

# Influence of Sb on Microstructure and Mechanical Properties of AZ61-1Sm Magnesium Alloy

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**Abstract**—The microstructure and mechanical properties of AZ61-1Sm magnesium alloy with Sb addition were analyzed by X-ray diffraction (XRD), light optical microscopy (OM), and scanning electron microscopy (SEM). The results demonstrate that addition of 0.5wt.%Sb to the AZ61-1Sm alloy obtains the highest ultimate tensile strength (UTS) after subsequent aging, and improves the elongation of the alloy, especially at the elevated temperature. The microstructure showed a typical non-equilibrium cast structure consisting mainly of  $\alpha$ -Mg matrix, eutectic compounds and some dispersive precipitates. Precipitation behavior of second phase particles and their effects on the strengthening mechanisms were investigated. The pronounced second phase particles are spherical and distributed dispersedly in grains and grain boundaries. The fracture mode changes from transgranular to micro-void coalescence fracture with increasing the temperature to 175 °C.

**Keywords**—AZ61-1Sm; Microstructure; Mechanical properties; Sb

## I. INTRODUCTION

As far as their cost, processing capability, mechanical performances are concerned in automobile industry. The requirement to reduce the weight of car components as a result in part of the introduction of legislation limiting emission has triggered renewed interest in magnesium [1,2]. The growth rate over the next 10 years has been forecast to be 7% per annum [3]. Especially AZ systems develop new Mg alloys for high temperature applications, the addition of rare earth (RE) elements such as Sb [4], Si [5], Sm and Bi is a group of alloying elements with the most acknowledged strengthening potential [6].

Mg grains refine and the melt-crystallization temperatures decrease with increase in the Al content [7]. Sm can improve the mechanical properties of AZ61 alloy by grain-refinement strengthening, Ramakrishnan strengthening and Gypen strengthening mechanism [8]. Upon aging, the equilibrium phase  $Mg_{17}Al_{12}$  precipitates from the supersaturated solid solution, affecting metal deformation and properties [9].

Therefore, pure Sb is added to the AZ61-1Sm alloy for investigating the changes of microstructures and properties in this study.

## II. EXPERIMENTAL PROCEDURE

The studied AZ61-1Sm alloys with and without Sb modification were prepared by melting the following materials: pure Mg (99.98 wt.%), pure Al (99.99 wt.%), pure Zn (99.9%), Mg-25wt.% Sm master alloy and pure Sb (99.9%). The experimental alloys were in the induction melting furnace and protected by under protective mixed atmosphere of  $SF_6$  (1 vol.%) and  $CO_2$  (bal.). Solution heat-treated at 693K for 20h and quenched in water. The aging treatment was performed at 473K for 10h. The tensile tests were carried out at a crosshead speed of 1mm/min at room temperature (25°C), 150°C and 175°C using AG-I 250kN precision universal material test machine.

The microstructures were observed by optical microscopy (OM), and scanning electron microscopy (SEM). Phase analysis was conducted by X-ray diffraction (XRD) with energy dispersive spectrometer (EDS).

The symbols and chemical compositions of experimental alloys are listed in TABLE I.

TABLE I. CHEMICAL COMPOSITION OF EXPERIMENTAL ALLOYS (MASS FRACTION, WT.%)

Alloys	Compositions (wt.%)				
	Al	Zn	Sm	Sb	Mg
A <sub>1</sub> (AZ61-1Sm-0.2Sb)	6	1	1	0.2	Bal.
A <sub>2</sub> (AZ61-1Sm-0.5Sb)	6	1	1	0.5	Bal.
A <sub>3</sub> (AZ61-1Sm-0.8Sb)	6	1	1	0.8	Bal.
A <sub>4</sub> (AZ61-1Sm-1.0Sb)	6	1	1	1.0	Bal.

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### III. RESULTS AND DISCUSSION

Fig. 1 shows the addition of 0.5wt% Sb to AZ61-1Sm (A<sub>2</sub>) was aged after solution treatment, and its mechanical properties are the best, with  $\sigma_b=214\text{MPa}$ ,  $\delta=9.1\%$  at room temperature,  $\sigma_b=208.6\text{MPa}$ ,  $\delta=12.8\%$  at  $150^\circ\text{C}$ , and  $\sigma_b=184.6\text{MPa}$ ,  $\delta=13.3\%$  at  $175^\circ\text{C}$ . The ultimate tensile strength of various alloys is good performance below  $150^\circ\text{C}$ . With the temperature increasing, the elongation of A<sub>2</sub> alloy decreases sharply. It can clearly be seen that the amount of alloying element Sb is not possible, but should be limited within a certain range.

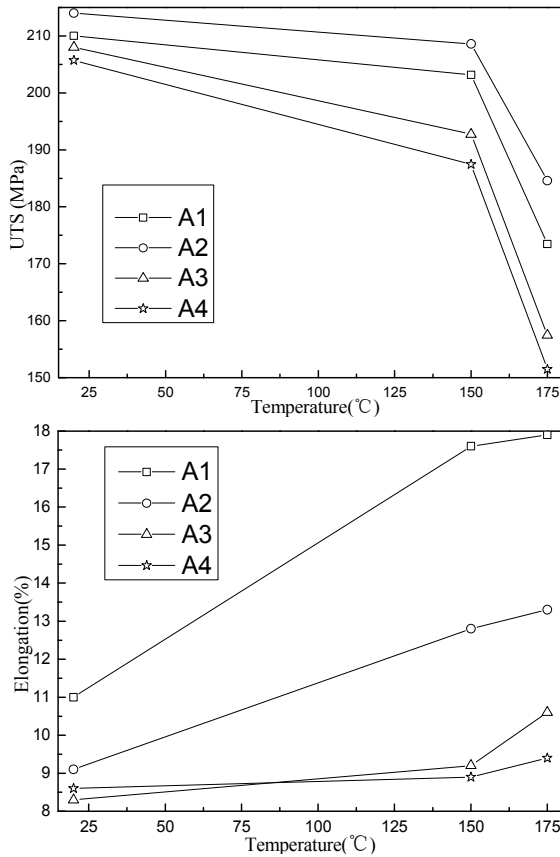


Figure 1. Mechanical properties of different alloys as a function of temperature

The optical micrographs of as-cast and peak-aged alloys are shown in Fig. 2, respectively. The typical dendritic structure of as-cast A<sub>1</sub> and A<sub>2</sub> alloys was obviously coarse-turns to typical equiaxed grain structure. The solution-aging treatment conditions were chosen to ensure that the precipitates could be dissolved into solid solution, from A<sub>1</sub> grained. The size of peak-aged alloy grains (c,d) are not become larger evidently compared to as-cast (a,b), but the grain boundaries become straighter and clearer, the micro structure alloy (a,c) we can see that all dendrites existed in grains are changed.

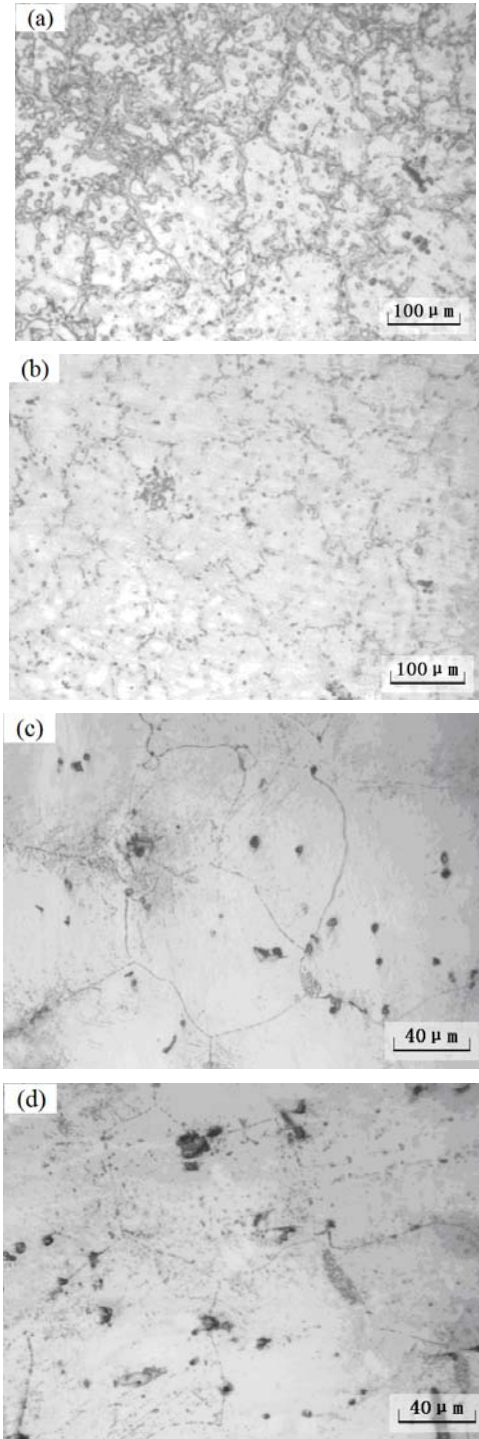


Figure 2. Optical micrographs of as-cast experimental alloys for as-cast (a)A<sub>1</sub> and (b)A<sub>2</sub>, peak-aged (c)A<sub>1</sub> and (d)A<sub>2</sub> alloy microstructures

Fig. 3 shows X-ray diffraction patterns of the peak-aged A<sub>1</sub> and A<sub>2</sub> alloys. The peaks in the peak-aged A<sub>1</sub> alloy can be indexed as  $\alpha$ -Mg matrix,  $\text{Mg}_{17}\text{Al}_{12}$  and eutectic compounds (containing RE), and those peaks of  $\text{Mg}_{17}\text{Al}_{12}$  phase slowly decrease compared to A<sub>2</sub> alloy with the raise of some new stronger peaks.

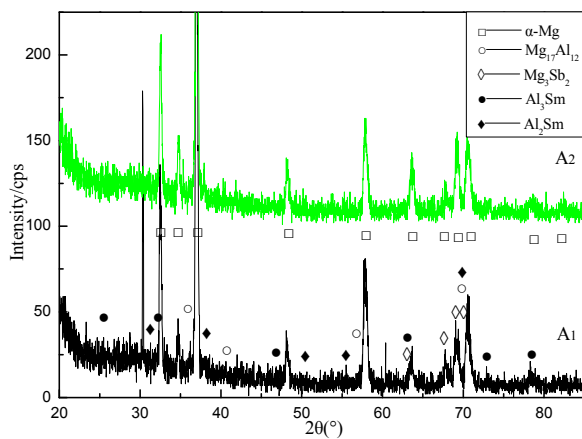


Figure 3. X-ray diffraction patterns of peak-aged A<sub>1</sub> and A<sub>2</sub> alloys

It is reported that the negative effect of high aluminum content is the formation of the interdentritic grain boundary phase  $Mg_{17}Al_{12}$  [10]. It lowers the strength within the fine-grained crystal structure and leads to limited ductility of the alloy. While, more and finer dispersed precipitates in Mg matrix as well as at  $\alpha$ -Mg grain boundaries are formed, which can be seen more clearly from SEM image in Fig. 4. From EDS analysis, these precipitation particles contain rare earth element, which have a high temperature stability. With combined addition of RE elements, but due to the formation of Mg-Al-Sm-Zn eutectic compounds.

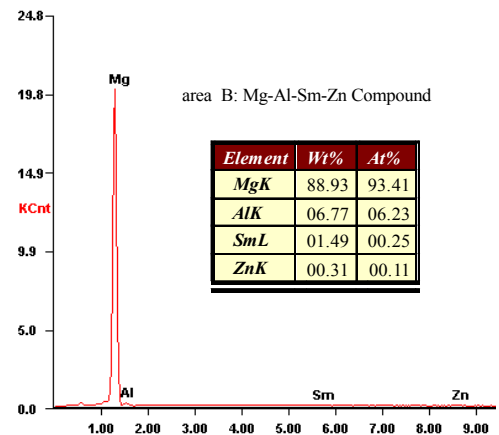
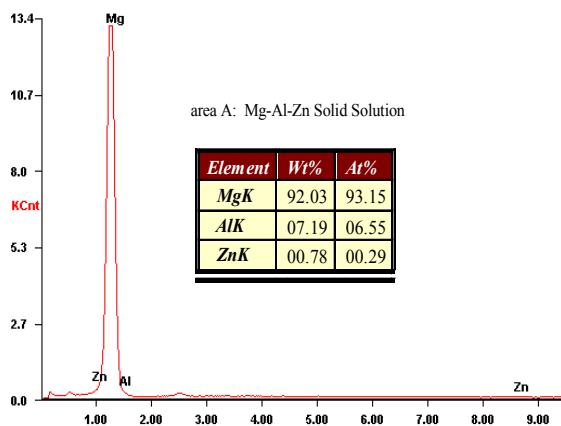
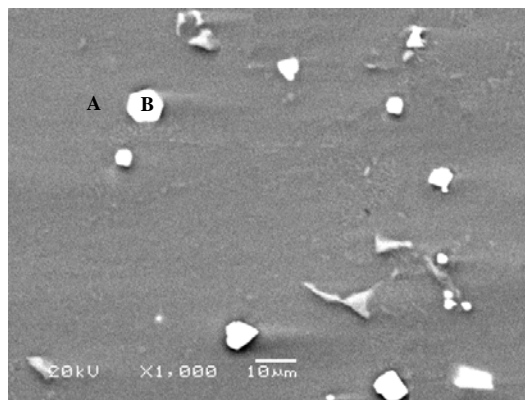
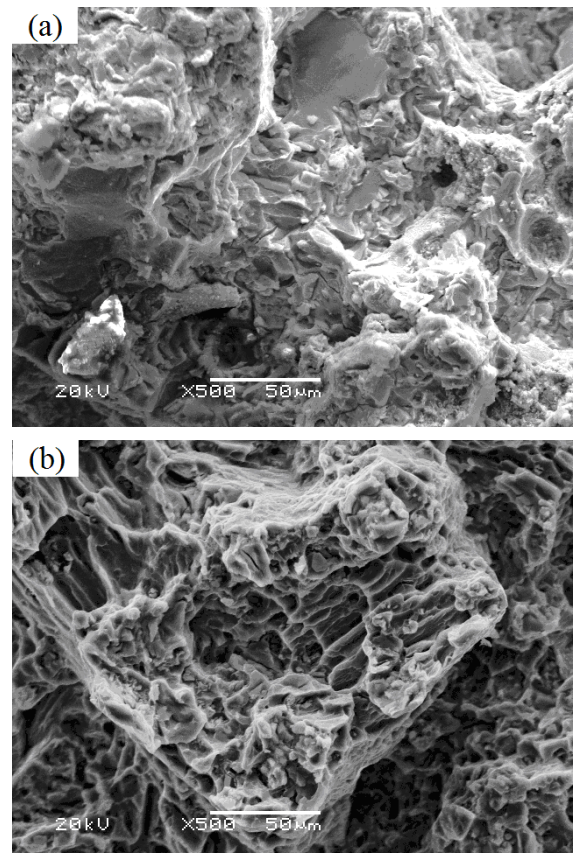


Figure 4. SEM image of peak-aged A<sub>2</sub> alloy and corresponding energy dispersive X-ray spectra of the points indicated in the image

The fractured surfaces of A<sub>2</sub> tensile specimens tested after ageing-treatment from room temperature to 175°C are shown in Fig. 5. Some micro-cracks and cleavage facets are observed. During tensile test at room temperature, the fracture model of the peak-aged A<sub>2</sub> alloy is mixtures of cleavage and ductile dimples, typical for a brittle transgranular fracture. Large cavities formed at grain boundaries are observed in the peak-aged sample tested at 175°C, corresponding to the intergranular fracture and the tensile fracture characteristic is mainly micro-void coalescence fracture combination the brittle cleavage fracture.



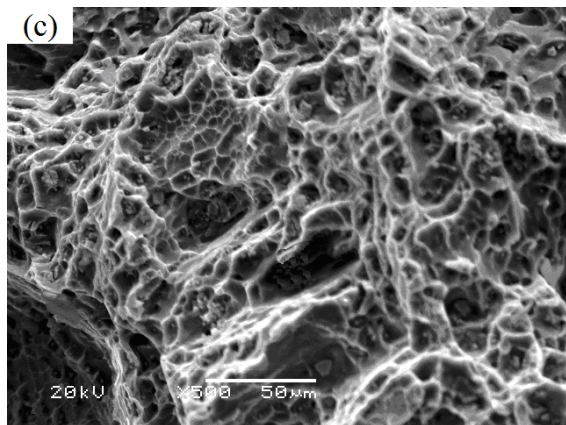


Figure 5. Fracture surfaces of A<sub>2</sub> tensile specimens tested at different temperatures: (a) room temperature; (b) 150°C; (c) 175°C

#### IV. CONCLUSIONS

For A<sub>2</sub> alloy exhibited maximum UTS and elongation at aged-peak hardness, and the values were 214 MPa and 9.1% at room temperature, 208.6 MPa and 12.8% at 150°C, and 184.6 MPa and 13.3% at 175°C, respectively. The Mg<sub>17</sub>Al<sub>12</sub> particles dissolved into the α-Mg matrix after solution-aging treatment, and the formation of high melting point RE eutectic compounds can improve the UTS and elongation. With increasing of the temperature, the characteristics of

transgranular cleavage fracture transforms into micro-void coalescence fracture.

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