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Metallic glass coatings fabricated by gas tunnel type plasma spraying

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ABSTRACT

Gas tunnel type plasma spraying is a renowned technique due to its greater advantages than other conventional plasma spraying followed by high speed and high energy density plasma jet. Furthermore, this is a simple and novel process for producing dense metallic coatings with and without secondary phases such as oxides and intermetallic phases under selective operating parameters. The present work was undertaken to study the formation mechanism and for examining the metallic glass coating properties formed through gas tunnel type plasma spraying process. For this purpose, Fe based, Zr based and Ni based metallic glass coatings were individually deposited by gas tunnel type plasma spray torch at optimum operating conditions with two different input currents (300 and 400 A). Phase and microstructure formations were examined and the results were correlated with the input current. Similarly, mechanical properties and electrochemical corrosion properties of each coating were examined and the results were correlated with the existing phase and the microstructures of the coatings. The examined results revealed that the Fe based metallic glass coatings have relatively less porosity (3–4%) and crystalline phase fraction (9–14%). These coatings also exhibit excellent sliding wear resistance (2.77×10^{-6} mm^3/nm^{-1}) and electrochemical corrosion resistance against 3.5% NaCl solution.

1. Introduction

Gas tunnel type plasma spraying done using high power gas tunnel plasma jet exhibits superior performance then existing conventional type plasma spraying system and also has great prospects for various applications in thermal plasma processing sectors [1–3]. Particularly, this is one of the most effective technologies for depositing high quality ceramic and metallic coatings and also for synthesizing functional materials because the plasma jet has high speed and high energy density under various operating conditions. The performances of gas tunnel type plasma jets have been clarified in numerous previous studies [4,5]. Recently, metallic glasses are emerging as a promising surface protection tool due to its excellent mechanical, tribological and electrochemical properties. Particularly, fully amorphous phase or partially crystalline amorphous phases of metallic glass have unique and attractive applications in surface engineering segments. Hence, variety of bulk metallic glass compounds and their coatings have been discovered based on magnesium, zirconium, lanthanum, cobalt, iron, palladium copper and nickel [6–8].

Due to the cost performance, surface coating techniques are preferred to widen the metallic glass applications in industrial components or large surface area. The existing conventional coating processes for metallic glass coatings face severe difficulty in forming thick surface layers over a wide area. Fortunately, the gas tunnel type plasma spraying is one of the potential tools to produce metallic glass coating over the component's surface with controlled phase and microstructures. Furthermore, this novel spraying method is cost and time effective when compared to the other conventional coating techniques [8].

Hence in the present work, the formation of Fe based, Zr based and Ni based metallic glass coatings through gas tunnel type plasma spraying process was investigated and their properties were studied. The above mentioned metallic glass coatings were individually deposited by gas tunnel type plasma spray torch at two different input currents (300 and 400 A) under optimum operating conditions. Phase and microstructure formation, mechanical properties and electrochemical corrosion properties of each coating were examined and the results were correlated with the existing phase in the coating microstructures.

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2. Experimental procedure

Fig. 1 shows the schematic of gas tunnel type plasma spray torch, which was used to produce Fe based, Zr based and Ni based metallic glass coatings in this study. Spherical shaped Fe, Zr and Ni based metallic glass powders were used for this spraying and their details are listed in Table 1. During spraying, metallic glass powders were fed into the gas tunnel plasma jet at the exit of the gas divertor nozzle (20 mm diameter) with the help of argon carrier gas. Here, in each category two types of coatings were sprayed, at 300 A and 400 A plasma current. All other operating parameters like plasma forming gas flow rate (180 lpm), spraying distance (50 mm), powder feed rates (15–20 gpm) and feeding angle (90°) were kept constant during spraying of all the above metallic glass powders. Number of scan was varied from 12 to 16 in order to get uniform coatings with average thickness of 200 μm in all the conditions. All these parameters were selected from numerous trial runs and the summary of earlier examinations [6,9,10]. All the coatings were formed on 304 stainless-steel flat substrates, which were previously sandblasted by alumina grit.

Phase formation of the metallic glass coatings was identified using JEOL JDX-3530M X-ray diffractometer with Cu-Kα radiation source at a voltage of 40 kV and a current of 40 mA. The microstructures of the coatings were examined by ERA8800FE scanning electron microscope equipped with energy dispersive X-ray spectroscopy (EDX). The detailed structure of the coating splat was further examined by JEOLl-JEM2100F transmission electron microscopy (TEM) coupled with an energy dispersive X-ray spectroscopy (EDX). Porosity of the coating microstructures was measured by image analysing software from the images of optical microscopy. For this purpose, four different areas of the microstructure were selected in each coating. The sliding wear resistance of the coatings was measured at room temperature in laboratory air with a relative humidity of about 60% using a conventional ball-on-disk tribometer (Teer Coatings Limited). The tests were performed at 10 N load conditions and 5 mm diameter WC ball was used as the counter body. After sliding, the wear volume of the coating specimens were measured accurately by using a three-axis profilometer (Taylor Hobson) equipped with a PC. Corrosion behaviour of the sprayed coatings was estimated by electrochemical measurements by using a conventional three electrode cell connected with a potentiostat (Autolab PGSTAT galvanostat/potentiostat).

Table 1
Details of metallic glass powders.

Powders	Chemical composition (at%)	Size (μm)
Fe based	$Fe_{50.26}Cr_{23.86}Mo_{20.85}Si_{2.41}B_{2.62}$	30–60
Zr based	$Zr_{50}Cu_{30}Al_{10}Ni_{5}$	10–60
Ni based	Ni_{60} $Nb_{20}Zr_{20}$	10–40

Potentiodynamic polarization curves were measured with a potential scan rate of 1 mV/s in 3.5% NaCl solution. The crystallization percentage of the coatings was measured by using differential scanning calorimetry (DSC) at a constant heating rate of 20 K/min under a continuous flow of argon. Vickers microhardness measurements were taken on polished coating surfaces with a load of 50 g.

3. Results and discussion

3.1. Coating formation

In gas tunnel type plasma spraying, externally injected metallic glass powders are fully or partially melted by the dense plasma jet. Then the molten particles are deposited on the substrate surface to form splats through rapid flattening and solidification processes. The short spraying (50 mm) distance and higher amount of working gas flow causes rapid solidifications on the molten splats during the coating microstructure formation. Hence, the maximum fraction of amorphous phase in the metallic glass coating microstructures was protracted. This particular uniqueness of the gas tunnel type plasma spraying makes it different from the conventional plasma spraying system. However, the oxidation and crystallization process on splats are inevitable in this spraying due to open atmospheric operation, but it can be controlled by choosing appropriate operating parameters. For example, increasing the plasma input current of the gas tunnel type plasma spraying significantly reduces the amorphous fraction in the metallic glass coatings. Here the effect of the plasma torch input current on the formation of Fe based, Zr based and Ni based metallic glass coatings was examined and the results are described in detail.

XRD patterns of the gas tunnel type plasma sprayed Fe based metallic glass coatings at 300 and 400 A plasma current is shown

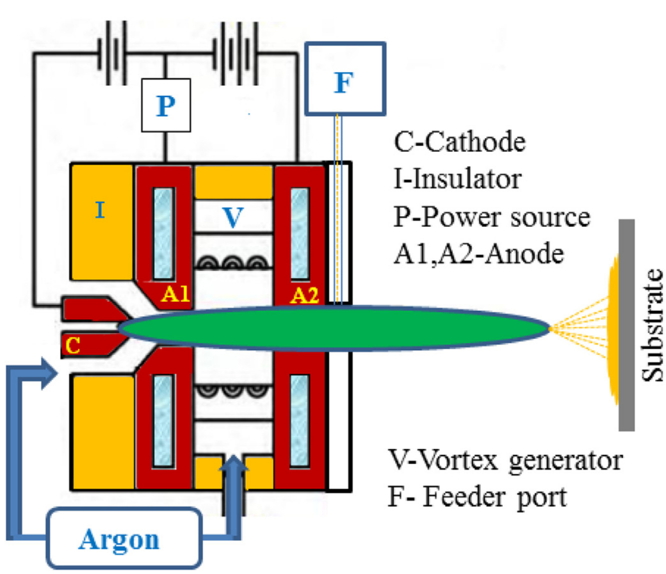

Fig. 1. Schematic of gas tunnel type plasma spray torch.

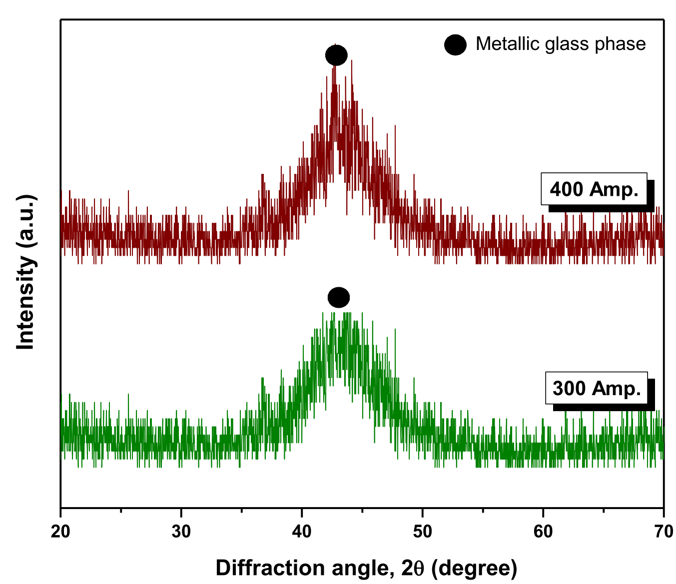

Fig. 2. XRD patterns of Fe based metallic glass coatings.