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Effect of Addition of Ag / Cu on Precipitation in Al-Mg-Si Alloys

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It has been known that Cu- or Ag-addition to Al-1.0mass%Mg_2Si (balanced) alloys shows higher hardness and elongation than Cu-free of Ag-free balance alloy. In this study, the effect of Cu or Ag addition to the balanced alloy, alloys with Si / Mg in excess have been investigated by hardness and tensile tests and HRTEM observation. Cu addition is effective for higher hardness, and Ag-addition is useful for improvement of elongation for peak-aged samples. Precipitates in peak aged these alloys have been confirmed by HRTEM and Cu-bearing alloys almost includes Q'-phase, and Ag-bearing alloys includes β'-phase. In this study, both of Cu and Ag have been added to the balanced alloy and its aging behavior, tensile properties, microstructure and the number density of precipitates in peak-aged the hardness, elongation and microstructure were also investigated. Simultaneous addition of Cu and Ag gives both of higher hardness and elongation and its microstructure was finer than alloys just including one element of Cu or Ag.

Keywords: *Aluminum-Magnesium-Silicon alloy, precipitation, Ag addition, Cu addition, tensile test, hardness.*

1. Introduction

The Al-Mg-Si alloy is usually remarked as the quasi binary alloy Al-Mg_2Si. It has been known that the mechanical properties will be different when the amount of Mg or Si is more than the quasi binary alloy (balance alloy) [1-3]. The alloy with excess Mg or Si comparing with the balance alloy is called ex.Mg or ex.Si alloy hereafter. It has been known [1, 3] the hardness and tensile strength will increase but elongation decrease for ex.Si alloy comparing with the balance alloy. On the contrary, the hardness and the tensile strength do not change so much but the elongation is improved for ex.Mg alloy. The transition metals such as Cr, Mn or Cu are usually added to these series Al-Mg-Si alloys to for the improvement of the grain size or the other chemical properties. Recently, it has been reported that these alloys with some quantity of the transition metals is usually used for the body sheet materials for cars [4]. We have observed and classified the various kinds of the precipitates for different Al-Mg-Si alloys using a high resolution transmission electron microscope, as well as the existence ratios of the precipitates which are different with the difference of the chemical compositions and the difference of the aging time [5-7].

The aim of this work is to investigate the effect of Cu and Ag addition on the properties of Al-Mg-Si alloy. Take this purpose in mind, the aging hardness, tensile test and microstructure of two Al-Mg-Si-Cu-Ag alloys are used in this work and taken to compare with the alloys of Al-Mg-Si-Cu alloy and Al-Mg-Si-Ag.

2. Experimental procedure

Ten kinds of alloys were prepared using 99.99% purity Al, 99.9% purity Mg, Si and Ag metals with composition given in Table 1. The concentration of the alloy with single additional metal has the sequence of A <B <C <D and E <F. For the alloys G and H, the total quantity of the additional metals is the same but the concentration of Cu is higher in alloy G than in alloy H. In addition, the total quantity of the additional metals is the same for the alloys B, E, G and the H, which is described as 0.35at.% and the total quantity of the additional metals is the same for the alloys C, F and I alloy is also the same, which is described as 0.7at.%. The samples with the thickness of 1mm and 0.2mm were made by hot- and cold-rolling, followed by solution heat treatment at 848K for 3.6ks and then quenched into chilled water. The as-quenched samples are taken for artificial aging at 423K, 473K and 523K with different time. The micro-Vickers hardness was measured with AKASHI MVK-E II (load: 0.98N, holding time: 15s). Tensile test was taken with DSS-5000 at room temperature. TEM and HRTEM (Topcon EM-002B) with EDS was operated at 120 or 200 kV.

3. Results and discussion

Figure 1 shows the age-hardening curves of four alloys B, E, G and H aged at (a) 423 K and (b) 473 K. The peak hardness of B alloy which is added Ag is the lowest expect for the balance alloy at two aging temperature. The peak hardness of E alloy which is added Cu and G, H alloys which are added Cu and Ag with different concentration are the similar with each other. The peak hardness of the four alloys with addition of transition metals has the sequence that H alloy is the highest, followed by G alloy, then B alloy, and E alloy is the lowest.

Figure 2 shows the result of the tensile test of balance alloy and B, E, G, H alloys. The 0.2% proof stress shows a strength order of E>G>H>B. The ultimate tensile strength of E, G and H alloys has the similar with each other, which is higher than B alloy. This is similar with the variation four the peak hardness of four alloys. That is to say, the effect of Cu addition on the strength is more beneficial than Ag. But there is no remarkable difference for the elongation comparing the alloy with Cu addition and Ag addition. On the other hand, the 0.2% proof stress and the ultimate tensile strength are the highest but the uniform tensile elongation is much lower, which is not shown in Figure 2.

Figure 3 is TEM bright-field images of each alloy aged to the peak hardness at 473K. The microstructure of the precipitates in alloys H, G and B is finer than the balance alloy. On the other hand, the needle-shaped precipitates are observed clearly on B alloy but not in G and H alloys.

Figure 4 shows HRTEM image of the precipitates in H alloys aged at 523K. Fig. 4 (a)-(d) show four typical precipitates in H alloys, i.e. (a)random-type precipitate, (b)parallelogram-type precipitate, (c)β''-phase and (d)β'-phase, which are also observed in the alloys. A different type of precipitate is observed in Cu addition alloy, which is described as Q'-phase.

4. Summary

The peak hardness has the tendency of the balance alloy<Ag-addition alloy (B)<(Cu+Ag) addition alloy (G, H)<Cu-addition alloy (E). The tendency of the tensile results are shown as follows: The proof Strength is the balance alloy<Ag-addition alloy (B)<(Cu+Ag)-addition alloy (H)<(Cu+Ag)-addition alloy (G)<Cu-addition alloy (E). U.T.S. is the balance alloy<Ag-addition alloy (B)< Cu+Ag) addition alloy (G, H)≈Cu-addition alloy (E). Elongation is the balance alloy<Cu-addition alloy (E)<(Cu+Ag) addition alloy(G)<Ag-addition alloy (B)<(Cu+Ag)-addition alloy (H). The number density of the precipitates becomes large with the tendency of the balance alloy, B alloy, G alloy and E alloy at 473K and the precipitates have different shape in the alloys with different chemical compositions according to the TEM images. Four typical types of precipitates, i.e. i.e. random-type precipitate, parallelogram-type precipitate, β''-phase and β'-phase are observed in the alloys without and with Cu or Ag addition. A different type of precipitate, Q'-phase, is observed in the alloy with Cu addition.

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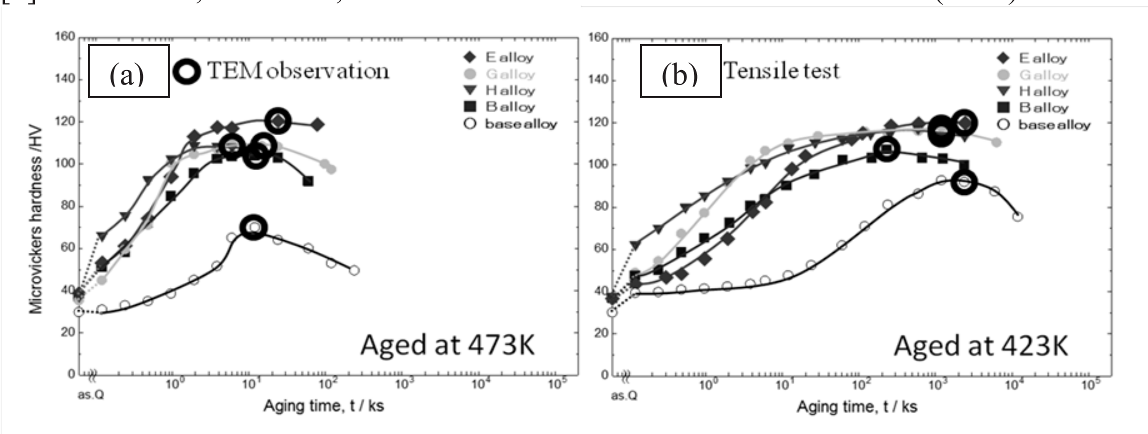

Fig. 1: Micro-Vickers hardness of different alloys aged at (a) 423K and (b) 473K.

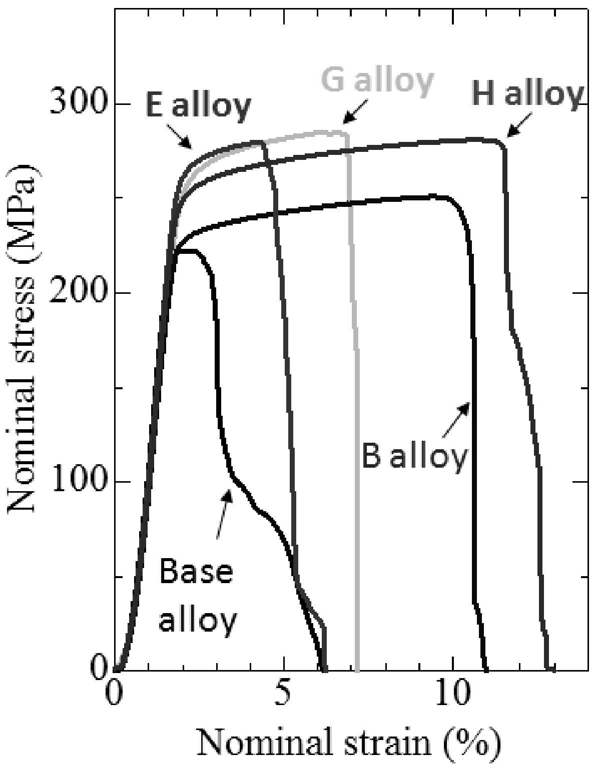

Fig. 2: Results of tensile test obtained for peak-aged base, B, E,G and H alloys.

	Alloy	element (at%)				
		Mg	Si	Cu	Ag	Al
	balance	0.7	0.35			bal.
A	0.14Ag	0.67	0.34		0.14	bal.
B	0.33Ag	0.67	0.35		0.33	bal.
C	0.69Ag	0.69	0.36		0.69	bal.
D	1.41Ag	0.72	0.36		1.4	bal.
E	0.35Cu	0.68	0.36	0.35		bal.
F	0.69Cu	0.68	0.35	0.69		bal.
G	0.29Cu–0.12Ag	0.66	0.35	0.29	0.12	bal.
H	0.11Cu–0.24Ag	0.74	0.33	0.11	0.24	bal.
I	0.34Cu–0.33Ag	0.68	0.36	0.34	0.33	bal.

Table 1: Chemical composition of alloys

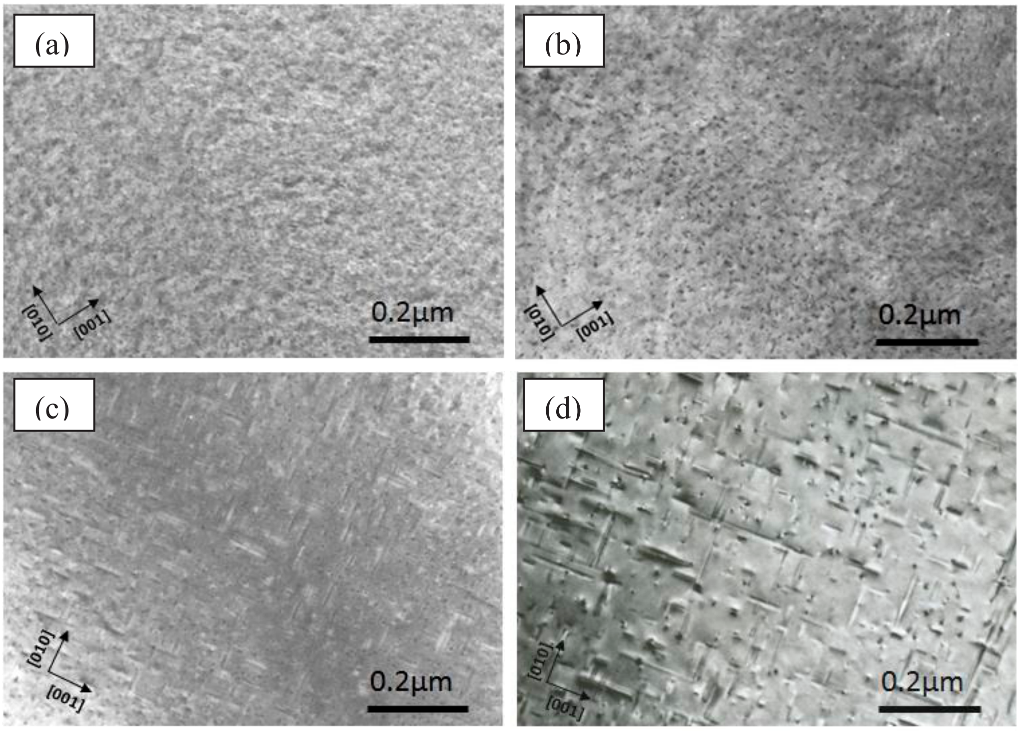

Fig. 3: TEM bright filed image of (a) H, (b) G, (c) B and (d) balanced alloy.

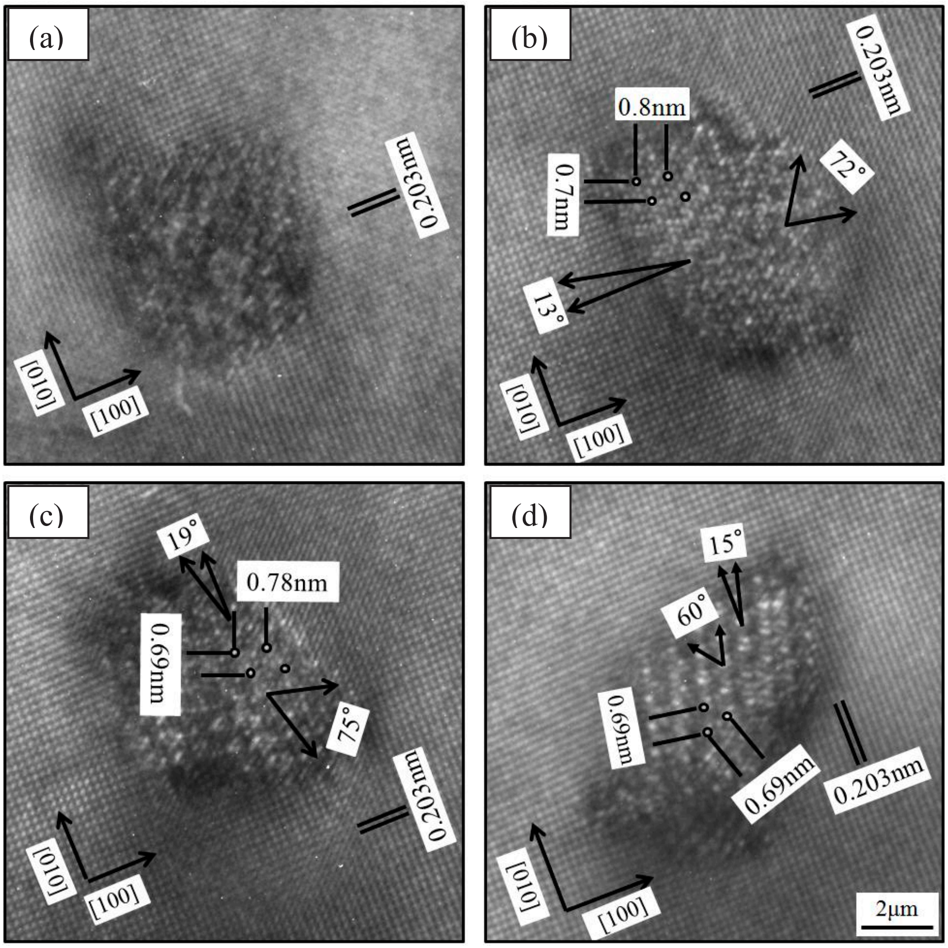

Fig. 4: HRTEM images of the precipitates: (a) random-type precipitate, (b) parallelogram-type precipitate, (c) β''-phase and (d) β'-phase.