

Real-Time Imaging of the Plasma Spray Process—Work in Progress

J.A. Brogan, C.C. Berndt, W.C. Smith, R.V. Gansert, S. Raghu, S. Sampath and H. Herman

A LaserStrobe Control Vision system was employed to examine water-stabilized plasma (WSP), gas-stabilized plasma (GSP), and single-wire arc plasma (SWAP) technologies. Visualization of the plasma spray process in each of these technologies has been made possible, in some instances, for the first time. Parameter optimization for the three processes was accomplished. This technology has significantly added to the theoretical and scientific knowledge of plasma diagnostics and plasma processing.

1. Introduction

THE GOAL of this program is fundamentally to understand the details of the thermal spray process. Key aspects to analyze include plasma-particle interactions, particle-substrate interactions, and molten particle impact dynamics (Ref 1). Employment of a LaserStrobe system allows a real-time visualization of the thermal spray process (Ref 2). The system bridges the gap of theory to application by allowing particle velocity measurements to be made and particle flow trajectories and patterns to be visualized. The Control Vision system is also used to verify that the various thermal spray control settings are optimum and that the plasma torch is operating within optimum limits.

2. LaserStrobe Operation

The LaserStrobe Control Vision system (Control Vision Inc., Idaho Falls, ID 83405) uses two lasers (2 pulsed nitrogen laser strobes with a 5 ns pulse width) with fiber-optic feed to transport and focus intense 337 nm light to the viewing area of interest. The reflected laser light from the site is brighter than either direct or reflected light from the thermal spray process. The high speed electronic shutter of 50 ns to 5 s duration (at 1 to 30 frames per second) is synchronized with the laser flashes. The laser is also synchronized with the framing of the video sensor and is fired once for each captured video frame. Temporal and spectral filtering results in an image that is free of process light. The moving particles are effectively frozen in place and subsequently recorded onto video tape.

The system control unit permits visual capturing of a particle displaced in flight to be measured as a function of time. These double exposures are used to calculate the velocities of the particles. The time it takes the particle to move from its original position to its double exposed position is known (i.e., the laser synchronization time). The captured video frame is imported

into a Macintosh Quadra supporting NIH software (Public Domain Software: Image 1.49, National Institute of Health, Bethesda, MD 20892) where the distance between the two particles is measured. The velocity of the particle is then calculated from the laser synchronization time and particle displacement.

3. Results

3.1 Water-Stabilized Plasma

The LaserStrobe system provides visualization of only the central part of the jet, which extends a few orifice diameters downstream of the nozzle corresponding to the jet core region. Figure 1 shows the core of the plasma and arc discharge attachment to the anode. The length of the plasma core was observed to vary as the system operates. The luminous core extends up to distances of 8 diameters downstream of the jet. Prior to this visualization technique, the stability of the plasma was observed only through variations in the output power. The plasma arc discharge has now been directly observed to be attached to the anode and traverse back and forth along its width as the anode

Keywords LaserStrobe, parameter optimization, particle velocity, plasma diagnostics, plasma spray

J.A. Brogan, C.C. Berndt, W.C. Smith, R.V. Gansert, S. Raghu, S. Sampath, and H. Herman, and State University of New York, Stony Brook, NY 11794, USA.

This summary of work in progress was presented at the NSF Design, Manufacturing and Industrial Innovation Grantees Meeting, San Diego, January 4-6, 1995.

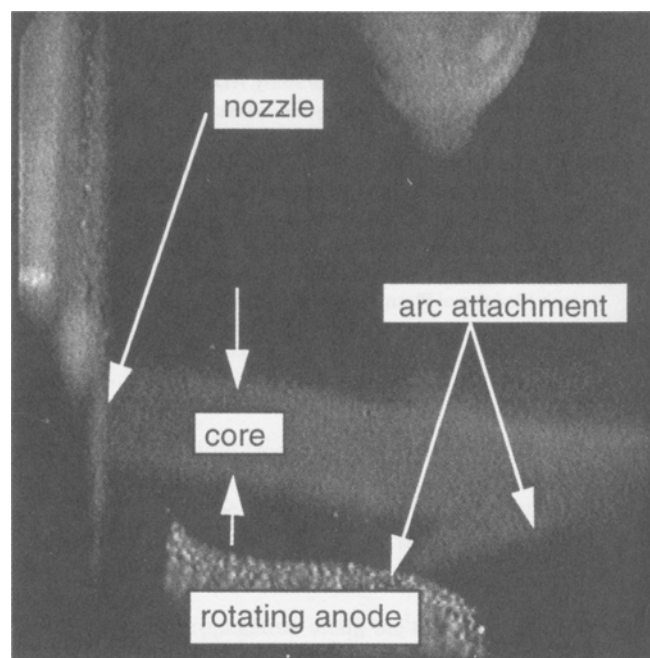


Fig. 1 LaserStrobe image water-stabilized plasma exiting nozzle

rotates in front of the nozzle exit. A “pinching” effect of the hot plasma core region is also observed resulting from a sheath of cooler gas, which is neither ionized nor conductive, encircling and constricting the plasma jet (Ref 3). This pinching effect increases the temperature of the plasma as well as centerline velocities (Ref 4). The outer shear layer as well as the downstream flow field was not observed due to entrainment and mixing of the plasma jet with the colder ambient air.

The particle velocity is dependent on the size of the particle as well as its location within the plume. Figure 2 shows the powder injection into the plasma plume. Some vaporization is observed as “comet trails” behind the particles. Many particles are seen to become entrained in a flow pattern (parallel to central flow field) near the central regions of the core (Ref 5). Particles sufficiently melted will impact the substrate and bond with previously deposited material. By correlating LaserStrobe images with deposit microstructures and operating conditions, powder injection was optimized with a feed angle of approximately 40° from horizontal at a feed rate of approximately 38 kg/h (for alumina feedstock).

Table 1 provides the mean, maximum, and minimum velocities at an average centerline distance of 5 cm downstream of the nozzle. Particles that were measured were mostly on the outer fringes of the plasma plume due to obscuring effects of the plume. Also, an average centerline distance is given because

Table Velocities for WSP and SWAP processes

Process	Mean stand-off, m	Velocity range, m/s	Mean velocity, m/s	Standard deviation, m/s
WSP	0.05	30-269	83	47
SWAP	0.005	29-63	43	8
SWAP	0.02	64-228	118	31

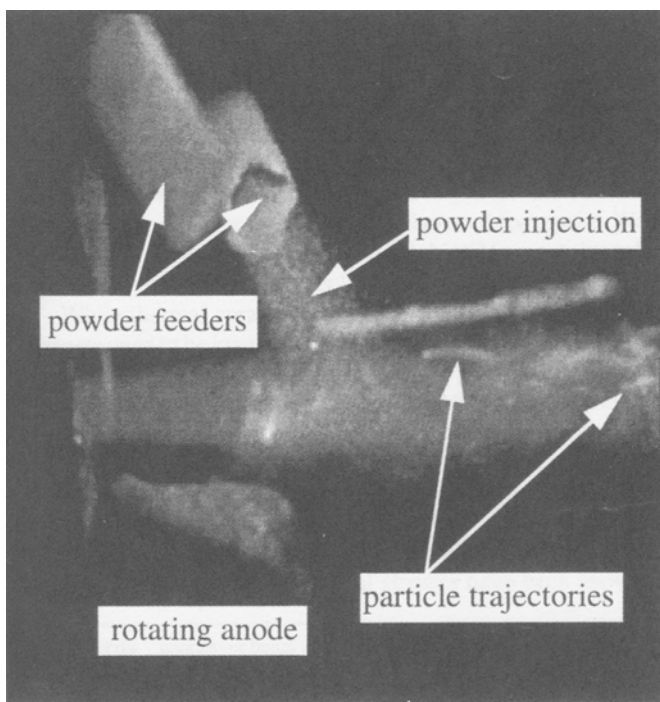


Fig. 2 LaserStrobe image of powder injection into water-stabilized plasma plume

particle measurements (30 particles for WSP and 50 particles for SWAP) were made in a range of distances along the centerline to provide an adequate sample size.

3.2 Gas-Stabilized Plasma

The structure of a Metco 3MB (Metco Inc., Westbury, NY) gas-stabilized plasma jet was investigated using the LaserStrobe

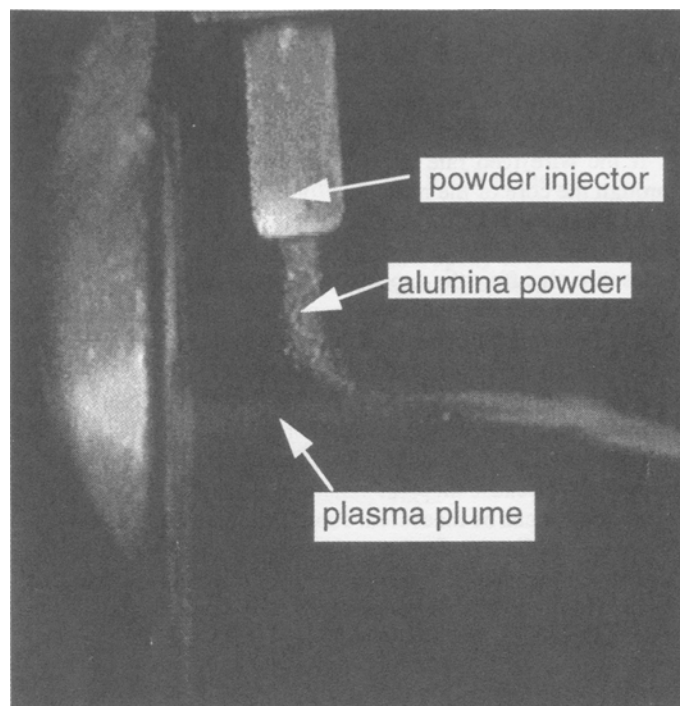


Fig. 3 LaserStrobe image of powder injection into gas-stabilized plasma plume

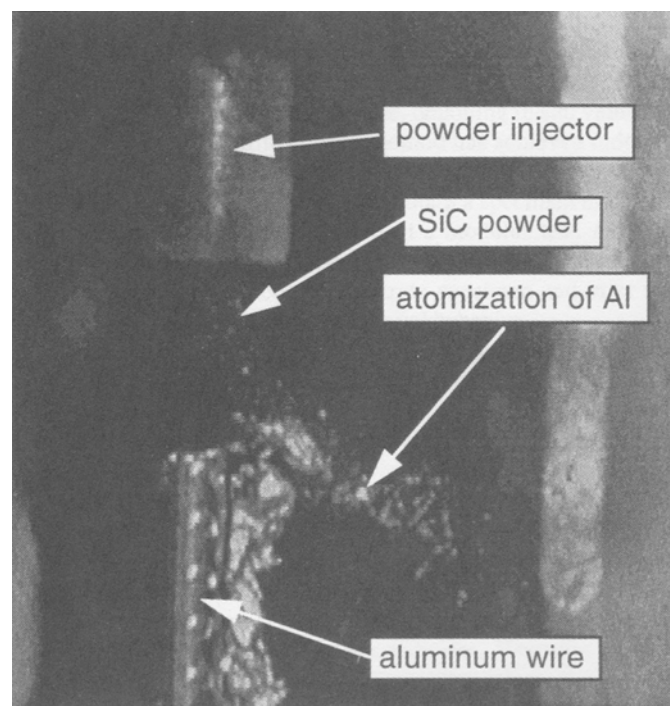


Fig. 4 Single-wire arc atomization of aluminum with SiC/air

system. It was observed that pinching of the luminous core occurred within 2 to 3 diameters downstream of the jet exit. See Fig. 3. This occurrence is most likely due to entrainment of cold ambient air into the core of the jet (Ref 4). Examination of the particle streaks indicates that the particle paths extend across the luminous core region of the jet. This suggests that there is a large variation in the thermal environment for the externally introduced particles into the jet.

3.3 Single-Wire Arc Plasma

The LaserStrobe system examined the SWAP gun and allowed direct visualization of the degree of atomization. See Fig. 4. If the wire feed rate is too high, the wire will be pushed through the core of the plasma before it is fully melted. In this case, the unmelted wire can be visualized along with a larger particle size distribution for the atomized metal. The larger particles directly affect the deposit quality by producing a rougher coating. The wire feed rate was monitored using the Control Vision system to ensure that complete atomization of the wire occurred; therefore, consistently smaller particle sizes resulted.

The control settings were chosen to remove the plasma plume from the SWAP gun in the recorded images. This allowed discrimination of the double exposed particles and, hence, particle velocity because the laser synchronization time and particle displacement can be measured. Table 1 summarizes these measurements for the atomized aluminum wire with respect to distance from the wire. An advantage of using Control Vision is that specific particles of interest are selectively chosen for measurement, unlike laser doppler velocimetry (LDVM), which meas-

ures the whole family of particles whereupon no particles are specifically discriminated (Ref 6). Velocity data as a function of distance away from the centerline of the nozzle along with a visual record of process phenomena are thus made possible.

Acknowledgments

This work is supported by the National Science Foundation under grant number MSS-9311053 as well as by Flame Spray Industries, Inc., Stony Brook, NY and Control Vision, Inc., Idaho Falls, ID.

References

1. H. Herman, Plasma Spray Deposition Processes, *MRS Bull.*, December 1988, p 60-67
2. J. Agapakis and T. Hoffman, Real-Time Imaging for Thermal Spray Process Development and Control, *J. Therm. Spray Technol.*, Vol 1 (No. 1), 1992, p 19-25
3. P. Chraska and M. Hrabovsky, *Thermal Spray: International Advances in Coatings Technology*, C C. Berndt, Ed., ASM International, 1992, p 81-85
4. J. Malinka, D. Varacalle, and W. Riggs, II, *Thermal Spray: International Advances in Coatings Technology*, C C. Berndt, Ed., ASM International, 1992, p 87-92
5. S. Raghu, G. Gotvenier, R.V. Gansert, "Plasma Diagnostics: A Comparative Study of the Structure of Gas Stabilized and Water Stabilized Plasma Jets Using the LaserstrobeTM and Focusing Schlieren Techniques," paper to be submitted to *Experiments in Fluids*.
6. W. Mayr, Rapid Optimization of Spraying Parameters by Means of an Automatic Laser Doppler Measuring Equipment, *Proc. 11th Int. Thermal Spraying Conf.*, Vol 11, 1986, p 221-230