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ELECTRICAL RESISTANCE ALLOYS

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This invention relates to electrical resistance alloys of the nickel-chromium type and to resistance elements made of these alloys, which are particularly suitable for use in electrical or electronic control devices.

Nickel-chromium electrical resistance alloys are commonly made with a base composed of Ni and from 10 to 30% of Cr. The resistivity and the temperature coefficient (T. C.) of products made of these alloys, such as wires, ribbons or other pliable strands, are properties of great importance to the usefulness of the products in electrical or electronic control devices, such as resistors, potentiometers and the like.

A typical alloy of 80% Ni and 20% Cr, when drawn into fine wire and subsequently strand annealed, shows a resistivity of approximately 612 ohms per circular mil foot (C. M. F.) and a temperature coefficient of resistance of about .00018 ohms per ohm per degree centigrade over the temperature range of 20° to 100° C. When suitably heat treated, its resistivity rises to about 650 ohms/C. M. F., and its temperature coefficient is reduced to about .00009 ohms/ohm/° C.

It is known that the reistivity of such alloys may be substantially increased by adding to a nickel-chromium base suitable amounts of certain alloying elements, particularly Si, Mn and Fe, V and Fe, Mn, V and Fe, Cu and Al, or Cu, Al and Fe. When suitably fabricated, strand annealed and heat treated, some of the resulting compositions show a very low temperature coefficient that varies from zero by not more than about .000020 ohms per ohm per degree C.

As far as we are aware, however, there is no known composition of a Ni-Cr type alloy that can be processed commercially into electrical resistance elements having both a very low temperature coefficient of the order stated above and a resistivity as high as approximately 1000 ohms per C. M. F. Yet products of that character are highly desirable for a variety of electrical and electronic uses.

It is the principal object of this invention to provide alloys which can be converted readily into electrical resistance elements having both a very low temperature coefficient of resistance and an extraordinarily high resistivity. Another object is to provide fine electrical re-

sistance elements possessing these valuable properties, which are especially suitable for use in precision instrumentation, such as in electrical and electronic control devices.

We have discovered that the objects of this invention can be achieved by the provision and utilization of alloy compositions consisting essentially of from 2 to 4.5% of Al, 2 to 8% of V and 15 to 25% of Cr in a nickel base.

Ni-Cr type alloys of this formulation possess valuable properties of corrosion resistance, strength and ductility similar to those of known electrical resistance alloys of the nickel-chromium type. Being both hot workable and cold workable, they can be readily converted from ingot form into the form of fine resistance elements, such as wires, ribbons or other pliable strands. We have further discovered, however, that when these alloys are suitably annealed and heat-treated, the products obtained have an extraordinarily high resistivity of at least 950 ohms per circular mil foot, and their temperature coefficient of resistance is so small that it departs from zero, if at all, by not more than about .000020 ohms per ohm per degree C. over the temperature range of 20° to 100° C.

Illustrative examples of the alloys and resistance elements of this invention are set forth in Table I hereof. As to each example, this table shows the weight percentage of the essential alloy ingredients, as determined by chemical analyses, the important resistance properties of heat treated .0253″ wire strands made of the alloy, and the conditions of heat treatment. The strands had been annealed at 1750° F. to 2150° F. in a 12 foot furnace at a speed of 42 ft./min., cooled rapidly and then heat treated in a reducing atmosphere of cracked ammonia at the temperatures and for the times listed in Table I. All the alloys contained as incidental elements very small amounts of C, Ca, Co, Fe, Mg, Pb, Si and Zr.

When the aluminum content of compositions like those of Table I is increased above 4.5%, the resistivity of heat treated strands of the alloys still reaches approximately 1000 ohms/C. M. F., but there is an inordinate increase of the temperature coefficient which makes the products unsuitable for the requirements of fine electrical resistance elements. When the vanadium content is increased above 8.0%, the compositions no longer have the desired ductility and working properties. When either the aluminum content or the vanadium content is reduced below 2%, the required high resistivity is not attained.

While the processing of the present alloys into resistance elements may be carried out in a variety of known ways, the following is one suitable procedure which has been employed in processing the examples referred to herein.

Table I

Example	Percent Al	Percent V	Percent Cr	Percent Ni	Strand anneal temp., °F.	Heat treat temp., °F.	Time of heat treat, hours	Heat treated strands	
								Resistivity, ohms/ C. M. F.	T. C., Ω/Ω/°C. (20–100° C.)
1	3.71	4.12	19.85	71.75	1,750	1,100	1	950	+0.000016
2	2.51	4.72	19.98	72.40	1,750	1,100	100	987	−0.000014
3	3.67	3.86	19.64	72.69	1,750	1,100	23	1,002	−0.000008
4	3.91	3.66	18.61	70.08	2,150	1,100	4	1,018	+0.000002
5	3.53	4.56	19.06	72.85	1,750	1,000	55½	1,010	0
6	2.4	7.0	20.34	70.41	1,750	1,100	8	985	+0.000005
7	3.97	3.92	19.45	72.54	1,750	1,000	3	994	+0.000020
8	3.53	4.38	16.6	74.74	1,750	1,100	2	1,011	+0.000011
9	3.81	5.12	21.32	69.7	2,150	1,000	113	1,030	−0.000004
10	4.34	5.20	21.38	69.29	2,150	1,000	1	1,005	+0.000005
11	3.89	5.60	19.89	70.37	1,750	1,100	1	995	−0.000008

Nickel and chromium in a weight ratio of approximately 4:1, together with the other essential ingredients of the composition, are melted together in an electric induction furnace. The melt usually contains minor amounts of incidental elements in the nature of impurities or degasifying elements, such as C, Ca, Ce, Co, Cu, Fe, Mg, Mn, Pb, Si and/or Zr. The melt is cast into ingots which are heated at about 2250° F. for 30 to 45 minutes and then are hot rolled to rod form. The rods are normalized for 1 hr. at 2150° F., then coated with a suitable die lubricant, such as by dipping them in a bath of molten lead, and then cold drawn through dies to the desired strand size. The cold drawing is effected in stages with intermediate steps of annealing at 1750° to 2250° F., pickling, and re-coating with lead. The final strands may be wires as fine as .001 inch, or even smaller, in diameter.

The drawn strands are given a final anneal at 1750° to 2150° F. in a 12 foot furnace at 42 ft./min. and then cooled rapidly, after which their full resistance properties are developed by heating them in a reducing atmosphere, such as one of hydrogen or cracked ammonia, at 900 to 1300° F. for ½ to 100 hours. In general, it has been found that a higher strand anneal temperature permits the use of a lower heat treating temperature or a shorter time of heat treatment within these ranges. For any given strand anneal temperature, the higher the heat treating temperature, the shorter is the time necessary to obtain the desired electrical properties.

When a composition is described or claimed herein as "consisting essentially" of named elements in stated proportions, this expression is intended to mean that the elements so specified are the essential ingredients of the alloy composition, but it is not intended to exclude the presence of minor amounts of various incidental elements in the nature of usual deoxidizing elements or impurities, such as C, Ca, Ce, Co, Cu, Fe, Mg, Mn, Pb, Si and Zr. Such elements commonly are found in the alloys as a result of the origin or the method of preparation of one or more of their essential ingredients. Neither is said expression intended to exclude the possible addition to the same composition of minor amounts of elements which are known to be compatible with electrical resistance alloys of the nickel-chromium type, to the extent that such additions do not deprive the products of the valuable resistance properties specified herein.

For example, copper may be added to the present alloys in amounts up to about 5%; iron or cobalt may be added to them in amounts up to 5%, or in somewhat larger amounts up to 10% if added at the expense of nickel; manganese may be added in amounts up to about 5%; silicon may be added in amounts up to about

2.5%; titanium may be added in amounts up to about 3.5%; tungsten may be added in amounts up to about 2%; and arsenic or beryllium may be added in amounts up to about .25%—in each case, while retaining the required workability of the alloys as well as their capacity to form electrical resistance elements having the distinctive properties described herein. Table II hereof gives illustrative examples of alloy compositions embodying this invention which contain some of such minor additions, and shows the resistance properties of heat treated .0253 inch wire strands made of the modified alloys.

Table II

Example	Base	Al	V	Cu	Fe	Mn	Si	Strand anneal temp., ° F.	Heat treat temp., ° F.	Time of heat treat, hours	Heat treated strands	
											Resisitivity, ohms/C. M. F.	T. C., Ω/Ω/°C. (20–100° C.)
11	Ni:Cr = 4:1	3.28	2.80	1.74	------	------	------	1,750	1,100	19	992	−0.000007
12	Ni:Cr = 4:1	3.70	4.80	------	5.37	------	------	1,750	1,000	32	1,005	−0.000018
13	Ni:Cr = 4:1	4.08	4.00	------	------	2.8	------	2,100	1,100	4	1,049	−0.000018
14	Ni:Cr = 4:1	3.77	4.06	------	------	------	0.72	1,750	1,100	1½	982	0

The principles of this invention and preferred ways of putting it into practice having been described hereinabove, its essential features which we intend to secure by Letters Patent are set forth in the following claims.

We claim:

1. An electrical resistance alloy consisting essentially of from 2 to 4.5% of Al, 2 to 8% of V and 15 to 25% of Cr in a Ni base.

2. An electrical resistance alloy consisting essentially of from 2 to 4.5% Al, 2.5 to 7.5% V, 16.5 to 22% Cr and 67 to 76% Ni.

3. An electrical resistance alloy consisting essentially of from 2 to 4.5% Al, 3.5 to 7% V, 16.5 to 22% Cr and 69 to 75% Ni.

4. An electrical resistance alloy consisting essentially of from 2.5 to 4.5% of Al, 3.5 to 6% V, 19 to 21% Cr and 67 to 76% Ni.

5. An electrical resistance alloy consisting of, approximately, 3.5 to 4% Al, 4.5 to 5.5% V, 19 to 21% Cr and 67 to 76% Ni, with nominal amounts of incidental elements from the group consisting of C, Ca, Ce, Co, Cu, Fe, Mg, Mn, Pb, Si and Zr.

6. An electrical resistance alloy consisting of, approximately, 2.5% Al, 7% V, 19 to 21% Cr and 67 to 76% Ni, with nominal amounts of incidental elements from the group consisting of C, Ca, Ce, Co, Cu, Fe, Mg, Mn, Pb, Si and Zr.

7. An electrical resistance element comprising a pliable strand of an alloy consisting essentially of from 2 to 4.5% Al, 2 to 8% V and 15 to 25% Cr in a Ni base, said strand having a resistivity of at least 950 ohms/C. M. F. and a temperature coefficient that does not vary from zero by more than .000020 ohms/ohm/° C. over the range of 20° to 100° C.

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