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3,694,195 HEAT-RESISTANT ALUMINUM ALLOYS FOR ELECTRIC CONDUCTORS

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U.S. Cl. 75—138 5 Claims

ABSTRACT OF THE DISCLOSURE

A heat-resistant aluminum alloy for electrical conductors which consists of 0.01 to 0.5% (by weight, as now and hereinafter referred to) zirconium, 0.0005 to 0.08% yttrium and/or 0.0003 to 0.08% erbium and the balance of which is essentially aluminum.

BACKGROUND OF THE INVENTION

(1) Field of invention

This invention relates generally to heat-resistant alloys for electric conductors and more particularly to such conductors which are used as all aluminum alloy conductors (AAAC) and aluminum alloy conductors which are steel reinforced for overhead transmission and distribution lines as well as conductors for other various types of electrical machines and appliances.

(2) Description of the prior art

It has been known for some time now that aluminum-zirconium alloy made by adding a very small quantity of zirconium to aluminum, may be used with some degree of success as a high resistance and high electrically conductive material for use in electric wires and cables, and in various electric machines and appliances. However, it has been a continuing struggle to provide such a heat-resistant aluminum alloy with ever-improved heat resistance characteristics without substantially lowering the electrical conductivity of this aluminum-zirconium alloy.

With this same object in mind, an attempt at improving the heat resistance characteristics of an aluminum-zirconium alloy by adding a quantity of 0.6 to 3.0% of one or two or more of the rare earth elements, chiefly mischmetal, was proposed in U.S. Pat. No. 3,278,300. That alloy, however, has shortcomings in that although it has an excellent heat-resistance characteristic at a comparatively low temperature range of 100 to 160° C., its properties are not found satisfactory at temperatures of 200 to 280° C., which is a temperature range that is now beginning to be prescribed for specification tests of heat-resistance characteristics of materials used in electrical conductors and the like.

SUMMARY OF THE INVENTION

It is the principal object of the present invention to provide a greatly improved aluminum alloy conductor which has a high heat-resistance characteristic without suffering any substantial loss in the electrical conductivity of an aluminum-zirconium alloy by adding thereto a very small quantity of yttrium and/or erbium.

The heat-resistant aluminum alloy of the present invention consists of 0.01 to 0.5% zirconium, at least one element taken from the group consisting of 0.0005 to 0.08% yttrium and 0.0003 to 0.08% erbium, and the balance of which is essentially aluminum.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With respect to the use of yttrium, it is known that the heat-resistance characteristic of aluminum is improved

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by adding yttrium by itself to aluminum. Compared with the zirconium-containing alloy, however, it has a much lower heat-resistance, although it has a higher electrical conductivity.

I have continually investigated not only the various components of mischmetal but also all the other elements as elements to be added for coexistence with zirconium. As a result, I have discovered that yttrium and erbium in a very small quantity remarkably improve the heat-resistance characteristic without detrimentally affecting electrical conductivity.

The characteristic of this invention is that the alloy of aluminum and zirconium (0.01 to 0.5%) is provided with a very small quantity of yttrium (0.0005 to 0.08%) and/or erbium (0.0003 to 0.08%). That is to say, this invention is based on the discovery that unlike ordinary rare earth elements, yttrium and erbium have, because of their high activity, a remarkable effect of improving the heat-resistance characteristics without lowering the electrical conductivity when added in a very small quantity.

The reason why the content of zirconium is prescribed here as 0.01 to 0.5% is similar to the reason given with respect to the ordinary aluminum-zirconium alloy. If the quantity is less than 0.01%, it has little effect toward the improvement of heat-resistance characteristics, while if it exceeds 0.5%, its effect or property to lower the electrical conductivity becomes dominant over its effect to improve heat-resistance.

The reason why the content of yttrium is prescribed to be 0.0005 to 0.08% is that if the quantity is less than 0.0005, it is scarcely effective for the improvement of heat-resistance characteristics, while if it exceeds 0.08%, it not only lowers the electrical conductivity but also gradually becomes less effective toward the improvement of the heat-resistance characteristics, thereby also becoming disadvantageous from the cost viewpoint.

The reason why the content of erbium is prescribed to be 0.0003 to 0.08% is that if the quantity is less than 0.0003%, it is scarcely effective for the improvement of the heat-resistance characteristics, while if it exceeds 0.08%, it not only lowers the electrical conductivity but also gradually becomes less effective for the improvement of the heat-resistance characteristics, thereby also becoming disadvantageous from the cost viewpoint.

While the afore-mentioned publicly known invention (U.S. Pat. No. 3,278,300) calls for rare earth elements in a quantity of 0.6 to 3.0%, an addition in a very small quantity is sufficient to attain the objective if yttrium and/or erbium is used. It is presumed that yttrium and erbium have a qualitatively different effect.

The alloy of this invention may be manufactured by the same casting and working methods as those for the manufacture of the known aluminum alloys for electric conductors. That is to say, aluminum is melted by the usual method, desired quantities of zirconium and yttrium and/or erbium are added thereto, and then cast and worked upon. For instance, aluminum for electrical purposes is melted. A mother alloy of aluminum-3% zirconium and yttrium and/or erbium are added, melted and cast. It is quite permissible if such usual impurities as, for example, Fe, Si, Mg, Zn, B, V, Ti, Mn, Cr, Cu, Sb, Be, etc., are contained in the alloys of this invention.

This invention will be explained in further detail, referring to examples (including examples for comparison) set forth hereinafter.

EXAMPLE 1

Aluminum for electric purposes, with the addition of Al-3% Zr mother alloy and yttrium in various combinations, was melted and cast in a metallic mold of 25 mm. in diameter at about 700° C. After hot-rolling of the casting at 500° C. to 19 mm. in diameter, it was drawn by a drawing machine into a wire rod of 4.0 mm. in diameter. This cold working is about 95% reduction in area. The electrical and mechanical properties of the wire rod obtained are shown in Table 1.

In this table, the residual value ratio is the ratio obtained by dividing the tensile strength after heating at 280° C. for 1 hour by the tensile strength before heating and multiplying the result by 100. The gauge length for measuring elongation was 250 mm.

in the effect on improvement of the heat-resistance characteristic.

Now, using Al-Zr alloy as the base, the difference in effect between the use of yttrium as taught by this invention and the rare earth elements of the afore-mentioned known invention (U.S. Pat. No. 3,278,300), especially mischmetal, will be investigated. Since the contents of the two are different from the beginning, the content of zirconium is made constant in comparing them. When the zirconium content is 0.04%, the alloys No. 2 to No. 4 of

TABLE 1.—(n=5)[1]

	Number	Compositions (weight-percent analytic value) Zr	Y	Mischmetal	Tensile strength (kg./mm.²)	Elongation (percent)	Electrical conductivity (percent)	Tensile strength after heating (kg./mm.²)	Residual value ratio (percent)
Alloys of this invention.	1	0.04	0.0006	----------	17.8	2.1	60.9	13.3	74.8
	2	0.04	0.005	----------	17.9	2.6	60.9	13.6	76.0
	3	0.04	0.01	----------	17.9	2.3	60.9	13.8	77.0
	4	0.04	0.04	----------	17.8	2.5	60.9	14.1	79.2
	5	0.04	0.06	----------	17.9	2.6	60.8	14.0	77.7
	6	0.10	0.004	----------	18.0	2.7	58.7	16.1	90.6
	7	0.10	0.07	----------	18.0	2.6	58.6	16.4	91.2
	8	0.30	0.05	----------	18.9	2.9	54.5	18.3	96.8
Alloys for comparison	9	0.04	0.09	----------	17.9	2.6	60.7	13.9	77.6
	10	0.10	0.10	----------	18.2	2.6	58.5	16.4	90.1
	11	0.30	0.19	----------	19.0	2.4	54.0	18.1	95.1
Alloys of prior art	12	0.04	--------	----------	17.8	2.3	60.9	13.1	73.5
	13	0.06	--------	----------	17.9	2.4	60.1	14.0	78.1
	14	0.10	--------	----------	18.0	2.2	58.7	15.6	86.6
	15	0.30	--------	----------	18.7	2.4	53.6	17.8	95.2
	16	--------	0.05	----------	17.9	2.6	62.3	12.0	67.0
	17	--------	0.10	----------	18.3	2.6	62.1	12.4	67.8
	18	--------	0.60	----------	21.1	2.8	60.6	12.5	59.2
	19	0.04	--------	0.07	17.9	2.1	60.7	13.1	73.5
	20	0.04	--------	0.20	18.1	2.0	60.5	13.3	73.2
	21	0.10	--------	0.20	18.2	2.1	58.2	15.7	86.7

[1] Each value is a mean value for 5 samples tested.

If the alloys No. 1 to No. 8 of this invention in the above Table are compared with alloys No. 9 to No. 11 for comparison and alloys No. 12 to No. 21 of prior art, then the effect of this invention is evident.

In case the zirconium content is in the neighborhood of 0.04%, the heat-resistance characteristic (residual value ratio) of the alloys No. 1 to No. 6 of this invention is about 75% or more, while that of the alloy No. 12 of the prior art is 73.5%. It can be seen from this that the heat-resistance characteristics of this inventive alloy is greatly improved without scarcely affecting the electrical conductivity (the electrical conductivity being about 60.9%). By comparing them with alloy No. 13 of the prior art having an increased content of zirconium, the superiority of this invention's alloys with respect to electrical conductivity may be understood.

With aluminum-zirconium alloys of the prior art, there were contradictory trends that if the zirconium content was increased to improve the heat-resistance characteristic, it lowers the electrical conductivity. With the alloys of this invention, however, it is possible to improve the heat-resistance characteristic while maintainng the electrical conductivity constant.

Even when the zirconium content is 0.1%, the same effect, i.e. an increase in the residual value ratio (improved from 86.6% to 91.2% or 90.6%), is observed if the alloys No. 6 and No. 7 of this invention are compared with the alloy No. 14 of the prior art. When the zirconium content is in the neighborhood of 0.30%, the effect on both electrical conductivity and the heat-resistance characteristic is observed if th alloy No. 8 of this invention is compared with the alloy No. 15 of the prior art.

Next, comparison will be made with an aluminum-yttrium alloy which is one of the alloys known in the prior art. The residual value ratio of the alloys No. 1 to No. 5 of this invention is 74 to 79% (electrical conductivity 60.9%), while that of the alloys No. 16 to No. 18 of the prior art is 59 to 67% (electrical conductivity 60 to 62%), from this, a difference may be distinctly observed this invention have a residual value ratio of 76.0%, 77.0% and 79.2%, respectively (electrical conductivity 60.9%), while the alloys No. 19 and No. 20 of the prior art have a ratio of 73.5 and 73.2% respectively (electrical conductivity 60.7 and 60.5%). Where the zirconium content is 0.10%, the alloys No. 6 and No. 7 of this invention have a residual value ratio of 90.6 and 91.2% respectively (electrical conductivity 56.7 and 58.6%), while the alloy No. 21 of the prior art has a ratio of 86.7% (electrical conductivity 58.2%). It is thus found that the alloys of this invention are superior in each case. That is to say, it is noted that ytrrium in a quantity less than the usual required quantity of mischmetal content is still more effective than mischmetal.

The alloys for comparison given in Table 1 are Al-Zr-Y alloys such as the alloys of this invention, but have different composition contents. That is to say, the content of yttrium is greater than 0.08%. If they are compared on the basis of the same zirconium content (for example, the alloy No. 5 of this invention compared with the alloy No. 9 for comparison, the alloy No. 8 of this invention with the alloy No. 11 for comparison), the alloys for comparison show a tendency of having a lower residual value ratio. (Their electrical conductivity is naturally lower.)

As is clearly seen from the afore-mentioned examples and the results of their investigating, the addition of a very small quantity of yttrium to aluminum-zirconium alloys according to this invention greatly improves the heat-resistance characteristic without substantially affecting electrical conductivity.

EXAMPLE 2

The mother alloy of Al-3% Zr and a very small quantity of erbium were added to aluminum for electric purposes in various combinations, and melted and cast in a metallic mold of 25 mm. in diameter. The conditions under which the samples were prepared and measurements were made are the same as in the case of the afore-mentioned Example 1. The results obtained are shown in Table 2.

TABLE 2.—(n=5)[1]

	Number	Compositions weight percent analytic value) Zr	Er	Tensile strength (kg./mm.^{2})	Elongation (percent)	Electrical conductivity (percent)	Tensile strength after heating (kg./mm.^{2})	Residual value ratio (percent)
Alloys of this invention	22	0.04	0.0005	18.0	2.4	60.9	13.6	75.5
	23	0.04	0.003	18.1	2.6	60.9	14.0	77.2
	24	0.04	0.009	17.9	2.4	60.9	14.3	80.0
	25	0.04	0.05	18.2	2.5	60.8	14.0	77.0
	26	0.10	0.004	18.2	2.4	58.7	16.4	90.2
	27	0.10	0.04	18.1	2.7	58.6	16.4	90.5
	28	0.31	0.03	18.9	2.8	54.5	18.4	97.2
Alloys for comparison	29	0.04	0.10	18.1	2.3	60.5	13.9	76.7
	30	0.10	0.10	18.3	2.6	58.4	16.4	89.5
	31	0.30	0.19	19.1	2.6	54.0	18.0	94.2

[1] Each value is a value for 5 samples tested.

The effect is obvious if the alloys No. 22 to No. 28 of this invention shown in the above table are compared with the alloys No. 29 to No. 30 for comparison and with the alloys No. 12 to No. 18 of the prior art shown in Example 1.

When the content of zirconium is in the neighborhood of 0.04%, the alloys No. 22 to No. 25 of this invention have a heat-resistance (residual value ratio) of about 77% or more, while the alloy No. 12 of the prior art shows a value of 73.6%. From this it can be seen that the heat-resistance characteristic is markedly improved without hardly affecting the electrical conductivity (electrical conductivity about 60.9%) at all. If comparison is made with the alloy No. 13 of the prior art which has an increased zirconium content, it will be understood that this invention is favorable with respect to electrical conductivity.

That is to say, in the case of the aluminum-zirconium alloy of the prior art there is a contradictory tendency that if the zirconium content is increased to improve the heat-resistance characteristic, it results in a decrease in electrical conductivity. If the alloys of this invention are used, however, it is possible to improve the heat-resistance characteristic while maintaining electrical conductivity constant.

Also, where the zirconium content is 0.1%, the same effect, namely an increase in the residual value ratio (improved from 86.6% to 90.2% or 90.5%), can be observed if the alloys No. 26 and No. 27 of this invention are compared with the alloy No. 14 of the prior art. When the zirconium content is in the neighborhood of 0.30%, the effect on both electrical conductivity and the heat-resistance characteristic is observed by comparing the alloy No. 28 of this invention with the alloy No. 15 of the prior art.

Now, using Al-Zr alloy as the base, the difference in effect between the use of erbium in accordance with this invention and rare earth elements, mischmetal, of the afore-mentioned known invention (U.S. Pat. No. 3,278,300) will be investigated. Because the quantities contained are different from the beginning, the quantity of zirconium contained is made constant for comparison. When the zirconium content is 0.04%, the alloys No. 22 to No. 24 of this invention have a residual value ratio of 75.5, 77.2 and 80.0%, respectively (electrical conductivity 60.9%), while the alloys No. 19 and No. 20 of the prior art have a ratio of 73.5 and 73.2% respectively (electrical conductivity 60.7 and 60.5%). When the zirconium content is 0.10%, the alloys No. 26 and No. 27 of this invention have a residual value ratio of 90.2 and 90.5% respectively (electrical conductivity 58.7 and 58.6%), while the alloy No. 21 of the prior art has a ratio of 86.7% (electrical conductivity 86.2%). From these examples, it can be seen that the alloy of this invention is superior in each case. That is to say, it is observed that erbium, in a quantity less than the usual required quantity of mischmetal, is more effective than mischmetal.

The alloys for comparison in the above table are

Al-Zr-Er

alloys such as the alloys of this invention, but have different composition contents. They are given an erbium content which exceeds 0.08%. If they are compared when the zirconium content is the same amount (for example, the alloy No. 25 of this invention compared with the alloy No. 29 for comparison, and the alloy No. 27 of this invention with the alloy No. 30 for comparison), the alloys for comparison show a tendency toward a decrease in the residual value ratio. (Naturally they have a lower electrical conductivity.)

As can be clearly seen from the afore-mentioned examples and the results of their investigation, the addition of a very small quantity of erbium to aluminum-zirconium alloy according to this invention greatly improves the heat-resistance characteristic without hardly affecting electrical conductivity at all.

EXAMPLE 3

Aluminum for electrical purposes with additions of Al-3% Zr mother alloy, erbium and yttrium in various combinations of quantities, was melted and cast in a metallic mold of 25 mm. in diameter. The conditions under which samples were prepared and measurements were made are the same as in the case of Example 1. Some of the results obtained are shown in the table below.

TABLE 3.—(n=5)[1]

	Nnmber	Compositions (weight percent, analytic value) Zr	Y	Er	Tensile strength (kg./mm.^{2})	Elongation (percent)	Electrical conductivity (percent)	Tensile strength after heating (kg./mm.^{2})	Residual value ratio (percent)
Alloys of this invention	31	0.04	0.01	0.002	18.1	2.6	60.9	14.4	79.5
	32	0.04	0.001	0.011	18.2	2.3	60.9	14.7	80.9
	33	0.10	0.01	0.01	18.3	2.6	58.7	16.5	90.5

[1] Each value is a mean value for 5 samples tested.

If the alloys No. 31 to No. 33 of this invention are compared with the alloys No. 12 and No. 14 of the prior art given in Example 1, it can be seen that a very small quantity of yttrium and erbium greatly improves the heat-resistance characteristic without affecting electrical conductivity.

The reason why only yttrium and erbium, among various mischmetals, have such a great effect is not completely understood. But it is considered that the mechanism for the effect may be that the very small quantity of yttrium and/or erbium in aluminum help the heat-resistance effect of the zirconium addition as a result of combining with voids or the like found therein.

I claim:

1. A heat-resistant aluminum alloy for electric conductors consisting of 0.01 to 0.5% zirconium, at least one element selected from the group consisting of 0.0005 to 0.08% yttrium and 0.0003 to 0.08% erbium, and the balance of which is essentially aluminum.

2. A heat-resistant aluminum alloy for electric conductors which consists of 0.01 to 0.5% zirconium, 0.0005 to 0.08% yttrium and the balance of which is essentially aluminum.

3. A heat-resistant aluminum alloy for electric conductors which consists of 0.01 to 0.5% zirconium, 0.0003 to 0.08% erbium and the balance of which is essentially aluminum.

4. A heat-resistant aluminum alloy for electric conductors which consists of 0.01 to 0.5% zirconium, 0.0005 to 0.08% yttrium, 0.0003 to 0.08% erbium and the balance of which is essentially aluminum.

5. A high heat-resistant aluminum alloy for electrical conductors having an improved heat resistance characteristic satisfactory at temperatures of 200° C. to 280° C. without detrimentally effecting the electrical conductivity consisting of a zirconium-aluminum containing 0.01 to 0.5% zirconium to which is added at least one element selected from the group consisting of 0.0005 to 0.08% yttrium and 0.0003 to 0.08% erbium.

References Cited

UNITED STATES PATENTS

3,278,300 10/1966 Koike .... 75—138

RICHARD O. DEAN, Primary Examiner

U.S. Cl. X.R.

148—32

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,694,195 Dated September 26, 1972

Inventor(s) Minoru Yokota

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

Col. 1, between lines 6 and 7, insert the following:

**-- Claims priority, application Japan
October 24, 1969 84650/1969;
January 31, 1970 8755/1970--**

Signed and sealed this 22nd day of May 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
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ROBERT GOTTSCHALK
Commissioner of Patents