

Enhanced and accelerated age hardening response of Al-5.2Mg-0.45Cu (wt%) alloy with Zn addition



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ABSTRACT

The age hardening responses of the Al-5.2Mg-0.45Cu alloy with Zn addition have been investigated in this study. It is found that the age hardening process of the Zn-containing Al-5.2Mg-0.45Cu alloys can be divided into four stages, namely the initial jump(I), the linear increase (II), the accelerated increase to the peak (III) and the overage (IV). The addition of Zn to the Al-5.2Mg-0.45Cu alloy leads to an enhanced and accelerated age-hardening response in two aspects: firstly introducing the T-[Mg₃₂(Al, Zn)₄₉] phase resulting from the high Mg/Zn ratio and relatively high aging temperature; secondly stimulating the precipitation of the Guinier-Preston-Bagaryatsky (GPB) zones by increasing the supersaturation upon quenching, and accelerating the precipitation of S-Al₂MgCu phase by increasing Cu/Mg ratio in the matrix due to the formation of the T phase. The peak hardness is from the synergetic effects of the S and T phases. The clustering and partitioning behaviors of solutes after 1 h aging treatment have been investigated in detail using atom probe tomography (APT) and high resolution transmission electron microscopy (HRTEM). It is shown that the formation of Mg-Cu clusters (precursor of the S phase) precedes that of Mg-Zn clusters (precursor of T phase), and the Mg-Cu clusters are responsible for the age hardening during the first two age hardening stages in the Cu-bearing alloys.

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1. Introduction

The Al-Mg alloys of the 5xxx series have in general excellent formability, and have been widely used in the automotive inner panel. Unfavorable bake-softening, however, is well-known to occur during paint-baking after press-forming. Some previous researches concluded that Cu addition could make Al-Mg alloys bake-hardenable due to the precipitation of the S'' precursor of Al₂MgCu during the paint-bake process, and the precipitation sequence in the Al-Mg-Cu alloy was represented as follows: α(supersaturated solid solution)→GPB zones →S''→S'→S. [1,2]. The notation "Al-Mg-Cu" is meant to imply that Mg is present in much higher concentration than Cu. However, the yield strengths after baking of the Al-Mg-Cu alloy sheets are not so high compared with that of advanced Al-Mg-Si alloy sheets. An increased amount of Cu can increase the precipitation hardening response [2], but high Cu content correlates to relatively poor corrosion resistance [3]. Recently, some efforts of adding alloying elements have been devoted to further increasing the strength of the Al-Mg-Cu alloys. Microalloying of an Al-Mg-Cu alloy with Si or Ag produced an

enhanced age-hardening response due to a modified precipitation process [4–6]. Ag addition, however, may be unacceptable in the cost aspect and high addition of Si may deteriorate the ductility of the alloy by the formation of insoluble particles [7,8]. Al-Mg-Zn alloys with high Mg/Zn ratio have been found precipitation hardenable by the formation of T-Mg₃₂(Al, Zn)₄₉ phase and its early-stage precipitates [9,10]. Moreover, the addition of Zn to the Al-Mg alloy has been found effective in enhancing the intergranular corrosion resistance and stress corrosion cracking by the precipitation of T-phase which suppresses the precipitation along the grain boundary and dramatically decreases the potential difference between grain boundary precipitates and the matrix [11,12]. On the other hand, the Al-Mg alloy with Zn addition exhibits delayed onset of serrated flow by forming coherent precipitates which can trap vacancies and hinder the vacancy-assisted diffusion of solute Mg atoms which lock the dislocations [13]. Based on these results, the Al-Mg-Cu alloys with Zn addition have high Mg/Cu and Mg/Zn ratios, which may cause dual hardening effects by the coexistence of S-type and T-type phases, and better balanced properties may be obtained. According to Suzuki [4], precipitates besides the S-type phase probably formed in the Al-3.0Mg-1.0Cu alloy with 0.4Zn addition because the higher yield strengths were obtained after prolonged aging time.

In this paper, we will systematically discuss the precipitation

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process of the Al-5.2Mg-0.45Cu alloy with Zn addition during aging at 180 °C. Special attention will be paid to the effect of Zn on the age hardening response of the Al-5.2Mg-0.45Cu alloy. The detailed information about the clustering behavior during the early stage of aging and the microstructure evolution during the aging process will be examined by employing APT and TEM.

2. Experimental procedures

The experimental alloys with compositions presented in

Table 1 were prepared by melting and chill casting into a steel mould. The ingots were homogenized, scalped, then hot rolled and cold rolled to a final thickness of 1 mm. The samples were solution treated at 525 °C for 10 min, followed by immediate quenching in cold water, and subsequently aged at 180 °C for various times. Hardness measurements were performed by using a macro Vickers hardness tester with 200 g load and a dwell time of 10 s. Each reported hardness value is the average of 10 individual measurements. Thin foils for TEM were prepared from 3 mm discs by double jet electropolishing in a 25% nitric acid/75% methanol solution at −35 °C. Conventional TEM, Energy-dispersive X-ray

Table 1

The compositions of the five alloys (wt%).

Alloy	Mg	Cu	Zn	Mn	Cr	Ti	Fe	Si	Al
Al-5.2Mg-0.45Cu	5.18	0.42	–	0.2	0.05	0.02	0.2	0.1	Balance
Al-5.2Mg-0.45Cu-0.6Zn	5.20	0.44	0.58	0.2	0.05	0.02	0.2	0.1	Balance
Al-5.2Mg-0.45Cu-1.2Zn	5.25	0.42	1.19	0.2	0.05	0.02	0.2	0.1	Balance
Al-5.2Mg-0.45Cu-2.0Zn	5.20	0.45	1.93	0.2	0.05	0.02	0.2	0.1	Balance
Al-5.2Mg-2.0Zn	5.19	–	1.90	0.2	0.05	0.02	0.2	0.1	Balance

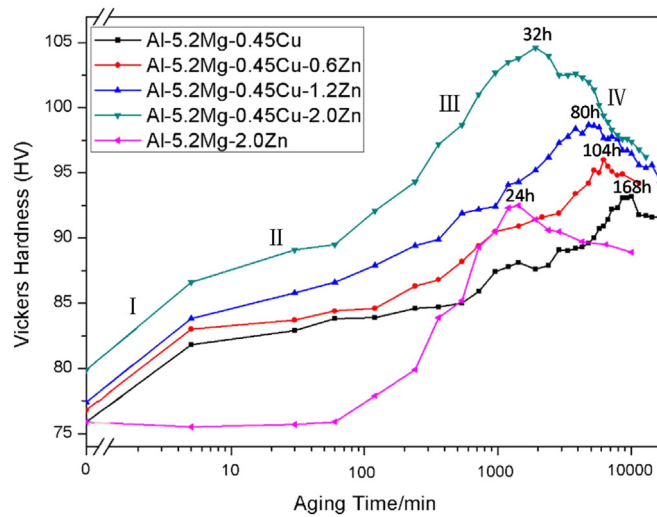


Fig. 1. Hardness curves for the five alloys during aging at 180 °C.

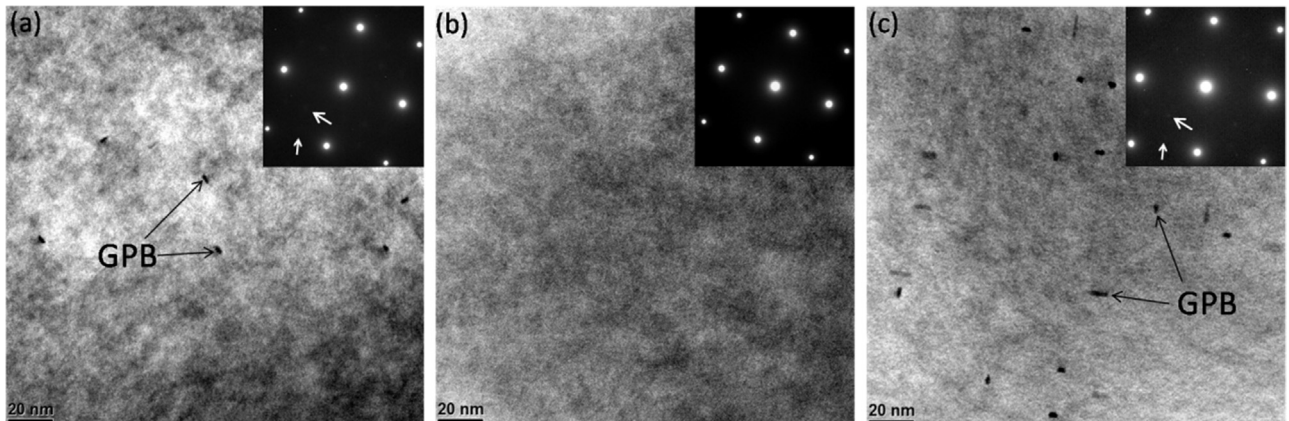


Fig. 2. TEM micrographs and the corresponding EDPs recorded along $\langle 001 \rangle_{\text{Al}}$ orientation from the three alloys aged for 1 h: (a) Al-5.2Mg-0.45Cu; (b) Al-5.2Mg-2.0Zn; (c) Al-5.2Mg-0.45Cu-2.0Zn.

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