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ALUMINUM ALLOYS FOR ELECTRIC CONDUCTORS

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This invention relates to improved aluminum alloys, more particularly to heat resistant aluminum alloy conductors and high strength heat resistant aluminum alloys for electric conductors.

Aluminum cable steel reinforced has been conventionally used for overhead power transmission lines: however, improved heat resistance and current carrying capacity of aluminum alloy conductors have long been required considering special transmission conditions such as bus conductors in heavy capacity power station, transmission lines having a load factor of 0.5 or less (single purpose transmission lines for connecting thermal power station and pumping-up power station), and for emergency transmission line for two circuits parallel operation in case of fault of a single circuit, etc. To meet the above requirements, various aluminum alloys for electric conductors have been studied, and an alloy including zirconium is disclosed in Japanese Patent No. 261,993. The heat resistance of Al-Zr alloys is improved as the Zr content is increased, on the other hand; the electric conductivity is reduced as zirconium increases, so that addition quantity of zirconium should be considerably limited in order to obtain an alloy having high electric conductivity and low ohmic loss. Within the said limitation, the heat resistance becomes very low, not adapted for the heat resistant conductive alloy conductors.

Aldrey alloys have been used for overhead power transmission as well as for aluminum cable steel reinforced; however, being a heat treated product, the said alloy needs a series of treatments in the process of manufacturing such as solution heat treatment-aging-wire drawing-aging, which make the alloy rather costly, and also, being an age hardening alloy, it has a disadvantage that the continuous operation temperature of the conductor cannot be made higher than that of an ordinary aluminum wire. As a non-heat treatable high strength aluminum alloy, Al-Mg alloys, for instance 5005 alloy, have been put into use; however, it being a solid solution type, it is difficult to increase its electric conductivity more than 55% when the tensile strength is not less than 25 kg./mm.². To increase electric conductivity, magnesium content must be reduced at the sacrifice of mechanical properties such as tensile strength and fatigue strength.

In addition to the high heat resistance, conductivity, tensile strength, and low manufacturing cost, overhead transmission line conductor is required to have excellent sag-tension characteristics, vibration fatigue strength, creep characteristics, etc.

The principal object of the invention is to obviate the defects of the conventional conductors and to provide aluminum base alloys having increased electric conductivity and substantially equivalent heat resistance to that of the conventional heat resisting conductive alloys.

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Another object of the invention is to provide aluminum alloys having high mechanical strength, high heat resistance and conductivity by improving the mechanical strength of conventional heat resistant aluminum alloy conductors.

A further object of the invention is to provide non-heat treatable aluminum alloys having excellent strength and high conductivity to be manufactured by the same process as ordinary aluminum conductors.

In order to attain the above objects, various researches were made on many multi-element alloys and the inventor has succeeded in obtaining aluminum alloys which have (1) high conductivity and heat resistance, or (2) high conductivity and heat resistance and substantially excellent mechanical strength, or (3) much higher conductivity than conventional heat resistant Al-alloys or high strength Al-alloys by adding to aluminum Misch metal having any composition of one or more of rare earth metals such as cerium or lanthanum (hereafter abridged as Re) and further a small amount of iron and also by adding to said aluminum-Re-iron alloy, a suitable quantity of zirconium or magnesium depending on the objects of use.

The essential ingredients of the alloys of the invention consist of 0.1-0.5% of iron, 0.6-3.0% of Re, and the remainder of aluminum. The reason for limiting the iron and Re contents to the above values in the invention is that for iron and Re contents of less than 0.1% and 0.6% respectively, heat resistance increase is not effective and that for iron content of more than 0.5%, heat resistance increase is saturated, which may possibly deteriorate electric conductivity and corrosion resistance.

The preferable composition of the alloys of the invention is 0.6-1.5% of Re, 0.15-0.25% of iron and the remainder of aluminum.

To improve the heat resistance of said ternary conductive aluminum alloys of Al-Fe-Re, the effect of addition of quaternary element was thoroughly investigated, and it has been ascertained that the addition of a small quantity of zirconium is very effective. The alloy developed was composed of 0.6-3.0% of Re, 0.1-0.5% of iron, 0.01-0.1% of zirconium and the remainder of aluminum. The reason for limiting the zirconium content of 0.01-0.1% is that at less than 0.01% of zirconium, heat resistance increase is not effective and that at more than 0.1%, the heat resistance increase is saturated while electric conductivity is reduced to less than 58% of I.A.C.S. and is unsuitable for conductor application.

The preferred composition of said alloy is 0.6-1.5% of Re, 0.15-0.25% of iron, 0.04-0.06% of zirconium and the remainder of aluminum.

The tensile strength of the aluminum conductor made of said alloys of the invention consisting of Al-Fe-Re or Al-Fe-Re-Zr is substantially the same as that of E.C. grade aluminum (99.60 Al) conductor. As a result of further research to develop a high strength heat resistant aluminum alloy, the inventor has found that addition of a small quantity of magnesium to Al-Fe-Re alloy increases the mechanical strength without impairing electric conductivity and heat resistance. That is, the alloy developed consists of 0.1-0.5% of iron, 0.6-3.0% of Re, 0.02-0.6% of magnesium and the remainder of aluminum. A magnesium content of 0.02-0.1% greatly improves the characteristics of heat resistant high strength aluminum alloy;

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a magnesium content of 0.1–0.6% improves characteristics of high strength heat resistant conductive aluminum alloy. The alloys of the invention can be grouped into two categories, namely, an alloy consisting of 0.1–0.5% of iron, 0.6–3.0% of Re, 0.02–0.1% of magnesium and the remainder of aluminum, and an alloy consisting of 0.1–0.5% of iron, 0.6–3.0% of Re, 0.1–0.6% of magnesium and the remainder of aluminum.

When the Fe-Re-Mg-Al alloy wire is compared with the conventional 5005 wire and Aldrey alloy or 6201 wire, the alloy of the invention has about 3–5% higher electric conductivity than conventional ones for the same tensile strength, and has higher tensile strength for the same electric conductivity.

	Tensile strength (kg./mm. ²)	Electric conductivity (I.A.C.S., percent)
Conductor of the alloy of the invention.	24	60
	32	56
5005 alloy conductor	24	55
Aldrey alloy conductor	32	53

In the alloys of the invention, impurities commonly included such as copper and silicon are allowable, but impurities to reduce electric conductivity such as titanium, manganese, chromium, vanadium, etc. are not allowable.

The invention will be further explained in detail with examples.

EXAMPLE 1

To the aluminum base metal of 99.99% purity, 0.01% and 0.25% of iron were added, and, to each mixture, 0.2–4.0% of Re was added. Cast 4" x 4.5" wire bars of the composition indicated in Table 4 were hot rolled to 13 mm. dia. redrawn rod and were drawn into 4.0 mm. dia. wire by ordinary working methods, and the tensile strength was measured after heating it at 150° C. for 1 hour. The rate of increase and decrease of the tensile strength was compared with the value measured at the beginning of the test. The results are shown in Table 1.

Table 1

	Re content (percent)	Rate of increase and decrease when Fe content is—	
		0.01 (percent)	0.25 (percent)
No. 1	0	—50.0	—5.2
No. 2	0.025	—22.0	—3.0
No. 3	0.6	—1.0	+1.0
No. 4	1.0	+3.0	+2.0
No. 5	2.0	+4.0	+5.0
No. 6	3.0	+3.0	+5.0
No. 7	4.0	+2.5	+5.0

NOTE.—Re used had the following composition:

Cerium	45%
Lanthanum	35%
Neodymium	15%
Praseodymium	4%
Samarium	Remainder
Iron	5%
Magnesium, Silicon	2%

As seen from the above table, the anti-softening characteristic on heating is greatly improved by adding a little amount of iron, and, for Re content of more than 0.6%, the alloy is hardened by heating. The lower limits of iron and Re were, therefore, taken as 0.1% and 0.6% respectively.

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EXAMPLE 2

By the use of alloys having a composition shown in Table 2, wires were produced through the process of casting-rolling- $\frac{3}{8}$ " wire rod-wire drawing-2.9 mm. dia. The conductivity and tensile strength of drawn wires are shown in Table 3.

Table 2

	Fe (percent)	Re (percent)	Al (percent)
No. 8	0.25	1.5	Remainder.
No. 9	0.25	2.0	Do.
No. 10	0.25	3.0	Do.
No. 11	0.5	1.5	Do.
No. 12	0.5	2.0	Do.
No. 13	0.5	3.0	Do.

Table 3

	Electric conductivity (I.A.C.S., percent)	Tensile strength (kg./mm. ²)
No. 8	60.3	20.4
No. 9	59.7	20.9
No. 10	58.7	21.5
No. 11	60.1	20.7
No. 12	59.6	20.7
No. 13	58.4	21.5

The above samples were further subjected to heating at 100° C., 130° C., 160° C., 190° C., and 220° C., for 2 hours each, and then the tensile strengths were measured to obtain the rate of increase and decrease. The results are shown in Table 4.

Table 4

	100° C.	130° C.	160° C.	190° C.	220° C.
	Percent	Percent	Percent	Percent	Percent
No. 8	+6.7	+10.5	+15.6	—5.6	—18.6
No. 9	+7.2	+12.0	+8.7	—4.8	—21.0
No. 10	+9.8	+15.1	+11.2	—3.6	—18.0
No. 11	+5.5	+9.0	+3.8	—10.0	—26.3
No. 12	+7.9	+11.0	+5.9	—7.4	—25.2
No. 13	+9.2	+12.6	+8.7	—5.8	—23.6

Judging from Tables 3 and 4, the hardening characteristic on annealing increases as the Re content increases, and, for the same Re content, Fe 0.5% has less hardening than Fe 0.25%. In case the conductivity is higher than 58% I.A.C.S., the upper limits for the iron and Re contents are limited to 0.5% and 3.0% respectively.

It seems that the alloy of the invention being hardened by heating instead of softening is due not to simple precipitation hardening but to a particular phenomenon related to the reciprocal action between solute foreign atoms and dislocations caused by cold working.

EXAMPLE 3

Alloys having the composition of Table 5 were made into wires of 3.2 mm. dia. to compare their characteristics with those of conductor grade aluminum wire with regard to conductivity, tensile strength, anti-softening characteristic on heating, and creep characteristic; the results are shown in Table 6.

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Table 5

Name of alloy	Fe (per- cent)	Si (per- cent)	Re (per- cent)	Al (percent)
Aluminum alloy wire of the invention:				
(14)-----	0.1	-----	0.6	Remainder.
(15)-----	0.25	-----	2.0	Do.
(16)-----	0.5	-----	3.0	Do.
Conductor grade aluminum wire-----	0.18	0.08	-----	Do.

Table 6

Name of Alloy	Electric conductivity (percent)	Tensile strength (kg./mm. ²)	Rate of increase and decrease (percent)	Creep characteristic (percent)
Aluminum alloy wire of the invention:				
(14)-----	61.8	18.2	+1.1	0.04
(15)-----	60.2	19.8	+8.5	0.021
(16)-----	58.5	21.6	+13.6	0.012
Conductor grade aluminum wire-----	62.4	17.9	-6.2	0.074

The rate of increase and decrease is expressed in terms of a ratio of the tensile strength after the wire is heated at 110° C. for 500 hours to the tensile strength at room temperature before heating. The creep characteristic is

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It is apparent from comparison of Table 4 and the above tables that the anti-softening characteristic after heating of Al-Fe-Re alloy is greatly improved by adding a small quantity of zirconium, and the effects are particularly remarkable in the high temperature zone.

EXAMPLE 5

The quaternary alloys consisting of Fe-Re-Zr-Al in the proportion shown in Table 9 were made into wires of 2.9 mm. dia. to measure the tensile strength and conductivity at room temperature and to determine the rate of increase and decrease in tensile strength by measuring

25 tensile strength after heating them at 120° C. for 15 days and by measuring the same strength after cooling them down to room temperature. The results are shown in Table 10.

Table 9

Name of alloy	Zr (per- cent)	Re (per- cent)	Fe (per- cent)	Si (per- cent)	Mg (per- cent)	Al (percent)
Aluminum alloy conductor of the invention:						
(23)-----	0.02	0.7	0.5	-----	-----	Remainder.
(24)-----	0.04	0.7	0.5	-----	-----	Do.
(25)-----	0.06	2.0	0.5	-----	-----	Do.
Ordinary aluminum conductor-----	-----	-----	0.18	0.08	-----	Do.
5005 alloy conductor-----	-----	-----	0.20	-----	0.6	Do.
Aldrey alloy conductor-----	-----	-----	0.15	0.5	0.5	Do.

a strain after the wire is subjected to a stress of 27 kg./mm.² and heating at 110° C. for 100 hours.

It is clear from the above table that the aluminum alloy conductor of the invention has a higher conductivity and a better anti-softening characteristic after heating for long time, and more excellent creep characteristics at high temperatures than conventional aluminum conductor.

EXAMPLE 4

Quaternary alloys consisting of Fe-Re-Zr-Al in the proportion shown in Table 7 were made into wires of 2.9 mm. dia. by ordinary working methods to measure their conductivity and tensile strength, and the results are shown in Table 7. The rates of increase and decrease of tensile strength after heating at the predetermined temperature for 2 hours are shown in Table 8.

Table 7

	Fe (per- cent)	Re (per- cent)	Zr (per- cent)	Al (percent)	Electric conductivity (I.A.C.S., percent)	Tensile strength (kg./mm. ²)
No. 17-----	0.25	1.5	0.04	Remainder...	59.7	20.4
No. 18-----	0.25	2.0	0.04	do-----	59.0	20.8
No. 19-----	0.25	3.0	0.04	do-----	58.1	21.3
No. 20-----	0.5	1.5	0.04	do-----	59.2	20.6
No. 21-----	0.5	2.0	0.04	do-----	58.9	20.7
No. 22-----	0.5	3.0	0.04	do-----	57.8	21.4

Table 8

	100° C.	130° C.	160° C.	190° C.	220° C.
	Percent	Percent	Percent	Percent	Percent
No. 17-----	+6.56	+11.2	+9.5	+0.64	-14.3
No. 18-----	+7.2	+12.3	+12.16	+2.98	-12.3
No. 19-----	+7.7	+14.1	+12.76	+2.5	-12.2
No. 20-----	+4.6	+10.4	+8.11	-1.1	-16.9
No. 21-----	+5.1	+11.2	+9.86	0	-15.1
No. 22-----	+7.7	+12.9	+11.95	+2.7	-14.8

70 It is apparent from the above tables that the conductivity and heat resistance of the quaternary Fe-Re-Zr-Al alloy are greatly improved compared with conventional heat resisting aluminum alloys (5005 alloy and Aldrey alloy).

EXAMPLE 6

The aluminum alloy conductors of the invention consisting of Mg-Fe-Re-Al in the proportion shown in Table 11 were compared with the conventional 5005 alloy con-

ductor (both in 2.9 mm. dia. wire form) with respect to tensile strength and electric conductivity. The results are shown in Table 11.

Table 11

Name of alloy	Mg (per-cent)	Fe (per-cent)	Re (per-cent)	Al (percent)	Tensile strength (kg./mm. ²)	Electric conductivity (percent)
5005.....	0.6	0.25	-----	Remainder...	24	55
Alloy of the invention:						
(26).....	0.05	0.2	1.5	do.....	24	60
(27).....	0.1	0.2	1.5	do.....	26	59

It is clearly shown in the above tables that the tensile strengths of the 5005 alloy and the alloys of the invention are substantially the same but that the electric conductivity of the latter alloys is far better than that of the former.

The rates of tensile strength decrease for the above aluminum alloy conductor of the invention, Aldrey alloy

It is apparent from the the above table that the aluminum alloy of the invention maintains substantially the same tensile strength at 150° C. as at room temperature.

EXAMPLE 7

The alloys having composition shown in Table 14 were cast into 4" x 4.5" wire bars which were hot rolled by a rod mill into 3/8" bars and then redrawn into 2.9 mm. dia. wires to measure their tensile strength and electric conductivity at room temperature. The results are shown in Table 14.

Table 14

	Mg (per-cent)	Re (per-cent)	Fe (per-cent)	Al (percent)	Tensile strength (kg./mm. ²)	Electric conductivity (percent)
No. 29.....	0.2	-----	0.15	Remainder...	24.4	60.7
No. 30.....	0.2	0.6	0.15	do.....	25.8	59.3
No. 31.....	0.2	1.0	0.15	do.....	26.8	58.8
No. 32.....	0.2	2.0	0.15	do.....	28.7	57.3
No. 33.....	0.4	-----	0.15	do.....	25.8	57.8
No. 34.....	0.4	0.6	0.15	do.....	28.2	56.7
No. 35.....	0.4	1.0	0.15	do.....	29.5	56.2
No. 36.....	0.4	2.0	0.15	do.....	31.7	55.0
No. 37.....	0.6	-----	0.15	do.....	27.4	54.9
No. 38.....	0.6	0.6	0.15	do.....	29.4	54.4
No. 39.....	0.6	1.0	0.15	do.....	30.5	54.1
No. 40.....	0.6	2.0	0.15	do.....	32.5	52.5

conductor, and 5005 alloy conductor were measured after heating them at 120° C. The results are shown in Table 12.

Table 12

Name of alloy	After heating for—		
	100 hours (percent)	500 hours (percent)	2,400 hours (percent)
Ordinary aluminum conductor...	4.6	9	-----
5005 alloy conductor.....	4.12	13.0	-----
Aldrey alloy conductor.....	5.0	17.0	-----
Aluminum conductor of the invention (26).....	2.0	5.7	11.3

Besides, the above aluminum alloy conductor of the invention consisting of said quaternary elements having diameter of 2.9 mm. was compared with a conventional heat resistant aluminum conductor by measuring their tensile strength after heating at 150° C. for 30 minutes. The results are shown in Table 13.

Table 13

Name of alloy	Mg (per-cent)	Re (per-cent)	Fe (per-cent)	Zr (per-cent)	Al (percent)	Tensile strength at room temp. (kg./mm. ²)	Rate of increase and decrease (percent)
Heat resistant aluminum conductor.	-----	-----	0.15	0.1	Remainder...	18	-21
Aluminum conductor of the invention (28).	0.05	0.6	0.25	-----	do.....	23	+1.8

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Table 15

	Mg (per- cent)	Re (per- cent)	Fe (per- cent)	Al (percent)	Bending limit diameter
No. 41-----	0.2	2	0.25	Remainder	1 D
No. 42-----	0.6	2	0.25	do-----	1 D
No. 43-----	0.8	2	0.25	do-----	3 D
No. 44-----	0.2	3	0.25	do-----	1 D
No. 45-----	0.6	3	0.25	do-----	3 D
No. 46-----	0.8	3	0.25	do-----	10 D
No. 47-----	0.2	4	0.25	do-----	10 D
No. 48-----	0.6	4	0.25	do-----	20 D
No. 49-----	0.8	4	0.25	do-----	50 D

Here, D stands for the diameter of the wire, and the larger the multiple is, the smaller the bendability.

Accordingly, the additions of Mg and Re are limited to 0.6% and 3.0% respectively from the angle of wire drawing workability and bendability.

EXAMPLE 9

The quaternary alloys of Mg-Re-Fe-Al having composition shown in Table 16 were compared with the conventional Aldrey alloy with regard to tensile strength, electric conductivity and the rate of decrease in tensile strength after heating at 120° C. for 1,000 hours. The results are shown in Table 16.

Table 16

Name of alloy	Mg (per- cent)	Re (per- cent)	Fe (per- cent)	Si (per- cent)	Tensile strength (kg./mm. ²)	Electric conduc- tivity (percent)	Rate of decrease (percent)
Aldrey alloy-----	0.5	-----	0.15	0.5	33	52	23
Aluminum alloy of the invention:							
(50)-----	0.2	1.5	0.25	-----	28	58.5	14.8
(51)-----	0.35	1.5	0.25	-----	30	56	19.1
(52)-----	0.5	2.0	0.25	-----	32	55.8	20.2

It will be apparent from the above table that the aluminum alloy of the invention has very high electric conductivity and anti-softening characteristic compared with the publicly known heat resistant aluminum alloy.

Of the aluminum alloys of the invention as explained above in detail, the ternary Fe-Re-Al alloys have better electric conductivity, tensile strength, anti-softening characteristic and creep characteristic than the ordinary aluminum conductor, while the quaternary Fe-Re-Zr-Al alloys have better heat resistance and electric conductivity than the conventional heat resistant aluminum alloys.

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Besides, by adding 0.02–0.1% of magnesium to the Fe-Re-Al alloys, the mechanical strength, heat resistance and electric conductivity thereof are greatly improved.

- 5 Besides, the addition of 0.1–0.6% of magnesium to the Fe-Re-Al alloys has great effect of considerably increasing the mechanical strength of the original alloys without affecting the electric conductivity.

What I claim is:

1. Heat resistant aluminum alloy for electric conduc-
tor consisting of 0.1–0.5%, preferably 0.15–0.25%, of
10 iron, 0.6–3.0%, preferably 0.6–1.5%, of Misch metal, and the remainder of aluminum.

2. Heat resistant aluminum alloy for electric conduc-
tor consisting of 0.1–0.5%, preferably 0.15–0.25%, of
15 iron, 0.6–3.0%, preferably 0.6–1.5%, of Misch metal, 0.01–0.1%, preferably 0.04–0.06%, of zirconium, and the remainder of aluminum.

3. High strength heat resistant aluminum alloy for
electric conductor consisting of 0.1–0.5%, preferably
20 0.15–0.25%, of iron, 0.6–3.0%, preferably 0.6–1.5%, of Misch metal, 0.02–0.1%, preferably 0.04–0.08%, of magnesium, and the remainder of aluminum.

4. High strength aluminum alloy for electric conduc-
tor consisting of 0.1–0.5%, preferably 0.15–0.25%, of
25 iron, 0.6–3.0%, preferably 0.6–1.5%, of Misch metal, 0.1–0.6% of magnesium, and the remainder of alumi-
num.

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