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Laser cladding Al-based amorphous-nanocrystalline composite coatings on AZ80 magnesium alloy under water cooling condition

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Al-based amorphous-nanocrystalline composite coatings were prepared by laser cladding $Al_{95-x}Cu_xZn_5$ (x = 5, 10, 15, at.%) powders on AZ80 magnesium alloy under a low-temperature water cooling condition. The microstructural observations indicate that all the cladding layers exhibit good metallurgical bonding to the substrates while the morphology of the cladding layer varies with the Cu content. The microstructure and properties of the $Al_{85}Cu_{10}Zn_5$ (x = 10, at.%) coating and the substrate were carefully characterized and analyzed. The XRD analysis and TEM observations show that the $Al_{85}Cu_{10}Zn_5$ cladding layer is constituted of amorphous phase, nanocrystallines and ternary intermetallics $Mg_{32}Al_{47}Cu_7$, τ-$Mg_{32}(Al,Zn)_{49}$, $AlMg_4Zn_{11}$ and S-Al_2CuMg. The surface performances of the AZ80 substrate are greatly improved by the $Al_{85}Cu_{10}Zn_5$ cladding layer. The average hardness of the $Al_{85}Cu_{10}Zn_5$ layer is 364 $HV_{0.05}$, which is about 4 times higher than that of the substrate (~86 $HV_{0.05}$), and the relative wear resistance of the $Al_{85}Cu_{10}Zn_5$ cladding layer is 5.5 times better than that of the substrate. Meanwhile, the corrosion potential (E_{corr}) is increased by 276.2 mV and the corrosion current density (I_{corr}) is decreased by two orders of magnitude. In addition, the reasons accounting for the improvements of the mechanical properties and corrosion resistance are elucidated accordingly.

1. Introduction

Magnesium (Mg) alloys have been well known as the lightest green metallic structural engineering materials in the 21st century. Due to the high specific strength and stiffness, good electromagnetic shielding performance, high damping capacity and good recyclability, the Mg alloys have a promising application prospect in many civil, construction and manufacturing fields [1,2]. However, the application of the Mg alloys was greatly impeded by its drawbacks, such as the low surface hardness, poor wear resistance and high chemical reactivity [3–5]. To overcome such problems, surface treatment is an efficient approach to improve the wear and corrosion resistance of magnesium alloy [6,7], among which the laser surface cladding method has attracted much attention in recent years. This technique is characterized by the fast laser-matter interaction within the near-surface region at extremely high heating and cooling rates (10^3~10^{10} K/s), which allows depositing a protective coating with nanocrystalline and even amorphous structure in the cladding layer on the substrate surface [8,9].

The element aluminium (Al) exhibits a good metallurgy consistency with the element magnesium (Mg), which could greatly improve the strength and reduce the corrosion rate of Mg alloys. Therefore, many efforts have been made on the surface modification of Mg alloys by laser cladding Al-based coatings [10–19]. The common Al-based laser cladding powder systems on the Mg alloys include single Al [10–12],binary Al-Cu [13], Al-Sn [14], Al-Si [15], Al-Mg [16] and metal-ceramic compounds of Al + Al_2O_3 [17], Al + SiC [18], Al + Si + Al_2O_3 [19]. It is well demonstrated that the wear and corrosion resistance of Mg alloys could be significantly enhanced owing to the formation of various intermetallic phases

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during the laser cladding process of Al-based powders. However, the ternary Al-Zn-Cu coatings on Mg alloys by the laser cladding method are rarely reported to date.

Al-based amorphous has been widely investigated due to its low density, high strength, excellent corrosion resistance and favorable plasticity in the recent decades [20,21]. The specific strength of Al-based amorphous is 2–3 times higher than that of Al alloys, and the strength of Al-based amorphous-nanocrystalline composite alloys is comparable with that of the steels, while the density of the former is only 40% of the later [22]. Unfortunately, the wide applications of the Al-based amorphous alloys are severely hindered by the low glass-forming ability (GFA) generated by the conventional fabrication methods [23]. Laser cladding is an effective method to obtain the Al-based amorphous coatings due to the aforementioned extremely high cooling rate. Moreover, it has been proved that the amorphous structure existed in Al-Zn-Cu thin films deposited by the DC-magnetron sputtering method [24]. In this study, we aimed to prepare Al-based amorphous-nanocrystalline composite coatings on the AZ80 Mg alloy by laser cladding the preplaced Al-Cu-Zn ternary powders to improve the surface performances for more potential applications of Mg alloy.

2. Experimental

2.1. Materials

AZ80 Mg alloy (Mg-8.81Al-0.27Zn-0.19Mn, wt.%) was used as the substrate material with the dimension of 45 mm × 25 mm × 10 mm. The raw materials are composed of pure (99.5% wt.%) Al powder, Zn powder (with an average particle size of 74 μm), and Cu powder (~48 μm). The mixed powder of the above three pure powders with an atomic ratio (at.%) of $Al_{80}Cu_{15}Zn_5$, $Al_{85}Cu_{10}Zn_5$ and $Al_{90}Cu_5Zn_5$ were chosen and preplaced on the AZ80 substrate with a thickness of about 1 mm.

2.2. Laser cladding process

A 5 kW continuous wave CO_2 laser processing system (TJ-HL-T5000) was used for the laser cladding process. The technology parameters were optimized as follows: laser power of 1.8 kW, scanning speed of 5 mm/s, laser beam size of 3 mm and overlapping track of 50%, as sketched in Fig. 1a. The home-made protective device was applied to prevent the oxidation and increase the cooling rate of the cladded specimens, as shown in Fig. 1b. Argon used as the shielding gas was blown into the protective device with a flow rate of 10 L/min and the specimen was partly immersed into the flowing 0–5 °C chilled water to accelerate the cooling of the cladding layer. The steady water level was controlled by adjusting the inlet and outlet valves.

2.3. Microanalysis

Microstructure and phase constitution were investigated by a JSM-6490LA scanning electron microscope (SEM) with an energy dispersive spectroscopy (EDS) and a X-D6 X-ray diffractometer (XRD) with Cu Kα radiation. The XRD system was operated at 40 kV and 35 mA in a 2θ range of 20–90° using a step size of 0.01°and a scan speed of 4°/min. TEM specimens of the cross-sections of the cladded specimens were examined by a JEOL-3000F transmission electron microscope (TEM).

2.4. Microhardness and wear tests

The microhardness of samples was measured by a HX-1000B type Vickers microhardness tester using a load of 50 g for 15 s. The given hardness value is averaged from 3 measurement points at the same depth along the cross-sectional direction of the cladding layer.

The specimens with a size of 50 × 50 × 15 mm were cut from the AZ80 Mg alloy and the laser cladded specimens for the wear test. Both of the specimens were ground on 1500 grit sizes emery paper to obtain the same surface roughness. The test was carried on a MMW-1A universal friction wear testing machine at room temperature with the testing parameters of loading 100 N, sliding speed 200 r/min and sliding for 20 min. The wear mass losses were measured by the electronic balance with an accuracy of 0.1 mg and the wear mechanism of the substrate and cladded specimen was investigated by the SEM worn morphologies and the corresponding EDS spectrum.

2.5. Corrosion resistance test

Quadrate samples of 10 mm × 10 mm were cut from the cladded specimen and the substrate for the corrosion resistance test. The sample surfaces were slightly ground on the 1500 grit emery paper and cleaned with acetone before testing. Potentiodynamic polarization tests were conducted to study the anodic polarization behavior in a 3.5% NaCl solution using a CS300 electrochemical workstation. A three-electrode cell, with the sample as the working electrode (WE),the saturated calomel electrode (SCE) as the reference electrode (RE) and the platinum sheet as the counter-electrode (CE), was employed in this study. The pH value of NaCl solution was adjusted to 7 and the temperature of the test solution was maintained at 25±1 °C. After 5 cycles, the corrosion was conducted to explore the corrosion failure mechanism of the cladded specimen, and the corrosion behavior of the substrate and cladded

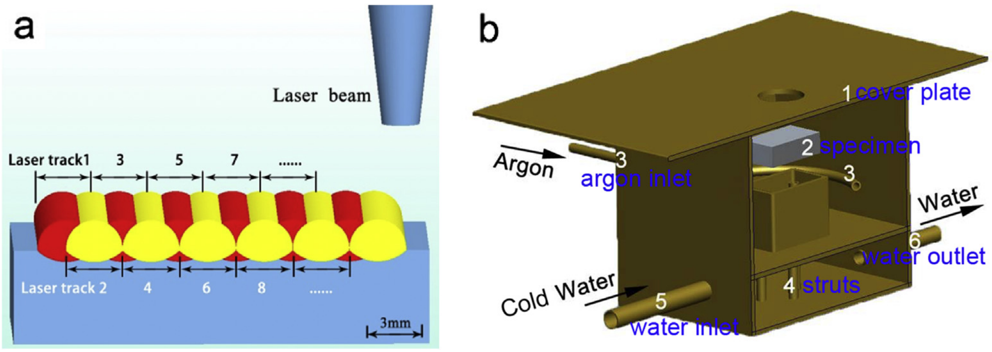

Fig. 1. Schematic diagrams of (a) the laser cladding process and (b) the protective device.