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ELECTRICAL CONDUCTOR

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My invention relates to electrical conductors and more particularly to electrical conductors made from copper and copper-base alloys of high copper content.

5 The object of my invention is to provide a metallic electrical conductor which is more easily fabricated and which has better properties than the conductors hitherto used.

10 Copper is by far the most important of all metals and alloys as a material for conductors. Silver has a lower resistance to the flow of electricity and heat but it is relatively expensive. Aluminum sometimes finds application as a material for certain types of conductors because, 15 although its resistance is higher, its specific gravity is less than one-third that of copper and, therefore, a conductor with a higher conductance for a given weight may be made. The disadvantages of aluminum are greater average cost, 20 poor resistance to corrosion by certain atmospheres, and greater bulk. Some other metals and alloys used as conductors for special purposes are iron, nickel, tungsten, chromium-nickel alloys, low melting white metals, and platinum.

25 Ordinary tough pitch electrolytic copper is really an alloy of approximately .02% to .12% by weight of oxygen, balance copper with traces of impurities. In the present-day, electrolytically refined copper the quantities of impurities 30 are of the order of thousandths and tenths of thousandths of a percent by weight. Fire refined copper may contain slightly higher percentages of impurities; the Lake brands may carry relatively large proportions of silver and in some 35 cases, arsenic. Typical compositions are given in Table I.

TABLE I

	Electro-lytic	Fire re-fined	Lake
40 Silver.....	.0007	.0074	.03
Arsenic.....	.0009	.0024	.0025
Antimony.....	.0009	.0031	.0005
Lead.....	.0014	.0002	.0006
45 Iron.....	.0026	.0015	.0025
Nickel.....	.0021	.0218	.0015
Selenium.....	.0001	.0071	.0000
Tellurium.....	.0001	.0007	.0036
Bismuth.....	.0000	.0001	.0000
50 Sulphur.....	.0021	.0042	.0015
Oxygen.....	.0350	.0441	.0420

55 For some purposes, to be discussed below, it is necessary to remove the oxygen from copper and thereby obtain deoxidized copper. This is accomplished by treating the copper in the molten state with a strong reducing agent. The

oxygen in the copper apparently combines with the reducing agent and passes off as slag or vapor. Among the more common reducing agents employed in deoxidizing copper are phosphorus, silicon, manganese, and calcium. The excess of these elements, necessary to make the reaction go to completion, alloys with the copper. Other reducing agents such as carbon, carbon monoxide, boron suboxide, and calcium boride do not alloy with the copper and, therefore, do not add to the impurities present.

The electrical conductivity of copper and copper alloys is usually expressed as a percentage of the conductivity of the International Annealed Copper Standard, abbreviated % I. A. C. S. A conductivity of 100% I. A. C. S. at 20° C. corresponds to a resistivity of 1.7241 microhm-centimeter at the same temperature. This was the average resistivity of the best commercial coppers at the time the standard was set up in 1913. 20 With the continual improvement in the quality of copper, it is not uncommon at the present time to find specimens with a resistivity less than 1.7241 microhm-centimeter so that conductivities of more than 100% I. A. C. S. frequently are 25 reported. Thus 101% I. A. C. S. is the conductivity of copper with a resistivity of 1.7070 microhm-centimeter at 20° C.

The conductivity of copper is influenced strongly by impurities in the metal. Their effect 30 on the conductivity is not what might be predicted on the basis of the relative volume of copper and impurities and the conductivities of the individual elements concerned, because foreign elements in quantities small enough to be regarded as impurities are, at least in part, in solid solution in the copper. Unfortunately the presence of even what might be called minute quantities of impurities greatly lowers the conductivity. 35 Some elements have more effect than others as is shown in Table II.

TABLE II

Effect of 0.1% of various elements on the conductivity of copper

[Conductivity of commercial copper, 100 to 101% I. A. C. S.]

Element added	Electrical conductivity % I. A. C. S.
45 Silver.....	99.8
Aluminum.....	88.1
Phosphorus.....	54.6
Silicon.....	65.5
50 Manganese.....	88.0

As may be seen from Table II the practical deoxidizing agents which alloy with copper greatly lower the electrical conductivity.

The most important reason for deoxidizing copper is that when oxygen-bearing copper is heated in a reducing atmosphere, such as those encountered in brazing, welding and sealing copper into glass in the manufacture of vacuum tubes, the copper is embrittled. Experiment has proved that the embrittlement results from the presence of oxygen in the copper. Copper which has been deoxidized absorbs oxygen when heated in air unless a comparatively large excess of residual deoxidizer remains. Therefore, it may behave the same as oxygen-bearing copper when heated in reducing atmospheres. Thus even though a copper may have been deoxidized in casting, it still can pick up oxygen in subsequent hot rolling and annealing operations.

Conductors made from oxygen-bearing copper have a satisfactory conductivity but they fail by embrittlement immediately upon being heated in a reducing atmosphere. Deoxidized copper conductors with either a small trace or no residual deoxidizer have a fair conductivity but are likely to pick up oxygen during fabrication into wire, bus bars, tubes, and the like. Coppers with a large amount of residual deoxidizer do not absorb oxygen readily but they have a low conductivity.

I have found that I can overcome all of these difficulties by making conductors from an alloy free from oxygen and containing 0.01% to 0.15% boron, balance copper. The conductivity of these copper-boron alloys depends upon the boron content. For example, with .011% boron I obtain a conductivity of 100.3% while with .113% boron I obtain a conductivity of 92.3%. To illustrate the resistance of my alloy to a reducing atmosphere, I annealed samples of .128" diameter wires of boron-copper alloys containing various percentages of boron and also a sample of the copper used to make the alloys in a hydrogen atmosphere for 1/2 hour at 800° C. and then subjected them to bend tests. In this test the boronized copper failed after fourteen 180° bends over an 8 m. m. radius, but the plain copper failed on the second bend. It is well known that copper containing oxygen is embrittled by heating in a reducing atmosphere but this test shows that as little as .011 excess of boron prevents embrittlement.

In another test I annealed together in hydrogen samples of an oxygen-free, high conductivity copper containing no residual deoxidizer and samples of my high conductivity boron-copper alloy, and found that both the copper and my alloy resisted embrittlement. When, however, I exposed another group of samples of the same two materials to air at a temperature of 850° C. for one hour, and then reannealed them in hydrogen the copper failed at two bends while my boron-copper still withstood fourteen bends without breaking. This shows that only one short anneal in air in the fabrication of a copper conductor without the boron would result in embrittlement when the metal is heated in a reducing atmosphere.

Copper deoxidized with silicon, with phosphorus, and with calcium also resist the embrittling effect of annealing alternately in oxidizing and reducing atmospheres to a certain extent. Their conductivities, however, are of the order of 60 to 80%, while my boron-copper alloys, with the same or better resistance to embrittlement, have conductivities of at least 95%. A

further advantage of the boron-copper alloys over calcium deoxidized copper, for example, is that their ductility, particularly at elevated temperatures, is as high as that of pure, undeoxidized copper.

The effect of boron on the conductivity of copper is very small as compared to that of all other elements except possibly silver which, of course, has no deoxidizing action. Therefore, it is possible to add to the molten copper, the amount of boron required to completely deoxidize it plus considerable excess without fear of adversely affecting the electrical conductivity. The effect of deoxidizers like phosphorus is so great that the slightest excess over that required to reduce the oxides lowers the conductivity of the copper greatly. There are so many variables involved in producing deoxidized copper on a commercial scale that frequently lots are found which are either not completely deoxidized, or which are even lower in conductivity than the average for this type of copper. Boron, on the other hand, may be added in sufficient excess to preclude any possibility of incomplete deoxidation and without fear of obtaining a low conductivity.

In practicing my invention, to secure highest conductivity I melt the copper and add to it a certain portion of a boron-copper alloy containing 2% to 5% of boron. I may also add the boron by one of the methods described in my copending application Serial No. 183,471 for boron-copper alloy and a method of producing it. If the boron is introduced by adding to the melt the other commercially available boron-bearing materials such for example as manganese-boron, ferroboron, and the like, the conductivity is lowered because these materials introduce the elements with which the boron is associated.

After the melt has been poured into a suitable mold to produce wire bars, ingots, cakes, billets, or other suitable castings, I may work it by forging, hammering, hot rolling, cold rolling, drawing, swaging, extruding, and pressing into sheet, rod, cables, profiles, wire, tube and other forms suitable for use in fabricating conductors.

Conductors made from, or bonded with, or coated with, the boron-copper alloys, as described, are particularly valuable in the manufacture of electric incandescent and luminescent lamps, and rectifiers, and in any articles such as radio, X-ray, and photo-electric tube, in which it is necessary to seal a copper conductor in glass. In applications where it is necessary to solder, braze, or weld a conductor, boron-copper is an ideal material because of its resistance to the embrittling effect of the torch gases and because of the fluxing action of the borate slag which may be formed. The presence of boron in copper also improves its strength so the alloy can profitably be used for all types of conductors which might be made from any kind of copper even though in some applications the resistance to embrittlement due to heating in reducing atmospheres might not be of great importance in these particular applications. It is well known that the thermal conductivity of alloys has a definite relation to electrical conductivity, so it follows that the boron-copper alloys are well adapted for parts of heat exchangers exposed to reducing gases where the alloys of copper and of other metals are not sufficiently conducting.

Although as indicated above a content of boron from .01% to .15% is sufficient for most purposes, the boron content may be as high as 1% for applications where lower electrical conductivity may

be permissible but high resistance to embrittlement when heated in a reducing atmosphere may be desirable.

For highest electrical conductivity boron alone should be used with the copper, but where lower conductivity is permissible small amounts of other deoxidizers may be added to the copper with the boron. Such materials are for example beryllium, aluminum, manganese, magnesium, calcium and lithium. For example, with commercial electrolytic copper containing 0.05% boron and 0.05% manganese the electrical conductivity would be about 91% which is lower than it would be with 0.1% boron alone (about 93% conductivity) and better than it would be with 0.1% manganese alone, which is about 87% conductivity. The presence of the small amounts of these other deoxidizers does not interfere with the action of the boron in increasing the resistance to embrittlement when the conductor is heated in a reducing atmosphere, or an alternating oxidizing and reducing atmosphere. For the usual commercial applications the boron content should be at least 0.01%, and for a conductivity not less than 85% the content of the other deoxidizers (one or more) should be not over 0.1%.

Having thus set forth the nature of my invention, what I claim is:

1. A conductor for electricity formed from an alloy composed of boron .01% to 0.15%, and balance copper.

2. A conductor characterized by increased resistance to the effect of reducing gases at elevated temperatures which is formed from an alloy of .01% to 1% boron, and balance substantially all copper.

3. A conductor characterized by increased resistance to the embrittling effect of reducing gases and an electrical conductivity of at least 90% I. A. C. S. which is formed from an alloy of boron .01% to .15%, and balance substantially all copper.

4. A conductor formed from copper deoxidized with boron, boron having been added to the copper in sufficient excess so that it is not embrittled by heating in hydrogen for one hour at 800° C., but in insufficient amount to reduce the conductivity below 90% I. A. C. S.

5. A conductor for electricity composed of a copper alloy characterized by high electrical conductivity and high resistance to embrittlement when heated in a reducing atmosphere, comprising .01% to .15% of deoxidizer including boron or at least .01% boron in combination with other deoxidizers, and balance copper.

6. A conductor for electricity composed of a copper alloy comprising from .01% to 1% of deoxidizer including boron or boron in combination with other deoxidizer with at least .01% boron and not more than .1% of the other deoxidizer, and balance copper.

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