„Understanding Multi-Arc Plasma Spraying“

Von der Fakultät für Maschinenwesen der
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Abstract

Multi-arc plasma spraying systems promise several advantages in comparison to the conventional single-arc systems. However, some of the underlying fundamentals of the multi-arc plasma spraying are still poorly understood. Intensive numerical research which has been conducted to identify the fundamentals of conventional single-arc plasma spraying has not been applied to multi-arc plasma spraying process yet. A comprehensive numerical research to understand the behavior of the plasma columns in the plasma torch as well as that of powder particles in the plasma jet in multi-arc plasma spraying were the subjects of this thesis.

In this study, the focus was set to the influence of relevant numerical aspects and model assumptions on the numerical results. The models which are necessary to analyze the plasma and particle behavior in multi-arc spraying systems have been subjected to intensive verification with respect to the underlying model assumptions and numerical aspects. Subsequently, the prediction powers of the models have been evaluated by comparing the results of the developed models with the results of advanced diagnostic systems. General characteristics of plasma columns within and outside of the spraying system as well as particle behaviors in the plasma jet have been analyzed using developed numerical models. Furthermore, the possible application areas of the developed models have been introduced exemplarily.

Good accuracy of the models regarding the predicted plasma jet characteristics and particle temperatures and velocities is evident. Due to the stable behavior of the plasma columns, modeling of multi-arc spraying systems promises accurate description of the process and a high predicting power allowing a successful deployment of the developed models with the purpose of designing and optimization of process and injection parameters.

Abstract (deutsch)

Das Mehr-Kathoden-Plasmaspritzen verspricht mehrere Vorteile im Vergleich zum herkömmlichen Ein-Kathode-Plasmaspritzen. Allerdings sind die Grundlagen dieses Prozesses noch wenig erforscht. Intensive numerische Untersuchungen, die zu einem besseren Verständnis der Grundlagen des konventionellen Ein-Kathode-Plasmaspritzens geführt haben, beziehen sich noch nicht auf das Multi-Elektroden-Plasmaspritzen. Daher war die Entwicklung der numerischen Modelle, die die physikalischen Vorgänge im Plasmagenerator sowie das Verhalten der Pulverpartikel im Mehr-Kathoden-Plasmaspritzen beschreiben, Gegenstand der Arbeiten in dieser Dissertation.

In dieser Studie wurde der Fokus auf den Einfluss der relevanten numerischen Aspekte und Modellannahmen auf die numerischen Ergebnisse gelegt. Die Modelle, die notwendig sind, um das Plasma- und das Partikelverhalten im Mehr-Kathoden-Plasmaspritzen zu analysieren, wurden in Bezug auf die zugrunde liegenden Modellannahmen und numerischen Aspekte einer intensiven Verifikation unterzogen. Anschließend wurde die Vorhersagefähigkeit der Modelle auf Basis eines umfangreichen Vergleichs zwischen den Ergebnissen der entwickelten Modelle und der experimentellen Diagnosesysteme bewertet. Die Eigenschaften der Plasmasäulen innerhalb und außerhalb des Plasmagenerators sowie das Partikelverhalten im Plasmastrahl wurden mittels entwickelter Modelle analysiert. Darüber hinaus wurden die möglichen Anwendungsbereiche der entwickelten Modelle exemplarisch vorgestellt.

Die hohe Genauigkeit der numerischen Modelle in Bezug auf die berechneten Plasmastrahleigenschaften, Partikeltemperaturen und -geschwindigkeiten ist evident. Aufgrund des stabilen Verhaltens der Plasmasäulen, verspricht die Modellierung vom Mehr-Kathoden-Plasmaspritzen eine genaue Beschreibung des Prozesses und eine hohe Vorhersagefähigkeit. Folglich ist ein erfolgreicher Einsatz der entwickelten Modelle mit dem Ziel der Entwicklung und Optimierung von Prozess- und Injektionsparametern zu erwarten.

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List of Abbreviations

EIT-1	Institute of Plasma Technology and Mathematics, University of the Federal Armed Forces, Munich, Germany
CCD	Charged-coupled device
CFD	Computational Fluid Dynamics
CT	Computed tomography
DC	Direct current
DNS	Direct numerical simulation
LANL	Los Alamos National Laboratory
LCE	Local chemical equilibrium
LDA	Laser Doppler anemometry
LES	Large eddy simulation
LTE	Local thermodynamic equilibrium
MHD	Magneto hydrodynamics
NASA	National Aeronautics and Space Administration
NLTE	Non-LTE
RANS	Reynolds-averaged Navier-Stokes
RF	Radio frequency
RMS	Root mean square
RNG	Renormalization Group Theory
SLPM	Standard liter per minute
SST	Shear Stress Transport

List of Symbols

A_i	Interfacial area
A_p	Cross sectional area of particle
Bi	Biot number
c	Courant number
C_D	Drag coefficient
c_{opt}	Optical magnification
Cp_g	Specific heat capacity of plasma gas
C_{vm}	Virtual mass coefficient
d	Distance
D_{AB}^{E}	Combined diffusion coefficient due to gradients in the electric field
D_{AB}^{P}	Combined diffusion coefficient due to gradients in the total pressure
D_{AB}^{T}	Combined diffusion coefficient due to temperature gradients
D_{AB}^{X}	Combined diffusion coefficient due to mole fraction gradients
d_{fc}	Diameter of flexible cord
d_i	Injector diameter
d_n	Nozzle outlet diameter
d_p	Particle diameter
E	Electric field
f	Frequency
F_D	Drag Force
F_{vm}	Virtual mass force
h	Heat transfer coefficient

I	Electric current
J_A	Diffusion mass flux of gas A
k	Turbulent kinetic energy
L	Path length
L_b	Latent heat of boiling
L_f	Latent heat of fusion
l_i	Length of injector head
Ma	Mach number
M()	Measured intensity
m_A	Mass of the heavy ions in gas A
m_B	Mass of the heavy ions in gas B
m_g	Mass of the plasma gas
$\dot{m}_{ig}$	Mass flow rate of injection gas
$\dot{m}_{l\rightarrow g}$	Rate of evaporation
m_p	Particle mass
$\dot{m}_p$	Mass flow rate of injected particles
$\dot{m}_{s\rightarrow l}$	Melting rate
n	Number density
Nu_p	Particle Nusselt number
p	Pressure
P	Spatial position
P_{el}	Electric Power
P_{loss}	Cooling loss

P_{net}	Net power
Pr_g	Gas Prandtl number
p_{tot}	Total pressure
Q_c	Convective heat transfer
Re_p	Particle Reynolds number
S	Electric Conductivity
s	Slip velocity
T	Temperature
t	Time
T_{Arb}	Arbitrary temperature
$T_{b,p}$	Boiling point of the feedstock material
T_g	Plasma gas temperature
$T_{m,p}$	Melting point of the feedstock material
T^{c}_{max}	Calculated max. temperature
T^{m}_{max}	Measured max. temperature
T_p	Particle temperature
v	Velocity
V	Electric potential
v_g	Velocity of plasma gas
v_p	Particle velocity
x_B	Mole fraction of gas B
Y_A	Mass fraction of gas A
Δ	Deviation

Δx	Distance between two laser strips
Δ_λ	Wavelength range
ε	emissivity
ε	turbulent dissipation
ε ()	emission intensity
θ	angle between two incident laser beams
κ	Thermal conductivity
κ_g	Thermal conductivity of plasma gas
κ_p	Thermal conductivity of particle
λ	Wave length
μ	Mean value
μ_g	Dynamic viscosity of plasma gas
ρ_g	Density of plasma gas
σ	Standard deviation
φ	Volumetric flow rate
$\varphi()$	Plasma gas property, i.e. density, viscosity, conductivity etc.
$\overline{\varphi}$	Plasma gas property averaged across the boundary layer
ω	Specific dissipation