Estimation of a Heat Distribution in a Part Plasma Coating Process

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ABSTRACT

This work presents theoretical derivations for a plasma gun motion speed estimation which can be applied to part surfaces of different types. The heat distribution model of plasma coating process for complex parts has also been developed.

INTRODUCTION

Currently, plasma deposition technology is considered to be one of the most robust, inexpensive and efficient durable film high power density coating processes.

Various physical and chemical processes take place upon plasma flow contacts a part surface. The temperature of a restorable part is one of the major parameters that define a plasma deposition process and a quality of the obtained coating. Multiple layer coating with a tight geometrical parameter control is achievable when a precise mathematical estimation is applied. Therefore, a functional coating of a particular part can be modeled using numerical simulations of plasma processes [1-3].

This work covers an actual problem of heat distribution estimation in complex surface profile parts processed with plasma coating.

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THEORETICAL BACKGROUND

An equation describing heat distribution in a part treated with a plasma flow can be expressed as follows [4]:

\[
T - T_0 = \frac{Q}{2\pi\lambda v} \times \frac{\exp\left(\frac{z_1}{4\alpha t}\right)}{\sqrt{\pi(t_0 + t)}}
\]

where \(T\) is a heated part temperature (K); \(T_0\) is an initial part temperature (K); \(y, z_1\) are width and depth of a heated spot, respectively (\(\mu m\)); \(t\) is time (s); \(t_0\) is an imaginary source spread time (s); \(Q\) is an effective plasma arc power (W); \(v\) is a heat source motion speed (m/s); \(\lambda\) is a thermal conductivity (W/mK); \(\alpha\) is a temperature conductivity coefficient.

According to equation (1) plasma gun motion speed \(v\) related to a processed part is one of the most crucial parameters affecting heat distribution on a treated surface. Consequently, a table describing plasma gun displacement speed for different part surface types was developed based on previous works [5-7], where \(\rho, \phi, z\) are cylindrical coordinates; \(\beta\) is a helical displacement step of a deposition spot on a treated surface; \(\beta_z\) is a deposition spot projection on z axis; \(tg\psi\) is a cone angle; \(R\) is a cylinder radius (mm); \(D\) is a helix outer diameter (mm); \(\phi_1\) is a helix slope angle; \(\alpha\) is a helix cut angle; \(\frac{dz}{dt}\) is a processed part rotation speed (m/s); \(\frac{d\rho}{dt}\) is a plasma gun longitudinal displacement speed (m/s); \(\frac{d\phi}{dt}\) is a plasma gun radial displacement speed (m/s).

<table>
<thead>
<tr>
<th>No.</th>
<th>Surface type</th>
<th>Plasma gun displacement speed equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Disc</td>
<td>(v_\rho = \sqrt{\frac{d\rho^2}{dt}} + \beta \phi^2 \frac{d\phi^2}{dt})</td>
</tr>
<tr>
<td>2.</td>
<td>Cone</td>
<td>(v_c = \sqrt{\left(\frac{d\rho}{dt}\right)^2 + \left(tg\psi \beta \phi\right)^2 \left(\frac{d\phi}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2})</td>
</tr>
<tr>
<td>3.</td>
<td>Cylinder</td>
<td>(v_{\phi_1} = \sqrt{R^2 \left(\frac{d\phi}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2})</td>
</tr>
<tr>
<td>4.</td>
<td>Helix</td>
<td>(v_\psi = \sqrt{\frac{\pi \left(\sqrt{D^2 (1 + tg\phi_1)} - D_1 \phi_1 (1 + tg\phi_1)\right)}{\alpha} \left(\frac{d\phi}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2})</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSIONS

Equation (1) allows to estimate a processed part heat temperature, but further mathematical corrections are needed for more precise temperature estimation.

Based on calculations by A. F. Ilyushenko [5] we introduce an equation expressing temperature conductivity coefficient:

\[ a = \frac{\lambda}{c \rho_{pc}} \]  

(2)

where \( c \) is a thermal conductivity; \( \rho_{pc} \) is a plasma coating density (kg/m\(^3\)).

We also plug in an equation defining thermal conductivity coefficient dependent on porosity by A. F. Puzryakov [7]

\[ \lambda = \lambda_M (1 - P) \times \lambda_B P \]  

(3)

where \( \lambda_M \) is a coating material thermal conductivity coefficient; \( \lambda_A \) is a thermal conductivity coefficient of air; \( P \) is a coating porosity.

However, given expression is used when alternating plasma coating and gas layers are parallel to a heat flow. So, in our case we use the Lichtnecker equation [8]:

\[ \lambda = \lambda_M^{1-P} \times \lambda_B^P \]  

(4)

As a result, considering introduced mathematical corrections (2,4) and modelled plasma gun motion speed equations [9,10], we derive a set of equations for temperature estimation in complex surface parts during plasma coating process:
\[ T_D = \frac{Q}{2\pi \lambda^{p, \rho}_M \lambda^p_R} \sqrt{\left( \frac{d \rho}{dt} \right)^2 + \beta \varphi^2 \left( \frac{d \varphi}{dt} \right)^2} \exp \left( \frac{z_c \rho_m}{4 \beta \lambda^{p, \rho}_M \lambda^p_R} \right) \sqrt{t(t_0 + t)} + T_0 \]

\[ T_c = \frac{Q}{2\pi \lambda^{p, \rho}_M \lambda^p_R} \sqrt{\left( \frac{d \rho}{dt} \right)^2 + \beta \varphi^2 \left( \frac{d \varphi}{dt} \right)^2} \exp \left( \frac{z_c \rho_m}{4 \beta \lambda^{p, \rho}_M \lambda^p_R} \right) \sqrt{t(t_0 + t)} + T_0 \]

\[ T_v = \frac{Q}{2\pi \lambda^{p, \rho}_M \lambda^p_R} \frac{\pi \left( D^2 (1 + t g \varphi) - D^2 (1 + t g \varphi) \right)}{\lambda^{p, \rho}_M \lambda^p_R} \alpha \left( \frac{d \varphi}{dt} \right)^2 + \left( \frac{d \varphi}{dt} \right)^2 \exp \left( \frac{z_c \rho_m}{4 \beta \lambda^{p, \rho}_M \lambda^p_R} \right) \sqrt{t(t_0 + t)} + T_0 \]

REFERENCES