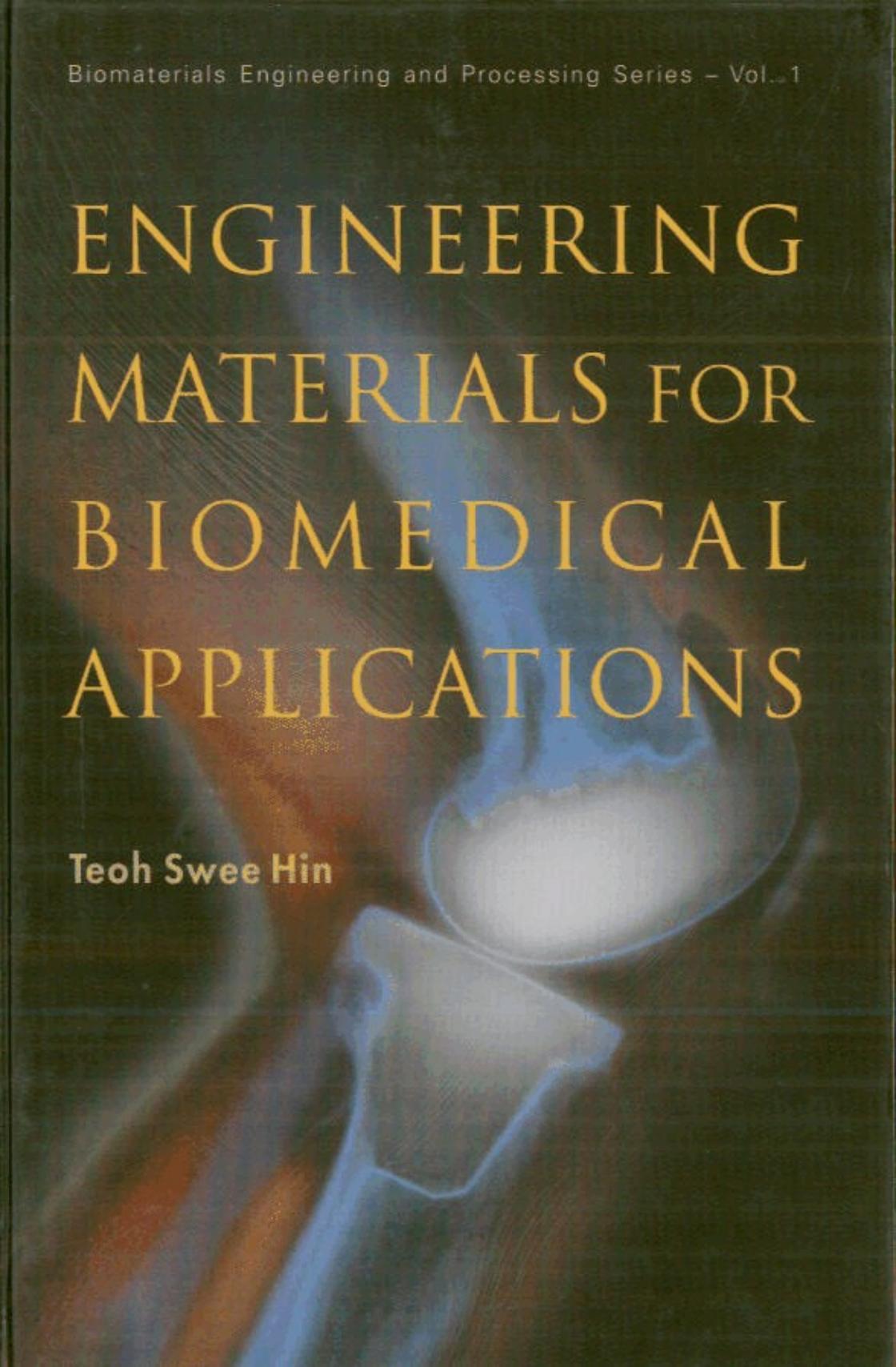


Biomaterials Engineering and Processing Series – Vol. 1

ENGINEERING MATERIALS FOR BIOMEDICAL APPLICATIONS



Teoh Swee Hin

CONTENTS

Foreword	xiii
Preface	xv
Acknowledgements	xvii
1 Introduction to biomaterials engineering and processing — an overview (<i>S. H. Teoh</i>)	1-1
1.1 Introduction	1-1
1.2 Requirements of biomaterials	1-2
1.3 Classification of biomaterials	1-3
1.4 Mechanical properties of biomaterials	1-4
1.5 Effects of processing on properties of biomaterials	1-5
1.5.1 Effect of post processing and grain size	1-5
1.5.2 Effect of molding conditions and irradiation on polymeric wear	1-9
1.5.3 Effect of composite lamination	1-9
1.6 Tissue engineering — new wave in biomaterials engineering	1-11
1.6.1 Need for organ and tissue replacement	1-11
1.6.2 Limitation of current technologies	1-11
1.6.3 Platform technology development in tissue engineering	1-12
1.6.4 Tissue engineering issues and challenges	1-13
1.7 Conclusions	1-14
References	1-15
2 Durability of metallic implant materials (<i>M. Sumita and S. H. Teoh</i>)	2-1
2.1 Introduction	2-1
2.2 Typical metallic biomaterials	2-3
2.2.1 Stainless steels	2-4
2.2.2 Cobalt–chromium alloys	2-6
2.2.3 Titanium and its alloys	2-6
2.2.4 Nickel–titanium alloys	2-8
2.3 Body environment to metallic materials	2-9
2.4 Life of implanted metallic materials	2-11
2.5 Corrosion, wear/fretting and fatigue	2-12
2.5.1 Fatigue testing method	2-12

2.5.2	Notes for fatigue/fretting fatigue tests	2-14
2.5.3	Corrosion fatigue	2-16
2.5.4	Fretting corrosion fatigue	2-17
2.5.4.1	Fretting fatigue	2-17
2.5.4.2	Metallic ions release from fretted side	2-20
2.5.4.3	Fatigue and fretting fatigue strengths at high cycle for typical metallic biomaterials in pseudo-body fluid	2-21
2.5.4.4	Some failures of implants	2-25
2.6	Toxicity reaction to metallic implants	2-25
2.7	Metallic biomaterials for the future	2-28
	References	2-29

3 Corrosion of metallic implants

(D. J. Blackwood, K. H. W. Seah and S. H. Teoh) **3-1**

3.1	Introduction	3-1
3.2	Corrosion theory	3-2
3.2.1	Basic thermodynamics of corrosion	3-2
3.2.1.1	The Nernst equation	3-2
3.2.1.2	Standard potentials (E^{θ}) and the electrochemical series	3-4
3.2.1.3	Potential-pH equilibrium diagrams (Pourbaix diagrams)	3-6
3.2.2	Basic electrochemistry	3-11
3.2.2.1	Electrode reactions	3-11
3.2.2.2	Electron transfer	3-11
3.2.2.3	Kinetics of electron transfer	3-12
3.2.2.4	Mixed potential theory	3-13
3.2.2.5	Cathodic reactions	3-14
3.2.2.6	Nature of electrode reactions	3-18
3.2.3	Passivation	3-18
3.2.3.1	Electrochemical behavior of active/passive metals	3-18
3.2.3.2	Nature of passive film	3-20
3.2.3.3	Influence of cathodic supporting reactions	3-22
3.3	Types of corrosion	3-23
3.3.1	General corrosion	3-23
3.3.2	Localized corrosion	3-23
3.3.2.1	Pitting corrosion	3-23
3.3.2.2	Crevice corrosion	3-24
3.3.2.3	Stress corrosion cracking	3-26
3.3.2.4	Corrosion fatigue	3-28

3.3.2.5	Fretting corrosion and mechanical wear	3-29
3.3.3	Galvanic corrosion (bimetallic corrosion)	3-30
3.3.4	Selective leaching	3-32
3.3.5	Intergranular attack	3-33
3.3.6	Influence of cold-working	3-33
3.4	Environments encountered in biomedical applications	3-34
3.4.1	Surgical implants	3-34
3.4.2	Dental applications	3-35
3.5	Common metals and alloys used in biomedical applications	3-36
3.5.1	Surgical implants	3-36
3.5.1.1	Stainless steel	3-36
3.5.1.2	Cobalt–chromium alloys	3-37
3.5.1.3	Titanium and titanium alloys	3-37
3.5.1.4	Porous titanium	3-38
3.5.1.5	Nickel–titanium alloy	3-38
3.5.2	Dental materials	3-38
3.5.2.1	Amalgams	3-38
3.5.2.2	Rare earth magnets	3-39
3.6	Detection methods	3-39
3.7	Corrosion prevention	3-41
3.7.1	Coatings and surface treatment	3-41
3.7.2	Quality control	3-42
3.7.3	Reduce risk of galvanic corrosion	3-42
3.7.4	Handling/Sterilization/Assembly	3-42
3.7.5	Education	3-43
3.8	Case histories	3-43
3.9	Summary and conclusions	3-48
	References	3-50

4 Surface modification of metallic biomaterials

	<i>(T. Hanawa)</i>	4-1
4.1	Surface of metals	4-1
4.2	Surface oxide film	4-2
4.2.1	Titanium	4-3
4.2.2	Titanium alloys	4-5
4.2.3	Stainless steel	4-6
4.2.4	Co–Cr–Mo alloy	4-6
4.2.5	Noble metal alloys	4-7
4.3	Reconstruction of surface oxide film	4-7
4.3.1	Titanium	4-8
4.3.2	Titanium alloys	4-10
4.3.3	Stainless steel	4-11

4.3.4	Co–Cr–Mo alloy	4-12
4.4	Adsorption of proteins	4-13
4.5	Adhesion of cells	4-14
4.6	Surface modification	4-16
4.6.1	Purpose	4-16
4.6.2	Dry process	4-18
4.6.3	Hydro-process	4-20
4.7	Apatite film formation	4-20
4.7.1	Apatite formation with dry process	4-20
4.7.2	Apatite formation with hydro-process	4-21
4.8	Surface-modified layer for bone formation	4-21
4.8.1	Immersion in alkaline solution and heating	4-22
4.8.2	Immersion in hydrogen peroxide solution	4-22
4.8.3	Immersion and hydrothermal treatment in calcium-containing solution	4-24
4.8.4	Calcium ion implantation	4-24
4.9	Titanium oxide layer formation	4-27
4.10	Titanium nitride layer formation	4-27
4.11	Modification with biomolecules and polymer	4-27
4.12	Morphological modification	4-29
4.13	Surface analysis	4-31
4.14	Future of surface engineering of metallic biomaterials	4-32
	References	4-33
5	Biorestorative materials in dentistry (A. U. J. Yap)	5-1
5.1	Introduction	5-1
5.2	Ceramics	5-2
5.2.1	Inorganic salts (dental cements)	5-2
5.2.2	Crystalline and non-crystalline ceramics	5-3
5.3	Polymers	5-5
5.3.1	Rigid polymers	5-5
5.3.2	Polymer composites	5-8
5.4	Metals	5-10
5.4.1	Alloys	5-10
5.4.2	Intermetallic compounds	5-14
5.5	Conclusions	5-15
	References	5-16
6	Bioceramics: an introduction (B. Ben-Nissan and G. Pezzotti)	6-1
6.1	Introduction	6-1
6.2	General concepts in bioceramics	6-2

6.3	Bioceramics and production methods	6-4
6.4	Bioinert ceramics in articulation	6-7
6.4.1	Alumina ceramics	6-9
6.4.2	Partially stabilized zirconia (PSZ)	6-10
6.4.3	New modified zirconia implants	6-13
6.5	Bioresorbable and bioactive ceramics	6-15
6.5.1	Calcium phosphates for bone replacement applications	6-15
6.5.2	Simulated body fluid (SBF)	6-17
6.5.3	Coralline apatites	6-17
6.5.4	Calcium phosphate coatings	6-19
6.5.5	Synthetic bone graft ceramics	6-20
6.5.6	Bioglasses and glass-ceramics	6-21
6.6	Nano-bioceramics, composites and hybrids	6-22
6.6.1	Nanoapatite-polymer fiber composites	6-22
6.6.2	Bioceramics in <i>in situ</i> radiotherapy and hyperthermia	6-23
6.6.3	Bone cement composites	6-24
6.6.4	Biomimetic hybrid composites	6-25
6.7	Design with bioceramics	6-27
6.8	Future of bioceramics	6-29
	References	6-31
7	Polymeric hydrogels (<i>J. Li</i>)	7-1
7.1	Introduction	7-1
7.2	Definition and classification of hydrogels	7-2
7.2.1	Definition of hydrogels	7-2
7.2.2	Classification of hydrogels	7-2
7.3	Chemical hydrogels and their biomedical applications	7-2
7.3.1	Copolymerization of monomer with cross-linker	7-5
7.3.2	Cross-linking of water-soluble polymers	7-7
7.4	Physical hydrogels and their biomedical applications	7-8
7.4.1	Natural biopolymer hydrogels	7-9
7.4.2	Thermo-shrinking hydrogels	7-11
7.4.3	Amphiphilic triblock copolymer hydrogels	7-12
7.4.4	Other novel synthetic copolymer physical hydrogels	7-12
7.4.5	Polyelectrolyte complex hydrogels	7-14
7.4.6	Supramolecular hydrogels formed by cyclodextrins and polymers	7-14
	References	7-17
8	Bioactive ceramic-polymer composites for tissue replacement (<i>M. Wang</i>)	8-1
8.1	Introduction	8-1

8.2	Structure and properties of bone	8-2
8.3	Bioceramics and biopolymers	8-6
8.3.1	Bioactive ceramics	8-6
8.3.2	Biocompatible polymers	8-8
8.4	Hydroxyapatite reinforced polyethylene composites for bone replacement	8-10
8.4.1	Combining hydroxyapatite and polyethylene for bioactive bone analogues	8-10
8.4.2	Manufacture of hydroxyapatite/polyethylene composites	8-10
8.4.3	Structure of hydroxyapatite/polyethylene composites	8-12
8.4.4	Mechanical properties of hydroxyapatite/polyethylene composites	8-14
8.4.5	<i>In vitro</i> and <i>in vivo</i> assessments	8-18
8.4.6	Clinical applications	8-20
8.4.7	Enhanced hydroxyapatite/polyethylene composites	8-20
8.5	Other bioceramic-polymer composites for medical applications	8-21
8.6	Concluding remarks	8-23
	Acknowledgements	8-24
	References	8-24
9	Composites in biomedical applications	
	<i>(Z. M. Huang and S. Ramakrishna)</i>	9-1
9.1	Introduction	9-1
9.2	Biomedical applications	9-4
9.2.1	Bone plates	9-4
9.2.2	Intramedullary nails	9-6
9.2.3	Spine instrumentation	9-7
9.2.4	Total hip replacement (THR)	9-8
9.2.5	Bone grafts	9-9
9.2.6	Dental materials	9-10
9.2.7	Prosthetic sockets	9-11
9.2.8	Tendons and ligaments	9-12
9.2.9	Vascular grafts	9-13
9.3	Composite fabrication	9-14
9.3.1	Filament winding	9-14
9.3.2	Pultrusion	9-15
9.3.3	Extrusion	9-16
9.3.4	Injection molding	9-16
9.3.5	Compression molding	9-17
9.3.6	Thermoforming	9-18
9.3.7	A fabrication example	9-19
9.4	Mechanics of composites	9-20
9.4.1	RVE and effective property	9-20

9.4.2	Moduli of UD composite — rule of mixture approach	9-22
9.4.3	Strengths of UD composite — bridging model formulae	9-24
9.4.3.1	Longitudinal tensile strength	9-25
9.4.3.2	Transverse tensile strength	9-26
9.4.3.3	In-plane shear strength	9-26
9.4.4	Example	9-27
9.4.5	Structure-property relationship	9-28
9.4.5.1	Mechanical properties of UD composite	9-29
9.4.5.2	Mechanical properties of laminated composite	9-31
9.4.5.3	Modeling procedure for a textile composite	9-34
9.4.5.4	Analysis outline for a braided fabric composite	9-35
9.4.5.5	Analysis outline for a knitted fabric composite	9-36
9.4.6	Mechanical properties of short fiber and particulate composites	9-38
9.5	Future advances	9-41
	Appendix	9-43
	References	9-44
10	New methods and materials in prosthetics for rehabilitation of lower limb amputees (<i>P. V. S. Lee</i>)	10-1
10.1	Introduction	10-1
10.2	Function and safety	10-3
10.3	Methods and materials	10-5
10.3.1	Prosthetic socket	10-6
10.3.1.1	Computer-aided design and manufacturing (CAD/CAM)	10-6
10.3.1.2	Intelligent CAD/CAM system	10-7
10.3.1.3	Prosthetic socket design	10-11
10.3.2	Prosthetic foot	10-17
10.3	Conclusion	10-18
	References	10-18
11	Chitin-based biomaterials (<i>E. Khor</i>)	11-1
11.1	Introduction	11-1
11.2	Chitin occurrence and isolation	11-1
11.3	Chitin as a biomaterial	11-3
11.3.1	Wound healing	11-3
11.3.2	Tissue engineering	11-5
11.3.3	Drug delivery	11-6
11.4	Processing	11-11

11.5 Chitin or chitosan	11-12
11.6 Future outlook	11-12
References	11-13
Subject index	SI-1