

# Contents

<b>1</b>	<b>Structure of Ceramic Materials</b>	<b>1</b>
1.1	Electronic Structure of Atoms	1
1.2	Types of Bonding	3
1.2.1	Metallic Bonding	4
1.2.2	Ionic Bonding	5
1.2.3	Covalent Bonding	6
1.2.4	The van der Waals Bond	7
1.3	The Crystal Lattice	9
1.3.1	Crystalline Structures	9
1.3.2	Silicate Structures	9
1.4	Noncrystalline Structures	13
1.5	Phase Diagrams	15
1.5.1	Single-Component Phase Diagrams	17
1.5.2	Binary Phase Diagrams	18
1.5.2.1	Phase Diagrams of Isomorphous Systems	19
1.5.2.2	Eutectic Phase Diagrams	21
1.5.2.3	Peritectic Phase Diagrams	22
1.5.3	Ternary Phase Diagrams	24
<b>2</b>	<b>Production and Properties of Ceramic Powders, Whiskers, Fibers, and Single Crystals</b>	<b>27</b>
2.1	Ceramic Powders	29
2.1.1	Conventional Powder Production Techniques	28
2.1.1.1	Alumina ( $\text{Al}_2\text{O}_3$ )	28
2.1.1.2	Zirconia ( $\text{ZrO}_2$ )	28
2.1.1.3	Silicon Carbide ( $\text{SiC}$ )	30
2.1.1.4	Silicon Nitride ( $\text{Si}_3\text{N}_4$ )	30
2.1.2	Modern Powder Production Techniques	31
2.1.2.1	Solution Techniques	31
2.1.2.2	Vapor-Phase Reaction Techniques	39
2.1.2.3	Powders from the Solid State	47
2.1.2.4	Gas-Solid Reactions	51

2.2	Ceramic Whiskers .....	51
2.2.1	Growth of Whiskers by Vapor-Phase Reactions .....	52
2.2.1.1	Evaporation-Condensation .....	52
2.2.1.2	Chemical Reduction .....	52
2.2.1.3	Vapor-Vapor Reactions (Chemical Vapor Deposition CVD) .....	56
2.2.2	Vapor-Liquid-Solid (VLS) Method .....	57
2.2.3	SiC Whiskers from Rice Hulls .....	59
2.2.4	Growth from Melt Solutions (Flux Growth) .....	60
2.2.5	Growth from Gels .....	62
2.2.6	Hydrothermal Growth .....	62
2.3	Ceramic Single Crystals .....	63
2.3.1	Verneuil (Flame Fusion) Method .....	63
2.3.2	Czochralski Method .....	64
2.3.3	Bridgman-Stockbarger Method .....	64
2.3.4	Zone Melting (Floating Zone) Method .....	64
2.3.5	Edge Defined Film Fed Growth (EFG) Method .....	65
2.3.6	Heat Exchanger Method (HEM) .....	66
2.4	Ceramic and Glass Fibers .....	66
2.4.1	Glass Fibers .....	66
2.4.2	Boron Fibers .....	68
2.4.3	Carbon Fibers .....	72
2.4.3.1	Fibers from PAN Precursors .....	72
2.4.3.2	Fibers from Cellulosic Precursors .....	73
2.4.3.3	Fibers from Pitch Precursors .....	76
2.4.4	Carbide and Nitride Fibers .....	77
2.4.5	Oxide Fibers .....	79
<b>3</b>	<b>Production of Ceramic Bodies .....</b>	<b>85</b>
3.1	Preconsolidation Processing .....	87
3.1.1	Milling and Sizing .....	85
3.1.2	Dispersion and Rheology of Slurries .....	93
3.1.2.1	Rheology .....	93
3.1.2.2	van der Waals Forces .....	95
3.1.2.3	Electrostatic or Ionic Forces in Nonpolar Media .....	96
3.1.2.4	Electrostatic Forces in Polar Media .....	96
3.1.2.5	Stabilization via Surfactants .....	98
3.1.2.6	Steric Stabilization .....	99
3.1.2.7	Capillary Forces .....	100
3.1.2.8	Other Important Forces .....	101
3.1.3	Drying and Granulation of Powders .....	102
3.2	Green Forming .....	104
3.2.1	Additives .....	104

3.2.1.1	Types and Functions	104
3.2.1.2	Removal of Organic Additives	108
3.2.2	Dry Pressing	111
3.2.2.1	Uniaxial Dry Pressing	111
3.2.2.2	Isostatic Pressing	113
3.2.3	Slip Casting	114
3.2.4	Pressure Casting (Wet Pressing)	120
3.2.5	Electrophoretic Casting	124
3.2.6	Injection Molding	128
3.2.7	Extrusion	131
3.2.8	Sol–Gel Processing and Gel Casting	135
3.2.8.1	Sol–Gel Processing	135
3.2.8.2	Gel Casting	136
3.2.9	Tape Casting	139
3.2.10	Centrifugal Casting	143
3.2.11	Other Forming Methods	146
3.2.11.1	Vacuum Casting	146
3.2.11.2	Freeze Casting	146
3.2.11.3	Vacuum Forming/Blow Molding	146
3.3	Conventional Consolidation Methods	147
3.3.1	Solid-State Sintering	146
3.3.1.1	Solid-State Sintering Models	148
3.3.1.2	Effect of Additives, Impurities, and Dispersed Phases on Sintering	155
3.3.1.3	Effect of Green Microstructure	160
3.3.1.4	Effect of Sintering Schedule and Heating Rate	164
3.3.1.5	Effect of Sintering Atmosphere	165
3.3.1.6	Effect of Defect-Generating Treatments	166
3.3.2	Liquid Phase Sintering	167
3.3.3	Hot-Pressing	174
3.4	Modern Production Methods	179
3.4.1	Hot Isostatic Pressing	179
3.4.2	Dynamic Consolidation	181
3.4.3	Reaction-Bonding	184
3.4.4	Plasma Sintering	189
3.4.5	Microwave Sintering	192
3.4.6	Self-Propagating Synthesis	195
3.4.7	Chemical Vapor Deposition (CVD) Processes	197
3.4.8	Eutectic Solidification	199
3.4.9	Melt Infiltration	202
3.4.10	Polymer Pyrolysis	202
3.4.11	Biomimetic Processes	205

<b>4</b>	<b>Properties of Ceramic Materials and Their Evaluation</b>	<b>209</b>
4.1	Mechanical Properties	209
4.1.1	Hardness and Elastic Modulus	209
4.1.1.1	Hardness Testing	211
4.1.1.2	Testing of Elastic Modulus	212
4.1.2	Strength	213
4.1.2.1	Strength Testing	213
4.1.2.2	Theoretical Strength	218
4.1.2.3	The Weibull Distribution	219
4.1.2.4	Strength of Monolithic Ceramics	222
4.1.2.5	Strength of Ceramic Matrix Composites (CMCs)	225
4.1.3	Fracture Toughness	236
4.1.3.1	Fracture Toughness Measurement	239
4.1.3.2	Toughening Methods and Mechanisms	244
4.1.3.3	Experimental Studies	260
4.1.4	Thermal Shock Resistance and Thermal Fatigue Resistance	262
4.1.5	Fatigue Resistance	265
4.1.5.1	Test Methods	269
4.1.6	Creep Resistance and Superplasticity	269
4.1.6.1	Creep Resistance	270
4.1.6.2	Superplasticity	275
4.1.7	Abrasive and Sliding Wear Resistance	278
4.1.8	Erosive Wear Resistance	284
4.2	Thermal Properties	287
4.2.1	Heat Capacity	288
4.2.2	Thermal Conductivity	292
4.2.3	Thermal Diffusivity	295
4.2.4	Coefficient of Thermal Expansion	296
4.3	Optical Properties	302
4.3.1	Transmittivity and Reflectivity	302
4.3.2	Refractive Index and Dispersion	303
4.3.3	Emissivity	305
4.3.4	Birefringence	309
4.3.5	Color	310
4.4	Electrical Properties	311
4.4.1	Electrical Conduction	311
4.4.1.1	Insulators (Dielectric Materials)	313
4.4.1.2	Semiconductors	315
4.4.1.3	Conductive Ceramics	317
4.4.1.4	Ionic Conduction	318
4.4.1.5	Superconductors	321
4.4.2	Polarization	327
4.4.2.1	Dielectric Constant and Permittivity	329

4.4.2.2	Loss Tangent .....	330
4.4.2.3	Dielectric Strength .....	331
4.4.2.4	Capacitors and Capacitance .....	333
4.4.2.5	Piezoelectricity .....	335
4.4.2.7	Ferroelectricity .....	337
4.5	Magnetic Properties .....	339
4.5.1	Diamagnetic Materials .....	342
4.5.2	Paramagnetic Materials .....	342
4.5.3	Ferromagnetic Materials .....	342
4.5.4	Ferrimagnetic Materials .....	343
4.5.4.1	Spinel Ferrites .....	344
4.5.4.2	Garnets .....	344
4.5.4.3	Hexagonal Ferrites .....	344
4.5.5	Antiferromagnetic Materials .....	345
4.6	Corrosion Resistance .....	346
4.6.1	Introduction .....	346
4.6.2	Liquid-Ceramic Reactions .....	350
4.6.2.1	Congruent Dissolution by Simple Dissociation .....	350
4.6.2.2	Congruent Dissolution by Chemical Reaction with the Solvent ....	352
4.6.2.3	Incongruent Dissolution Forming Crystalline Reaction Products ....	352
4.6.2.4	Incongruent Dissolution Forming Noncrystalline Layers .....	353
4.6.2.5	Ion Exchange .....	353
4.6.2.6	Kinetics .....	353
4.6.3	Gas-Ceramic Reactions .....	354
4.6.4	Corrosion Resistance of Some Important Ceramics .....	356
4.6.4.1	$Al_2O_3$ .....	356
4.6.4.2	$MgO$ .....	357
4.6.4.3	$ZrO_2$ .....	357
4.6.4.4	$AlN$ .....	358
4.6.4.5	$BN$ .....	358
4.6.4.6	$Si_3N_4$ .....	358
4.6.4.7	$SiC$ .....	359
4.6.4.8	Glasses .....	360
4.6.5	Corrosion Testing .....	361
<b>5</b>	<b>Characterization .....</b>	<b>363</b>
5.1	Density and Porosity Measurement .....	363
5.2	Microstructural Analysis .....	366
5.2.1	Optical Ceramography .....	366
5.2.1.1	Sample Preparation for Optical Ceramography .....	366
5.2.1.2	Geometrical Characterization .....	368

5.2.2	Scanning Electron Microscopy .....	371
5.2.3	Transmission Electron Microscopy .....	373
5.2.4	Scanning Probe Microscopy .....	379
5.2.5	Scanning Ion Microscopy .....	380
5.3	Diffraction Techniques .....	381
5.3.1	Electron Diffraction .....	381
5.3.2	X-Ray Diffraction .....	384
5.3.3	Neutron Diffraction .....	388
5.4	Nondestructive Evaluation .....	389
5.4.1	X-Ray Imaging Techniques .....	389
5.4.1.1	X-Ray Radiography and X-Ray Microscopy (Microradiography) ...	389
5.4.1.2	X-Ray Computed Tomography .....	389
5.4.2	Nuclear Magnetic Resonance Imaging .....	391
5.4.3	Acoustic (Ultrasonic) Imaging Techniques .....	392
5.4.4	Birefringence .....	393
5.4.4.1	Optical Birefringence .....	393
5.4.4.2	Ultrasonic Birefringence .....	393
5.4.5	Penetrant Techniques .....	393
5.5	Chemical and Compositional Analysis .....	394
5.5.1	X-Ray Emission Spectroscopy .....	394
5.5.1.1	Electron Probe X-Ray Microanalysis (EPMA) .....	394
5.5.1.2	X-Ray Fluorescence (XRF) .....	394
5.5.1.3	Spectrometers for X-Ray Emission Spectroscopy .....	395
5.5.2	X-Ray Photoelectron Spectroscopy (XPS) .....	396
5.5.3	Auger Electron Spectroscopy .....	397
5.5.4	Secondary Ion Mass Spectrometry .....	397
5.5.5	Laser Ionization Mass Spectroscopy (LIMS) .....	398
5.5.6	Rutherford Backscattering Spectroscopy (RBS) .....	401
5.5.7	Electron Energy Loss Spectroscopy (EELS) .....	401
5.5.8	Fourier Transform Infrared Spectroscopy (FTIR) .....	401
5.5.9	Raman Spectroscopy .....	403
5.5.10	Nuclear Magnetic Resonance (NMR) Spectroscopy .....	404
<b>6</b>	<b>Applications of Ceramic Materials .....</b>	<b>407</b>
6.1	Structural Applications .....	407
6.2	Military Applications .....	414
6.3	Cutting Tools and Abrasives .....	415
6.3.1	Cutting Tools .....	415
6.3.2	Abrasives .....	418
6.4	Automotive and Aerospace Applications .....	421
6.5	Refractory Applications .....	426

6.6	Ceramics for Energy Production .....	428
6.7	Biotechnological Applications .....	430
6.8	Electrical, Electronic, and Magnetic Applications .....	435
<b>7</b>	<b>Structure and Properties of Conventional Ceramics .....</b>	<b>447</b>
7.1	Unvitrified Pottery .....	447
7.1.1	Terra-Cotta .....	447
7.1.2	Earthenware .....	448
7.2	Whiteware Compositions .....	448
7.2.1	Tableware .....	450
7.2.2	Sanitary Ware .....	452
7.2.3	Wall Tiles .....	453
7.2.4	Glazes .....	454
7.2.5	Colorants .....	456
7.3	Cement .....	457
7.4	Refractories .....	461
7.4.1	Compositions and Properties .....	461
7.4.2	Production of Refractories .....	462
7.5	Glass .....	462
7.5.1	Compositions and Properties .....	462
7.5.2	Production of Glassware .....	464
<b>Appendix</b> .....		<b>467</b>
<b>References</b> .....		<b>553</b>
<b>Subject Index</b> .....		<b>611</b>



<http://www.springer.com/978-3-540-67687-4>

Engineering Ceramics

Bengisu, M.

2001, XXI, 620 p., Hardcover

ISBN: 978-3-540-67687-4