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Effect of processing environment on laser-induced darkening evolution in magnesium alloy

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ABSTRACT

Laser-induced darkening effect is an important phenomenon for Mg alloys to provide potential engineering applications in product identification, photocatalysts, and bio-optical implants. This work reports darkening evolution on Mg alloy by KrF excimer laser irradiation. Effort was made to study how processing environment influence morphological evolution and chemical variation of laser-irradiated surface. All irradiated surfaces were characterized using Talysurf surface profiler, atomic force microscope, scanning electron microscope and energy dispersive X-ray spectrometer. The results showed that oxygen content played a critical role in determining darkening effect on the Mg alloy, and surface morphology transferred from network structures to granular structures and protruding oxide particles when darkening occurred. Mechanism of laser-induced darkening in Mg alloy was further discussed.

1. Introduction

Laser-induced coloration of material surfaces provides many promising engineering applications including decorations, photocatalysts, product identification, and biocompatible implants, and it also offers an alternative approach to understanding of coloration theory [1–9]. Zhao et al. [1] and He et al. [6] ascribed laser-induced coloration of WO_3 to photoinduced thermochromism, which was different from ordinary photochromism induced by UV light. Zheng et al. [7–9] studied color change of different material surfaces following laser irradiation, and they found that color generation was result of controlled surface oxidation during laser beam interaction with metal surfaces. Qian et al. [10] demonstrated formation of different oxides layer on laser-irradiated Ti surface, and they proposed that morphological change of irradiated area played an important role in determining the laser-induced coloration.

Nowadays, driven by energy and environmental concerns, Mg alloys have been increasingly used in industries due to their low density and high specific strength. However, actual use of Mg alloys has been limited in many applications because of poor surface properties [11–18]. Recent studies have showed that application of Mg alloys can be explored to more fields on basis of advanced surface engineering technology [12,13]. As one of the most promising processes, laser surface engineering has been widely considered to improve surface performance without altering global properties of bulk materials [14–18]. In our previous work, improved corrosion resistance of AZ91D Mg alloy following laser surface melting was associated with microstructure refinement and Al concentration enrichment in the molten pool [16,18]. Wettability of laser-melt Mg alloy was also enhanced, and this was useful to improve adhesion of Mg alloy substrates for better coating quality [19].

In this paper, surface darkening was achieved on AZ31B Mg alloy following by KrF excimer laser irradiation. The objective of current research is to understand how laser processing environment affects darkening evolution of Mg alloy. Special attention was made to study morphological difference and chemical variation of the irradiated areas in different environment.

2. Experimental procedures

The material studied was wrought AZ31B Mg alloy with following chemical composition (in wt. %): Al 2.89, Zn 0.87, Mn 0.39, Si 0.015, Cu 0.001, Ni 0.0005 and Mg balance. The specimens of dimensions 20 mm by 30 mm by 3 mm were ground with progressively finer SiC paper (180, 400, 800, 1200, 2400 and 4000 grit), cleaned with alcohol, and then irradiated with laser at atmospheric pressure and room temperature.

The krypton–fluorine (KrF) excimer laser (with wavelength of 248 nm and pulse duration 25 ns) was used by following parameters:

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laser fluence 655 mJ/cm^2 and repetition rate 10 Hz. Laser beam was operated with a square beam spot of 3 mm side length, and number of laser pulses was varied from 100 to 800. In order to demonstrate effect of oxygen in processing environment on irradiated surface, the specimens were irradiated in air, under 0.5 bar Ar using jet nozzles and 2.0 bar Ar in well-sealed chamber, respectively, as shown in Fig. 1.

After laser irradiation, microstructural features of irradiated areas were investigated using JEOL 5600 LV SEM, equipped with an energy-dispersive X-ray spectrometer (EDS). The EDS measurements provided information on chemical composition. Surface topography with low laser pulses was measured using AFM in tapping mode. The surfaces produced with large number of laser pulses were too rough to be characterized with AFM, so their topography was characterized using a Taylor Hobson Precision Talysurf profiler.

3. Results and discussion

Observation of AZ31B Mg alloy surface after Excimer laser irradiation by naked eyes is shown in Fig. 2. Darkening effect was obtained at most of laser-irradiated surfaces both in air and under Ar nozzles. With the increasing number of laser pulses, the color became darker significantly. Compared to the specimens irradiated in air, color transition on the surface was slower under Ar nozzles. When laser irradiated Mg alloy in Ar chamber, evolution of color change was not obvious, only partially darkening occurred at the irradiated area under large laser pulses.

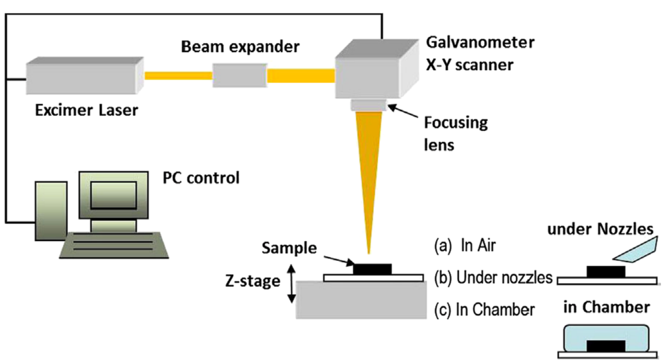

Fig. 1. Schematic diagram of experimental setup for Excimer laser on AZ31B Mg alloy in air (a), under 0.5 bar Ar using jet nozzles (b) and 2.0 bar Ar in well-sealed chamber (c), respectively.

Morphological evolution of all surfaces before and after laser processing was investigated using SEM. Before laser irradiation, surface of AZ31B Mg alloy was smooth due to fine grinding and polishing mechanically. After laser irradiation, the surfaces were roughened significantly with the increasing number of laser pulses. In order to study color transition of irradiated areas, SEM results were presented to show the morphological evolution with progressive laser pulses under Ar nozzles, as shown in Fig. 3. Fig. 3 (a) and (b) displays network structures at the surface when the number of laser pulses was 100 and 200. When laser pulses increased to 300, granular structures together with small particles were observed, as shown in Fig. 3(c). At large number of laser pulses from 400 to 800, the amount of particles increased significantly, and surface features became coarse and poorly defined, as shown in Fig. 3(d)–(f). Morphological evolution of irradiated surfaces both in air and in Ar chamber was also observed. SEM results of laser pulses 800 are shown in Fig. 4. Fig. 4(a) presents a large amount of particles at the coarse surface after laser irradiation in air. Fig. 4(b) displays network structures and few granular structures as well as few particles at the smooth surface after laser irradiation in Ar chamber. It should be noted that the surface features of three irradiated areas were similar, thus subsequent study will be mainly focused on the transition results obtained using Ar nozzles.

Since SEM images cannot reveal all information of morphological evolution in the irradiated area when laser pulses are low (Fig. 3(a) and (b)), those areas were further characterized using AFM. Fig. 5 shows clearly that surface topography of the irradiated areas changed from network structures when laser pulses were 100, to granular structures together with small particles when laser pulses were 200. Fig. 6 presents the distinct boundary between irradiated area and non-irradiated area in the periphery region, and the irradiated area was found to be above the non-irradiated area based on line profile drawn from AFM image, as shown in Fig. 6(b).

When laser pulses increased to 300, granular structures and small particles totally replaced network structures at the irradiated areas, as shown in Fig. 3 (c)–(f). However, such area was too rough to be characterized with AFM, so the Talysurf surface profiler was used to study the surface topography. Fig. 7 shows

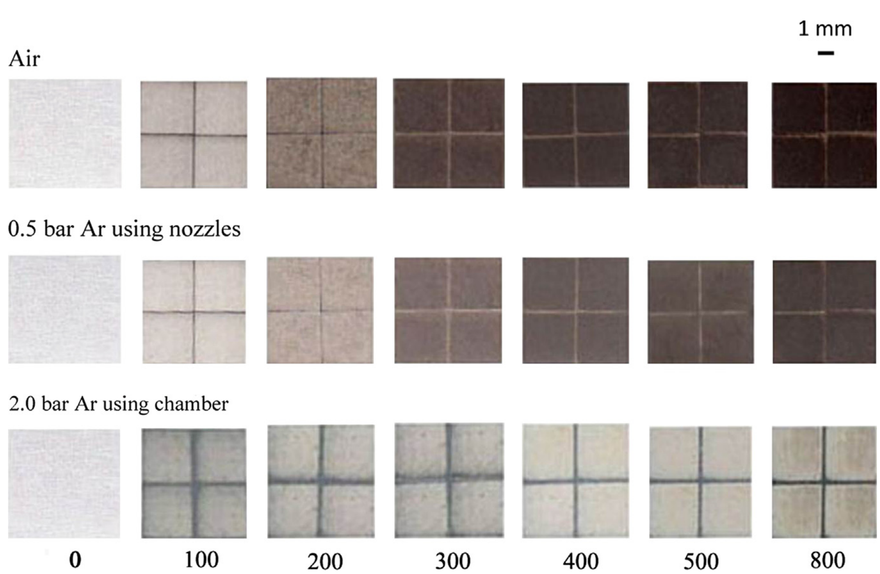

Fig. 2. Photo showing darkening evolution of irradiated areas with progressive laser pulses on AZ31B Mg alloy in air, under Ar nozzles and in Ar chamber, respectively.