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Characterization of atmospheric plasma spray $NiCr–Cr_2O_3–Ag–CaF_2/BaF_2$ coatings

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Abstract

A blended $NiCr–Cr_2O_3–Ag–CaF_2/BaF_2$ feedstock was sprayed using an atmospheric plasma spray process. Physical and thermophysical properties of each constituent phase are quite different and resulting interactions of each constituent with the plasma jet can be expected to be different. Thus, attempts to change the plasma jet characteristics by changing the hydrogen gas flow rate in view of the thermophysical properties of the plasma jet were tried. Phase compositions and microstructures were evaluated as a function at hydrogen gas flow rate. The effects of phase composition and microstructure on the Vickers microhardness and bond strength were also evaluated. For empirically tracing each constituent particle trajectory, spot spraying bead was produced. Finally, particle temperature and velocity as a function of the hydrogen gas flow rate was measured using alumina–titania particle instead of the blended feedstock.

Keywords: Atmospheric plasma spraying; $NiCr–Cr_2O_3–Ag–BaF_2/CaF_2$ blended feedstock; Coating microstructure

1. Introduction

There are many kinds of thermal spray processes according to the heat source [1]. Among them, various materials as a monolithic or a composite can be sprayed owing to unique properties of thermal plasmas. In atmospheric plasma spraying, a coating is considered to result from the build-up of individual particles [2]. After a particle is injected into the plasma jet, the particle continuously interacts with the plasma jet during flight to reach a certain energy state which is composed of thermal energy and kinetic energy. In view of the individual particle deposition, a splat formation is dependent on the particle energy at the moment of impact [3]. Dissimilar to the kinetic spraying process [4], thermal energy including melting state and temperature is more important for the particle to be deposited because the impacting particle velocity in the thermal spraying process is not as high as the critical velocity in the kinetic spraying process. The number density of unmelted particles is generally proportional to the porosity and also the deposition efficiency increases with the decrease of the frequency of unmelted particles within a coating. In our other study, effects of process parameters on the in-flight particle velocity and temperature were investigated. As shown in Fig. 1, particle velocity and temperature decreased with the increase of the spraying distance. However, they could be tailored by the plasma gas composition. Particle velocity linearly increased with the argon gas flow rate, while particle temperature increased with the hydrogen gas flow rate.

On the other hand, particle trajectory is a very important aspect for the composite coating formation, especially, when the blended feedstock was used like in this study [5]. There are a lot of factors affecting the particle trajectory [6–9]. They can be divided into three parts: particle parameter, injection parameter, and plasma jet characteristics. Among particle parameters, particle density and size are critical factors for particle trajectory. As the particle density and size

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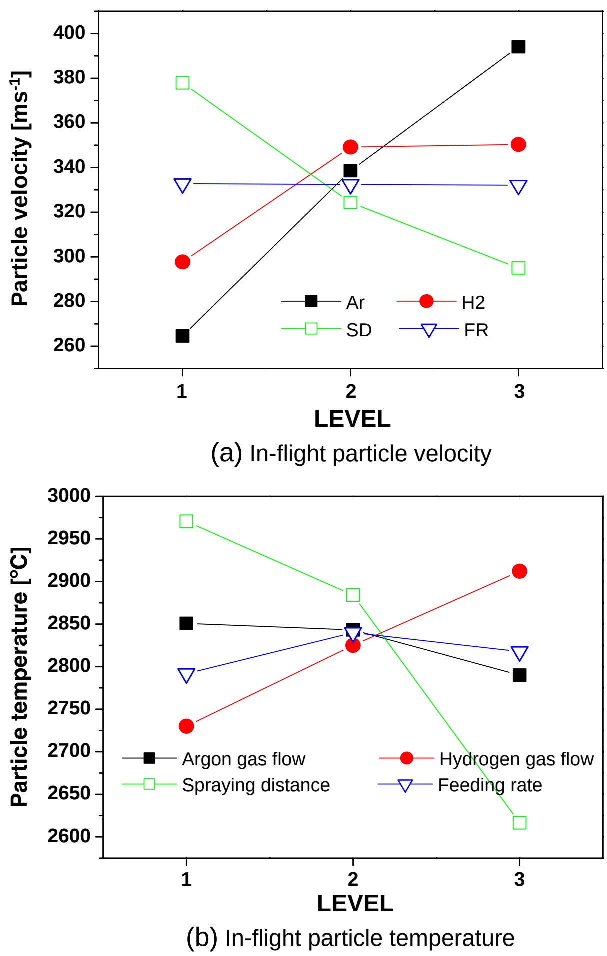

Fig. 1. (a–b) Effects of the plasma gas composition on the in-flight particle properties [In-flight alumina-titania particle diagnostics were conducted using DPV-2000 under the experimental table of the orthogonal array (L9(3^4)). For the argon gas flow rate, 75, 100, and 125 SCFH are for levels 1, 2, and 3, respectively. And 5, 15, and 25 SCFH hydrogen gas flow rates for levels 1, 2, and 3].

decrease, injected particles can be easily deflected by the momentum of the plasma jet due to its lower inertia force. In view of the microstructural homogeneity, the trajectory needs to be optimized to have a similar distribution within a cross-section of mass flux during flight. In this study, a blended feedstock was injected into a plasma jet through a single-feeding system though physical and thermophysical properties of each constituent phase are quite different. Therefore, it could be deduced that the interactions of each constituent particle within the plasma jet were different. In the case of the particle trajectory which is dependent on the physical properties of the feedstock such as size and density, force acting on the injected feedstock from the plasma jet is inversely proportional to the particle size and density. Accordingly, deflection and acceleration of the particles having lower density and smaller size are expected to be fast. Since densities of Ag and NiCr are almost two times larger than those of Cr_2O_3 and eutectic, separate trajectories could be expected during flight.

According to the thermophysical properties, the heat transfer reaction between each particle and the plasma jet are different. And also thermal energy of the particle characterized by the melting state and temperature is dependent on the heat transfer reaction. In the thermal spray process, there is a certain critical thermal energy which determines the individual particle deposition. When the thermal energy of an impacting particle is above it, the particle can be deposited by the solidification and/or plastic deformation. From this aspect, process optimization needs to be firstly focused on the adjustment of thermal energy. However, the thermophysical properties of each constituent phase are also different. For example, the melting point of Cr_2O_3 is higher than the boiling point of Ag. This means that the coating chemistry will be quite different from the feedstock chemistry according to the plasma jet characteristics.

2. Experiment

A blended feedstock material, PS304 [5], was characterized using scanning electron microscopy, energy dispersion spectroscopy, and laser scattering methods.

From the viewpoint of the physics and the current state of the art of in-flight particle diagnostics, trajectory and particle properties of each constituent particle in a blended feedstock cannot be obtained separately. Thus the trajectory was measured by forming the spot-spraying bead [10] while the effects of plasma gas composition on the in-flight particles were measured not using the blended feedstock but using an alumina–titania feedstock: alumina–titania has intermediate thermophysical properties of the blended feedstock. Using DPV-2000, the particle temperature and velocity were measured at the spraying distance of 100 mm along the vertical direction of the plasma jet downstream.

Table 1
Process parameters

Designation	Plasma gas composition		Arc voltage [V]	Arc current [A]	Spraying distance [mm]	Feeding rate [gm^{-1}]
	Ar [SCFH]	H_2 [SCFH]				
PS 1	100	5	46	500	100	30
PS 2		10	50			
PS 3		15	54			
PS 4		20	58			