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ELECTRICAL RESISTOR ELEMENT AND
METHOD OF PRODUCING THE SAME

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This invention relates to electrical resistance elements and more particularly to electrical resistance elements having the physical and electrical properties adapting the same for use as electrical resistors in electrical circuits commonly employed in radio, television, radar and the like devices.

The object of the invention is to provide a wire product consisting of an alloy having a relatively high specific resistance, a low temperature coefficient of resistance at temperatures below 300° C. and having good ductility and high tensile strength adapting the same to be coiled or otherwise formed into an electrical resistor element.

Another object is to provide a method of processing a wire product comprised of an alloy of the nickel-chromium type of electrical resistance alloys to impart thereto a temperature coefficient of resistance and a specific resistance which are, respectively, lower than and higher than normally present in the alloy.

Still another object is to provide a wire product consisting of a nickel-chromium alloy of the 80/20 type of electrical resistance alloy having a temperature coefficient of resistance which is lower than normally obtained in the alloy and a specific resistance which is higher than normally obtained in the alloy and having ductility and a tensile strength adapting the wire product for forming into an electrical resistor element.

A further object is to provide a method of processing nickel-chromium alloys of the 80/20 electrical resistance type to condition the same for use as an electrical resistor element in electrical circuits common to radio, radar and television devices.

Still another object is to provide a method of treating nickel-chromium alloys of the 80/20 type of electrical resistance alloys to impart thereto improved electrical and physical properties.

Other objects and advantages will be apparent as the invention is more fully hereinafter disclosed.

In accordance with these objects I have discovered, as described and claimed in my prior filed application Serial No. 562,901, filed on November 10, 1944, now abandoned and entitled "Electrical Resistance Alloy," of which the present application is a continuation-in-part, that nickel-base alloys and nickel-chromium alloys generally and nickel-chromium alloys of the type known in the art as electrical resistance alloys, such as the standard type of alloy consisting of 20% Cr and 80% Ni, particularly, are unex-

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pectedly improved in their physical and electrical properties when they are subjected to heat-treatment for an extended time interval at a temperature within the range 780° F. to 1000° F., and preferably at a temperature approximating 850° F., when in either their annealed or in their work-hardened condition.

The beneficial result of this heat-treatment operation on the alloy is ascribed to an orderly rearrangement of the atoms within each grain of the alloy unaccompanied by any structural or phase change in the alloy as the heat-treatment, per se, appears to produce substantially the same improved result irrespective of the condition of strain present in the alloy at the time of heat-treatment and to be unaccompanied by any detectable difference in internal structure.

The heat-treatment, per se, also appears effective irrespective of specific alloy composition or content in the nickel-base alloy, although with different alloy constituents present in the alloy the order of the improvement obtained varies, as one skilled in the art would expect.

In the case of electrical resistance alloys consisting essentially of chromium 10% to 30%, balance nickel, of which the 20% Cr-80% Ni alloy is a standard and well recognized example, heat-treatment of this alloy, when in wire form at final size, at a temperature approximating 850° F. for a time interval approximating one (1) hour in a hydrogen atmosphere, is effective in lowering the temperature coefficient of resistance of the alloy from the usual value of from .00013 to .00018 ohm in the annealed and hard drawn condition, respectively, to a value approximating .00007 ohm, or a reduction approximating 50%. At the same time the specific resistance of the alloy is increased from the usual value of 600 ohms per C. M. F. (in the hard drawn condition) and 650 ohms per C. M. F. (in the annealed condition) to a value approximating 720 ohms per C. M. F., an increase approximating 20%. In addition to these improvements in electrical properties there is a general increase in the tensile strength of each type of alloy amounting to about 10% and no apparent loss in the ductility or formability of the wire product.

While this general lowering of the temperature coefficient of the standard type of 80/20 Ni-Cr alloy by the practice of this heat-treatment is beneficial and opens the alloy to wide utility as a resistor element in many types and kinds of electrical circuits, in electrical circuits of the type employed in radio, television, radar and the like electrical devices, it is desirable to lower this

temperature coefficient to zero or as close to zero as is possible.

Heretofore in the art, as indicated by prior Patents No. 2,293,878, issued August 25, 1942; No. 2,343,039 and No. 2,343,040, each issued on February 29, 1944, to Victor O. Allen and Joseph F. Polak, joint inventors, the present applicant being the same Victor O. Allen, various attempts have been made, by the addition of various alloy constituents to the standard type of 80/20 Ni.Cr electrical resistance alloy, to lower the temperature coefficient of the alloy.

I have found that in each of these types of 80/20 Ni.Cr alloy the temperature coefficient of the alloy may be still further lowered by the practice of the heat-treatment operation of the present invention after the wire has been subjected to a recrystallization annealing operation, preferably by strand-annealing at temperatures approximating 1950° F., the extent of improvement obtained being usually to a value which is about 50% (or one-half) of that obtained in the alloy after recrystallizing annealing.

As an example of this improvement, but not as a limitation of the present invention, in the alloy composition described and claimed in Patent No. 2,293,878, namely, one consisting of 10% to 30% Cr, Al from small fractional percentages up to about 5%, Cu from small fractional percentages up to about 3%, with the total Al and Cu not over about 6%, balance nickel, the aluminum content of the alloy is primarily relied on to lower the temperature coefficient of the alloy and the copper content is primarily relied on to off-set or counterbalance the detrimental effect of the aluminum content on the hot and cold working properties of the alloy, an amount of aluminum much over 5% being undesirable in the alloy for this reason and for the additional reason that copper in amounts over 3% to off-set the detrimental effects of the aluminum, is detrimental to the hot working properties of the alloy.

In alloys of this type, however, under commercial production conditions various other constituents may be present in the alloy, such as iron, manganese, silicon and residual amounts of one or more of the degasifier metals Ti, Zr, Be, Mg and Ca. In general, the Mn and Si content of the alloy is held to under 1% but the Fe content of the alloy may vary from small fractional percentages up to 5% without essential departure from the invention. The main effect of Fe in the alloy is to lower the maximum temperature of operation of the alloy as an electrical resistance heating element, substantially as disclosed in Patent No. 2,343,040. As the operating temperature of electrical resistors in electrical circuits common to radio, television and radar devices is substantially below 300° C., the presence of iron in the 80/20 Ni.Cr alloy in such electrical resistor elements is essentially immaterial particularly in amounts as high as 5%. Such iron content normally off-sets or counterbalances the detrimental effect of the aluminum on the working properties of the alloy permitting the use of higher aluminum as well as minimum copper, and in this respect Fe and Mn, each, may be considered as substantial equivalents for the Cu of the alloy composition in Patent No. 2,293,878, where the operating temperature of the alloy is not a major factor, as in the instant invention, although I have found that best results are obtained when some copper (i. e., about 1.0%) is present in the alloy.

As one specific embodiment of the present in-

vention, but not as a limitation of the same, the invention will be described insofar as it has been adapted to the processing of alloys of the 80/20 type of nickel-chromium alloys described and claimed in the Patent No. 2,293,878.

In this adaptation of the present invention the alloy composition is formed substantially as described in the patent and is hot and cold worked by standard methods applicable to this type of alloy down to wire sizes. At final wire size the wire is usually strand-annealed or recrystallized at a temperature approximating 1950° F. at a rate approximating 20 feet per minute in a hydrogen atmosphere for a time interval sufficient to provide a substantially recrystallized metal structure having the required ductility and tensile strength best adapting the same for forming into the required diameter electrical resistance or resistor coils.

As may be noted from the disclosure of this patent the electrical resistance and temperature coefficient of resistance of this type of alloy at this stage in the processing method varies markedly with variation in the aluminum content of the alloy and a large number of high resistance alloys are obtainable having progressively lower temperature coefficients by varying the relative proportions of the aluminum and copper in the alloy.

The Example No. 3 given in the said patent, namely, one containing 3% Al and 3% Cu, together with 20% Cr and 74% Ni, produced a temperature coefficient of resistance approximating .00002 ohm when so processed. In the commercial production of this alloy, however, an iron content varying from .50 to 1.50% and usually approximating 1% and a manganese content approximating but usually less than 1% is commonly present in the alloy together with silicon in fractional percentages approximating .50% but not over 1.0% and substantially small fractional (residual) amounts of one or more of the degasifier elements Ti, Zr, Ca, Mg and Ce.

The commercial alloy of this general composition usually evidences a temperature coefficient of about .00004 to .00005 and an electrical resistance approximating 715 ohms following recrystallization annealing due to this difference in composition.

I have found that the temperature coefficient of this commercial grade of alloy may be lowered to between .00001 and .00002 by heat treating the recrystallized structure of the wire comprised of this commercial grade of alloy (obtained on strand-annealing at 1950° F.) for from one to three hours at a temperature approximating 850° F. in a hydrogen atmosphere. At the same time the specific resistance of the alloy increases about 10%, or from 715 to about 775 ohms and the tensile strength of the wire also usually is increased about 10%. These are average values.

The following typical examples are given of this type of 80/20 Ni.Cr electrical resistance alloy treated in accordance with the present invention:

Example #1.—A wire comprised of the 3% Al.3% Cu commercial grade of alloy above mentioned hot and cold worked to a final size of .005 inch in accordance with standard practices, was strand-annealed (recrystallized) in hydrogen at 1950° F. at a rate approximating 20 feet per minute in accordance with standard practice. The strand-annealed wire, on test, had a specific resistance of 715 ohms (C. M. F.) and a

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T. C. (temperature coefficient) of .000046 ohm. On box annealing this wire for one (1) hour at 842° F. in a hydrogen atmosphere the specific resistance was increased to 773 ohms (C. M. F.) and the T. C. was lowered to .000014 ohm.

Another sample of the same wire product on box annealing in a hydrogen atmosphere at 850° F. for one (1) hour had a T. C. of .000017 ohm and a specific resistance of 794 ohms (C. M. F.).

Still another sample of the same wire, strand-annealed at 1925° F. and heated at 850° F. for one (1) hour in a hydrogen atmosphere developed a T. C. of .000006 ohm and a specific resistance of 767 ohms (C. M. F.).

Still another sample of the same alloy drawn down to .032 inch wire by standard practice, annealed at 1750° F., drawn down to .005 inch and strand-annealed at 1925° F. showed, on test, a specific resistance of 705 ohms (C. M. F.) and a temperature coefficient of .000059 ohm. On pot annealing for one (1) hour at 850° F. in an atmosphere of hydrogen the specific resistance was increased to 758 ohms (C. M. F.) and the temperature coefficient dropped to .000026 ohm. On heat-treatment for an additional hour at 850° F. the specific resistance increased to 788 ohms (C. M. F.) and the temperature coefficient of resistance dropped to .0000123 ohm. On heat treating at 850° F. for three (3) hours the temperature coefficient of resistance was lowered to .0000055 ohm without further increase in the specific resistance.

Any of these heat-treated wire products have a T. C. which is acceptable for use in a resistor element in electrical circuits of the type employed in radio, radar and television devices, the said T. C. being that constant for all temperatures below about 300° C. and down to as low as -50° C.

Example #2.—An alloy consisting of 20% Cr, 1½% Cu, 1½% Al, balance Ni, except for the same small amounts of associated constituents present in Example #1, was formed and was hot and cold worked by the usual practices down to a wire size of .005 inch and was strand-annealed at 1925° F. in the usual manner to condition the same for service use as an electrical resistance element. The electrical resistance of this alloy approximated 668 ohms (C. M. F.) and the temperature coefficient approximated .00011 ohm (C. M. F.). Following heat-treatment at 850° F. for one (1) hour the specific resistance of this alloy was increased to 750 ohms (C. M. F.) and the temperature coefficient of resistance was lowered to .000033 ohm.

Example #3.—An alloy consisting of Cr 20%, Al 5%, Cu 3%, Fe 12%, Mn 1%, Si .40%, CaSi .10%, balance Ni, at a wire size of .0056 inch was annealed at 1925° F., and showed on testing a specific resistance of 708 ohms (C. M. F.) and a temperature coefficient of resistance of .00011 ohm. On heat treating for three (3) hours at 850° F. in an atmosphere of hydrogen the specific resistance of the alloy was increased to 748 ohms (C. M. F.) and the temperature coefficient was lowered to .000078 ohm.

The examples given illustrate the effectiveness of the heat-treatment operation of the present invention on the specific resistance and temperature coefficient of the 80/20 type of Ni.Cr alloy in which aluminum is present as an alloying constituent to lower the T. C. value of the alloy and are believed to demonstrate that irrespective of the associated alloy constituents present in the Al-containing 80/20 Ni.Cr alloy the heat-treatment of the present invention is effective in

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lowering the temperature coefficient of the alloy and in increasing the specific resistance of the alloy, as compared to the values for these properties obtained after recrystallization annealing the drawn alloy at the usual strand-annealing temperature.

In the practice of this invention the heat-treatment of the annealed wire product at a temperature approximating 850° F. and within the range 780° to 1000° F. is performed, preferably, upon the drawn wire product at the desired final size and preferably also after the wire product has been pre-conditioned, as by annealing and recrystallization, for subsequent forming into electrical resistance coils, the heat-treatment at 850° F. in addition to increasing the specific resistance and decreasing the temperature coefficient properties of the alloy also producing a general increase in tensile strength amounting usually to about 10% with no decrease in the formability of the alloy.

Whereas, in the specific example given the temperature of treatment is specified as approximating 850° F., various other tests have indicated that the treating temperature range is from 780° to 1000° F. with the time at temperature decreasing with increase in temperature and vice versa. The time at temperature at 1000° F. being approximately one-half (½) that at 850° F. for equivalent results. The time at temperature at 780° F. being about one-third (⅓) longer than at 850° F. for equivalent results. At 850° F. I have found that a time interval approximating one (1) hour is generally sufficient to produce about a 50% reduction in the T. C. value of the annealed wire and that on extending this time interval of heating a further lowering in the T. C. value may be expected.

It is believed apparent from the above disclosure that the heat-treating practice of the present invention is applicable to a wide variety of alloy compositions of the 80/20 type of nickel-chromium alloys heretofore utilizable as electrical resistance elements, and is particularly applicable to such alloys containing, in addition to nickel and chromium, alloyed constituents heretofore found effective in lowering the temperature coefficient and raising the specific resistance properties of the 80/20 Ni.Cr alloy, such as Al and Be, together with such associated constituents off-setting or counterbalancing the impairment to the working properties of the 80/20 type of Ni.Cr alloy incident to the presence of these T. C. lowering constituents, such as Cu, Fe and Mn, substantially as hereinabove disclosed.

In view thereof all modifications and departures from the invention are contemplated as may be included within the scope of the following claims.

What I claim is:

1. An electrical resistance element comprising an alloy consisting of about 3% Al, 3% Cu, 10-30% Cr, 1% each of the metals Fe and Mn, .50-1.0% Si, balance substantially nickel, that has been recrystallized annealed at a temperature approximating 1950° F. and heat-treated for a period of 1 to 3 hours at a temperature within the range 780° to 1000° F. and having a temperature coefficient below .00008.

2. The method of processing an electrical resistance wire comprised of a nickel-chromium alloy containing 10-30% Cr, from small fractional amounts up to 5% Al, from small fractional amounts up to 3% Cu, with the total Al and Cu not exceeding 6%, and the balance Ni, to condi-

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tion the wire for use as a low temperature coefficient resistor in electrical circuits, which comprises heating the wire when at desired final size for 1 to 3 hours in a hydrogen atmosphere at a temperature within the range 780°-1000° F.

3. The method of claim 2, wherein prior to said heating the wire is recrystallized annealed at a temperature approximating 1950° F.

4. The method of claim 2, wherein said alloy contains in addition to the constituents specified from .50 to 1.50% Fe, about 1% Mn and from small amounts up to 1% Si.

5. The method of claim 2, wherein the temperature of said heating approximates 850° F.

6. A low temperature coefficient resistor element for electrical circuits, said element being comprised of a wire consisting of a nickel-chromium electrical resistance alloy containing 10 to 30% Cr, from small fractional percentages up to 5% Al, from small fractional percentages up to 3% Cu, with the total Al and Cu not exceeding 6%, and the balance Ni, said element having a temperature coefficient at temperatures below 300° C. approximating zero, said temperature coefficient resulting from heating the wire when at

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desired final size for from 1 to 3 hours in a hydrogen atmosphere at a temperature within the range 780° to 1000° F.

7. The resistor element of claim 6, the said wire having a recrystallized structure.

8. The resistor element of claim 6, said alloy also containing from .50 to 1.50% Fe, about 1% Mn, and from small amounts up to 1% Si.

VICTOR O. ALLEN.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,715,543	Elmen	June 4, 1929
1,803,468	Driver	May 5, 1931
1,910,309	Smith et al.	May 23, 1933
2,293,878	Allen	Aug. 25, 1942
2,460,590	Lohr	Feb. 1, 1949

OTHER REFERENCES

Technical Information; Monel, Nickel and Nickel Alloys; Properties and Uses of Inconel; Bulletin T-7, revised as of January, 1939; pages 3, 5 and 8. Published by the International Nickel Co., New York.