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Applied Surface Science 252 (2005) 1723–1731

applied surface science

www.elsevier.com/locate/apsusc

Microstructure analysis of magnesium alloy melted by laser irradiation

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Received 13 October 2004; received in revised form 22 December 2004; accepted 11 March 2005
Available online 9 April 2005

Abstract

The effects of laser surface melting (LSM) on microstructure of magnesium alloy containing Al8.57%, Zn 0.68%, Mn0.15%, Ce0.52% were investigated. In the present work, a pulsed Nd:YAG laser was used to melt and rapidly solidify the surface of the magnesium alloy with the objective of changing microstructure and improving the corrosion resistance. The results indicate that laser-melted layer contains the finer dendrites and behaviors good resistance corrosion compared with the untreated layer. Furthermore, the absorption coefficient of the magnesium alloy has been estimated according to the numeral simulation of the thermal conditions. The formation process of fine microstructure in melted layers was investigated based on the experimental observation and the theoretical analysis. Some simulation results such as the re-solidification velocities are obtained. The phase constitutions of the melted layers determined by X-ray diffraction were β-$Mg_{17}Al_{12}$ and α-Mg as well as some phases unidentified.

PACS: 61.82.B; 42.60.R; 42.70.H; 02.60

Keywords: Magnesium alloy; Nd:YAG pulsed laser; Laser surface melting; Numerical simulation

1. Introduction

The attractive mechanical properties of magnesium and its alloys increase their use for many technical applications [1], i.e. automobile, aerospace components, household equipment, etc. [2]. The characteristic properties of magnesium alloys, offer many advantages such as low densities and high specific strength (σ/ρ), high damping capacity [3], good recycling properties and other desirable properties [4]. However, their applications have often been restricted because of theirs poor resistance to wear and notorious for their poor corrosion resistance. To improve the surface properties, a variety of surface modification technologies have been proposed and investigated. Laser surface engineering is one of these

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2005.03.110

Nomenclature

d	beam diameter (m)
e	base of natural logarithms (=2.718)
I_0	laser power (w/m^2)
K	thermal diffusivity (10^{-6} m^2 s^{-1})
t	time for heat to diffuse over a distance equal to the beam radius (s)
T_0	room temperature (25 °C)
T	surface temperature below the laser beam surface (K)
z	depth below surface (m)
Greek letters	
η	absorption coefficient or coupling coefficient (dimensionless unit)
κ	thermal conductivity (W/mK)
τ	interaction time (s)

technologies that have attracted vast research interest recently. Laser surface melting, alloying or cladding are main methods to improve the surface dependent properties [5–7]. Laser melted surface layers produces a fine microstructure that reduces the size of galvanic couples and expand the solid solution range of alloying elements. These factors can potentially improve the overall corrosion resistance [6]. Shibaev [8] studied the effect of pulsed-laser surface melting on the corrosion resistance of an Mg–Y–Zn alloy, reporting that laser surface melting increased the corrosion resistance significantly. This was attributed to a uniform distribution of the alloy elements in the laser melted zone and the appreciable supersaturation of the alloy phases. Subramanian [9] reported that laser cladding of Mg–Zr powders on Mg-substrate by using high power laser could significantly increase the corrosion resistance of the materials. Dutta et al. has carried out mach work on laser processing of magnesium alloys [10–12] has reported that microstructure of the surface melted zone is characterized by epitaxially grown fine columnar grains oriented perpendicular to the solid–liquid interface. The enhanced corrosion resistance of laser-remelted specimens is attributed to the combined influence of grain refinement, dissolution of intermetallic phases, and retention of alloying elements (rare earth elements) in extended solid solution.

In this paper, we report the formation of fine microstructure of as casted magnesium alloy by the Nd:YAG laser surface irradiation. Numerical analysis results were estimated according to the numeral simulation of the thermal conditions in our experimental condition.

2. Experimental

Cast plates of the magnesium alloys with a composition (wt.%), as determined by ARL 4460 Metals Analyzer, of 8.57Al, 0.68Zn, 0.15Mn, 0.52Ce and Mg-balance, were used for laser melting. These plates were polished with 1000-grit SiC paper prior to laser surface treatment in order to produce an unvarying and smooth surface finish, free from mold contaminants. They were then washed with alcohol, air dried and laser treated shortly after preparation. Surface melting was carried out by a pulsed Nd:YAG laser with 1062 nm wavelength. The pulse duration and the pulse rate were 1.5 ms and 10 s^{-1}, respectively. Laser energy was 1.0 J and the spot-to-spot overlapping rate was 80%. Typically, laser beam with a spot size of 300 μm diameter was focused on the sample surface. The specimens were mounted on a computer-controlled X-Y stage that was moved at a speed of 140 mm/min. A continuous coaxial flow of high purity argon protected the surface of specimens during laser treatment. Melted depths of approximately 166 μm were typically produced. The corrosion behavior of the laser-treated sample was evaluated by an EG&G Parc Model 271 corrosion measurement system. Anodic polarization tests were carried out in a 3.5 wt.% NaCl solution which was prepared using analytical grade reagents. The samples were driven from −1500 to −900 mv (SCE) at a scan rate of 0.5 mv/s to produce potentiodynamic polarization plots. Microhardness of the top surface and the cross-section of the laser surface melted layer were measured by a Vickers microhardness tester with a 25 g applied load. The microstructure of laser-melted layer was characterized by scanning electron microscope (SEM) (Model JSM-5310, Japan) and transmission electron microscope (TEM) (Model H-800, Japan). Structural identification of phases formed in laser-melted layers was performed by X-ray diffractometer (Model D/Max 2500PC Rigaku, Japan) Cu Kα was used.