PROPERTIES OF METALLIC GLASS COATINGS ON AN ALUMINUM ALLOY SUBSTRATE PRODUCED USING A HVOF SPRAYING PROCESS

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ABSTRACT

An 170μm thick, Fe-based bulk metallic glass ($Fe_{43}Cr_{16}Mo_{16}C_{15}B_{10}$) coating was successfully formed on an aluminum alloy (A5052) metal substrate using an HVOF (High Velocity Oxygen Fuel) spraying process. X-ray diffraction analysis determined that the sprayed remains amorphous after spraying. The amorphous coating shows good adhesion to the metal substrate, and has a high hardness of HMV 900-1000, very low wear loss, and a comparably high friction coefficient of 0.5 to 0.6 determined using a ball-on-disc wear tester.

INTRODUCTION

Aluminum alloys are widely used in industry for their lighter weight, energy efficient and recyclable goods, the need to replace many materials, both with technical and economical considerations, and so on. However, aluminum materials in general exhibit poor wear resistance because of their softness. To avoid this disadvantage, the implementation of wear resistance coatings deposited by spraying process has been proposed [1-5].

Significant interest has been generated in amorphous alloys due to their unique physical, mechanical, and chemical properties [6]. Consequently, a variety of technologies have been used to produce such coatings. Recently, it has been discovered that special multi-component alloys can form amorphous structure with much slower cooling rate (around 100K/sec) during solidification than conventional alloys [6-7]. It is known that the cooling rate required for the formation of amorphous structure of conventional alloys is usually higher than 10^5K/sec. These alloys with high glass forming ability are called BMG (Bulk Metallic Glass) alloys.

It is known that the Fe-based metallic glass is a promising candidate due to high hardness and corrosion resistance [7-10]. Because of the absence of crystalline anisotropy the Fe-based buck metallic glass exhibits higher strength and hardness as compared with the corresponding crystalline phase.

Thermal spraying is probably the most economical method for the production of thick amorphous surface layers. However, few successful thermal sprayed coatings have been developed and commercialized since it is difficult to produce fully amorphous structure in air. Furthermore, thermal sprayed coatings with partially amorphous structure do not give anticipated excellent protection on wear and corrosion since defects such as lamellar structure and pores which are unique in thermal sprayed coatings overwhelm the beneficial effects of amorphous structure.

Most of previous investigations have worked with Fe- and Ni-based alloys with eutectic composition containing metalloid such as B, Si, and C [7-8, 11-12]. Although it was reported that the initial powder state has little or no influence on the amorphous content of the coatings, utilizing the fully amorphous content of the coatings since the HVOF spraying frequently contains unmelted particles. It is also expected that utilizing the HVOF spraying may prevent the formation of the oxide phase in the coating since the atmosphere of the HVOF spraying is reducing rather than oxidizing.

This article reports on the amorphous phase formation of Fe-based BMG forming alloy by HVOF spraying. This is a new approach that the BMG forming alloys with high hardness and good wear resistance praying process.

EXPERIMENTAL DETAILS

Preparation of the powders for spraying

One of the well-known BMG alloys, $Fe_{43}Cr_{16}Mo_{16}C_{15}B_{10}$ (at. %) was used for this investigation [7-10]. The preparation of the powders for spraying was manufactured by water atomization. The shape of the powders is spherical as shown in Fig. 1. Table 1 shows the compositions of the powder prepared for spraying material.

Table 1 Chemical composition (at. %) of the powder.

Composition (at. %)					Size (μm)
Fe	Cr	Mo	C	B	
43	16	16	15	10	25□45

Spraying conditions

HVOF spraying experiments were conducted using a TAFA JP-5000 system. Fuel was Kerosene and the substrate was A5052 with a thickness 5mm. The substrate was blasted with Al_2O_3 grit prior to spraying in order to enhance the adhesive strength between coatings and substrate. A typical set of spray parameters used is presented in Table 2. Deposition thicknesses of 150-200μm were achieved from 12 vertical passes of the gun.

Characterization of the coatings

The microstructure of the coatings was examined by optical microscopy and SEM (Scanning Electron Microscopy) equipped with EDS (Energy Dispersive Spectroscopy). The porosity (% area) of the coatings was measured by image analyzer at a magnification of 500 (KEYENCE Digital microscope VHX-200). About 10 measurements of each sample were conducted to have the average value of the coatings. Phase identification was conducted by XRD on the as-received powder and as-sprayed coatings using Cu K_α radiation at 40kV, 40mA. The scanning rate was 0.02°/sec. for 2θ range of 20-80°. The hardness of the sprayed coatings was measured using a microvickers hardness tester (AKASHI AAV-500 series automatics hardness testing machine) at the load of 0.98N.

Tribological behavior of $Fe_{43}Cr_{16}Mo_{16}C_{15}B_{10}$ bulk metallic glass HVOF sprayed coating on the aluminum alloy substrate was evaluated using a ball-on-disk tribometer under room temperature. Ball of alumina with a diameter of 4.8 mm was used as the counterface materials. The normal load was 10N. The sliding distance was 47.48m and the sliding speed was controlled at 0.21m/s. Coefficient of friction was recorded during each test.

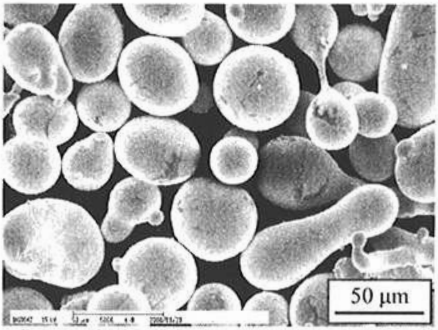

Fig. 1 Scanning electron micrograph showing the morphology of the powder.

Table 2 Experimental conditions of the HVOF spraying using a TAFA JP-5000 spraying gun.

Spray gun	TAFA JP-5000HP
Fuel flow rate	5.1, 6.1, 7.1 GPH*
Oxygen gas flow rate	1800 SCFH**
Pass	12 Pass
Step	5 mm
Gun traverse speed	1000 mm/sec.
Spray distance	380 mm

* GPH: gallon per hour, **SCFH: standard cubic feet per hour

RESULTS AND DISCUSSION

Microstructure of the coatings

Fig. 2 shows the cross sectional microstructures of the sprayed coatings with a variation of the fuel flow rates. As the fuel flow rate is increased, the microstructure of the coatings tends to be denser, that is, less pores and thinner lamellae thickness. Fig.3 shows the SEM morphology of the surface of the coating sprayed with different fuel flow rate. According to the fuel flew rates, cross sectional microstructure changes of the as-sprayed Fe-based metallic glass coating can be seen Fig. 2 and Fig. 3. Similar to the other thermal spraying process, HVOF sprayed coating microstructure is largely dependent on the impacting particle energy and resulting deposition phenomena. Energy state of particle at the moment of impact could be estimated from the microstructural features according to the fuel flow rates. As the fuel flow rates are increased, unmelted particle size and number density are decreased and then it disappears. The flattening ratio is considered to be increased with the increased of the fuel flow rates from the viewpoint of splat thickness.

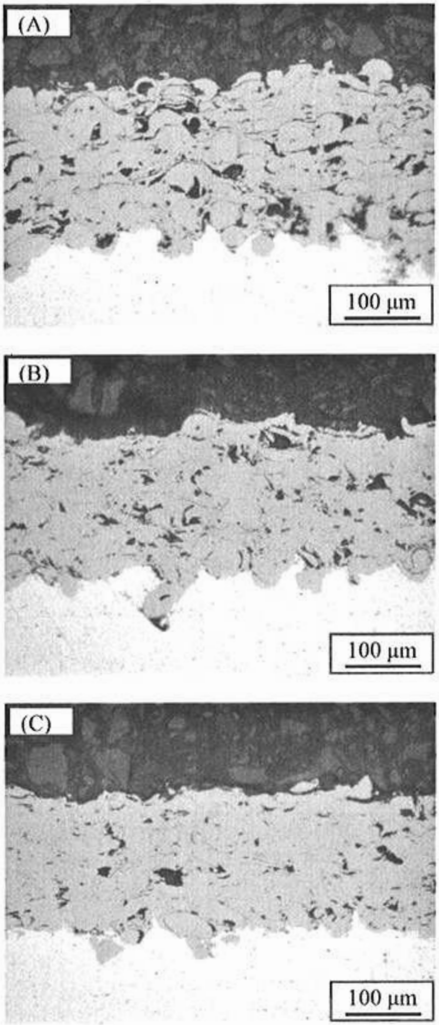

Fig. 2 Optical micrographs of the cross section of the coatings sprayed with different fuel flow rates; (A) 5.1GPH, (B) 6.1 GPH, (C) 7.1GPH.

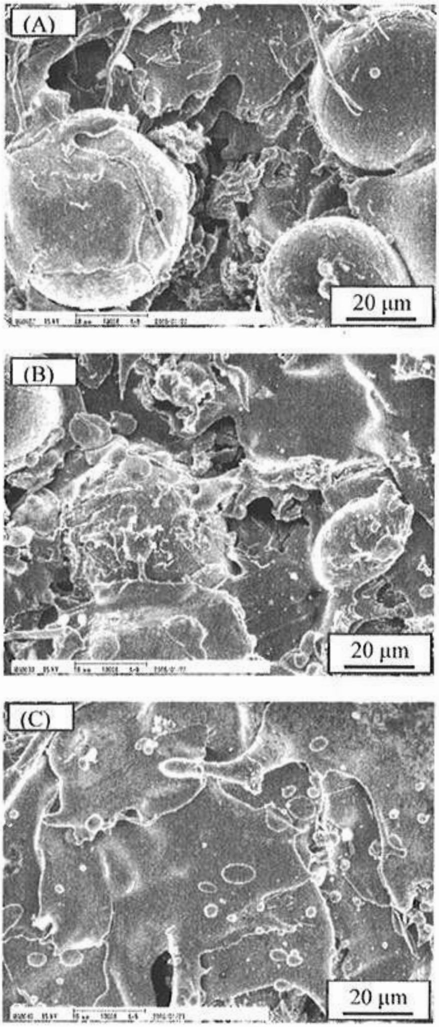

Fig. 3 SEM morphology of the surface of the coatings sprayed with different fuel flow rates; (A) 5.1GPH, (B) 6.1 GPH, (C) 7.1GPH.

The results of the quantitative measurements of porosity by image analysis are shown in Fig. 4. It is shown that as the fuel flow rate is increased; the porosity of the coatings is decreased. Fig. 5 shows the XRD patterns of the as-sprayed coating surface in compare with used spraying powder. All of the diffraction patterns show hallow patterns that are typical of amorphous structure.

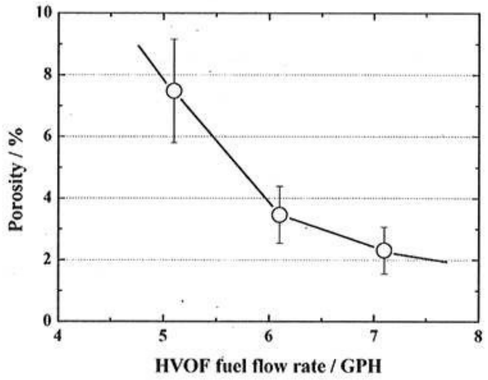

Fig. 4 Porosity variations of the sprayed coatings with different fuel flow rates.

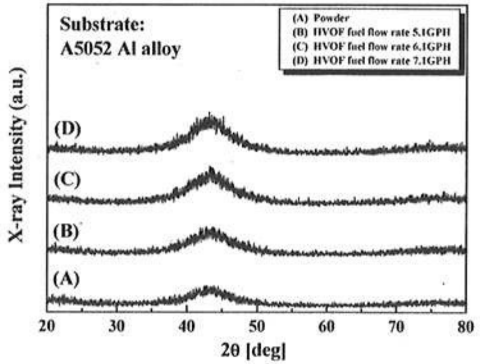

Fig. 5 XRD spectra of the sprayed coatings with different fuel flow rates.

Mechanical properties of sprayed coating

The microvickers hardness profiles of the cross section of the sprayed coatings with the fuel flow rates are shown in Fig. 6. The average hardness of the sprayed coating is slightly increased with the increased fuel flow rates. Fig. 7 shows the weight loss of the sprayed coating after ball-on-disc wear test. Fig.8 indicates the relationship between microhardness and wear loss of the coatings.

Fig.9 shows the evolution of the friction coefficient as a function of the friction time when sliding against the Al_2O_3 ball. It is shown that as the fuel flow rate is increase, the friction coefficient of the coatings is decreased. Friction coefficient of a certain material system can be affected by a great number of factors such as phase composition, porosity, microhardness, and so on. Friction coefficient was decreased with the increased of porosity in the as-sprayed coating.

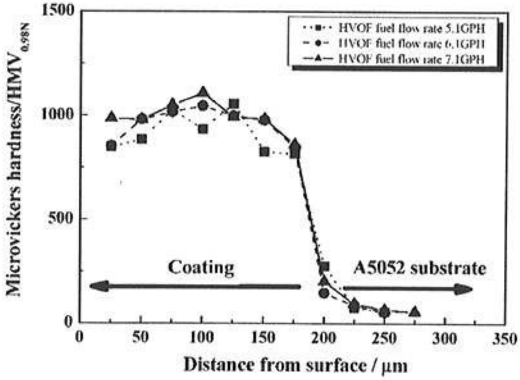

Fig. 6 Microvickers hardness profiles of the cross section of the sprayed coatings with different fuel flow rates.

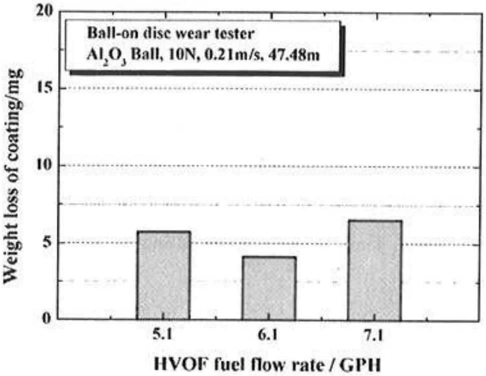

Fig. 7 Weight loss of the sprayed coatings with different fuel flow rates.

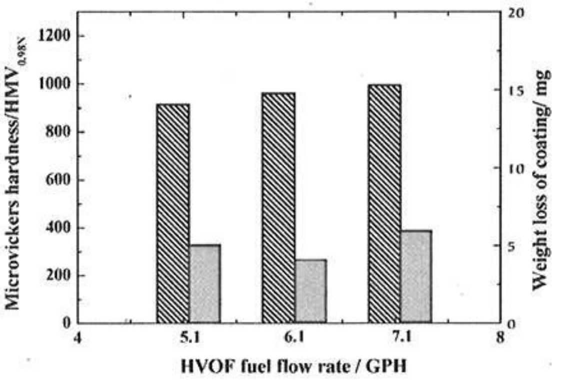

Fig.8 Relationship between microvickers hardness and weight loss of coatings with different fuel flow rates.

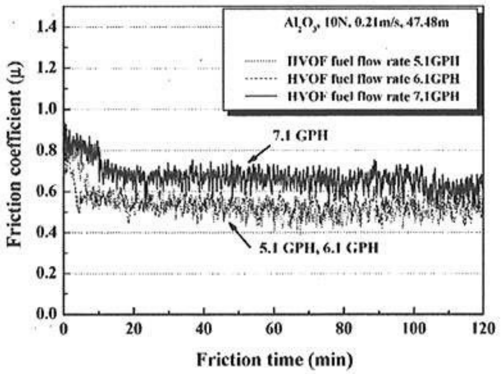

Fig. 9 Variation of friction coefficient of the sprayed coatings during ball-on-disc wear test.

CONCLUSION

A Fe-based metallic glass powder was sprayed using an HVOF process, and the effects of the fuel flow rates on the microstructure of the sprayed coating were investigated. Additionally, microhardness and porosity effects on the friction and wear loss of the metallic glass coating were investigated. The results of the study can be summarized as follow:

1. An amorphous coating was produced using the HVOF process, and, as the fuel flow rates are increased, the microstructure of the coatings tends to be denser.

2. The sprayed coating has a high hardness of HMV 900-1000, very low wear loss, and a comparably high friction coefficient of 0.5 to 0.6 as determined using a ball-on-disc wear tester.
3. The friction coefficient decreases with the increasing porosity of the as-sprayed coating.

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