**Relationship Between Heat Treatment And Mechanical Properties Of Al-Si-Mg Alloy**

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**Abstract.** The relationship between heat treatment and mechanical properties of Al-Si-Mg alloy was investigated. Solution treatment at 808K for 6 hours, preliminary aging at room temperature for 60 hours and artificial aging at 473K for 1 hour were conducted. Not preliminary aged samples were prepared for comparison. The strength improved and the elongation decreased with increasing the amount of Mg. This trend was seen both preliminary aged and not preliminary aged samples. However, preliminary aged samples showed relatively high tensile strength and elongation comparing with not preliminary aged samples. EPMA analysis revealed that the precipitation of Mg₂Si in preliminary aged samples was larger than that of not preliminary aged samples, and which possibly contributed to the improvement of strength of the preliminary aged samples. Thermodynamic calculation showed that Mg₂Si phase was not undissolved at the solution temperature, 808K, and these undissolved Mg₂Si particles might influenced on mechanical properties negatively.

**Keywords:** Al–Si-Mg alloy, heat treatment, mechanical properties

1. **Introduction**

In recent years, global warming is a serious problem, and countermeasures against it are made in various fields. Particularly in the automobile industry it is strongly required to regulate automobile exhaust gas and improve fuel economy. Then, the aluminum material has a specific gravity of one third as compared with the steel material and has good workability. So, it is expected to be an effective material for weight reduction of the car body. At the actual production process, heat treatment is often applied after casting to improve the mechanical properties[1,2]. From the viewpoint of energy saving, if the influence of heat treatment on cast material is clarified, a more efficient production system should be prepared. Therefore, in this study, we aimed to investigate the influence of composition and heat treatment on mechanical properties by applying heat treatment to Al-Si-Mg based alloy which has both good ductility and strength[3].
2. Experimental procedure

2.1. Material preparation

In this study, Al-4wt.%Si-xwt.%Mg alloy with different heat treatment/composition was used as test materials. Procedures for preparing each sample are shown below. The composition is shown in weight percent. The master alloys, 99.99%Al, Al-10%Mg, Al-4%Si-0.5%Mg and Al-24.3%Si, were cut, weighted and blended in a predetermined composition. The samples were fabricated by gravity casting and listed in Table 1. The weighted master alloys were put into an alumina crucible and heated in an electric furnace to 1073 K and casted. Two types of heat treatment, non-pre aged and pre aged, were applied in this study as shown in Fig. 1. After casting, samples were maintained at 808 K for 6 hours as a solution treatment, followed by water cooling with water at room temperature. For pre aged samples, preliminary aging treatment at room temperature was conducted at 303 K for 60 h and then an artificial aging treatment was conducted at 473 K for 1 hour in an oil bath.

Table 1 Prepared samples in this study.

| Heat treatment     | Composition             |
|--------------------|-------------------------|
| non-pre aged       | Al-4%Si-0.4%Mg          |
|                    | Al-4%Si-0.6%Mg          |
|                    | Al-4%Si-0.8%Mg          |
| pre aged           | Al-4%Si-0.4%Mg          |
|                    | Al-4%Si-0.8%Mg          |
|                    | Al-4%Si-1.2%Mg          |

Fig.1 Heat treatment procedure of samples.

2.2. Evaluation method

A tensile test was conducted to measure tensile strength and elongation of samples. The tensile speed was 1 mm/min. The elongation was determined from the change in gauge distance. The
samples were polished until the surface became a specular surface, and microstructural observation by SEM and elemental analysis by EPMA were carried out in order to investigate the relationship between the microstructure and tensile properties of the samples. JEOL JXA8900 was used with the acceleration voltage of 15kV.

3. Results and Discussion

3.1. Mechanical properties

Fig. 2 shows mechanical properties of samples. Although the ultimate tensile strength of the pre-aged Al-4%Si-0.8%Mg slightly decreased comparing with Al-4%Si-0.4%Mg, Al-4%Si-1.2%Mg shows a high strength exceeding 300MPa. However, the elongation of Al-4%Si-1.2%Mg greatly decreased. The strength of the non-pre aged samples increased with the amount of Mg and the elongation decreased. When comparison between non-pre aged and pre aged Al-4%Si-0.4%Mg is made, pre aged sample showed high ultimate tensile strength, as shown in Fig. 2(a), and this means that pre aged heat treatment affected positively. On the other hand, when comparison between non-pre aged and pre aged Al-4%Si-0.8%Mg is made, pre aged sample show low ultimate tensile strength, and this means that pre aged heat treatment affected negatively. Elongations of pre aged samples was higher than that of non-pre aged samples, and this means that pre aged heat treatment affected positively in elongation.

![Fig.2 Mechanical properties of samples, (a)Ultimate tensile strength and (b)Elongation.](image)

3.2. Structure observation

Magnesium silicide (Mg₂Si) is commonly formed in Al-Si-Mg based alloys[4]. Precipitation of Mg₂Si increased with increasing the amount of Mg in both pre aged and non-pre aged samples. However, precipitation of Mg₂Si in pre aged samples was larger than that of non-pre aged samples. In particular, Mg₂Si precipitates in pre aged Al-4%Si-0.8%Mg was formed along grain boundaries. Increase of precipitation of Mg₂Si possibly contributed to the improvement of the strength of pre aged samples.
In this study, we used a thermodynamic calculation software called JMatPro to investigate the correlation between the proportion of each phase in the sample and the temperature. The result of the Al-4%Si-0.4%Mg alloy is shown in Fig. 4. It can be confirmed that the temperature at which all of the Mg and Si is solid solution is 773K or more. This means that a solution treatment should be conducted between 773K and solidus temperature, 833K. The difference between solid solution temperature and solidus temperature was defined as $\Delta T$, and Fig. 5 shows the relationship between $\Delta T$ and amount of Mg. $\Delta T$ decreased with increasing amount of Mg. In case of Al-4%Si-0.6%Mg, the temperature at which all the Mg and Si is solid solution is 813K or more, and it is close to the solidus temperature. In case of Al-4%Si-0.8%Mg, the Mg$_2$Si phase does not solve until solidus temperature and it is considered that the unsolved Mg$_2$Si phase remained at 808K which was the solution temperature of this experiment. In case of Al-4%Si-1.2%Mg, considerable amount of unsolved Mg$_2$Si phase remained, and it had a negative influence on elongation.
4. Conclusions

The influence of composition and heat treatment on mechanical properties of Al-4%Si-\(x\)%Mg alloy was investigated. The results are summarized as follows.

1. The strength improved and the elongation decreased with increasing the amount of Mg. This trend was seen in both non-pre aged and pre aged samples.

2. When comparing non-pre aged and pre aged samples, pre aged samples showed relatively high tensile strength and elongation.

3. EPMA analysis revealed that the precipitation of Mg\(_2\)Si in pre aged samples was larger than that of non-pre aged samples, and which possibly contributed to the improvement of strength of the pre aged samples.

4. The difference between solid solution temperature and solidus temperature decreased with increasing amount of Mg in Al-4%Si-\(x\)%Mg alloy. When amount of Mg was larger than 0.6%, the unsolved Mg\(_2\)Si phase possibly remained at 808K which is the solution temperature of this experiment.

5. References

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