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Variation of Aging Behavior for Al-Mg-Si Alloys with Different TMs Addition

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The transition metals such as chromium and manganese are usually added to 6000 series Al-Mg-Si alloys to control recrystallization and grain size and thus the properties of alloys. In Cr/Mn-addition alloys, Cr or Mn will expense Si to form the dispersoids as AlMnSi or AlCrSi and tend to decrease its aging effect. The aim of this work is to investigate the effect of transition metals (TMs) addition on the hardness and the microstructural features of Al-Mg-Si alloys. Al-Mg-Si alloys, which can be remarked as the quasi-binary alloys of Al-Mg_2Si, are prepared with Cr or Mn addition by laboratory casting. Some other transition metals, such as Co and Ni, are also added to Al-Mg-Si alloys. The grain size of four alloys decreases with TMs addition, which consequently increases the as-quenched hardness of the alloys comparing with that of the Al-Mg_2Si alloy without TMs addition. The difference between Cr/Mn-addition alloy and Co/Ni-addition alloy is that the dispersoids are formed in Co/Ni-addition alloy without expensing Si. Therefore, there is little effect on the aging effect of Si in Co/Ni-addition alloy.

Keywords: *transition metals, hardness, microstructural, Al-Mg_2Si, dispersoids.*

1. Introduction

In the continuing requirement for automobile weight reduction, the 6000 series Al-Mg-Si alloys has been considered as the promising candidates for age-hardenable bodysheet materials. Transitional metals (TMs) such as Cr, Fe and Mn, are usually added to Al-Mg-Si alloys for grain modification. But these transitional elements will easily form some dispersoids with the expense of Si. The variation of AlFeSi intermetallic phases has been investigated in details [1], and the effect of Cr and Fe addition on the age-hardening behavior of 6000 series alloys has been reported [2]. They indicated that the addition of (Cr+Fe) decreased peak hardness. And (Cr+Fe)-bearing alloys included AlSi(CrFe) and AlSiFe dispersoids, which had precipitate free zones around them, and the number density of precipitates decreased in those alloys. Laughlin et al. [3] reported an investigation of the effect of Mn content on the aging kinetics of Al alloys based on the 6022 composition and concluded that the Mn level had very little effect on the peak hardness which developed in the 6022 variants because there is some excess Si in 6022 alloy, comparing with the balanced alloy of Al-1.0%Mg_2Si. Effect of the small addition of Mn, Cr, Ni and Co on the tensile strength and electrical conductivity of Al-Mg-Si ternary alloy has also been investigated [4].The variation of aging behavior and microstructure for the alloys with Mn or Cr addition, especially with Co or Ni addition has not been studied in details, though G. Gustafsson et al. [5] and M.Mahta et al. [6] have reported on how the undesirable effect of β-Al_5FeSi-needles could be neutralized by adding small amounts of Cr and Co.

The aim of this work is to focus on the different aging behavior of the alloys with different TMs addition, such as Cr, Mn, Co and Ni. Vickers hardness test and transmission electron microscopy (TEM) are used to determine these properties of Al-Mg-Si alloys with TMs addition.

2. Experimental

The TMs-addition alloys (at.%) of Al-1.06Mg_2Si-0.2Cr, Al-1.06Mg_2Si-0.25Mn, Al-1.06Mg_2Si-0.2Co, and Al-1.06Mg_2Si-0.2Ni were prepared by laboratory casting. It was melting in air using

99.99mass% pure Al, 99.9mass% pure Mg, 99.9mass% pure Si, and 99.9mass% pure TM. The composition analysis of the obtained alloy is given in Table 1.
Vickers hardness was measured using Akashi MVK-EII hardness tester (load: 0.98N, holding time: 15s). The hardness values reported here represent the average of at least ten measurements. TEM observations were performed using Topcon EM-002B equipped with an energy dispersive X-ray spectroscopy (EDS). The accelerating voltage was 120kV. All samples were solution heat treated at 848K for 3.6ks in a circulating air furnace, cold water quenched, and followed by the artificial aging treatments at 473K for different periods of time.

3. **Results and discussions**

The base alloy of Al-1.0mass%Mg_2Si without TM addition, which is prepared in the same condition [2], was taken for compare in this work.
Fig. 1 shows the optical micrographs of five alloys. The mean grain size is calculated as 649μm, 106μm, 40μm, 95μm and 257μm for the base, Cr-, Mn-, Co- and Ni-bearing alloys, respectively. The addition of TMs decreases the grain size. And Mn has the best grain modification comparing the other three additional alloys.
Fig. 2 shows the variation of Vickers hardness curves of five alloys aged at 473K, which is plotted as a function of aging time. The as-quenched hardness of the alloys with TMs addition is increased because of the grain modification of TMs. The peak hardness has the sequence of Ni-bearing alloy>Co-bearing alloy>base alloy>Cr-bearing alloy>Mn-bearing alloy.
TEM images are taken for five alloys peak-aged at 473K, which are indicated in Fig. 3. There are only needle-shaped precipitates aligning with $<100>_{Al}$ direction. The number density of the precipitates is counted as 157μm^{-2}, 247μm^{-2}, 34μm^{-2}, 261μm^{-2} and 369μm^{-2}.
On the other hand, TMs (such as Mn, Fe and Cr) usually expense Si to form the dispersoids of Al(TM)Si with the size much bigger than the precipitates. The dispersoids formed with TMs are observed in four TM-addition alloys, as shown with Fig. 4 (a)-(d). And the corresponding EDS profiles are shown in Fig. 5 (a)-(d). It can be seen that, there is some Si in the dispersoids formed in Cr- and Mn-bearing alloys but there is no Si in the dispersoids formed in Co- and Ni-bearing alloys. The expense of Si for the formation of the dispersoids will decrease the micro Vickers hardness of Cr- and Mn-bearing alloy.

4. **Conclusions**

The grain size decreases for four alloys in this work, which is attributed to the grain modification effect of TMs. The decrease of the grains further increases the as-quenched hardness of four alloys.
The fine precipitates are observed in Cr-, Co- and Ni-bearing alloys peak-aged at 473K with a higher number density, which results in the increase of the peak hardness. The expense of Si for the formation of the dispersoids, however, decreases the peak hardness of Cr-bearing alloy. The coarsen precipitates with a lower number density, and the further expense of Si for the formation of the dispersoids result in the lowest peak hardness of Mn-bearing alloy in five alloys.

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Table 1 Composition analysis result of the alloys used in this work (at.%).

samples	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ni	Co	Al
Cr-addition alloy	0.72	0.36	<0.01	<0.01	<0.01	0.19	<0.01	0.00	0.00	bal.
Mn-addition alloy	0.75	0.31	<0.01	<0.01	0.24	<0.01	<0.01	0.00	0.00	bal.
Co-addition alloy	0.71	0.36	<0.01	<0.01	<0.01	0.00	<0.01	0.18	0.00	bal.
Ni-addition alloy	0.69	0.33	<0.01	<0.01	<0.01	0.00	<0.01	0.00	0.18	bal.

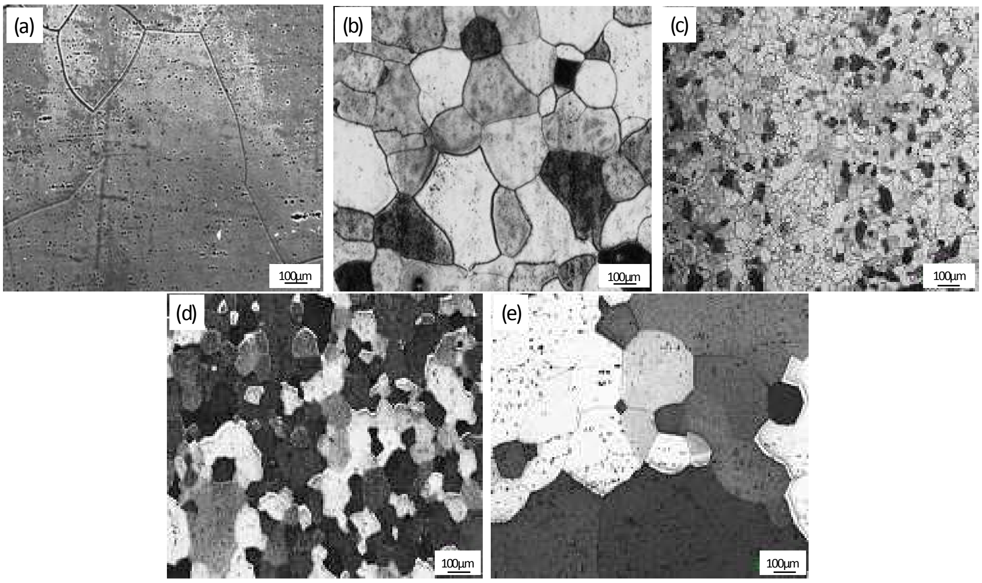

Fig. 1 Optical micrographs of (a) base alloy, (b) Cr-bearing alloy, (c) Mn-bearing alloy, (d) Co-bearing alloy and (e) Ni-bearing alloy.

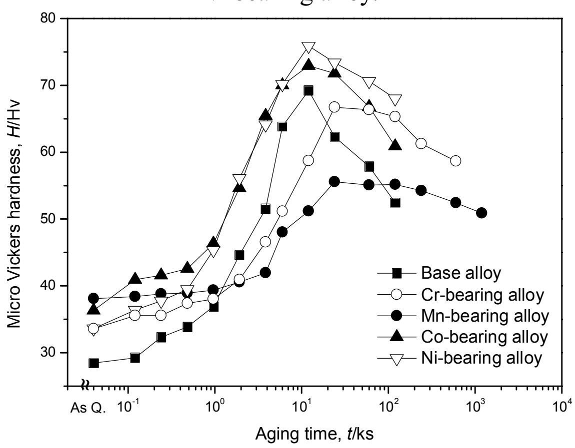

Fig. 2 Micro Vickers hardness curve of five alloys.

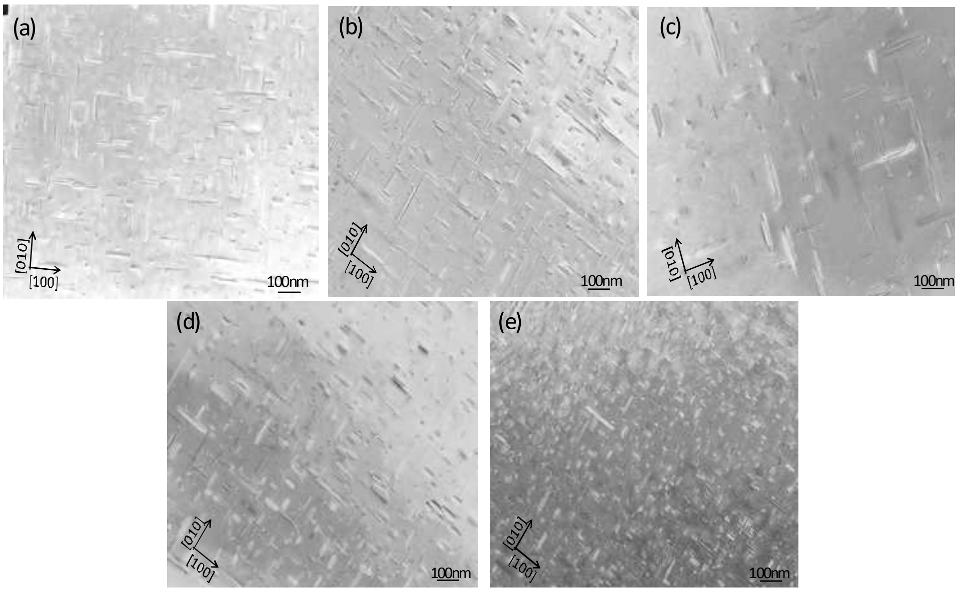

Fig. 3 TEM bright-field images of (a) base alloy, (b) Cr-bearing alloy, (c) Mn-bearing alloy, (d) Co-bearing alloy and (e) Ni-bearing alloy.

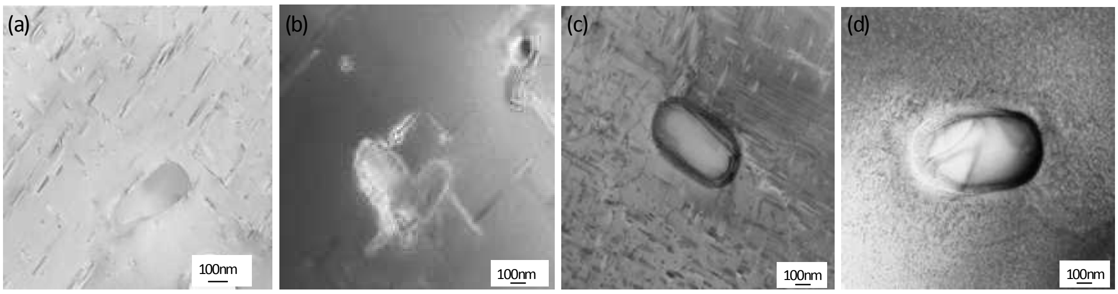

Fig. 4 TEM images of the dispersoids formed in (a) Cr-bearing alloy, (b) Mn-bearing alloy, (c) Co-bearing alloy and (d) Ni-bearing alloy.

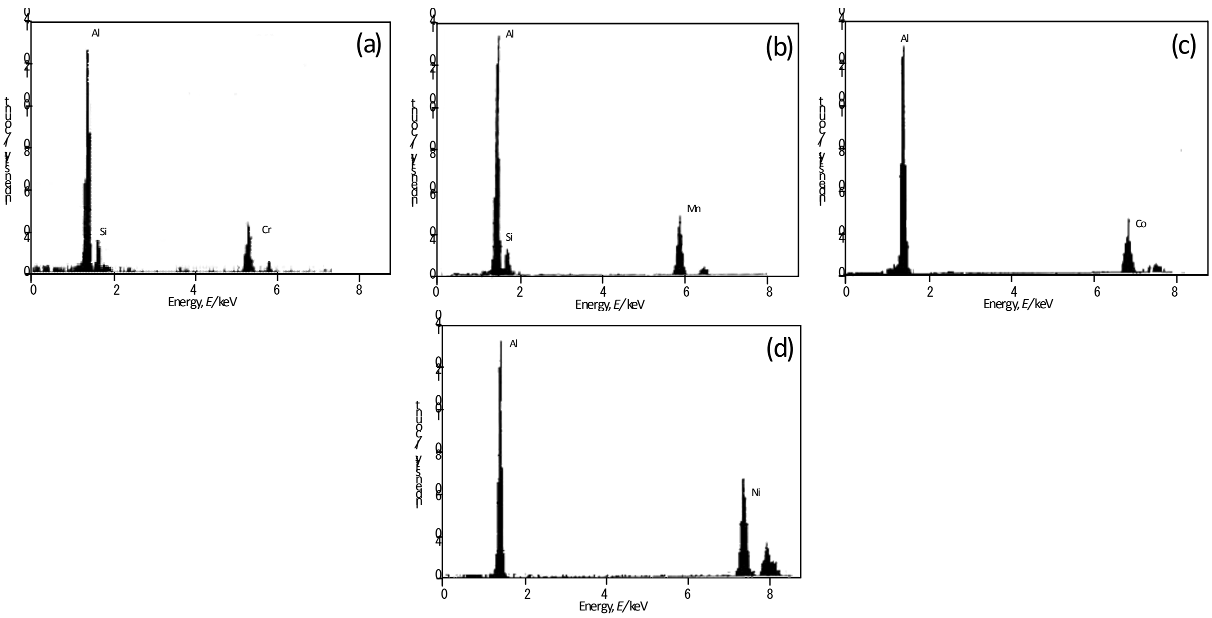

Fig. 5 EDS profiles of the dispersoids formed in (a) Cr-bearing alloy, (b) Mn-bearing alloy, (c) Co-bearing alloy and (d) Ni-bearing alloy.