迅捷响应•共享仿真

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

Modelling Non-Reinforced-, Fiber-Reinforced-Polymers and Composites with MF-GenYld+CrachFEM

1st ShareFEA CrachFEM Seminar, 25 April 2018, Shanghai

Authors: G. Oberhofer, H. Dell, M. Oehm

Date: April 25, 2018

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MATFEM

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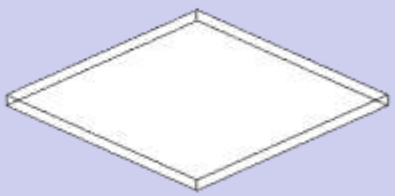
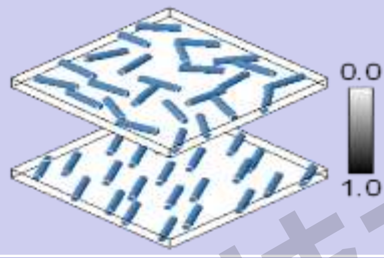
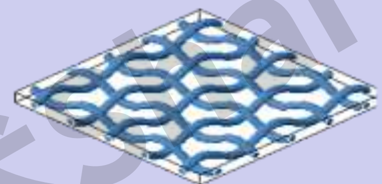
MATFEM

Different Classes of Polymers and Composites

Unreinforced polymers	Short-fiber-reinforced polymers	Endless-fiber-reinforced polymers	
		Organic fabric	Unidirectional layer
			
• High ductility (typically) • Stress state dep. hard • Compressibility • Ductile failure crit. suitable	• Reduced ductility • Stress state dependent hardening • Anisotropy of elasticity • Anisotropy of hardening • Ductile failure criterion suitable • Anisotropy of fracture	• Strongly reduced duct. in fiber directions • Significant ductility in other directions • Anisotropy of elasticity • Stress state dep. Hard • Anisotropy of hardening • Ductile failure criterion for ductile direction • Additional stress based failure crit. reasonable • Anisotropy of fracture	• Generally very low ductility • Anisotropy of elasticity • Stress state dependent hardening • Anisotropy of hardening • Stress based failure criterion reasonable • Anisotropy of fracture

Motivation

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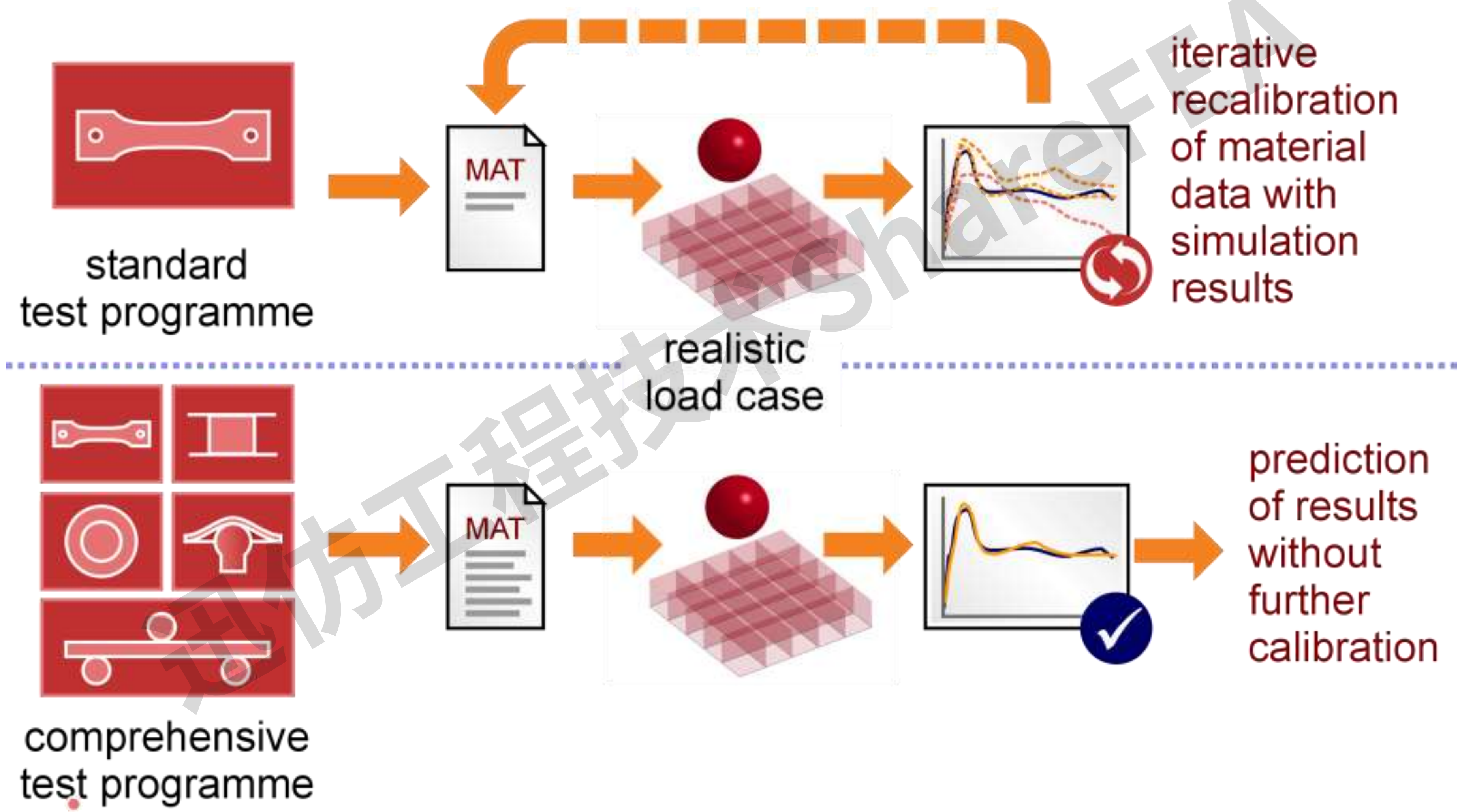
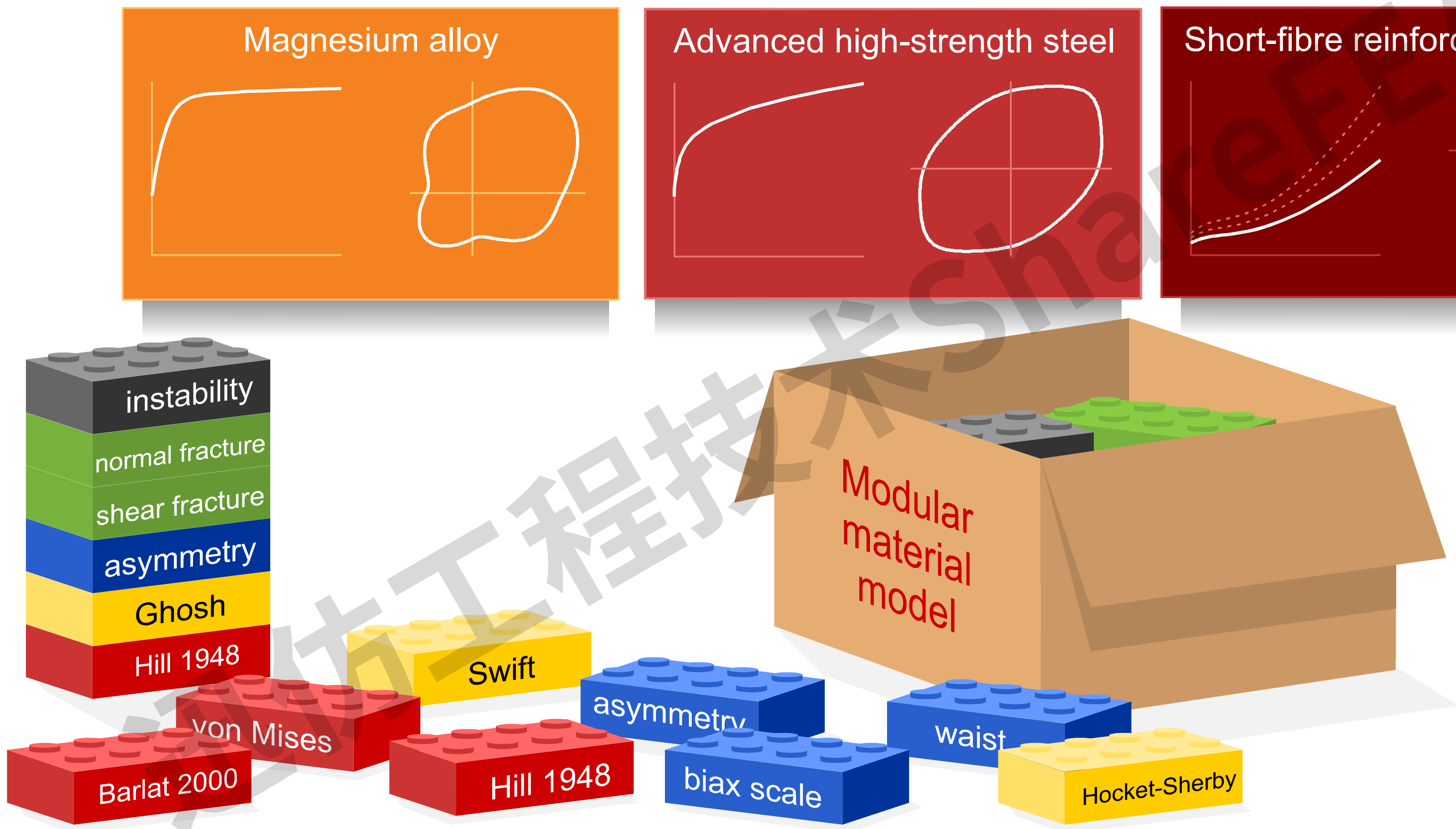
Predictive Material Description for Polymers and Composites



Modular Material Model MF-GenYld+CrachFEM



Motivation

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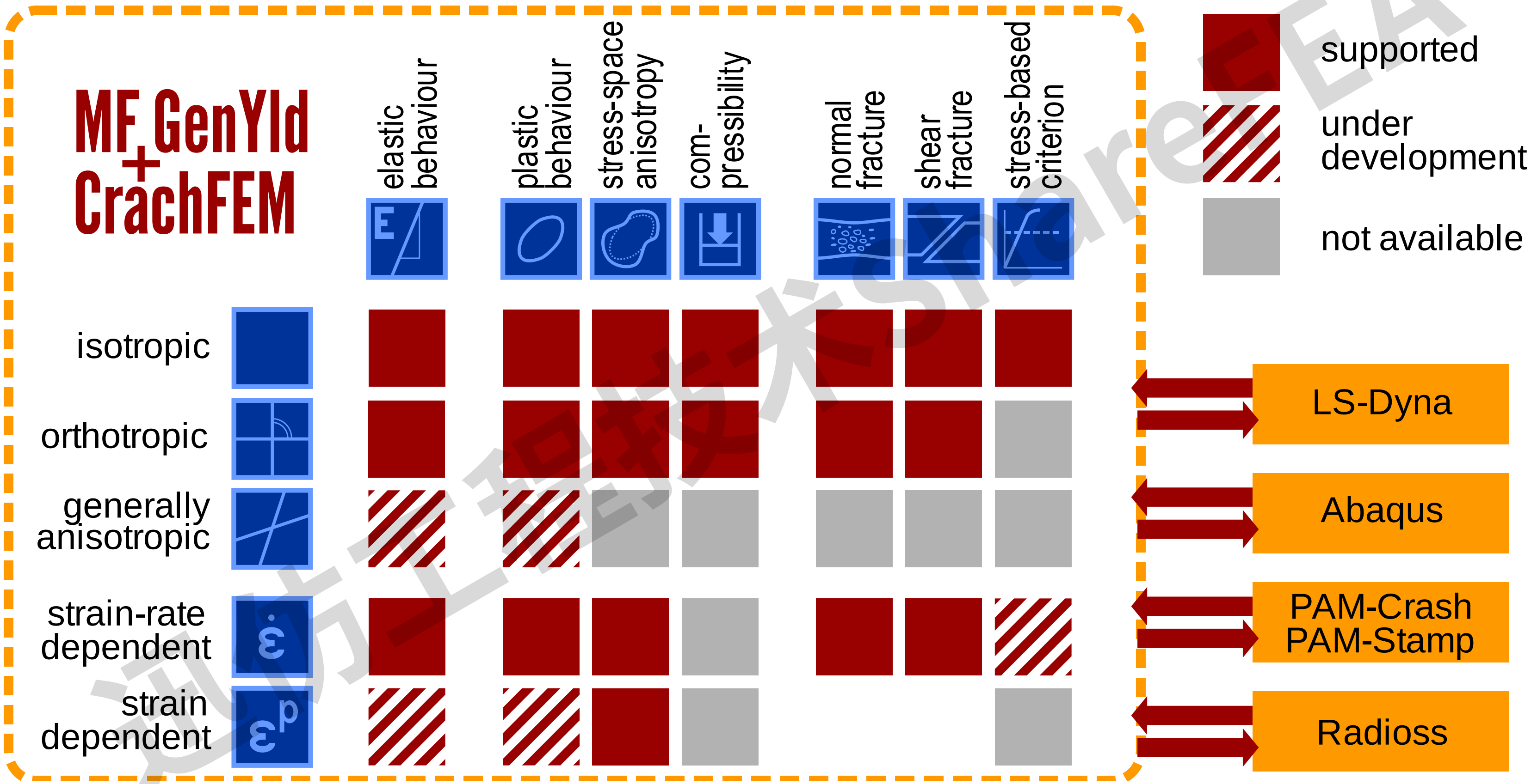
Modular Material Model MF-GenYld+CrachFEM for Polymers and Composites



Motivation

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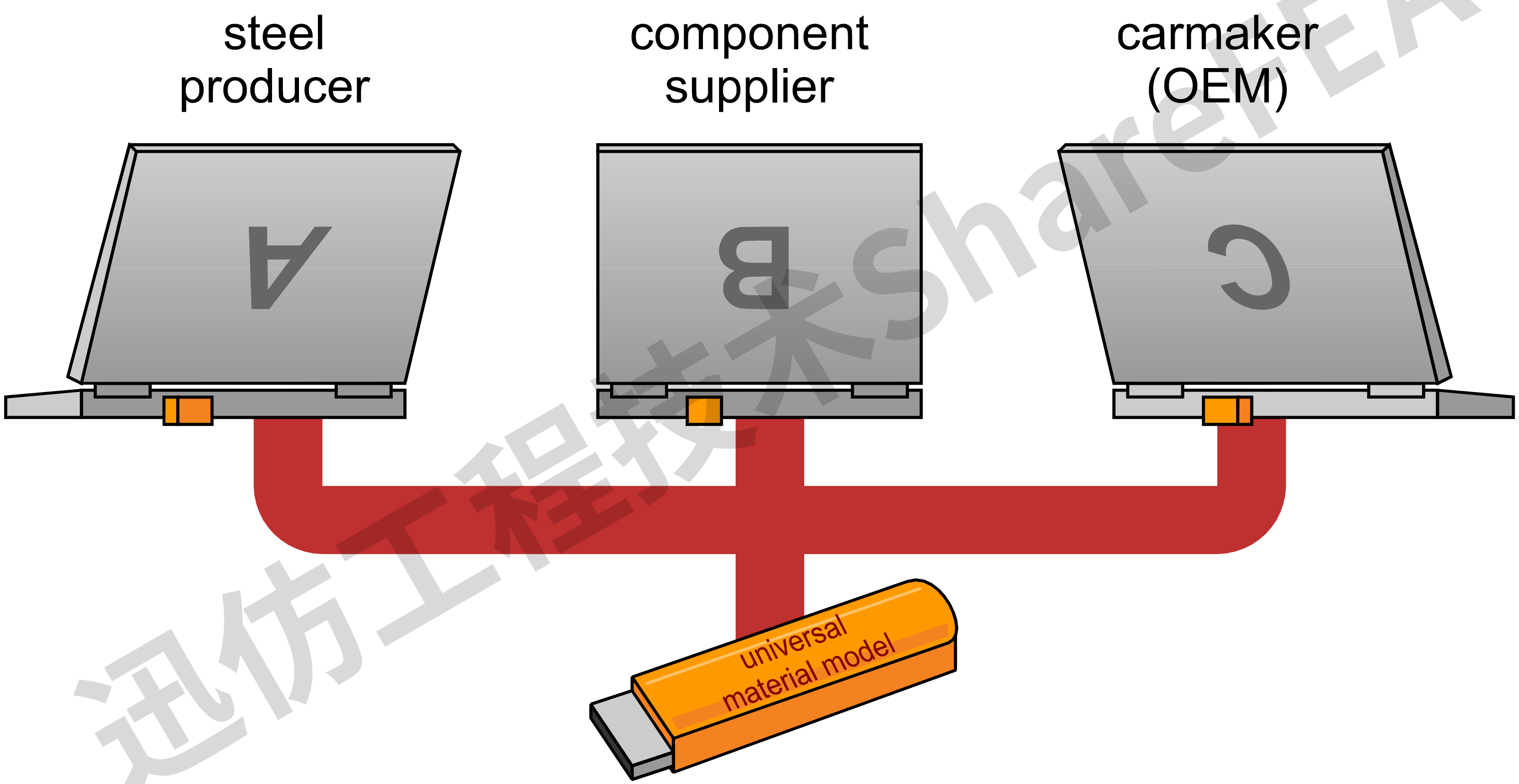
Modular Material Model MF-GenYld+CrachFEM for polymers and CFRPs



Motivation

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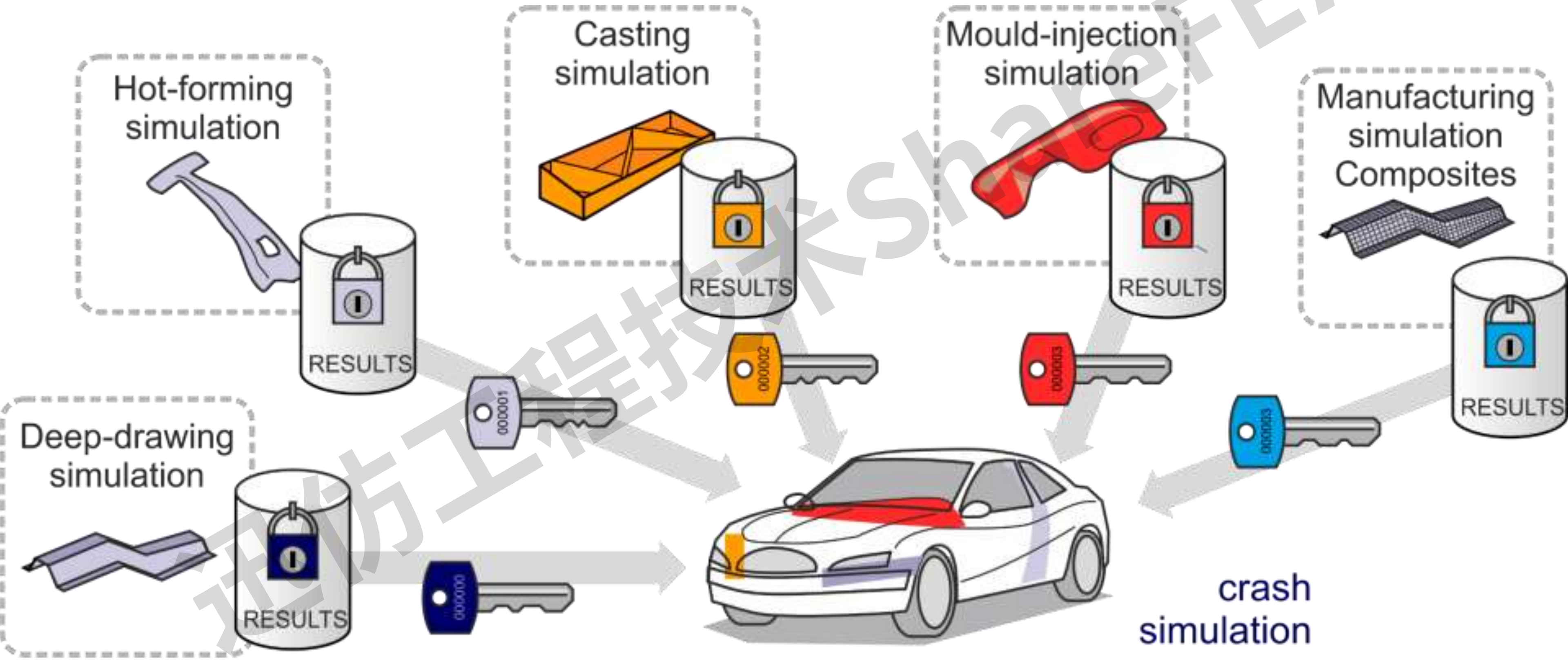
Modular Material Model MF-GenYld+CrachFEM for polymers and CFRPs



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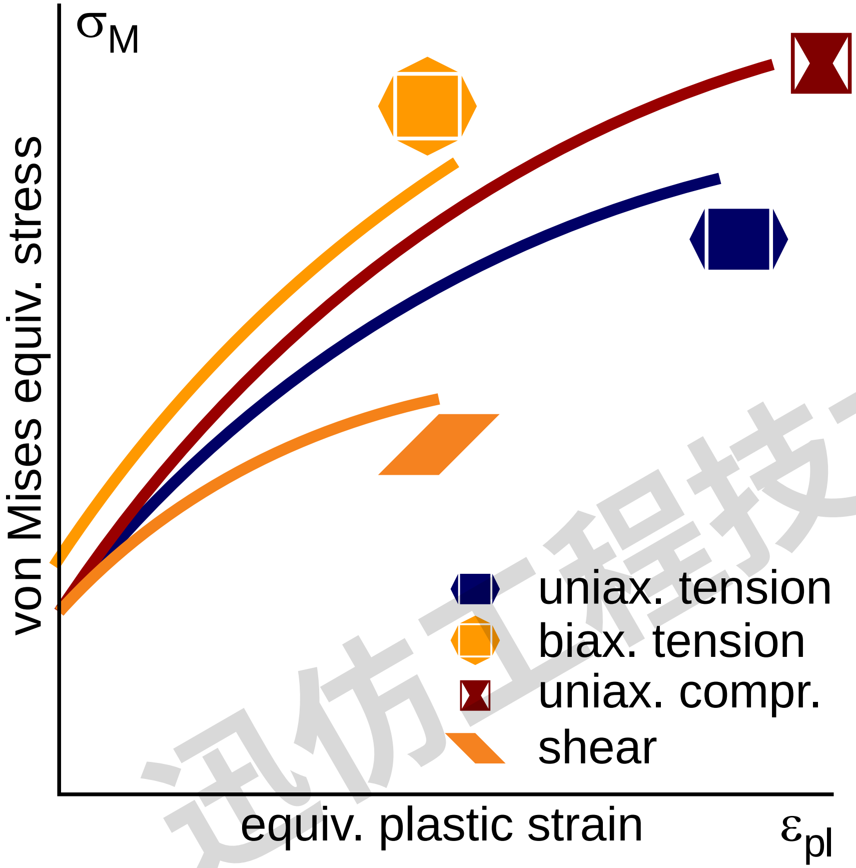
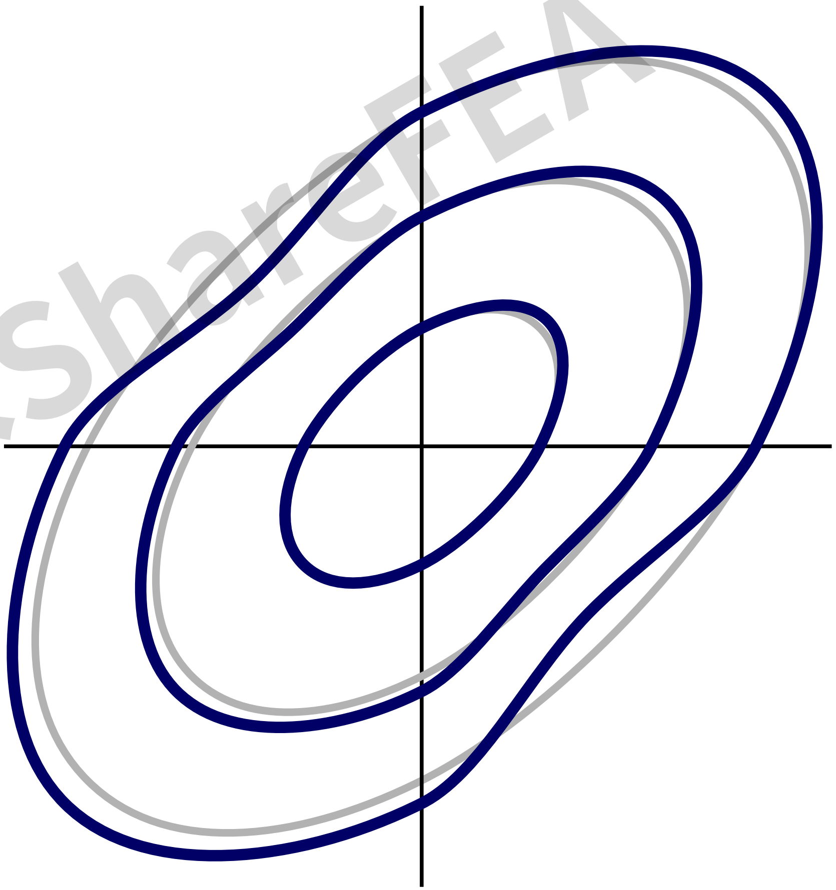
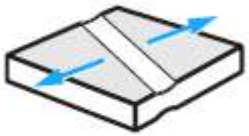
Anisotropic hardening





Austenitic steel sheets, magensium sheets and polymers show marked anisotropic hardening

Ductile fracture behaviour

			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

Currently not used for polymers

MF-GenYld+CrachFEM for non-reinforced polymers

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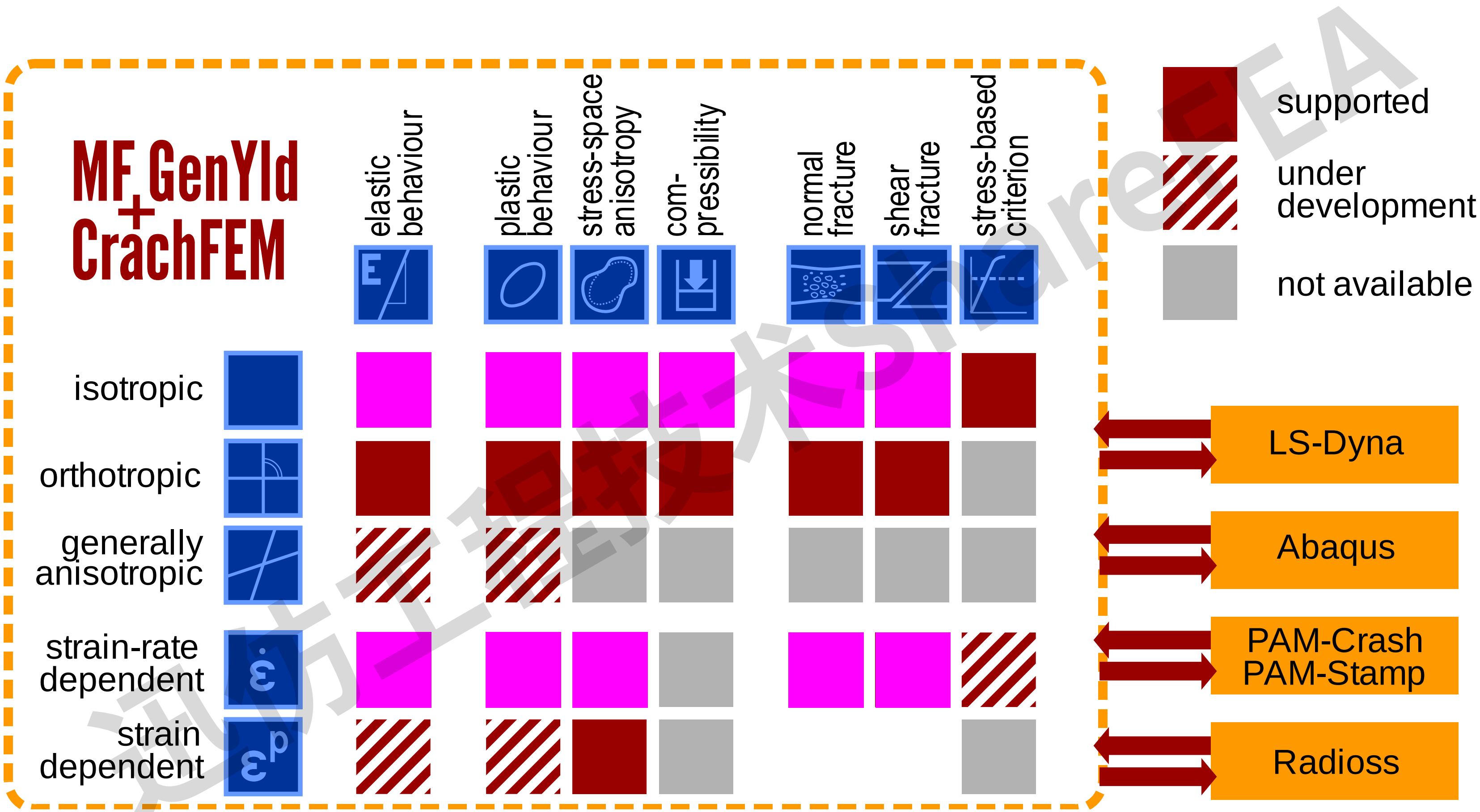
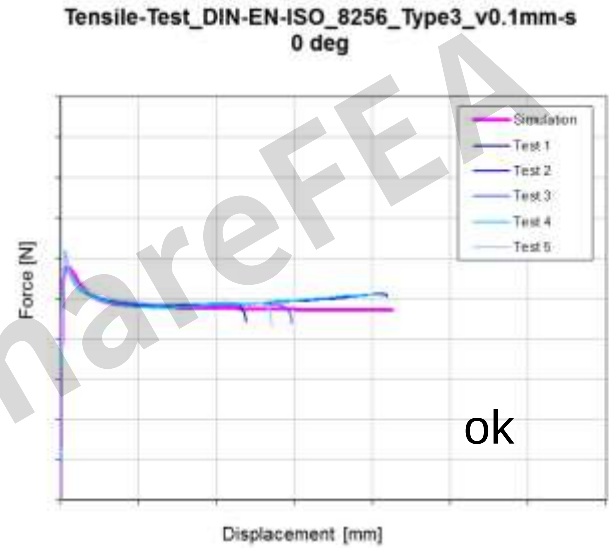
Relevant Modules

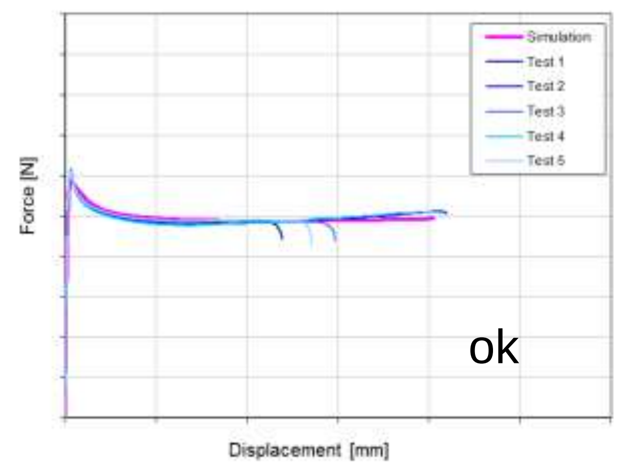


Influence of compressibility onto failure in case of non-reinforced polymers

Plastic compressibility



Plastic incompressibility

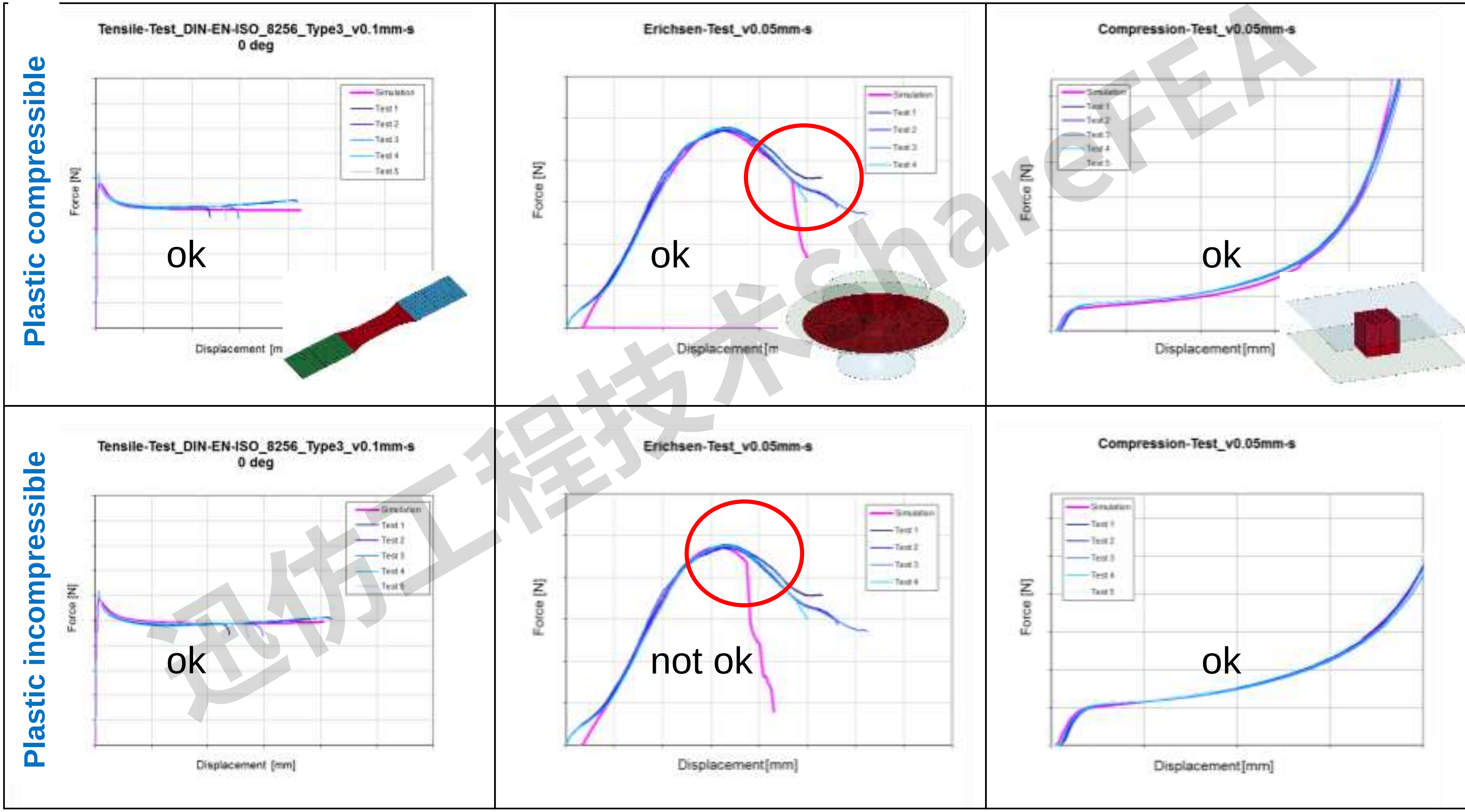


➡ Failure behaviour in case of uniaxial tension ok for both representations

MF-GenYld+CrachFEM for non-reinforced polymers

MATFEM

Influence of compressibility onto failure in case of non-reinforced polymers



➡ Not all stress states can be described well with the incompressible approach

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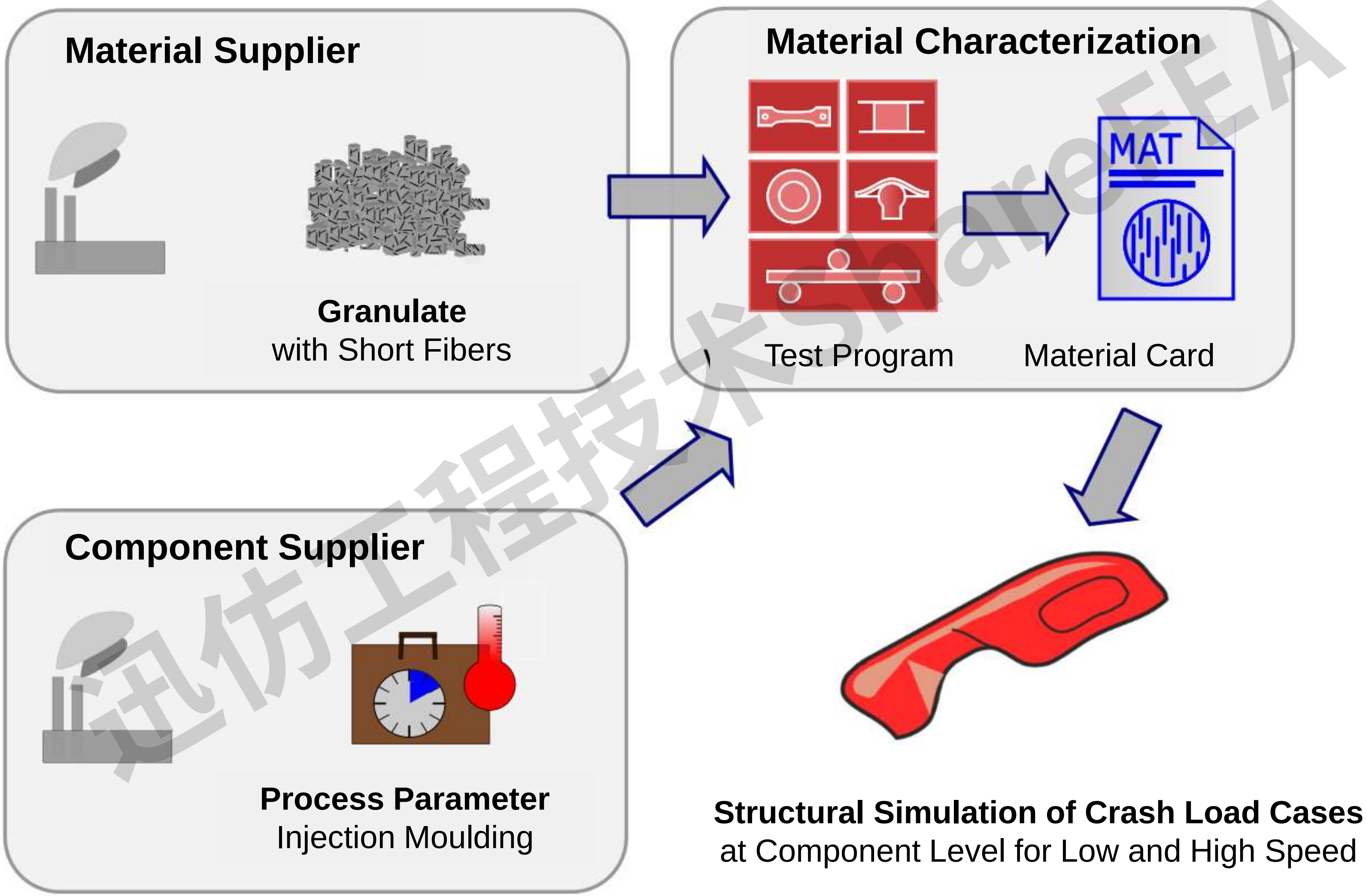
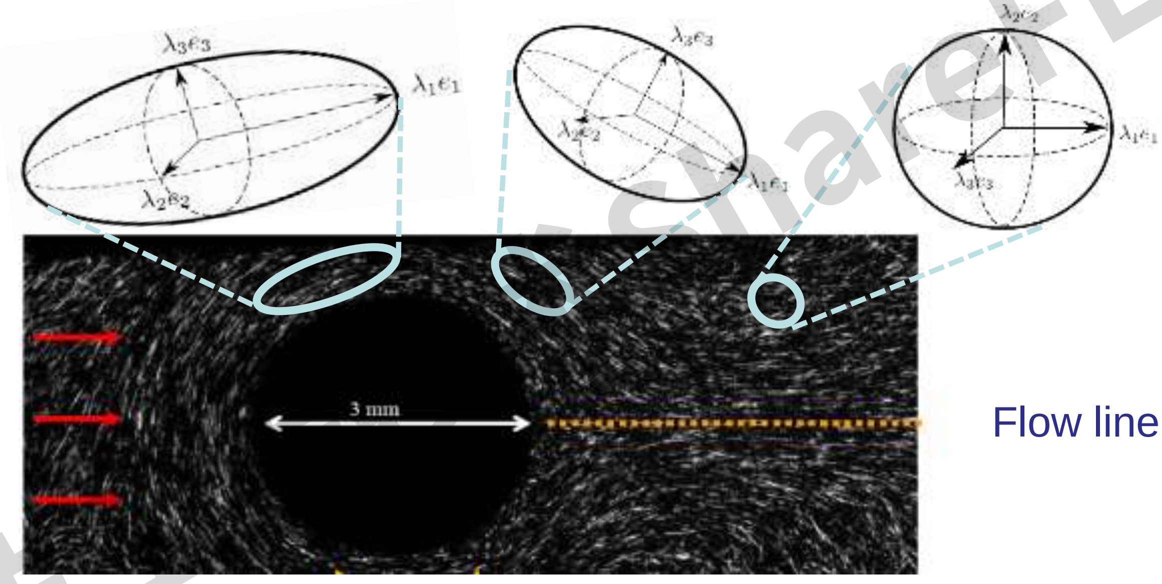
- ► MF-GenYld+CrachFEM for non-reinforced polymers
- ► MF-GenYld+CrachFEM for short fiber reinforced polymers
- ► MF-GenYld+CrachFEM for endless fiber reinforced polymers – Organic sheets
- ► MF-GenYld+CrachFEM for endless fiber reinforced composites (CFRP)
- ► Current developments
- ► Status of CrachFEM application

Influence of production process



Mapping from mould injection simulation

Flow direction



Flow line

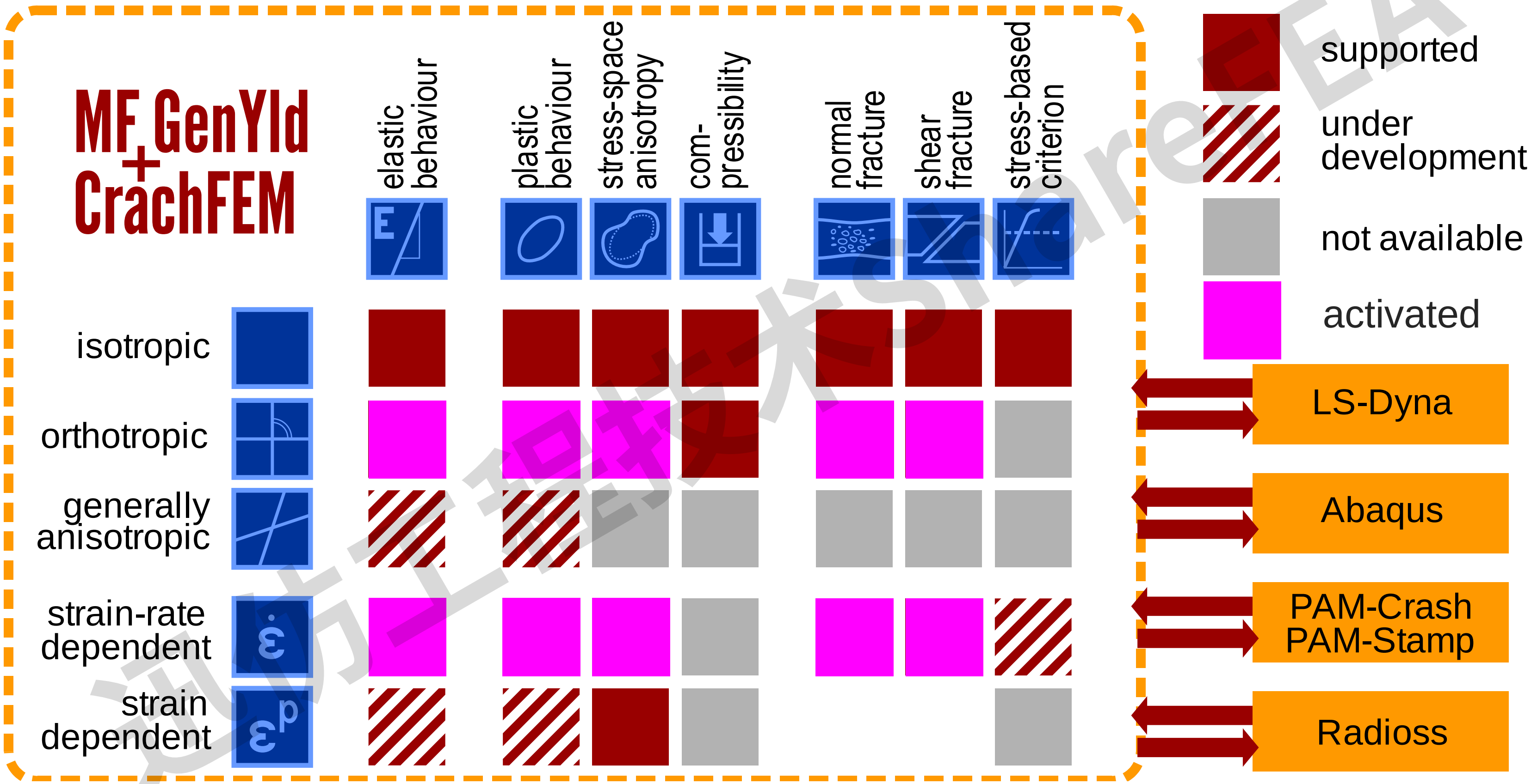
CT-Scan of an injection moulded plate with barrier and flow line

Quelle: M. Vogler „New Material modeling approaches for thermoplastics, composites and organic sheet“, 9th European LS-Dyna Conference 2013

MF-GenYld+CrachFEM for short fiber reinf. polymers

MATFEM

Relevant Modules

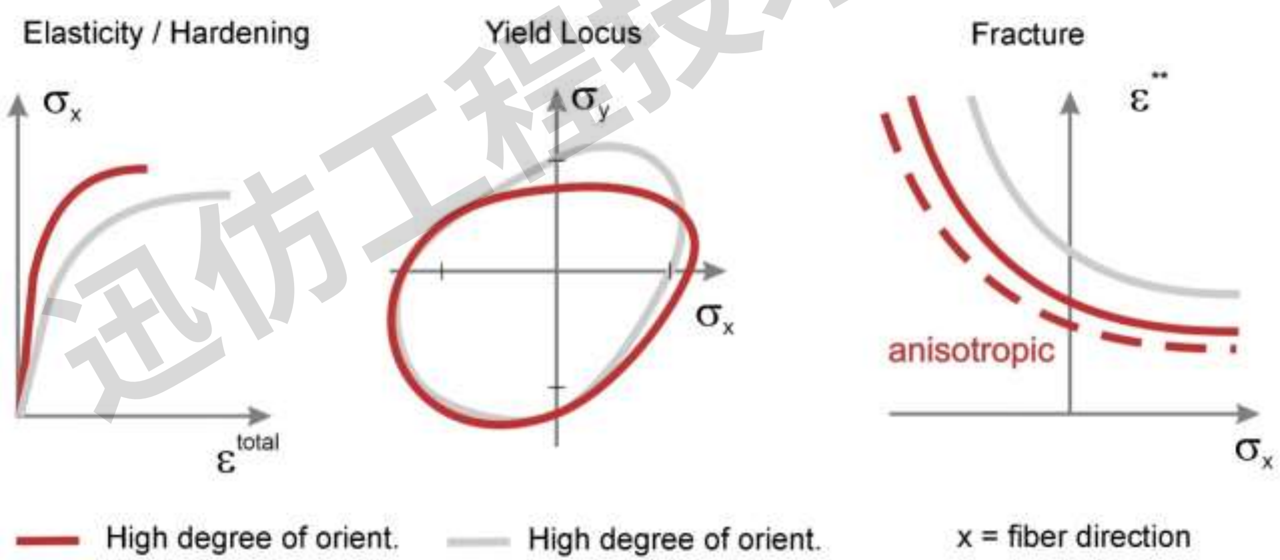


Anisotropic behaviour in case of short fiber reinforced Polymers

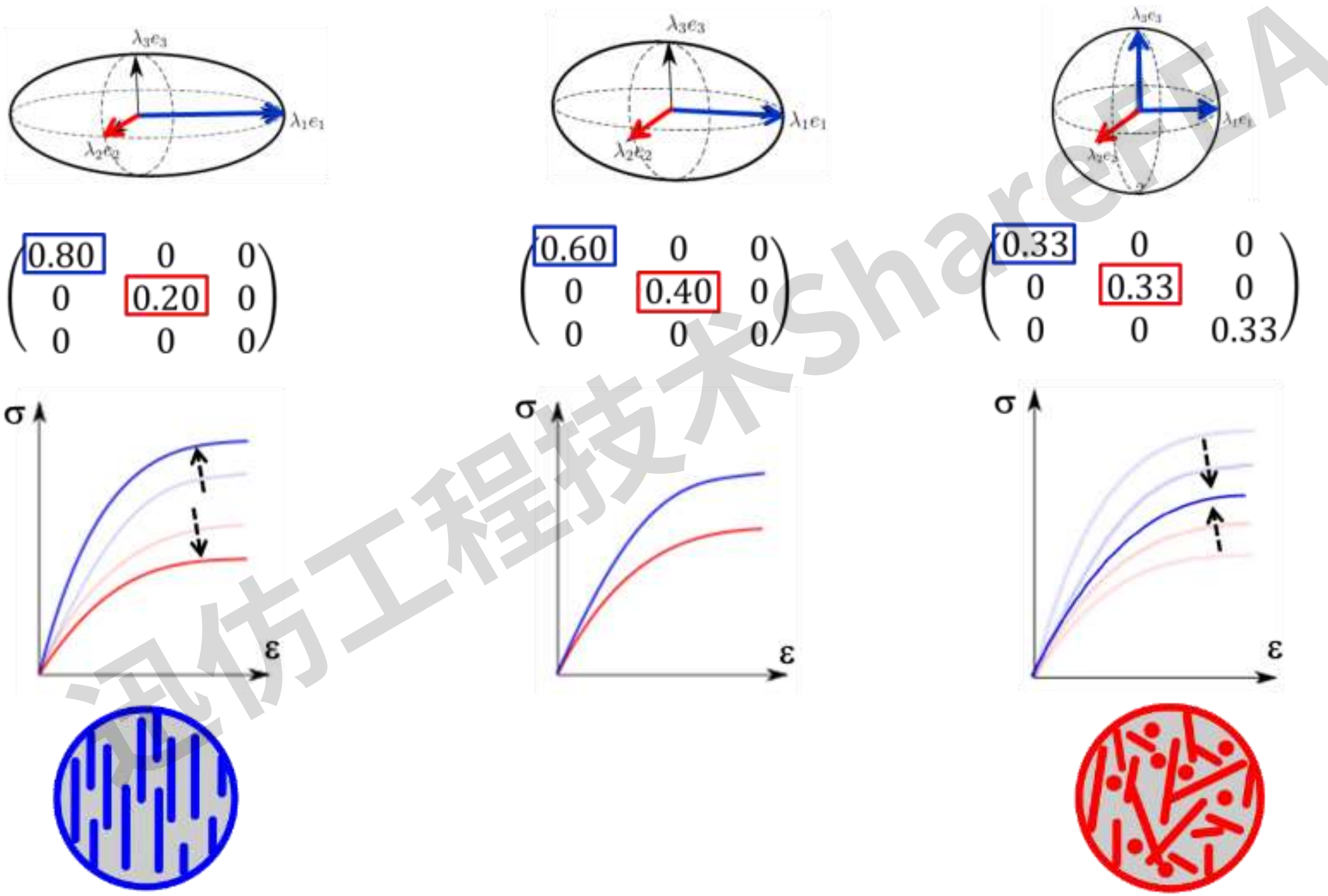
Random
Fiber Orientation

Unidirectional
Fiber Orientation

MF GenYld+CrachFEM supports automatic interpolation between different states



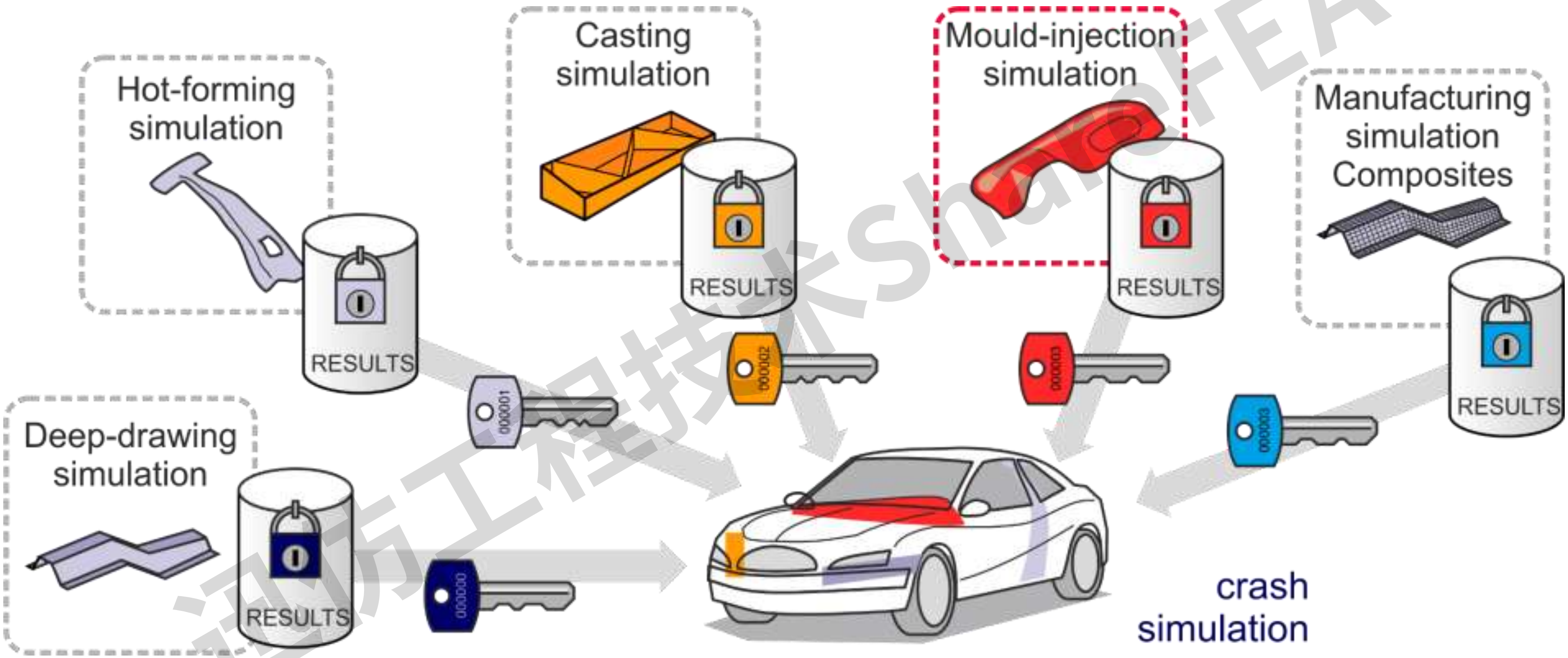
Mapping from mould injection simulation – Orientation tensor



$$\begin{pmatrix} \boxed{0.80} & 0 & 0 \\ 0 & \boxed{0.20} & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \begin{pmatrix} \boxed{0.60} & 0 & 0 \\ 0 & \boxed{0.40} & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \begin{pmatrix} \boxed{0.33} & 0 & 0 \\ 0 & \boxed{0.33} & 0 \\ 0 & 0 & 0.33 \end{pmatrix}$$

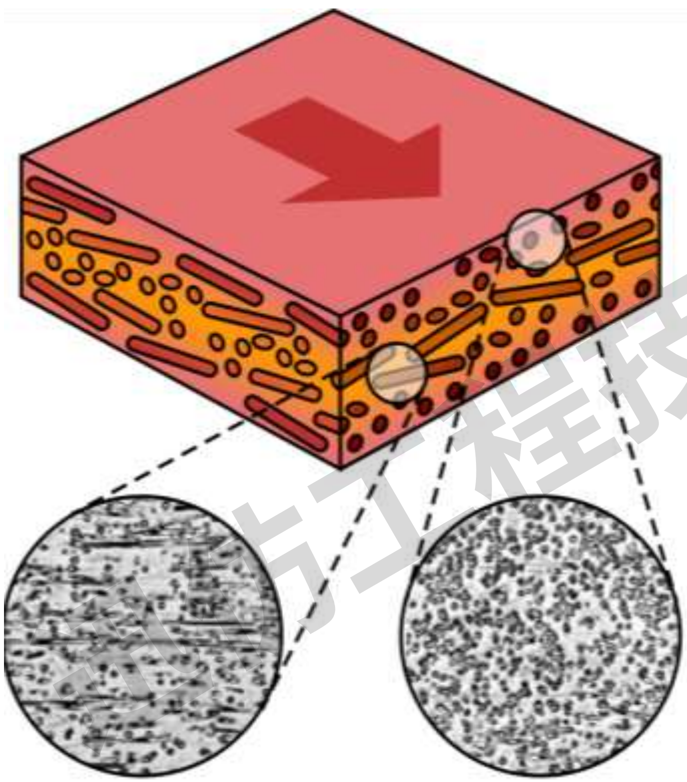
Quelle: M. Vogler „New Material modeling approaches for thermoplastics, composites and organic sheet", 9th European LS-Dyna Conference 2013

Mapping from mould injection simulation

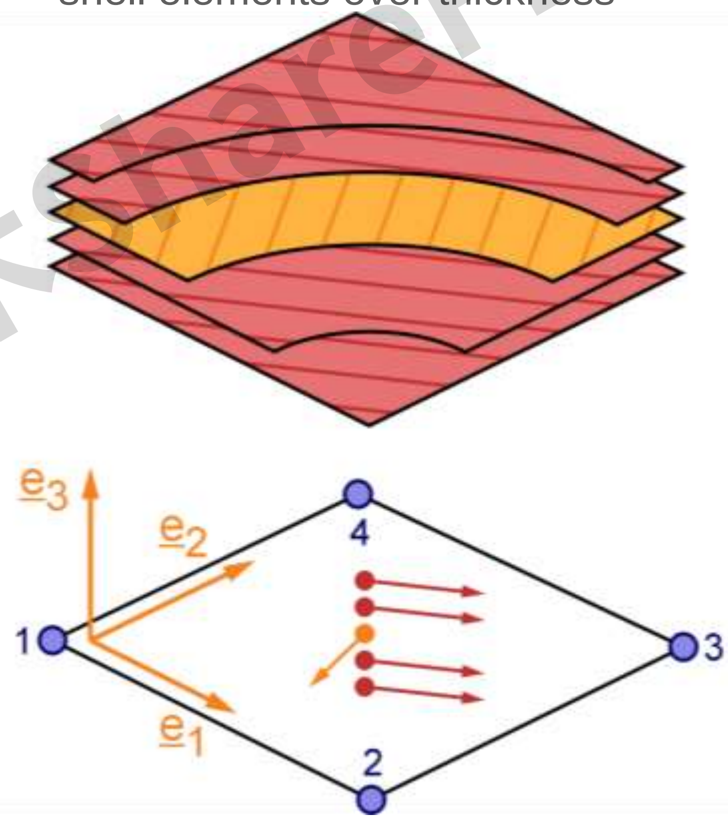


Mapping from mould injection simulation

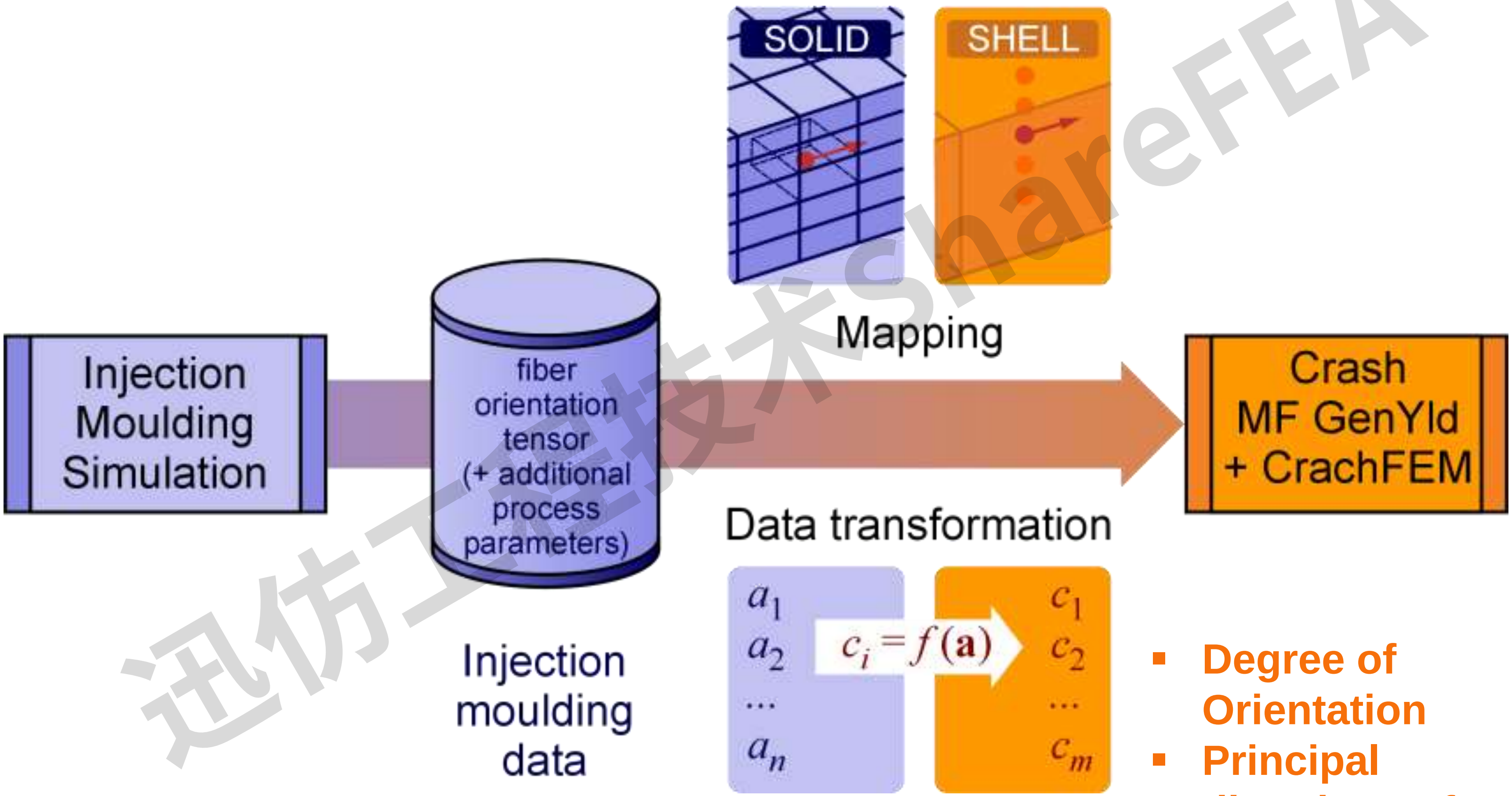
Different orientation of fibers over wall thickness resulting from material flow



Initialization of material orthotropy for different integration points of shell elements over thickness



Mapping from mould injection simulation



- **Degree of Orientation**
- **Principal directions of anisotropy**

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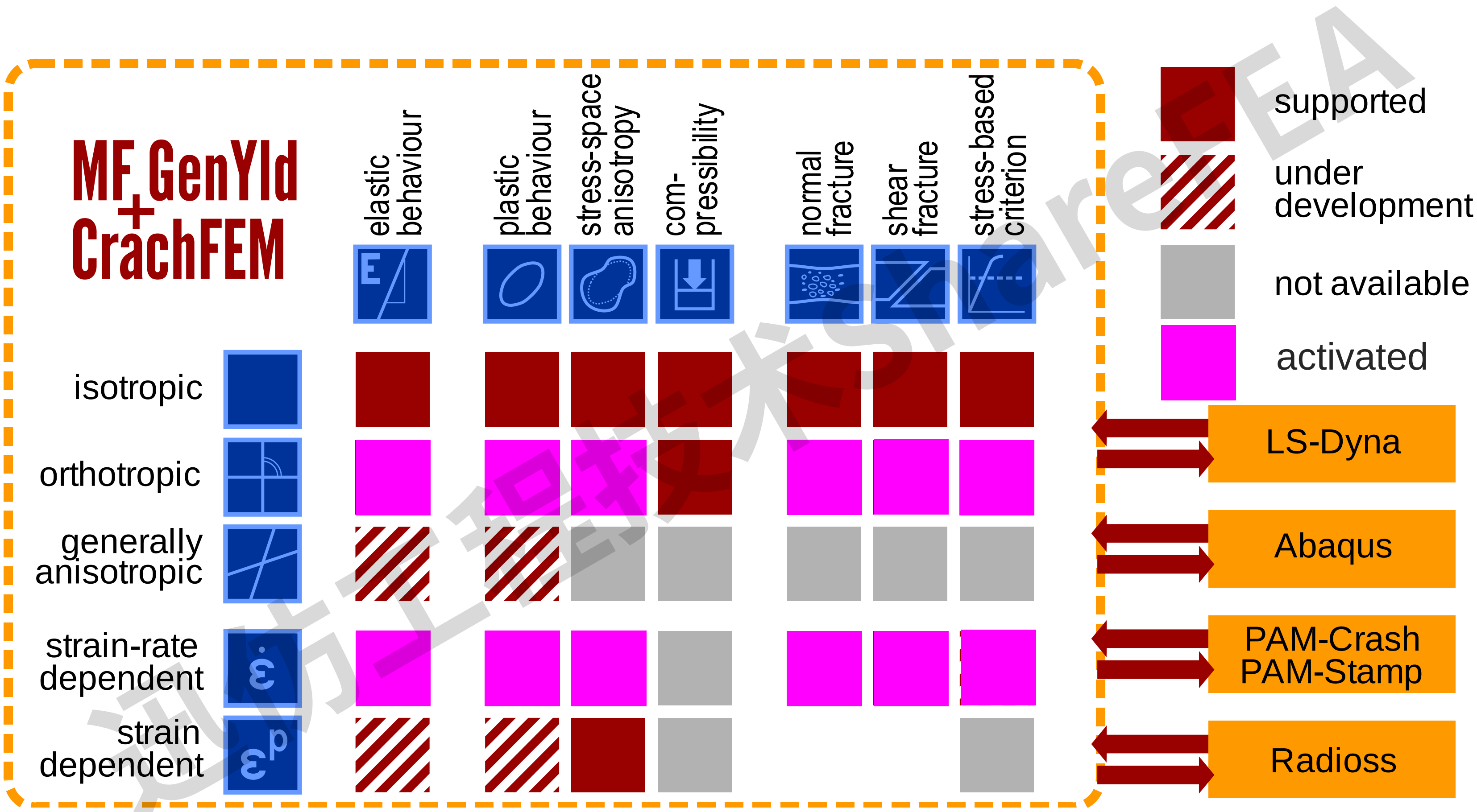
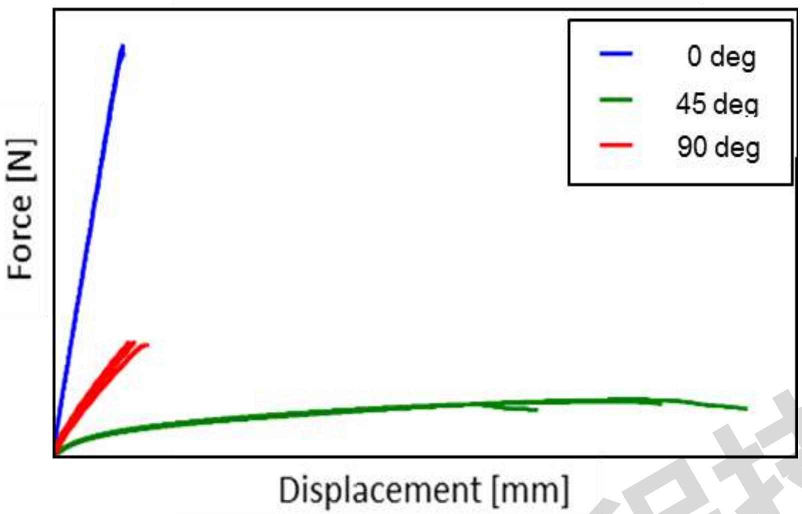
- ► Current developments
- ► Status of CrachFEM application

Relevant Modules



Characteristic Tensile Behavior

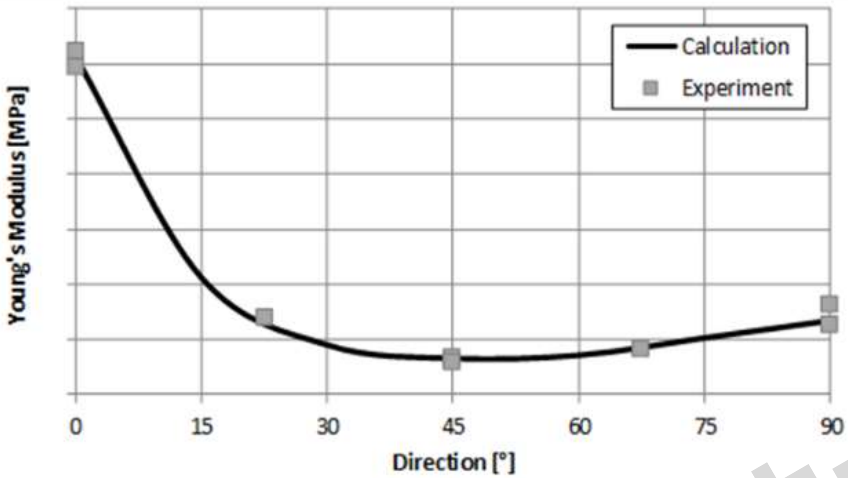


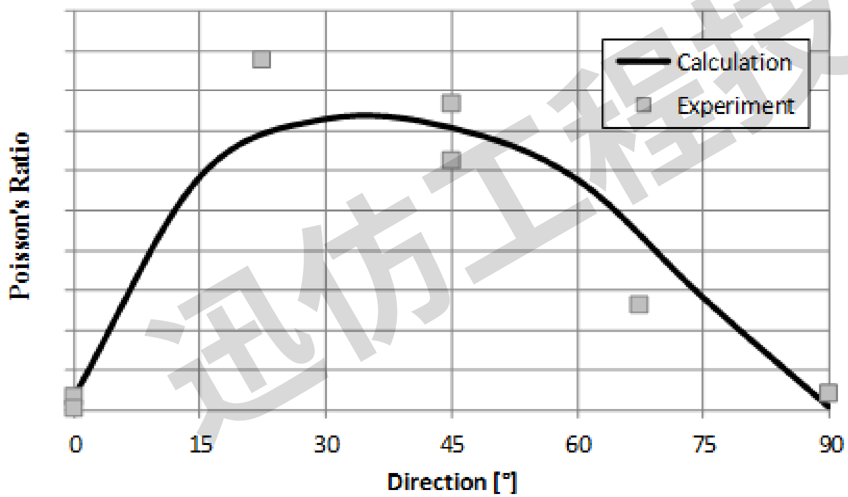
- Strongly reduced ductility in fiber directions
- Significant ductility in other directions
- Anisotropy of elasticity
- Stress state dependent hardening
- Anisotropy of hardening
- Ductile failure criterion suitable for ductile direction
- Additional stress based failure criterion reasonable
- Anisotropy of fracture

Challenging behavior for material model with respect to elasto-plastic and failure behavior
Behavior can be different between tension and compression

Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

Elastic Material Behavior





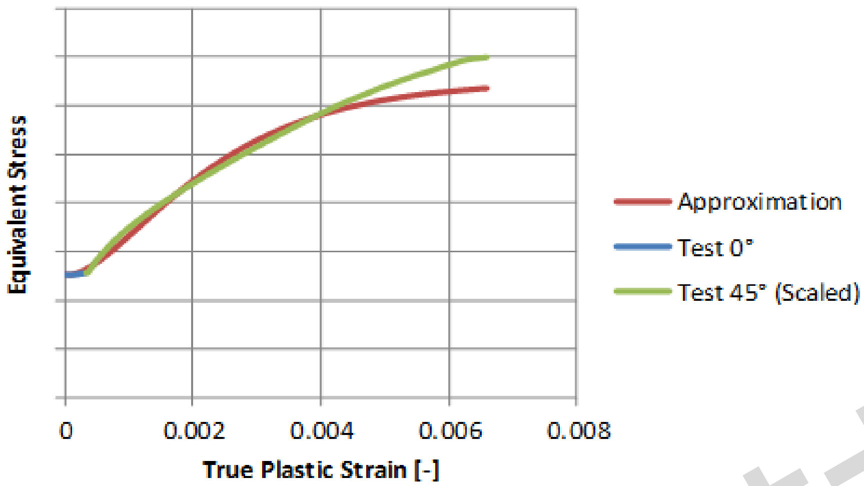
- Elastic behavior is assumed to be linear
- A significant rate dependency has not been observed
- Due to the different fiber density in 0° and 90° orientation the Young-'s modulus differs significantly in these orientations

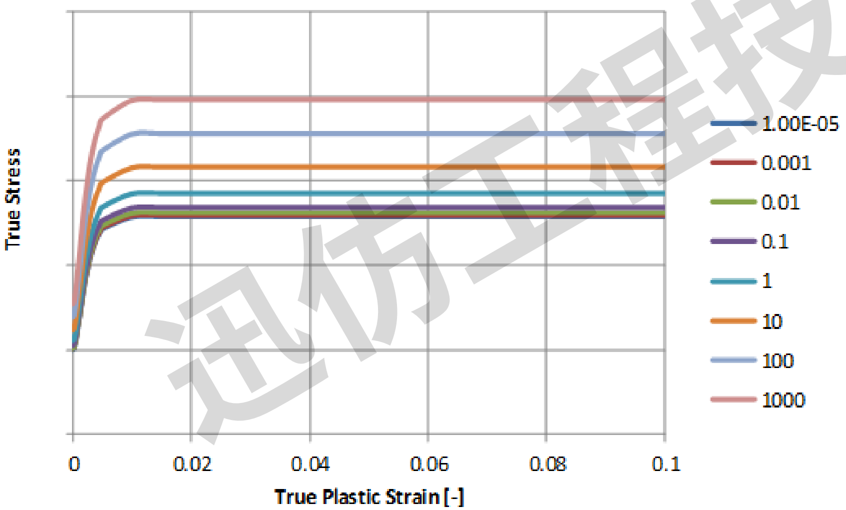
Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

MF-GenYld+CrachFEM for Organic sheets

MATFEM

Elasto-Plastic Material Behavior

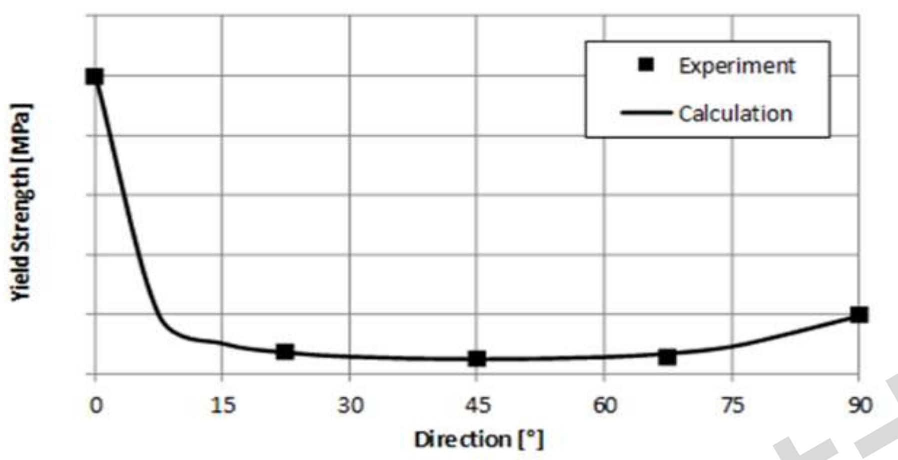


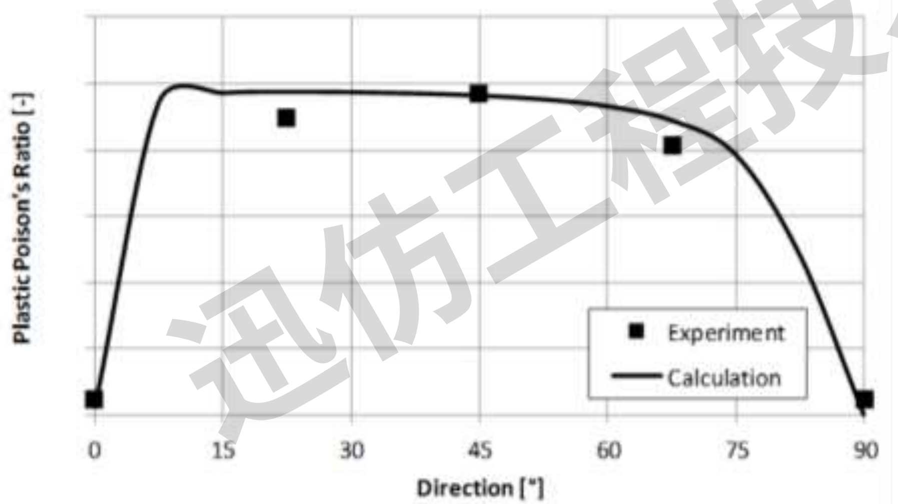


- Reference hardening curve is hardening curve for uniaxial tension in 0°
- Experimentally determined hardening curve is approximated and extrapolated to higher strains
- Based on tensile tests at different strain rates the yield strength is defined as a function of plastic strain and strain rate
- Even though failure in uniaxial tension happens at very low plastic strains the reference curves must be defined up to high plastic strains due to high fracture strains for other loadings

Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

Elasto-Plastic Material Behavior

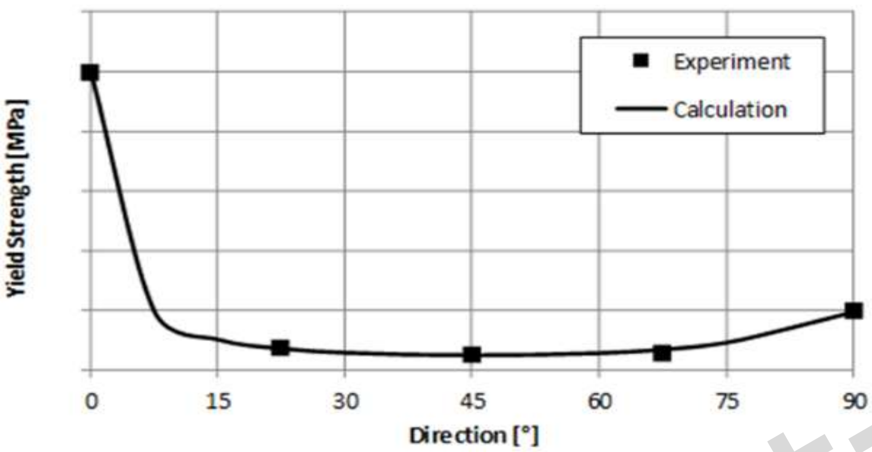


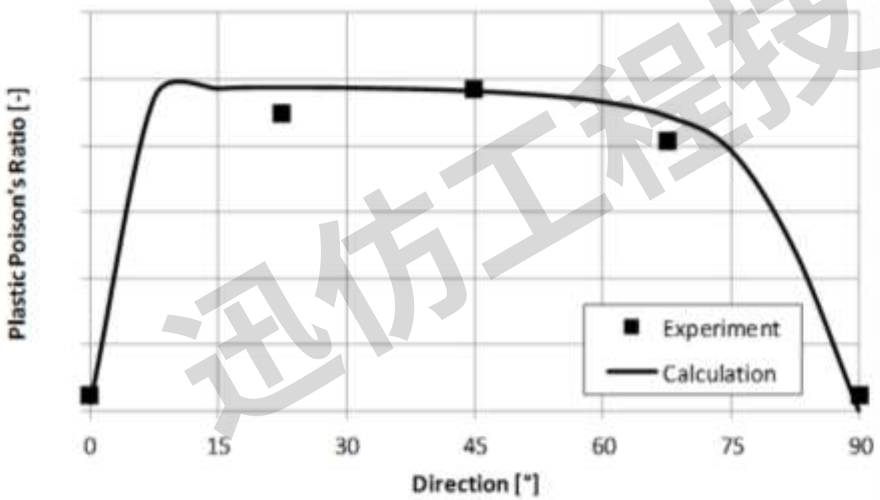


- Plastic orthotropy is characterized by direction dependency of yield strength and plastic Poisson's ratio
- Due to the different fiber density in 0° and 90° orientation the yield strength differs significantly in these orientations

Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

Elasto-Plastic Material Behavior





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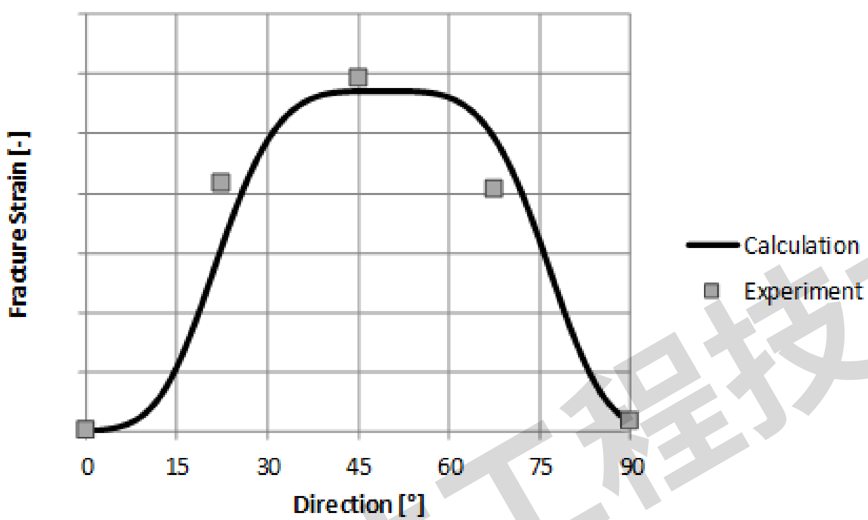
Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau" March 28/29, 2017, Mannheim

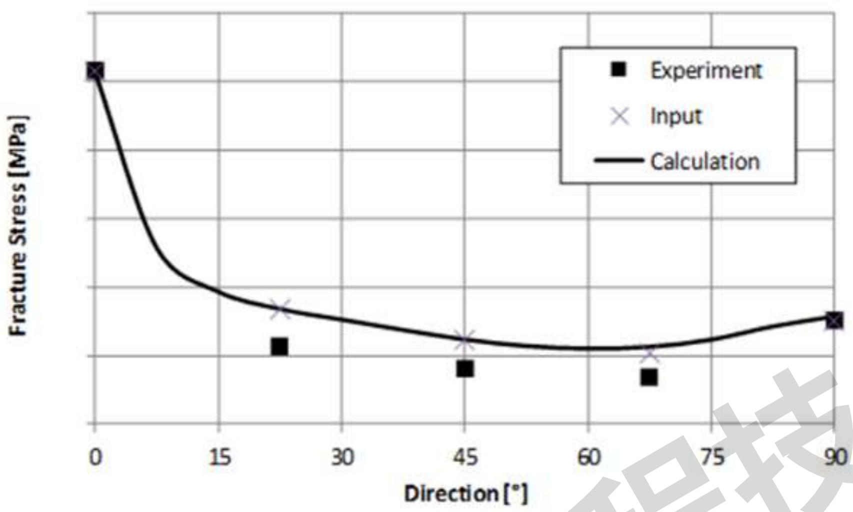
Strain Based Failure Behavior



- Comparatively ductile behavior for loading angles beyond fiber orientation
- Comparatively brittle behavior in fiber orientation
- Purely strain based failure criteria can cause problems in the vicinity of the fiber orientation causing an unphysical brittle behavior

Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

Stress Based Failure Behavior



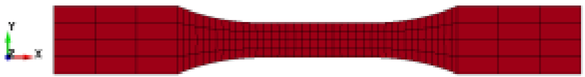
- Comparatively ductile behavior for loading angles beyond fiber orientation
- Comparatively brittle behavior in fiber orientation
- Purely stress based failure criteria can cause problems in ductile orientation as the hardening behavior is very low (stress based criteria 'unsharp')

The use of stress based criteria in combination with strain based criteria us used further on and gives promising results

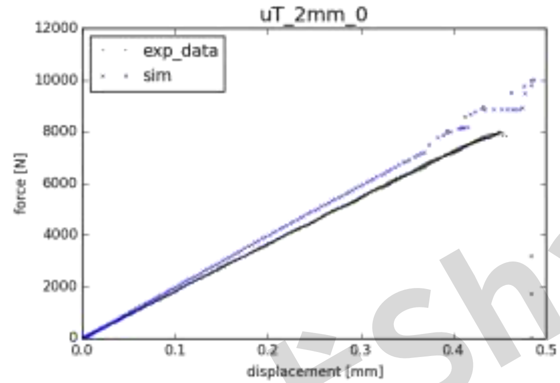
Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

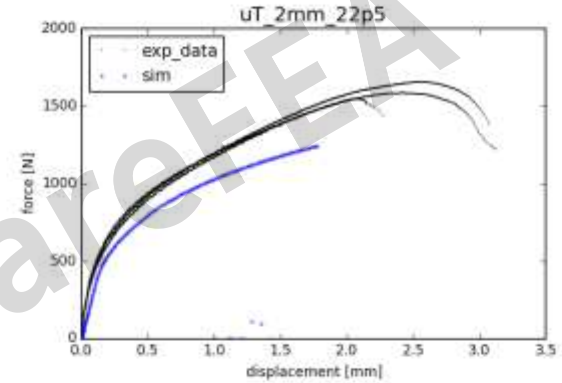
Tensile Tests (Different Orientations)

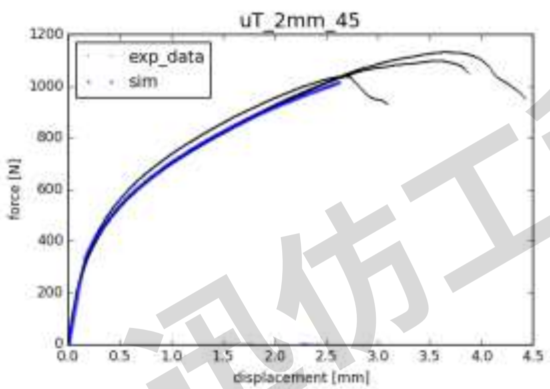
Simulation
Experiment

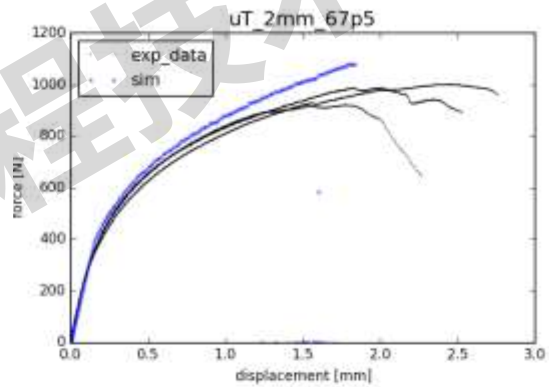


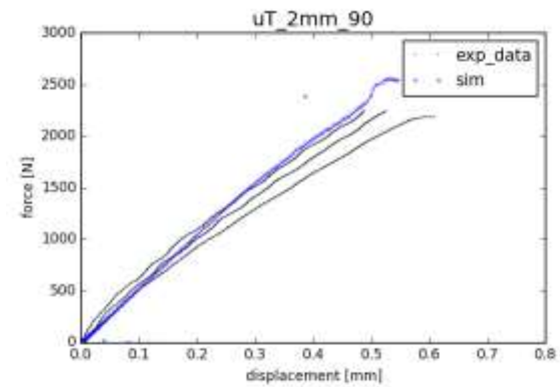
LS-DYNA
Shell Elements
Element length: 2 mm





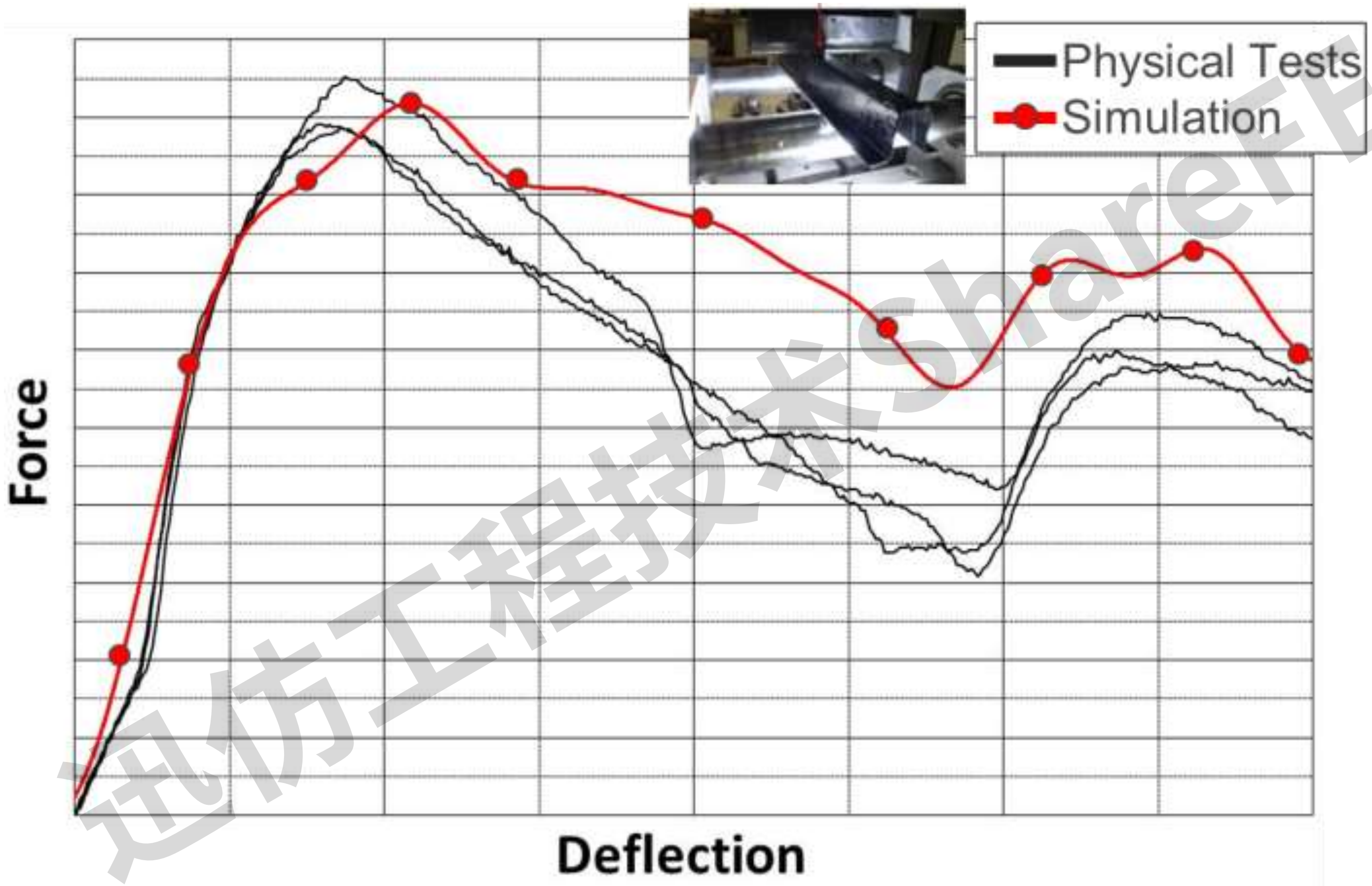






Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

Component Validations – quasi static – 3-Point-Bending - 80/20



Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau“ March 28/29, 2017, Mannheim

MF-GenYld+CrachFEM for Organic sheets

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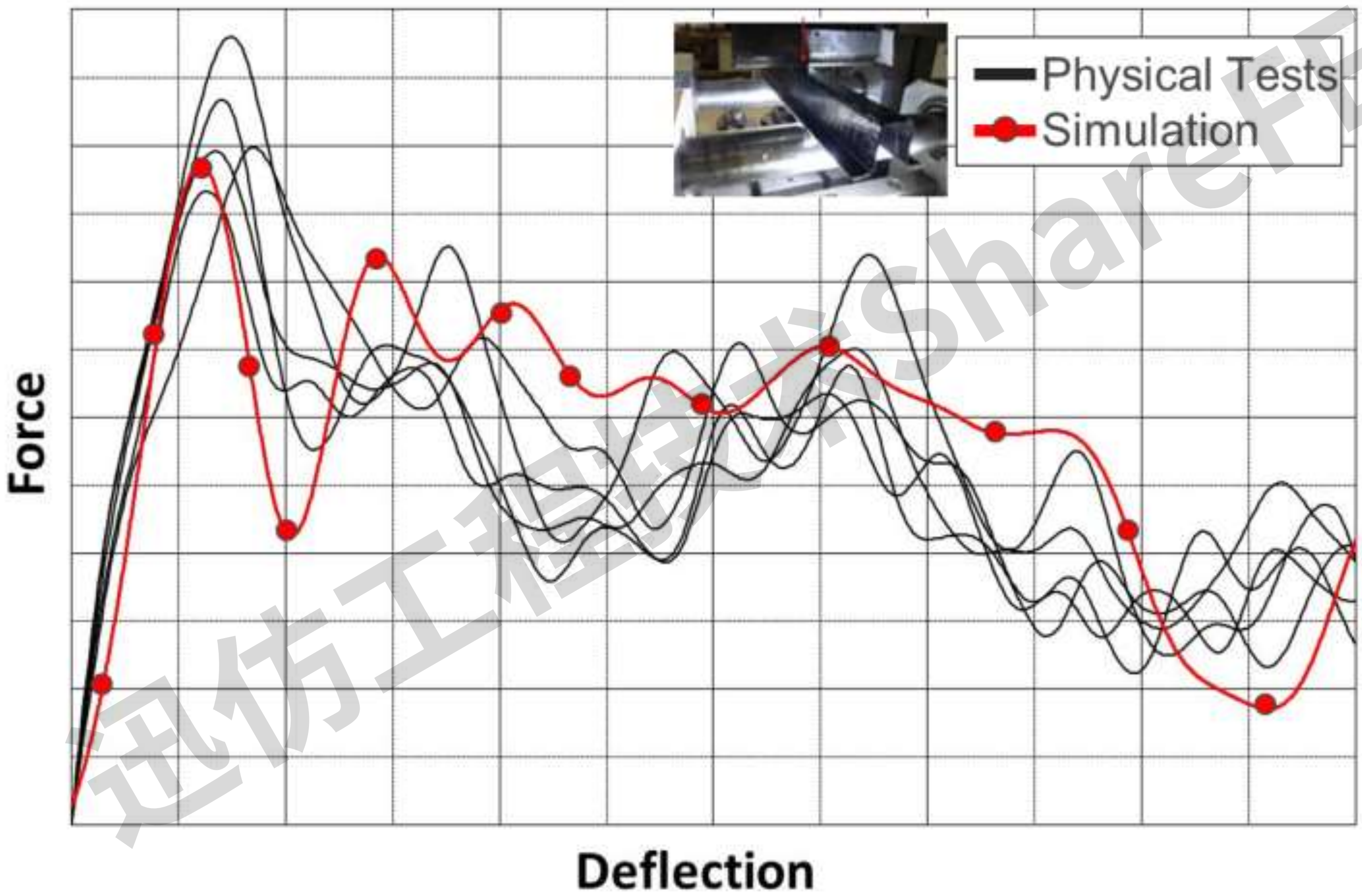
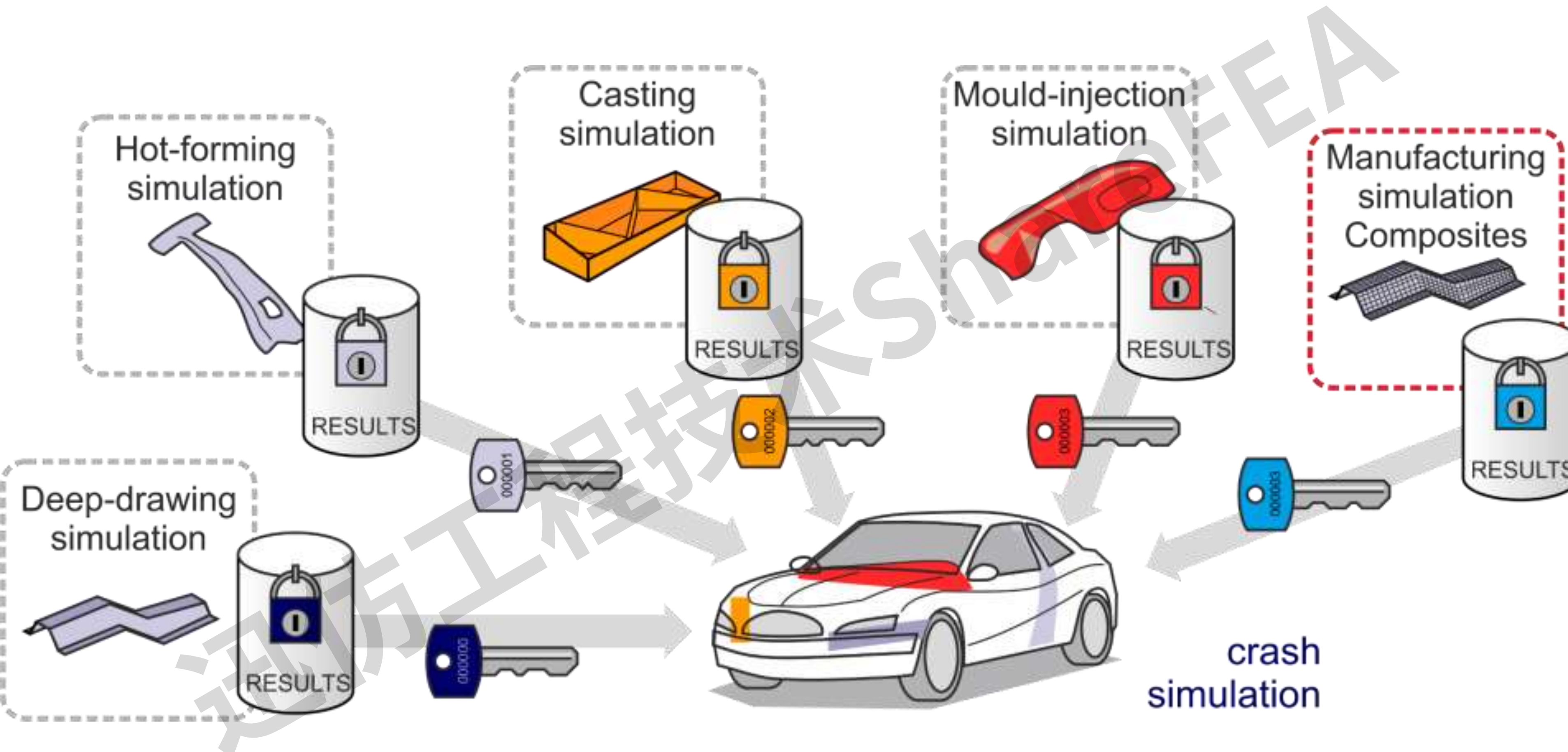
Component Validations – dynamic – 3-Point-Bending - 80/20



Source: M. Franzen et al.; Improved Crash Simulation of Continuous-Fiber-Reinforced Thermoplastics: Organic Sheets; International Congress „Kunststoffe im Automobilbau" March 28/29, 2017, Mannheim

Mapping from manufacturing simulation



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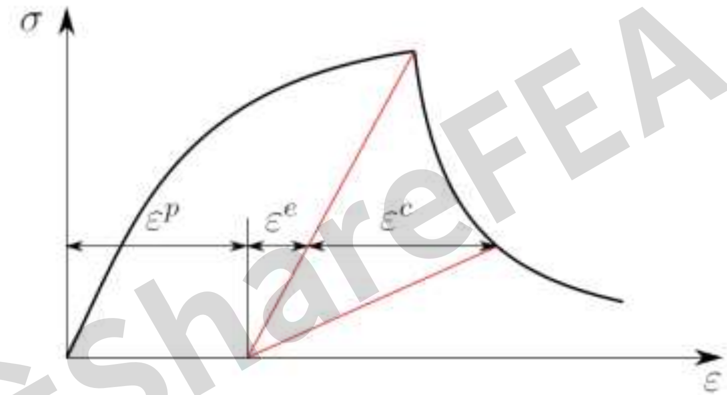
- ► Status of CrachFEM application

MF-GenYld+CrachFEM for GFRP / CFRP

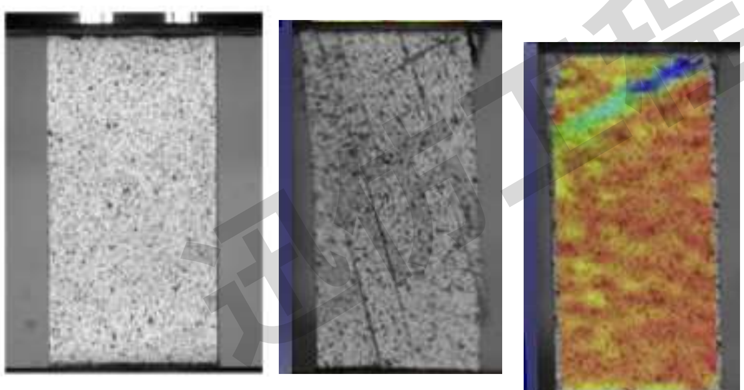
MATFEM

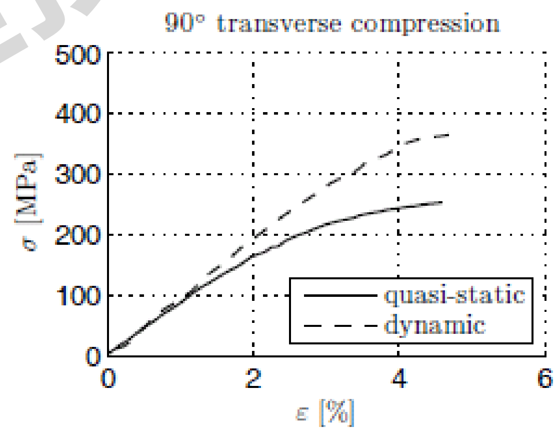
Schematic Material Behaviour

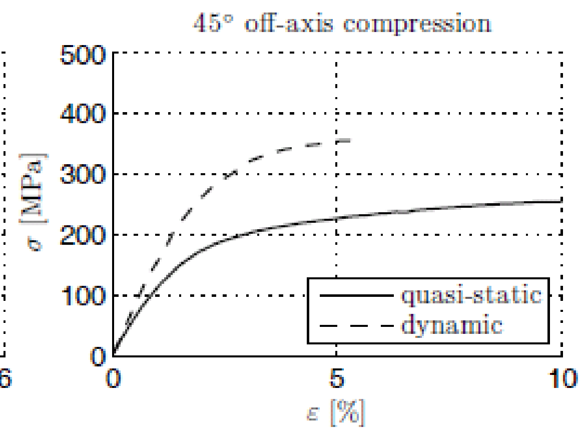
- ▶ Prefailure nonlinearities
- ▶ Fracture behavior



Quasi-static and dynamic off-axis compression tests





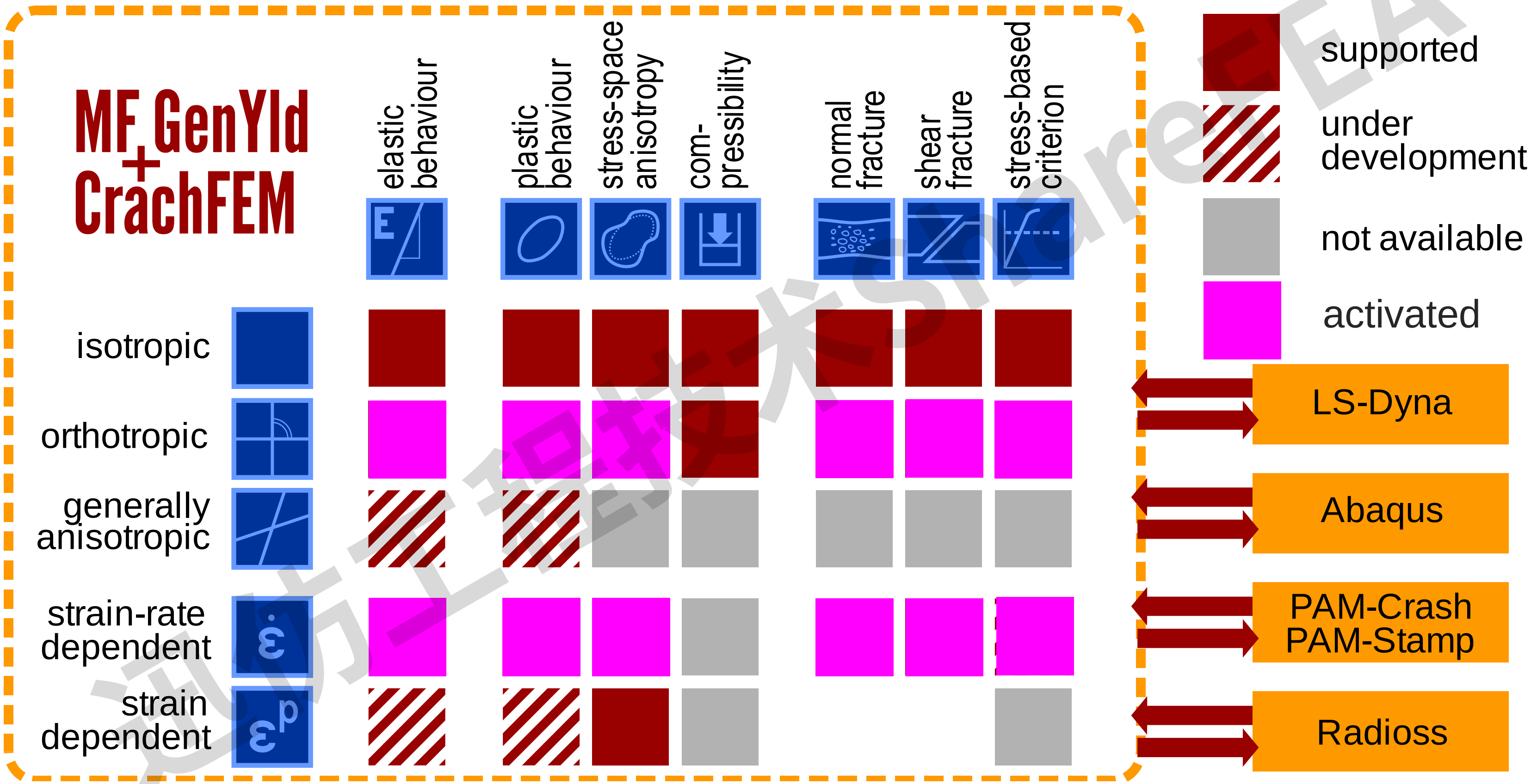


Source: Koerber et al.: “High strain rate characterisation of unidirectional carbon-epoxy IM7-8552 in transverse compression and in-plane shear using digital image correlation”

MF-GenYld+CrachFEM for GFRP / CFRP

MATFEM

Relevant Modules

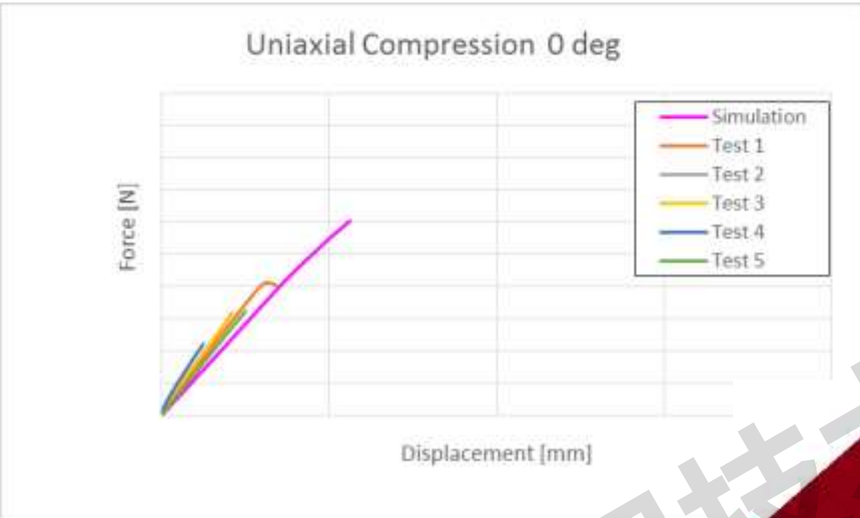


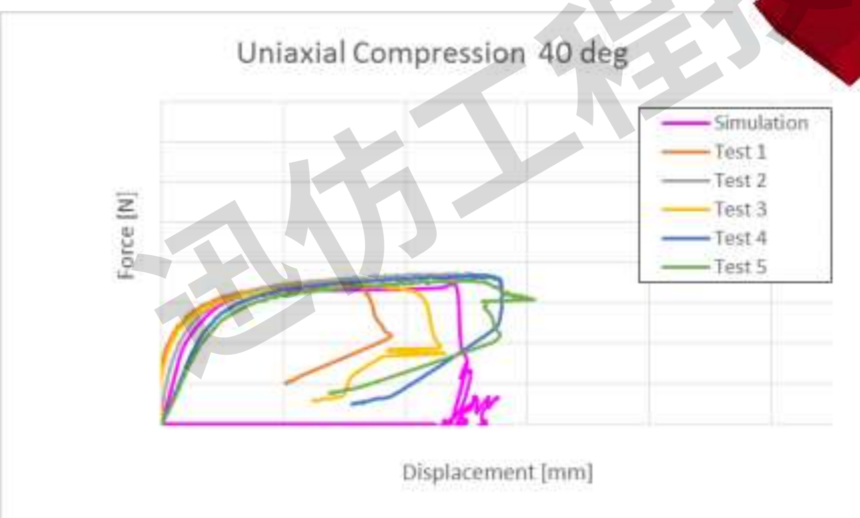
MATFEM

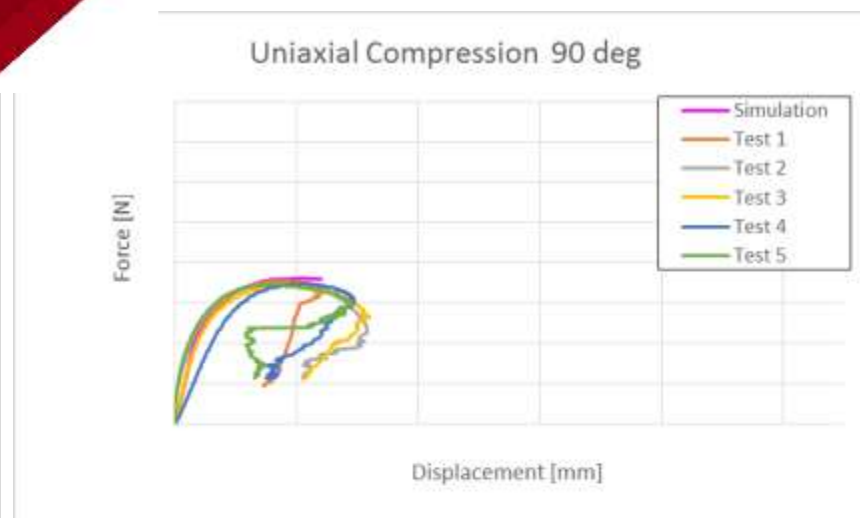
Tensile Tests (Different Orientations)

By Courtesy of Ford Research & Advanced Engineering Europe

Compression Tests (Different Orientations)







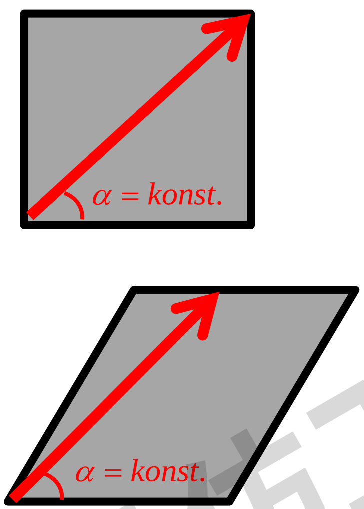
By Courtesy of Ford Research & Advanced Engineering Europe

Contents

MATFEM

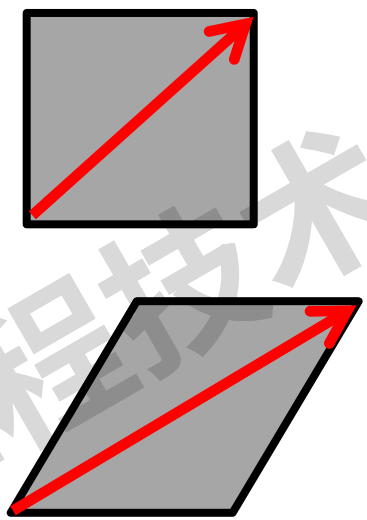
Tracking of directions for composite materials

Method 1
fixed angle between
element axis and fiber direction



- not precise in shear
- only one direction can be tracked

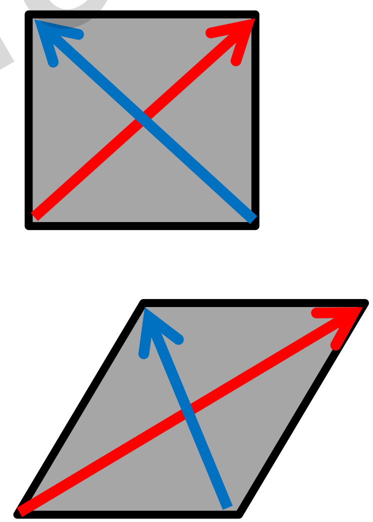
Method 2
shape functions
(e.g. PAMCRASH)



$$a_i = x_{iI} N_I^A$$
$$b_i = x_{iI} N_I^B$$
$$n^1 = \frac{a}{|a|}$$
$$n^3 = \frac{a \times b}{|a \times b|}$$
$$n^2 = n^3 \times n^1$$

- precise
- Only one direction can be tracked

Method 3
deformation gradient



$$a = F\ a^0$$
$$b = F\ b^0$$
$$n^1 = \frac{a}{|a|}$$
$$n^2 = \frac{b}{|b|}$$

- precise
- Multiple directions can be tracked

Source: G. Oberhofer, H. Dell, M. Vogler, H. Gese; Current solutions and open challenges in modeling organic sheets; Automotive CAE Grand Challenge April 12+13, 2016, Hanau

MATFEM

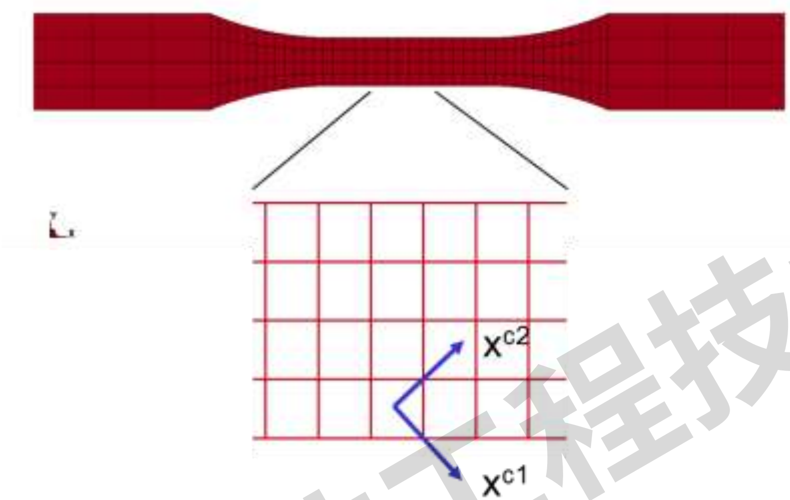
General Anisotropy for Composite Materials

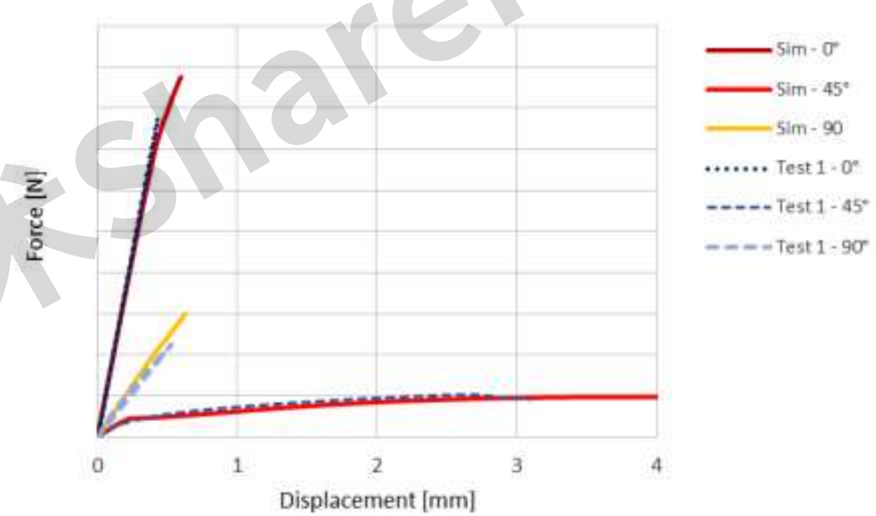
- Superposition of two or multiple transversely-isotropic components or
- Structural tensors (implementation according to Ph.D. thesis of M. Vogler)

MATFEM

Superposition of two or multiple transversely-isotropic components

Example: +/- 45° tensile test of organic sheet:

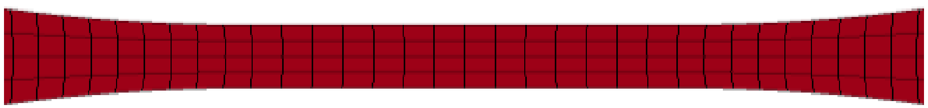


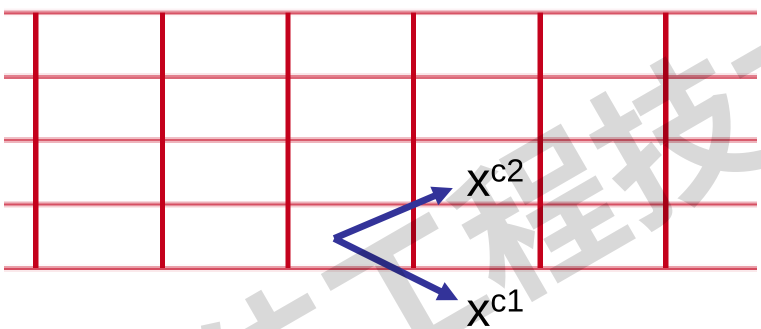


Source: G. Oberhofer, H. Dell, M. Vogler, H. Gese; Current solutions and open challenges in modeling organic sheets; Automotive CAE Grand Challenge April 12+13, 2016, Hanau

Superposition of two or multiple transversely-isotropic components

Example: +/- 45° tensile test of organic sheet:



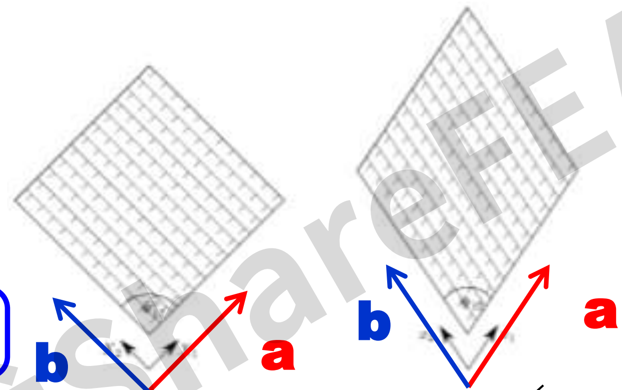


- Relative rotation of the x-axes of the two components: x^{c1} and x^{c2}

Source: G. Oberhofer, H. Dell, M. Vogler, H. Gese; Current solutions and open challenges in modeling organic sheets; Automotive CAE Grand Challenge April 12+13, 2016, Hanau

Structural tensors (implementation according to Ph.D. thesis of M. Vogler)

$\boxed{\mathbf{B} = \mathbf{b} \otimes \mathbf{b}}$



$\boxed{\mathbf{A} = \mathbf{a} \otimes \mathbf{a}}$

➡ a and b not necessarily perpendicular to each other! a $\not\perp$ b

➡ Monoclinic material behavior (not orthotropic anymore)!

$$\boxed{f = \hat{f}(\boldsymbol{\sigma}, \bar{\varepsilon}^p, \mathbf{A}, \mathbf{B}) = \alpha_1 I_1 + \alpha_2 I_2 + \alpha_3 I_3 + \underline{\alpha_7 I_7} - 1}$$

- Mixed Invariant $I_7 := \underline{\mathrm{tr}\left[\mathbf{AB}\left(\boldsymbol{\sigma}^{\mathrm{pind}}\right)^2\right]}$ has to be regarded in the yield surface formulation and in the elasticity law
- Additional anisotropy parameter $\underline{\alpha_7}$

  … which physical meaning?

  … how to determine?

Contents

MATFEM

- Motivation
- MF-GenYld+CrachFEM for non-reinforced polymers
- MF-GenYld+CrachFEM for short fiber reinforced polymers
- MF-GenYld+CrachFEM for endless fiber reinforced polymers – Organic sheets
- MF-GenYld+CrachFEM for endless fiber reinforced composites (CFRP)
- Current developments
- Status of CrachFEM application

MATFEM

Benefits for users of MF GenYld+CrachFEM

- One material model for different FEA codes
- Improved modelling of advanced materials (e.g. with anisotropic hardening)
- CrachFEM also predictive in case of non-linear strain path (isotropic-kinematic hardening of algorithm Crach; tensorial description of damage in fracture models
- FLC prediction and fracture prediction also possible for orthotropic materials
- MATFEM offers also experimental material characterization for material model => material model development is motivated and directly supported by material tests
- MATFEM is partner in research projects to include new innovative features in MF GenYld+CrachFEM

Status of CrachFEM application

MATFEM

Benefits for users of MF GenYld+CrachFEM

- Further development is driven by a growing number of licensees from different industrial branches (aerospace, automotive, consumer products, medical devices, currently approx. 50 users worldwide)
- MF GenYld+CrachFEM is in wide use in industry. Customers include: Airbus Operations, BMW AG, Ford, Hyundai-Mobis, Mercedes-Benz AG, ThyssenKrupp Steel Europe AG, ...