Deposition of multicomponent coatings by Cold Spray

Ecole Nationale d’Ingénieurs de Saint-Etienne (ENISE), DIPI Laboratory,
58 rue Jean Parot, 42023 Saint -Etienne Cedex 2, France
Contact person: Prof. Igor SMUROV
e-mail : smurov@enise.fr;

Objectives

The objectives of the present study is to up-grade the cold spray technology for spraying of multicomponent coatings with the mixture preparation directly in the gas flow.

To reach this goal a new design of the cold spray nozzle was developed and the following advancements were achieved:

- Calculation of the gas parameters in the nozzle for the case of subsonic and supersonic flows mixing.
- Calculation of the particles outlet parameters (velocity and temperature values) depending on the location of the powder injection point.
- Experimental testing of the nozzle with spraying of different multicomponent coatings.

Main equations

Equations for calculation of particles velocity and temperature

$$m_p v_p \frac{dv_p}{dz} = C_x \frac{\rho (v - v_p)^2}{2} S_{mid}$$

$$\rho_p v_p c_p \frac{dT_p}{dz} = Nu \frac{6\lambda}{d_p^2}(T_0 - T_p)$$

Approximation of Henderson

$$\mathrm{M}_p = \frac{v - v_p}{a}$$

$$\mathrm{Re}_p = \frac{(v - v_p)\rho d_p}{\mu}$$

$$C_{x1} = \frac{24}{\mathrm{Re}_p + 3.06\sqrt{\gamma}} + \frac{4.5 + 0.0114\mathrm{Re}_p + 0.1825\sqrt{\mathrm{Re}_p}}{1 + 0.03\mathrm{Re}_p + 0.48\sqrt{\mathrm{Re}_p}} + 0.3$$

$$C_{x2} = C_{x1} + 0.1\mathrm{M}_p^2 + 0.2\mathrm{M}_p^8 - 0.3$$

$$C_x = \begin{cases} C_{x1}, & \mathrm{M}_p < 1 \\ C_{x2}, & \mathrm{M}_p > 1{,}75 \\ C_{x1} + 1{,}33(\mathrm{M}_p - 1)\left(0{,}9 + \frac{0{,}34}{1{,}75} - C_{x1}\right), & 1 < \mathrm{M}_p < 1{,}75 \end{cases}$$

Equations for calculation of gas parameters

$$\sqrt{(n+1)(n+n\theta+\vartheta)}\,z(\lambda_3) = z(\lambda_1) + n\sqrt{\theta}\,z(\lambda_2)$$

$$z(\lambda) = \lambda + \frac{1}{\lambda}; \quad \theta = \frac{T_2}{T_1}; \quad n = \frac{q(\lambda_2)}{\Pi\alpha\sqrt{\theta}\,q(\lambda_1)}$$

$$\Pi = \frac{p_{01}}{p_{02}}; \qquad q(\lambda) = 1{,}58\lambda(1 - 0{,}167\lambda^2)^{2,5}$$

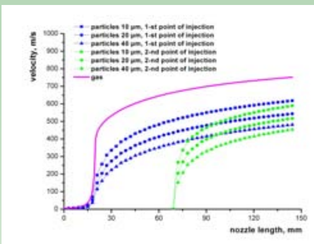
$$\frac{p_{03}}{p_{01}} = \frac{\sqrt{(n+1)(1+n\theta+\vartheta)}}{1+\frac{1}{\alpha}} \frac{q(\lambda_1)}{q(\lambda_2)}$$

$$\frac{d\mathrm{M}}{\mathrm{M}} = \frac{\left(1 + \frac{k-1}{2}\mathrm{M}^2\right)}{\mathrm{M}^2 - 1}\left(\frac{dS}{S} - \frac{kF_f\,dx}{\rho a^2 S}\right)$$

$$\left[\begin{array}{l} \dfrac{z(\lambda_1') - z(\lambda_1)}{z(\lambda_2) - 2} = n\sqrt{\theta} \\[2ex] \dfrac{1}{\Pi}\dfrac{\frac{1}{q(\lambda_1')} - \frac{1}{q(\lambda_1)}}{\frac{1}{q(\lambda_2)} - 1} = n\sqrt{\theta} \end{array}\right.$$

Equations to calculate gas and particle parameters

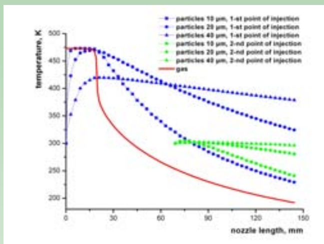
Calculation of gas and particle parameters



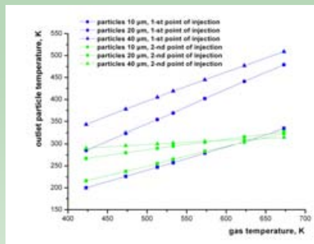
Evolution of the particle velocity in the nozzle.

$V_1 = V_2$

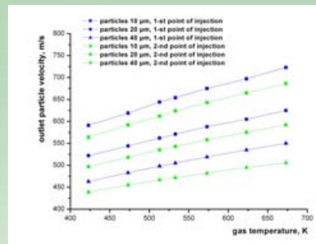
$T_1 > T_2$



Evolution of the particle temperature in the nozzle.

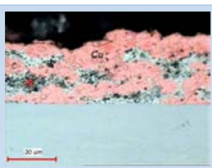


Calculation of the particle outlet temperature

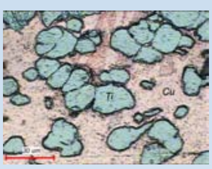


Calculation of the particle outlet velocity

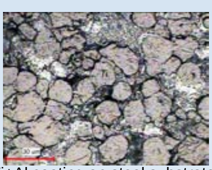
Examples of the sprayed multicomponent coatings



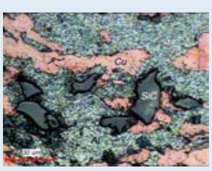
Cu+Al coating on aluminium substrate
Initial composition of the mixture:
50%Cu - 50%Al



Ti+Cu coating on steel substrate
Initial composition of the mixture:
50%Cu - 50%Ti

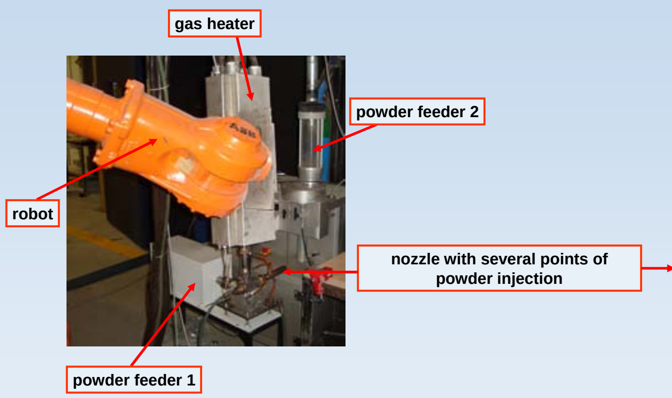


Ti+Al coating on steel substrate
Initial composition of the mixture:
30%Al - 70%Ti



Cu+Al+SiC coating on steel substrate
Initial composition of the mixture:
30%Cu - 40%Al - 30%SiC

Experimental setup



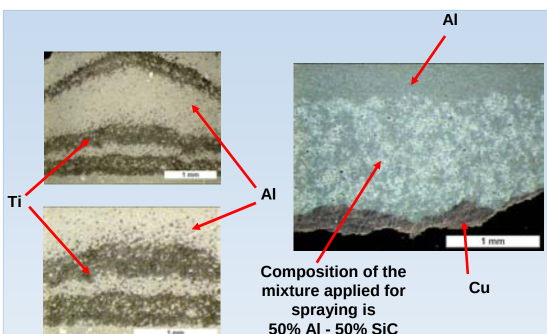
Main parameters

Gas pressure	10 – 30 MPa
Gas temperature	up to 600 °C
Gas consumption	0,5 – 2 m³ /s
Electric consumption	1 – 30 kW

Advantages:

- **It is possible to vary concentration of each powder component during spraying**
- **Particles of each component have the optimal value of velocity and temperature**

Spraying of graded coatings



Composition of the mixture applied for spraying is 50% Al - 50% SiC

Graded coatings were sprayed on Al substrate.

Conclusions

A new design of the cold spray nozzle with two points of powder injection is proposed.

Several multicomponent coatings including graded ones were successfully sprayed.