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2,996,378

ELECTRICAL RESISTANCE WIRE

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This invention relates to electrical resistance alloys, to methods of processing wire made from such alloys to produce products with controlled temperature coefficients of resistivity and to the novel products resulting therefrom. More particularly it relates to alloy compositions containing from 10% to 30% by weight Cr, between about 2 and 5% by weight Al, between 1% and 4% by weight Co, balance substantially all nickel except for incidental amounts of trace elements, deoxidizers, degasifiers and impurities incidental to the normal production of the type of alloy in commercial amounts and to a heat treatment in the range of 800° to 1200° F. for relatively limited time intervals, usually shorter than 45 minutes after the alloy has been fabricated into wire by combinations of hot working and cold working and prior to its incorporation into a finished article of manufacture such as a potentiometer, resistor or other electrical apparatus.

One object of the invention is to production of alloys from which wire with desirably low coefficients of resistivity and desirably high electrical resistances is reproducibly obtained.

Another object is to provide a wire product having a controlled temperature coefficient of resistance which may be positive, or negative, or zero according to the specific processing to which the wire is subjected.

Still a further object is to provide an alloy which may be formed into wire having a combination of high resistance, low temperature coefficient of resistance, improved stability and uniformity of the relation between resistance and temperature.

These and other objects will be apparent from the more complete disclosure of preferred aspects of our invention which follows.

The use of wire products of nickel-chromium alloys of the 80/20 type is known and taught in Patents 2,585,613 and 2,638,425 for example, and it is also known that such alloys may be improved for certain purposes by the incorporation therein of small amounts of Al as taught in U.S. Patent 2,533,735 for example, or small amounts of Al and Cu, as taught in Patents 2,293,878 and 2,343,040, or small amounts of Al and Fe as taught in Patent 2,460,590, or small amounts of Al and Mn as taught in 2,533,736. These and other prior art disclosures reveal that to produce product with temperature coefficients of resistance below 0.00008 and specific resistances of at least 800 ohms per circular mil foot, tedious and expensive processing was required when working with such alloys.

Patent 2,460,590 may be regarded as typical of the prior art in this field. In this patent, the effects of modifying 80/20 Ni/Cr alloys by the incorporation therein of Al and combinations of Al and Fe and Al and Mn, together with a heat treatment subsequent to annealing at temperatures of upwards of 1700° F. and usually upwards of 1900° F. are set forth as responsible for improvements in the two constants of principal interest in alloys of this class, namely temperature coefficient of resistance and specific resistance. While the results reported in the above mentioned patents indicated that heat treatment of the annealed alloy produced improved products, no heat treated alloy product was reported in said patents to have a specific resistance at least as high as 900 ohms

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per circular mil foot and a temperature coefficient of less than 0.00002 ohm per ohm ° C.

By suitably processing the alloys of the present invention, stable products with specific resistances at least as high as 840 ohms per circular mil foot and usually higher than 900 ohms per circular mil foot and temperature coefficients no greater than .00002 max. over a temperature range of -85° F. to 482° F. are readily and reproducibly obtained.

We have now discovered that the addition of cobalt to Ni-Cr-Al alloys such as those above disclosed, in place of iron, copper, manganese or other previously employed modifiers results in a product which is much more amenable to processing and from which much more readily reproducible results are obtainable.

While we do not wish to be bound by any particular theory as to why such properties are possessed by the Ni-Cr-Al-Co alloys of the present invention, it is possible that the close-packed hexagonal structure possessed by cobalt and not found in other previously employed additives, contributes stability and uniformity to the products formed of alloys containing significant amounts of cobalt within the range specified by us. It is also possible that the close-packed hexagonal lattice characteristic of cobalt acts as a key to lock in the properties and to resist changes in same. It may be further noted that cobalt has the lowest compressibility of the commonly used transition elements and this indicates a stronger bonding and consequently an increased atomic cohesion. Other factors which may be responsible, in part, for the enhanced properties of alloys produced in accordance with our invention are the high anisotropy constant and the relatively low magnetostriction constant possessed by cobalt, as compared with iron, copper and manganese.

Essentially, as indicated above, the improved alloys of the present invention may be broadly defined as those containing between 10% and 30% by weight Cr; between about 2% and 5% by weight Al; between about 1% and 4% Co and the balance nickel, except for deoxidizers, degasifiers and metallic or non-metallic contaminants whose presence is incidental to manufacture from secondary metal raw materials.

Preferred alloys in accordance with the present invention are those containing between about 19% and 21% Cr, between about 2.7% and 3.2% Al; from 1.75% to 2.5% Co, not more than 0.5% Mn, not more than 0.5% Cu, not more than 0.3% Fe, a maximum of 0.05% C and less than 0.005% of P or S, the balance nickel, except for minor amounts of deoxidizers and degasifiers such as Zr, Ti, Si and the like, totalling less than 0.5%.

In the example which follows the processing of one specific alloy will be set forth in detail, but it is to be understood that this is intended to be illustrative rather than limitative of our invention.

An alloy was prepared by vacuum melting a charge of suitable composition in an induction furnace. Ingot of the following specific analysis was cast after deoxidation of the melt, in the usual manner:

	Percent by weight
Chromium	19.18
Aluminum	2.72
Cobalt	2.40
Iron	0.27
Manganese	0.46
Copper	0.16
Silicon	0.11
Carbon	0.015
Sulfur	0.005
Phosphorus	0.002
Nickel	Balance

The melt was cast into ingot and processed in the usual manner to hot rolled rod, 9/32" in diameter and thence to a convenient intermediate breakdown size of 0.032" diameter preparatory to drawing the rod down to commercial product between 0.0004" and 0.010", for use in electrical apparatus.

The hot rolled 9/32" diameter rod was reduced in size to the desired breakdown diameter of .032" by a series of cold drawing steps, after each of which the wire was annealed, in order to recrystallize the cold worked alloy and to prepare it for the next drawing step. The scheduled drafts did not reduced the cross sectional area more than 65% through the dies in any one series of cold drawing steps in order that the optimum grain structure was obtained following each intermediate anneal. The schedule of drafts was controlled to obtain a product peculiarly adapted to be processed by a novel short stabilizing heat treatment of the fine diameter wire after it has been drawn to the final size.

The resulting 0.005" diameter strand was annealed at about 2050° F., a temperature selected for optimum recrystallization for wire of the stated size and chosen to yield product with a zero temperature coefficient as shown in Table I.

TABLE I

Properties of 0.005" diameter wire annealed at temperatures from 1900° F. to 2150° F. and then stabilized at 1100° F. for 30 minutes

Sample	Basic anneal temp. (° F.)	Specific res. ohms/cmf.	Temperature coefficient of resistivity (25° C. - 125° C.) ohm/ohm, ° C.	Elongation, percent	Tensile strength
1.-----	1,900	853	+ .0000200	22	178,000
2.-----	1,950	854	+ .0000170	22	163,000
3.-----	2,000	857	+ .0000092	23	161,500
4.-----	2,050	858	± 0	26	158,000
5.-----	2,100	860	- .0000055	26	152,800
6.-----	2,150	861	- .0000078	26	143,000

Wire 0.0004" diameter would preferably be annealed at temperatures as low as 1900° F. and wire 0.010" diameter would be annealed at temperatures as high as 2150° F. Thus the final anneal should preferably be between 1900° F. and 2150° F., depending to some extent on the size wire being annealed.

After final anneal, the wire was heat treated to impart the combination of low temperature coefficient of resistance and high specific resistance required in electrical resistance alloys of the present type.

Prior to such heat treatment the alloy, after final anneal at 2050° F. had a specific resistance of 755 ohms per cmf. and a temperature coefficient of resistance of 0.000058 ohm per ohm degree centigrade over the temperature range from -85° F. to 482° F.

Heat treatment in a hydrogen atmosphere at the temperatures indicated below increased the specific resistance and lowered the temperature coefficient of resistance as shown in the following table:

Temp., ° F.	Duration, minutes	Specific resistance, ohms/cmf.	Temperature coefficient of resistance, ohms/ohm, ° C.
800.-----	15	845	+ .0000290
	30	847	+ .0000293
	45	851	+ .0000270
900.-----	15	846	+ .0000172
	30	846	+ .0000130
	45	847	+ .000010
1,000.-----	15	853	+ .0000130
	30	852	+ .0000112
	45	855	+ .0000100
1,100.-----	15	857	+ .0000052
	30	857	+ .0000043
	45	861	- .0000039
1,200.-----	15	860	- .0000090
	30	861	- .0000107
	45	861	- .0000124

It will be seen, from the above, that alloys containing cobalt in the specified amount were amenable to processing to produce electric resistance wire products with greatly enhanced properties, as compared with those heretofore obtainable.

Other Ni-Cr-Al alloys containing between 1% and 4% Co may be processed in similar fashion to produce wire having specific resistances of at least 840 ohms per circular mil foot and usually above 900 ohms per circular mil foot and temperature resistance coefficients of substantially less than 0.00002 ohm per ohm ° C.

We claim:

1. An electrical resistance wire having a specific resistance of at least 800 ohms per cmf. and a temperature coefficient of resistivity of at most .00002 ohm per ohm ° C. over a temperature range of from minus 85° F. to plus 482° F. said wire comprising a nickel-base alloy consisting essentially of between about 10% and 30% Cr, between about 2% and 4% Al, between about 1% and 4% Co and the balance, except for impurities and residuals, nickel which wire has been subjected to a plurality of cold workings, each followed by an anneal at a temperature between about 1900° F. and 2150° F. to recrystallize the cold worked product; and which wire has been thereafter subjected to a further heat treatment at a temperature between about 800° F. and 1200° F. for an interval between about 15 minutes and 45 minutes to develop an electrical resistance wire product having a specific resistance of at least 800 ohms and a temperature coefficient of resistivity below 0.00002 ohm per ohm per degree centigrade.

2. The wire product of claim 1 wherein the nickel-base alloy consists essentially of the following, by weight; 19% to 21% Cr; 2.7 to 3.2% Al, 1.75 to 2.5% Co, not more than 0.05% C; less than 0.5% Mn; less than 0.5% Cu, less than 0.3% Fe, balance nickel except for impurities and residuals.

3. A method of processing a nickel-base electrical resistance element consisting of between 10% and 30% Cr; between 2% and 5% Al; between 1% and 4% Co; balance, except for residuals and impurities, essentially all nickel which comprises cold working the alloy to a wire product; then recrystallizing the cold worked product annealing the cold worked product at a temperature between about 1900° F. and 2150° F.; thereafter heat treating the annealed product for a period of from 15 to 45 minutes at a temperature of between 800° F. and 1200° F., to yield a heat treated wire product whose specific resistance is at least 800 ohms per cmf. and whose temperature coefficient of resistivity is not greater than .00002 over the temperature range -85° F. to 482° F.

4. A method of processing a nickel-base electrical resistance element consisting of between 10% and 30% Cr; between 2% and 5% Al; between 1% and 4% Co; balance, except for residuals and impurities, essential all nickel which comprises cold working the alloy to a wire product; then recrystallizing the cold worked product annealing the cold worked product at a temperature between about 1900° F. and 2150° F.; and thereafter heat treating the annealed product for a period of about 30 minutes at a temperature of about 1100° F., to yield a heat treated wire product whose specific resistance is at least 800 ohms per cmf. and whose temperature coefficient of resistivity is not greater than 0.00002 over the temperature range -85° F. to 482° F.

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583,807 Great Britain _____ Dec. 31, 1946

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Edward E. Edmunds et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 12, for "reduced" read -- reduce --;
column 4, line 19, for "4%" read -- 5% --.

Signed and sealed this 16th day of January 1962.

(SEAL)

Attest:

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