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Heat treatment induced intermetallic phase transition of arc-sprayed coating prepared by the wires combination of aluminum-cathode and steel-anode

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ABSTRACT

A method to prepare intermetallic composite coatings employing the cost-efficient electric arc spraying twin wires assistant with suitable heat treatment was developed. In this study, a Fe–Al composite coating was produced by spraying twin wires, i.e. a carbon steel wire as the anode and an aluminum wire as the cathode. The inter-deposited Fe–Al coating was transformed in-situ to Fe–Al intermetallic composite coating after a post annealing treatment. The effect of annealing treatment conditions on phase composition, microstructure and mechanical properties of the coating was investigated by using XRD, SEM, EDS and OM as well as microhardness tester. The results show that the desirable intermetallic phases such as Fe_2Al_5, FeAl and Fe_3Al are obtained under the annealing condition. The main oxide in the coating is FeO which can partially transform to Fe_3O_4 up to the annealing condition.

1. Introduction

Iron aluminde intermetallic alloys are attractive candidates for use in high temperature environments because of their low cost, low density and availability of raw materials with good corrosion and oxidation resistance [1–5]. Nevertheless, industrial applications of these alloys have been limited by their brittleness at room temperature and their poor creep resistance as well as difficulty in shaping [6]. To avoid these problems, the coating processing techniques such as self-propagating high-temperature synthesizing (SHS), hot dipping and thermal spraying have been used [7–9]. Previous literature [10–13] has reported the preparation of microstructured Fe–Al intermetallic coatings achieved by high velocity oxy-fuel (HVOF) spraying technique and atmospheric plasma spraying (APS) technique. Some nanostructured Fe–Al based coatings with high hardness have also been successfully produced using the milled powders and HVOF [13,14].

Among the available thermal spraying methods for producing coatings or net-shape forming, twin-wire electric arc spraying, as one of the most cost-effective techniques, has been widely accepted in industry. Unlike the HVOF or APS process, the electric arc spraying uses two metal wires as the feedstock, namely the material to be deposited is introduced in the arc in form of two wires serving as consumable electrodes. Fabrication of intermetallic coatings is therefore a little difficult because no available pre-alloyed wires with intermetallic composition can be provided. Recently, this drawback has been substantially improved by using the cored wires [15,16] where alloyed and/or mixed powder is packed by metal strips. Once arc spraying is performed, the powder will metallurgically react with the strips to form aluminides. For example, Binshi Xu et al. [17,18] investigated the feasibility of depositing Fe–Al intermetallic composite coatings using electric arc spraying technique and cored wires.

Besides the developments of arc-sprayed composite coatings by cored wires, another new method is to deposit coatings using two different metal wires serving as the consumable anode and cathode. This fabrication process is capable of providing a wide variety of composition combinations of the relevant wires. For instance, some composite coatings were successfully prepared by

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the combination of titanium and aluminum wires [19–21], carbon steel and copper wires [22,23], stainless steel and aluminum wires [24,25], zinc and aluminum wires [26] and so on. Most of the studies show that dense composite coatings can be produced from several wire combinations, nearly no alloy reactions between the materials of anode and cathode are found in these processes, and thus the coatings are just mechanically mixed with the components of individual wires. However, none of the works on subsequent processing such as heat treatment were performed on these coatings.

It is noticeable that a method for producing intermetallics has been developed recently where metal powder mixtures (Ti/Al [27,28], Ni/Al [29] and Fe/Al [30,31]) were compacted using a spraying technique called cold spray, these dense composites transformed into aluminides under controlled thermal treatments. Although cold sprayed coatings have the properties such as small grain size and low oxide content, the higher cost and relatively lower efficiency performed by cold spraying limit its applications in industry as compared with thermal spraying techniques, especially the electric arc spraying technique. In addition, requirements to the feedstock powders are very strict for cold spraying, especially for the Fe–Al powders, which have to be pretreated with a high-energy ball mill before spraying [30,31]. The present work is therefore aimed to study the feasibility of electric arc spraying carbon–steel and aluminum twin wires to form composite coating, and to investigate the phase transitions, e.g. intermetallics formation, between steel and aluminum splats under controlled annealing conditions.

2. Experimental

The experimental set-up of producing coatings is shown in Fig. 1. An arc spraying system developed by National Key Laboratory for Remanufacturing of China consists of a power supply, a wire feeder, a control unit and a high velocity arc spraying gun. Commercially available high carbon steel wire (with composition Fe – 0.82 wt.% C – 0.6 wt.% Mn – 0.1 wt.% Cr) and aluminum wire (99.6 wt.% purity) with 2 mm diameter were used as the spraying feedstock. Mild steel substrate with a dimension of 25 mm × 65 mm × 6 mm was grid blasted before spraying. It has been experimentally confirmed that using higher melting point wire as the anode and lower melting point wire as the cathode can improve the arc stability owing to the relatively balanced melting rates at the two electrode tips [20]. Therefore, the high carbon steel wire was used as the anode and aluminum wire as the cathode. The spray processing parameters are shown in Table 1.

Heat treatment process was performed on the as-sprayed specimens using a box-type resistance furnace. Three samples were annealed for 2 h at 450, 550 and 650 °C, respectively. Subsequently, a water quenching process was performed on all samples.

Phase composition analysis of the as-sprayed and annealed samples was performed with X-ray diffraction (XRD). Measurements were carried out at room temperature with a Bruker D8 Advance (Germany) diffractometer using Cu Kα radiation for an angle range of 2θ = 20–100°, with voltage 40 kV, current 25 mA and a step of 0.03°. In order to improve the test precision of XRD, all the samples were looking-glass polished. Standard metallographic and optical microscopy (OM) techniques were applied. The microstructure and chemical elements analysis of the samples were performed by using a Quant 200 type scanning electron microscope (SEM) coupled with an energy dispersion spectroscope (EDS). An Olympus PMG3 type optical microscope was also used to analyze the coating microstructure. Microhardness was measured with a IIMT-3 microhardness tester under the conditions of 100 g load for 15 s.

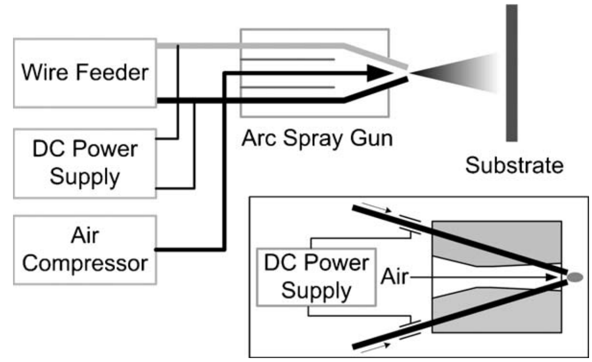

Fig. 1. Schematic diagram of the experimental set-up.

Table 1
Electric arc spraying parameters.

Parameter	Setting
Arc voltage	36 V
Arc current	140 A
Atomizing gas	Air
Gas pressure	0.7 MPa
Spray distance	200 mm

3. Results and discussion

3.1. Microstructure characteristics of deposited coating

The SEM image of the steel/aluminum coating of Fig. 2 shows a lamellar structure with almost separate steel and aluminum splats, mingled with a little oxides and micropores. The thickness of both steel splats and aluminum splats is less than 10 μm. Furthermore, several SEM images of the as-sprayed coating show that some continuous oxide films cohered on the metal splat interfaces are broken due to the intensive deformation, and that some small oxide films (particles) are immixed into the insides of metal splats. Disruption of the thin oxide films at the interface of splats would expose fresh and active material, which is brought into intimate conformal contact between aluminum and steel splats. As a result,

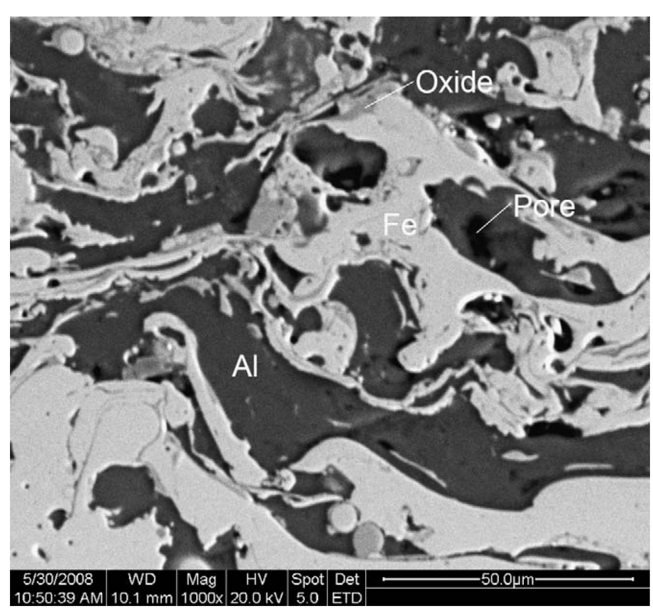

Fig. 2. SEM image showing structure of as-sprayed steel-aluminum coating.