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Study on laser surface remelting of plasma-sprayed Al–Si/1 wt% nano-Si_3N_4 coating on AZ31B magnesium alloy

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ABSTRACT

Plasma sprayed micro-structured Al–Si based and 1 wt% nano-structured Si_3N_4 coating was successfully fabricated on an AZ31B magnesium alloy using a high efficiency supersonic atmosphere plasma spraying system, and then the as-sprayed coating was remelted by a continuous wave CO_2 laser. The remelted coating was investigated by optical microscope, scanning electron microscope, energy-dispersive spectroscopy, X-ray diffractometer and Vickers microhardness tester. The results indicated that the laser remelted coating possessed an excellent metallurgical bonding to the substrate. A finer dendritic structure was exhibited after laser remelting. The nano-Si_3N_4 decomposed fully in the coating, and the remelted coating was mainly composed of Al, AlN, Al_9Si, $Al_{3.21}Si_{0.47}$ and Mg_2Si. Moreover, the microhardness of remelted coating was enhanced to 200–514$HV_{0.05}$, which was much higher than that of the substrate(about 50 $HV_{0.05}$).

1. Introduction

Magnesium and its alloy which is called green engineering material in 21st century for the characteristics of lower density, higher strength, etc., has become the third largest metal engineering material posterior to the steel and aluminum material [1,2]. However, the wider application and research of magnesium and its alloy is considerably restricted all over the world by lower mechanics capability under normal temperature, poorer corrosion resistance, and so on [3–5].

Mostly, it is necessary for the surface of magnesium alloy components instead of the whole parts possess excellent synthetical performance, such as higher hardness, wear resistance and corrosion resistance, which are the sticking points that restrict the application of magnesium alloy. Therefore, one of the best ways to solve the disadvantage of performance of magnesium alloy is to improve its surface characteristics. This method can only improve hardness, wear resistance and corrosion resistance of the surface, but has little effect on the own characteristics of magnesium, such as density and so on.

The aluminum and magnesium are similar in physical and chemical compatibility, and silicon could enhance the flow of molten pool, thus Al–Si alloy is usually used for the surface modifying of magnesium alloy. Whereas the effect of modifying is not very well [6–8].

Ceramic materials generally possess more excellent corrosion and wear properties, but lower thermal shock resistance and fracture toughness [9,10]. Furthermore, it is easy to produce cracks in simplex prepared ceramic materials. If possible, integrate the Al–Si alloy and ceramic as a compositive coating on the surface of magnesium alloy. It may be an effective way to modify the magnesium alloy. Particularly, the nano-structured ceramic materials have more superior physical, chemical, mechanical, and wear and corrosion properties owing to their quantum size and surface effects [11].

Plasma spraying is one of the most common and appropriate techniques for metal surface modifying. However, there are still some major problems concerning plasma spraying. For instance, the coating presents lamellar structures and microdefects including pores and microcracks. Moreover, the coating and the substrate are bonded by insufficient mechanical strength [12]. These problems may reduce hardness, wear and corrosion performances, and cause the coating to peel off from the substrate under heavy load.

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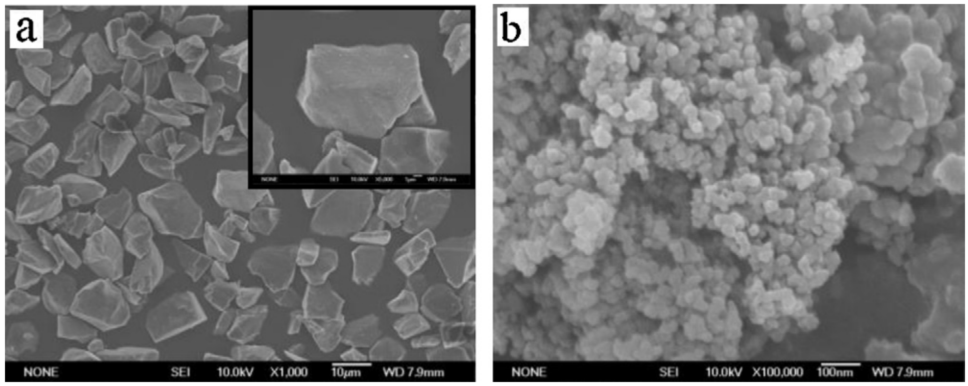

Fig. 1. SEM micrographs of the raw material powders: (a) Al–Si alloy powder and (b) nano-Si_3N_4 powder.

Laser surface modifying is an effective surface modifying technique developed rapidly recently with the advantages of non-contact, high precision, wide application, etc.

Post-treatment for plasma spraying by laser is a new and promising process which could solve the disadvantage of plasma sprayed coating [13]. The metallurgical bonding between sprayed coating and substrate could be obtained. And due to remelting, the defects in the coating could be reduced.

Nowadays, laser remelting of plasma sprayed ceramic coating has been well studied. However, most of the plasma sprayed ceramics are presently focused on Al_2O_3, Al_2O_3–TiO_2, and ZrO_2 [14–16]. There is rare work devoted to the Si_3N_4 ceramic, because of its oxidizability under high temperature and poor wettability. It could reduce the thermal stress and defects caused by solidification shrinkage, and could improve the wettability to adopt the Al–Si powders as basal powders integrating with Si_3N_4 ceramics and reasonably control the preparation technology. Moreover, few contributions have been conducted to the laser remelting modifying of plasma sprayed magnesium alloy.

In this study, Al–Si based 1 wt% nano-Si_3N_4 coating was successfully fabricated by plasma spraying on AZ31B magnesium alloy. Then the as-sprayed coating was remelted by a CO_2 laser subsequently. The aim of this study is mainly to investigate the microstructure, interface reaction, phase composition, as well as the microhardness, and to discuss the reasons of phenomena appeared during the laser melted process. This research also provided essential experimental and theoretical basis to promote the application of the combination of pre-plasma spraying and post-laser remelting technique.

2. Experimental materials and procedures

2.1. Experimental materials

In the present investigation, a hot-rolling AZ31B magnesium alloy was used as the substrate material, which was cut into coupons with a dimension of 180 mm × 75 mm × 10 mm by means of wire electrical discharge machining. The chemical composition (wt%) of the substrate material is listed as follows: 3.22 Al, 1.15 Zn, 0.400 Mn, 0.0133 Si, 0.0019 Fe, and the balance is Mg.

The raw material powders are composed of 99 wt% Al–Si alloy with particle size of 1–30 μm and 1 wt% nano-Si_3N_4 with particle size of 30–50 nm. The scanning electron microscopy (SEM) micrographs of the raw material powders are shown in Fig. 1. All the raw powders were mixed in ethanol liquor for 2 h in order to prevent from reuniting of nano-particles, to improve the wetting capability between nano-particles and other materials. Then, the slurry was dried, well-distributed and commixed by a boult, and the powders were used as the composite powders for plasma spraying.

2.2. Plasma spraying and post-laser treatment

Plasma spraying was performed by a high efficiency supersonic atmosphere plasma spraying system (HEPJII) to deposit a sprayed coating. Before plasma spraying, the substrate had been pretreated in order to strengthen the adherence to the coating. It was grit blasted with brown corundum for wiping off the surface oxide and greasy dirt, and then was washed by acetone and aired dry. A mixture of Ar and H_2 was used for the plasma gas, and Ar was used for the powder carrier gas. The atmospheric plasma spraying parameters are listed in Table 1.

After plasma spraying, the as-sprayed coating was remelted by a continuous wave CO_2 laser (HUST-JKT5170) operating at a wavelength of 10.6 μm with a maximum output power of 5 kW. The laser remelting processing parameters, optimized from adequate number of preliminary experiments during the present efforts, were laser output power 3500 W and laser beam scanning speed 240 mm/min. During the laser remelting process, the laser beam was defocused to a spot of 3 mm in diameter at the surface of the as-sprayed coating. The as-sprayed coating was dissolved into the molten pool, and surface oxidation was prevented by Ar gas (99.99% purity) with the flowing rate of 15 L min^{-1}. When it was necessary for the remelted coating to lap the track, the over lap was 20% of one track, which was controlled by a computer. After one track was remelted, the next track would be remelted till the temperature was reduced to room temperature.

2.3. Characterization

The remelted sample was cut along transverse section, then polished and etched. The microstructure, phase constituents and compositions of the sample were examined by a CMM-20 OM (optical microscope), a Y-2000 X-ray diffractometer (XRD), and a JSM-6700F scanning electron microscope (SEM) equipped with X-ray energy-dispersive spectroscopy (EDS). Microhardness of the sample was measured by a HVS-1000A Vickers microhardness tester with a 50 mg applied load and a 15 s dwell time.

Table 1
Atmospheric plasma spraying parameters.

Spraying parameters	Al–Si + nano-Si_3N_4
Arc voltage (V)	130
Arc current (A)	370
Flow rate of primary gas (Ar) (L min^{-1})	70
Flow rate of secondary gas (H_2) (L min^{-1})	12
Flow rate of carrier gas (Ar) (L min^{-1})	8
Rate of powder feeding (g min^{-1})	35
Rate of spraying gun (mm s^{-1})	800
Spraying distance (mm)	100