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TEM Observation of Cu and Ag Added Al–Mg–Si Alloy

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It is well known that Cu and Ag addition on Al–Mg_2Si alloy can enhance its mechanical properties due to solid solution hardening. Several reports are available about the effect of each alloying elements, Cu and Ag, on Al–Mg–Si alloys. In this research, Al–Mg–Si–Cu–Ag alloys have chemical compositions of (1) 0.18Cu–0.18Ag and (2) 0.35Cu–0.35Ag [at.%] fixed Cu/Ag rate of 1.0 are prepared using casting to estimate effects of Cu and Ag amount to precipitation behaviour and mechanical properties. The Vickers microhardness measurement was conducted to estimate mechanical property after ageing treatment microstructure observation was carried out using transmission electron microscopy. In peak-aged at 473 K hardness of each alloys was almost the same, but in peak-aged at 523 K, hardness of 0.35Cu–0.35Ag was higher than 0.18Cu–0.18Ag alloy.

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1. Introduction

Al–Mg–Si system alloys have been used widely in industries as structural materials. It has been reported that the mechanical properties can be improved by Cu or Ag addition in Al–Mg_2Si alloys by solid solution precipitation sequence and shape of precipitates hardening. Also, they affect the mechanical properties by changing during ageing treatment [1, 2], as we already reported the effect of each Cu or Ag addition to the microstructure, the change of precipitation sequence and crystal structure, as well as the improvement of the number density of precipitates. The effect of Cu and Ag on the properties of Al–Mg_2Si alloy is the subject of present study, because it has not been investigated in detail. The aim of this work is to study the effect of Cu and Ag addition with fixed Cu/Ag rate of 1.0 on Al–1.0at.%Mg_2Si alloy for the ageing behavior by means of hardness measurements and transmission electron microscopy (TEM) observations.

2. Experimental

The chemical composition of the all alloys is shown in Table I. Al–1.0Mg_2Si alloy is base alloy. Cu and Ag added alloys were prepared. Cu and Ag ratio of two types Cu and Ag added alloys are Cu/Ag = 1, but the amount of Cu and Ag is different. The specimens were solution heat treated at 848 K for 3.6 ks in an air furnace, quenched in iced water. Alloys were subjected to ageing treatment at the temperatures of 473 K and 523 K. To estimate the mechanical property, Micro Vickers hardness tester (Mitutoyo HM-101) was used with a load of 0.98 N for the duration of 15 s. TEM observation was performed with TOPCON TEM-002B operated at 120 kV.

TABLE I

Chemical composition of alloys.

Alloy	Mg		Si		Cu		Ag		Al
	[at.%]	[wt%]	[at.%]	[wt%]	[at.%]	[wt%]	[at.%]	[wt%]	
base	0.70	0.63	0.35	0.36	0	0	0	0	bal.
0.18Cu–0.18Ag	0.72	0.64	0.36	0.37	0.19	0.44	0.18	0.71	bal.
0.35Cu–0.35Ag	0.68	0.64	0.36	0.37	0.34	0.78	0.33	1.3	bal.

3. Result and discussion

Figure 1 shows hardening curve aged at 473 K and 523 K. The hardness of the Cu and Ag addition alloy is higher than of the base alloy. The ageing time to the maximum hardness of the alloy with Cu and Ag is earlier than of the base alloy. The maximum hardness of 0.35Cu–0.35Ag alloy is highest. The difference of hardness between 0.18Cu–0.18Ag and 0.35Cu–0.35Ag is small in alloy aged at 473 K, but the maximum hardness is more different in specimen aged at 523 K.

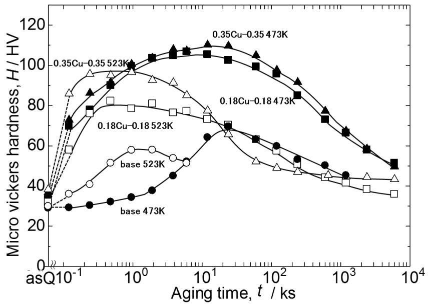

Fig. 1. Micro Vickers hardness variation against ageing time.

Figure 2 shows the TEM bright field images of 0.18Cu–0.18Ag and 0.35Cu–0.35Ag alloys each aged 0.12 ks and 12 ks at 523 K. The incident beam direction is parallel to the [100] Al direction. There are needle-shape and probably those are cross-sections of needle precipitates. Those precipitates elongated are parallel to the $\langle 001 \rangle_{Al}$direction.

Figure 3 shows precipitation density of each alloy aged at 473 K and 523 K.

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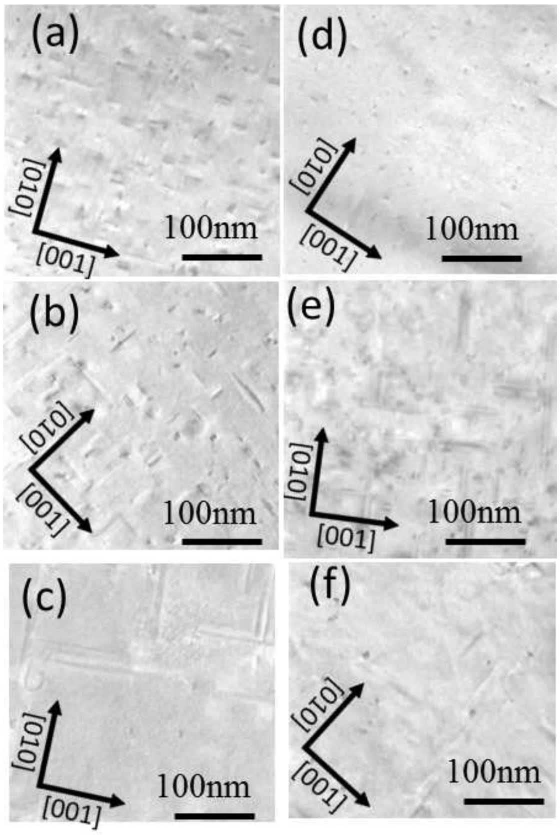

Fig. 2. TEM bright-field images of (a,b,c) 0.18Cu–0.18Ag alloy and (d,e,f) 0.35Cu–0.35Ag alloy 0.12 ks, 0.98 ks, 12 ks aged at 523 K, respectively.

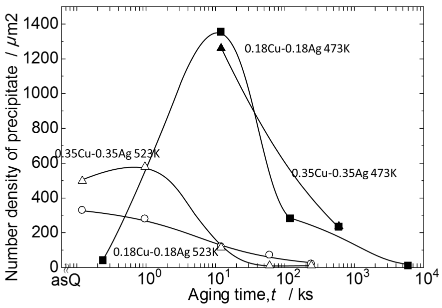

Fig. 3. The variation of precipitate density during ageing treatment.

Precipitation density decreases with increase of ageing time. The density is different for high concentration alloy (0.35Cu–0.35Ag) and low concentration alloy (0.18Cu–0.18Ag) aged for 0.96 ks, at 523 K. On the other hand, the density is similar for 0.18Cu–0.18Ag and 0.35Cu–0.35Ag in either ageing time at 473 K.

Figure 4 shows HRTEM image of precipitates. The precipitation observed in 0.18Cu–0.18Ag alloy aged at 523 K for 12 ks have hexagonal network of dots (representing column of atoms), which are observed with the spacing about 1.04 nm, and the ⟨1120⟩ direction of the precipitate inclined by 10° to $\langle 100\rangle_{\mathrm{Al}}$ direction of the matrix. This precipitation is similar to Q' phase in the base-Cu alloy (Al–1.0%Mg_2Si–0.2%Cu alloy in at.%) was

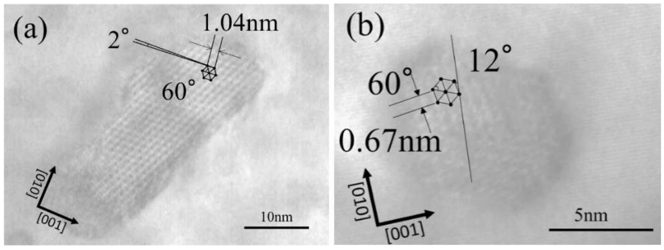

Fig. 4. HRTEM image of precipitation in alloy aged at 523 K: (a) 0.35Cu–0.35Ag, (b) 0.18Cu–0.18Ag.

reported in Ref. [3]. On the other hand, precipitation observed in 0.35Cu–0.35Ag alloy aged at 523 K for 12 ks have ⟨1120⟩ direction of precipitate almost parallel to $\langle 100\rangle_{\mathrm{Al}}$ of the matrix (Fig. 4a). This angle relationship is different for 0.18Cu–0.18Ag alloy of the precipitation.

Figure 4b shows another precipitate observed in 0.18Cu–0.18Ag alloy aged at 523 K for 12 ks showing hexagonal network of dots (representing columns of atoms), which is observed in ⟨1120⟩ direction of the precipitate inclined by 12° to $\langle 100\rangle_{\mathrm{Al}}$ direction of the matrix. This precipitate is similar to that of β' phase. But, β' observed in base alloy has hexagonal network of dots with the spacing about 0.71 nm. The precipitate in Fig. 4b have smaller lattice parameter than β' in Al–1.0wt%Mg_2Si alloy reported in Ref. [4].

4. Conclusions

- Microhardness of 0.35Cu–0.35Ag alloy is higher than 0.18Cu–0.18Ag alloy after quenched (As. Q) and peak aged condition regardless ageing temperature.
- Difference of peak hardness between 0.18Cu–0.18Ag alloy and 0.35Cu–0.35Ag alloy is small at 473 K, however, it became larger when aged at 523 K.
- Q' phase is observed in both alloys, but β' phase is observed only in 0.18Cu–0.18Ag alloy aged at 523 K.
- Q' phase in 0.18Cu–0.18Ag alloy has the same angular relationship with matrix compared to only Cu added alloy.
- But Q' phase in 0.35Cu–0.35Ag alloy showed different angular relationship compared to only Cu added alloy.
- Interatomic distance in β' phase observed in 0.18Cu–0.18Ag alloy is smaller than already reported in β' in Al–Mg–Si alloys without Cu or Ag addition.

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