Effect of Mg on age hardening and precipitation behavior of an AlSiCuMg cast alloy

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Many investigations were carried out to study the effect of an increased Mg content on the mechanical properties of Al-Si-Cu cast alloys [1–3]. Their results show that the tensile strength and hardness have been increased obviously while increasing the Mg content from 0.1 to 0.4 wt%. Solution treatment and quenching followed by an artificial aging are normally applied in order to enhance the mechanical properties. Solution treatment temperature of the Mg containing Al-Si-Cu alloy is limited because polynary eutectic phases with lower melting point is formed, and much work has been done on the solution treatment of Al-Si-Cu and Al-Si-Cu-Mg alloys [4–6]. But there is a little information about the effect of Mg on the precipitation and aging behavior of Al-Si-Cu alloys [7–9].

This study was undertaken to investigate the effect of adding 0.4 wt%Mg on the precipitation and age hardening behavior of Al8Si3Cu alloy by hardness measurement, differential scanning calorimety (DSC) and transmission electron microscopy (TEM) analysis. The examined samples were cast in permanent mold. Samples of both alloys were solution treated at 773 K for 24 h and then water quenched before precipitation and aging analysis based on conventional solution treatment system and data shown in Fig. 1.

DSC analysis was performed using a differential scanning calorimeter (Netzsch DSC 404). During DSC measurements, samples were protected under an argon atmosphere with a flow rate of 80 ml min^{-1}; a super purity aluminum specimen of equal mass was used as a reference. Hardness testing was carried out using a macro Vickers hardness tester with a load of 20 kg and a dwell time of 30 s. TEM specimens were thinned by mechanical polishing, followed by ion milling. They were then examined in a H-800 TEM transmission electron microscope operating at 150 kV.

Fig. 2 shows age hardening curves during aging at 433 K for both alloys respectively. Although the hardness value for as-quenched samples increased a little, the age hardening response was significantly enhanced by adding 0.4 wt%Mg to Al8Si3Cu alloy. Hardness increase in value during peak aging (ΔHV_{max}) was 17 HV for Al8Si3Cu and 43 HV for Al8Si3Cu0.4Mg, which means that the age hardening response of Al8Si3Cu0.4Mg alloy is about 2.6 times of Al8Si3Cu alloy. There was a hardness reduction in the initial aging stage for both alloys and it was more obvious for Al8Si3Cu0.4Mg alloy, which is thought to be caused by the dissolution of the GP zones existing in the as-quenched samples as analyzed by DSC results.

DSC traces with a scanning rate of 10 K min^{-1} obtained by heating the as quenched specimens are shown in Fig. 3. According to the previous DSC investigations, low temperature peak at around 373–473 K was associated with the formation or dissolution of various GP zones, middle temperature peaks at about 453–593 K corresponded to the precipitation of coherent and semi-coherent phases respectively [10–12]. The peak temperature depended upon the specific reaction for a given heating rate.

Exothermic peak at around 373–473 K was not detected, instead, one endothermic peak appeared on both DSC curves and the endothermic peak was broader for Al8Si3Cu0.4Mg alloy. This indicates that GP zones precipitated in as-quenched condition and at least some of them dissolved during heating the quenched sample. The broader endothermic peak for Al8Si3Cu0.4Mg alloy suggests that different kinds of GP zones existed in the as-quenched sample.

One broad exothermic peak 2 centered at about 548 K was detected within middle temperature range on DSC curve of Al8Si3Cu alloy, which suggests that only θ' phases precipitated during heating the quenched sample. DSC curve of Al8Si3Cu0.4Mg alloy showed two exothermic peaks, peak 1 centered at about 523 K and peak 2 centered at about 548 K. It indicates that coherent phases precipitated first before the precipitation of semi-coherent phases during heating the quenched Al8Si3Cu0.4Mg sample.

Fig. 4 shows TEM micrograph of Al8Si3Cu alloy with peak hardness. Only semi-coherent θ' phases (metastable phases of $CuAl_2$) were observed, which

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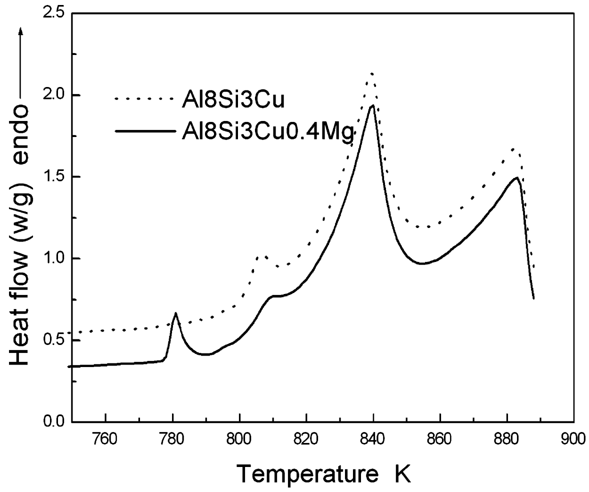

Figure 1 DSC curves for as-cast samples with a scanning rate of 10 K min^{-1}.

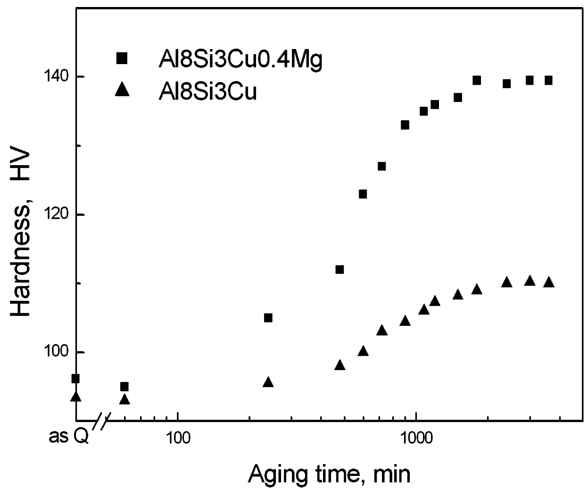

Figure 2 Hardness versus aging time for quenched samples aging at 433 K.

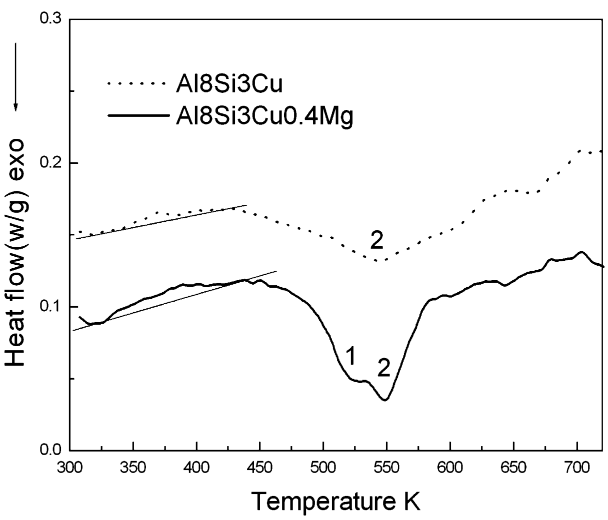

Figure 3 DSC curves for as quenched samples with a scanning rate of 10 K min^{-1}.

were wavelike because of precipitation on dislocations. This was consistent with the above DSC analysis result. The deficiency of coherent phase because of preferential θ' phases precipitated on dislocations

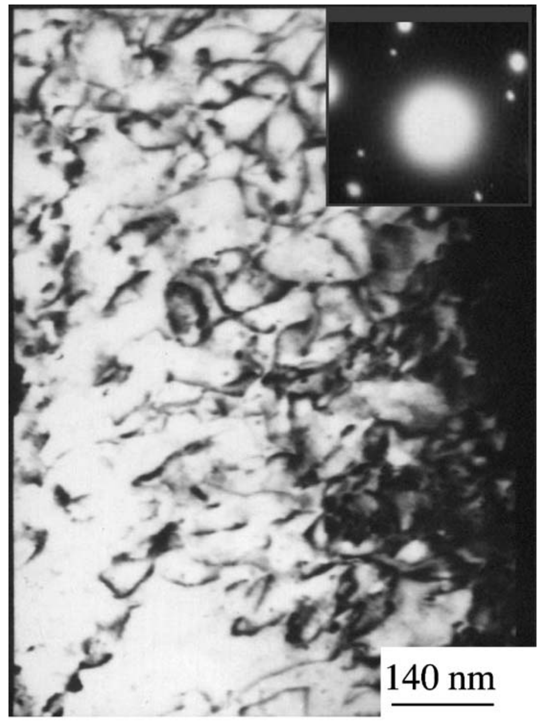

Figure 4 TEM micrograph of Al8Si3Cu alloy during peak aging.

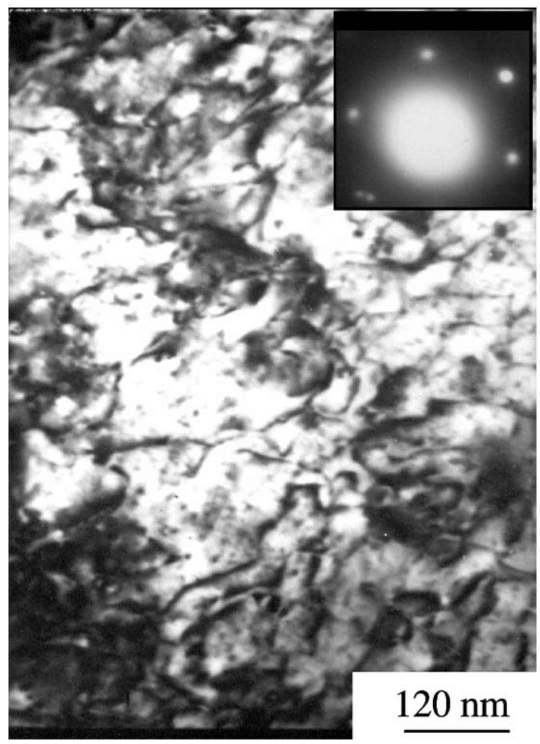

Figure 5 TEM micrograph of Al8Si3Cu0.4Mg alloy during peak aging.

results in the less age hardening response for Al8Si3Cu alloy.

Fig. 5 shows TEM micrograph of Al8Si3Cu0.4Mg alloy with peak hardness. Investigations on wrought Al-Cu-Mg-Si alloys showed that precipitates responsible for age hardening were precursors of θ and S (Al_2CuMg) phases [14, 15], precursors of Q ($Cu_2Mg_8Si_6Al_5$) phase were also observed [16]. Analysis results shown in Fig. 5 indicates that the age hardening precipitates for cast Al8Si3Cu0.4Mg alloy were wavelike θ' phases formed on dislocations and dot shaped Q'' phases (metastable phases of $Cu_2Mg_8Si_6Al_5$) coherent with the matrix. This result indicates that during aging at 433 K for Al8Si3Cu0.4Mg alloy, Mg atoms will co-precipitate with Cu, Si and Al to form Q'' phase, and excessive Cu in supersaturated solution will precipitate in θ' phases on dislocations. The above DSC and TEM analyses results suggest that the excellent aging response of Al8Si3Cu0.4Mg alloy is the result of Q'' precipitation during aging.

In conclusion, the age hardening response of Al8Si3Cu0.4Mg alloy is about 2.6 times of Al8Si3Cu alloy during aging at 433 K. The excellent age hardening response of Al8Si3Cu0.4Mg alloy is the result of precipitation of coherent Q'' phases except for θ' phase formed on dislocations, while for Al8Si3Cu alloy, the age hardening precipitate is only semi-coherent θ' phase precipitating on dislocations.

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