EFFECT OF PREDEFORMATION AND EXCESS SILICON CONTENTS ON PRECIPITATION IN Al-Mg_2Si ALLOYS

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Abstract

The effect of predeformation on age-hardening in Al-Mg_2Si alloys and Al-Mg_2Si-0.4mass%Si alloys containing several Mg_2Si content were investigated by hardness measurement and transmission electron microscope. The maximum hardness of predeformed Al-Mg_2Si alloys containing Mg_2Si less than 0.8% and also predeformed Al-0.4%Mg_2Si-0.4%Si alloy increased with increasing amount of predeformation. The precipitates of predeformed specimens became finer and denser than those of non-predeformed ones. And the precipitate having elongate shaped cross section was existed in predeformed specimens.

Introduction

It had been well known that Al-Mg_2Si alloys can be improved their own mechanical properties by combination of deformation and thermal treatment(TMT)[1]. The previous studies about TMT in this alloy[2] were almost performed using 6000 series commercial alloys. Then chemical compositions of alloys were complex and also the condition of TMT were complicated. These factors form barriers for systematic understanding of the effect of TMT on age-hardening in this alloy system.
In this study, the effect of predeformation after solution heat treatment on age-hardening in Al-Mg_2Si alloys and Al-Mg_2Si-0.4mass%Si alloys containing various Mg_2Si contents were investigated by hardness measurement and transmission electron microscope(TEM) observation. In addition, the HRTEM(high resolution electron microscope) images of precipitates in predeformed Al-Mg_2Si alloys were compared with those of non-predeformed Al-Mg_2Si alloys.

Experimental

Al-Mg_2Si alloys (balanced alloys) and Al-Mg_2Si-0.4%Si alloy (excess Si alloys) were prepared using 99.99% aluminum, 99.9% magnesium and 99.9% silicon. Table 1 shows the chemical composition of alloys. The ingot was formed into sheets by hot and cold rolling. This sheet was solution heat treated at 848K for 3.6ks. Predeformation prior to aging was provided by 1 ~60% cold-rolling and it required for 10 minutes. Aging treatment after predeformation was at 473K in an oil bath. The hardness was measured by a Vickers micro hardness tester (MVK-EII, AKASHI Seisakusho,LTD.) at load of 0.98N (100gf) for 15 seconds. Thin specimens for TEM were made by the electrolytic polishing method. A HRTEM was used a EM-002B type (TOPCON,Co.Ltd.) operating at 200 kV.

Table 1. Chemical composition of alloys. (mass%)

Alloy	Mg	Si	Al	Mg_2Si	excess Si
0.4%Mg_2Si	0.27	0.16	bal.	0.43	----
0.6%Mg_2Si	0.37	0.21	bal.	0.58	----
0.8%Mg_2Si	0.50	0.28	bal.	0.78	----
1.0%Mg_2Si	0.58	0.35	bal.	0.91	----
1.6%Mg_2Si	1.00	0.58	bal.	1.58	----
0.4%Mg_2Si-0.4%Si	0.23	0.54	bal.	0.36	0.41
0.6%Mg_2Si-0.4%Si	0.37	0.62	bal.	0.58	0.40
0.8%Mg_2Si-0.4%Si	0.49	0.72	bal.	0.77	0.43
1.0%Mg_2Si-0.4%Si	0.59	0.76	bal.	0.92	0.42

Results and discussion

Hardness measurement

Figures 1(a) and 1(b) show the age-hardening curves of the balanced alloys and the excess Si alloys respectively. The hardness in each alloy increases with increasing aging time up to a peak value and then decreases monotonously. The higher maximum hardness value could be obtained from higher Mg_2Si content alloys. Conversely, the time to maximum hardness degreases with increasing Mg_2Si content. The maximum hardness of excess Si alloys are higher than that of balanced alloys containing the same Mg_2Si contents.

Figure 2 show age-hardening curves of 5% predeformed alloys after solution heat treatment. When comparing Figures 1(a) with Figure 2(a), the maximum hardness in predeformed balanced alloys containing Mg_2Si less than 0.8% are higher than the maximum hardness of non-predeformed alloys. Whereas the maximum hardness in balanced alloys containing Mg_2Si more than 1.0% are nearly equal to non-predeformed alloys ones. In the case of excess Si alloys, the maximum hardness in predeformed specimen containing 0.4%Mg_2Si is higher than that of non-predeformed specimen. While the maximum hardness in excess Si alloys containing Mg_2Si more than 0.6% are almost similar value to non-predeformed specimens as shown in Figures 1(b) and 2(b).

Figure 3 shows the effect of amount of predeformation on the age-hardening curves in the both of the balanced alloy and the excess Si alloy containing 0.8%Mg_2Si. The maximum hardness increases with increasing amount of predeformation, on the contrary, the time to maximum hardness decreases with increasing amount of predeformation as shown in Figure 3(a). Similar result was obtained on the balanced alloys containing 0.4% and 0.6%Mg_2Si and on the excess Si alloy containing 0.4%Mg_2Si. As shown in Figure 3(b), the maximum hardness dose not varied but the time to maximum hardness decreases with increasing amount of predeformation. Similar tendency was appeared on the balanced alloys containing 1.0% and 1.6% Mg_2Si, and on the excess Si alloys containing 0.6% and 1.0%Mg_2Si.

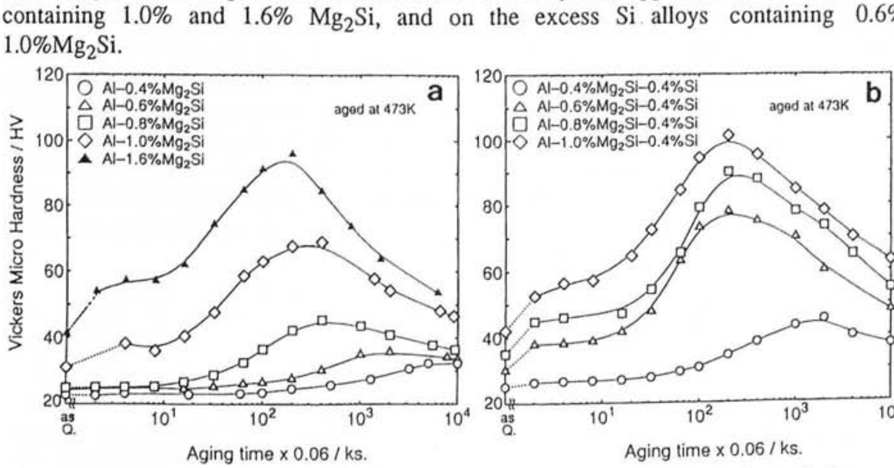

Figure 1. Changes in Vickers micro-hardness with aging time. (a) the balanced alloys and (b) the excess Si alloys.

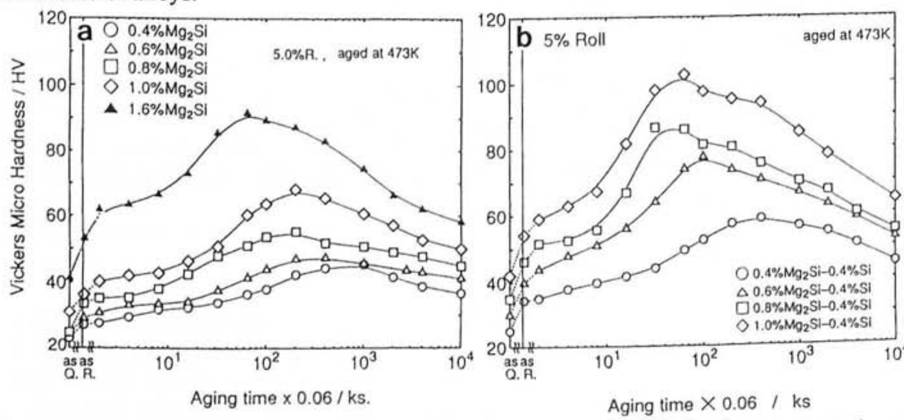

Figure 2. Age-hardening curves of 5% predeformed alloys after solution heat treatment. (a) the balanced alloys, (b) the excess Si alloys.

TEM observation

Figures 4(a)$\sim$4(d) show the bright field images of aged balanced alloys with predeformation up to 10% and Figures 4(e)$\sim$4(h) show images of same alloys without predeformation. It can be seen a tendency that the rod-shaped precipitates become finer with increasing Mg_2Si content. A particle marked by an arrow in Figure 4(a) is an equilibrium phase (Mg_2Si). It is noted that the precipitates in predeformed specimens are finer and denser than those of non-predeformed specimens as compared Figures 4(e) and 4(f) with Figures 4(a) and 4(b). Contrary to above results, the precipitates in predeformed specimens are coarser than those of non-predeformed specimens as compared Figure 4(g) and 4(h) with Figures 4(c) and 4(d).

Figures 5(a)～5(d) show bright field images of aged excess Si alloys with predeformation up to 5% and Figures 5(e)～5(h) are images of the same alloys without predeformation. Obviously, the rod-shaped precipitates in excess Si alloys containing 0.4%Mg_2Si are coarser than those of excess Si alloys containing Mg_2Si more than 0.6% as shown in Figures 5(a) ~ 5(d). The Si precipitates could be seen at some area in the excess Si alloy containing 0.4%Mg_2Si. When comparing Figure 5(e) with Figure 5(a), the precipitates in the predeformed specimen are finer and denser than that of the non-deformed specimen. While, the precipitates in predeformed specimens are coarser than those of non-deformed specimens when comparing Figures 5(f), 5(g) and 5(h) with Figures 5(b), 5(c) and 5(d). Thus, the changes of maximum hardness of each aged alloys (as shown in Figures 1 and 2) with predeformation may be caused by the changes of the number, size and distribution of precipitates.

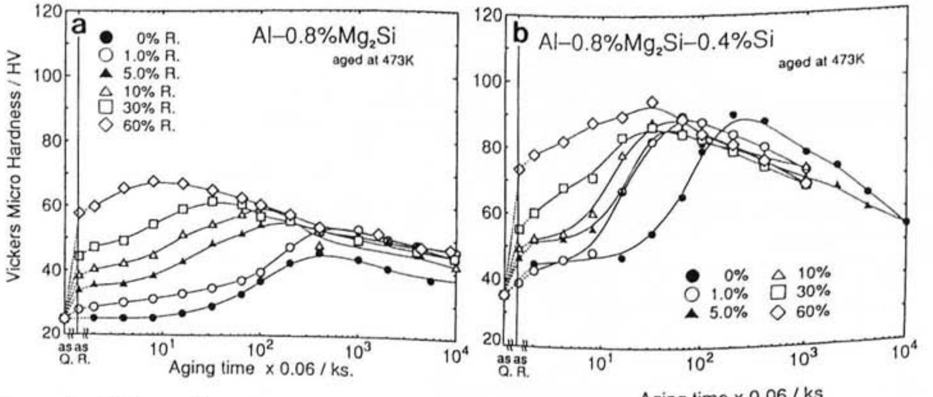

Figure 3. Effects of amount of predeformation on the age-hardening curves in both of the balanced and the excess Si alloys containing 0.8%Mg_2Si.

HRTEM Observation

Figure 6(b) shows an enlarged photograph of an area indicated by a rectangle in Figure 6(a) in the predeformed (10%) balanced alloy containing 1.0%Mg_2Si. Precipitates marked by arrows can be seen along a dislocation line. Size of these precipitates are clearly smaller than the rod-shaped precipitates along <100> matrix direction as shown in Figure 6(a). Typical high resolution image of such characteristic precipitate is shown in Figure 6(c). The precipitate has an elongate feature and white dots in it arrange a parallelogram. The size of two sides of the parallelogram are about 0.9nm and 0.4nm. An angle between its elongated direction and <100> matrix direction is about 10 degrees. We call this the "elongate-shaped precipitate" hereafter. The outline and arrangement of bright dots in a high resolution image of the elongate-shaped precipitate are clearly different from those of the cross-section of the rod-shaped precipitate that existed dominantly in the non-predeformed Al-1.0%Mg_2Si alloy in our previous report [3]. We call this (conventional rod-shaped precipitate) the "normal hexagon" hereafter. The normal hexagon simultaneously exists together with the elongate-shaped precipitate in the predeformed specimen as shown in Figure 6(b) indicated by a double arrow. The relative frequency of number of normal hexagon among all precipitate in unit area was always more than 50%. Each number of two kinds of precipitates in balanced alloys was plotted for Mg_2Si contents in Figure 7. The number of elongate-shaped precipitates tends to increases with increasing Mg_2Si contents and is not affected amount of predeformation. The number of normal hexagons increases with increasing amount of predeformation in balanced alloys containing low Mg_2Si, while that of high Mg_2Si alloys decreases extremely. From these result, it must be considered that the number of the normal hexagon is a controlling factor on age-hardening in the predeformed balanced alloys. In the excess Si alloys, the elongate-shaped precipitate was observed, too. But it can not identify whether the elongate-shaped precipitate in the excess Si alloys is the same as that of balanced alloys or not. Because the precipitates that have different features on their high resolution images existed simultaneously in the excess Si alloys[4]. We need further observation about precipitates in predeformed excess Si alloys.

Conclusions

The effects of predeformation on age-hardening in Al-Mg_2Si alloys and Al-Mg_2Si-0.4mass%Si alloys containing several Mg_2Si contents were investigated by hardness measurement and transmission electron microscope observation.

(1) The maximum hardness in all alloys aged at 473K increases with increasing Mg_2Si contents. At the same time, the shorter time needs to reach at the maximum hardness in alloys containing higher Mg_2Si contents. The times to maximum hardness in all alloys predeformed after solution heat treatment were shorter than those in all alloys without predeformation. The maximum hardness in both of the predeformed Al-Mg_2Si alloys containing Mg_2Si less than 0.8% and the predeformed Al-0.4%Mg_2Si-0.4%Si alloy increased with increasing amount of predeformation. The maximum hardness in the predeformed Al-Mg_2Si alloys containing 1.0% and 1.6%Mg_2Si and the predeformed Al-Mg_2Si-0.4%Si alloys containing Mg_2Si more than 0.6% were similar to those of the non-predeformed alloys.

(2) Precipitates in the predeformed Al-Mg_2Si alloys containing Mg_2Si less than 0.8% and predeformed Al-0.4%Mg_2Si-0.4%Si alloy were finer and denser than those of non-predeformed alloys. While precipitates in the predeformed Al-Mg_2Si alloys containing 1.0% and 1.6%Mg_2Si and the predeformed Al-Mg_2Si-0.4%Si alloys containing Mg_2Si more than 0.6% tend to coarser as compared with those of non-predeformed alloys.

(3) The elongate-shaped precipitates were existed along a dislocation line in the predeformed Al-Mg_2Si alloys. These may be the cross-sections of rod-shaped precipitates that differ from the conventional rod-shaped precipitates in this alloy system. The number of this precipitate increased with increasing Mg_2Si contents and were independent on the amount of predeformation.

References

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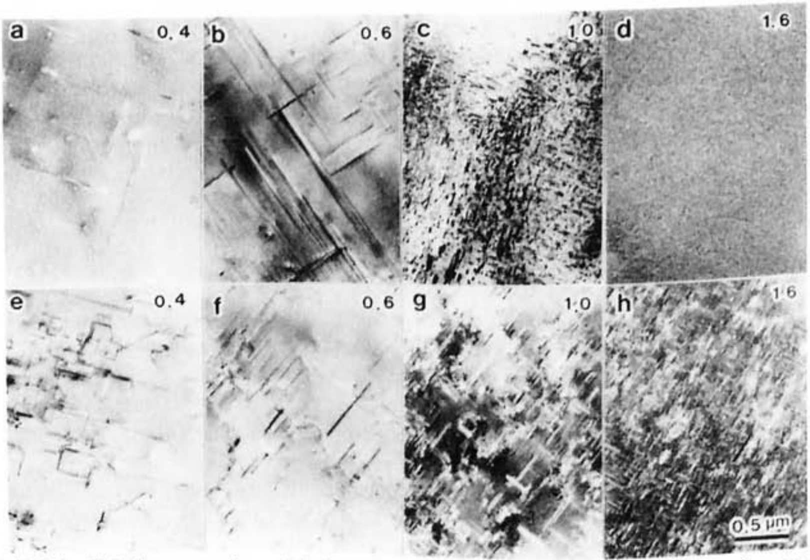

Figure 4. Bright field images of aged balanced alloys. (a) ~ (d) with predeformation up to 10%, (e) ~ (h) without predeformation.

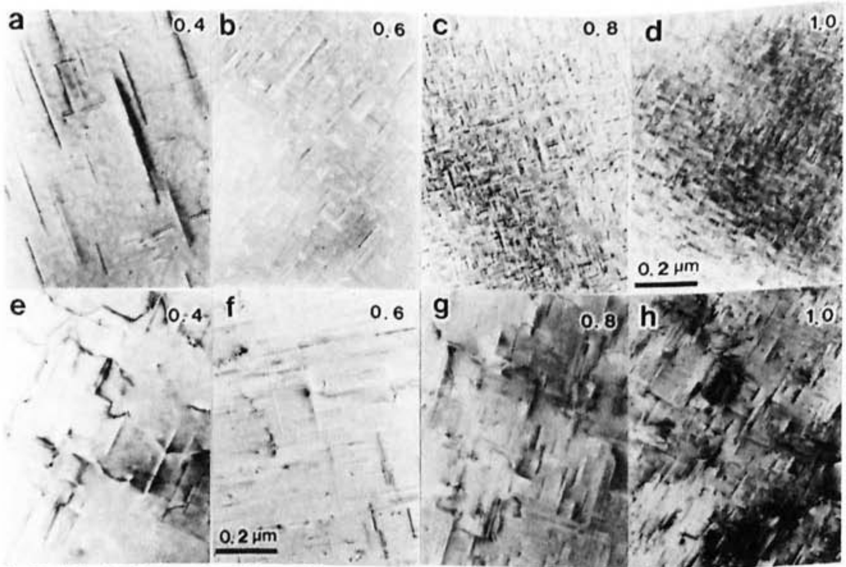

Figure 5. Bright field images of aged balanced alloys. (a) ~ (d) with predeformation up to 5%, (e) ~ (h) without predeformation.

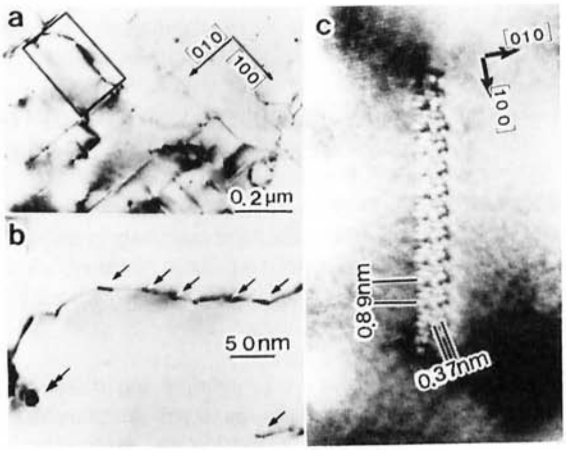

Figure 6. (a) Bright field image of the 10% predeformed balanced alloy containing 1.0%Mg_2Si, (b) an enlarged photograph of an area indicated a rectangle in (a), (c) a typical high resolution image of a characteristic precipitate. We call this the elongate-shaped precipitate.

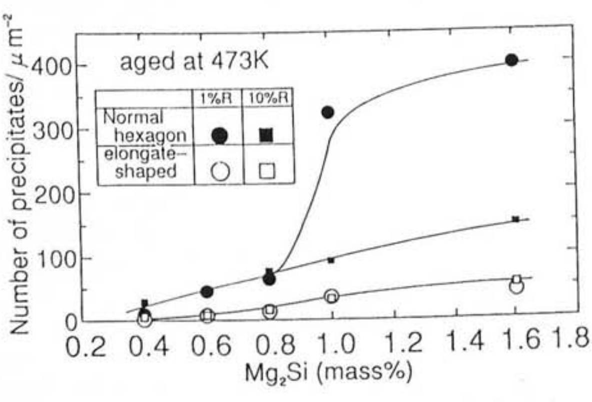

Figure 7. Changes in the number of two kinds of precipitates in the balanced alloys with Mg_2Si contents. Symbols (●, ■) indicate results of the normal hexagons in the predeformed specimens up to 1% and 10%, respectively. Symbols (○, □) indicate the results of the elongate-shaped precipitates in the predeformed specimens up to 1% and 10%, respectively.