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Microstructure and properties of the low-power-laser clad coatings on magnesium alloy with different amount of rare earth addition

Rundong Zhu, Zhiyong Li*, Xiaoxi Li, Qi Sun

The Welding Research Center, College of Material Science and Engineering, North University of China, Tai Yuan 030051, PR China

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ABSTRACT

Due to the low-melting-point and high evaporation rate of magnesium at elevated temperature, high power laser clad coating on magnesium always causes subsidence and deterioration in the surface. Low power laser can reduce the evaporation effect while brings problems such as decreased thickness, incomplete fusion and unsatisfied performance. Therefore, low power laser with selected parameters was used in our research work to obtain Al–Cu coatings with Y_2O_3 addition on AZ91D magnesium alloy. The addition of Y_2O_3 obviously increases thickness of the coating and improves the melting efficiency. Furthermore, the effect of Y_2O_3 addition on the microstructure of laser clad Al–Cu coatings was investigated by scanning electron microscopy. The energy-dispersive spectrometer (EDS) and X-ray diffractometer (XRD) were used to examine the elemental and phase compositions of the coatings. The properties were investigated by micro-hardness test, dry wear test and electrochemical corrosion. It was found that the addition of Y_2O_3 refined the microstructure. The micro-hardness, abrasion resistance and corrosion resistance of the coatings was greatly improved compared with the magnesium matrix, especially for the Al–Cu coating with Y_2O_3 addition.

1. Introduction

Due to its advantageous physical properties such as high specific strength, low specific weight, excellent damping characteristics, large thermal conductivity, good machinability and electromagnetic shielding characteristics, magnesium alloy is widely used for automation, aerospace, communication and electronics device [1,2]. However, magnesium alloys also have some disadvantageous surface and chemical properties like poor corrosion and wear resistance, high chemical reactivity and poor creep resistance, so that their extensive use is rather limited in many other applications [3,4]. To improve their surface and chemical properties as micro-hardness, abrasion resistance and corrosion resistance, many surface modification techniques, such as conversion coating, gas phase deposition process, anodizing and organic coating have been used. Sebastien Pommiers et al. [5] had tried to form chromium conversion coatings on the surface of magnesium alloy but due to the toxicity of hexavalent chromium the process has strong limitation. Pichel et al. [6] had obtained coating with TiN on AM60 magnesium alloy by physical vapor deposition but in such case the manufacturing parameters are difficult to be controlled. Li Wei-ping et al. [7] fabricated Mg_2SiO_4 films on AZ91D magnesium alloy by non-sparking anodization process but the composition of the electrolyte in this process is too complicated and therefore it takes a long time to form the film. Consequently all the above processes turn out to be highly expensive and have a rather low efficiency.

Laser cladding is an effective material processing method that produces a surface layer with many advantages. It has already been applied to metals such as carbon steel and Ni-based super alloy to improve their properties. However, the application of laser cladding to magnesium alloy cannot be so successful because of its high evaporation rate at elevated temperature. When the laser beam is focused on the surface of the materials, the energy is transferred to the matrix producing large amount of magnesium fume in a short time. The evaporation leads to bad formation of the coating and increases the dilution rate of the matrix. Furthermore, the properties of the clad coating are not satisfying even though researchers have tried different parameters for the laser cladding of magnesium alloy. According to our previous work [8], it turns out that when the laser energy is too high, it may cause subsidence due to evaporation of the matrix, even when the speed is suitably chosen. With low power laser, the energy transmitted to the matrix is limited and the solidification rate of the coating is faster, which can protect

* Corresponding author. Tel.: +86 13753115250.
E-mail addresses: lizhiyong@nuc.edu.cn, lzhy_2002@126.com (Z. Li).

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Table 1
Chemical composition (wt.%) of AZ91D magnesium alloy.

Chemical composition	Mg	Al	Zn	Mn	Si	Be	Others
Relative amount (%)	89.97	8.99	0.71	0.25	0.048	0.0071	≤0.002

the matrix from evaporation. However, when the power is too low, the coating always undergoes an incomplete fusion and it attains a limited thickness. It is critical to get coatings with satisfying formation and properties for the laser cladding of magnesium alloy. Therefore, in this paper we try to use a laser, which has lower power than that used for other research work [9–11], in the attempt to clad magnesium alloys with an acceptable formation of the coating and a suitable thickness by adding different amount of Y_2O_3.

With strong chemical activities and large atomic radius, rare earth can react easily with many elements, playing a favorable role in alloys [12]. Rare earths are widely used in metallurgy. Furthermore, the rare earth oxides are unpurified particles in magnesium alloys which are liable to absorb more laser energy than the uniform alloys. In this research work, the rare earth oxide added into the Al–Cu powders help to form laser clad coatings on magnesium alloy with increased thickness.

In recent years, rare earths are gradually introduced to modify the surface properties of engineering components by flame spraying, laser cladding and electric plating [13–15]. Sharma et al. [16] had added different amount of La_2O_3 into flame sprayed Ni based coatings to study its effects on the microstructure, hardness and abrasive wear behavior of the coatings. The result showed that the optimal addition of La_2O_3 was 1.2 wt.%. Li Ming-Xi et al. [17] studied the effect of Y_2O_3 on microstructure of laser clad cobalt-based alloy coating on Ni-based super-alloy. Both the fine and short dendritic microstructure was found and the columnar to equiaxed transition occurred when Y_2O_3 was added. Wang Hong-Yu et al. [18] had added CeO_2 into the NiCoCrAlY coatings to study the effects of CeO_2 on microstructure and properties of the coatings. The results show that with the addition of CeO_2 the growth pattern of interface grain was changed. The microstructure was refined and the microhardness, the thermal shock resistance were improved. However, few reports about the rare-earth oxides applied to magnesium alloy surface modification are available in the published literatures.

According to our previous experiments in which Y_2O_3, La_2O_3 and CeO_2 are added into cladding powders which are put on AZ91D magnesium alloy, the laser clad coatings with Y_2O_3 addition showed to have the best formation. According Wu Yu-Rong's research [19], La_2O_3 and CeO_2 are light rare earth oxide while Y_2O_3 belongs to heavy rare earth oxide. Heavy rare earth oxides are always better than light rare earth oxides for improving the mechanical properties of the magnesium alloy. Therefore, Y_2O_3 was selected to be the additive in the laser cladding powders in our research work. We study the effects of Y_2O_3 on the microstructure, micro-hardness, wear and corrosion properties of the Al–Cu alloy coatings of AZ91D magnesium alloy, which could offer an experimental and theoretical basis for a promising application of rare-earth oxide on magnesium alloy.

2. Experimental procedures

2.1. Preparation of samples

The matrix used in the study is AZ91D magnesium alloy with dimension of 15 mm × 15 mm × 4 mm and the primary powders are Al (98.0% purity) and Cu (98.0% purity) (the mass ratio of Al:Cu is 7:3). The chemical composition of the AZ91D magnesium alloy is shown in Table 1. The plates were polished with metallographic sand paper, washed with alcohol and dried in air in order to produce a smooth surface without contaminants. The rare earth oxide Y_2O_3 was added into the primary powders with 0 wt.%, 0.4 wt.%, 0.8 wt.%, 1.2 wt.% and 2.0 wt.% respectively. As shown in Table 2, Five groups of cladding powders were prepared in which the Al–Cu alloy powders and Y_2O_3 were mixed with adhesives. After having uniformly milled, the mixed powders were preplaced onto the AZ91D magnesium alloy plate with a thickness of 0.8 mm. In order to make the results reliable and reproducible, enough specimens for different groups were prepared for comparing the performance and observing their microstructure.

2.2. Preparation of the coatings

A 0.4KW pulsed Nd:YAG laser system was used for cladding. After a series of tests, the optimal experimental parameters were selected as given in Table 3. Argon (99.999% purity) was used for shielding the melting region from being oxidized. As the laser beam moves, the metals are deposited on the matrix, forming the coatings (unmodified coating: the coating without Y_2O_3. Y_2O_3-modified coating: the coating with Y_2O_3).

2.3. Analysis on microstructure, the elemental and phase compositions of the coatings

The microstructure of the coatings with and without Y_2O_3 was investigated with a SU-1500 model scanning electron microscope. The elemental composition of the coatings was identified by a Thermo type energy disperse spectroscopy. The D/max-RB model X-ray diffractometer was used to examine the phase compositions of the coatings.

2.4. Investigation of the properties of the coatings

The micro-hardness was measured by a DHV-1000 vickers hardness tester with load of 1.96 N and loading time of 15 s. The micro-hardness was measured every 0.1 mm along the vertical direction of the transverse cross section. Wear resistance of the coatings was evaluated with a UMT-3 reciprocating type sliding wear tester. The load is 3 N and the duration is 10 min. The ball of the friction pair is GCr15 with the radius of 2 mm. The electrochemical corrosion of coatings was measured by a ZF-3 type constant potential rectifier.

3. Results and analysis

3.1. Microstructure

The micrographs of the coatings at low magnification (30×) are shown in Fig. 1 where the average thickness of coatings is in the range of 0.5–0.8 mm. The serrated morphology at bonding zone

Table 2
Specimen groups and Chemical composition (wt.%) of coatings.

Specimen group	Composition
1	Al–Cu + 0 wt.% Y_2O_3
2	Al–Cu + 0.4 wt.% Y_2O_3
3	Al–Cu + 0.8 wt.% Y_2O_3
4	Al–Cu + 1.2 wt.% Y_2O_3
5	Al–Cu + 2.0 wt.% Y_2O_3