Acta Materialia xxx (2016) 1–27

Contents lists available at ScienceDirect

Acta Materialia

journal homepage: www.elsevier.com/locate/actamat

By invitation only: overview article

Cold spraying – A materials perspective

H. Assadi*, H. Kreye, F. Gärtner, T. Klassen

Helmut Schmidt University, Institute of Materials Engineering, Hamburg, Germany

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form
13 June 2016
Accepted 14 June 2016
Available online xxx

Keywords:
Cold spraying
Coating
Additive manufacturing
Deposition mechanism
Deformation

ABSTRACT

Cold spraying is a solid-state powder deposition process with several unique characteristics, allowing production of coatings or bulk components from a wide range of materials. The process has attracted much attention from academia and industry over the past two decades. The technical interest in cold spraying is twofold: first as a coating process for applications in surface technology, and second as a solid-state additive manufacturing process, offering an alternative to selective laser melting or electron beam melting methods. Moreover, cold spraying can be used to study materials behaviour under extremely high strain rates, high pressures and high cooling rates. The cold spraying process is thus considered to be relevant for various industrial applications, as well as for fundamental studies in materials science. This article aims to provide an overview of the cold spray process, the current understanding of the deposition mechanisms, and the related models and experiments, from a materials science perspective.

Contents

* Corresponding author. Brunel University London, Brunel Centre for Advanced Solidification Technology (BCAST), Uxbridge, Middlesex, United Kingdom.
E-mail address: hamid.assadi@brunel.ac.uk (H. Assadi).

http://dx.doi.org/10.1016/j.actamat.2016.06.034
1359-6454/

Abbreviations and symbols

Abbreviation

AD	aerosol deposition
AM	additive manufacturing
ASI	adiabatic shear instability
BMG	bulk metallic glass
CNT	carbon nanotube
CS	cold spraying
DE	deposition efficiency
E-FEM	Eulerian finite element method
FEM	finite element method
FFT	fast Fourier transform
FIB	focused ion beam
GND	geometrically necessary dislocation
HA	hydroxyapatite
L-FEM	Lagrangian finite element method
MD	molecular dynamics
MPA	metal powder application
MPW	magnetic pulse welding
SEM	scanning electron microscopy
SPH	smoothed-particle hydrodynamics
TEM	transmission electron microscopy

Symbol

a, b	fitting constants in critical velocity formula, 1[11]
A, B	Johnson-Cook parameters, Pa
C	Johnson-Cook parameter, 1
c_p	heat capacity of particle, J kg^{-1} K^{-1}
d	nozzle diameter, m
d_p	particle diameter, m
E	total energy per unit mass of particle, J kg^{-1}
E_k	kinetic energy per unit mass of particle, J kg^{-1}
E_k^0	reference kinetic energy, J kg^{-1}
$\overline{E}_k$	normalised kinetic energy, 1
E_{th}	thermal energy per unit mass of particle, J kg^{-1}
E_{th}^0	reference thermal energy, J kg^{-1}
$\overline{E}_{th}$	normalised thermal energy, 1
f	powder feed rate, kg s^{-1}
F^*	force to compress particle to height of $d_\mathrm{p}/2$, N
l	nozzle length (supersonic part), m
l_pre	prechamber length, m
m, n	Johnson-Cook parameters, 1
p_gas	process gas stagnation pressure, Pa
r	nozzle expansion ratio, 1
s	standoff distance, m
t	time, s
T	temperature, K
T_g	glass transition temperature, K
T_gas	process gas stagnation temperature, K
T_m	melting temperature, K
T_p	particle temperature, K
T_ref	reference temperature, K
T_sub	substrate temperature, K
T_x	crystallization temperature, K
v_c	velocity of contact point in explosive welding, m s^{-1}
v_cr	critical particle impact velocity for bonding, m s^{-1}
v_gun	traverse speed of gun, m s^{-1}
v_p	particle impact velocity, m s^{-1}
x	characteristic system dimension, m
α	thermal diffusivity, m^2 s^{-1}
β	adiabaticity parameter ($x^2/\alpha/t$), 1
ε	plastic strain, 1
$\dot{\varepsilon}$	plastic strain rate, s^{-1}
$\dot{\varepsilon}^*$	normalised plastic strain rate, 1
γ_cr	critical shear strain at the start of localisation, 1
$\gamma_\mathrm{max\ stress}$	strain at max stress in adiabatic deformation, 1
η	normalised particle impact velocity ($v_\mathrm{p}/v_\mathrm{cr}$), 1
η_E	sum of normalised energy terms ($\overline{E}_k + \overline{E}_{th}$), 1
θ	normalised temperature, 1
ρ	density of particle, kg m^{-3}
σ	flow stress, Pa
σ_UTS	ultimate tensile strength of particle, Pa
ω	spraying angle, 1

1. Introduction

Cold spraying (CS) is a solid-state material deposition technique, where micron-sized particles of a powder bond to a substrate as a result of high-velocity impact and the associated severe plastic deformation. Acceleration of particles to high velocities is obtained via expansion of a pressurised and (ironically) 'hot' gas through a diverging-converging nozzle. Despite heating the process gas – which is to provide higher acceleration of the gas and also to facilitate particle deformation through thermal softening – the feedstock remains in the solid state throughout the entire process; hence the name 'cold' spraying. This is to underline the contrast to

Please cite this article in press as: H. Assadi, et al., Cold spraying – A materials perspective, Acta Materialia (2016), http://dx.doi.org/10.1016/j.actamat.2016.06.034