

## Effect of Be on Aging Behavior of an Al11Si3Cu Cast Alloy

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**Keywords:** aluminum cast alloy; age hardening; precipitation; effect of Be.

**Abstract.** Effect of Be addition on age hardening and precipitation behaviors of Al11Si3Cu alloy was investigated by hardness measurement and differential scanning calorimetry (DSC) analysis. The age hardening results show that 0.25% Be addition increases the peak hardness of Al11Si3Cu alloy about 20HV. DSC results show that Be addition inhibits precipitation of Cu and /Si clusters or GP zones before artificial aging and increases the volume of  $\theta'$  precipitates during artificial aging. The precipitation dynamic analysis results show that  $\theta'$  phases are two-dimensional precipitates that is unaffected by Be addition. The nucleation density dependent parameter  $k$  for Be containing alloy is 2.75 times of the base alloy, which suggests that Be addition accelerates the nucleation density of  $\theta'$  phases.

### Introduction

Artificial age treatment for T4 treatment sample is an important method to improve the mechanical properties of Al-Si-Cu cast alloys, which is called the T6 treatment<sup>[1,2]</sup>. The T4 treatment consists of solution treatment at a high temperature to dissolve the intermetallic compounds and homogenize the alloying elements in  $\alpha$ (Al) followed by quenching at a high cooling rate to retain a high concentration of vacancies and solutes in  $\alpha$ (Al). For Cu contain aluminum alloys, Cu atoms oversaturated in  $\alpha$  (Al) after T4 treatment and coherent  $\theta''$  and/or  $\theta'$  phases precipitated with the duration of artificial aging treatment to produce the maximum strengthening of the material<sup>[3-5]</sup>. Heat treatment parameters, such as solution temperature and time, quenching temperature, artificial aging temperature and time, could have a great influence on age hardening behaviors<sup>[6,7]</sup>.

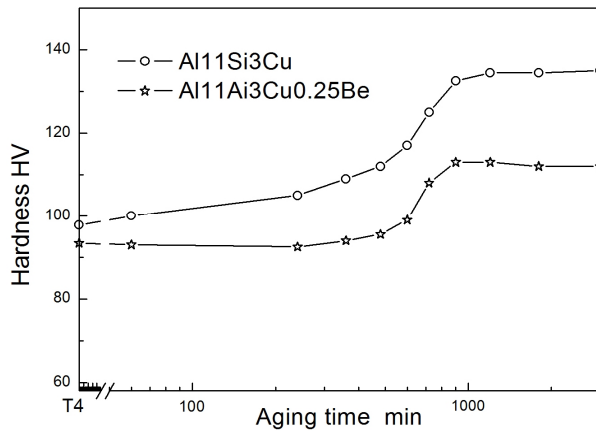
In addition, alloying elements have important influence on age hardening behavior of aluminum alloys<sup>[8-10]</sup>. Early study shows that Be addition to aluminum alloy increases the age hardening response<sup>[11,12]</sup>. In this research, the effect of Be on the age hardening and precipitation behaviors of Al11Si3Cu cast alloy has been studied by hardness measurement and DSC analysis.

### Results and discussion

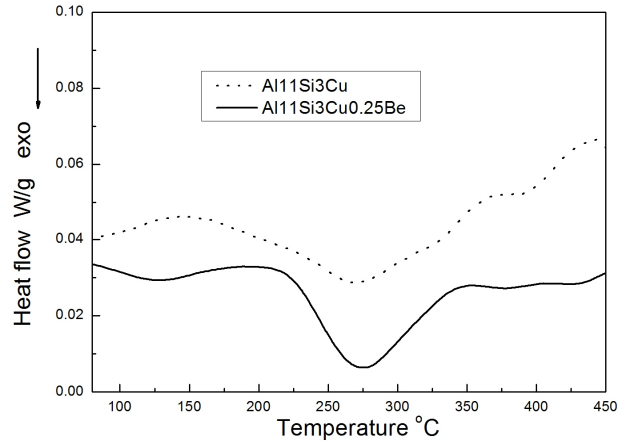
**Effect of Be on age hardening precipitation.** Fig.1 shows age hardening behaviors at 180 °C for heating T4 samples of Al11Si3Cu and Al11Si3Cu0.25Be alloys respectively. Hardness increases after aging more than 240 min and attains 110 HV at about 900 min for Al11Si3Cu alloy, but there is a slight hardness decrease at the early stage of aging for this alloy. Hardness increases with aging time and attains 130 HV at about min For Al11Si3Cu0.25Be alloy. The age hardening results show that Be addition increases the age hardening response of Al11Si3Cu alloy. Because there is little age hardening effect for Al-Be binary alloy<sup>[11]</sup>, the effect of Be additions on age hardening of Al11Si3Cu may be attributed to the precipitation mechanisms.

The phenomena of the nucleation and growth of precipitation phases were investigated by DSC. Fig.2 shows the DSC curves of T4 treated Al11Si3Cu and Al11Si3Cu0.25Be samples at a heating rate of 10 °C min<sup>-1</sup>. There is an endothermic peak between 100-200 °C and an exothermic peak is detected between 200~350 °C for Al11Si3Cu alloy. Based on age precipitation analysis of Al-Si-Cu cast alloys, exothermic peak at around 250 °C may be caused by  $\theta'$  precipitation that are the main age hardening precipitates for Al11Si3Cu alloy<sup>[2, 5]</sup>. Endothermic peak between 100-200 °C may be

caused by the dissolution of clusters or GP zones precipitated before aging, which leads to the hardness decrease at early aging stage of Al11Si3Cu alloy as shown in Fig.1. Exothermic peak at around 150 °C corresponding with GP zones precipitation and exothermic peak at around 250 °C caused by  $\theta'$  precipitation are detected for Al11Si3Cu0.25Be alloy. Comparing two DSC curves in Fig.2, Be addition inhibits precipitation of Cu and /Si clusters or GP zones before artificial aging.

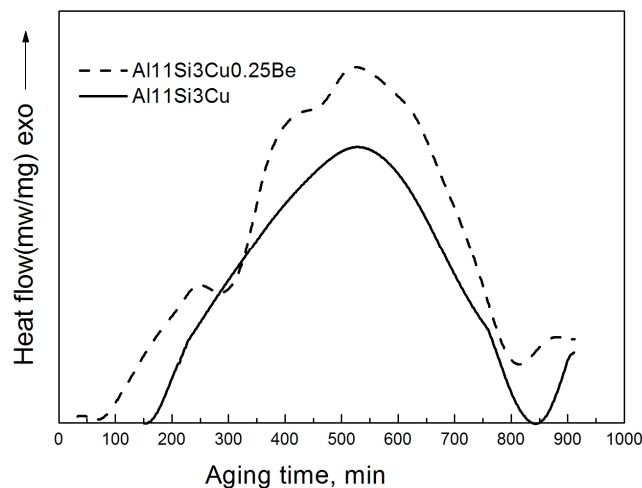


**Fig.1:** Hardness vs. lgt for T4 samples aged at 180 °C



**Fig.2:** DSC curves at a heating rate of 10 °Cmin<sup>-1</sup>

Heating the T4 treatment samples to 180 °C with a heating rate of 10 K min<sup>-1</sup> and holding at this temperature, the isothermal DSC curves both of Al11Si3Cu and Al11Si3Cu0.25Be are shown in Fig.3. Exothermic peaks detected in isothermal DSC curves should correspond with precipitation of  $\theta'$  phases. There is an incubation period before precipitation reaction for both alloys. The precipitation process of  $\theta'$  phases starts at 50 min and ends at 800 min for Al11Si3Cu alloy. For Al11Si3Cu0.25Be alloy, the precipitation process of  $\theta'$  phases starts at 150 min and ends at 850 min. This result suggests that Be addition to Al-11Si-3Cu alloy promotes  $\theta'$  precipitation.



**Fig.3** Isothermal DSC curves at 180 °C

The amount of heat released from the precipitation reaction during aging should be proportional to the volume of the precipitates. The heats released during  $\theta'$  precipitation are 38kJmol<sup>-1</sup> and 43kJmol<sup>-1</sup> respectively for Al11Si3Cu and Al11Si3Cu0.25Be alloys respectively. This indicates that adding 0.25%wt Be addition to Al-11Si-3Cu alloy has increased the volume of  $\theta'$  during aging , which is consistent with the age hardening response shown in Fig. 1.

**Precipitation kinetic analysis.** The volume fraction of  $\theta'$  increases along with artificial aging time and reaches a maximum amount after a long period aging time that peak hardness has been attained.

According to DSC analysis by Malinov and Guo <sup>[15]</sup>, the transformed fraction of the precipitate is equal to the fraction of heat released.

$$f(t) = \frac{\int_{t_s}^t \frac{\partial h}{\partial t} dt}{\int_{t_s}^{t_E} \frac{\partial h}{\partial t} dt} = \frac{\int_{t_s}^t H dt}{\int_{t_s}^{t_E} H dt} \quad (1)$$

Where  $t_s$  and  $t_E$  represent the start and end time of transformation respectively,  $f(t)$  represents transformed fraction at time  $t$ ,  $H$  is the measured heat flow.

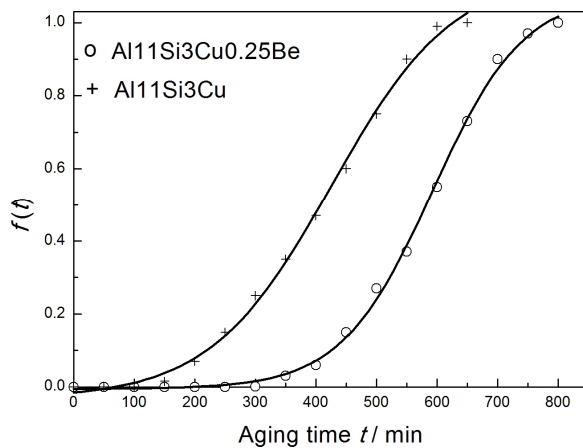
From the DSC signal of Fig.3 and equation (1), the fraction of  $\theta'$  precipitates  $f(t)$  as a function of the aging time  $t$  can be calculated and plotted. The calculated results for Al11Si3Cu and Al11Si3Cu0.25Be alloys aging at 180°C are plotted as shown in Fig.4.

The kinetics of isothermal transformations is usually expressed by the Avrami type equation:

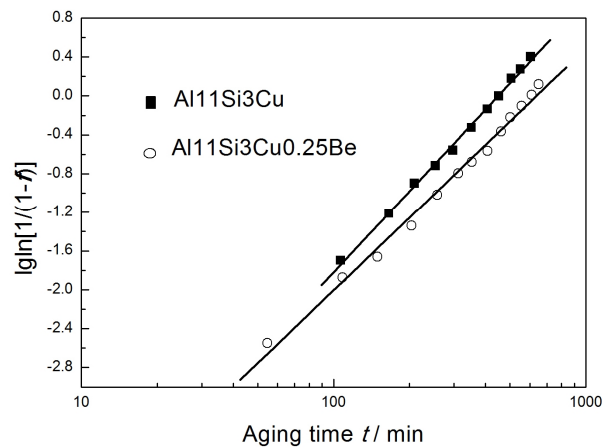
$$f(t) = 1 - \exp(-kt^n) \quad (2)$$

Where  $n$  is a parameter depending on the growth mechanism of precipitates, and  $k$  is a nuclei density parameter.

Fig. 5 shows the liner relationship of  $\lg \ln(1/(1-f))$  versus  $\lg t$  that is calculated according data shown in Fig.4, and  $n$  and  $k$  can be calculated from the slope and the ordinate intercept. The parameters  $n$  are 2.4 and 2.6 for Al11Si3Cu and Al11Si3Cu0.25Be alloys respectively, which is consistent with the observed piece like morphology of  $\theta'$  precipitates (two-dimensional growth), and also indicates that the growth mechanism of the  $\theta'$  precipitate is unaffected clearly by the Be addition. The calculation results show that the nucleation density dependent parameter  $k$  for Be containing alloy is 2.75 times of the base alloy, which indicates that the Be addition accelerated the nucleation density for  $\theta'$  precipitate.



**Fig.4** Transformed volume fraction vs. aging time



**Fig.5**  $\lg \ln(1/(1-f))$  versus  $\lg t$  for samples aged at 180°C

## Discussions

The microstructure of the T4 treatment sample of Al11Si3Cu cast alloy is in non-equilibrium that vacancies, Cu and Si atoms are oversaturated in  $\alpha$  (Al). The oversaturated vacancies will accumulate during T4 samples stored at room temperature that accelerate the diffusing of Si and Cu atoms to

form Si and/or Cu atoms clusters. Heating this T4 sample to 180°C for artificial aging, the Si and/or Cu atoms clusters formed at room temperature will dissolve because the size of Si and/or Cu clusters is not big enough as the nuclei of  $\theta'$  phases. This phenomenon is verified by the DSC curve shown in Fig.2 that an endothermic peak between 100-200 °C is detected for Al11Si3Cu cast alloy. The hardness decrease at early aging stage of Al11Si3Cu alloy as shown in Fig.1 should be caused by the dissolution of Si and/or Cu atoms clusters formed at room temperature before artificial aging. Moreover, there are little homogenous nuclei acted as the nuclei of  $\theta'$  phases that should lead to  $\theta'$  phases precipitating at grain boundaries.

The addition of 0.25% Be to Al11Si3Cu cast alloy increasing the nucleation density of  $\theta'$  phases can be explained by the high Be-vacancy binding energy ( 0.26 eV<sup>[12]</sup> ) in Be containing alloy. For the T4 sample of Al11Si3Cu0.25Be alloy, oversaturated vacancies will combined with Be atoms because of the high Be-vacancy binding energy that inhibits the diffusion of Si and Cu atoms to form Si and/or Cu atoms clusters during stored at room temperature. Heating this T4 sample to 180°C for artificial aging, the vacancies initially bound by Be are released and accelerate the diffusing of Si and Cu atoms to form GP zones at around 150 °C that is verified by the endothermic peak between 100-200 °C in DSC curve of Al11Si3Cu0.25Be cast alloy shown in Fig.2. These GP zones should act as the nuclei of  $\theta'$  phases that accelerated the precipitation  $\theta'$  phases and then higher age hardening response has been obtained.

## Conclusions

Addition 0.25%Be to Al11Si3Cu alloy increase age hardening response obviously and peak hardness 130HV is obtained for samples aging at 180°C about 900 min.

The precipitation mechanism of  $\theta'$  phases is unaffected clearly by the Be addition, but Be addition accelerated the nucleation density of  $\theta'$  precipitates.

## Acknowledgements

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