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MAGNETIC SUSCEPTIBILITY AND IRON  
CONTENT OF CAST RED BRASS

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*Bureau of Standards*

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# MAGNETIC SUSCEPTIBILITY AND IRON CONTENT OF CAST RED BRASS.

By L. H. Marshall<sup>1</sup> and R. L. Sanford.

## ABSTRACT.

The presence of iron in commercial brass is often objectionable, particularly if it occurs as discrete, poorly alloyed particles. In order to obviate any such harmful effects, a very low ferrous content is frequently specified. Therefore, a rapid, non-destructive method for quantitatively determining its presence would be of great value in practice. A magnetic method of inspection would fulfill the requirements of such a test if a definite relationship exists between some magnetic property and the iron content of the metal.

With these facts in mind a study was made of the magnetic characteristics of a series of specially prepared samples of tin-red brass.<sup>2</sup> The composition of these specimens was quite uniform except for the intentional variation in iron content from about 0 to 0.75 per cent. Magnetic properties were determined in the cast condition and after annealing 15 minutes at 625° C., 8 hours at 800° C., and 16 hours at 800° C.

Microscopic examination indicated that less than 0.14 per cent iron went into solid solution in the matrix of the alloy, as this amount, or more, caused the appearance of an iron-rich constituent. These ferrous aggregates occurred as pale, rounded areas, which were apparently unaffected by the annealing treatments mentioned above. It was possible to estimate roughly the per cent of iron present from the number and size of these areas. The iron content had no noticeable effect on the grain size of the brass.

The results showed that (a) the magnetic properties are not a precise index of the iron content of the cast metal; (b) the magnetic susceptibility is markedly affected by changes in physical condition produced by heat treatment; (c) even after the material has been thoroughly annealed, there is still no simple relationship between the magnetic susceptibility and the iron content.

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<sup>2</sup> Nomenclature as recommended for this type of alloy by Com. B-2, A. S. T. M.; 1920.

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## I. INTRODUCTION.

The presence of iron in brass is usually objectionable for at least two reasons. First, it ordinarily replaces a much more expensive metal and so, merely from a consideration of the scrap value of the alloy, should be kept as low as possible. Second, the physical properties of such material are noticeably, and in many instances, adversely, affected by the presence of even small amounts of iron. Sometimes iron is intentionally added to brass because the increase in hardness and tensile strength it produces is beneficial in certain special cases. Such alloys are not in general use in this country, however, and their production requires careful supervision and treatment. The usual practice, therefore, is to obviate any possible ill effects from the presence of iron by specifying a low ferrous content. Iron has a particularly harmful influence on the machining qualities of brass, especially when the ferrous metal is not well disseminated throughout the mass. In practice poorly diffused iron sometimes occurs in brass and bronze castings due, in spite of the use of a magnetic separator, to the inadvertent presence of core pins, nails, iron turnings, or similar materials in the scrap metal employed in the melt. Such inclusions naturally cause trouble in machining. A nondestructive method for rapidly and accurately determining the proportion of iron contained as an impurity in cast brass would be, therefore, of considerable value in the industry. With this in mind a study was made, in cooperation with the Ohio Brass Co., of the magnetic properties of a series of samples of tin-red brass contaminated with iron.

The literature seems to be almost silent on this particular problem, most of the investigative work having been done either on iron-rich alloys, or else on metals of the Heusler type. Some data are available, however, on the magnetic properties of binary copper alloys containing no iron<sup>3</sup> and on high zinc brass contaminated with minute quantities of iron.<sup>4</sup> This information may be summarized for the present purpose, however, by the statement that the copper-rich brasses and bronzes, free from iron, are diamagnetic while the 50-50 copper-zinc alloy becomes paramagnetic when 0.023 per cent, or more, of iron is present.

<sup>3</sup> A. S. Smith, *Jour. Franklin Inst.*, 192, pp. 69, 157; 1921.

<sup>4</sup> K. Overbeck, *Annalen der Physik*, 351, p. 677; 1915.

## II. MATERIAL.

The alloy used in this investigation was of the type 82 copper, 15 zinc, and 3 tin. A special series of samples was made up in which the composition, as far as the nonferrous constituents were concerned, was maintained as uniform as possible, while the iron content ranged from scarcely more than a trace up to 0.75 per cent. The copper, zinc, and tin used were good commercial grades.

The metal was cast horizontally into bars, 37 cm (15 inches) long and 1.9 cm (three-fourths inch) in diameter by the Ohio Brass Co. The procedure followed was to melt the electrolytic copper in a crucible then add the tin and zinc. When this metal was ready to pour the iron was introduced as cast-iron turnings, average fineness 54.3, mixed with ammonium chloride. Four bars from each alloy were cast in the same mold and from the same gate. One bar from each mold was then turned down to 1.2 cm (0.5 inch) in diameter and two specimens about 15 cm (6 inches) in length were cut from it.

A charge of between 50 and 100 pounds of metal was used for each pouring and consisted of copper, 80.8; zinc, 16.2; and tin, 3.0 per cent by weight. The excess zinc was added to take care of the usual small loss of this metal by volatilization. About 40 minutes' heating was required to melt the metal and get the alloy ready for pouring at about 1100° C. Chemical analysis showed that the following results were obtained:

TABLE 1.—Iron Content of Specimens.

[Analysis by J. A. Scherrer, associate chemist, Bureau of Standards.]

| Specimen. | Iron content. | Specimen. | Iron content. |
|-----------|---------------|-----------|---------------|
|           | Per cent.     |           | Per cent.     |
| 1.....    | 0.010         | 5.....    | 0.137         |
| 2.....    | .065          | 6.....    | .75           |
| 3.....    | .132          | 7.....    | .35           |
| 4.....    | .141          |           |               |

A quantitative, chemical determination of the nonferrous constituents gave the following averages: Copper, 82.1; tin, 2.89; lead, 0.07; and zinc (by difference), 14.7 per cent. The greatest divergence from these figures was a value of 15.4 per cent for the zinc content of one specimen, a variation of only 0.7 per cent from the mean, so that the composition of the base alloy of the various bars was uniform to a satisfactory degree. If manganese were present in any instance, it might possibly produce a combination



having magnetic properties similar to those of the Heusler alloys. Qualitative tests, however, showed no trace of manganese in any of the samples. The ferrous content was verified in every instance by making another determination on metal from a different part of the specimen. Microscopic examination indicated that the iron present had alloyed with the nonferrous matrix to form about as intimate a mixture as possible in each case. The results from these specimens, therefore, were not complicated by the presence of unalloyed particles of iron.

### III. APPARATUS.

The specimens were magnetized in a solenoid 50 cm (20 inches) long. The concentration of the winding was such that the numerical value of the magnetizing force within the middle portion of the solenoid was approximately 100 times that of the current in amperes. The test coil of 1200 turns was wound on a brass form and extended over about two-thirds of the specimen. The readings of magnetic induction were taken by means of a ballistic galvanometer.

On account of the low susceptibility of the brass bars it was necessary to balance out the magnetizing force in order to attain a reasonable degree of accuracy in the measurements. This was done by connecting the primary of a variable mutual inductance in series with the magnetizing coil while the secondary was connected in series opposition with the test coil. A diagram of connections is given in Figure 1. A storage battery, *E*, furnished the magnetizing current, which was regulated by the resistance *R* and measured with an ammeter *A*. The reversing switch, *C*, served to reverse the direction of the magnetizing current when taking a ballistic deflection. *S* is the magnetizing solenoid, with the test coil *TC*, and *M* is the variable mutual inductance. The sensitivity of the galvanometer, *G*, was controlled by means of the series and parallel resistances, *RS* and *RP*. As all of the coils were wound on brass forms, eddy currents were found to be troublesome, giving a double kick upon reversal of the magnetizing current. In order to obviate this difficulty the magnetizing solenoid was surrounded with another coil *D*, which was short-circuited through a resistance. This resistance could be so adjusted as to eliminate the double kick.

The form upon which the test coil was wound was apparently very slightly magnetic and consequently it was necessary to read-



just the mutual inductance for each value of magnetizing current used. The procedure was as follows: First adjust  $M$  and  $D$  till upon reversal of the magnetizing current there is no deflection of the ballistic galvanometer. Then insert the specimen and note the deflection upon reversal of the current. The deflection is proportional to  $B-H$ . The galvanometer was calibrated by means of the mutual inductance in the usual way, the connections being changed so that the calibrating current did not flow through the magnetizing solenoid.

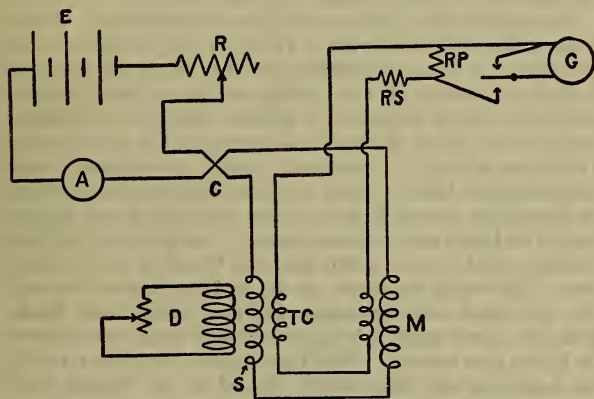


FIG. 1.—Diagram of connections for apparatus for the magnetic testing of brass bars

#### IV. OBSERVATIONS AND RESULTS.

The specimens described above were tested, as cast, with 10 different values of magnetizing force, varying from 25 to 500 gilberts per centimeter. The use of stronger fields was impossible because of the heating of the coils. Samples of the copper and zinc used in preparing the specimens were also tested, but neither they nor the brass bars to which no iron had been intentionally added (specimen 1), gave any readable deflection; so that the method employed, although it would detect susceptibilities as low as  $4 \times 10^{-6}$ , did not indicate paramagnetism in these substances. In the preliminary runs all of the samples were tried out, but the duplicate specimens from the same bar agreed so well that it was considered sufficient, in general, to test only one sample from each

bar. After measurements were made on the specimens in the cast condition, they were annealed; first for 15 minutes at  $625^{\circ}\text{C}$ ., then for 8 hours at  $800^{\circ}\text{C}$ ., and finally for 8 hours more at  $800^{\circ}\text{C}$ ., and cooled slowly with the furnace each time. In the cast condition the samples apparently were quite uniform from one end to the other. After the first 8-hour anneal, however, samples 2, 5, and 7 developed a small difference in susceptibility between the two ends of the bar. This divergence persisted after reannealing. Sample 2 showed the greatest variation, having a difference in susceptibility at the two ends of about 15 per cent.

The accompanying graphs present the results obtained. Figure 2 shows the relation between  $B-H$  and  $H$  for the alloys in the cast state.  $H$  is the magnetizing force in gilberts per cm, while  $B-H$  is the increase in flux density due to the brass (metallic induction), and is expressed in gausses. Figure 3 is a similar graph of the results obtained after annealing the specimens for 15 minutes at  $625^{\circ}\text{C}$ . Samples 2, 3, and 7 are noticeably more magnetic than before. Since this brief heat treatment caused an appreciable change in some of the specimens, it was decided to give the bars a more prolonged anneal. Accordingly, they were loosely packed in clean white sand and heated to  $800^{\circ}\text{C}$ . for 8 hours, after which the results shown in Figure 4 were obtained. The thin black scale (averaging 0.04 mm (0.0015 inch) thick), probably cupric oxide, which then covered them was removed by lightly sand blasting. With the exception of numbers 2 and 3 the specimens were all markedly affected by this thermal treatment. As a further heating might produce yet other changes in the magnetic characteristics, a second 8-hour anneal at  $800^{\circ}\text{C}$ . was given them. There was no material change produced, however, and the results are not shown.

## V. MICROSTRUCTURE.

Since the condition in which the iron existed in the specimens would markedly influence the magnetic effects, it was essential to learn as much as possible about the constitution of the brass tested. The accompanying photographs are all of specimens taken from sample 6, but sections of all the other specimens were examined as well. Figure 5 (a) shows the alloy as cast. The usual dendritic structure of cast metal of this type is the only noticeable feature. Figure 5 (b) represents the appearance after annealing for 8 hours at  $800^{\circ}\text{C}$ . The original cored structure has almost disappeared, showing that the matrix of the metal has

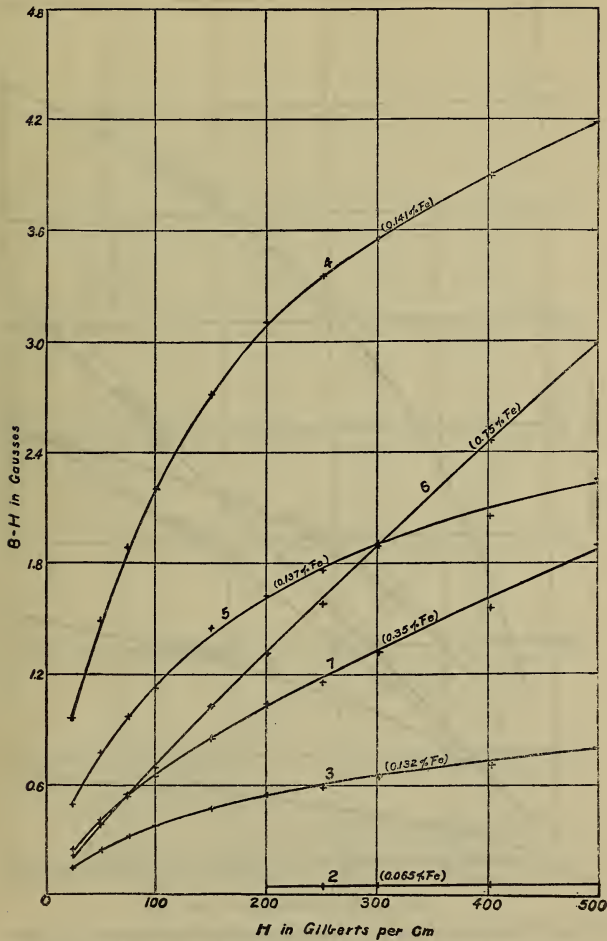


FIG. 2.—The variation of flux density with magnetizing force for specimens as cast

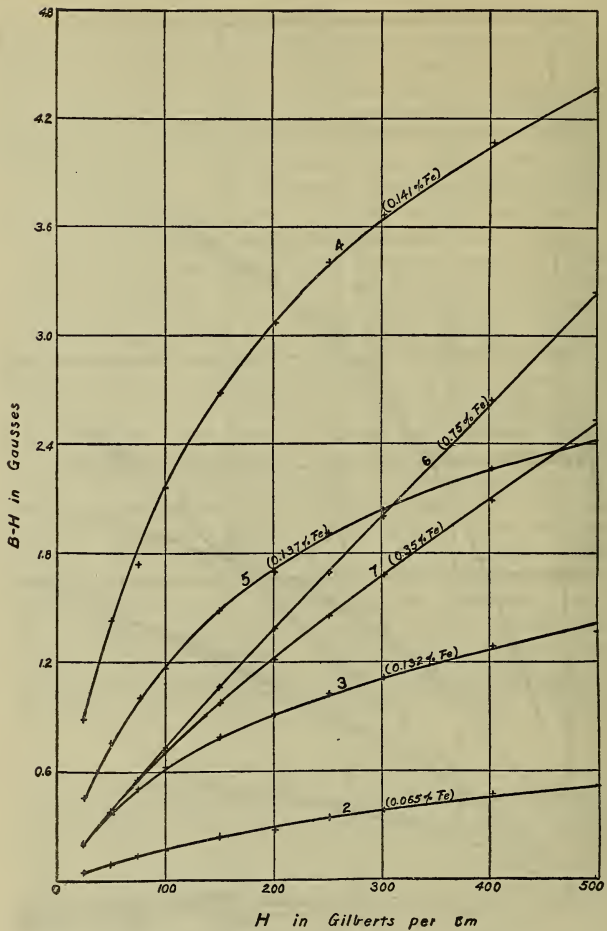


FIG. 3.—The variation of flux density with magnetizing force for specimens after annealing 15 minutes at 625° C

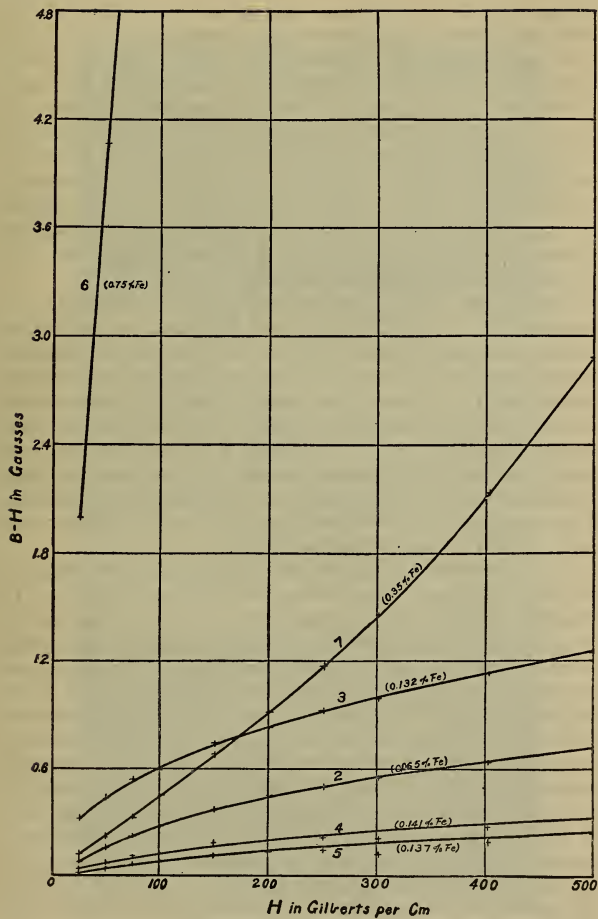


FIG. 4.—The variation of flux density with magnetizing force for specimens after annealing 8 hours at 800° C

become much more uniform in composition. A very thin outside layer (not shown in the picture), in general less than 0.25 mm (0.01 inch) thick, recrystallized into small polygonal grains similar to those formed in worked and annealed alpha brass. This behavior was due to the straining of the outer skin of metal by the cutting tool in turning the specimens to size. Further annealing did not change the structure appreciably. All of the samples contained the numerous dark areas frequently attenuated into mere lines, noticeable in this view (Fig. 5 (b)). These defects are due to oxide inclusions, shrinkage cavities, or gas evolution during the freezing of the metal. At this low magnification (50 diameters) no trace of iron was found.

Figure 5 (c) shows the structure of the cast sample as seen at a magnification of 500 diameters. The light area inclosed in the circle is an iron segregation, while the other light-colored, irregular shaped areas are the eutectoid resulting from the interaction of copper and tin. There is no great difficulty in distinguishing between these two constituents, since the ferrous aggregates are a somewhat darker shade of gray and, unlike the eutectoid, are sharply outlined in the unetched samples. Some minute zinc oxide inclusions<sup>5</sup> were visible in each of the specimens before etching. They were darker in color than the iron segregations, however, and were frequently associated with cavities.

The information available in the literature as to the mode of occurrence of iron in brass and bronze is not very extensive. It is known, however, that a certain small amount, 0.35 per cent in 70-30 brass,<sup>6</sup> goes into solid solution in the matrix of the metal. When present in larger quantities than this, pale, rounded areas of an iron-rich constituent make their appearance. Iron, as an impurity in gun metal (88 copper, 10 tin, 2 zinc), is said to combine with tin and separate out in hard masses,<sup>7</sup> even as little as 0.11 per cent iron making itself known in this way.<sup>8</sup> In the present investigation iron-rich areas, frequently almost circular in shape, were observed only in those samples containing 0.137 per cent or more of iron. These ferrous segregations were quite uniformly distributed over the cross section of the specimen, and since the number and size of these areas increased proportionately with the iron content, it was possible to estimate roughly the per cent of iron present from the microscopic examination.

<sup>5</sup> Comstock, *Jour. Am. Inst. of Metals*, 12, p. 5, 1918; or *Foundry*, 47, p. 79, 1919.

<sup>6</sup> Smalley, *Metal Industry (London)*, 17, p. 421; 1920.

<sup>7</sup> Dewrance, *Journ. Inst. of Metals (British)*, 11, p. 214; 1914.

<sup>8</sup> Primrose, *Metal Industry (London)*, 12, p. 437; 1918.



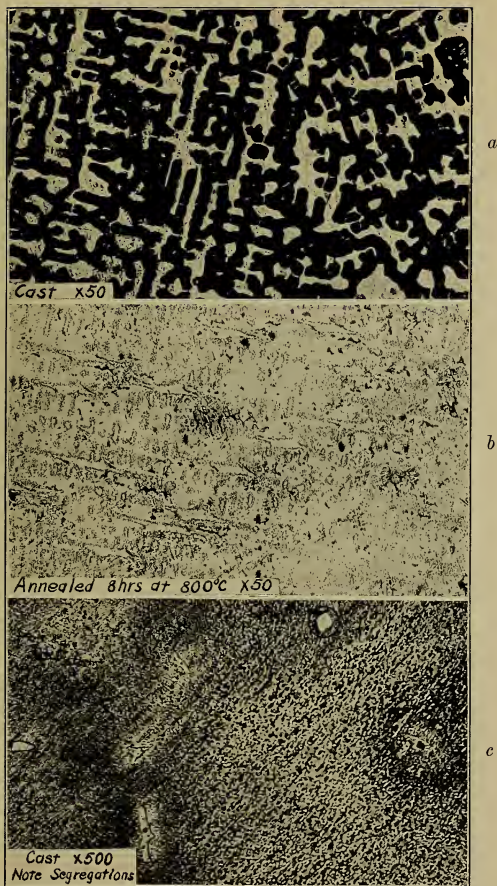


FIG. 5.—Microstructure of specimen 6 (0.75 per cent iron) after etching with ammonium hydroxide plus hydrogen peroxide.

The cored structure of the cast metal largely disappears on annealing. At the higher magnification the iron segregation, inclosed in a circle, and the other light irregular-shaped areas, due to the eutectoid, can be distinguished.





After annealing for 8 hours at 800° C. the eutectoid almost entirely disappeared but the iron-rich constituent was not noticeably affected. In fact, a sample of the brass containing 0.75 per cent iron was heated to 900°C., held there 30 minutes, and quenched in water without any appreciable influence on the ferrous aggregate. On the other hand, when a similar sample was heated to 950° C. and quenched, the iron-rich areas disappeared. They made their appearance again, however, on reheating to the same temperature and cooling slowly. From this behavior it may be seen that these areas do, indeed, represent an iron-rich constituent and not simply particles of undissolved iron. These ferrous areas were identified in a specimen which contained only 0.137 per cent iron and had been heated to 950° C. and very slowly cooled. The solubility of iron in this type of brass is, therefore, less than 0.14 per cent.

As a result of some experimental work on brasses containing iron Smalley<sup>9</sup> concluded that the presence of small amounts of iron produces a finer grain size in alpha brass, both in the cast condition and after it has been worked and annealed. A careful examination of the present series of specimens, however, failed to reveal any definite difference in crystal size that could be attributed to the variation in iron content. The metal of bar 3, at the end farthest from the pouring gate and, therefore, more quickly cooled than the rest of the specimen, was finely crystalline in structure. The end near the gate, nevertheless, contained the usual coarse dendrites. Bar 3 was poured at 1040° C., or about 60° C. below the average casting temperature of these specimens, so that this low temperature, coupled with the chilling effect encountered at the outer end of the bar, may reasonably be accepted as the real cause of the formation of the small crystals. This variation in grain size did not result in any marked difference in the magnetic properties of the two ends of the specimen.

## VI. DISCUSSION.

An examination of the data presented graphically above reveals several interesting points. For instance, Figure 3 shows that the magnetic susceptibility of the cast metal does not vary directly with the iron content. Not only do the curves from the samples of high and low ferrous content seem to be indiscriminately mixed, but their slopes also vary, frequently causing them to cross each

<sup>9</sup> See footnote 6.

other. Then Figures 3 and 4 show that the magnetic properties of the specimens are markedly affected by the changes in physical condition as influenced by heat treatment. Concrete evidence of this fact is furnished by the change in numbers 2 and 3 in the 15-minute anneal and the general shift in the characteristics of almost all the samples in the subsequent 8-hour anneal. Yet it is evident from Figure 4 that, even after this prolonged heating, the susceptibility can not be taken as an index of the iron content.

Figure 6, in which the magnetic susceptibility is plotted against iron content, distinctly shows their lack of correlation. In the cast condition, particularly, there seems to be no direct relation-

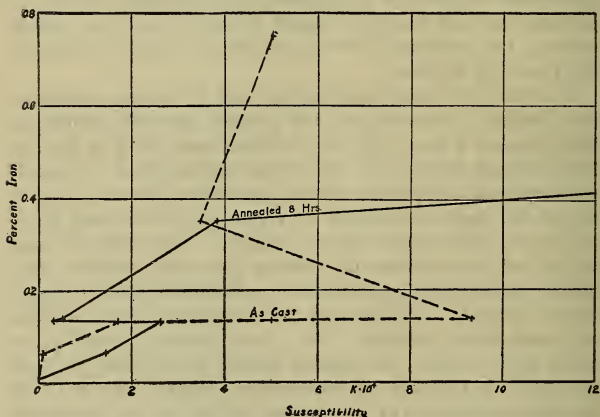


FIG. 6.—The variation of magnetic susceptibility with iron content  $H=300$

ship. The determined points approach a smooth curve much more closely, however, after the specimens have been annealed for 8 hours. Besides this, the break in the curve at 0.14 per cent iron coincides with the initial appearance of the iron-rich constituent in the structure of the metal. The microscopic examination indicated that up to 0.14 per cent the iron occurred as a solid solution in the matrix of the alloy, but with higher ferrous content iron-rich aggregates were also present. The absence of a direct relationship between iron content and magnetic properties is not difficult to account for in view of the two conditions thus shown to exist. The mere difference in the mode of distribution of the iron

would account for wide variations in the observed values of magnetic susceptibility even though the iron had intrinsically identical magnetic properties in the two cases. This is due to the unequal self-demagnetizing effect of ferrous aggregates of different dimensions. The presence of unalloyed iron particles would complicate matters still further. The apparent discontinuity at 0.14 per cent iron can probably be traced to the appearance of the iron-rich constituent previously described.

From the above considerations an explanation of the seeming vagaries of the two curves of Figure 6 can be offered. The points determined for the cast metal did not lie on a smooth curve, because the metal in this case was not representative of equilibrium conditions since the relatively rapid rate of cooling from the casting temperature did not permit a uniform distribution of the constituents of the alloy. This lack of homogeneity resulted in abnormal magnetic properties. The graph of the susceptibility of the annealed samples, on the other hand, may be considered as being made up of two fairly smooth curves. The first, extending from 0 to 0.14 per cent iron, obtains for the condition that the ferrous impurity is all in solid solution. The second, for iron contents of 0.14 per cent or more, applies to those cases where the iron-rich constituent is present. While it is recognized that more extensive data are necessary to really prove this matter of a double curve for the annealed metal, such work was felt to be outside the scope of the present investigation which was primarily concerned with cast brass.

One interesting point to be noted is the change in curvature of the graphs for bar No. 7. It is seen that in Figure 2, for the cast condition, the curve for this specimen is convex upward; while the graph for the same sample after the 8-hour anneal (Fig. 4) is convex downward. In the first case, therefore, the susceptibility decreases with increasing values of magnetizing force, but in the second case it increases.

The iron present in the alloys examined is undoubtedly the cause of the observed magnetic properties since a qualitative test for manganese, which is the essential constituent of the nonferrous magnetic alloys, failed to indicate a trace of this element. In addition to this fact, the iron-free samples were not sufficiently magnetic to evidence a susceptibility that could be measured with the apparatus employed. For iron contents of 0.06 per cent or more, however, an indication was always obtained.

## VII. SUMMARY.

The presence of iron in commercial brass is often objectionable, particularly if it occurs as discrete, poorly alloyed particles. In order to obviate any such harmful effects, a very low ferrous content is frequently specified. Therefore, a rapid, nondestructive method for quantitatively determining its presence would be of great value in practice. A magnetic method of inspection would fulfill the requirements of such a test if a definite relationship exists between some magnetic property and the iron content of the metal. With these facts in mind a study was made of the magnetic characteristics of cast, tin-red brass contaminated with iron.

A series of samples was prepared containing various small proportions of iron up to 0.75 per cent. A small quantity, less than 0.14 per cent, of the iron went into solid solution, but when amounts greater than this were present, an iron-rich constituent made its appearance as pale, rounded areas. The iron content had no noticeable effect on the grain size of the brass.

Magnetic properties were determined in the cast condition and after being annealed 15 minutes at 625° C., 8 hours at 800° C., and 16 hours at 800° C.

From the results of this investigation the following conclusions seem to be warranted:

1. The magnetic properties are not a precise index of the iron content of the cast metal.
2. The magnetic susceptibility is markedly affected by changes in physical condition produced by heat treatment.
3. After the material has been thoroughly annealed there is still no simple relationship between the magnetic susceptibility and the iron content.

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