Robert B. Heimann

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Plasma Spray Coating

Principles and Applications

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Robert B. Heimann

Plasma-Spray Coating

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Preface

Thermal spraying encompasses a variety of apparently simple surface engineering processes by which solid materials (wire, rods, particles) are rapidly heated by a plasma jet or a combustion flame, melted and propelled against the substrate to be coated. Rapid solidification of the molten particles at the substrate surface builds up, splat by splat, into a layer which may have various functions including protection against wear, erosion, corrosion and thermal or chemical degradation. The coating may also impart special electrical, magnetic or decorative properties to the substrate. Thick coatings are applied in many industrial areas to restore or attain desired workpiece dimensions and specifications.

The text has been written bearing in mind the theoretical and practical requirements of students of materials engineering and materials science. It has been developed from the topics presented to classes of Master students of the Materials Engineering Program at the School of Energy and Materials, King Mongkut's Institute of Technology Thonburi, Bangkok, Thailand between 1991 and 1995 as well as to students of Technical (Applied) Mineralogy at Freiberg University of Mining and Technology since 1993. The author has also gained experience in plasma spray technology during his work from 1987 to 1988 as the head of the Industrial Products and Materials Section of the Industrial Technologies Department of the Alberta Research Council, Edmonton, Alberta, Canada, and from 1988 to 1993 as the manager of the Institutional and International Programs Group of the Manufacturing Technologies Department of the same organization.

It is nearly impossible to consider the entire body of literature on the subject of thermal spraying. Therefore, instead of an exhaustive coverage of applications of plasma-sprayed coatings only typical examples and case studies will be given to illustrate the various physical processes and phenomena occuring within the realm of this technology.

Many colleagues and friends helped with the production of this text. I owe thanks to Professor Dr. Dr. h.c. Walter Heywang, formerly director of Corporate Research and Development of Siemens AG in Munich for suggesting the idea of this book. I am much indebted to Mr. Liang Huguong, Dr. Ulrich Kreher and Mr. Dirk Kurtenbach who prepared diligently the numerous diagrams and graphs. The critical comments of my graduate students and Professor Jürgen Niklas, Institute of Experimental Physics, Freiberg University of Mining and Technology were most welcome. My wife Giesela patiently endured my idiosyncrasies and irritations during some phases of the preparation of this text, and suffered through many lonely weekends. Last but not least, VCH Weinheim, represented by Frau Dr. Ute Anton, supported and encouraged me in the endeavour to complete the manuscript. Special thanks are due to Tommaso Albinoni and Antonio Vivaldi.

Robert B. Heimann Freiberg, March 1996

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List of Symbols and Abbreviations

a.c. = alternating current
AE = acoustic emission
AJD = anode jet dominated
APS = air plasma spraying
BE = back wall echo
CAPS = controlled atmosphere plasma spraying
CBC = chemical barrier coatings
CCF = cross-correlation function
CFC = carbon fiber composite
CJD = cathode jet dominated
CSZ = completely stabilized zirconia
CTE = coefficient of thermal expansion
CVD = chemical vapor deposition
CW-PTR = continuous wave photothermal radiometry
d.c. = direct current
E, EM, M, T, and S = plasma types
EB-PVD = electron beam PVD
ECM = electrochemical machining
EMI = electromagnetic interference
EP = electrode plasma
f.c.c. = face centered cubic
FFT = fast Fourier transform
FGM = functional gradient material
FPA = fracture profile analysis
FTIR = Fourier transformed infrared
HAp = hydroxyapatite
HOSP = hollow-spherical-powder
HPPS = high power plasma spraying
HRC = Rockwell hardness
HTSC = high temperature superconducting coatings
HV = Vickers' hardness
HVOF = hypervelocity oxyfuel gun
ICP = inductively coupled plasma

IE = interfacial echo
IGPS = inert gas plasma spraying
IPS = inductive plasma spraying
JIT = just-in-time
LCF = low cycle fatigue
LDA = laser Doppler anemometry
LPPS = low pressure plasma spraying
LPS = laser plasma spraying
LTE = local thermodynamic equilibrium
MHD = magnetohydrodynamic
MRP = main regime parameters
OCTA = oxide-cobalt-titanium anodes
ORTA = oxide-ruthenium-titanium anodes
p.p.m. = parts per million
PA-CVD = plasma assisted CVD
PAVD = plasma assisted vapor deposition
PEN = positive electrode-electrolyte-negative electrode
PLZT = lead lanthanum zirconate titanate
PMMA = polymethylmethacrylate
PMRS = plasma melted rapidly solidified
PSI = particle-source-in (model)
PSZ = partially stabilized zirconia
PTA = plasma transferred arc
PVD = physical vapor deposition
PZT = lead zirconate titanate
QFD = quality function deployment
RFS = radio frequency spraying
RT = room temperature
SCFH = standard cubic feet per hour
SDE = statistical design of experiments
SEM = scanning electron microscopy
SES = statistical experimental strategy
SIA = slit island analysis
SLPM = standard litres per minute
SME = small and medium sized enterprises
SOFC = solid oxide fuel cell
SPC = statistical process control
SPE = solid particle erosion
SPS = shrouded plasma spraying
SQA = statistical quality assurance
SQC = statistical quality control
STF = strain to fracture
TBC = thermal barrier coatings
TEM = transmission electron microscopy
TI = transmitted impulse
TQM = total quality management

TRIR = time resolved infrared radiometry
TTBCs = thick TBCs
TTT = temperature-time-transformation (diagram)
ULSI = ultra large scale integration
UPS = underwater plasma spraying
UTS = ultimate tensile strength
VPS = vacuum plasma spraying
Y-PSZ = yttria-partially stabilized zirconia