

Experiments and Modelling of Elasto-Viscoplasticity for Thermoplastics with Asymmetric Effects

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Abstract

Experimental tests for thermoplastics exhibit different behaviours for different loading types such as tension, compression and shear. This observation is called asymmetric effects. Also strain rate and temperature influence the mechanical behaviour of thermoplastics. One objective of this thesis is to formulate constitutive equations which can simulate the elasto-viscoplastic deformation of polymers taking into consideration the asymmetric, strain rate and temperature effects. Therefore different frameworks at small and large strains are presented. These frameworks are based on the concept of stress mode dependent weighting functions with a characteristic behaviour dependent on the loading state. In this concept, an additive decomposition of the flow rule is assumed into the sum of weighted stress mode related quantities. A main advantage of the concept is, that the stress modes can directly be associated to certain characteristic loading scenarios, such as tension, compression and shear, which are experimentally investigated in the laboratory. The capability of the proposed models is assessed by simulating a laser transmission welding process and a cold drawing process using a finite element programs such as ABAQUS. Another objective of this thesis is to model the induced anisotropic effects exhibited in the tensile/compressive tests using polymeric specimens. Thus another constitutive framework has been developed. In this framework a spectral decomposition is done for the inelastic strain tensor resulting into its eigenvalues and eigenvectors. Therefore the yield function can be formulated as a function of the maximum eigenvalue of the inelastic strain. The capability of the proposed approach is assessed by depicting the start of strain localization in the middle of a tension specimen and the propagation of plastic strain over the whole specimen.

Zusammenfassung

Experimentelle Versuche für die Thermoplaste zeigen verschiedene Verhaltensweisen für unterschiedliche Belastungstypen wie beispielsweise Zug-, Druck- und Scherversuche. Diese Beobachtung wird als Asymmetrie-Effekt bezeichnet. Auch die Dehnrate und die Temperatur beeinflussen das mechanische Verhalten für Thermoplaste. Ein Ziel dieser Arbeit ist die Formulierung von konstitutiven Gleichungen, welche die elasto-viskoplastische Deformation von Polymeren simulieren können, mit Berücksichtigung der Asymmetrie-, der Dehnrate- und der Temperatureffekte. Daher werden unterschiedliche frameworks von kleinen und großen Deformationen präsentiert. Diese basieren auf dem Konzept der Wichtungsfunktionen, deren charakteristisches Verhalten in Abhängigkeit zum Belastungszustand steht. In diesem Konzept wird die additive Dekomposition der Fließregel angenommen, als Summe von Spannungsmoden von abhängigen Anteilen. Der Hauptvorteil dieses Konzepts ist, dass die Spannungsmoden direkt mit bestimmten Belastungszuständen wie zum Beispiel Zug-, Druck- und Scherversuchen (die durch Experimente im Labor untersucht werden) assoziiert werden können. Die Fähigkeit des vorgestellten Modells wird bewertet durch die Simulation des Laserdurchstrahlschweiß-Prozesses und des Kaltziehen-Prozesses, in dem unter anderem das Finite-Elemente-Programm ABAQUS genutzt wird. Ein weiteres Ziel dieser Arbeit ist die Modellierung der induzierten Anisotropie-Effekte, welche durch Zug- und Druckversuche von polymeren Proben gezeigt werden sollen. Deshalb wurde ein weiterer konstitutiver Rahmen entwickelt. Dazu wird die spektrale Dekomposition für den inelastischen Verzerrungstensor durchgeführt, um seine Eigenwerte und -vektoren zu erhalten. Damit kann die Fließfunktion in Abhängigkeit von dem Maximum der Eigenwerte der inelastischen Verzerrung formuliert werden. Die Fähigkeit des vorgestellten Ansatzes wird bewertet durch die anschauliche Darstellung des Beginns der Dehn-Lokalisierung in der Mitte einer Zugprobe sowie die Ausbreitung der plastischen Verzerrung durch die ganze Probe.

Preface

The work presented in this thesis was carried out in the field of experiments and modelling for polymers when I was employed as a research associate at the Chair of Engineering Mechanics (LTM), the Faculty of Mechanical Engineering at the University of Paderborn.

I would like to take this opportunity to thank God for his help in my life and in finishing this thesis. The financial support provided by the Deutsche Forschungsgemeinschaft (DFG) under two successive grants:

1. Ma 1979/4-1 “Experimente und Modellbildung zur Eigenspannungsentwicklung beim Laserdurchstrahlschweißen von Thermoplasten unter besonderer Berücksichtigung des druckabhängigen und asymmetrischen Werkstoffverhaltens” and
2. Ma 1979/7-2 “Experimente und Modellbildung zur Eigenspannungsentwicklung beim Quasi-Simultan-Laserdurchstrahlschweißen von Thermoplasten unter besonderer Berücksichtigung großer Deformationen und der daraus folgenden Anisotropieentwicklung”

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List of Publications

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2. POTENTE, H.; WILKE, L.; RIDDER, H.; MAHNKEN, R.; SHABAN, A. (2008): *Simulation of the residual stresses in the contour laser welding of thermoplastics*. Polymer Eng. Sci., 48(4): 767–773.
3. MAHNKEN, R.; SHABAN, A.; POTENTE, H.; WILKE, L. (2008): *Thermoviscoplastic modelling of asymmetric effects for polymers at large strains*. Int. J. Solids Struct., 45: 4615–4628.
4. BONEFELD, D.; POTENTE, H.; SHABAN, A.; MAHNKEN, R. (2010): *Residual stresses at the quasi-simultaneous laser transmission welding of amorphous thermoplastics*. Polymer Eng. Sci., 50(8): 1520–1526.
5. MAHNKEN, R.; SHABAN, A.: *Finite elasto-plastic model for polymers including asymmetric effects*. Submitted to Archive of Applied Mechanics in 2011.
6. MAHNKEN, R.; SHABAN, A.; SCHÖPPNER, V.: *Modelling and simulation of induced anisotropy in glassy polymers*. Submitted to Int. J. Solids Struct. in 2011.

Contents

1	Introduction	1
1.1	Polymers	1
1.2	Phase diagram	2
1.3	Yielding of polymers	4
1.4	Asymmetric effects	6
1.5	Scope of thesis	6
1.6	Contents of thesis	6
2	Experimental work and molecular theories of yielding	9
2.1	Introduction	9
2.2	Mechanical behaviour of thermoplastics under tension test	12
2.3	Asymmetric effects between tension and compression	20
2.4	Strain rate effect	23
2.5	Temperature effects	24
2.6	Relaxation tests	26
2.7	Molecular theories of yielding	27
2.7.1	Reduction of glass transition temperature by stress application	27
2.7.2	Stress-induced increase in free volume	28
2.7.3	Break-down of entanglements under stress	28
2.7.4	Eyring model	28
2.7.5	Robertson model	29
2.7.6	Theoretical shear strength - Frank's modification of Frenkel model	29
2.7.7	Disclinations	30
3	Stress mode dependent elasto-viscoplasticity at small strains	33
3.1	Introduction	33
3.2	Framework for stress mode dependent elasto-viscoplasticity at small strains	34
3.2.1	Kinematics	34
3.2.2	Dissipation inequality	34
3.2.3	Flow rule for asymmetric elasto-viscoplasticity	35
3.3	Formulation of stress mode related weighting functions at small strains	36
3.4	Modelling of stress mode dependent elasto-viscoplasticity at small strains	38
3.4.1	Prototype model	38
3.4.2	Thermodynamic consistency	40
3.5	Numerical implementation at small strains	40
3.5.1	Integration scheme	41

3.5.2	Local iteration	42
3.5.3	Algorithmic tangent modulus	42
3.6	Parameter identification	44
3.7	Results and Discussion	45
4	Stress mode dependent thermoviscoplasticity at large strains	47
4.1	Introduction	47
4.2	Framework for stress mode dependent thermoviscoplasticity at large strains	48
4.2.1	Kinematics	48
4.2.2	Entropy inequality principle	49
4.2.3	Flow rule for asymmetric thermoviscoplasticity	50
4.3	Formulation of stress mode related weighting functions at large strains	52
4.4	Modelling of stress mode dependent thermoviscoplasticity at large strains	53
4.4.1	Prototype model	53
4.4.2	Thermodynamic consistency	55
4.5	Numerical implementation at large strains	55
4.5.1	Integration scheme	56
4.5.2	Algorithmic tangent modulus	57
4.6	Results and Discussion	57
5	Simulation of laser transmission welding	59
5.1	Introduction	59
5.2	Process of laser transmission welding	60
5.3	Theoretical Principles	62
5.4	Modelling of laser transmission welding	65
5.5	Results and Discussion	67
5.5.1	Temperature distribution	68
5.5.2	Evolution of equivalent inelastic strain with temperature	70
5.5.3	Residual stresses	71
5.5.4	Effect of welding parameters	74
5.5.5	Conclusion	76
6	Finite elasto-plastic model including asymmetric effects	77
6.1	Introduction	77
6.2	Finite elasto-plastic framework	78
6.2.1	Kinematics	78
6.2.2	Free Helmholtz energy	78
6.2.3	Dissipation inequality	79
6.2.4	Flow rule for elasto-plasticity	79
6.3	Modelling of asymmetric effects	80
6.3.1	Prototype model	80
6.3.2	Thermodynamic consistency	82
6.4	Numerical implementation	82
6.4.1	Integration scheme	82
6.4.2	Local iteration	84
6.4.3	Algorithmic tangent modulus	84
6.5	Parameter identification	84
6.6	Simulation of cold drawing process	85

7	Modelling and simulation of induced anisotropy	91
7.1	Introduction	91
7.2	Framework for elasto-plasticity including induced anisotropy	92
7.2.1	Kinematics	92
7.2.2	Dissipation inequality	93
7.2.3	Yield function	93
7.2.4	Evolution equations	94
7.3	Modelling of elasto-plasticity including induced anisotropy	94
7.3.1	Prototype model	94
7.3.2	Algorithm to calculate anisotropic tensor	96
7.4	Numerical implementation	97
7.4.1	Integration scheme	97
7.4.2	Local iteration	97
7.4.3	Algorithmic tangent modulus	98
7.5	Parameter identification	99
7.6	Simulation of tension test	100
8	Summary and outlook	103
A	Basic concepts of tensor calculus for multiplicative plasticity	105
B	Proof	107
	References	109