



TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN



Lehrstuhl für Werkstoffkunde

Christian Leinenbach

Cyclic Deformation Behaviour of Surface Modified Titanium Implant Alloys in Simulated Physiological Media

Werkstoffkundliche Berichte

Band 12/ 2005

Herausgeber: Prof. Dr.-Ing. habil. D. Eifler

Table of Contents

1	Introduction	1
2	Fundamental Aspects of Metallic Implant Materials	5
2.1	Mechanical and Biological-Chemical Aspects of Metallic Implant Materials.....	5
2.2	Titanium as Implant Material	6
2.2.1	Physical and Chemical Properties of Pure Titanium	6
2.2.2	Commercially Pure Titanium and Titanium Alloys	7
2.2.3	Surface Properties of Titanium and Titanium Alloys.....	9
2.2.4	Surface Modification Techniques	12
2.3	Principles of Corrosion and Repassivation Processes	18
2.3.1	Basic Corrosion Processes and Experimental Techniques	18
2.3.2	Corrosion and Repassivation Behaviour of Titanium and Titanium Alloys in Physiological Media	26
3	Fundamental Aspects of Metal Fatigue	29
3.1	Characterisation and Estimation of the Cyclic Deformation Behaviour	29
3.1.1	Cyclically Loaded Metallic Materials and Fatigue Life Prediction	29
3.1.2	Microstructural Processes and Characterisation Techniques	31
3.2	Cyclic Deformation Behaviour and Fatigue of Titanium and Titanium Alloys.....	34
3.2.1	Influence of the Microstructure	34
3.2.2	Influence of the Surface Properties	36
3.2.3	Influence of Loading and Environmental Conditions	38
4	Detection of Cyclically Induced Surface Damages by Electrochemical Techniques – Theoretical Aspects	39
4.1	Corrosion Potential and Current Measurements.....	39
4.2	Electrochemical Impedance Spectroscopy	44
5	Experimental Techniques and Characterisation Methods.....	49
5.1	Experimental Setups	49
5.1.1	Electrochemical Corrosion Testing Setup	49
5.1.2	Experimental Setup for Scratch Tests	50
5.1.3	Servohydraulic Testing Equipment.....	51
5.1.4	Rotating Bending Testing Equipment.....	53
5.2	Microscopic and Analytical Methods	54

5.2.1	Imaging and Topography.....	55
5.2.2	Chemical Composition and Structure.....	55
6	Materials, Surface Properties and Testing Media.....	57
6.1	Materials.....	57
6.1.1	Commercially Pure Titanium.....	57
6.1.2	The Alloy Ti-6Al-7Nb.....	58
6.1.3	The Alloy Ti-6Al-4V.....	59
6.2	Specimen Geometries.....	60
6.3	Surface Modification Techniques and Surface Properties.....	62
6.3.1	Mechanically Polished Surfaces.....	62
6.3.2	Thermally and Anodically Oxidised Surfaces.....	63
6.3.3	Corundum Grit Blasted Surfaces.....	68
6.4	Testing Media.....	72
7	Characterisation of Non-Damaged Specimen Surfaces.....	75
7.1	Electrochemical Analysis.....	75
7.1.1	Open Circuit Potential Measurements.....	75
7.1.2	Potentiodynamic Measurements.....	76
7.1.3	Electrochemical Impedance Spectroscopy.....	78
7.2	Preliminary Investigations on Electrochemical Measurements in Fatigue Testing Setup.....	80
8	Surface Damages Induced by Scratching.....	85
8.1	Corrosion Potential and Current Measurements on Polished Specimens – Repassivation Behaviour.....	85
8.2	Impedance Measurements on Oxidised Specimens.....	90
8.3	Analysis of the Repassivated Surfaces.....	93
9	Fatigue Induced Surface Damage in Axial Fatigue Tests.....	97
9.1	Investigations on Mechanically Polished Specimens.....	97
9.1.1	Fatigue Life and Cyclic Deformation Behaviour.....	97
9.1.2	Characterisation of Fatigue Crack Initiation and Propagation by Corrosion Potential and Current Measurements.....	99
9.1.3	Characterisation of the Cyclic Deformation Behaviour and Fatigue Induced Surface Damages in Stepwise Load Increase Tests.....	109
9.1.4	Influence of the Testing Media Composition.....	112
9.2	Investigations on Oxidised Specimens.....	114
9.2.1	Fatigue Life and Cyclic Deformation Behaviour.....	114
9.2.2	Stepwise Load Increase Tests.....	119
9.2.3	Microstructural Investigations.....	122

9.2.4	Detection of Surface Damages by Impedance Spectroscopy	126
9.2.5	Summarising Discussion	130
9.3	Investigations on Corundum Grit Blasted Specimens	131
9.3.1	Fatigue Life and Cyclic Deformation Behaviour	131
9.3.2	Stepwise Load Increase Tests	134
9.3.3	Microstructural Investigations	135
9.3.4	Summarising Discussion	136
10	Fatigue Induced Surface Damage in Rotating Bending Tests.....	137
10.1	Investigations on Mechanically Polished Specimens.....	137
10.1.1	Fatigue Life and Cyclic Deformation Behaviour	137
10.1.2	Characterisation of Fatigue Crack Initiation and Propagation Processes	140
10.2	Investigations on Oxidised Specimens	146
10.2.1	Fatigue Life and Cyclic Deformation Behaviour	146
10.2.2	Microstructural Investigations	149
10.2.3	Summarising Discussion	150
10.3	Investigations on Corundum Grit Blasted Specimens	152
10.3.1	Fatigue Life and Cyclic Deformation Behaviour	152
10.3.2	Microstructural Investigations	154
10.3.3	Summarising Discussion	155
11	Summary and Outlook	157
	Semester Work Theses.....	161
	Publications.....	161
	References.....	163