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Effect of Magnesium Content on Age Hardening in Al-Si-Mg Alloy Castings

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Al-10-(mass%)Si alloys containing a small amount of Mg were cast into the copper gravity mold with Y-shaped cavity and subsequently aging treatment was carried out at various temperatures and times. All specimens were water quenched at 773 K just after casting and were left to natural aging at room temperature for 48 h before they were artificial aging(T5). The age hardening curve of specimens at aging treatment clearly showed the hardness development of a typical age hardening alloy at all the temperatures. To understand the age hardening behavior of these alloys in detail, the optical microscope and scanning electron microscope were used for observation. In the optical microscopy, this study confirmed that these alloys were structured of primary α-Al phase and eutectic phase. These hardness measured and the volume fraction of those phases respectively, and calculated the age hardening curve by the composite rule. In addition, the precipitate in each phase in overaging was confirmed with the scanning electron microscope.

Keywords: *Al-10mass%Si alloy, Age hardening curve, Composite rule, Precipitate.*

1. Introduction

Al-Si eutectic alloys are used for most of aluminum die-casting. These alloys have excellent castability and sufficient strength in combination with other alloying elements. Especially, Al-Si alloy containing Mg used for high-quality die-casting is well-known as a high strength alloy brought by appropriate heat treatment and consequential precipitation hardening of Mg_2Si intermediate phase[1]. T6-heat treatment must be applied for maximum strength, but solution at high temperature and quenching treatment often causes product deformation and extra cost for correction[2]. Therefore an only artificial aging (T5-heat treatment) at comparatively lower temperature is mainly applied to industrial die-casting products. However, there are few studies on age hardening characteristics supplied by T5-heat treatment to Al-Si eutectic alloys.

Al-Si alloy including a small amount of Mg was cast into the copper gravity mold with Y-shaped cavity and subsequently aging treatment was carried out at various temperatures and times. The present study will report on the influence of Mg content on age hardening characteristics in Al-Si-Mg alloy castings.

2. Experimental procedure

2.1 Material

The present study casts Al-10mass%Si-0.5mass%Mg and Al-10mass%Si-0.8mass%Mg alloys as a target composition. Al-20mass%Si alloy, pure Mg and pure Al were used for the ingot fabrication, and weighed alloys so that the total might become 2 kg.

2.2 Casting procedure

An electric furnace, the phosphorizer and the dross removal stick were used to dissolve the casting specimens. The copper made mold was prepared in a Y-shaped cavity as shown in Fig.1. BN was spread on the mold as mold wash. TiO_2 was spread on the phosphorizer used for the addition of pure Mg as mold wash. The temperature of the mold and the center part of the casting was measured with K-type thermocouple with the diameter of 0.2mm, respectively. Based on the target composition, measured ingots were dissolved by the temperature of the electric furnace in 993 K. After the dissolution, dross was removed from the surface of molten metal, moreover pure Mg was added with the phosphorizer. Pouring was begun when the temperature of molten metal and mold were 953 K and 433-443 K. After the pouring, it detached from the mold in 10s when the temperature of castings fell at 773 K, Furthermore it was in situ water-quenched during 10s. After quenching, casting was completed by maintaining the casting specimen at the room temperature. The chemical composition of castings is shown in Table 1

2.3 Aging treatment

In the present study, test specimens having dimensions of 10 × 10 × 2.5 mm were machined from right under the riser of casting. According to the process of the T5 treatment that is being adopted in an industrial field, accordingly, the specimens were left to naturally age at room temperature for 172.8 ks, before they were heat treated for three different artificial aging treatment temperature at 423 K, 473 K and 523 K for various durations (: 0, 240, 480, 960, 1920 ks,...).

2.4 Hardness measurement

The measured section of the specimens were mechanically polished using diamond paste. Vickers hardness was measured in a micro hardness testing machine under a load of 4.9 N for a dwelling time of 20 s moreover an average of twelve readings was reported. Each primary α phase and the eutectic part was measured under a load of 0.098 N.

2.5 Microstructure observation

The aging samples were applied to metallographic specimens. The specimens were mechanically ground progressively on grades of SiC impregnated emery paper (#500-1200) sizes using water as the lubricant. The ground samples were then polished using diamond paste with the diameter of 1μm. Following the polishing operation, etching of the polished specimen was done using 1 mass% hydrofluoric acid. The structure obtained was observed using an optical microscope (OM). The volume fraction of the each α and eutectic phase was measured from the microstructures by the picture processing.

In addition to the foregoing microstructural observation, the specimen was mechanically ground progressively after it was polished using diamond paste. After the polishing operation, observation and elementary analysis were carried out using the scanning electron microscope (SEM).

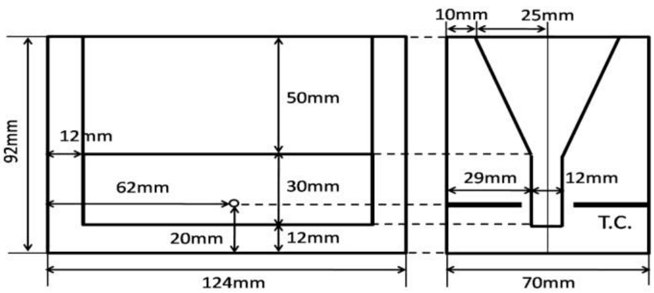

Fig. 1 Schematic diagram of Y-block shaped mold.

Alloy	Si	Mg	Zn	Fe	Mn	Ti	Al
Al-10%Si-0.5%Mg	9.94	0.51	<0.01	0.16	<0.01	0.01	bal.
Al-10%Si-0.8%Mg	9.81	0.81	<0.01	0.16	<0.01	0.01	bal.

Table 1 Chemical composition of Al-10%Si-Mg alloys used. (mass %)

3. Results and discussion

3.1 Age hardening

Fig.2 and Fig.3 show hardness in the natural aging of Al-10%Si-0.5%Mg and Al-10%Si-0.8%Mg alloys. According to the graphs, age hardening that originated in the natural aging wasn't able to be confirmed clearly. Therefore, it can be said that the influence on the age hardening in the natural aging is extremely low.

The age hardening curve at temperatures (423, 473 and 523 K) of Al-10%Si-0.5%Mg and Al-10Si-0.8%Mg alloys is shown in Fig. 4 and Fig. 5, respectively. For the age hardening curve in the Al-10%Si-0.5%Mg alloy in Fig. 4, the hardness change of an age hardening alloy such as the sub-aging, aging peak and over aging is shown. The aging peak increases more hardness when the aging temperature is lower, moreover, the time to reach of the peak has increased.

In Al-10%Si-0.8%Mg alloy in Fig. 5, the aging behavior similar to Fig. 4 is shown. However, all aging temperature gets shorter in the reaching time of peak when it's compared Fig. 4 with Fig. 5, and the tendency for hardness to increase is shown. It's thought that the reason for this fact is that the precipitation hardening owing to aging was promoted by increasing the amount of Mg because of an increase at the nucleation speed by the artificial aging[3, 4].

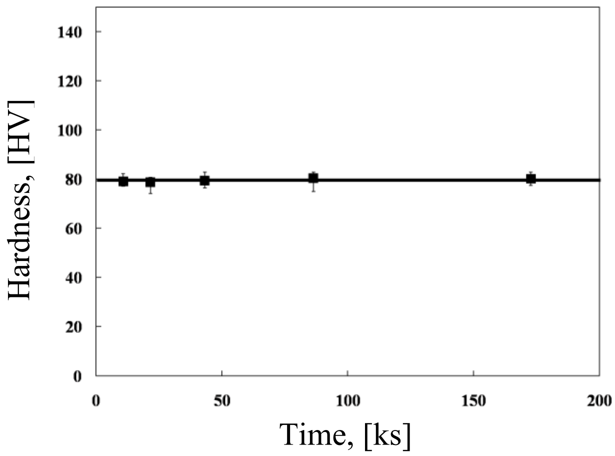

Fig. 2 Natural aging of Al-10%Si-0.5%Mg alloy.

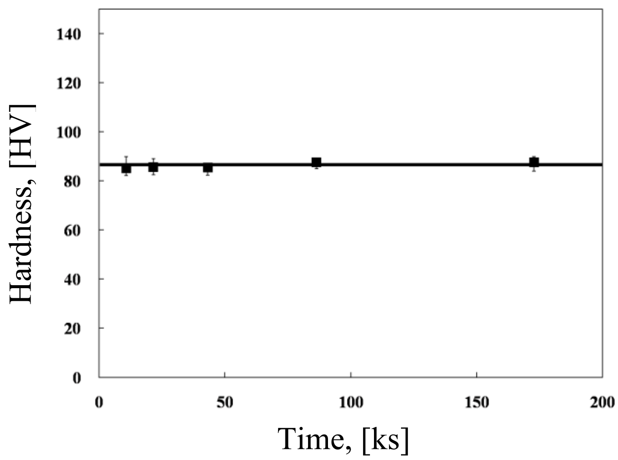

Fig. 3 Natural aging of Al-10%Si-0.8%Mg alloy.

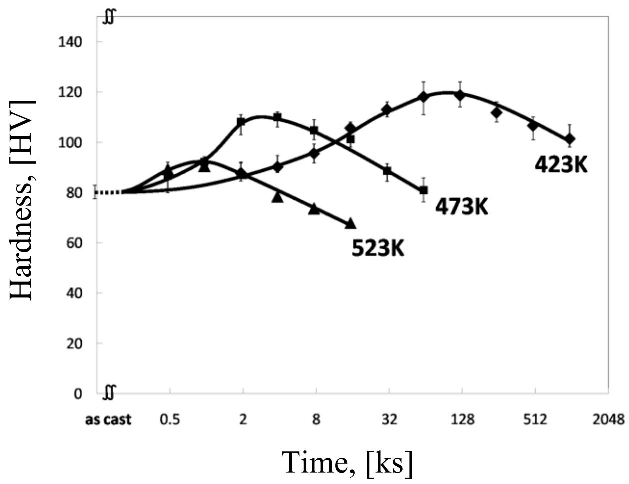

Fig. 4 Age hardening curve of Al-10%Si-0.5%Mg alloy aged at 423, 473 and 523 K.

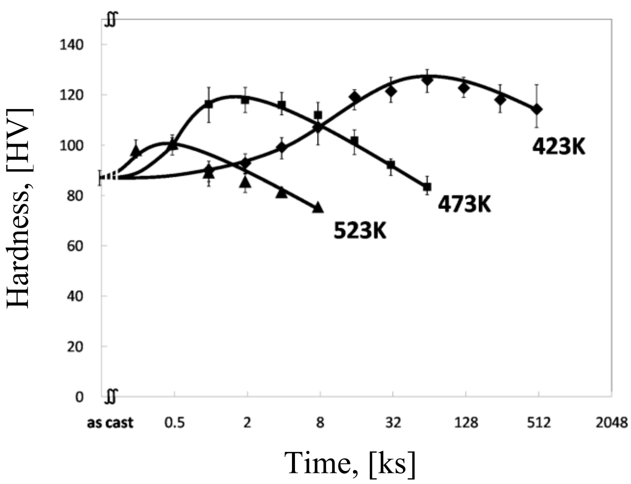

Fig. 5 Age hardening curve of Al-10%Si-0.8%Mg alloy aged at 423, 473 and 523 K.

To examine the behavior of age hardening, the present study made an observation by OM and SEM. The images in Fig.6 confirmed the presence of α and eutectic phase within them. The main structure phase of the specimens was roughly divided into α and eutectic Si phases, hardness of the respective phases were measured separately and the hardness of the aged sample by the composite rule was calculated from equation (1):

$$HV = HV\alpha \times V_f\alpha + HVe \times V_f e \quad (1)$$

where HVα and $V_f\alpha$ are the hardness and the volume fraction of α phase. Similarly, HVe is the hardness of eutectic, $V_f e$ is volume fraction of eutectic phase. The volume fraction of eutectic phase of Al-10%Si-0.8%Mg alloy at 423 K was almost fixed in each time, as a result of the measurement, the mean value showed 0.40. Therefore, $V_f e$ and $V_f\alpha$ applied the composite rule as 0.40 and 0.60. Similarly, the result of aged at 423 K in Al-10%Si-0.8%Mg alloy, $V_f e$ and $V_f\alpha$ were calculated with 0.47 and 0.53. The measured age hardening curves by calculated hardness by the composite rule where the aging temperature is drawn by using the age hardening curve of Al-10%Si-0.8%Mg alloy (eutectic phase, α phase and average) and the composite rule at 423 K is shown in Fig. 7. As in the past report, age hardening of Al-Si-Mg alloy generally is considered to be the main cause of the precipitation-based hardening in α phase[5]; nevertheless, its precipitation occurred in eutectic phase from the present study. From Fig. 7, calculated hardness is similar to the measured hardness. It has been understood that the value calculated by using the composite rule from the above-mentioned agreed with the hardness change of the actual alloy. Similar to a little while ago, Al-10%Si-0.8%Mg alloy aging at 473 K applied the composite rule. Fig. 8 shows the result. A clear age hardening phenomenon was seen also in the eutectic part as well as the aging curve obtained with Fig. 7, moreover it was confirmed that theoretical hardness using the composite rule drew a similar curve to the average hardness in an actual measurement. Therefore, it is thought that average hardness of the alloys can be calculated by using the composite rule in 423-473 K.

OM and SEM images are shown in Fig. 9 where the specimen made coarsening of precipitates when it was treated with high temperature and over aging. Consequently, it was able to be confirmed that the precipitates existed in a high density within α phase. In contrast, new precipitates could hardly be observed in the eutectic part. However, age hardening appears plainly also in the eutectic part in the result of composite rule. This cause means that the precipitates could not be confirmed by the SEM observation; further examination is needed in the future.

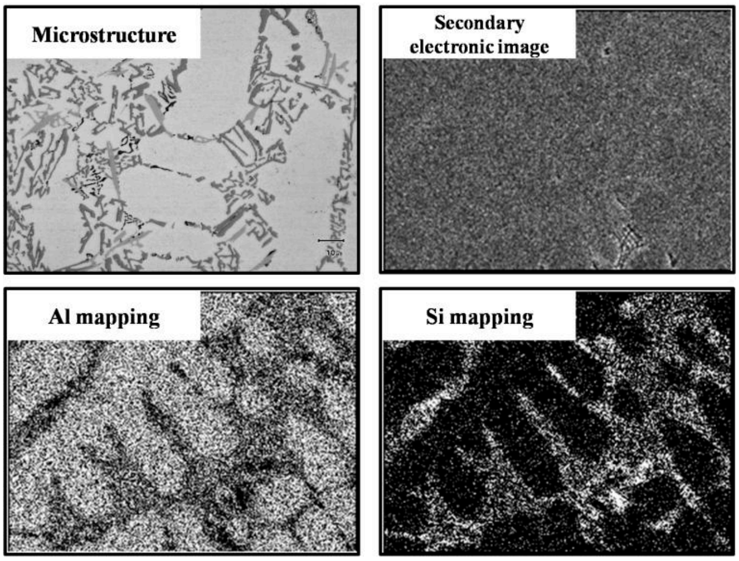

Fig. 6 SEM image of as cast Al-10%Si-0.8%Mg alloy.

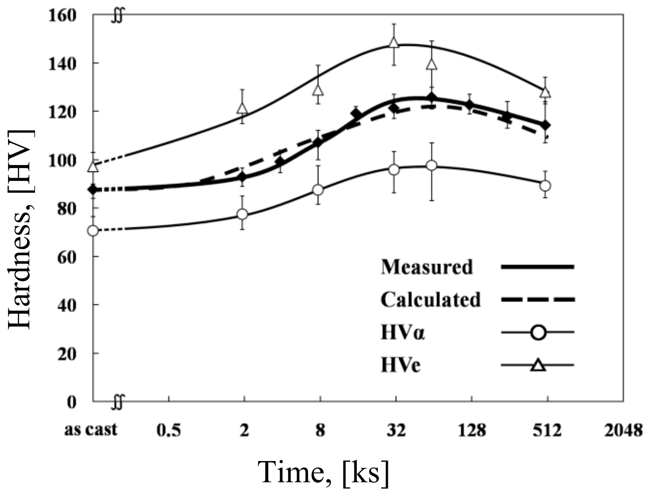

Fig. 7 Age hardening curve of Al-10%Si-0.8%Mg alloy aged at 423 K by composite rule.

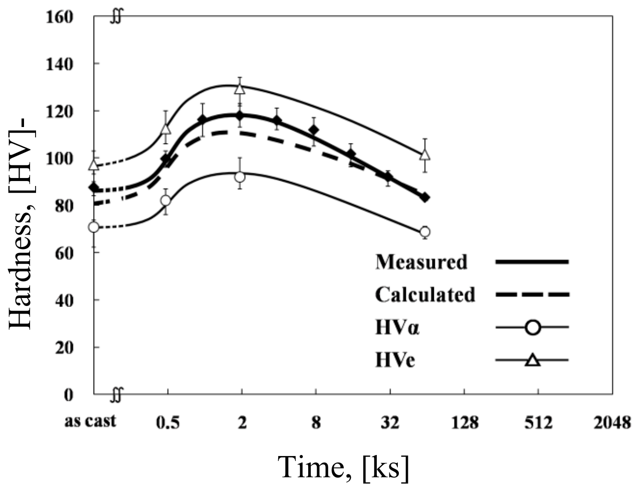

Fig. 8 Age hardening curve of Al-10%Si-0.8%Mg alloy aged at 473 K by composite rule.

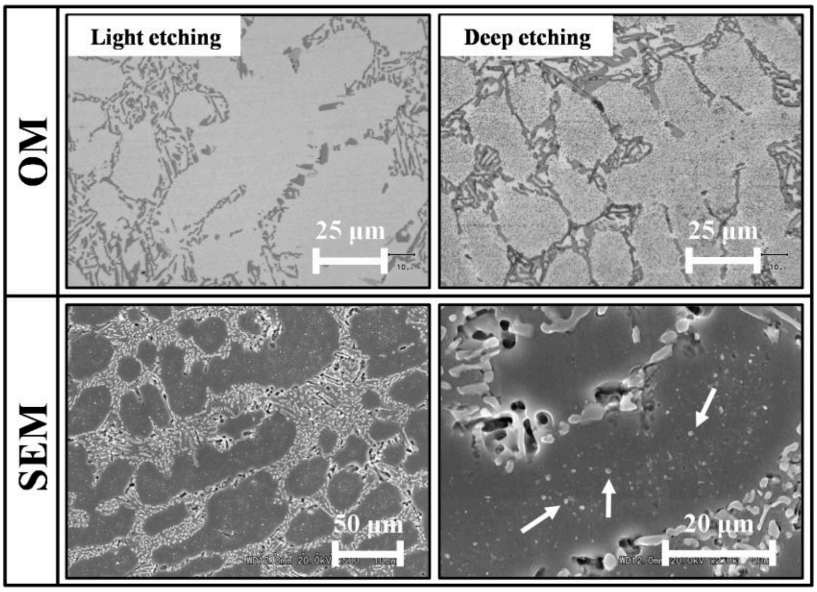

Fig. 9 OM and SEM images of Al-10%Si-0.8%Mg alloy aged at 673 K.

4. Conclusions

From the results of the investigations, the following conclusions have been made.

(1) Al-10%Si-0.5%Mg and Al-10%Si-0.8%Mg alloy quenched in iced water, naturally aged at room temperature and artificially aged at 423-523 K, showed conspicuously age hardening behavior.
(2) The age hardening curve obtained from the theoretical hardness by the composite rule almost agreed with age hardening curve from the measurement. Consequently, it's thought that the age hardening of these alloys is composed with change of hardness in the two phases.
(3) The present study was observed with the photon microscope and SEM about the precipitated phase, which made its precipitate coarsened by over-aging treatment with 673 K and 3.6 ks. As a result, the precipitate wasn't able to be confirmed in the eutectic part though it was confirmed in the α phase. To understand the influencing for strengthening of the alloy in the eutectic part needs further examination.

References

[1] Japan Institute of Light Metals: *The Structure and Property of Aluminum*, (1991), 231-244.
[2] N. Nishi: Japan Foundry Engineering Society, 80 (2008), 677-683.
[3] M. Kitada: *Elementary Metal Physics*, AGNE Sho-Fu-Sya, (1978), 153-158.
[4] C. R. Barrett, W. D. Nix and A. S. Tetelman: *The Principles of Engineering Materials*, BAIFUKAN CO., LTD, (1980), 115-118.
[5] S. Iwasaka, T. Yamaguchi, S. Saikawa, K. Hayashi, S. Kamado and Y. Kojima: Japan Foundry Engineering Society, 74 (2002), 296.