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Experimental Study of Particle Deposition Characteristics of Alumina Using Plasma Spraying

P. Saravanan, V. Selvarajan, and M.P. Srivastava

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Plasma spraying is one of the most versatile techniques used to form coatings for protection against oxidation, corrosion, and wear. The plasma spraying is ideally suited for refractory materials, but there are a number of variables that need to be controlled to obtain dense coatings. In spite of considerable progress made in the theoretical understanding of this complex process, there is a need for a simple method to evaluate the interaction between the plasma flame and powder particles that form the coatings. As reported in the literature, this involves metallographic observation of the powders collected from the plasma. In the present study, the structure and morphology of plasma-sprayed splats are experimentally investigated using different power levels and spray distances for alumina powder. The results show that the splashing occurs during splatting of a completely molten droplet. It is found that at higher power levels and shorter spray distances, spreading of molten droplets improves considerably.

Keywords alumina, microstructure, powder deposition, splat formation, splat morphology

1. Introduction

Plasma spray deposition is one of the most important technologies available for producing the high-performance surfaces required by modern industry.[1,2] In this process, powder of the coating material is fed into high-temperature plasma, which melts and accelerates the powder; the molten particles subsequently hit and solidify on the surface to be coated. Most of the applications require coatings with a high density, which are well bonded to the substrate.[3,4] To obtain good quality coating, the powder particle must be at least partially molten and hit the substrate with a high velocity.[5]

The flattening characteristics of the droplets impinging on a substrate are important determinants in governing the eventual quality of the plasma spray coating. Because the mechanical performance of the coatings depends crucially on the particles flattening and intersplat bonding, such studies are very important to unravel the complex interaction between spray parameters and coating properties. The physical aspects of splat formation deal with the spreading of the molten droplet, interactions with the substrate, *etc.* These characteristics are mainly affected by the temperature, viscosity, and surface tension of the splat. Splat morphology depends on a number of factors, most important of which are the size, velocity, and temperature of the particle and substrate surface profile.[6] Therefore, investigation of the flattening mechanism of the sprayed particle is significantly meaningful in the practical use of the plasma-spraying process. Hence, much attention has been paid to the research on splat formation through experiments[7,9] and numerical evaluation.[10,11]

Among plasma-sprayed ceramic and cermet coatings, alumina (Al_2O_3) is the most widely established coating material, and these coatings have been used for many applications in textile, electronic, aerospace, and aircraft industries because of their dielectric and wear resistance properties. Even though several reports are available on the plasma-particle interaction, the coating dynamics, and the particle thermochemistry for Al_2O_3,[12–15] studies on the metallographic observation of Al_2O_3 particle deposition are limited.[16,17] Therefore, the object of the present investigation is to carry out a detailed metallographic analysis of Al_2O_3 powder particles deposited at various power levels and at various spray distances from the plasma gun.

2. Experimental Procedure

The present work was carried out using thermal spray grade powder (Metco 105 SFP aluminum oxide powder) ranging in size from 5 to 20 μm, procured from Metco Inc. (Westbury, IL). The powder is fused and angular blocky in appearance, as illustrated in Fig. 1. A Metco 7MB plasma-spraying unit was used for spraying of Al_2O_3 powder and the parameters listed in Table 1 were used. Copper substrates (rounds) of size 30 mm diameter were used for powder deposition. The substrates were all ground to an 800-grit finish prior to spraying in order to obtain mirror polished substrates. The substrates were kept at room temperature during deposition, and the spreading and flattening characteristics of the impinging Al_2O_3 particles at different power levels and spray distances were investigated by scanning electron microscopy (SEM). The power level and spray distance for the Al_2O_3 powder were chosen from the specified optimum pa-

V. Selvarajan, Department of Physics, Bharathiar University, Coimbatore - 641 046, India; **P. Saravanan,** Defence Materials & Stores Research Development & Establishment, Kanpur - 208 013, India; and **M.P. Srivastava,** Defence Metallurgical Research Laboratory, Hyderabad - 500 058, India. Contact e-mail: physics@as250.bharathi.ernet.in.

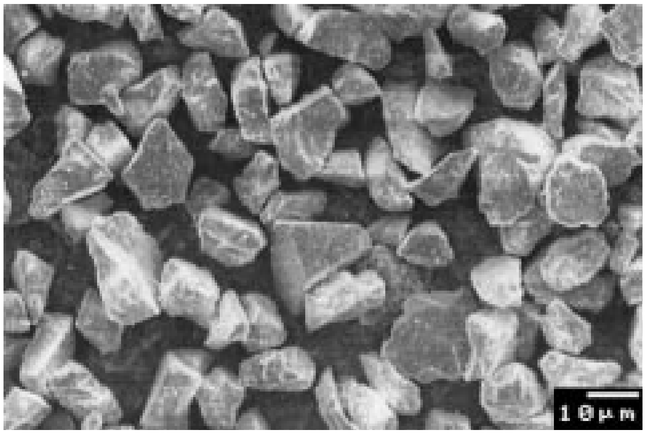

Fig. 1 Scanning electron micrograph of as-received Al_2O_3 powder

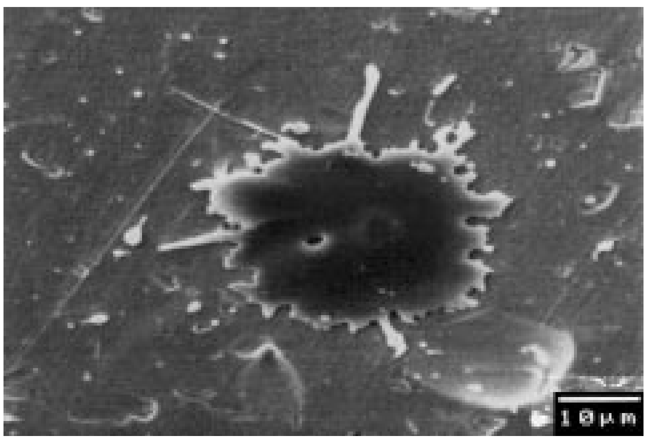

Fig. 2 Scanning electron micrograph of Al_2O_3 splats collected at a spray distance of 75 mm and a power level of 30 kW

Table 1 Plasma spray parameters for spraying of Al_2O_3 powder

Spray gun	Metco type 7MB
Gases	
Primary gas	Argon
Pressure, MPa	0.69
Flow, L/min	71
Secondary gas	Hydrogen
Pressure, MPa	0.35
Flow, L/min	4.70
Carrier gas	Argon
Flow, L/min	28.3
Powder feed rate, g/min	25
Arc current, A	500
Voltage, V	60
Spray distance, mm	75

rameters as given in the Metco spraying tables (Table 1); observations were made on the coating with 3 kW and 15 mm, respectively, on either side of the optimum. The effect of these spray variables on the microstructure of the sprayed Al_2O_3 deposits was also studied.

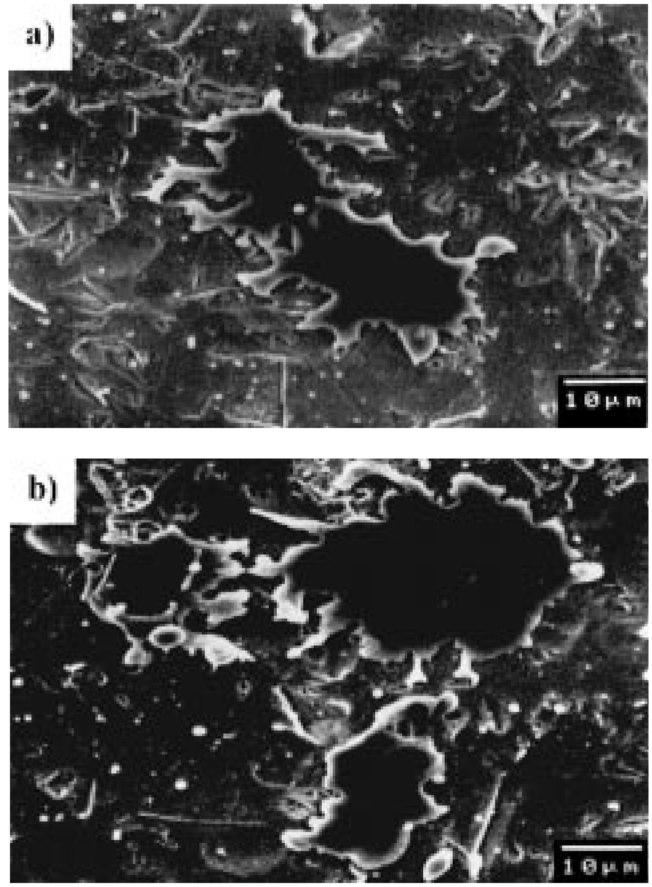

Fig. 3 Scanning electron micrographs of Al_2O_3 splats collected at a spray distance of 75 mm using different power levels: (**a**) 27 kW and (**b**) 33 kW

3. Results and Discussion

Observation of splats by a microscope, formed under the same spray conditions as those likely to be used to develop the coatings, can provide information regarding particle melting and acceleration. Figure 2 shows the SEM photograph of the Al_2O_3 powder collected for the specified optimum parameters as in Table 1. Figure 3 shows the SEM photographs of Al_2O_3 splats collected at spray distance of 75 mm from the plasma gun nozzle tip collected at two different power levels of 27 and 33 kW. It is assumed that the SEM photograph in each case contains one complete particle, *i.e.*, none of the splats has been removed, and there is no compositional variation among the splats. The typical photographs shown in Fig. 3 suggest that the Al_2O_3 powder particle is molten at both power levels. However, the molten particle flow patterns vary substantially in each case, with the spreading being rather poor at 27 kW (Fig. 3a). The spreading improves considerably by increasing the power level to 30 kW (Fig. 2) or 33 kW (Fig. 3b); the streaks of solidified material and other fragmented particles must have impinged on the surface with somewhat greater velocity than in the case of 27 kW splat. In general, higher power input to plasma torch produces a plasma flame of higher temperature and higher velocities, resulting in particles attaining a higher molten state with higher velocities before im-

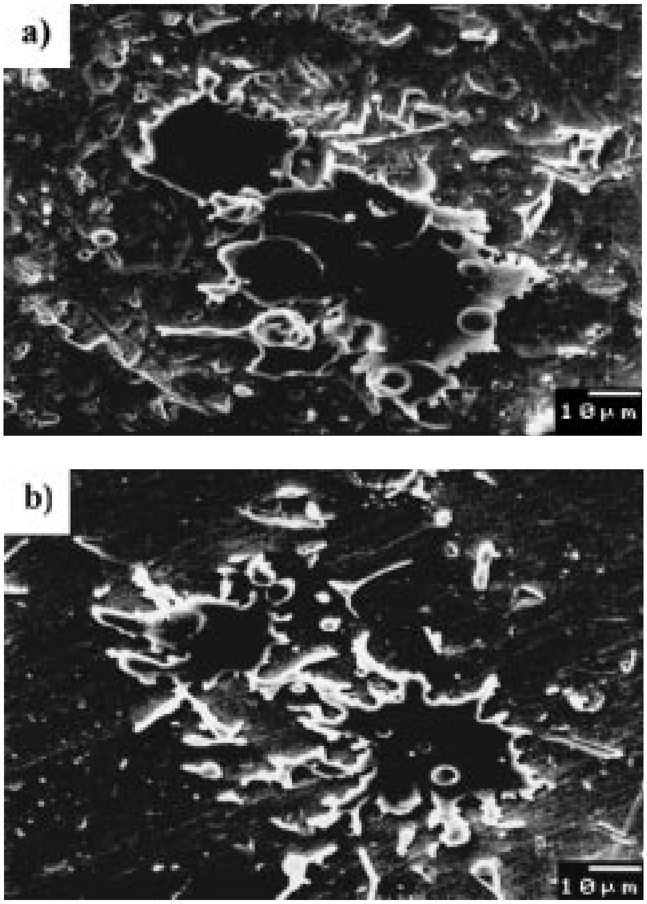

Fig. 4 Scanning electron micrographs of Al_2O_3 splats collected at a power level of 30 kW using different spray distances: (**a**) 90 mm and (**b**) 60 mm

pinging on the substrate. This is explained and substantiated by reports in the literature that the velocity attained by particles during spraying increases with an increase in power level.[18]

The SEM photographs of Al_2O_3 powder particles collected at spray distances of 90 and 60 mm from the plasma gun shown in Figs. 4(a) and (b), respectively, reveal that the powders are molten at both spray distances. However, only at spray distances of 60 and 75 mm is the splat thin (by observation). Much splashing occurred around the residual splat (part of the splat formed initially by the impinging molten droplet on the substrate). Around the central part of the splat, there were a lot of radial arms, which had resulted from the splashing during droplet flattening (Fig. 4b). Such morphology indicates that splashing evidently occurred at a high velocity of the molten droplets obtained at shorter spray distances. It was found that, when the spray distance was increased to 75 mm, the splat became much regular disk (Fig. 2). At a higher spraying distance (90 mm), the particles cool in flight and hence droplet flattening is comparatively less (Fig. 4a). Therefore, it can be said that the spray distance of 75 or 60 mm is appropriate for the formation of dense Al_2O_3 coatings in the present study.

Figure 5 and 6 illustrate the cross-sectional microstructures of the plasma-sprayed Al_2O_3 coatings formed at two different power levels (27 and 33 kW, respectively). In accordance with

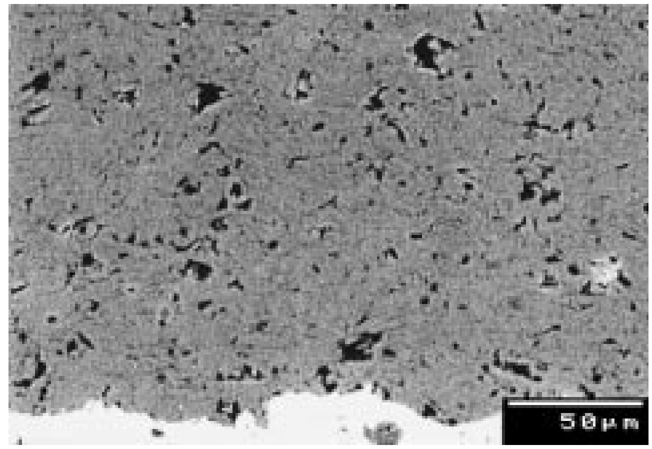

Fig. 5 Typical cross-sectional microstructures of Al_2O_3 coating sprayed at a power level of 27 kW

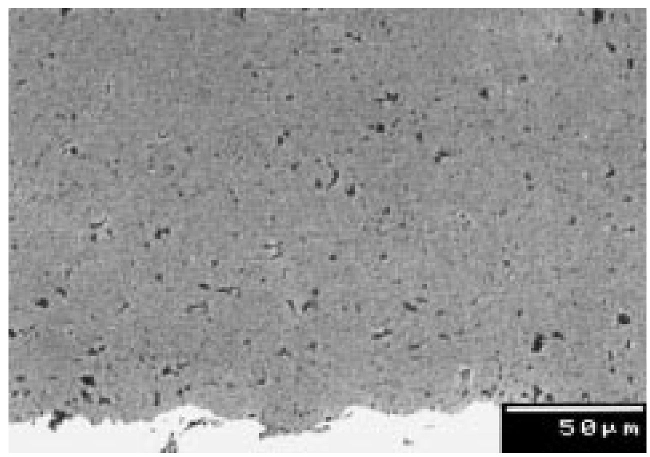

Fig. 6 Typical cross-sectional microstructures of Al_2O_3 coating sprayed at a power level of 33 kW

the observed influence of the plasma arc power on the particle deposition characteristics (Fig. 3a and b), the coating formed at 27 kW consists of very large pores (pores of size >15 μm). The greater amount of porosity in the coating formed at the lower power can be attributed to poor particle flattening on impact. On the other hand, dense and uniform coating formed at 33 kW has a pore size typically less than 10 μm. Clearly, the low-porosity coating would be expected for a stream of completely molten particles with high velocity, obtained at a higher power level.[12]

4. Conclusions

The present report deals with an experimental study of Al_2O_3 particle deposition characteristics using plasma spraying. The study is designed to investigate the influence of the primary spray variables of power and spray distance on the particle deposition characteristics. The observation of splats collected on polished copper surfaces suggests that the molten flow pattern improves considerably when the power level is increased. The results of this study evidently showed that higher power level and shorter spray distance produce high heat input and high flame velocities, resulting in particles predicted to be in a highly molten state and attaining higher velocities before impinging on the substrate. Higher power and shorter spray distance are appropriate for the formation of dense Al_2O_3 coatings in the present investigation. The study can be extended further to optimize other plasma variables such as particle size, arc gas flow rate, type of gas, and nozzle dimensions.

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