Effect of Two–Step Solution Treatment and Sr Addition in Al-Si-Cu Alloy on Microstructure and Mechanical Properties

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1. Introduction

At present, the environmental problems such as exhaustion of fossil fuels, global warming, and air pollution worldwide require specific tolerance standards for CO_2 emissions or vehicle fuel consumption in the automobile industry [1-2]. There is an urgent need to study the weight reduction of automobiles that can reduce the emission of harmful gas and improve fuel efficiency in accordance with these social demands. Effective automobile weight reduction is more related to materials than structure design, and aluminum alloy has been studied for a long time as automobile lightweight material and is already applied as a substitute material. Al-Si-Cu alloys are widely used in cylinder blocks, cylinder heads, engine mount brackets, etc., because they have excellent mechanical properties and castability [3-6]. The heat treatment process technology for improving the strength and elongation at the same time is still not well established and many studies [7-9] are needed. Therefore, in this study, the microstructural and mechanical properties of Al-Si-Cu alloy were studied on two-step heat treatment and the addition of strontium to improve strength and elongation.

2. Experimental Details

Al-Si-Cu alloy was prepared by gravity cast. The melting temperature of θ-Al2Cu phase was calculated by Thermo-Calc simulation. The melting temperature is 510°C, which is agreed well with other reports. Table 1 shows the schedule of solution heat treatment condition for stage 1 and stage 2. For the microstructure analysis, specimens were observed by optical microscope (OM) after etching using Keller's solution. For more precise investigation, several phases in matrix were observed and analyzed by scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and electron probe micro analysis (EPMA). X-ray diffraction (XRD) was performed for crystal structure analysis. The micro hardness tester was used for evaluation of surface hardness. Tensile test was performed at room temperature using a tensile tester (Shimadzu, Table top Ag-20kNX).

Table 1. Schedule of solution heat treatment

Specimen	solution				
	stage 1		stage 2		Quenching
	℃	h	℃	h	
As-cast	-	-	-	-	-
T44A	485	4	-	-	Water
T44A-DS8A	485	4	515	8	Water
T44A-DS8B	485	4	525	8	Water
T44B	495	4	-	-	Water
T44B-DS8A	495	4	515	8	Water
T44B-DS8B	495	4	525	8	Water

Table 2. Chemical composition of Al-Si-Cu (wt%).

Element	Si	Cu	Fe	Mn	Al
wt.%	6.01	2.09	1.03	0.19	Bal.

3. Result and Discussion

Fig. 1(a) - (d) are the results of back-scattered electron (BSE) photographs of each phase in matrix of as-cast and T48A-DS4B specimens in gravity cast. In Fig. 1(a) and Fig. 1(c), there are four typical phases distinguished with different contrast and shapes; α-$Al_{15}(Fe,Mn)_3Si_2$, Fe-rich phase, β-Al_5FeSi phase, θ-Al_2Cu and eutectic Si phase. Fig. 2(a)-(d) show the optical micrographs of various Sr additive alloys. As the content of Sr increased, the Si phase was modified and observed to be fine. In tensile tests, ultimate tensile strength increased from 185 MPa to a maximum of 248 MPa (T44B-DS8B). The yield strength increased from 152 MPa to a maximum of 181 MPa and elongation increased up to 2.65%.

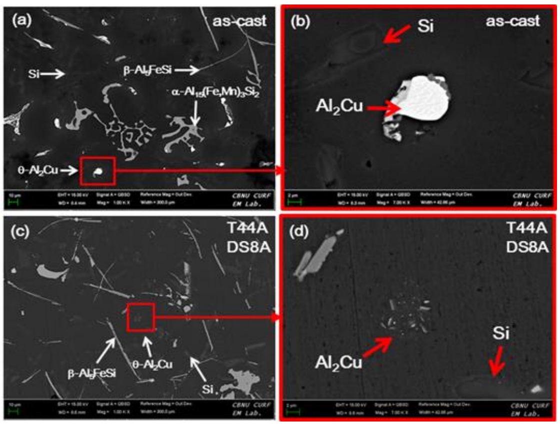

Fig. 1 BSE micrographs showing various phases of Al-Si-Cu alloy, ; (a,b) for as-csat and (c,d) for T44A-DS8A.

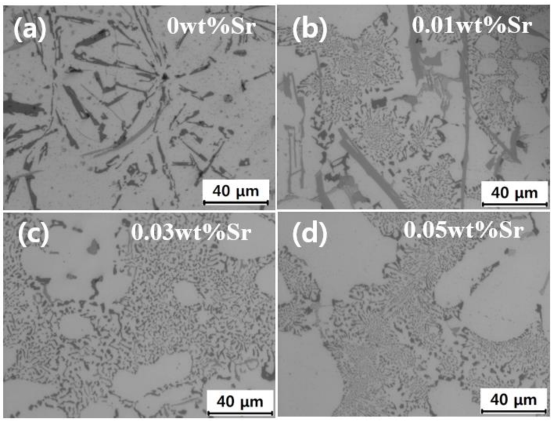

Fig. 2 Optical micrographs of various Sr additive alloys: (a) as-cast, (b) 0.01wt%Sr, (c) 0.03wt%Sr, and (d) 0.05wt%Sr.

The Cu atoms may contribute to solid solution strengthening as they are redissloved into the aluminum matrix during the solution heat treatment. The elongation probably increases due to area reduction and spheroidization of the eutectic Si.

4. Conclusion

In this study, we investigated the effect of the heat treatment on the microstructure and mechanical properties of the Al-Si-Cu alloys. It is concluded as follows.

1. The microstructure of gravity-casted Al-Si-Cu alloys has been investigated. Chinese script shape α-$Al_{15}(Fe,Mn)_3Si_2$, Fe-rich, β-Al_5FeSi phase, θ-Al_2Cu and eutectic Si phase were observed and analyzed. This is in agreement with the thermodynamically calculated equilibrium phase diagram.
2. XRD analysis depicts that the diffraction peaks at 2θ = 41.94 were identified as Al_2Cu phase in the gravity cast specimens, but the peaks were not observed in solution treatment because of the dissolution of Al_2Cu phase.
3. The mechanical properties increased after solution heat treatment. For the T44B-DS8B specimen, the ultimate tensile strength and elongation increases up to 34% and 95%, respectively.
4. The α-$Al_{15}(Fe,Mn)_3Si_2$ phase in the Al matrix, Fe-rich the β-Al_5FeSi phase, θ-Al_2Cu phase are segmented and refined by the addition of Sr. Especially, the Si phase was modified and became very fine.
5. The hardness of Sr addition decreased by about 15% ~ 20% at 107Hv compared with as-cast. The hardness of aged alloys increased by about 20% due to generation of fine Al_2Cu precipitated in matrix.

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