Influence of laser scanning speed on Cu-Zr-Al composite coatings on Mg alloys

Ya-li Gao1, Meng Jie2, and Hai-bo Zhang1

1) School of Mechanical Engineering, Northeast Dianli University, Jilin 132012, China
2) School of Mechanical and Electrical Engineering, Jilin Institute of Chemical Technology, Jilin 132022, China
(Received: 30 July 2012; revised: 4 September 2012; accepted: 17 September 2012)

Abstract: To improve the surface properties of magnesium alloys, a study was conducted on Cu-Zr-Al composite coatings on AZ91HP magnesium alloy by laser cladding. The influence of laser scanning speed on the microstructures and properties of the coatings was discussed. The coatings consist of amorphous phase, Cu8Zr3, and Cu10Zr7. With the increase of laser scanning speed, the amorphous phase content of the coatings increases and reaches 60.56wt% with the laser scanning speed of 2.0 m/min. Because of the influence of laser scanning speed on the amorphous and crystal phases, the coatings show the maximum elastic modulus, hardness, and wear resistance at the laser scanning speed of 1.0 m/min. At the laser scanning speed of 2.0 m/min, the coatings have the best corrosion resistance.

Keywords: magnesium alloys; composite coatings; amorphous; laser cladding; speed

1. Introduction

Because of low density, high specific strength, and good elastic modulus, Mg alloys arouse the interest of materials scientists [1-5]. However, Mg alloys have a number of undesirable properties, including poor corrosion resistance, poor wear resistance, and high chemical reactivity, which limit their extensive applications in many industry fields [6-9].

As a surface modification method, laser surface treatment has shown a great potential for improving the corrosion resistance and mechanical properties of Mg alloys [10-17]. Cu-Zr-based amorphous alloys have the higher wear and corrosion resistance and a better physic-chemical consistency with Mg alloys, which is considered to be ideal modified materials for Mg alloys [18].

If Cu-Zr-based amorphous alloy coatings can be prepared on Mg alloys by laser cladding, the wear and corrosion resistance of Mg alloys will be significantly improved, and the applications in many industry fields can be extended. Therefore, based on Cu-Zr-Al amorphous alloys designed by the cluster line approach, a laser cladding Cu58.1Zr35.9Al6 amorphous alloy was carried out with a higher glass-forming ability on AZ91HP Mg alloy, and the changes of microstructure, hardness, elastic modulus, and wear and corrosion resistance of the coatings with laser scanning speed were systematically studied in this article.

2. Experimental

2.1. Materials

In the present investigation, AZ91HP magnesium alloy with 60 mm × 30 mm × 10 mm was used as the substrate material. Its chemical composition is listed in Table 1. Cu, Zr, and Al elements were melted according to Cu58.1Zr35.9Al6 by arc-melting method and ball milled, then the cladding material was obtained.

2.2. Laser processing

A 5-kW continuous wave CO2 laser processing system was used as the heat-generating source. Argon gas was blown into the molten pool to provide shielding during
laser cladding. The cladding material was mixed with sodium silicate in a certain proportion to produce a pre-placed coating with the depth of 0.5 mm. The technology parameters of laser cladding were as follows: laser power, 4.5 kW; laser scanning speed, 0.5-2.0 m/min; and laser beam size, 3 mm.

2.3. Microanalysis

A detailed analysis of the coatings was carried out by X-ray diffractometry (XRD) on a SHIMADZU 6000 diffractometer. The microstructure of the coatings was analyzed by scanning electron microscopy (SEM) with an energy dispersive X-ray analyzer and transmission electron microscopy (TEM).

2.4. Microhardness and wear resistance

The hardness and elastic modulus of the coatings were measured by a nano-indenter with a Berkovich tip. The samples with the size of 20 mm × 20 mm × 10 mm were ground on 1500 grit emery paper and polished. The depth embedded in the test zone was 100 nm, and the average value of 10 dots tested in each zone was adopted.

Samples used for the wear study with the size of 10 mm × 10 mm × 5 mm were cut from the as-received Mg alloy and laser cladding samples and ground on 1500 grit emery paper to obtain the same surface finish. Wear resistance was measured by a ball-on-disk type apparatus with the steel ball bearing 5 mm in diameter and the hardness 58 HRC. The testing parameters were as follows: load, 5 N; sliding speed, 1 mm/s; sliding time, 30 min; and reciprocating sliding distance, 5 mm.

2.5. Corrosion resistance

Immersion test was carried out in 5 wt% NaCl solution (pH 7) for 12 h. Samples with the size of 12 mm × 12 mm × 6 mm were taken from the laser cladding samples and as-received Mg alloy, and sealed by epoxide resin with coagulator. Fresh surfaces were produced by slightly grinding the samples on 1500 grit emery paper. Corrosion rate was calculated as mass loss in mg/(cm²·h⁻¹).

3. Results and discussion

3.1. Influence of laser scanning speed on the microstructure of coatings

Fig. 1 shows the classical X-ray diffraction pattern of the coating with the laser power of 4.5 kW and the laser scanning speed of 2.0 m/min. It can be seen that there exist diffuse peaks at 2θ = 34°-46° in the X-ray diffraction pattern, characterizing the amorphous phase, and crystal diffraction peaks are superimposed on the diffuse peaks. Phase analysis shows that the crystal phase has an orthorhombic structure in the form of Cu₃Zr₃ and Cu₁₀Zr₁₇.

The amorphous phase content of the coating is calculated as

\[ X_a = \frac{I_a}{\Sigma I_c + I_a} \times 100\% \quad [19-20] \]

where \( X_a \) is the amorphous phase content, \( I_a \) the intensity of amorphous diffuse peaks, \( \Sigma I_c \) the intensity of crystal diffraction peaks. By calculation, the amorphous phase content of the coating is about 60.56 wt%.

After being etched by 5vol% HNO₃ + 5vol% HCl + 3vol% HF, the microstructure of the coating is shown in Fig. 2. TEM analysis in Fig. 2(a) shows that the coating exists in a characteristic area without quality contrast. A typical selected-area electron diffraction pattern (SADP) of the characteristic zone exhibits an obvious amorphous diffuse circle in Fig. 2(b). Therefore, it can be concluded that the coating exerts a large influence on the amorphous structure. Moreover, in other view of the coating, there exists nanocrystal with the dimension of 15-25 nm, as shown in Fig. 2(c). The corresponding SADP is shown in Fig. 2(d).

From XRD and TEM analysis, it is evident that the composite coatings are composed of the amorphous and nanocrystal. Therefore, it is clearly shown that when cladding the Cu₃₈.₁Zr₃₅.₉Al₁₆ alloy with a higher glass-forming ability on the Mg alloy, there still exists crystal phases in the coating. The reason is that laser cladding is a quick heating and cooling process, and some factors, such as nonhomogeneous nucleation, epitaxial growth of the matrix, and oxygen impurity in the coating, improve the critical cooling rate of the amorphous alloy and make the glass-forming ability of the amorphous phase weaken.

When the laser power is fixed at 4.5 kW, X-ray diffraction patterns of the coatings with different laser scanning speeds are shown in Fig. 3(a). The amorphous phase content calculated by Eq. (1) is shown in Fig. 3(b). It can be seen that at the selected parameters, the amorphous content of the coating increases with the increase of laser scanning speed, and the maximum amorphous content is about 60.56 wt% when the laser scanning speed is 2.0 m/min.

The increase of laser scanning speed improves the cooling rate of the molten pool and strengthens the glass-forming ability of the amorphous. However, it can be predicted that the amorphous content of the coating does not