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Microstructure and properties of plasma remelted AZ91D magnesium alloy

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Abstract: The surface of AZ91D magnesium alloy was remelted by plasma beam. The microstructure, composition, hardness, wear and corrosion resistance of the plasma remelted layer (PRL) were characterized. The results show that there is extremely fine and dendrite structure in the PRL at low magnification observation, which is still composed of α-Mg and β-$Mg_{17}Al_{12}$ phases. But at high magnification observation, the microstructure of the PRL is equiaxial crystalline grains with size of 3−5 μm. And also the content of α-Mg phase decreases while that of β-$Mg_{17}Al_{12}$ increases and distributes more uniformly in α-Mg matrix compared with the substrate. The hardness of the PRL is much higher than that of the substrate. There are plastic deformation, grains uprooting and tearing evidence with tiny even dimples in the tensile fracture of the PRL, which are different from the substrate. Furthermore, the surface wear and corrosion resistance of AZ91D are improved significantly after plasma remelting.

Key words: magnesium alloy; plasma remelting; solid solution strengthening; refined crystalline strengthening; wear resistance; corrosion resistance

1 Introduction

Magnesium alloys are applicable to automobile and aviation industry due to their low density, high specific strength and stiffness, and good shock absorption and noise reduction [1]. But their wide application is limited because of poor wear and corrosion resistance. It is difficult to improve the wear and corrosion resistance by alloying due to the segregation of alloying elements and formation of undesirable brittle intermetallic phases in magnesium alloy [2]. As most of the wear and corrosion damages start with the surface, it is very important to change the surface composition and microstructure of magnesium alloy. In order to improve the surface properties, a variety of surface modification technologies such as laser surface cladding [3−7], laser surface melting [8,9], micro-arc oxidation [10,11], metal plating [12], vapor deposition [13], organic coating [14], and chemical conversion coating [15,16] have been studied. Among them, laser surface melting and cladding are the most promising methods, as they can allow the formation of hard and dense protective coatings even at fast speed.

By making use of high energy laser, the surface of magnesium alloy could be melted or cladded quickly, the microstructure and properties can be improved significantly [17−19]. COY and VIEJO [20] found that by laser melting (LSM) the surface of die cast AZ91D alloy, a kind of homogeneous and refined microstructure was obtained, and the dissolution of a large amount of coarse intermetallic phases made the enrichment of aluminum in matrix greatly. Hence, the corrosion resistance especially localized corrosion resistance of AZ91D alloy was improved compared with the substrate. ZHANG et al [21] reported the wear behavior of AM50 magnesium alloy after LSM. They found that after laser melting, the microstructure became fine columnar dendrite. Although the wear friction coefficient curve was similar to that of the untreated AM50 substrate, the wear volume of the laser melted layer was decreased by 42%. Thus, the hardness and wear resistance of the laser melted layer were improved due to the grain refinement.

Plasma beam is a kind of compressed arc with high energy density and extremely high temperature. Compared with laser processing, plasma cladding is simpler and easier to operate. Furthermore, the cost of the plasma equipment is much lower than that of laser equipment [22].

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In this work, a kind of plasma remelted layer (PRL) on the surface of AZ91D was obtained by high energy density plasma beam. The microstructure, hardness, tensile fracture and wear and corrosion resistance were analysed, with intent of providing theoretical and experimental reference for improving the properties of magnesium alloys.

2 Experimental

The raw material used in this work was AZ91D. The device was DGR-5 atmospheric plasma apparatus with Ar as ionizating and protecting gas. AZ91D alloy plate was cut into samples with dimensions of 30 mm×30 mm×20 mm with line cutting machine. Then, the sheets were fixed to the working platform, and the surface was scanning remelted with plasma beam as shown in Fig. 1. The selected diameter and compression ratio of plasma generator nozzle for testing were 10 mm and 2, respectively, the distance between the nozzle and sample, i.e., the beam length was 10 mm, and the overlap ratio while scanning heating was 20%. All the parameters of the remelting process are listed in Table 1.

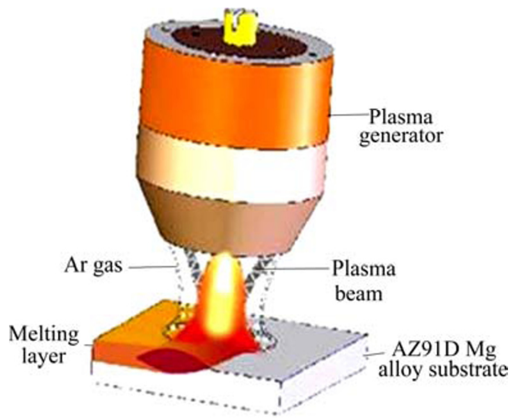

Fig. 1 Schematic illustration of plasma beam scanning remelting surface

The samples were characterized by X-ray diffraction (XRD, D/Max, Cu K_α, λ=1.542 Å, scanning speed of 0.02 (°)/s) to identify the crystalline phases. The polished and chemical etched samples were prepared for the analyses of microstructure and composition which were carried out on scanning electron microscope (SEM, KYKY2800B, voltage of 20 kV) and electron probe microanalysis (EPMA, JXA-8230, image current of 5×10^{-10} A, composition current of 5×10^{-8} A, voltage of 15 kV), respectively. The microhardnesses of different regions were measured by microhardness tester (FM-700, load of 100 N, 15 s). The tensile test was carried out on WDW-3100 electronic universal testing machine. The wear resistance was tested with M-2000 wear-test machine (load: 100 N; velocity: 200 r/min; time: 5 min). The anodic polarization of the melted layer and the raw AZ91D alloy was measured in 3.5% NaCl solution by using an electrochemical workstation (PARSTAT, 2273) at a scan rate of 1 mV/s. Three-electrode system was applied. The reference electrode was a saturated calomel electrode (SCE), and the counter electrode was a platinum electrode.

3 Results

3.1 Phase analysis

Figure 2 shows the XRD results of AZ91D PRL and substrate. It is obvious that after plasma remelting, the PRL is still composed of α-Mg and β-$Mg_{17}Al_{12}$ phases despite of the content of each phase changing. Figure 3 shows the ratio of I_β/I_α of the PRL with different electric currents. It indicates that I_β/I_α of the PRL is larger than that of the substrate. The larger the current is, the more the β-$Mg_{17}Al_{12}$ phase is. Because of the high temperature during the remelting process, some of Mg and Al elements may be burned or evaporated out in the molten bath due to the low melting point, and the loss rate of Mg is larger than that of Al. This may result in the formation of more β-$Mg_{17}Al_{12}$ phase in the PRL. As the energy density of the plasma beam increases with the current increasing the larger the current is, the more obvious this kind of phenomenon is.

3.2 Microstructure and element distribution analysis

Figure 4 shows the microstructures of the samples. Plasma melting results in grain refinement and the formation of fine dendrites as a result of the high speed heating and cooling, directional heat dissipating (Fig. 4(a)). At higher magnifying observation, the grains 3−5 μm in size and nearly dendrite shape as arrow *A* pointed in Fig. 4(a). Figure 4(b) shows the morphology of the cross-section which consists of two parts, the left part is PRL and the right part is near the substrate. The

Table 1 Parameters of plasma beam remelting process

Sample No.	Selected diameter/mm	Compression ratio	Beam length/mm	Overlap ratio/%	Scanning speed/(mm·s^{-1})	Flow rate/ (m^3·h^{-1})	Current/A
1	10	2	10	20	2	0.2	45
2	10	2	10	20	2	0.2	55
3	10	2	10	20	2	0.2	65