A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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HRTEM OBSERVATION OF THE PRECIPITATES IN Cu AND Ag ADDED Al-Mg-Si ALLOYS

OBSERWACJA WYDZIELEŃ W STOPACH Al-Mg-Si Z DODATKIEM Cu I Ag TECHNIKĄ WYSOKOROZDZIELCZEJ TRANSMISYJNEJ MIKROSKOPII ELEKTRONOWEJ

It has been known that Cu- and Ag-added Al-1.0mass%Mg_2Si alloys (Al-Mg-Si-Cu alloy and Al-Mg-Si-Ag alloy) have higher hardness and elongation than those of Al-1.0mass%Mg_2Si alloy. In this study, the aging behaviour of Al-Mg-Si-Cu alloy, Al-Mg-Si-Ag alloy and (Cu+Ag)-addition Al -1.0 mass% Mg_2Si alloy has been investigated by hardness test and TEM observation. The Al-Mg-Si-Cu-Ag alloy has the fastest age-hardening rate in the early aging period and the finest microstructure at the peak hardness among three alloys. Therefore the microstructure of the precipitate in Al-Mg-Si-Cu-Ag alloy has been investigated by HRTEM observation to understand the effect of Cu and Ag addition on aging precipitation.

Keywords: Al-Mg-Si alloy, precipitation, effect of Ag/Cu, TEM

Znanym jest, że stopy Al-1.0 %wag. Mg_2Si z dodatkiem Cu i Ag (stopy Al-Mg-Si-Cu i Al-Mg-Si-Ag) charakteryzują się wyższą twardością i większym wydłużeniem niż stopy Al-1.0 %wag. Mg_2Si. W pracy badano proces starzenia stopów Al-Mg-Si-Cu, Al-Mg-Si-Ag oraz Al-1.0 %wag. Mg_2Si z dodatkiem (Cu+Ag) przy użyciu pomiarów twardości i transmisyjnej mikroskopii elektronowej. Stop Al-Mg-Si-Cu-Ag charakteryzuje się najszybszym wzrostem twardości w początkowym etapie starzenia i najbardziej rozdrobnioną mikrostrukturą dla maksimum twardości spośród trzech badanych stopów. W związku z tym, mikrostruktura wydzieleń w stopach Al-Mg-Si-Cu-Ag zbadana została techniką wysokorozdzielczej mikroskopii elektronowej w celu zrozumienia wpływu Cu i Ag na proces wydzielenia podczas starzenia.

1. Introduction

It has been reported that the mechanical properties and microstructure will be improved for the Al-Mg_2-Si alloy with Cu or Ag addition [1].We reported that the maximum hardness was increased, the aging time to the maximum hardness was decreased, and the elongation in tensile tests was increased both for Cu- and Ag- added Al-Mg_2-Si alloys. We also reported the effect of Cu or Ag addition on microstructure, such as the change of the precipitation sequence or crystal structure, as well as the improvement for the number density of the precipitate [2]. The precipitate observed in the Al-Mg-Si-Ag alloy was similar to the quaternary AlMgSiCu (Q') phase, which precipitated dominantly in the Cu-added alloy [3,4]. The effect of Ag and Cu on the properties of Al-Mg_2-Si alloy, however, has not been investigated in detail. The aim of this work is to study the effect of simultaneous addition of Cu and Ag on the aging behavior of Al-1.0mass%Mg_2Si alloy by hardness measurement TEM observation.

2. Experimental procedure

The Al-1.0mass%Mg2Si (base alloy), Cu- or Ag-added alloys were prepared, as well as both Cu and Ag added alloy by laboratory casting. The chemical composition of the alloys is shown in Table 1. The specimens were solution heat treated at 848K for 3.6ks in an air furnace, quenched in chilled water, followed by an aging treatment at 523K. The micro-Vickers hardness was measured using AKASHI MVK-EII hardness tester (load: 0.98N, holding time: 15s). The specimens for TEM observations were prepared by electrolytic polishing and twin-jet electro polishing. And the TEM observation was perfomed with TOPCON TEM-002B operated at 120kV.

TABLE 1
Chemical composition of alloys (at. %)

Samples	Mg	Si	Cu	Ag	Al
base alloy	0.70	0.35	–	–	bal.
0.35Cu alloy	0.68	0.37	0.35	–	bal.
0.35Ag alloy	0.67	0.35	–	0.33	bal.
0.2Cu-0.1Ag alloy	0.66	0.35	0.29	0.12	bal.
0.1Cu-0.2Ag alloy	0.74	0.33	0.11	0.24	bal.

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3. Results and discussion

Fig. 1 shows the age hardening curves obtained for the alloys aged at 523K. The hardness of the alloys with Cu and/or Ag addition is higher than the base alloy. And the aging time to the maximum hardness of the alloys with Cu and/or Ag addition is shorter than the base alloy. 0.35Cu alloy has the highest maximum hardness. The age hardening curves of Cu and Ag added alloys were located between that of 0.35Cu alloy and 0.35Ag alloy.

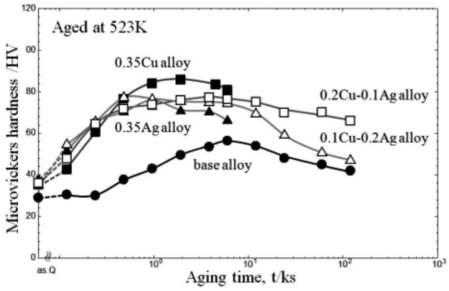

Fig. 1. Age-hardening curves of alloys aged at 523 K

Fig. 2 shows the TEM bright-field images obtained from 0.2Cu-0.2Ag and 0.1Cu-02Ag alloys peak aged at 523K. The incident beam direction is parallel to the $[100]_{Al}$ direction. There are only needle -shape precipitates aligning with $\langle 100 \rangle_{Al}$ direction. The microstructure of 0.1Cu-0.2Ag alloy was finer than that of 0.2Cu-0.1Ag alloy. It means that microstructure in the alloy become finer with increasing Ag content.

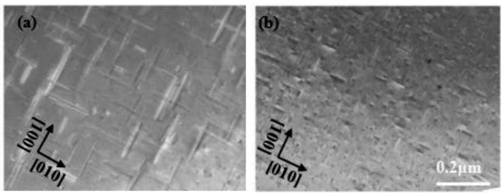

Fig. 2. TEM bright-field images of (a) 0.2Cu-0.1Ag and (b) 0.1Cu-0.2Ag alloys peak aged at 523K

Fig. 3 (a) shows the HRTEM image of the precipitate obtained for the 0.1Cu-0.2Ag alloy aged at 523K for 6.0ks, which is the cross section of the rod-shape precipitate. The hexagonal network of the bright dots in this precipitate was observed with the spacing about 0.69nm, and the <1120> direction of the precipitate was inclined by 15° to $\langle 100 \rangle_{Al}$ direction of the matrix. This is the similar to β'phase in the base alloy without Cu and Ag. Fig. 3 (b) also shows the HRTEM image of the precipitate obtained for the 0.1Cu-0.2Ag alloy aged at 523K for 60.0ks. The hexagonal network of the bright dots in this precipitate was also observed but this precipitate showed the spacing about 1.04nm, and the <1120> direction of the precipitate was inclined by 20° to $\langle 100 \rangle_{Al}$ direction of the matrix. These are similar to Q'-phase in the Cu-added Al-Mg-Si alloy.

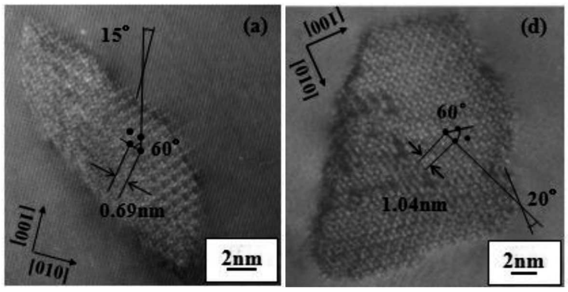

Fig. 3. HRTEM images of precipitates in 0.1Cu-0.2Ag alloy aged at 523K for (a) 6.0ks and (b) 60.0ks

The precipitates observed by HRTEM were classified into random-type, parallelogram-type, β'-phase and Q'-phase with different aging time. Relative frequency of all kind of precipitates changed by aging times. For example in the 0.1Cu-0.2Ag alloy aged at 523K, a lot of parallelogram-type precipitate existed for 0.48ks, and β'-phase for 6.0ks. A lot of Q'-phase were precipitated for 60.0ks. Precipitation of many Q'-phase and parallelogram-type precipitate is the characteristic in 0.1Cu-0.2Ag alloy which includes Cu and Ag, simultaneously.

4. Conclusion

The age hardening curves of Cu and Ag added alloys were located between that of 0.35Cu alloy and 0.35Ag alloy. The microstructure of 0.1Cu-0.2Ag alloy was finer than that of 0.2Cu-0.1Ag alloy. The precipitates observed by HRTEM were classified into different kind of the precipitates during aging time. Precipitation of many Q'-phase and parallelogram-type is the characteristic of precipitation in 0.1Cu-0.2Ag alloy.

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