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Characterization and tribology performance of Fe-based metallic glassy composite coatings fabricated by gas multiple-tunnel plasma spraying

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ABSTRACT

In the present study a novel of gas multiple-tunnel plasma spraying technology was adopted to fabricate composite coatings with various content of Fe-based metallic glass and ZrO_2. By this way the glassy formation ability of the Fe-based metallic glass is not affected, and proportion of the two phases in the composite coatings can be regulated according to design. The tribological test results indicate that the addition of ZrO_2 improves the wear resistance. However, the wear rate of the composite coating is nonlinear related to the fraction of ZrO_2. There is a transformation from toughness to brittleness with the increase of ZrO_2 in the composite coating. Therefore, the wear failure mechanism of the composite coating is changed from abrasive wear to fatigue wear.
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1. Introduction

Bulk metallic glasses (BMGs) possess excellent mechanical properties, such as large elastic limit, high strength, high hardness and high corrosion resistance [1–4]. However, due to the limitation of the glassy forming ability, the thickness (or diameter) of BMGs is usually small, which restricts its application as engineering material. Therefore, it's a good idea to design and process metallic glasses as wear and corrosion-resistance coatings. Shen [5] reported the Fe-based metallic glassy coating had higher corrosion resistance in aggressive H_2SO_4 solutions than 921 A navy steel and Ti-6Al-4 V. Kobayashi [6] obtained Fe-based metallic glassy coating and researched the mechanical properties. The results indicated that the Vickers hardness of metallic glassy coating was similar to that of the original powder and the abrasive wear resistance was higher than the SUS substrate.

However, since the deformation of BMGs is highly localized in a few shear bands that many of them exhibit poor plasticity [7]. It results in the brittle spalling of the coatings during abrasive wear. Generally, in order to improve the plasticity of BMGs, the method of introducing crystalline phases to form bulk metallic glassy composites (BMGCs) is adopted. Previous work indicated that the BMGCs with ZrO_2 [8], Ta [9], Nb [10] and Si_3N_4 [11] obtained large plastic strain. For the metallic glassy coatings, the abrasive wear property also can be improved by introducing crystalline phases into the metallic glassy matrix. G. Liu [12] obtained Fe_2B and (Fe,Cr)B in the Fe-based metallic glassy coatings by heat treatment above 873 K, and the wear loss was reduced obviously. The research of Yugeswaran [13] indicated the wear property was improved by precipitated crystalline phases during spraying coating process.

Nevertheless, there is a problem that the fraction of the crystalline phases in the metallic glassy composite coatings which was obtained by heat treatment [14] or formation during sprayed process [15,16] cannot be regulated. In other words, the composition cannot be obtained according to the application conditions. Therefore, it is necessary to develop a new method to realize the fabrication of the composite coatings can be gained with designed composition.

In order to avoid crystallization during spraying, multiple-tunnel feeding technology was adopted to fabricate composite metallic glassy coatings in the present study. In this spraying system, the ceramic ZrO_2 and Fe-based metallic glassy powders were feeded into the plasma flame flow, respectively. The ZrO_2 ceramic powders were feeded in the plasma spray gun at the high temperature of the plasma flame flow. Meanwhile, the Fe-based metallic glassy powders were feeded out of the plasma spray gun at the low temperature of the plasma flame flow. Using this method, the Fe-based metallic glass and ZrO_2 composite coatings were obtained. The glassy formation ability of the Fe-based metallic glass is not affected, and proportion of the two phases in the composite coatings can be regulated according to design. And the composite coatings exhibit superior wear resistance than Fe-based coating.

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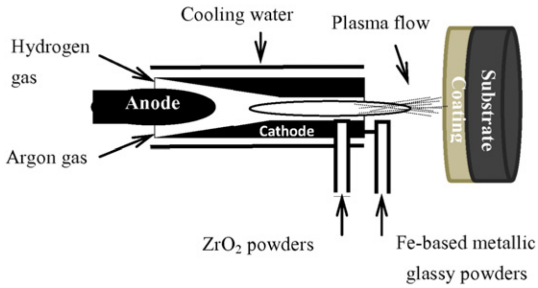

Fig. 1. Schematic of gas multiple-tunnel plasma spraying torch.

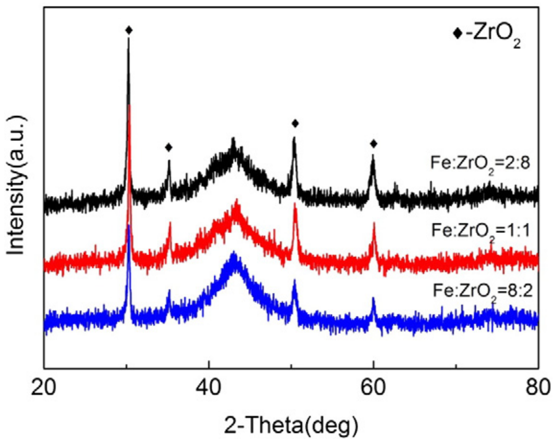

Fig. 2. XRD patterns of composite coatings.

2. Experimental procedures

Commercially available Fe-based amorphous powders (FeCrMoBC provided by Metalliquid Co., Ltd. (China)) with a size of about 10–50 μm were prepared by alloy gas atomization. The composition of the feedstock powders is $Fe_{45}Cr_{16}Mo_{16}C_{18}B_5$ by atomic ratio. Ceramic powders (ZrO_2) provided by Jinjiang Spraying Materials Co., Ltd. (China) with size about 20–40 μm.

The coatings were prepared by plasma spraying equipment, which includes a GP-80 electric power of 80 KW and a BT-G3 gun manufactured by Taixing Yeyuan Device Company in China. The carbon steel (0.14–0.22 wt.% C) substrate was machined into samples of 10 mm × 10 mm × 10 mm. Before spraying process the substrate was sand-blasted. The Ni_{60} powder was plasma sprayed on the treated substrate as bond coating. The Fe-based metallic glassy coating, ZrO_2 coating and composite coatings with various proportion (20 wt.% ZrO_2, 50 wt.% ZrO_2 and 80 wt.% ZrO_2) were fabricated. For the fabrication of composite coatings, the ZrO_2 powders were feeded into the sprayed gun to reach the flame flow with highest temperature. The Fe-based metallic glassy powders was feeded out of the sprayed gun, and the distance to the sprayed gun nozzle is 16 mm. The spraying schematic diagram is shown in Fig. 1. The plasma spraying parameters were as follow: (a) spraying current was 500 A, (b) spraying voltage was 70 V, (c) primary gas (Ar) flow rate was 80 L/min, (d) secondary gas (H_2) flow rate was 20 L/min, (e) spraying distance was 90–110 mm.

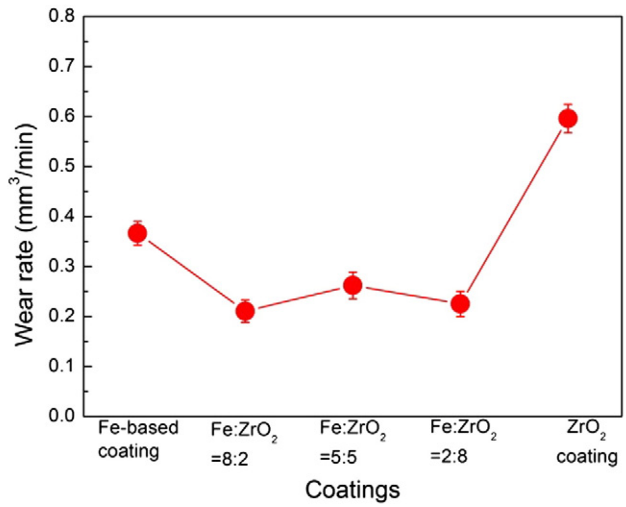

Fig. 4. Sliding wear rate of Fe-based metallic glassy coating, ZrO_2 coating and composite coatings at applied load 30 N.

The surface morphology and microstructure of coatings were investigated with a Scanning Electron Microscopy (SEM, S-4800, Hitachi, Japan), in combination with energy dispersive X-ray analysis (EDAX). The phase constitution of the metallic glassy powders and the composite coatings were characterized by X-ray diffraction (XRD, Philips X'-Pert MPD) with Cu Kα radiation. A ball-on-disc tribometer (SFT-2M, Zhongkekaihua, Technology development Co., Ltd., China) was adopted to evaluate the tribological properties of the Fe-based metallic glassy coating and the composite coatings sliding against commercially obtained Si_3N_4 balls (5 mm in diameter) in air. The tests were performed under the applied loads of 30 N. In all tests, the sliding speed was selected at a constant value of 800 r/min and the duration of sliding was 15 min.

3. Results and discussion

Fig. 2 shows the XRD patterns of composite coatings with various proportion of ZrO_2 and Fe-based metallic glass. The results show that the composite coatings are consisted of ZrO_2 and Fe-based metallic

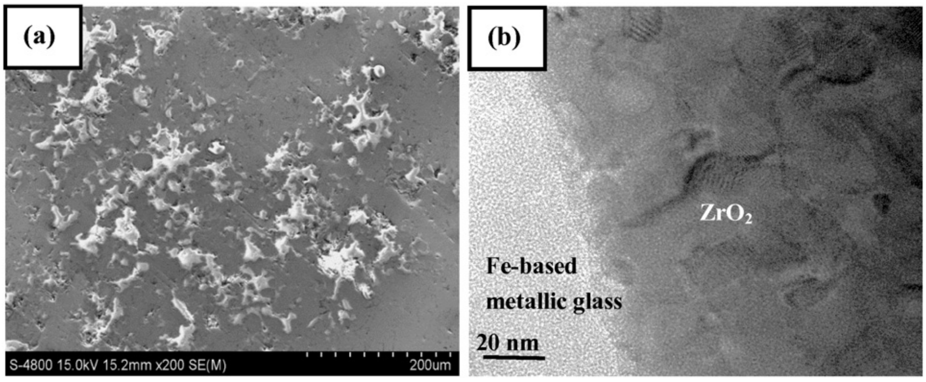

Fig. 3. SEM morphology of the composite coating with 20 wt.% ZrO_2 (a) and TEM morphology of the interface (b).

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