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EFFECTS OF ALUMINUM AND OF ANTIMONY ON CERTAIN PROPERTIES OF CAST RED BRASS

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ABSTRACT

Additions of aluminum in amounts from 0.005 to 0.10 percent were made to red brass, made of remelted metal, of the nominal composition of 85 percent of copper and 5 percent each of tin, zinc, and lead. Determinations of tensile properties, density, hardness, the running property, and the ability to withstand hydraulic pressure, made on various types of test bars and test specimens, showed that all additions of aluminum had a deleterious effect on the properties and the structure. The effect was more pronounced with the higher concentrations of aluminum and was particularly evident on the ductility and the resistance to hydraulic pressure.

Additions of antimony to this alloy in the amounts ranging from 0.10 to 0.25 percent had only a nominal effect on all of the propeıties studied except the running property, which was increased.

These results indicated that the presence of 0.25 percent of antimony is permissible, but that even 0.005 percent of aluminum has a deleterious effect on the alloy.

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I. INTRODUCTION

Upon the recommendation of the American Society for Testing Materials, the Non-Ferrous Ingot Metal Institute has sponsored at the National Bureau of Standards, since 1930, a study of the physical properties of copper-base alloys. A typical alloy of the red-brass group, widely used in industry, having the nominal composition of 85 percent of copper and 5 percent each of tin, zinc, and lead, has been under investigation.

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In 1932 [1] [2] a paper was presented before the American Society for Testing Materials containing the results obtained on the study of the effect of type of test bar and of pouring temperature upon the physical properties of this alloy when made from virgin metal and from remelted metal.

The next phase of the investigation was to study the effect of impurities on the physical properties of the alloy, made from remelted metal. A paper [2] was presented before this Society in 1933 containing the results of the study of the effects of sulfur and iron as individual impurities to the alloy. Since that time, studies have been made of other elements added individually, and the influence of these elements on the physical properties of the alloy has been determined. In the present paper, data on the effects of aluminum and antimony on the remelted alloy are presented.

In carrying out this phase of the work, three types of test bars were used. These were the sand-cast ¼-in. web fin-gate bar, the immersed-crucible bar and the no-side-chill bar cut from a chill-mold ingot. Dimensioned drawings of each of these types of test bars were shown in the first paper of this investigation [1]. By using these three types of test bars, it was possible to obtain comparative data on the physical properties of a heat of the alloy from: (a) specimens uninfluenced by pouring or mold conditions, obtained in a suitably covered crucible immersed beneath the surface of the molten metal, (b) specimens cast in green-sand molds, and (c) specimens cast in chill molds. The test bars were representative of heats of the remelted alloy to which additions of aluminum from 0.005 to 0.10 percent had been made, and from heats containing additions of antimony ranging from 0.10 to 0.25 percent. Specimens were cast at three pouring temperatures: 1,065° C (1,950° F), 1,150° C (2,100° F), and 1,230° C (2,250° F).

Determinations of the following physical properties were made on each bar: Tensile properties, density, and Brinell hardness. In addition, electrical resistivity, the ability to withstand hydraulic pressure, and the fluidity or running property when cast in a green-sand mold were determined. Special test specimens were required for measurements of the two latter properties.

II. MATERIALS AND METHODS OF CASTING

Virgin copper, tin, zinc, and lead similar in grade to those reported in 1932 were used. By chemical analysis, the only significant impurities found in the metal of these grades were approximately 0.005 percent of iron in the copper, 0.01 percent of iron in the zinc, 0.015 percent of iron and 0.1 percent of bismuth in the lead, and 0.02 percent of iron in the tin. Small quantities of commercial antimony were used for additions of this element to the alloy. A copper-aluminum "hardener", containing approximately 50 percent of aluminum, was prepared from virgin copper and notched-bar aluminum and was used for small additions of aluminum.

1. MOLDING, MELTING, AND POURING

Early in this investigation a "standard practice" of molding, melting, and pouring was adopted. This consisted in the preparation of a stock material made from virgin metals melted in a high-frequency

[2] Figures in brackets indicate the literature references at the end of this paper.

induction furnace of the "lift-coil" type and cast into ingots. A portion of the stock (approximately 100 lb) was melted, as needed, under a "Purite" (sodium carbonate) slag in a double-wall clay-graphite crucible. A double-wall crucible, with the interstices filled with chrome ore, was used to avoid an excessive temperature drop during the casting of the test bars. Even when this special crucible was used, it was found that there was a temperature drop of the molten metal of 25° C during the pouring of the 12 molds at 1,230° C (2,250° F). The drop in temperature of the molten metal was less for lower pouring temperatures, being only 15° C at 1,065° C (1,950° F). Because of this cooling of the molten metal during the pouring of each set of specimens, the first bar in each group was poured at a temperature of 10° C above the nominal pouring temperature. The mean pouring temperature for each group of bars, therefore, is a close approximation to the desired pouring temperature.

The green-sand molds used were prepared from grade 00 Albany sand. A permeability number of 12 to 16 (AFA units), a compressive strength of 5 to 7 lb/in.^{2}, and a moisture content of 6 to 7 percent were maintained throughout the preparation of all of the green-sand molds.

Antimony additions were made without difficulty directly to the molten alloy through the Purite slag. However, considerable difficulty was encountered at first in retaining the desired amount of aluminum in the alloy. A method found satisfactory for retaining the desired amount of aluminum was as follows: The metal was melted under a Purite slag which was later removed and replaced by a cover of hot charcoal. The necessary amount of the copper-aluminum hardener was thrust through the charcoal into the molten metal, and the stirring action of the furnace insured a thoroughly uniform distribution throughout the molten metal in the crucible. The melt was then brought to the desired maximum temperature (56° C (100° F) above the pouring temperature), removed from the furnace, allowed to cool to the first pouring temperature, and poured into the molds.

III. RESULTS AND DISCUSSION

The tensile properties were determined with an Amsler universal testing machine of 50,000-lb. capacity, adjusted to give a rate of travel of the free crosshead of 0.1 in./in./min. The test specimen used was 0.505 in. in diameter, with threaded ends and a 2-in. gage length. In most cases, the determinations of tensile strength of the duplicate bars agreed within 1,000 lb/in.^{2} (about ± 3 percent), although there were a few larger variations. In such cases, the higher values were accepted as being more characteristic of the sound metal.

1. TENSILE STRENGTH

In figure 1 are shown the results obtained on the remelted alloy containing additions of aluminum in progressively increasing amounts. A definite but somewhat irregular decrease in tensile strength may be observed. A comparison of the data with the "minimum tensile strength expected for this alloy" (27,000 lb./in.^{2}), indicated by the broken line [3], shows that the addition of even 0.005 percent of aluminum (the amount now permitted in ASTM Specification B 30–36) adversely affected the alloy. The results in figure 2, however, indicate that antimony did not have a very pronounced influence on the tensile properties of this alloy. A comparison of the values obtained

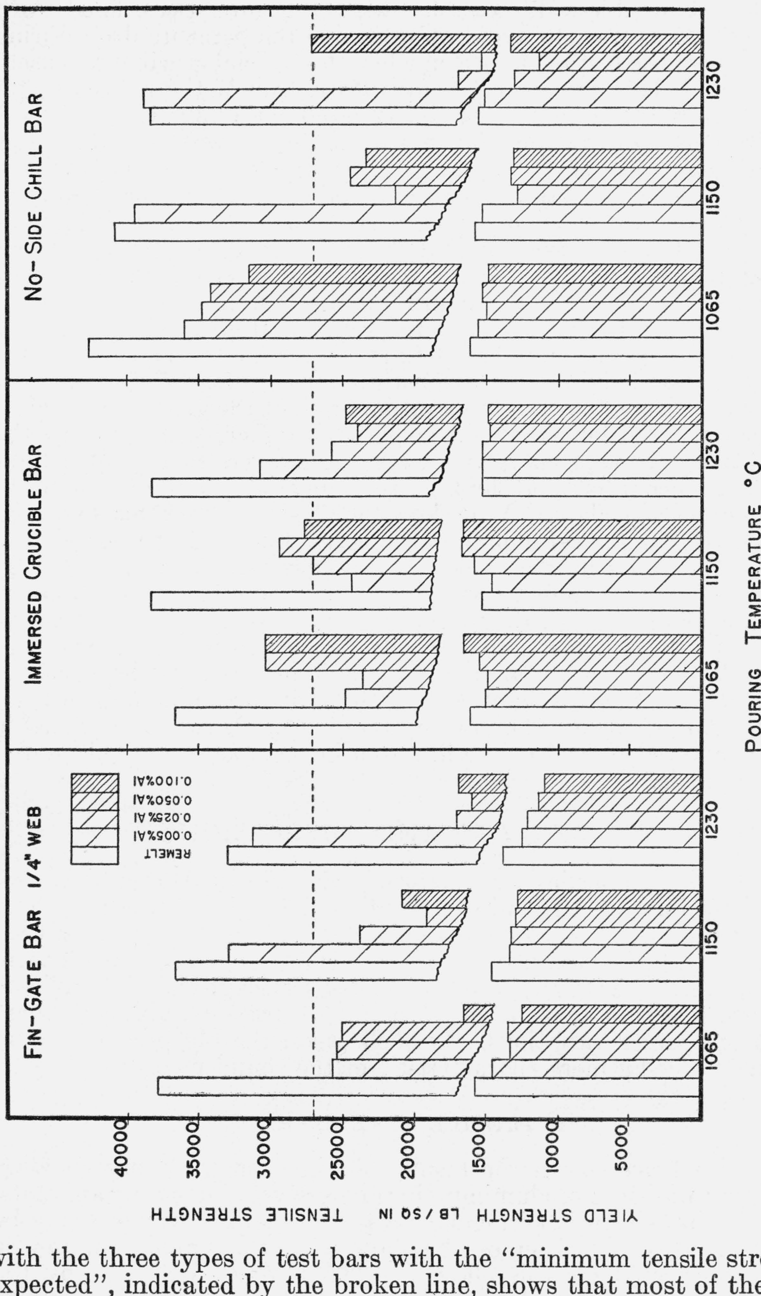

Figure 1.—*Effect of additions of aluminum on the yield strength and tensile strength of cast red brass (85–5–5–5) test bars.*

Minimum tensile strength for this alloy (ASTM Spec. B 30-36) is shown by the broken line.

with the three types of test bars with the "minimum tensile strength expected", indicated by the broken line, shows that most of the bars had a tensile strength well above this "minimum."

2. YIELD STRENGTH

Figures 1 and 2 show also the data obtained for yield strength of the alloy containing progressively increasing small additions of aluminum or of antimony. The method used was that outlined in the ASTM Standards (1933) [4] for a permanent set of 0.1 percent.

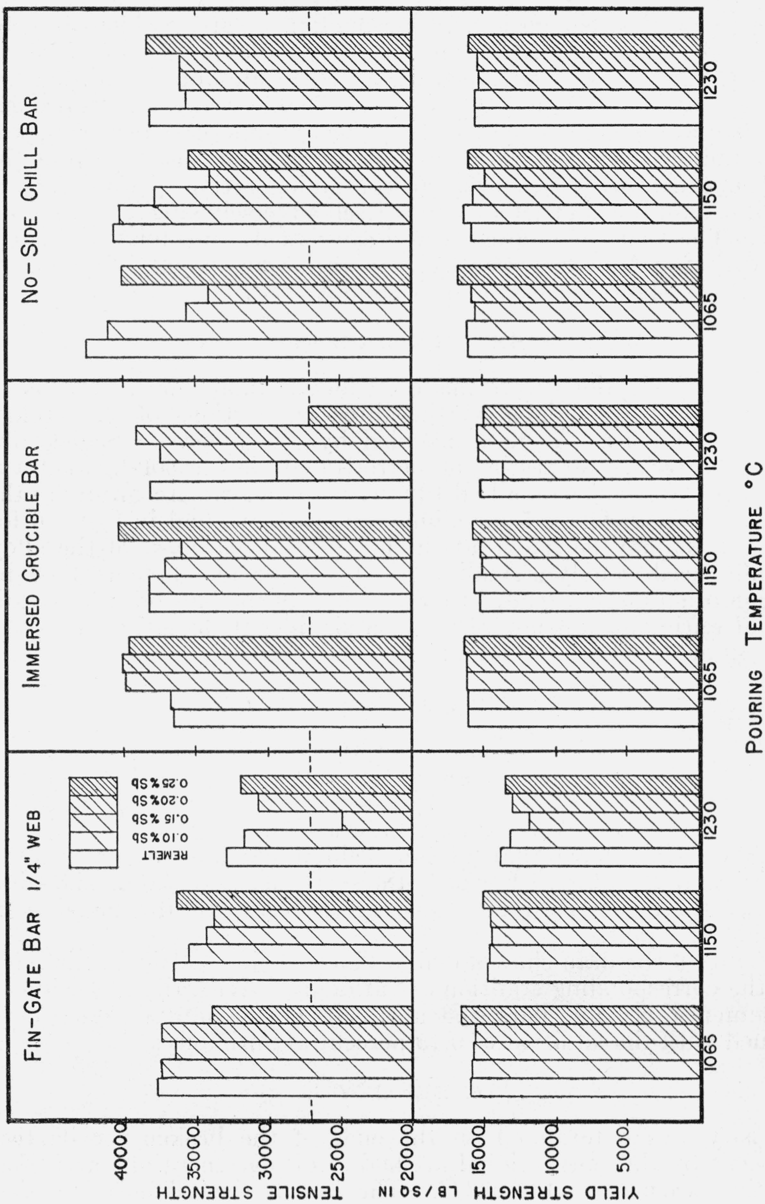

FIGURE 2.—*Effect of additions of antimony on the yield strength and tensile strength of cast red brass (85–5–5–5) test bars.*

Minimum tensile strength for this alloy (ASTM Spec. B 30-36) is shown by the broken line.

According to figure 1, the influence of aluminum in the sand-cast test bars was to produce a gradual reduction in yield strength, which became more pronounced as the pouring temperature was increased.

For the other types of test bars, however, the apparent effect on the yield strength was by no means uniform. As shown in figure 2, antimony, in the small amounts used, did not have a marked influence on the yield strength of the alloy.

3. DUCTILITY

The properties, elongation, and reduction of area, which may be considered as criteria of the ductility of an alley, will be considered together. In figure 3 are shown the effects of aluminum additions on both elongation and reduction in area. The decrease in both properties was quite large, and, particularly for the sand-cast test bars, was rather uniform as the aluminum content was increased. From the results obtained with the specimens containing antimony (fig. 4), however, it cannot be said that antimony itself adversely affects these properties. The variations noted were inconsistent, and, for several test bars with the higher percentages of antimony, results superior to those of the plain remelted alloy were obtained.

4. BRINELL HARDNESS

Brinell indentations were made on longitudinal parallel flat faces ⅝ in. in width, machined on the threaded portions of the broken tension specimens. As recommended by the American Society for Testing Materials, for testing nonferrous materials, a 500-kg load was applied for 30 seconds on a ball 10 mm in diameter. According to the results, shown in figure 5 for aluminum additions and in figure 6 for antimony, it may be said that the indentation hardness of the alloy was influenced to only a small degree by either added element. The addition of aluminum tended to lower slightly the hardness, but additions of antimony did not result in a significant deviation from the hardness of the untreated alloy.

5. ELECTRICAL RESISTIVITY

Determinations of electrical resistivity were made on the machined specimens used subsequently for tension tests. These determinations were carried out in accordance with the procedure recommended by the American Society for Testing Materials [5].

In figure 5 it is shown that the added aluminum greatly increased the resistivity of the alloy. For both the sand-cast and the no-side-chill test bars the resistivity increased progressively with the increase in aluminum content.

In figure 6 the data show a definite increase in electrical resistivity with the corresponding addition of antimony. With the exception of the immersed-crucible bars cast at 1,230° C, maximum values were obtained with the addition of 0.15 percent of antimony.

6. DENSITY

Density was determined on the ends of the broken tensile test specimens by the conventional method of displacement of water, and the values are corrected to 20° C. The data on the influence of added aluminum are summarized in figure 7 and for antimony in figure 8. In figure 7 it is shown that the general trend is for a lowering in density, which can be attributed to the aluminum present. The

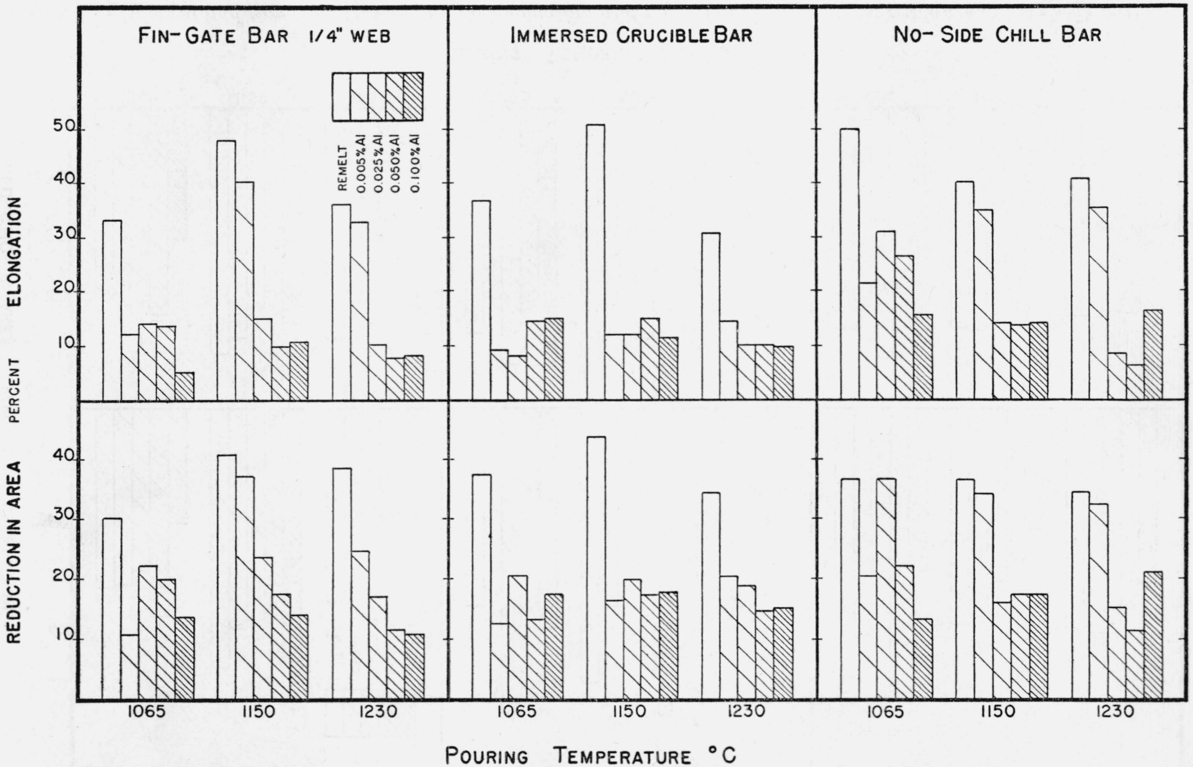

FIGURE 3.—*Effect of additions of aluminum on the elongation and reduction in area of cast red brass (85–5–5–5) test bars.*

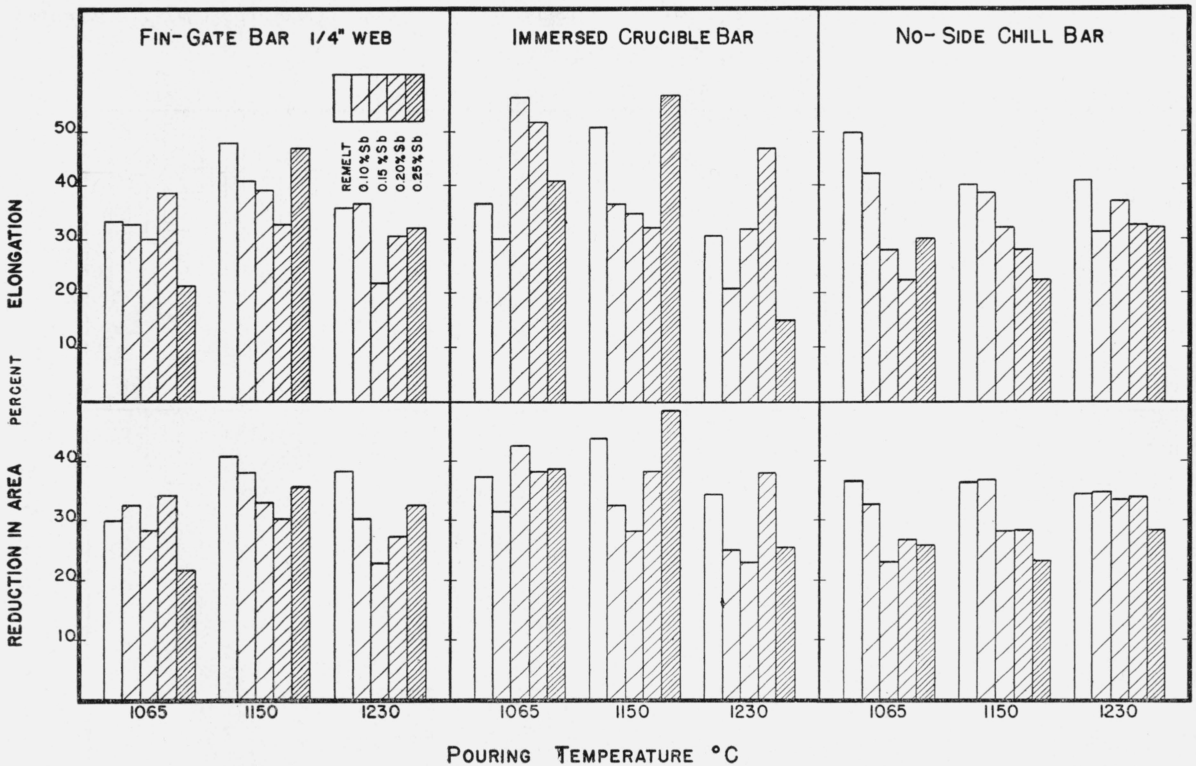

FIGURE 4.—*Effect of additions of antimony on the elongation and reduction in area of cast red brass (85–5–5–5) test bars.*

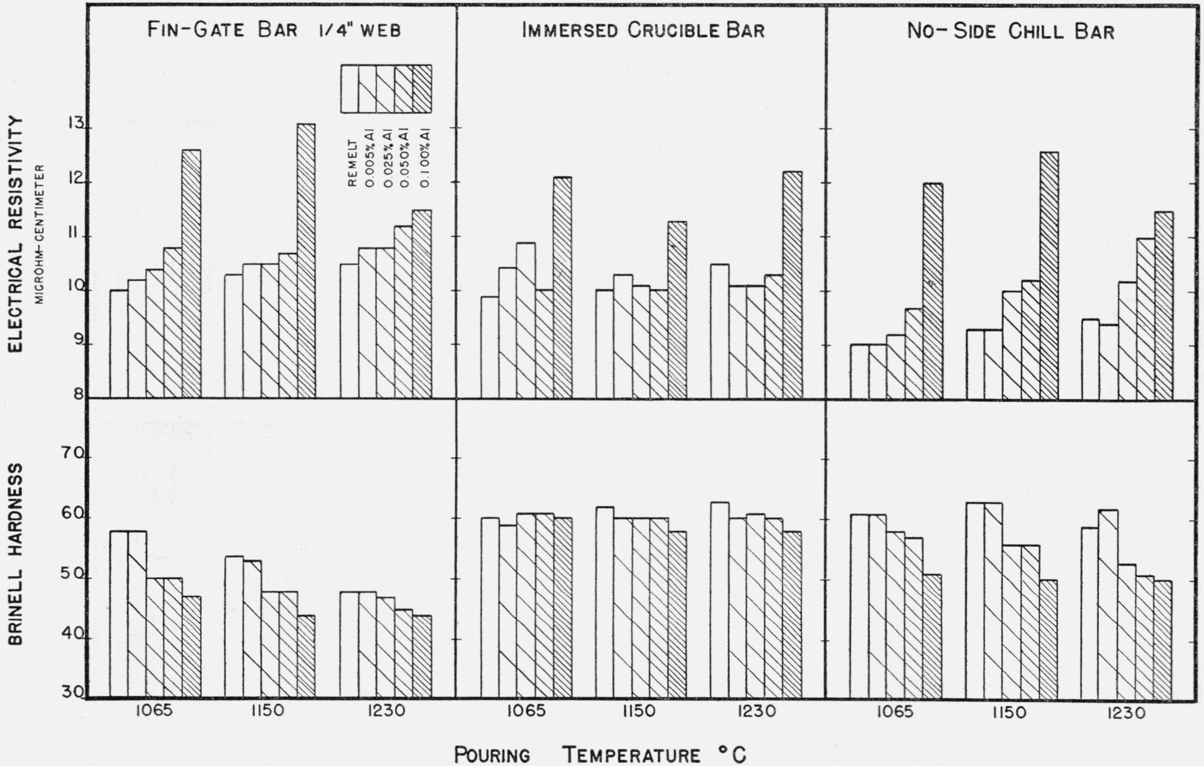

FIGURE 5.—*Effect of additions of aluminum on the electrical resistivity and Brinell hardness of cast red brass (85–5–5–5) test bars.*

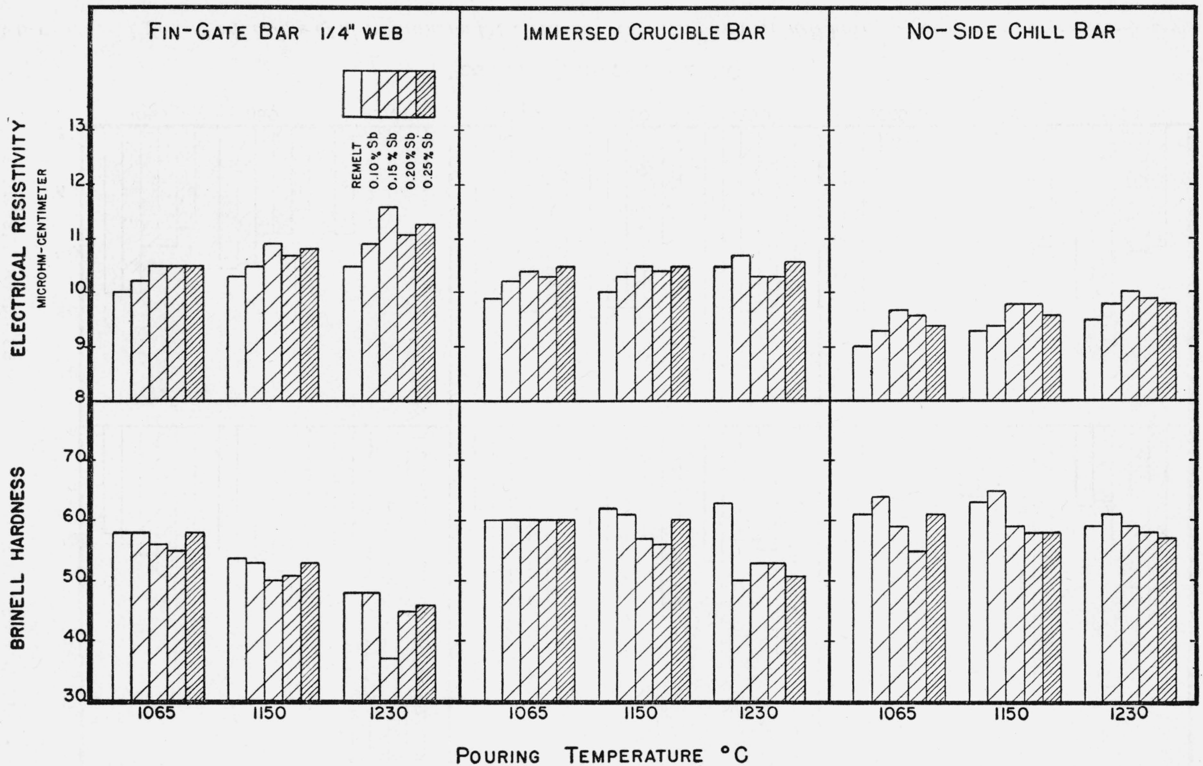

FIGURE 6.—*Effect of additions of antimony on the electrical resistivity and Brinell hardness of cast red brass (85–5–5–5) test bars.*

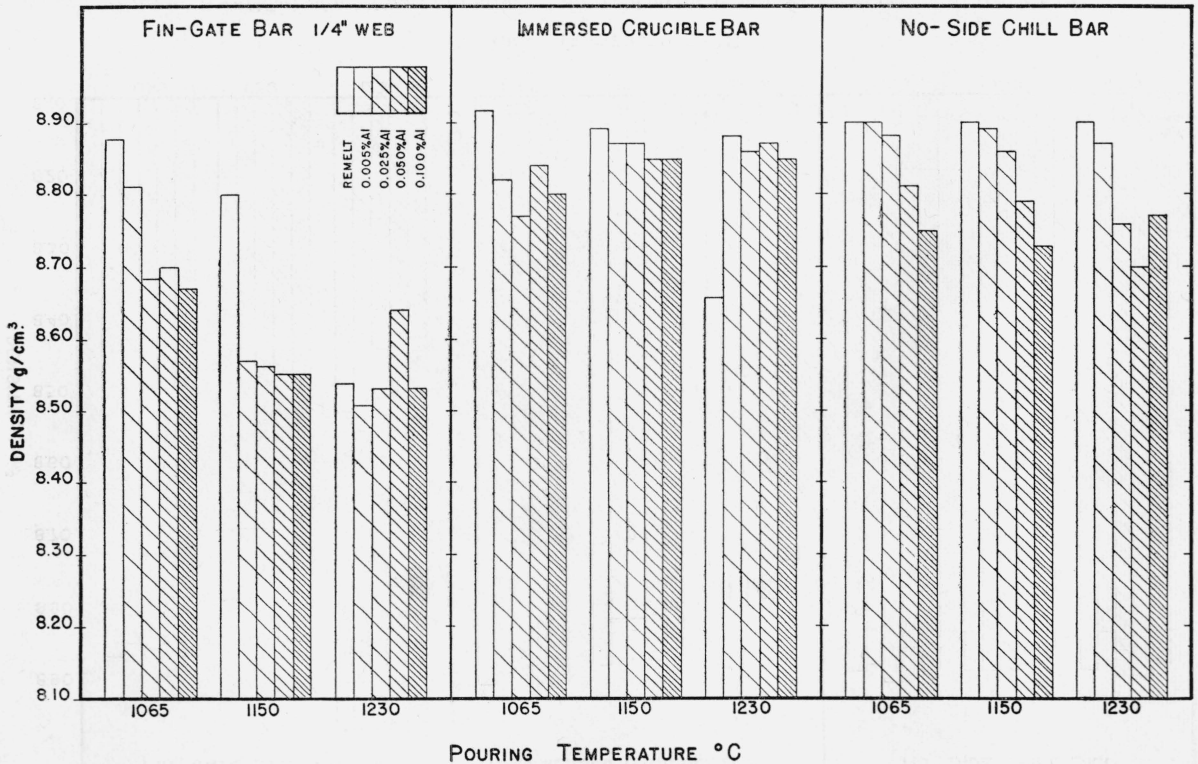

FIGURE 7.—*Effect of additions of aluminum on the density of cast red brass (85–5–5–5) test bars.*

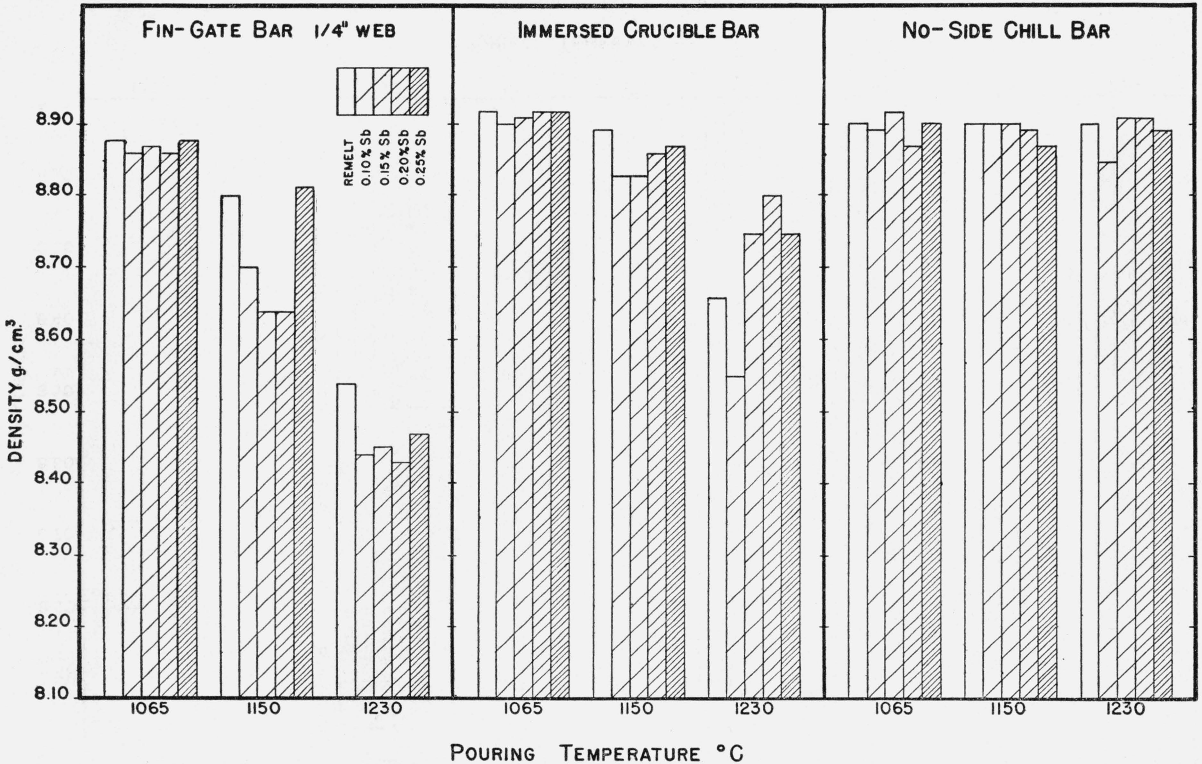

Figure 8.—*Effect of additions of antimony on the density of cast red brass (85–5–5–5) test bars.*

no-side-chill bars cast at 1,065° C (1,950° F) and 1,150° C (2,100° F) are the only ones, however, where this decrease was uniform. In figure 8 the deviation from remelted alloy, due to the addition of antimony, was nominal for the bars cut from the chill ingot. The sand-cast bars poured at 1,230° C (2,250° F) showed the most pronounced irregular deviation. Additional determinations of density were made on stepped-bar castings poured from each heat that was cast into tensile bars. Figure 9 shows the dimensions of the stepped-bar castings. In figures 10 and 11 are shown the density data obtained with this type of bar for alloys with added aluminum and antimony, respectively. The general effect of increasing the aluminum content was to decrease the density. The density also tended to decrease with reduction of the thickness of the stepped-bar casting, although this reduction is somewhat irregular. There are some indications, too, of a decrease in density with an increase in pouring temperature, particularly for the specimens with 0.05 and 0.10 percent of aluminum. In general, the addition of antimony had very little effect on the density of the stepped-bar specimens. There were fewer irregularities in the density determinations of the stepped-bars containing antimony than for the corresponding bars containing aluminum. There was a slight tendency for the density to decrease with reduction in thickness of casting of specimens poured at 1,065° C (1,950° F) and 1,150° C (2,100° F), but this was not so evident with specimens cast at 1,230° C (2,250 °F).

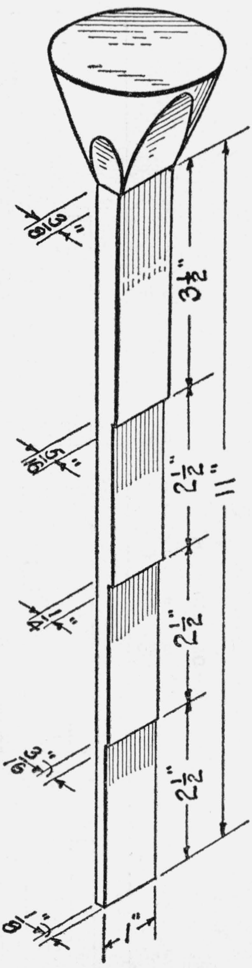

FIGURE 9.—*Dimensions of stepped-bar castings.*

7. RUNNING QUALITIES

The effect of aluminum and of antimony on the running quality of the alloy was studied by the method developed by Saeger and Krynitsky [6], which consists essentially in casting in a green-sand mold a strip of small cross section in the form of a spiral. According to the data summarized in figure 12, aluminum increased the running quality of the alloy. Likewise, the results presented in figure 13 show a marked increase in the running quality of the alloy, which can be attributed to the presence of the antimony. For the specimens poured at temperatures of 1,065° C (1,950° F) and 1,150° C (2,100° F), maximum values were obtained with an antimony content of 0.15 percent, but for the test specimens poured at 1,230° C (2,250° F) the best results corresponded to an antimony content of 0.10 percent.

8. PRESSURE TESTING

Since this alloy is widely used in the manufacture of pressure castings, its tightness is a major factor. This was studied by hydraulic testing. A hydraulic pressure of 300 lb/in.^{2} was applied to the inte-

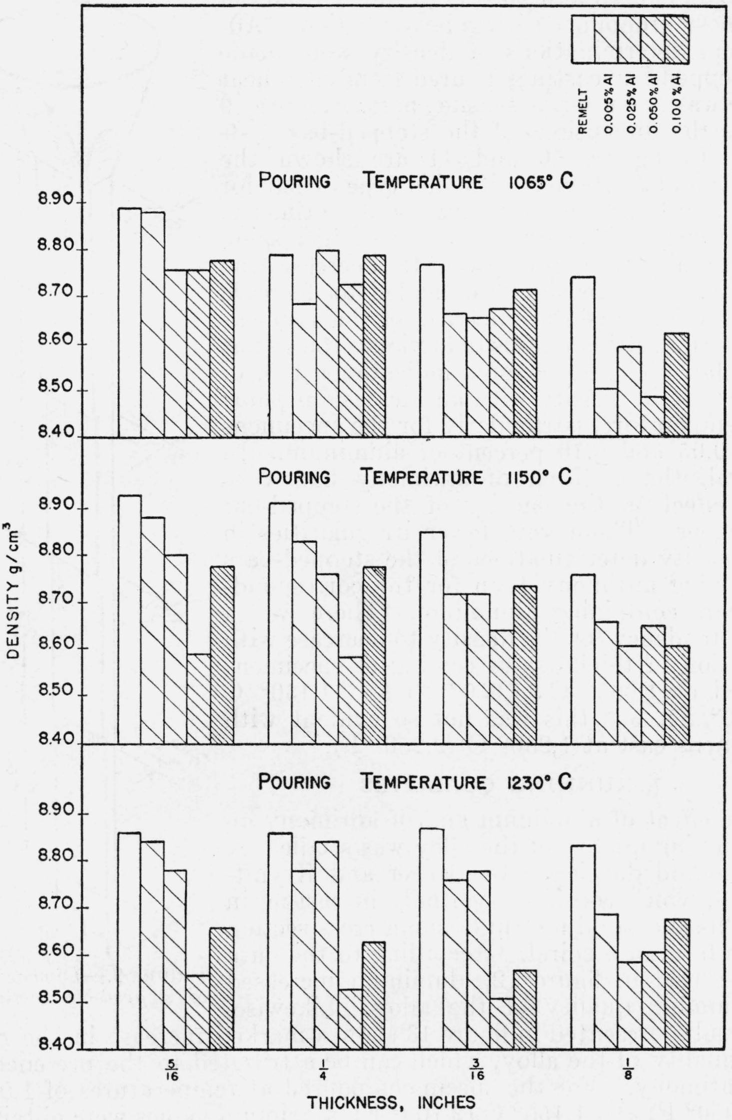

FIGURE 10.—*Effect of additions of aluminum on the density of stepped-bar castings of cast red brass (85–5–5–5).*

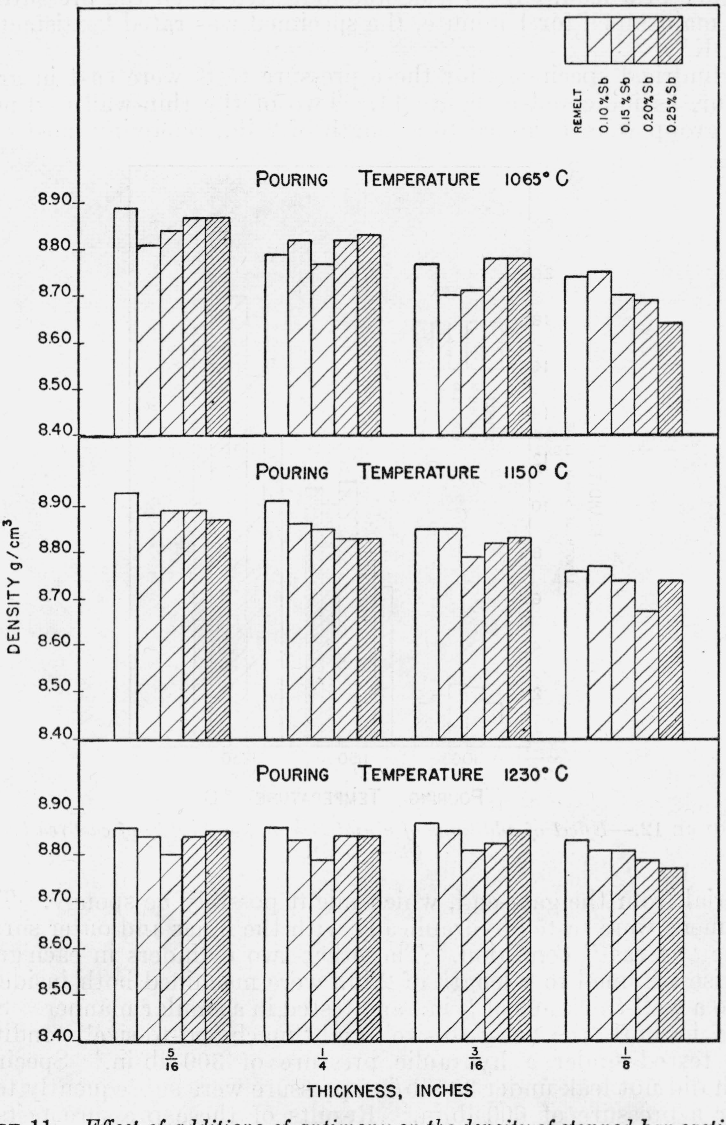

FIGURE 11.—*Effect of additions of antimony on the density of stepped-bar castings of cast red brass (85–5–5–5).*

rior of cylindrical castings. The water within the specimen contained a soluble blue dye, and the appearance of the blue coloration on the outer surface of the specimen under pressure constituted visual evidence of a leak. If no leak was indicated when the pressure had been maintained for 1 minute, the specimen was rated "satisfactory" or "OK".

Cylindrical specimens for these pressure tests were cast in groups of four, as indicated in figure 14. Two of the thin-wall castings in each group were trimmed to a length of 2 in., removing most of the

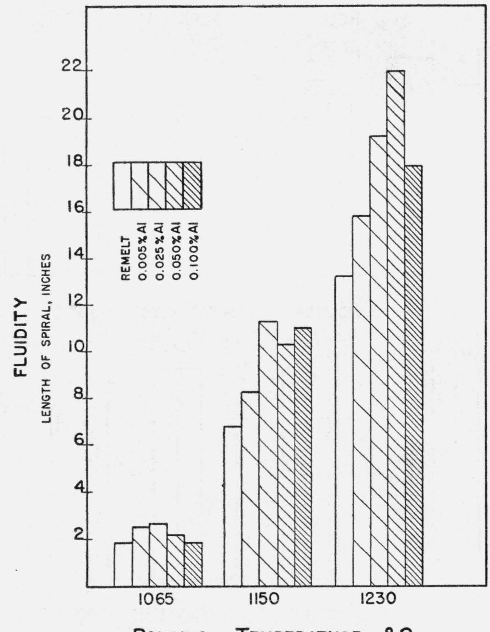

FIGURE 12.—*Effect of additions of aluminum on the fluidity of cast red brass (85–5–5–5).*

material from the gate-end, which might possibly be spongy. These specimens were tested hydraulically with the inner and outer surfaces in the "as cast" condition. The other two cylinders in each group, likewise trimmed to a length of 2 in., were machined both inside and out to a wall-thickness of ⅛ in., and tested in a similar manner. Specimens in both the "cast-to-size" and "machined-to-size" conditions were tested under a hydraulic pressure of 300 lb/in.^{2} Specimens which did not leak under 300 lb/in.^{2} pressure were subsequently tested under a pressure of 600 lb/in.^{2} Results of these pressure tests are listed in tables 1 and 2. The tests at 300 lb/in.^{2} are also shown graphically in figure 15. These data show:

1. The "cast-to-size" specimens were superior to the "machined-to-size" specimens in resistance to hydraulic pressure. This indicates that an important part of the resistance to hydraulic pressure is located in the skin of the casting and that the removal of the surface

skin by machining decreases the capacity of the metal to withstand hydraulic pressure.

2. The best results were obtained with metal cast at the higher pouring temperatures.

3. The presence of aluminum in the alloy increased the tendency for leaks or porosity, particularly when 0.05 percent or more of this element was present.

4. The presence of antimony decreased the porosity of red brass but the effect was practically constant within the range of 0.10 to 0.25 percent of antimony.

5. For the test specimens containing aluminum, all of the "cast-to-size" specimens that withstood 300-lb/in.² pressure were also able to

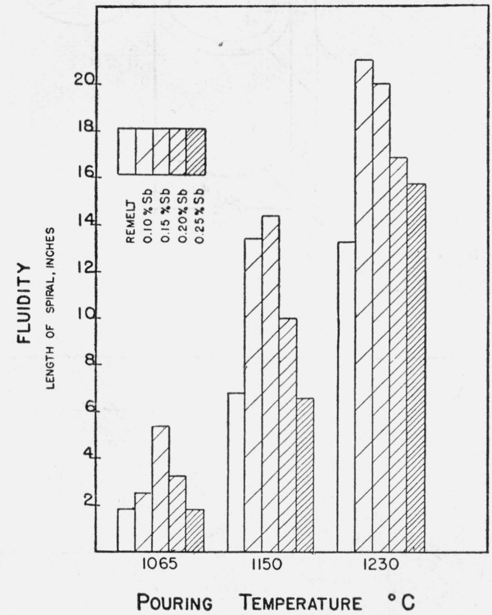

FIGURE 13.—*Effect of additions of antimony on the fluidity of cast red brass (85–5–5–5).*

withstand 600-lb/in.² pressure. Only two of the six "machined-to-size" specimens that withstood 300-lb/in.² pressure passed the 600-lb/in.² test.

6. Most of the "cast-to-size" specimens containing antimony that withstood 300-lb/in.² pressure were satisfactory under 600-lb/in.² pressure, and one-half of the "machined-to-size" specimens tested in like manner were satisfactory.

In general, then, it may be seen that aluminum has a deleterious effect on the pressure tightness of the alloy but that antimony does not deleteriously affect this property. It was interesting to note that the leaks observed in the specimens that failed under test were not localized but were distributed over all portions of the surface of the test specimens.

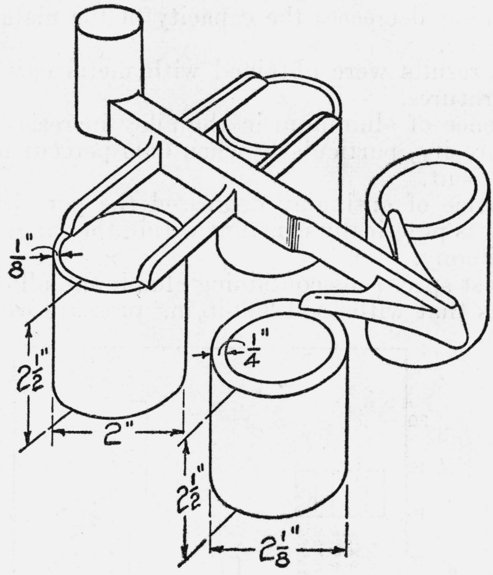

FIGURE 14.—*A casting of specimens for hydraulic tests.*

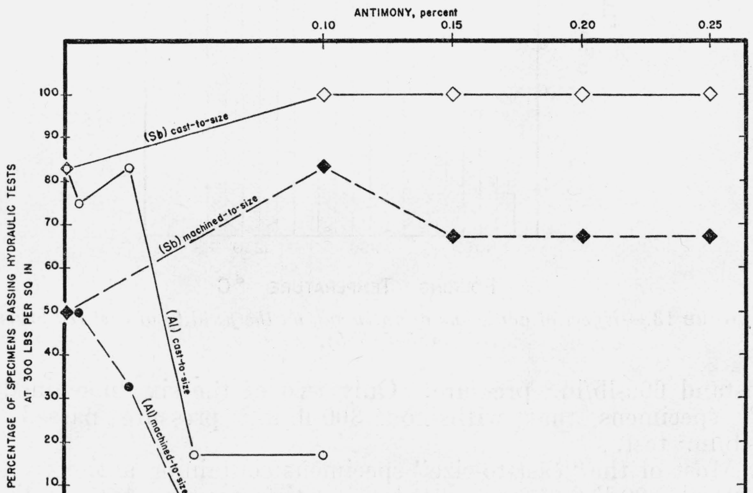

FIGURE 15.—*Effect of additions of aluminum or antimony on the ability of "cast-to-size" and "machined-to-size" specimens of red brass to withstand hydraulic pressure.*

TABLE 1.—*Pressure tests of remelted "85–5–5–5" alloy, with addition of aluminum*

[Only those specimens that withstood a pressure of 300 lb/in.² were tested at 600-lb pressure.]

Pouring temperature	Type of metal	Cast-to-size		Machined-to-size	
		300 lb	600 lb	300 lb	600 lb
°C					
1,065	Remelt	NG OK	--- OK	NG NG	--- ---
1,150	do	OK OK	OK NG	OK OK	NG NG
1,230	do	OK OK	OK OK	OK NG	OK ---
1,065	Remelt, plus 0.005% of Al	[1]	---	NG NG	--- ---
1,150	do	OK NG	OK ---	OK NG	NG ---
1,230	do	OK OK	OK OK	OK OK	OK OK
1,065	Remelt, plus 0.025% of Al	NG OK	--- OK	NG NG	--- ---
1,150	do	OK OK	OK OK	NG NG	--- ---
1,230	do	OK OK	OK OK	OK OK	NG NG
1,065	Remelt, plus 0.05% of Al	NG NG	--- ---	NG NG	--- ---
1,150	do	NG NG	--- ---	NG NG	--- ---
1,230	do	NG OK	--- OK	NG NG	--- ---
1,065	Remelt, plus 0.10% of Al	NG NG	--- ---	NG NG	--- ---
1,150	do	NG OK	--- OK	NG NG	--- ---
1,230	do	NG NG	--- ---	NG NG	--- ---

TABLE 2.—*Pressure tests of remelted "85–5–5–5" alloy with additions of antimony*

[Only those specimens that withstood a pressure of 300 lb/in.² were tested at 600-lb pressure]

Pouring temperature	Type of metal	Cast-to-size		Machined-to-size	
		300 lb	600 lb	300 lb	600 lb
°C					
1,065	Remelt	NG OK	--- OK	NG NG	--- ---
1,150	do	OK OK	OK NG	OK OK	NG NG
1,230	do	OK OK	OK OK	OK NG	OK ---
1,065	Remelt, plus 0.10% of Sb	OK OK	OK OK	OK OK	NG NG
1,150	do	OK OK	NG OK	OK NG	NG ---
1,230	do	OK OK	OK OK	OK OK	OK OK
1,065	Remelt, plus 0.15% of Sb	OK OK	NG OK	NG NG	--- ---
1,150	do	OK OK	OK OK	OK OK	NG NG
1,230	do	OK OK	OK NG	OK OK	OK OK
1,065	Remelt, plus 0.20% of Sb	OK [1]	NG ---	NG OK	--- NG
1,150	do	OK OK	OK OK	NG OK	--- OK
1,230	do	OK OK	OK OK	OK OK	OK OK
1,065	Remelt, plus 0.25% of Sb	OK [1]	NG ---	NG NG	--- ---
1,150	do	OK OK	OK OK	OK OK	NG NG
1,230	do	OK OK	OK OK	OK OK	OK OK

[1] Misrun.

9. METALLOGRAPHIC EXAMINATION

Specimens of the remelted alloy (85–5–5–5) with additions of aluminum and of antimony, cast at 1,150° C (2,100° F), were examined to ascertain the effect of the added element on the microstructure of the alloy. Micrographs in figure 16 show the typical appearance of specimens containing 0.0, 0.005, 0.025, 0.05, and 0.10 percent of aluminum, respectively. There may be observed fine networks at the interdendrite boundaries of the specimens containing 0.025 to 0.10 percent of aluminum that were not seen in the untreated alloy or in the specimen containing 0.005 percent of aluminum. These lines were visible on the polished surfaces previous to etching and constitute a characteristic structural feature of the alloys containing the higher aluminum contents. Examination at a magnification of ×500, of both etched and unetched specimens, leads to the conclusion that this structural feature represents solid material, perhaps a film, at some of the dendritic boundaries and does not simply represent shrinkage cracks in the material, although shrinkage may be involved to some extent. It could not be determined whether the film consisted of intermetallic compounds or nonmetallic material. Whatever the nature of these imperfections may be, their presence is associated with the inferior properties, that is, low ductility and high electrical resistivity of the test bars of higher aluminum content, and may be a factor in the increased leakage of these alloys under hydraulic pressure.

In Figure 17 are shown micrographs of companion specimens of the alloy containing 0.0, 0.10, 0.15, 0.20, and 0.25 percent of antimony cast at 1,150° C (2,100° F). No unusual structural condition attributable to the presence of antimony is to observed. Evidently antimony in these amounts exists in solid solution in the copper-rich matrix.

IV. SUMMARY

The influence of pouring temperature, in this phase of the investigation, was subordinate to that of the added elements.

Aluminum had a marked detrimental influence on most of the properties that were studied. The presence of this element lowered the tensile strength, the ductility and the Brinell hardness. It increased the electrical resistivity (i. e., lowered the electrical conductivity) and the porosity of the alloy. The only beneficial effect observed for additions of aluminum was an increase in the fluidity or running property of the alloy.

Antimony, however, had little influence on the properties of the alloy other than a slight increase in the electrical resistivity and, to a somewhat greater degree, an increase of the running quality. Its effect on the other physical properties studied was not significant.

The alloy containing the higher percentages of aluminum shows microstructural imperfections, herein called films, which are not visible in the aluminum-free alloy. It is probable that the low ductility, high electrical resistivity, and possibly the failure of the alloy to withstand hydrostatic pressure are associated with local concentrations of these films at the dendrite interstices.

It was thought that possibly some direct correlations might be observed from the data obtained for the different properties studied. However, no correlation could be established between the electrical

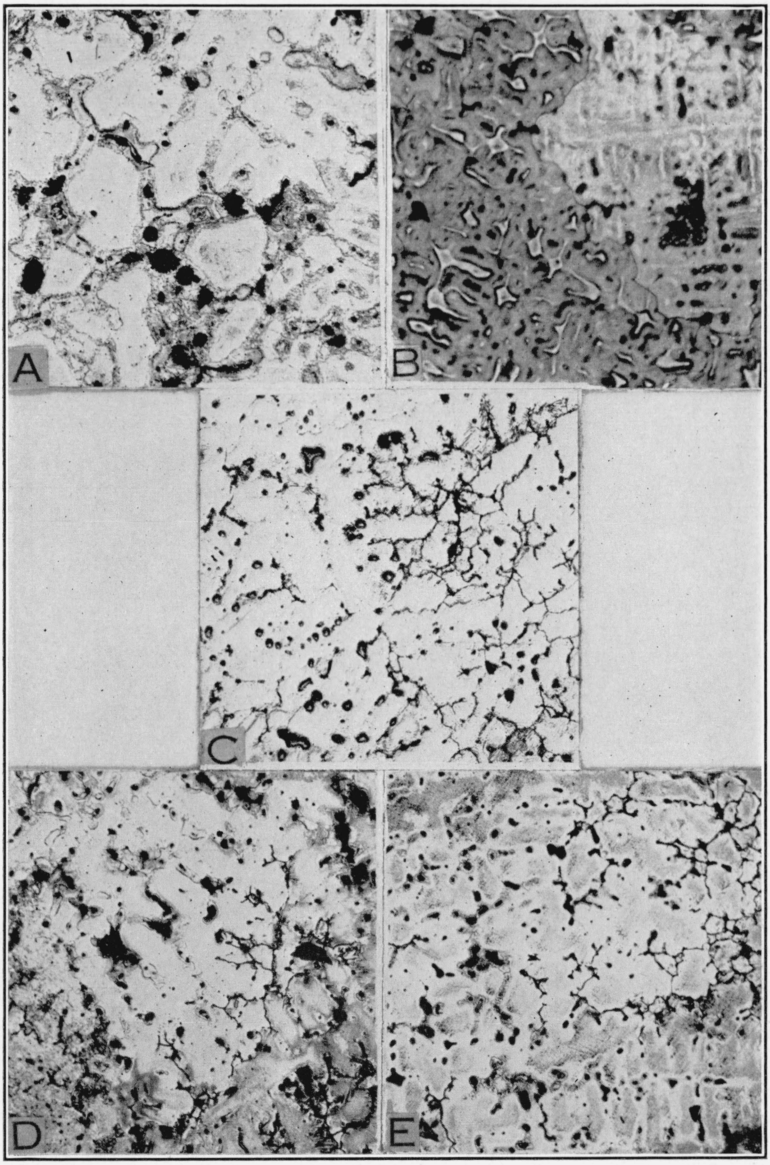

FIGURE 16.—*Microstructure of specimens.*

A, remelted 85–5–5–5; *B*, remelted metal plus 0.005 percent of Al; *C*, remelted metal plus 0.025 percent of Al; *D*, remelted metal plus 0.05 percent of Al; *E*, remelted metal plus 0.10 percent of Al etched electrolytically in 10 percent of ammonium persulphate, ×100.

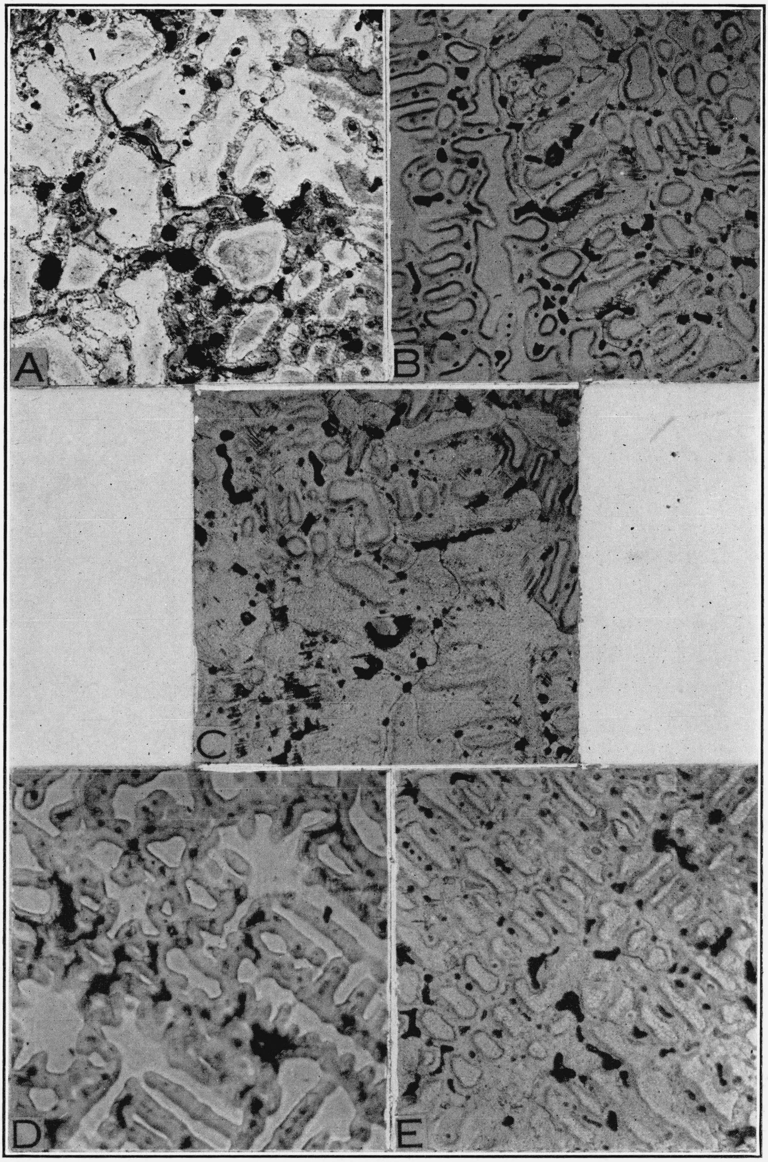

FIGURE 17.—*Microstructure of specimens.*

A, Remelted 85–5–5–5; *B*, remelted metal plus 0.10 percent of Sb; *C*, remelted metal plus 0.15 percent of Sb *D*, remelted metal plus 0.20 percent of Sb; *E*, remelted metal plus 0.25 percent of Sb etched electrolytically in 10 percent of ammonium persulphate, ×100.

resistivity and the physical properties studied, nor between the results of the pressure tests and the density determinations made either on the ends of the tension specimen or on the various sections of the stepped-bar castings. This suggests particularly that density is not a satisfactory indication of the ability of the material to withstand hydraulic pressure. It was found impossible to correlate the data here presented other than as indicative of a general trend. While it has been shown that aluminum has a deleterious effect on the alloy, the diminution of no physical or electrical property studied is proportional to, or regular for the progressively increasing amounts of this element added.

The most important conclusions which the results of this investigation warrant are:

1. The restriction on the presence of aluminum, in the present ASTM Specification B 30–36, is amply justified by the results obtained.

2. The present data indicated that antimony up to 0.25 percent does not have a deleterious effect on this alloy.

V. REFERENCES

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