# PRECIPITATION BEHAVIOR IN TWO STEP AGED Al-$Mg_2$Si ALLOY CONTAINING SILICON IN EXCESS

**Tokimasa KAWABATA*, Kenji MATSUDA**, Tsutomu NAOI***
**Tatsuo SATO***, Akihiko KAMIO***, Susumu IKENO****

* Graduate Student, Toyama University, 3190, Gofuku, Toyama, 930-8555, Japan
** Faculty of Engineering, Toyama University, 3190, Gofuku, Toyama, 930-8555, Japan
*** Faculty of Engineering, Tokyo Institute of Technology, 2-12-1, O-okayama
Meguro-ku, Tokyo, 152, Japan

**ABSTRACT** The behavior of two step aging in the Al-1.0mass%$Mg_2$Si-0.4mass%Si alloy (excess Si alloy) was investigated by HRTEM. The maximum value of the hardness (HVmax) of the excess Si alloy aged at 473K after 293K pre aging for 60ks was lower than that aged at only 473K and this was a typical negative effect. The HVmax of the excess Si alloy aged at 473K after pre aging for 60ks more than 343K were higher than that aged at only 473K and this was a typical positive effect. There were a lot of the random type precipitates in the excess Si alloy aged at 473K for HVmax after 423K pre aging for 60ks that indicated positive effect. This was the same tendency of that of the Al-$Mg_2$Si alloy without excess Si. There were a lot of the $\beta''$ phase in the excess Si alloy aged at 473K for HVmax after 293K pre aging for 60ks that indicated negative effect.

**Keywords** :*aluminum-magnesium-silicon alloy, two step aging, precipitation, metastable phase, high resolution transmission electron microscopy*

## 1. INTRODUCTION

It is well known that the maximum hardness in the Al-$Mg_2$Si alloys final aged relatively higher temperature after pre aging at room temperature is lower than that aged at only final aging temperature. This behavior is called the negative effect in Al-Mg-Si alloys[1]. The behavior of two step aging in the balanced Al-$Mg_2$Si alloy have been investigated in our recent work by high resolution transmission electron microscopy (HRTEM)[2]and the precipitates which contribute to both the negative and positive effects have been clarified.

It is very important to understand the behavior of two step aging and the mechanism of the negative effect in the Al-$Mg_2$Si alloy containing silicon in excess (the excess Si alloy, hereafter), because it is reported that this effect remarkably appear in the excess Si alloy rather than in the balanced Al-$Mg_2Si$ alloys[1]. The excess Si alloy is focused as materials for body sheet of automobile and structural materials[3], recently.

In this work, it is investigated the precipitation sequence and the behavior of precipitation in two step aged excess Si alloy by HRTEM.

## 2.EXPERIMENTALS

The Al-1.0mass%$Mg_2Si$-0.4mass%Si (the excess Si) alloy was prepared using 99.99% aluminum, 99.9% magnesium and 99.9% silicon ingots. The obtained ingot was formed to sheets by hot and cold rolling. The solution heat treatment was 848K for 3.6ks, and then quenched into the chilled water around 273K. The pre aging was at 293, 343 and 423K for 60ks, and the finally aging was at 473K. The pre aging time for 60ks was the same as that of our recent report.

The pre aging at 293K was performed in the room controlled by the air conditioner and the pre aging at other temperatures were performed in the silicone oil bath. The aged specimens were used for the vickers micro hardness and electrical resistivity measurements, and the transmission electron microscopy. A vickers micro hardness tester was used MVK-II type (Akashi co.ltd) at 0.98N. The electrical resistivity was measured by current four terminal method in liquid nitrogen. The thin specimen for HRTEM was prepared by the electrolytic polishing. HRTEM was used 200kV TEM (Topcon, EM-002B type).

## 3. RESULTS AND DISCUSSION

Fig.1 shows the age-hardening curves of the specimens pre aged for 60ks at several temperatures prior to final aging at 473K. The maximum hardness (HVmax) in the specimen pre aged at 293K for 60ks ( ○ ) is lower than HVmax of the specimen aged at only 473K( ▽ ). This is the negative effect in Al-Mg-Si alloy. The HVmax of the specimens pre aged at 343 ( □ ) , 373 ( ◇ ) and 423K ( △ ) for 60ks are higher than that of the specimen aged at only 473K ( ▽ ) and the positive effect is appeared.

Fig.2 shows the bright field images of TEM in the specimens pre aged at 293, 343 and 423K for 60ks and then 473K for HVmax. The needle shaped precipitates of the specimen pre aged at 293K in Fig.2(b) are coarse and the number of precipitates decrease. The mean size($\bar{L}$) and the number of the precipitates (N) of the specimen pre aged at 343K in Fig.2(c) is the same as those of the specimen aged at only 473K in Fig.2(a). The $\bar{L}$ and N of the precipitates of the specimen pre aged at 423K in Fig.2(d) is finer and denser to be than those of the specimen only aged at 473K in Fig.2(a).

Fig.3(a) is a HRTEM image of a precipitate observed in Fig.2(a) and this precipitate is a typical precipitate in the specimen indicated the negative effect. This is the end-on of the $\beta$ '' phase[4]. The arrangement of bright dots in this end-on appears a parallelogram network having spacings of 0.77 and 0.67nm, and interior angle of 75°. The angle between the one side of the $\beta$ '' phase and the[100]direction of the matrix is about 20°. Fig.3(b) shows a HRTEM image of the precipitate in Fig.2(d) and this is the random type precipitate[4]. The changes in the relative frequencies of those precipitates of the specimens pre aged at several temperatures prior to finally aging at 473K for HVmax with pre aging temperature were investigated. There are the $\beta$ '' phase of 50%, the random type precipitate of 40% and the parallelogram type precipitate of 10% in the specimen only aged at 473K. When the two step aging was performed for the specimen, the frequency of the $\beta$ '' phase decreased with increasing aging temperature. The random type precipitate in the specimen pre aged at 423K drastically increased and its frequency achieves 70%. The parallelogram type precipitate increased with increasing of pre aging temperature and achieved the maximum value of 40% at 343K pre aging and then decreases with increasing pre aging temperature.

## 4. CONCLUSIONS

The behavior of two step aging in the Al-1.0mass%$Mg_2Si$-0.4mass%Si alloy was investigated by HRTEM. The obtained results are as follows ;

(1) The HVmax of the excess Si alloy aged at 473K after 293K pre aging for 60ks was lower than that aged at only 473K and this was a typical negative effect. The HVmax of the excess Si alloy aged at 473K after pre aging for 60ks more than 343K were higher than that aged at only 473K and this was a typical positive effect.

(2) There were a lot of the random type precipitates in the excess Si alloy aged at 473K for HVmax after 423K pre aging for 60ks that indicated the positive effect. This was the same tendency in the balanced alloy. There were a lot of the $\beta$ '' phase in the excess Si alloy aged at 473K for HVmax after 293K pre aging for 60ks that indicated the negative effect.

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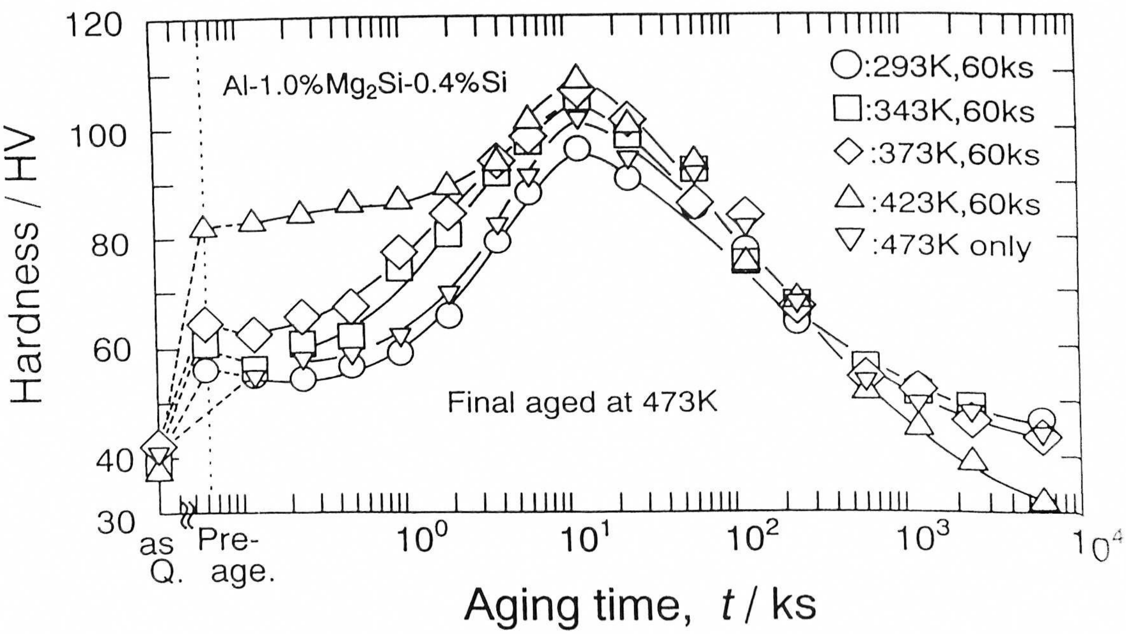



Fig.1 Changes in the micro vickers hardness of the specimens aged at 473K after pre aging for 60ks at several temperatures with aging time.

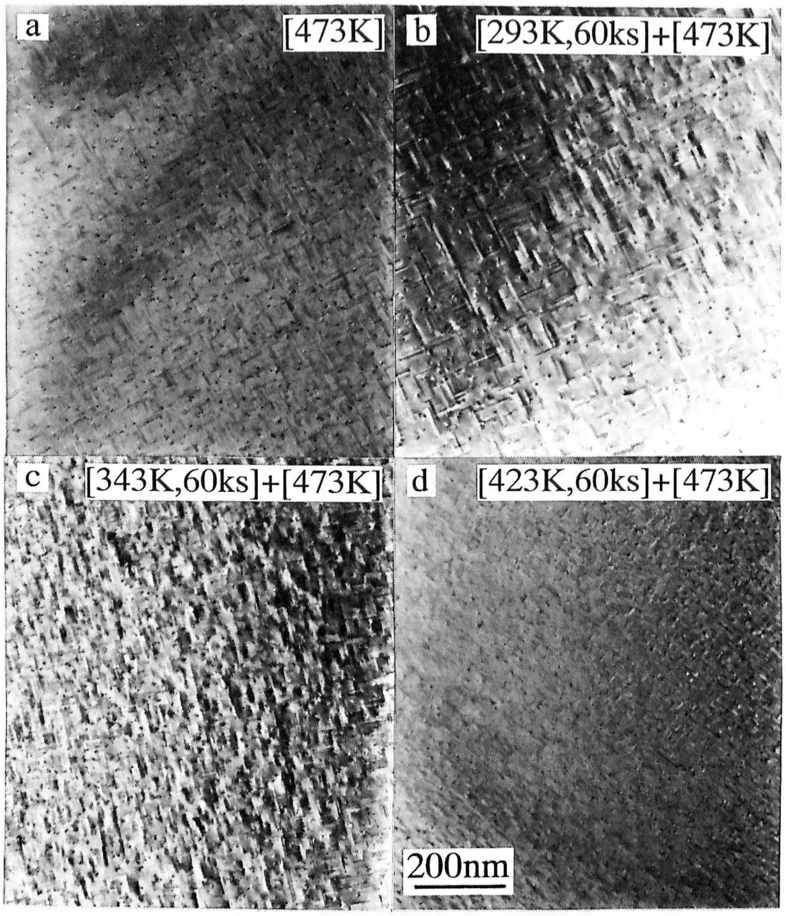
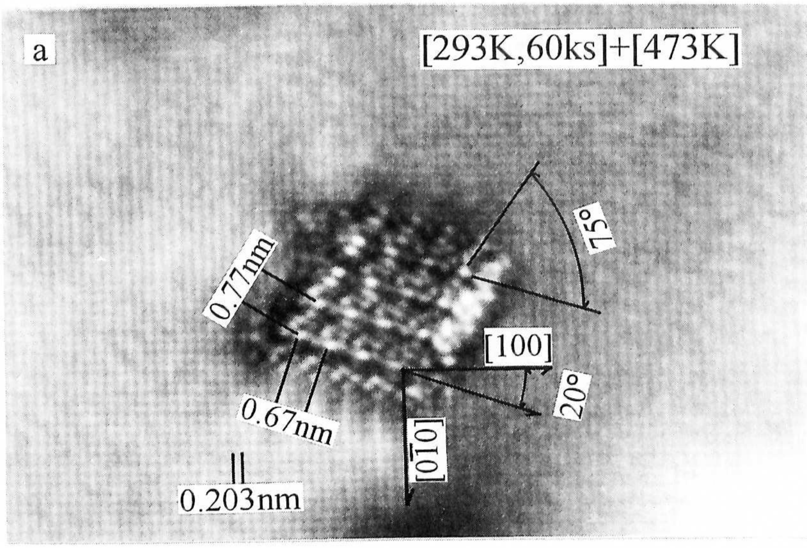



Fig.2 Transmission electron micrographs of specimens aged at 473K up to the maximum hardness. (a) aged at only 473K, (b), (c) and (d) aged at 473K after pre aging for 60ks at 293, 343 and 423K, respectively.



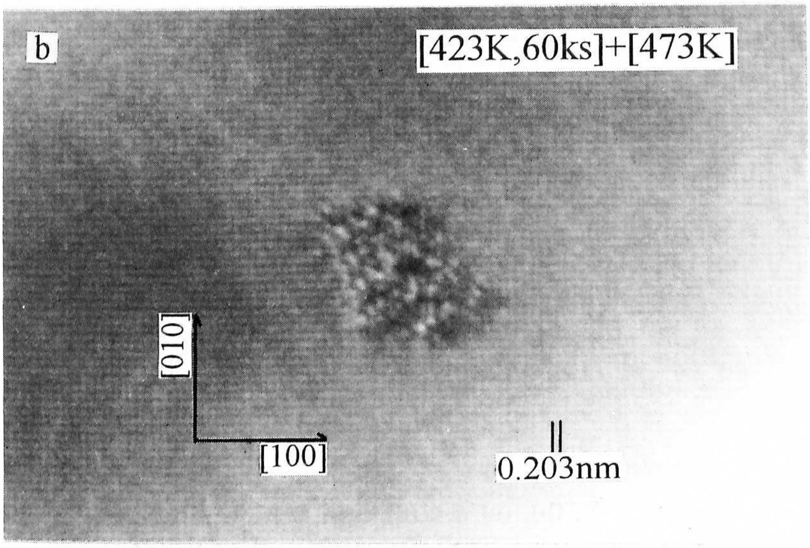




Fig.3 HRTEM images of the specimens aged at 473K up to the maximum hardness after pre aging for 60ks at (a) 293K and (b) 423K.