

I. INTRODUCTION

The effects of varying compositions upon the properties of bronze bearing metals have been previously reported from the Bureau of Standards in three papers.[2] [3] [4] As a continuation of this work, the

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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. Reasearch, vol. 1 (RP13); 1928.

[3] E. M. Staples, and H. J. French, Bearing Bronzes with and without Zinc, B. S. Jour. Research vol. 2 (RP68); 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): 1930.

present paper reports the effects of variations in casting temperature and of the addition of varying amounts of iron upon the properties of an 80–10–10 bearing bronze (80 per cent copper, 10 per cent tin, and 10 per cent lead). This particular alloy was chosen for study because it has been used for many years as an all-round general bearing bronze. The fact that the tin content of this alloy is close to the eutectoid composition of tin in copper (12.5 to 13.0 per cent), that the lead content is sufficient for ample study of its distribution throughout the copper-tin matrix, and that the alloy presents no hazards in founding and machining, made this alloy an excellent one for the proposed experiments.

It is the general opinion that iron has a deleterious effect upon bearing bronzes and especially upon leaded bronzes.[5] Since the use of virgin metals is not economical, small amounts of iron are almost always found in the finished casting. This minor constituent of bronze makes its way into the metal through the use of iron or steel stirrers, contaminated machine-shop products, and through the reclamation of unserviceable and "worn out" bronze bearings.

In the founding of brass and bronze, it is seldom possible to pour all castings at the same temperature. It has been shown by Carpenter and Elam,[6] Karr,[7] and Rowe [8] that variations in the casting conditions may appreciably affect the properties of the bronze or brass.

This investigation forms one phase of the study of bearing bronzes which has been in progress for the last three years in cooperation with the Bunting Brass & Bronze Co. on the research associate plan.[9]

II. PREPARATION OF THE CASTINGS

Two sets of test castings were prepared for study, only virgin copper, tin, and lead being used. The first set of castings was poured at different temperatures into test castings. The second set of castings, which was poured at a constant temperature, contained additions of iron up to 1 per cent. The chemical composition of the various test castings and the casting temperatures employed are given in Table 1.

In order to approximate the structure and the properties of the bushing bearings generally used in the automotive and allied industries, the test castings were of relatively thin section. Castings for wear-test specimens were hollow cylinders, while those used for impact, pounding, and hardness tests were in the form of plates as described in previous papers.[10] The method of casting and gating employed was typical of that used in brass and bronze foundries at the present time.

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[5] S. L. Hoyt, Metallography: Part II. The Metals and Common Alloys, p. 125. McGraw-Hill Book Co.

[6] H. C. H. Carpenter and Miss C. F. Elam, Causes of Unsound Castings of Admiralty Bronze, J. Inst. Met., vol. 19, p. 155; 1918.

[7] C. P. Karr, Standard Test Specimens of Zinc Bronze, B. S. Tech. Paper No. 59; 1916.

[8] F. W. Rowe, The Effect of Casting Temperature on the Physical Properties of a Sand-Cast Zinc Bronze, J. Inst. Met., vol. 31, p. 217; 1924.

[9] B. S. Circular No. 296.

[10] See footnotes 3 and 4, p. 67.

TABLE 1.—*Chemical compositions and pouring temperatures of the bronzes studied*

Alloy No.	Casting temperature	Chemical composition				Alloy No.	Casting temperature	Chemical composition			
		Copper	Tin	Lead	Iron			Copper	Tin	Lead	Iron
	°*F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		°*F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
5	1,850	81.4	10.2	8.5	---------	50	2,000	79.9	9.9	10.1	0.01
2	1,920	81.3	9.3	9.4	---------	80	2,000	80.0	9.3	10.4	.10
1	2,000	78.4	9.5	12.1	---------	60	2,000	79.8	9.7	10.1	.31
3	2,040	81.5	8.8	9.7	---------	70	2,000	79.7	10.0	9.8	.51
4	2,120	81.4	8.8	9.7	---------	40	2,000	78.9	9.9	10.1	1.02

NOTE.—These analyses were made by L. M. Long, plant metallurgist, at the chemical laboratory of the Bunting Brass & Bronze Co., Toledo, Ohio.

Separate melts were made for each casting temperature and for each test casting containing an addition of iron. The weight of the metal in each heat was 35.5 pounds, consisting of 28.5 pounds of copper, 3.5 pounds of tin, and 3.5 pounds of lead. All melting was done in a gas-fired crucible furnace.

The casting procedure was as follows: The copper (and iron, when this element was added) was melted under a slag of glass and a mixture of sodium carbonate and borax. The tin and lead were added after the charge had become molten and some of the slag was then removed. After a short reheating period, the melt was removed from the furnace, skimmed free of slag, stirred, and cast into sand molds equipped with core strainers in the pouring gates. The iron additions consisted of very thin, cleaned iron strips and small iron brads. Due to some of the iron brads becoming entangled in the glass slag during melting, the iron content was always slightly lower than that anticipated.

In the process of casting, it was noted that as the temperature of the melt was lowered to about 1,850° F. the metal became sluggish and some difficulty was experienced in obtaining a complete set of test castings. No difficulty was experienced in pouring the test castings at 2,000° F. However, examination of the wear-test castings containing 0.5 and 1.0 per cent of iron, after removal from the sand molds, showed that these castings should have been poured at a higher temperature as a few cold shuts were observed.

The casting temperature measurements were made with a chromel-alumel thermocouple and a portable potentiometer. The chromel-alumel thermocouple was incased in a glazed porcelain tube which, in turn, was inclosed in a graphite tube. Readings were taken in the crucible immediately before pouring.

III. TEST METHODS

It was not the purpose of the present investigation or of the methods of test employed to parallel ideal conditions of bearing service, but rather to show what may be expected when design and lubrication are at fault. The character of the bearing metal is of vital importance when good service conditions begin to fail.

With only one exception, the methods of test employed in this investigation were similar to those described in previously reported bearing bronze studies[11] and the reader is referred to these studies

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[11] See footnotes 2, 3, and 4, p. 67.

for complete information on the testing apparatus, test castings, and test specimens.

In addition to the method of wear testing previously described,[11] wear tests were also made on the Amsler machine under low loads in the presence of kerosene. In these "wet" wear tests a stream of kerosene was allowed to flow between the steel and the bronze test specimen. The kerosene prevented surface films from forming by keeping the specimens cool and washing away any small particles of material produced by the abrasion of the wearing surfaces. By means of suitably calibrated springs the pressure between the wear test specimens could be varied to give any desired value. The apparatus equipped for wear testing in the presence of kerosene and its description is given in Figure 1.

All of the "dry" wear tests were made under a load of 37.5 pounds (the dead weight of the head of the Amsler machine) corresponding to a maximum pressure of 31,000 lbs./in.^{2} as calculated by Hertz's theory. It should be noted that Hertz's theory becomes inaccurate as soon as the material is stressed beyond the proportional limit. The actual stresses would be considerably smaller. In all of the wear tests the bronze specimen was mounted on the lower spindle of the machine. The "wet" wear tests were made under loads of 5 and 10 pounds, corresponding to maximum pressures of 10,000 and 12,000 lbs./in.^{2}. Since the value of the proportional limit of 80–10–10 bronze as usually determined is slightly higher than 12,000 lbs./in.^{2}, the stresses induced in the bronzes during the "wet" wear tests did not exceed the proportional limit.

The other tests made were Rockwell and Brinell hardness, pounding, and Izod impact (single blow). These tests were made at room temperature, 350° and 600° F.

IV. RESULTS AND DISCUSSION

1. EFFECT OF CASTING TEMPERATURE

The effect of casting temperature on thin-walled castings is more noticeable than on thick-walled castings. The casting temperature of large castings containing appreciable amounts of lead should be low enough to produce rapid cooling of the metal and so entangle the lead before it has an opportunity to settle out or segregate. The quick freezing of leaded bronzes does not necessarily offer a solution for lead sweating, but there will be less lead sweat with low pouring temperatures. It is to be expected and has been previously confirmed by investigators that the rate of cooling as well as the type of mold used will have an appreciable effect upon the properties of the finished casting.[12] [13]

(a) STRUCTURE

Visual examination of the etched specimens without magnification showed a grain size which increased as the casting temperature increased. Specimens cast at 1,850° F. had a fine grain size while specimens cast at 2,120° F. had a coarse columnar grain.

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[11] See footnotes 2, 3, and 4, p. 67.

[12] H. C. Dews, The Effect of Casting Temperatures on the Physical Properties of Nonferrous Alloys, Met. Ind., London, vol. 25, Nov. 21, 1924, p. 498.

[13] J. W. Bolton and J. A. Weigland, Incipient Shrinkage in Some Nonferrous Alloys, Tech. Publ. No. 163, A. I. M. M. E., 1929.

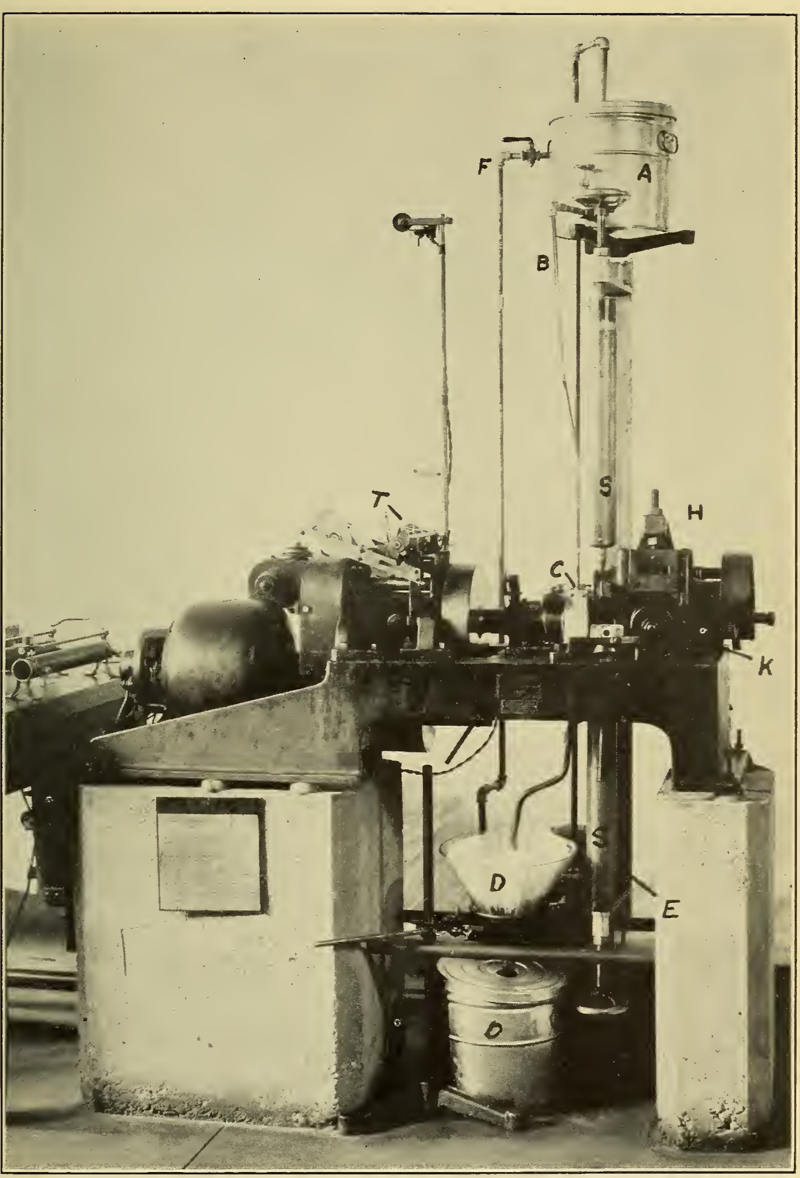

Figure 1.—*Amsler machine adapted to the determination of resistance to wear in the presence of kerosene*

C, Specimens; *T*, friction dynamometer; *S′*, equalizing spring to offset weight of head *H*; *S*, calibrated spring for adjusting pressures between test specimens; *D*, filter and reservior for reclaiming kerosene; *E*, pump for transmitting reclaimed kerosene back to reservoir *A* through pipe *E*; *F*, overflow pipe for maintaining a constant head of kerosene in *A*.

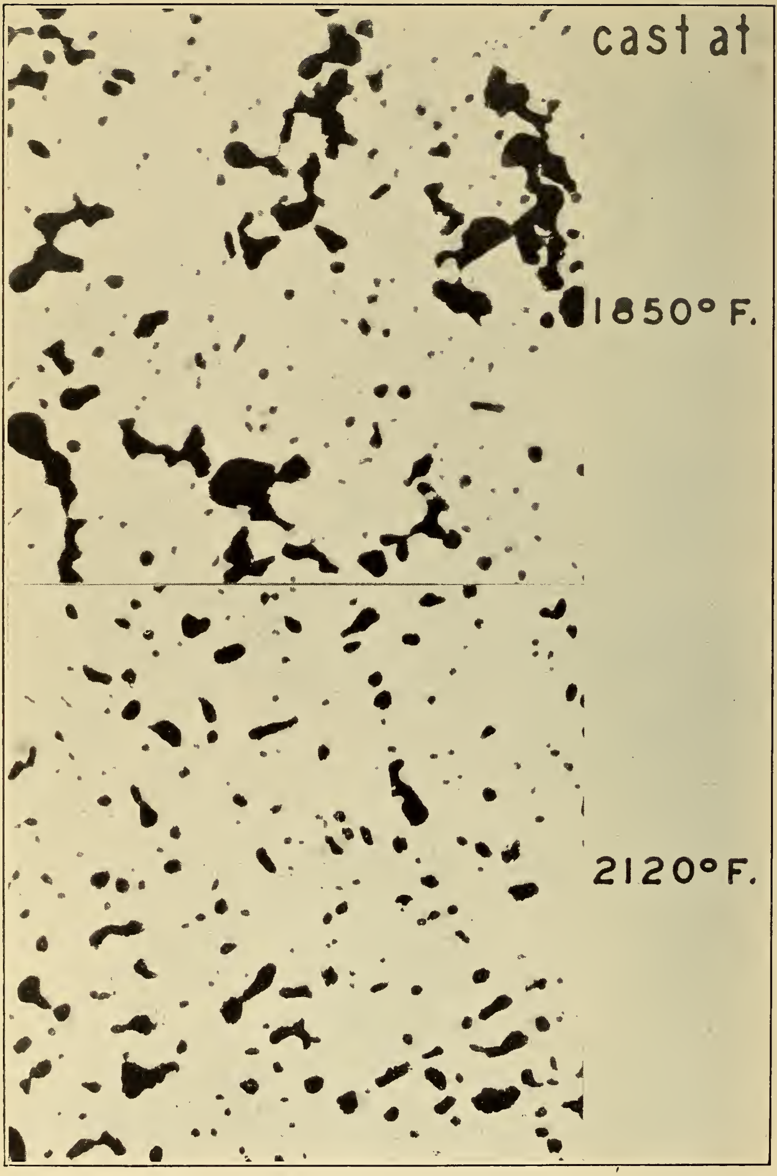

FIGURE 2.—*Distribution of lead in 80–10–10 bronze cast at various casting temperatures. Not etched.* × *100*

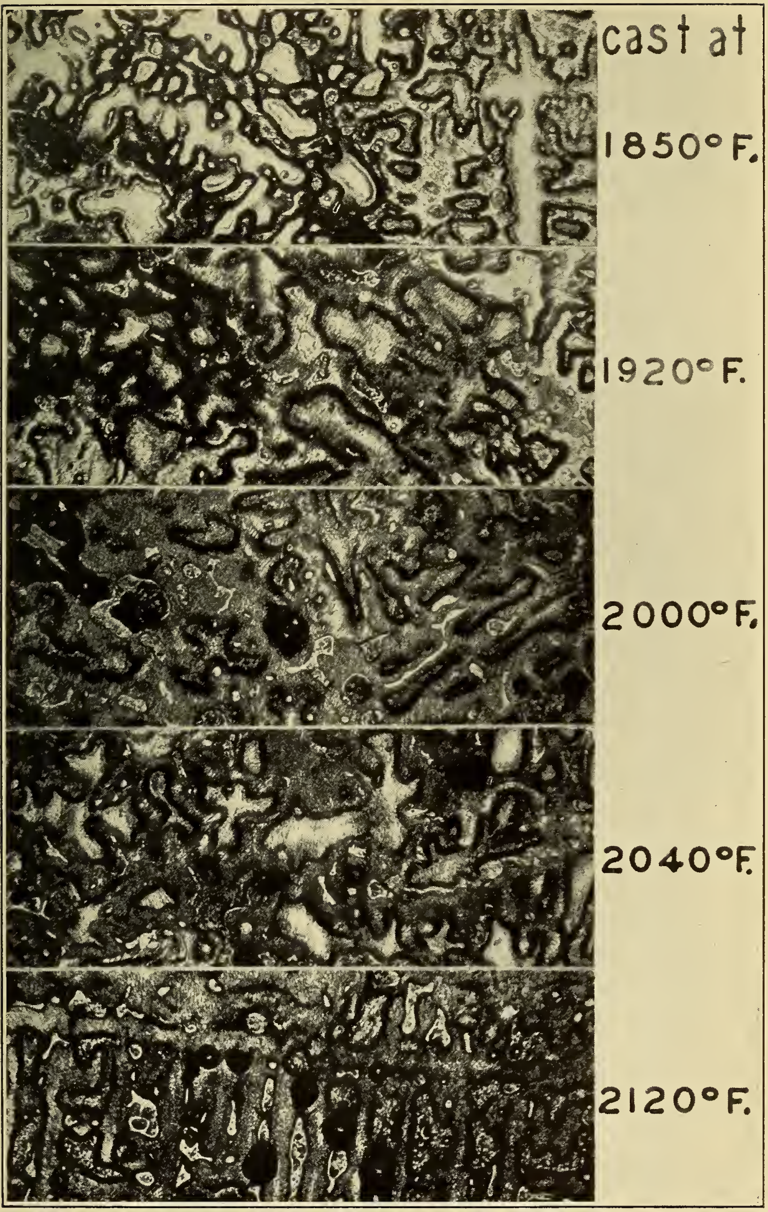

FIGURE 3.—*Microstructure of 80–10–10 bronze cast at various temperatures. × 100*

Etched with solution of 3 parts of NH_4OH plus 1 part H_2O_2 followed by solution of $FeCl_3$ in HCl (10 g $FeCl_3$ plus 30 ml concentrated HCl plus 120 ml H_2O)

The effect of casting temperatures upon the lead distribution and structure of the bronzes studied is shown in Figures 2 and 3.

No marked differences in the distribution of the lead particles (the black areas in fig. 2) were noticed in specimens cast between 1,850° and 2,040° F. In the specimens cast at 2,120° F., the lead particles were quite uniformly distributed and of rather smaller size.

The etched structures of the bronzes cast at different temperatures (fig. 3) are typical of a copper-tin-lead alloy. The hard delta constituent is shown in relief in the copper-tin-solid solution matrix. Practically no difference can be seen on the etched structures of the bronzes cast at different temperatures.

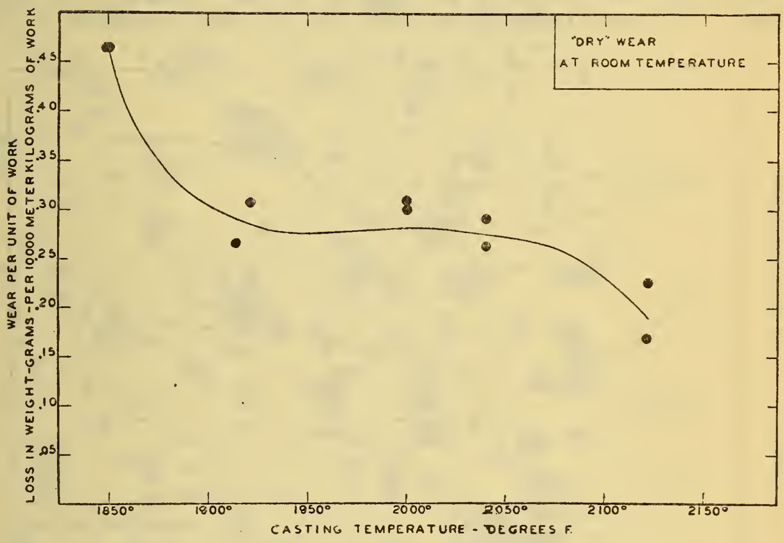

Figure 4.—*Effect of casting temperature on the wear resistance of 80–10–10 bronze*

(b) RESISTANCE TO WEAR

In studying the resistance to wear of the bronzes cast at various temperatures, the specimens were run "dry" on the Amsler wear-testing machine. Tests were conducted at room temperature and at 350° F. Because of the difficulties caused by film formation in the tests made at 350° F., none of the results of these tests are given. Figure 4 gives the results obtained at room temperature. It will be noted from this figure that the bronze cast at a low temperature (1,850° F.) shows a high rate of wear. Intermediate casting temperatures gave somewhat lower rates of wear while the highest casting temperature (2,120° F.) resulted in a marked decrease in the rate of wear. In general, it may be said that the rate of wear per unit of work decreased with higher casting temperatures. The preceding statement is in keeping with results previously obtained on the rate of wear per unit of work of sand-cast and chill-cast specimens, which showed that the rate of wear increased with decreased grain size.[14]

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[14] See footnote 2, p. 417 of Research Paper No. 13 (vol. 1); 1928.

(c) RESISTANCE TO POUNDING

The effect of casting temperature on the resistance to deformation under pounding is shown in Figure 5. Tests made at room temperature, 350°, and 600° F. indicated that the bronze specimens cast at 1,920° F. deformed the least.

(d) RESISTANCE TO SINGLE-BLOW IMPACT

In Figure 6 are given the results of Izod impact tests on bronzes cast at different temperatures. At all test temperatures (room temperature, 350°, and 600° F.) the test specimens representing the highest casting temperature (2,120° F.) has the greatest resistance to Izod impact. At room temperature and 350° F. the toughness of the test specimens decreased with increasing casting temperatures up to 2,000° F. An increase in the casting temperature above this point resulted in a rapid increase in the Izod impact resistance. In the tests made at 600° F., the impact resistance increased gradually with increasingly high casting temperatures. The effect of the temperature of test upon the notch toughness was very noticeable. A test temperature of 350° F. resulted in a comparatively small lowering of the impact resistance while a test temperature of 600° F. lowered the impact resistance to a small fraction of its value at room temperature.

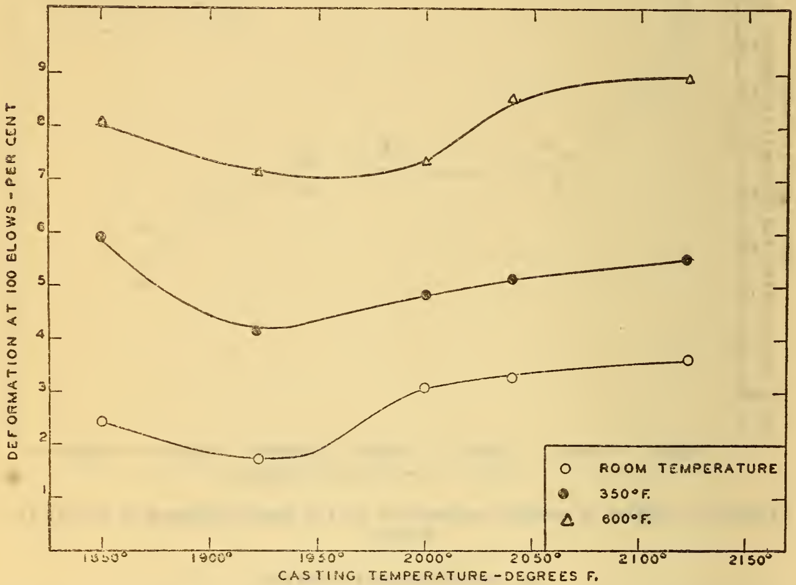

FIGURE 5.—*Effect of casting temperature on the resistance to deformation under pounding at various temperatures on 80–10–10 bronze*

(e) HARDNESS

The effect of casting temperatures on the Brinell hardness of the bronzes studied was slight. Figure 6 shows that increasing the casting temperature resulted in only a slight lowering of the hardness.

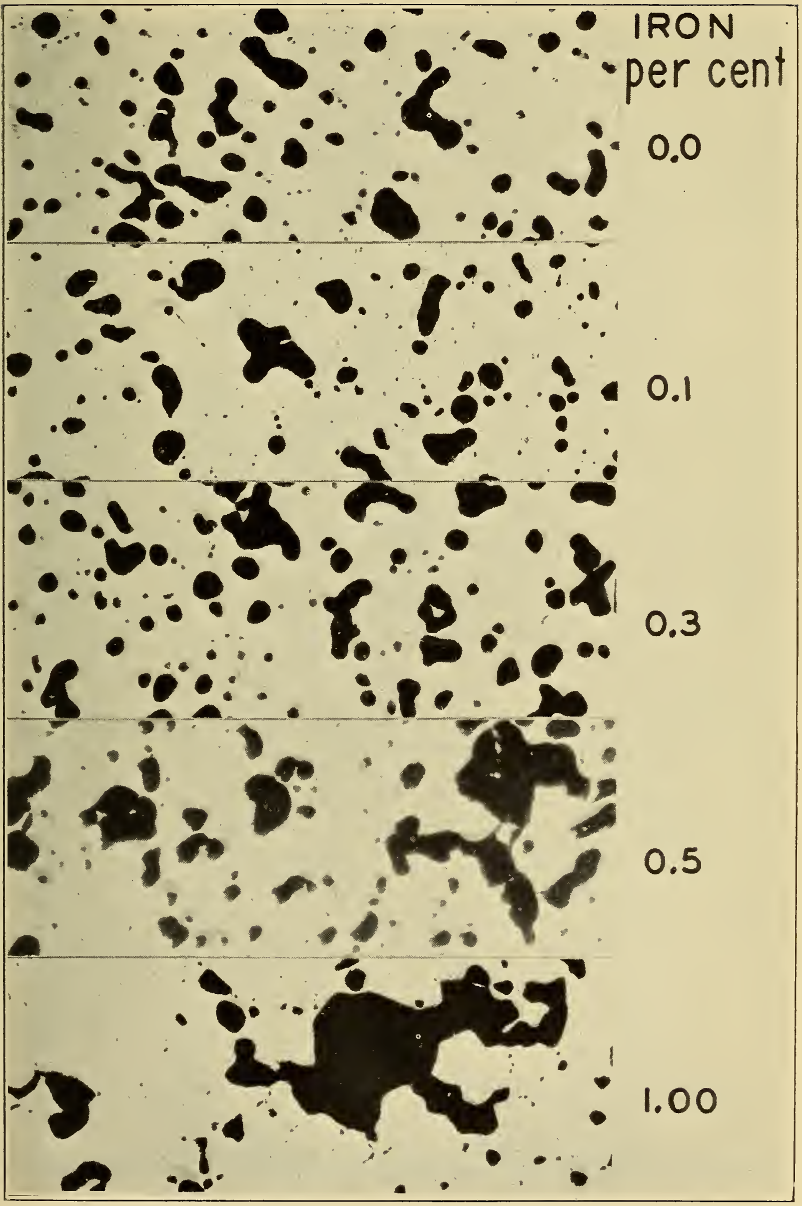

Figure 7.—*Distribution of lead in 80–10–10 bronze containing additions of iron. Not etched.* × *100*

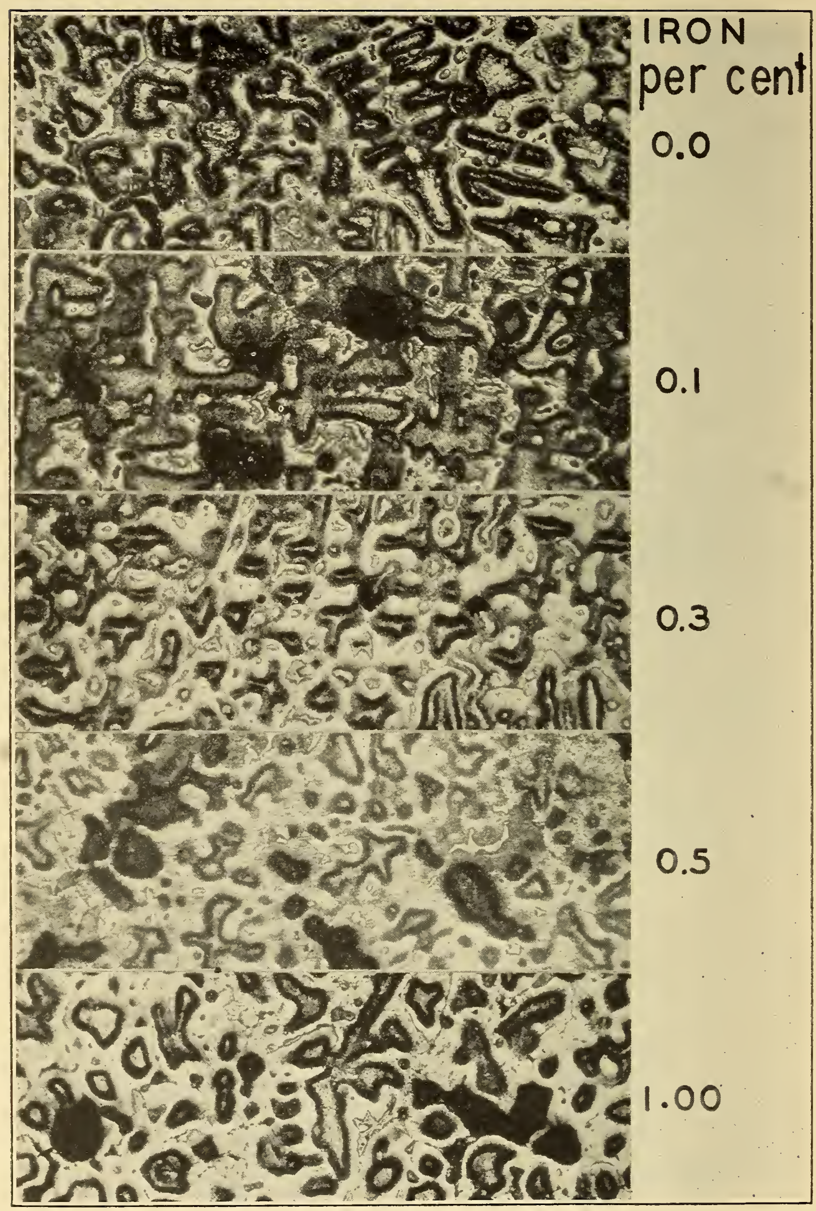

FIGURE 8.—*Microstructure of 80–10–10 bronze with iron additions.* × *100*

Etched with solution of 3 parts NH_4OH plus 1 part H_2O_2 followed by solution of $FeCl_3$ in HCl (10 g $FeCl_3$ plus 30 ml concentrated HCl plus 120 ml H_2O).

2. EFFECT OF ADDITIONS OF IRON

The addition of iron to brass and bronze is considered with favor by some and with equal disfavor by others with the result that many opinions have been expressed on the subject. It has been rather clearly shown by various investigators that additions of iron to brass produce greater hardness, tensile strength, and toughness.[15] [16] [17] [18] The addition of iron to bronze is not considered so favorably. According to Hoyt [15] and Evans,[16] iron may be present up to 0.3 or 0.4 per cent in solid solution and not materially affect the mechanical properties. Hoyt reports that additions of iron above 0.3 per cent render gun metal brittle, but increase the hardness and tensile strength. Iron is also added to copper-lead bearing alloys to prevent the liquation of the lead.[15] Carbon-free iron additions do not produce the undesirable results in brass and bronze that are attributed to iron additions in the form of steel. This is believed to be due to the ease with which practically pure iron is taken into solution as compared with the difficulty of bringing about complete solution of the steel in molten brass and bronze. [19]

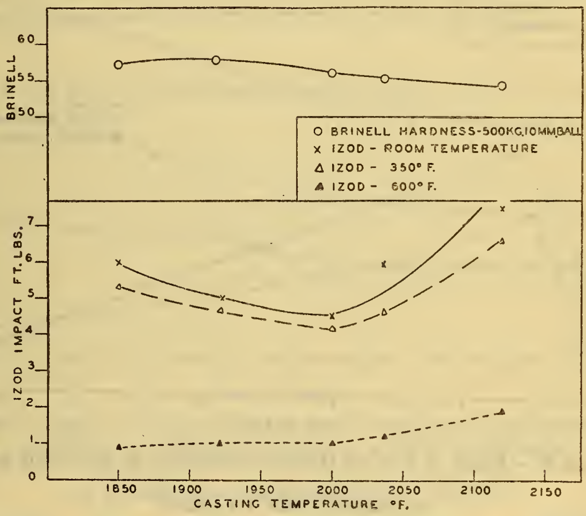

FIGURE 6.—*Results of Brinell hardness and single-blow impact tests at various temperatures on 80–10–10 bronze cast at different casting temperatures*

(a) STRUCTURE

Visual examination of the polished and etched bronze specimens revealed that the grain structure was normal and typical of sand-cast bronze in the specimens containing up to 0.3 per cent iron. The grain size was slightly larger in the specimens containing 0.1 and 0.3 per cent iron than in the iron-free bronze. The specimens containing 0.5

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[15] S. L. Hoyt, Metallurgy. Part III. The Metals and Common Alloys, pp. 123, 125, 128. McGraw-Hill Book Co.; 1921.

[16] U. R. Evans, Metals and Metallic Compounds, (book) Longman, Green & Co., N. Y., vol. 4, p. 61; 1923.

[17] O. Smalley, Effect of Iron on Brass, Met. Ind., vol. 17, p 421; 1920.

[18] F. Johnson and R. E. Rednell, Iron in Brass, Met. Ind., vol. 18, pp. 101–125; 1921.

[19] See footnote 16.

and 1.0 per cent iron had a considerably smaller grain size. The grain size of the bronze containing 1.0 per cent iron was so small that it could not be detected without the aid of the microscope. The presence of free iron in the bronze specimens was not detected under the microscope.

Representative sections of the specimens containing additions of iron are shown in Figures 7 and 8. Microscopic examination of the polished and unetched specimens (fig. 7) showed little difference in the structures of the bronzes containing 0.3 per cent or less of iron. The effect of additions of iron over 0.3 per cent was to produce segregation of the lead particles.

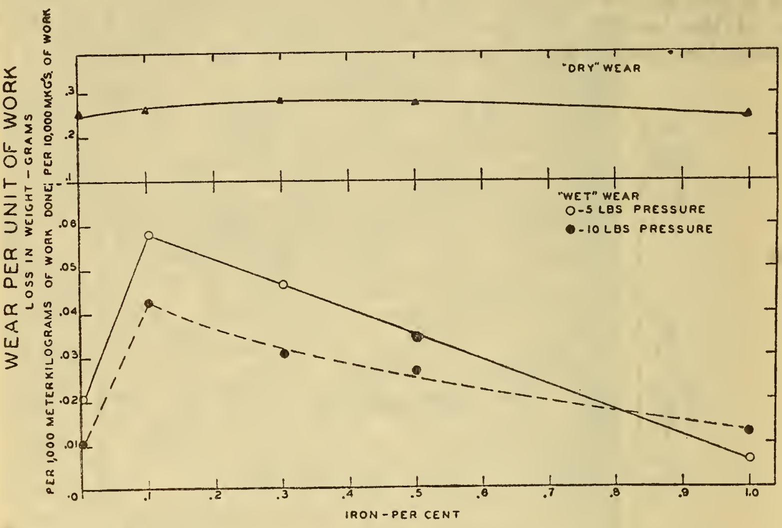

Figure 9.—*Effect of iron on the wear resistance of 80–10–10 bronze*

(b) RESISTANCE TO WEAR

Due to the formation of oxide films on the surfaces of bronze specimens during wear tests at elevated temperatures (350° F.), "dry" wear tests, under a test load consisting of the weight of the head of the Amsler wear-testing machine, were made at room temperature only. The upper part of Figure 9 shows additions of iron to be practically without effect on the rate of "dry" wear per unit of work done of 80–10–10 bronze.

Although the "dry" method of wear testing showed practically no difference in the rate of wear with iron additions, tests made in the presence of kerosene at reduced pressures showed rather clearly the effect of additions of iron on the rate of wear per unit of work. The lower part of Figure 9 gives the results of "wet" wear tests at loads of 5 and 10 pounds. It will be noted from this figure that the first additions of iron (up to about 0.3 per cent) increased the rate of wear markedly. Further additions of iron decreased the rate of wear steadily until at 1 per cent iron the rate of wear was practically the same as that of the iron-free bronze.

Under a load of 10 pounds the weight lost by the test specimens was actually greater than under a load of 5 pounds. The higher load, however, resulted in such an increased frictional force between the test specimens as to give smaller weight losses per unit of work than the lower load.

(c) RESISTANCE TO POUNDING

The effect of additions of iron on the resistance to pounding of 80–10–10 bronze is summarized in Figure 10.

The deformation under pounding decreased with additions of iron up to 1 per cent, this decrease being more marked in the lower range of iron content than in the higher range. Increasing the temperature of test resulted in increased deformation under pounding.

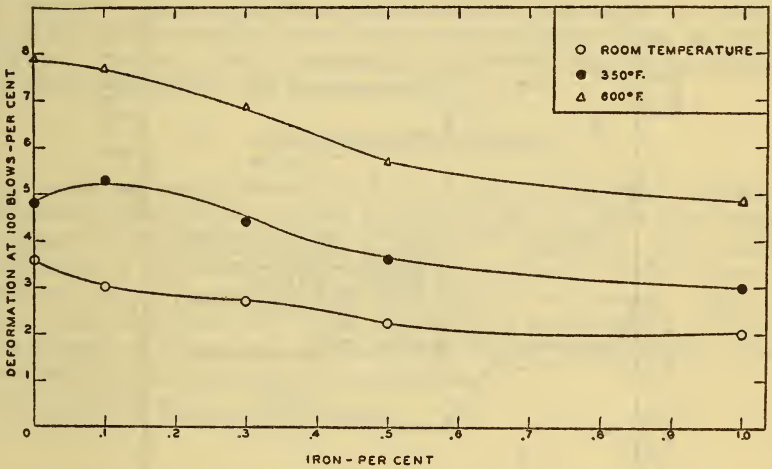

Figure 10.—*Effect of additions of iron on the resistance to deformation under pounding at various temperatures of 80–10–10–bronze*

(d) RESISTANCE TO SINGLE-BLOW IMPACT

The effect of additions of iron on the resistance to Izod impact is shown in the lower part of Figure 11. Increasing the iron content over 0.3 per cent decreased the notch toughness of the bronze tested at all temperatures. A test temperature of 350° F. did not materially affect the notch toughness, but the test temperature of 600° F. lowered the notch toughness markedly. Considering the resistance to impact at all test temperatures, it may be stated that additions of iron up to 0.3 per cent do not affect the notch toughness of 80–10–10 bronze.

(e) HARDNESS

Small additions of iron (up to 0.3 per cent) increase the hardness of 80–10–10 bronze. Further additions (up to 1 per cent) result in a slight decrease in the hardness, but this decrease is not great enough to offset the additional hardness gained by small additions. As shown in the upper part of Figure 11, the maximum hardness is acquired with iron additions of about 0.3 per cent.

V. SUMMARY AND CONCLUSIONS

The effect of casting temperatures (from 1,850° to 2,120° F.) and the effect of additions of iron (up to 1.0 per cent) on the wear resistance, resistance to pounding, resistance to single-blow impact, hardness, and microstructure of a bearing bronze containing 80 per cent copper, 10 per cent tin, and 10 per cent lead were studied. Many of the tests were made at 350° and 600° F. as well as at room temperature.

1. EFFECT OF CASTING TEMPERATURES

In general, an increase in the pouring temperature of the bronze from 1,850° to 2,120° F. decreased the rate of wear per unit of work; decreased the deformation under pounding within the range of 1,850° to 1,950° F.; decreased the notch toughness of the bronzes cast close to 2,000° F.; and decreased the hardness slightly. The various temperatures of casting had very little effect on the distribution of the lead particles in the bronzes cast from 1,850° to 2,040° F. Smaller and more evenly distributed lead particles were apparent in bronzes cast at 2,120° F. An increase in the size of the grain was noted as the casting temperature increased.

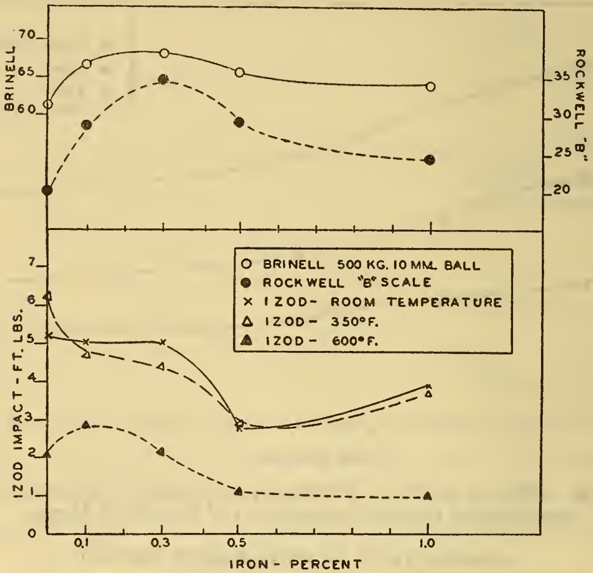

FIGURE 11.—*Effect of additions of iron on the Brinell and Rockwell hardness and Izod notch toughness values of 80–10–10 bronze*

It is to be kept in mind, however, that these conclusions regarding the specific effects of casting temperature on the properties of 80–10–10 bronze are strictly applicable only to sand-cast specimens and to castings of sizes or sections comparable to those employed in this experimental work.

2. EFFECT OF ADDITIONS OF IRON

The rate of wear per unit of work under "wet" tests was increased with small additions of iron. Further additions lowered the rate of wear until at 1 per cent iron the rate of wear was about the same as that of the iron-free bronze. The addition of iron up to 1 per cent decreased the deformation under pounding, this decrease becoming relatively small for additions over 0.5 per cent. Additions of iron over 0.3 per cent decreased the notch toughness. Additions of iron increased the hardness, the maximum hardness being obtained with 0.3 per cent iron. Additions of iron to the bronze caused segregation of the lead particles and considerably reduced the grain size when the iron content was over 0.3 per cent.

In general, it is therefore, to be concluded that small amounts of iron in the bronze studied were unfavorable in their effects on several of those properties which presumably are among the chief factors in determining suitability for bearing service.

VI. ACKNOWLEDGMENTS

The author is deeply grateful to L. M. Long, metallurgist, and other members of The Bunting Brass & Bronze Co. for their cooperation throughout the various phases of this investigation. The skillful assistance of L. D. Jones, senior laboratory mechanic of the Bureau of Standards, helped materially in the founding of the bronzes. Acknowlegments are also made to Dr. R. L. Dowdell, metallurgist, formerly of the Bureau of Standards, and to Louis Jordan, metallurgist, under whose supervision the work was carried on.

WASHINGTON, September 10, 1931.