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Characterization of Fe-based alloy coating deposited by supersonic plasma spraying

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HIGHLIGHTS

- Fe-based coating exhibited few oxides, high density and bond strength.
- Amorphous/nanocrystalline phases were found in the coating.
- Formation mechanism of excellent coating was investigated.

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ABSTRACT

The objective of the present study is to characterize the Fe-based alloy coating deposited by the supersonic plasma spraying process. The condition of the melting particles was in situ monitored. The microstructure of the coating was examined by scanning electron microscope and high resolution transmission electron microscope. The phase composition was examined by X-ray diffraction. The microhardness and porosity were also measured, respectively. Results show the prepared coatings have excellent properties, such as few oxides, high microhardness and a low porosity amount. At the same time, a mass of amorphous/nanocrystalline phases was found in the coating. The mechanism of the formation of amorphous/nanocrystalline phases was investigated. The appropriate material composition of spraying material and flash set process of plasma spraying are the key factors. Moreover, the mechanism for oxidation resistance is also investigated, where the separation between melting metal and oxygen by the formation of SiO_2 films is the key factor.

1. Introduction

Thermal spraying is a type of surface engineering technology which is utilized in many industrial fields [1–3]. Recently many kinds of thermal spraying techniques have been developed, such as flame spray, arc spraying, plasma spraying and high-velocity oxy-fuel (HVOF) [4–6]. All thermal spraying techniques have a similar process. Firstly, the spraying material is melted; secondly, the melted material is driven to deposit on the substrate; finally, the coating with laminated structures and rich in pores is prepared. Thermal spraying technique is suitable to increase the surface property, but has no significant effect on the substrate.

Plasma spraying technique is always noticed for the high material fusion temperature and particle jet velocity. Hence, it is usually employed to deposit high-melting materials, such as ceramics and cermet [7–9]. Moreover, the coatings prepared by plasma spraying process possess excellent performance, such as high density, few defects and high bond strength [10,11]. Nevertheless, the relative low-melting material, such as Fe based alloy does not seem suitable for plasma spraying process, because the high fusion temperature may result in the superfusion of the alloy particle. Taking into account the nature of the plasma arc resulted from the gas ionization, excellent Fe-based coating can be obtained by delivering the Fe-based powders to the lower temperature region of the plasma arc.

In the present study, a supersonic plasma spraying system was used to deposit the Fe-based alloy coating. A novel gun which can deliver the powders to designated region of the plasma arc was introduced. Microstructure of the coating was characterized by scanning electron microscope (SEM), and high resolution transmission electron microscope (HRTEM). The phase structure was examined by X-ray diffraction (XRD) technique. The microhardness was measured by Vickers hardness tester. The measurement of the porosity amount was evaluated by image analysis software. The properties of the coating were also investigated.

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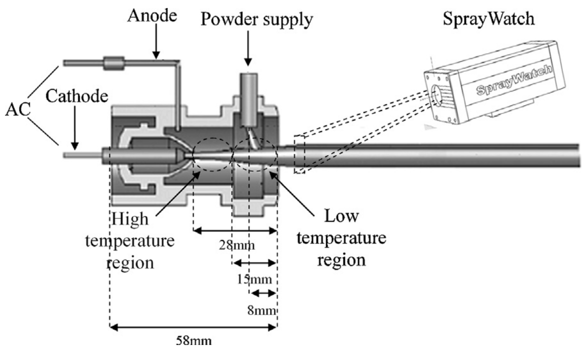

Fig. 1. Schematic of supersonic plasma spraying gun.

2. Experimental procedures

2.1. Preparation of coatings

High-efficiency plasma spraying system with the novel spraying gun was employed to deposit the coating system, i.e. the surface coating and undercoating. Fig. 1 shows the schematic of the nozzle of the novel gun. It can be seen that the low-melting Fe-based powders were transported to the low temperature region for the optimal design of location of the powder supply.

The conditions of melting particles were in situ monitored by a SprayWatch device. It is constituted by a CCD camera with high spectral resolution lens and a control computer with special image processing software. The schematic plan of working SprayWatch device is showed in Fig. 1. The temperature and velocity of melting particles were continuously recorded, and then the average values were calculated, as shown in Fig. 2(a). Fig. 2(b) shows an example of the temperature on-line monitoring of melting particles during the plasma spraying process by SprayWatch device. The vertical ordinate indicates the width of spraying flame and horizontal ordinate represents the temperature of the melting particles. Based on the on-line monitor, this plasma spraying device enabled supersonic spraying and greatly improved the coatings quality by obtaining lower porosity and high bond strength, but at low consumption [12].

A commercially available Fe–Cr–B–Si self-fluxing alloy powder with the nominal composition Cr-13.6, B-1.6, Si-1.1, C-0.16, Fe-balance (wt.%) was deposited for its higher micro-hardness and better wear-resistance at room temperature [13], Fig. 3 shows the morphologies of Fe-based powders. The powder with the diameter ranging from 20 to 40 μm exhibits spheric shape and therefore has excellent flowing power during the spraying process. The commercial Ni–Al alloy powders with the nominal composition Ni-90, Al-10 (wt.%) were used as undercoating material. The bond strength between the coating and substrate will be increased by the heat-producing reaction between the melting aluminum and nickel as impinging on substrate [14]. The AISI 1045 steel with ring-type geometry was used as substrate.

Prior to plasma spraying, in order to reduce contaminations and obtain a clean and rough surface for enhancing the bond strength between the coating and substrate, the plane surface of substrate was cleaned by acetone solution in an ultrasonic bath and sand-blasted by using the corundum with powder of mesh 48 size, blasting pressure of 0.6 MPa, blasting angle of 70°, standoff distance of 100 mm and blasting time of 15–25 s. During the plasma spraying process, argon gas was used as the primary gas, hydrogen gas and nitrogen gas were used as secondary gases. Table 1 lists the relevant details of the supersonic plasma spraying parameters.

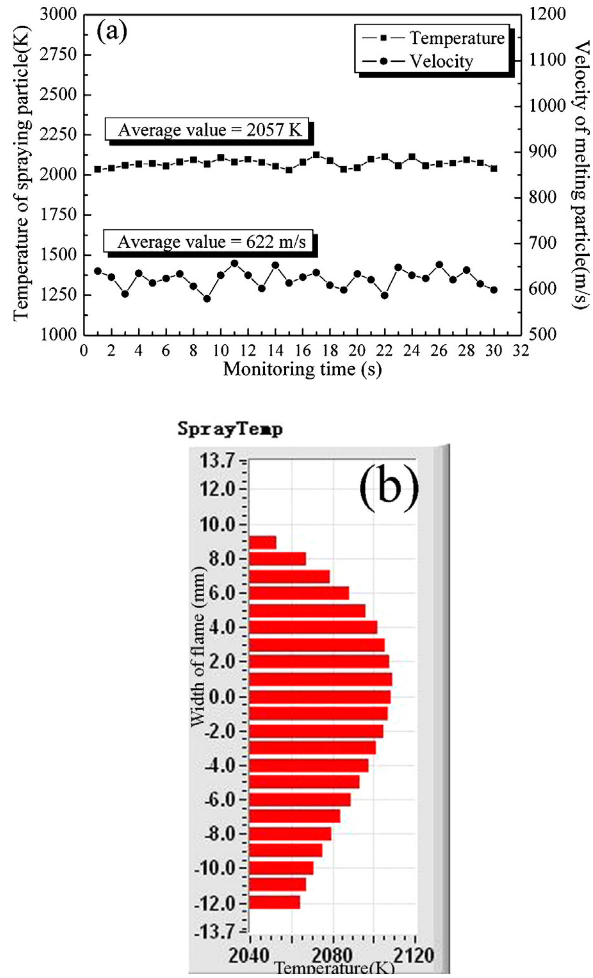

Fig. 2. Monitor of melting particles by SprayWatch: (a) the average values of temperature and velocity of the particle; (b) the proof of the temperature of melting particle temperatures.

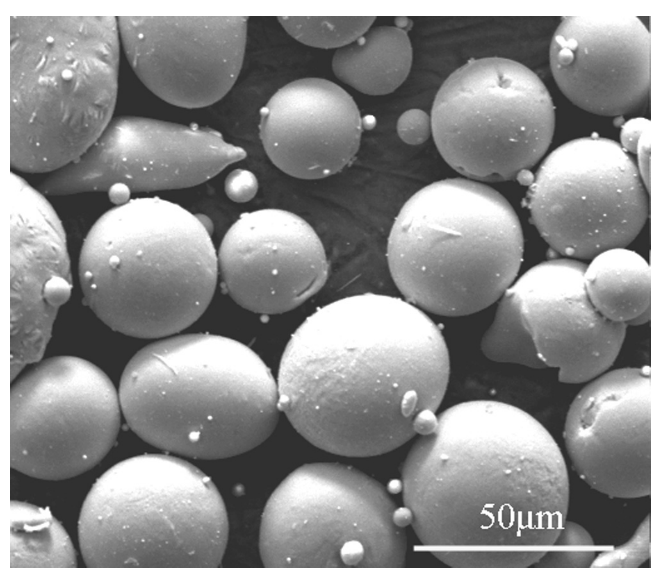

Fig. 3. Morphologies of Fe-based powders.