



Fabrication, tribological and corrosion behaviors of detonation gun sprayed Fe-based metallic glass coating



Hong WU¹, Xiao-dong LAN¹, Yong LIU¹, Fei LI², Wei-dong ZHANG¹, Zi-jin CHEN¹, Xiong-fei ZAI¹, Han ZENG¹

1. State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, China;

2. State Key Laboratory of Construction Machinery,

Zoomlion Heavy Industry Science and Technology Co., Ltd., Changsha 410013, China

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Abstract: A metallic glass coating with the composition of $\text{Fe}_{51.33}\text{Cr}_{14.9}\text{Mo}_{25.67}\text{Y}_{3.4}\text{C}_{3.44}\text{B}_{1.26}$ (mole fraction, %) on the Q235 stainless steel was developed by the detonation gun (D-gun) spraying process. The microstructure and the phase aggregate were analyzed by scanning electron microscopy and X-ray diffractometry, respectively. Microhardness, wear resistance and corrosion behavior were assessed using a Vickers microhardness tester, a ball-on-disk wear testing machine and the electrochemical measurement method, respectively. Microstructural studies show that the coatings possess a densely layered structure with the porosity less than 2.1%. The tribological behavior of the coatings examined under dry conditions shows that their relative wear resistance is five times higher than that of the substrate material. Both adhesive wear and abrasive wear contribute to the friction, but the former is the dominant wear mechanism of the metallic glass coatings. The coatings exhibit low passive current density and extremely wide passive region in 3.5% NaCl solution, thus indicating excellent corrosion resistance.

Key words: Fe-based metallic glass coating; detonation gun spraying; microstructure; tribological behavior; corrosion behavior

1 Introduction

In the past decades, metallic glasses have attracted significant interest due to their superior mechanical, physical and chemical properties, compared with their crystalline counterparts [1–3]. It is well known that metallic glass alloys exhibit high hardness, high tensile strength and good fracture toughness [4]. The unique properties of bulk glassy alloys originate from the random atomic arrangement of metallic glasses that contrasts with the regular atomic lattice arrangement found in crystalline alloys, which makes bulk glassy alloys extremely attractive for structural and functional uses [5].

However, as a matter of fact, industrial applications of metallic glass alloys have been restricted due to the difficulties encountered in the production of bulk quantities and brittleness of bulk metallic glass alloys [6]. To overcome the limitations and expand the applications

of metallic glass alloys, researchers have developed the process to deposit metallic glass coatings on structural or functional components, which can combine excellent mechanical properties of the substrates and metallic glass coatings and significantly improve the properties such as corrosion resistance and wear resistance. Fe-based metallic glass alloys have been selected as a prominent candidate to work as surface coatings that protect the surface of structural materials owing to their excellent wear and corrosion resistance, and relatively low cost [7]. Up to now, there exist various techniques to produce metallic glass coatings, such as high velocity oxygen fuel (HVOF) spraying [8], magnetron sputtering [9], vacuum plasma spraying [10] and laser surface processing [11]. Each of these techniques has advantages and disadvantages over its counterparts. Compared with the plasma spray process and laser clad, the detonation gun (D-gun) spraying technique is an especially suitable method to prepare Fe-based metallic glass coatings due to its ability to produce high-density coatings with larger

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Corresponding author: Yong LIU; Tel: +86-731-88830406; E-mail: yonliu@csu.edu.cn, yonliu11@aliyun.com

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compressive stress and improved metallurgical bonding to the substrate. The previous works also demonstrated that Fe-based metallic glass coatings prepared by D-gun spraying can increase the density of the coating up to 98% and thus improve the wear, adhesion and mechanical properties moderately [12]. Some attempts have been made on preparation of amorphous alloy coatings by the D-gun spraying process [13–15], and most of the coatings show prominent properties. However, there is a lack of information concerning the wear behavior and related wear mechanism of Fe-based metallic glass coatings.

In the present study, the microstructure characteristics and tribological behavior of Fe-based metallic glass coatings fabricated by the D-gun spraying were systematically investigated in order to understand the wear mechanism, and the comprehensive corrosion behavior of the coatings in NaCl solutions was also examined.

2 Experimental

The powders with nominal composition of Fe_{51.33}Cr_{14.9}Mo_{25.67}Y_{3.4}C_{3.44}B_{1.26} (mole fraction, %) were manufactured using water atomization technique. The water-atomized powders with particle sizes in the range of 50–100 μm were deposited via D-gun spraying onto the Q235 steel sheet substrate with dimensions of 300 mm × 90 mm × 8 mm for their good fluidity. The surface of the substrate was activated by grit-blasting pretreatment after the removal of the oxide layer. Then, the substrate was degreased by acetone and dried in air. The detailed parameters of the spraying are listed in Table 1 and the thickness of the Fe-based metallic glass coatings is between 300 and 500 μm.

Table 1 Parameters employed in D-gun spraying

Parameter	Value (condition)
Working gas	O ₂ +C ₂ H ₂
Oxygen flow/(m ³ ·h ⁻¹)	1.25
Acetylene flow/(m ³ ·h ⁻¹)	1.1
Feed rate/(g·min ⁻¹)	40
Spray distance/mm	160
Working frequency/s ⁻¹	4

The as-deposited coatings were cut by wire electrical discharge machining and polished to mirror finish according to the standard procedures. The morphology of the powders and cross-sectional microstructures of as-deposited coatings were characterized by scanning electron microscopy (SEM) combined with EDAX analyzer. X-ray diffraction (XRD) was carried out using a Rigaku D/max-2550VB

diffractometer (Cu K_α radiation) with 2θ diffraction angle ranging from 20° to 80°, at a scanning rate of 0.02 (°)/s. Jade software 6.0 was used for analysis of the amorphous phase content in the D-gun deposited metallic glass coatings. Firstly, the XRD pattern of the sample was smoothed in order to remove all kinds of chance fluctuations (noise). Secondly, the strength of amorphous peak was fitted in the whole pattern and then fitted manually until all the diffraction peaks in XRD pattern were fitted. Finally, the crystallinity (X_c) of the sample was calculated according to the Jade formula:

$$X_c = \frac{\sum I_c}{\sum I_c + \sum I_a} \quad (1)$$

where I_c is the total diffraction integral strength for the crystallization part and I_a is the total diffraction integral strength for the amorphous part. Microhardness measurement of the coatings (Vickers scale) was conducted on the central part of the cross-section samples using a Vickers microhardness tester with an applied load of 50 g and indentation time of 10 s. The average of 10 measurements was determined to be the final value of the microhardness. Friction and wear experiments were conducted under dry condition using a ball-on-disk sliding apparatus (CERT UMT-3, USA). Wear loss and friction coefficient were constantly recorded during sliding. The corrosion behavior of the Fe-based metallic glass coatings was investigated by electrochemical measurement on CHI600B. Electrolyte used was 3.5% NaCl solution. Electrochemical measurements were conducted in a three-electrode cell using a platinum counter electrode and a saturated calomel reference electrode. Potentiodynamic polarization curves were measured at a potential sweep rate of 30 mV/min in the solutions open to air at 298 K after immersing the specimens for several minutes, when the open-circuit potentials became almost steady. For comparison, Q235 steel sheet and Fe-based metallic glass coatings sprayed by D-gun spraying were selected to perform the electrochemical measurements under the same conditions.

3 Results and discussion

3.1 Coating characteristics

The typical SEM images of the water-atomized Fe-based alloy powders with diameters of 50–100 μm are presented in Fig. 1. It is shown that most of the as-atomized powders are spherical or near-spherical although some of them have small satellites attached. During the water atomization, different particle sizes have different solidification rates. It is universally accepted that the solidification rate is inversely proportional to the particle size. Thus, the powders with

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