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BORON-CONTAINING ALUMINUM WIRE AND
METHOD OF ITS PRODUCTIONRaymond T. Whitzel and William E. King, Mas-
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This invention relates to aluminum wire used for conducting an electric current and more specifically it is concerned with wire which has a better combination of strength and electrical conductivity than has been available heretofore.

Aluminum has been used many years for transmitting electric power, one of the most outstanding examples of this character being overhead transmission lines. For this and similar purposes it has been necessary to use aluminum of relatively high purity in order to obtain close to the maximum electrical conductivity of which the metal is capable. Metal of the required purity is commonly referred to as conductor grade aluminum, which has a minimum aluminum content of 99.45%, the balance being composed of small amounts of well known elements such as iron, silicon, copper and the like. In wire made of this high purity metal the electrical conductivity is improved if the wire is annealed after it has been drawn.

However, the wire in the annealed condition has a lower tensile strength than wire which has not been thus annealed. Inasmuch as conductor wires are generally subjected to some stress in service, it is desirable to provide strength greater than that found in the annealed product. Hence, it is customary to omit a final anneal and use the wire in the cold drawn condition. Annealing the rod from which the wire is to be made is beneficial to the conductivity of the wire, but since cold working of aluminum reduces its electrical conductivity to some extent, the benefit is not as great as if the drawn wire were annealed. As a result, for commercial purposes, an electrical conductivity below the potential maximum has been accepted in order to gain the requisite strength. For these reasons a minimum average electrical conductivity equal to 61% of the International Annealed Copper Standard (hereinafter referred to as the IACS) on a volume basis has been specified for aluminum conductor wire. This wire is supplied commercially in sizes of about 0.050 to 0.210 inch in diameter and it is this size range with which this invention is concerned.

It is the principal object of this invention to provide cold worked aluminum conductor wire made from non-annealed rod having as high a tensile strength as has been available heretofore, but with a higher electrical conductivity. Another and more specific object is to provide a cold drawn aluminum wire having a higher minimum tensile strength without decrease in electrical conductivity than it has been possible to obtain by previous fabricating procedures. An-

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other object is to provide a method of fabricating wire having high strength accompanied by improved electrical conductivity.

We have found that these objects can be realized by adding from about 0.001 to 0.5% boron to the conductor grade aluminum and cold working the hot rolled rod without any annealing or softening operation. Our invention is directed to both the improved wire product and a method of making the same. In practice we have discovered that an average tensile strength of at least 26,000 p. s. i. is obtained in all commercial wire sizes if the reduction in cross-sectional area by cold working from the hot rolled rod exceeds about 65% and at the same time the wire has an electrical conductivity above 61% and usually over 61.5%. The latter minimum conductivity value is preferred. This advantage is particularly evident in the larger wire sizes where the minimum average specified tensile strengths have been as low as 24,000 p. s. i. It will be appreciated, of course, that an increase in tensile strength can also be obtained in the smaller wire sizes with no loss in electrical conductivity. In general, at least as high tensile strength is obtainable in wire containing boron within the above specified range and produced from hot mill rod which is not annealed as has been obtained in wire containing no boron made from annealed rod and in addition the conductivity is improved. It will be understood that the tensile strength and conductivity values mentioned are average values of at least several tests.

The boron content of the conductor metal as mentioned previously may range between 0.001 and 0.5 per cent, the concentration selected for any particular case being determined to some extent by the conductivity desired. To obtain any significant benefit from the boron at least 0.001% should be employed while on the other hand there appears to be no advantage in using more than 0.5 per cent. Particularly favorable results are obtained by using .007 to .08% of the element. The boron may be added in any of the known manners, for example, in the form of a boron-rich alloy or by decomposition of a boron-containing compound.

In producing the cold drawn wire, the metal is melted in the usual manner and cast into convenient form for rolling such ingots or wire bars. These are heated to a suitable hot working temperature of say 650–850° F. and then rolled on conventional rod mills. Generally, the ingots or bars are of such a size that they can be directly rolled to a rod diameter adapted to start the wire drawing operation. However, larger ingots can be utilized and the hot rolling operation in-

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interrupted, for example, to permit cutting the billet into short lengths or reheating to gain proper working characteristics. The hot rolling operation is conveniently carried to the point where a rod of about $\frac{3}{8}$ inch diameter is produced. The temperature of this rod leaving the mill may be lower than at the beginning of the rolling operation and preferably is within the range of about 300–700° F. Control of the finishing temperature is helpful in obtaining the desired strength in the subsequent cold drawn wire. Regardless of the finishing temperature the rolling of the ingot or billet to rod form is considered to be a hot rolling operation, particularly since a major portion of the rolling is done within the conventional hot working range for aluminum. Moreover, for the purpose of this invention, the product of this portion of the fabrication procedure is regarded as a hot mill product. The rod may be, and generally is, allowed to cool to room temperature before effecting further reduction by cold working.

The rod is next subjected to conventional cold working operations to produce the desired size of wire. Contrary to previous practice of annealing the rod within a temperature range of about 400 to 700° F. just prior to cold working which causes at least some softening, the hot rolled rod containing boron is not subjected to any annealing treatment before, during, or after cold working. The practice of annealing the rod before drawing is herein referred to as intermediate annealing. The omission of any such treatment at this stage in fabrication of the wire is essential to the development of the required tensile strength in the finished wire. For this reason, the wire is referred to herein as non-annealed wire. The cold working is most conveniently and accurately accomplished by cold drawing the rod through conventional dies. To obtain a minimum average tensile strength of 26,000 p. s. i. in the wire it is necessary to effect at least a 65% reduction in cross-sectional area of the rod by the cold working operation. Greater reductions are made to produce the majority of the common commercial wire sizes. Such reductions of course serve to bring about further increase in strength, but reductions in excess of about 99% are not employed. An increase in tensile strength is particularly evident where the reduction exceeds 90%, and yet the conductivity is higher than that in the wire produced by the former practice which included an anneal.

As previously mentioned, the finishing temperature on the hot mill bears a relationship to the tensile strength developed by cold working. The lower the finishing temperature, the smaller is the amount of cold work necessary to produce the minimum tensile strength requirement. Thus, a low finishing temperature is desirable in making larger wire sizes, and conversely a higher finishing temperature is useful where small sized wire is produced. The selection of the proper finishing temperature may be made after a few simple tests. The characteristics and layout of one rolling mill may indicate that a certain combination of finishing temperature and subsequent cold working is the most efficient and economical one to employ for producing a given size of wire whereas a different combination may be most practicable on another mill. In any case, however, it will be found to be advantageous under most conditions to control the hot mill finishing temperature and relate it to the subsequent cold working operation.

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An important advantage which has been gained by the use of our invention, especially in making the smaller wire sizes, in addition to a reduction in time and cost of fabrication, is that of greater uniformity in tensile strength and electrical conductivity. In the product of the former practice which included an annealing operation, particularly when the annealing was done in the lower portion of the temperature range, considerable variation in those properties occurred from lot to lot of wire, since the annealing was not generally carried to the point of producing complete softness, i. e. relief of all work hardening strains. Such limited softening was useful in obtaining the desired strength in the final wire product. The variation attributable to annealing has been reduced to a minimum by the omission of the annealing operation in fabricating the boron-containing conductor metal.

The improved properties which characterize our new product are illustrated in the following examples. In each instance the conductor metal ingot was rolled to $\frac{3}{8}$ " diameter rod on the hot mill at a finishing temperature of at least 300° F.

EXAMPLE 1

The effect of boron upon electrical conductivity is shown by the following comparison between average test results on large and medium sized cold drawn wire where the $\frac{3}{8}$ " diameter rod was not annealed prior to the drawing operation. The 0.105" dia. wire underwent a reduction of about 92% by drawing while the 0.188" dia. wire had a reduction of about 75%. One group contained no boron while the second had 0.04% of this element present.

TABLE I

Effect of boron upon electrical conductivity

Dia. of Wire, Inches	No Boron, Conductivity, Per Cent I. A. C. S.	Boron Present, Conductivity, Per Cent I. A. C. S.
0.105	60.92	61.74
0.188	60.70	61.67

It is quite evident that the boron addition has not only increased the conductivity above the 61% minimum but it has raised the value by a significant amount.

EXAMPLE 2

The effect of annealing upon average properties of wire of three sizes is shown below. In the first group, containing no boron, the rod was given the conventional annealing treatment whereas the boron-containing material (nominal 0.04% boron) was not annealed.

TABLE II

Effect of annealing upon strength and electrical conductivity

Dia. of Wire, Inches	Annealed, No Boron		Not Annealed, Containing Boron	
	T. S., p. s. i.	Conductivity, Per Cent I. A. C. S.	T. S., p. s. i.	Conductivity, Per Cent I. A. C. S.
0.077	29,840	61.62	31,880	61.74
0.097	28,400	61.62	29,410	61.78
0.188	26,120	61.56	26,940	61.67

From these values it will be seen that cold working the rod containing no boron without any anneal has served to raise the tensile strength and at the same time the conductivity has been improved. Although the differences in properties between the two groups, especially in conductivity, may appear to be unimportant they are significant, nevertheless, since they are based upon a large number of tests.

EXAMPLE 3

The variation in properties in the smaller size of wire may be illustrated by comparison of averages for tensile strength and conductivity of conductor wire 0.077" in diameter produced over an extended period. Wire which contained no boron and which had received an intermediate anneal showed a variation of 2700 p. s. i. in tensile strength between the maximum and minimum values, and the conductivity varied over a range of 0.32%. In contrast, non-annealed boron-containing wire produced over a similar period of time exhibited a variation of but 300 p. s. i. in tensile strength and the conductivity was within a range of 0.19%.

It will be understood that the foregoing represent embodiments of our invention and that various modifications may be made all within the scope of the appended claims. The expression, aluminum conductor wire, as herein employed refers to conductor wire made from aluminum of not less than 99.45% purity.

We claim:

1. An electrical conductor wire of conductor grade aluminum cold drawn to a diameter of 0.210 inch or less containing from 0.001 to 0.5 per cent boron, said wire being cold drawn from hot rolled rod without any anneal of said rod or wire, the amount of boron being sufficient that the wire will have an electrical conductivity of not less than 61 per cent of that of the International Annealed Copper Standard on a volume basis and an average tensile strength of at least 26,000 p. s. i. for wire drawn to a diameter of 0.210 inch and an increasingly higher strength for wires drawn to smaller diameters.

2. An electrical conductor wire of conductor grade aluminum cold drawn to a diameter of 0.210 inch or less containing from 0.001 to 0.5 per cent boron, said wire being cold drawn from hot rolled rod without any anneal of said rod or wire, the amount of boron being sufficient that the wire will have an electrical conductivity of not less than 61.5 per cent of that of the International Annealed Copper Standard on a volume basis and an average tensile strength greater than that of conductor grade aluminum wire devoid of boron drawn to the same size from hot rolled rod which has received an intermediate anneal, said average tensile strength being at least 26,000 p. s. i.

3. An electrical conductor wire of conductor grade aluminum cold drawn to a diameter of 0.210 inch or less containing from 0.007 to 0.08 per cent boron, said wire being cold drawn from hot rolled rod without any anneal of said rod or wire, the amount of boron being sufficient that the wire will have an electrical conductivity of not less than 61.5 per cent of that of the International Annealed Copper Standard on a volume basis and an average tensile strength of at least 26,000 p. s. i. for wire drawn to a diameter of 0.210 inch and an increasingly higher strength for wires drawn to smaller diameters.

4. The method of producing cold drawn aluminum conductor wire comprising hot rolling a body of conductor grade aluminum containing from 0.001 to 0.5 per cent boron to rod size, cold drawing said rod to the final size of wire of 0.210 inch or less, without any anneal of said rod or wire, with a reduction of at least 65 per cent, the amount of boron being sufficient that the wire will have an electrical conductivity of not less than 61 per cent of that of the International Annealed Copper Standard on a volume basis and an average tensile strength of at least 26,000 p. s. i. for wire drawn with said minimum reduction and an increasingly higher tensile strength for greater reductions.

5. The method of producing cold drawn aluminum conductor wire comprising hot rolling a body of conductor grade aluminum containing from 0.001 to 0.5 per cent boron to rod size and maintaining the finishing temperature of said rod within the temperature range 300 to 700° F., cold drawing said rod to the final size of wire of 0.210 inch or less, without annealing said rod or wire, with a reduction of at least 65 per cent, the amount of boron being sufficient that the wire will have an electrical conductivity of not less than 61 per cent of that of the International Annealed Copper Standard on a volume basis and an average tensile strength of at least 26,000 p. s. i. for wire drawn with said minimum reduction and an increasingly higher tensile strength for greater reductions.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,252,421	Straup	Aug. 12, 1941

FOREIGN PATENTS

Number	Country	Date
141,367	Switzerland	Oct. 1, 1930