Contents

Abstract iii
Zusammenfassung v
Acknowledgement vii
Structure of the thesis ix

I Introduction 3

1 Motivation 5

2 State of the art 9
2.1 Hydrogels 9
2.2 Hydrogel compositions 10
2.3 Tough hydrogels 11
2.3.1 Nano-composite gel
2.3.2 Slide-ring gel
2.3.3 Tetra-PEG hydrogel
2.3.4 Double network hydrogel
2.4 Mechanics of hydrogels 14
2.4.1 Swelling
2.4.2 Tensile behavior
2.5 The complexity in modeling inelastic behavior of tough hydrogels . 17

II Polymer physics 19

3 Polymers and polymer chains 21
3.1 Polymers 21
3.2 Polymer chains 23
3.2.1 Polymer chain conformations
3.2.2 Gaussian chain
3.2.3 non-Gaussian chain

4 Full network models 29
4.1 Introduction 29

Bibliografische Informationen
http://d-nb.info/1130878171

digitalisiert durch DEUTSCHE NATIONAL BIBLIOTHEK

4.2 Mechanics of a hyperelastic polymer network 30
4.2.1 Three-dimensional generalization using integration over the unit sphere
4.2.2 Constitutive equation for the ideal chain model
4.2.3 Application of the ideal chain model to double network hydrogels
4.3 Concluding remarks 35

III Constitutive modeling 37

5 Stress softening in double network hydrogels 39
5.1 Introduction 39
5.2 Modeling 42
5.2.1 The first network decomposition
5.2.2 Probability density of a chain existence in a network and the chain de-bonding
5.2.3 The network reorganization
5.2.4 Final formulations for the stress softening
5.2.5 Parameter study
5.3 Validation 55
5.4 Concluding remarks 57

6 Yielding and Necking in double network hydrogels 59
6.1 Introduction 59
6.2 Modeling 64
6.2.1 Second network decomposition
6.2.2 Characterization of the yielding and the necking
6.2.3 Final formulations for the yielding and the necking with the stress softening
6.2.4 Parameter study for the yielding and the failure criterion
6.3 Validation 74
6.3.1 1. validation
6.3.2 2. validation
6.4 Concluding remarks 78

7 Self-healing in double network hydrogels 81
7.1 Introduction 81
7.2 Modeling 83
7.2.1 Third network decomposition
7.2.2 Reactivation of broken bonds
7.2.3 Conformation of polymer chains after healing
7.2.4 Reloading
7.2.5 Thermodynamic consistency

7.3 Validation 92
7.4 Concluding remarks 93

IV General conclusion and appendices 97

8 General conclusion 99

A Tensor analysis 103
A.1 Vector operations 103
A.2 Tensor operations 104
A.2.1 Derivation with respect to a tensor

B Foundations of the continuum mechanics 109
B.1 Kinematics of deformation 109
B.1.1 Material configurations
B.1.2 Tangent vectors and dual bases
B.1.3 Deformation gradient
B.1.4 Deformation of surface and volume elements: Nanson's Formula
B.1.5 Strain and Stretch measures
B.1.6 Velocity Gradient
B.2 Cauchy theorem and stress measures 114
B.3 Balance principles 115
B.3.1 Linear momentum balance
B.3.2 Energy balance
B.3.3 Entropy balance and dissipation inequality in constitutive modeling
B.3.4 Incompressible materials

C Nomenclature 119
C.1 Glossary symbols 119