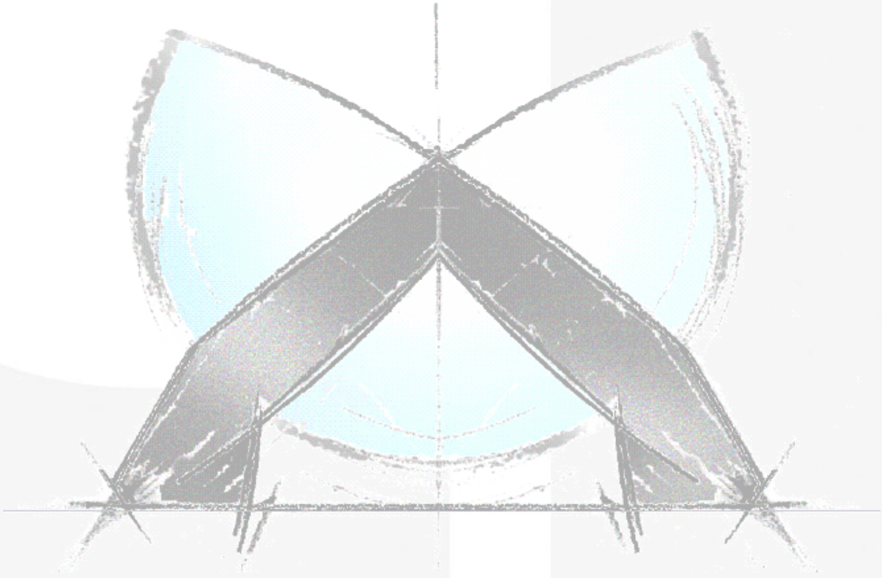
Failure models for plastics - material characterization for *MAT_ADD_EROSION (DIEM)

A. Fertschej, B. Hirschmann, P. Reithofer, M. Rollant



11th European LS-DYNA Conference
9th – 11th May 2017, Salzburg, Austria

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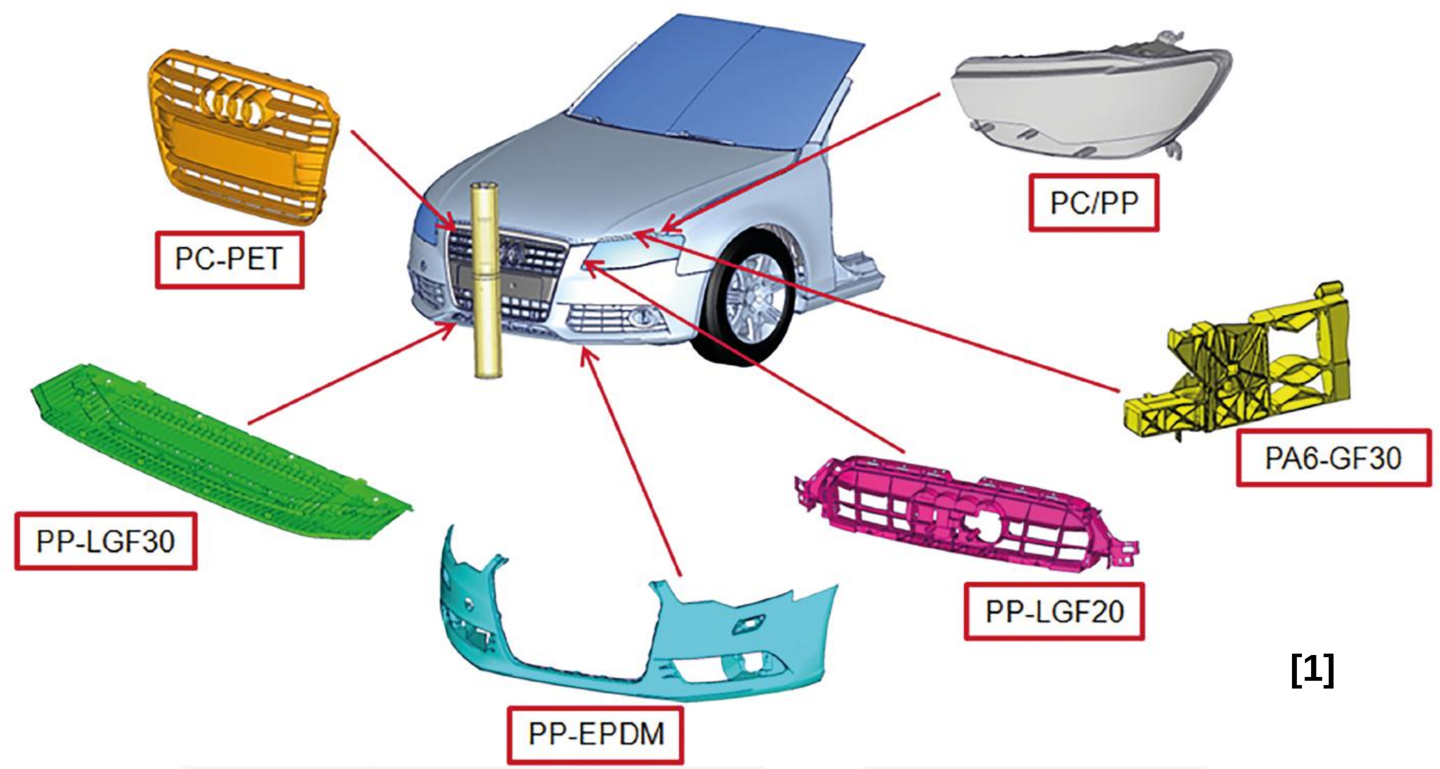
http://impetus.4a.co.at/en

Content

Introduction

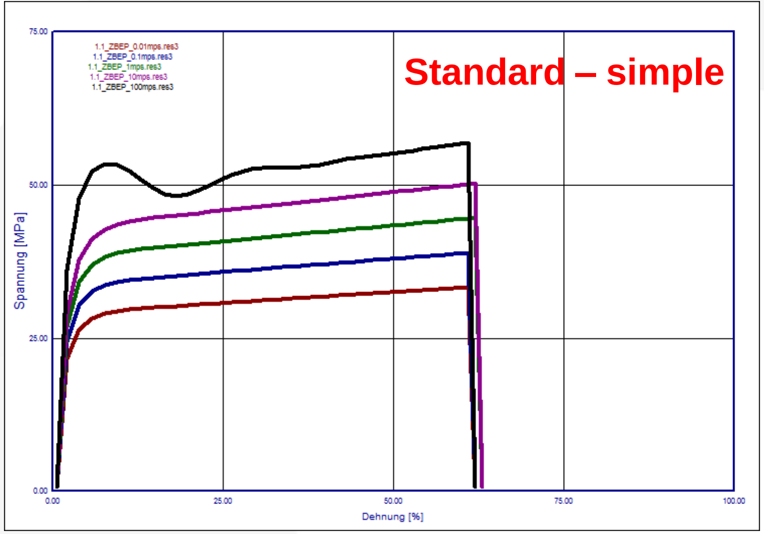
- Plastics in automotive pedestrian protection show different deformation and fracture behavior → **Energy absorption**
- Failure is a function of load type, time, temperature, processing, …



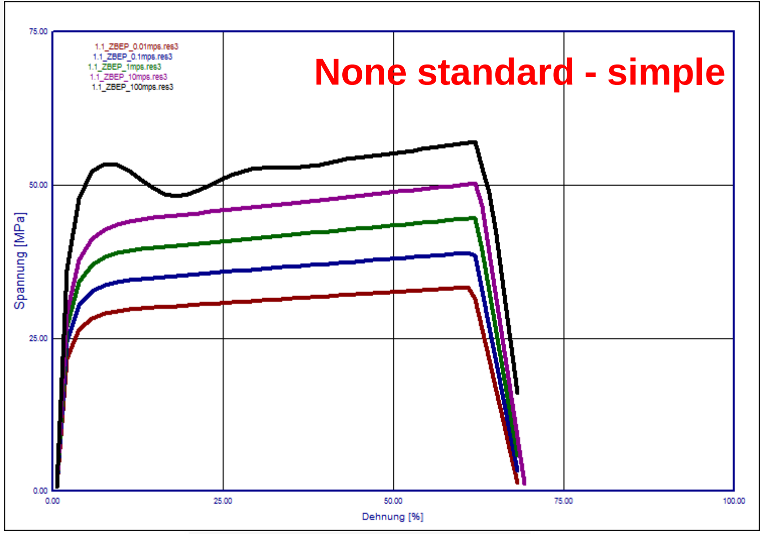
[1] H. Staack, D. Seibert, H. Baier - Application oriented failure modeling and characterization for polymers in automotive pedestrian protection, COMPLAS 2015, Barcelona

Failure Models in LS-Dyna

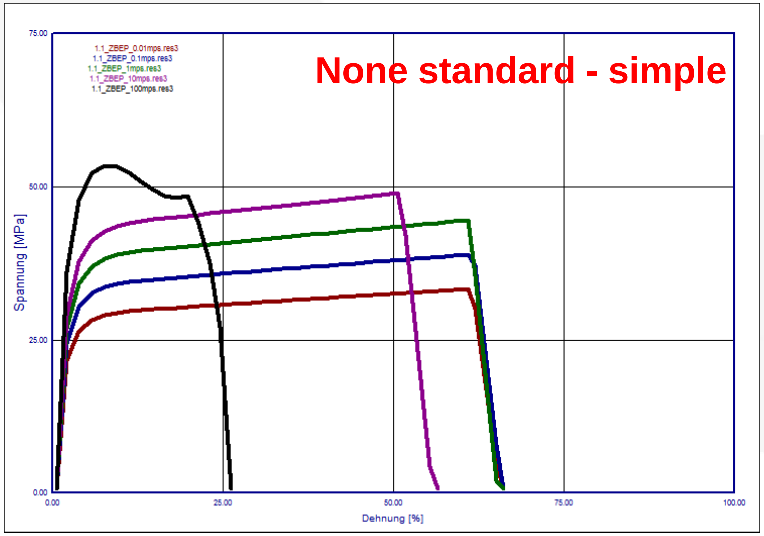
constant plastic strain


Standard – simple

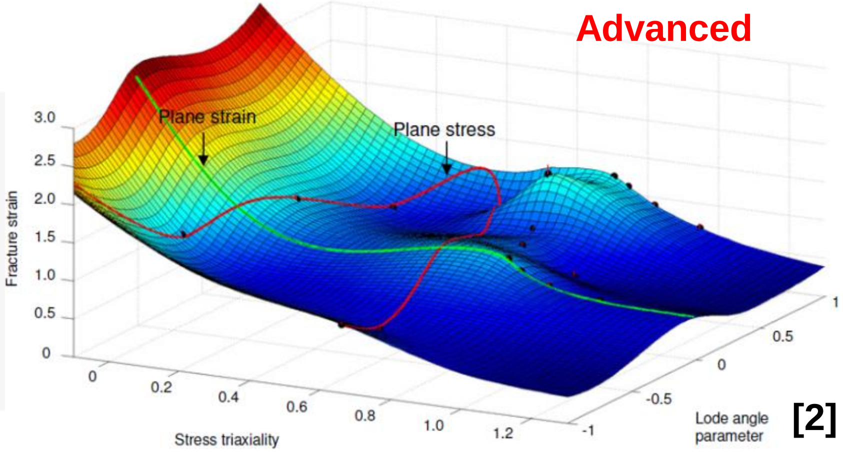
constant plastic strain + damage evolution


None standard - simple

Plastic strain as function of strain rate


None standard - simple

Failure as function of triaxiality and strain rate

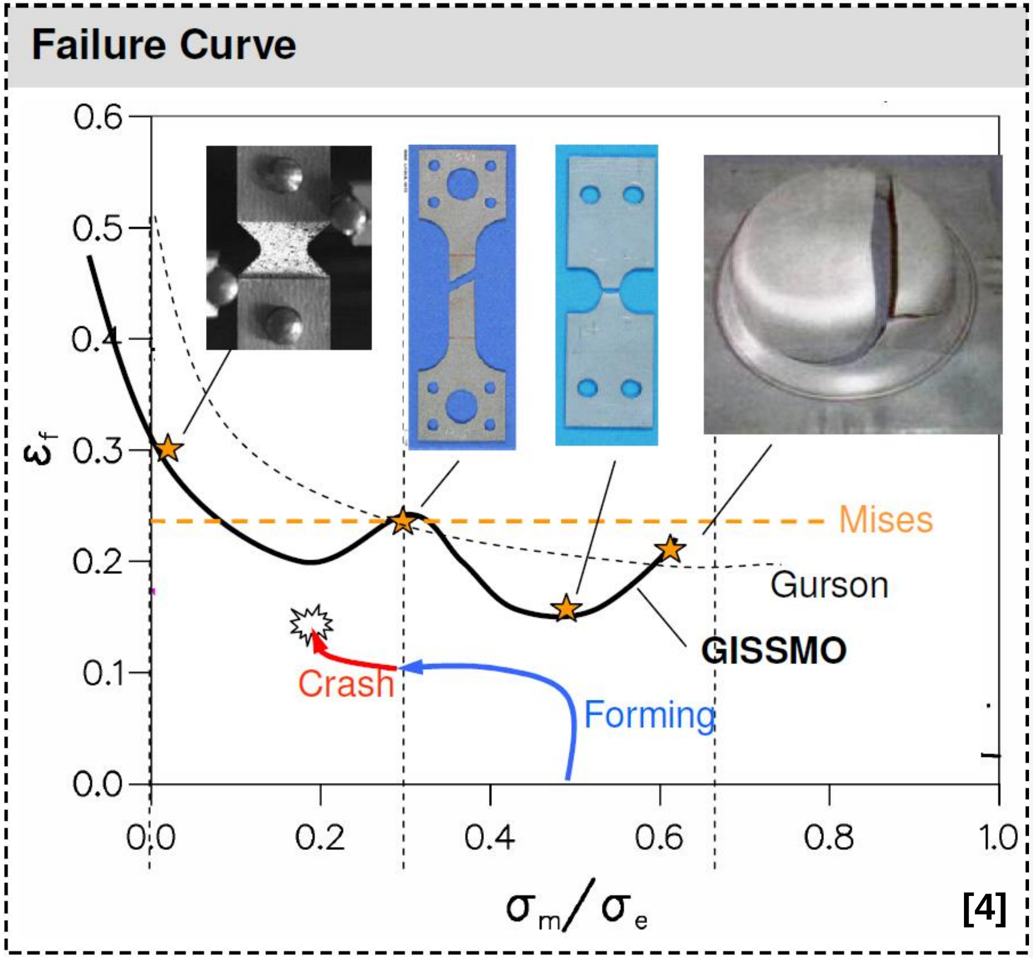

Advanced

[2]

[2] M. Basaran, S. Wölkerling, F. Neukamm, M. Feucht, D. Weichert – An extension of the GISSMO damage model based on Lode angle dependence, LS-Dyna Developer Forum 2010, Bamberg

Failure Models for Metals

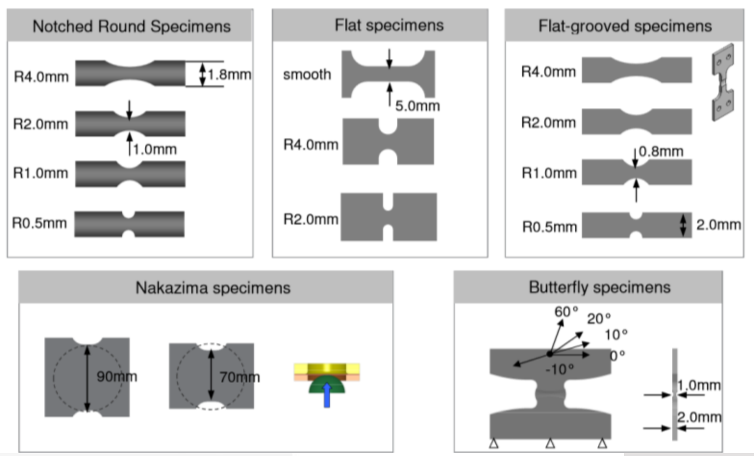
- Many well known failure criteria for ductile materials [3]



[4]

- Tresca or maximum shear stress criterion
- von Mises yield criterion
- Gurson yield criterion for pressure-dependent metals
- Hosford yield criterion
- Hill yield criteria
- various criteria based on the invariants of the Cauchy stress tensor

[3] https://en.wikipedia.org/wiki/Material_failure_theory



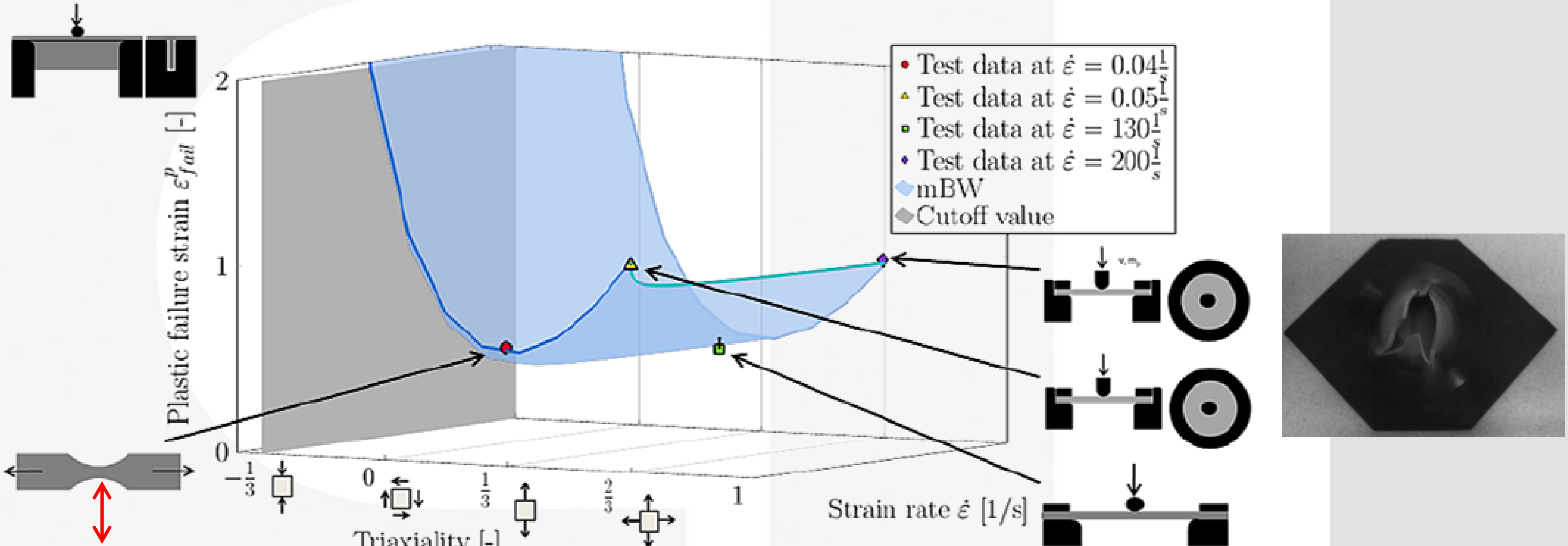
[2]

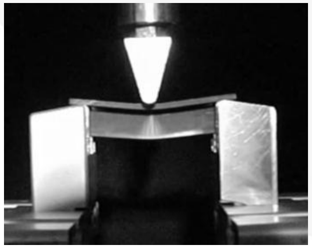
[4] F. Neukamm, M. Feucht, A. Haufe, P. DuBois – GISSMO – Material modeling with a sophisticated failure criteria, LS-Dyna Developer Forum 2011, Stuttgart

Failure Models for Plastics

DIEM-Model

- Failure surface in dependence of triaxiality and strain rate



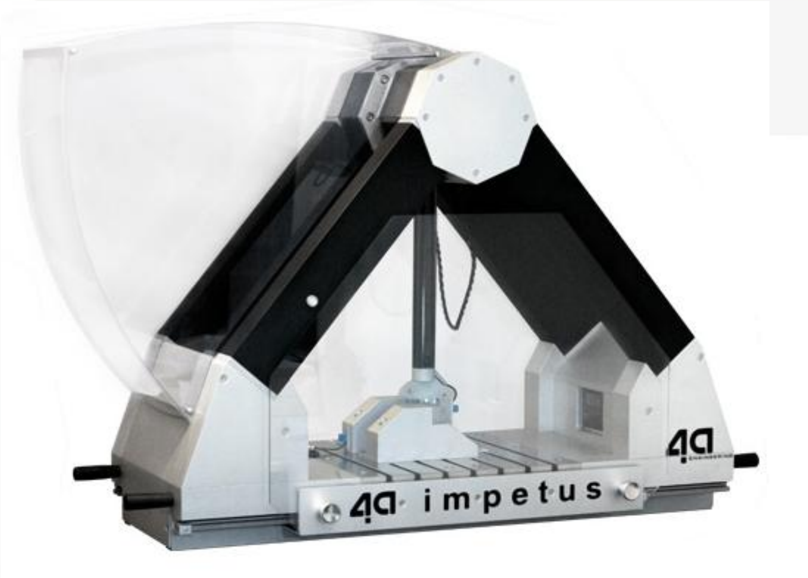


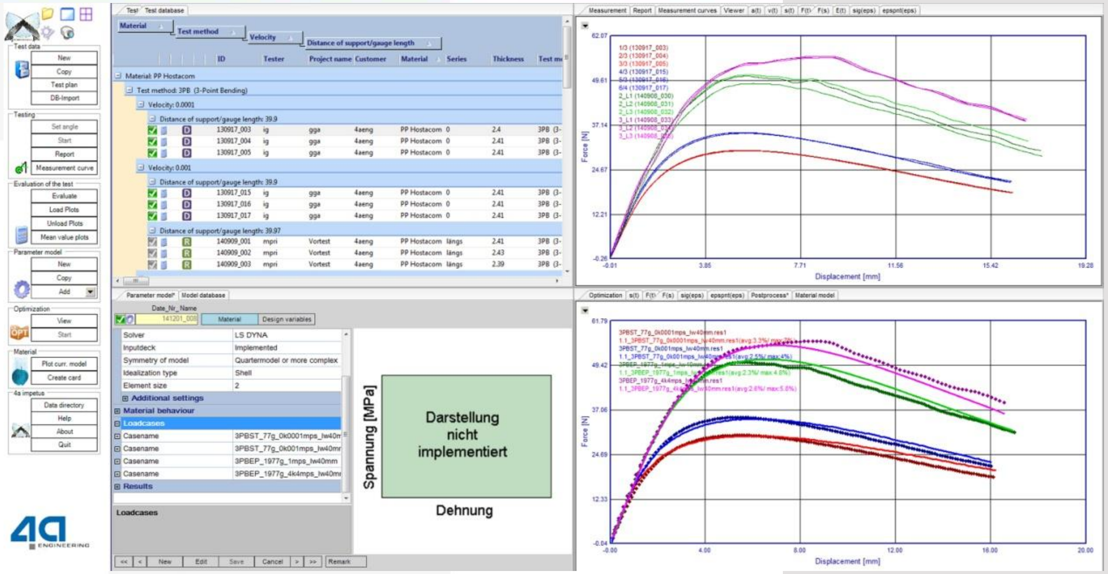
[1]

[1] H. Staack, D. Seibert, H. Baier - Application oriented failure modeling and characterization for polymers in automotive pedestrian protection, COMPLAS 2015, Barcelona

4a impetus

Reverse engineering





Material | Test method | Velocity | Distance of support/gauge length

ID	Tester	Project name	Customer	Material	Series	Thickness	Test m
Material: PP Hostacom							
Test method: 3PB (3-Point Bending)							
Velocity: 0.0001							
Distance of support/gauge length: 39.9							
130917_003	ig	gga	4aeng	PP Hostacom	0	2.4	3PB (3-
130917_004	ig	gga	4aeng	PP Hostacom	0	2.41	3PB (3-
130917_005	ig	gga	4aeng	PP Hostacom	0	2.41	3PB (3-
Velocity: 0.001							
Distance of support/gauge length: 39.9							
130917_015	ig	gga	4aeng	PP Hostacom	0	2.41	3PB (3-
130917_016	ig	gga	4aeng	PP Hostacom	0	2.41	3PB (3-
130917_017	ig	gga	4aeng	PP Hostacom	0	2.41	3PB (3-
Distance of support/gauge length: 39.97							
140909_001	mpri	Vortest	4aeng	PP Hostacom	längs	2.41	3PB (3-
140909_002	mpri	Vortest	4aeng	PP Hostacom	längs	2.43	3PB (3-
140909_003	mpri	Vortest	4aeng	PP Hostacom	längs	2.39	3PB (3-

Parameter model* | Model database

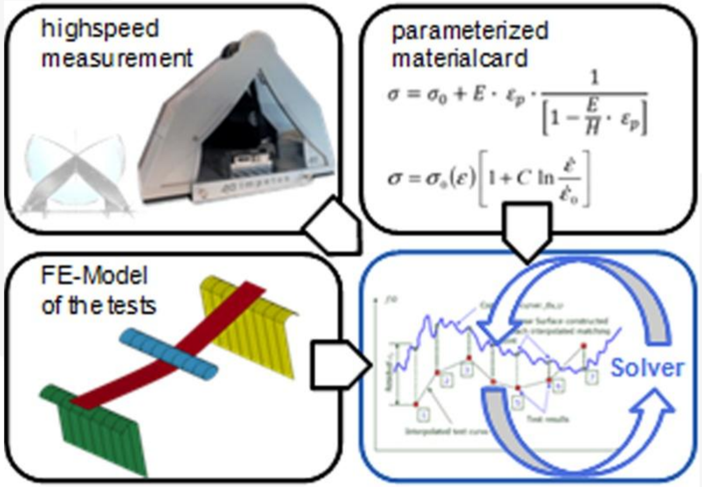
Date_Nr_Name: 141201_008 | Material | Design variables

Solver	LS DYNA
Inputdeck	Implemented
Symmetry of model	Quartermodel or more complex
Idealization type	Shell
Element size	2
Additional settings	
Material behaviour	
Loadcases	
Casename	3PBST_77g_0k0001mps_lw40m
Casename	3PBST_77g_0k001mps_lw40mr
Casename	3PBEP_1977g_1mps_lw40mm
Casename	3PBEP_1977g_4k4mps_lw40mr
Results	

Loadcases

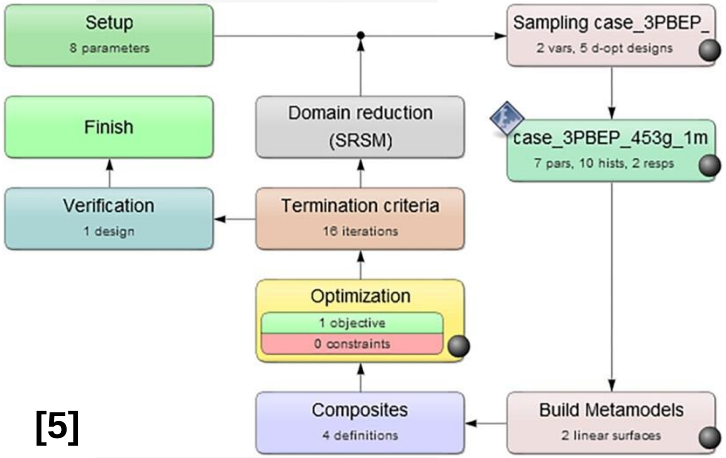
Spannung [MPa] – Darstellung nicht implementiert – Dehnung

<< < New Edit Save Cancel > >> Remark



$$\sigma = \sigma_0 + E \cdot \varepsilon_p \cdot \frac{1}{\left[1 - \frac{E}{H} \cdot \varepsilon_p\right]}$$

$$\sigma = \sigma_s(\varepsilon)\left[1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$$



- Setup – 8 parameters
- Sampling case_3PBEP_ – 2 vars, 5 d-opt designs
- case_3PBEP_453g_1m – 7 pars, 10 hists, 2 resps
- Build Metamodels – 2 linear surfaces
- Composites – 4 definitions
- Optimization – 1 objective – 0 constraints
- Termination criteria – 16 iterations
- Domain reduction (SRSM)
- Verification – 1 design
- Finish

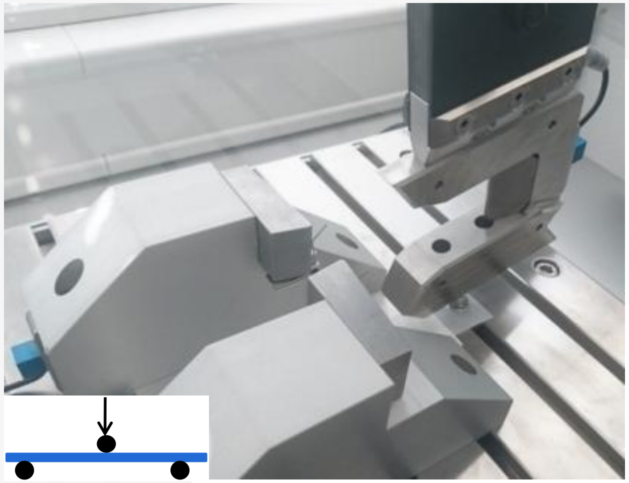
[5]

[5] https://www.carhs.de/en/companion-poster/product/caecompanion-print.html

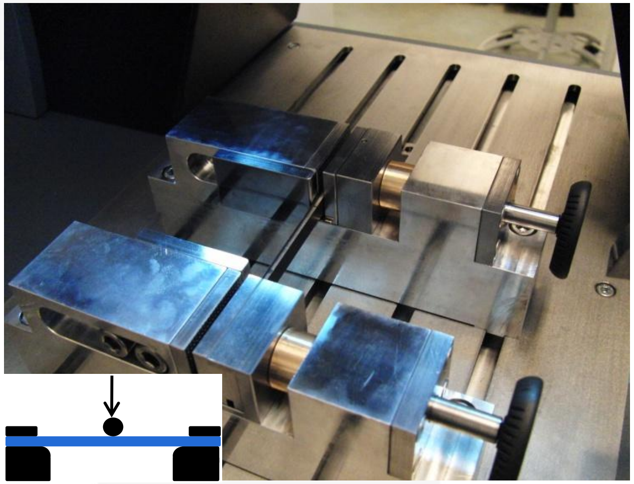
(Failure) Measurement Possibilities using 4a impetus

Test specimens, test setup

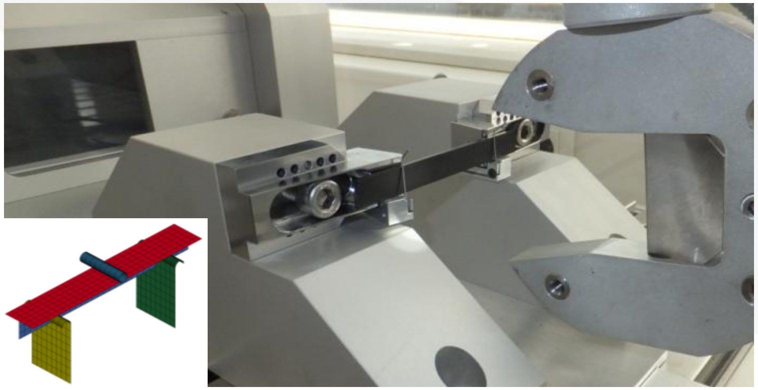
3-point bending 0.1 mm/s - 4.5 m/s



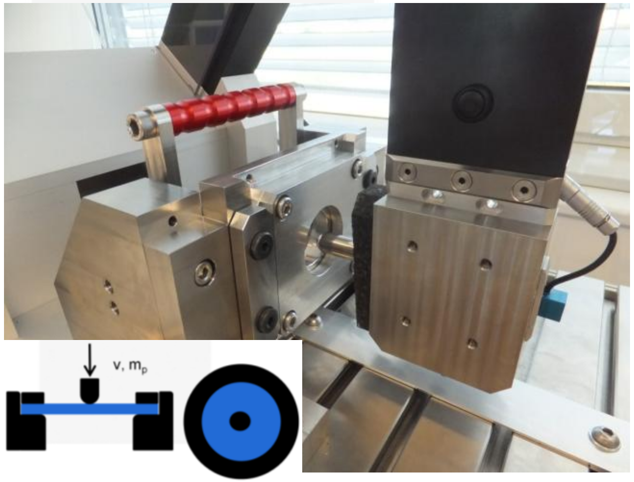
Clamped bending - 4.5 m/s



T-specimen (rib) 0.1 mm/s - 4.5 m/s



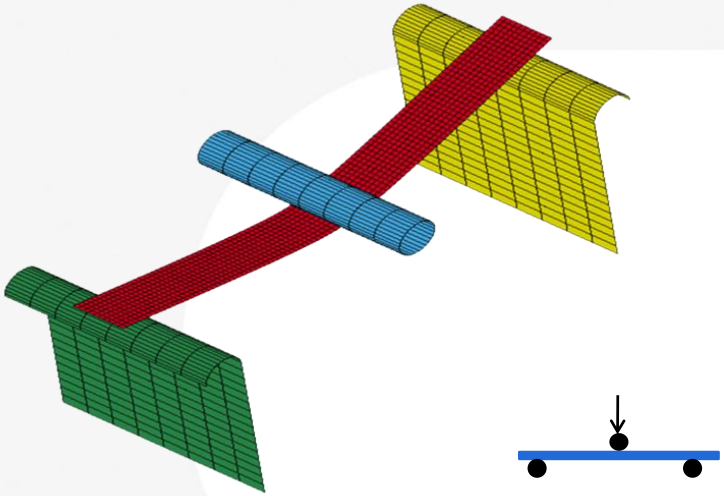
Puncture test 0.1 mm/s - 4.5 m/s



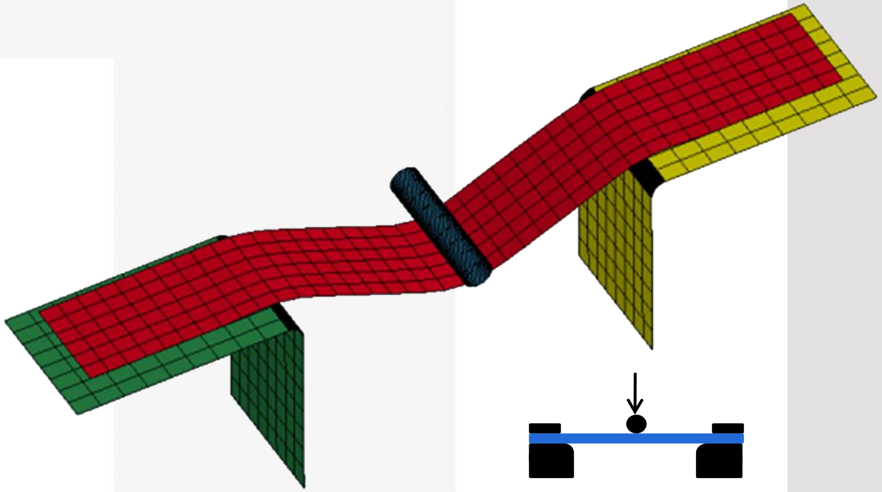
Simulation Possibilities using 4a impetus

Test specimens, test setup

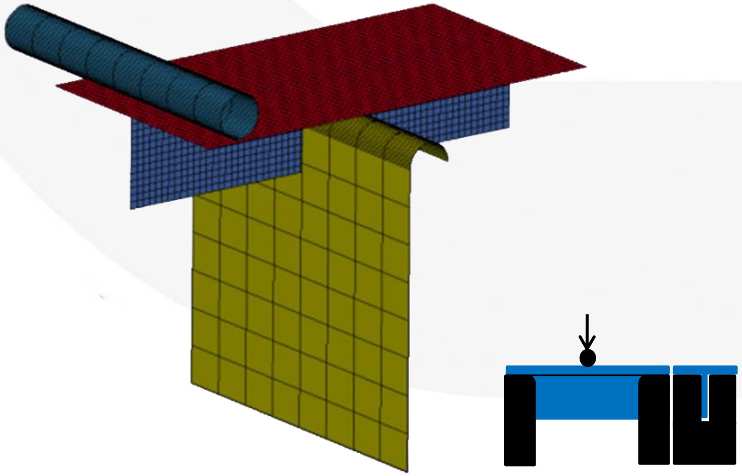
3-point bending 0.1 mm/s - 4.5 m/s



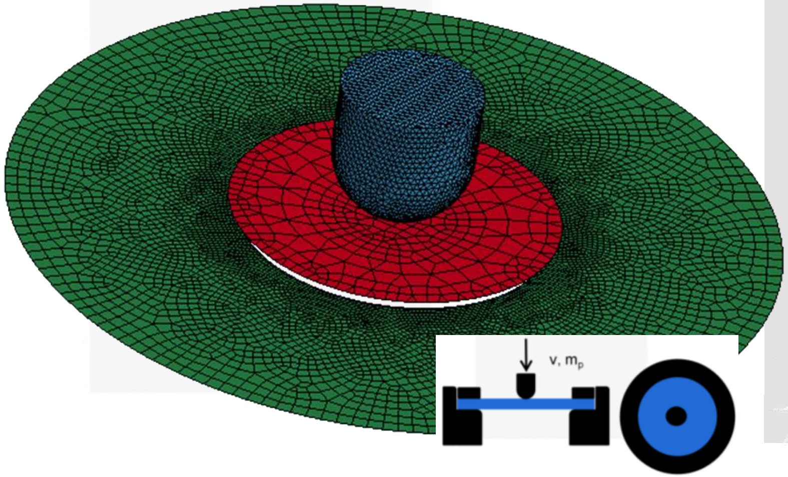
Clamped bending - 4.5 m/s



T-specimen (rib) 0.1 mm/s - 4.5 m/s



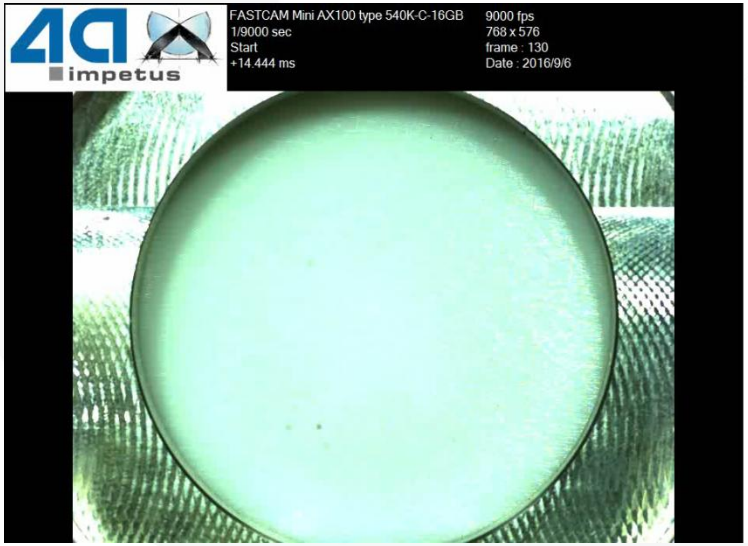
Puncture test 0.1 mm/s - 4.5 m/s

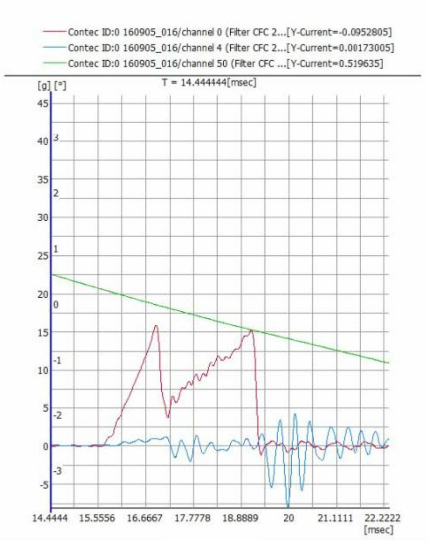


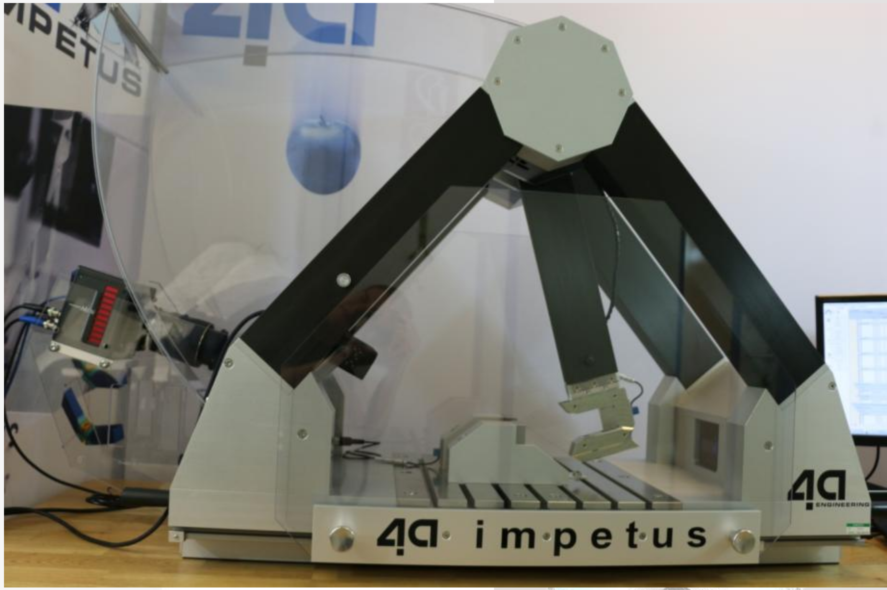
Measurement Possibilities using 4a impetus

High-speed camera

- **Visualization of dynamic failure behavior** of the material during test (crack initiation and propagation)
- Easy view, different angles possible
- Trigger signal from 4a impetus → **synchronizing**

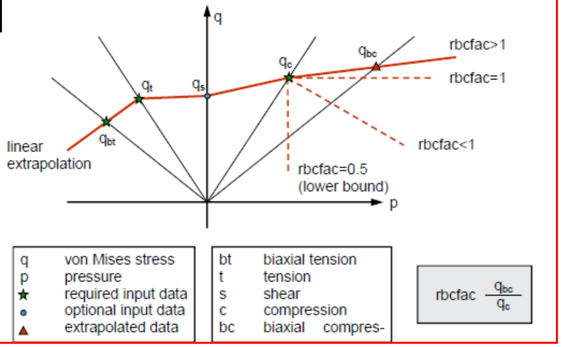
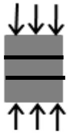
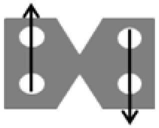
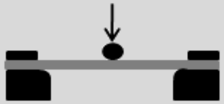
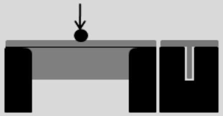
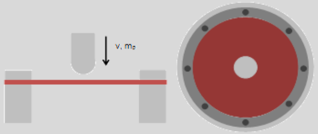






Material Modeling for Plastics

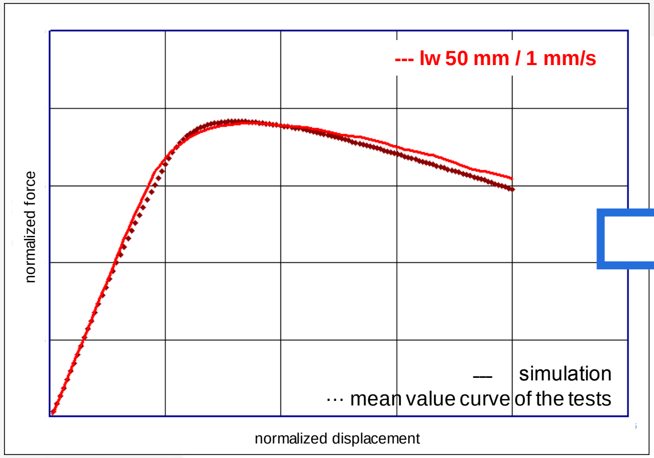
Complex yield surface + failure

Load cases		Plasticity Complex yield surface	Failure
	static, dynamic (2x)	**Classical approach** [6] 	**Should be done with DIC (difficult at high strains !)**
	static		**Typical no failure for plastics**
	static		**Typical failure under tension**
	static (2x), dynamic (3x)	**Strain rate dependency**	**Only brittle materials, no failure for ductile materials**
	dynamic	**4a impetus approach** **reverse engineering**	**4a impetus approach** **reverse engineering**
	static, dynamic		
	static, dynamic		

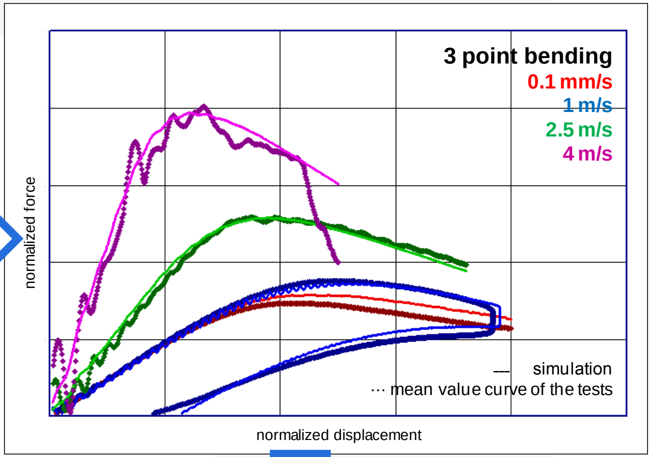
Material Modeling – Plasticity + Hardening

Workflow for *MAT_SAMP-1

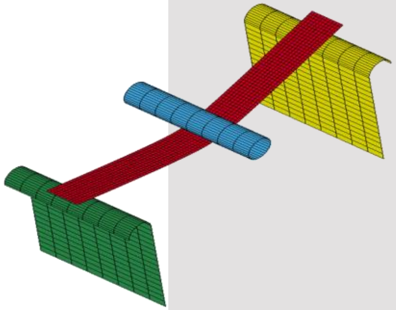
Reverse engineering process with 4a impetus [7]



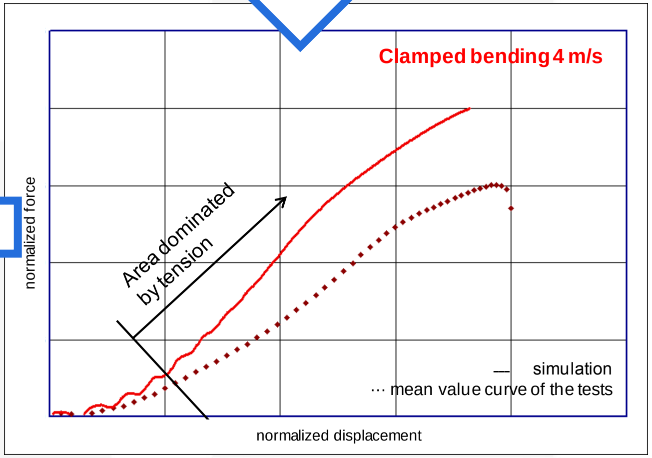
static behavior - yield



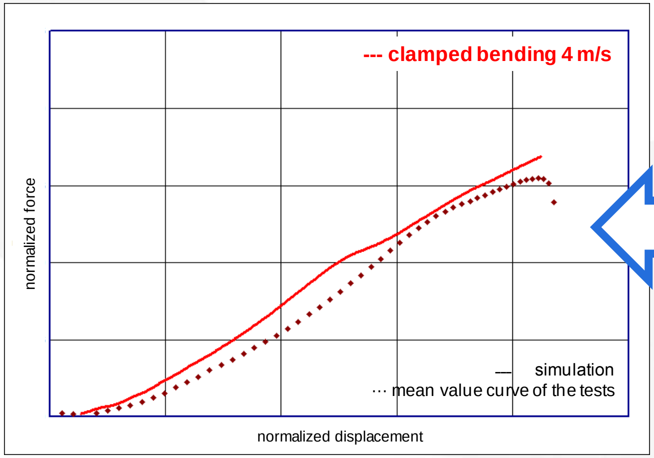
dynamic behavior – strain rate



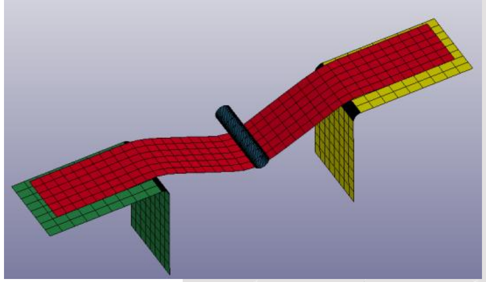
3-point-bending



check compression/tension behavior



fit compression/tension behavior

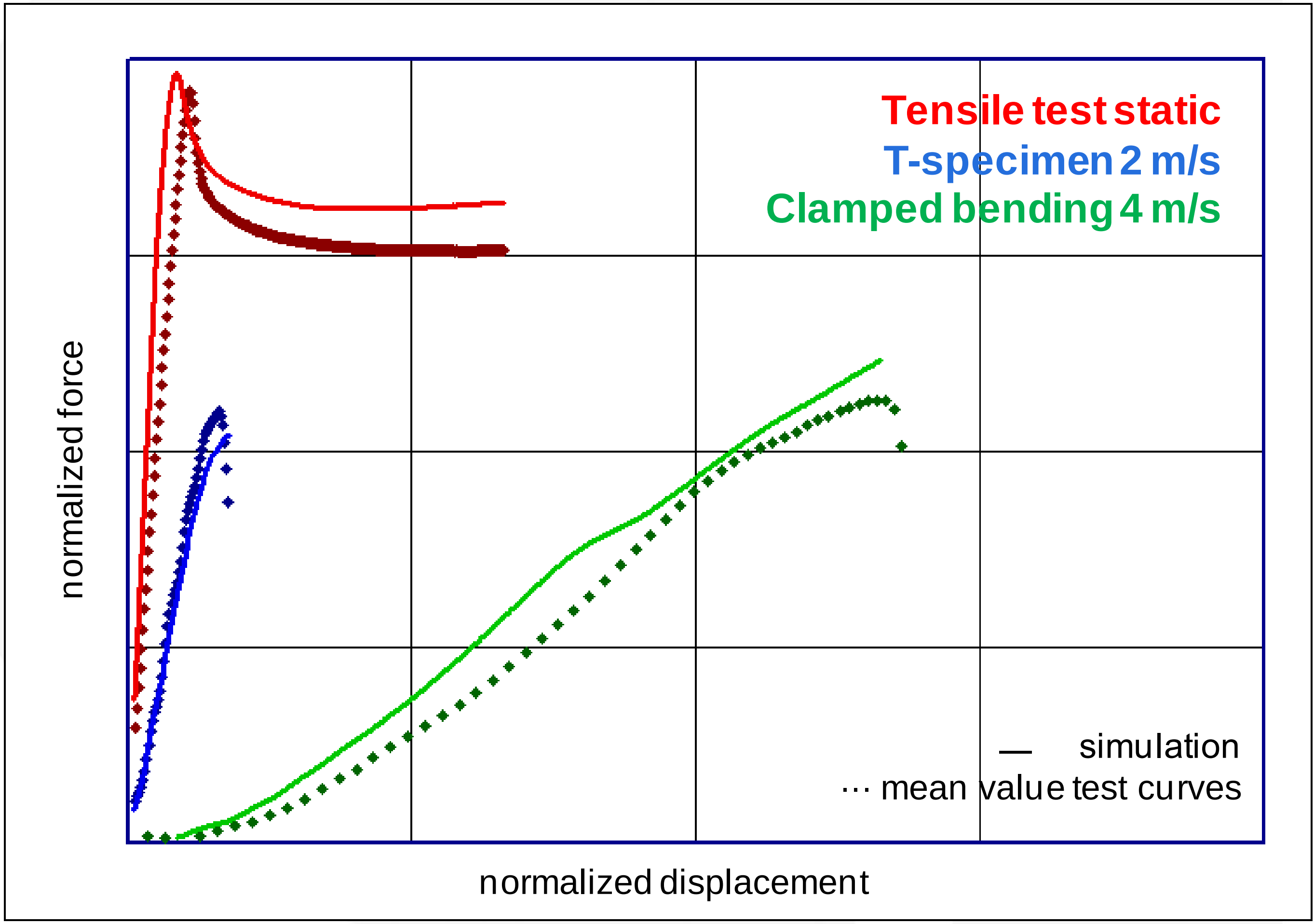


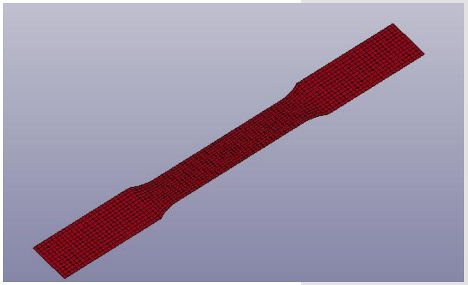
3-point-bending clamped

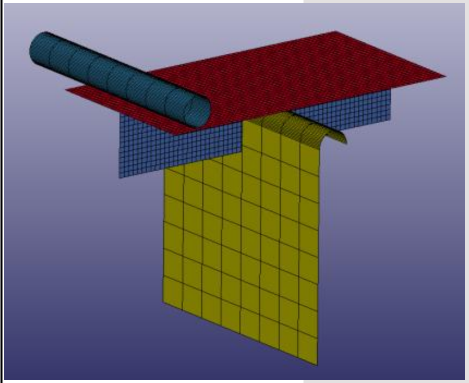
Material Modeling – Validation

Validation for *MAT_SAMP-1

Validation on further tests (*MAT_SAMP-1) [7]







Failure Models for Plastics

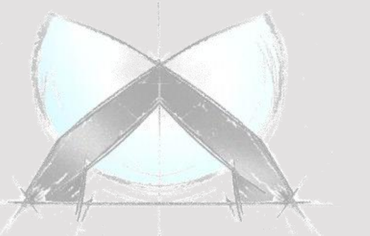
DIEM-Model

- DIEM: Damage Initiation and Evolution Model [6]
- Base: Standard material model (e.g. *MAT_SAMP-1)
- 3 individual criteria can be used:
  - Ductile criterion: $\boxed{\varepsilon_D{}^P = \varepsilon_D{}^P(\eta, \dot{\varepsilon}^p)}$
  - Shear criterion: $\varepsilon_D{}^P = \varepsilon_D{}^P(\theta, \dot{\varepsilon}^p)$
  - Instability criterion: $\varepsilon_D{}^P = \varepsilon_D{}^P(\alpha, \dot{\varepsilon}^p)$ $\quad \alpha = \dfrac{\dot{\varepsilon}_{\min or}{}^P}{\dot{\varepsilon}_{major}{}^P} \longrightarrow \omega_D = \max \dfrac{\varepsilon^P}{\varepsilon_D{}^P}$

$$\boxed{\omega_D = \int_0^{\varepsilon^P} \frac{d\varepsilon^P}{\varepsilon_D{}^P}}$$

- After initiation the damage evolution occurs:

$$\sigma = (1-D)C^{ep} : \varepsilon$$

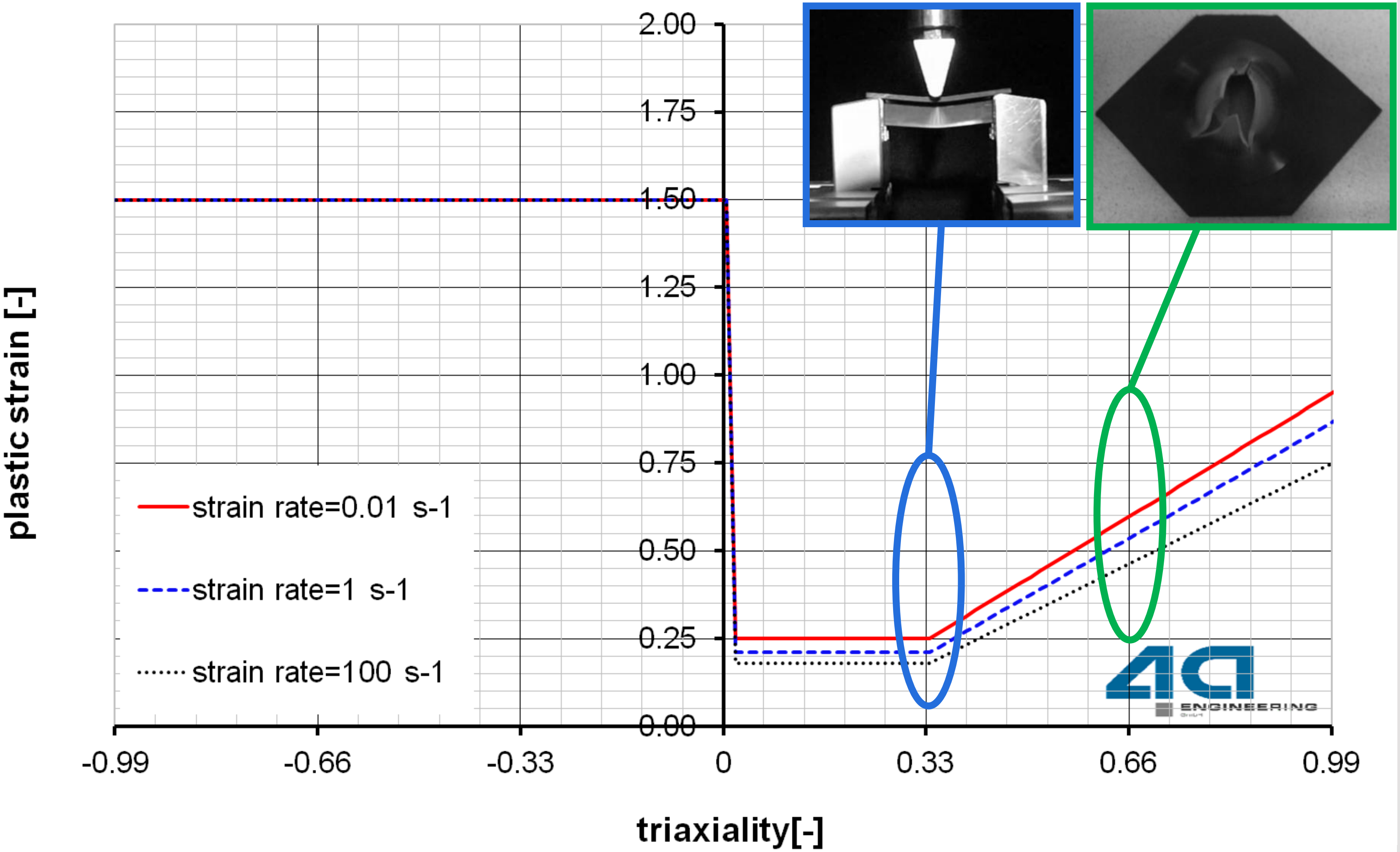


[6] LS-DYNA© KEYWORD USER'S MANUAL - VOLUME II - Material Models

4a impetus

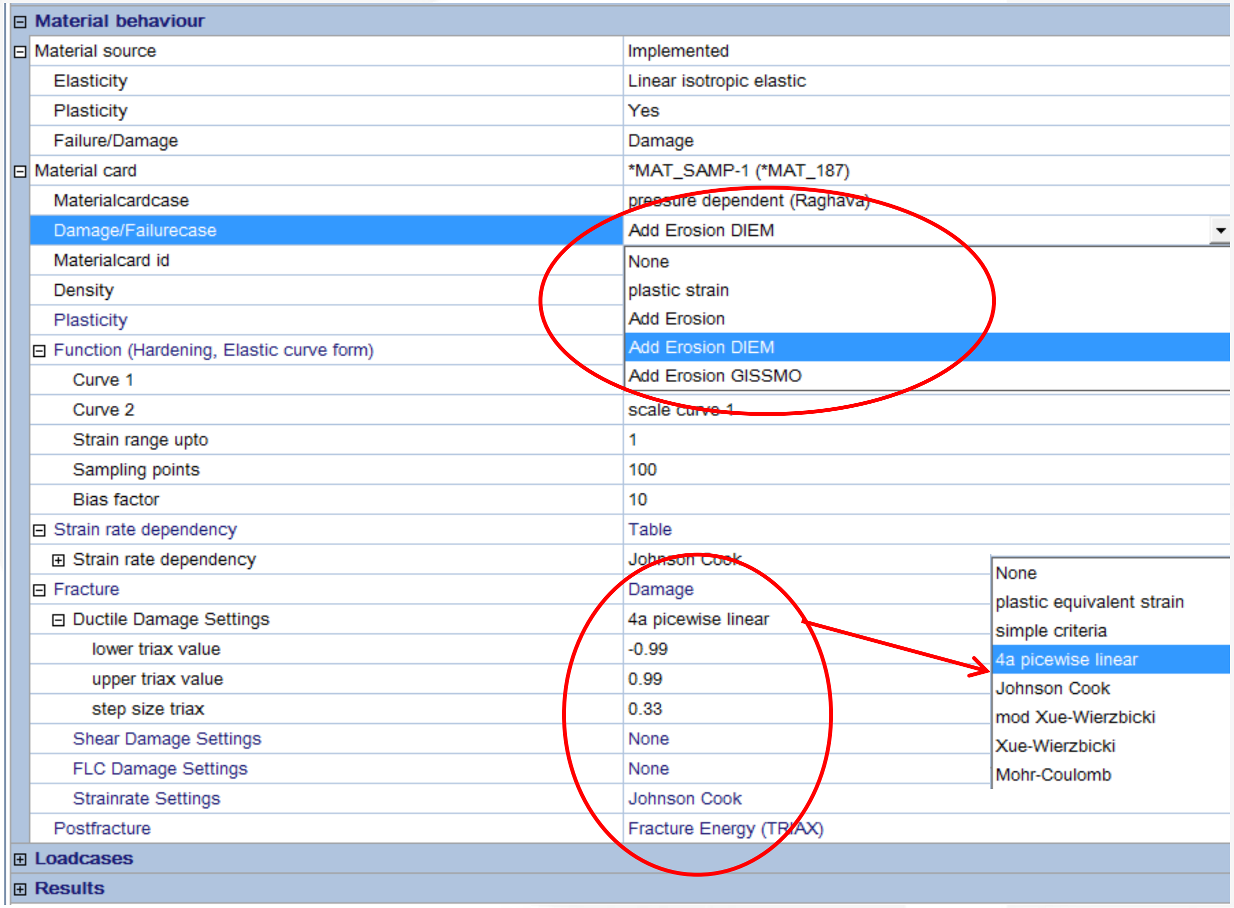
Test data for *MAT_ADD_EROSION (DIEM)

- Evaluation of the failure strains

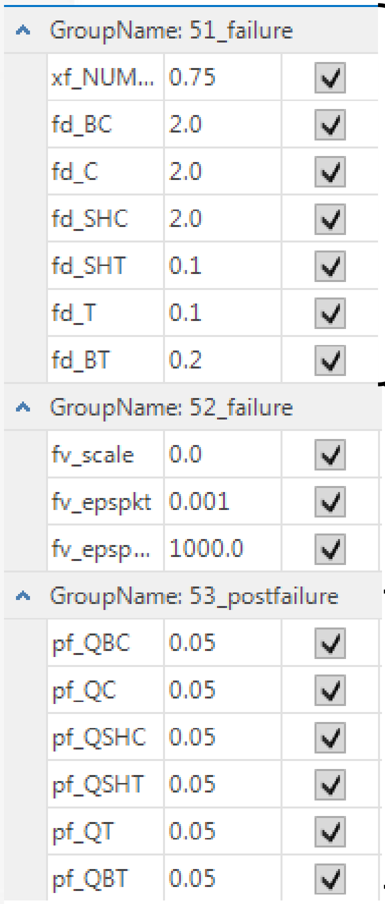


4a impetus
Failure models

- GUI – different possibilities to setup failure models



⊟ **Material behaviour**	
⊟ Material source	Implemented
Elasticity	Linear isotropic elastic
Plasticity	Yes
Failure/Damage	Damage
⊟ Material card	*MAT_SAMP-1 (*MAT_187)
Materialcardcase	pressure dependent (Raghava)
Damage/Failurecase	Add Erosion DIEM
Materialcard id	
Density	
Plasticity	
⊟ Function (Hardening, Elastic curve form)	
Curve 1	
Curve 2	scale curve 1
Strain range upto	1
Sampling points	100
Bias factor	10
⊟ Strain rate dependency	Table
⊞ Strain rate dependency	Johnson Cook
⊟ Fracture	Damage
⊟ Ductile Damage Settings	4a picewise linear
lower triax value	-0.99
upper triax value	0.99
step size triax	0.33
Shear Damage Settings	None
FLC Damage Settings	None
Strainrate Settings	Johnson Cook
Postfracture	Fracture Energy (TRIAX)
⊞ **Loadcases**	
⊞ **Results**	



GroupName: 51_failure		
xf_NUM...	0.75	☑
fd_BC	2.0	☑
fd_C	2.0	☑
fd_SHC	2.0	☑
fd_SHT	0.1	☑
fd_T	0.1	☑
fd_BT	0.2	☑
GroupName: 52_failure		
fv_scale	0.0	☑
fv_epspkt	0.001	☑
fv_epsp...	1000.0	☑
GroupName: 53_postfailure		
pf_QBC	0.05	☑
pf_QC	0.05	☑
pf_QSHC	0.05	☑
pf_QSHT	0.05	☑
pf_QT	0.05	☑
pf_QBT	0.05	☑

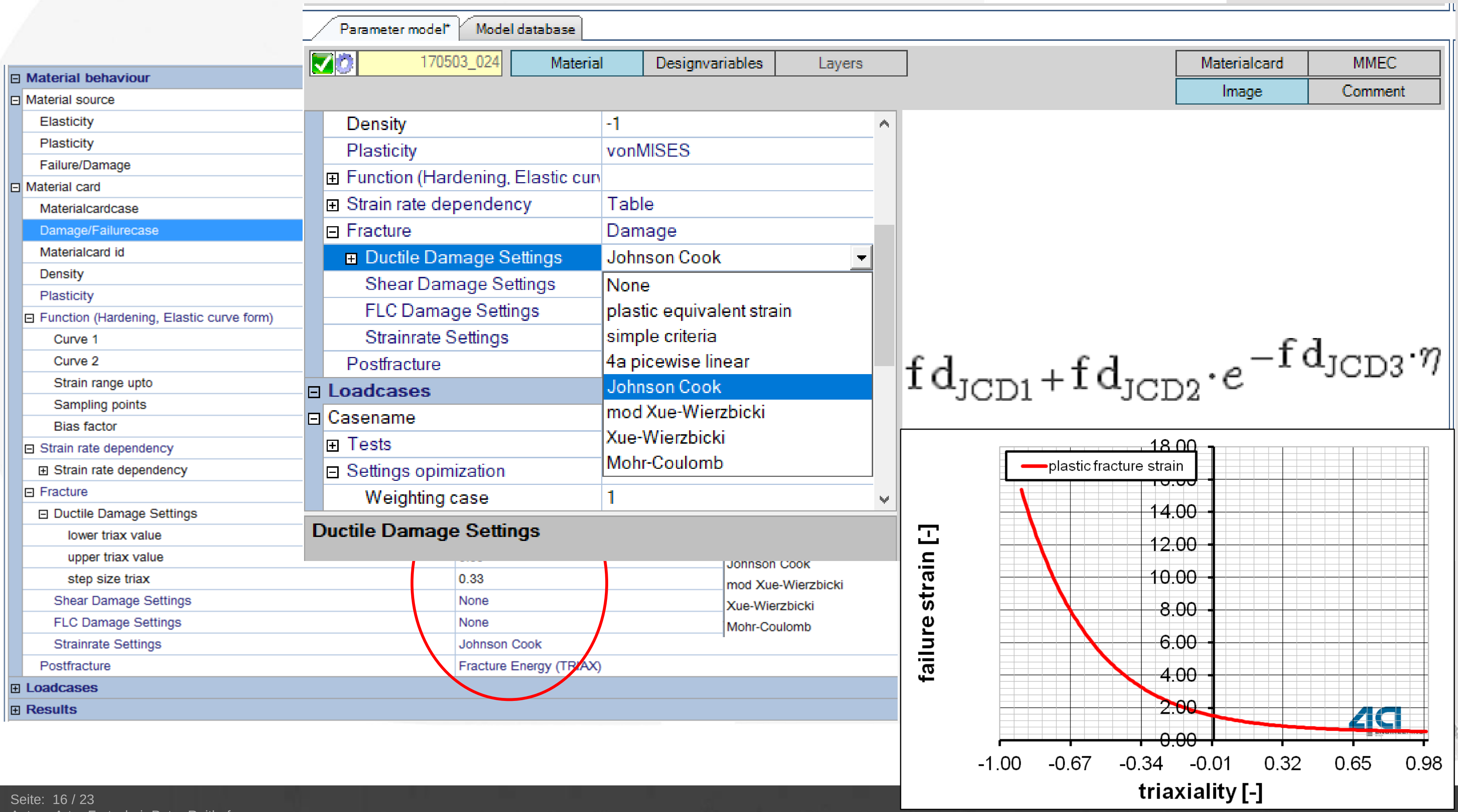
Triaxiality

Strain rate dependency

Post failure

4a impetus
Failure models

- GUI – different possibilities to setup failure models



Parameter model* | Model database

170503_024 | Material | Designvariables | Layers | Materialcard | MMEC | Image | Comment

Density: -1
Plasticity: vonMISES
Function (Hardening, Elastic curv
Strain rate dependency: Table
Fracture: Damage
Ductile Damage Settings: Johnson Cook
Shear Damage Settings
FLC Damage Settings
Strainrate Settings
Postfracture
Loadcases
Casename
Tests
Settings opimization
Weighting case: 1

None
plastic equivalent strain
simple criteria
4a picewise linear
Johnson Cook
mod Xue-Wierzbicki
Xue-Wierzbicki
Mohr-Coulomb

Ductile Damage Settings

Material behaviour
Material source
Elasticity
Plasticity
Failure/Damage
Material card
Materialcardcase
Damage/Failurecase
Materialcard id
Density
Plasticity
Function (Hardening, Elastic curve form)
Curve 1
Curve 2
Strain range upto
Sampling points
Bias factor
Strain rate dependency
Strain rate dependency
Fracture
Ductile Damage Settings
lower triax value
upper triax value
step size triax: 0.33
Shear Damage Settings: None
FLC Damage Settings: None
Strainrate Settings: Johnson Cook
Postfracture: Fracture Energy (TRIAX)
Loadcases
Results

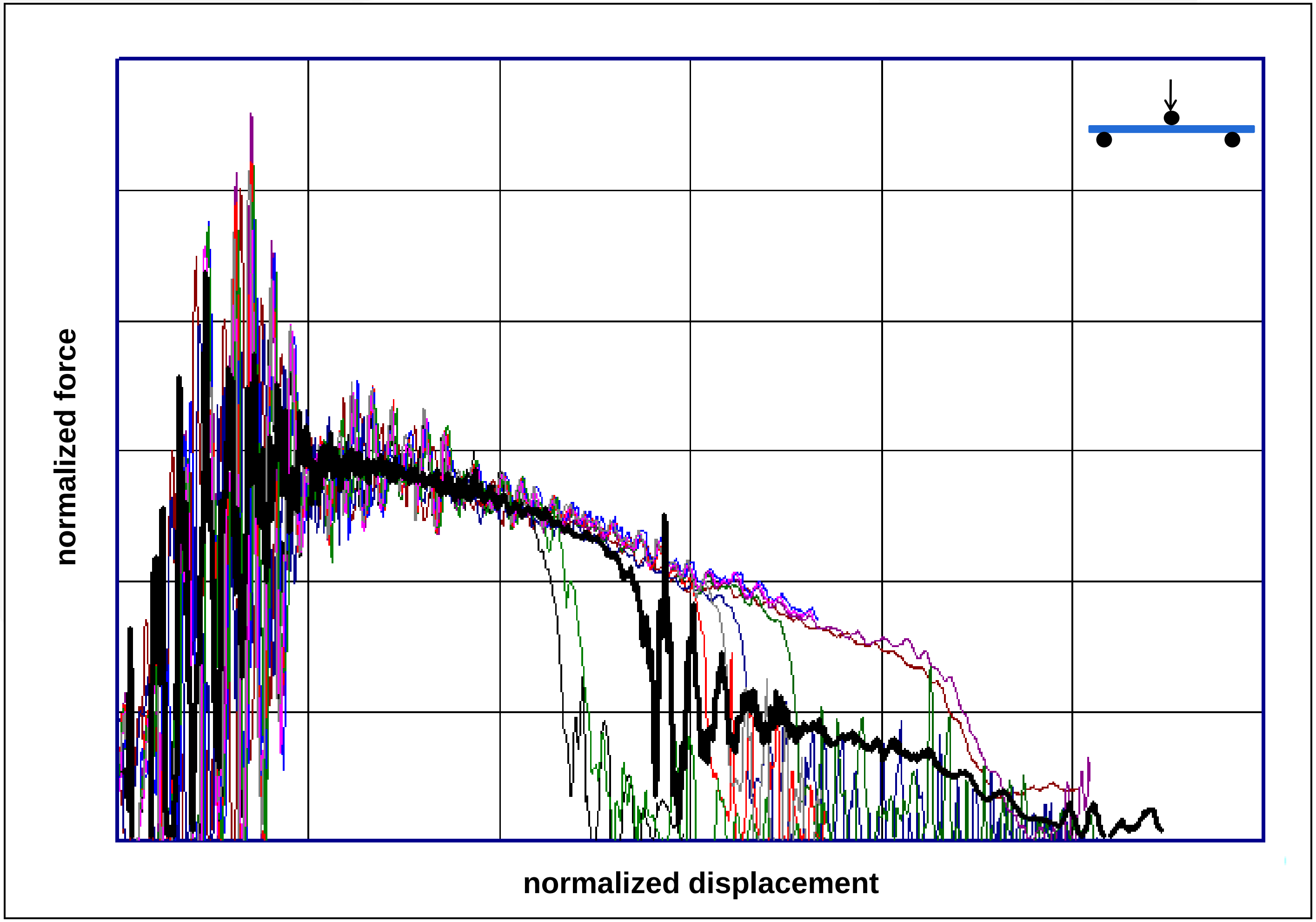
Johnson Cook
mod Xue-Wierzbicki
Xue-Wierzbicki
Mohr-Coulomb

$$fd_{JCD1}+fd_{JCD2}\cdot e^{-fd_{JCD3}\cdot\eta}$$

Failure Modeling - Validation

*MAT_SAMP-1 with *MAT_ADD_EROSION

- 3-point-bending, 4 m/s, unfiltered curves
- The test curves are matched very well [7]

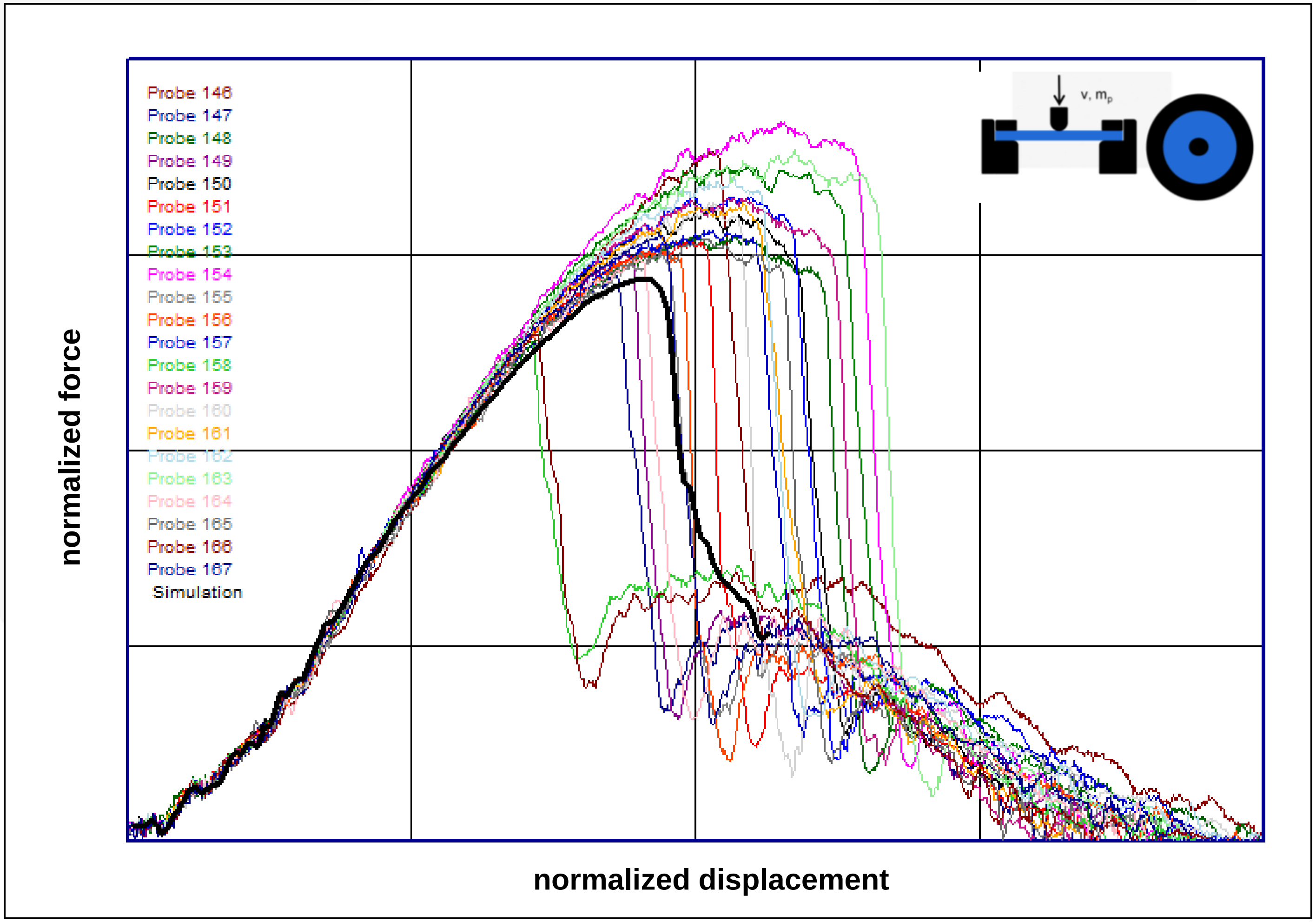


Colored: Test curves
Black: Simulation

Failure Modeling - Validation

*MAT_SAMP-1 with *MAT_ADD_EROSION

- Dynamic puncture test, 6.3 m/s
- The test curves are matched very well [7]



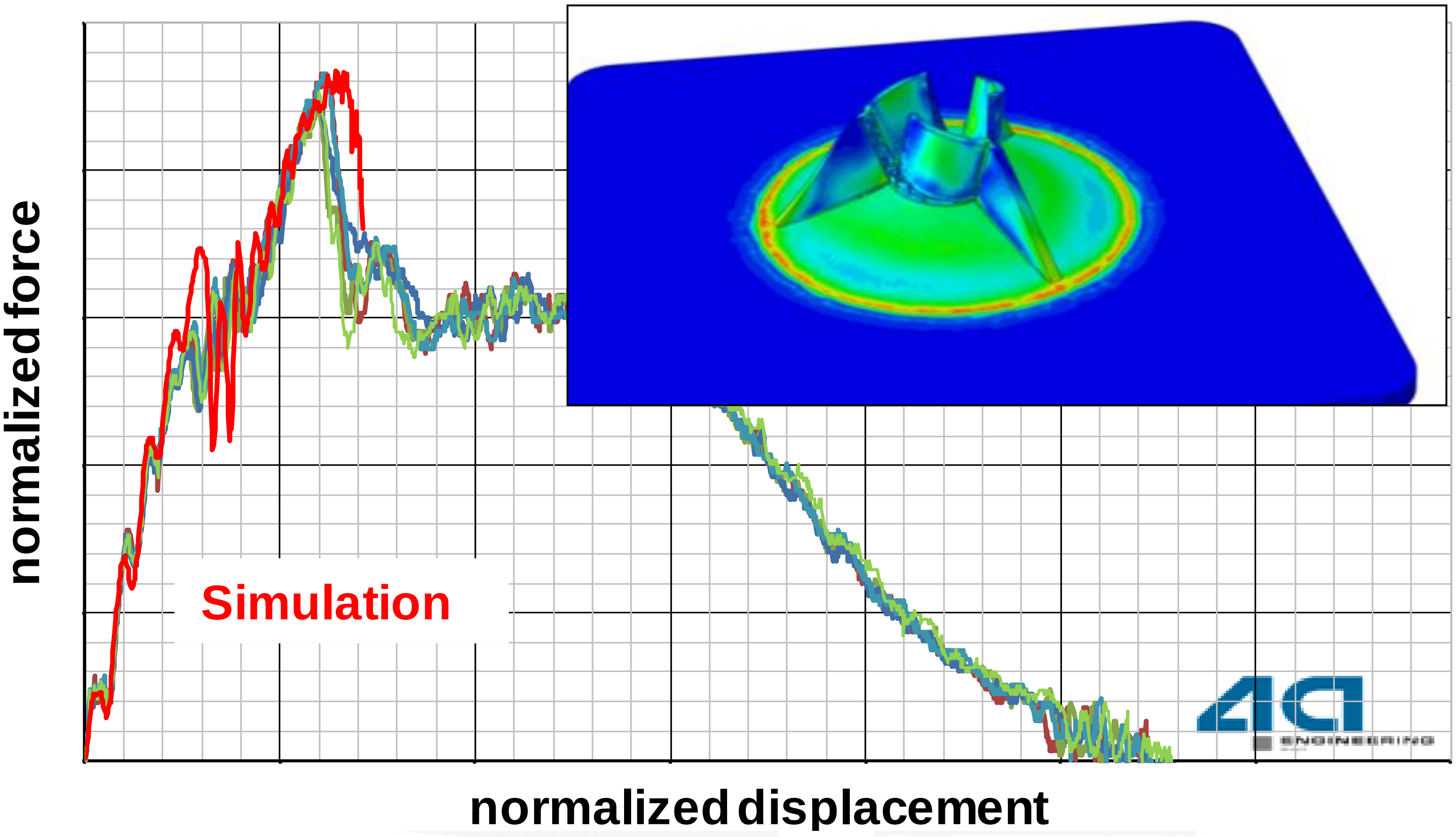
Colored: Test curves

Black: Simulation

Failure Modeling - Validation

*MAT_SAMP-1 with *MAT_ADD_EROSION

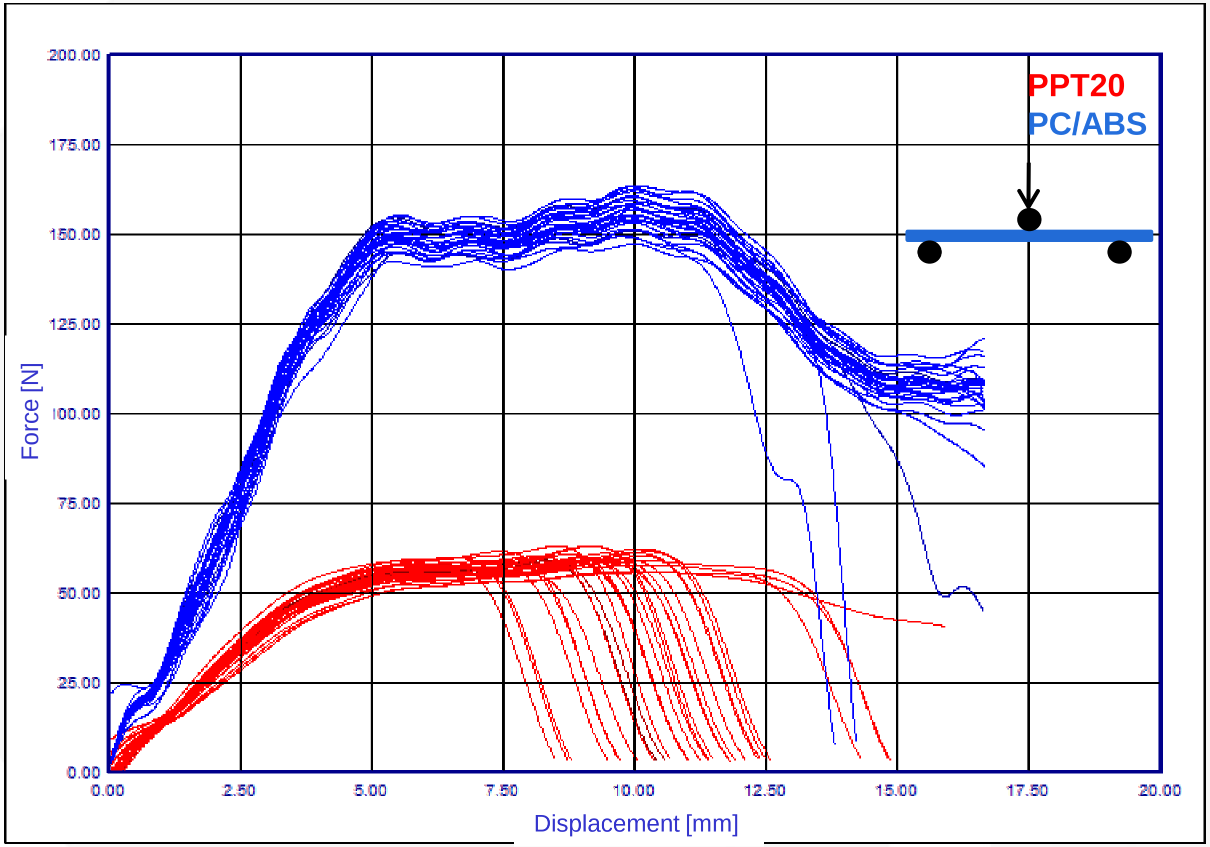
- Dynamic puncture test with the part, 4.3 m/s
- The test curves are matched very well [7]

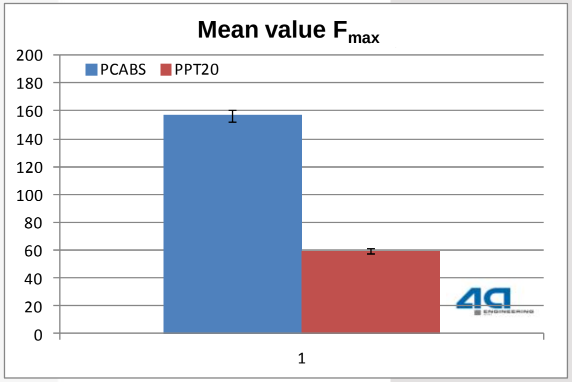


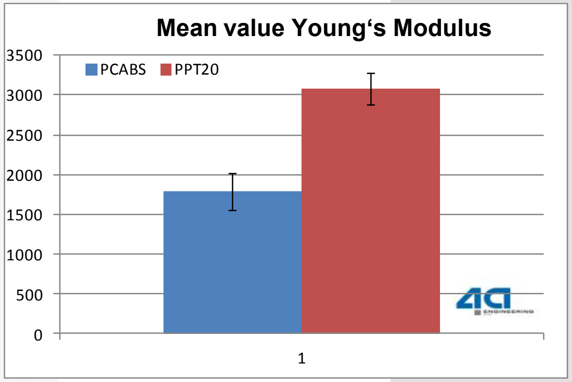
[7] A. Fertschej, P. Reithofer, M. Rollant - Failure of thermoplastics - PART 2, Material modeling and simulation, LS-DYNA Konferenz 2015, Würzburg

Failure Modeling - Validation

Statistical evaluation in 4a impetus



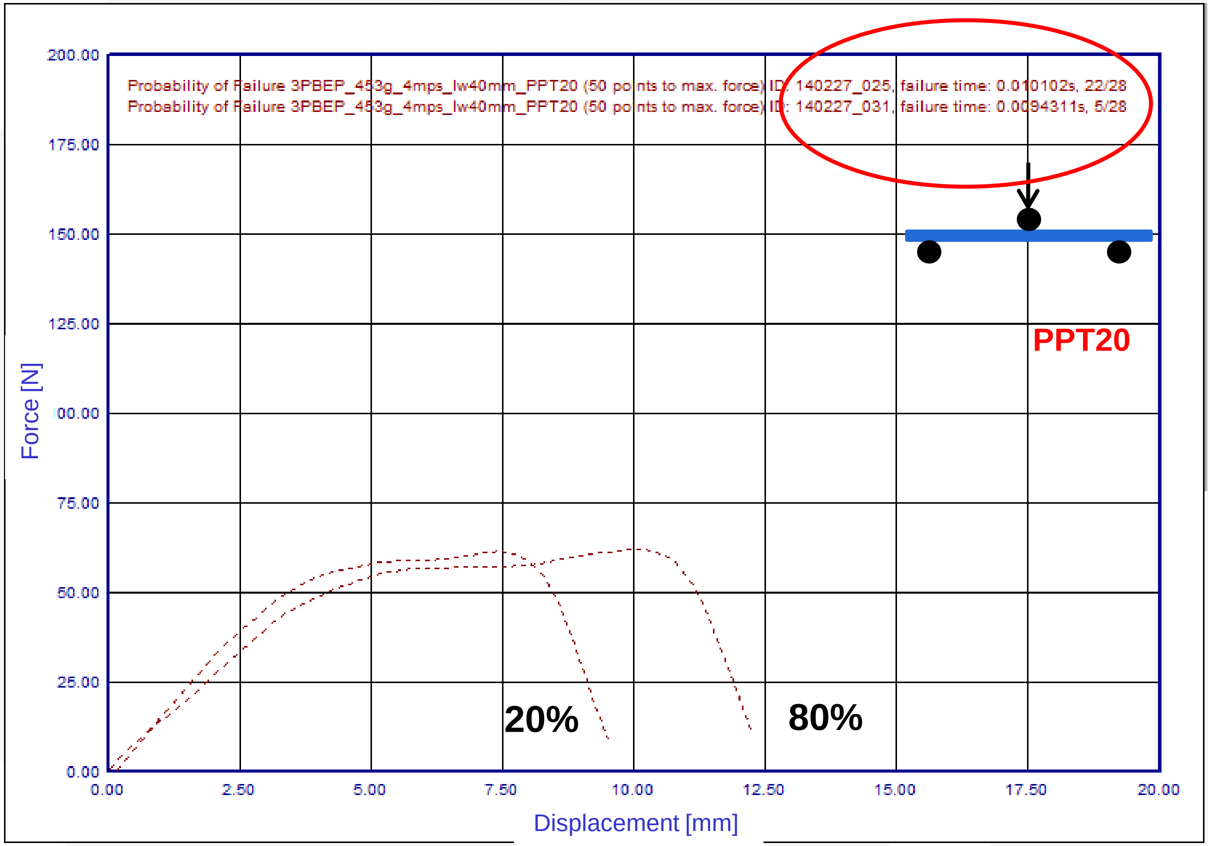


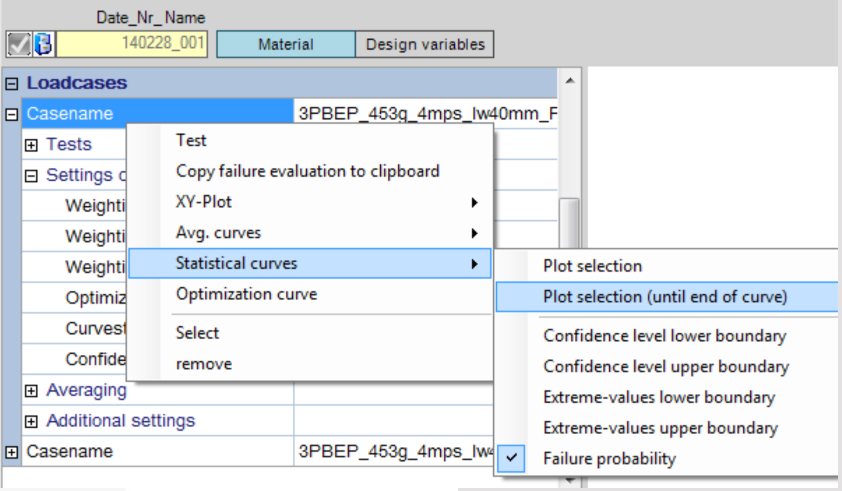


Example: 30 measurements for both materials (30 users)

Failure Modeling - Validation

Statistical evaluation in 4a impetus





Date_Nr_Name: 140228_001

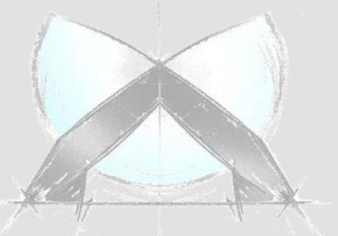
Casename: 3PBEP_453g_4mps_lw40mm_F

Casename: 3PBEP_453g_4mps_lw4

Failure probability: 20% and 80%

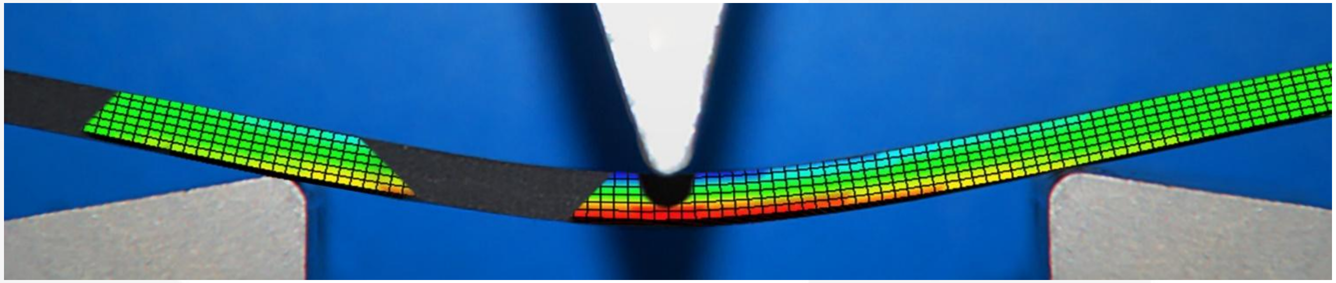
Summary

- Material behavior of plastics depends on load type, time, temperature, processing, …
- Easy evaluation of failure at high strain rates → Clamped 3-point-bending tests and puncture tests on 4a impetus
- *MAT_SAMP-1 + *MAT_ADD_EROSION → material can be reproduced best possible and close to reality
- The reverse engineering process to determine the material parameters using 4a impetus works properly
- The latest software release of 4a impetus includes up to date failure modeling → accurate material modeling



Thank you for your attention!

Wednesday, 8:30:	Workshop: MPIP – Material Parameter Identification Process with 4a impetus
Thursday, 8:55:	*MAT_4A_MICROMEC – Theory and Application Notes
Thursday, 11:30:	Biotex BigBag Simulation – LS-Dyna Airbag Tool – Unusual Application



15th 4a TECHNOLOGIETAG

28th February – 1st March 2018
in Schladming, Austria

„Plastics – Testing and Simulation"
further information: *http://technologietag.4a.co.at/*