

Contents

Preface *xiii*

Chapter 1 **Introduction** *1*

 References *3*

Chapter 2 **Key historical contributions** *5*

 2.1 **Before 1962** *5*

 2.2 **From 1962 to 1982** *9*

 2.3 **From 1982 to the present** *9*

 References *17*

Chapter 3 **Types of superplasticity** *22*

 3.1 **Fine-structure superplasticity (FSS)** *22*

 3.1.1 **Fine grain size** *23*

 3.1.2 **Second phases** *24*

 3.1.2.1 **Strength of the second phase particle** *24*

 3.1.2.2 **Size, morphology, and distribution of the second phase** *24*

 3.1.3 **Nature of grain-boundary structure** *25*

 3.1.3.1 **Grain-boundary orientation** *25*

 3.1.3.2 **Homophase and heterophase** *26*

 3.1.4 **Texture and shape of grains** *27*

3.1.5	<i>Mobility of grain boundaries</i>	28
3.1.6	<i>Grain boundaries and their resistance to tensile separation</i>	28
3.2	Internal-stress superplasticity (ISS)	28
3.3	High-strain-rate-superplasticity (HSRS)	29
3.4	Other mechanisms	29
	References	30
Chapter 4	Mechanisms of high-temperature deformation and phenomenological relations for fine-structure superplasticity	32
4.1	Creep mechanisms	32
4.1.1	<i>Diffusional creep (n=1)</i>	34
4.1.1.1	<i>Nabarro–Herring creep</i>	34
4.1.1.2	<i>Coble creep</i>	34
4.1.2	<i>Grain-boundary sliding (n=2)</i>	36
4.1.3	<i>Dislocation creep</i>	36
4.1.3.1	<i>Glide-controlled creep (n=3)</i>	37
4.1.3.2	<i>Climb-controlled creep (n=4–5)</i>	37
4.1.4	<i>Dispersion-strengthened alloys (n>8)</i>	38
4.2	Grain-boundary sliding with various accommodation processes	40
4.3	Optimizing the rate of superplastic flow in FSS materials	49
	References	54
Chapter 5	Fine-structure superplastic metals	58
5.1	Aluminum-based alloys	58
5.1.1	<i>Academic studies</i>	60
5.1.2	<i>Alloys designed for room-temperature properties as well as superplasticity</i>	63
5.1.3	<i>Commercial alloys</i>	64
5.2	Magnesium-based alloys	69
5.3	Iron-based alloys	73
5.3.1	<i>Plain carbon steels</i>	73
5.3.1.1	<i>Hypoeutectoid and eutectoid steels</i>	73
5.3.1.2	<i>Hypereutectoid steels</i>	74
5.3.1.3	<i>White cast irons</i>	76
5.3.2	<i>Low- and medium-alloy-content steels</i>	76
5.3.2.1	<i>Ferrite and austenite</i>	77
5.3.2.2	<i>Austenite</i>	77
5.3.3	<i>Microduplex stainless steels</i>	77

Contents

ix

5.3.4	<i>Nonsuperplastic steels made superplastic by lamination</i>	79
5.4	Titanium-based alloys	79
5.5	Nickel-based alloys	83
	References	85
Chapter 6	Fine-structure superplastic ceramics	91
6.1	Monolithic ceramics	93
6.1.1	<i>Yttria-stabilized tetragonal zirconia polycrystal</i>	93
6.1.1.1	<i>Microstructure</i>	93
6.1.1.2	<i>Stress-strain curve</i>	95
6.1.1.3	<i>Grain size</i>	96
6.1.1.4	<i>Strain-rate-sensitivity exponent</i>	96
6.1.1.5	<i>Activation energy</i>	98
6.1.2	<i>Alumina</i>	99
6.1.3	<i>Hydroxyapatite</i>	100
6.1.4	<i>β-Spodumene glass ceramics</i>	100
6.2	Ceramic composites	101
6.2.1	<i>Zirconia-based composites</i>	101
6.2.2	<i>Alumina-based composites</i>	105
6.2.3	<i>Silicon nitride-based composites</i>	106
6.2.4	<i>Iron carbide-based composites</i>	107
6.3	Constitutive equations and microstructures	109
6.3.1	<i>Constitutive equations</i>	109
6.3.2	<i>Grain-boundary structure and segregation</i>	110
6.3.3	<i>Grain-boundary cavitation</i>	114
6.4	Ingot processing route for superplastic ceramics	115
6.5	Superplasticity in geological materials	117
	References	119
Chapter 7	Fine-structure superplastic intermetallics	125
7.1	Nickel-based intermetallic compounds	126
7.1.1	<i>Nickel silicide (Ni_3Si)</i>	126
7.1.2	<i>Nickel aluminide (Ni_3Al)</i>	131
7.2	Titanium-based intermetallic compounds	135
7.2.1	α_2 - <i>Titanium aluminides (Ti_3Al)</i>	135
7.2.2	γ - <i>Titanium aluminides ($TiAl$)</i>	136
7.3	Iron-based intermetallic compounds	140
	References	141

Chapter 8	Fine-structure superplastic composites and laminates	145
8.1	Aluminum-based metal-matrix composites	145
8.1.1	<i>Thermal-cycling superplasticity</i>	147
8.1.2	<i>Isothermal superplasticity</i>	147
8.2	Magnesium-based metal-matrix composites	148
8.3	Zinc-based metal-matrix composites	149
8.4	Metal laminates	149
	References	151
Chapter 9	High-strain-rate superplasticity	154
9.1	Experimental observations	154
9.1.1	<i>Metal-matrix composites</i>	154
9.1.1.1	<i>SiC whisker-reinforced 2124Al composite</i>	155
9.1.1.2	<i>Si₃N₄ whisker-reinforced Al composites</i>	161
9.1.2	<i>Mechanically alloyed alloys</i>	162
9.1.2.1	<i>Aluminum-based alloys</i>	163
9.1.2.2	<i>Nickel-based alloys</i>	164
9.1.3	<i>Metal alloys</i>	166
9.1.3.1	<i>Aluminum</i>	166
9.2	Origin of HSRS	168
9.2.1	<i>Grain size</i>	168
9.2.2	<i>Interfaces</i>	170
9.3	Cavitation in HSRS materials	178
9.4	Perspective of HSRS and deformation map	181
	References	185
Chapter 10	Ductility and fracture in superplastic materials	189
10.1	Tensile ductility in superplastic metals	189
10.2	Tensile ductility in superplastic ceramics	192
10.2.1	<i>Tensile elongation as a function of flow stress</i>	194
10.2.2	<i>Tensile elongation as a function of grain size</i>	197
10.2.3	<i>Cavitation in superplastic ceramics</i>	198
10.3	Tensile ductility in superplastic intermetallic compounds	203
	References	204

[Contents](#)

xi

Chapter 11	Internal-stress superplasticity (ISS)	208
11.1	Whisker- and particle-reinforced composites	209
11.2	Anisotropic expanding polycrystalline materials	211
11.3	Materials undergoing polymorphic changes	213
	References	216
Chapter 12	Other possible superplasticity mechanisms	219
12.1	Class I superplasticity in coarse-grained materials	219
12.2	Viscous creep mechanisms for superplasticity	223
12.3	Ultrahigh-strain-rate superplasticity	225
	References	228
Chapter 13	Enhanced powder consolidation through superplastic flow	231
13.1	ISS compaction of white cast iron powders	231
13.2	FSS compaction of ultrahigh carbon steel powders	233
13.3	FSS consolidation of Ni-based superalloy powders	234
13.4	FSS extrusion and sinter forging of ultrafine ceramic powders	235
	References	237
Chapter 14	Superplastic forming and diffusion bonding	239
14.1	Metals	240
14.1.1	Titanium	240
14.1.2	Iron and steels	242
14.1.3	Aluminum	242
14.2	Ceramics	246
14.2.1	Superplastic forming	246
14.2.2	Diffusion bonding	251
	References	252
Chapter 15	Commercial examples of superplastic products	256
15.1	Titanium alloys	256
15.2	Nickel alloys	257
15.3	Iron alloys	259
15.4	Aluminum alloys	261
	References	268
	<i>Index</i>	270