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Sensitivity Analysis of Laser Effect on Mg-Gd-Er Alloy

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Mg alloys, due to their advantages on mechanical properties, are considered to be the most promising candidates for automobile and 3D industries[1]. However, the low strength and poor heat resistance have severely limited the application of Mg alloys. Literatures report that the heavy rear earth (HRE) elements, such as Gd, Nd, Er, Y, Sc, can largely improve the mechanical properties at room and elevated temperate[2]. Therefore these HRE containing Mg alloys are attracting great research interests recently.

It is well known that the precipitates (β″, β′ and β phase) formed during the heat treatment contribute to the improvement of mechanical properties of these HRE containing Mg alloys. However the precipitates formation is rather a complicate process and not well understood. To date, atom probe tomography (APT) is widely used in the characterization of the chemical composition of these precipitates[3, 4]. Even the values of evaporation fields of HRE elements are not available in the literatures, it is expected that the evaporation fields of Mg and HRE element are very different. Therefore, to guarantee the accuracy of the APT analysis, it is necessary to conduct a sensitivity analysis of the experimental parameters used in the laser evaporation process of HRE containing Mg alloys.

A Mg-1.34Gd-0.16Er(at.%) alloy was chosen, with other minor alloying elements. The precipitate containing in the alloy was β phase (Mg_5RE). APT specimens were prepared using focused ion beam (FIB) sample preparation method. Each specimen contained only the β phase to avoid the stress induced fracture during the APT analysis, which could easily occur at the interface between β phase and the matrix. APT experiments were conducted on a LEAP™-4000X Si, with laser energy varied from 50pJ to 80pJ, and pulse frequency varied from 200kHz to 500kHz. The analysis chamber base temperature was kept at 20K. The data reconstruction and analysis was performed using IVAS 3.6.12. Ga affected regions in specimen surface introduced by the FIB were removed in the reconstruction.

Table 1 shows the measured chemical compositions of β phase under three different experimental conditions. At 500kHz, the compositions of Mg increase from 50pJ to 80pJ. The Gd, Er and Nd demonstrate opposite trend with the compositions decrease. HRE elements should have higher evaporation fields than Mg. At 50K, Mg with lower evaporation field was more easily removed by standing DC voltage between pulses. Therefore it resulted in the preferential evaporation of Mg and the lost of its composition. When the laser energy increased at 80pJ, the actual specimen temperature also increased with the DC voltage decreased. Comparing with 50pJ case, in general less Mg atoms were lost during pulses and therefore resulted in the increase of Mg composition and the decrease of other HRE element composition.

By further examining the 1D concentration profiles plotted along the Z direction of data No.2 (80pJ, 500kHz), the effect of specimen temperature on the chemical composition is more clearly revealed. As shown in Fig.1, the Mg composition slightly decreases along the Z direct while HRE element compositions increase. In the ideal case, the specimen should be heated by each laser pulse and then cooled down to the chamber temperature between pulses. However in reality, due to the low thermal conductivity of alloy itself and the high pulse frequency, there was not enough time between pulses for the specimen to fully cool down. Therefore as the evaporation process going, the actual specimen temperature gradually increased into a certain level higher than the base temperature. The increasing in temperature would again give chance to the Mg atoms to be removed by DC voltage between pulse. The result of data No.3 (80pJ, 200kHz) perfectly supports such explanation. By dropping the pulse frequency to 200kHz, the time between each pulse was longer. The specimen should be able to cool down to a lower temperature than 500kHz case. The lost of Mg atoms was then less severe than the 500kHz case as well.

This preliminary sensitivity analysis on the laser effect has demonstrate the importance of specimen actual temperature. The choice of experimental conditions in APT could not only affect the evaporation behavior, but also the accuracy of the chemical analysis, especially for the alloys which contain elements having very different evaporation fields. More experiments are needed to further optimize the laser condition of HRE containing Mg alloys.

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Table 1. Chemical composition of three APT analysis

Ion Type	50pJ,500khz (Data No.1)	80pJ,500khz (Data No.2)	80pJ,200khz (Data No.3)
	Chemical composition (at.%)		
Mg	84.17	85.16	85.82
Gd	14.66	13.85	13.01
Er	0.43	0.38	0.35
Nd	0.44	0.39	0.38

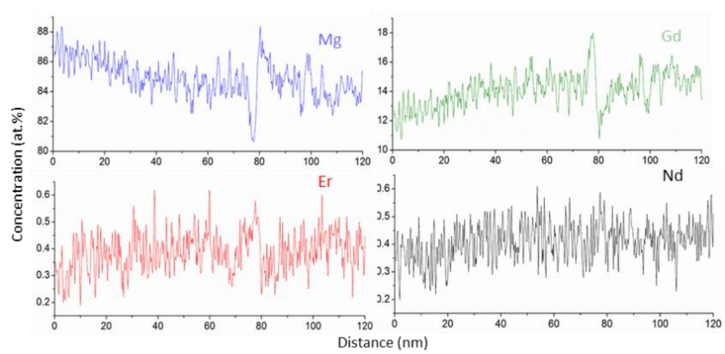

Figure 1. 1D concentration profiles of Mg, Gd, Er and Nd plotted along the Z direction of data No.3.

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