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HIGH CONDUCTIVITY TIN-BEARING ALUMINUM ALLOY

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This invention relates to aluminum alloy and particularly to an aluminum alloy having high electrical conductivity. The new alloy is particularly characterized by the presence of a small but significant amount of tin in an aluminum base of electrical conductivity grade.

In the transmission of electric power the consumption of electrical energy in the power lines is proportional to the electrical resistance of the said lines so that any reduction in the electrical resistivity of the material from which the conductors of the transmission lines are drawn will result in energy savings.

In the case of aluminum conductors it has been known that an increase in the purity of the aluminum metal from which the conductors are drawn will result in an increase in electrical conductivity, but, at the same time a decrease in tensile strength. Reduction of tensile strength of conductors is objectionable, particularly for overhead transmission lines, because such a reduction requires shorter spans and a concomitant increase in the number of transmission line towers or poles.

It is a particular object of my invention to provide an aluminum alloy for fabrication into conductors having increased electrical conductivity without significant reduction in tensile strength.

Electrical conductivity is customarily expressed on a volume basis, as a percentage of the conductivity of the International Annealed Copper Standard, abbreviated IACS. Thus, very pure aluminum is known to have an electrical conductivity in excess of 64% IACS, and the industrial conductivity requirement for electrical conductivity (EC) grade aluminum is 61% IACS. The difference between the electrical conductivity of very pure aluminum and the conductivity of EC grade aluminum is due to the presence of small quantities of other elements normally present as impurities. A typical analysis of commercial EC grade aluminum suitable for electrical conductor showed the following impurities (percentages by weight): 0.20% iron, 0.07% silicon, 0.002% copper, 0.003% manganese, 0.001% magnesium, 0.001% titanium, 0.002% vanadium, 0.02% zinc, and 0.002% nickel. Other impurities frequently present are chromium, molybdenum, and zirconium.

It has been known that the addition of small percentages (such as 0.01 to 0.2%) of boron has the effect of counteracting some or all of the loss of conductivity induced by the impurities chromium, titanium, zirconium, molybdenum, and vanadium. Preferably, the boron has been added in an amount within the limits 0.02 to 0.05% by weight.

Further efforts to increase the conductivity of aluminum by the addition of alloying elements have failed and resort has been had to the reduction in the percentage of impurities. Reduction in impurities, on the other hand, has the effect of reducing tensile strength below industry requirements. As an example of such a requirement, the American Society for Testing Materials (abbreviated ASTM) Designation B230–58 for Hard Drawn Aluminum Wire for Electrical Purposes, specifies a minimum average of 27,000 p.s.i. (pounds per square inch) for wire 0.1000 inch in diameter.

I have discovered that the electrical conductivity of EC grade aluminum is increased by the addition of small percentages of tin. Particularly, I have discovered that aluminum in which the conductivity has been improved by the addition of boron can be further improved by the addition of a small quantity of tin.

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The impurity most universally present in greatest quantity in commercial electrical grade aluminum is iron. The complete removal of iron, besides being commercially unfeasible, results in an aluminum of relatively low tensile strength. Aluminum with an iron content in excess of 0.45% by weight would not normally be satisfactory for electrical conductivity grade and aluminum with an iron content as low as 0.05% by weight has its conductivity improved by the addition of tin in accordance with this invention. The presence of at least 0.05% iron is advantageous to improve the tensile strength of the alloy.

The addition of tin in quantities as low as 0.002% by weight will have a noticeable effect on increasing the conductivity of commercial aluminum. A tin content above 0.3% by weight, however, results in hot-shortness to a degree that might effectively prevent hot rolling. The new alloy may contain any amount of tin between these limits. However, preferred limits of tin addition, depending in part on the impurities present, are from 0.01 to 0.1% by weight.

Preferably also the new alloy contains from 0.02 to 0.05% by weight boron, and at least 0.05% by weight iron. Wires cold worked from the new alloy to a diameter less than 0.1 inch possess a tensile strength substantially meeting or exceeding the above mentioned ASTM standard of 27,000 p.s.i., and possess an electrical conductivity generally in excess of 62% IACS.

The new high conductivity aluminum alloy may be made by any desired procedure. For example, it may be made by introducing the desired quantity of tin into molten aluminum of EC grade when the metal is melted for casting into wire bars, or at any other convenient time. The desired amounts of boron and iron may be present in the EC grade aluminum used, or may be added (or supplemented) by additions of master boron-aluminum or iron-aluminum alloy concurrently with the tin. Alternatively, all or some of the tin, boron and iron may be added by electrolytic reduction from a tin, boron or iron compound present in the alumina charge to the reduction pot in which the aluminum metal is originally produced.

High conductivity aluminum alloys according to the invention, prepared as described above or otherwise, contain at least 99.5% by weight of aluminum, and preferably at least 99.6% by weight of aluminum, together with from 0.002% to 0.3% by weight tin and, preferably, from 0.02% to 0.05% by weight boron and upwards of 0.05% by weight iron. They are readily fabricated by conventional procedures into wires and other forms of electrical conductors. For example, cast bars of the alloy may be hot rolled into rods, and such rods may be cold drawn to wire of the desired final size.

Following are specific examples of aluminum alloys prepared in accordance with the invention:

To each of two batches of EC grade aluminum of similar impurity content were added about 0.026% by weight boron, by the introduction of borax into the alumina charged to the reduction pot cells. To one of the boron-containing batches was added about 0.045% by weight tin, by means of the addition of metallic tin to the molten metal in the holding furnace from which wire bars were cast. This tin-bearing metal is hereinafter referred to as "tin-alloy." The other boron-containing aluminum alloy is referred to as "regular." The wire bars cast from both batches of aluminum were hot rolled into rods ⅜ inch in diameter. Half the tin-alloy rod was rolled to an H–12 temper and half to an H–14 temper. In like manner half the regular rod was rolled to an

H–12 temper and half to an H–14 temper. (These temper designations are industry standards. ASTM designation B–233 defines H–14 temper as having a tensile strength of 14–20,000 p.s.i. and H–12 temper as having a tensile strength of 12–17,000 p.s.i.)

Both the regular and the tin-alloy in both the H–12 and H–14 temper were drawn into wires of different sizes and the conductivities and tensile strength measured, with the results set forth in Table I (conductivity and tensile strength for each wire size is the average of from three to twelve individual samples).

Table I

Alloy	Wire Size	Rod Temper	Conductivity, Percent IACS	Tensile Strength, p.s.i.
Regular	.0772	H–12	62.23	28,667
Do	.1052	H–12	62.26	27.860
Do	.1327	H–14	62.19	26,758
Do	.1878	H–14	62.20	24,633
Average for four sizes			62.22	27,128
Tin alloy	.0772	H–12	62.32	29,600
Do	.1052	H–12	62.42	27,550
Do	.1327	H–14	62.32	26,850
Do	.1878	H–14	62.35	25,075
Average for four sizes			62.35	27,269

The grand average of conductivities of wire drawn from tin-alloy rod is seen to be 0.13% greater than the average of wire drawn from regular rod. Table I illustrates also that the addition of tin had the surprising result of increasing both the conductivity and the tensile strength.

A coil of H–14 tin-alloy rod and a coil of H–14 regular rod, both ⅜ inch in diameter, were drawn down to 0.1327 inch hard aluminum wire. Prior to drawing into wire, the conductivity of the tin-alloy rod was measured and found to be 62.5% IACS. Correspondingly, the conductivity of the regular rod was 62.45% IACS. Conductivity and tensile strength of the wire so drawn were measured with the following result:

Table II

Sample No.	Tensile Strength		Conductivity, Percent IACS	
	Regular	Tin-Alloy	Regular	Tin-Alloy
1	26,500	26,700	62.1	62.2
2	26,200	26,500	62.1	62.3
3	26,100	27,500	62.1	62.2
4	26,100	27,000	62.1	62.2
Average	26,225	27,175	62.1	62.225

It is to be noted that the conductivity of the tin-alloy decreased proportionately less than that of the regular alloy as a result of drawing to wire of smaller size, while its tensile strength increased proportionately more.

Similar results were obtained when ⅜ inch rods of H–12 tin-alloy and H–12 regular alloy were drawn to a diameter of 0.0772 inch. The tensile strengths and conductivities of the wire so drawn are set forth in Table III.

Table III

Sample No.	Tensile Strength		Conductivity, Percent IACS	
	Regular	Tin-Alloy	Regular	Tin-Alloy
1	29,200	29,600	61.9	62.0
2	29,600	29,800	61.9	62.0
3	29,000	29,600	62.0	62.0
4	29,000	29,600	61.9	62.0

When coils of H–14 rod were measured for conductivity, the values set forth in Table IV were obtained.

Table IV

Sample No.	Conductivity, Percent IACS	
	Regular	Tin-Alloy
1	62.35	62.45
2	62.30	62.50
3	62.45	62.50
4	62.45	62.50
Average	62.3875	62.4875

I claim:

1. A high conductivity aluminum alloy comprising at least 99.5% by weight aluminum, from 0.002 to 0.3% by weight tin, at least 0.05% by weight iron, and impurities normally present in aluminum of electrical conductivity grade, said composition having an electrical conductivity of at least 62% IACS.

2. A high conductivity aluminum alloy comprising at least 99.6% by weight aluminum, from 0.01 to 0.1% by weight tin, at least 0.05% by weight iron, and impurities normally present in aluminum of electrical conductivity grade, said composition having an electrical conductivity of at least 62% IACS.

3. A high conductivity aluminum alloy comprising at least 99.5% by weight aluminum, from 0.002 to 0.3% by weight tin, at least 0.05% by weight iron, and impurities normally present in aluminum of electrical conductivity grade, said composition having when cold worked into wire less than 0.1 inch in diameter a tensile strength exceeding 27,000 p.s.i. and an electrical conductivity of at least 62% IACS.

4. A high conductivity aluminum alloy comprising at least 99.5% by weight aluminum, from 0.002 to 0.3% by weight tin, from 0.02 to 0.05% by weight boron, at least 0.05% by weight iron, and impurities normally present in aluminum of electrical conductivity grade, said composition having when cold worked into wire less than 0.1 inch in diameter a tensile strength exceeding 27,000 p.s.i. and an electrical conductivity of at least 62% IACS.

5. A high conductivity aluminum alloy consisting essentially of at least 99.6% by weight aluminum, from 0.01 to 0.1% by weight tin, at least 0.05% by weight iron, and impurities normally present in aluminum of electrical conductivity grade, said composition having when cold worked into wire less than 0.1 inch in diameter a tensile strength exceeding 27,000 p.s.i. and an electrical conductivity of at least 62% IACS.

6. A high conductivity aluminum alloy consisting essentially of at least 99.6% by weight aluminum, from 0.01 to 0.1% by weight tin, from 0.02 to 0.5% by weight boron, at least 0.05% by weight iron, and impurities normally present in aluminum of electrical conductivity grade, said composition having when cold worked into wire less than 0.1 inch in diameter a tensile strength exceeding 27,000 p.s.i. and an electrical conductivity of at least 62% IACS.

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