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BEHAVIOR OF ALUMINA PARTICLES IN ATMOSPHERIC PRESSURE PLASMA JETS.

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ABSTRACT

The distribution of Al_2O_3 particle size, velocity and temperature was mapped over the flow field of a 31.5 kW plasma torch. The effects of varying the powder loading were studied. The powder feed rate was varied between .45 and 2.05 kg/hr independent of the carrier gas flow rate. The particle flow field was non-symmetric due to the method of particle injection. The data indicate that powder feed rate does not significantly affect either the temperature or velocity of the particles, for typical plasma spray conditions, and that the assumption of a dilute particle flow field is valid.

INTRODUCTION

In the modeling and optimization of plasma spray processes, the simplifying assumption of a dilute particle flow field is often made. In effect, this assumption decouples the mathematical description of the plasma from the behavior of the particles, allowing for independent calculation of the plasma and particle flow fields. In this paper we have investigated the validity of this assumption for chemically inert, non-vaporizing Al_2O_3 particles over a range of powder feed rates which are consistent with typical industrial spray coating processes. The measurement technique used for simultaneously obtaining the size, velocity, temperature, and local number density of particles entrained in high temperature flow fields is briefly described, and the characteristics of the Al_2O_3 spray system are discussed.

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MEASUREMENT TECHNIQUE

The measurement system developed for the simultaneous measurement of particle size, velocity and temperature integrates a laser Doppler velocimeter (LDV) system with a scattered light particle size measurement and a high speed two-color pyrometer. Since the measurement system has been described in detail elsewhere [1], only a brief description will appear here. All optics and the laser are rigidly mounted on a precision translatable table. The movement of the table results in a precise movement of the measurement volume relative to the plasma device. The particle size is determined from the absolute magnitude of scattered laser light, particle velocity is determined by a dual crossed-beam LDV, and temperature is determined from a measurement of light emitted by the individual incandescent particles at two wavelengths. A multi-line 6 W Ar ion laser is used as the light source for velocity and sizing. The LDV measurement volume, consisting of the intersection of two 514 nm laser beams, is situated in the center of the larger diameter 488 nm beam. The intersection of the LDV measurement volume and the second beam constitutes the particle size measurement volume. Simultaneously, the light emitted by the hot, incandescent particles passing through this same region is observed. The particle temperature is derived from the ratio of the signals at each of the two wavelengths observed, with gray body behavior assumed. The spatial resolution of <1 mm^3 is such that the distribution of particle size, velocity and temperature can be mapped over typical flow fields. The estimated measurement uncertainties are 125 K at 2500 K for particle temperature, 4.9 μm for particle size and better than 5 m/s for particle velocity.

RESULTS

The commercial plasma torch used in this study has a nozzle exit diameter of 8 mm. Particles are injected radially into the flow, on the nozzle diameter, at a single axial location, 18mm upstream of the torch exit. The torch operating condition was 900 A at 35 V, for a total power input of 31.5 kW. Under these conditions the torch is 69 % efficient. The Ar:He torch gas flow rate was 2.8 and 1.3 SCMH respectively, and the Ar powder carrier gas flow rate was 0.24 SCMH. The atmospheric pressure is 86 kPa. The powder feed rate was varied between 0.45 and 2.05 Kg/hr and is independent of the carrier gas flow rate. The measured average particle injection velocity was 14.4 m/s with a standard deviation of 1.5 m/s.

Alumina particles (Al_2O_3) have been used extensively at this laboratory as a baseline spray system. Alumina powders are commercially important, inexpensive, chemically inert, and feed reliably. Initially, the particles are irregular, sharp edged shards (Figure 1a) with 80% falling in

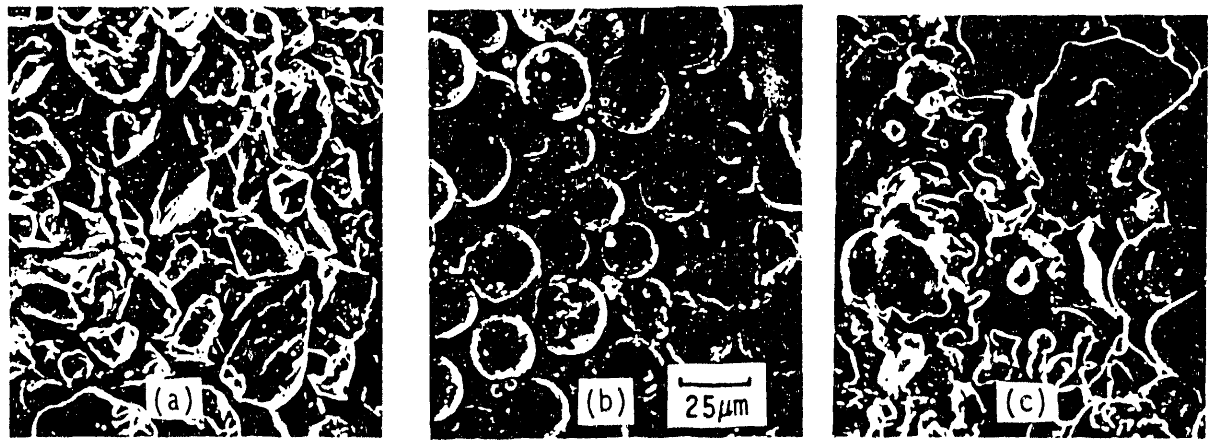

Figure 1. (a) Alumina Unsprayed. (b) Plasma sprayed, cooled before impact. (c) Impacted on substrate.

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the 25 to 37 μm size range. Also shown in Figure 1 are sprayed particles that cooled before impact, Figure 1b, and after impact at 76 mm on a substrate, Figure 1c. Examination of the substrate indicates that virtually all the particles are fully molten on impact. The measured average centerline particle temperature is illustrated in Figure 2. Also shown in Figure 2 is thermocouple measurement of gas temperature starting at 70 mm. Emission spectroscopy indicates that the plasma temperature at 40 mm is approximately 8000 K. The steep temperature gradient in this region implies that the plasma temperature decreases to below the melting point of alumina at an axial location between 65 and 70 mm. The average particle surface temperature at 40mm from the torch exit is slightly above the melting point of alumina. Due to the bright plasma background 40 mm is the closest to the nozzle exit that a particle temperature measurement can be made. The particle temperature remains close to the melting point of alumina out to about 150 mm. Splat tests on stainless steel substrates were also conducted at various axial locations. The splat tests indicate that significant numbers of the particles still contain solid cores at 40 and 60 mm, hence the melting process is still underway well into the tail flame of the torch. Once molten the particles remain in their molten state for a relatively long flight distance before freezing.

Though not shown, the local relative particle number density data indicate that the particle flow field is asymetric with respect to the centerline of the torch. In general, the particles fly through the hot plasma plume and emerge on the side opposite the radial injection point. The average particle size data, Figure 3, do not indicate any significant aerodynamic particle sizing, although a slight trend is suggested. Assuming equal injection velocities, the larger, heavier particles will be preferentially distributed near the top of the graph farthest from the injection point. The behavior

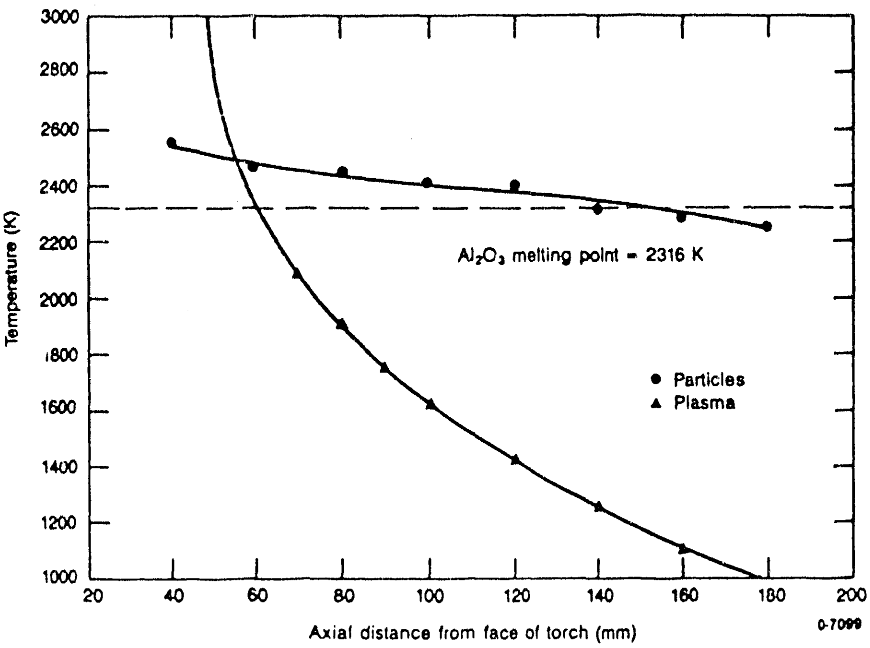

Figure 2. Average centerline particle temperature.

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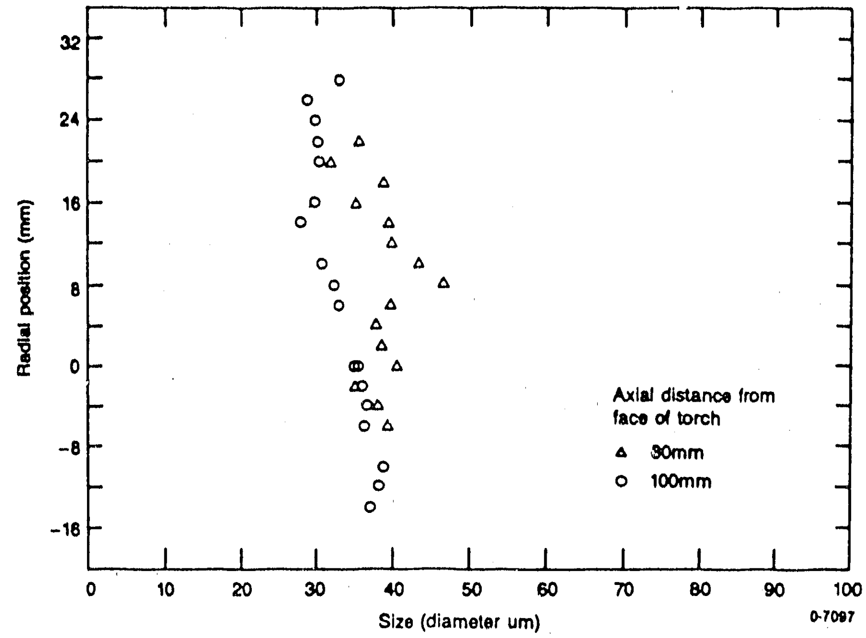

Figure 3. Average radial distribution of particle size.

indicated in Figure 3 is contrary to this expectation. The observed effect may be explained by the velocity distribution of the particles at the injection point. Despite the skewed nature of the particle flow field, the radial particle temperature data are remarkably uniform, Figure 4 and the radial velocity data are reasonably symmetric, Figure 5.

The effect of particle injection rate or particle loading was investigated by observing changes in average centerline particle velocity and temperature at the nominal substrate standoff distance of 76 mm. These data versus powder injection rate are plotted in Figure 6 and 7, respectively. At powder

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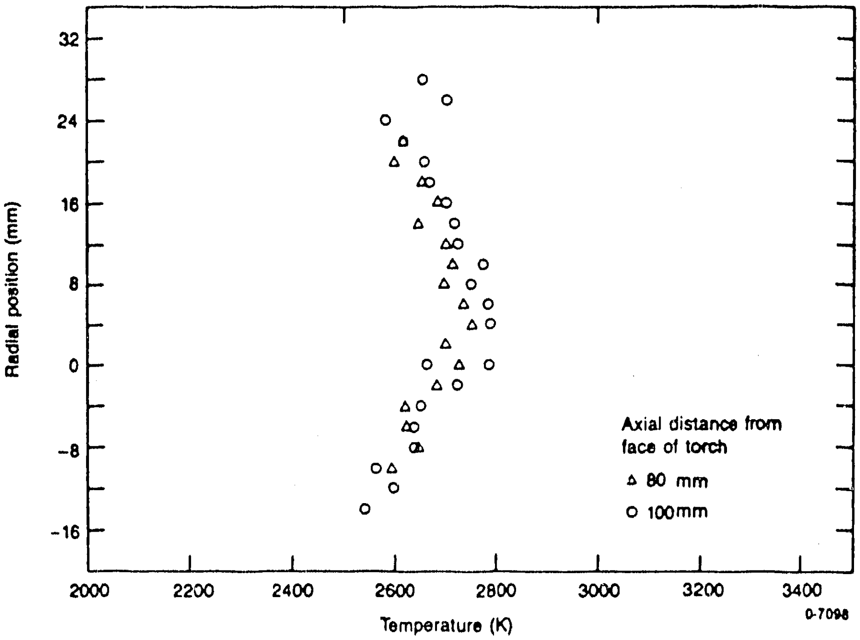

Figure 4. Average radial particle temperature data.

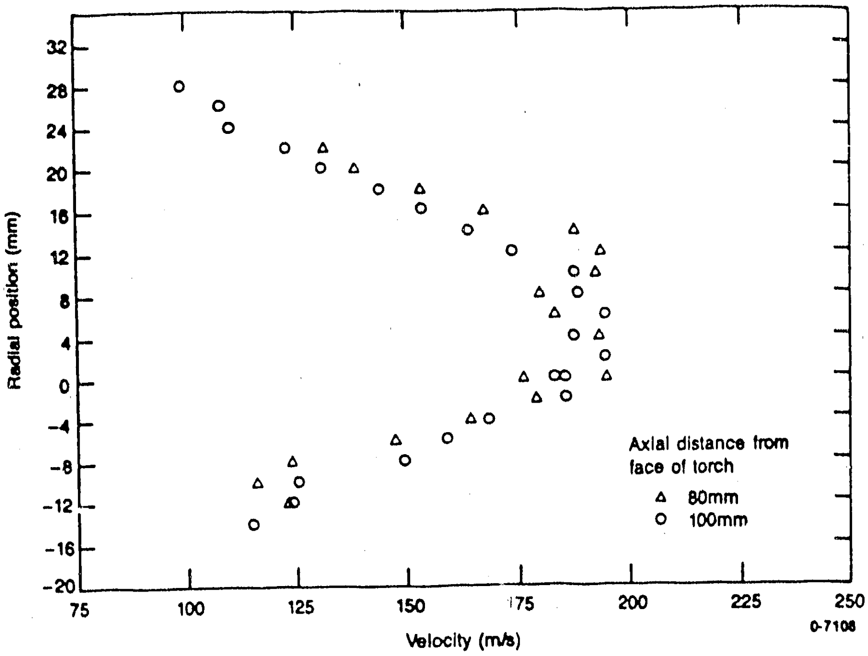

Figure 5. Average radial particle velocity data.

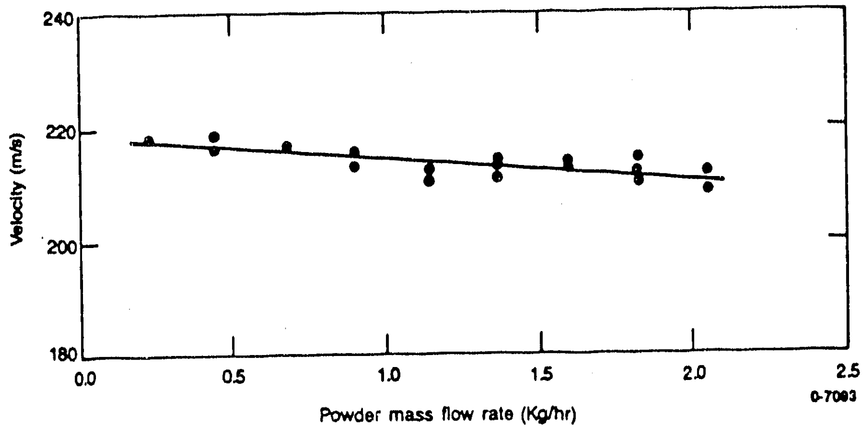

Figure 6. Average centerline particle velocity at 76 mm as a function of particle loading.

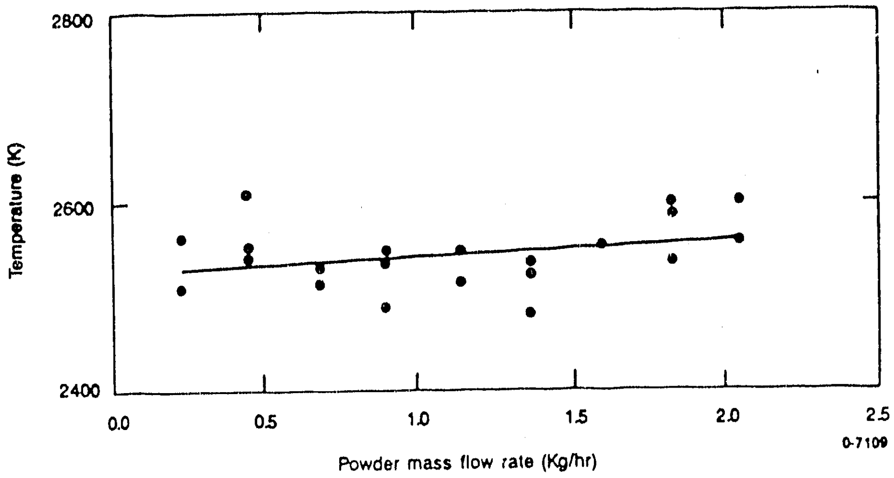

Figure 7. Average centerline particle temperature at 76 mm as a function of particle loading.

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injection rates typical of industrial spraying the effect of particle loading is insignificant. Spray coating systems tend to be quite dilute in concentration (<3000 cm^{-3}) and, even though the mass flow rate fraction of the particles is significant (30 %) compared to the gas flow rate the energy extracted from the plasma that goes into heating the particles and the momentum transfer required to accelerate the particles is only 5% of the total available. The implication is that the heat, mass and momentum transfer to the particle are controlled locally in spray systems with little particle/particle interaction or overall affect on the plasma flow field.

CONCLUSIONS

In-flight particle parameter data (particle size, velocity, temperature, and relative number density) provides the necessary link between the spray process parameters, in-flight particle behavior and, ultimately, the characteristics of the coating produced. Data of this type will eventually lead to more detailed and physically accurate models describing the spray coating process. The result will be greater insight into the important parameters in the process and ultimately, better coatings. In this work the primary parameter investigated was the particle injection rate, or particle loading. For loadings typical of industrial spray coating operations little effect on the particle velocities and temperatures are observed indicating that the process investigated is insensitive to the injection rate and the assumption of a dilute flow field is justified.

ACKNOWLEDGMENT

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