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Effect of Particle Size Distribution of the Feedstock Powder on the Microstructure of Bulk Metallic Glass Sprayed Coating by HVOF on Aluminum Alloy Substrate

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Abstract The Fe-based bulk metallic glass ($Fe_{43}Cr_{16}Mo_{16}C_{15}B_{10}$) sprayed coating with the thickness about 220μm was successfully deposited on an aluminum alloy (A5052) metal substrate using an HVOF (High Velocity Oxygen Fuel) spraying process. All sprayed coating has still kept the amorphous state after spraying. The Fe-based bulk metallic glass coating shows good adhesion to the aluminum alloy metal substrate, and has a high hardness with HMV 913~1120. It has been found that better properties can be obtained in the sprayed coating by using finer powder.

Introduction

Aluminum alloys are widely used in industry for their lighter weight, energy efficient and recycle efficiency, as the need to replace many materials with technical and economical considerations increases. However, aluminum materials in general show poor wear resistance because of their softness. To improve this disadvantage, the implementation of wear resistance coatings deposited by spraying process has been proposed [1-2].

Significant interesting of amorphous alloys due to their unique physical, mechanical, and chemical properties. Consequently, a variety of technologies have been used to produce such coatings [3-5]. It is known that the Fe-based bulk metallic glass is a promising candidate due to high hardness and corrosion resistance. Because of the absence of crystalline anisotropy, the Fe-based bulk metallic glass shows higher strength and hardness as compared with the corresponding crystalline phase [5-8].

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.

This article reports about the amorphous phase formation of Fe-based bulk metallic glass on the aluminum alloy substrate by HVOF spraying process. This is a new approach that the bulk metallic glass alloy is studied for the amorphous coating by thermal spraying technology.

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Experimental details

Gas atomized $Fe_{43}Cr_{16}Mo_{16}C_{15}B_{10}$ (at. %) bulk metallic glass powder was used for this investigation [6-8]. Two types of particle size of the powders with near spherical are shown in Fig. 1. Coarse and fine powders are 25 to 53μm and 10 to 25μm in particle size, respectively. Spraying coatings were conducted using a TAFA JP-5000HP system. A typical set of spray conditions used is presented in Table 1. Fuel was Kerosene and the substrate was A5052 with a thickness of 5mm. Deposition thickness of 200~250μm was achieved from 16 vertical passes of the gun.

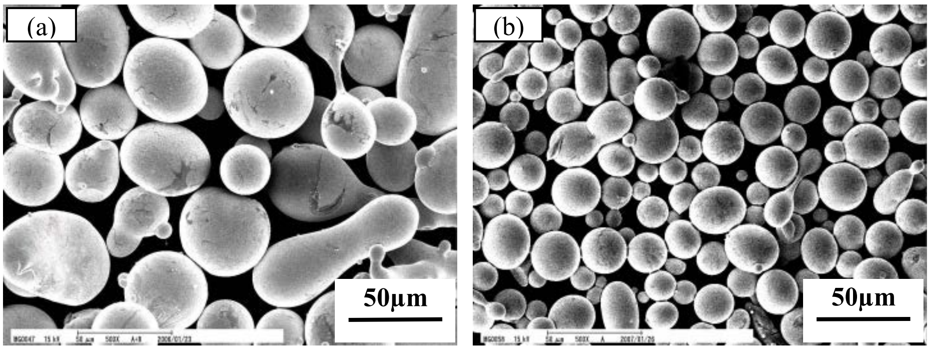

Fig. 1 Scanning electron micrograph showing the morphology of the feedstock powder; (a) Coarse powder, (b) Fine powder.

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

Spray gun	TAFA JP-5000HP
Fuel flow rate	5.1, 6.1, 7.1 GPH*
Oxygen gas flow rate	1800 SCFH**
Coating thickness	200~250μm
Step	5 mm
Gun traverse speed	1000 mm/sec.
Spray distance	380 mm

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

The microstructure of 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 get the average value of the coatings. 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. Phase identification was conducted by X-ray diffraction analysis on the as-received powder and as-sprayed coatings using Cu K_α radiation at 40kV, 40mA. The scanning rate was 0.02°/s for 2θ range of 20-80°.

Results and Discussion

Optical microscopy morphologies on the cross sectional microstructures of the sprayed coatings in Fig. 2 indicate distinct difference in the particle size distributions between the two coatings. Denser coating was obtained by fine powder. Furthermore, 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 morphologies of the surface of the coating sprayed with different fuel flow rate. According to the fuel flow rates, cross sectional microstructure changes of the as-sprayed Fe-based metallic glass coating can be seen in Fig. 2 and 3. The HVOF sprayed coating microstructure is largely dependent on the impacting particle energy and resulted deposition phenomena. Energy

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state of particle at the moment of impact could be estimated from the microstructure features according to the fuel flow rates. As the fuel flow rates are increased, the size and the number density of unmelted particle are decreased and then it disappears. The flattening ratio is considered to be increased with increasing the fuel flow rates from the viewpoint of splat thickness. The results of the quantitative measurements of porosity by image analysis are shown in Fig. 4. Fig. 5 are summarized the average values of hardness as a function of fuel flow rate from the results. Hardness is related to their particle size and porosity. Fig. 6 shows the XRD patterns of the as-sprayed coating surface in comparison with feedstock powder and fuel flow rate. All of the diffraction patterns show hallow patterns that are typical of amorphous structure.

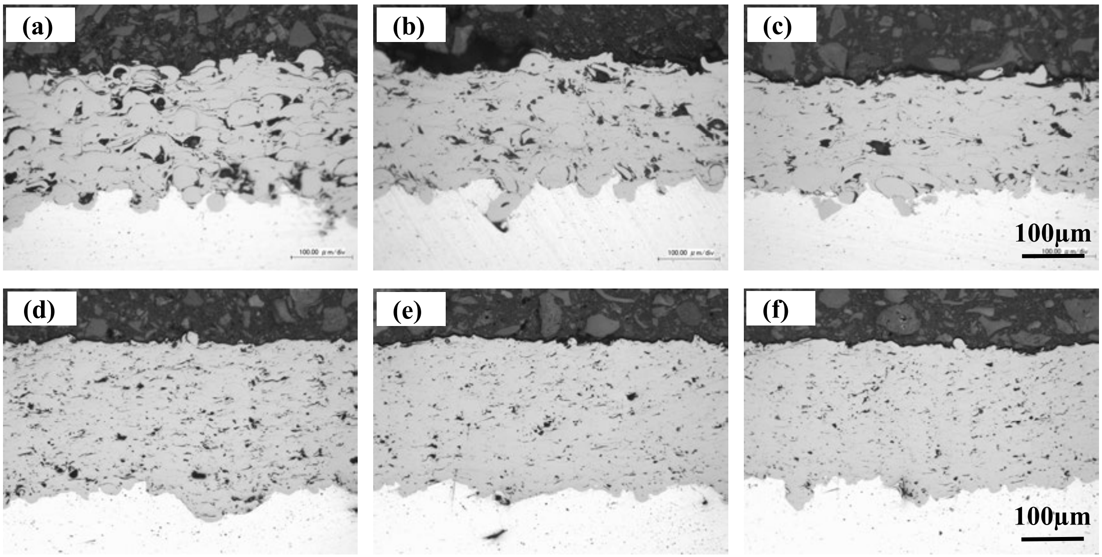

Fig. 2 Optical micrographs on the cross section of the coatings sprayed with different fuel flow rates; (a) 5.1GPH, (b) 6.1 GPH and (c) 7.1GPH with coarse powder; (d) 5.1GPH, (e) 6.1 GPH and (f) 7.1GPH with fine powder.

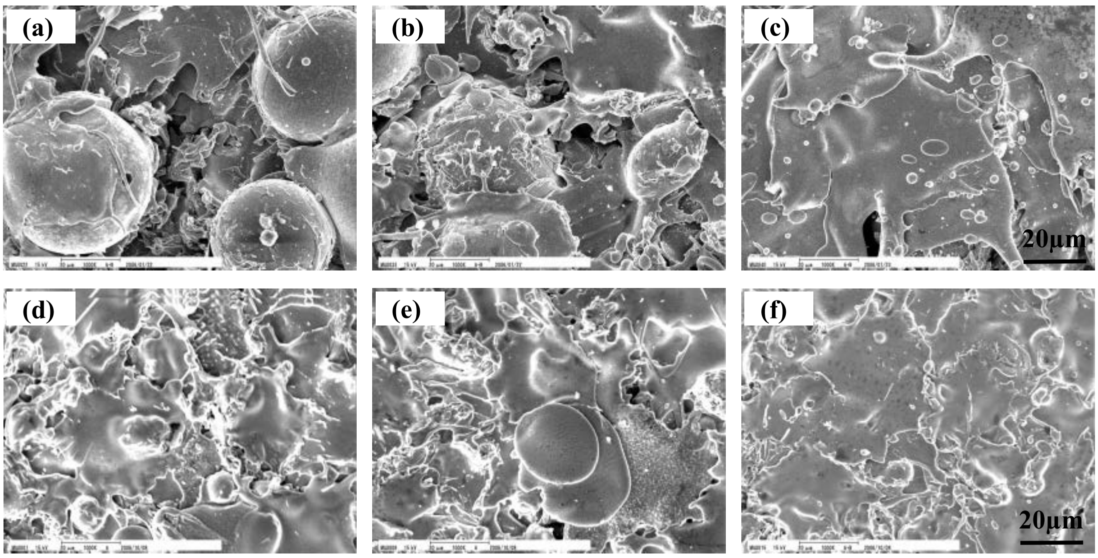

Fig. 3 SEM morphology of the surface of the coatings sprayed with different fuel flow rates; (a) 5.1GPH, (b) 6.1 GPH and (c) 7.1GPH with coarse powder; (d) 5.1GPH, (e) 6.1 GPH and (f) 7.1GPH with fine powder.

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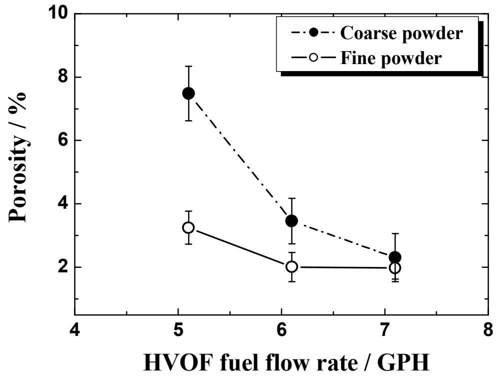

Fig. 4 Porosity variations of the sprayed coatings with different fuel flow rates.

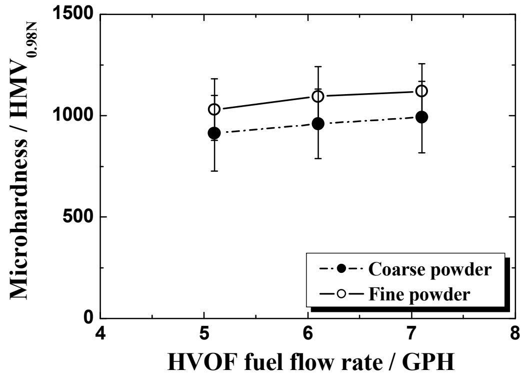

Fig. 5 Hardness variations of the sprayed coatings with different fuel flow rates.

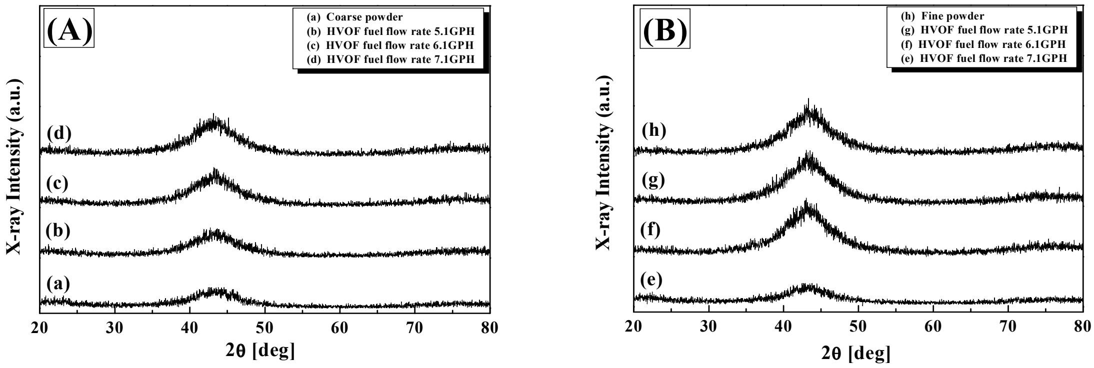

Fig. 6 XRD patterns of the sprayed coatings with different fuel flow rates; (A) Coarse powder and its sprayed coatings, (B) Fine powder and its sprayed coatings.

Conclusion

The Fe-based metallic glass powder, $Fe_{43}Cr_{16}Mo_{16}C_{15}B_{10}$ was sprayed using an HVOF process on the A5052 metal substrate, and effects of the fuel flow rates on the microstructure, hardness and porosity of the sprayed coating were investigated. The results obtained can be summarized as follow:

(1) The Fe-based metallic glass coating produced using the HVOF process tends to be denser with decreasing the particle size of the feedstock powder, and with increasing the fuel flow rates are increased.

(2) The Fe-based metallic glass coating has a high hardness of HMV 913-1120 and the hardness of coating by using the fine powder is higher than that with the coarse powder.

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