Comparison of material models for crash simulation – experimental and simulation work

Sebastian Mönnich [1,*], Florian Becker [1], Bernhard Fellner [2]

[1] German Institute for Polymers (DKI), Department of Mechanics and Simulation
Schlossgartenstr. 6, D-64289 Darmstadt, Germany

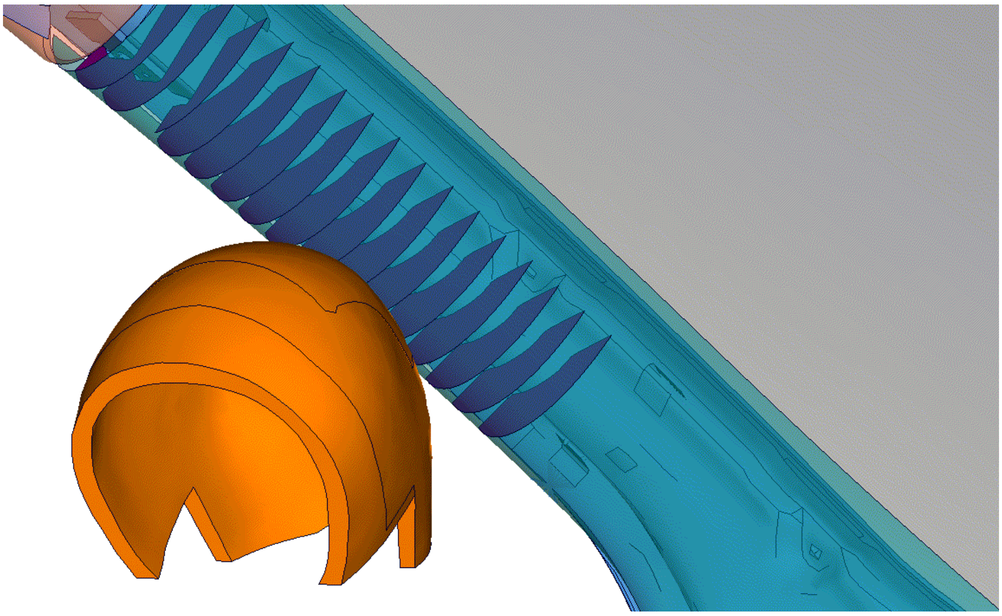
[2] MAGNA STEYR Fahrzeugtechnik AG & Co KG,
Liebenauer Hauptstrasse 317, 8041 Graz, Austria

* corresponding author, e-mail: smoennich@dki.tu-darmstadt.de

Outline

- Motivation
- Preparation of test specimens
- Measuring equipment
- Test results
- Material models
- FE model
- Parameter identification
- Simulation results

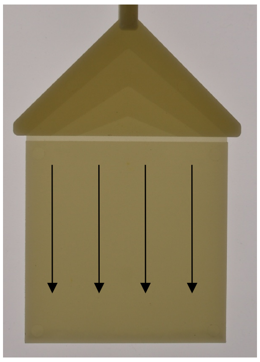
Motivation

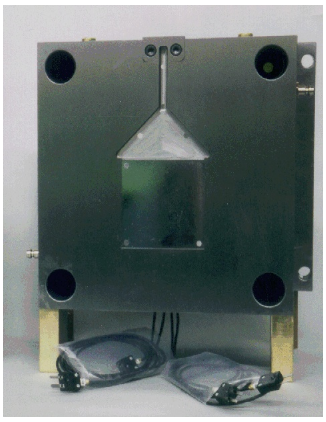


- increasing number of polymer parts in automotive industries
- higher requirements on crash simulation
- standard „steel“ models not satisfactory

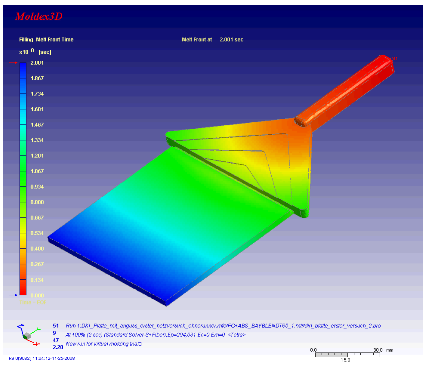
→ which material model is best suited to model thermoplastic material behaviour?

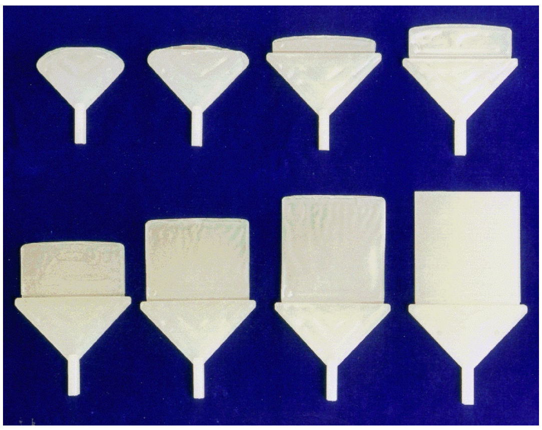
Injection Moulding of Plates



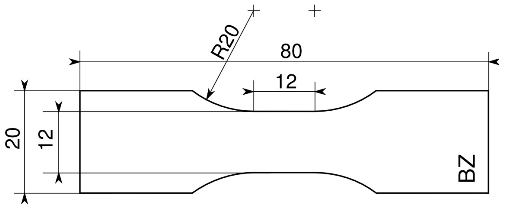


- plate 80 mm x 80 mm.
- constant thickness of 2,5 mm.
- parallel melt front

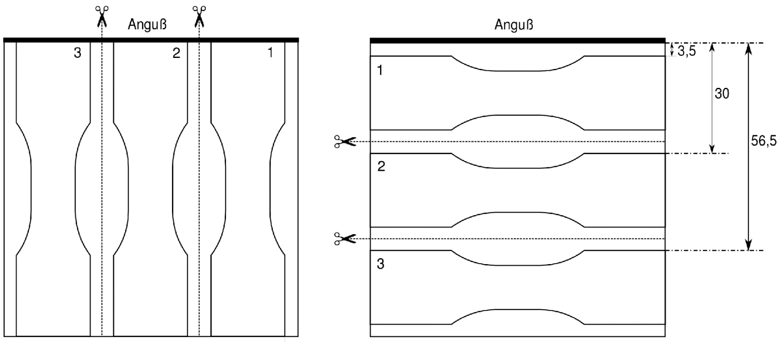




Specimen Preparation - Tension



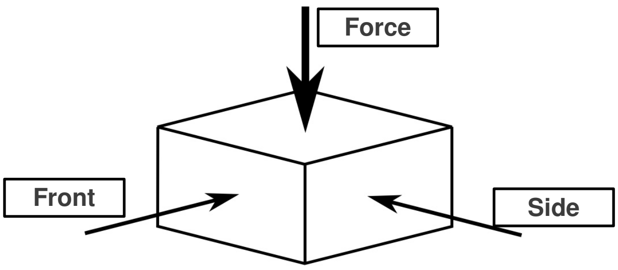
BZ-geometry

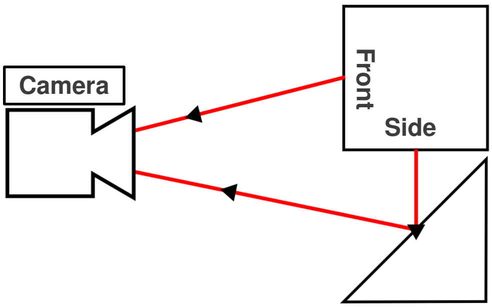


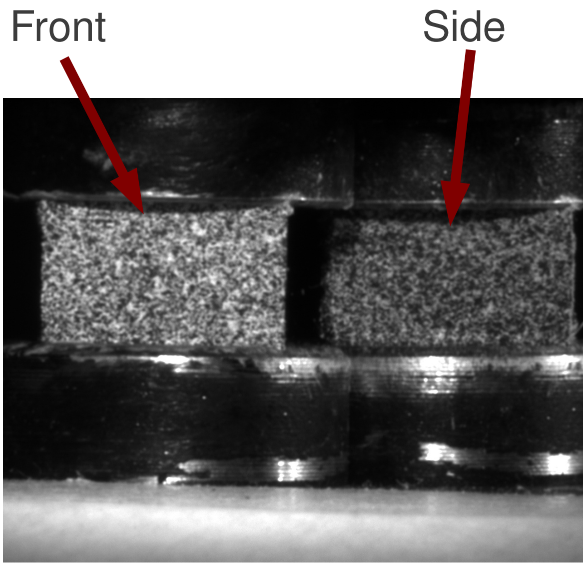
longitudinal *transveral*

- optimized test specimen for high strain rates
- preparation from 2,5 mm plates with constant thickness
- prepared specimens longitudinal and transversal to flow direction to check isotropic material properties

Specimen Preparation - Pressure

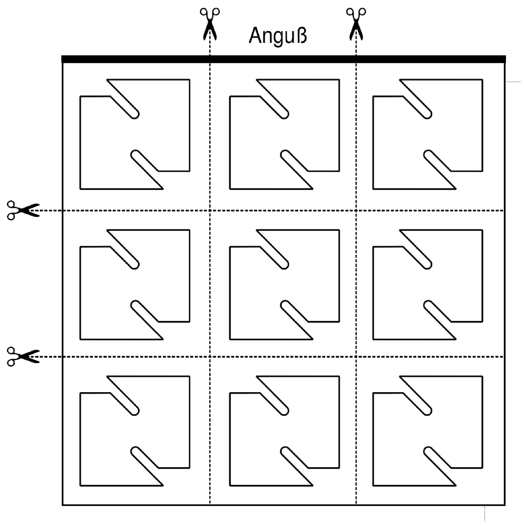




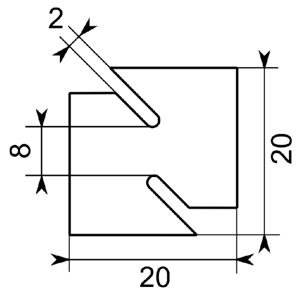


- separate evaluation of front and side grey scale pattern
- image defects are repaired

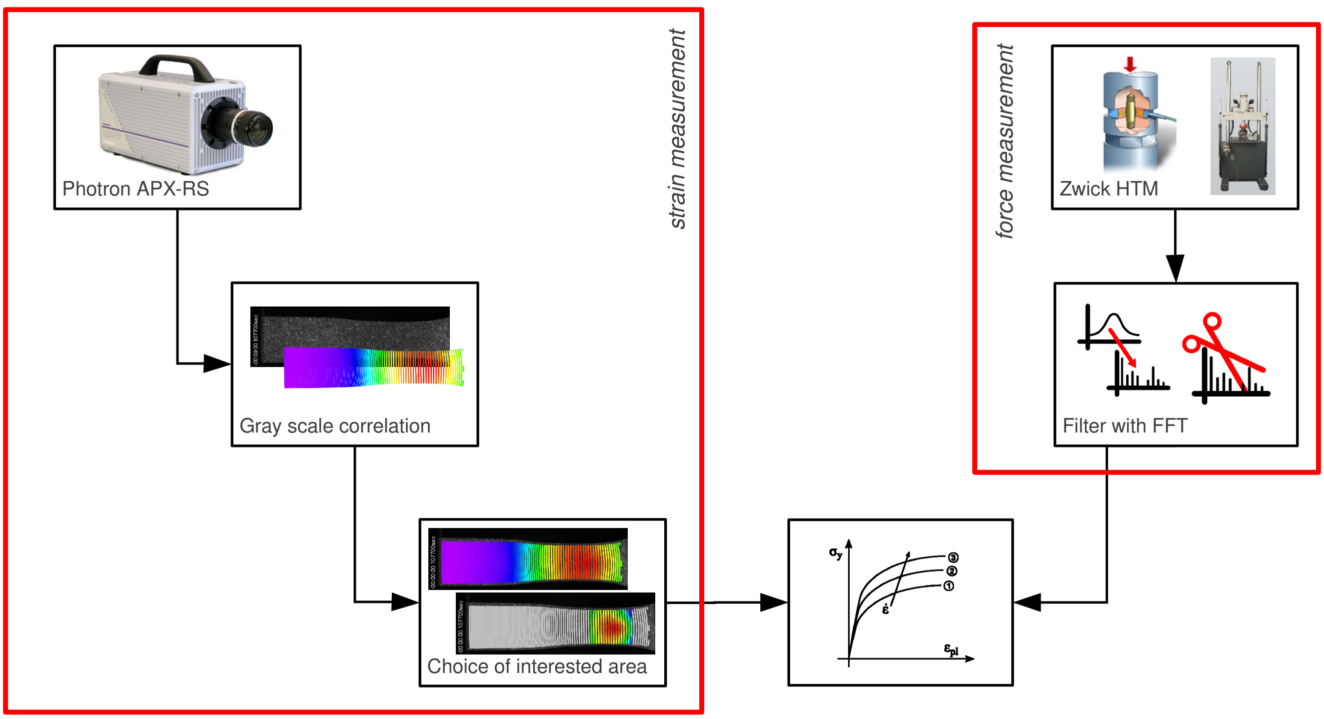
Specimen Preparation - Shear



- direction of specimen preparation uninteresting for shear
- specimen geometry optimized for high strain rates



Acquisition of Test Data



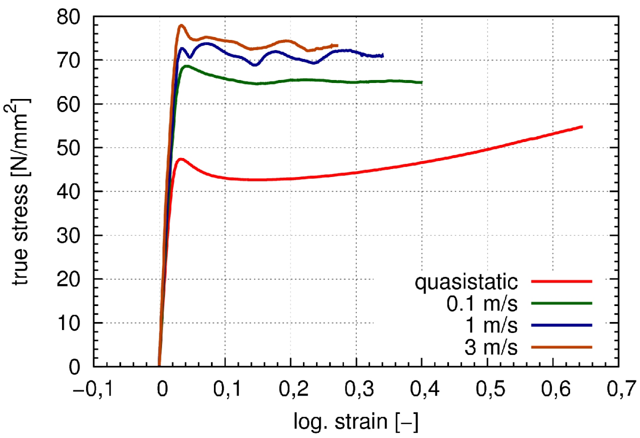
Experimental Design

		Material BASF Luran S778T	
load case	**velocity**	longitudinal	transversal
tension	quasistatic	x	x
	0.1 m/s	x	x
	1 m/s	x	x
	3 m/s	x	x
shear	quasistatic	x	
	0.1 m/s	x	
	0.5 m/s	x	
	1 m/s	x	
pressure	quasistatic	x	

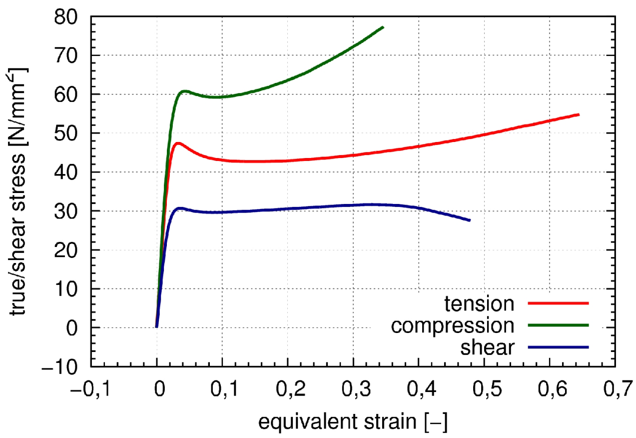
- 4 repetitions for each setting
- total of tests: 104

Luran S 778T – Tension Test Stress – Strain behaviour

Luran S778T – tension, different testing velocities



Luran S778T – tension, compression and shear load



- strain rate depended stress-strain behaviour
- significant reduction of failure strain with increasing strain rate
- yield stress depends on the loadcase

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Strain Rate Dependent Material Models

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Lfd.Nr.:	*MAT	Beschreibung	Anw.	SRATE	FAIL	EOS	THERM	ANISO	DAM	TENS
1	3	Plastic Kinematic/Isotropic	Pl, Mt, Cm	x	x					
2	11	Steinberg: Temp. Dependent Elastoplastic	Mt, Hy	x	x	x	x			x
3	15	Johnson/Cook Plasticity Model	Mt, Hy	x	x	x	x		x	x
4	18	Power Law Plasticity	Mt, Pl	x						
5	19	Strain Rate Dependent Plasticity	Mt, Pl	x	x					
6	24	Piecewise Linear Plasticity (Isotropic)	Mt, Pl	x	x					
7	33	Barlat Anisotropic Plasticity (YLD96)	Cr, Mt	x				x		
8	35	Plastic-Green Naghdi Rate	Mt	x						
9	36	Three Parameter Barlat Plasticity	Mt	x				x		
10	51	Bamman (Temp./Rate Dependent Plasticity)	Gn	x			x			
11	52	Bamman Damage	Mt	x	x		x		x	
12	64	Rate Sensitive Powerlaw Plasticity	Mt	x						
13	65	Zerilli-Armstrong (Rate/Temp Plasticity)	Mt	x		x	x			x
14	81	Plasticity with Damage	Mt, Pl	x	x				x	
15	82	Plasticity with Damage Ortho	Mt, Pl	x	x			x	x	
16	88	MTS	Mt	x		x	x			
17	89	Plasticity Polymer	Pl	x						x
18	98	Simplified Johnson Cook	Mt	x	x					
19	99	Simplified Johnson Cook Orthotropic Damage	Mt	x	x					
20	101	GE Plastic Strain Rate	Pl	x	x					x
21	102	Inv Hyperbolic Sin	Mt, Pl	x			x			
22	103	Anistropic Viscoplastic	Mt, Pl	x	x			x		
23	104	Damage 1	Mt	x	x			x	x	
24	105	Damage 2	Mt	x	x				x	
25	106	Elastic Viscoplastic Thermal	Pl	x			x			
26	107	Modified Johnson Cook	Mt	x	x		x		x	
27	112	Finite Elastic Strain Plasticity	Pl	x						
28	114	Layered Linear Plasticity	Mt, Pl, Cm	x	x					
29	120	Gurson	Mt	x	x				x	x
30	123	Modified Piecewise Linear Plasticity	Mt, Pl	x	x					
31	124	Plasticity Compression Tension	Mt, Pl	x	x					x
32	133	Barlat YLD2000	Mt	x				x		
33	135	Weak and Stron Texture Model	Mt	x	x			x		
34	141	Rate Sensitive Polymer	Pl	x						
35	151	Evolving Microstructural Model of Inelast.	Mt	x	x		x	x	x	
36	153	Damage 3	Mt, Pl	x	x				x	
37	167	McCormick	Mt	x						
38	187	Semi-Analytical Model for Polymers - 1	Pl	x	x				x	

Legende:
SRATE = Dehnratenabhängig
FAIL = Versagenskriterium
EOS = Zustandsgleichung
THERM = Temperaturabhängig
ANISO = Richtungsabhängig
DAM = Schadensmodell
TENS = Zug/Druck

Pl = Kunststoff
Mt = Metall
Cm = Composite
Hy = Hydrodynamic Material

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Material Models

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Selected material models:

- MAT003
  - simple parameter model
- MAT019
  - parameter model with strain rate dependent failure
- MAT187
  - semianalytical material model

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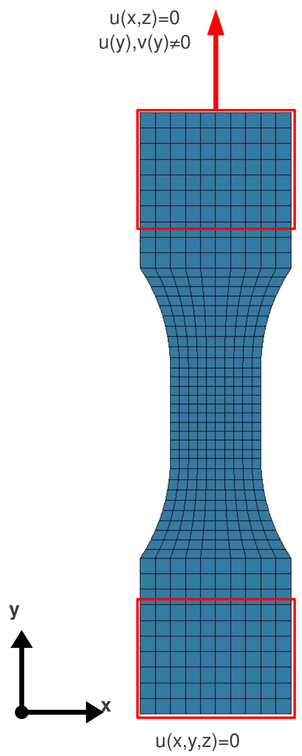
FE Model

- depending on the local strain measurements chosen element size, fully integrated shell elements (elform 16)
- bottom area defined as fixes bearing
- top area defined as floating bearing (u(x,z)=0)
- boundary condition u(y)≠0 is set as testing machine pull off speed



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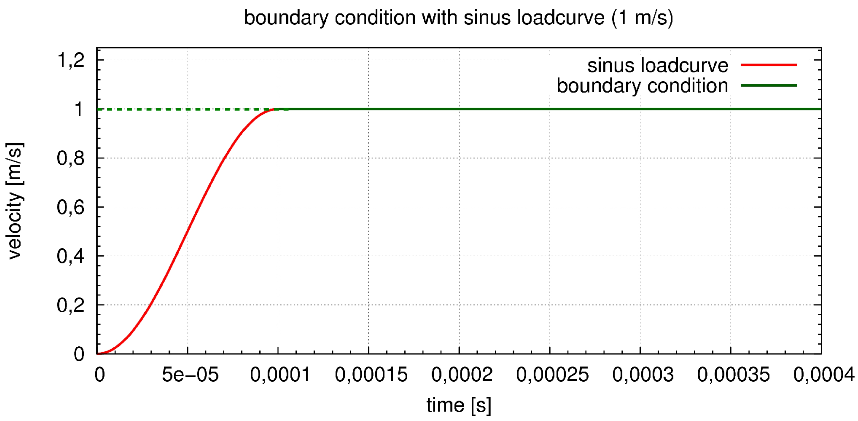
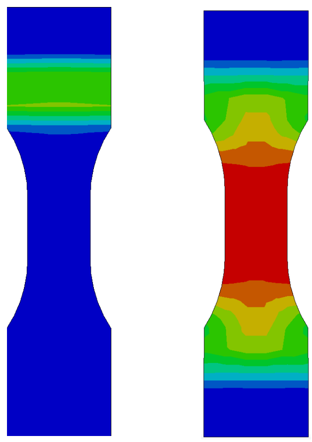
FE Modell

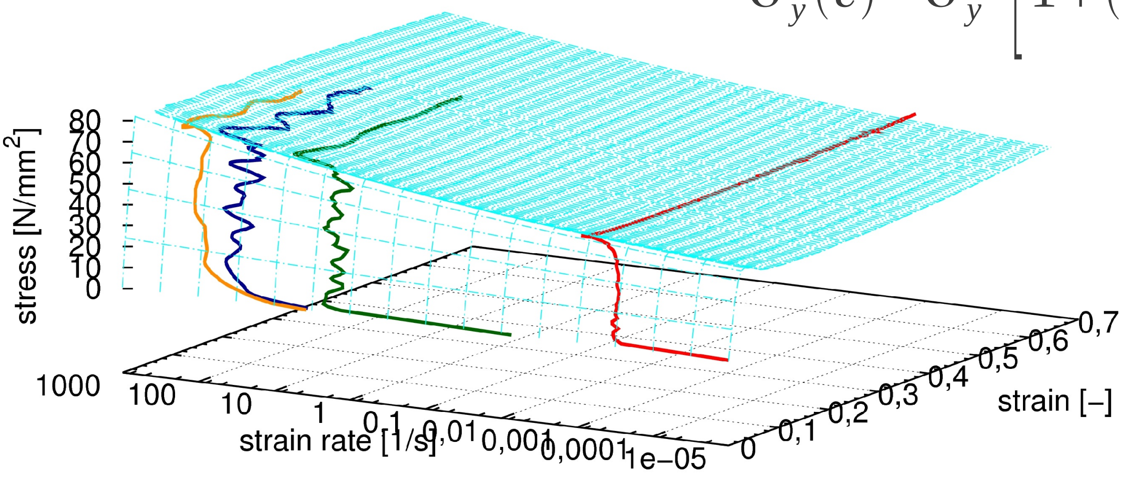




- mass effects distort stress – strain behaviour if the velocity is stepwise
- this can be prevented by applying the load “slowly”
- sinus loadcurve (1/100 of total simulation time) with tangent intersection

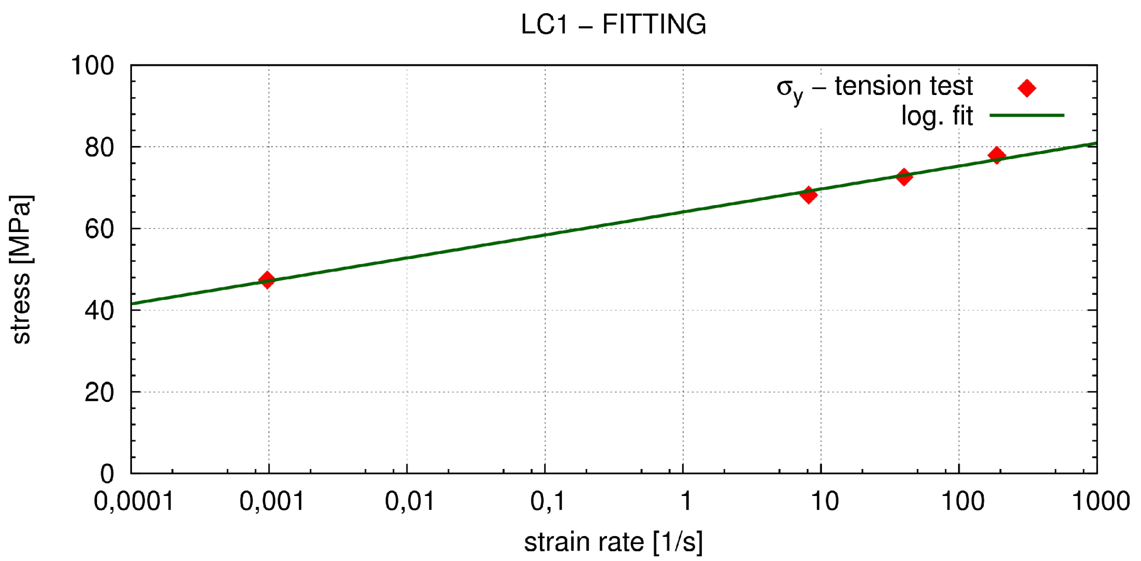
Parameter Identification MAT003

$$\sigma_y(\dot{\varepsilon}) = \sigma_y^{qs} \cdot \left[1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{1/p}\right]$$



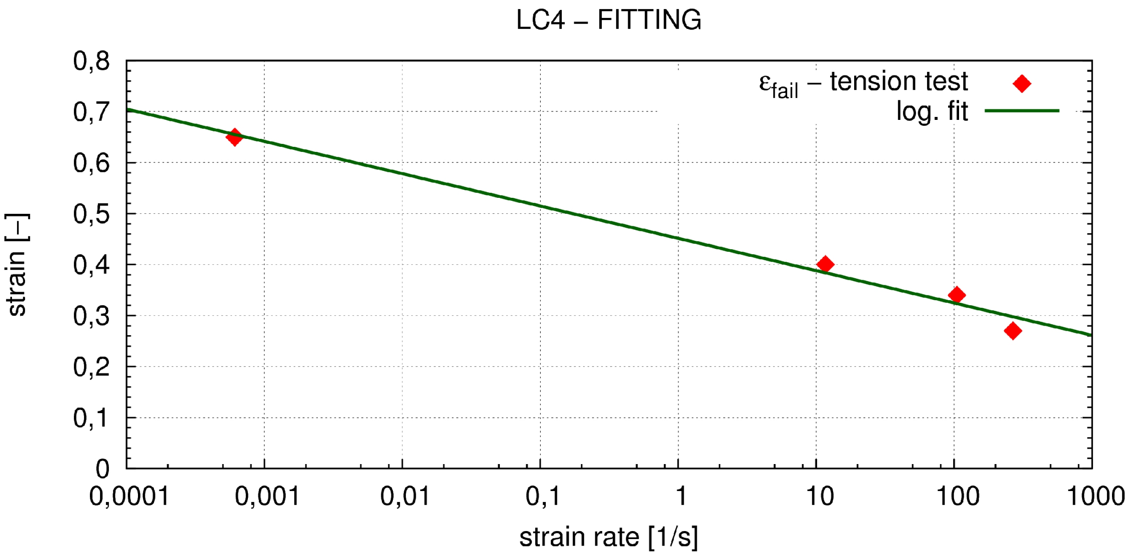
- simple parameter driven material model using Cowper – Symonds model
- parameters sigma_y and p must be identified
- 3D fit of Cowper – Symonds model with the tensile test data

Loadcurve Yield Stress MAT019



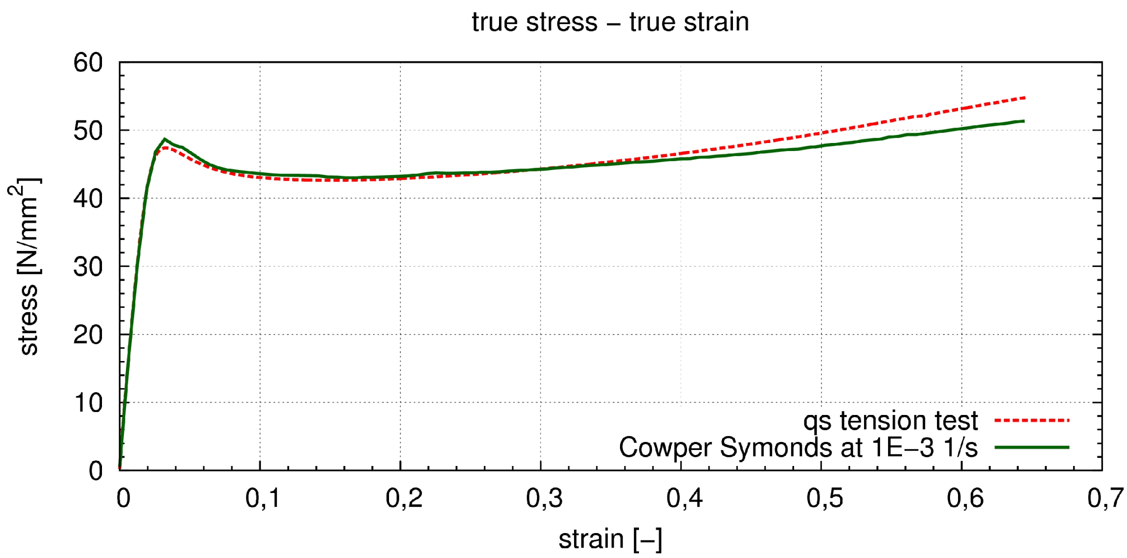
- yield stress from tension test vs. strain rate
- log. function fitted to the measured values
- function values define loadcurve for strain rate dependent yield stress

Loadcurve Failure Strain MAT019



- equivalent plastic strain at failure vs. strain rate
- log. function fitted to the measured values
- function values define loadcurve for strain rate dependent failure

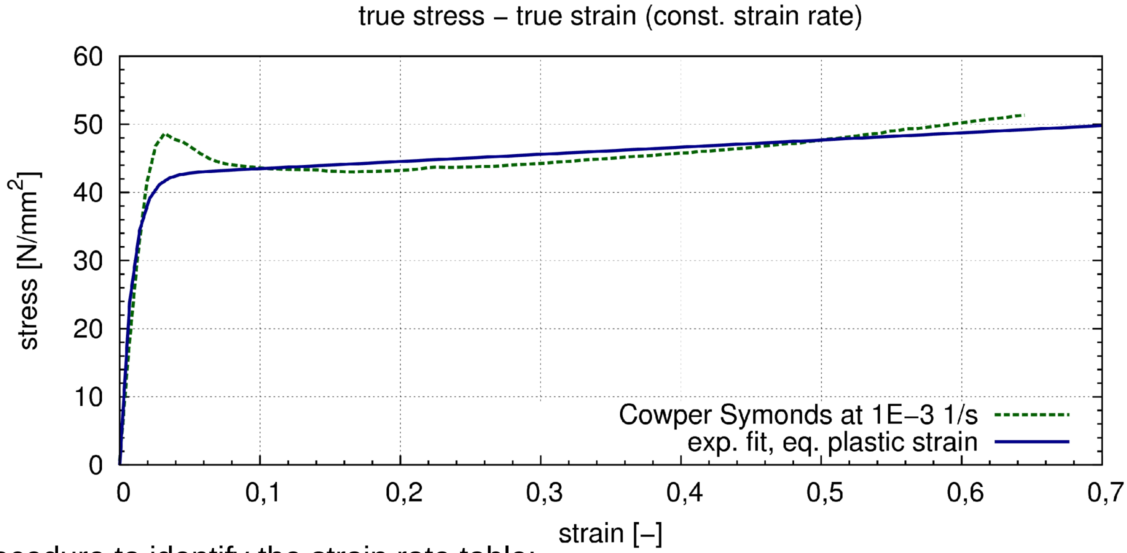
Loadcurves Tension MAT187



Procedure to identify the strain rate table:

- using the tension test results to generate strain rate constant loadcurves (e.g. Cowper-Symonds, Johnson-Cook)
- fitting of strain rate constant with an appropriate function
- calculation of the equivalent plastic strain and removing of the elastic part

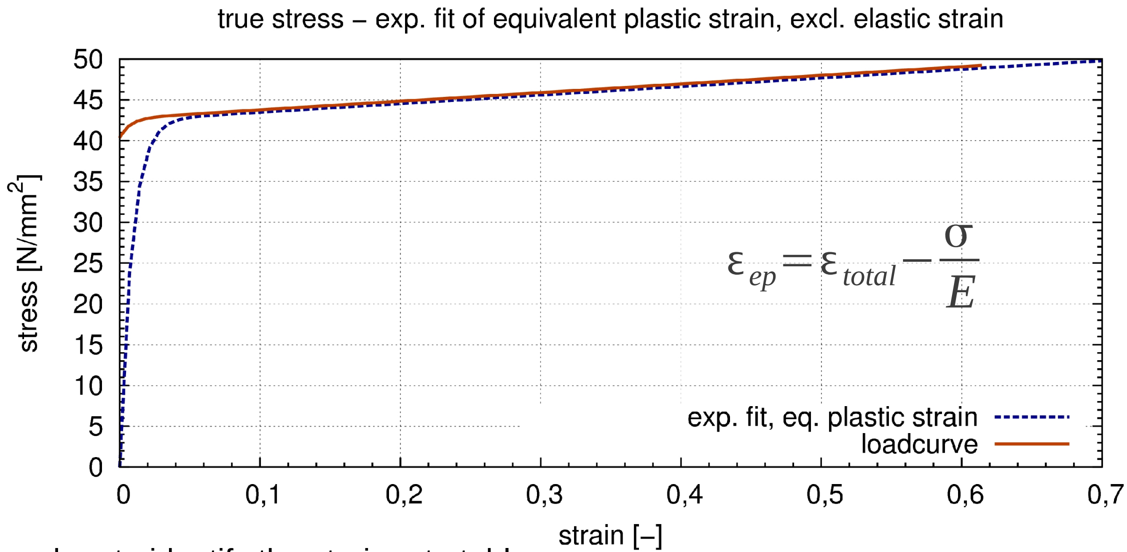
Loadcurves Tension MAT187



Procedure to identify the strain rate table:

- using the tension test results to generate strain rate constant loadcurves (e.g. Cowper-Symonds, Johnson-Cook)
- fitting of strain rate constant curve with an appropriate function
- calculation of the equivalent plastic strain and removing of the elastic part

Loadcurves Tension MAT187



Procedure to identify the strain rate table:

- using the tension test results to generate strain rate constant loadcurves (e.g. Cowper-Symonds, Johnson-Cook)
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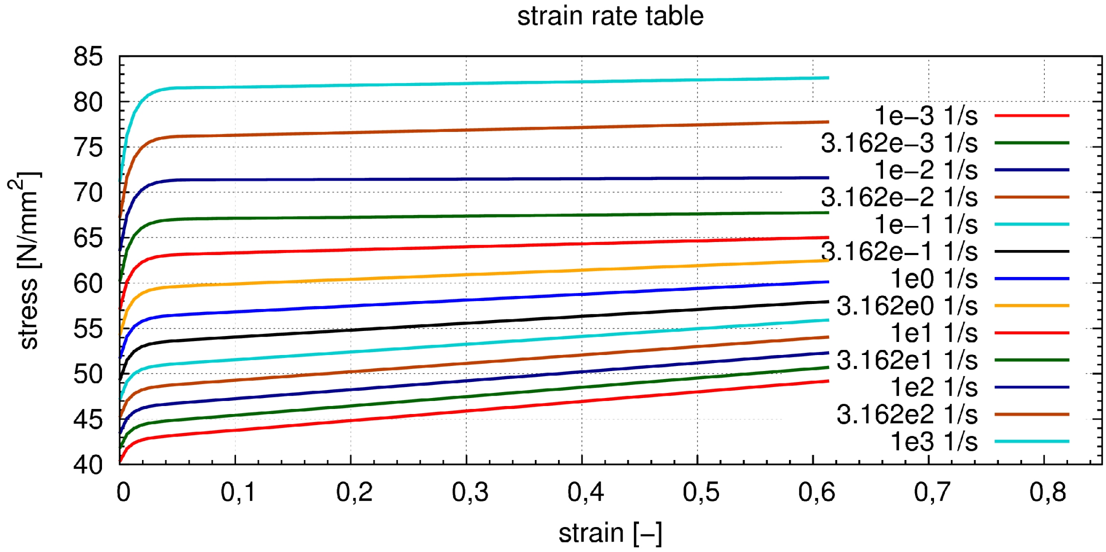
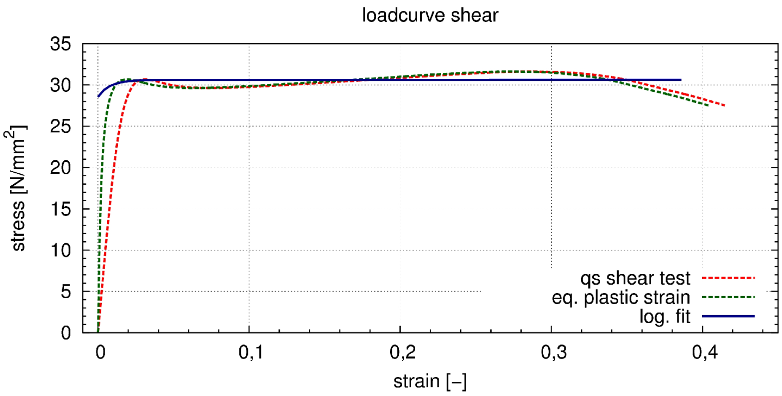
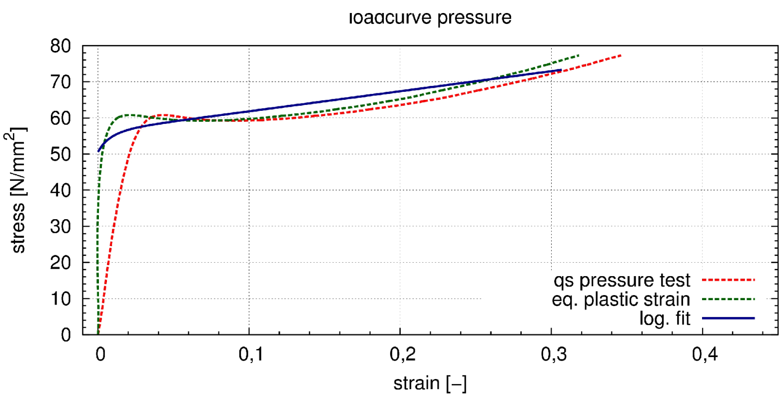
Strain Rate Table MAT187



- strain rate dependency realised by allocating a loadcurve to a strain rate
- the strain rates are stored in a table
- if a not defined strain rate occurs, the model interpolates the existing values

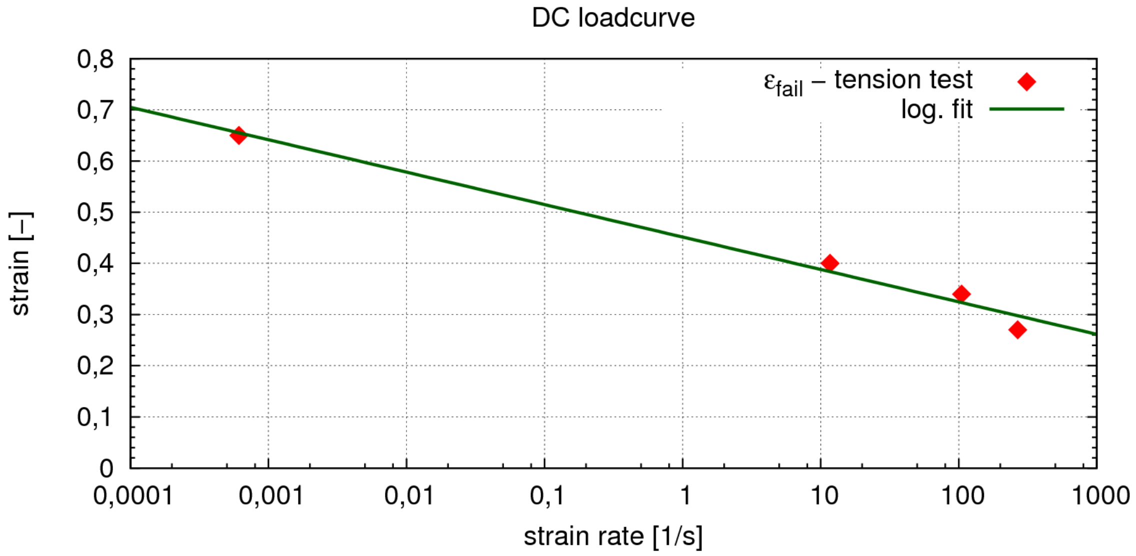
Loadcurves Shear and Pressure MAT187





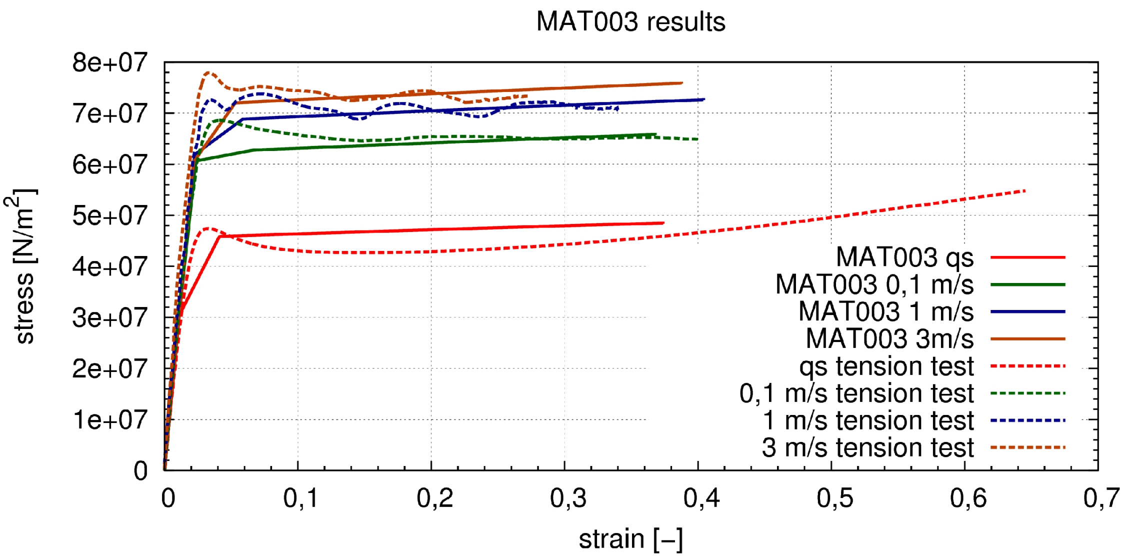
- similar procedure for shear and pressure test data
- no need to tabular the load-curves
- MAT187 scales shear and pressure strain rate dependencies like tension strain rate table

Strain Rate Dependent Failure



- equivalent plastic strain at failure vs. strain rate
- log. function fitted to the measured values
- function values define loadcurve for strain rate dependent failure

MAT003 Results



- simple model, few parameters
- cpu time for quasistatic tension test, single core: 24h
- result quality is good with reference to the material models capabilities

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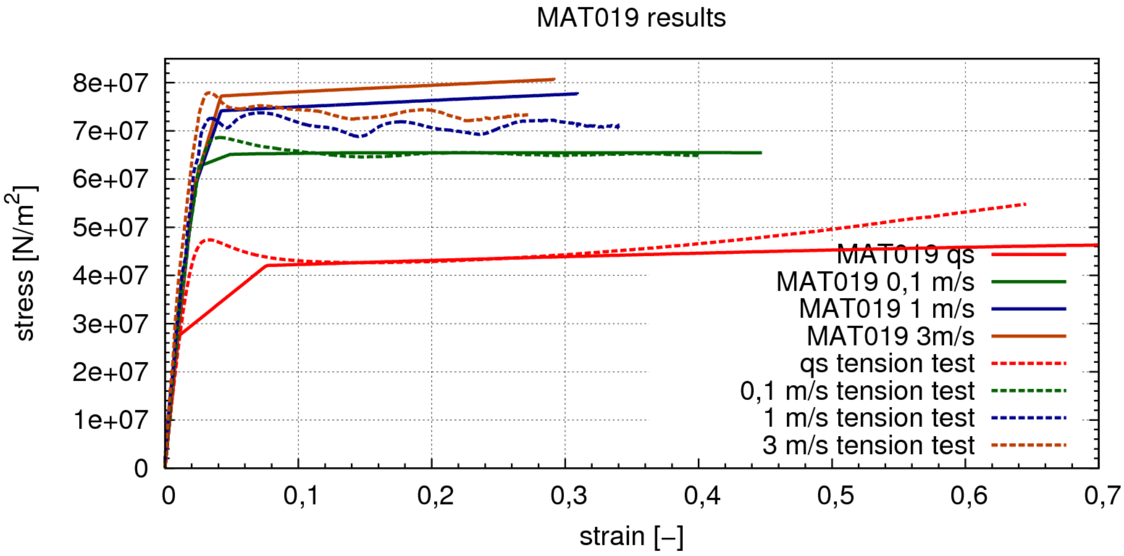
MAT019 Results



- simple model, loadcurves needed
- cpu time for quasistatic tension test, single core: 98h
- result quality is very good with reference to the material models capabilities
- failure strain dependency

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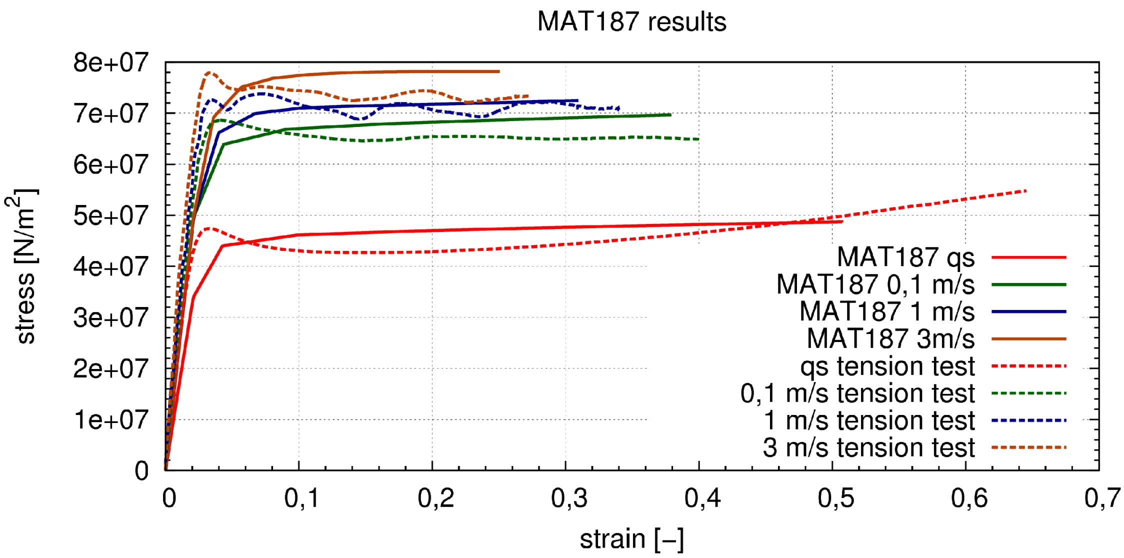
MAT187 Results



- sophisticated material model, loadcurves needed, mechanical background
- cpu time for quasistatic tension test, single core: 108h
- result quality is very good
- the real strength of MAT187 (different yield points for different loadcases, taking triaxiality into account) can not be shown in a simple tension test simulation

Summary

- the quality of simulation results depends strongly on the quality of the experi-mental work and optimization of input parameters
- most important is the usage of strain rate constant loadcurves
- parameter driven material models calculate them internally
- material models with loadcurve input need externally calculated strain rate constant loadcurves
- MAT003: is fast and easy to handle, might be of good usage for total vehicle simulations
- MAT019: has much higher costs than MAT003 but is easy to handle and sup-ports strain rate dependent failure strain
- MAT187: sophisticated material model, can be used in many varieties, costly, true strength is triaxiality which is not simulated at the moment