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FINITE – ELEMENT ANALYSIS FOR THERMAL OPTIMIZATION OF PLASMA ARC COATING PROCESS

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ABSTRACT

In this paper, the Thermal Spray Coating process is studied and thermal profile is gained in this process. Plasma thermal coating process simulation and its effective parameter by ANSYS software, the thermal field of workpiece the affected of the parameter variation on thermal fields and finally coating process optimization discussion are the main part of this paper.

Anode erosion in plasma spray torches results in coating deterioration. The usable life of a torch anode is strongly dependent on the fluid dynamic behavior of the plasma inside the torch, which in turn depends on the geometric design of the anode and the operating parameters. To study the relative importance of these effects, cold flow investigations have been performed with a torch having a glass anode with the same geometric dimensions as a commercial plasma torch. The density differences between the arc and the cold gas were simulated by injecting heated helium from the tip of the cathode into the cold argon gas flow from the regular gas injector. Flow visualization was achieved by seeding the flow with micron-sized particles. A finite-element computational fluid dynamics code was used to simulate the cold flow structure. The results were compared with erosion patterns observed with an actual plasma torch. The results indicate that recirculation eddies inside the torch will force a preferred anode attachment, which is different for different gas injectors. The minimization of such recirculation regions by appropriate fluid dynamic design will result in more random attachment of the arc and prolonged anode life.

Keywords: Coating, Temperature Field, Thermal, Optimization, plasma arc, Workpiece

1. INTRODUCTION

Thermal spray is a technique used for surface coating of many materials in a continuous process, thus forming a system with the substrate where one could not exist without its counterpart. It is a method in which any material can be coated by practically any material. Thermal Spray is a process in which thermal energy is combined with

kinetic energy, heat is combined with particle acceleration, to form a dispersion of droplets that impact on the surface of a substrate where they splat, spread, solidify and build up incrementally as the new surface in produced over the original surface. As seen in Fig.1, gas (for some processes air) mixes with energy, in the form of heat, to provide the kinetic and thermal energies needed to coat the substrate by producing a jet of disperse particles to be spray on the original part. This process is usually done for metallic parts that need improvement such as thermal barrier coatings (TBCs), enhanced insulation or conduction, wear resistance, corrosion resistance, decorative additions and abradable parts.

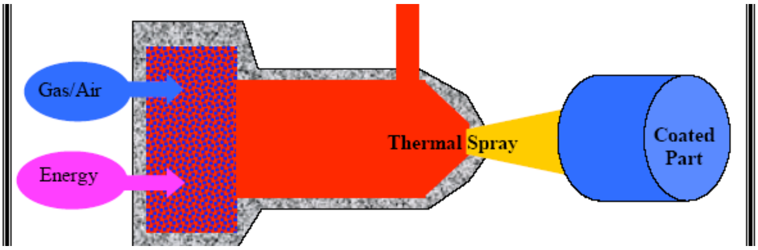

Figure 1. Schematic of the Thermal Spray process

A form of Thermal Spray is Plasma Spray. In this process an arc is produced to melt feed material at tremendously high temperatures of over 20000K. Although this extremely high temperature which creates a plasma will provide the thermal energy to the feedstock material thus allowing it to be sprayed, it is only a localized process in which the temperature decreases drastically as distance from the arc increases. This means that the substrate will stay relatively cool, unless it is made to be part of the electrode setup, so little or no changes in microstructure will occur to it while spraying. This process maybe the most inefficient as far as power consumption is concerned as it uses roughly 1% of the input power to actually melt the feed material. As shown in Fig.2, the process of Plasma Spraying can been seen in where the cathode and anode produces an arc to atomize the particles.

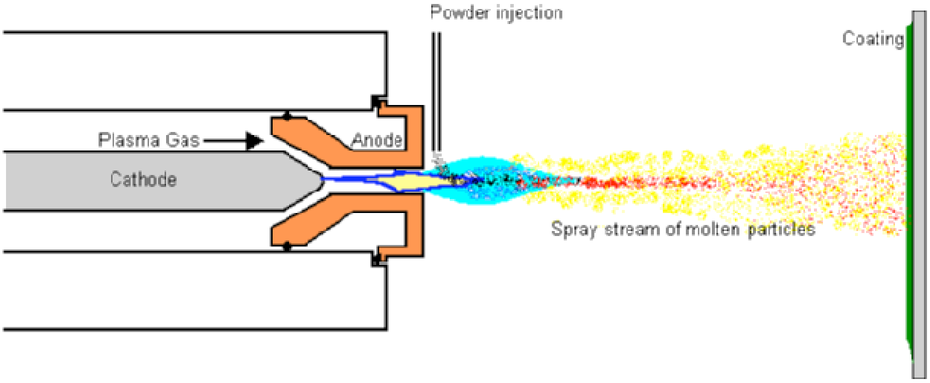

Figure 2. Diagram of Plasma Spray

Fig.3 shows a schematic representation of the flow inside a direct current (DC), nontransferred arc plasma torch, as typically used in plasma spraying. After the working gas enters the torch, it is heated by the arc formed between a nozzle-shaped anode and a cylindrical cathode, forming a plasma, which is ejected as a jet. It can be observed that, despite the axisymmetry of the geometry and boundary conditions (i.e., inflow velocity profile, constant potential at the anode surface), the flow is inherently three-dimensional. Furthermore, any movement of the arc (i.e., movement of the anode attachment) will significantly affect the outflow from the torch, forcing the jet. The dynamics of the arc are a result of the balance between the drag force caused by the interaction of the incoming gas flow over the arc and the electromagnetic (or Lorentz) force caused by the local curvature of the arc . The length of the arc is proportional to the variation of the magnitude of the voltage fluctuations.

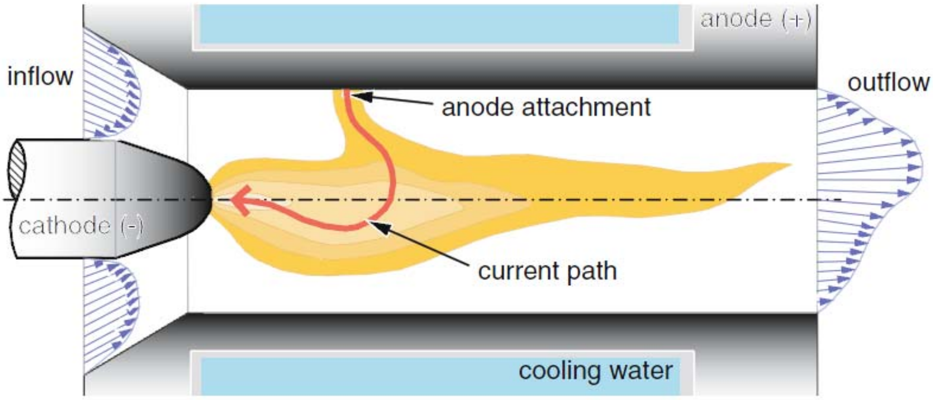

Figure 3. Idealized representation of the flow inside a DC non-transferred arc plasma torch

2. FLOW CALCULATIONS

The three-dimensional flow structures inside the torch have been calculated using the commercial computational fluid dynamics (CFD) code ANSYS-FLOTRAN (ANSYS, Inc., Southpointe, PA). A slightly simplified geometry has been assumed consisting of two cylinders with the nozzle diameter and the diameter of the flow channel surrounding the cathode, respectively.

Fig.4. shows as an example for the results of the velocity distribution in the torch for flow injected with a straight flow injector. What is notable is that the flow shows a strong recirculation in the region where the Ar flow meets the He flow. Increasing the He flow rate moves the location of the recirculation upstream. Similar observations have been made for the flow with the four-hole swirl injector.

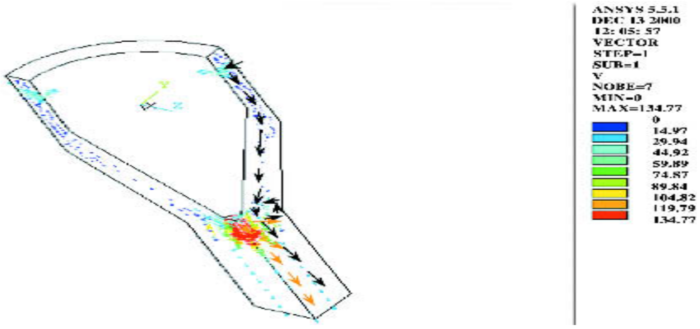

Figure 4. Velocity vector distribution inside an SG 100 plasma torch with a cold-flow, four-hole straight gas injector, 8.87 slm of Ar flow, and 5 slm of He flow. p = 1 atm at the nozzle exit, and the actual velocities at the injection holes have been used. No slip conditions have been used for the wall boundaries.

3. DISCUSSION

The results show that there appears to be correlations among the recirculation region described in the cold-flow CFD simulation, the deposition of the powder on the wall in the cold-flow experiments, and the erosion pattern in the plasma torch. In Fig.5, the results from the different studies are compared for the case of a four-hole swirl injector, with the powder deposition in the cold-flow experiments at the top, the distribution of the *z* component of the velocity below (i.e., the component out of or into the paper plane), and the sectioned plasma torch anode showing the erosion region at the bottom. The

anode has been sectioned not in the mid plane to show a larger part of the circumference and therefore to show more clearly the circumferential asymmetry of the erosion pattern.
To avoid the recirculation pattern, the channel between the arc at the cathode tip and the wall needs to be small and not converging (i.e., the cathode tip should be in the straight part of the anode nozzle). Obviously, for low gas flow rates the problem exists that the arc may attach upstream of the cathode tip, resulting in even stronger erosion.

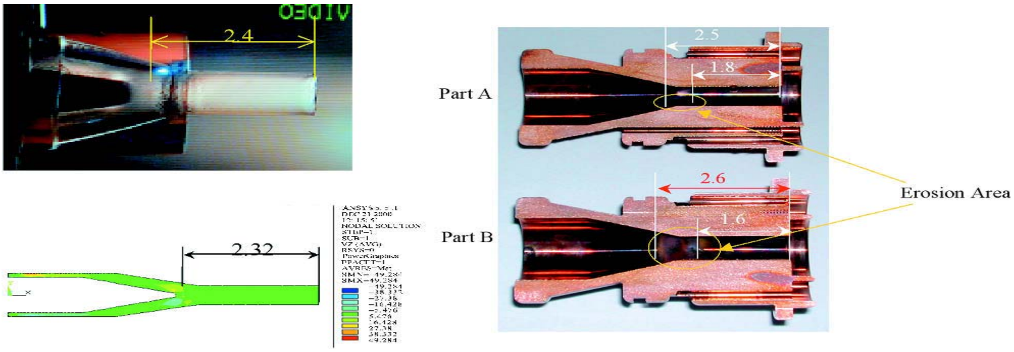

Figure 5. Comparison of powder deposition region in the cold-flow experiment (top), the distribution of the z component of the velocity in the cold-flow CFD simulation, and images of a sectioned anode showing the erosion area. All results are for a four-hole swirl injector. The numbers in the space markers indicate the distance from the nozzle exit in centimeters.

4. CONCLUSIONS

Low-temperature experiments have been performed with plasma spray torch geometry to study the fluid dynamics within the torch. These experiments have been supplemented by CFD simulations of the cold flow and by erosion measurements with actual plasma torches. The results indicate that:

- The low-temperature experiments and calculations provide some insight into the torch fluid dynamics.
- Are circulation region exists in which the gas flow meets the low-density plasma (simulated by the use of heated He in the low-temperature measurements).
- This recirculation affects the location of the arc anode attachment and consequently the erosion.

5. ACKNOWLEDGMENTS

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