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Effect of laser surface melting with alternating magnetic field on wear and corrosion resistance of magnesium alloy

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ABSTRACT

Laser surface melting (LSM) with alternating magnetic field was applied to the AZ91D magnesium alloy using a 2 kW fiber laser. The microstructure and phase composition of melted layer with and without alternating magnetic field were studied by optical microscopy (OM) and X-ray diffraction (XRD) measurement. The micro-and nano-hardness, wear and corrosion resistance of the modified layers and as-received magnesium alloy were measured by microhardness tester, nanoindenter, pin-on-disc wear tester and electrochemical workstation, respectively. Results showed that the LSM treatment resulted in a highly homogeneous modified layer with refined grains. Compared to the melted layer without electromagnetic stirring (EMS), the microstructure of melted layer became finer and more uniform, the dendritic crystal was changed to an approximately equiaxial crystal under the action of EMS application treatment. The microhardness of the melted layer with and without EMS ($70.8Hv_{0.1}$ and $62.9Hv_{0.1}$) is higher than the as-received magnesium ($55.53Hv_{0.1}$) microhardness, regarding especially the melted layer with EMS.·The friction coefficient and wear mass loss of the melted layer with EMS were 0.2175 and 0.1616 g accordingly, subsequently having decreased by 14.8% and 6.1% compared to the melted layer without EMS. From the worn-out appearance of the melted layer without and with EMS, the wear mechanism turning from a slight abrasive wear into a slight plastic deformation during EMS-assisted. The corrosion potential and corrosion current density of the melted layer with EMS were increased by 18.7% and decreased by 4% compared to the corresponding effects without the EMS-assisted, respectively. Experimental results showed that the melted layer assisted by EMS displayed the best wear and corrosion resistance properties.

1. Introduction

Magnesium alloy, with high specific strength and low density, have been widely used in the aerospace, automobile, electronics device and other industries, it is currently one of the most potential structural material [1–3]. However, the poor wear and corrosion resistance along with high chemical reaction have limit its application scope. The surface modification technology can improve the surface abrasion and corrosion resistance of magnesium alloy, leading to extend its application range [4]. There are many surface modification technologies such as micro-arc oxidation [5], vapor deposition [6,7], electroless plating [8], thermal [9–13] and cold spraying [14] as well as the anodizing [15]. However, most of the above surface treatment techniques have some defects such as poor bond strength, thin coating layer and low coating preparation efficiency, therefore they cannot have meet the increasingly harsh service environment.

Nowadays, laser surface modification technologies have been widely used in surface engineering field, which including the laser surface melting (LSM) [16], laser transformation hardening [17], laser surface alloying [18] and laser cladding [19]. Among the widely used laser surface modification technologies, the LSM process is gaining more attention in recent years due to its advantages of without adding alloy elements, natural metallurgical bonding interface and only the surface is modified while the overall intrinsic performance of the matrix remains unaltered.

So far, the effects of LSM treatment on the wear and corrosion behaviour of magnesium alloys have been investigated by different researchers. For example, Cancan Liu et al. [20] reported that LSM with a 10 kW continuous wave CO_2 laser improved the corrosion resistance of AZ91D magnesium due to the reduced corrosion susceptibility of Al enriched $\alpha-$Mg matrix and the barrier effect of uniformly distributed β-phase of the LSM modified layer. C.·Taltavull et al. [21] investigated that the LSM AM60B magnesium alloy presents better wear behaviour in many conditions but in the slow sliding speed ones. Zhihui Zhang et al. [22]studied the effects of LSM on the wear resistance of the AZ91D magnesium and concluded that the grain refinement and very small sized β-$Mg_{17}Al_{12}$ dendrite had the largest dependency. In contrast, Chakraborty Banerjee et al. [23] exhibited the effects of LSM on the corrosion behaviour of ZE41 and found that there have little effect

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on the corrosion resistance of the ZM41 magnesium alloy after 3 h of immersion in the electrolyte. Dubé et al. investigated the characterization and performance of laser melted AZ91D and AM60B, the results of their study showed that even though the microstructure of both magnesium alloy were refined, the corrosion resistance had not significantly improved [24].

From the above studies, it is concluded that the LSM process can improve the comprehensive mechanical properties of the magnesium alloy, but the effect is not very obvious. So we want to use LSM process with alternating magnetic field to further improve its mechanical properties. Electromagnetic stirring (EMS) has many advantages of refining the internal structures, increasing the fraction of the dendritic crystal changed to equiaxed grains and reducing the segregation, shrinkage cavity, porosity and inclusion [25]. As inferred from its advantages, the external alternating electromagnetic field-assisted LSM can make the quality of the melted layer better and fewer defects.

Significant efforts have been made to use the ideal effects associate with the application of electromagnetic stirring during laser welding [26], laser cladding [27], laser drilling [28] etc. However, a few attempts have been made to use the EMS during LSM process. In the present work, the main purpose of the study was take the alternating electromagnetic field-assisted LSM method to modify the surface of the AZ91D magnesium alloy with the use of fiber laser. Microstructural changes subjected to LSM with and without EMS treatment was examined and its effect on wear and corrosion behaviour were investigated in detail.

2. Experimental details

2.1. Materials

In this study, a die cast plates of AZ91D magnesium alloy were used as target for laser surface melting, of which the size was 40mm × 40mm × 5mm. Their chemical composition is as follows: 8.5wt%Al, 0.6wt%Zn, 0.35wt%Mn, 0.05%Si, 0.0025%Cu, and Mg in balance. They were polished with the use of water-based abrasive papers of decreasing grit SiC paper (800, 1000, 1500) prior to laser surface treatments in order to produce an unvarying surface finish. Sprayed with a thin layer of black carbon to enhance absorption of laser and to avoid the oxidation, and there have no effect on wear and corrosion properties.

2.2. Experimental setup and procedure

The LSM process with EMS is illustrated schematically in Fig. 1. The LSM treatment were carried out using a 2 kW fiber laser with 1.06 μm wavelength (IPGYLR-2000). The laser spot was scanned over the surface of the specimen. The optimized process parameters were as follows: laser power was 1500 W, the laser scanning speed and the distance between the laser head and the specimen surface were 600 mm min^{-1} and 12 cm, respectively. The laser beam spot size is 3 mm in diameter with a Gaussian distribution of energy density. Taking argon as shielding gas at a pressure of 0.3 MPa. For the follow-up wear and corrosion tests, the overlapping ratio was 50%. The overlapping (O) was calculated from the equation $O = \frac{d-f}{d} \times 100\%$, where d is laser beam diameter (mm), and f is the distance between the axes of adjacent tracks (mm) [29].

An alternating magnetic field of different magnetic field intensity consisting of an induction coil with 550 turns and an iron core of $\varphi 30 \times 20$mm, which was equipped under the sample to form an alternating magnetic field coaxial with the laser beam. In the test, 8.6A current was selected, with the magnetic field intensity output of 25.8 mT at a fixed frequency of 50 Hz measured by the Gaussmeter.

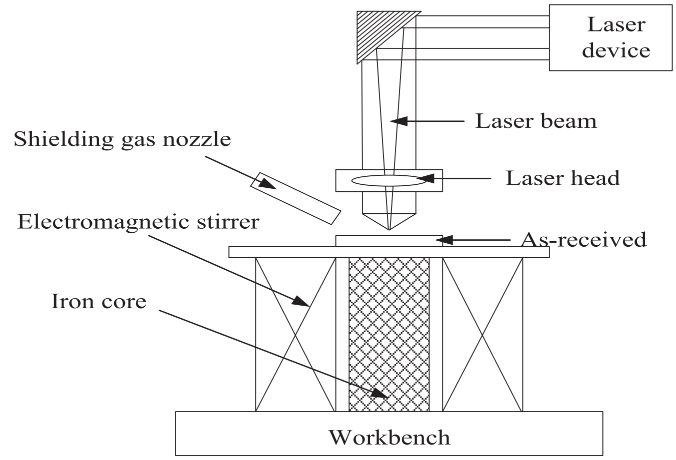

Fig. 1. Schematic of LSM with EMS apparatus.

2.3. 2.3. Characterization

Cross-section of the laser surface melted layers were sectioned by wire-electrode cutting, mounted in bakelite, polished and etched using 5%Nital solution. The microstructure of the melted layers were analyzed by optical microscopy (OM). X-ray diffraction (XRD) was used to analyze the phase composition of the melted layer with and without EMS as well as as-received. The scans were performed with 4°/min step size in the 2θ range of 10-80°.

The microhardness measurements were conducted on the cross-sections of the melted zone and as-received using the Vickers Microindentor (MH-5) with the loads of 100 g applied for 10 s. Each microhardness was measured for three points and the average value was obtained. Nanoindentation tests were carried out using a nanoindenter system (TriboIndenter In-Situ Nanomechanical Test System, HYSITRON) to investigate the nano-hardness (H) and modulus of elasticity (E) of all samples using Oliver and Pharr analysis. A direct and continuous measure of dynamic indentation nano-hardness and modulus varying with the depth can be offered from the loading-unloading curve. At each test of all samples, the loading and unloading time kept 15 s with load of 2000 μN for each cycle and dwell time of 2 s at peak load.

The tribological properties were measured using a pin-on-disc wear tester (HT-1000) at room-temperature, sliding contact against the GCr15 steel ball (5 mm in diameter, 60–65HRC, and mass fraction: C 0.95%–1.1%, Si 0.15%–0.35%, Mn 0.5%, P 0.025%, Cr 1.3%–1.6%). The tests were run at the constant normal load of 10 N, the rotation speed and time were 300 r/min and 15 min, respectively. The wear resistance was determined by measuring the mass loss and friction of the samples. The mass loss of each specimen was measured by averaging five Data. The friction coefficient was obtained directly through the device system. Wear surface morphologies of each specimen was investigated by an FEI Quanta250 scanning electron microscope. Three dimensional morphology of wear scar were observed by Laser scanning confocal microscopy of type LEXTOLS4000 to determine the width and depth of wear scar.

The corrosion resistance of the specimens (as-received, melted layer with and without EMS) was evaluated by potentiodynamic polarization curves in a standard three-electrode cell, with the sample as the working electrode, platinum electrode as auxiliary electrode and saturated calomel electrode as reference electrode. Scanning speed of polarization curves test was 2 mv/s within a potential range between −1 V and 1.2 V. The specimen with an area of 1 cm^2 was immersed into the 3.5%NaCl solution at room temperature and were performed in three times to ensure the reproducibility.