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Effect of Zr addition on properties of Al–Mg–Si aluminum alloy used for all aluminum alloy conductor

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ABSTRACT

The effects of Zr addition on mechanical property in the aged Al–Mg–Si alloy exposed to thermal-resistant treatment (180–250 °C) have been studied by using both Brinell Hardness tests and tensile tests. The softening process at 180 °C and 230 °C has been investigated by transmission electron microscope (TEM). The Arrhenius Model is introduced to simulate the strength evolution in the thermal-resistant treatment. The results show that tensile strength and thermal-resistant property are improved by addition of Zr, and both the Brinell Hardness and Tensile Strength could maintain no less than 90% of their initial values when the alloy is exposed to heat treatment at 180 °C for 400 h and 230 °C for 2 h. The presence of rod-shaped phases and coarsening particles results in decreasing the hardness of the sample. The relationship between thermal-resistant life and temperature is derived by the Arrhenius Model. When the Al–Mg–Si–Zr alloy is heated at 130 °C, the duration described in the Arrhenius plot could reach to 40 years.

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1. Introduction

The 6xxx series aluminum alloys containing Mg and Si as major solutes have been used for almost half a century in electrical engineering field as overhead line conductor for transferring electrical energy over long distances [1–3]. The most common types of electrical conductor alloy in 6xxx series are the 6101 aluminum alloy and the 6201 aluminum alloy. The 6101 aluminum alloy has the higher electrical conductivity and lower tensile strength compared with the 6201 aluminum alloy. As the economy has developed rapidly in the past few decades, the all aluminum alloy conductor (AAAC) which is based on the use of Al–Mg–Si alloy has shown promising properties in this area. AAAC affords better sag characteristics than traditional All Aluminum Conductors (AAC) due to the high strength-to-weight ratio. It also performs higher resistance to corrosion than Aluminum Conductors Steel reinforced (ACSR) conductors. Nowadays, higher transmission capacity is desired and several strategies have been developed for this purpose. One possible alternative is to increase the current intensity, however, the poor thermal-resistant property of Al–Mg–Si alloys still restricts higher operating temperature of all aluminum alloy overhead conductor.

The thermal-resistant property of aluminum alloy wire means that the material does not anneal after heating and reduction of its tensile strength is limited to a certain value [4,5]. The Al–Zr system exhibits potential promise for developing thermally stable, precipitation-strengthened aluminum alloys and the crystallographic nature of Al_3Zr dispersoids has been studied for a long time [6,7]. The Al_3Zr dispersoids could retard the grain boundary motion during heat treatment and increase the recrystallization temperature. However, very little is investigated about the effect of Zr addition on thermal-resistant property of Al–Mg–Si alloys under elevated temperature between 180 °C and 250 °C for different lengths of time, and the softening process is not studied quantitatively.

In this paper, the effects of Zr additions on the metallurgical structure, tensile strength, thermal-resistant properties and electrical conductivity of alloys used for AAAC have been investigated. Furthermore, the existence of Zr element in Al–Mg–Si alloy has been discussed. The Arrhenius Model is introduced to simulate the strength evolution in the thermal-resistant treatment, and the experiment results are used to validate the predictions.

2. Experiments

The alloys studied in the work were prepared using commercial pure aluminum (99.7%), industrial pure magnesium (99.9%) and master alloys of Al–10% Si and Al–5% Zr (mass fraction). The idea of melting in the same furnace and casting in different sequence was adopted to minimize variation in the composition of the alloy elements. After melting, the alloy was cast into ingots (200 mm × 60 mm × 30 mm) by iron mold which was kept at 300 °C. The content of Zr was verified by Inductive Coupled Plasma Emission Spectrometer, given in Table 1.

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