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Spraying of Fe-based amorphous coating with high corrosion resistance by HVAF

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ABSTRACT

Fe-based amorphous coating with composition of $Fe_{42.87}Cr_{15.98}Mo_{16.33}C_{15.94}B_{8.88}$ has been deposited on a mild steel substrate by high velocity air fuel thermal spraying. The microstructure and corrosion properties of the Fe-based alloy coating were studied in detail. It was found that the obtained Fe-based coating showed fully amorphous state with about 100 μm in thickness. Also, the obtained coating exhibited very dense structure with a porosity of 1.5%. Polarization tests demonstrated that the coating exhibited better corrosion resistance than stainless steel in NaOH solution and simulated seawater. The reasons of superior corrosion have been discussed from the alloy elements and the homogeneous structure of Fe-based amorphous coating.

1. Introduction

Due to the lack of grain boundaries and dislocations, metallic glasses have gained an interest of their well combinations high strength, high elastic limit, excellent wear resistance, and superior corrosion resistance [1]. So far, numerous metallic glasses with high glass forming ability have been explored in Ti- [2], Zr- [3], Fe- [4], and Cu-based alloy systems [5]. However, the limited glass formation ability has significantly hindered the range of engineering applications. In order to widen their industrial application fields, the route of spraying as coating has been recognized as an efficient way to overcome the drawback [6]. In the past years, several coating technologies have been used to fabricate amorphous coatings, such as plasma spraying [7], arc spraying [8,9], laser surface process [10,11], high velocity oxygen fuel spraying (HVOF) [12,13], high velocity air fuel spraying (HVAF) [14,15], and so on. Compared with the methods mentioned above, HVOF thermal spraying is one of the most widely used process for depositing coatings such as metals, cermets, ceramics, and metallic glasses, which seems more feasible due to its high cooling rate of 10^7–10^{10} K/s[16]. However, in comparison with the HVOF process, HVAF system which combusts a mixture of compressed air and fuel gas in the combustion chamber has a lower spraying temperature (1600 K) than HVOF (1900 K) process. So, the chemical uniformity by controlled oxidation in the coating by HVAF can be improved [17]. Moreover, the high particle velocity, typically over 700 m/s, of the HVAF process has been reported to provide lower porosity in the coating and well adhesion strength than HVOF. Furthermore, the use of air instead of oxygen for combustion by HVAF is expected to lower the cost of the spraying and promote its competitiveness over other processes [18]. Up to now, some attempts have been made on preparation of amorphous alloy coatings by means of HVAF process. Liu et al. have reported that Fe-based amorphous coatings were prepared by HVAF and HVOF processes on a mild steel substrate. Corrosion resistance in 3.5 wt % NaCl solution of the coatings prepared by the two processes was comparatively studied. The results demonstrate that HVAF with less cost can be a promising spray process to fabricate the Fe-based amorphous coating for industrial applications [14]. Ye et al. have carefully researched the influence of spraying parameters on coating by tuning the spraying gun length, spraying distance, and powder feed rate. Results indicate that spraying gun length is the key factor in forming perfect amorphous coating [19]. In previous studies, most of the coating prepared by HVAF has been studied, but the systematic studies on corrosion behavior is still lacking.

Among the metallic glasses systems being researched, Fe-based amorphous metallic glasses are considered to be extremely viable candidates as surface protective coatings owning to their high crystallization temperature, superior corrosion, good magnetic properties, and relatively low material cost. In this paper, a $Fe_{42.87}Cr_{15.98}Mo_{16.33}C_{15.94}B_{8.88}$ (at %) with high glass formation ability was selected to prepare amorphous alloy coating by HVAF

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spraying. The microstructure and the morphology of the cross-section of the as-sprayed metallic glass coatings were examined. The corrosion behavior of the Fe-based metallic glass coating was assessed by comparing with different solution.

2. Experimental

A mixture of pure elements of Fe, Cr, Mo, C, and B with 99.9 wt % purity was induction melted under high purity argon atmosphere and then atomized. The chemical composition of atomized powder is $Fe_{42.87}Cr_{15.98}Mo_{16.33}C_{15.94}B_{8.88}$ (at %). The particle size distribution was examined by using a laser-assisted particle size analyzer (MS-2000). The mild steel (0.45 wt % C) was used as substrates with a dimension of $10 \times 10 \times 10\,mm^3$. All substrates were sand blasted followed by washing with acetone and methanol to clean the surface. The main spraying parameters are air pressure 0.62 MPa, fuel pressure 0.55 MPa, spraying distance 250 mm, and powder delivery rate 5 rpm. The percentage of porosity of the amorphous coatings was evaluated by SEM micrograph analysis using an Image Pro Plus software. Scanning electron microscopy (SEM), and X-ray diffraction (XRD) were used for the microstructure characterization and phase analysis of the gas-atomized powders and as-sprayed Fe-based alloy coatings. The corrosion behavior of the samples was evaluated by electrochemical measurement with a three-electrode cell using a platinum counter electrode and a saturated calomel reference electrode. The working electrode was exposed to an area of $1\,cm^2$. Electrolytes used were NaOH alkali solutions (0.5 mol/L, 1 mol/L, 2 mol/L), and 3.5% NaCl (mass %) aqueous solution which simulated seawater. Potentiodynamic polarization curves were measured with a potential sweep rate of 0.01 mV/s from −1 V to 1.5 V in all solutions open to air at 298 K after immersing the specimens with half-hour, when the open-circuit potentials became almost steady. For comparison, cast 304 stainless steel plates were also selected to perform the electrochemical measurements in the same way.

3. Results and discussion

Fig. 1(a) presents the SEM images of the Fe–Cr–Mo–C–B alloy powders. It can be seen that the majority of the particles produced by gas atomization in an argon atmosphere are spherical or near-spherical in shape. Some large powders have small satellites with a size of 10–15 μm, as shown the inset of Fig. 1a. During gas atomization process, some smaller particles in the powder experienced a higher solidification rate can easily adhere to the molten surfaces of larger particles, resulting in the formation of such attached particle morphology. Most of them exhibit smooth surface as the meaning of good fluidity [20]. Fig. 1(b) shows the size distribution of Fe-based alloy powders. It can be seen that the Fe-based alloy powders exhibit a lognormal size distribution. The particle size ranges from 20 to 50 μm, and the average particle diameter is 35 μm.

Fig. 2(a) shows the typical region from cross-sections of the coatings which reveal its dense layered structure, although, some pores exist as very dark regions can be seen. In general, the big pores located between flattened droplets are mainly caused by the loose packed layer structure of gas porosity phenomenon, while the small pores with the flattened particles originate from the shrinkage porosity. In despite of the presence of these defects, the coatings express a low porosity below 1.5% which is typical of AC-HVAF thermal sprayed deposits. During thermal spraying,

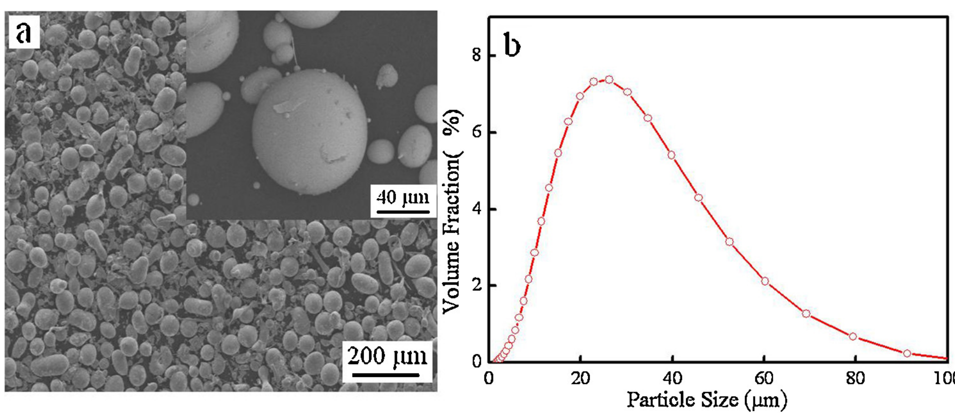

Fig. 1. (a) SEM images and (b) particle size distribution of Fe-based alloy powders.

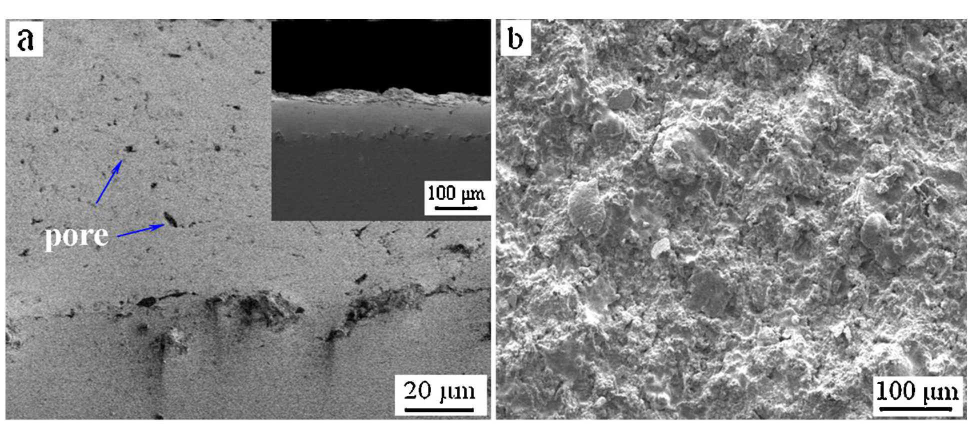

Fig. 2. (a) SEM image of cross-section and (b) planar view of Fe-based alloy coating.