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# Study on the solidification microstructure in AZ91D Mg alloy after laser surface melting

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ABSTRACT

Laser surface melting (LSM) is known to enhance the wear and corrosion resistance of Mg alloys, but its effect on microstructural evolution of Mg alloys is not well understood. An effort has been made to study the effect of rapid solidification following LSM on the microstructural evolution of AZ91D Mg alloy. The results of X-ray diffractometry, scanning electron microscopy, transmission electron microscopy and energy-dispersive X-ray spectroscopy indicated that the solidification microstructure in the laser-melted zone was mainly cellular/dendrite structure of primarily $\alpha$-Mg phase and continuous network of $\beta$-$Mg_{17}Al_{12}$ phase. Numerical prediction of the laser-melted zone suggested that cooling rates increased strongly from the bottom to the top surface in the irradiated regions. An attempt has been made to correlate dendrite cell sizes of the solidification microstructure with the cooling rates in the laser-treated AZ91D Mg alloy.



## 1. Introduction

Magnesium alloys have been increasingly used in the automobile, communication and aerospace industries owing to their many attractive properties, such as low density, high specific strength, and good castability. However, their poor resistance to corrosion and wear limits their extensive use in many applications [1,2].

The effect of laser surface melting (LSM) on magnesium alloys has attracted considerable attention in recent years because surface-related properties of the laser-treated layer can be enhanced significantly [3–7]. Abbas et al. [4] and Liu et al. [5] found that the improved corrosion resistance of AZ31, AZ61 and WE43 Mg alloys following LSM was associated with the increased concentration of Al and microstructure refinement in the laser-melted zone due to surface melting and rapid solidification during the laser process.

In the past study, most of researchers focused on the improved wear and corrosion resistances of Mg alloys after laser treatment, but no good understanding has been obtained on the microstructural evolution induced by laser irradiation [3–7]. Therefore, an understanding of the as-received microstructure and its response to laser treatment is required for magnesium alloys in order to study the rapid solidification microstructure under non-equilibrium condition.

In this paper, the microstructural evolution of an as-cast AZ91D magnesium alloy following LSM was studied in three different regions of the laser-melted zone. Moreover, cooling rates of these regions were calculated from a numerical simulation based on the heat flow model in the literature [8–11]. The aim was to study the kinetics of phase transformation and the effect of cooling rates on the solidification microstructure under rapid solidification condition induced by laser processing.

## 2. Experimental procedures

The material studied was an as-cast AZ91D Mg alloy with the following chemical composition (wt.%): Al 8.97, Zn 0.78, Mn 0.31, Si 0.023, Cu 0.002, Ni 0.0005 and Mg balance. The specimens were extracted from the ingot, ground with progressively finer SiC paper (180, 400, 800, 1200, 2400 and 4000 grit), cleaned with alcohol, and then irradiated with Lumonics JK704 Nd:YAG laser system (with wavelength of 1084 nm) using the following parameters under high purity Ar gas protection: power density $3.82 \times 10^4$ W/$cm^2$, scanning speed 10 mm/s, frequency 100 Hz, pulse duration 1.0 ms, and spot overlap 50%. The laser was operated in a near TEM00 mode at a chosen power, and the beam was defocused to 1 mm in diameter (the distance between two subsequent tracks was around 500 $\mu$m).

An X-ray diffractometor (Philips PW1830 series) was used to identify phases both in the as-received alloy and in the laser-treated layer (the laser-treated specimen was polished to less than

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50 μm thick to remove the untreated substrate). Microstructural features of the specimens were studied using a JEOL 5600 LV SEM, equipped with an energy-dispersive X-ray spectrometer (EDS). The EDS measurements provided information on the chemical composition.

Furthermore, microstructure of top surface layer in the laser-melted zone was studied using a JEOL 2010 transmission electron microscope equipped with EDS, operated with an accelerating voltage of 200 kV. A selected area electron diffraction technique (SAD) in TEM was used to extract crystallographic information. The TEM thin foils were obtained first by polishing mechanically on the side of substrate until the samples were less than 30 μm thick. Disks of 3 mm diameter were punched from the foils for subsequent jet electro-polishing in a solution composed of an electrolyte of 750 ml methanol, 150 ml butoxyethanol, 16.74 g magnesium perchlorate, and 7.95 g lithium chloride at −20 °C and an applied voltage of 40 V. Finally, ion beam was used on a Gatan precision ion polishing system under conditions of 5.0 kV and an incident angle of 4–5°.

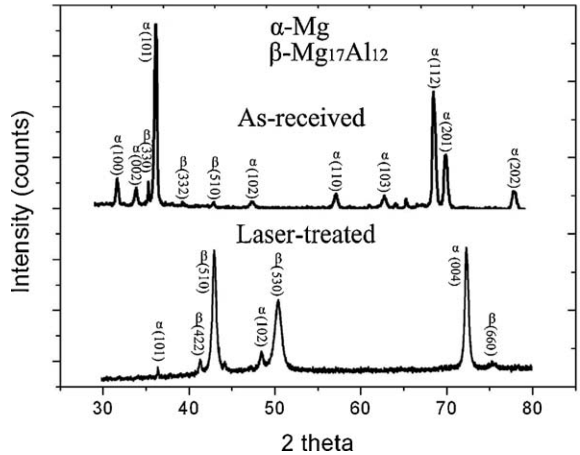


**Fig. 1.** X-ray diffraction patterns of the as-received AZ91D ingot and the sample sectioned from the laser-treated surface.

## 3. Results and discussion

Microstructure of the as-received AZ91D Mg alloy contained bulk and lamellar β-$Mg_{17}Al_{12}$ phase distributed non-homogeneously in a matrix of α-Mg grains [12,13]. After laser irradiation, XRD analyses indicated that the laser-melted layer also consisted of β-$Mg_{17}Al_{12}$ and α-Mg phases, as shown in Fig. 1.

Solidification microstructure in the LSM AZ91D alloy presented a continuous network of β-$Mg_{17}Al_{12}$ phase precipitated at dendrite/cellular boundaries as bright areas and the primary α-Mg solid phase as dark areas in the melted zone, as shown in Fig. 2. Fig. 2(a) indicates the whole morphology of the solidification microstructure within the laser-melted zone, and the melted depth is nearly 150 μm. It can be found that the refined microstructure is not uniform in the melted zone and coarse network of β-$Mg_{17}Al_{12}$ along the overlapped regions might be formed due to the inadequate energy distribution near the tail of Gaussian distribution in the laser beam together with the re-melted process during laser irradiation [5]. Al–Mn intermetallics were also found in both laser-melted zone (they did not melt during LSM due to high melting point) and substrate microstructure. Moreover, the heat affected zone (HAZ) in our experiment was very small due to the rapid laser heating and subsequent rapid cooling. The depth of HAZ is typically less than 50 μm.

At the bottom of the melted zone, coarse dendrite structure was found derived from the partial melted bulk β-$Mg_{17}Al_{12}$ phase due to insufficient heat and relatively low cooling rate. Moreover, the re-solidified microstructure had grown epitaxially from the

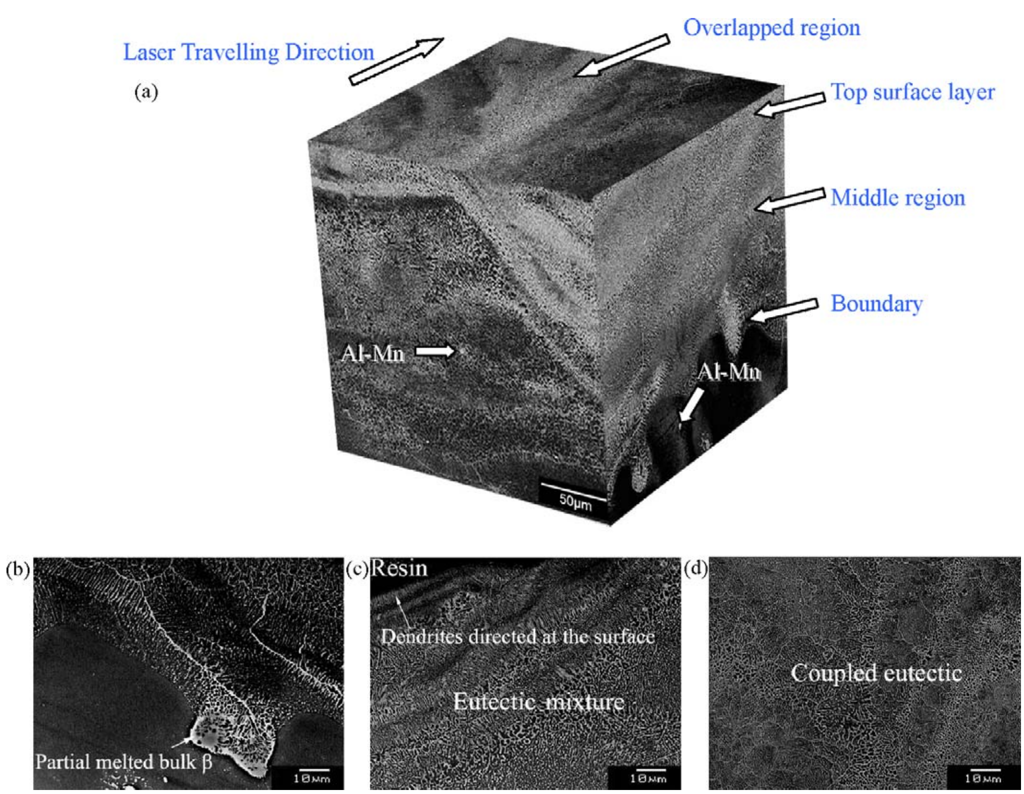


**Fig. 2.** Typical solidification microstructure of AZ91D Mg alloy after laser irradiation: (a) three-dimensional image of the laser-melted zone; (b) magnified view of the boundary between laser-melted region and substrate; (c) magnified view of the middle region; (d) magnified view of the top surface.