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C. F. ALBAN
ELECTRICAL RESISTOR
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2,448,757

FIG. 1.

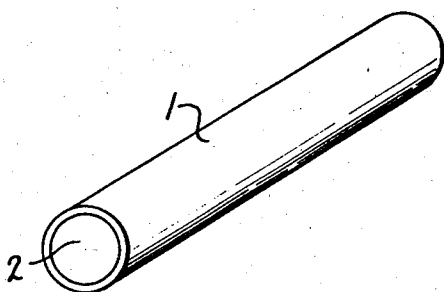


FIG. 2.

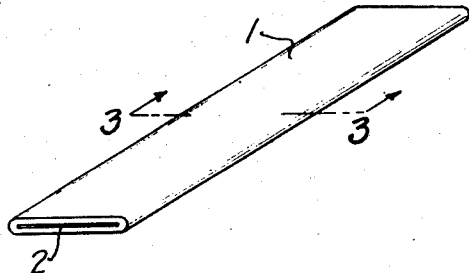
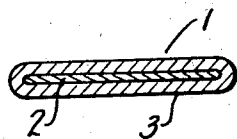


FIG. 3.



INVENTOR

Clarence F. Alban

Barney Kinelle, Laughlin & Leisch
BY

ATTORNEYS

UNITED STATES PATENT OFFICE

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ELECTRICAL RESISTOR

Clarence F. Alban, Pontiac, Mich., assignor to
W. M. Chace Company, Detroit, Mich., a corporation of Michigan

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8 Claims. (Cl. 201—63)

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This invention relates to an electrical resistor and more particularly to a composite high temperature resistor and a method of fabricating the same.

In the electrical resistor field it is highly desirable to produce a resistor of a given cross section and length but the electrical resistivity of which can be varied over a wide range, say, for example, 10 ohms to 1000 ohms per circular mil foot. Where such a resistor is subjected to high temperatures, say, for example 1500° to 1800° F., such a resistor must be made from a metal or alloy which can stand up when subjected to such temperature, that is, an alloy having high strength and corrosion resistance at elevated temperatures. However, a resistor made from an alloy having high strength and high corrosion resistance at elevated temperatures will have but a single resistivity for a given cross section and length and thus will have a restricted field of use.

It is an object of this invention to produce a resistor having high strength and high corrosion resistance at elevated temperatures and the resistivity of which can be varied over a wide range for a given cross sectional area and length.

This object is accomplished by fabricating the resistor of given cross sectional area and length and predetermined resistivity of composite metals or alloys, the outer lamination or layer being selected to give high strength and high corrosion resistance at elevated temperatures and the core or inner lamination being correlated therewith in cross sectional area and resistivity to give the predetermined desired resistivity for the resistor.

In the drawing:

Fig. 1 is a perspective showing my resistor in composite rod form,

Fig. 2 shows my resistor in composite flat strip or ribbon form, and

Fig. 3 is a section along the line 3—3 thereof.

My composite high temperature resistor consists of the combination of two or more metals or alloys to give a predetermined electrical resistivity. The outer layer 1 is selected to give the desired physical properties such as high tensile strength and the desired chemical properties such as high resistance to corrosion and scaling when subjected to high or elevated temperatures, such, for example, as temperatures between 1500° and 1800° F. The outside layer can be made from almost any alloy having high strength and high corrosion resistance at elevated temperatures, such, for example, as nickel-chromium alloys and nickel-chromium-iron alloys. A suitable nickel-

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chromium alloy comprises essentially about 80% nickel and 20% chromium by weight. Representative nickel-chromium-iron alloys that can be used for the outside layer are as follows:

1. Nickel 65%, chromium 15%, balance iron;
2. Nickel 78.5%, chromium 13.5%, balance iron;
3. Nickel 35%, chromium 15%, balance iron;
4. Nickel 8%, chromium 18, balance iron.

The core or inside layer can be made from pure nickel, copper, silver, or nickel-copper alloys, or an alloy comprising essentially 72% manganese, 18% copper, 10% nickel. These alloys are merely set forth for purposes of description and not by way of limitation because the outer layer of my resistor will be made from an alloy having high strength and corrosion resistance at elevated temperatures and the core will be made from a metal or alloy selected primarily to give the electrical resistivity desired for the resistor and capable of withstanding the elevated temperatures to which the resistor will be subjected.

In obtaining a wide range of electrical resistivity for a resistor having a given cross sectional area and length, I fabricate the resistor according to the following formula:

$$\frac{r_2^2}{R} = \frac{(r_2 - r_1)(r_2 + r_1)}{R_1} + \frac{r_1^2}{R_2}$$

where

R=Resistivity of composite resistor.

R₁=Resistivity of the alloy comprising the outer layer.

R₂=Resistivity of the metal or alloy comprising the core.

r₂=Radius of outside tube.

r₁=Radius of core.

In fabricating a resistor such as shown in Fig. 1, outside layer 1 can comprise an alloy of nickel 78.5%, chromium 13.5%, balance iron, and the inside layer or core 2 can comprise an alloy of 72% manganese, 18% copper, 10% nickel. The tube 1 had an outside diameter of three inches with a wall thickness of approximately .148 inch and an inside diameter of 2.705 inches. Core 2 had an outside diameter of 2.706 inches. Outside tube 1 was heated to about 400° F. and inside cylinder or core 2 cooled to about -20° F. Tube 1 was then slid over the inside core 2 and the composite ingot allowed to cool to room temperature so that tube 1 had a shrink fit on tube 2. The shrink fit gives improved bonding during hot rolling. It also excludes air, and in general no flux or bonding alloy is required.

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The actual calculation to obtain a resistor having a resistance (R) of 940 ohms per circular mil foot at room temperature was made as follows: An alloy comprising 78.5% nickel, 13.5% chromium, balance iron (known as Inconel) has an electrical resistivity of 650 ohms per circular mil foot. An alloy of 72% manganese, 18% copper, 10% nickel has a resistivity of 1050 ohms per circular mil foot. Outside tube 1 had an outside diameter of 3 inches, a radius of 1.5 inches. Core 2 had an outside diameter of 2.7 inches and a radius of 1.35 inches. Inserting these figures in the above formula we have the following:

$$\frac{(1.5)^2}{R} = \frac{(1.5 - 1.35)(1.5 + 1.35)}{650} + \frac{(1.35)^2}{1050}$$

R=940 ohms per circular mil foot calculated for room temperature.

The composite ingot can be drawn into wire of various diameters and then rolled flat to produce a ribbon 3, such as shown in Fig. 2.

The formula set forth above on page 4 relates to cylindrical resistors, such, for example, where the outer lamination is a tube and the inner core a cylinder. However, laminated resistors can be made from flat plates or sheets of selected alloys. The following formula gives the basic method for correlating materials and areas for obtaining a laminated resistor of any required resistance, both for cylindrical resistors, Fig. 1, as well as resistors made from laminations of flat plates or sheets of selected alloys welded or bonded together.

Both Formula 1 and Formula 2 are required to give the predetermined result.

$$(1) \quad \frac{A}{R} = \frac{A_1}{R_1} + \frac{A_2}{R_2} \dots \frac{A_n}{R_n}$$

Where:

A=Total cross sectional area of resistor.

R=Total resistance.

A₁=Cross section area of lamination A₁.

R₁=Resistance of lamination A₁.

A₂=Cross section area of lamination A₂.

R₂=Resistance of lamination A₂.

and so on to lamination A_n with a resistance R_n

(2) Another requirement is that

$$A = A_1 + A_2 + \dots A_n$$

Utilizing the basic Formulas 1 and 2, the resistor of 940 ohms per circular mil foot set forth above can be calculated as follows:

$$\frac{(1.5)^2 \times 3.1416}{R} = \frac{((1.5)^2 \times 3.1416) - ((1.35)^2 \times 3.1416)}{650} + \frac{(1.35)^2 \times 3.1416}{1050}$$

R=940 ohms per circular mil foot calculated for room temperature.

In the above (A), the total cross sectional area of the resistor, was equal to (A₁), the cross sectional area of lamination 1, plus (A₂), the cross sectional area of the inner lamination or core 2.

Utilizing these formulas and these same alloys, I can obtain a wide range of resistivities for a resistor having a given cross sectional area and length (for example, circular mil foot) at a given temperature by varying the radii of the outside tube and core. I can obtain a still wider range of resistivities for the same unit size resistor by varying the alloys, for example, to obtain a resistor having a still lower resistivity per circular mil foot, I can make core 2 of copper instead of manganese-nickel-copper alloy, but, here again, I correlate the cross-sectional area of the core and

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outer layer with their respective resistivities to obtain the desired resistivity for the resistor. By selecting an alloy having high corrosion resistance and high strength for the outer layer and a metal or alloy having a high conductivity for the inner layer or core, and then by correlating their cross-sectional areas or radii, I can obtain a resistor of predetermined cross-section and length having low resistivity, e. g., 10 ohms per circular mil foot. Thus, following the above formulas, I can also obtain a wide range of resistivities for a given unit size resistor by varying not only the cross-sectional areas of the inner and outer layers but also their analyses.

15 I claim:

1. An electrical resistor having high strength and high corrosion resistance at high temperatures and a predetermined cross-sectional area and length and a predetermined electrical resistance consisting of a metallic outer layer having high strength and corrosion resistance and an inner layer of a different metallic material wherein the cross sectional areas and resistivities of the inner and outer layers are correlated according to the following formula:

$$\frac{r_2^2}{R} = \frac{(r_2 - r_1)(r_2 + r_1)}{R_1} + \frac{r_1^2}{R_2}$$

wherein R is the resistivity of the composite resistor, R₁ the resistivity of the alloy comprising the outer layer, R₂ the resistivity of the metal or alloy comprising the core, r₂ the radius of the outside tube, and r₁ the radius of the core.

2. An electrical resistor having high strength and high corrosion resistance at high temperatures and a predetermined cross-sectional area and length and a predetermined electrical resistance consisting of a metallic outer layer in the form of a sleeve having high strength and corrosion resistance and an inner layer in the form of a core of a different metallic material, said sleeve having a shrink fit on said core, the cross sectional areas and resistivities of the inner and outer layers being correlated according to the following formula:

$$\frac{r_2^2}{R} = \frac{(r_2 - r_1)(r_2 + r_1)}{R_1} + \frac{r_1^2}{R_2}$$

wherein R is the resistivity of the composite resistor, R₁ the resistivity of the alloy comprising the outer layer, R₂ the resistivity of the metal or alloy comprising the core, r₂ the radius of the outside tube, and r₁ the radius of the core.

3. The method of fabricating an electrical resistor having high strength and high corrosion resistance and a predetermined cross-sectional area and length and a predetermined electrical resistivity R selected from a wide range of resistivities comprising the steps of selecting a metallic outer layer having high strength and corrosion resistance and a known resistivity R₁ and an inner layer of a different metallic material having a known resistivity R₂ and correlating the cross-sectional areas and resistivities to obtain the predetermined electrical resistivity R desired according to the following formula:

$$\frac{r_2^2}{R} = \frac{(r_2 - r_1)(r_2 + r_1)}{R_1} + \frac{r_1^2}{R_2}$$

wherein R is the resistivity of the composite resistor, R₁ the resistivity of the alloy comprising the outer layer, R₂ the resistivity of the metal or alloy comprising the core, r₂ the radius of the outside tube, and r₁ the radius of the core.

4. The method of fabricating an electrical resistor having high strength and high corrosion re-

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istance and a predetermined cross-sectional area and length and a predetermined electrical resistivity R selected from a wide range of resistivities comprising the steps of selecting a metallic outer layer in the form of a sleeve having high strength and corrosion resistance and a known resistivity R_1 and an inner layer in the form of a core of a different metallic material having a known resistivity R_2 , shrinking said sleeve on said core, and correlating the cross-sectional areas and resistivities to obtain the predetermined electrical resistivity R desired according to the following formula:

$$\frac{r_2^2}{R} = \frac{(r_2 - r_1)(r_2 + r_1)}{R_1} + \frac{r_1^2}{R_2}$$

wherein R is the resistivity of the composite resistor, R_1 the resistivity of the alloy comprising the outer layer, R_2 the resistivity of the metal or alloy comprising the core, r_2 the radius of the outside tube, and r_1 the radius of the core.

5. An electrical resistor having high strength and high corrosion resistance at high temperatures and a predetermined cross-sectional area and length and a predetermined electrical resistance consisting of at least one metallic lamination having high strength and corrosion resistance and at least one lamination of a different metallic material wherein the cross-sectional areas and resistivities of the said laminations are correlated according to the following formula:

$$\frac{A}{R} = \frac{A_1}{R_1} + \frac{A_2}{R_2} \dots \frac{A_n}{R_n}$$

where A is the total cross-sectional area of resistor, R the total resistance, A_1 the cross-sectional area of lamination A_1 , R_1 the resistance of lamination A_1 , A_2 the cross-sectional area of lamination A_2 , R_2 the resistance of lamination A_2 , A_n the cross-sectional area of lamination A_n , R_n the resistance of lamination A_n , and where

$$A = A_1 + A_2 + \dots A_n$$

6. An electrical resistor having high strength and high corrosion resistance at high temperatures and a predetermined cross-sectional area and length and a predetermined electrical resistance consisting of a metallic lamination having high strength and corrosion resistance and a lamination of a different metallic material joined thereto, the cross-sectional areas and resistivities of the said laminations being correlated according to the following formula:

$$\frac{A}{R} = \frac{A_1}{R_1} + \frac{A_2}{R_2}$$

where A is the total cross-sectional area of resistor, R the total resistance, A_1 the cross-sectional area of lamination A_1 , R_1 the resistance of lamination A_1 , A_2 the cross-sectional area of lamination A_2 , R_2 the resistance of lamination A_2 , and where

$$A = A_1 + A_2$$

7. The method of fabricating a laminated electrical resistor having high strength and high cor-

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rosion and oxidation resistance and a predetermined cross-sectional area and length and a predetermined electrical resistivity R selected from a wide range of resistivities comprising the steps of selecting at least one metallic lamination having high strength and corrosion resistance and a known resistivity R_1 and at least one lamination of a different metallic material having a known resistivity R_2 and correlating the cross-sectional areas and resistivities to obtain the predetermined electrical resistivity R desired according to the following formula:

$$\frac{A}{R} = \frac{A_1}{R_1} + \frac{A_2}{R_2} \dots \frac{A_n}{R_n}$$

where A is the total cross-sectional area of resistor, R the total resistance, A_1 the cross-sectional area of lamination A_1 , R_1 the resistance of lamination A_1 , A_2 the cross-sectional area of lamination A_2 , R_2 the resistance of lamination A_2 , A_n the cross-sectional area of lamination A_n , R_n the resistance of lamination A_n , and where

$$A = A_1 + A_2 + \dots A_n$$

8. The method of fabricating a laminated electrical resistor having high strength and high corrosion and oxidation resistance and a predetermined cross-sectional area and length and a predetermined electrical resistivity R selected from a wide range of resistivities comprising the steps of selecting a metallic lamination having high strength and corrosion resistance and a known resistivity R_1 and a lamination of a different metallic material having a known resistivity R_2 , joining said laminations together, and correlating the cross-sectional areas and resistivities to obtain the predetermined electrical resistivity R desired according to the following formula:

$$\frac{A}{R} = \frac{A_1}{R_1} + \frac{A_2}{R_2}$$

where A is the total cross-sectional area of resistor, R the total resistance, A_1 the cross-sectional area of lamination A_1 , R_1 the resistance of lamination A_1 , A_2 the cross-sectional area of lamination A_2 , R_2 the resistance of lamination A_2 , and where

$$A = A_1 + A_2$$

CLARENCE F. ALBAN.

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