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Review

Cold gas dynamic spray technology: A comprehensive review of processing conditions for various technological developments till to date

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ABSTRACT

Today, cold gas dynamic spray (CGDS) technology has thrived with considerable capabilities for manufacturing various technological depositions. The deposition conditions have been developed through many years and that have led to produce ample experimental data which is available in the literature. But, recent research and development activities also reveal innovative findings regarding various deposition conditions. This paper contains a review of experimental deposition procedures for the cold spray additive manufacturing. Details of processing conditions are reported and classified into various categories of baseline working conditions, specific processing including deposition of nanotechnological components, composites-based structures and hybrid coating with substrate deposition. Available substrate treatments and their contributions on the deposition capability were also included. A large collection of experimental data from the literature is addressed.

Contents

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Nomenclature

Latin script symbols

a,b	Dimensionless number (–)
d_p	Particle diameter (m)
A	Radial cross section of the nozzle (m^2)
A_e	Radial cross section of the nozzle outlet (m^2)
A_i	Radial cross section of the nozzle inlet (m^2)
A^*	Radial cross section of the nozzle throat (m^2)
r	Nozzle radius along the nozzle axis (m)
r_e	Radius of nozzle exit (m)
r_{throat}	Radius of nozzle throat (m)
d_{throat}	Diameter of nozzle throat (m)
z	Coordinate of nozzle axis (m)
C	Drag coefficient of particle (–)
Cp	Specific heat ($J\,kg^{-1}\,K^{-1}$)
L_{div}	Length of nozzle supersonic part (–)
M	Mach number (–)
P	Gas pressure along the nozzle axis (Pa)
P_0	Input stagnation pressure of the propellant gas (Pa)
Pr	Prandtl number (–)
Q	Flow rate of particles ($kg\,s^{-1}$)
Rs	Specific gas constant ($J\,kg^{-1}\,K^{-1}$)
Ra	Roughness (m)
Re	Reynolds number (–)
Re_{p0}	Reynolds number of particle for $\rho=\rho_0$ (–)
SoD	Standoff distance (distance nozzle exit – substrate) (m)
T	Gas temperature along the nozzle axis (K)
T_0	Input stagnation temperature of the propellant gas (K)
T_m	Melting temperature of particle (K)
T_i	Impact temperature of particle (K)
T_R	Reference temperature (ambient temperature) (K)
V	Gas velocity along the nozzle axis ($m\,s^{-1}$)
V_{cr}	Critical velocity of particle for adhesion ($m\,s^{-1}$)
V_i	Impact velocity of particle ($m\,s^{-1}$)
V_{nozzle}	Velocity of nozzle displacement ($m\,s^{-1}$)

Greek-script symbols

γ	Ratio of specific heat (–)
ε	Ratio of nozzle sections (r_{exit}/r_{throat}) (–)
λ	Thermal conductivity ($W\,m^{-1}\,K^{-1}$)
μ	Dynamic viscosity ($kg\,m^{-1}\,s^{-1}$)
ρ	Specific mass (density) ($kg\,m^{-3}$)
ρ_0	Initial density of the propellant gas ($kg\,m^{-3}$)
σ_u	Ultimate yield strength (Pa)

Abbreviations

ABS	Acrylonitrile butadiene styrene
AISI	American iron and steel institute
BMG	Bulk metallic glass
cBN	Cubic bore nitride
CFD	Computational fluid dynamics
CGDS	Cold gas dynamic spray
CFRC	Carbon fibre reinforced composite
CNT	Carbon nanotube
CTE	Coefficient of thermal expansion
DBC	Direct bonded copper
DSSC	Dye sensitive solar cell
FTO	Fluorine doped tin oxide
DE	Deposition efficiency
GFRC	Glass fibre reinforced composite
HA	Hydroxyapatite
HDPE	High-Density polyethylene
HRTEM	High resolution transmission electron microscopy
ITO	Indium tin oxide
LPCS	Low pressure cold spraying
LZT	Lead zirconate titanate
MMC	Metal matrix composite
MWCNT	MultiWall carbon NanoTube
ND	NanoDiamond
NPDS	NanoParticle deposition system
PA	Polyamide
PC	Polycarbonate
PEEK	Polyetheretherketone
PEG	Polyethylene glycol
PES	Polyether sulfone
PET	Polyethylene terephthalate
PVDF	Polyvinylidene fluoride
PMC	Polymer matrix composite
PP	Polypropylene ; PPA, polyphthalamide
PPSU	Polyphenylsulfone
PS	Polystyrene
PSU	Polysulfone
PTFE	Polytetrafluoroethylene
PU	Polyurethane
PVC	Polyvinyl chloride
SEM	Scanning electron microscopy
SoD	Standoff distance
SS	Stainless steel
WC	Tungsten carbide

Subscript symbol

g	Gas
Nc	nanocrystalline
np	Nanoporous
ns	Nanosized
p	Particle

1. Introduction: developments and capabilities of CGDS technology

Cold spraying is an innovative additive manufacturing method and it has recently become a promising technique in the material processing field. Primarily, cold spraying is a powder deposition method and it exploits the self-consolidation capability of the solid particles which join together while they retain in their solid state. A high velocity impact enables such self-consolidation capability that is governed by a solid state bonding. This technique was developed in the early twentieth century by Thurston [1]. Later, a blast or a pressurized gas was used to accelerate metallic powders to a maximum velocity of about 300 m/s and subsequently, the high speed