迅捷响应•共享仿真

MATFEM SHAREFEA 迅仿工程技术

首届CrachFEM失效模拟研讨会

1st ShareFEA CrachFEM Seminar

25 April 2018, Shanghai

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MATFEM

Partnerschaft
Dr. Gese & Oberhofer
Maschinenbauingenieure

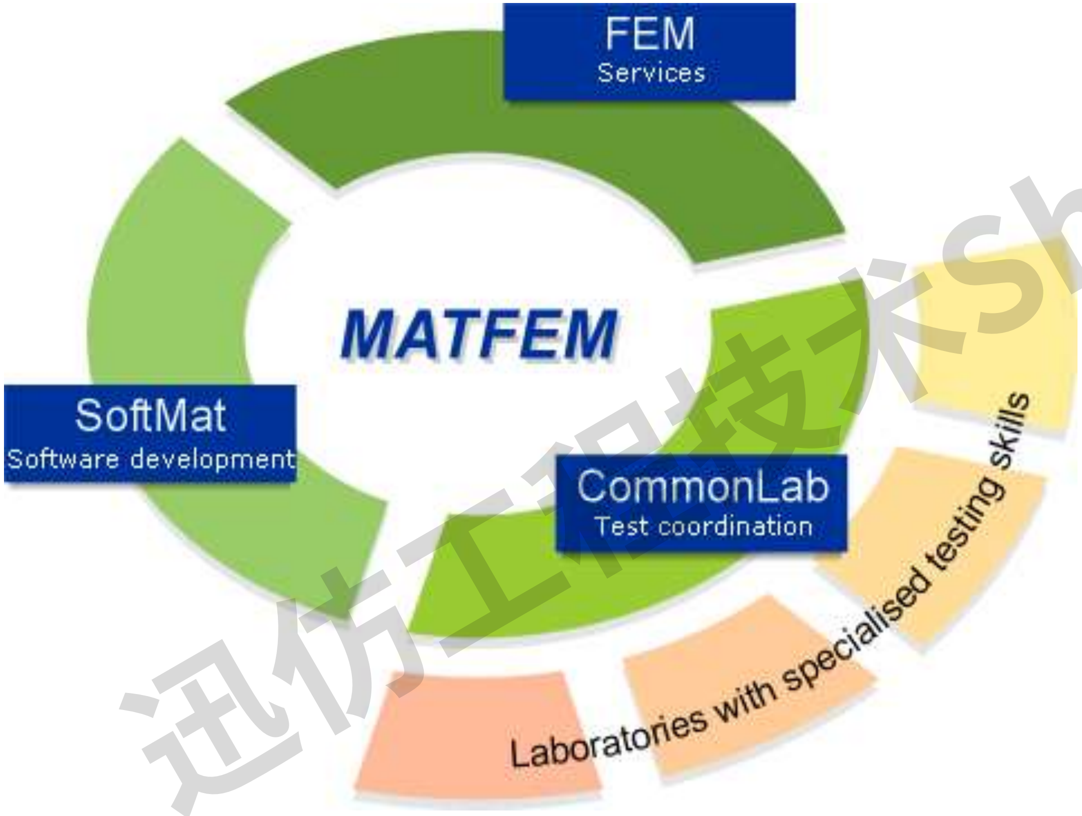
15 years of failure prediction with CrachFEM

1st ShareFEA CrachFEM Seminar, 25 April 2018, Shanghai

H. Gese, H. Dell, G. Oberhofer Authors

April 25, 2018 Date

Overview



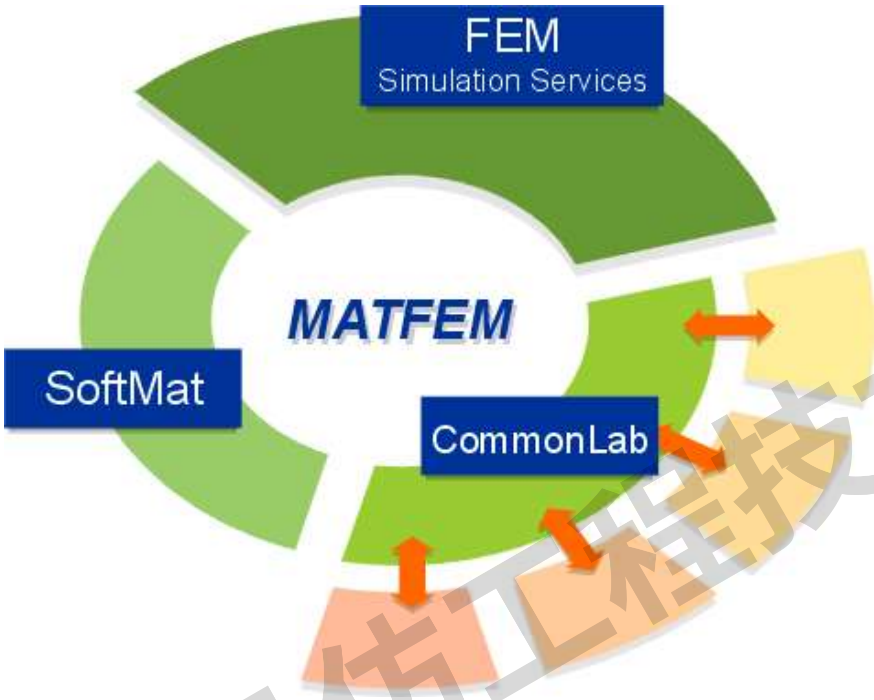
MATFEM facts & figures:

- founded in year 1993
- approx. 80 customers worldwide
- cooperation with 10 partner labs in Europe

Introduction of MATFEM

MATFEM

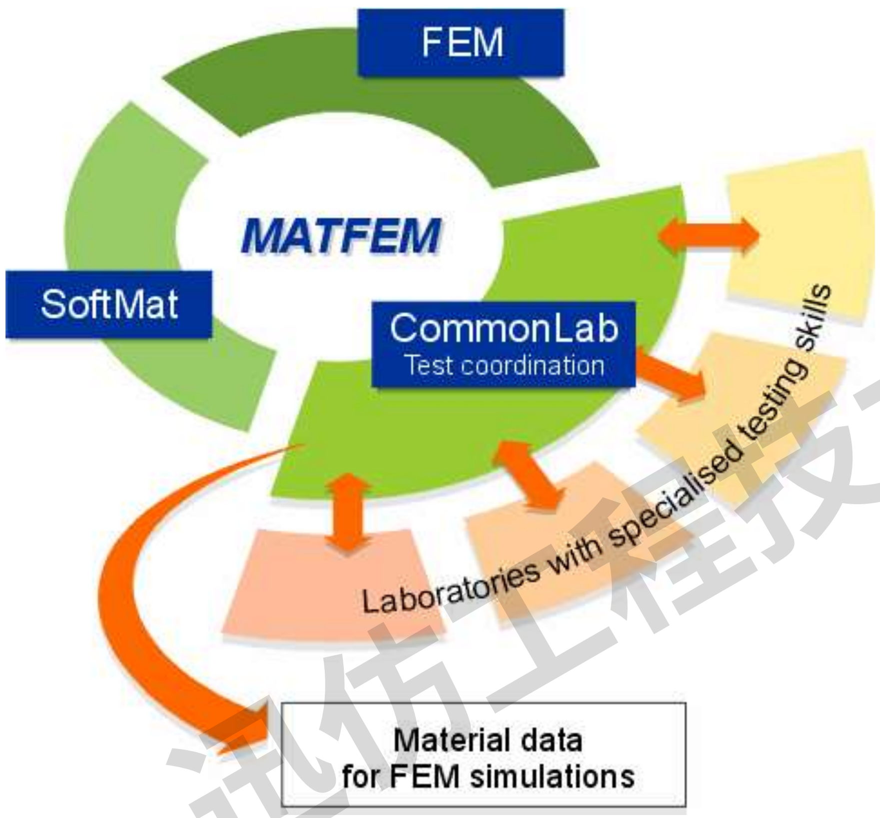
Branch FEM Services



- FEM consulting with various FE codes*
- consulting projects and method development for
  - Manufacturing processes
  - Crashworthiness load cases
  - misuse load cases
  - fatigue
- Key customers:
  - automotive industry
  - aerospace industry
  - sheet metal producers
  - producers of medical devices

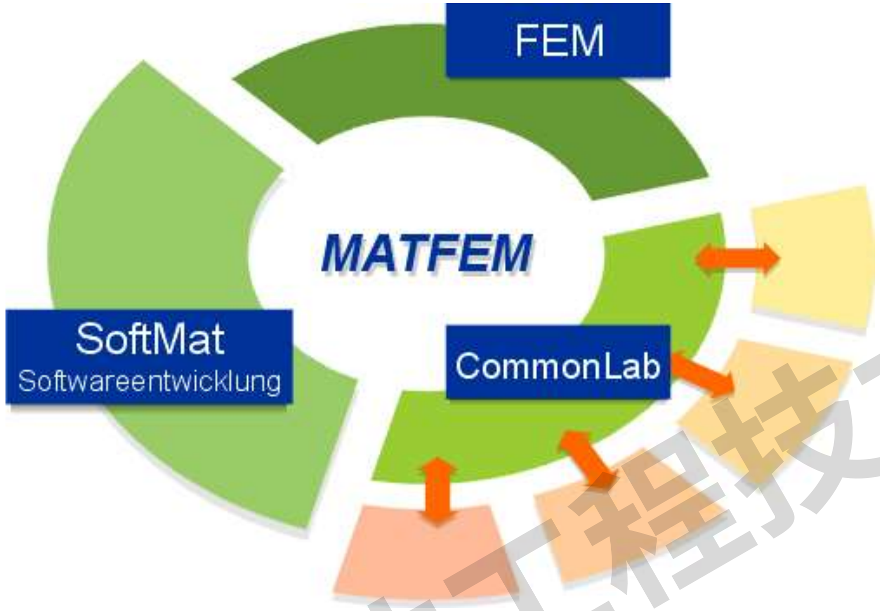
* ABAQUS/Standard
ABAQUS/explcit
LS-Dyna
PAM-Stamp/-Crash
RADIOSS

Branch CommonLab



- develop new testing and evaluation methods
- characterize metals, polymers and composites for FEA
  - define test program
  - choose suitable testing laboratories
  - coordinate test performance
  - approximate measured data with given models
  - generate material input cards for FEM codes
  - validate material cards in FEM

Branch SoftMat



- Commercial software solutions
  - Modular material model MF GenYld + CrachFEM
  - Material viewer MFview
  - CrachLab for the versatile prediction of FLCs
- Research projects to support implementation of new features in MF GenYld+CrachFEM
- In-house auxiliary programs
  - approximation programs
  - Mapping interfaces and converters
- Development of customized software solutions

Contents

MATFEM

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Contents (continued)

MATFEM

- ► Introduction of model for post instability strain (2008)
- ► Coupling of CrachFEM to ABAQUS/explicit via user-material interface (2009)
- ► Introduction of module for prediction of fracture probability (2010)
- ► Extension of CrachFEM for high pressure die cast components (EU-funded project NADIA 2007-2010)
- ► Influence of discretization on fracture prediction in cast components (2012-2013)
- ► Forming-to-Crash Mapping with AUTOFORM and LS-DYNA (2012-2013)
- ► Extension of CrachFEM for orthotropy of ductile fracture (2014)
- ► Coupling of CrachFEM with r-adaptivity in LS-DYNA for „bulk forming“ (2015)
- ► Local scaling of material properties to account for stress concentrators (2016-2017)
- ► Current status of CrachFEM

Motivation for advanced material models

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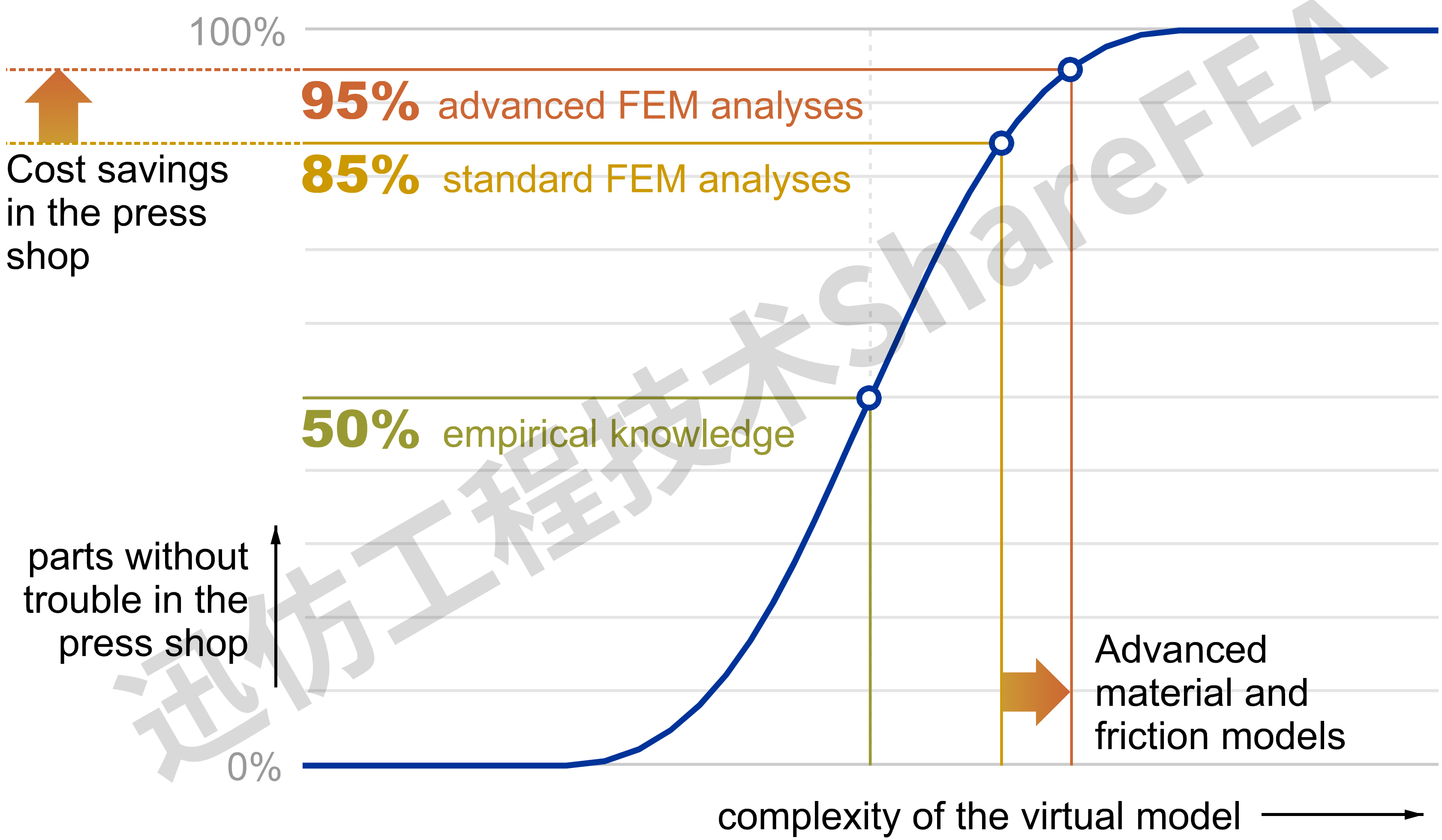
Reduce critical processes in the press shop



Motivation for advanced material models

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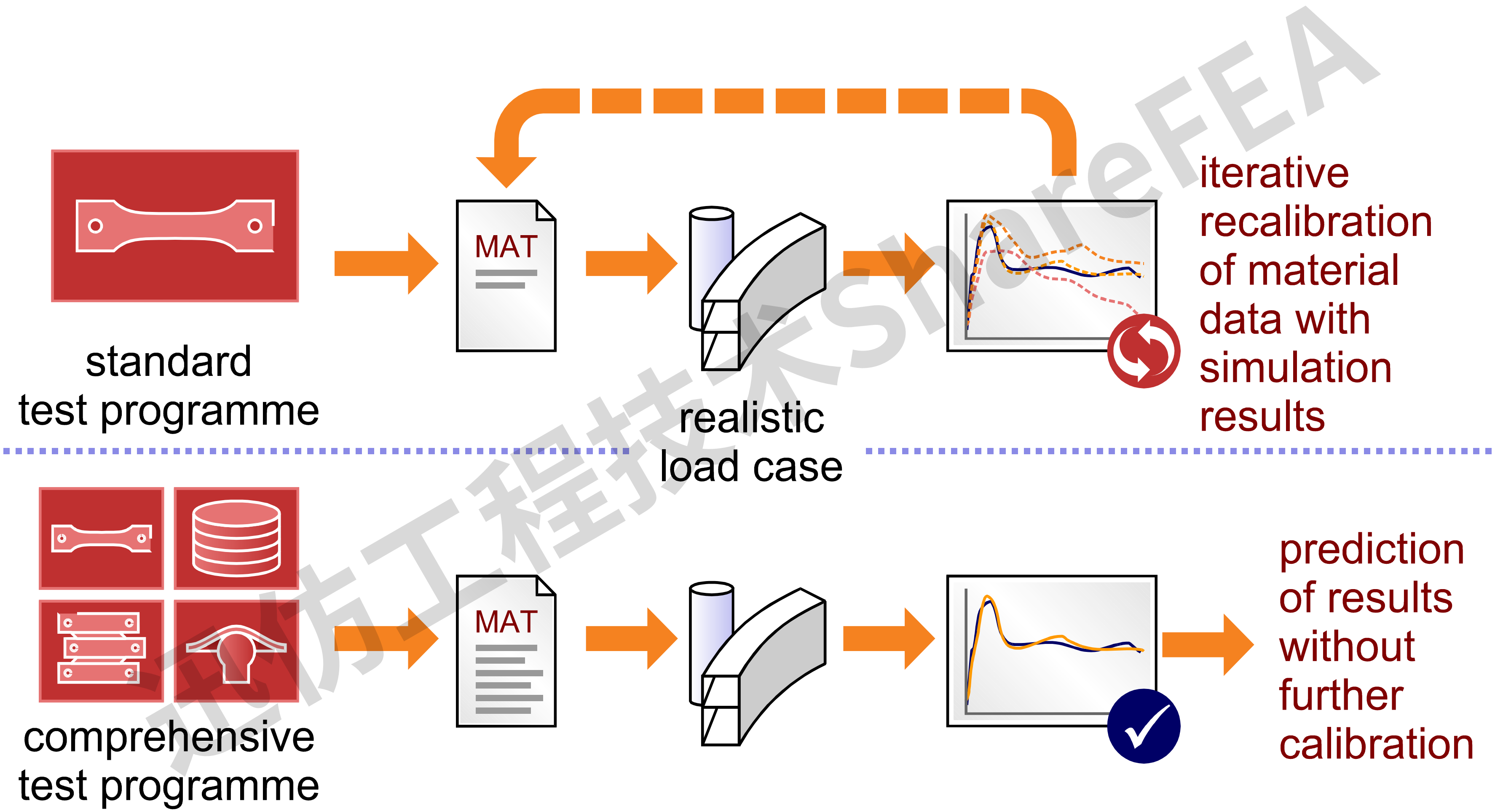
Reduction of development time & costs by predictive crashworthiness simulation



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Prediction of necking for nonlinear strain paths

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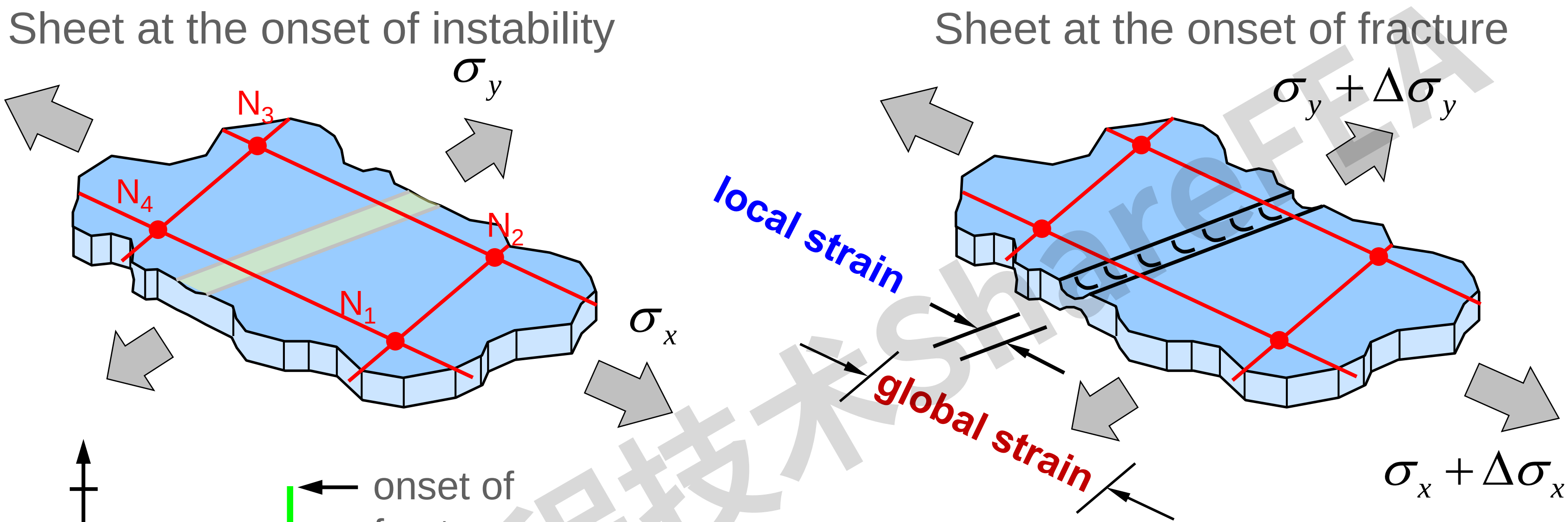
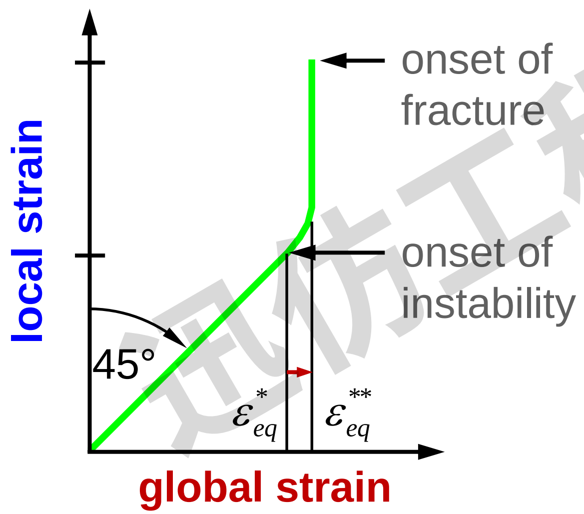
Prediction of localized necking in contrast with shell discretization



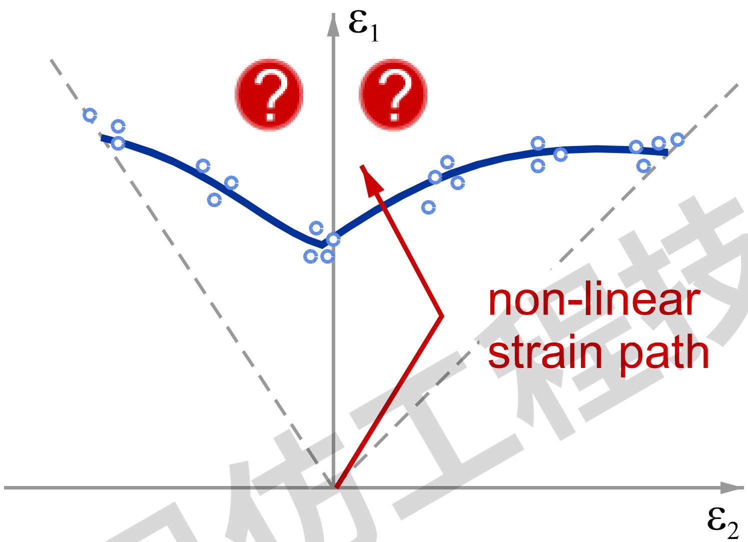


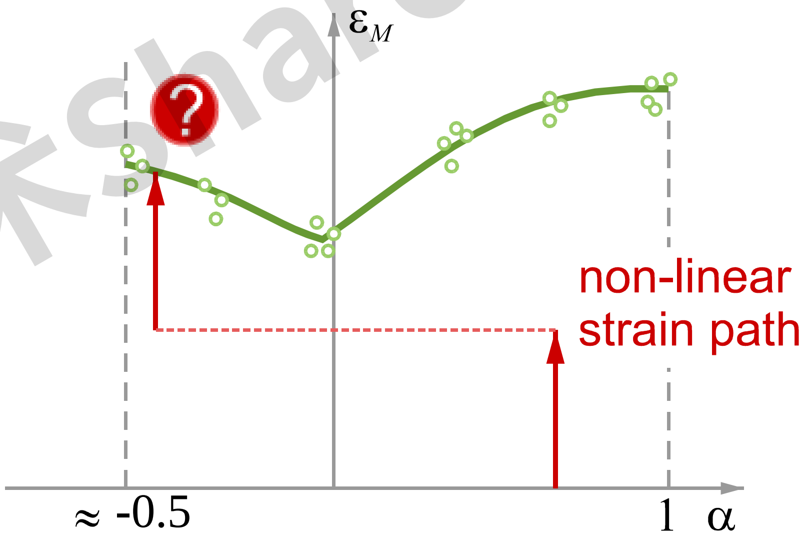
- ► No significant increase in global strain from onset of instability to fracture
- ► Instability is directly used as a fracture criterion

Source: H. Werner, H. Dell, G. Metzmacher, L. Kessler, A. Heath: Methodology, Validation and Application of a Failure Model Based on Transient Forming Limit Curves for Coupled Stamping and Crash Processes as Part of the IMPACT Project, Proceedings of EUROPAM 2003, Mainz, October 16-17, 2003

Forming limit diagram - standard criterion for onset of localized necking in sheets

$$\alpha = \varepsilon_2 / \varepsilon_1$$





Classical representation:
1st principal strain vs. 2nd principal strain

Diagram according to Müschenborn and Sonne

Prediction of necking for nonlinear strain paths

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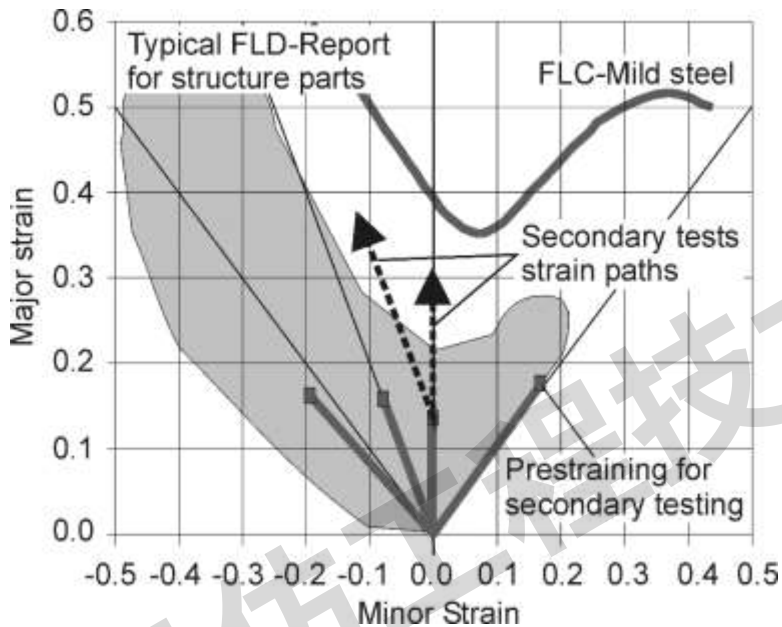
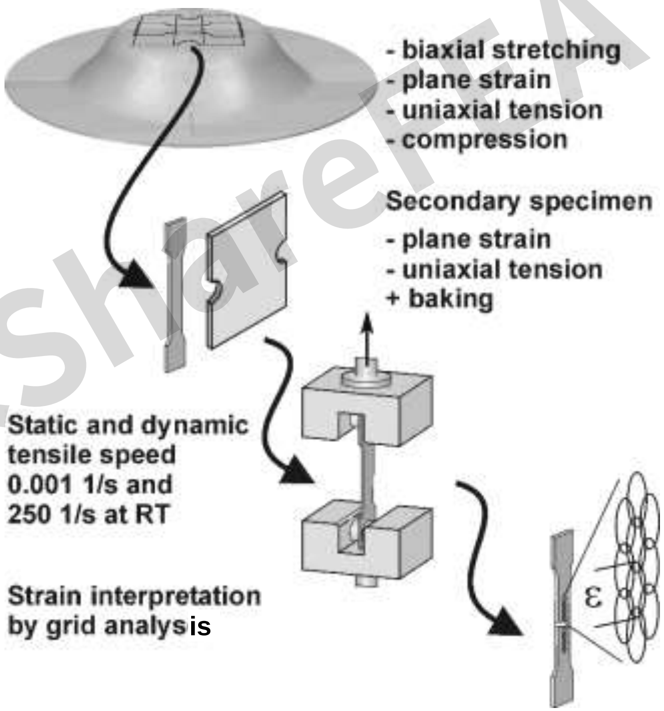
Experimental approach for defined bilinear strain paths (forming and crash)



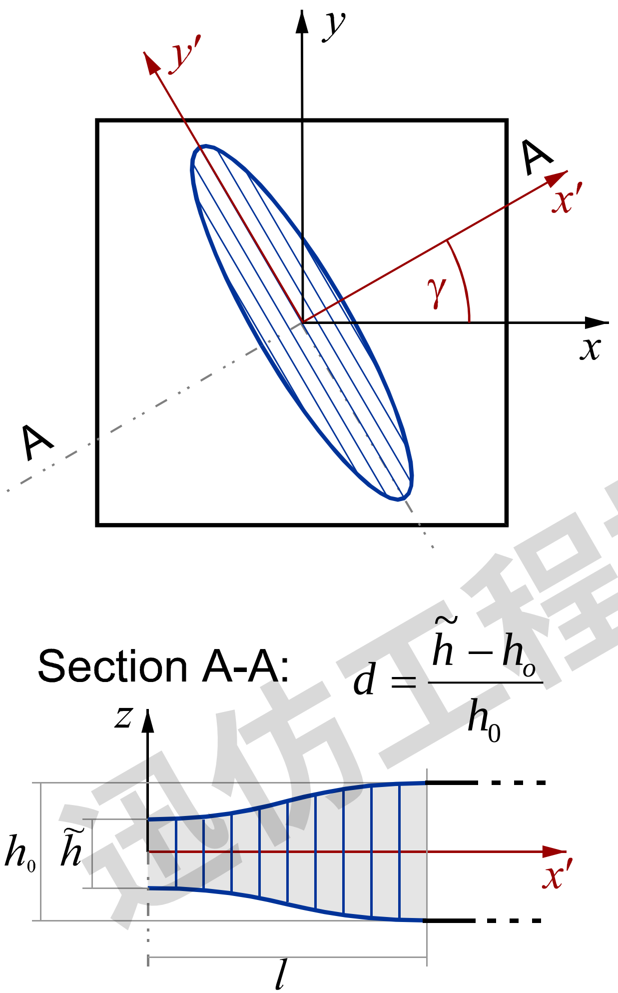
Typical plastic strains resulting from deep drawing of sheet component



Static prestraining and static/dynamic testing at the laboratory scale

Source: Dell, H.; Gese, H.; Kessler, L.; Werner, H.; Hooputra, H.: 'Continuous Failure Prediction Model for Nonlinear Load Paths in Successive Stamping and Crash Processes', New Sheet Steel Products and Sheet Metal Stamping (SP-1614), SAE 2001 World Congress, Michigan, SAE-Paper 2001-01-1131, 2001.

Instability model in algorithm Crach



The Crach algorithm predicts local instability for the tension-tension regime.

Crach requires the following data:

- plastic orthotropy (Hill 1948)
- total hardening (e.g. Swift)
- kinematic hardening (Backhaus)
- strain rate sensitivity m
- initial inhomogeneity d

Localized necking is identified either by non-convergence or by increase of strain rate in critical section by factor 1000.

Prediction of necking for nonlinear strain paths

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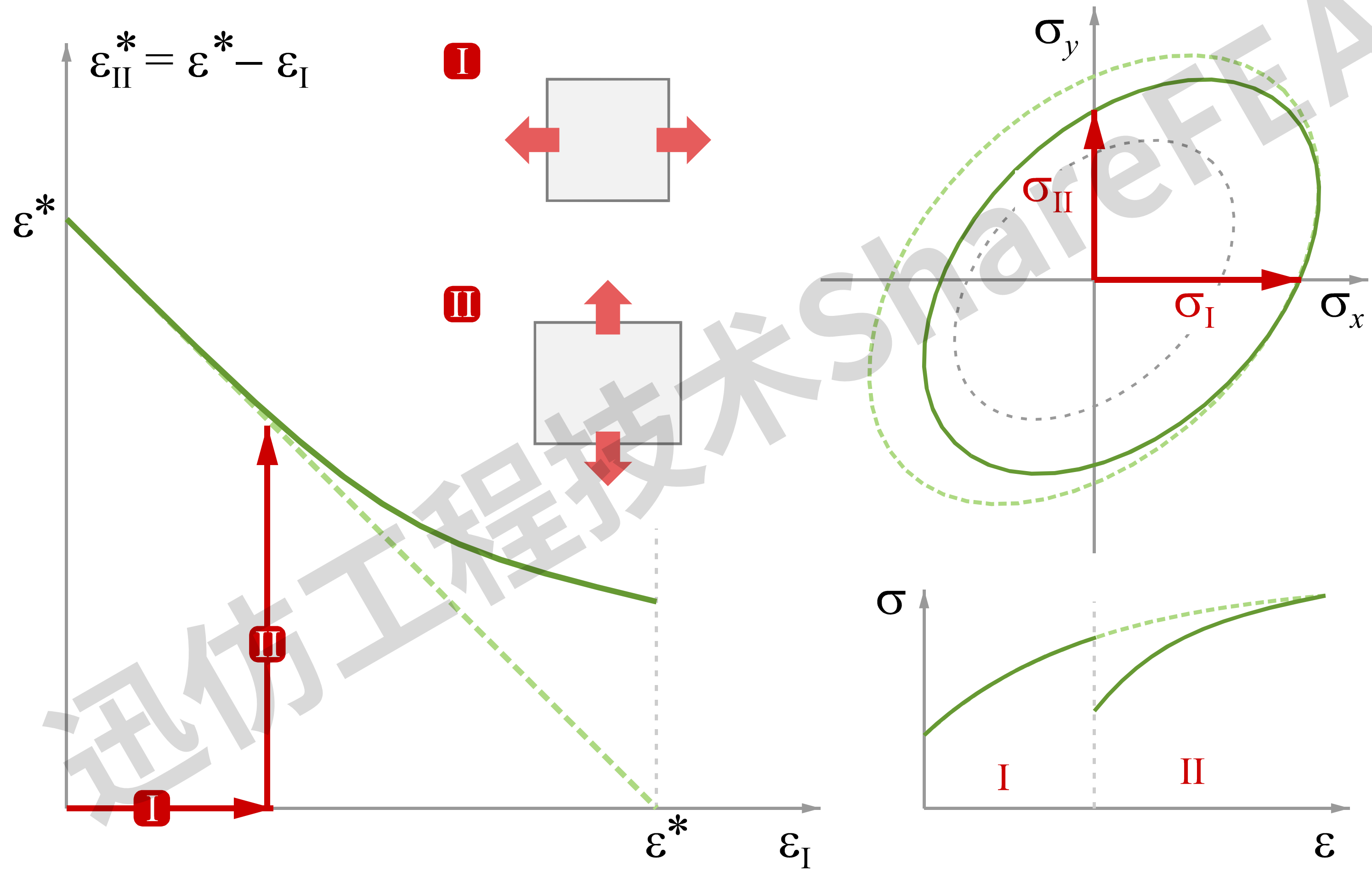
Influence of kinematic hardening on localized necking



ε*: necking strain

Prediction of necking for nonlinear strain paths

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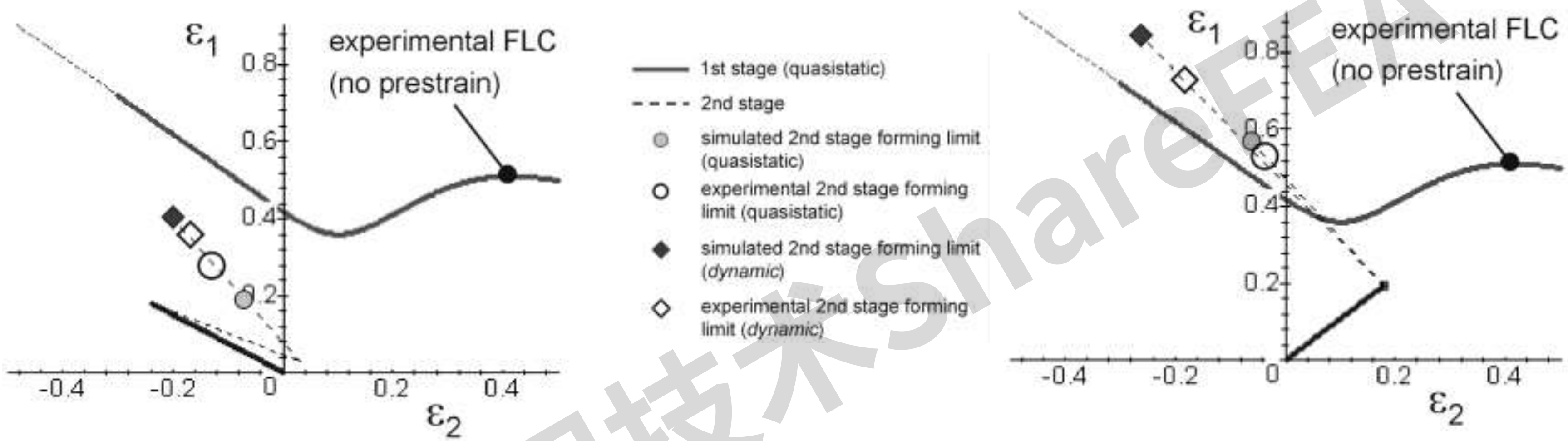
Bi-linear strain paths - prediction of algorithm Crach vs. experiments



Quasistatic uniaxial compression in 1st stage followed by uniaxial tension

Quasistatic equibiaxial tension in 1st stage followed by uniaxial tension

- ► Bi-linear strain paths cannot be predicted with conventional forming limit diagram
- ► Algorithm Crach provides a good prediction for static-static and state-dynamic case

Source: Dell, H.; Gese, H.; Kessler, L.; Werner, H.; Hooputra, H.: 'Continuous Failure Prediction Model for Nonlinear Load Paths in Successive Stamping and Crash Processes', New Sheet Steel Products and Sheet Metal Stamping (SP-1614), SAE 2001 World Congress, Michigan, SAE-Paper 2001-01-1131, 2001.

Prediction of necking for nonlinear strain paths

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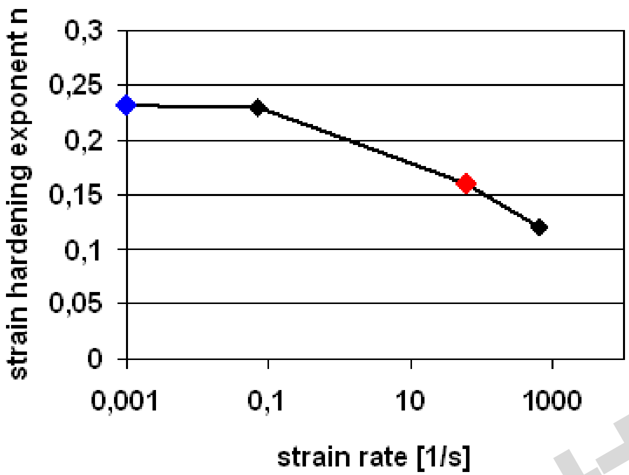
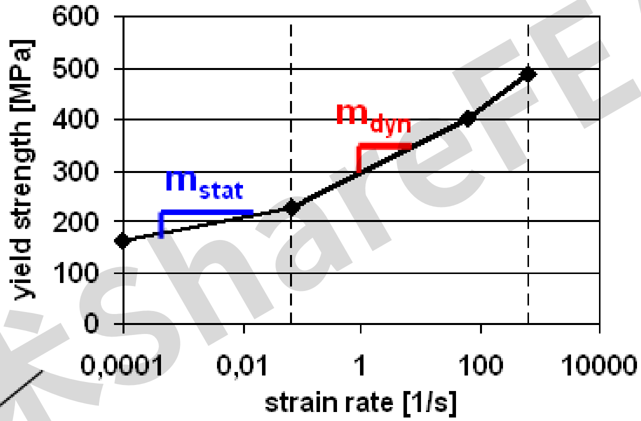
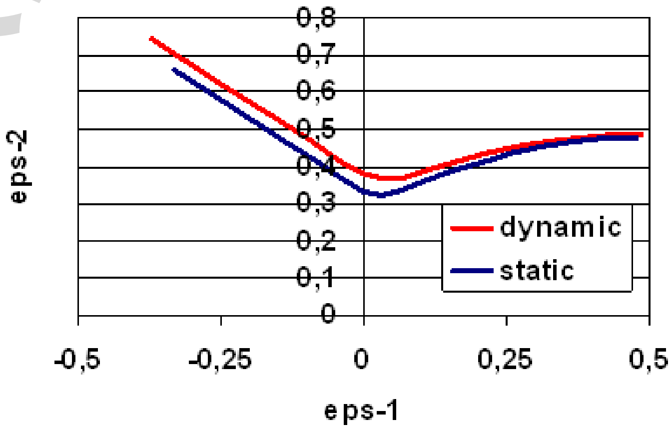
Influence of strain rate regime on forming limit curve for mild steel based on Crach





$$\sigma_{eq} = a \cdot \left(\varepsilon_0 + \varepsilon_{eq}\right)^n \cdot \dot{\varepsilon}_v^{\,m}$$

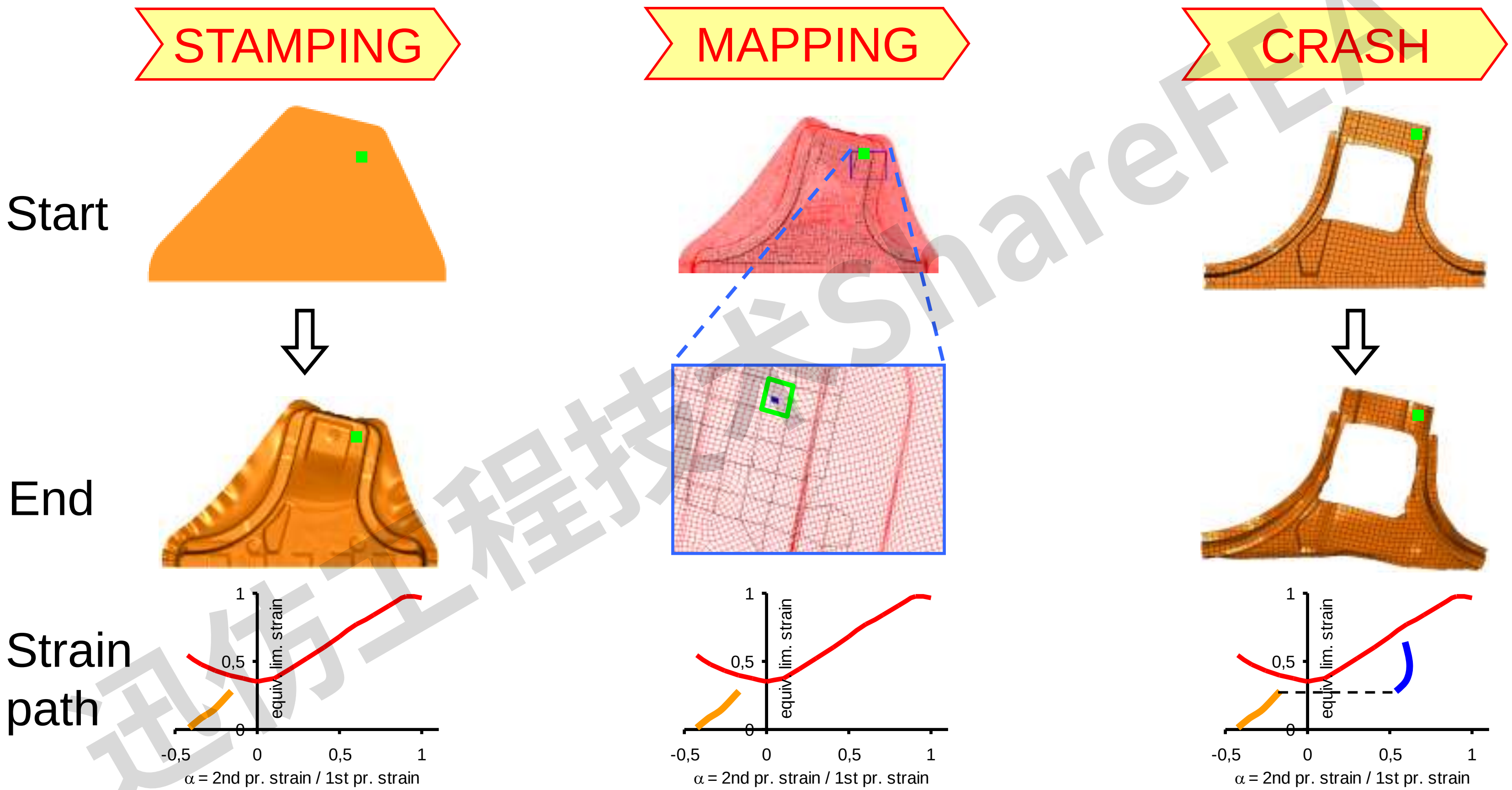
Example: mild steel DC04



prediction of algorithm Crach

Prediction of necking for nonlinear strain paths

First validation of algorithm Crach for stamping+crash (postprocessing of strain paths)

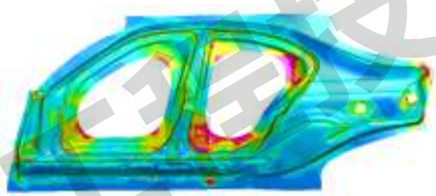
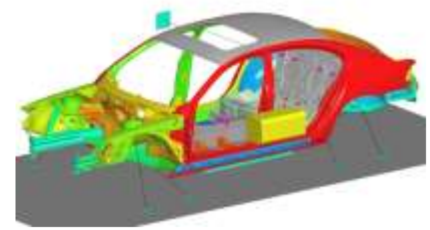


<u>Source</u>: H. Werner, H. Dell, G. Metzmacher, L. Kessler, A. Heath: Methodology, Validation and Application of a Failure Model Based on Transient Forming Limit Curves for Coupled Stamping and Crash Processes as Part of the IMPACT Project, Proceedings of EUROPAM 2003, Mainz, October 16-17, 2003

First full scale validation of algorithm Crach (coupled to FEM) for stamping+crash

Raw Material → **Forming** → **Drying** (after painting) → **Crash**



Material-test → PAM-STAMP / CrachFEM (Material 128) → Last state after forming / Condensed history of the strain path → PAM-CRASH / CrachFEM (Material 128)

Source: H. Werner, H. Dell, G. Metzmacher, L. Kessler, A. Heath: Methodology, Validation and Application of a Failure Model Based on Transient Forming Limit Curves for Coupled Stamping and Crash Processes as Part of the IMPACT Project, Proceedings of EUROPAM 2003, Mainz, October 16-17, 2003

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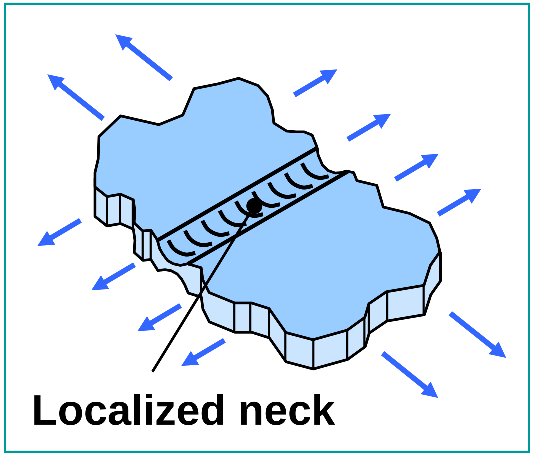
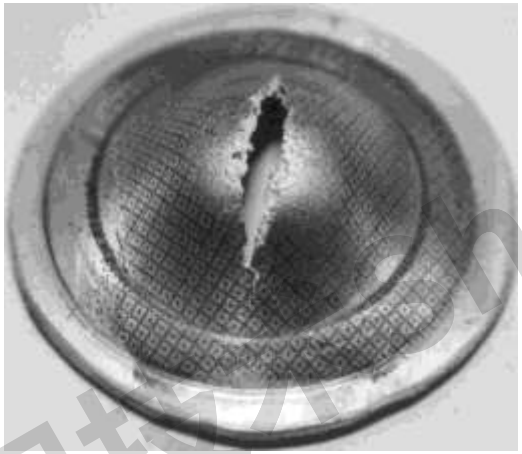
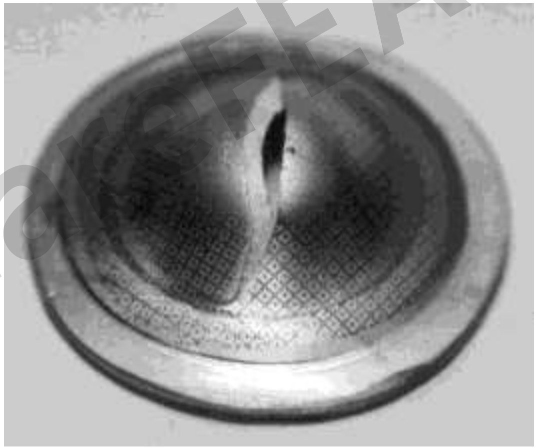
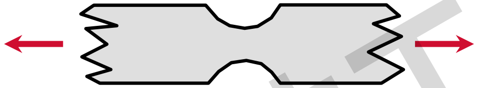
Overview on failure modes for metallic materials

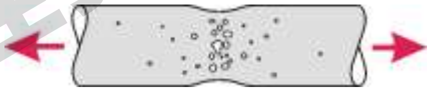
Sheet Instability | **Ductile fracture** | **Shear fracture**

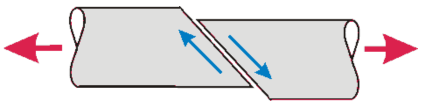












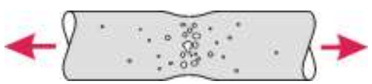
Failure modes depend on:

- Material
- Loading situation (state of stress / strain, strain rate)
- Process history (e.g. pre-strain, heat treatment, ...)

Criteria for ductile normal fracture and ductile shear fracture (in 2004)

Normal fracture

$\varepsilon^{**}(\eta)$



$$\eta = \frac{-3 \cdot p}{\sigma_M}$$

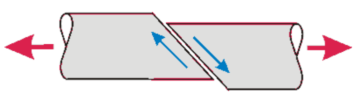
$$\varepsilon_{eq}^{**} = \frac{\varepsilon_{NF}^{+} \sinh\left(c \cdot \left(\eta^{-} - \eta\right)\right) + \varepsilon_{NF}^{-} \sinh\left(c \cdot \left(\eta - \eta^{+}\right)\right)}{\sinh\left(c \cdot \left(\eta^{-} - \eta^{+}\right)\right)}$$

Parameter c can be orthotropic

Shear fracture

$\varepsilon^{**}(\theta)$

$$\theta = \frac{1 - k_{SF} \cdot \eta}{w}$$



$$w = \frac{\tau_{max}}{\sigma_M}$$

$$\varepsilon_{eq}^{**} = \frac{\varepsilon_{SF}^{+} \sinh\left(f\left(\theta - \theta^{-}\right)\right) + \varepsilon_{SF}^{-} \sinh\left(f\left(\theta^{+} - \theta\right)\right)}{\sinh\left(f\left(\theta^{+} - \theta^{-}\right)\right)}$$

ε^{**}: equivalent plastic strain st fracture

New innovative stress state parameter θ for ductile shear fracture; parameter is defined as a function of two stress invariants; the influence of stress triaxiality is weighted by a material dependent parameter.

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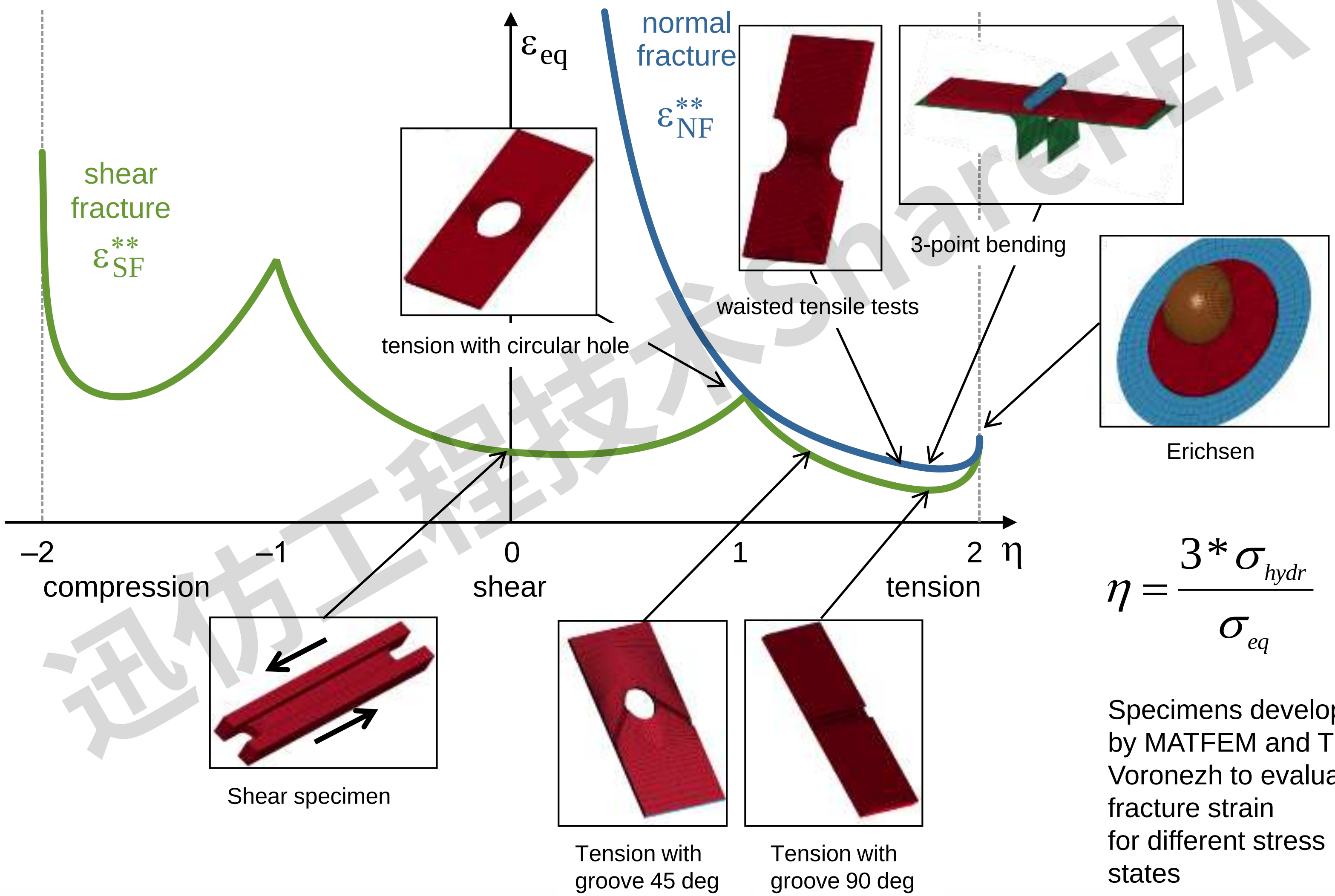
Experiments for identification of initial fracture limit curves (shown for plane stress)



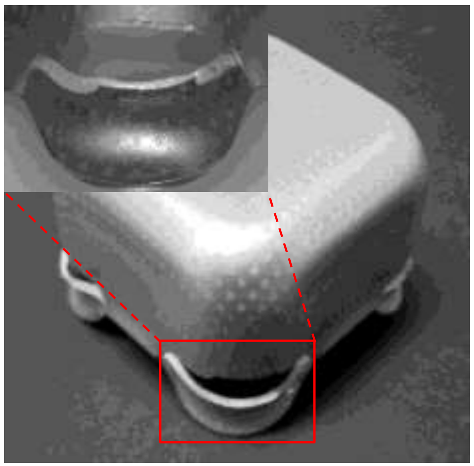
$$\eta = \frac{3 * \sigma_{hydr}}{\sigma_{eq}}$$

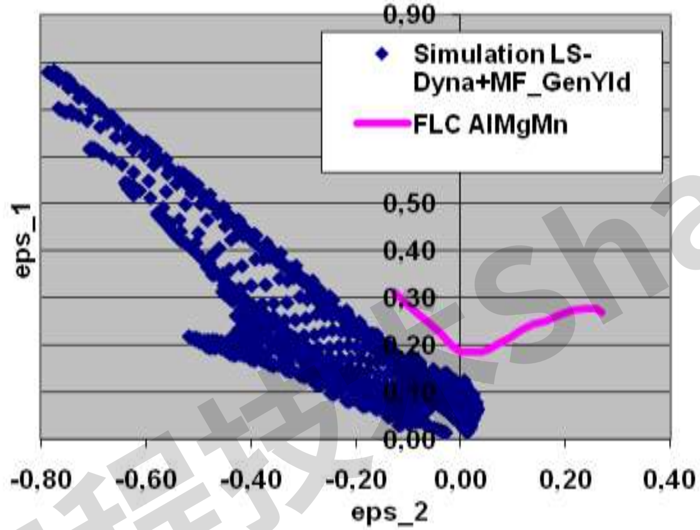
Specimens developed by MATFEM and TEST-Voronezh to evaluate fracture strain for different stress states

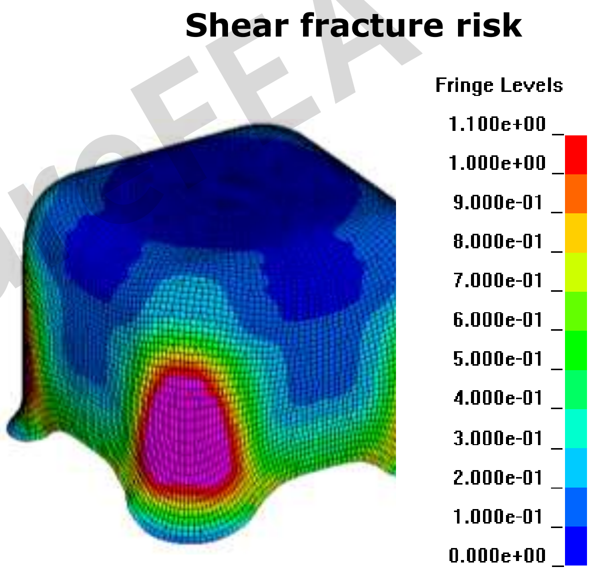
Fracture criteria in CrachFEM

MATFEM

Prediction of ductile shear fracture in deep drawing simulation







Fracture in corners of cup for drawing ratio 1.85 < ß < 2.08 in experiment (AlMgMn sheet)

Fracture at corners cannot be predicted with initial FLC (=> relevant mechansim is not localized necking)

Correct prediction of critical shear fracture risk when using CrachFEM

Source: H. Gese, S. Keller und Harry Dell: Verbesserte Plastizitäts- und Versagensmodelle in der Umformsimulation, Tagung: Numerische Simulation – Verarbeitungsprozesse und prozessgerechte Bauteilgestaltung, 2.-3. November 2004, Kompetenzzentrum Neue Materialien, Bayreuth

Fracture criteria in CrachFEM

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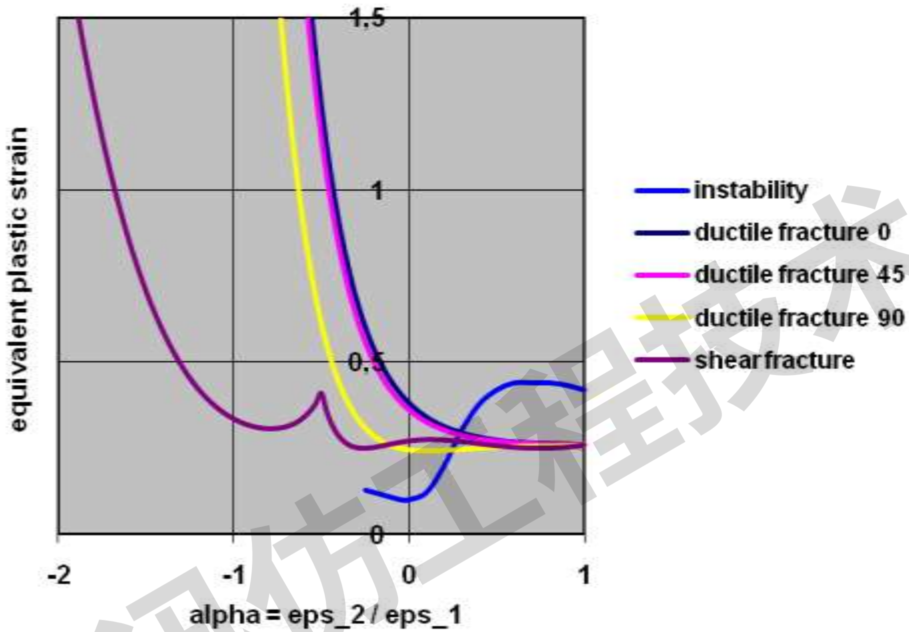
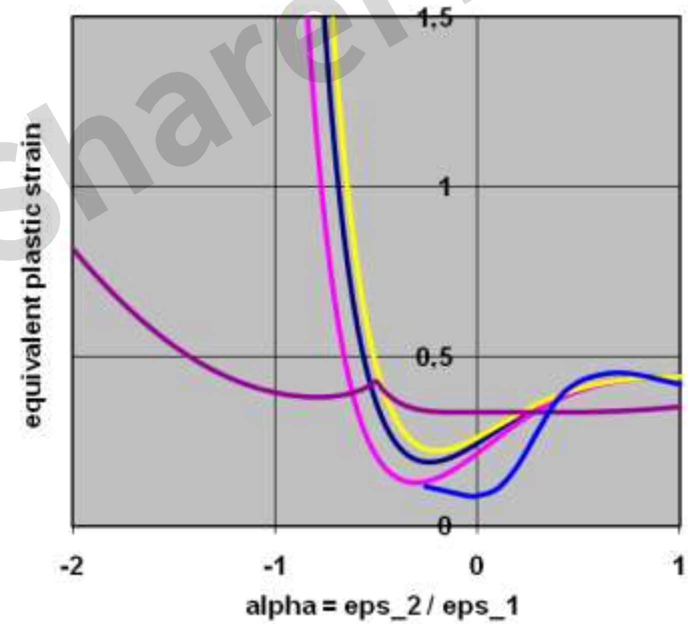
Prediction of failure for axial crash of aluminium extrusions with CrachFEM

Fracture map with all fracture limit curves (shown curves are valid for linear strain paths) of aluminium alloy of type AA7108.50-T6



Limit curves for quasi-static tests

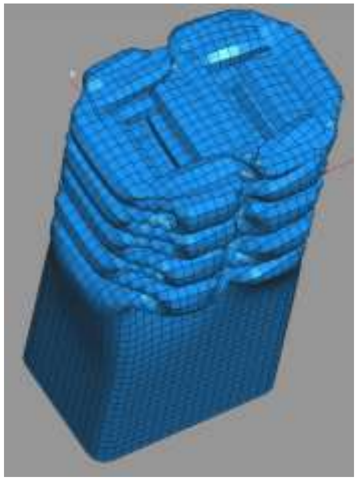


Limit curves for dynamic tests (250 s-1)

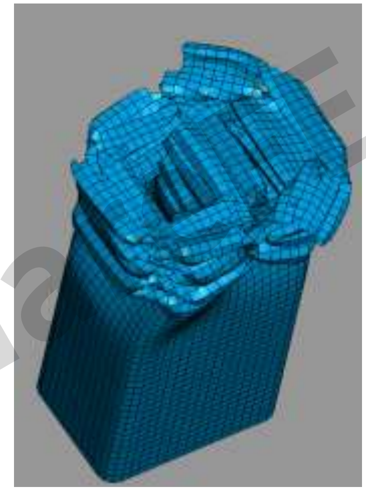
Source: Hooputra, H.; Gese, H.; Dell, H.; Werner, H.: A Comprehensive Failure Model for Crashworthiness Simulation of Aluminum Extrusions. International Journal of Crashworthiness, Vol. 9, No. 5 (2004), pp. 449–463

Prediction of failure for axial crash of aluminium extrusions with CrachFEM

quasi-static simulation without any failure criteria

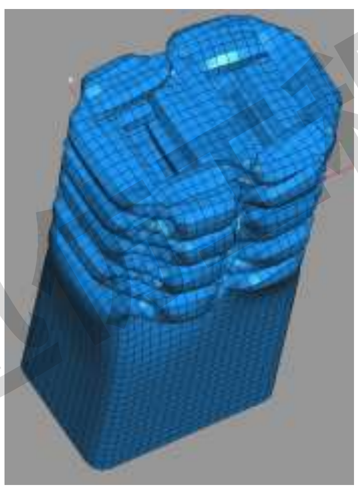


quasi-static drop test

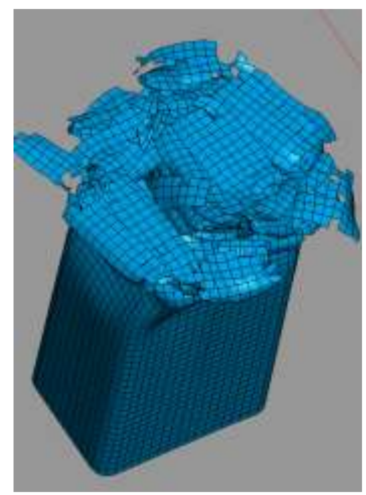


quasi-static simulation with CrachFEM

quasi-static simulation without any failure criteria



dynamic drop test



dynamic simulation with CrachFEM

Source: Hooputra, H.; Gese, H.; Dell, H.; Werner, H.: A Comprehensive Failure Model for Crashworthiness Simulation of Aluminum Extrusions. International Journal of Crashworthiness, Vol. 9, No. 5 (2004), pp. 449–463

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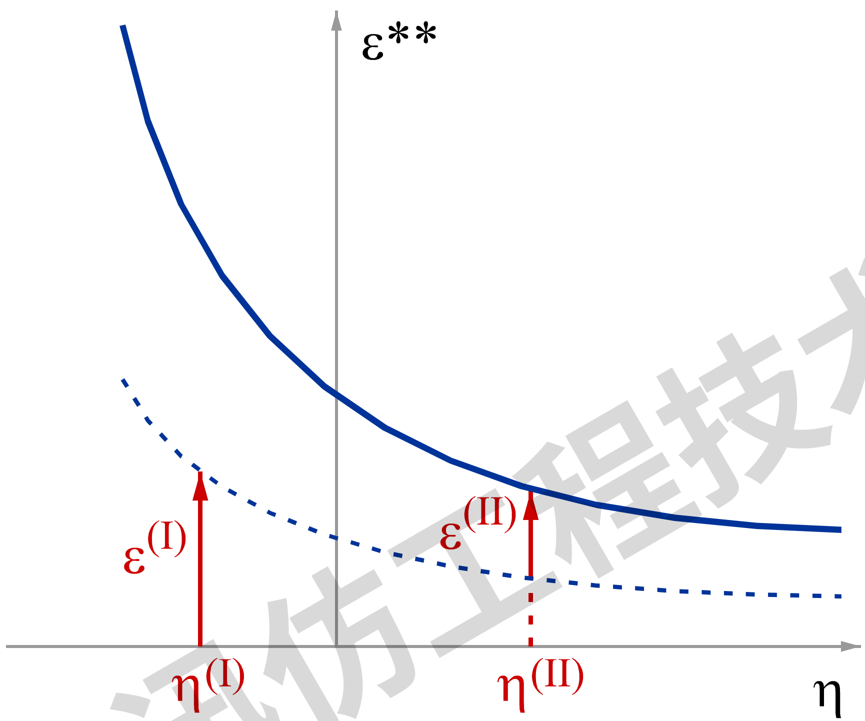
Integral damage accumulation with scalar description of damage



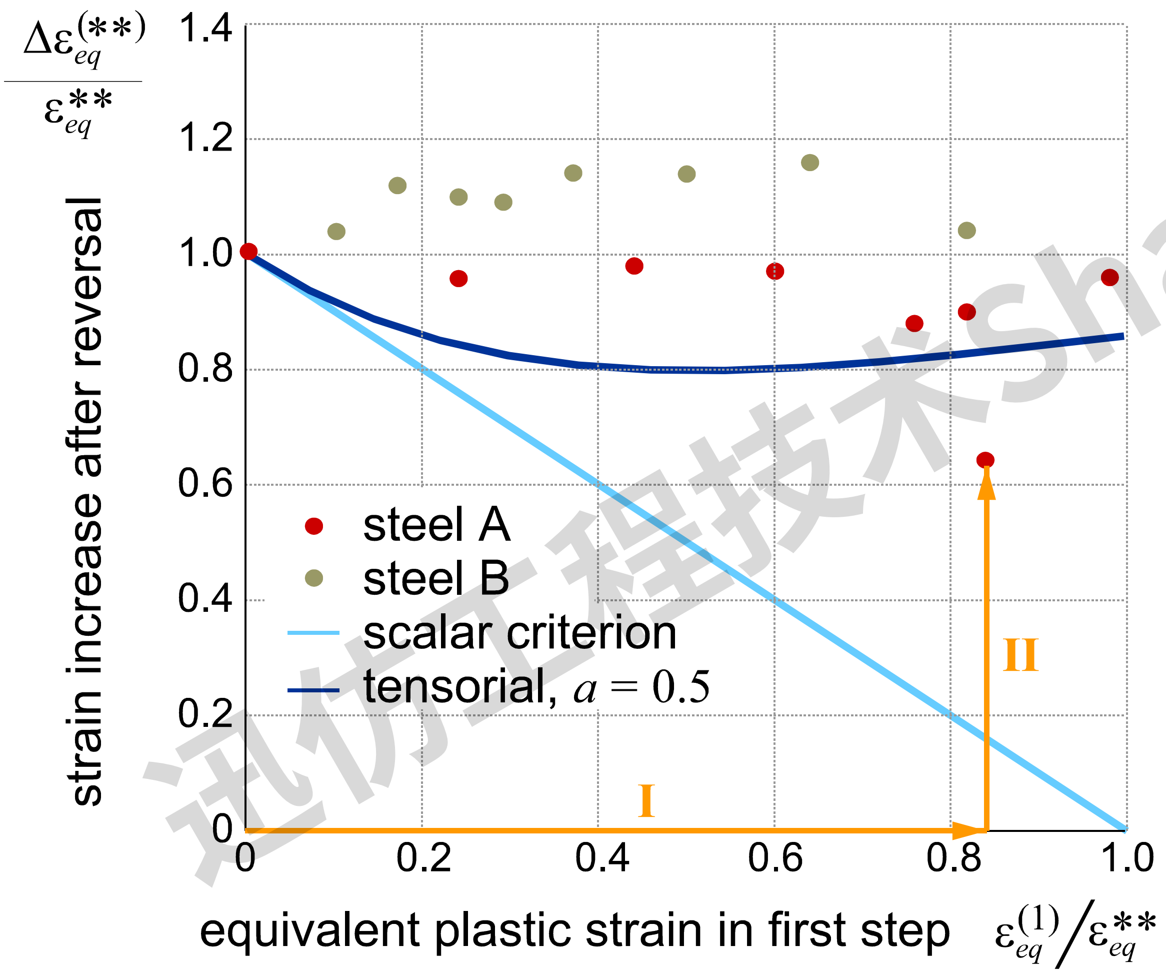
- The fracture is described by curves of fracture strain over the stress state. For linear strain paths, this is the exact fracture criterion.
- Non-linear strain paths can be accounted for by using an integral failure criterion according to Kolmogorov:

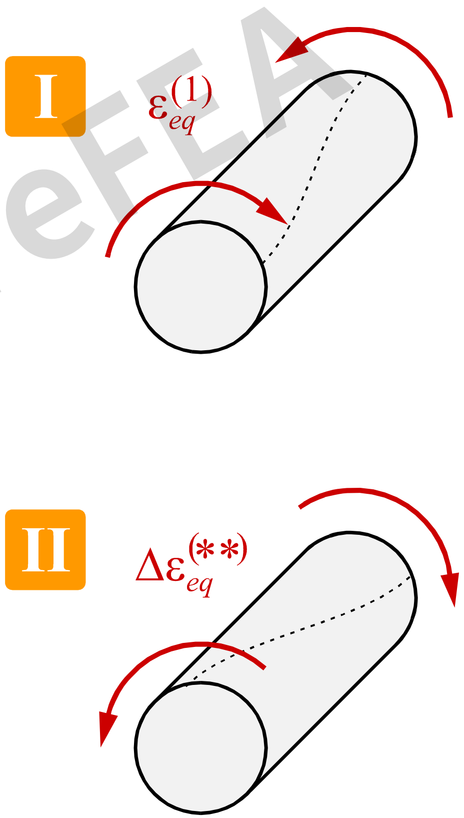
$$\Psi = \int_0^{\varepsilon_{eq}^{**}} \frac{d\varepsilon_{eq}}{\varepsilon_{eq}^{**}(\eta)} \approx \sum_{n=0}^{n^{**}} \frac{\Delta\varepsilon_{eq}^{(n)}}{\varepsilon_{eq}^{**}\left(\eta^{(n)}\right)} \leq 1$$

- Scalar description of damage is mainly used in fracture models of commercial FE codes

MATFEM

Integral damage accumulation with tensorial description of damage in CrachFEM





ε_{eq}^{**} monotonic fracture strain

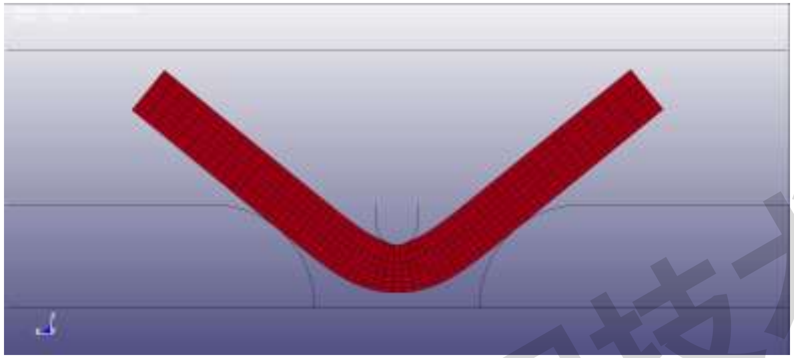
Fracture criteria in CrachFEM

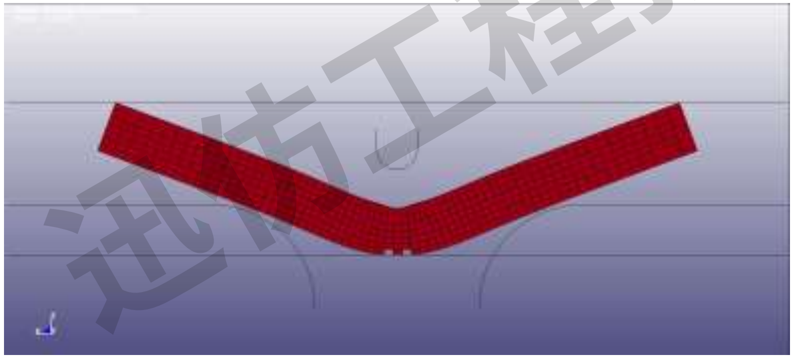
MATFEM

Tensorial vs. scalar descripton of damage

- Example: Al sheet, step 1: bending to 90 deg, step 2: flattening between horizontal tools
  FE model with one row of hexahedrons under plane strain tension

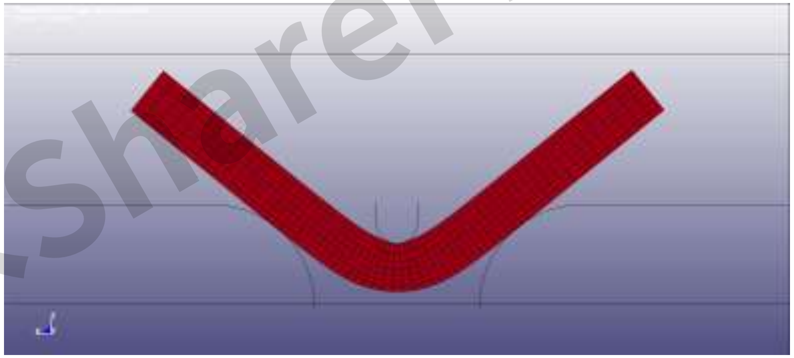
scalar description of damage

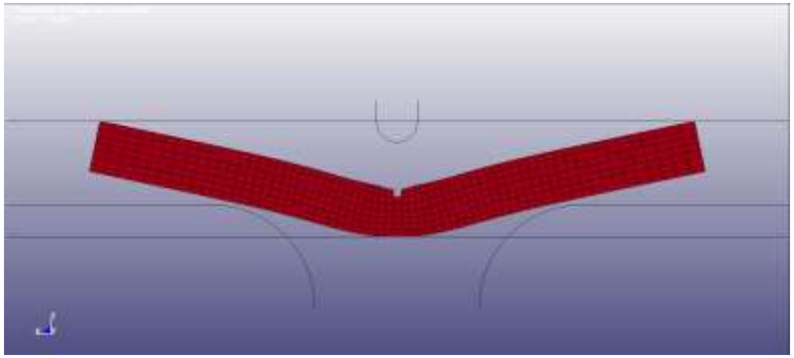




- Failure predicted too early and on wrong side of sheet

tensorial description of damage



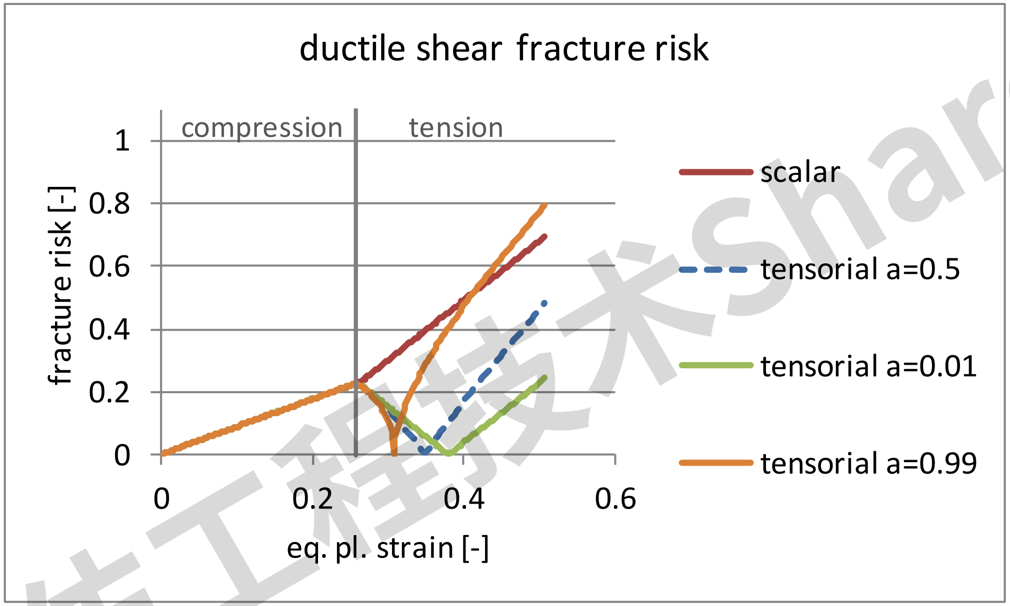


- Failure predicted on correct side of sheet

MATFEM

Influence of damage evolution parameter *a* of the tensorial model in CrachFEM

- Example: compression followed by tension, shear fracture model



- The decrease/increase of the fracture risk after the change in loading direction is controlled by the damage evolution parameter *a*
  - a → 0: complete recovery of the material is assumed
  - a → 1: damage evolution after change in loading path is increasing
  - a = 0.5: default

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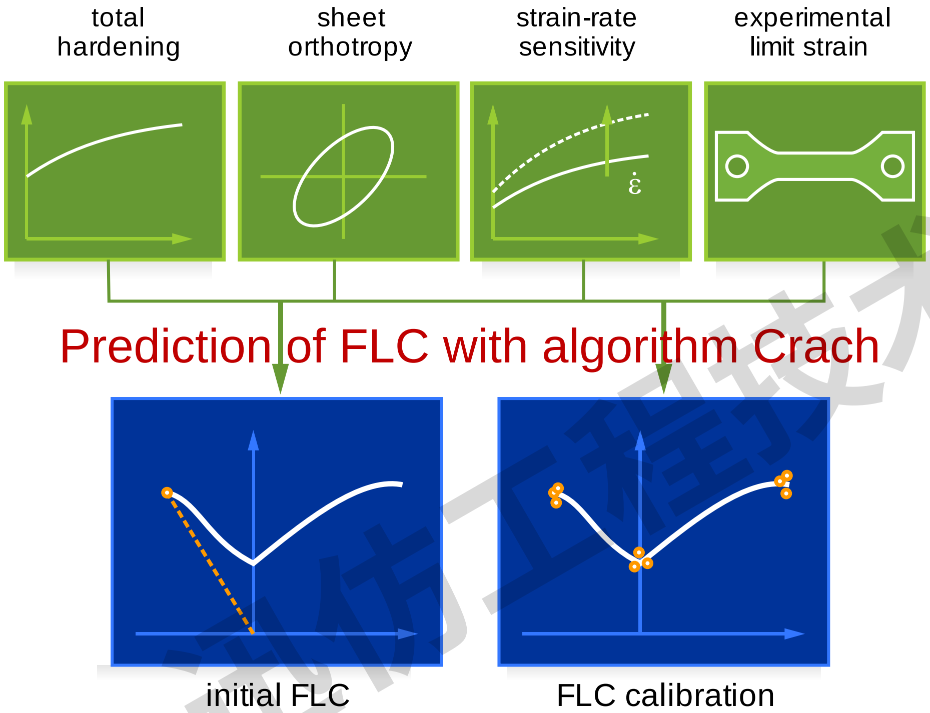
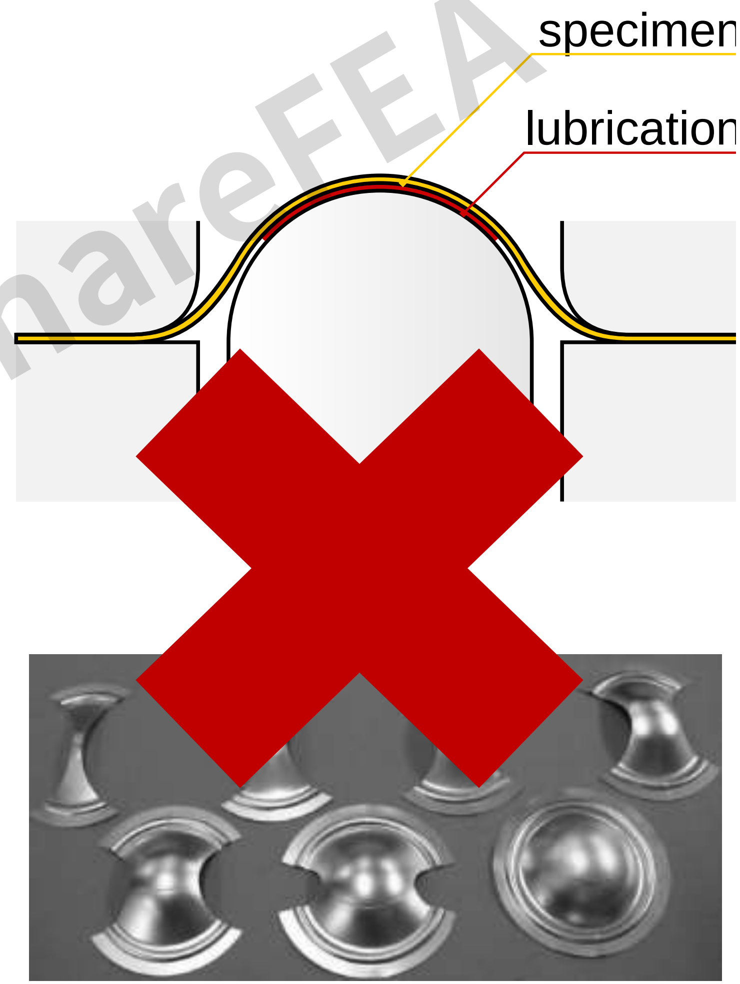
CrachFEM for quenched boron sheets

MATFEM

Prediction of forming limit diagram with software CrachLab/CrachFEM (virtual experiment) vs. Nakajima test



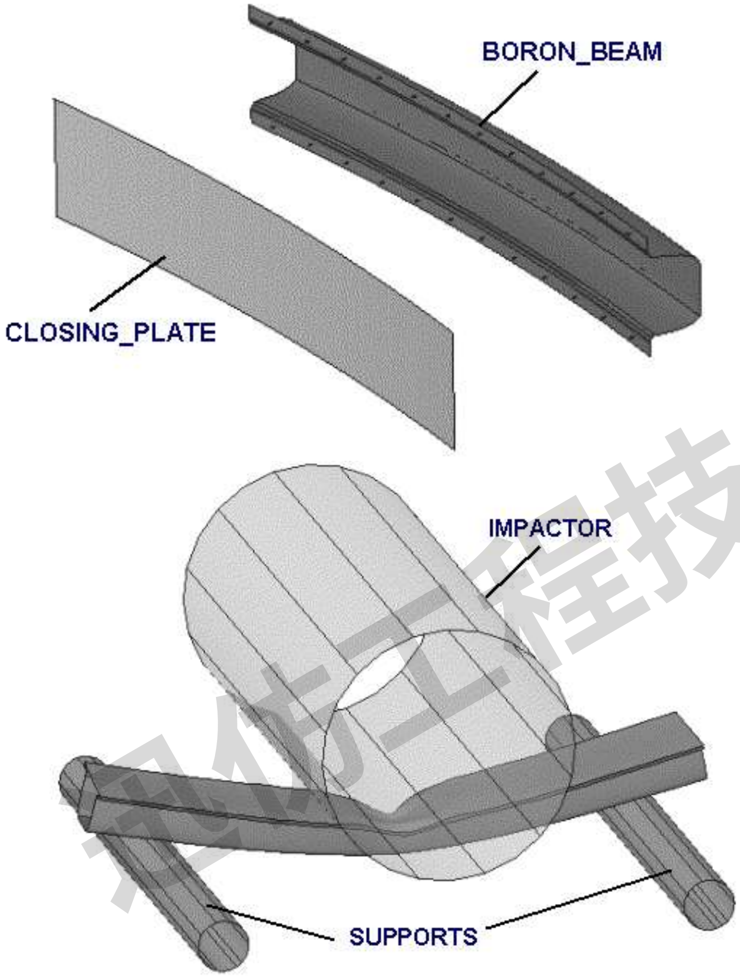


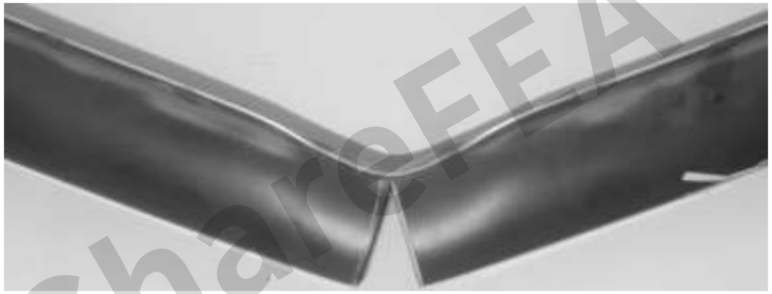
Experimental approach not possible for press hardened boron steel

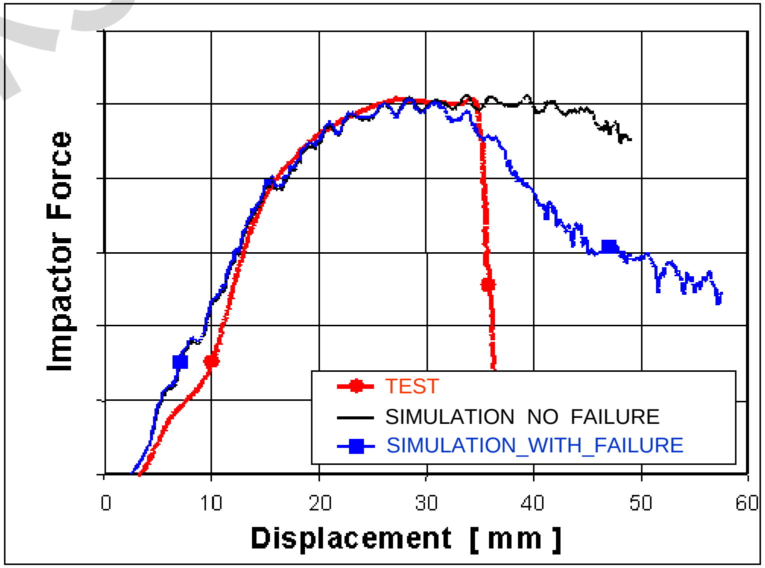
CrachFEM for quenched boron sheets

MATFEM

Failure prediction with CrachFEM for components made from quenched boron steels



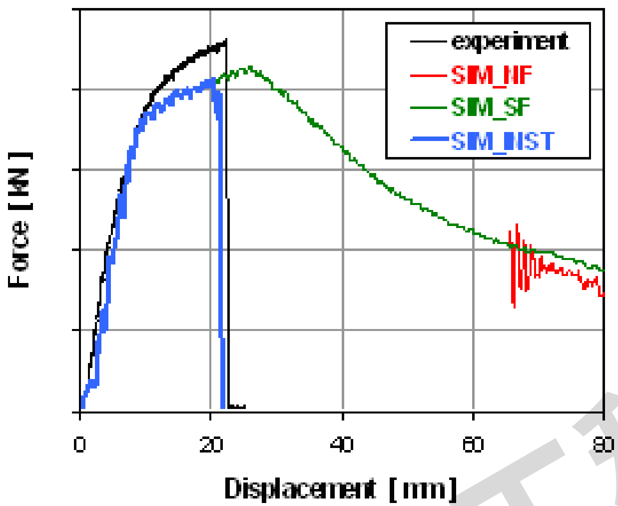


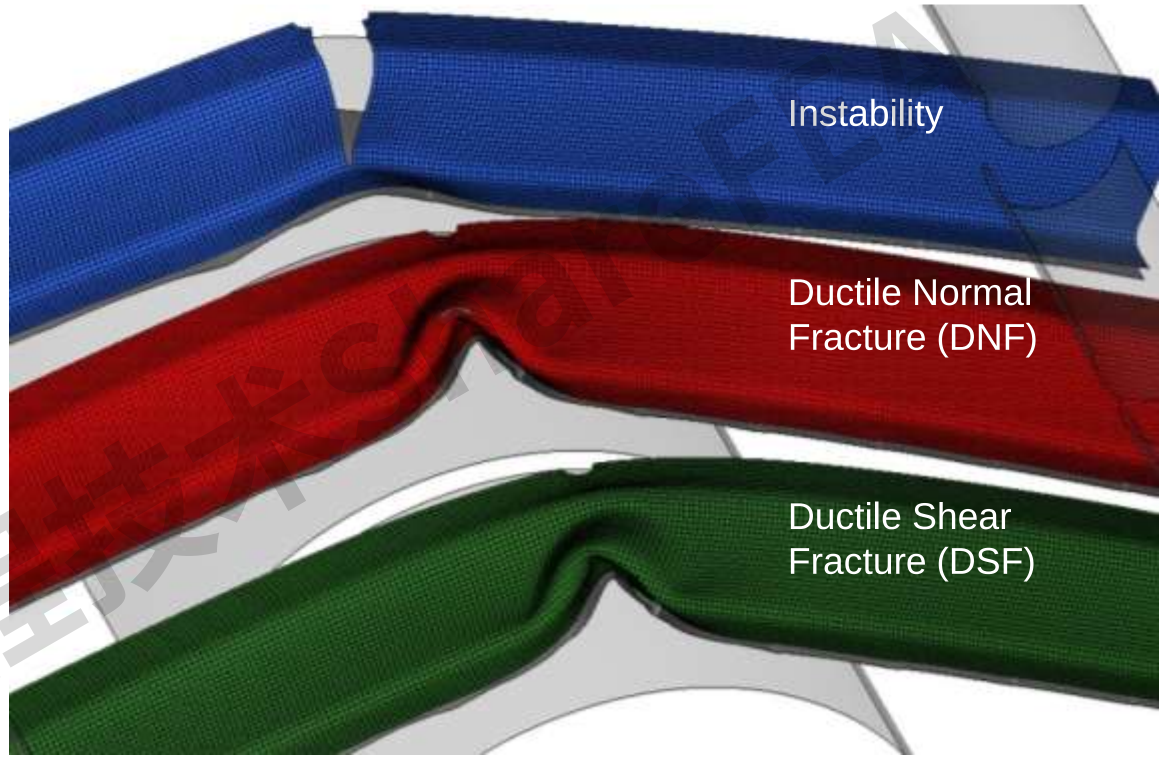


Source: H. Lanzerath, A. Bach, G. Oberhofer, H. Gese: ‘Failure prediction of boron steels in crash’, SAE 2007 World Congress, Michigan, SAE-Paper 2007-01-0989, 2007.

CrachFEM for quenched boron sheets

Failure prediction with CrachFEM for components made from quenched boron steels
 - generic component with circular hole





- The relevant failure mechanism is necking
- The FEM shell mesh is too coarse to model necking itself
- Need to account for instability as a separate failure criterion (=> algorithm Crach)

Source: G. Oberhofer, A. Bach, M. Franzen, et al, *A Systematic Approach to Model Metals Compact Polymers and Structural Foams in Crash Simulations with a Modular User Material,* 7th European LS-DYNA Conference, Salzburg 2009

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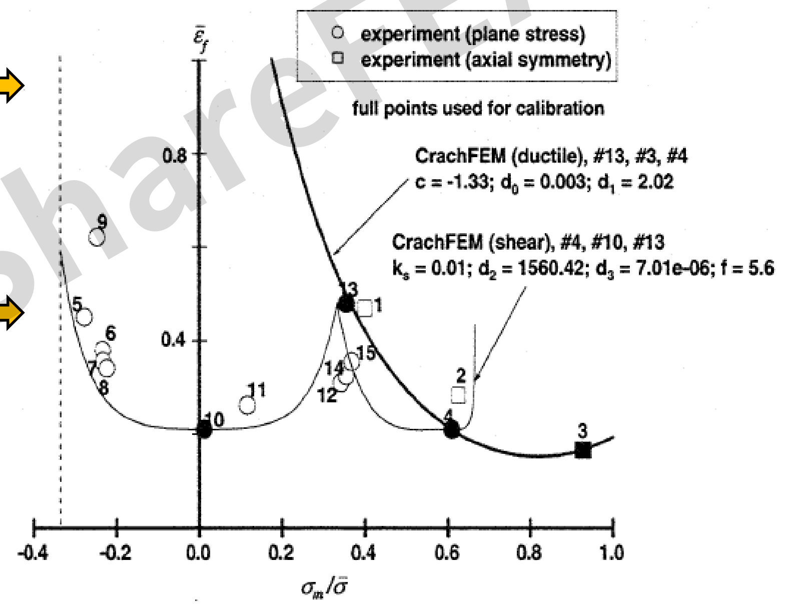
Improved model for ductile normal fracture

Prediction of fracture limit curves with CrachFEM for AA2024-T3 (2005)
In the frame of fracture benchmark of Prof. Wierzbicki and co-workers

$$\varepsilon_{eq,f}^{DNF-I} = d_0 \exp(-c\eta) + d_1 \exp(c\eta)$$

$$\varepsilon_{eq,f}^{DSF} = d_2 \exp(-f\,\theta) + d_3 \exp(f\theta) \text{ with } \theta = \frac{1-k\eta}{\tau_{max}/\sigma_{eq}}$$

- CrachFEM uses two different criteria for ductile normal fracture (DNF) and ductile shear fracture (DSF)
- DSF model uses a stress state parmeter θ, which depends on two stress invariants; good approximation of all experiments with shear fracture
- Older DNF-I model of CrachFEM gives good approximation of axialsymmetric tests but is not unique for experiments „2“ and „4“



Source (Figure): T. Wierzbicki et al. , International Journal of Mechanical Sciences 47 (2005) pp. 719-743

Improved model for ductile normal fracture

MATFEM

Improved prediction of ductile normal fracture with CrachFEM for AA2024-T3

Normal fracture

$$\varepsilon^{**}(\beta)$$

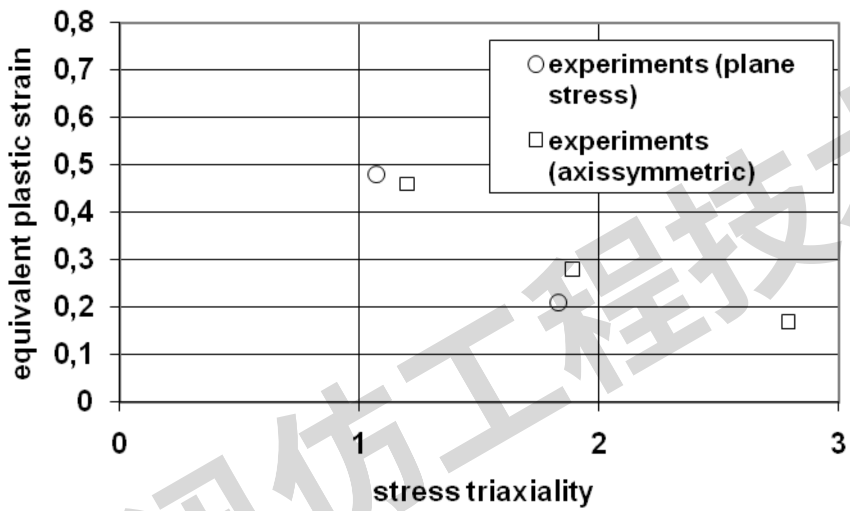
$$\eta = -3 * p / \sigma_M$$

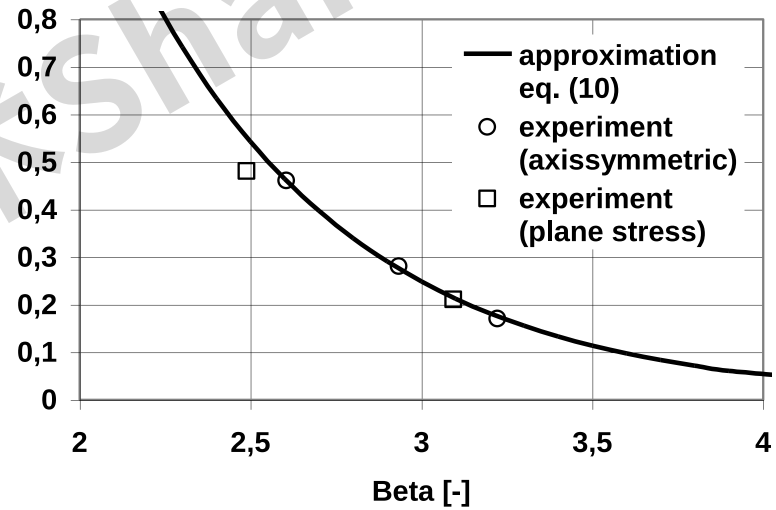
$$\beta = (1 - s_{NF}\,\eta)/\nu$$

$$\beta = \beta(\eta, \nu)$$

$$\nu = \sigma_1 / \sigma_M$$

$$\varepsilon_{eq}^{**} = d \cdot e^{q \cdot \beta}$$





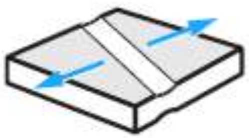
Old ductile fracture model DNF-I based on stress triaxiality η is no longer unique for 3D stress states. Ductile normal fracture model DNF-II based on new stress state parameter β shows good fit for all experimental data.

Source: Dell, H., Gese. H. und Oberhofer, G.: CrachFEM - A Comprehensive Approach for the Prediction of Sheet Metal Failure. Materials Processing and Design: Modeling, Simulation and Applications. Part 1. Numiform '07. American Institute of Physics (2007), pp. 165-170.

Improved model for ductile normal fracture

MATFEM

Overview of failure criteria in CrachFEM

			shell	solid
	Local instability (necking)	Initial FLC (approximate)		(1)
		Prediction with Crach		(1)
		Post-critical elongation		(1)
	Ductile normal fracture	$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\eta)$		(2)
		$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\beta)$		
	Ductile shear fracture	$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\theta)$		

2D: shells 3D: solid elements (1) not reasonbable (2) not recommended

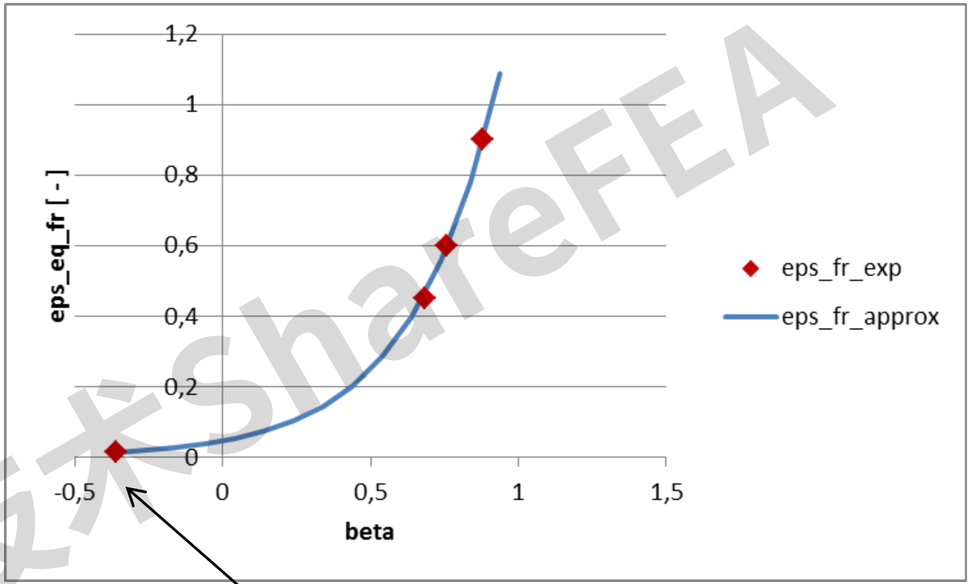
Tensorial description of damage for nonlinear strain paths

Improved model for ductile normal fracture

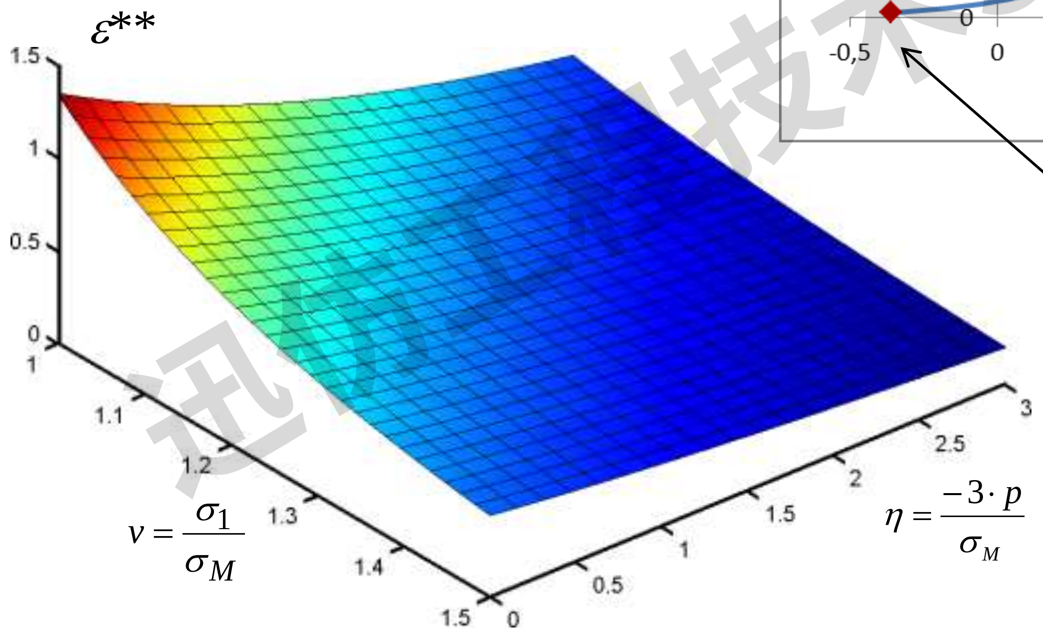
MATFEM

Use of β-model for approximation of data with normal fracture in CrachFEM

- Approximation of experiments with beta-model for ductile normal fracture; optimization by variation of parameters (right)
- Derived 3D fracture surface for ductile normal fracture (below)



triaxial tension for β = -3s

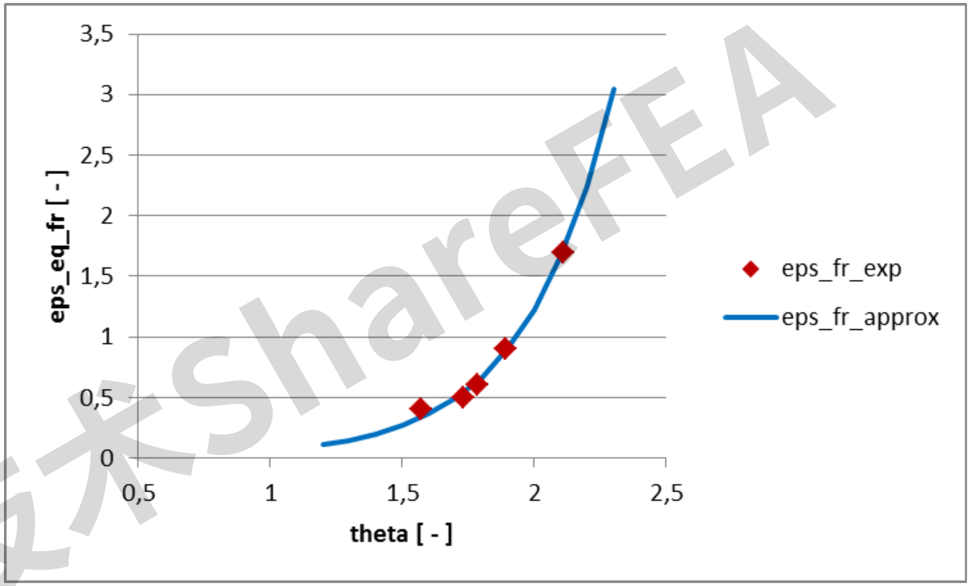


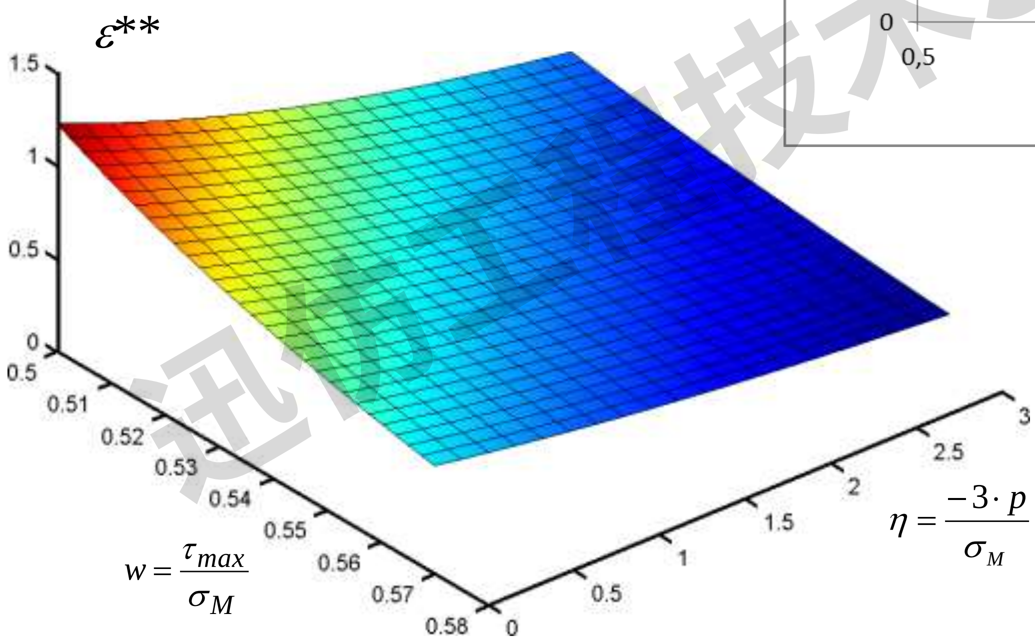
Improved model for ductile normal fracture

MATFEM

Use of θ-model for approximation of data for ductile shear fracture in CrachFEM

- Approximation of experiments with theta-model for ductile shear fracture; optimization by variation of parameter k (right)
- Derived 3D fracture surface for ductile shear fracture (below)





- Level curves of derived 3D fracture surfaces for ductile normal fracture and ductile shear fracture can be easily combined to a common fracture surface for other integral fracture limit criteria defined via sampling points $\varepsilon^{**} = \varepsilon^{**}$(triaxiality, Lode angle)

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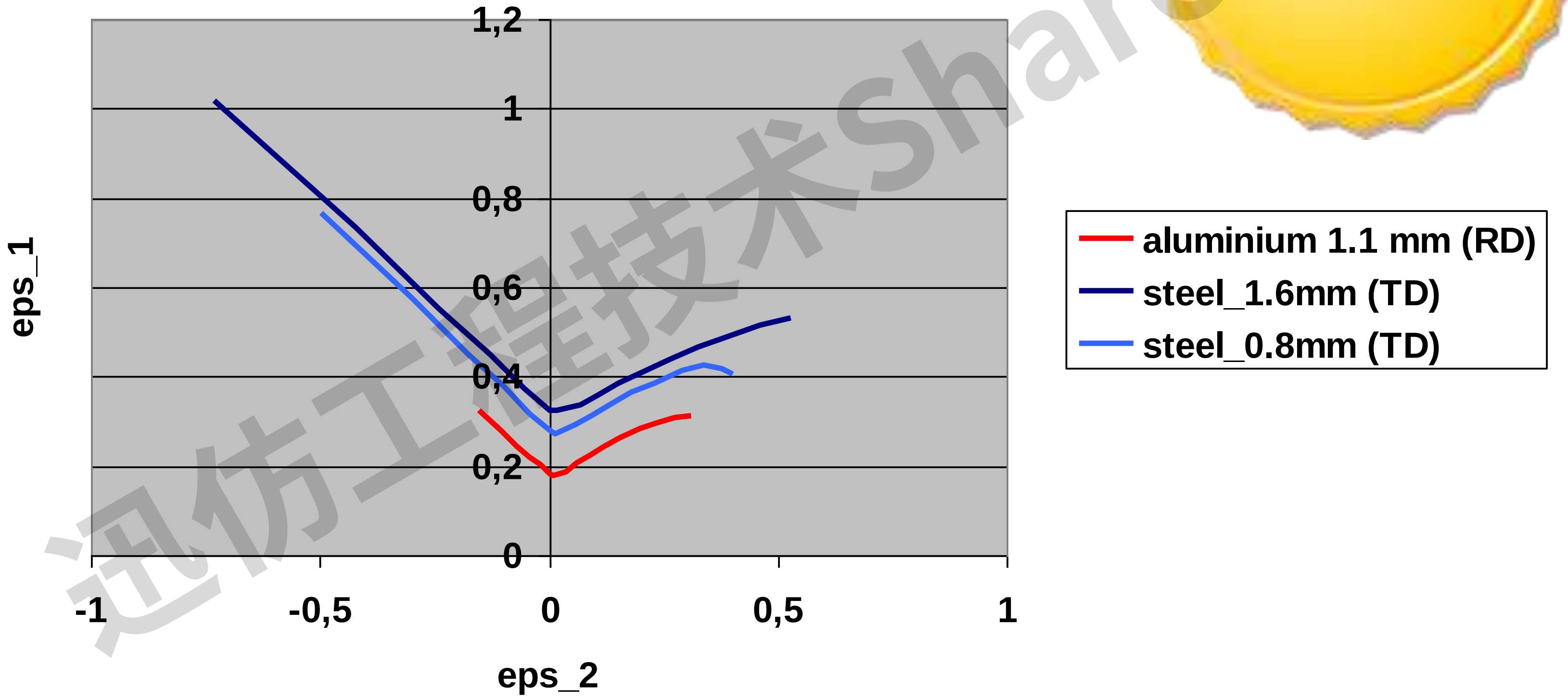
Results with CrachLab/CrachFEM for Benchmark 1 of Numisheet 2008

CrachLab shows best performance in the FLC benchmark at Numisheet 2008!



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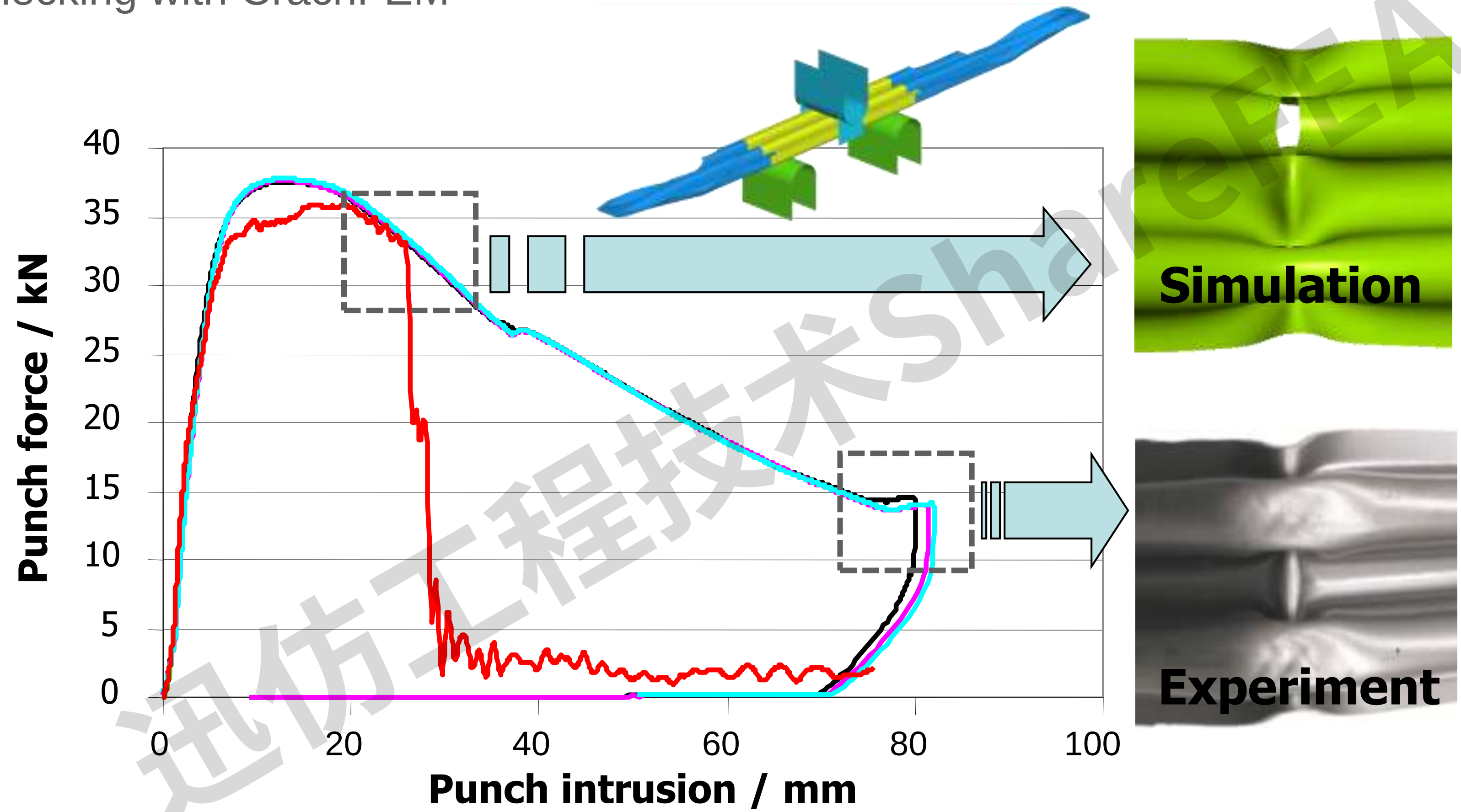
Model for post instability strain

MATFEM

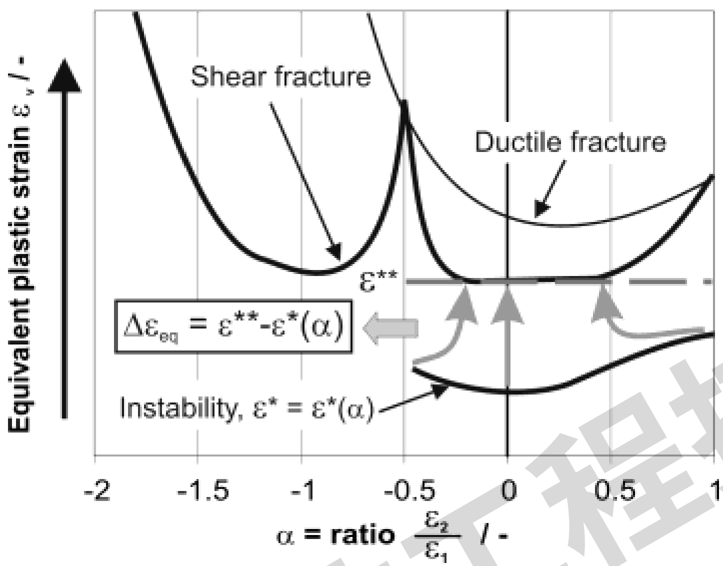
Extremely conservative prediction by direct element elimination due to localized necking with CrachFEM

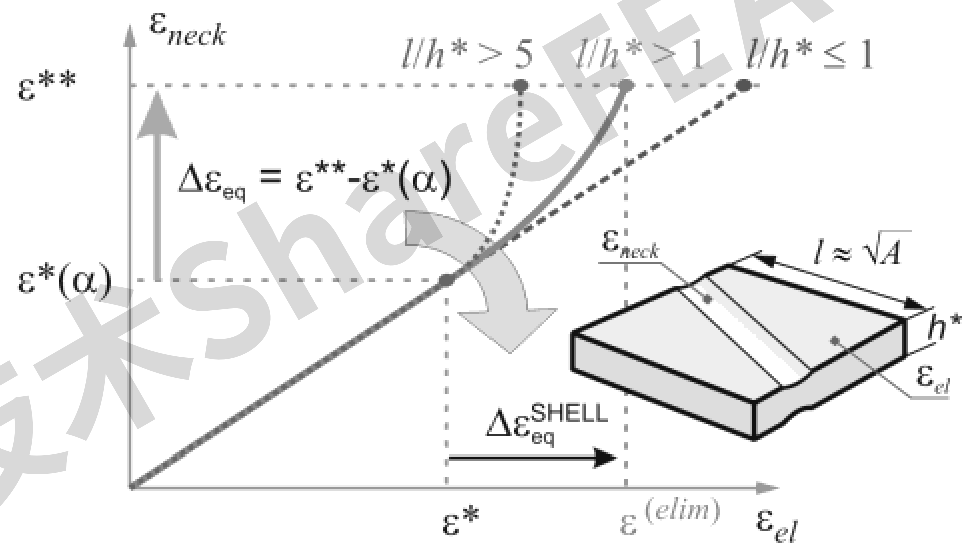


Source: L. Keßler, H. Gese, G. Metzmacher, H. Werner: 'An approach to model sheet failure after onset of localized necking in industrial high strength steel stamping and crash simulations', SAE 2008 World Congress, Michigan, SAE-Paper 2008-01-0503, 2008.

Model for post instability strain

Mesh size independent evaluation of post instability strain in CrachFEM (PIS-model)

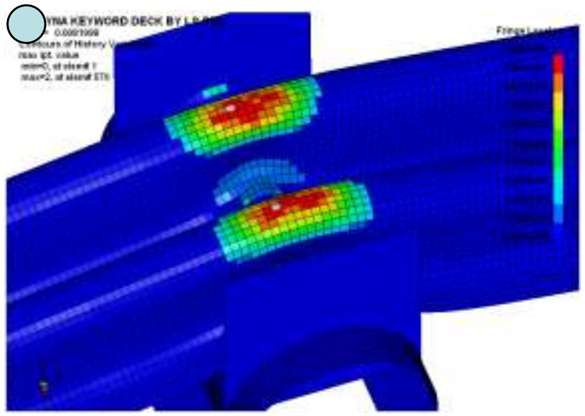




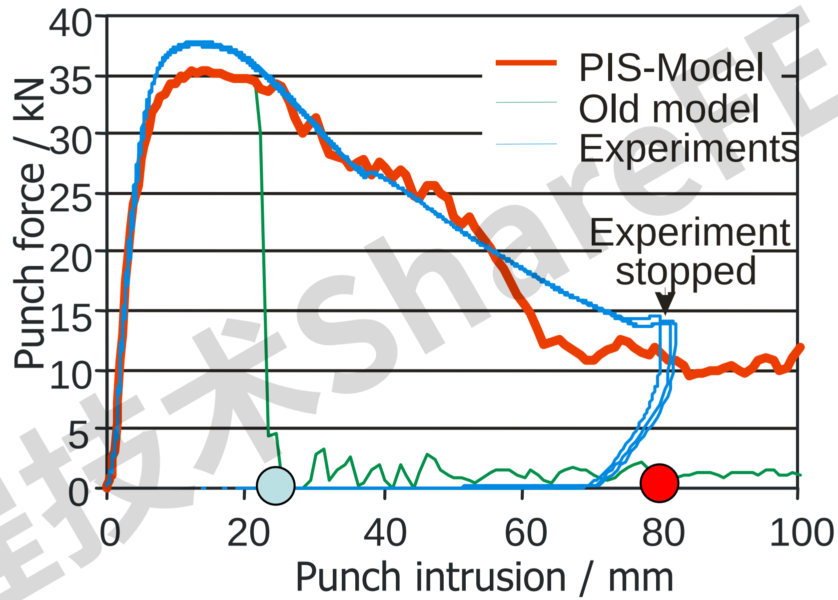
$$\Delta\varepsilon_{eq}^{\text{shell}} = \left(\varepsilon^{**}-\varepsilon^{*}\right)^{k} \cdot \mathrm{e}^{-c\cdot\frac{\sqrt{A}}{h^*}}$$

Source: L. Keßler, H. Gese, G. Metzmacher, H. Werner: 'An approach to model sheet failure after onset of localized necking in industrial high strength steel stamping and crash simulations', SAE 2008 World Congress, Michigan, SAE-Paper 2008-01-0503, 2008.

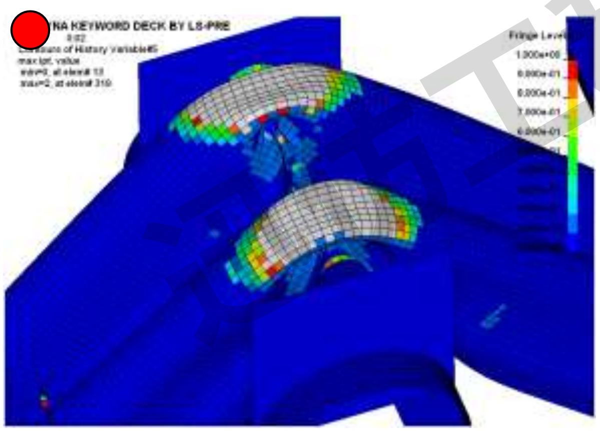
Significantely improved prediction after introduction of post instability strain



Risk for localized necking after punch displacement of 23 mm



punch 80 mm



Initialization of localized necking for risk > 1.0
Element with PIS are indicated by risk of 2.0 (grey)

Risk for localized necking after punch displacement of 80 mm

Source: L. Keßler, H. Gese, G. Metzmacher, H. Werner: 'An approach to model sheet failure after onset of localized necking in industrial high strength steel stamping and crash simulations', SAE 2008 World Congress, Michigan, SAE-Paper 2008-01-0503, 2008.

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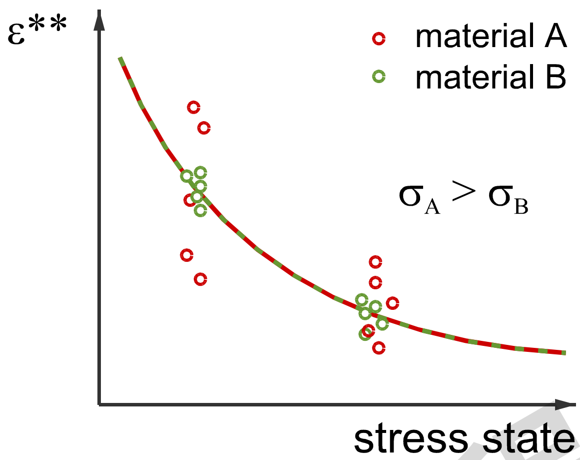
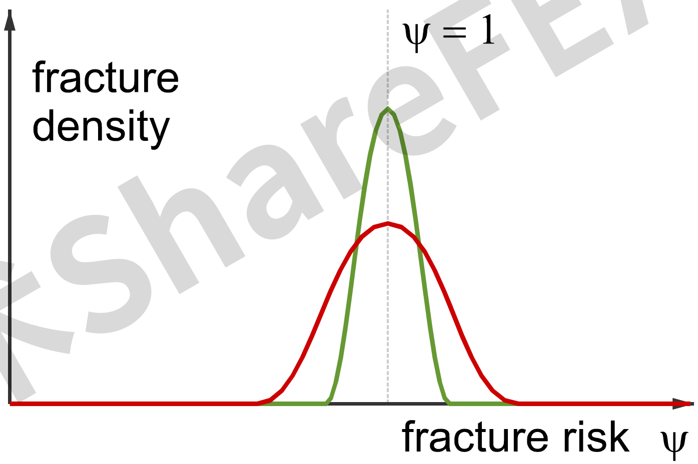
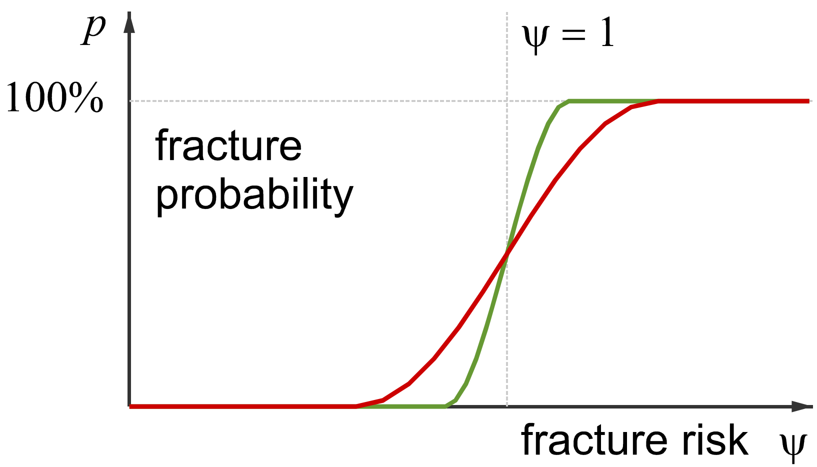
Failure Probability in CrachFEM

MATFEM

Overview





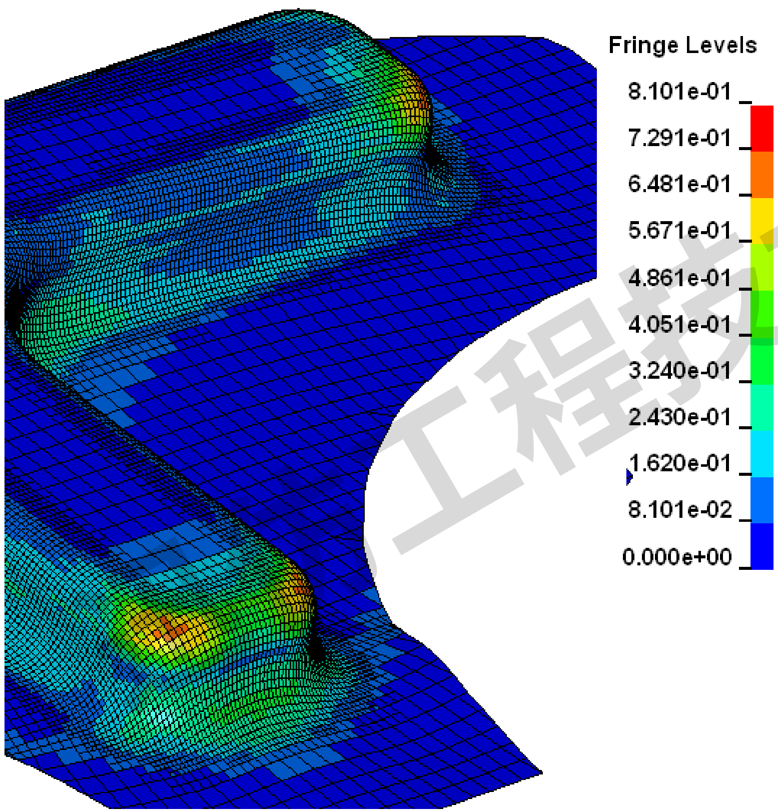


The fracture probability depends on scatter in the fracture behaviour of the material. Statistical data, e.g. standard deviation σ is required to evaluate fracture probability

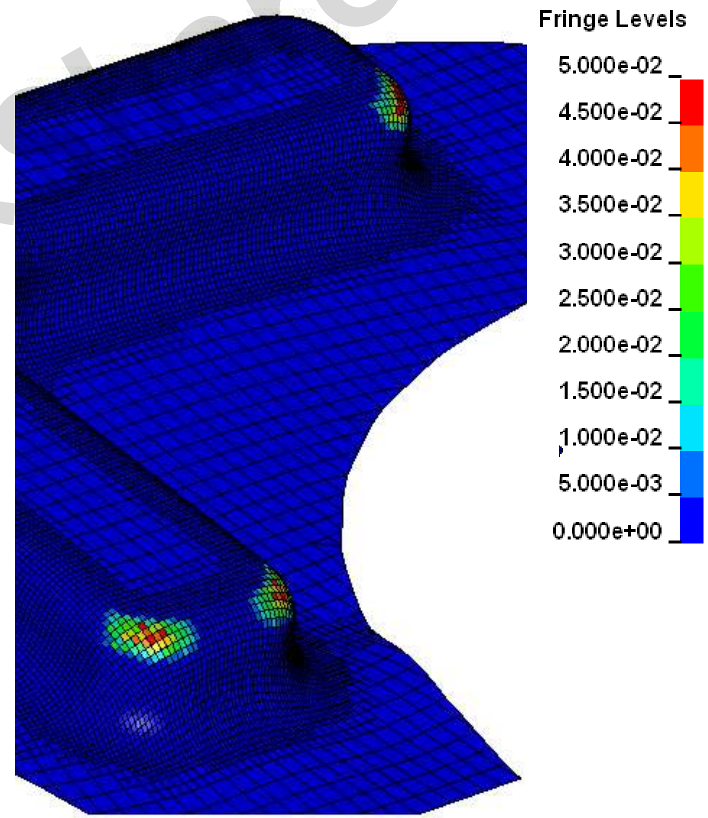
MATFEM

Fracture risk vs. fracture probability

Ductile shear fracture risk



Ductile shear fracture probability



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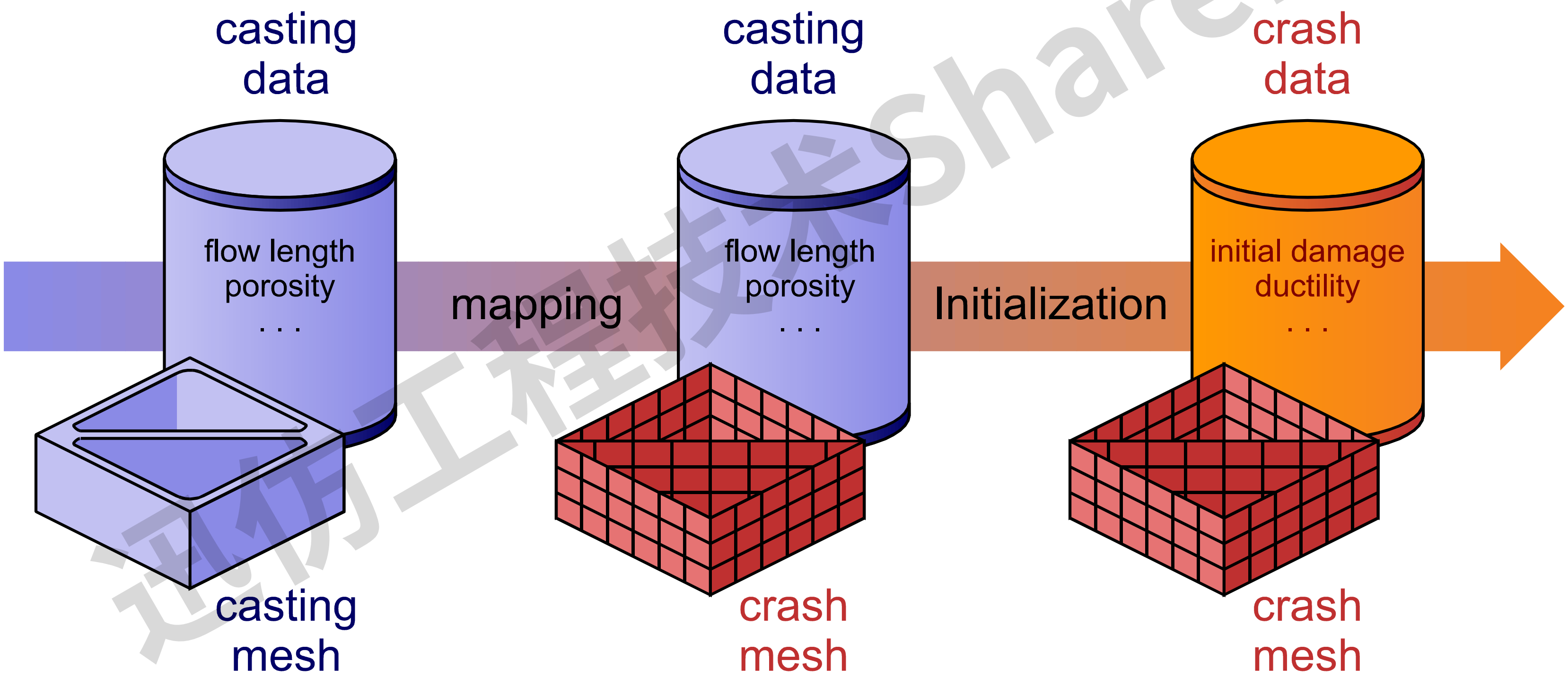
CrachFEM for high pressure die cast materials

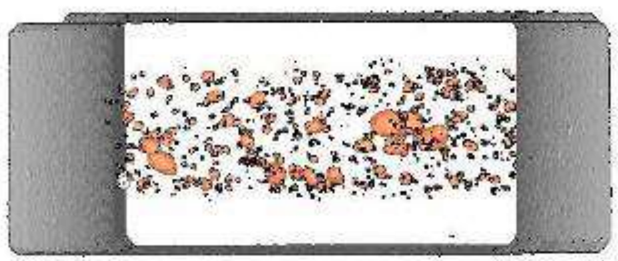
MATFEM

Multi-trade approach for HPDC components
(developed during project NADIA)

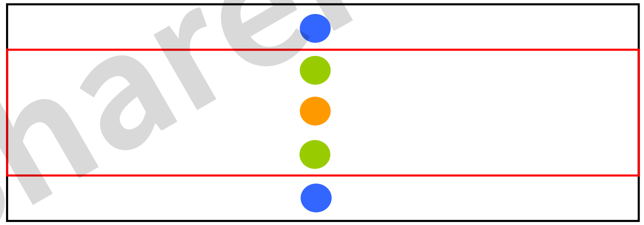


Extension of model for ductile normal fracture
- introduction of initial microporosity

NADIA
New Automotive components Designed for and manufactured by Intelligent processing of light Alloys



CT Scan of AM60 by S. Tewes (Foundry Institute, Aachen)



Initialisation of porosity on integration points

The microporosity in the core zone can be modeled by an initialisation of a non-zero porosity damage at defined integration points of a shell element. The actual solution is an initialisation of the 3 inner integration point with a non-zero porosity damage (calibrated by tensile tests).

The evolution of porosity damage p is a function of the stress triaxiality η. Only the damage ψ for ductile normal fracture is increased by porosity.

Evolution of porosity damage:

$$dp = c_1(1 - e^{-c_2\eta})p\frac{d\varepsilon_M}{\varepsilon_M^{**}}$$

Fracture criterion:

$$\psi + p = 1$$

$$\eta = \frac{\sigma_{hydr}}{\sigma_M}$$

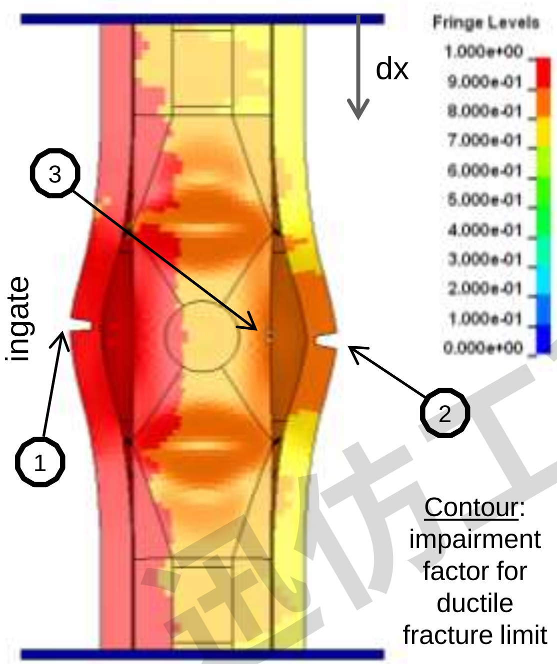
CrachFEM for high pressure die cast materials

MATFEM

Mechanical simulation of Mg-HPDC – predictive quality

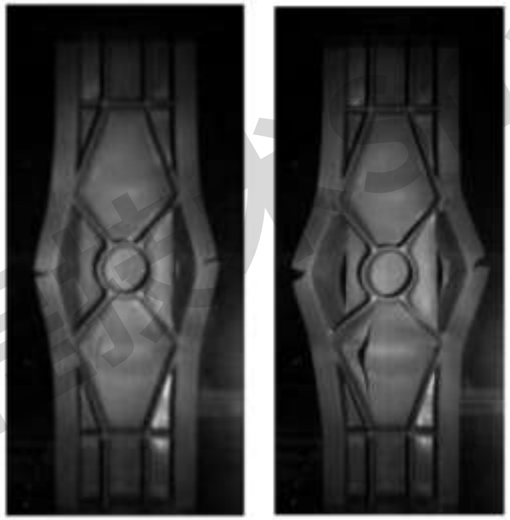
NADIA
New Automotive components Designed for and manufactured by Intelligent processing of light Alloys

Dynamic axial crash of Y-Box (AM60) with central ingate

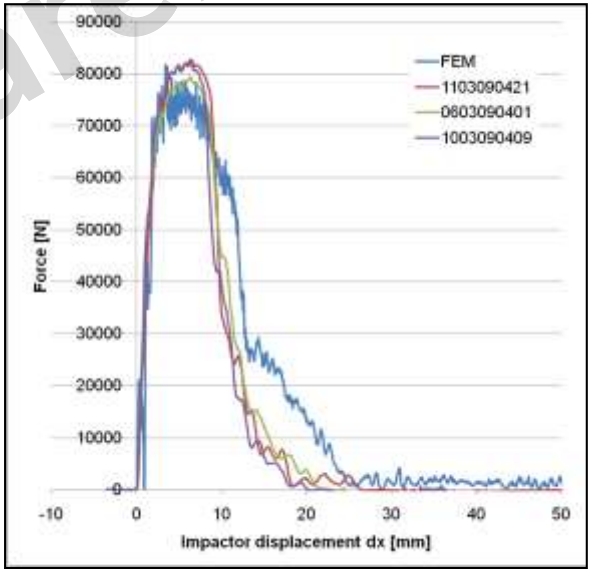


Contour: impairment factor for ductile fracture limit

FE simulation for dx= 10.7 mm with fracture initiation at locations 1-3



experiments provided for dx= 8 mm and dx=11 mm



force-deflection of experiments and FEM

➔ Good prediction of force-deflection and failure initation in FEM

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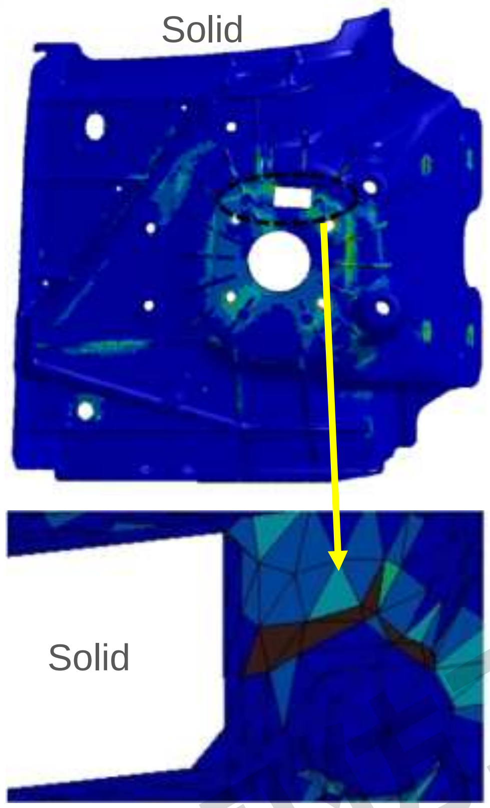
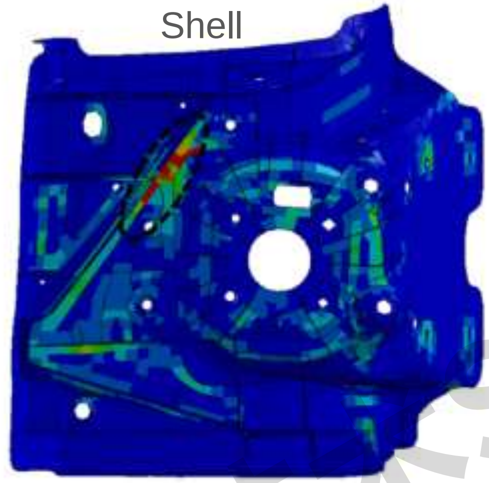
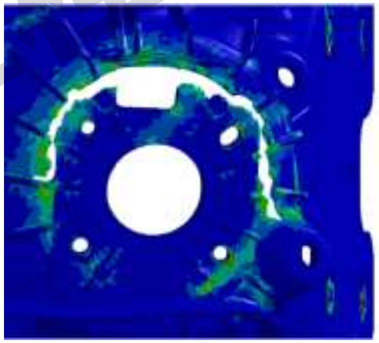
Fracture prediction in real HPDC component with tetrahedron (left) and shell (right) models





- Precise prediction of crack initiation with tetrahedron models
- Shells show not even elevated failure risk at push out points
- Crack propagation in tetrahedron models agree also well with tests

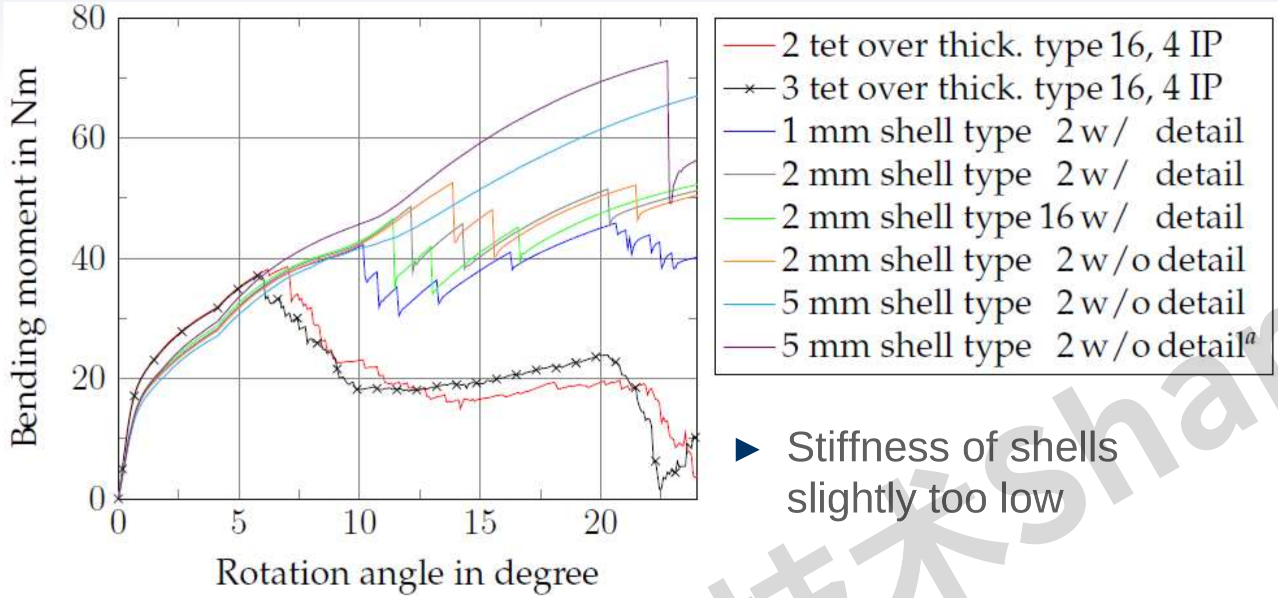
Solid

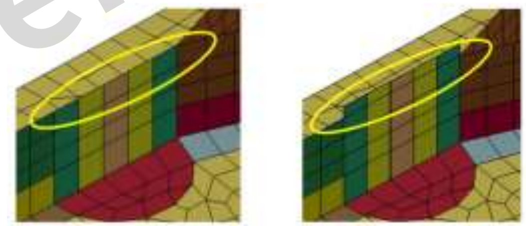


Source: F. Brenner, M. Buckley, H. Gese, G. Oberhofer, Influence of Discretisation on Stiffness and Failure Prediction in Crashworthiness Simulation of Automotive High Pressure Die Cast Components, 9th European LS-DYNA Conference, Manchester, 2013

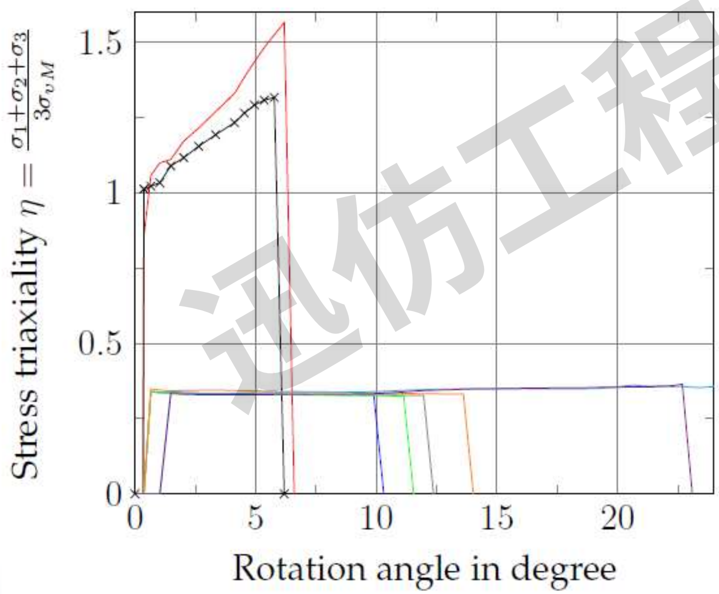
Influence of discretization on failure prediction for cast components

MATFEM





(a) Detail neglected (b) Detail taken into account



- Stiffness of shells slightly too low
- Shells show pronounced mesh dependency of failure prediction
- Compared to tetrahedrons failure occurs too late for shells
- No elevated stress triaxiality in shells
- Stress state is not captured correctly by shells

Source: F. Brenner, M. Buckley, H. Gese, G. Oberhofer, Influence of Discretisation on Stiffness and Failure Prediction in Crashworthiness Simulation of Automotive High Pressure Die Cast Components, 9th European LS-DYNA Conference, Manchester, 2013

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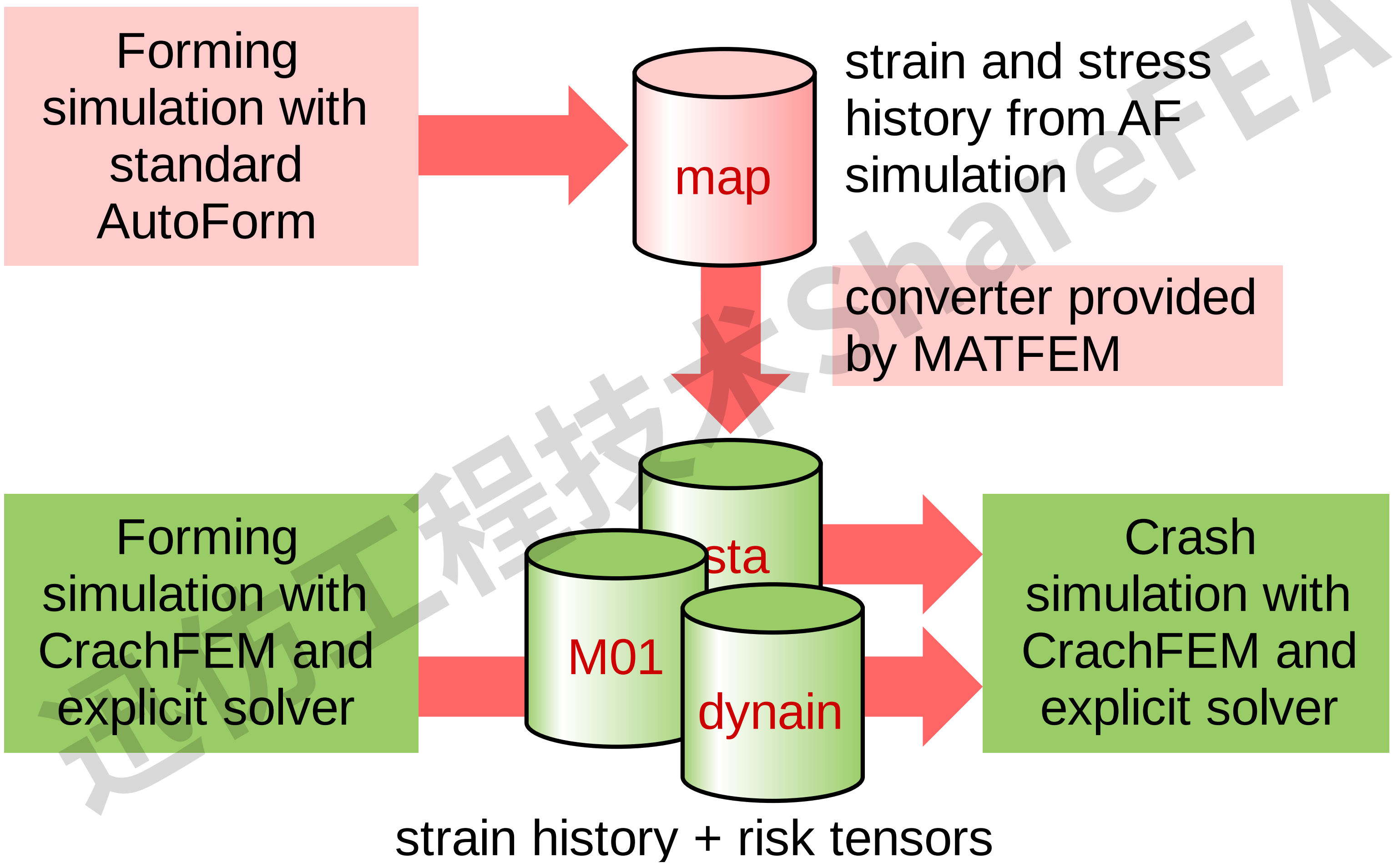
Different options for mapping to crash simulation with MF GenYld+CrachFEM

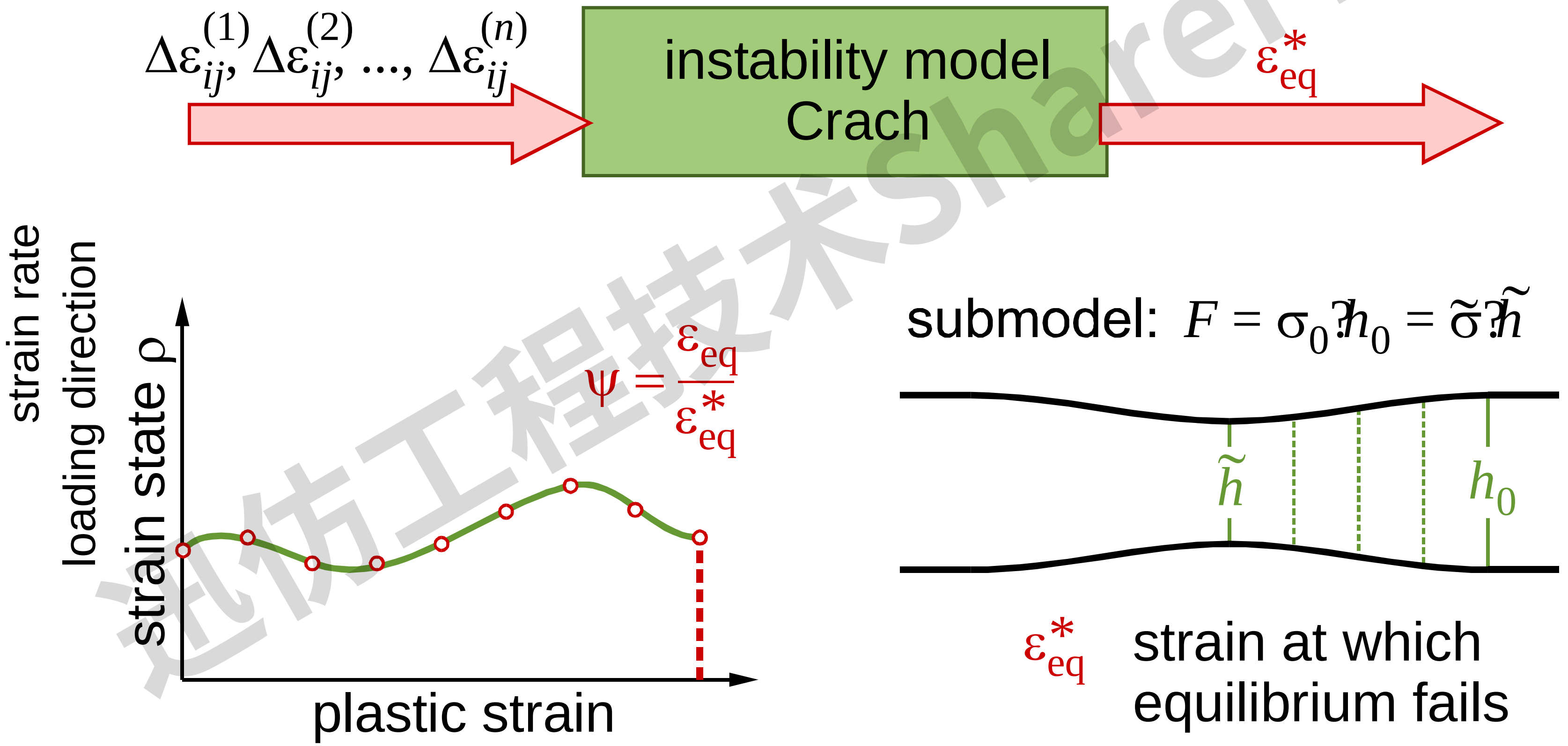


AutoForm is a registered trademark

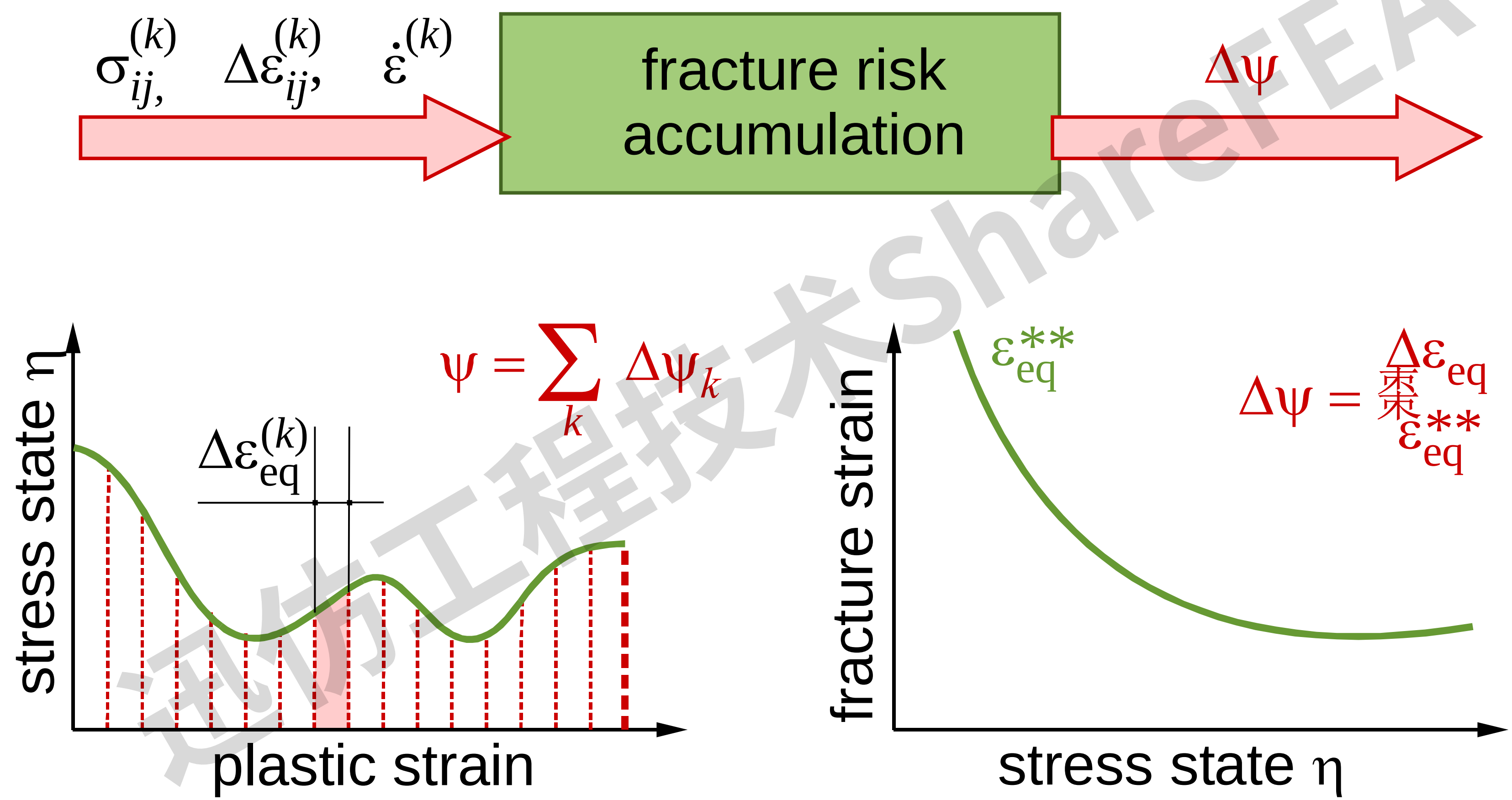
F2C-mapping of process history and damage

MATFEM

Mapping of strain history for algorithm Crach

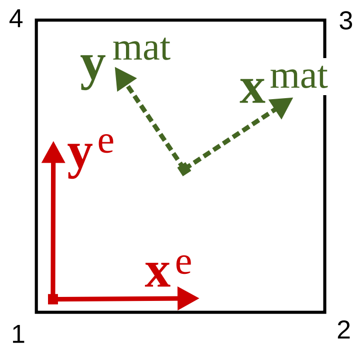


Mapping of damage tensor and accumulated damage for fracture models



Strain tensor (i.e. magnitude + direction for each element) required for tensorial accumulation and stress tensor to determine stress state η

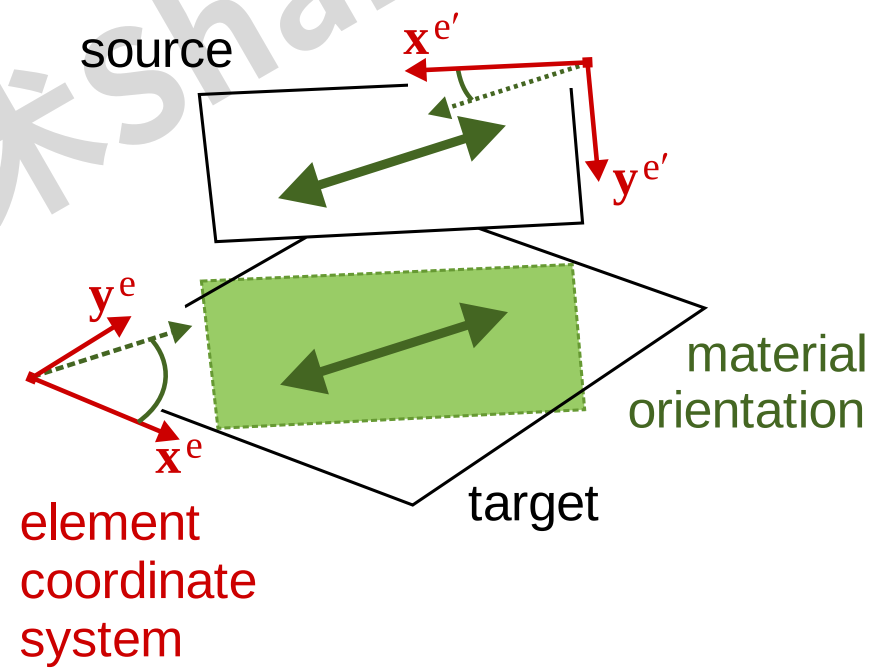
Mapping of orientation of rolling direction



History variables are represented in the material coordinate system.

Orientation applies to:

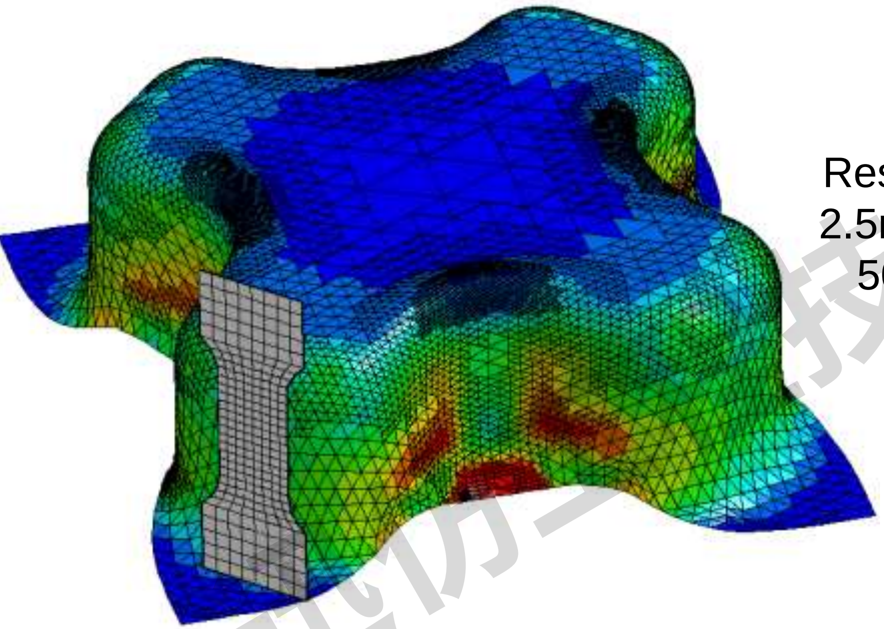
- damage tensors
- strain history



F2C-mapping of process history and damage

MATFEM

Cross-die: results for crash phase in selected position

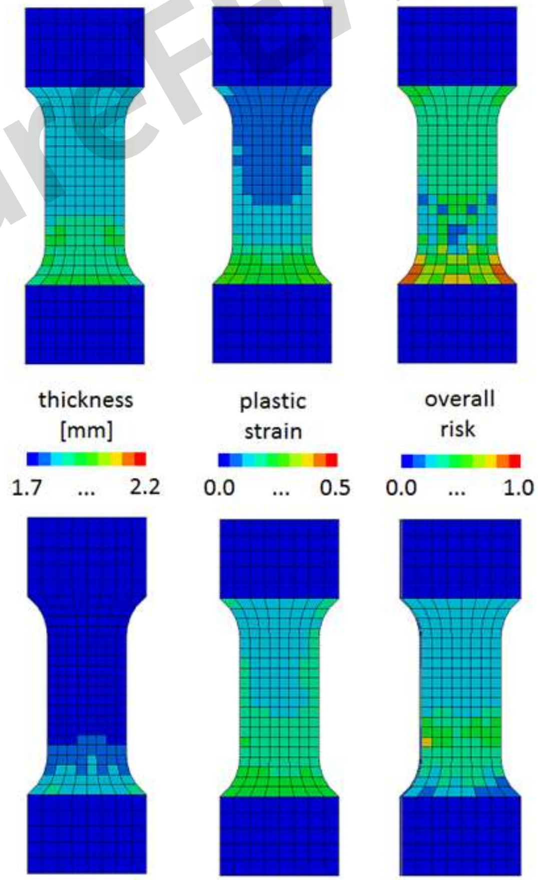


Results mapped onto 2.5mm elements on a 50mm tensile test specimen

→

DYNA

AF2Dynain

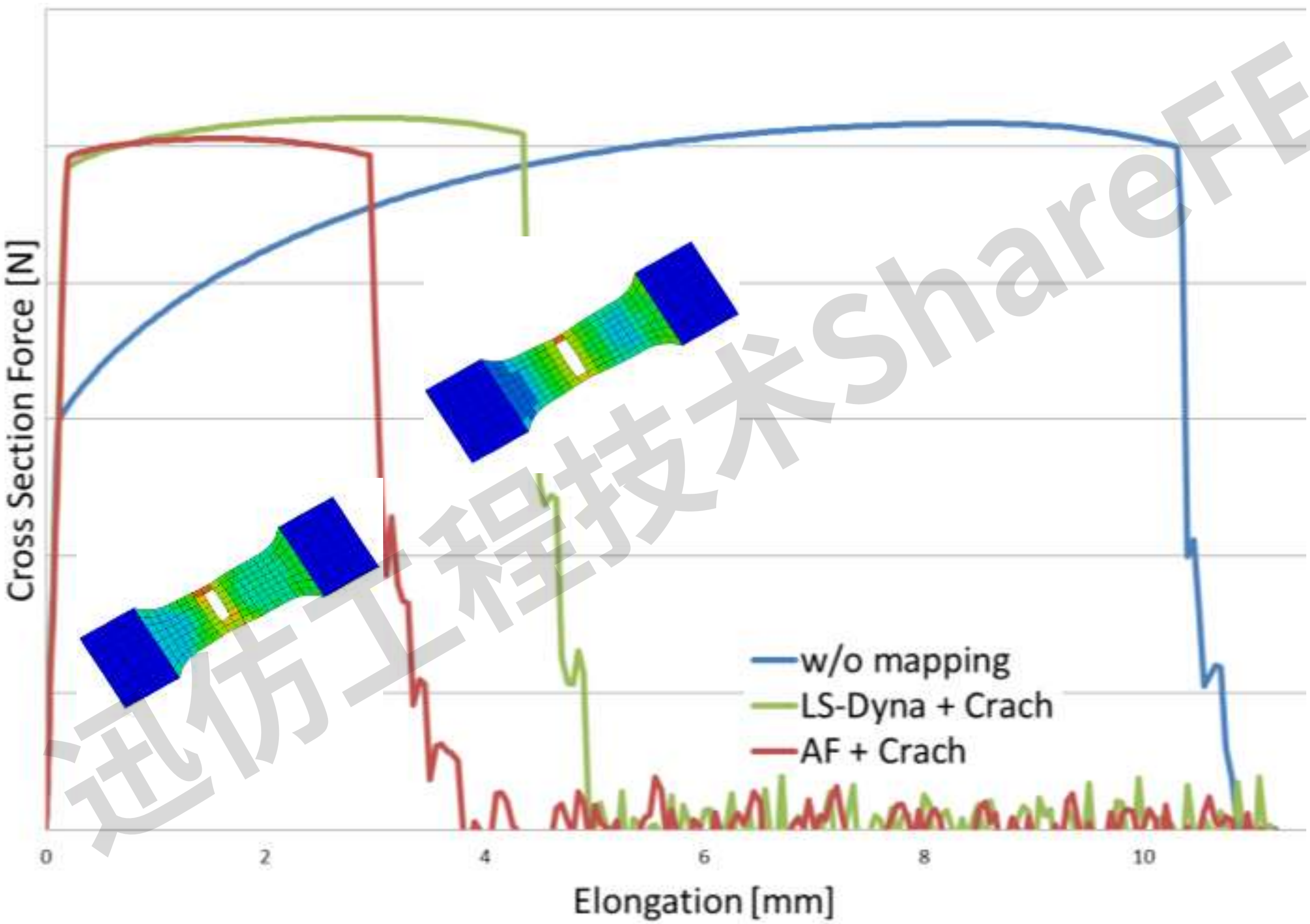


Source: M. Buckley, D. Hollingdale, M. Oehm, MF GenYld & CrachFEM in the Automotive Safety Environment, 2nd MATFEM Conference, October 17th 2012, Munich

F2C-mapping of process history and damage

MATFEM

Cross-die: results for crash phase in selected position



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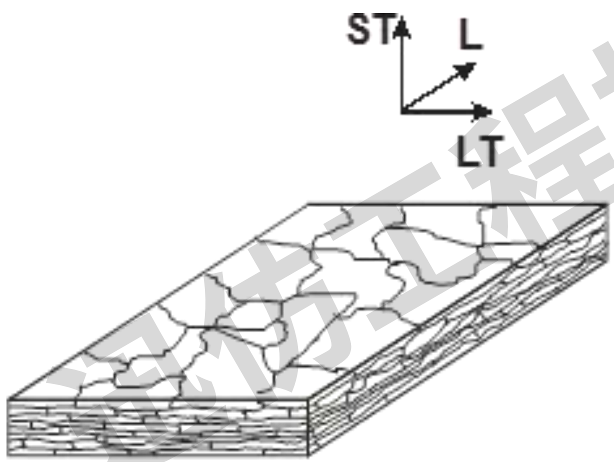
MATFEM

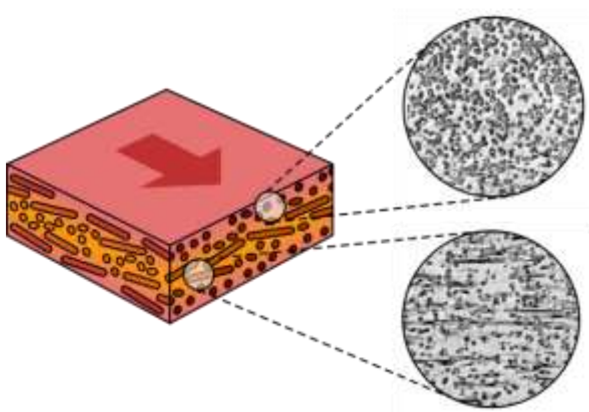
Orthotropic fracture - relevant materials

A number of technical materials exhibit an orthotropic ductility as a result of their production process and corresponding microstructure

- Aluminium and magnesium extrusions
- Hot rolled sheets and plates
- Short-fiber reinforced polymers with a high degree of fiber orientation



„pancake" grain structure in a hot rolled aluminium plate (schematic)

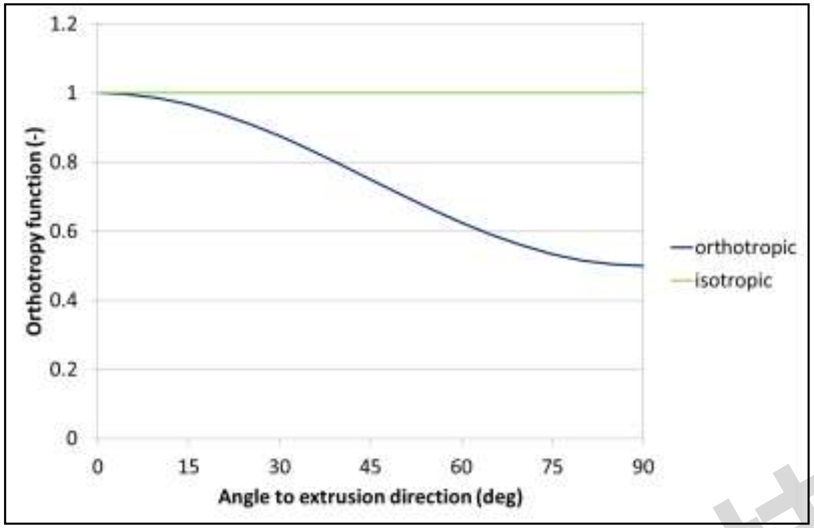


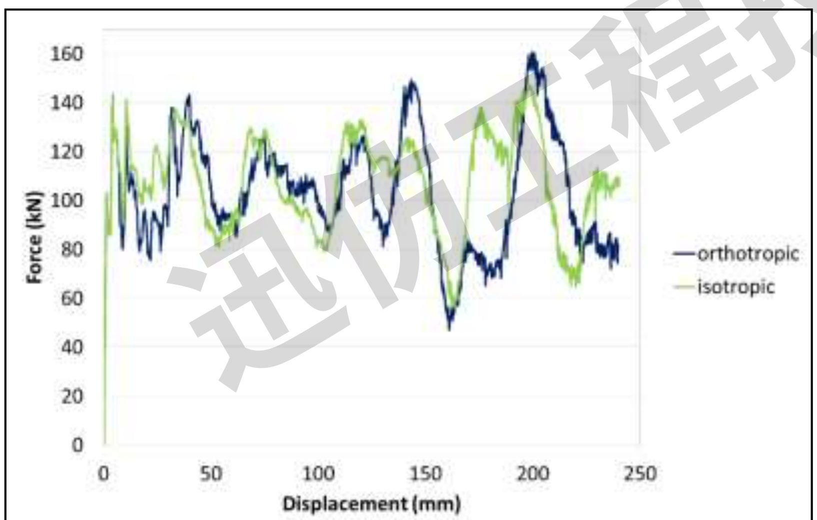
Different zones with high degree of fiber orientation in a short-fiber reinforced polymer (schematic left with real microscans right)

Orthotropy of ductility with CrachFEM

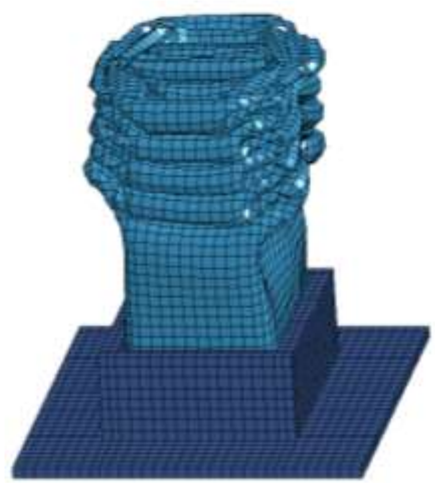
MATFEM

Results with new orthotropic fracture model in *CrachFEM* for Al-extrusion

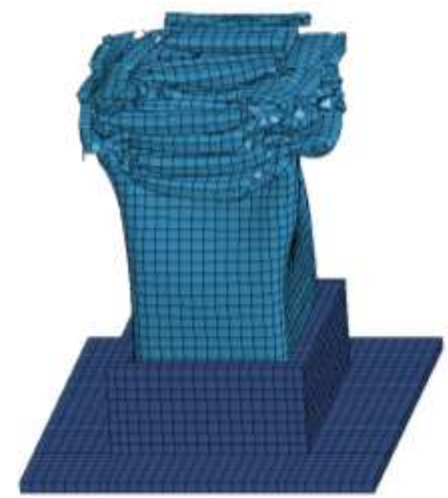




- Axial crash of Al-double chamber profile with isotropic and orthotropic fracture model
- Weakest direction normal to extrusion direction
- Significant deviation in force-deflection and deformation is observed



isotropic fracture



orthotropic fracture

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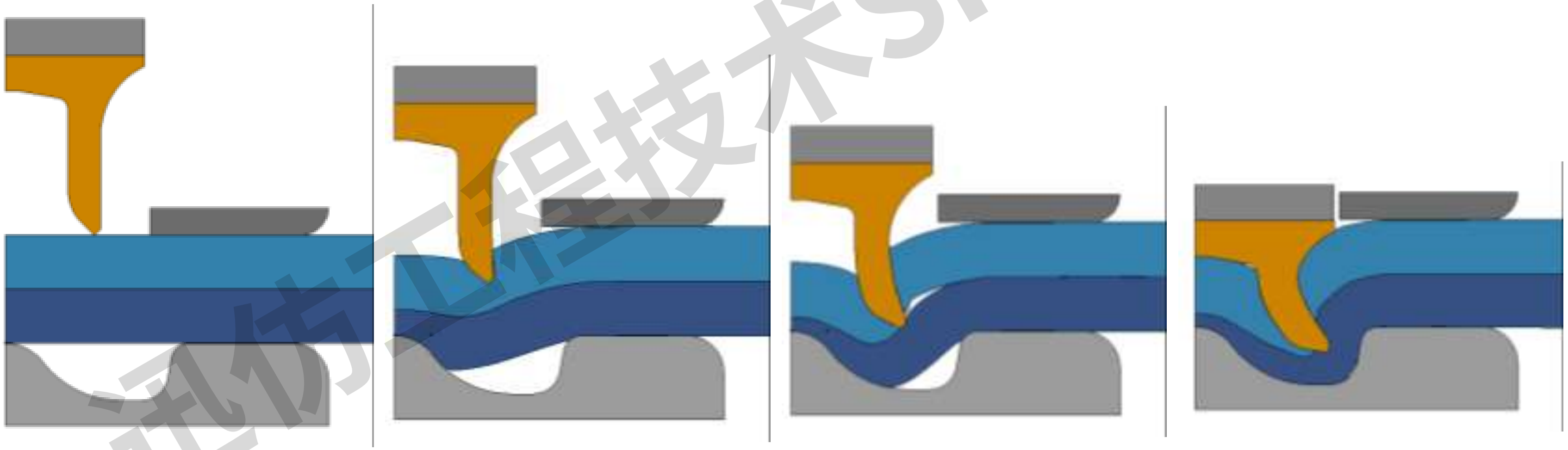
Coupling of CrachFEM with r-adaptivity in LS-DYNA

Simulation of a self piercing rivet (SPR) process in cooperation with JLR [1]

- In car design SPRs are used in a lot material and thickness combinations
- Simulation method could help to design the combination types with manageable cost and effort
- Increased prediction accuracy due to the adaptive simulation method and material modelling
- However tensorial description of damage in CrachFEM cannot be used currently in combination with r-adaptivity in LS-DYNA (no mapping of material coordinate system between refinement steps). Simulations have been performed with scalar description of damage.



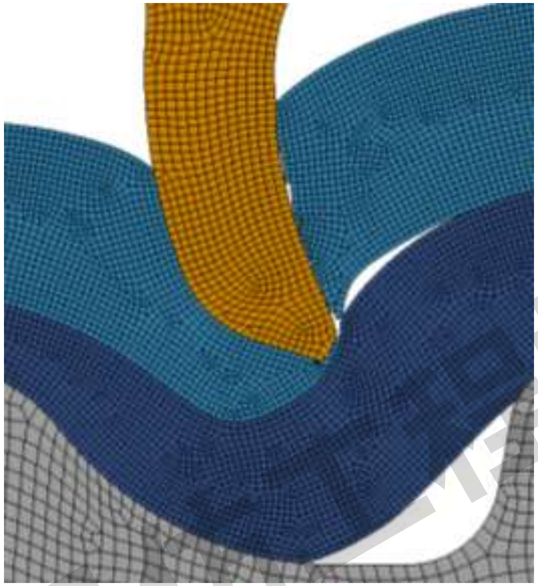
[1] *M. Buckley, H. Gese, M. Reissner, G.Oberhofer: Simulation of the Manufacturing Process of Self-Piercing Rivets with LS-DYNA with Focus on Failure Prediction for Sheets and Rivet*; 10th European LS-DYNA Conference 2015, Würzburg, Germany.

Coupling of CrachFEM with r-adaptivity in LS-DYNA

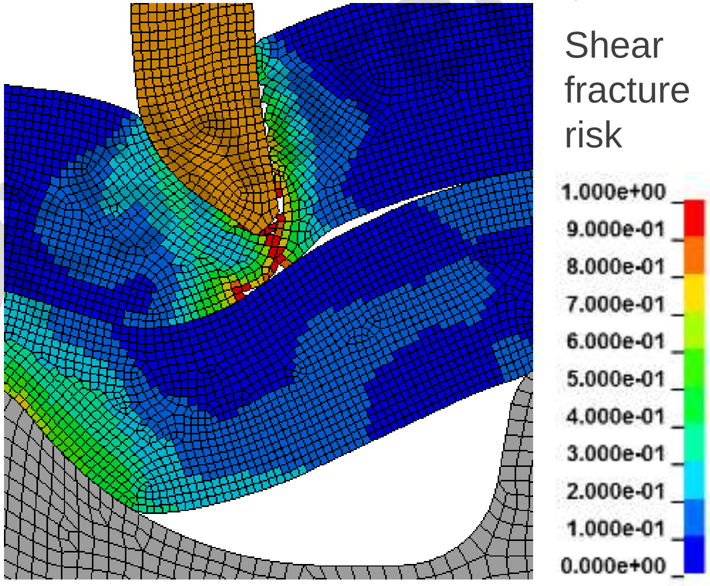
MATFEM

Simulation of a self piercing rivet (SPR) process in cooperation with JLR [1]

- Standard method is using residual thickness for prediction of material failure (left)
- New method is using CrachFEM fracture models for prediction of material failure (right); in addition one gets the fracture risk to estimate the residual strength of the lower sheet.



Standard method: residual thickness as criterion for sheet separation



New method: fracture model as criterion for sheet separation

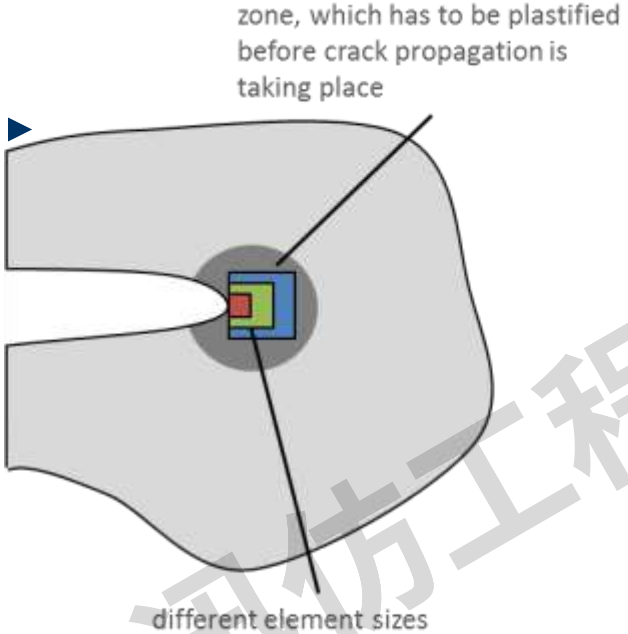
[1] *M. Buckley, H. Gese, M. Reissner, G.Oberhofer: Simulation of the Manufacturing Process of Self-Piercing Rivets with LS-DYNA with Focus on Failure Prediction for Sheets and Rivet*; 10th European LS-DYNA Conference 2015, Würzburg, Germany.

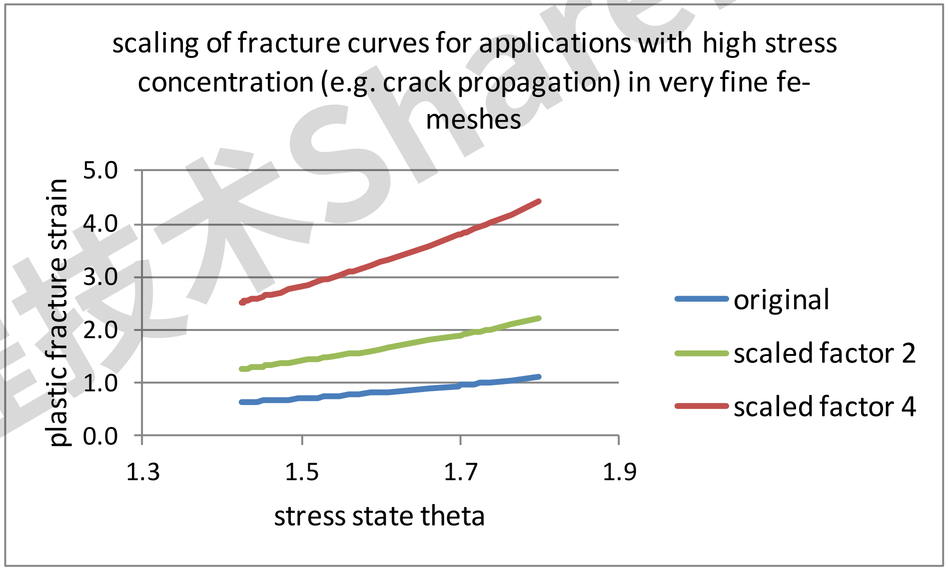
Coupling of CrachFEM with r-adaptivity in LS-DYNA

MATFEM

Simulation of a self piercing rivet (SPR) process in cooperation with JLR [1]

Following the ideas of Wilkins (1977) a mesh size dependent scaling of fracture curves can be used in crack propagation





Source: M.L. Wilkins, et al.: Fundamental Study of Crack Initiation and Propagation Annual Progress Report, 1977. In: Report UCRL-52296, Lawrence Livermore National Laboratory, Livermore, CA.

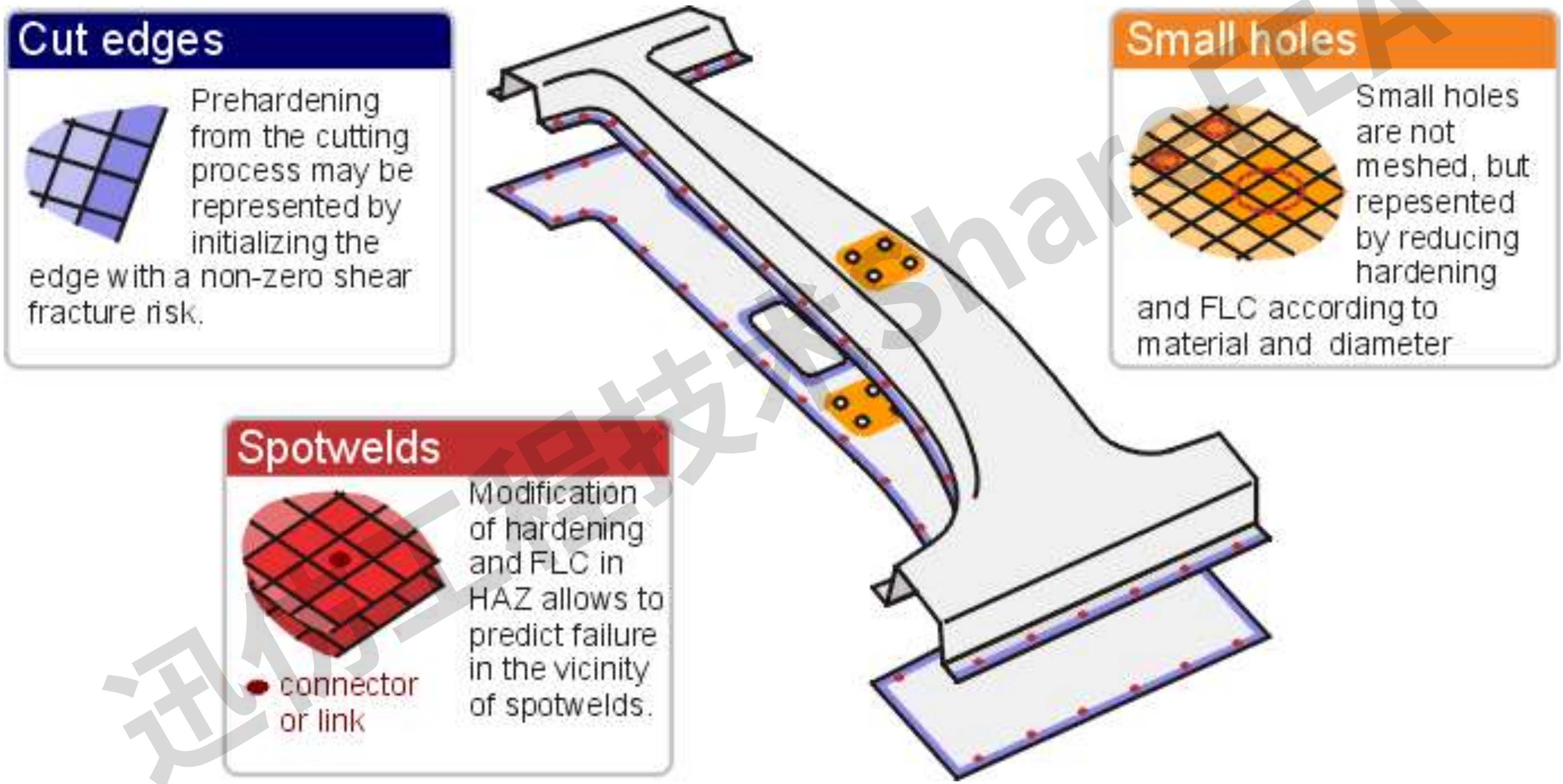
Contents (continued)

MATFEM

Local scaling of material properties

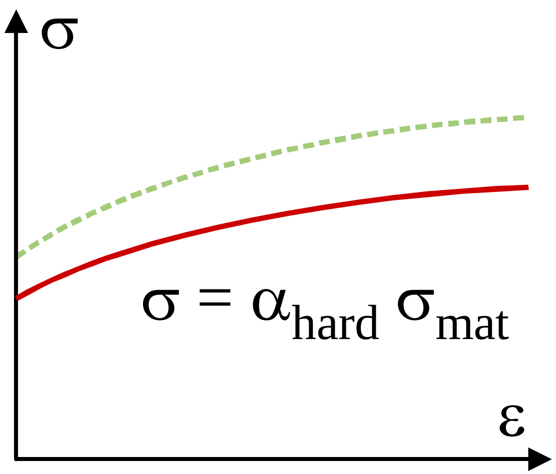
MATFEM

Initialization of modified material properties for holes, spotwelds and cut edges

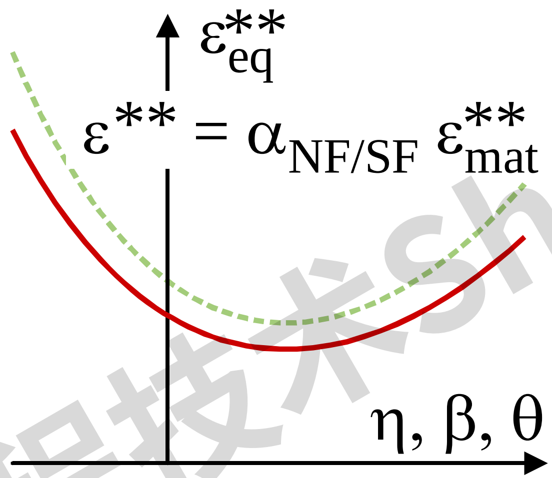


Initialization of modified material properties for holes, spotwelds and cut edges

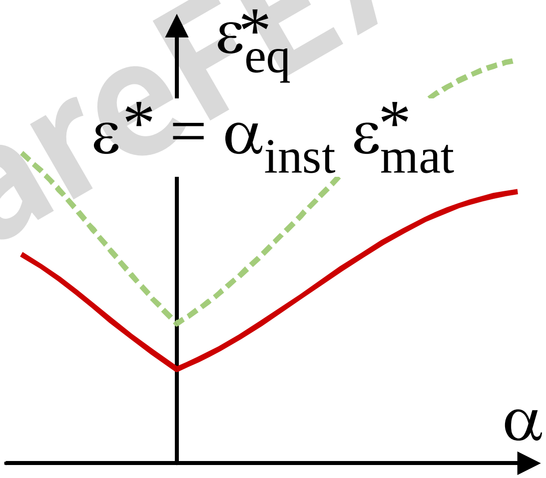
hardening



fracture



initial FLC



material properties

actual element properties

variable		scales
HV 16	α_{hard}	plastic hardening
HV 17	α_{NF}	normal fracture strain
HV 18	α_{SF}	ductile fracture strain
HV 19	α_{inst}	instability strain

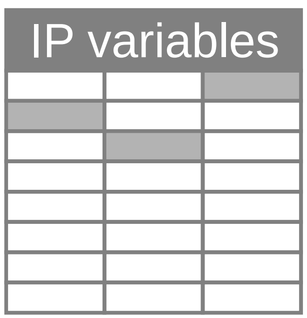
Local scaling of material properties

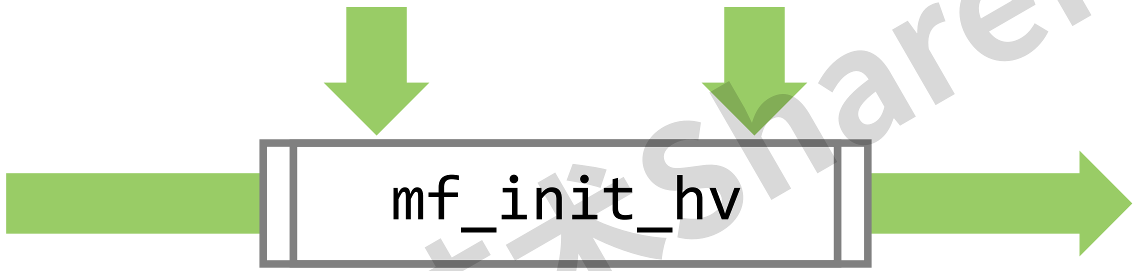
Automatic initialization by user-definable routine

basic geometry:
thickness
IP coord
char. length

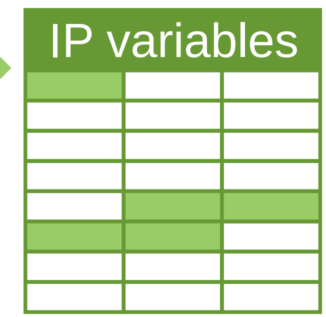
material
dependent
data as curve
`MF_INIT`

input





output



data vector, possibly filled in by direct initialization, but usually blank (all 0’s).

Routine called from user-defined shared object **mfuser.so**.

The routine can be compiled with standard C compilers, eg **gcc**.

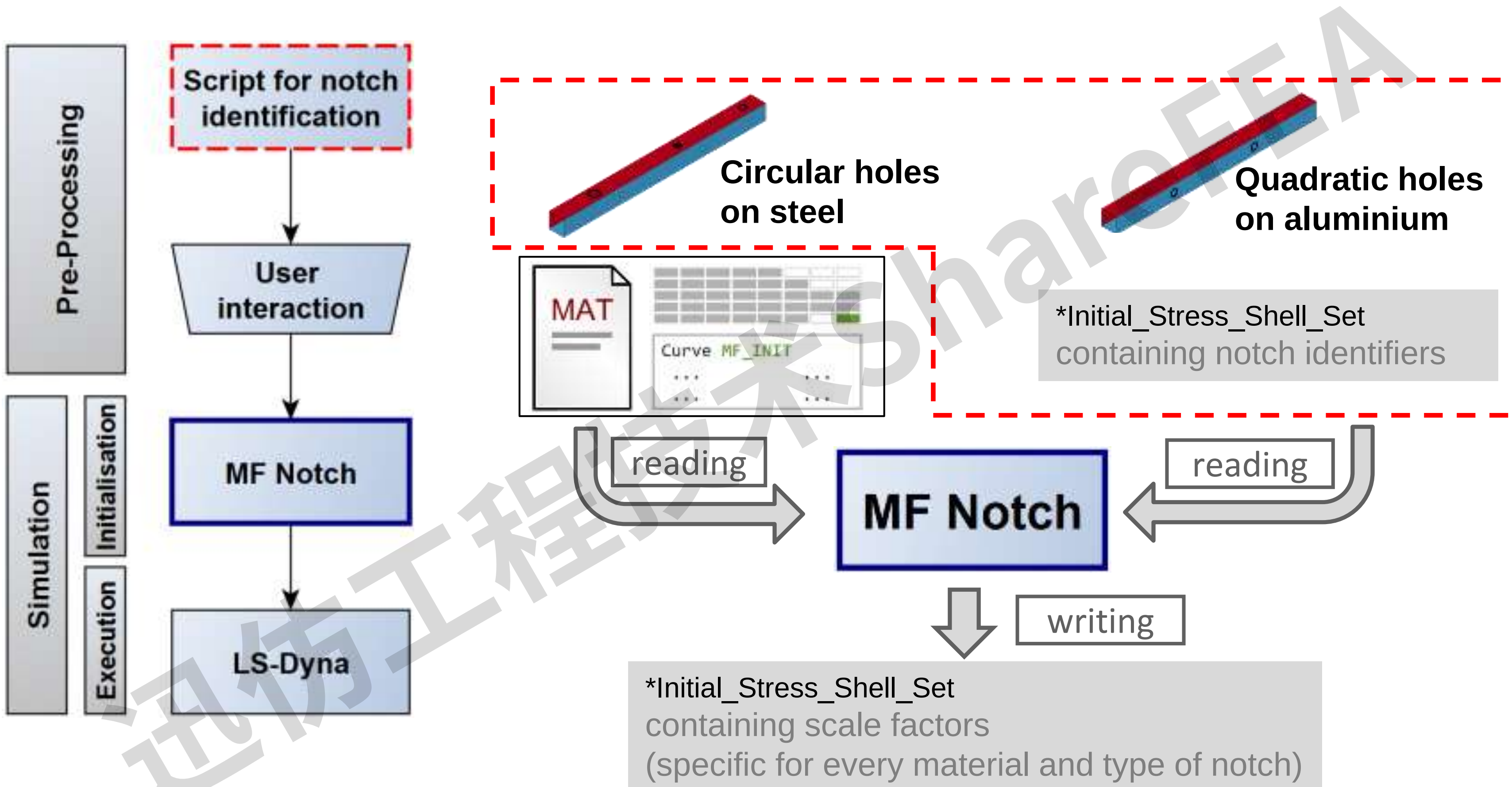
vector of congruent MF GenYld IP data:

$var_1 \equiv \varepsilon \geq 0$

Local scaling of material properties

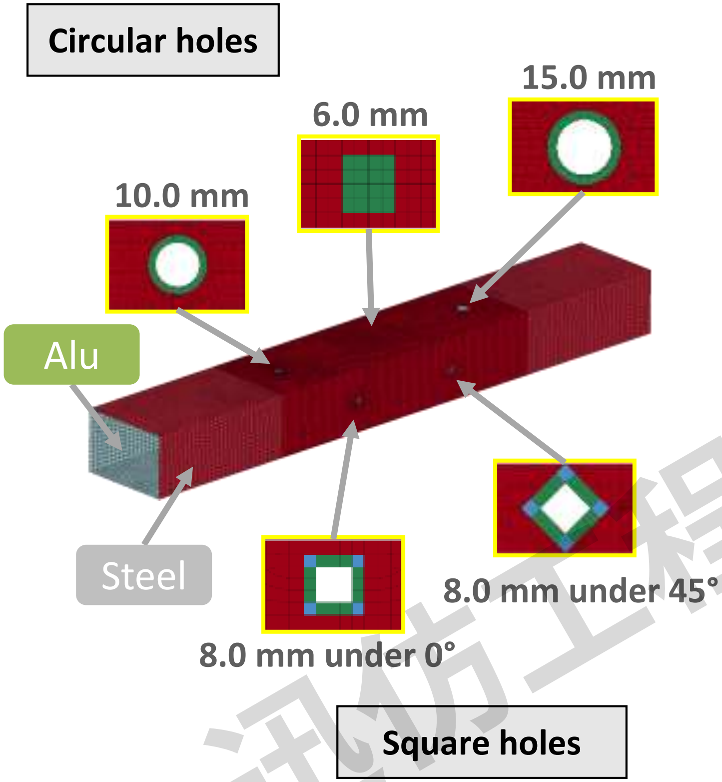
MATFEM

Automatic initialization by user-definable routine

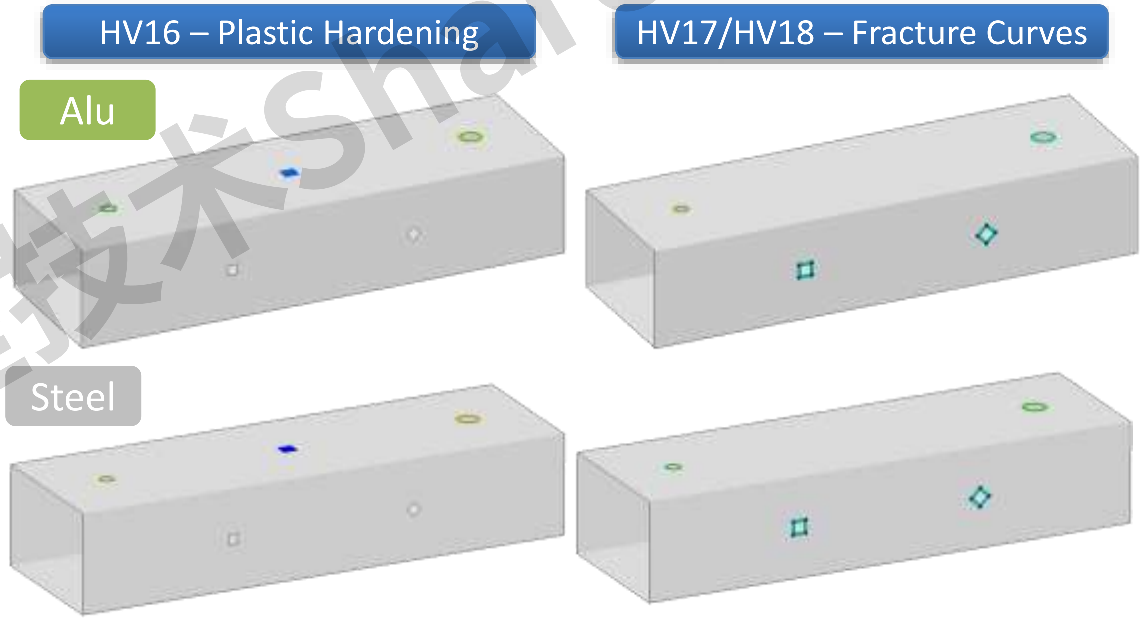


MATFEM

Automatic initialization by user-definable routine



Initialisation of the notch elements with material specific scaling factors



For further information: H. Lacy, M. Buckley, M. Richter, F.Brenner, H. Gese; Notch Stress Raiser Detection & Handling in Automotive Body Structures - An Approach at Jaguar Land Rover; 4th MATFEM Conference; 25 April 2017, Schloss Hohenkammer

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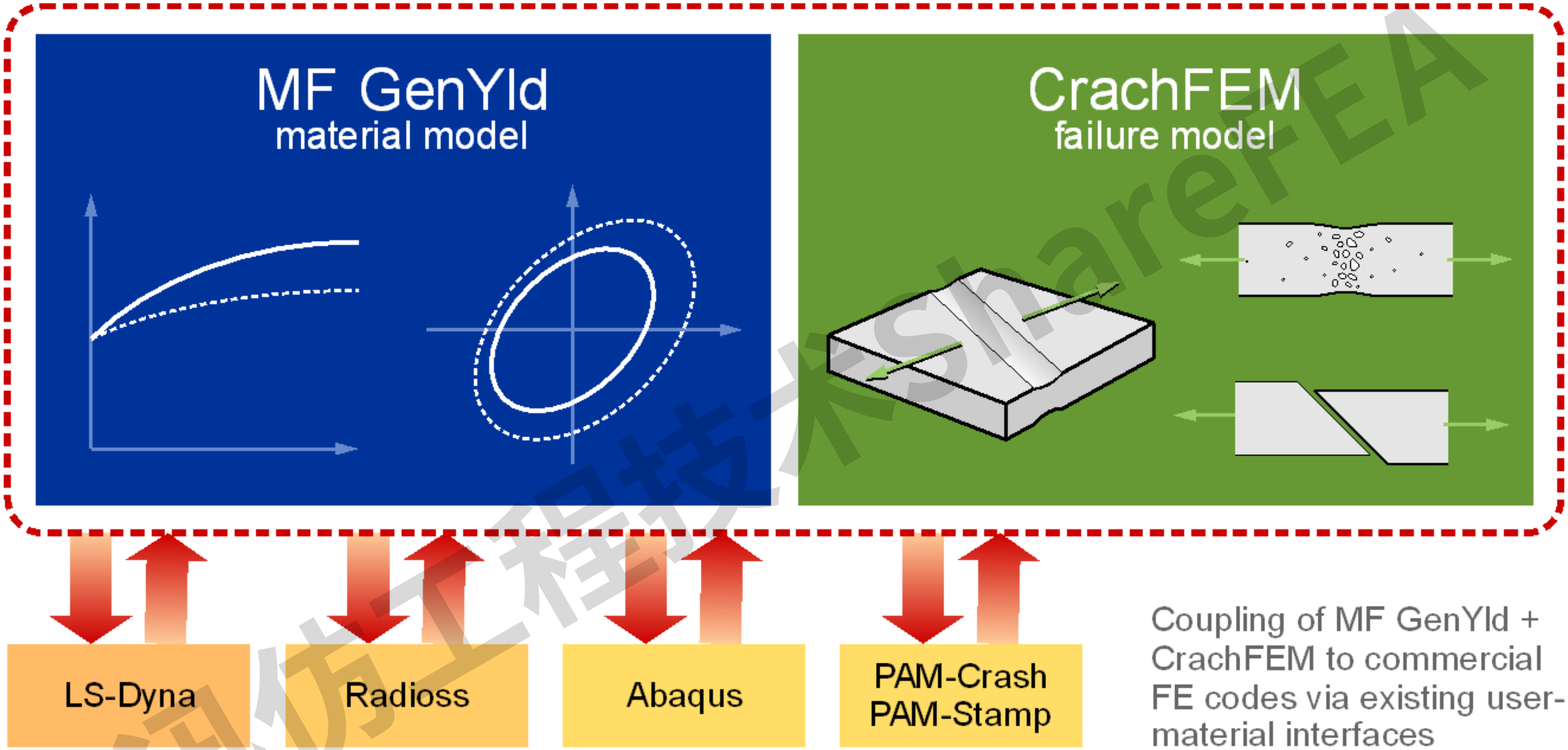
MATFEM

Compatibility to commercial FEA Codes



Coupling of MF GenYld + CrachFEM to commercial FE codes via existing user-material interfaces

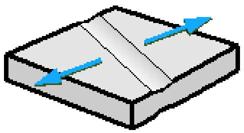
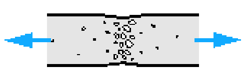
LS-Dyna, RADIOSS, ABAQUS, PAM-Crash and PAM-Stamp are registered trademarks.

Full support of all explcit-dynamic solvers; still limited support for implicit solvers

Current status of CrachFEM

MATFEM

Comprehensive model for failure prediction of metallic materials

				shell	solid	
orthopropy		Local instability (necking)	Initial FLC (approximate)			Underlying material model also covers nonlinear strain paths
			Prediction with Crach			
			Post-critical elongation			
orthotropy		Ductile normal fracture	$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\beta)$			Tensorial description of damage
		Ductile shear fracture	$\varepsilon_{eq}^{**} = \varepsilon_{eq}^{**}(\theta)$			