

Contents

- 1 Introduction 1**
 - 1.1 Needs for Coatings 1
 - 1.2 Thin Films vs. Thick Films 2
 - 1.3 Thermal Spray Coating Concept 2
 - 1.4 Description of Different Thermal Spray Coating Processes 4
 - 1.5 History of Thermal Spray 7
 - 1.6 Thermal Spray Applications 8
 - 1.7 Overview of Book Content 13
 - References 14

- 2 Overview of Thermal Spray 17**
 - 2.1 Surface Treatments or Coatings 17
 - 2.1.1 Why Surface Treatment or Coatings 17
 - 2.1.2 Surface Treatments 18
 - 2.1.3 Coatings 19
 - 2.2 Brief Descriptions of Thermal Spray Applications 25
 - 2.3 Overview of Thermal Spray Processes 27
 - 2.3.1 Compressed Gas Expansion 28
 - 2.3.2 Combustion Spraying 28
 - 2.3.3 Electrical Discharge Plasma Spraying 28
 - 2.4 Substrate Preparation 32
 - 2.5 Energetic Gas Flow Generation 33
 - 2.5.1 Cold Spray 33
 - 2.5.2 Flame Spray 35
 - 2.5.3 High-Velocity Oxy-fuel Spraying 36
 - 2.5.4 Detonation Gun Spraying 38
 - 2.5.5 Direct Current Blown Arc Spraying
or d.c. Plasma Spraying 39
 - 2.5.6 Vacuum Induction Plasma Spraying 40
 - 2.5.7 Wire Arc Spraying 42
 - 2.5.8 Plasma-Transferred Arc Deposition 43

2.6	Material Injection	44
2.6.1	Powder Injection	44
2.6.2	Wire, Rod, or Cord Injection	47
2.6.3	Liquid Injection	50
2.7	Energetic Gas-Particle Interactions	51
2.7.1	Momentum Transfer	51
2.7.2	Heat Transfer	52
2.7.3	Effect of the Surrounding Atmosphere	54
2.8	Coating Formation	57
2.8.1	Coatings from Fully or Partially Melted Particles in Conventional Spraying	57
2.8.2	Adhesion of Conventional Coatings	60
2.8.3	Coatings Resulting from Solution or Suspension Spraying	63
2.8.4	Residual Stresses	64
2.9	Control of Coating Formation	65
2.9.1	Coating Temperature Control Before, During, and After Spraying	65
2.9.2	Control of Other Spray Parameters	67
2.10	Summary and Conclusions	69
	References	70
3	Fundamentals of Combustion and Thermal Plasma	73
3.1	Combustion	73
3.1.1	Definitions	73
3.1.2	Combustion at Equilibrium	74
3.1.3	Combustion Kinetics	76
3.1.4	Combustion or Deflagrations, Detonations	79
3.2	Thermal Plasmas Used for Spraying	84
3.2.1	Definition	84
3.2.2	Plasma Composition	85
3.2.3	Thermodynamic Properties	88
3.2.4	Transport Properties	89
3.3	Basic Concepts in Modeling	95
3.3.1	Introduction	95
3.3.2	Conservation Equations	95
3.3.3	Gas Composition, Thermodynamic, and Transport Properties	104
3.4	Summary and Conclusions	106
	References	110
4	Gas Flow-Particle Interaction	113
4.1	Introduction	113
4.2	Single Particle Trajectory	114
4.2.1	Single Particle Motion	114
4.2.2	Particle Injection and Trajectory	116
4.2.3	Drag Coefficient: Micrometer Sized Single Sphere	128

4.2.4	Drag Coefficient: Submicron and Nanometer-Sized Particles	138
4.3	In-Flight Single Particle Heat and Mass Transfer and Chemical Reactions	140
4.3.1	Basic Conduction, Convection, and Radiation Heat Transfers	140
4.3.2	In-Flight Particle Heating and Melting	142
4.3.3	Heat Transfer to a Single Sphere	148
4.4	Ensemble of Particles and High-Energy Jet	176
4.4.1	General Remarks	176
4.4.2	Particle Injection	178
4.4.3	Particles and Plasma Jet with No Loading Effect	187
4.4.4	Loading Effect	191
4.5	Liquid or Suspension Injection into a Plasma Flow	195
4.5.1	Liquid Injection	196
4.5.2	Liquid Penetration into the Plasma Flow	202
4.5.3	Liquid Fragmentation	203
4.5.4	In-Flight Heat Transfer to Droplets	207
4.5.5	Cooling of the Plasma Flow by the Liquid	208
4.5.6	Influence of Arc Root Fluctuations	209
4.5.7	Case of No Fragmentation	211
4.6	Summary and Conclusions	212
	References	215
5	Combustion Spraying Systems	227
5.1	Historical Perspective and General Remarks	227
5.2	Flame Spraying	228
5.2.1	Principle	228
5.2.2	Powder Flame Spraying	229
5.2.3	Liquid Flame Spraying	235
5.2.4	Wire, Rod, or Cord Spraying	235
5.2.5	Flame Modeling	238
5.3	High Velocity Flame Spraying (HVOF–HVOF)	239
5.3.1	HVOF or HVOF Powder Spraying	239
5.3.2	HVOF Wire Spraying	260
5.3.3	Applications: General Remarks	262
5.3.4	Coatings Sprayed with Combustible Gases and Oxygen	262
5.3.5	Coatings Sprayed with Liquid Fuel and Oxygen	265
5.3.6	HVOF–HVOF Modeling	266
5.4	Detonation Gun (D-Gun)	269
5.4.1	Process Description	269
5.4.2	In-Flight Particle Properties	275
5.4.3	Graded Coatings	278
5.4.4	Coating Properties	278
5.5	Summary and Conclusions	290
	References	292

6	Cold Spray	305
6.1	Introduction to the Different Cold Spray Processes	305
6.1.1	High-Pressure Cold Spray	305
6.1.2	Low Pressure Cold Spray	309
6.1.3	Vacuum Cold Spray	311
6.2	High-Pressure Cold Spray Process	312
6.2.1	Process Gas Dynamics	312
6.2.2	Coating Adhesion and Cohesion	326
6.2.3	Deposition Parameters	342
6.3	Coating Materials and Applications	356
6.3.1	General Remarks	356
6.3.2	Metals	356
6.3.3	Composites	363
6.3.4	Ceramics	366
6.4	Low Pressure Cold Spray (LPCS)	369
6.4.1	Coating Formation	369
6.4.2	Examples of Coatings	370
6.5	Summary and Conclusions	372
	References	374
7	D.C. Plasma Spraying	383
7.1	Description of Concept	383
7.2	Equipment and Operating Parameters	386
7.3	Fundamentals of Plasma Torch Design	388
7.3.1	Torch Cathode	389
7.3.2	Arc Column	391
7.3.3	Torch Anode	393
7.3.4	Arc Voltage and Power Dissipation	394
7.3.5	Arc Stability	394
7.3.6	Electrode Erosion	400
7.4	Particle Injection	403
7.5	Plasma Torch and Spray Process Modeling	408
7.6	Plasma Torch and Jet Characterization: Time Averaged	412
7.6.1	Effect of Plasma Gas	413
7.6.2	Effect of Plasma Gas Injector Design	416
7.6.3	Effect of Anode Nozzle Design	418
7.6.4	Effect of Surrounding Atmosphere	421
7.6.5	Effect of Cathode Shape	421
7.6.6	Effect of Standoff Distance	422
7.6.7	Summary of Design and Operating Parameters	424
7.7	Plasma Jet Characterization: Transient Behavior	424
7.7.1	Plasma Jet Instability	424
7.7.2	Effect of Arc Voltage Fluctuations on Plasma Jet and Particle Characteristics	427

7.8	Different Plasma Torch Concepts	433
7.8.1	Shrouds and Other Fluid Dynamic Jet Stabilization	433
7.8.2	Fixed Anode Attachment Position	437
7.8.3	Central Injection Torches	440
7.8.4	Torches for Inside Diameter Coatings	443
7.8.5	High-Power Plasma Spray Torch	444
7.8.6	Water-Stabilized Plasma Torch	444
7.9	Low Pressure and Controlled Atmosphere Plasma Spraying . . .	446
7.10	Plasma-Sprayed Materials and Coatings	454
7.10.1	Oxide Materials	455
7.10.2	Non-oxide Ceramics	460
7.10.3	Cermets	462
7.10.4	Metals or Alloys	463
7.11	Summary and Conclusions	465
	References	467
8	R.F. Induction Plasma Spraying	479
8.1	Introduction	479
8.2	The r.f. Induction Plasma Torch	481
8.2.1	Basic Concepts	481
8.2.2	Energy Coupling Mechanism	483
8.2.3	Induction Plasma Torch Design	490
8.2.4	Temperature, Fluid Flow, and Concentration Fields	497
8.3	Modeling of the Inductively Coupled Plasma Discharge	509
8.3.1	Basic Assumption	511
8.3.2	Governing Equations	511
8.3.3	Typical Results of Fluid Dynamic Modeling	521
8.4	Plasma-Particle Interaction Model	532
8.4.1	Governing Equations	534
8.4.2	Typical Result: Effect of Particle Loading	536
8.5	Vacuum Induction Plasma Spraying	549
8.5.1	Basic Equipment Design	549
8.5.2	Parametric Analysis and Operating Conditions	554
8.5.3	Reactive Induction Plasma Spraying	562
8.5.4	Suspension Induction Plasma Spraying	564
8.5.5	Supersonic Induction Plasma Spraying	567
8.6	Summary and Conclusions	569
	References	571
9	Wire Arc Spraying	577
9.1	Description of Concept	577
9.2	Equipment and Operating Parameters	579
9.3	Wire Materials and Specific Applications	582
9.3.1	Wires	582
9.3.2	Cored Wires	585
9.4	Metal Droplet Formation	587

9.5	Process Characterization	597
9.5.1	Gas Velocity Measurements	599
9.5.2	Metal Droplet Velocity Distributions	600
9.5.3	Metal Droplet Temperature	607
9.5.4	Coating Characteristics	608
9.5.5	Fume Formation	612
9.6	Process Modeling	613
9.7	Single Wire Arc Spraying	618
9.8	Special Developments: Low-Pressure Wire Arc and 90° Angle Spraying	622
9.9	Summary and Conclusions	623
	References	624
10	Plasma-Transferred Arc	631
10.1	Description of Concept	631
10.1.1	Tungsten Inert Gas	633
10.1.2	Metal Inert Gas	633
10.2	Equipment and Operating Parameters	634
10.3	Coating Materials and Applications	639
10.3.1	Corrosion and Wear	639
10.3.2	Self-Lubricating Coatings	641
10.3.3	Rebuilding of Parts	642
10.3.4	Free-Standing Shapes	642
10.4	Process Characterization	642
10.4.1	Temperature Distributions in the Arc and Arc Voltages	643
10.4.2	Heat Flux to the Substrate	646
10.4.3	PTA Process Modeling	650
10.5	Effect of Process Parameter Changes on Coating Properties	652
10.6	Process Modifications and Adaptations	655
10.6.1	Variation of Ratio of Pilot Arc Current to Transfer Arc Current	656
10.6.2	Variation of Powder Feed	656
10.6.3	Nitriding of Coating	656
10.6.4	Modulation of Deposition Parameters	657
10.6.5	High-Energy PTA	658
10.6.6	PTA Combined with Tape Casting	660
10.6.7	PTA Deposition with a Negative Work Piece Polarity	660
10.6.8	Hard Coatings on Magnesium	661
10.7	Examples of Specific Applications	661
10.7.1	Increasing Hardness	661
10.7.2	Increasing Wear Resistance	662

10.7.3	Abrasive Wear in Petrochemical, Mining, and Agricultural Applications	664
10.7.4	Combined Corrosion and wear	665
10.7.5	Refurbishing of Worn Parts	666
10.7.6	Freestanding Shape Fabrication	666
10.8	Summary and Conclusions	667
	References	669
11	Powders, Wires, Cords, and Rods	675
11.1	Powders	676
11.1.1	Introduction	676
11.1.2	Powders Manufacturing Techniques	678
11.1.3	Examples of the Influence of Powder Morphologies on Coating Properties	716
11.1.4	Conventional Particle Classification Method	719
11.1.5	Characterization	722
11.1.6	Powder Feeders	728
11.1.7	Hazards Related to Particulate Materials	732
11.2	Wires	734
11.2.1	Wire Materials	734
11.2.2	Cored Wires	735
11.2.3	Wire Feeders	736
11.3	Rods	736
11.4	Cords	736
11.5	Polymer Particles	737
11.5.1	General Remarks	737
11.5.2	Sprayed Polymer Powders	739
11.6	Summary and Conclusions	744
	References	746
12	Surface Preparation	755
12.1	Introduction	755
12.2	Machining	755
12.3	Cleaning	757
12.3.1	Vapor Degreasing	757
12.3.2	Baking in an Oven	758
12.3.3	Ultrasonic Cleaning	758
12.3.4	Wet or Dry Blasting	758
12.3.5	Acid Pickling	758
12.3.6	Brushing	758
12.3.7	Dry Ice Blasting	759
12.4	Masking	760
12.5	Roughening by Grit Blasting	761
12.5.1	Roughness Measurement	761
12.5.2	Grit-Blasting Equipment	766

12.5.3	Grit-Blasting Nozzles	767
12.5.4	Grit Material	768
12.5.5	Blasting Parameters	771
12.5.6	Grit Residues	776
12.5.7	Grit Wear	781
12.5.8	Residual Stress Induced by Grit Blasting	783
12.5.9	Conclusion	784
12.6	High-Pressure Water Jet Roughening	786
12.6.1	Equipment and Description of the Process	786
12.6.2	Water Jet-Blasting Parameters	788
12.6.3	Comparison Grit and Water Jet Blasting	792
12.7	Abrasive Water Jetting	793
12.8	Laser Treatment: Protal [®] Process	793
12.8.1	Laser Ablation	793
12.8.2	Protal [®] Experimental Setup	795
12.8.3	Example of Results	796
12.9	Summary and Conclusions	799
	References	801
13	Conventional Coating Formation	807
13.1	Introduction	807
13.2	Spray Parameters	810
13.3	Physical and Chemical Description of Substrates	812
13.3.1	Physical Aspect of Substrate Surfaces	813
13.3.2	Oxide Layer Development on Metals or Alloys	816
13.4	Single Particle Impact, Flattening, and Solidification (When Melted)	820
13.4.1	Introduction	820
13.4.2	Different Possibilities of Particle or Splat–Substrate Adhesion	822
13.4.3	Splat Formation from Unmelted Particles Impacting on Smooth Substrates	832
13.4.4	Splat Formation from Molten Particles Impacting onto Smooth Substrates	839
13.4.5	Splat Formation from Partially Molten Particles on Smooth Substrates	863
13.4.6	Splat Formation from Unmelted Particles Off Normal on Smooth Substrates	866
13.4.7	Flattening and Solidification of Molten Particle on a Smooth Substrate	866
13.5	Splat Formation on Rough Surfaces	868
13.5.1	Solid Ductile Particles	868
13.5.2	Molten Metal, Alloy, Ceramic, and Cermet Particles	869
13.5.3	Polymer Particles	873

13.6	Coating Formation	874
13.6.1	Molten Particles Deposited by Thermal Spraying	874
13.6.2	Polymer Coatings	887
13.6.3	Ductile Particles	892
13.6.4	PTA Coatings	896
13.6.5	Coatings Obtained by Very Low Pressure Plasma Spray	897
13.6.6	Use of Robot Manipulators	900
13.6.7	Coating Structure Modeling	902
13.7	Temperature Control of Substrate and Coating in Thermal Spraying	903
13.7.1	Introduction	903
13.7.2	Splat Cooling	905
13.7.3	Cooling Methods	908
13.7.4	Coating Mean Temperature Control	913
13.8	Influence of Powder Manufacturing Process on Coating Properties	915
13.8.1	Chemical Reactions	915
13.8.2	Particle Morphology	917
13.8.3	Nanostructured Agglomerated Particles	919
13.9	Influence of Wire, Cored Wires, Rods, and Cords on Coating Properties	920
13.9.1	Flame or HVOF or HVAF-Sprayed Wires	920
13.9.2	Flame-Sprayed Rods	922
13.9.3	Arc Sprayed	922
13.10	Stresses Within Coatings	924
13.10.1	Residual Stress	924
13.10.2	Service Stresses	937
13.10.3	Conclusions Relative to Residual Stresses	941
13.11	Finishing Coatings	941
13.11.1	Machining (Turning, Milling)	941
13.11.2	Grinding	941
13.11.3	Abrasive Belt Grinding and Polishing	942
13.11.4	Other Finishing Methods	943
13.12	Post Treatment of Coatings	943
13.12.1	Fusion of Self-Fluxing Alloys	944
13.12.2	Heat Treating or Annealing	946
13.12.3	Hot Isostatic Pressing	948
13.12.4	Austempering Heat Treatment	949
13.12.5	Laser Glazing	949
13.12.6	Sealing	952
13.12.7	Spark Plasma Sintering	956
13.12.8	Peening or Rolling Densification	957
13.12.9	Diffusion	958
13.13	Summary and Conclusions	958
	References	962

14	Nanostructured or Finely Structured Coatings	981
14.1	Introduction	982
14.1.1	Why Nanostructured Coatings	982
14.1.2	How to Spray Nanostructure Coatings?	985
14.2	Spraying of Complex Alloys Containing Multiple Elements to Form Amorphous Coatings	987
14.2.1	Amorphous Alloys Containing Phosphorus	987
14.2.2	NiCrB and FeCrB Alloys	988
14.2.3	Iron-Based Amorphous Alloys	989
14.3	Agglomerated Ceramic Particles Spraying with Hot Gases	993
14.3.1	Spray Conditions	993
14.3.2	Applications	1004
14.4	Attrition or Ball Milled Cermets or Alloy Particles Sprayed with Hot Gases	1013
14.4.1	Alloys	1014
14.4.2	Cermets	1015
14.5	Spraying Hypereutectic Alloys with Hot Gases	1017
14.6	Production of Nanostructured Coatings by Cold Spray	1019
14.6.1	Alloys	1019
14.6.2	Composites	1020
14.6.3	Amorphous Alloys	1022
14.7	Solutions or Suspensions Spraying	1023
14.7.1	Sub-Micrometer and Nanometer-Sized Particles in Plasma or HVOF Jets	1024
14.7.2	Liquid Injection	1030
14.7.3	Spray Torches Used	1037
14.7.4	Solutions or Suspensions Preparation	1040
14.7.5	Liquid Stream: Hot Flow Interactions	1045
14.7.6	Coating Manufacturing Mechanisms	1056
14.7.7	Applications	1083
14.8	Summary and Conclusions	1093
	References	1096
15	Coating Characterizations	1113
15.1	Introduction to Coating Characterizations and Testing Methods	1115
15.1.1	Differences Between Coatings and Bulk Materials	1115
15.1.2	Characterization and Testing Methods Used for Coatings	1116
15.1.3	Statistical Methods	1117
15.2	Nondestructive Methods	1121
15.2.1	Visual Inspection	1121

15.2.2	Laser Inspection	1122
15.2.3	Coordinate Measuring Machines	1122
15.2.4	Machine Vision and Robotic Evaluation	1122
15.2.5	Acoustic Emission	1123
15.2.6	Laser-Ultrasonic Techniques	1123
15.2.7	Thermography	1124
15.2.8	Coating Thickness	1125
15.3	Metallography and Image Analysis	1125
15.3.1	Coating Preparation	1126
15.3.2	Microscopy	1131
15.4	Materials Characterization	1137
15.4.1	X-Ray Spectroscopy or X-Ray Fluorescence	1138
15.4.2	Infrared Spectroscopy	1138
15.4.3	Mössbauer Spectroscopy	1139
15.4.4	X-Ray Diffraction	1139
15.4.5	Small- and Ultrasmall-Angle X-Ray Diffraction (USAXF)	1141
15.4.6	Neutron Scattering	1143
15.4.7	X-Ray Absorption Spectroscopy	1145
15.4.8	Electron Probe X-Ray Microanalysis	1146
15.4.9	Auger Electron Spectroscopy	1146
15.4.10	X-Ray Photoelectron Spectroscopy	1146
15.4.11	Other Techniques	1147
15.5	Void Content and Network Architecture	1147
15.5.1	Archimedean Porosimetry	1149
15.5.2	Mercury Intrusion Porosimetry (MIP)	1150
15.5.3	Gas Permeation and Pycnometry	1150
15.5.4	Small-Angle Neutrons Scattering	1152
15.5.5	Ultrasmall-Angle X-Ray Scattering	1153
15.5.6	Stereological Protocols (Coupled to Image Analysis) (ST)	1155
15.5.7	Electrochemical Impedance Spectroscopy	1160
15.6	Adhesion–Cohesion	1161
15.6.1	Introduction	1161
15.6.2	Simple Adhesion Tensile Test	1162
15.6.3	Other Types of Tensile Tests	1164
15.6.4	Shear Stress	1166
15.6.5	Fracture Mechanics Approach	1167
15.6.6	Bending Test: Adhesion and Interface Toughness Measurements	1169
15.6.7	Indentation: Interface Toughness Measurement	1171
15.6.8	Other Methods	1173
15.7	Mechanical Properties	1177
15.7.1	Hardness and Indentation Test	1177
15.7.2	Young's Modulus	1184

15.7.3	Toughness	1186
15.7.4	Residual Stress	1187
15.8	Thermal Properties	1193
15.8.1	Mass Density	1193
15.8.2	Expansion Coefficient	1194
15.8.3	Thermal Conductivity and Thermal Diffusivity	1194
15.8.4	Specific Heat at Constant Pressure	1196
15.8.5	Thermal Shock Resistance	1197
15.8.6	Differential Thermal Analysis, Thermogravimetry, and Differential Scanning Calorimetry	1199
15.9	Wear Resistance	1203
15.9.1	Abrasive Wears	1203
15.9.2	Adhesive Wears	1204
15.9.3	Erosive Wear	1206
15.9.4	Surface Fatigue	1209
15.9.5	Corrosive Wears	1213
15.9.6	Fretting	1217
15.10	Corrosion Resistance	1218
15.10.1	General Remarks	1218
15.10.2	Corrosion Characterization	1222
15.11	Summary and Conclusions	1225
	References	1235
16	Process Diagnostics and Online Monitoring and Control	1251
16.1	Introduction	1252
16.1.1	What Is Expected from Thermal-Sprayed Coatings?	1252
16.1.2	Coatings Repeatability, Reliability, and Reproducibility	1252
16.1.3	How Sprayed Coatings Quality Was Improved Through the Spray Process Monitoring	1255
16.1.4	Spray Process Parameters That Should Be Controlled	1257
16.2	High-Energy Jets Characterization	1258
16.2.1	Plasma Jets	1259
16.2.2	Flames and Cold Spray	1266
16.3	Sensors	1269
16.3.1	Hot Gases Flow: Enthalpy Probe	1270
16.3.2	Particles In-Flight Distribution	1274
16.3.3	In-Flight Hot Particle Temperature and Velocity Measurement	1284
16.3.4	In-Flight Velocity Measurements of Cold Particles	1303
16.3.5	Are Such Measurements Sufficient to Monitor Coating Properties?	1306
16.3.6	Coating Under Formation	1308

16.4	Online Control or Monitoring?	1311
16.4.1	Coating Properties Monitoring	1311
16.4.2	Online Control?	1320
16.5	Other Possible Measurements	1320
16.5.1	Particle Vaporization	1320
16.5.2	Splat Formation	1321
16.5.3	Plasma-Liquid Injection	1328
16.6	Summary and Conclusions	1333
	References	1337
17	Process Integration	1351
17.1	Introduction	1352
17.2	Potential and Real Risks	1352
17.2.1	Powders: Respiratory Problems and Explosions	1353
17.2.2	Gases	1355
17.2.3	Prevention and Safety Measures	1357
17.2.4	Other Risks	1359
17.3	Ancillary Equipment	1362
17.3.1	The Spray Booth	1362
17.3.2	Exhaust Systems	1365
17.3.3	Power Supply	1365
17.3.4	Gas Supply	1366
17.3.5	Compressed Air Supply	1366
17.3.6	Cooling Water	1366
17.3.7	Micrometer-Sized Powder Feeders and Solutions or Suspensions Feeders	1367
17.3.8	Gun Movements	1368
17.3.9	Control Panel	1368
17.4	Controlled Atmosphere	1368
17.4.1	Soft Vacuum Plasma Spraying	1368
17.4.2	Vapor Phase Deposition	1373
17.4.3	Inert Plasma Spraying	1374
17.4.4	Cold Spray with Helium	1375
17.5	Finishing and Post-Treatment of Coatings	1375
17.5.1	Finishing	1376
17.5.2	Fusion of Self-Fluxing Alloys	1378
17.5.3	Heat Treating or Annealing	1381
17.5.4	Hot Isostatic Pressing	1383
17.5.5	Austempering Heat Treatment	1384
17.5.6	Laser Glazing	1384
17.5.7	Sealing	1387
17.5.8	Spark Plasma Sintering	1392
17.5.9	Peening or Rolling Densification	1392
17.5.10	Diffusion	1393
17.6	Summary and Conclusions	1393
	References	1394

18	Industrial Applications of Thermal Spraying Technology	1401
18.1	Introduction	1403
18.2	Advantages and Limitations of the Different Spray Processes	1404
18.2.1	Flame Spraying	1404
18.2.2	D-Gun Spraying	1406
18.2.3	HVOF–HVOF Spraying	1406
18.2.4	Wire Arc Spraying	1407
18.2.5	Plasma Spraying	1407
18.2.6	Plasma-Transferred Arcs (PTA)	1409
18.2.7	Plasma Transferred Arc	1410
18.2.8	Cold Spray	1411
18.3	Thermal-Sprayed Coating Applications	1411
18.3.1	Wear Resistant Coatings	1412
18.3.2	Corrosion and Oxidation Resistant Coating	1433
18.3.3	Thermal Protection Coatings	1446
18.3.4	Clearance Control Coatings	1455
18.3.5	Bonding Coatings	1457
18.3.6	Electrical and Electronic Coatings	1458
18.3.7	Freestanding Spray-Formed Parts	1462
18.3.8	Medical Applications	1466
18.3.9	Replacement of Hard Chromium	1469
18.3.10	Applications Under Developments	1471
18.4	Thermal-Sprayed Coatings by Industry	1474
18.4.1	Aerospace	1475
18.4.2	Land-Based Turbines	1478
18.4.3	Automotive	1478
18.4.4	Electrical and Electronic Industries	1481
18.4.5	Corrosion Applications for Land-Based and Marine Applications	1483
18.4.6	Medical Applications	1486
18.4.7	Ceramic and Glass Manufacturing	1487
18.4.8	Printing Industry	1488
18.4.9	Pulp and Paper	1490
18.4.10	Metal Processing Industries	1492
18.4.11	Petroleum and Chemical Industries	1495
18.4.12	Electrical Utilities	1498
18.4.13	Textile and Plastic Industries	1499
18.4.14	Polymers	1499
18.4.15	Reclamation	1501
18.4.16	Other Applications	1503
18.4.17	Thermal-Sprayed Coatings in the Different Countries	1505

- 18.5 Economic Analysis of the Different Spray Processes 1513
 - 18.5.1 Different Cost Contribution Factors 1513
 - 18.5.2 Direct Cost Factors 1514
 - 18.5.3 Indirect or Fixed Cost Factors 1521
 - 18.5.4 Few Examples 1522
- 18.6 Summary and Conclusions 1529
- References 1545

Thermal Spray Fundamentals

From Powder to Part

Fauchais, P.L.; Heberlein, J.V.R.; Boulos, M.I.

2014, LVI, 1566 p. 953 illus., 235 illus. in color. In 2 volumes, not available separately., Hardcover

ISBN: 978-0-387-28319-7