

[54] **PROCESS FOR OBTAINING ALUMINUM ALLOY CONDUCTOR**

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**Related U.S. Application Data**

[60] Division of Ser. No. 92,289, Nov. 23, 1970, Pat. No. 3,711,339, which is a continuation-in-part of Ser. No. 66,067, Aug. 21, 1970, abandoned, which is a continuation-in-part of Ser. No. 885,315, Dec. 15, 1969, abandoned, which is a continuation-in-part of Ser. No. 715,552, March 25, 1968, abandoned.

[52] U.S. Cl. .... **72/364, 72/700, 148/11.5 A**

[51] Int. Cl. .... **B21c 9/02**

[58] Field of Search ..... **72/364, 700; 148/11.5 A; 75/143**

[56]

**References Cited**

**UNITED STATES PATENTS**

|           |         |                      |          |
|-----------|---------|----------------------|----------|
| 3,697,260 | 10/1972 | Hunsicker.....       | 148/11.5 |
| 3,219,492 | 11/1965 | Anderson et al. .... | 148/11.5 |
| 3,512,221 | 5/1970  | Schoerner.....       | 75/143   |
| 2,572,562 | 10/1951 | Harrington.....      | 148/12.7 |
| 1,932,795 | 10/1933 | McCullough .....     | 75/143   |

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[57]

**ABSTRACT**

An improved aluminum alloy conductor. The conductor is characterized by a combination of good mechanical and electrical properties and contains from 0.04 to 1.0 percent iron, 0.02 to 0.2 percent silicon, 0.1 to 1.0 percent copper, 0.001 to 0.2 percent boron, balance essentially aluminum.

**6 Claims, No Drawings**

## PROCESS FOR OBTAINING ALUMINUM ALLOY CONDUCTOR

### CROSS REFERENCE TO RELATED APPLICATIONS

This application is a division of application Ser. No. 92,289, by Fred A. Besel and William C. Setzer for "Aluminum Alloy Conductor" filed Nov. 23, 1970, now U.S. Pat. No. 3,711,339, which in turn is a continuation-in-part of application Ser. No. 66,067, by Fred A. Besel and William C. Setzer for "Aluminum Alloy Conductor," filed Aug. 21, 1970, now abandoned, which in turn is a continuation-in-part of application Ser. No. 885,315, by Fred A. Besel for "High Conductivity Aluminum Alloys," filed Dec. 15, 1969, now abandoned, which in turn is a continuation-in-part of Ser. No. 715,552, by Fred A. Besel for "Super-Strength, High Conductivity Aluminum Alloys," filed Mar. 25, 1968, now abandoned.

### BACKGROUND OF THE INVENTION

The present invention relates to the art of electrical conductors.

It is highly desirable to obtain high strength and high conductivity aluminum alloy conductors with excellent formability, that is, with the capability of taking many reverse plastic bends and manipulations, etc., without cracking. One may readily appreciate that it is highly desirable commercially to obtain wire having the foregoing characteristics and to obtain it at a reasonable cost.

The foregoing is particularly important in communication wire. In this application, high conductivity is important; however, electrical grade (EC grade) aluminum having high conductivity often has low strength or is susceptible to elevated temperature strength degradation and room temperature creep and relaxation. This naturally has an adverse effect on mechanical electrical contacts.

The higher strength alloys which overcome the foregoing strength deficiencies are generally deficient with respect to electrical conductivity.

High purity aluminum can only be moderately strengthened by cold working; likewise, cold working causes a loss in formability.

However, there are many applications where the excellent formability is not critical, as, for example, in overhead electric transmission lines. In these applications, it is important to achieve a combination of high strength and high conductivity in order to reduce the number of supporting line poles or line towers. Thus, in these applications, it is important to achieve a combination of high strength and high conductivity.

Accordingly, it is a principal object of the present invention to provide improved aluminum base alloy conductors.

It is a further object of the present invention to provide improved aluminum alloy conductors which are characterized by a combination of high strength and high conductivity.

It is a still further object of the present invention to provide improved conductors as aforesaid which have excellent formability or ductility.

An additional object of the present invention is to provide an improved conductor which satisfies the foregoing objectives and which is obtainable at a reasonable commercial cost.

### SUMMARY OF THE INVENTION

In accordance with the present invention it has now been found that the foregoing objects and advantages may be readily obtained. The present invention provides improved conductors comprising an aluminum base alloy conductor having a diameter between 0.002 and 0.375 inch containing from 0.04 to 1.0 percent iron, from 0.02 to 0.2 percent silicon, from 0.1 to 1.0 percent copper, from 0.001 to 0.2 percent boron, balance essentially aluminum.

The iron, silicon and boron alloying additions are substantially contained in the matrix in a dispersion of extremely fine precipitate.

The copper addition is substantially present in solid solution.

Thus, the conductor of the present invention has impurity and the alloying elements, except for copper, precipitated throughout the matrix. The copper addition is present as a solid solution addition to provide some solid solution strengthening of the matrix rather than as a dispersion or precipitation hardening agent as is normally the case for this addition.

One conductor of the present invention achieves high strength and high conductivity in combination with excellent formability. In this case, the diameter would generally be between 0.002 and 0.125 inch and the copper content should be maintained between 0.1 and 0.4 percent and the boron content should be maintained between 0.001 and 0.1 percent.

It has been found that the foregoing conductor readily achieves the objectives of the present invention and attains high strength and high conductivity in combination with excellent formability. Formability may be characterized as a combination of ductility and bendability at a sufficiently high strength level such that the material may be distorted from its original shape or formed into a new shape without fracture. Thus, in its most flexible form, i.e., the fully annealed condition, the conductor of the present invention has a minimum IACS conductivity of 60 percent and readily obtains a minimum tensile strength of 16,000 psi and an elongation in excess of 10 percent. Further, the tensile strength of the wire in the annealed condition can be increased to 18,000 psi, the yield strength to 16,000 psi, by an additional wire reduction with almost no measurable loss in conductivity or formability, and with an elongation in excess of 2 percent. This reduction is limited to about 25 percent. Greater reductions cause a decrease in formability in the cold worked wire.

The tensile properties of heavily cold worked material are significantly higher than those of the annealed material; however, cold worked material has significantly less mechanical formability. Hence, with very large cold reductions one may achieve mechanical strengths of at least about 42,000 psi tensile strength in combination with at least 57 percent IACS electrical conductivity, but with an elongation of about 2 percent and limited formability.

Alternatively, when excellent formability is not a prerequisite, another conductor of the present invention has an excellent work hardening rate which may be used to achieve a combination of higher strength and high conductivity. In this case one obtains an improved combination of strength and conductivity. Thus, one may obtain increased conductivity at strength levels comparable to conventional materials or conversely in-

creased strength levels at conductivities comparable to conventional materials or variations therebetween. For example, the conductivity is at least 57 percent IACS and the tensile strength may be, for example, at least 48,000 psi at 0.081 inch gage. The material having these properties is capable of passing the conventional wrap test (ASTM-B-398-67). The material having said excellent combination of strength and conductivity should be processed in the following manner:

- A. provide an aluminum base alloy bar containing from 0.04 to 1.0 percent iron, 0.02 to 0.2 percent silicon, 0.1 to 1.0 copper, 0.001 to 0.2 percent boron, balance essentially aluminum;
- B. deform said material at least 10 percent at a temperature of 400°F up to 950°F; and
- C. cold deform said material to final gage with a reduction of at least 75 percent and preferably at least 90 percent.

#### DETAILED DESCRIPTION

As stated hereinabove, the conductors of the present invention may be obtained having a good combination of strength and conductivity with excellent formability or alternatively some formability may be sacrificed in order to obtain an excellent combination of strength and conductivity.

The first portion of the specification will discuss that modification which obtains high strength and high conductivity with excellent formability.

#### CONDUCTOR HAVING HIGH STRENGTH, HIGH CONDUCTIVITY AND EXCELLENT FORMABILITY

As stated hereinabove, this conductor of the present invention contains iron in an amount from 0.04 to 1.0 percent and preferably from 0.1 to 0.3 percent. The silicon content ranges from 0.02 to 0.2 percent. Too high a silicon content causes loss in conductivity. The preferred silicon range is from 0.02 to 0.1 percent. The copper content may range from 0.1 to 0.4 percent and is preferably present in an amount from 0.25 to 0.35 percent. The boron is present in an amount from 0.001 to 0.1 percent. The balance of the alloy is essentially aluminum.

Small amounts of magnesium, zirconium, manganese and chromium or other elements may be added for particular reasons, such as added strength or thermal stability; however, these materials adversely affect electrical conductivity and additions should be limited on this basis. Titanium may be added as a grain refiner in amounts less than the stoichiometric quantity necessary to form  $TiB_2$  and in an amount such that electrical conductivity is not materially affected. Similarly, conventional impurities may be tolerated in amounts such that electrical conductivity is not materially affected.

In addition to the solid solution hardening provided by the copper, it is significant that the conductor of the present invention contains a dispersion of extremely fine precipitate of the iron, silicon and boron alloying additions. The precipitate acts as a hardening dispersion, at the same time depleting the matrix of solute to critical levels in order to retain high conductivity.

This conductor of the present invention is provided in wire form having a diameter of from 0.002 inch to 0.125 inch. This conductor may be readily employed in industrial conductor sizes in the range of B and S gages including transmission, communication and building

wire. The conductor may be readily employed advantageously as a single strand conductor, as a multi-stranded conductor or a stranded conductor in combination with alloys or EC grade aluminum or a steel wire core.

This conductor of the present invention may be processed in accordance with conventional techniques. Thus, the alloy may be cast in a conventional manner. The as-cast billet may then be deformed to rod in a conventional manner, such as by rod rolling. The rod may then be drawn to gage or drawn, annealed and drawn to gage.

Thus, this conductor of the present invention can be processed in accordance with conventional or specialized techniques for processing communications wire, transmission wire, building wire, etc. The advantages of this conductor of the present invention resides in its critical chemistry which yields the desired combination of conductivity, strength and formability.

As indicated hereinabove, this conductor of the present invention is characterized by several advantages, especially a combination of good strength, conductivity and formability.

Formability may be measured or determined by a free loop bend test wherein a two inch length of, for example, 0.020 inch wire is pushed together and pulled apart repeatedly. If this can be done 10 times without failing as by cracking, the wire has satisfactory formability. The wire of the present invention has formability such that generally above 15 free loop bends can be performed even when the elongation is low. Normally a substantially higher number can be performed.

It is a particular advantage of the present invention that the highly desirable characteristics of the instant conductor are obtained with ease of manufacture.

Thus, this conductor of the present invention is useful in a wide variety of applications and is especially useful for building wire or communications wire where its high formability allows a high level of bendability. Furthermore, the presence of fine precipitate to stabilize the mechanical properties will provide a significant improvement in room temperature relaxation or creep which has been found to be troublesome in terminal connections involving spring or set screw clamping devices.

The precipitated particles present before annealing assist the nucleation of recrystallization during the anneal, hinder grain growth, and prevent exaggerated grain growth which would be particularly deleterious to formability. The alloy content (primarily that in solid solution) and fine grain size both serve to cause an initially higher strength level in the annealed wire, and both, together with the precipitated particles, an increased work hardening rate. Further the small grain size causes any local deformation to be redistributed over many small grains and thus over a greater volume of material. All of these factors interact synergistically to cause a significant increase in formability.

#### CONDUCTOR HAVING EXCELLENT COMBINATION OF STRENGTH AND CONDUCTIVITY

As stated hereinabove, one of the conductors of the present invention may be obtained which achieves an excellent combination of strength and conductivity. This conductor contains iron in an amount from 0.04 to 1.0 percent and preferably from 0.5 to 1.0 percent.

The silicon content ranges from 0.02 to 0.2 percent and preferably 0.02 to 0.1 percent. The copper content may range from 0.1 to 1.0 percent and preferably 0.35 to 0.5 percent. The boron is present in an amount from 0.001 to 0.2 percent. The balance of the alloy is essentially aluminum. Small amounts of zirconium, magnesium, manganese, and chromium or other elements may be added for particular improvements, such as added strength or thermal stability; however, these materials adversely affect electrical conductivity and additions should be limited on this basis. Titanium is a preferred addition as a grain refiner in an amount less than the stoichiometric quantity necessary to form  $TiB_2$  and in an amount such that the electrical conductivity is not materially affected, in amounts generally less than 0.5 percent. Zirconium and magnesium are preferred additions for thermal stability. Magnesium also increases the work hardening rate. Zirconium is generally present in amounts less than 0.1 percent and magnesium less than 0.2 percent. Similarly, conventional impurities may be tolerated in amounts such that the electrical conductivity is not materially affected.

In this modification, as in the previous modification, the conductor contains a dispersion of extremely fine precipitate of iron, silicon and boron alloying additions, with the copper addition being substantially present in solid solution.

For this modification, the conductor is provided in wire form having a diameter from 0.002 to 0.375 inch, that is, improvement is obtained up to large diameters including redraw rod. Most often, the wire diameter is from 0.060 to 0.200 inch.

As stated hereinabove, the particular advantage of this modification is that due to the high work hardening rate an excellent combination of strength and conductivity is obtained. Thus, by cold working, one may readily achieve improved strength at conductivity levels comparable to conventional materials or improved conductivity at strength levels comparable to conventional materials. In both cases, the material is capable of passing the standard wrap test referred to hereinabove which involves wrapping the wire around itself without fracture. In fact, the conductor of the present invention readily passes this test at high strength levels and is readily capable of being wrapped around itself a plurality of times.

The basis for the excellent characteristics of the conductor of the present invention is that the chemistry of the material provides an increased work hardening rate. Therefore, less work is required to achieve a given strength level. In addition, as will be apparent, the conductor of the present invention is subjected to a large amount of cold work.

Thus, in accordance with this modification, the alloy may be cast in a conventional manner. The as-cast billet or bar may or may not be homogenized, if desired, for example, at  $930^\circ F \pm 40^\circ F$  for eight hours or more.

The material is deformed at an elevated temperature above  $400^\circ F$ , preferably above  $600^\circ F$  and at a temperature up to  $950^\circ F$ . This hot or warm deformation step has been found to be important in obtaining the desired properties.

The material is then cold deformed directly to gage. The material is cold deformed to a reduction of at least 75 percent and preferably at a reduction of at least 90 percent in order to obtain high mechanical properties. Naturally, the amount of cold reduction required to

achieve a given strength level is dependent upon the particular chemistry and the hot rolling profile.

The present invention will be more readily apparent from a consideration of the following illustrative examples.

#### EXAMPLE I

A  $2 \times 2 \times 7$  inches billet was prepared in a conventional manner having the following compositions: iron 0.18 percent, silicon 0.06 percent, boron 0.015 percent, copper 0.25 percent, balance essentially aluminum. The billet was hot rolled from  $750^\circ F$  without reheating to  $\frac{1}{8}$  inch redraw rod. The material was drawn to 0.29 inch and annealed for 24 hours at  $550^\circ F$ . The material was then drawn to wire having a diameter of 0.021 inch and given an anneal of short duration which fully recrystallized the material. Properties were determined on the fully recrystallized material which are given in the table below. The material was then given an additional small amount of cold work — between about 4 and 12 percent and the properties determined on this material. These properties are also given in the table below.

Both the fully recrystallized material and the fully recrystallized and cold worked material were characterized by having a fine grain size, high strength, high conductivity and excellent formability. The iron, silicon and boron were substantially present as a dispersion of extremely fine precipitate and the copper was substantially present in solid solution.

The properties are shown in the table below.

TABLE  
Fully Recrystallized

| UTS<br>(ksi)                         | Y.S.<br>(ksi) | Elong.<br>(%) | Free<br>Loop<br>Bends | Cond.<br>%<br>IACS | Grain<br>Size<br>(mm) |
|--------------------------------------|---------------|---------------|-----------------------|--------------------|-----------------------|
| 17.5                                 | 7.2           | 19            | 10-24                 | 62.1               | 0.008-0.016           |
| Fully Recrystallized and Cold Worked |               |               |                       |                    |                       |
| UTS<br>(ksi)                         | Y.S.<br>(ksi) | Elong.<br>(%) | Free<br>Loop<br>Bends | Cond.<br>% IACS    | Grain<br>Size<br>(mm) |
| 18.5                                 | 17.8          | 7             | 10-25                 | 61.7               | 0.008-0.016           |

#### EXAMPLE II

Several  $2 \times 2 \times 7$  inches billets were prepared in the conventional manner having the following nominal compositions: iron 0.6 percent, silicon 0.04 percent, boron 0.01 percent, copper 0.4 percent, balance essentially aluminum. All the materials were homogenized at a temperature of  $930^\circ F$  for 8 hours. All billets were then hot rolled to  $\frac{1}{8}$  inch redraw rod with an entry temperature of  $850^\circ F$  and an exit temperature of  $375^\circ F$ .

One billet was then given a cold deformation reduction of 75 percent from 0.365 inch to 0.182 inch. The material had an ultimate tensile strength of 36,000 psi and a conductivity of over 59 percent. The second material was given a cold deformation of 90 percent from 0.365 inch to 0.114 inch and had an ultimate tensile strength of 39,000 psi and a conductivity of over 59 percent. A third bar was given a cold deformation of 95 percent from 0.365 inch to 0.081 inch and had an ultimate tensile strength of 48,000 psi and a conductivity of over 59 percent IACS.

All materials successfully passes the wrap test. In all cases the iron, silicon and boron were substantially present as a dispersion of extremely fine precipitate and the copper was substantially present in solid solution.

### EXAMPLE III

Two additional billets were prepared and processed in the same manner as Example II except that they were hot rolled to 0.660 inch gage instead of being hot rolled to  $\frac{3}{8}$  inch redraw rod.

One sample billet was cold deformed from 0.660 to 0.182 inch and had resultant properties of 42,000 psi ultimate tensile strength and electrical conductivity over 59 percent.

A second billet was cold deformed from 0.660 gage to 0.135 inch gage and had an ultimate tensile strength of 46,000 psi with an electrical conductivity of over 59 percent IACS.

Both materials successfully passed the wrap test. The iron, silicon and boron were substantially present as a dispersion of extremely fine precipitate and the copper was substantially present in solid solution.

This invention may be embodied in other forms or carried out in other ways without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered as in all respects illustrative and not restrictive, the scope of the invention being indicated by the appended claims, and all changes which come within the meaning and range of equivalency are intended to be embraced therein.

What is claimed is:

1. A process for obtaining an improved aluminum base alloy conductor having high strength and conductivity which comprises:

5 A. providing an aluminum base alloy consisting essentially of from 0.04 to 1.0 percent iron, from 0.02 to 0.2 percent silicon, from 0.1 to 1.0 percent copper, 0.001 to 0.2 percent boron, balance aluminum;

10 B. deforming said material to redraw rod at a temperature between 400° and 950°F; and

C. cold deforming said material to a diameter of between 0.002 to 0.375 inch at a reduction of at least 75 inch,

15 wherein the resultant conductor has copper substantially present in solid solution and iron, silicon and boron substantially present as a dispersion of extremely fine precipitate.

20 2. A process according to claim 1 wherein said cold deformation (C) is at a reduction of at least 90 percent.

3. A process according to claim 1 wherein said deformation (B) is at a temperature between 600° and 950°F.

25 4. A process according to claim 9 including an annealing step.

5. A process according to claim 4 wherein said material is drawn to gage following said annealing step.

30 6. A process according to claim 5 wherein the resultant conductor has a final diameter of between 0.002 inch and 0.125 inch.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,763,686

Dated October 9, 1973

Inventor(s) Fred A. Besel et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 6, line 57, correct the spelling of the word "temperature".

In Column 7, line 1, correct the spelling of the word "passed".

In Column 8, line 14, correct "75 inch" to read ---75 percent---

In Column 8, line 24, Claim 4, change the numeral "9" to read ---1---

Signed and sealed this 6th day of August 1974.

(SEAL)  
Attest:

McCOY M. GIBSON, JR.  
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Commissioner of Patents