

Development of Aluminum Wire for Low-Voltage Automotive Wiring Harnesses

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ABSTRACT

From the viewpoint of reducing the environmental impacts by automobile emission, improving fuel efficiency is essential. That is why automobiles need to be lightened. However, more and more electrical systems have been necessary in an automobile to ensure safety and comfort. With the increase in the number of electrical systems, the weight of Electrical Distribution System (EDS) also has become increased. In order to reduce the weight of EDS, it was decided to evaluate a change of material from copper to aluminum. In fact, aluminum wires have been used for high-voltage wires, but they have almost never been used for low-voltage wires. SUMITOMO ELECTRIC GROUP developed an aluminum wire that is available for low-voltage wire harnesses and started mass production of the wire from October 2010. In this paper, I'm reporting mainly on our development of a new aluminum alloy that can be used for aluminum wires.

The target properties of the aluminum alloy to be developed were to have a tensile strength of 110MPa and an electrical conductivity^{*1)} of 58%IACS. We determined the composition of the alloy considering misfit strain. The misfit strain was calculated based on first-principles calculations. The annealing conditions were specified based on a careful study of the precipitation conditions of Al-Fe intermetallic compounds in the aluminum alloy. Under these conditions, we developed a new aluminum alloy with a tensile strength of 120MPa and an electrical conductivity of 60%IACS, exceeding our targets.

We manufactured aluminum wires of 0.75 to 2.5 mm² in size. The wire weight was reduced by 60% compared to that of our conventional copper wires of the same size. The wiring harness weight was also reduced by about 30% using this newly developed aluminum wire.

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INTRODUCTION

Automobile exhaust gas regulations have become more stringent in terms of reducing the influence on the environment. To comply with these regulations it is necessary to improve fuel efficiency of automobiles greatly, and to achieve this, reducing automobile weight is essential. However, the weight of Electrical Distribution System (EDS) has increased as more systems are mounted on automobiles to improve safety and amenities. Considering this background,

we determined to start examining changing wire conductor materials from copper to aluminum in order to reduce the weight of EDS.

When aluminum is used for wire conductors, a reduction of wire price can also be expected. The price of copper was less than \$2,000/ton until 2004 or so, but it began to rise sharply from 2005 and reached almost \$10,000/ton in 2011, which is very expensive. On the other hand, the price of aluminum is \$2,000/ton to \$3,000/ton, which is lower and more stable compared with copper.

As described above, using aluminum for wire conductors produces two advantages: reduction in weight of wiring harnesses and price reduction.

Aluminum conductor wires are generally used in power transmission lines or distribution lines. For automobile cables as well, industrial pure aluminum has been used for battery cables etc. However, the application of aluminum is very rare for thin low-voltage cables composed of bunched thin elemental wires for mass production vehicles.

SUMITOMO ELECTRIC GROUP developed aluminum wires of 0.75 to 2.5 mm² that can be used in low-voltage cables for automobile wiring harnesses, and began to produce these from October 2010. This document reports the development of aluminum alloy that can be used for conductors of aluminum wires.

BODY

1. Development of Automobile Aluminum Wire

1-1. Development target

Both tensile strength and electrical conductivity are required for automobile aluminum wires. The purpose of this development was to achieve the replacement of conventional 0.5 mm² copper wires generally used in low-voltage power cables with 0.75 mm² aluminum wires. The specific target performance of the wire to be developed is to meet the relevant public standards including ISO. The properties required for the aluminum alloy are a tensile strength of at least 110MPa based on the terminal crimping strength data of conventional copper wires, and a conductivity of at least 58%IACS to realize conductor resistance equal to that of ISO-compliant products with wires of one size larger than the conventional copper wires that are generally used.

1-2 Alloy design

Although the conductivity of general industrial pure aluminum (AA1060: Purity 99.6%UP) is high (62%IACS), the tensile strength is low (70 MPa). ¹⁾ Therefore the strength must be improved to be suitable for use in automobile wires.

Alloying by adding a strength element is an effective way to improve strength. The elements to be added was determined based on the following two indexes.

1) Misfit strain (MS) ²⁾

MS indicates the degree of influence where the crystal lattice on the aluminum parent phase is deformed when an additive element is solidifying in the aluminum parent phase. This is calculated using first-principles calculation.

- The strength improves as MS increases.
- As MS increases, however, the crystal lattice becomes more deformed and the work hardening exponent increases, causing the material to break through exceeding the working limit while drawing thin wires or bunching elemental wires.

2) Solid solubility at room temperature

This indicates the limit where the alloying element can be solidified in the aluminum parent phase at room temperature.

- Although the solid solution of the element improves the strength, the conductivity decreases significantly.

Table 1 shows the MS and solid solubility at room temperature for general metallic elements.

Table 1. MS and solid solubility at room temperature of each element

Element	MS	Solid solubility at R.T. mass%	Element	MS	Solid solubility at R.T. mass%
Fe	3.9	0.03	Cu	1.6	2.48
Mn	3.5	0.62	Ti	1.0	0.70
Cr	3.2	0.37	Mg	1.0	18.60
Ni	2.9	0.11	Li	0.7	14.00
Sn	2.2	0.00	Si	0.6	1.50
W	2.0	0.05	Zn	0.4	67.00
Mo	2.0	0.06	Au	0.3	0.60
Pt	1.8	0.00	Ag	0.2	23.50

To be suitable for automobile wires, it is important to improve the strength while minimizing the decrease in conductivity. Therefore we assumed that an element with a low solid solution and high MS would be most effective.

After examining the MS and solid solution of each element in Table 1, we selected Fe as an additive element. Figure 1 shows the relationship between the Fe content and material properties. Details of thermal refining will be described later, these properties obtained after annealing at low temperature and slow cooling.

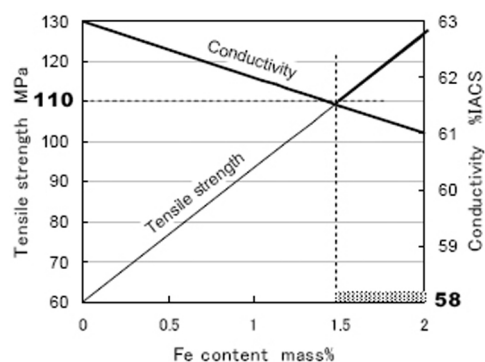


Figure 1. Relationship between the Fe content and material properties