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MICROSTRUCTURAL, ELECTRICAL AND MECHANICAL PROPERTIES OF THE Al-Zn-Mg-Mn ALLOY WITH STRONTIUM ADDITION

This study investigated the improvement in the electrical conductivity and mechanical properties obtained by adjusting the amount of the Sr addition to the Al-Zn-Mg-Mn alloy. The addition of Sr formed an intermetallic compounds, and the volume fraction of the intermetallic compounds increased with increasing Sr content. As the amount of Sr added increased from 0 to 1.0 wt%, the electrical conductivity of the extruded alloy decreased to 48.9, 45.2 and 42.5% IACS. As the addition amount of Sr increased, the average grain size of the rolled alloy decreased to 55.5, 53.1 and 42.3 µm. And, the ultimate tensile strength increased to 195, 212 and 216 MPa.

Keywords: Sr addition; Electrical conductivity; Mechanical properties; Microstructure

1. Introduction

Aluminum alloys are widely used in the fields of electrical materials, electrical conductors, transmission lines, communication cables, and automotive wires due to their high conductivity, low cost, good formability, low density and corrosion resistance. The high conductivity Al alloys used in these various parts require high conductivity and mechanical properties [1-4]. For electrical products, if heat retrieving characteristics are not secured, life expectancy and efficiency rapidly drop, so heat removal efficiency is needed for elevated output. However, as the amount of alloying elements increases, the conductivity is lowered due to grain boundaries, solute atoms, precipitates, and dislocations. Therefore, it is difficult to satisfy both high strength and high conductivity, and research on improving strength while minimizing the decrease in conductivity is required. However, in studies related to the conductivity of aluminum, most studies improve the conductivity by changing the content of the main alloying elements of existing aluminum, such as Fe, Si, Mg, Cu, and Mn [5-7].

Al-based immiscible systems are regarded as prospective materials for excellent conductors because they have low solubility in aluminum and have minute effect on conductivity. However, the addition of an excessive amount of elemental compounds may cause a loss of electrical conductivity, so control is required [8,9].

The microstructure of the alloy is determined by the overall composition, and the phase composition could be changed by adding modifiers. In Al alloys, Sc, Sb, Bi and Sr elements have been reported to be excellent modifiers. It is well known that modification treatment with addition of tiny amounts of Sr results in refining of the eutectic phases, specifically grain refinement of the eutectic Al phase. Additions in the Sr modify the eutectic Si morphology from coarse plate-like into tiny fibrous, thereby improving the mechanical characteristic and castability [10]. However, there is still lack of systematic study on effect of Sr on microstructure, electrical and mechanical properties of Aluminum alloys.

Therefore, this study investigated the improvement in the electrical conductivity and mechanical properties obtained by adjusting the amount of the Sr addition to the Al-Zn-Mg-Mn alloy.

2. Experimental

The alloys used in this study had the nominal composition of Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn-xSr alloys (x = 0, 0.5 and 1.0 wt%). For alloy melting, a graphite crucible was filled with alloying elements and maintained at 820°C for 20 minutes in a high-frequency induction furnace. To remove residual moisture and prevent rapid cooling of the molten metal, steel mold

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(height = 250 mm, diameter = 75 mm) were preheated to 200°C before gravity casting. The prepared cast billet was processed by lathe processing to form an extruded billet with a height of 90 mm and diameter of 70 mm a suitable for extrusion. The machined billets were hot extruded into a plate shape of 4 mm thickness and 50 mm width without any defects. The specimens were finally made by rolling process to the thickness of 1 mm. The microstructure was observed using an emission scanning electron microscope (SEM_JEOL-JSM 700F), energy dispersive X-ray spectrometer (EDS_EDAX), and electron backscatter diffraction (EBSD_EDAX). The electrical conductivity was measured by eddy current method at room temperature. The mechanical properties were measured with a universal testing machine (UTM_SHIMADZU) according to the ASTM E8M standard. Tensile tests were performed at an initial strain rate of 1.0×10^{-3} s^{-1}.

3. Results and discussion

In order to identify the types of phases formed in each of the designed alloy systems, they were investigated using the Pandat software program. Fig. 1(a) show the estimated vertical section of the Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn-xSr phase diagram. With an increase in added Sr from 0 to 0.5 and 1.0 wt%, fraction of intermetallic compound increased from 2.13 to 2.26 and 3.06%. Fig. 1(b) shows EDS results of the as-cast Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn-1.0 wt%Sr alloy. The α-Al matrix has a dark contrast, and the bright contrast intermetallic compounds were observed. These intermetallic compounds were identified to be the Al-Mg-Zn, Al-Mn and eutectic Sr phases, as revealed by the EDS results.

Fig. 2 shows SEM-BSE images of as-cast, as-extruded and as-rolled according to the change in the amount of Sr added to Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn. In the case of the cast material (Fig. 2(a)-(c)), the α-Al matrix has a black contrast, and the gray and white contrast needle shaped intermetallic compounds are distributed along the grain boundaries. The mechanical properties of metals are largely determined by the size and volume fraction of grains or phases [11]. The intermetallic compound fraction of Al-Zn-Mg-Mn alloys with various amounts of Sr addition was investigated using an image analyzer. As the amount of Sr added increased to 0, 0.5 and 1.0 wt%, the

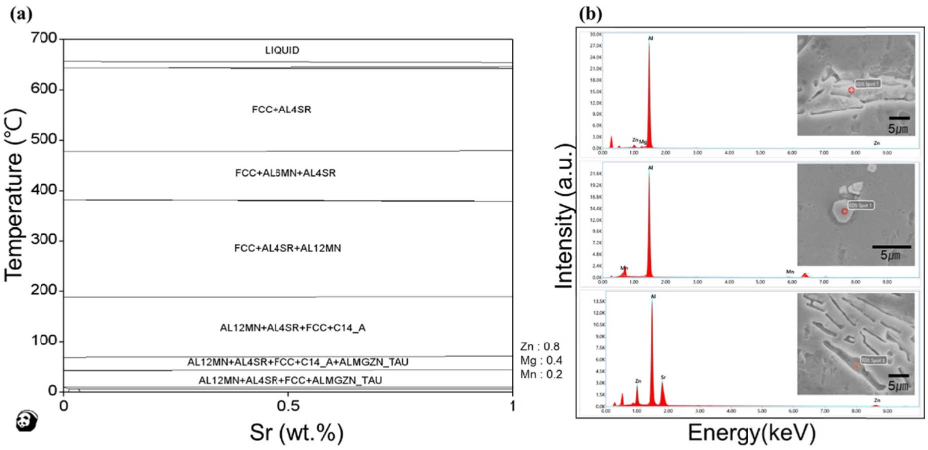

Fig. 1. The equilibrium phase diagram of Al-Zn-Mg-Mn-Sr alloys calculated using Pandat software (a) and EDS analysis of the as-cast Al-0.8Zn-0.4Mg-0.2Mn-1.0Sr alloy (b)

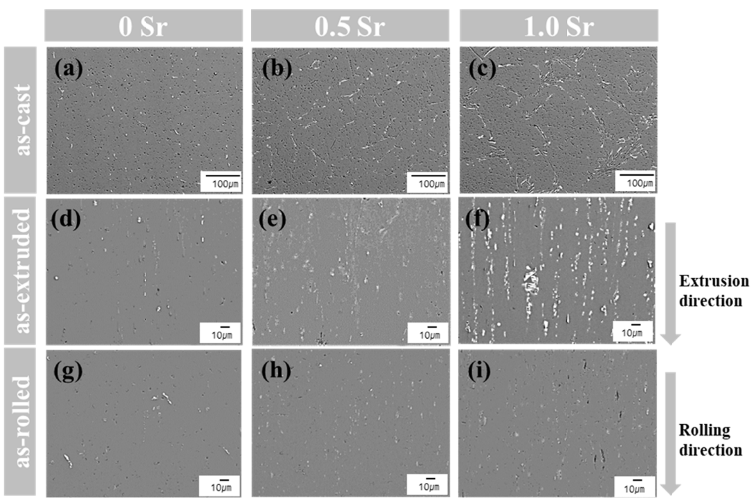

Fig. 2. Back scattered electron (BSE) images of the as-cast((a), (b) and (c)), as-extruded ((d), (e) and (f)) and as-rolled ((g), (h) and (i)) Al-0.8Zn-0.4Mg-0.2Mn-xSr alloys (x = 0 ((a), (d) and (g)), 0.5((b), (e) and (h)), and 1.0 wt% ((c), (f) and (i))

fraction of intermetallic compounds increased to 1.59, 2.89 and 4.04%.

As shown in the Fig. 2((d)-(f)), as hot extrusion progressed in all Sr-added alloys, the microstructure of the cast material was elongated in the extrusion direction due to large plastic deformation during extrusion, and the intermetallic compound was broken into fine particles. The size of the intermetallic compound gradually grew as the amount of Sr added increased, similar to the tendency of the cast material. In addition, it was confirmed that the spacing between particles narrowed as the amount of Sr added increased. SEM-BSE images of the as-rolled alloys are shown in Fig. 2((g)-(i)). Due to severe deformation during rolling, it was broken into fine particles and arranged in the rolling direction. It was confirmed that the intermetallic compound of the rolled material was finer and dispersed than the extruded material due to the additional cold rolling process.

Fig. 3 shows the inverse pole figure (IPF) and grain boundary map of the as-extruded and as-rolled according to the amount of Sr added in the Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn alloy. A plane parallel to the extrusion direction was observed, and as the Sr content increased to 0, 0.5 and 1.0 wt%, the average grain size significantly increased to 418, 500 and 695 μm, respectively. In the case of the Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn alloy, coarse and fine grains were observed. It is considered to be caused by the difference in crystal grain growth due to the non-uniform distribution of the intermetallic compound [12]. As shown in the Fig. 3((b)-(f), unrecrystallized grains were elongated along the extrusion and rolling direction. In the grain boundary map of Fig. 3, the low angle grain boundaries (LGBs) (angles of 2-15°) are shown in red and green areas, and high angle grain boundaries (HGBs) (angles of 15-180°) are shown in blue areas, respectively. The unrecrystallized grain areas showed LGBs. In the case of as-rolled, with an increase in added Sr from 0, 0.5 and 1.0 wt%, the average grain sizes decreased from 56, 53 and 42 μm.

Fig. 4(a) shows the variety in electrical conductivity of Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn-xSr alloys (x = 0, 0.5 and 1.0 wt%) alloys according to the as-cast, as-extruded and

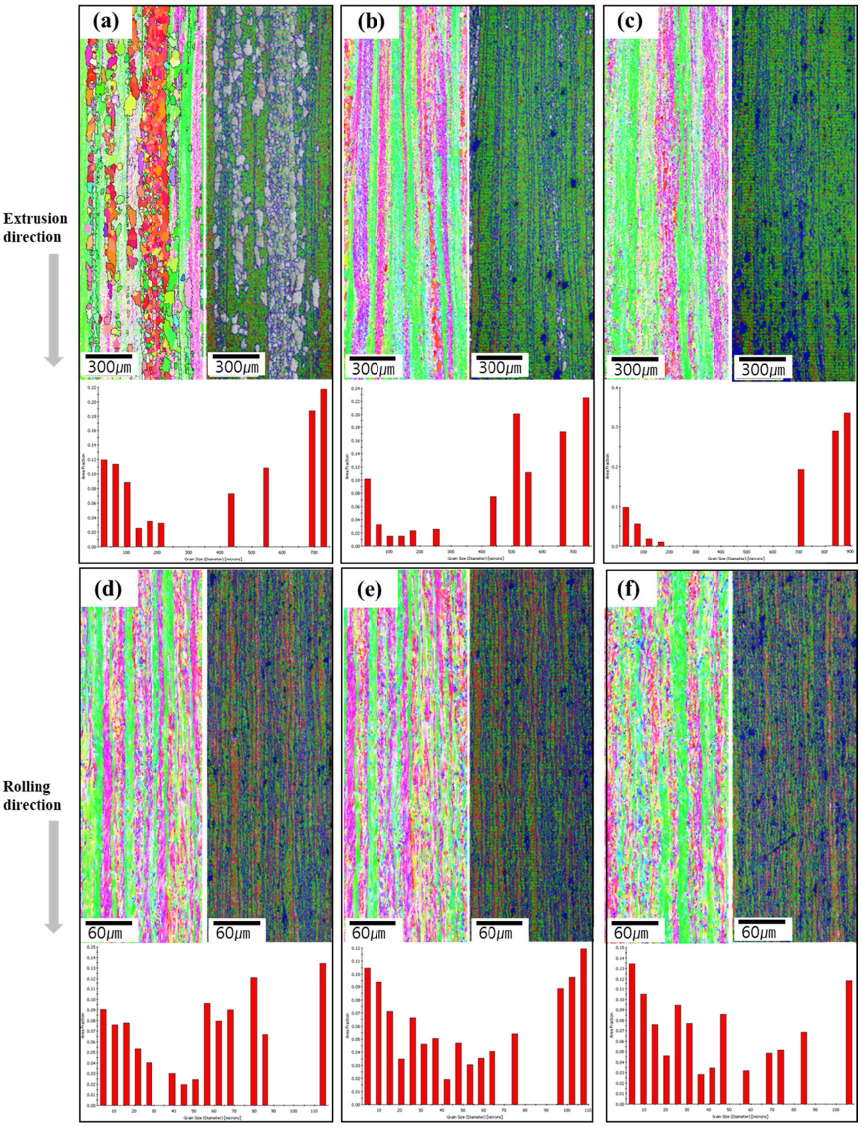

Fig. 3. Inverse pole figure(IPF) and grain boundary map of the as-extruded ((a), (b) and (c)) and as-rolled ((d), (e) and (f)) Al-0.8Zn-0.4Mg-0.2Mn-xSr alloys (x = 0 ((a) and (d)), 0.5((b) and (e)), and 1.0 wt% ((c) and (f))

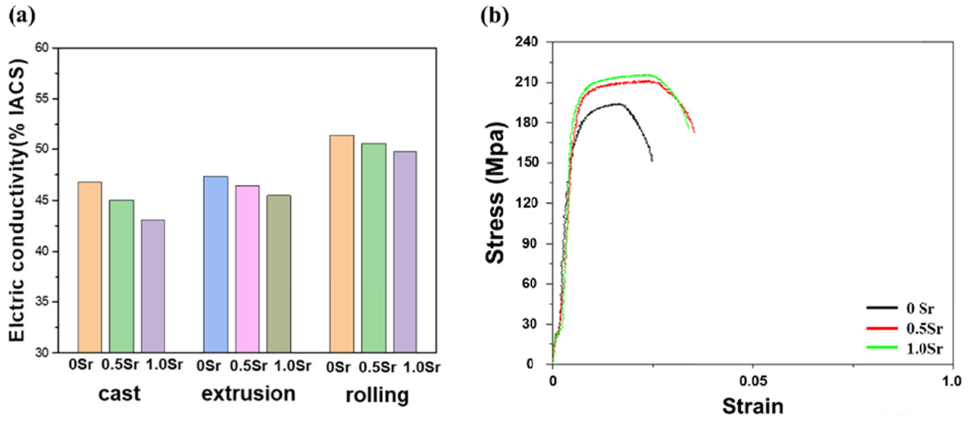

Fig. 4. Electric conductivity (a) and tensile stress-strain curves (b) of the Al-0.8Zn-0.4Mg-0.2Mn-xSr alloys (x = 0, 0.5 and 1.0 wt%)

as-rolled. As the amount of Sr added increased to 0, 0.5 and 1.0 wt%, the electrical conductivity decreased to 46.8, 45.0 and 43.1%IACS for the cast material and to 44.9, 41.6 and 39.5%IACS for the extruded material. In the case of rolled material, it decreased to 51.4, 50.6 and 49.8%IACS. In the case of the electrical conductivity of the cast material, the electrical conductivity is lower than that of the extruded material due to the porosity and fine casting defects. Also, as Sr was added, the electrical conductivity decreased, which is believed to be due to the increase in intermetallic compounds, as confirmed by a SEM-BSE. As Sr was added, it had a solid solution in α-Al and affected the electrical conductivity of the alloy. Elemental additions affect electrical conductivity in various ways. As the amount of alloying elements increases, the Al solid solubility was exceeded and intermetallic compounds or precipitates of different morphologies are formed. The addition of Sr decreased the electrical conductivity due to the increase of the grain boundary phase, and in the case of the extruded and rolled material. It is believed that this is caused by lattice distortion at the interface between the phase and the aluminum matrix due to the intermetallic compound distribution. In the case of extruded and rolled materials, the distribution of the grain boundary precipitation phase was improved and the electric conductivity increased compared to the cast material [13,14]. Fig. 4(b) show the mechanical properties of the as-rolled Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn alloys with increasing Sr contents. The ultimate tensile strength increased to 195, 212 and 216 MPa as the amount of Sr added increased to 0, 0.5 and 1.0 wt%, and the elongation also increased from 2.46% to 3.43%. An increase in intermetallic compounds and a decrease in grain size contributed to the improvement of mechanical properties.

4. Conclusions

We studied effect of Sr addition (0, 0.5 and 1.0 wt%) on microstructure, mechanical properties and thermal conductivity of the extruded Al-0.8wt%Zn-0.4wt%Mg-0.2wt%Mn based alloy. With an increase in added Sr from 0, 0.5 and 1.0 wt%, the fraction of intermetallic compound increased from 1.59 and 4.04%. The intermetallic compound was elongated in the direction of refinement and extrusion due to severe deformation during the extrusion process, and the average grain size increased from 418 μm to 695 μm as the amount of Sr added increased from 0 to 1.0 wt%. As the amount of Sr added increased, the electrical conductivity decreased. It is believed that this is caused by lattice distortion at the interface between the phase and the aluminum matrix due to the intermetallic compound distribution. The addition of Sr improved the ultimate tensile strength from 195 to 216 MPa. The Sr addition in aluminum alloy played an important role in mechanical properties.

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