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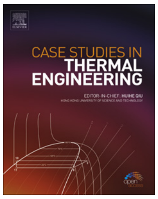

Scrutiny of plasma spraying complexities with case study on the optimized conditions toward coating process control

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ABSTRACT

In the present study, we investigate a PSP using the *Jets&Poudres* soft. The plasma gas understanding is given to highlight the effects of gas mixtures proportions on diffusion parameters. An overview on the process complexities at main subsystems is given with focus on Argon plasma and optimal mixing; the powder acceleration and heat-up modeling are also presented. Under literature conditions and for He–Ar–H_2 65–30–5% gas, it was found that the droplet's primary way is to coat. The used ternary mixture gives superior efficiency compared to the pure Argon which shows a prior way to rebound. Moreover, medium particles ($d_p \approx 45$ μm) present the high deposited rate among the splashed mass, a 100% molten ratio is observed for the small powder and only particles of size below 40.3 μm have evaporated, particles of initial diameter between 40.3 and 49 μm are fully molten and all particles above 71.9 μm are fully solid. The coat formed by the deposited mass will transfer a large amount of heat to the substrate (9–58 MW/m^2). The crushed particle's rate is about 4% from the investigated number and the average fully molten particle's rate is about 72% and the rest of particles arrive in solid sate.

1. Introduction

Coating treatment of surfaces by plasma spraying remains an important manufacturing process which is extensively used in industrial applications to enhance the performance of engineering components such as coating of pistons, piston rings and shafts, and improving resistance to thermal degradation, corrosion and wear.

Besides, the arc PSP is of great complexity due to the various parameters involved in three levels [1–5]. First, the generation of the plasma arc into the torch (nozzle diameter, current *I*, voltage *U*).

Second, we cite the plasma jet flow in interaction with the powder material jet, where the plasma jet parameters (composition, enthalpy, temperature, velocity, viscosity and thermal conductivity, etc.) are highly variable, the jet length and the air engulfment in the jet enhancing turbulence. Others parameters are related to the powder-injector (internal diameter, position, tilting angle, carrier gas: composition and feed rate, etc.), adding the parameters related to the powder itself (material morphology, shape, size, residence time in the jet, etc.). In a third level, the parameters correspond to the coat formation (materials properties, substrate preparation, spraying distance, relative movement torch/target, incidence tilt, substrate cooling, residual stresses, etc.) and eventually the variability of the above-mentioned parameters (dispersion). The various cited parameters make the plasma spraying a multi-complexity problem.

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Nomenclature

Vector quantities

$\vec{u}_g$	gas velocity (m/s)
$\vec{u}_p$	particle velocity (m/s)
$\vec{x}_p$	particle position (m)
$\vec{F}_d$	drag force (N)
$\vec{F}_g$	gravity force (N)
$\vec{F}_{ma}$	force due to additive mass (N)
$\vec{F}_{th}$	thermophoretic force (N)
$\vec{g}$	gravitational field (=9.81 m/s²)

Physical parameters

a	thermal accommodation coefficient
A_p	particle surface, $=\pi {d_p}^2$
C_D	drag coefficient
C_{pp}	particle specific heat (J/mol K)
d_{inj}	injector diameter (m)
d_p	particle diameter (m)
f_{kn}	corrective factor related to Knudsen effect
f_{prop}	corrective factor related to boundary layer effect
h_f	convective heat transfer coefficient ($W/m^2/K$)
Kn^*	Knudsen number
k_p	particle conductivity ($W/m^2/K$)
L_e	material latent heat of boiling (J/kg)
L_m	material latent heat of melting (J/kg)
m_p	Liquid–solid averaged particle mass (kg)
N_f	modified Nusselt number
Pr_w	Prandtl number of hot gas at Tw
Q_{conv}	convective heat flux received by the particle (W/m^2)
Q_{net}	total heat flux received by the particle (W/m^2)
Q_{rad}	radiative heat flux received by the particle (W/m^2)
Re	relative Reynolds number, $\nu_g d_p/\lvert\vec{u}_g-\vec{u}_p\rvert$
Re_p	particle Reynolds number, $=\rho_p d_p u_p/\mu_p$
t	particle time (s)
T	physical gas temperature (K)
T_∞	local jet temperature (K)
T_a	ambient temperature, 300 K
T_e	material boiling point (K)
T_m	material melting point (K)
T_p	particle temperature, $=T_p(t, r)$
T_w	particle–wall temperature
X_p	volumetric melt fraction of the particle
ρ_g	gas density: volumetric mass (kg/m^3)
ρ_p	particle density (kg/m^3)
μ_g	gas dynamic viscosity (kg/m/s)
γ	specific heat ratio

Subscripts, superscripts and abbreviations

b	boiling
g	gas
ma	additive mass
p	particle
$prop$	gas property
th	thermophoresis
w	wall
FD	Finite Differences
LTE	Local Thermal Equilibrium
ODE	Ordinary Differential Equations
PSP	Plasma Spraying Process
∞	far from particle
$\dot{m}$	rate of mass vaporization
min	minimum value
max	maximum value
av	average value

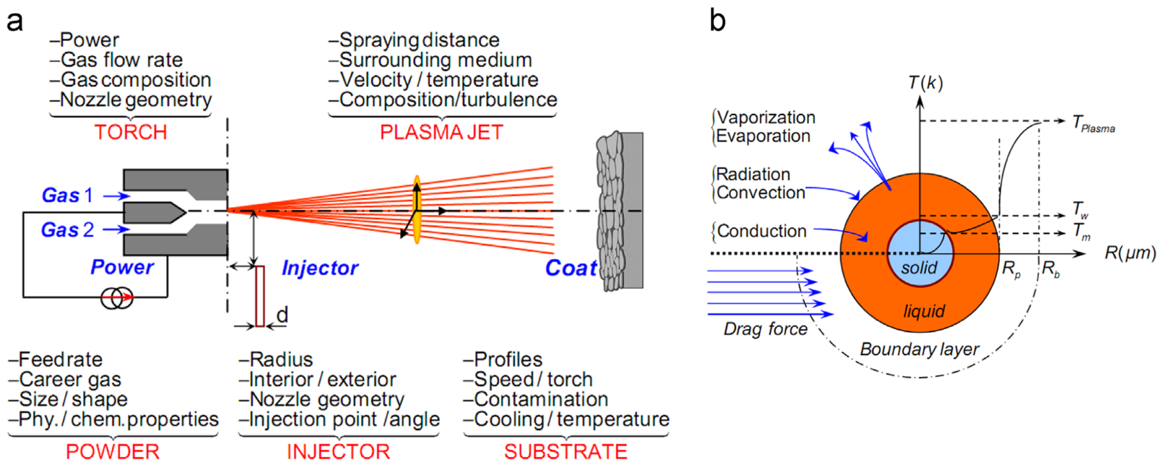

Fig. 1. Sketch of the plasma spraying principle and complexities. (a) The DC plasma torch, the plasma jet, the powder injector, the substrate and the coat formation. (b) Zoomed view of particle momentum, heat and mass transfer phenomena occurring in its surrounding boundary layers.