MATFEM

Partnerschaft
Dr. Gese & Oberhofer
Maschinenbauingenieure

Modelling Short-Fiber Reinforced Polymers with Material Model MF GenYld+CrachFEM

4A Engineering Technologietage, 3. + 4. März 2011, Schladming, Austria

G. Oberhofer Authors

March 2011 Date

www.matfem.de

Content

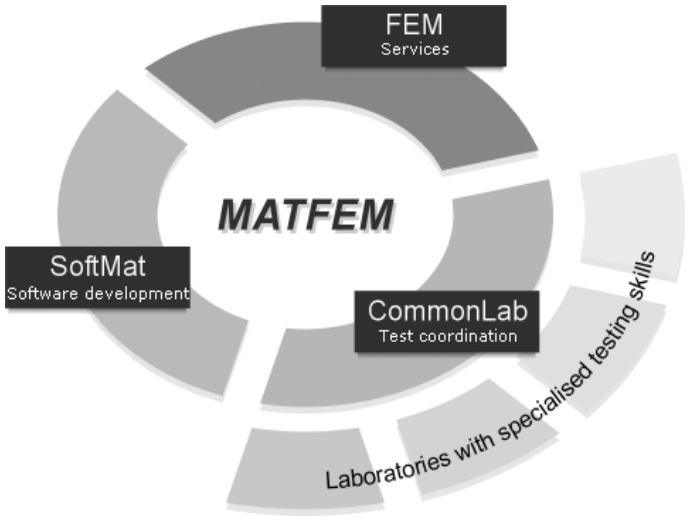
MATFEM

Modelling Short-Fiber Reinforced Polymers with MF GenYld+CrachFEM

- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Development

Introduction of MATFEM

MATFEM



Content

MATFEM

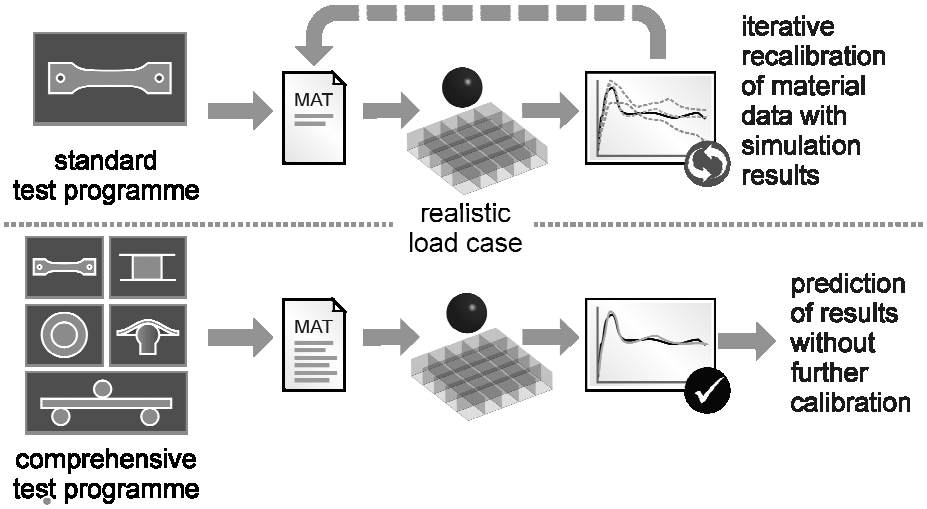
Modelling Short-Fiber Reinforced Polymers with MF GenYld+CrachFEM

- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Development

Material Model MF GenYld + CrachFEM (1)

MATFEM

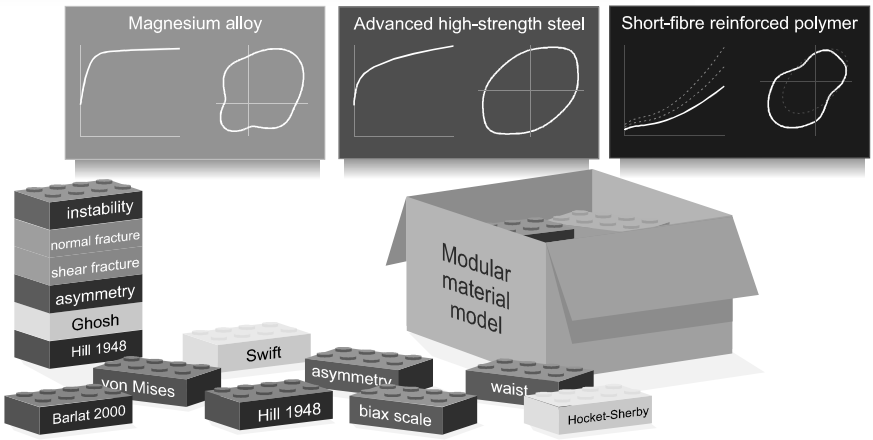
Predictive Material Model



Material Model MF GenYld + CrachFEM (2)

MATFEM

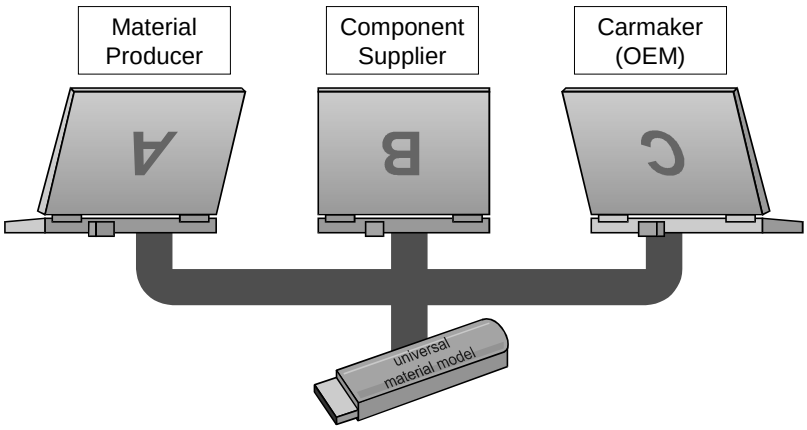
Modular Material Model



Material Model MF GenYld + CrachFEM (3)

MATFEM

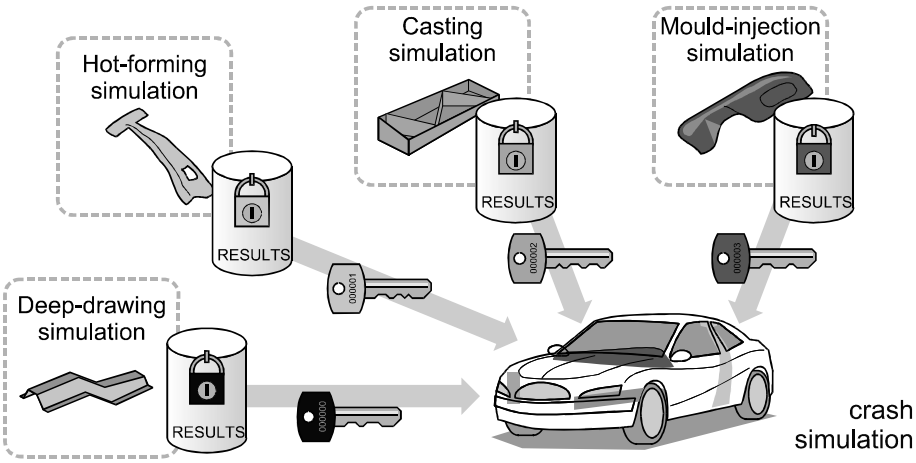
Universal Material Model



Material Model MF GenYld + CrachFEM (4)

MATFEM

Common Material Model throughout the Process Chain - Concept



Content

MATFEM

Modelling Short-Fiber Reinforced Polymers with MF GenYld+CrachFEM

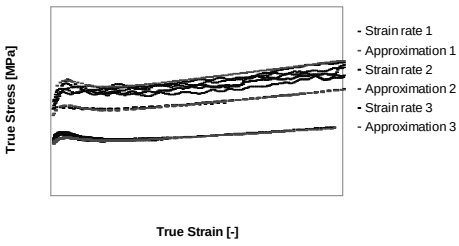
- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Development

MF-GenYld+CrachFEM for Non-Reinforced Polymers

MATFEM

Strain Rate Dependent Hardening

Material Modelling

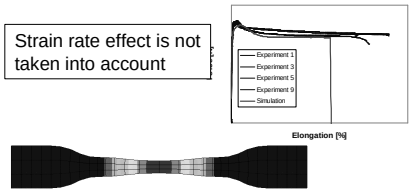


Hardening model for polymers

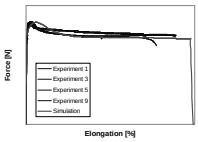
$$\sigma_{eq} = \left(f_1 + f_2 \cdot \varepsilon_{eq}^{f_3} + f_4 \cdot \varepsilon_{eq}^{f_5} \cdot e^{-f_6 \cdot \varepsilon_{eq}}\right) \cdot \left(1 + f_7 \cdot \lg \dot{\varepsilon}\right)$$

Simulation

Strain rate effect is not taken into account



Strain rate effect is taken into account



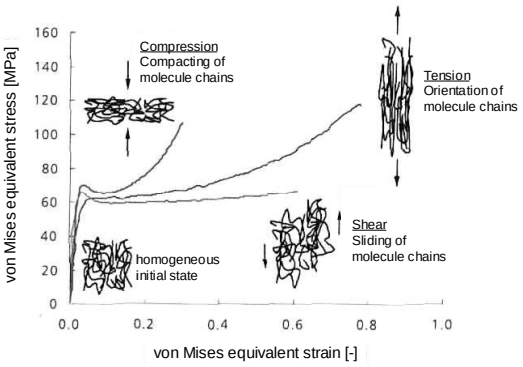
Source: G. Oberhofer / M. Franzen: Modelling of Non-Reinforced Polymeric Material Behaviour in the Explicit FEM Method for Crash Simulation, Fachtagung "Kunststoffe+Simulation" 13.&14.Juni 2007 Fellbach/Stuttgart, 2007

Simulation with LS-Dyna 9.71+ MF-GenYld+CrachFEM

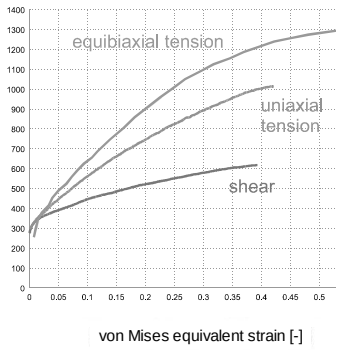
MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Stress State dependent Hardening = Anisotropic Hardening

Polymer*



Stable Austenitic Steel

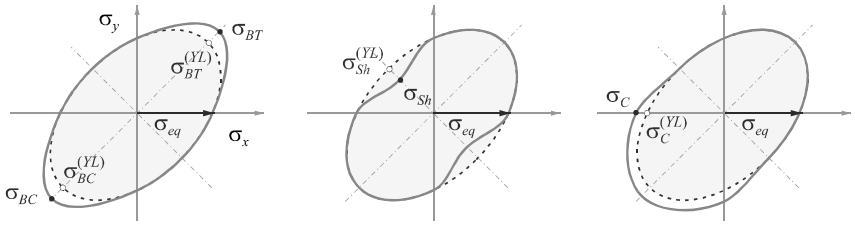


* Source: M. Junginger: Charakterisierung und Modellierung unverstärkter thermoplastischer Kunststoffe zur numerischen Simulation von Crashvorgängen, Dissertation am Fraunhofer-Institut für Kurzzeitdynamik (Ernst-Mach-Institut), Schriftenreihe „Forschungsergebnisse aus der Kurzzeitdynamik", Heft Nr. 3, 2004

MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Yield-locus modification in MF GenYld

- Yield locus modification can be done for all available yield loci in MF GenYld
- Scaled yield loci are still monotonic for yield stress and normality rule
- Reference yield locus or scaled yield locus can be used as plastic potential



Biaxial correction
Here: $b_T = b_C > 1$

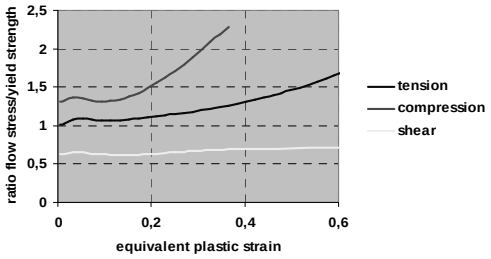
Waist for shear
Here: $a > 1$

Tens./compr. asymmetry
Here: $f < 1$

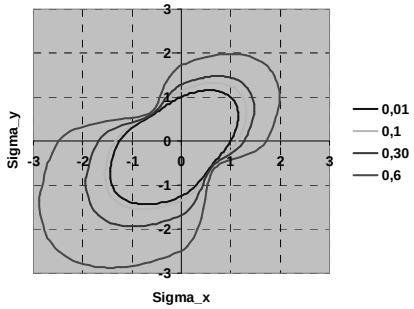
$$\sigma_{eq} = \mathrm{f}^*\left(k \cdot \sigma_{ij}, q_k\right) = k \cdot \mathrm{f}^*\left(\sigma_{ij}, q_k\right)$$

MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Stress state dependent Hardening = Anisotropic Hardening



Quasi-static flow stress curves for a non-reinforced polymer from uniaxial tension, uniaxial compression and pure shear

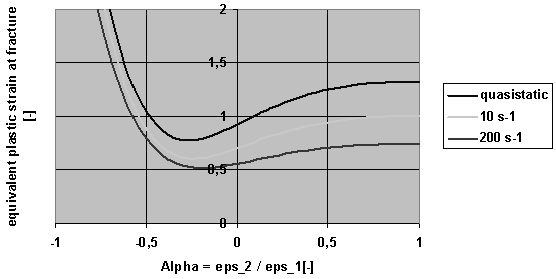


Evolution of yield loci for non-reinforced polymer with increasing equivalent plastic strain; evolution described with MF_GenYld

Source of material data: M. Junginger: Charakterisierung und Modellierung unverstärkter thermoplastischer Kunststoffe zur numerischen Simulation von Crashvorgängen, Dissertation am Fraunhofer-Institut für Kurzzeitdynamik (Ernst-Mach-Institut), Schriftenreihe „Forschungsergebnisse aus der Kurzzeitdynamik“, Heft Nr. 3, 2004

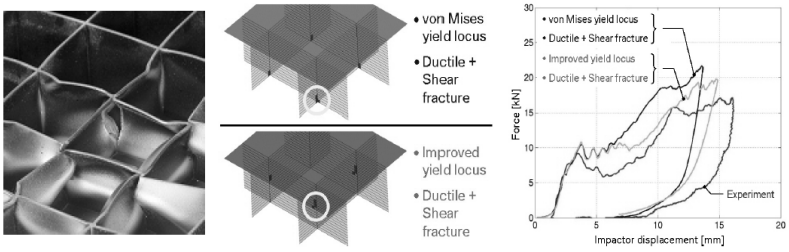
MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Strainrate- and State-of-Stress- Dependency of failure



MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

- Indentation of Impactor in honeycomb structure of PC-ABS
- Simulation with symmetric Mises yield locus compared to simulation with anisotrop evolution of yield locus in MF Polymer (now part of MF GenYld)
- Models for ductile normal fracture and ductile shear fracture as a function of strain rate



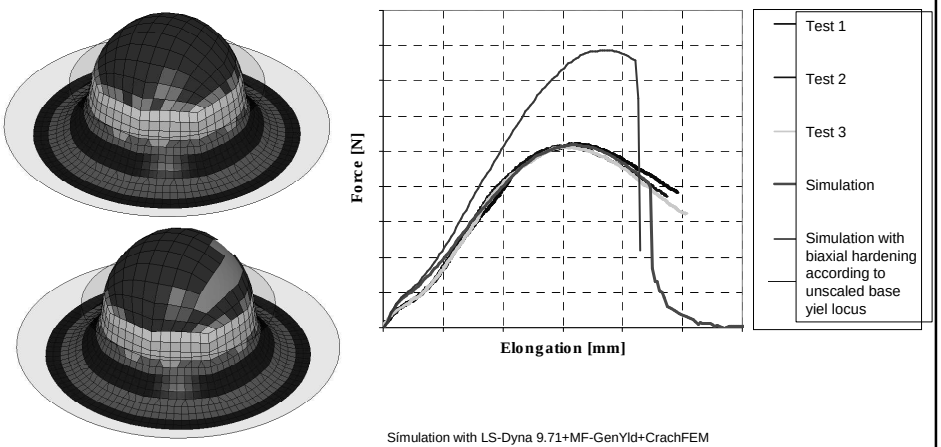
- Improved prediction of force level, deformation mode of walls and location of failure with anisotropic model

Source: Werner, H.; Hooputra, H. ; Weyer, S.; Gese, H.: Proceedings of VIII International Conference on Computational Plasticity COMPLAS, Oñate E.; Owen D.R.J. (Eds.) – CIMNE, Barcelona, 2005

MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Stress state dependent Hardening = Anisotropic Hardening

Simulation of Erichsen Test (non-reinforced PP material)



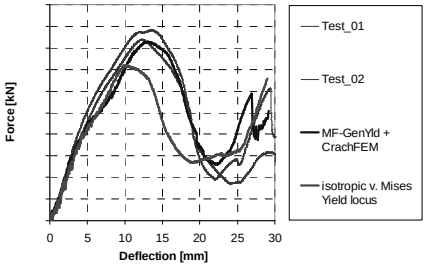
Simulation with LS-Dyna 9.71+MF-GenYld+CrachFEM

MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Stress state dependent Hardening = Anisotropic Hardening

Simulation of component test

Force-deflection curves for component test



- Maximum force is correctly displayed
- Energy absorption is much closer to physical test results

Source: G. Oberhofer, A. Bach, M. Franzen, et al, 7th European LS-DYNA Conference, Salzburg 2009

MF-GenYld+CrachFEM for Non-Reinforced Polymers **MATFEM**

Benefits

- ► Strain rate dependency of hardening behaviour can be predicted
- ► Anisotropic hardening can be described correctly
- ► Failure can be described taking into account the strain rate- and state of stress-dependency
- ► Reliable Material parameters can be evaluated by simple experimental tests

Contents

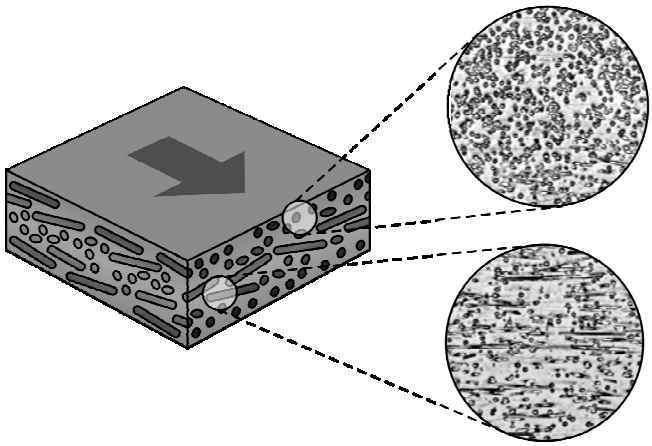
MATFEM

- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Development

Anisotropy of Short Fiber Reinforced Polymers

MATFEM

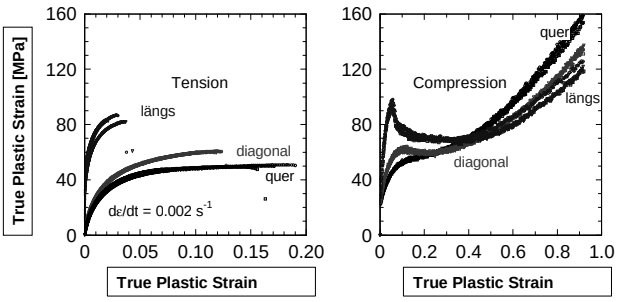
Different orientation of fibers over the wall thickness resulting from material flow



Anisotropy of Short Fiber Reinforced Polymers

MATFEM

Directionality of elasto-plastic behaviour for tensile and compressive load cases



- Anisotropy of elasticity
- Anisotropy of plasticity
- Anisotropy of fracture behaviour

Experimentally derived elastic parameters*

Material Parameter	Testing direction		
	"1" / 0º /	"2" / 90º /	"3" / 45º /
Youngs Modulus	5,59	2,35	2,61
Poisson's Ratio	0,44	0,24	0,31

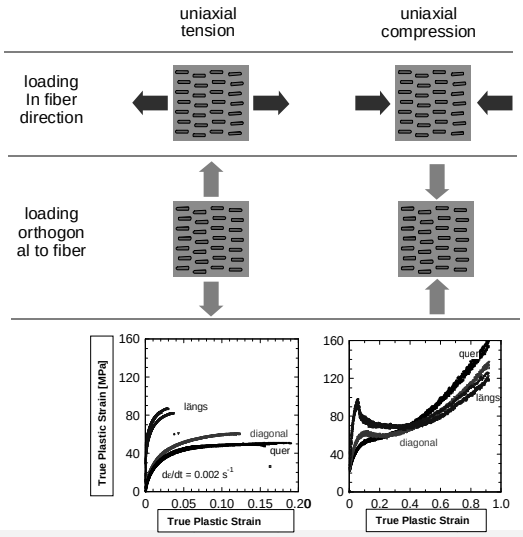
***Tests have been carried out at Fachhochschule München in behalf of BMW AG, 2004**

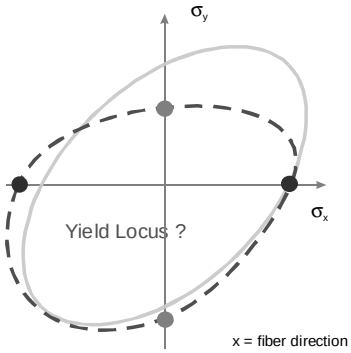
Souce: Oberhofer, G., Weyer, S., Dell, H. und Gese, H., Problemseminar: Material- und Versagensmodell zur Modellierung von Kunststoffen unter Crashbelastung Deformations- und Bruchverhalten von Kunststoffen, Merseburg 2005

Anisotropy of Short Fiber Reinforced Polymers

MATFEM

Different Orthotropy of Yield Locus in Tension and Compression





Contents

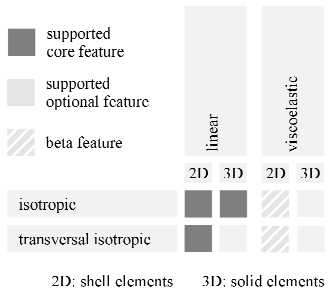
MATFEM

- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Development

Elastic Material Behaviour in MF GenYld

MATFEM

Elastic Anisotropy



$$\{\sigma\} = [D]\{\varepsilon\}$$

Elastic Orthotropy (3D-Stress State):

D_{00}, D_{01}, D_{02}, D_{11}, D_{12}, D_{22}, D_{33}, D_{44}, $D_{55} \neq 0$

→ Transversal Orthotropy (3D-Stress State): $D_{01} = D_{02}$, $D_{11} = D_{22}$, $D_{33} = D_{55} = 0$

Elastic Orthotropy (2D-Stress State): D_{00}, D_{01}, D_{11} und $D_{22} \neq 0$

→ No simplification for transversal Orthotropy (if principal orthotropy direction is directed in plane)

Plastic Material Behaviour in MF GenYld

MATFEM

■ supported core feature
▒ supported optional feature
▨ beta feature

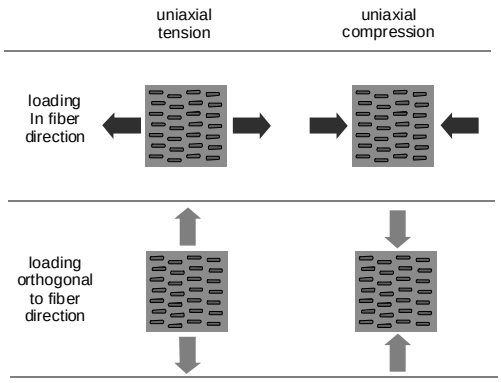
	isotropic hardening		isotropic-kinematic hardening		tension/compression asymmetry of orthotropy		anisotropic hardening: tension/comp. asymmetry for hardening		anisotropic hardening: waist function under shear		anisotropic hardening: scaling of biaxial point		compressibility		damage evolution	
	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D
isotropic von Mises	■	■	■	■	–	–	■	■	■	■	■	■	■	■		▨
Hill 1948	■	■	■	■	■	■	■	■	■	■	■	■	■	■		▨
Hill 1990	■	–	■	–	■	–	■	–	■	–	■	–	■	–		–
Barlat 1996	■	–	■	–	■	–	■	–	■	–	■	–	■	–		–
Barlat-Lian 1989	■	–	■	–	■	–	■	–	■	–	■	–	■	–		–
Barlat 2000	■	–	■	–	■	–	■	–	■	–	■	–	■	–		–
Barlat, Lege Brem	■	■	■	■	■	■	■	■	■	■	■	■	■	■		▨
Dell	■	■	■	■	■	■	■	■	■	■	■	■	■	■		▨
Bron-Besson	■	■	■	■	■	■	■	■	■	■	■	■	■	■		▨

2D: shell elements 3D: solid elements – not applicable

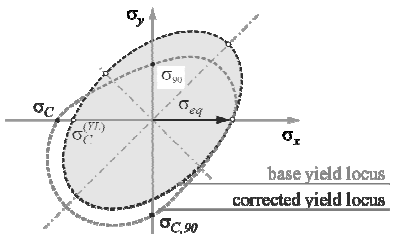
Plastic Material Behaviour in MF GenYld

MATFEM

MF GenYld_allows for asymmetric orthotropy

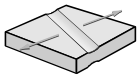


Here:
Tension orthotropic,
Compression isotropic



Comprehensive Failure Model CrachFEM

MATFEM

			2D (shells)	3D (solids)
	Local instability (necking)	Initial FLC (approximate)	✓	not reasonable
		Prediction with Crach	✓	not reasonable
		Post-critical elongation	✓	not reasonable
	Ductile normal fracture	$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\eta)$	✓	✓ *
		$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\beta)$	✓	✓
	Ductile shear fracture	$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\theta)$	✓	✓

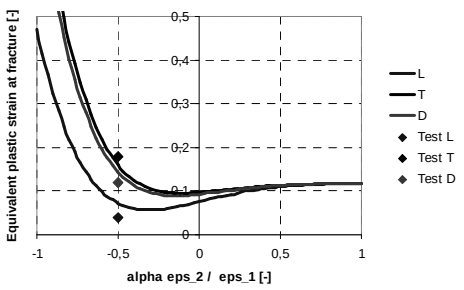
*) not recommended

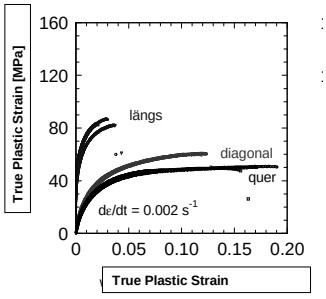
Due to progressive hardening of polymers necking will generally not cause failure in polymers
→ Crach algorithm not needed

Comprehensive Failure Model CrachFEM

MATFEM

Directionality of the fracture strain for a short fiber reinforced polymer





- The ductile normal fracture diagram shows a strong dependency of the fracture strain from the loading direction
- The models for ductile normal fracture and ductile shear fracture can be used for polymers (similar test programme compared to sheet material)
- Due to progressive hardening of polymers necking will generally not cause failure in polymers (Crach algorithm not needed)

Content

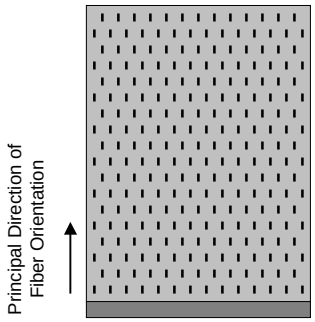
MATFEM

- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Developement

Example – Tension and Compression Test

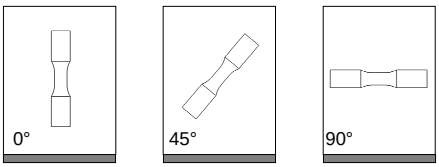
MATFEM

Plaque with homogeneous fiber orientation in plane (reference quality)

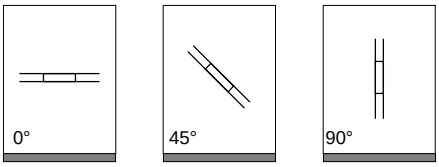


Test Program

Tensile Test



Compression Test

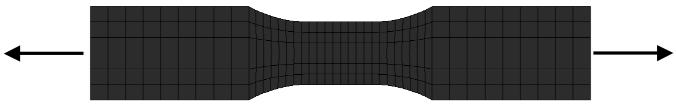


Example – Tension and Compression Test

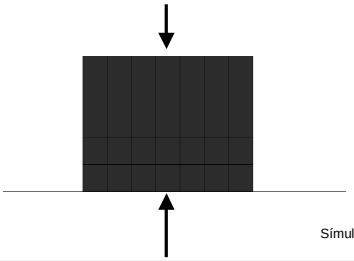
MATFEM

Finite Element Model of Tensile and Compression Specimen

Tensile Test (Shell discretization)



Compression Test (Solid discretization)

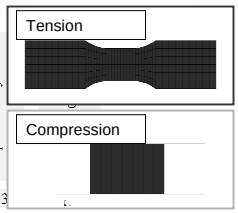


Simulation with LS-Dyna 9.71 R5.0 +MF-GenYld+CrachFEM 3.8

Example – Tension and Compression Test

MATFEM

Simulation assuming isotropic v. Mises Plasticity



supported core feature
supported optional feature
beta feature

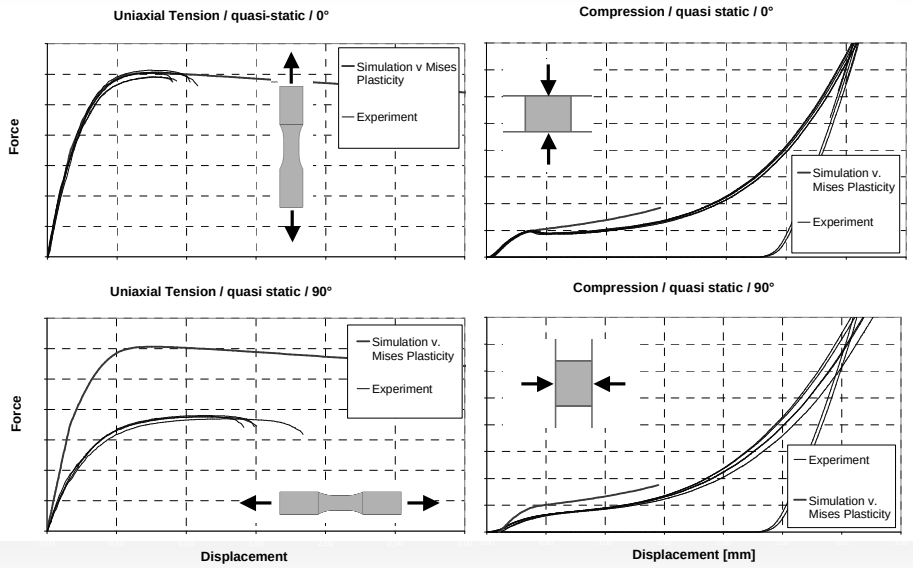
	isotropic hardening		isotropic-kinematic hardening		tension/compression asymmetry of orthotropy		anisotropic hardening: tension/comp. asymmetry for hardening		anisotropic hardening: waist function under shear		anisotropic hardening: scaling of biaxial point		compressibility	
	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3
isotropic von Mises	■	■	■	■	–	–	■	■	■	■	■	■	■	■
Hill 1948	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Hill 1990	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat 1996	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat-Lian 1989	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat 2000	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat, Lege Brem	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Dell	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Bron-Besson	■	■	■	■	■	■	■	■	■	■	■	■	■	■

2D: shell elements 3D: solid elements – not applicable

Example – Tension and Compression Test

MATFEM

Simulation assuming isotropic v. Mises Plasticity



Example – Tension and Compression Test

MATFEM

Simulation assuming isotropic v. Mises Plasticity

- The force displacement curve of the uniaxial tensile test in reference direction (principal direction of fiber orientation) can be predicted with good accuracy
- The force displacement curve of the uniaxial tensile test in cross direction cannot be predicted correctly
- The asymmetric hardening behaviour between tension and compression cannot be predicted correctly
- The asymmetry of orthotropy cannot be predicted correctly
- The elastic orthotropy cannot be prediced correctly
- Failure is not considered in this case

Example – Tension and Compression Test

MATFEM

Simulation taking into account transversal isotropic elastic behaviour

Tensile Test (Shell Elements)

Compression Test (Solid Elements)

► transversal isotropic elasticity currently not available for the 3D stress state

	linear		viscoelastic	
	2D	3D	2D	3D
isotropic	■	■	▨	
transversal isotropic	■		▨	

■ supported core feature
▨ supported optional feature
▨ beta feature

2D: shell elements 3D: solid elements

	linear		viscoelastic	
	2D	3D	2D	3D
isotropic	■	■	▨	
transversal isotropic	■		▨	

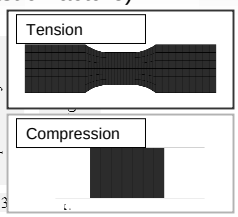
■ supported core feature
▨ supported optional feature
▨ beta feature

2D: shell elements 3D: solid elements

Example – Tension and Compression Test

MATFEM

Simulation taking into account orthotropic behaviour (elastic, plastic fracture)



■ supported core feature
▨ supported optional feature
▨ beta feature

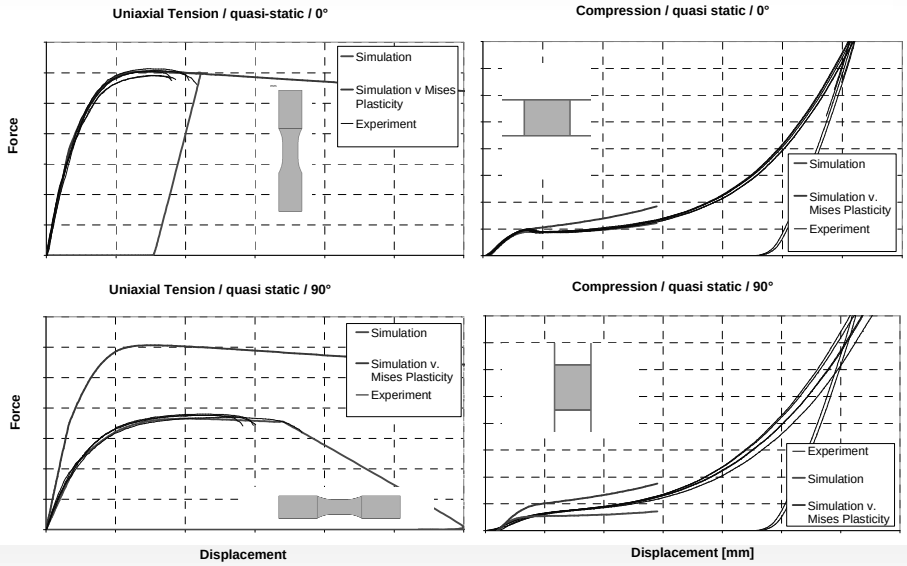
	isotropic hardening		isotropic-kinematic hardening		tension/compression asymmetry of orthtropy		anisotropic hardening: tension/comp. asymmetry for hardening		anisotropic hardening: waist function under shear		anisotropic hardening: scaling of biaxial point		compressibility	
	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3
isotropic von Mises	■	■	■	■	–	–	■	■	■	■	■	■	■	■
Hill 1948	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Hill 1990	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat 1996	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat-Lian 1989	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat 2000	■	–	■	–	■	–	■	–	■	–	■	–	■	–
Barlat, Lege Brem	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Dell	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Bron-Besson	■	■	■	■	■	■	■	■	■	■	■	■	■	■

2D: shell elements 3D: solid elements – not applicable

Example – Tension and Compression Test

MATFEM

Simulation taking into account orthotropic behaviour (elastic, plastic fracture) - Comparison



Content

MATFEM

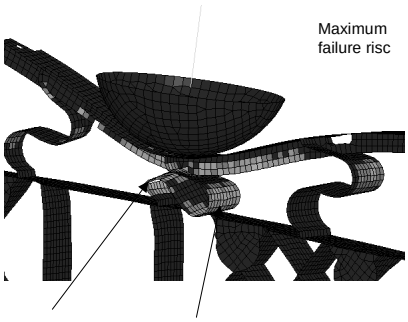
- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Established Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Developement

Example – Component Simulation

MATFEM

Simulation taking into account orthotropic behaviour (elastic, plastic fracture)

Simulation*



Test**

* Simulation with explicit Finite Element Code PamCrash and user Materialmodell MF-Polymer
** Tests performed at Frauenhofer-Institut für Kurzzeitdynamik, Erst-Mach-Institut, im Auftrag der BMW AG

Souce: Oberhofer, G., Weyer, S., Dell, H. und Gese, H., Problemseminar: Material- und Versagensmodell zur Modellierung von Kunststoffen unter Crashbelastung Deformations- und Bruchverhalten von Kunststoffen, Merseburg 2005

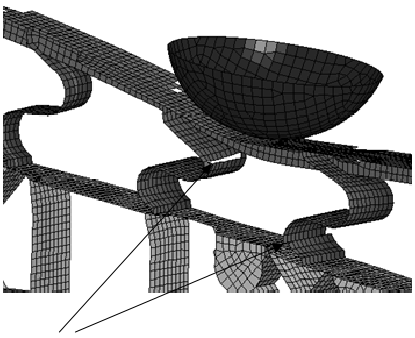
Example – Component Simulation

MATFEM

Simulation taking into account orthotropic behaviour (elastic, plastic fracture)

Failure

Simulation*



Test**

* Simulation with explicit Finite Element Code PamCrash and User Materialmodell MF-Polymer
** Tests performed at Frauenhofer-Institut für Kurzzeitdynamik, Erst-Mach-Institut, im Auftrag der BMW AG

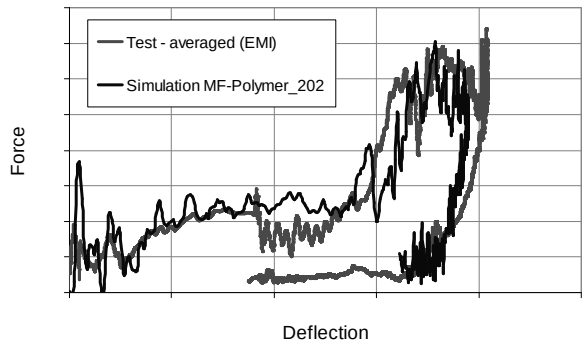
Souce: Oberhofer, G., Weyer, S., Dell, H. und Gese, H., Problemseminar: Material- und Versagensmodell zur Modellierung von Kunststoffen unter Crashbelastung Deformations- und Bruchverhalten von Kunststoffen, Merseburg 2005

Example – Component Simulation

MATFEM

Simulation taking into account orthotropic behaviour (elastic, plastic fracture)

Force-Deflection Curve (Material bahaviour elastic orthotropic, plastic orthotropic, orthotropic Failure)



- Force level is predicted with good accuracy
- Locations of failure are predicted correctly

- Simulation with explicit Finite Element Code PamCrash and user Materialmodell MF-Polymer
- Tests performed at Frauenhofer-Institut für Kurzzeitdynamik, Erst-Mach-Institut, im Auftrag der BMW AG
- Functionality of material model MF-Polymer is integrated in material model MF-GenYld+CrachFEM

Souce: Oberhofer, G., Weyer, S., Dell, H. und Gese, H., Problemseminar: Material- und Versagensmodell zur Modellierung von Kunststoffen unter Crashbelastung Deformations- und Bruchverhalten von Kunststoffen, Merseburg 2005

MF-GenYld+CrachFEM for Reinforced Polymers

MATFEM

Results

- The force displacement curve of the uniaxial tensile test in reference direction (principal direction of fiber orientation) can be predicted correctly
- The force displacement curve of the uniaxial tensile test in cross direction can be predicted correctly
- The asymmetric hardening behaviour between tension and compression can be predicted correctly
- The asymmetry of plastic orthotropy can be predicted correctly
- The elastic orthotropy can be prediced correctly in case of shell discretization
- Currently the elastic orthotropy cannot be prediced correctly in case of solid discretization (feature available in upcoming releases of version 4)
- Failure can be predicted correctly, taking into account different fracture strains in different orientations; the compression test cannot be used to identify the corresponding fracture strain as the state of stress changes at high deformations; the simulation has been evaluated below values of equivalent plastic strain of approximately 40%
- Currently the orthotropy of fracture cannot be prediced in case of solid discretization (feature available in upcoming releases of version 4)

Content

MATFEM

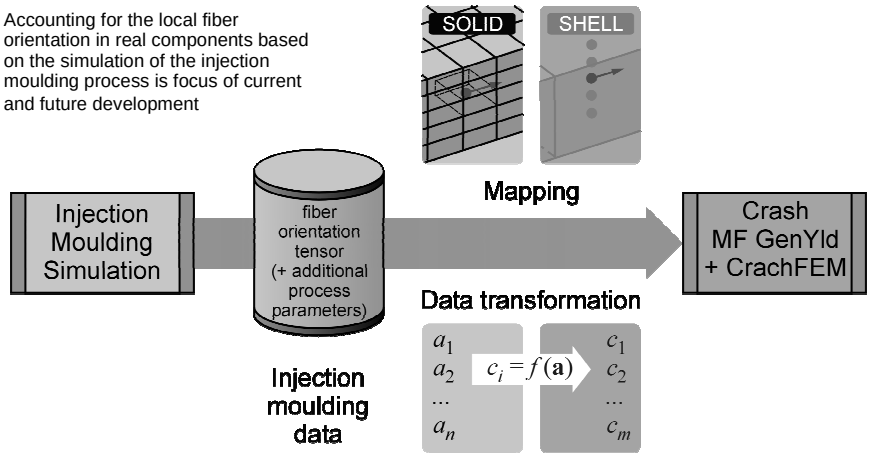
- Introduction of MATFEM
- Material Model MF GenYld + CrachFEM
- Enstablished Description of Non-Reinforced Polymers with MF-GenYld+CrachFEM
- The Anisotropy of Short Fiber Reinforced Polymers
- Applicability of MF GenYld + CrachFEM for Short Fiber Reinforced Polymers
- Validation by Simulation of Basic Test Cases
- Validation by Simulation of Component Test
- Future Development

Future Development – Crash of Polymer Components

MATFEM

Mapping and initialization of local properties from process simulation

Accounting for the local fiber orientation in real components based on the simulation of the injection moulding process is focus of current and future development



Future Development – Universal Material Model

MATFEM

Common material model throughout the process chain /
Lock-and-key principle for data transfer