Effect of aging heat treatment on thermal and electric conductivity of Al-Zn-Mg-Cu alloy

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Al-Zn-Mg-Cu aluminum alloy has excellent strength/hardness and multi-functional characteristics, so it is used in various industrial fields such as automotive industries, personal mobility, marine robots, and eco-friendly mechanics. The Al-Zn-Mg-Cu aluminum alloy changes in the shape and size of the precipitated phases occur through artificial aging precipitation, mechanical, electrical and thermal properties are affected by these changes. In addition, these properties change according to the amount dissolved in the aluminum matrix. Therefore, in this study, changes of electric and thermal properties of Al-Zn-Mg-Cu aluminum alloy by aging heat treatment process was investigated. The solution heat treatment was carried out at 480 °C for 6 hours and then rapidly cooled with water at room temperature. The aging treatment was carried out under various conditions from 0.5 hours to 24 hours at 120 °C. The microstructure was analyzed with optical microscope and FE-SEM/EDX. The test for electric conductivity properties evaluation was conducted in the form of ASTM E 1004, and the thermal conductivity was analyzed using TMA equipment. It was concluded that the phase change (η, η') of $MgZn_2$ has the greatest influence on the change in the coefficient of thermal expansion between 150-300℃ as the artificial aging treatment time increases.

Keywords: *aging heat treatment, thermal conductivity , electric conductivity, Al-Zn-Mg-Cu alloy*

Introduction

7075 Al alloy based on a heat treatable Al-Zn-Mg-Cu alloy system has good durability and average workability, however, it is difficult to weld and is known to have a weak corrosion resistance compared to many other alloys [1]. Due to their high strength and low-density properties, 7075 Al alloy is widely used in the military, automotive, and aerospace industries [2–4]. The formation of aging precipitates through T6 heat treatment is a typical process for improving the mechanical properties of alloys. The generally accepted precipitation sequence for Al-Zn-Mg-Cu alloys is as follows: supersaturated solid solution → G.P. zones →metastable η′ phase → stable η phase [1,2]. The type and amount of precipitates by heat treatment significantly affects the mechanical properties, and also the thermal properties change according to the change in solubility of the solute in the aluminum matrix [5].

Most investigations have focused on the effect of these precipitation phases on mechanical properties during solution heat treatment [6–8]. For instance, Zou et al. [7] investigated the effects of solution treatment on the evolution of the second and mechanical properties of 7075 Al alloy. They reported that the dissolution of the secondary phase during solution heat treatment could improve the plasticity of the alloy by lowering the resistance to dislocation motion. Some researchers have also reported results on conductivity. For example, Sun et al. [9] mentioned the change in specific heat and thermal conductivity between room temperature and 400 °C of 7075T6 Al alloy used as a drill pipe. However, further information on the thermal properties of this alloy were not discussed. Pankade et al. [10] studied the influence of heat alloy and showed that the electrical conductivity improved for all the aging treatment conditions. They reported that the change in electrical conductivity for different heat treatment conditions for 7075 Al alloy is due to the precipitation stages formed during artificial aging treatment. However, most studies only provide limited information on the effect of precipitation on thermal properties during the aging heat treatment. As the usage environment of 7075 Al alloy is diversified, mechanical properties and thermal properties in a high-temperature environment are required as core properties. Therefore, this study investigated the effect of changes in the precipitates according to the aging time on coefficient of thermal expansion in the artificial aging precipitation process using thermal properties analyzers.

Experiment

The alloy used in this study was manufactured by gravity casting from commercial Al-5.8%Zn-2.2%Mg-1.6%Cu. Table 1 shows the chemical composition of the alloy. As shown in Figure 1, the solution heat treatment (SST) of the alloy was carried out at 480 °C for 6 hours, followed by rapid cooling in room temperature (RT) water. The alloy in the hypersolid solution state was aged at 120 °C for 0.5, 4, 8, and 24 hours, and cooled to 25 °C in the air. Specimens for microstructure observation were mirror-polished with SiC and diamond suspension. The microstructure of each specimen was observed using FE-SEM, and the components of the crystallized and precipitated phase were analyzed using EDX. In addition, the tensile test for mechanical property evaluation was performed in the form of an ASTM E8M plate at a tensile speed of 1 mm/min.

To investigate the effect of artificial aging treatment on the thermal expansion coefficient of the alloy, the lattice expansion of the alloy was measured using a thero-mechanical apparatus (TMA). Specimens for linear expansion coefficient analysis were processed to a diameter of 6 mm and a height of 25 mm, and were analyzed from 150 to 500 °C at a heating rate of 10 °C min-1. During the thermal expansion analysis, high-purity nitrogen gas (99.999% N2) was used as the furnace atmosphere gas, and the force of the push rod was maintained at 50 mN. As a thermomechanical analyzer, NETZSCH's TMA 402F1 model was used.

Calorimetric analysis was conducted to confirm the precipitation reaction and reaction temperature of the Al-5.8%Zn-2.2%Mg-1.6%Cu alloy, and a heat flux type differential scanning calorimetry (DSC) was used. . Specimens for calorimetric analysis were prepared with a diameter of 6 mm and a thickness of 1 mm. In the DSC analysis, a specimen was placed in a platinum-radium alloy crucible and scanned at a rate of 10 °C mm-1 from 25 to 500 °C to measure the change in calorific value. The atmosphere in the heating furnace was maintained with high-purity nitrogen gas, and an empty platinum-radium crucible was used as the standard specimen.

Results

Figure 1 shows the time dependence of the mechanical properties on the alloy with different aging times. As the temperature of the specimen increased, the ultimate tensile strength decreased, the elongation increased.

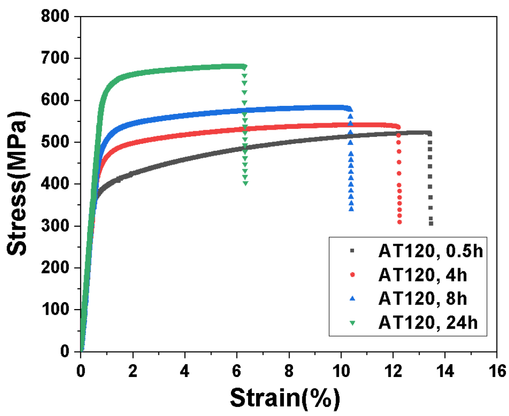

Figure 1. Result of tensile test at different aging time

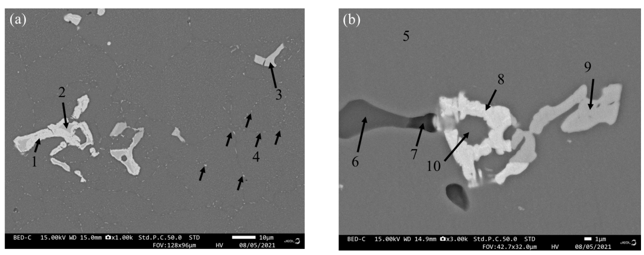

Fig. 2. Micro-structure change according to aging time: (a) as-cast, (b) AT120, 24 h.

Figure 2 shows the scanning electron microscope (SEM) images of as-cast and artificially aged specimens. The $MgZn_2$ phase seen in the as-cast state was not observed because it was dissolved in the aluminium matrix after solution heat treatment (Figure 1(b)). $MgZn_2$ phase was not observed even in the specimen after aging for 24h (Figure 1(c)). As a result of EDS analysis (Table 1), most of these particles were composed of a ternary phase of AlCuFe.

Table 1. Chemical compositions of secondary phases in Fig. 2

Phase	x(Al)/%	x(Mg)/%	x(Si)/%	x(Zn)/%	x(Cu)/%	x(Fe)/%
1	54.5				31.5	14.0
2	62.9	1.3	0.5		6.9	28.4
3	66.6	1.6			7.4	24.4
4	92.1	4.2		3.6		
5	90.1	3.1		6.8		
6	7.5	58.7	32.7	1.1		
7	24.8	40.9	32.8	1.5		
8	55.1				31.1	13.8
9	70.0				23.2	6.8
10	89.7	3.0		7.3		

The generation of such precipitated phase can also be verified from the XRD results. Figure 3 shows the changes in the XRD pattern according to the heat treatment conditions. The intensity peaks corresponding to the$MgZn_2$ phase of the SST and aged samples were very small compared to the annealed sample. This change in mechanical properties also affects thermal and electrical conductivity.

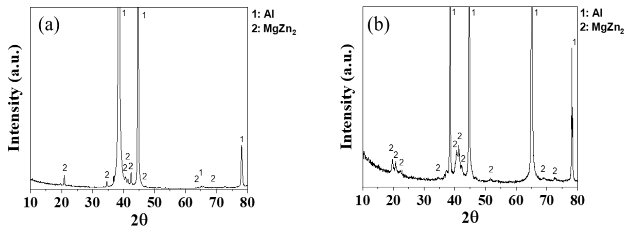

Fig. 3. Changes of XRD pattern according to heat treatment conditions: (a) SST, (b) aged at 120 °C for 24 h

Conclusions

The changes of thermal and mechanical properties of Al-Zn-Mg-Cu aluminum alloy by aging heat treatment process was investigated. As a result of analyzing the mechanical properties, the hardness and ultimate tensile strength increased as the artificial aging time increased, but the elongation tended to decrease.

As a result of analyzing the coefficient of thermal expansion using TMA, the CTE changed due to the formation and dissolution of the G.P zone and the formation of the metastable phase η', the phase transformation to the stable phase η, and the dissolution of the η phase. In temperature rages (200~300 degrees), as for the decrease in the coefficient of thermal expansion, it was found that the phenomenon in which η' and η are formation/dissolution in the matrix has a greater effect on the shrinkage than the expansion of aluminum.

In Al-Mg-Zn-Cu-based aluminum alloys, as the artificial aging treatment time increased, the amount of precipitated phase increased, which affected the mechanical properties and CTE of the alloy.

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