A GAS - SHROUDED PLASMA SPRAY TORCH

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ABSTRACT

The application of an argon shroud surrounding an argon plasma jet leads to an axial extension of the isotherms and, at the same time, air entrainment is substantially reduced. Measured isotherms are in reasonable agreement with analytical predictions. Computer simulation of particle injection (30-40 μm Al₂O₃ particles) indicates that gas shrouding improves particle heating and reduces oxidation of metallic particles.

1. INTRODUCTION

Plasma spraying technology has until recently been a rather empirically oriented science. Most of the improvements made over the years have been achieved by successful experimentation.

In this paper, a combined effort of experimentation and numerical modeling is presented with the goal of improving the quality of plasma sprayed coatings in ambient air.

Plasma spraying of metals and metal alloys in ambient air suffers from oxide formation, resulting in degradation of the coatings. Oxidation may be prevented by spraying in a controlled environment, i.e. in soft vacuum or in a protective gas environment. This approach, however, requires substantial equipment investment and in addition, handling of the parts to be sprayed becomes cumbersome.

The approach discussed in this paper involves the use of a coaxial gas shroud around the plasma jet which both reduces air entrainment and extends the length of the plasma jet. The latter increases the dwell time of particles injected into the plasma. This concept has been described in the patent literature [1-3], but no publications on such a design for plasma spraying could be found in the open literature.

2. APPARATUS

The design of the gas-shrouded plasma torch is based on a conventional DC plasma spray torch, consisting of a
tungsten (2% thorium) cathode and a copper anode nozzle with a 7.9 mm dia bore. A shroud gas manifold surrounds the anode. The outside of the anode nozzle is slightly curved for providing a smooth transition of the shroud gas from the manifold into the outlet. The shroud gas outlet consists of an annular slot 0.64 mm wide and coaxially arranged with the plasma jet. Argon is the working gas for both plasma jet and shroud.

3. SPECTROSCOPIC TEMPERATURE MEASUREMENTS

Emission spectroscopy is employed for measuring temperatures in the plasma jet. Details of the experimental set-up are described in [4]. The measurements reported in this paper refer to absolute continuum measurement at 4312 Å. Due to turbulence in the plasma jet and movement of the anode arc root, measurements reveal a relatively high noise level. Thus, a data averaging procedure over 5–10 data sets is used at each axial location. The resulting averaged profiles show reasonable symmetry. Since the luminous intensity of the plasma jet drops rapidly with increasing distance from the anode nozzle, the signal-to-noise ratio decreases accordingly and it was not possible to cover the entire length of the plasma jet. The covered portion, however, is still large enough for meaningful comparisons with the results of the modeling work.

4. MODELING WORK

Modeling includes simulation of the turbulent flow field as well as mixing of the argon plasma with the ambient air. The proposed model is based on the following assumptions:

1) The plasma is steady and optically thin;
2) gravity and heat dissipation due to viscosity are negligible;
3) mixing takes place only between the two components air and argon;
4) the plasma is in LTE, but the temperature of the entrained air is substantially lower than that of the main jet;
5) the flow is of the parabolic type, i.e. axial diffusion is negligible;
6) Boussinesq's eddy viscosity concept is valid.

Based on these assumptions, the governing equations are established. The molecular thermodynamic and transport properties are calculated using the mixing rule. For an estimate of the turbulent properties, a four-equation turbulence model is adopted [5–7]. The dependent variables in these equations are mass-weighted mean variables, where the density is used as the weighting function. This approach has been reported in the literature [8] and is chosen here because of large density variations in the flow.
field due to large temperature variations in the plasma. Using this method simplifies the governing equations to those used for incompressible flow. Since the actual spectroscopic measurements are unweighted mean values, a method to relate mass-weighted and unweighted solutions has to be found. A two parameter probability density function is introduced and the density fluctuations are considered to be only affected by the temperature fluctuations. With these assumptions, the differential equations have been solved by a computer program for parabolic flow [9].

5. RESULTS AND DISCUSSION

Qualitative investigations (photographs) of the gas shroud on the plasma jet are summarized in Table I which also contains the operating parameters of the plasma torch. The results demonstrate that the maximum plasma jet extension occurs at a shrouding/main gas flow ratio of approximately 1:1 and the jet extension starts to decrease for ratios greater than 4:1. The jet extension is more pronounced at lower power levels and lower main gas flow rates. Using air instead of argon as shrouding gas does not produce any jet extension.

Spectrometric measurements as well as numerical calculations based on the parameter settings listed in Table I show the same trends.

Table I: Parameter settings for plasma torch operation

<table>
<thead>
<tr>
<th>CASE</th>
<th>U[V]</th>
<th>I[A]</th>
<th>MAIN GAS [g/min]</th>
<th>SHROUD GAS [g/min]</th>
<th>THERMAL EFF. [%]</th>
<th>L*[mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21.0</td>
<td>300</td>
<td>25.2</td>
<td>--</td>
<td>39.3</td>
<td>26.3</td>
</tr>
<tr>
<td>2</td>
<td>20.8</td>
<td>300</td>
<td>25.2</td>
<td>25.2</td>
<td>38.7</td>
<td>33.9</td>
</tr>
<tr>
<td>3</td>
<td>21.2</td>
<td>400</td>
<td>25.2</td>
<td>--</td>
<td>35.6</td>
<td>29.2</td>
</tr>
<tr>
<td>4</td>
<td>20.9</td>
<td>400</td>
<td>25.2</td>
<td>25.2</td>
<td>36.3</td>
<td>39.5</td>
</tr>
</tbody>
</table>

L*: length of luminous plasma jet

Comparisons between experimental data and numerical results (Figs. 1-4) show reasonable agreement. Both show an extension of the plasma jet due to the gas shroud. The measured isotherms from 9,000 to 12,000 K show for case 2 and 4 (see Table I) a substantial axial extension and the calculations predict this extension down to the 6,000 K isotherm. The higher temperature isotherms close to the anode nozzle, however, are almost unaffected. Numerical calculations of the air entrainment show a strong reduction of the relative concentration (Figs. 5,6) of air in the plasma jet due to the gas shroud.

Results of computer simulations of 30-40 μm Al₂O₃ particles injected into the plasma jet are summarized in Table II.
Table II: Percentage of completely molten particles with and without shroud.

<table>
<thead>
<tr>
<th>Case</th>
<th>Standoff Distance</th>
<th>5 [cm]</th>
<th>6 [cm]</th>
<th>7 [cm]</th>
<th>8 [cm]</th>
<th>9 [cm]</th>
<th>10 [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (w/o shrouding gas)</td>
<td>69%</td>
<td>72%</td>
<td>75%</td>
<td>78%</td>
<td>78%</td>
<td>77%</td>
<td></td>
</tr>
<tr>
<td>4 (w shrouding gas)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

This table shows the percentage of particles which are in a completely molten state at different distances from the nozzle exit for cases 3 and 4 (see Table I). The heating environment for particles is obviously more favorable when using an argon shroud. Also, oxidation of metallic particles during their flight should be reduced due to the previously mentioned reduction of air entrainment.

ACKNOWLEDGEMENTS:

This work has been supported by DOE/DE-FG02-24ER45173 through the Corrosion Research Center at the University of Minnesota. Contributions of L. Gochberg to this work are gratefully acknowledged.

REFERENCES

Fig. 1-4: Temperature fields.

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Fig. 5: Relative air concentration in the plasma jet 300 A.

Fig. 6: Relative air concentration in the plasma jet 400 A.