Contents

List of contributors Preface

1 Introduction

Victor K. Champagne References

2 The development of the cold spray process Dennis Helfritch, Victor K. Champagne and A. Papyrin

- 2.1 Pre-1980 work
- 2.2 The development of modern cold spray
- 2.3 Recent theoretical and experimental cold snrav research

	4.5	Recent medicular and experimental cold spray research	44
	2.4	Commercial systems development	27
	2.5	Applications development	32
	2.6	Some comments on the patent situation	35
		References	38
3	Con	paring cold spray with thermal spray coating technologies	43
	Keit	h A. Kowalsky, Victor K. Champagne and Mark F. Smith	
	3.1	Introduction	43
	3.2	Traditional thermal spray technologies	43
	3.3	Comparison of cold spray with traditional thermal spray	53
	3.4	Conclusions	62
		References	62
4	Colo	l spray economics	65
		Eden, A.J. Naccarelli, A.M. Birt and J.A. Heelan	
	4.1	Introduction	65
	4.2	Cold spray basics—calculating gas and powder costs	66
	4.3	Cold spray systems, infrastructure, and workforce	81
		oping by biolino, initiability and workford	UL

ix

xi

7

9

9

9

84

85

85

4.5 Cold spray systems, infrastructure, and workforce
 4.4 Summary
 Acknowledgment
 References

5		cess parameters and control	89	
	Ozar	n Çağatay Özdemir		
	5.1	Introduction	89	
	5.2	Cold spray process	90	
	5.3	Operating principles of the CS process	93	
	5.4	Bonding criteria	97	
	5.5	Gas dynamic models	97	
	5.6	Process variables	105	
	5.7	Process qualification and quality control methods	124	
		References	130	
6	Stuc	lies of single-particle impact	135	
	Jae-Hwang Lee and Mostafa Hassani			
	6.1	Introduction	135	
	6.2	Characteristics of single-particle impact	137	
	6.3	Applications	138	
	6.4	Advances in numerical modeling with single-particle		
		characterizations	144	
	6.5	Perspectives	146	
		References	146	
7	Bon	ding mechanisms in cold spray	149	
	Mostafa Hassani, Victor K. Champagne and Dennis Helfritch			
	7.1	Solid-state bonding	149	
	7.2	What provides the conditions for solid-state bonding		
		in cold spray?	152	
	7.3	Adiabatic shear instability	153	
	7.4	Jetting: a shock-induced phenomenon	156	
	7.5	Surface oxide and hydroxide effects	159	
		References	162	
8	Col	d spray equipment	165	
		istian Widener, Aaron Nardi and H. Höll		
	8.1	Introduction	165	
	8.2	A brief history of cold spray equipment development	165	
	8.3	Cold spray system description	169	

8.3 Cold spray system description
8.4 Cold spray system components
8.5 Auxiliary equipment
References

9	Chara	acterization of cold-sprayed material consolidations	205
	Bryer	C. Sousa, Mark Aindow, Seok-Woo Lee, Diana Lados,	
	Antho	ony G. Spangenberger, Christopher M. Sample and Danielle L. Cote	
	9.1	Advanced microscopy	205
	9.2	Nanoindentation and micromechanical testing	215
	9.3	Micropillar compression and microtensile testing	244
	9.4	Macrohardness and instrumented indentation testing	248
	9.5	Profilometry-based indentation plastometry	255
	9.6	Surface roughness and topography	266
	9.7	Mechanical properties and damage mechanisms of cold-sprayed	
		light metals	273
		References	286
10	Cold	spray particle deposition for improved wear resistance	299
	Aaron	n Nardi and Victor K. Champagne	
	10.1	Introduction	299
	10.2	Objective	300
	10.3	Materials and methods	301
	10.4	Modeling methods	303
	10.5	Cold spray equipment and technology	303
	10.6	Modeling and characterization methods	304
	10.7	Results and discussion	305
	10.8	Powder commercialization	323
		References	324
11	Appli	ications of cold spray	325
	Victor	r K. Champagne, Aaron Nardi and Christian Widener	
	11.1	Introduction	325
	11.2	Variety of applications	326
	11.3	Repair of B-1 bomber forward equipment bay panels	327
	11.4	B-1 bomber hydraulic lines	330
	11.5	AH-64 static mast support	333
	11.6	Periscope repair	342
	11.7	Insulated gate bipolar transistor baseplates	343
	11.8	Through-hole repairs of magnesium gearbox housings	347
	110	Planetary gear shaft from a nower shovel renair	348

i miletary gear shart nonn a power shover repair 210 11.10 Freeform cold spray additive manufacturing 348 11.11 Manufacturing at the point of need 350 11.12 Camouflaged SPEE3D printer 350 11.13 Repair of stainless steel nuclear waste canisters 351 11.14 Mobile robotic repair of large radioactive waste storage systems 352 References 355

12	The u	se of cold spray coating for corrosion protection		357
	R.C. McCune			
	12.1	Introduction		357
	12.2	Cold spraying of metals as a coatings technology for		
		corrosion control		358
	12.3	Galvanizing of steel structures to prevent corrosion		361
	12.4	Preventing aqueous and hot-surface corrosion		363
	12.5	Conclusions		365
		References		365
13	Repai	r of magnesium components by cold spray techniques		369
	Victor	K. Champagne		
	13.1	Introduction		369
	13.2	Problems in using magnesium components		369
	13.3	Limitations of current technologies		372
	13.4	Key issues in using the cold spray process		373
	13.5	Developing and testing cold spray coating of magnesium		374
	13.6	Cold spray technology for coating magnesium		376
	13.7	Predictive modeling for process optimization		378
	13.8	Cold spray trials		379
	13.9	Coating characterization		381
	13.10	Cost savings and implementation		388
	13.11	Conclusions		389
		References		390
14	Adva	nces in cold spray additive deposition		393
	Bryer	C. Sousa, Danielle L. Cote and Victor K. Champagne		
	14.1	Introduction		393
	14.2	Deposition of functional coatings and materials		396
	14.3	Machine learning, statistical, and data-driven analysis		404
	14.4	Refined insights into bonding mechanisms		410
	14.5	Powder and feedstock preprocessing		413
	14.6	Nondestructive evaluation for cold spray		420
		References		424

