

PATENT SPECIFICATION

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(54) ALUMINIUM-MAGNESIUM-SILICON ALLOYS ✓

(71) We, SOCIETE DE VENTE DE L'ALUMINIUM PECHINEY, a body corporate organised under the laws of France, of 23 bis, rue Balzac, 75008 Paris, France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an improvement in the mechanical and electrical characteristics of aluminium-magnesium-silicon alloys.

Weakly alloyed Al—Mg—Si alloys (magnesium up to approximately 1%, Si up to approximately 1%) have been used for almost half a century as electrical conductors, especially in the form of overhead cables for carrying power over long distances. The alloy commonly known as "Almelec" or AGS/L (according to French standard A 02 001), which is the subject of French Standard AFNOR NF—C—34125, has to show the following minimal characteristics in the case of wires smaller than or equal to 3.6 mm in diameter:

- minimal ultimate tensile strength: 33 Kg/mm²;
- minimum average for cables: 34.5 kg/mm²;
- elongation at break: 4%;
- maximum resistivity at 20° C: 3.28 $\mu\Omega$. cm;
- maximum average resistivity for cables: 3.25 $\mu\Omega$. cm.

Its chemical composition is of the following order: Mg 0.6%, Si 0.6%, Fe $\leq$ 0.35%.

A significant increase in the mechanical characteristics without any loss of conductivity would be an obvious advantage either with a view to increasing span without modifying the height of the pylons or with a view to obtaining a greater mechanical safety coefficient for the same span.

A significant improvement in the mechanical characteristics, for a given electrical resistivity, cannot be obtained simply by increasing the content of alloying elements (especially Mg and Si) since this would be reflected in a reduction in drawability.

It has now been found that it is possible to obtain improved conductor wires of AGS/L by combining:

1. Tepid drawing, i.e. drawing at a temperature in the range of from 110 to 180° C and preferably in the range of from 130 to 160° C, of the wire rod previously subjected to solution heat treatment and quenching;
2. A slight modification in its chemical composition by the addition of copper in a quantity up to a maximum of 0.40%; and
3. An artificial ageing treatment after drawing which may be carried out either in a static furnace or, preferably, continuously.

The manufacture of wires of Al—Mg—Si alloys of the AGS/L type for overhead cables may be carried out by various processes. Among these, reference is made in particular to three processes comprising the following series of operations:

First process: rolling square billets or extruding blooms in a press, welding rings of wire rod end to end to produce a great length of wire, drawing to approximately 3 times the required final diameter, solution heat treatment, quenching, drawing to the final diameter and artificial ageing.

Second process: semi-continuous press extrusions of blooms with water quenching at the output end of the press, drawing to the final diameter and artificial ageing.

Third process: continuous casting and rolling of machine wire in machines of the PROPERZI or SECIM (formerly SPIDEM) type, solution heat treatment in a furnace of spools of wire rod weighing approximately 1 tonne, followed by quenching, drying, drawing to the final diameter and artificial ageing.

The last of these processes has been the most commonly used for about 20 years because it has the best productivity level both at the production stage of the wire rod and at the processing stage. It is used for Al—Mg—Si alloys of which the chemical composition may vary from 0.15 to 0.35% for iron, from 0.30 to 0.80% for magnesium, and from 0.30 to 0.70% for silicon, the other elements being those generally present in electrical-grade aluminium alloys. This process is also the process which lends itself best to the application of the invention.

It is known among experts that the mechanical characteristics of Al—Mg—Si alloys after solution heat treatment, quenching and artificial ageing in the case of profiles, or after solution heat treatment, quenching, drawing and artificial ageing in the case of wires, may be substantially improved by the addition of copper.

On the other hand, however, electrical resistivity increases to a significant extent and, so far as the second process mentioned above is concerned, suitability for extrusion is significantly reduced which offsets the practical advantage of such an addition. In addition, the copper content has to be limited in view of the corrosion risk which its presence may involve.

In addition, it is known (cf. French Patent No. 1,499,266 in the name of PECHINEY) that the drawing of wires of Al—Mg—Si alloy, after quenching and ageing, at a temperature below the rapid precipitation temperature which is of the order of 200° C and above the normal drawing temperatures of from 20° C to 70° C results, in the case of drawing at 110° C, in an increase in the ultimate tensile strength of from 1 to 1.5 kg/mm² for equal resistivity after the final artificial ageing recovery treatment carried out at a temperature of 165° C.

The present invention relates to a process for the production of distinctly improved conductor wires of AGS/L characterised by:

- combinations of mechanical and electrical characteristics which are distinctly better in terms of performance than those obtained with conventional processes;
- improved thermal stability and creep strength;
- a fatigue resistance at least equivalent to that of the prior art.

The invention therefore provides an electrical conductor comprising an aluminium-based alloy which contains from 0.15% to 0.35% of iron, from 0.30% to 0.70% of silicon, from 0.30% to 0.80% of magnesium, and from 0.008% to 0.40% of copper, the balance consisting of aluminium and conventional impurities, the said electrical conductor having

an ultimate tensile strength of at least 37 kg/mm², an elongation at break of at least 4% and an electrical resistivity of at most 3.28 micro-ohms/centimetre.

The invention also provides a process for producing an electrical conductor as defined above from wire rod previously subjected to a solution heat treatment, followed by quenching, which comprises drawing the wire rod at a temperature of from 110 to 180° C with an elongation of at least 350%, and subjecting the drawn wire rod to artificial ageing at a temperature of from 130 to 240° C. The quenching is optionally continuous.

The electrical conductor preferably has a creep resistance over a period of 1000 hours at 60° C of less than $4.0 \cdot 10^{-2}\%$, as measured on a 2.2 mm diameter wire under a stress of 7.1 kg/mm².

According to the invention copper is added to an Al—Mg—Si alloy (AGS/L or "Almelec") in a quantity not exceeding 0.40% and preferably not exceeding 0.20%, and the wire rod obtained, for example by process No. 3 described above, is subjected to so-called tepid processing by drawing between the solution heat treatment and quenching of the wire rod and the artificial ageing treatment of the drawn wire, these treatments being carried out either in batches in a static furnace or continuously.

The tepid drawing process is carried out in a temperature range corresponding to a low precipitation rate of Mg₂Si, such as from 110 to 180° C in the case of an Al—Mg—Si alloy with the following composition: Fe 0.15—0.35%, Si 0.30—0.70%, Mg 0.30—0.80%. Drawing is carried out at these temperatures with a reduction of area of at least 350%.

$$\left(\frac{S-s}{s} \right) \times 100 \geq 350\%$$

S being the initial section of the wire and s the final section of the wire). This surprisingly enables the final characteristics (values of ultimate tensile strength and resistivity) obtained after final artificial ageing to be improved by virtue of a finer distribution of the hardening Mg₂Si constituents which precipitate during the tepid drawing operation and by virtue of the elimination during the tepid drawing operation of Guinier-Preston zones formed by ageing after quenching, which zones contribute significantly towards the electrical resistivity, but only negligibly to structural hardening.

It has surprisingly been found that the combination of the addition of copper in quantities limited to 0.4% and preferably to 0.2% and tepid drawing enables very high final mechanical and electrical property levels to be obtained without any need to use

excessive copper contents which would adversely affect both drawability under normal conditions and also corrosion resistance.

In addition, taking into account the effect which it has upon precipitation hardening, tepid drawing enables the drawn wires to be subjected to a continuous artificial ageing treatment.

The tepid drawing operation may be carried out with wire rod in different ways, i.e. with a spool of cold wire, in which case the wire is cold on entering the drawing machine or, preferably, is gradually preheated to the tepid drawing temperature, or with a spool of wire preheated in a furnace to a temperature below the tepid drawing temperature and not exceeding 140° C, at which temperature a significant hardening effect is obtained, being reflected in reduced drawability.

One method of carrying out the tepid drawing operation comprises, for example, drawing the wire in a multiple-pass machine with in-line capstans and functioning by immersion, the bath of lubricant being thermostatically controlled to the tepid drawing temperature and the drawing die being sprayed with this same thermostatically controlled lubricant. In this case, the temperature of the lubricant is adjusted to between 110 and 180° C and preferable to between 130 and 160° C in dependence upon the drawing conditions (cold-working level, drawing rate and, hence, drawing time).

After tepid drawing, the wire is heat-treated either in a static batch furnace at nominal temperatures in the range of from 130 to 170° C for periods ranging from 30 minutes to 12 hours or, preferably, continuously on leaving the tepid drawing arrangement at nominal temperatures in the range of from 180 to 240° C over periods ranging from 1 to 30 seconds. One way of carrying out a heat treatment such as this is, for example, to pass the wire continuously through a thermostatically controlled oil-bath furnace which also makes it possible to obtain a wire which is perfectly lubricated and, hence, eminently suitable for the subsequent cable-forming operation.

This heat treatment has a recovery effect and also promotes precipitation hardening which is reflected in:

- an increase in electrical conductivity,
- a restoration of plasticity (elongation at break and bending), whilst the mechanical strength of the wires (ultimate tensile strength) remains at a high level.

The process according to the invention is illustrated by the following Examples.

EXAMPLE 1.

Four alloys A, B, C and D with the following compositions were drawn in a conventional manner:

	Fe %	Si %	Cu %	Mg %
A	0.18	0.55	<0.008	0.66
B	0.18	0.57	0.05	0.70
C	0.18	0.58	0.20	0.69
D	0.20	0.56	0.55	0.67

The processing cycle was as follows:

- press extrusion of blooms 100 mm in diameter giving a wire rod 9.5 mm in diameter;
- solution heat treatment of the 9.5 mm diameter wire rod for 3 hours at 540° C;
- quenching with cold water;
- ageing for 8 days at ambient temperature;
- drawing on a single-pass block to a diameter of 2.2 mm at ambient temperature at a rate of 40 metres per minute;
- final artificial ageing in a static furnace at 165° C with residence times ranging from 30 minutes to 9 hours.

Variable ultimate tensile strength resistivity associations were obtained, according to the artificial ageing times, for which it is possible

to trace curves of $R=f(\rho)$ (where R =ultimate tensile strength and ρ =resistivity). Taking into account only the resistivity value $\rho=3.25 \mu\Omega \cdot \text{cm}$, the following ultimate tensile strengths were obtained:

Alloy

- A: 36.4 kg/mm²
- B: 36.8 kg/mm²
- C: 39.5 kg/mm²
- D: 41.5 kg/mm²

$\rho=3.25 \mu\Omega \cdot \text{cm}$

EXAMPLE 2.

Composition of the alloy: Fe 0.30%, Si 0.60%, Mg 0.64%, Cu 0.015%.

Processing cycle:

- casting, followed by continuous rolling in a PROPERZI machine of a 9.5 mm diameter wire rod;
- solution heat treatment of the wire rod:

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- 3 h at 540° C;
 — quenching with cold water;
 — ageing for 4 days at ambient temperature;
 5 — drawing on a single-pass block to a diameter of 2.2 mm at 4 successive temperatures:
 ambient (approximately 20° C)
 10 110° C
 140° C
 160° C.

bath, the die also being heated to the drawing temperature.

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— final artificial ageing treatment (static furnace) at 165° C for periods ranging from 1 hour to 7 hours.

Variable R— ρ associations were obtained according to the artificial ageing times. On the basis of these associations, it is possible to draw curves of $R=f(\rho)$ for each drawing temperature. Taking into account only the resistivity value $\rho=3.25 \mu\Omega \cdot \text{cm}$, the following ultimate tensile strengths were obtained:

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For drawing at 110, 140 °C and 160° C, the wire was heated before each pass by residence in a thermostatically controlled oil

Drawing temperature °C	R kg/mm ²	$\rho \mu\Omega \cdot \text{cm}$
Ambient 20°	35.0	3.25
110°	37.7	„
140°	39.8	„
160°	38.9	„

EXAMPLE 3.

- 30 The 2.2 mm diameter wire obtained in accordance with Example 2 by drawing at 140° C was subjected to continuous artificial ageing by passage through an oil bath heated to different temperatures, namely 180° C, 200° C and 220° C. The rate of travel of the
 35 wire through the bath was such that the

residence time at the artificial ageing temperature was 15 seconds.

The characteristics obtained for the various artificial ageing temperatures and immediately after tepid drawing are as follows (A=elongation at break; $A_{200}\%$ =percent elongation at break measured on a test wire 200 mm long):

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Artificial ageing temperature in °C	R Kg/mm ²	$A_{200}\%$	$\rho \mu\Omega \cdot \text{cm}$
180°	39.1	4.5	3.255
200°	38.5	4.5	3.243
220°	37.4	4.5	3.228
immediately after tepid drawing	39.9	2.2	3.30

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EXAMPLE 4.

- 45 Tepid drawing was carried out with three samples of 9.5 mm diameter wire rod corresponding to the compositions A, B and C of Example 1 which had been subjected to the same processing cycle as in that Example, except for the drawing operation which was carried out at 140° C.

As in the preceding Examples, different R— ρ associations were obtained according to the artificial ageing conditions. On the basis of these associations, it is possible to draw a curve of $R=f(\rho)$ for each alloy, the values of R corresponding to the resistivity value $\rho=3.25 \mu\Omega \cdot \text{cm}$ being retained.

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The following results were obtained:

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Alloy	R kg/cm ²	$A_{200}\%$	$\rho \mu\Omega \cdot \text{cm}$
A	40	5	3.25
B (0.05% Cu)	40.5	5	3.25
C (0.2 % Cu)	42	5	3.25

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EXAMPLE 5.

Under otherwise the same conditions as in Example 4, the wire was drawn to a diameter of 3.45 mm with the following results:

Alloy	R kg/mm ²	$\rho \mu\Omega \text{ cm}$
A	38.3	3.25
B	39.1	3.25
C	41	3.25

EXAMPLE 6.

Wires of alloys A and C of Example 1 (respective copper contents $\leq 0.008\%$ and 0.20%) processed in accordance with Example 4, with tepid drawing at 140°C followed by artificial ageing in a static furnace, were subjected to various heat treatments in order to characterise the thermal stability of the mechanical characteristics of the wires and their creep resistance.

The mechanical characteristics were measured at 20°C before and after heating for 1 hour at 175 to 200°C and at 250°C and for 100 hours at 125°C . The results obtained were as follows:

Heating	Alloy A		Alloy C	
	R kg/mm ²	A 200%	R kg/mm ²	A 200%
None	39.5	4.8	40.8	4.0
1h at 175°C	37.1	5.7	40.2	4.0
1h at 200°C	31.6	4.8	36.1	3.7
1h at 250°C	21.7	4.5	25.7	4.5
100h at 125°C	36.4	5.4	39.8	4.0

By way of comparison, the 2.2 mm wires of Example 2 processed in accordance with the prior art, with normal drawing at 20°C , gave the following results:

ceding Table), were subjected to creep tests over a period of 1000 hours at 60°C under a stress of 7.1 Kg/mm^2 . The creep elongations recorded are respectively:

Heating	R Kg/mm ²	$A_{1000} \%$
None	35	5.5
1h at 175°C	32.8	4.5
1h at 200°C	28.5	4.0
1h at 250°C	18.7	6.2
100h at 125°C	33.6	6.3

A: $4.55 \times 10^{-3} \text{ mm}$ over 125 mm, i.e. $\epsilon\% = 3.64 \times 10^{-3}\%$
C: $3.65 \times 10^{-3} \text{ mm}$ over 125 mm, i.e. $\epsilon\% = 2.92 \times 10^{-3}\%$

In the case of wires similar in their chemical composition to alloy A and processed by conventional methods, the creep elongations obtained under the same test conditions are generally $4 \times 10^{-3}\%$.

EXAMPLE 7.

Using 9.5 mm diameter machine wire, obtained by continuous casting and rolling on a PROPERZI machine, of two alloys with the following chemical composition:

	Fe %	Si %	Cu %	Mg %
Alloy E	0.28	0.57	0.020	0.57
Alloy F	0.28	0.54	0.10	0.56

and having been successively subjected in the form of 1 tonne spools to

- quenching with cold water
- drying for 6 hours at 100°C ,

- solution heat treatment for 10 hours at 540°C

tepid drawing was carried out in a four-pass drawing machine, the output rate being 100

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m/minute. The tepid drawing temperature was 160° C.

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The wire entered the machine cold and was brought to the tepid drawing temperature by immersion in a bath of lubricant thermostatically controlled to that temperature, the dies and heads of the drawing machine themselves being immersed in the lubricant.

The 3.45 mm diameter wire obtained in

two drawing operations under the above conditions was then subjected to different artificial ageing treatments either in a static furnace or by passage through an oil bath.

The mechanical traction characteristics and the electrical resistivity values obtained immediately after tepid drawing and after artificial ageing for 12 hours at 150° C are for example as follows:

Alloy	Artificial ageing conditions	R kg/mm ²	A ₂₀₀ %	ρ $\mu\Omega \cdot \text{cm}$
E	Immediately after tepid drawing	34.7	5.7	3.447
	After artificial ageing for 12 h at 150° C	38.0	8.7	3.240
F	Immediately after tepid drawing	35.6	5.3	3.480
	After artificial ageing for 12 h at 150° C	39.0	8.5	3.240

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EXAMPLE 8.

3.45 mm diameter wire obtained as in Example 7 for each of the two alloys was subjected immediately after tepid drawing to a third drawing operation under the same

conditions in order to reduce it to a diameter of 2.25 mm.

This wire was also subjected to the artificial ageing treatments of Example 7, the corresponding mechanical and electrical characteristics being for example:

Alloy	Artificial ageing conditions	R kg/mm ²	A ₂₀₀ %	ρ $\mu\Omega \cdot \text{cm}$
E	Immediately after drawing	37.1	5.1	3.414
	After artificial ageing for 12 h at 145° C (static)	40.0	7.8	3.240
	After artificial ageing for 15 seconds at 230° C (oil bath)	37.0	5.0	3.265
F	Immediately after drawing	38.4	5.0	3.450
	After artificial ageing for 12 h at 145° C (static)	41.0	8.0	3.240
	After artificial ageing for 15 seconds at 230° C (oil bath)	37.5	5.0	3.270

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The associations of mechanical and electrical characteristics obtained compare favourably with those obtained by conventional industrial processing with drawing at ambient

temperature as illustrated in Example 2 in reference to an alloy with a similar composition to alloy E processed by PROPERZI casting and rolling and then drawn to the

same diameter after quenching at the level of 9.5 mm diameter wire rod.

WHAT WE CLAIM IS:—

- 5 1. An electrical conductor comprising an aluminium-based alloy which contains from 0.15% to 0.35% of iron, from 0.30% to 0.70% of silicon, from 0.30% to 0.80% of magnesium, and from 0.008% to 0.40% of copper, the balance consisting of aluminium and conventional impurities, the said electrical conductor having an ultimate tensile strength of at least 37 kg/mm², an elongation at break of at least 4% and an electrical resistivity of at most 3.28 micro-ohms/centimetre.
- 10 2. An electrical conductor as claimed in Claim 1, wherein the aluminium-based alloy contains up to 0.20% of copper.
- 15 3. An electrical conductor as claimed in Claim 1 or 2, which has a creep resistance over a period of 1000 hours at 60° C of less than 4.0.10⁻²%, as measured on a 2.2 mm diameter wire under a stress of 7.1 kg/mm².
- 20 4. An electrical conductor as claimed in Claim 1, substantially as herein described with reference to any of the specific Examples.
- 25 5. A process for producing an electrical conductor as defined above from wire rod previously subjected to a solution heat treatment, followed by quenching, which comprises drawing the wire rod at a temperature of from
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110 to 180° C with an elongation of at least 350%, and subjecting the drawn wire rod to artificial ageing at a temperature of from 130 to 240° C.

6. A process as claimed in Claim 5, wherein the wire rod is drawn at a temperature of from 130 to 160° C. 35

7. A process as claimed in Claim 5 or 6, wherein artificial ageing is carried out in a static furnace over a period ranging from 30 minutes to 12 hours at a temperature in the range of from 130 to 170° C. 40

8. A process as claimed in Claim 5 or 6, wherein artificial ageing is carried out continuously over a period of from 1 to 30 seconds at a temperature in the range of from 180 to 240° C. 45

9. A process as claimed in Claim 5, substantially as herein described with reference to any of the specific Examples. 50

10. An electrical conductor when produced by a process as claimed in any one of claims 5 to 9.

ELKINGTON & FIFE,
Chartered Patent Agents,
High Holborn House,
52/54, High Holborn,
London, WC1V 6SH,
Agents for the Applicants.

same diameter after quenching at the level of 9.5 mm diameter wire rod.

WHAT WE CLAIM IS:—

1. An electrical conductor comprising an aluminium-based alloy which contains from 0.15% to 0.35% of iron, from 0.30% to 0.70% of silicon, from 0.30% to 0.80% of magnesium, and from 0.008% to 0.40% of copper, the balance consisting of aluminium and conventional impurities, the said electrical conductor having an ultimate tensile strength of at least 37 kg/mm², an elongation at break of at least 4% and an electrical resistivity of at most 3.28 micro-ohms/centimetre.
2. An electrical conductor as claimed in Claim 1, wherein the aluminium-based alloy contains up to 0.20% of copper.
3. An electrical conductor as claimed in Claim 1 or 2, which has a creep resistance over a period of 1000 hours at 60° C of less than $4.0 \cdot 10^{-2}\%$, as measured on a 2.2 mm diameter wire under a stress of 7.1 kg/mm².
4. An electrical conductor as claimed in Claim 1, substantially as herein described with reference to any of the specific Examples.
5. A process for producing an electrical conductor as defined above from wire rod previously subjected to a solution heat treatment, followed by quenching, which comprises drawing the wire rod at a temperature of from

110 to 180° C with an elongation of at least 350%, and subjecting the drawn wire rod to artificial ageing at a temperature of from 130 to 240° C.

6. A process as claimed in Claim 5, wherein the wire rod is drawn at a temperature of from 130 to 160° C.

7. A process as claimed in Claim 5 or 6, wherein artificial ageing is carried out in a static furnace over a period ranging from 30 minutes to 12 hours at a temperature in the range of from 130 to 170° C.

8. A process as claimed in Claim 5 or 6, wherein artificial ageing is carried out continuously over a period of from 1 to 30 seconds at a temperature in the range of from 180 to 240° C.

9. A process as claimed in Claim 5, substantially as herein described with reference to any of the specific Examples.

10. An electrical conductor when produced by a process as claimed in any one of claims 5 to 9.

ELKINGTON & FIFE,
Chartered Patent Agents,
High Holborn House,
52/54, High Holborn,
London, WC1V 6SH,
Agents for the Applicants.

