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Effects of aging on the microstructures and mechanical properties of extruded AM50 + *x*Ca magnesium alloys

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Abstract: The effects of aging treatment on the microstructures and mechanical properties of extruded AM50 + *x*Ca alloys (x = 0, 1, 2 wt.%) were studied. The results indicated the secondary phase $Mg_{17}Al_{12}$ precipitated from the saturated α-Mg solid solution while Al_2Ca changed slightly when the aging time was increased. The hardness of extruded AM50 + *x*Ca alloys increased initially to its peak, and then dropped to reach its original hardness with the increase in aging time. With the increase in aging temperature, the hardness of the AM50 + 2Ca alloy decreased, whereas the hardness of AM50 and AM50 + 1Ca alloys decreased in the initial stages of aging treatment and increased in the later stages of aging treatment. The tensile strengths of AM50 and AM50 + 1Ca alloys increased after aging treatment for the precipitation of $Mg_{17}Al_{12}$ phase, which increases the resistance against dislocation movement at the grain boundary; with increase in aging temperature, their tensile strengths increased. For AM50 + 2Ca alloy, the tensile strength declined after aging at 150°C and 175°C, while it increased slightly at 200°C. The ductility of AM50 + *x*Ca alloys (x = 0, 1, 2 wt.%) declined after aging treatment.

Key words: AM50 + *x*Ca alloys; aging; extrusion; mechanical properties

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1. Introduction

The magnesium alloy, as the lightest structural metal, has been widely used in electronics and aerospace industries [1] owing to its desirable properties. However, magnesium alloys have not been widely used in automobiles so far due to their poor elevated-temperature properties and poor creep resistance. The characteristics of magnesium alloys also restrict their application as a light structural material. The research indicated that wrought magnesium alloys has higher strength, better elongation and other mechanical properties than those of as-cast magnesium alloys [2]; Ca can increase the elevated-temperature strength and creep resistance of Mg-Al series magnesium alloys [3-4]; aging treatment can improve the microstructure and mechanical properties [5]. However, there are only a few studies on wrought magnesium alloys and few reports about the effect of aging treatment and calcium on wrought magnesium alloys. In this article, the effect of aging treatment on the microstructure and mechanical properties of extruded AM50 + *x*Ca (x = 0, 1, 2 wt.%) has been investigated.

2. Experimental

The AM50 + *x*Ca (x = 0, 1, 2 wt.%) magnesium alloys studied here were smelted from commercial AM50 and calcium, and their compositions are

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listed in Table 1. These alloys were melted under $SF_6 + CO_2$ atmosphere in an electronic resistance furnace and poured into a metal mold. The tensile samples were machined from the as-extruded material. Before extruding, all the specimens were heated to 410°C and held for 30 min. The extruded process is as follows: first, extrusion was performed at a mold temperature of 400°C and the extrusion rate was 9:1 (ϕ60 mm to ϕ20 mm); second, the as-extruded ϕ20 mm bar was held at 410°C for 30 min, then extrusion was performed at a mold temperature of 315°C and the extrusion rate was 16:1 (ϕ20 mm to 2 mm × 10 mm). After extrusion, the extruded specimens were solution-treated at 415°C for 20 h and air-cooled. Then the samples were aging-treated at temperatures of 150°C, 175°C, and 200°C for 0.5-24 h. Tensile samples were machined along the extruded direction of the sheets. The microstructure was observed using optical microscopy (LEICA MEF4M). The tensile specimens were tested on the universal test machine (SHIMADZU AG100Kn A). The hardness was tested on a microhardness tester (HX-500), the experimental load was 19.6 N, and the holding time was 15 s.

Table 1. Composition of the studied alloys wt.%

Alloy	Al	Mn	Ca
AM50	4.33	0.36	—
AM50 + 1Ca	4.33	0.35	1.23
AM50 + 2Ca	4.33	0.33	2.33

3. Results and discussion

3.1. Microstructures

The microstructure of the as-extruded AM50 alloy consists of α-Mg and $Mg_{17}Al_{12}$. As shown in Fig. 1(a), some $Mg_{17}Al_{12}$ surrounds the primary Mg, and the others distribute along the extruded direction.

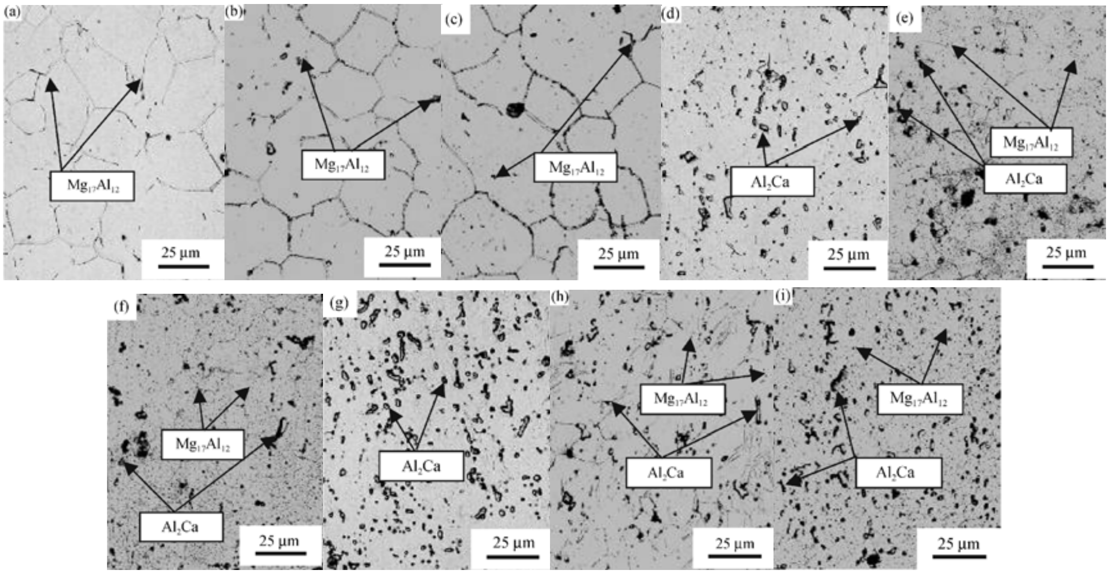

Fig. 1. Effect of aging treatment on the microstructure of extruded AM50 +x Ca alloys: (a) AM50, T4 (415°C and 24 h); (b) AM50, T6 (175°C and 1 h); (c) AM50, T6 (175°C and 24 h); (d) AM50 + 1Ca, T4 (415°C and 24 h); (e) AM50 + 1Ca, T6 (175°C and 1 h); (f) AM50 + 1Ca, T6 (175°C and 24 h); (g) AM50 + 2Ca, T4 (415°C and 24 h); (h) AM50 + 2Ca, T6 (175°C and 1 h); (i) AM50 + 2Ca, T6 (175°C and 24 h).

When Ca is added to the AM50 alloy, the number of $Mg_{17}Al_{12}$ becomes fewer, the grain size decreases remarkably, and intermetallics Al_2Ca is found as shown in Figs. 1(d) and 1(g). To show the evolution of microstructure of AM50 + *x*Ca alloys in the course of aging treatment, the samples aging-treated at 175°C are taken as examples. As shown in Figs. 1(a-c, d-f), with the increase in aging time, $Mg_{17}Al_{12}$ phase is precipitated from the saturated α-Mg solid solution, whereas Al_2Ca phase is rather stable, which changes only slightly during aging treatment. Besides, with the increase in Ca content, the grains refine and the content of Al_2Ca phase increases.

3.2. Mechanical properties

3.2.1. Hardness

Fig. 2 shows the effect of aging at different temperatures on the hardness of extruded AM50 + *x*Ca alloys. For aging time $t < 1$ h, the hardness increases sharply to reach its peak during the continuous precipitation of second phase; for $t > 1$ h, the hardness decreases because the pattern of precipitation of the second phase changed as the aging treatment continued. As the aging time increased, the unstable second phase transformed from the metastable phase to steady phase, which leads to the decline of hardness. For the AM50 + 2Ca alloy, the hardness decreases with the aging-treatment temperature. For the AM50 + 1Ca and AM50 + 2Ca alloys, the hardness decreases in the initial stages of aging treatment and increases in the later stages of aging treatment.

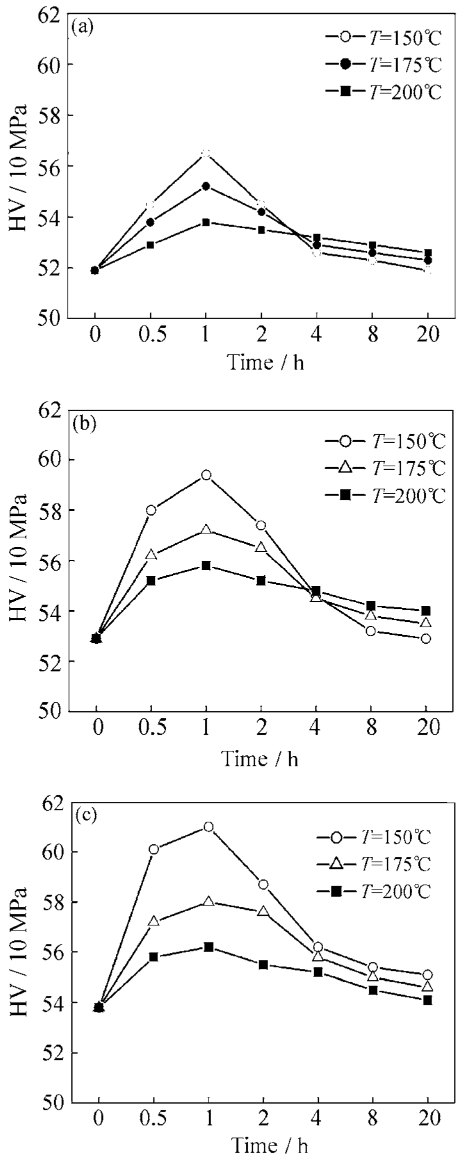

Fig. 2. Effect of aging treatment on the hardness of extruded AM50 + *x*Ca magnesium alloys: (a) AM50; (b) AM50 + 1Ca; (c) AM50 + 2Ca.

3.2.2. Tensile properties

Fig.3 shows the effect of aging treatment on the tensile strength of the extruded AM50 + *x*Ca alloys. After aging treatment, $Mg_{17}Al_{12}$ phase precipitates from the α-Mg solid solution; however, the Al_2Ca phase changes slightly. For the AM50 and AM50 + 1Ca alloys, $Mg_{17}Al_{12}$ phase is precipitated in aging treatment, which can resist dislocation movement at the grain boundary and increase the tensile strength of the alloys. For the AM50 + 2Ca alloy, the second phase is mainly Al_2Ca phase and no $Mg_{17}Al_{12}$ phase is precipitated. Therefore, the tensile strength declines after aging at 150°C and 175°C, while it increases slightly at 200°C.

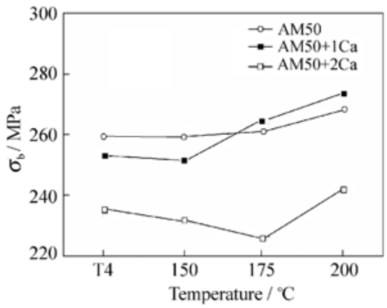

Fig. 3. Effect on aging treatment on the tensile strength of extruded AM50 + *x*Ca alloys.

Fig. 4 shows the effect of aging treatment on the elongation of the extruded AM50 + *x*Ca alloys. After aging treatment, the elongation declines. Besides, with the increase in Ca content, the elongation of AM50 + *x*Ca alloys decreases, for Ca reduces the ductility of the alloys.

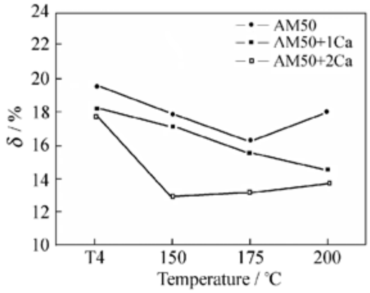

Fig. 4. Effect on aging treatment on the elongation of extruded AM50 + *x*Ca alloys.

3.3. Tensile fractographs

Fig. 5 shows tensile fractographs of the extruded AM50 + *x*Ca alloys at room temperature after aging treatment at various temperatures. The fractographs display abundant river-like patterns formed by cleavage facets and cleavage steps, which shows that the ductility of alloys is poor and fracture mode is mainly transcrystalline crack. In local areas of the fractographs, some tearing edges can be seen which indicates that quasi-cleavage cracks exist in local areas.

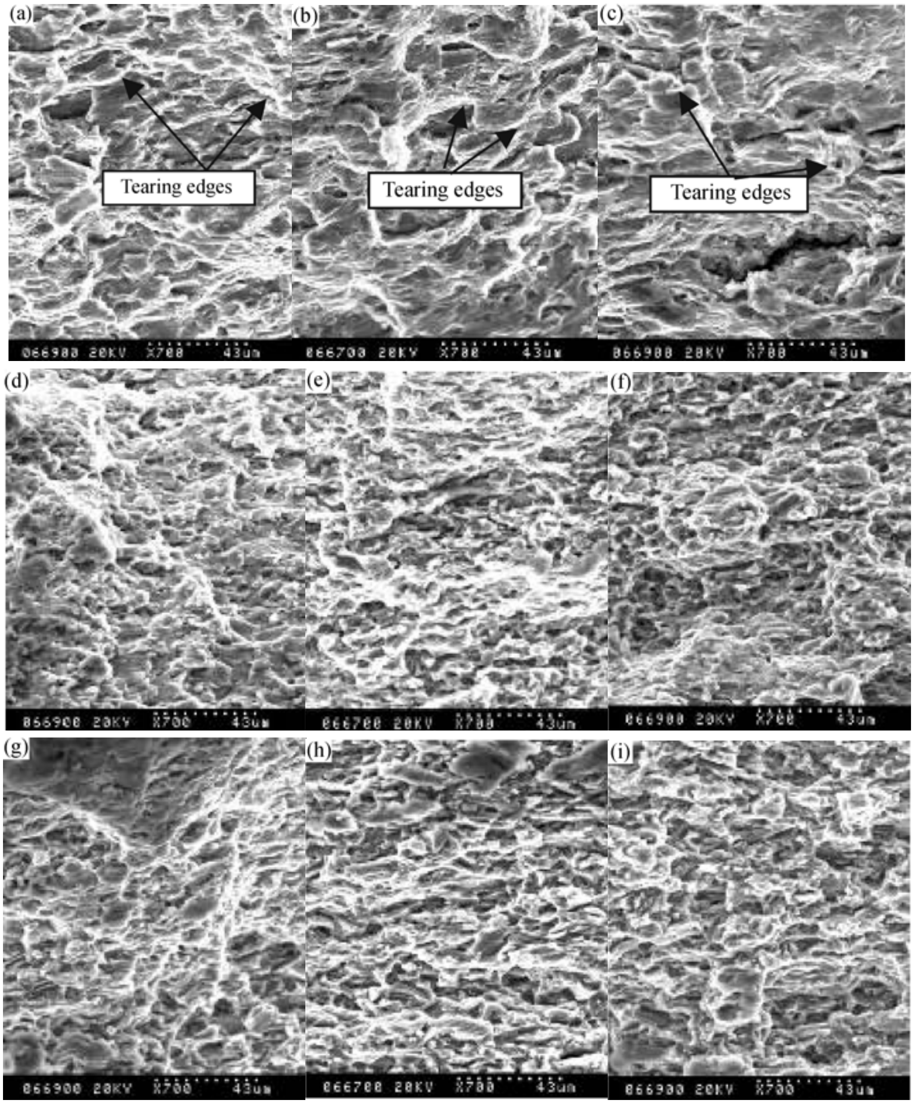

Fig. 5. Fracture surface SEM of extruded AM50 + *x*Ca alloys after aging treatment: (a) AM50, T6 (150°C × 20 h); (b) AM50, T6 (175°C × 20 h); (c) AM50, T6 (200°C × 20 h); (d) AM50 + 1Ca, T6 (150°C × 20 h); (e) AM50 + 1Ca, T6 (175°C × 20 h); (f) AM50 + 1Ca, T6 (200°C × 20 h); (g) AM50 + 2Ca, T6 (150°C × 20 h); (h) AM50 + 2Ca, T6 (175°C × 20 h); (i) AM50 + 2Ca, T6 (200°C × 20 h).

After aging treatment, few tearing edges can be observed. So the ductility of the extruded AM50 + *x*Ca alloys decreases after aging treatment.

4. Conclusions

(1) With the increase in aging time, $Mg_{17}Al_{12}$ is precipitated from the saturated solid solution, whereas Al_2Ca is rather stable and changes slightly.

(2) In the initial stage of aging treatment, the hardness of the extruded AM50 + *x*Ca alloys increases sharply to reach its peak, then drops to its original hardness in the later stages of aging treatment. For the AM50 + 2Ca alloy, the hardness decreased with the increase in aging-treatment temperature. For the AM50 + 1Ca and AM50 + 2Ca alloys, the hardness decreased in the initial stages of aging treatment and increased in the later stages of aging treatment.

(3) For the AM50 and AM50 + 1Ca alloys, the tensile strength increases after aging treatment for the precipitation of $Mg_{17}Al_{12}$ phase and the tensile strength increases with the increase in aging temperature. For the AM50 + 2Ca alloy, the tensile strength declines after aging at 150°C and 175°C, while it increases slightly at 200°C. The ductility of all the alloys declines after aging treatment.

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