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C. D. McLAIN

3,039,867

COPPER-BASE ALLOYS

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FIG. 1

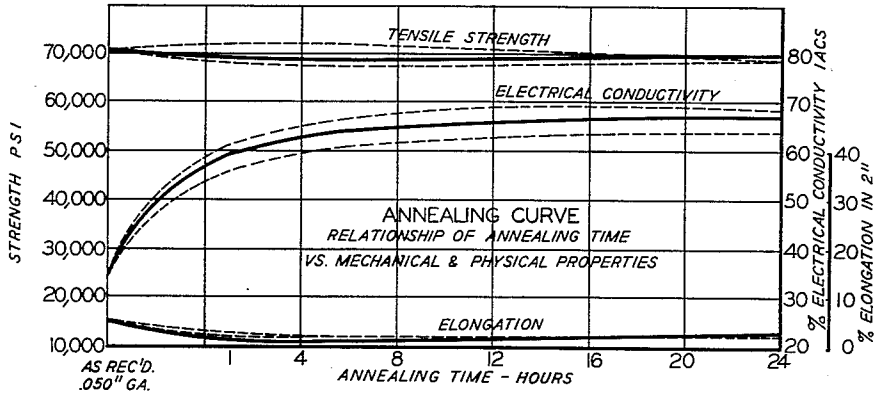


FIG. 2

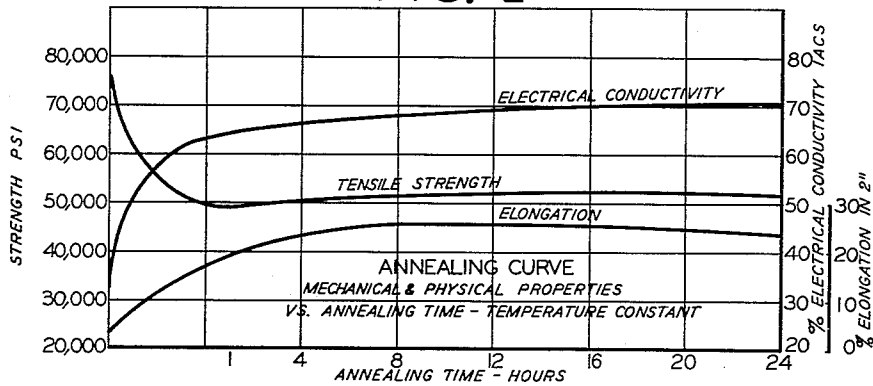
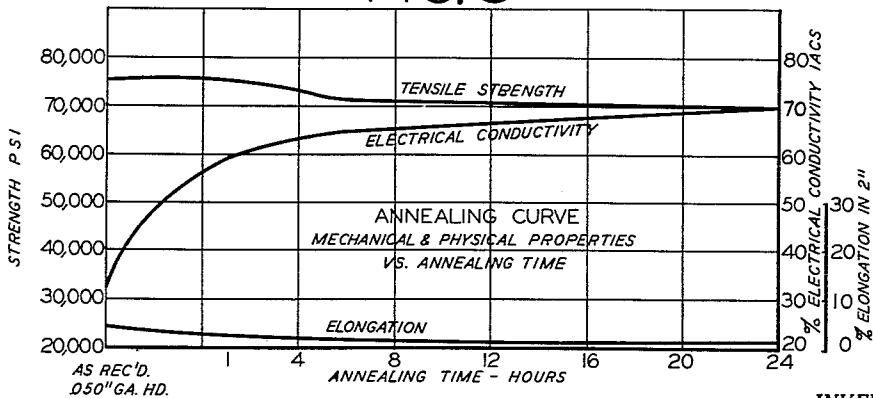


FIG. 3



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COPPER-BASE ALLOYS

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This invention relates to a copper-base alloy and more particularly to an alloy suitable for use for electrical conductors.

Although copper is an excellent conductor of electricity, it is deficient in strength for many applications. Heretofore, it has been proposed to increase the strength of copper by the addition of small amounts of various elements such as tin, iron, cadmium and the like, however, by so doing, electrical conductivity of copper is reduced by marked amounts. Since high conductivity combined with increased strength is desired for various applications, optimum combinations of increased strength with high conductivity have been the subject of extensive research.

Among the elements proposed to be added to copper, iron has been found to greatly increase tensile strength of the resultant alloy, however, rapidly lowering the conductivity of copper to as much as 40% with an iron content of 0.4%, and to a conductivity of 30% for an iron content of 0.7%. It has heretofore been assumed that the reduction of conductivity of copper is directly proportional to the iron content, and accordingly, that large amounts of iron, above 1.0%, should be avoided. However, in spite of the aforesaid disadvantages, the addition of iron imparts to the alloy properties which are desirable if they could be obtained without any prohibitive loss in conductivity. An additional benefit of iron addition to copper is a widening of the temperature range in which the alloy may be treated at low temperatures. Since the presence of iron makes the alloy more stable to variations in temperatures encountered in conventional heat treating furnaces, the iron addition makes it possible to obtain uniform hardness and properties in the alloys. In view of the above advantages, iron has heretofore been proposed to be incorporated with the copper by the addition of other alloying elements to form ternary or higher alloys in order to minimize the loss in conductivity.

Accordingly, it has been proposed to incorporate iron with copper as an iron-cadmium-copper alloy, a nickel-zinc-cadmium-iron-copper alloy and in the form of a manganese-phosphorous-iron and copper alloy. However, the methods heretofore proposed for alloying iron, copper and other elements are extremely difficult to control and highly sensitive to minor variations in chemical analysis, with the alloy having fixed properties of conductivity and strength.

Accordingly, it is an object of this invention to provide an electric conductor composed of relatively inexpensive elements whose properties of conductivity and strength can be varied above a minimum combination of electric conductivity and physical strength.

Another object of this invention is to provide a novel and economical method for obtaining an improved copper-base alloy.

Still another object of this invention is to provide a novel copper-base alloy having a high electrical conductivity combined with a high tensile strength.

A further object of this invention is to provide a novel copper-base alloy having increased resistance to softening.

A still further object of this invention is to provide an improved electric conductor formed largely of copper which is more easily fabricated.

Other objects and advantages of the invention will be-

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come more apparent in the following description and drawings in which:

FIGURE 1 is a graph illustrating the relationship between electrical conductivity, tensile strength and elongation of the alloy which is one embodiment of this invention and subjected to varying solution annealing temperatures and precipitation treatments.

FIGURE 2 is a graph illustrating the relationship between electrical conductivity, tensile strength and elongation when the alloy which is another embodiment of this invention after subjecting to a series of operations, hereinafter described; and

FIGURE 3 is a graph illustrating the relationship between electrical conductivity, tensile strength and elongation when the alloy of this invention is subjected to an additional operation to those employed for FIGURE 2.

It has been discovered that the above objects may be accomplished in accordance with this invention by providing, as the metal for the conductor, an alloy composed of 2.0% to 3.0% iron, phosphorous to a maximum content of 0.04% with the balance copper. A preferred composition of the alloy in accordance to this invention is a composition consisting of 0.02% to 0.04% phosphorous, 2.1% to 2.6% iron and 97.3% to 97.8% copper as the balance. With the compositions of this invention, alloys can be obtained having a tensile strength greater than 50,000 p.s.i. and a conductivity greater than 50% IACS (International Standard for Annealed Copper) an elongation greater than 5% and a resistance to grain growth at a temperature of about and above 1300° F. for a period of time up to eight seconds. With the preferred composition, an alloy was obtained having electrical conductivity of approximately 70% IACS with a tensile strength exceeding 50,000 p.s.i., and an elongation exceeding 5% minimum and was able to withstand rapid heating to 1300° F. for a period of eight seconds without recrystallizing to a grain size greater than 0.020 mm.

Although the phosphorous may be present in the alloy from a maximum 0.04% to a minimum limit consisting of at least a trace, it is essential that the phosphorous be present, even though in minute amounts. Accordingly, in the composition described above and hereinafter, the phosphorous content ranges from a trace to 0.04%.

Further, with the phosphorous present within the aforesaid limits, it has been found the iron must be present with the range of 2.0% to 3.0% if the prescribed minimum limits of electrical conductivity and strength are to be obtained. Variation in either the iron content or phosphorous content from the prescribed combined limits produces alloys in which the conductivity and/or the strength is unalterably below the prescribed minimums, that is, either the conductivity will fall below 50% and/or the tensile strength will be below 50,000 p.s.i.

In addition, the alloys obtained in accordance with this invention can be readily worked to alter the proportion of tensile strength to electrical conductivity to provide a specific combination of properties, desired for specific applications well above the minimum of 50,000 p.s.i., and 50% electrical conductivity. Also, with the alloys of this invention, the electrical conductivity can be held at a fairly high percent while mechanical properties are varied by cold working procedures. Thus, in accordance with this invention, a versatile alloy is obtained whose properties may be varied to yield varied combinations of tensile strength and electrical conductivity.

The importance in the discovery of the critical limits required of the components in the alloy of this invention is evidenced in the versatility and capability of the novel alloy in having its properties of tensile strength and electrical conductivity varied, at will, above the prescribed

minimum combined limits of 50,000 p.s.i. tensile strength and 50% electrical conductivity. This versatility of the alloy permits its use in various applications heretofore thought impossible for a single copper alloy. These applications range from use in electrical transmission lines to current carrying contact members in various electrical devices. Although various copper alloys containing iron and phosphorous have been known, the alloy of this invention and the critical limitations thereof have not heretofore been disclosed. Accordingly, as a part of the present invention, it has been determined that in order to obtain the aforesaid versatility and combined high tensile strength and high electrical conductivity, it is critical that the phosphorous be present at or below a maximum of 0.04% together and with iron present in a range of 2.0% to 3.0% by weight.

In the fabrication of the alloy of this invention, it is preferred to cast the alloy into billets of conventional size, subjecting them to hot working, as by rolling in the conventional size. Although hot working alone has been found to be sufficient to obtain a solution of the iron and copper in the preferred process, the billet after hot working, may be subjected to a solution anneal to insure that a solution of the iron and copper is complete. The alloy is then precipitation treated by annealing at low temperatures to increase its electrical conductivity. Thereafter, the alloy is cold worked, as by rolling or drawing, to finished size and to increase its tensile strength, during which the electrical conductivity remains relatively constant.

By way of example, a series of castings 1/2 inch thick were formed of an alloy composed of copper 97.7%, iron 2.2% and phosphorous 0.026% to 0.027%, and rolled at 900° C. to different thicknesses, of 0.05 inch to 0.025 inch gauge, without annealing. It was found that solution annealing although optional, if desired as noted above, is not a necessary treatment if the hot rolling is carried out at a temperature of 900° C.

The rolled bars were then given a precipitation treatment at various temperatures and times, and tests made thereon for tensile strength and electrical conductivity. The results are tabulated in Table 1. Thereafter each bar after the precipitation treatment was then cold rolled to a 50% reduction and tests were again carried out to determine the corresponding tensile strength and conductivity as set forth below in Table 1.

Table 1

Bar	Precipitation Treatment, Temp. ° C. and Time in Hrs.	Without Reduction		With 50% Reduction by Cold Rolling	
		Tensile Strength, p.s.i.	Percent Conductivity	Tensile Strength, p.s.i. min.	Percent Conductivity
1-----	480 at 24 hrs---	50,400	70.1	68,900	67.9
2-----	480 at 24 hrs---	50,700	70.2	70,400	66.8
3-----	480 at 40 hrs---	49,000	72.0	68,500	69.9
4-----	480 at 40 hrs---	52,300	71.5	72,000	69.3
5-----	480 at 48 hrs---	51,300	73.5	68,400	70.2
6-----	480 at 48 hrs---	51,000	71.4	71,400	68.4
7-----	550 at 8 hrs---	49,000	62.4	67,100	60.6
8-----	550 at 8 hrs---	50,100	62.0	70,800	58.8
9-----	550 at 16 hrs---	48,400	63.4	67,800	61.5
10-----	550 at 16 hrs---	49,700	63.8	71,200	60.3
11-----	550 at 24 hrs---	47,100	63.8	67,500	63.0
12-----	550 at 24 hrs---	49,400	64.5	70,100	60.7
13-----	600 at 8 hrs---	47,600	57.6	67,200	55.2
14-----	600 at 8 hrs---	48,600	56.4	68,700	53.8
15-----	600 at 16 hrs---	47,400	56.4	67,000	54.1
16-----	600 at 16 hrs---	47,600	55.4	68,300	54.4
17-----	600 at 24 hrs---	46,600	56.9	66,400	55.5
18-----	600 at 24 hrs---	47,600	56.3	69,100	54.7

As can be seen from the above table, by selection of the temperature at which the alloy is precipitation treated, alone or combined with further cold working, any variation of properties may be imparted into the alloy. As can be further seen, electric conductors prepared in the manner described above can be obtained having a minimum tensile strength of 50,000 p.s.i. to as high as 71,

000+ p.s.i. with conductivity well above 50%, with values exceeding 70%.

The production of electric conductors in accordance with this invention can further be varied as compared with the examples given above. For example, a casting 1 1/2 inches thick can be obtained of an alloy composed of 2.3% iron, 0.023% to 0.024% phosphorous and remainder copper, hot rolled to reduce the bar to 0.200 gauge with further cold rolling to obtain a thickness of 0.05 inch. The alloy was then annealed to effect a complete solution of the various elemental components at varying temperatures of 700°, 800° and 900° C. The alloy is then cold rolled to further reduce the metal to 0.025 inch in thickness, and precipitation treated at 480° C. for various lengths of time. After precipitation treating, the alloy is then cold rolled to 0.0125 inch in thickness. The results of this last example are shown in FIGURE 1 which correlates the tensile strength of the alloy with the electrical conductivity and the elongation. As can be seen by observation of FIGURE 1, the alloy has after a short period of precipitation treatment has an electrical conductivity exceeding well above 50% with a tensile strength above 65,000.

To further illustrate the versatility of the novel alloy obtained in accordance with this invention, another casting 1 1/2 inches thick was formed of an alloy composed essentially of 2.3% iron, 0.024% phosphorous with the remainder essentially copper, heated to 900° C. and hot rolled to a thickness of 0.200 inch. The bar was then cold rolled to a thickness of 0.025 inch. A series of samples were then taken from the bar and annealed at 480° C. for a varying length of time, as indicated in FIGURE 2, and tested for electrical conductivity and tensile strength. The results obtained are illustrated in FIGURE 2, having conductivity extending to above 70% with tensile strength above 50,000 p.s.i.

As is seen, a solution of the components, of the alloy of this invention, can be obtained either by subjecting the alloy to sustained heat above 700° C. or by hot rolling the cast alloy at 900° C. Accordingly, hereinafter and in the claims, the hot working of the alloy at 900° C. is deemed the equivalent of the annealing operation above 700° C.

The remainder of the annealed samples were then further cold rolled to a thickness of 0.0125 inch and again tested for electrical conductivity and tensile strength with the results illustrated in FIGURE 3.

As can be seen by the above, although optimum properties of combined tensile strength and electrical conductivity can be obtained by a precipitation treatment, low temperature anneal followed by cold working, as by rolling, the cold working operation may be omitted to give combined tensile strength and electrical conductivity above 50,000 p.s.i. and 50% conductivity. By reference to FIGURE 2, graphically illustrating the results obtained by a final operation consisting of a low temperature annealing, a sample annealed for 24 hours at 480° C. can be seen to have a tensile strength of approximately 52,000 p.s.i. and an electrical conductivity of 71%. If a corresponding sample is further cold worked to 0.025 inch in thickness, the sample is found to have a 70,000 p.s.i. tensile strength and a 70% electrical conductivity. In like manner, a sample with only a final anneal has a 52,000 p.s.i. tensile strength and a 69+ % conductivity which upon being subjected to additional cold working is found to have its tensile strength increased to approximately 71,000 p.s.i. with only a slight decrease in electrical conductivity to a value of 67%.

Although in the last described example, the amount of cold working was performed to an extent of 50%, it has also been found that after precipitation treatment by annealing at the desired temperature, approximately 450° to 600° C., the strength of the metal can be altered to give increased tensile strength while maintaining the electrical conductivity fairly constant.

Although a 50% reduction has been set forth in the

examples given above, it is to be understood that the reduction may be varied, with the above specific value of 50% setting the preferred amount of reduction. Further, although rolling has been specifically applied as a means of working the alloy, it is to be understood that it is intended to include other operations which result in altering dimensions in a mass of metal as produced by drawing, extruding or the like.

The low temperature annealing step is essential to obtaining the advantages of high electrical conductivity and tensile strength. It is believed that during the initial high temperature annealing, of approximately 900° C., the iron is completely in solution within the copper. When the alloy is subjected to the low temperature annealing operation, i.e., 480° C., the iron is precipitated from solution to form in the boundaries of the grains of the alloy and during the precipitation it is modified by the presence of the phosphorous to give increased conductivity with corresponding decrease in the strength of the alloy to above 50,000 p.s.i. tensile strength. The alloy may then be fabricated into the shape required for specific applications or may be further strengthened to increase the tensile strength of the metal by conventional cold working operations.

The specific function of the phosphorous is not understood, however, it is believed that it, both, does alloy with the iron, and does act as a dioxidizer. Irrespective of the function of the phosphorous in the alloy, to obtain a conductor having desirable properties of combined high tensile strength and high electrical conductivity, it is essential that the phosphorous be present from a minute or residual amount to a maximum of 0.04%.

Although it is preferable that the alloy consist essentially of iron, phosphorous and copper, it is to be understood that when it is stated that the alloy consists essen-

tially of iron, phosphorous and copper, that small amounts of impurities may be permitted in the alloy, provided such impurities are not present in sufficient amount to deleteriously alter the conductivity, strength and other desirable properties of the alloy.

Although the invention has been described with reference to specific embodiments, materials and details, various modifications and changes will be apparent to one skilled in the art and are contemplated to be embraced within the invention.

What is claimed is:

1. A copper-base alloy consisting essentially of 2.1% to 2.6% iron, a trace to a maximum 0.04% phosphorous and balance copper.

2. A copper-base alloy consisting essentially of 2.1% to 2.6% iron, 0.024% to 0.04% phosphorous and remainder copper.

3. A copper-base alloy consisting essentially of 2.3% iron, 0.023% to 0.024% phosphorous and balance copper.

4. A copper-base alloy consisting essentially of 2.3% iron, 0.024% phosphorous and balance copper.

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