Anisotropes Materialverhalten
über kurz oder lang zur Materialkarte

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Content

- Introduction 4a engineering & 4a impetus
- Short overview composites
- Short & long fiber reinforced thermoplastics
  - Material behavior
  - ***MAT_24** - state of the art
  - ***MAT_157** - „key enabler“ micro mechanic
  - ***MAT_215** - micromechanical material model
- Endless fiber reinforced composites
- Summary

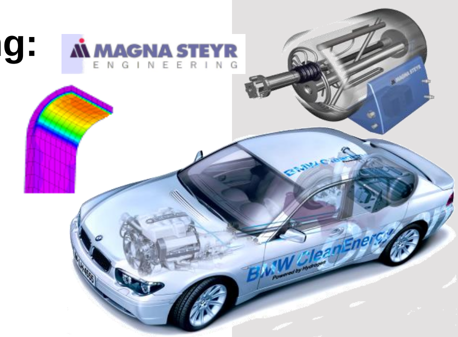
4a engineering GmbH
4a impetus

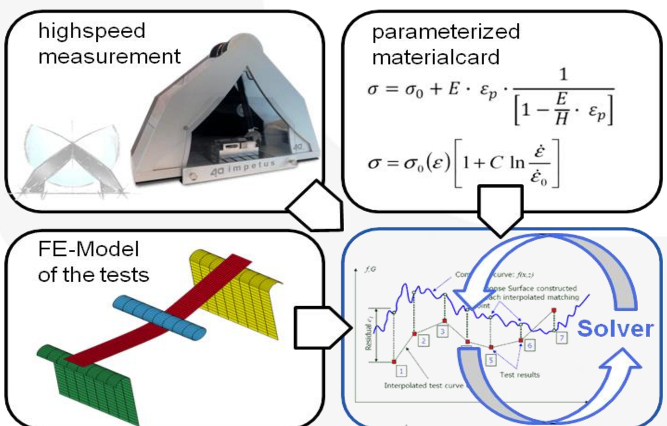
4a engineering GmbH

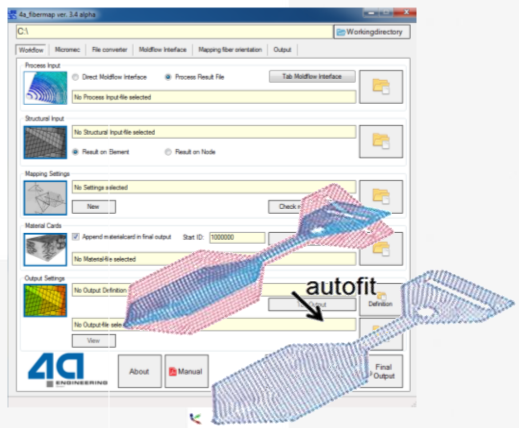
- polymer and materials science
- numerical simulation methods
- fiber reinforced plastics and composites
- method and software development
- material characterization
- product development

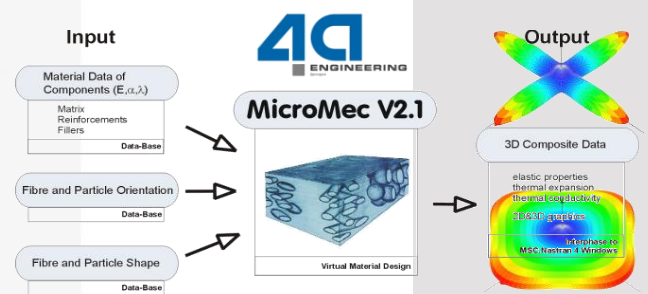
strut bar:

LH_2 – tank mounting:

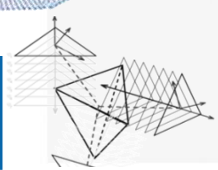




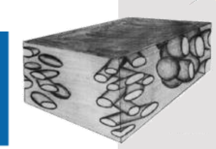




IMPETUS



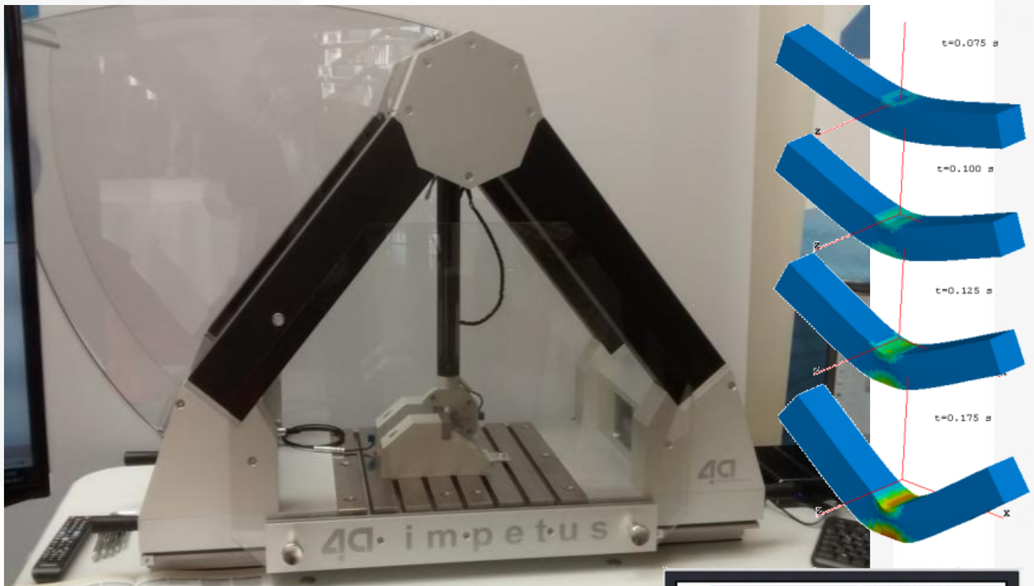
FIBERMAP

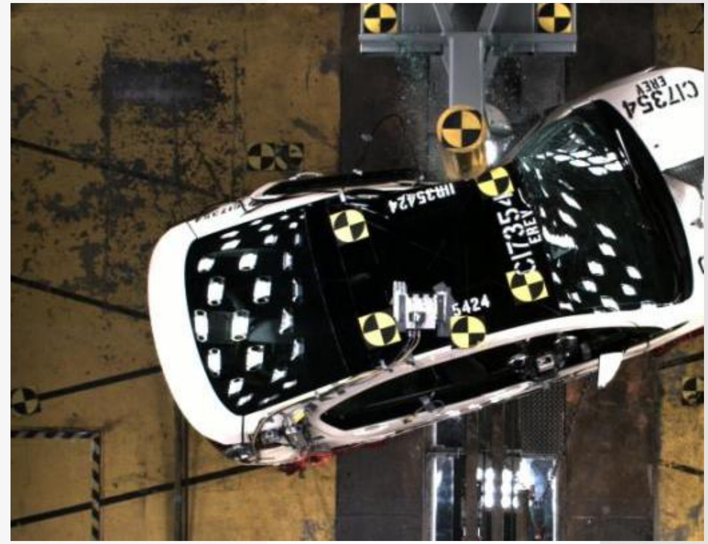


MICROMEC

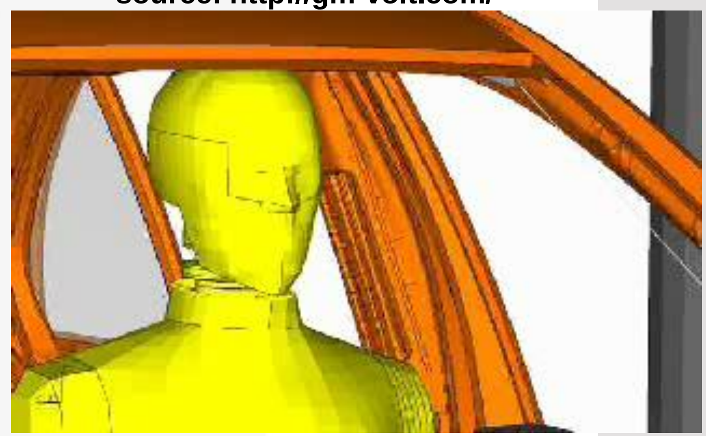
4a impetus
Material characterization

- **efficient high-dynamic testing**
- **crash-behaviour of plastics**
- **material data for simulation**





source: http://gm-volt.com/



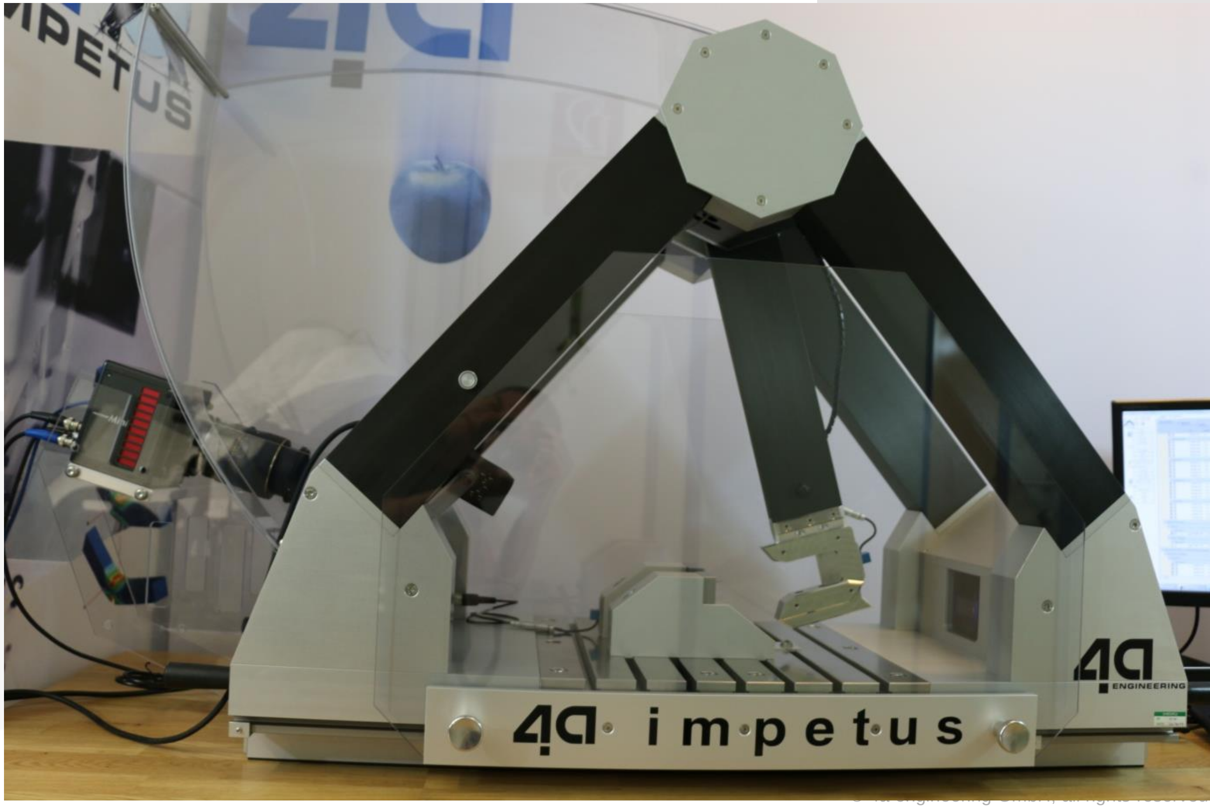
source: Dynamore GmbH

4a impetus – new hardware features

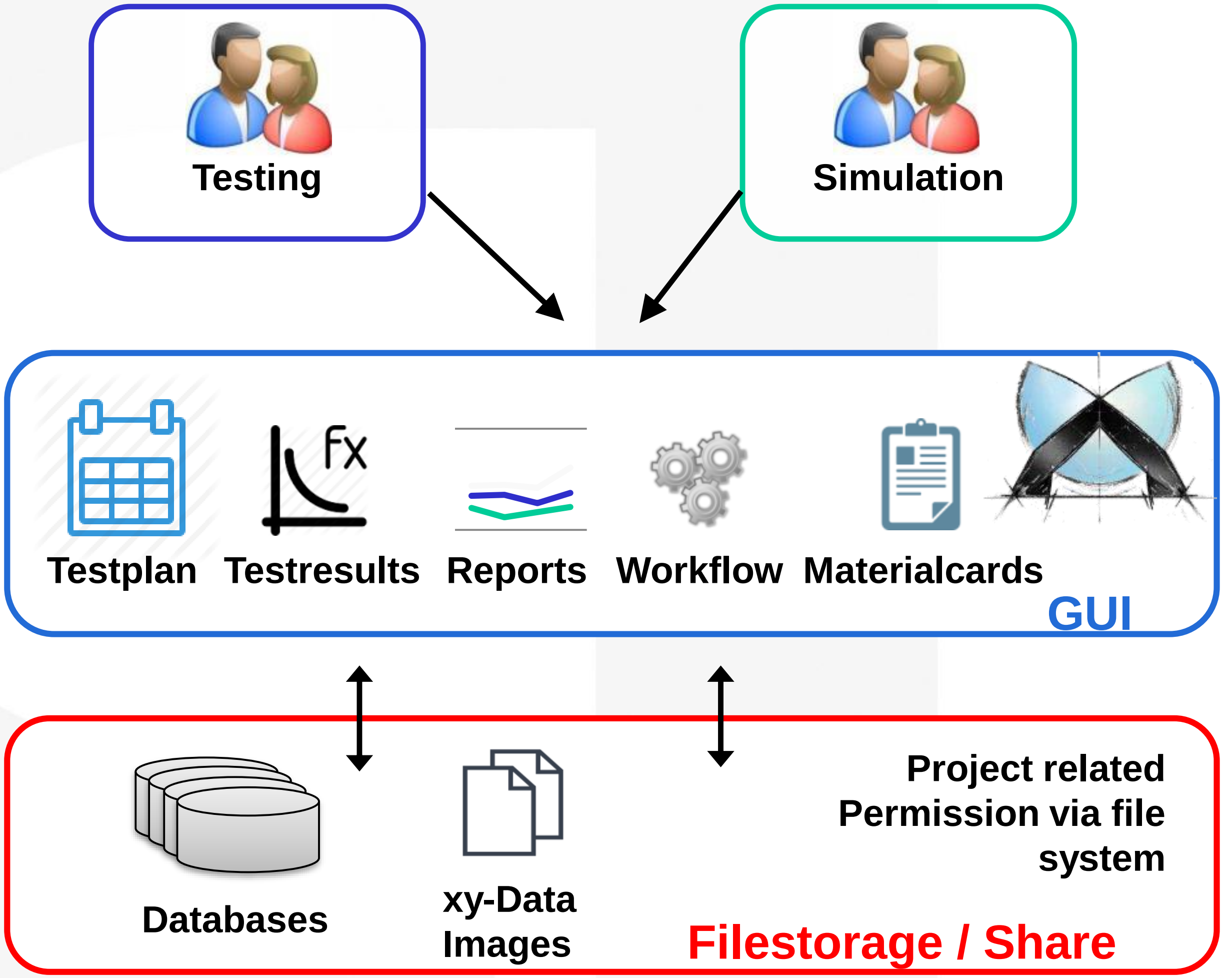
High-speed camera

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

  → **synchronizing**

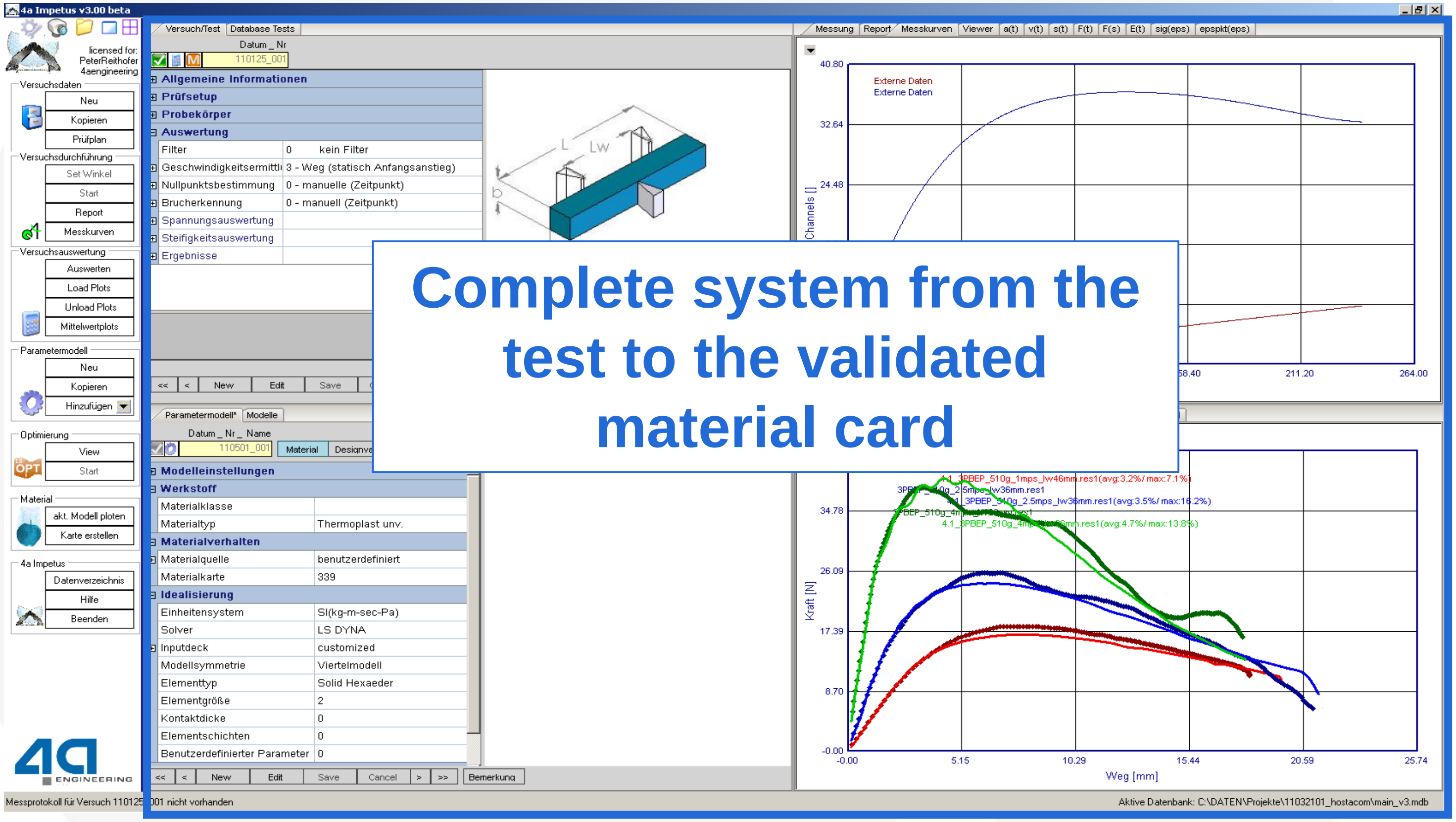


4a impetus
Software solution from the test to the material card

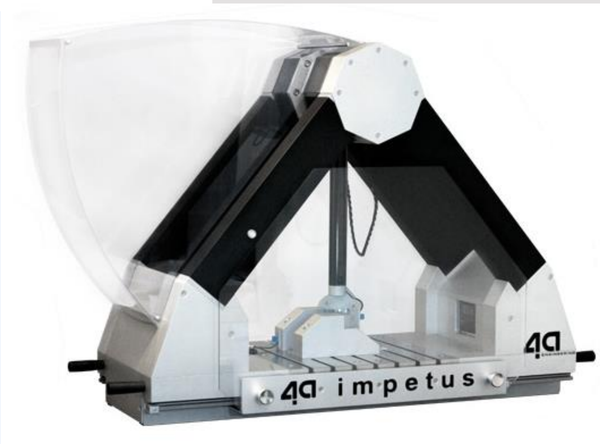


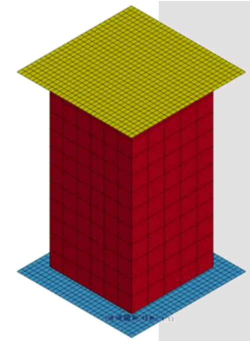
4a impetus - intelligent testing systems
powered by 4a engineering GmbH

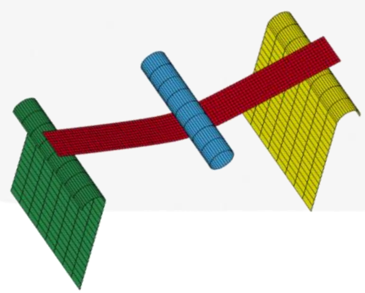
4a impetus

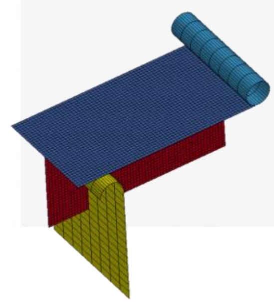


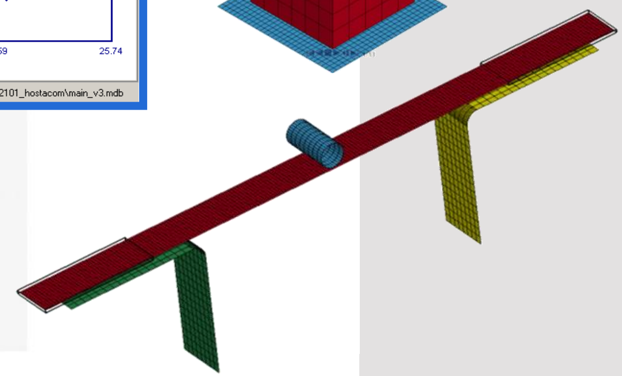
Complete system from the test to the validated material card









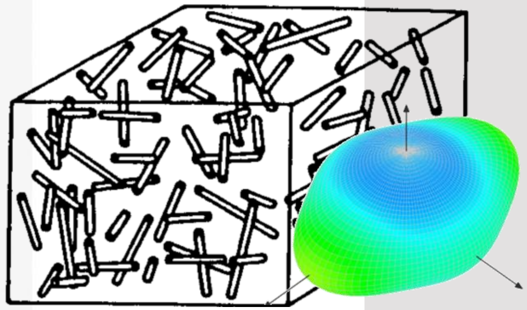


Short overview composites

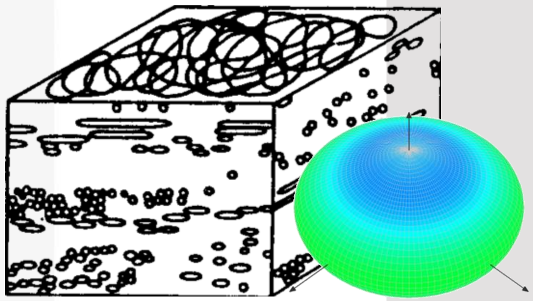
Overview composites

Polymer composites

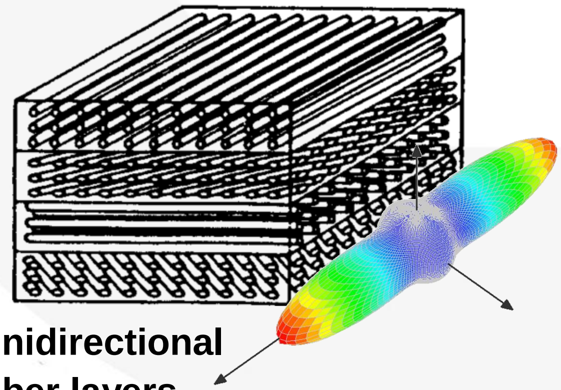
- Unreinforced
- Particle reinforced (l/d<1)
- Short fiber reinforced **(l/d 20-40, d~10µm)**
- Long fiber reinforced **(l/d 100-200, d~20µm)**
- Endless fiber reinforced (l/d >> 1000)



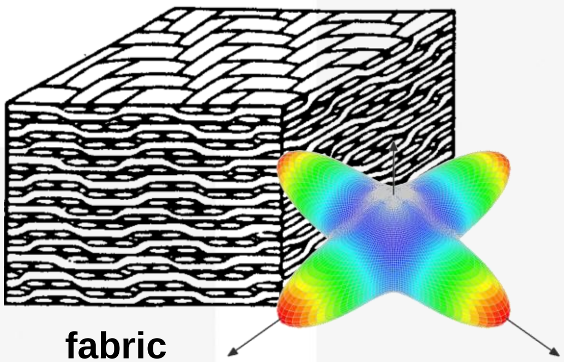
Short resp. long fiber



fiber mat



unidirectional fiber layers



fabric

Source: Physik und Werkstoffkunde der Kunststoffe VO02/03, Montanuniversität Leoben

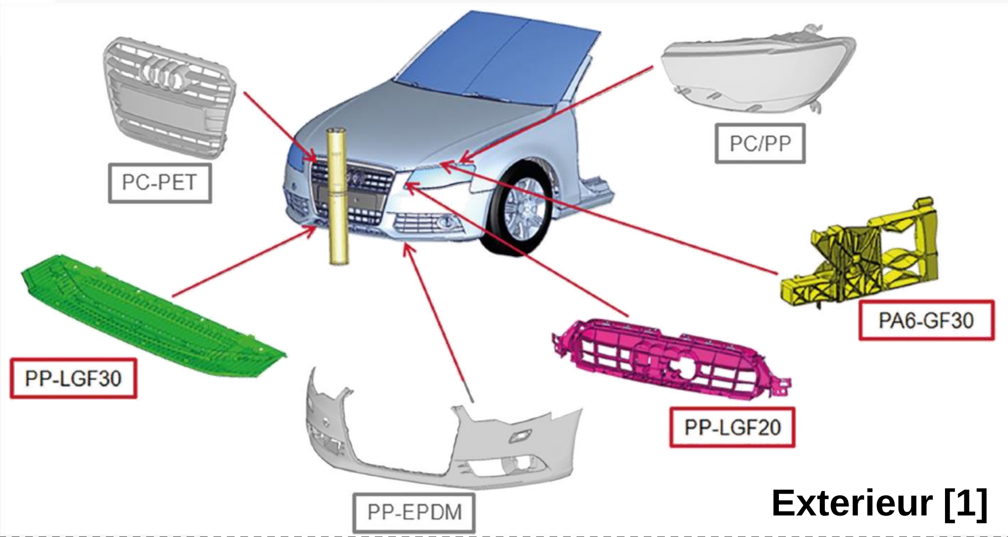
Overview composites
Material models in LS DYNA

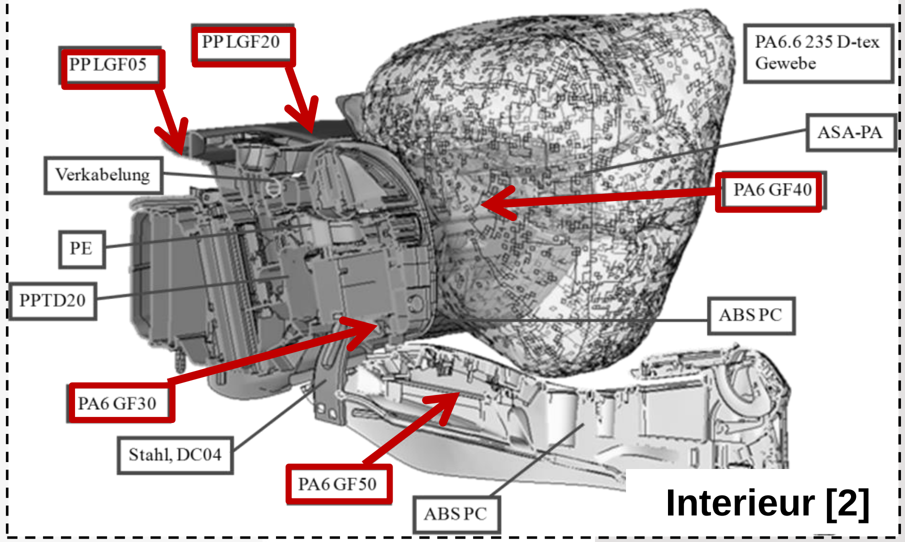
No.	Elastic	Plastic	Damage	Strain rate	Failure	
2	**Ortho / Anisotropic**	**None**	**None**	**None**	***MAT_ADD_EROSION**	SFRT / LFRT
24	Isotropic	Mises	None	Plasticity	*MAT_ADD_EROSION	
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION	
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION	
157	**Anisotropic**	**Hill**	**None**	**Plasticity**	***MAT_ADD_EROSION**	
215	***MAT_4a_micromec in development: Model based on MORI TANAKA MEANFIELD**					
22	Orthotropic	None	None	None	Orientation dependent	Carbon, Glass, Kevlar endless & fabric
54/55	Orthotropic	None	Elastic Orthotropic	Strength	Chang-Chang/ Tsai-Wu Orientation dependent	
58	Orthotropic	None	Elastic Orthotropic	Strength, Stiffness	mod. Hashin Orientation dependent	
158	Orthotropic	None	Elastic Orthotropic	Visco-elasticity	Orientation dependent	
261	Orthotropic	None	Elastic Orthotropic	None	failure Pinho (Puck) Orientation dependent	
262	Orthotropic	None	Elastic Orthotropic	None	failure Camanho (Puck) Orientation dependent	

Short and long fiber reinforced thermoplastics

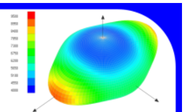
No.	Elastic	Plastic	Damage	Strain rate	Failure	
2	**Ortho / Anisotropic**	**None**	**None**	**None**	***MAT_ADD_EROSION**	SFRT / LFRT
24	Isotropic	Mises	None	Plasticity	*MAT_ADD_EROSION	
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION	
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION	
157	**Anisotropic**	**Hill**	**None**	**Plasticity**	***MAT_ADD_EROSION**	
215	***MAT_4a_micromec in development: Model based on MORI TANAKA MEANFIELD**					

Short and long fiber reinforced thermoplastics
Typical applications and materials

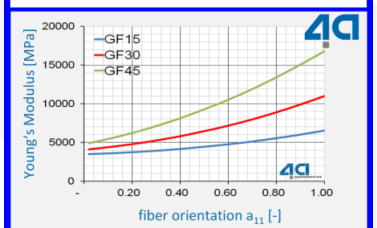




H1

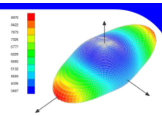


PA6GF30
polyamide short glass fiber reinforced

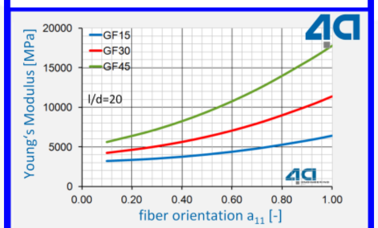


P: 3.4 €/kg — ρ: 1.4 g/cm³
E_1: 9700 MPa — α_1: $64\cdot10^{-6}$ 1/K
σ_y: 140 MPa — ε_B: 4%
T_G: 50 °C — a_c: 100(15) kJ/m²

H2

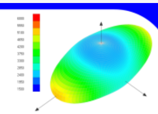


PBTGF30
polybutylene terephthalate short glass fiber reinforced

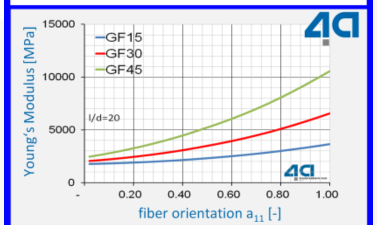


P: 3 €/kg — ρ: 1.5 g/cm³
E_1: 9500 MPa — α_1: $25\cdot10^{-6}$ 1/K
σ_y: 92 MPa — ε_B: 3%
T_G: 30 °C — a_c: 67(11) kJ/m²

H3

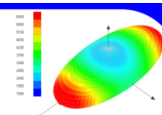


PPGF30
polypropylene short glass fiber reinforced

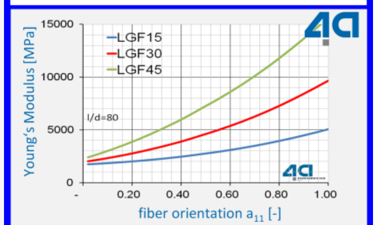


P: 2.3 €/kg — ρ: 1.1 g/cm³
E_1: 6000 MPa — α_1: $38\cdot10^{-6}$ 1/K
σ_y: 70 MPa — ε_B: 4%
T_G: -10 °C — a_c: 20(5) kJ/m²

H4



PPLGF30
polypropylene long glass fiber reinforced



P: 2.5 €/kg — ρ: 1.1 g/cm³
E_1: 6900 MPa — α_1: $40\cdot10^{-6}$ 1/K
σ_y: 76 MPa — ε_B: 5%
T_G: -10 °C — a_c: 70(18) kJ/m²

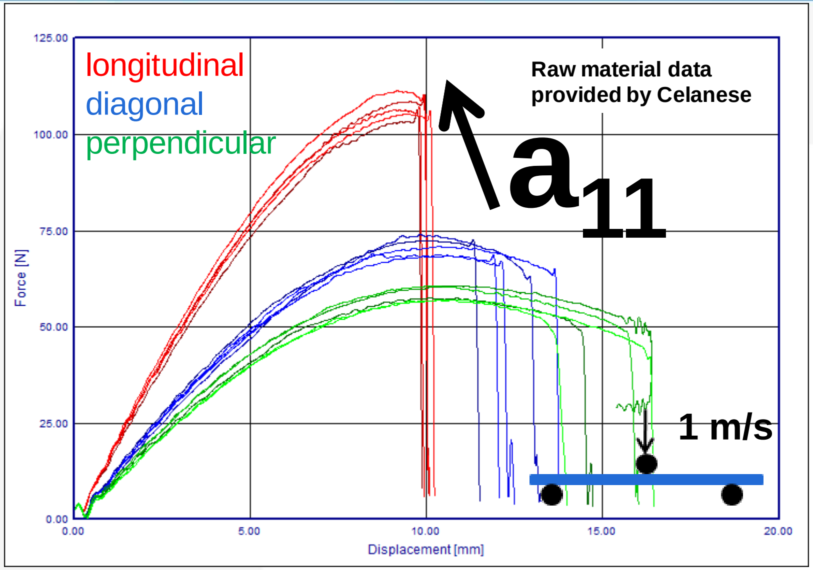
[1] A. Koukal, Audi AG - *Crash- und Bruchverhalten von Kunststoffen im Fußgängerschutz von Fahrzeugen*, TU München, 2014

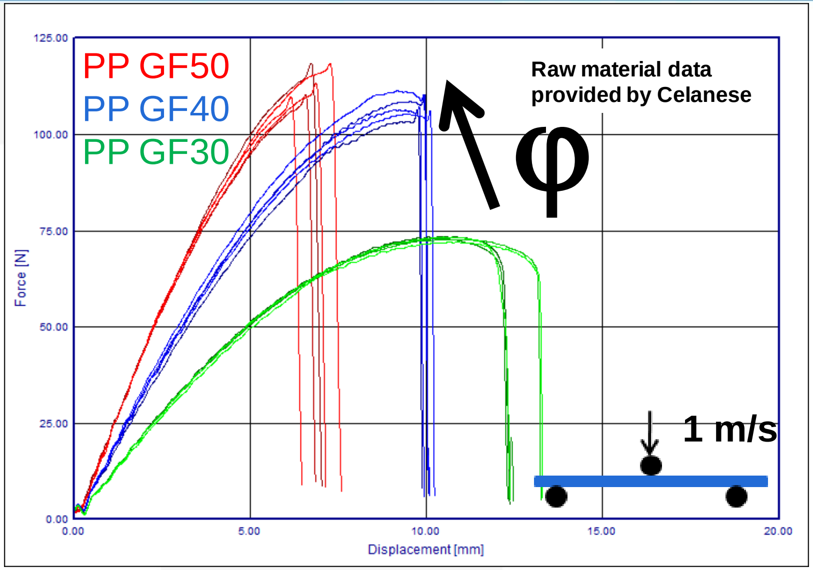
[2] R. Luijkx, Audi AG - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG*, 4a Technologietag 2010

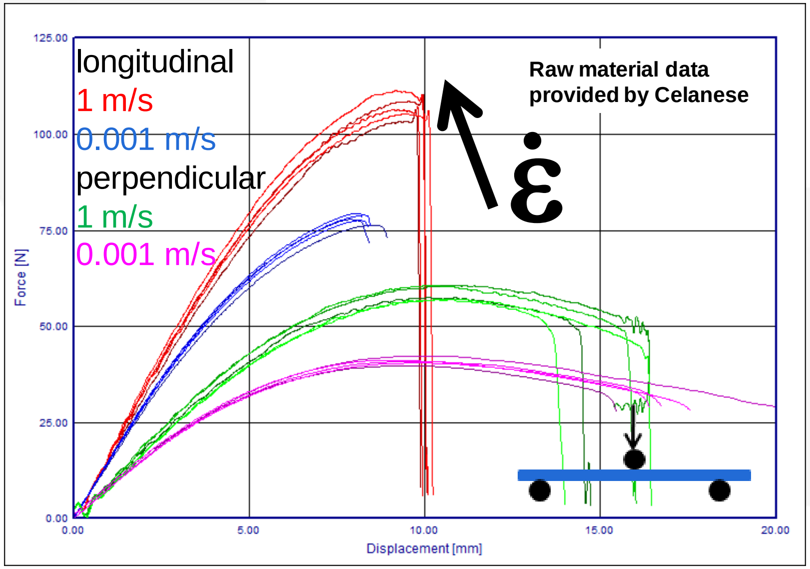
Short and long fiber reinforced thermoplastics

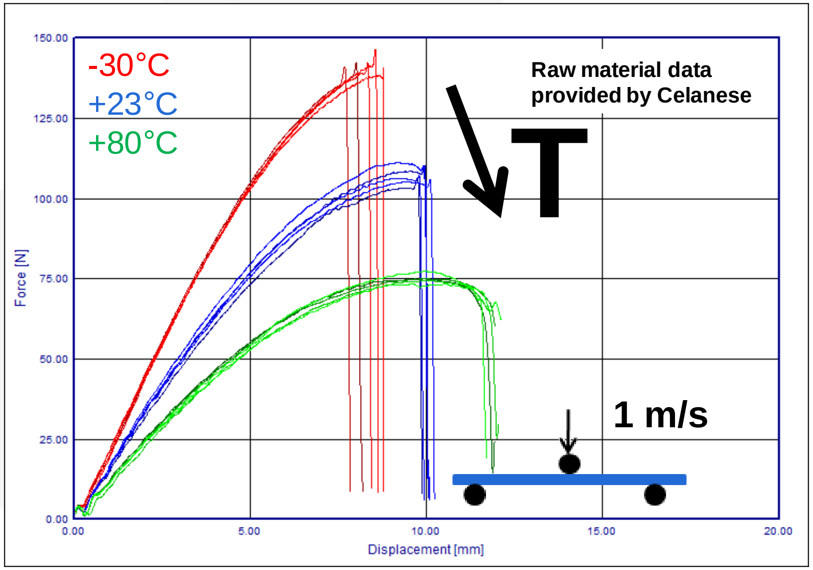
Typical material behavior

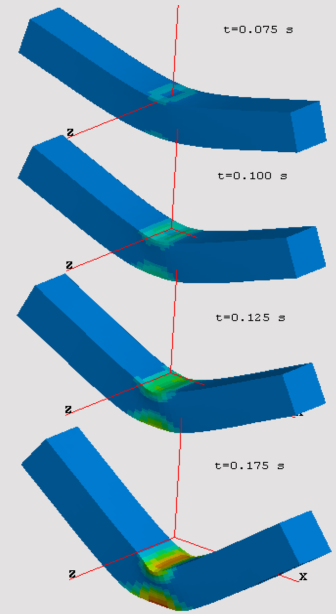
4a ENGINEERING GmbH











4a IMPETUS

Celanese
The chemistry inside innovation™

IMPETUS

ADVANCED

dynamic testing system

validated material cards

intelligent software solution

IN PHYISCS WE TRUST

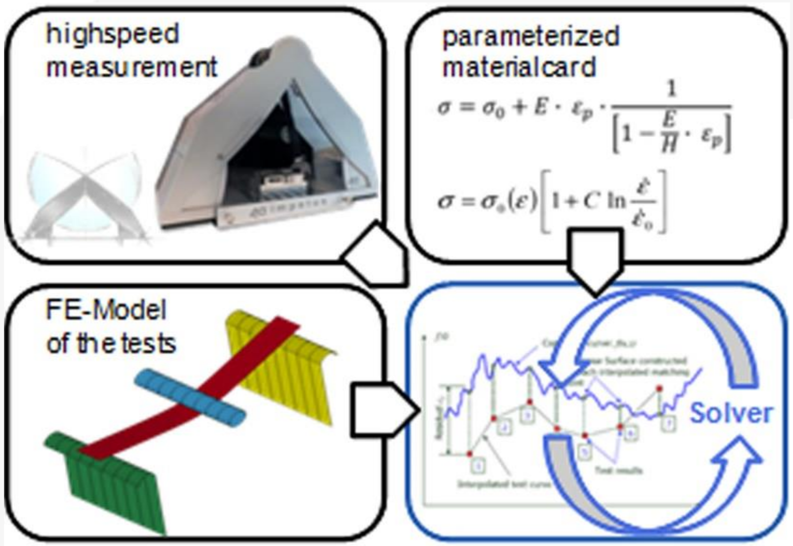
Video: www.youtube/

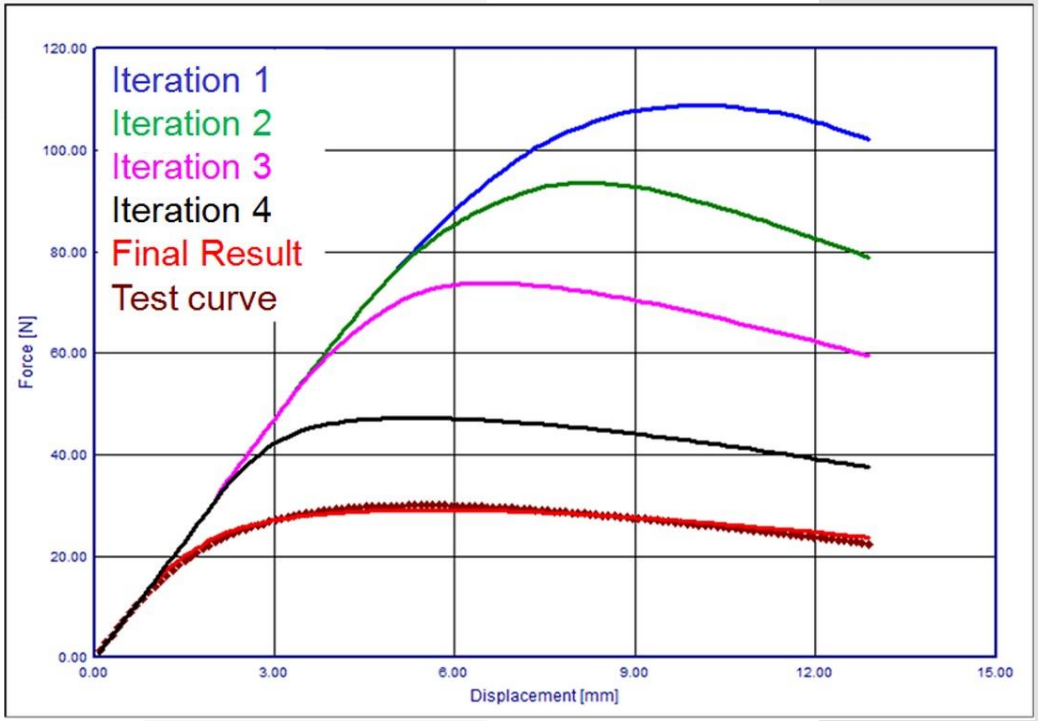
Short and long fiber reinforced thermoplastics

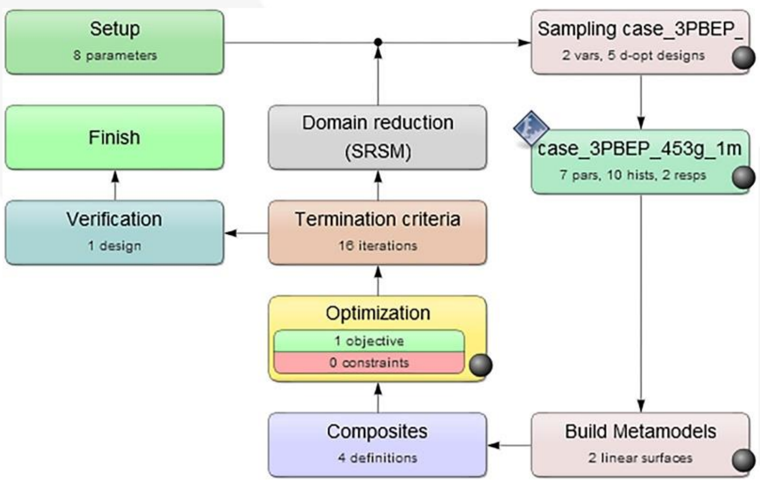
No.	Elastic	Plastic	Damage	Strain rate	Failure	
2	**Ortho / Anisotropic**	**None**	**None**	**None**	***MAT_ADD_EROSION**	**SFRT / LFRT**
24	Isotropic	Mises	**State of the art (Quick&Dirty)**			
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION	
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION	
157	**Anisotropic**	**Hill**	**Composite (LSDYNA R9)**			
215	***MAT_4a_micromec in development: Model based on MORI TANAKA**				**(LSDYNA R10)**	

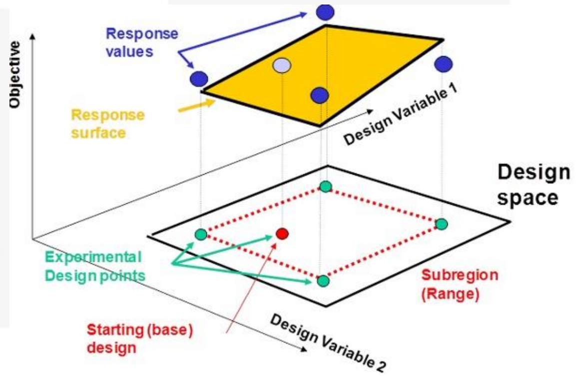
Short and long fiber reinforced thermoplastics

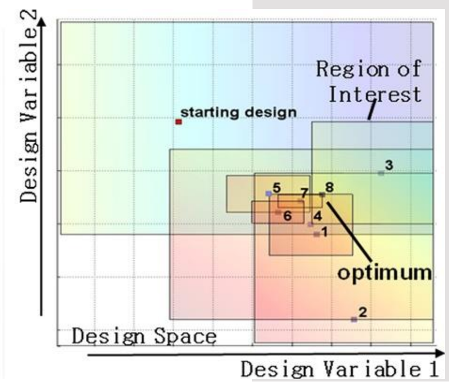
4a impetus *MAT_024 – PP-GF40 diagonal, 23°C







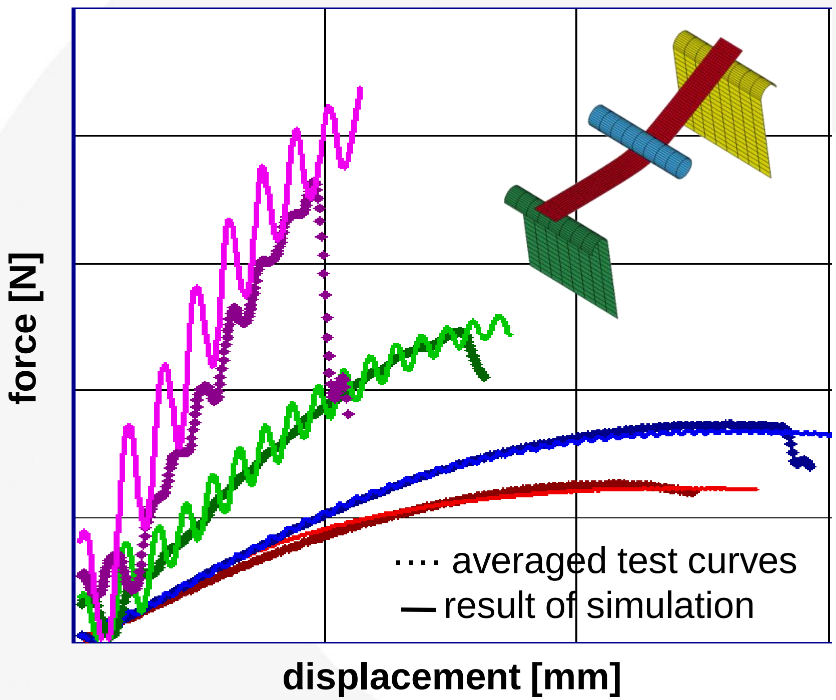


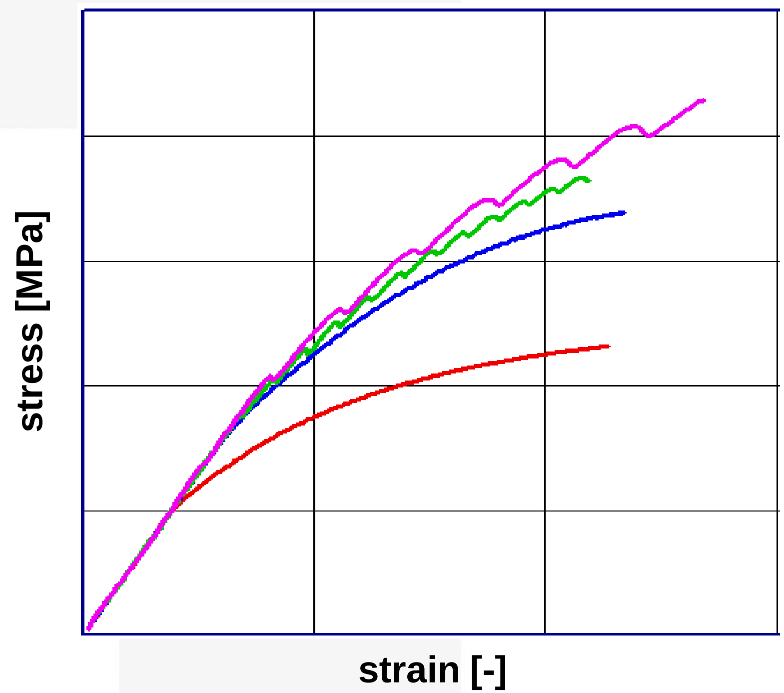


Source: Dynamic Material Characterization Using 4a impetus – PPS Conference 2015, Graz

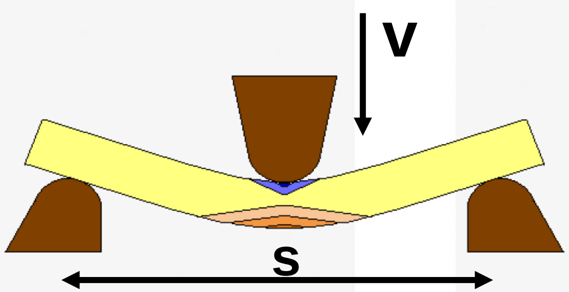
Short and long fiber reinforced thermoplastics

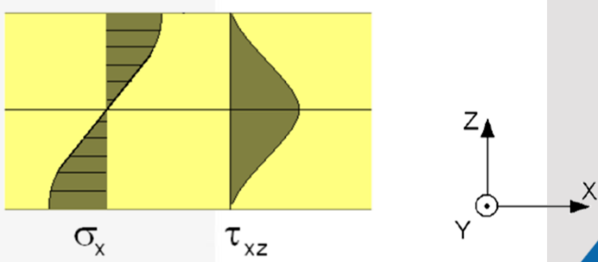
4a impetus *MAT_024 – PP-GF40 diagonal, 23°C





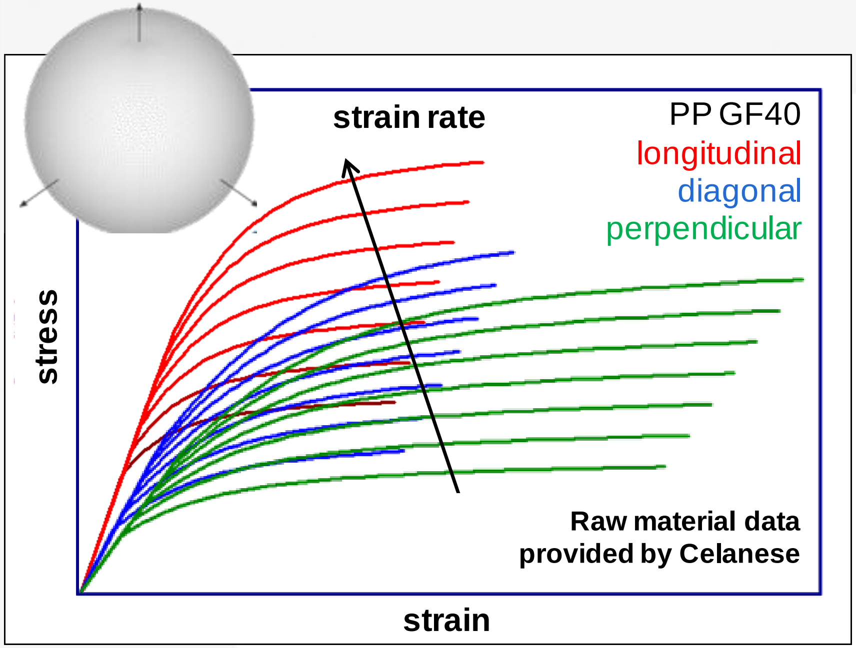
v [m/s]	s [mm]
0.001	50
1	50
2.5	40
4.3	30

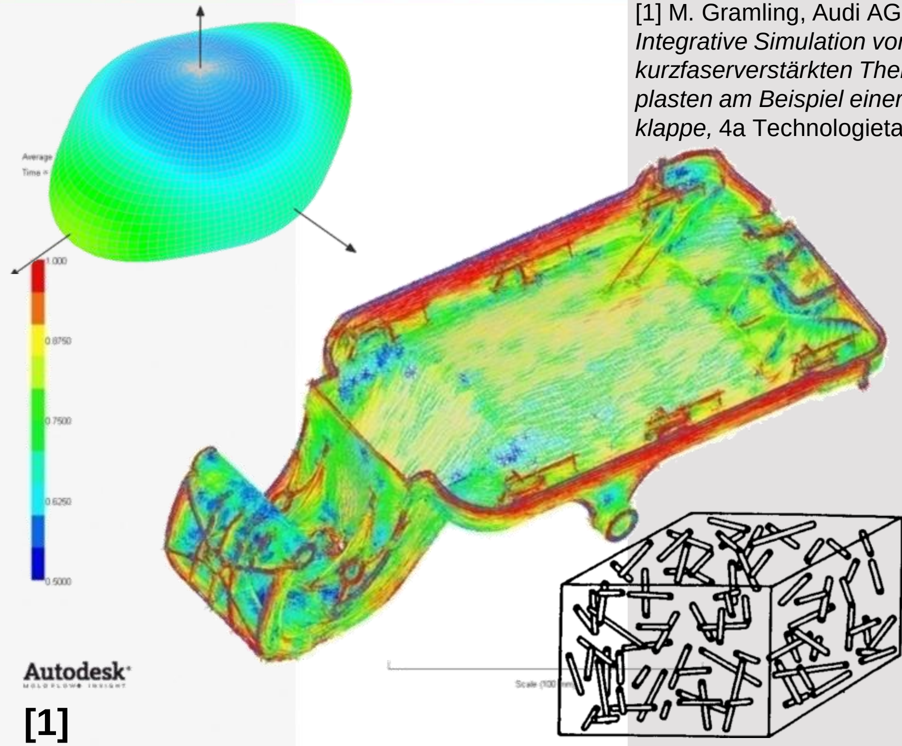




Source: M.Fritz - Ermittlung von Werkstoffparametern für die Fahrzeug-Crashsimulation aus Biegeversuchen, Diploma thesis, Montanuniversität Leoben

Short and long fiber reinforced thermoplastics
Actual approaches





[1]

[1] M. Gramling, Audi AG - *Integrative Simulation von kurzfaserverstärkten Thermoplasten am Beispiel einer Tankklappe*, 4a Technologietag 2012

- quick&dirty isotropic material card (CAMPUS / average / worst case)

→ critical loading transversal to fiber orientation

- micro mechanic modelling (mean field homogenization / RVE)

→ high costs (CPU time)

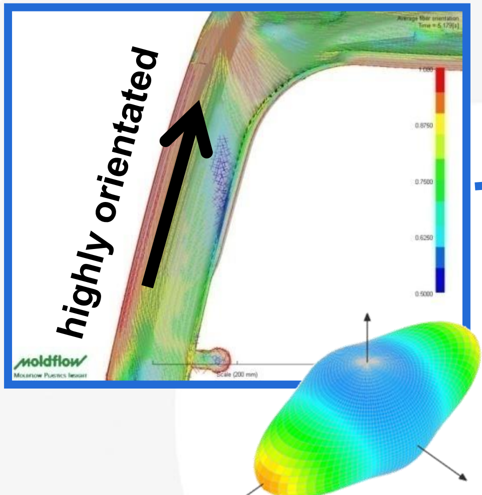
→ no standard (understanding)

Short and long fiber reinforced thermoplastics

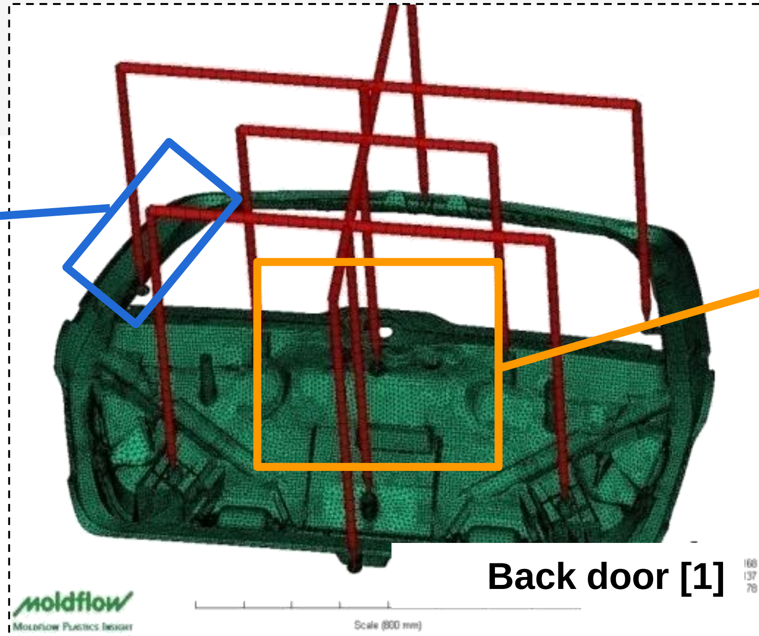
No.	Elastic	Plastic	Damage	Strain rate	Failure	
2	**Ortho / Anisotropic**	**None**	**None**	**None**	***MAT_ADD_EROSION**	**SFRT / LFRT**
24	Isotropic	Mises	None	Plasticity	*MAT_ADD_EROSION	
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION	
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION	
157	**Anisotropic**	**Hill**	**Composite (LSDYNA R9)**			
215	***MAT_4a_micromec in development: Model based on MORI TANAKA**				**(LSDYNA R10)**	

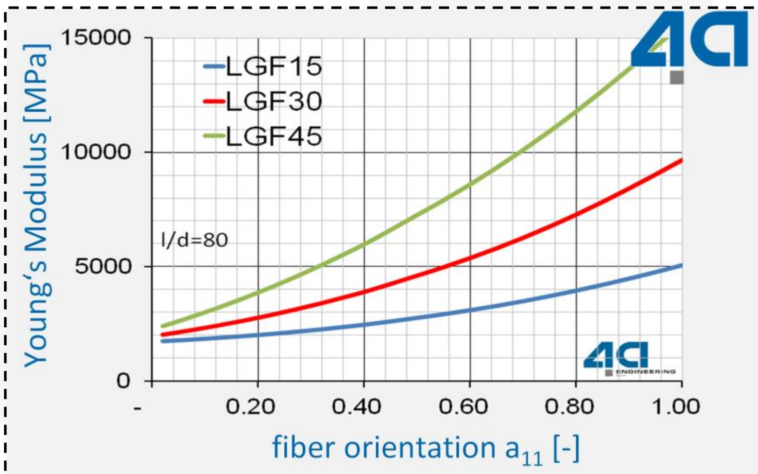
Short and long fiber reinforced thermoplastics

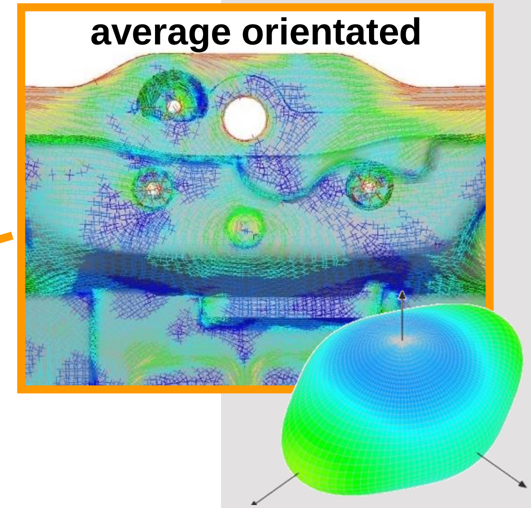
Fiber orientation



$$a_{ij} = \begin{bmatrix} 0{,}87 & 0 & 0 \\ 0 & 0{,}11 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$







$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

FIBERMAP

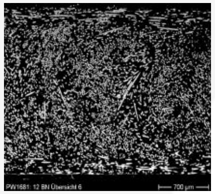
[1] P. Reithofer - *Integrative Simulation – Berücksichtigung der prozessbedingten Anisotropie*, 4a Technologietag 2011

Short and long fiber reinforced thermoplastics

Simulation process chain

ENGINEERING GmbH

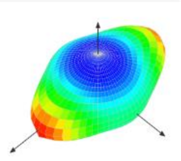
Injection molding
(Moldflow, Moldex, ...)



$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

fiber orientation

micromechanic modeling
(4a micromec, ...)



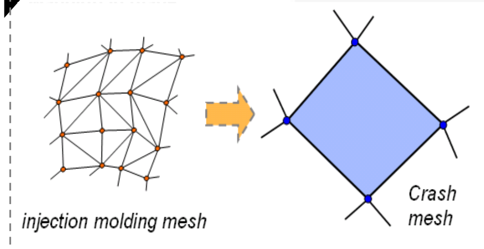
$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ & & C_{33} & C_{34} & C_{35} & C_{36} \\ & & & C_{44} & C_{45} & C_{46} \\ & & & & C_{55} & C_{56} \\ & & & & & C_{66} \end{bmatrix}$$

anisotropy

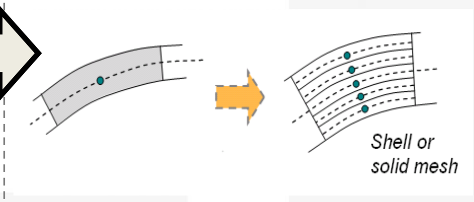
4a MICROMEC

Mapping
(4a fibermap, ...)

In plane mapping



Mapping in thickness direction



4a FIBERMAP

Material Model

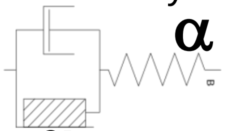
Mean Field homogenization

$$\overline{\sigma}^{C} = \varphi \overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

*MAT_215

Standard Material Model

Hill Plasticity



*MAT_157

LSTC Livermore Software Technology Corp.

LS-DYNA®

Structural Simulation

[2014SimuliaManual]

- Hill plasticity → „extended“ von Mises

$$\sigma_{eq} = \sqrt{F(\sigma_{22}-\sigma_{33})^2 + G(\sigma_{33}-\sigma_{11})^2 + H(\sigma_{11}-\sigma_{22})^2 + 2L\sigma_{23}^2 + 2M\sigma_{31}^2 + 2N\sigma_{12}^2}$$

$$F = \frac{(\sigma^0)^2}{2}\left(\frac{1}{\bar{\sigma}_{22}^2} + \frac{1}{\bar{\sigma}_{33}^2} - \frac{1}{\bar{\sigma}_{11}^2}\right) = \frac{1}{2}\left(\frac{1}{R_{22}^2} + \frac{1}{R_{33}^2} - \frac{1}{R_{11}^2}\right), \quad L = \frac{3}{2}\left(\frac{\tau^0}{\bar{\sigma}_{23}}\right)^2 = \frac{3}{2R_{23}^2},$$

$$G = \frac{(\sigma^0)^2}{2}\left(\frac{1}{\bar{\sigma}_{33}^2} + \frac{1}{\bar{\sigma}_{11}^2} - \frac{1}{\bar{\sigma}_{22}^2}\right) = \frac{1}{2}\left(\frac{1}{R_{33}^2} + \frac{1}{R_{11}^2} - \frac{1}{R_{22}^2}\right), \quad M = \frac{3}{2}\left(\frac{\tau^0}{\bar{\sigma}_{13}}\right)^2 = \frac{3}{2R_{13}^2},$$

$$H = \frac{(\sigma^0)^2}{2}\left(\frac{1}{\bar{\sigma}_{11}^2} + \frac{1}{\bar{\sigma}_{22}^2} - \frac{1}{\bar{\sigma}_{33}^2}\right) = \frac{1}{2}\left(\frac{1}{R_{11}^2} + \frac{1}{R_{22}^2} - \frac{1}{R_{33}^2}\right), \quad N = \frac{3}{2}\left(\frac{\tau^0}{\bar{\sigma}_{12}}\right)^2 = \frac{3}{2R_{12}^2},$$

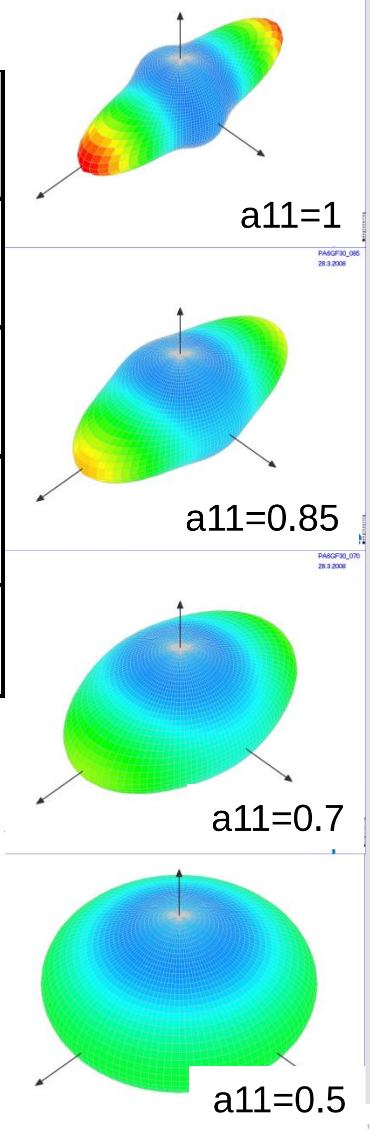
Short and long fiber reinforced thermoplastics
LS-Dyna material model *MAT_157

- Material model based on **composites properties**

description	variables	Number of variables	dependencies
anisotropic stiffness	Cij	21	$C_{ij}\left(a_{ij},\varphi,C^{M},C^{F}\right)$
Hill plasticity	3D: F, G, H, L, M, N 2D: r00, r45, r90	6	$f\,(a_{ij},\varphi,\sigma^{M},\sigma^{F})$
stress-strain curve	Loadcurve	3	$f\,(a_{ij},\varphi)$
failure	Loadcurve	6	$f\,(a_{ij},\varphi)$

- Not possible to generate samples with **explicit defined and varying a_{ij}**
- **Hard to characterize, too many possibilities in a_{ij}**

→ Micro mechanical model is needed



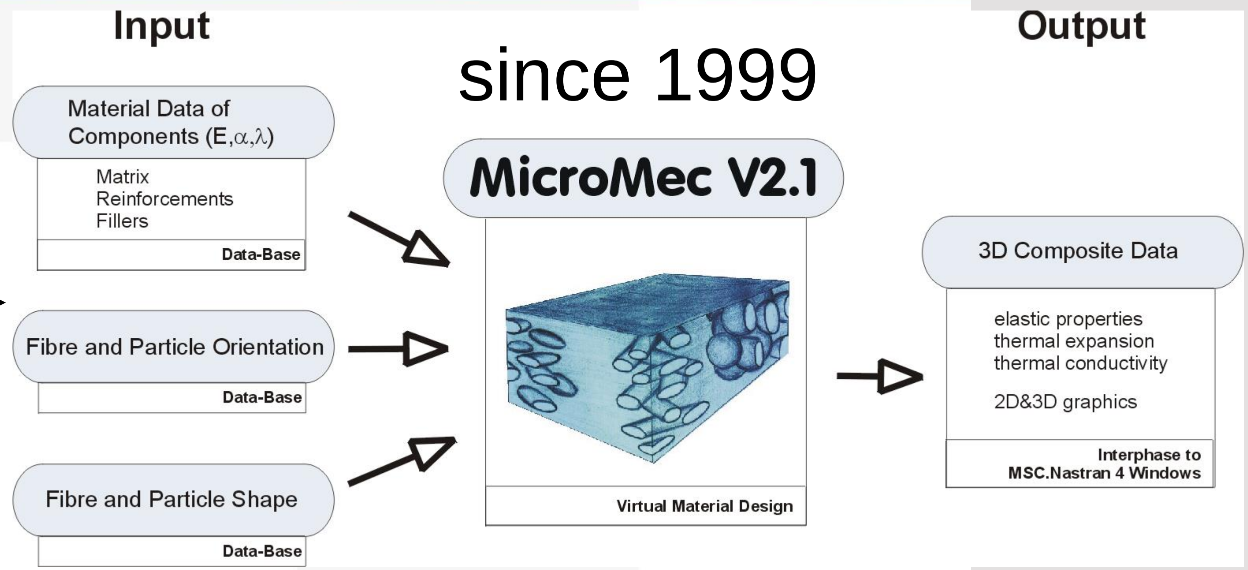
„key enabler“ - micromechanics

No.	Elastic	Plastic	Damage	Strain rate	Failure	
2	**Ortho / Anisotropic**	**None**	**None**	**None**	***MAT_ADD_EROSION**	SFRT / LFRT
24	Isotropic	Mises	None	Plasticity	*MAT_ADD_EROSION	
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION	
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION	
157	**Anisotropic**	**Hill**	**Composite (LSDYNA R9)**			
215	***MAT_4a_micromec in development: Model based on MORI TANAKA MEANFIELD**					

Micromechanical approach
Mean field homogenization

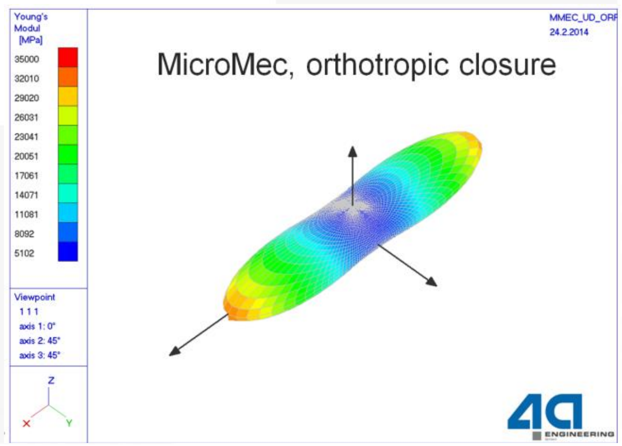
MICROMEC

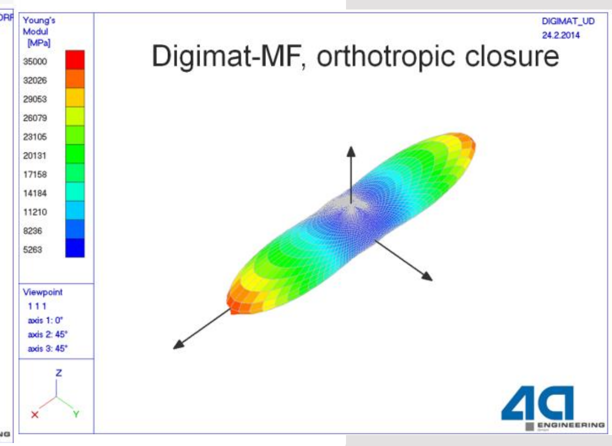
Standalone product



$$\overline{\sigma}^{C} = \varphi\overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

C...composite, F...fiber, M...matrix





[1]

Comparison by University of Leoben

[1] Ch. Bodor - *Kopplung µCT und FEM Berechnung,* 4a Technologietag 2014

Micromechanical approach
Mean field homogenization

4a MICROMEC

Standalone product

Library →

4a IMPETUS

***MAT_157**

calculate parameter for constitutive law

$$\overline{\sigma}^{C} = \varphi\overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

C...composite, F...fiber, M...matrix

160223_006 | Material | Designvariablen | Layers

⊟ Strain rate dependency	Table	
⊞ Strain rate dependency	Johnson Cook	
⊟ Micromec	User defined	
⊟ Matrix		
Density of the matrix	900	matrix
E-Modulus	1500	matrix
Poisson's ratio	0.3	matrix
Yield strength	15	matrix
Strength at Break	17	matrix
Failure strain	0.05	matrix
⊟ Fiber		
Fillerlength	1000	filler
Fillerdiameter	20	filler
Phi or Psi	φ	filler
Phi	12.9	filler
Psi	30.1	filler
Fillermaterial	E-Glas	filler
⊟ Orientation		
⊟ Fillerorientationtype	CA lin. OF	orientation
Fillerorientationvalue 1	0.6	orientation
Fillerorientationvalue 2	0.33	orientation

Composite Density	1126	[g/dm³]
c_C11	6172	[MPa]
c_C12	1808	[MPa]
c_C13	1231	[MPa]
c_C14	0	[MPa]
c_C15	0	[MPa]
c_C16	0	[MPa]
c_C22	4135	[MPa]
c_C23	1181	[MPa]
c_C24	0	[MPa]
c_C25	0	[MPa]
c_C26	0	[MPa]
c_C33	2616	[MPa]
c_C34	0	[MPa]
c_C35	0	[MPa]
c_C36	0	[MPa]
c_C44	1554	[MPa]
c_C45	0	[MPa]
c_C46	0	[MPa]
c_C55	888.6	[MPa]
c_C56	0	[MPa]
c_C66	957.5	[MPa]
y_r00	1	[1]
y_r45	0.5105	[1]
y_r90	0.2665	[1]
y_scalematrix0	3.076	[1]

Micromechanical approach

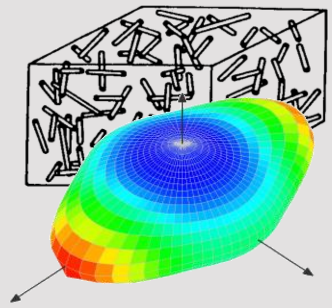
4a impetus – example *MAT_157

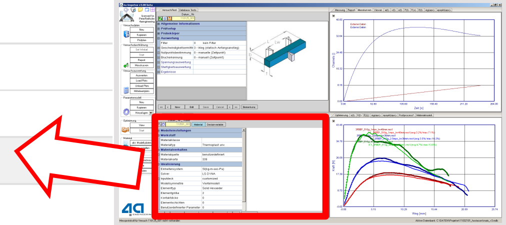
160223_006 | Material | Designvariablen | Layers

Name	Start	const...	Description
GroupName: 10_elasticity			
c_C11	MMEC	✓	constitutive matrix 11
c_C12	MMEC	✓	constitutive matrix 12
c_C13	MMEC	✓	constitutive matrix 13
c_C14	MMEC	✓	constitutive matrix 14
c_C15	MMEC	✓	constitutive matrix 15
c_C16	MMEC	✓	constitutive matrix 16
c_C22	MMEC	✓	constitutive matrix 23
c_C23	MMEC	✓	constitutive matrix 23
c_C24	MMEC	✓	constitutive matrix 24
c_C25	MMEC	✓	constitutive matrix 25
c_C26	MMEC	✓	constitutive matrix 26
c_C33	MMEC	✓	constitutive matrix 33
c_C34	MMEC	✓	constitutive matrix 34
c_C35	MMEC	✓	constitutive matrix 35
c_C36	MMEC	✓	constitutive matrix 36
c_C44	MMEC	✓	constitutive matrix 44
c_C45	MMEC	✓	constitutive matrix 45
c_C46	MMEC	✓	constitutive matrix 46
c_C55	MMEC	✓	constitutive matrix 55
c_C56	MMEC	✓	constitutive matrix 56
c_C66	MMEC	✓	constitutive matrix 66

160223_006 | Material | Designvariablen | Layers

Name	Start	const...	Description
GroupName: 10_elasticity			
GroupName: 20_yield			
y_0	90	■	yield stress
y_scale...	MMEC	✓	yield scale 11 direction
y_r00	MMEC	✓	yield hill anisotropy ratio 0°
y_r45	MMEC	✓	yield hill anisotropy ratio 45°
y_r90	MMEC	✓	yield hill anisotropy ratio 90°
GroupName: 21_hardening			
h_ET	50	■	
h_y	90	✓	
GroupName: 31_strainrate			
v_epspkt	0.01	✓	initial strain rate threshold
v_p	15	■	strain rate scale (1/vp)
GroupName: 51_failure			
xf_NUM...	0.75	✓	Number of failed integration points prior to





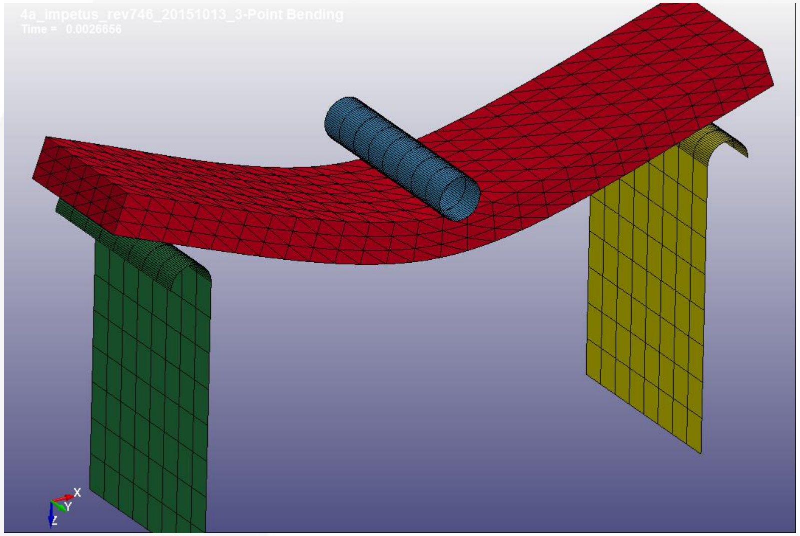
e.g.: 30 design variables for ***MAT_157**

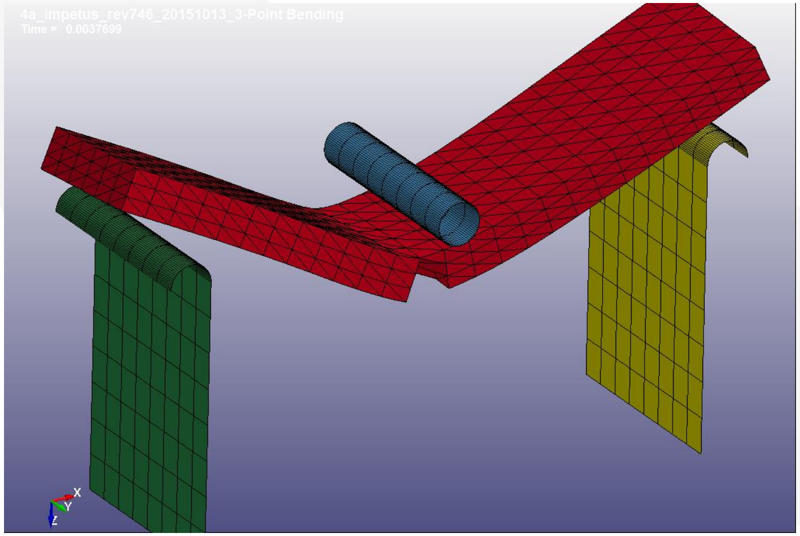
MMEC – design variable calculated by micro mechanic model

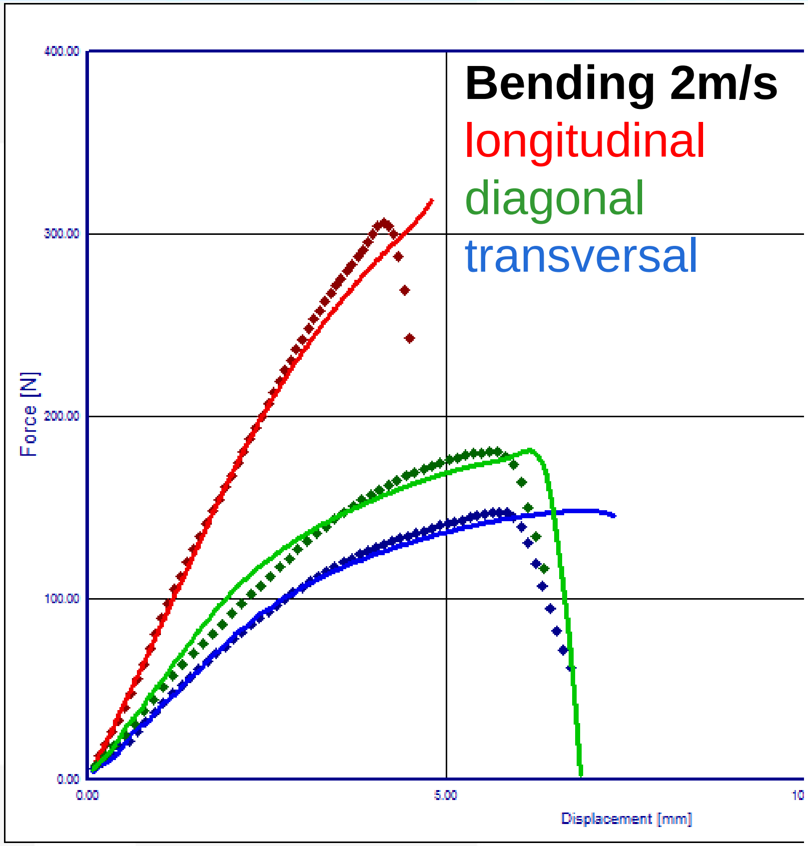
Less free design variables left for material parameter identification

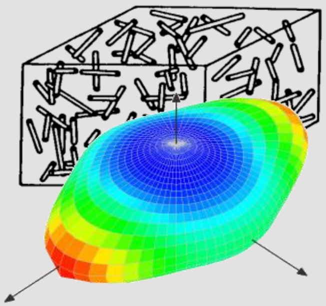
Micromechanical approach

4a impetus – example *MAT_157









[P. Reithofer et al - Material characterization of composites using micro mechanic models as key enabler, CAE Grand Challenge 2016, Hanau]

4a ENGINEERING GmbH

4a MICROMEC

- Standalone product
- Library → 4a impetus
- usermaterial

Main Framework
Mori Tanaka Mean Field Theory

Composite stresses, strains (i)
↓
Matrix stresses, strains → **Yield condition**
↓
Fiber stresses, strains
↓
Failure, Damage Criteria
↓
Composite stresses, strains (i+1)

plug able
possible extensions other plasticity formulations, ...

↓

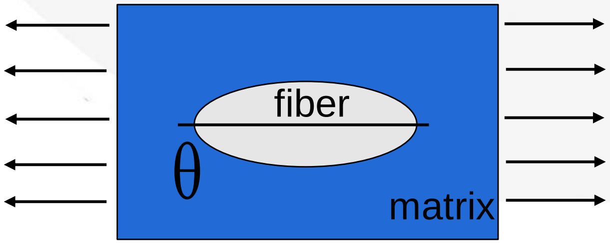
→ J2 Plasticity
Isotropic Harding

Table Lookup or Parameter Setup

$$\overline{\sigma}^{C} = \varphi\overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

C...composite, F...fiber, M...matrix

assumption elliptical inclusion
(Eshelby Tensor **)**



$$\Delta\varepsilon^{C} \Rightarrow \Delta\varepsilon^{M}, (\Delta\varepsilon^{F})$$

$$\Delta\varepsilon^{M} = \frac{1}{\varphi\overline{B}_{i} + (1-\varphi)I}\Delta\varepsilon^{C}$$

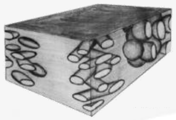
$$\Delta\varepsilon^{M} \Rightarrow E_{M}^{T}, \Delta\varepsilon^{M}{}_{pl}, \Delta\sigma^{M}$$

$$\overline{B}_{i+1} = f\left(fo^{(4)}, E_{M}^{T}, {}^{l}\!/_{d}\right)$$

$$\overline{A} = S^{F}\,\overline{B}_{i+1}C^{M}$$

$$\Delta\sigma^{C} = \left[\varphi\overline{A} + (1-\varphi)I\right]\Delta\sigma^{M}$$

Micromechanical approach
Mean field homogenization



MICROMEC

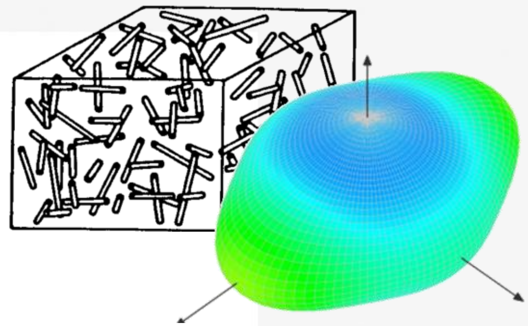
- Standalone product
- Library→4a impetus
- usermaterial
- *MAT_4A_MICROMEC

LSTC Livermore Software Technology Corp.

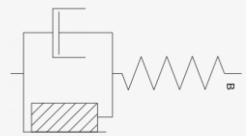
LS-DYNA®

DYNA MORE

SFRT / LFRT



***MAT_215**



matrix:

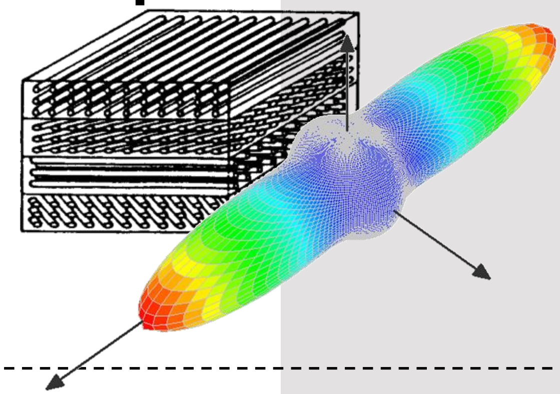
- isotropic elastic viscoplastic (like MAT_024)

fiber:

- isotropic elastic

INITIAL_STRESS

Composite



***MAT_215**

matrix:

- isotropic elastic

fiber:

- transversal isotropic elastic

COMPOSITE (PLY)

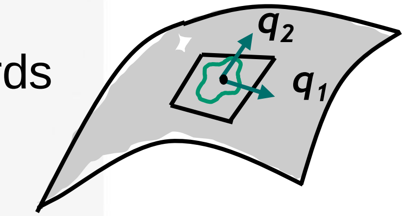
*MAT_215 / *MAT_4A_MICROMEC

No.	Elastic	Plastic	Damage	Strain rate	Failure	
2	**Ortho / Anisotropic**	**None**	**None**	**None**	***MAT_ADD_EROSION**	SFRT / LFRT
24	Isotropic	Mises	None	Plasticity	*MAT_ADD_EROSION	
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION	
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION	
157	**Anisotropic**	**Hill**	**None**	**Plasticity**	***MAT_ADD_EROSION**	
215	***MAT_4a_micromec in development: Model based on MORI TANAKA**				**(LSDYNA R10)**	

CARD 1: General Options / Parameter

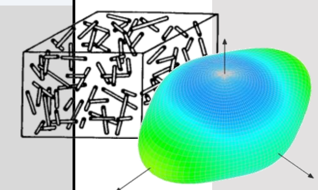
CARD 2-3: Element orientation*

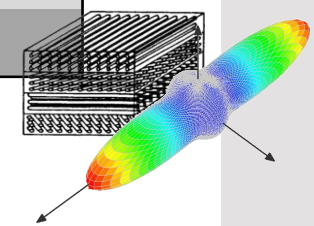
analog to LSDYNA standard anisotropic material cards



CARD 4: Composite Buildup*

Card 4	1	2	3	4	5	6	7	8
	FVF		FL	FD		A11	A22	
PP GF30	**-0.3**		**200.0**	**10.0**		**0.7**	**0.25**	
PP LGF50	**-0.5**		**1000.0**	**20.0**		**0.65**	**0.30**	
PA6 GF45	**-0.45**		**250.0**	**10.0**		**0.8**	**0.15**	
Carbon UD	**0.6**		**10000.0**	**10.0**		**1.0**	**0.0**	





FVF > 0: fiber volume fraction → Composite
FVF < 0: fiber mass fraction → SFRT/LFRT

*may be overwritten by
*INITIAL_STRESS_SHELL/SOLID

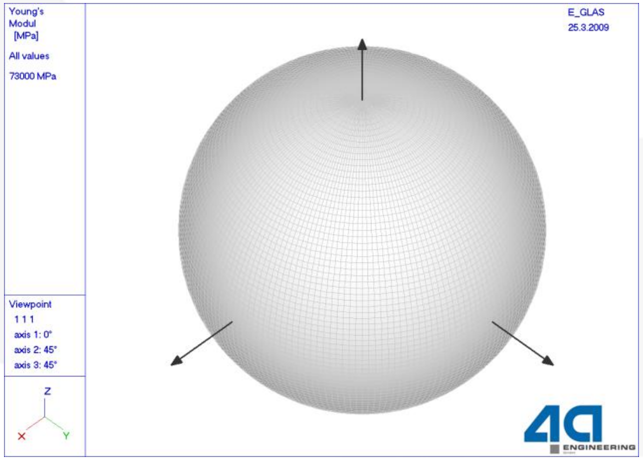
exemplary values without any warranty

CARD 5: fiber material

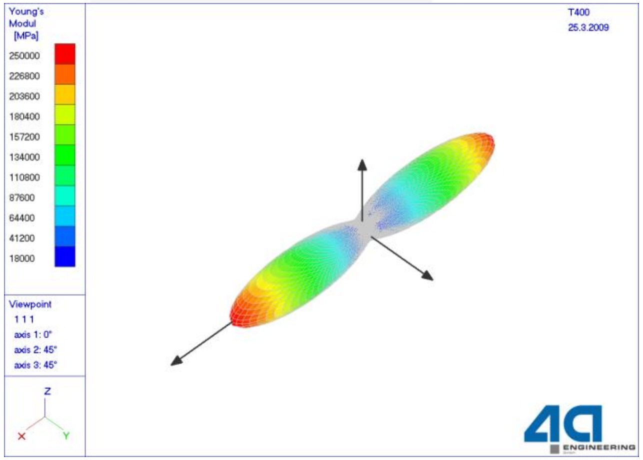
Standard values from literature

Card 5	1	2	3	4	5	6	7	8
FIBER	ROF	EL	ET	GLT	PRTL	PRTT		
UNITS	kg/mm³	GPa	GPa	GPa	-	-		
glass	**2.59E-6**	**70.0**	**70.0**	**28.8**	**0.217**	**0.217**		
T400	**1.76E-6**	**218.8**	**28.0**	**50.0**	**0.02943**	**0.390**		

glass fiber (isotropic)



T400 (transversal isotropic)



exemplary values without any warranty

CARD 7-8: matrix material

from material characterization (e.g. 4a impetus MPIP)

Card 7	1	2	3	4	5	6	7	8
Matrix	ROM	E	PR					
Units	kg/mm³	GPa	-					
PP	**0.9E-6**	**1.5**	**0.4**					
PA6 dry	**1.2E-6**	**3.2**	**0.35**					
PA6 cond.	**1.2E-6**	**2.0**	**0.35**					

elasticity

Card 8	1	2	3	4	5	6	7	8
Matrix	SIGYT	ETAN			EPS0	C		
Units	GPa	GPa	-		1/ms	-		
PP	**0.015**	**0.5**			**1.E-6**	**10**		
PA6 dry	**0.06**	**1.0**			**1.E-6**	**15**		
PA6 cond.	**0.04**	**0.8**			**1.E-6**	**10**		

visco plasticity

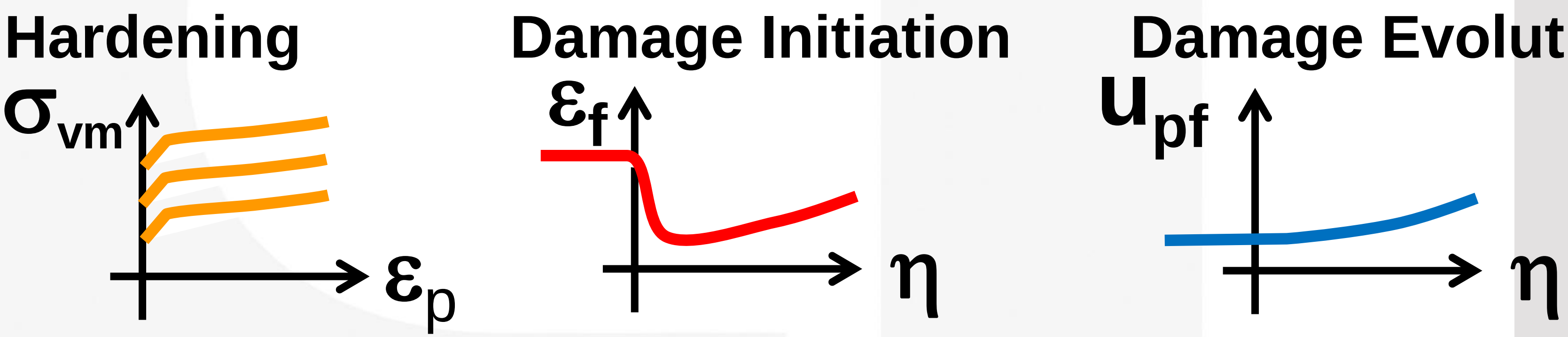
Bilinear + Johnson Cook

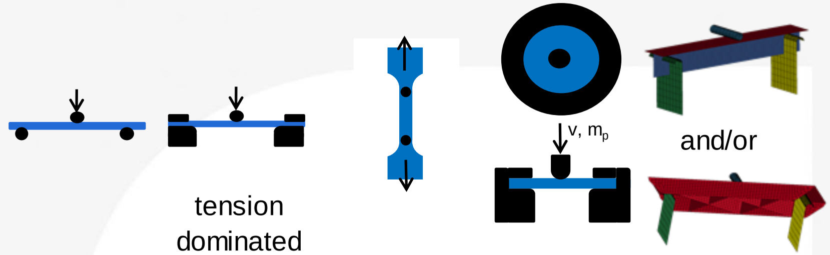
exemplary values without any warranty

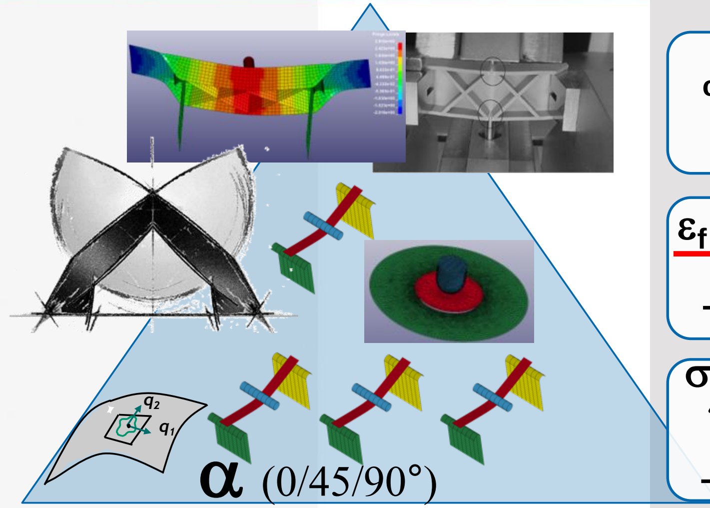
CARD 9: matrix material tables

Card 9	1	2	3	4	5	6	7	8
Variable	LCIDT				LCDI	UPF		
Type	F				F	F		
Default	0				0	0.0		

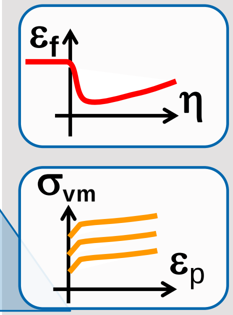
LCIDT	Effective stress (Table)
LCDI	Damage initiation (Table)
UPF	Damage evolution parameter







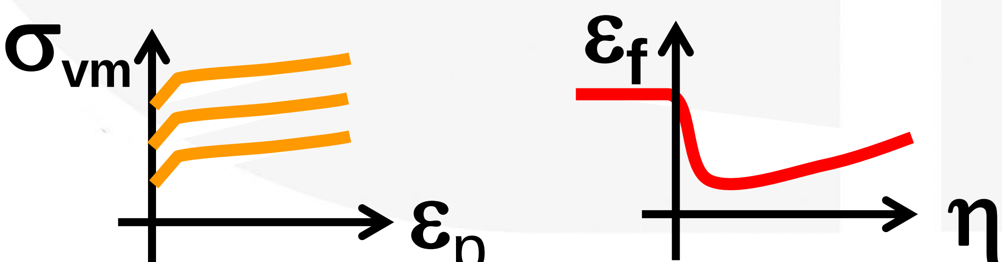
component validation



	bending		tension dominated bending		tension		puncture		validation		
	static	dynamic		dynamic	static	dynamic	static	dynamic	static	dynamic	comment
*MAT_024	✓	✓									Materialcard for each direction
*MAT_157 *MAT_215	✓	✓		✓	✓		✓	✓	✓	✓	µCT

Upcoming ISO
Plate 120 x 80 x 2 mm

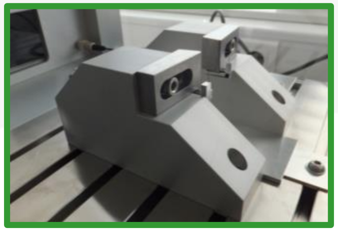
injected samples

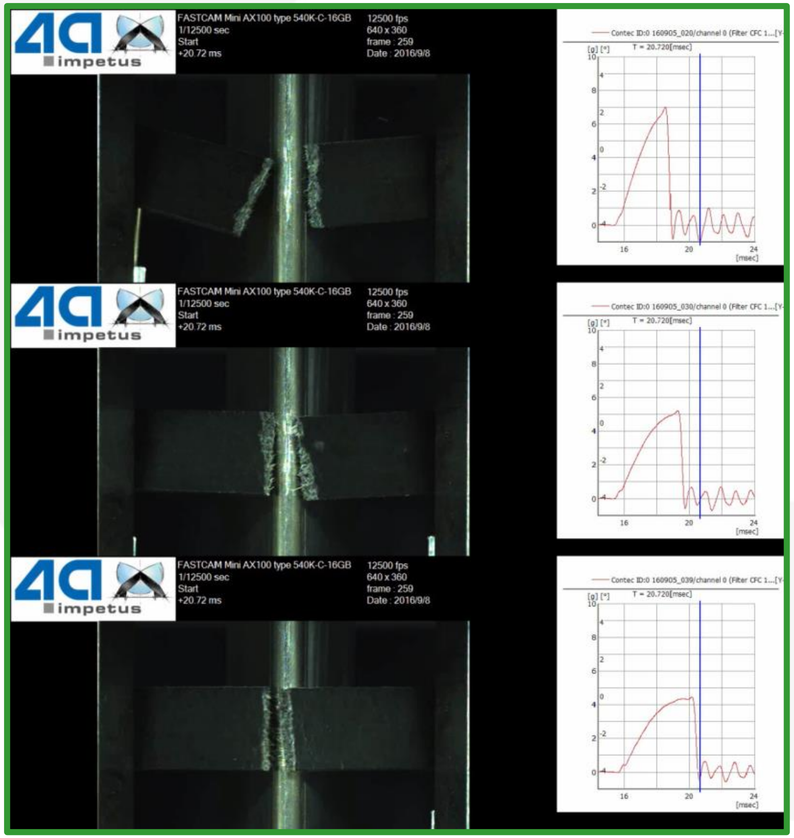


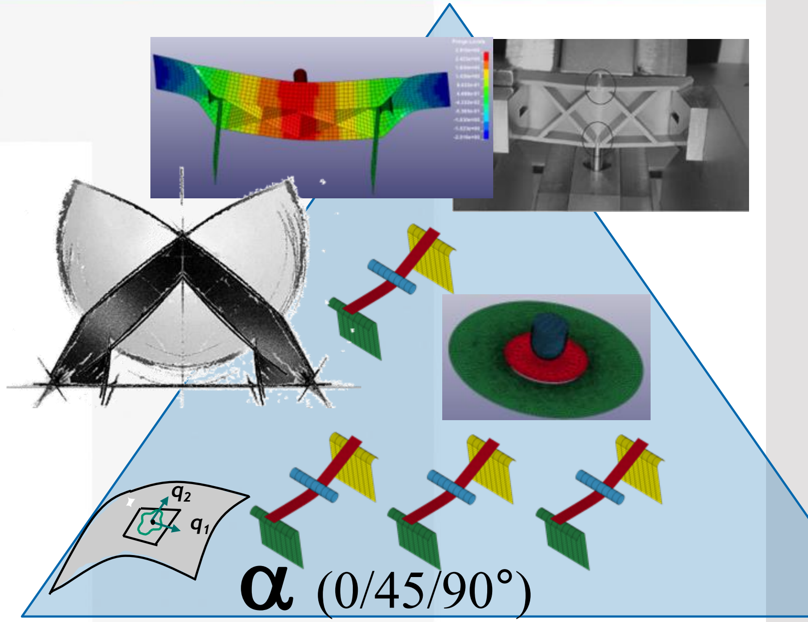
Source: LS DYNA Forum 2016 - *MAT_4A_MICROMEC – micro mechanic based material model

*MAT_215 - *MAT_4A_MICROMEC
Material characterization

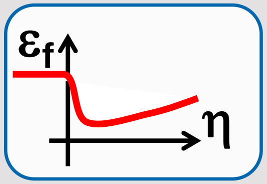
bending

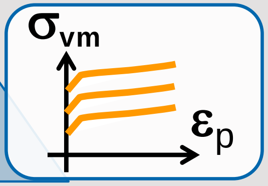


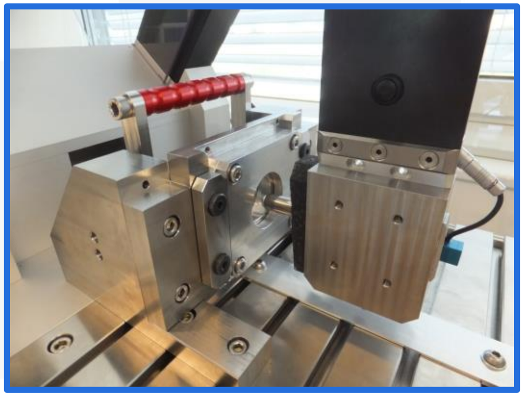


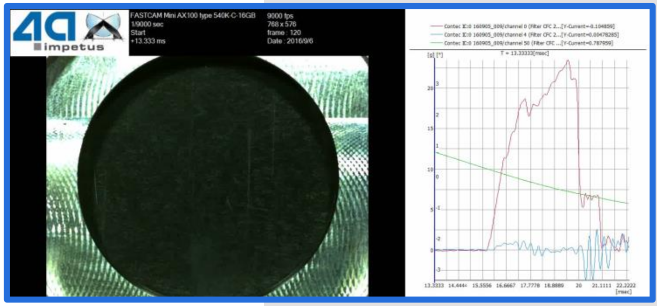


component validation





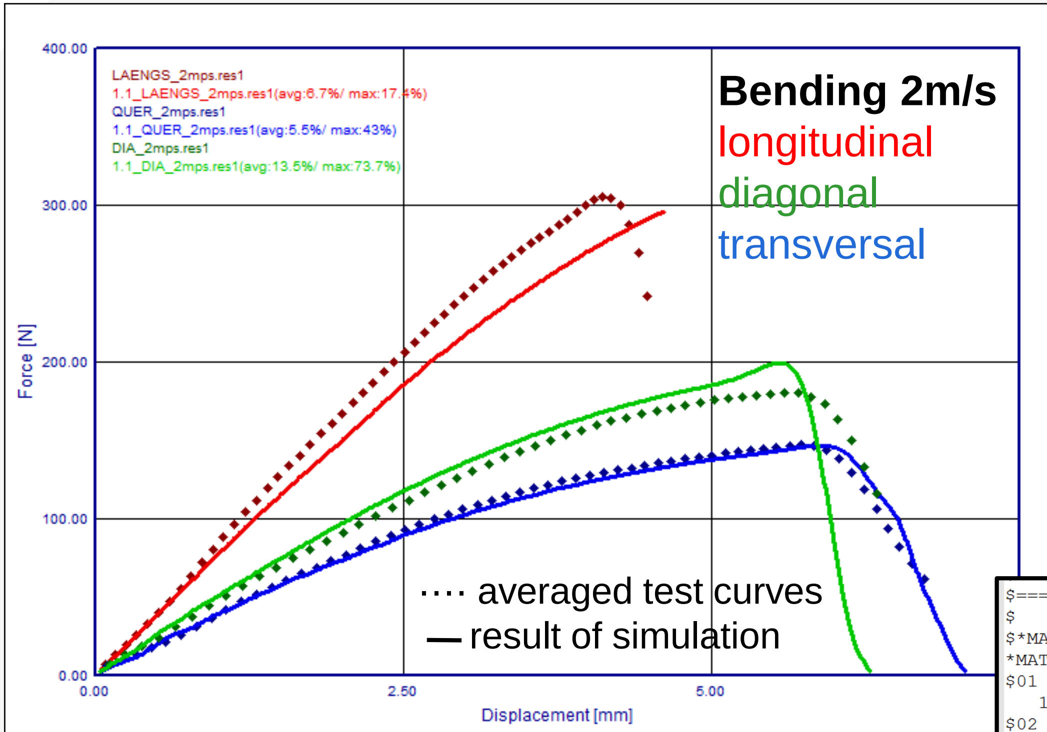


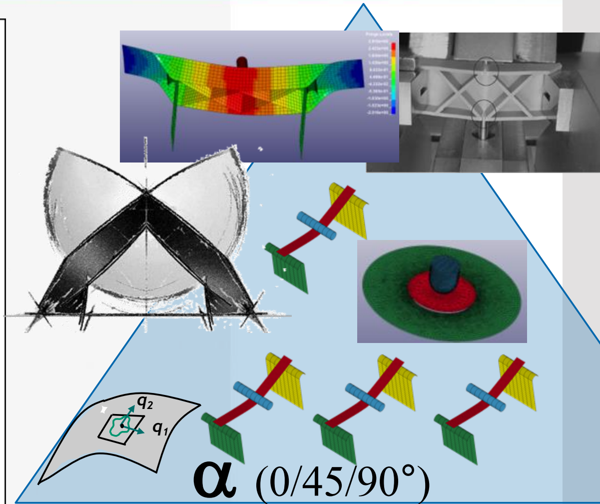


puncture test

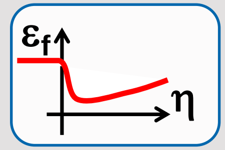
Source: LS DYNA Forum 2016 - *MAT_4A_MICROMEC – micro mechanic based material model

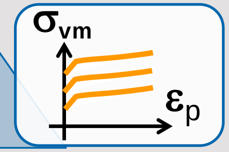
*MAT_215 - *MAT_4A_MICROMEC
Material characterization





component validation



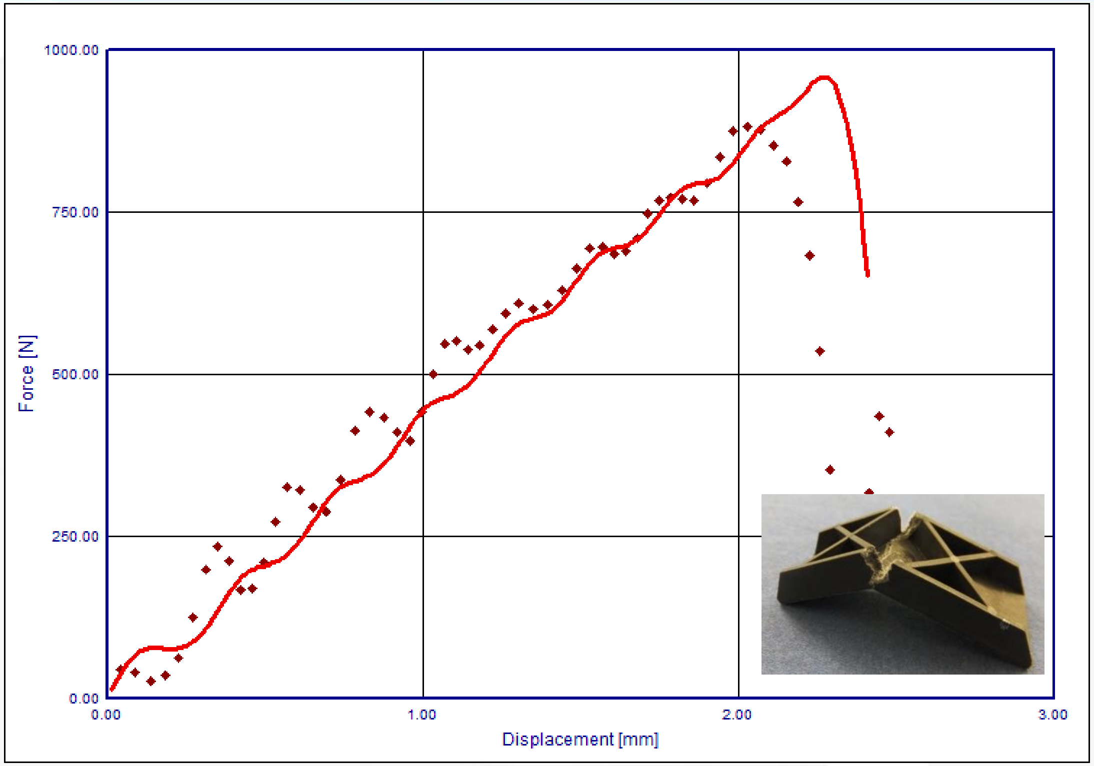


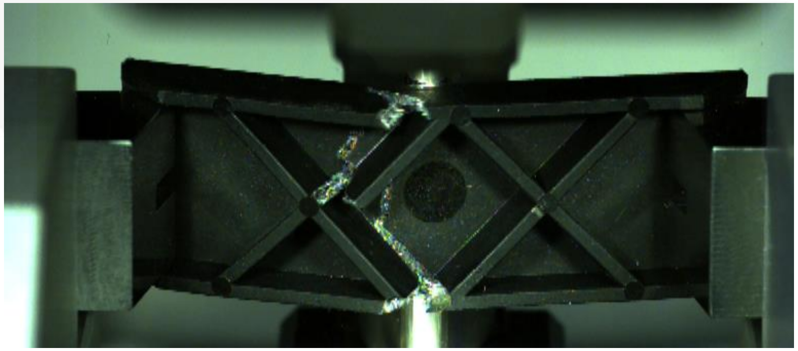

```
$===========================================================================
$
$*MAT_215
*MAT_4A_MICROMEC
$01     mid     mmopt      bupd        --        --     failm     failf    NUMINT
    1000000       1.0      0.01                              1.        0.      -65.
$02    aopt      macf        xp        yp        zp        a1        a2        a3
          0         0       0.0       0.0       0.0       1.0       0.0       0.0
$03      v1        v2        v3        d1        d2        d3      beta        --
        0.0       0.0       0.0       0.0       0.0       1.0        0.
$04     fvf        --        fl        fd        --       a11       a22        --
       .115                 53.       1.0                  .7       .25
$05     rof        el        et       glt      prtl      prtt        --        --
2.5899e-09    70000.    70000.    28759.     0.217     0.217
$06      xt        --        --        --        --        --    SLIMXT    NCYRED
      2800.                                                          0.01        10
$07     rom         e        pr        --        --        --        --        --
    9.1e-10     1500.       0.3
$08   sigyt     etant        --        --      eps0         c

$09    LCST        --        --        --      LCDI       UPF
    1000000                                 1000020  -1000026
$===========================================================================
```

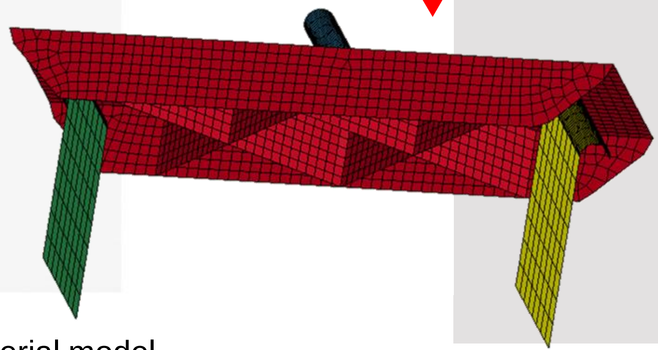
Source: LS DYNA Forum 2016 - *MAT_4A_MICROMEC – micro mechanic based material model

*MAT_215 - *MAT_4A_MICROMEC
Material characterization



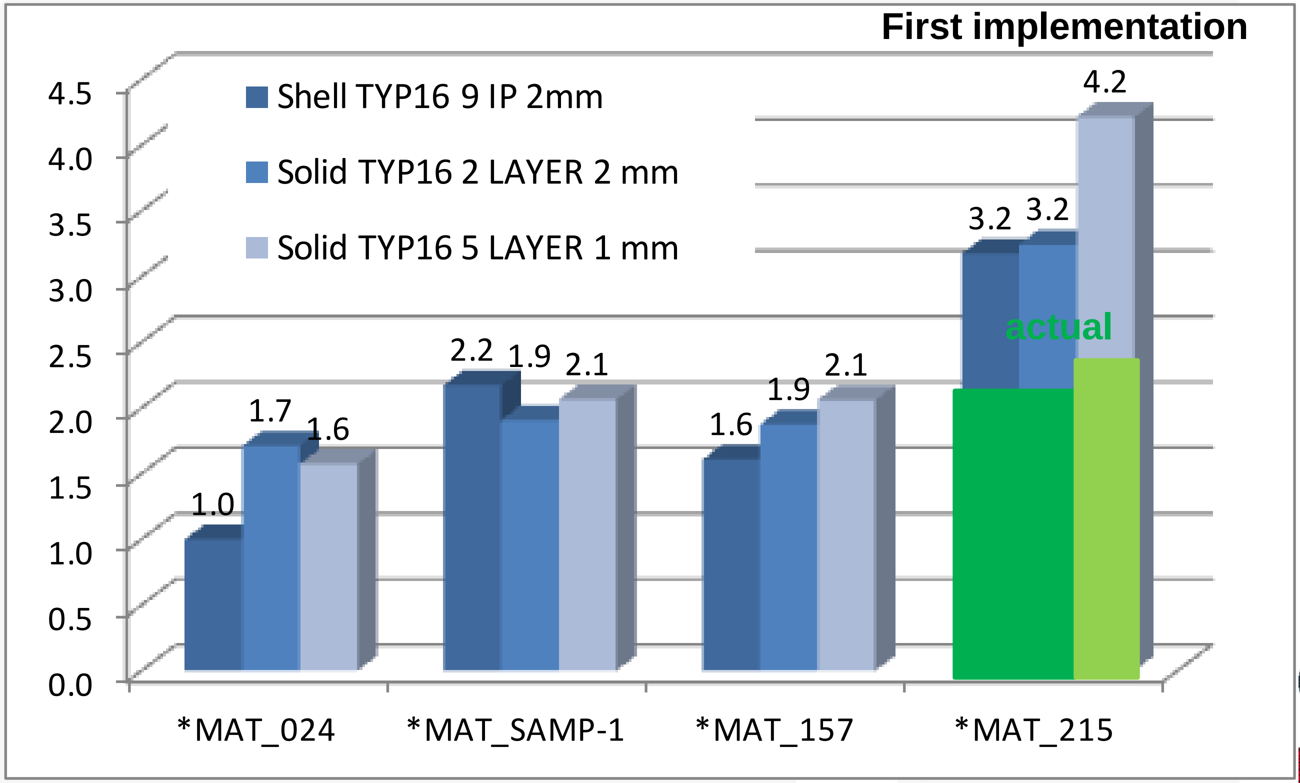


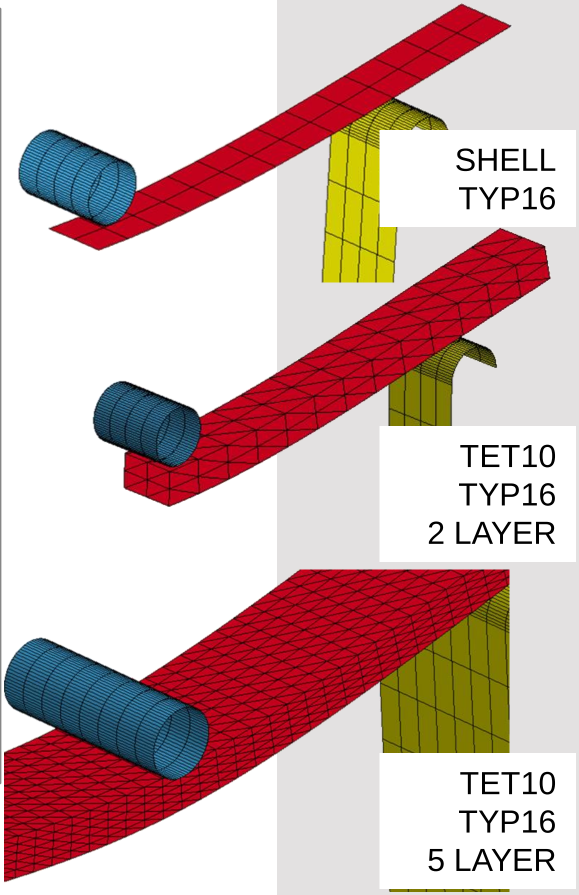
4a FIBERMAP



Source: LS DYNA Forum 2016 - *MAT_4A_MICROMEC – micro mechanic based material model

*MAT_215 - *MAT_4A_MICROMEC
CPU time per integration point (SMP 1 CPU)





- ***MAT_215 - possible improvements**
  - timestep calculation (conservative implementation)
  - compiler options – optimizations for cluster
  - ...

Endless fibers - fabric

22	Orthotropic	None	None	None	Orientation dependent	Carbon, Glass, Kevlar endless & fabric
54/55	Orthotropic	None	Elastic Orthotropic	Strength	Chang-Chang/ Tsai-Wu Orientation dependent	
58	Orthotropic	None	Elastic Orthotropic	Strength, Stiffness	mod. Hashin Orientation dependent	
158	Orthotropic	None	Elastic Orthotropic	Visco-elasticity	Orientation dependent	
261	Orthotropic	None	Elastic Orthotropic	None	failure Pinho (Puck) Orientation dependent	
262	Orthotropic	None	Elastic Orthotropic	None	failure Camanho (Puck) Orientation dependent	

Composites
Adaption of material cards - influences of orientation

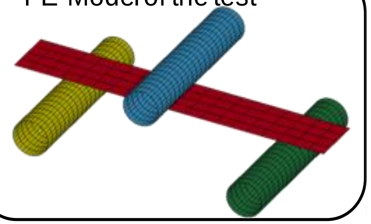
The influence of the manufacturing process on the material behavior (fiber orientation) is included in the process chain.

Element orientation e.g.

*ELEMENT_SHELL_BETA

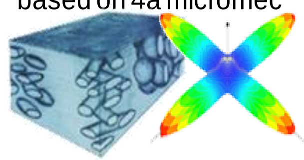
*PART_COMPOSITE

FE-Model of the test



Material angle

Parameterized Materialcard based on 4a micromec



4a impetus

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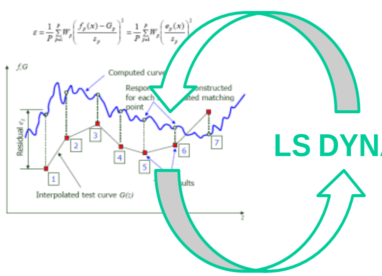
Composite Layup

LS PREPOST©

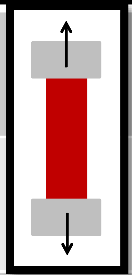
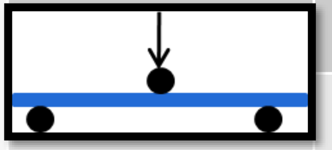
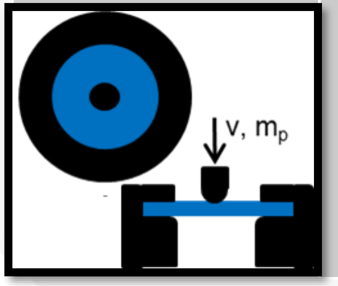


LS DYNA©

Reverse Engineering

DATABASE
measurement, models

ORIENTATION
e.g. 0°, 45°, 90°

	specimen	0°	45°	90°
	UD	static		
	MD		static, cyclic	
	UD	static, dynamic		
	MD	static, dynamic		
	MD	Puncture		

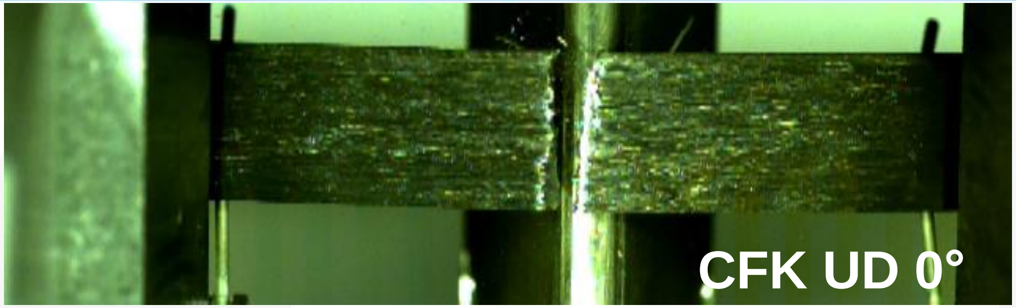
Material Card

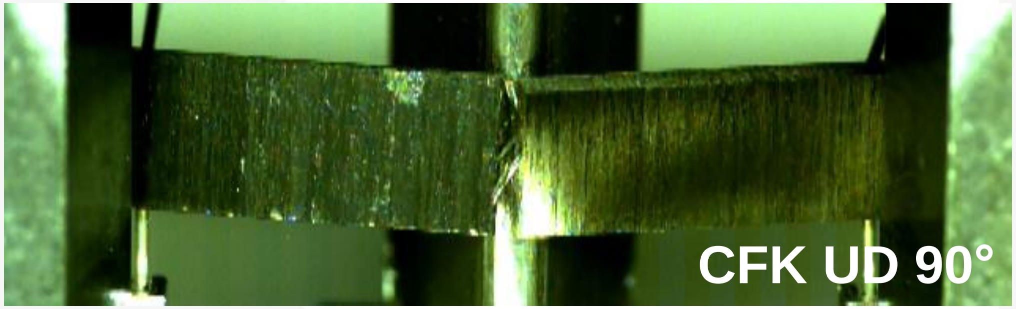
Validation

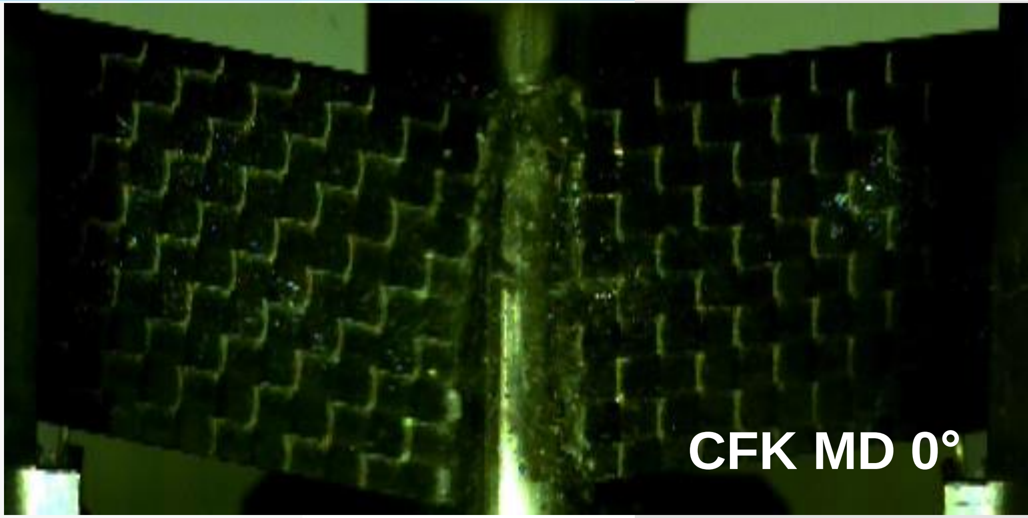
4a impetus - intelligent testing systems
powered by 4a engineering GmbH

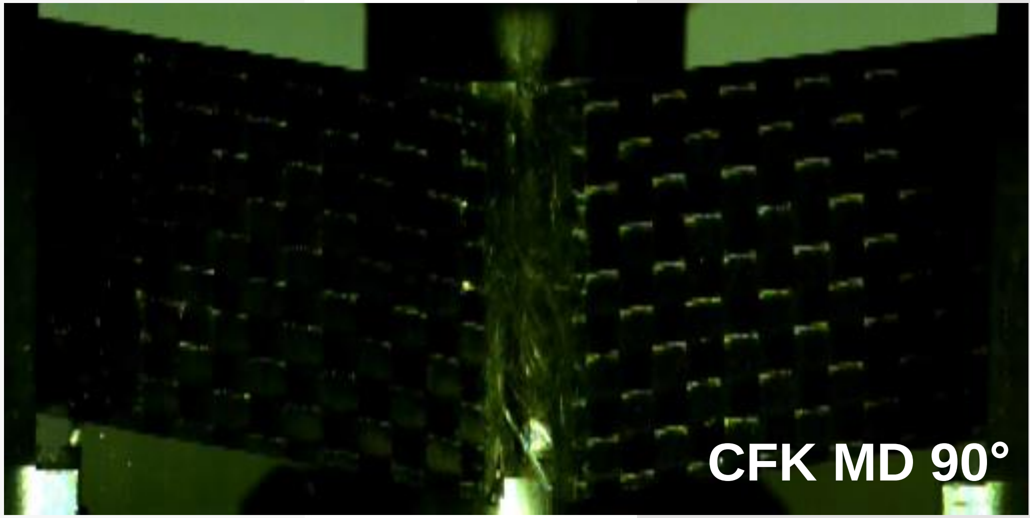
Composites – Material characterization

Typical results for carbon fiber reinforced material



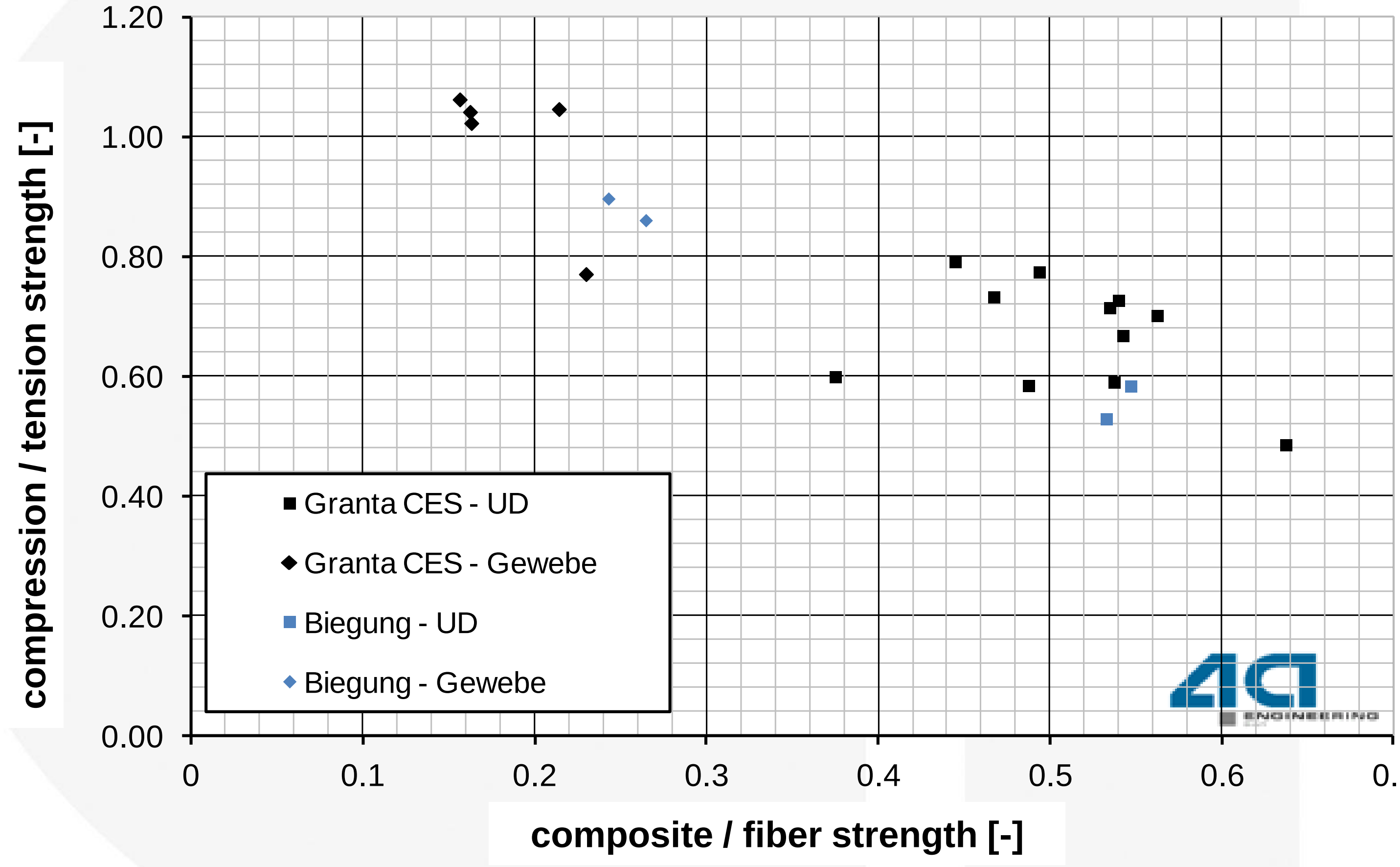


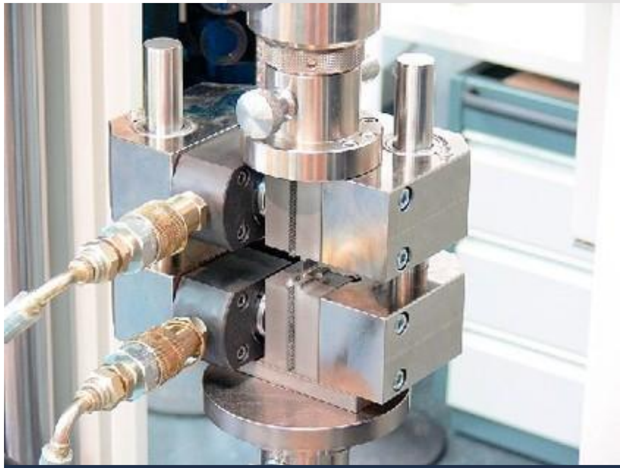


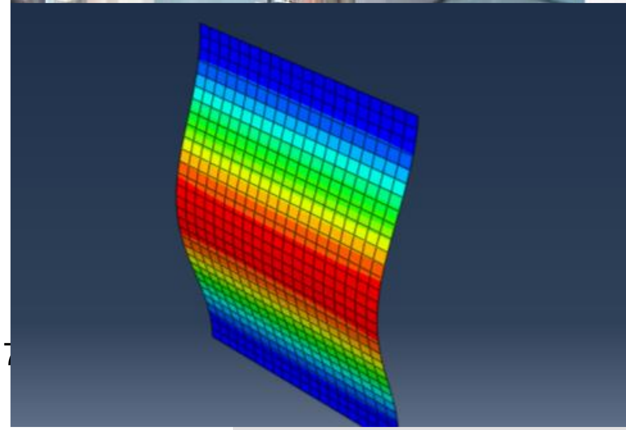


Composites

Verification of measurements - Compression







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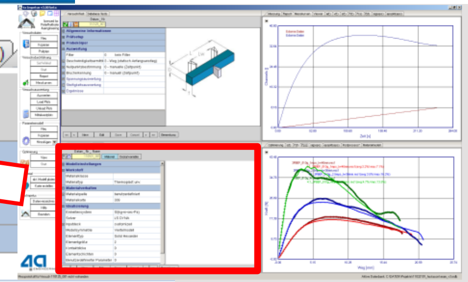
Composites

4a micromec: Current 4a impetus 3.4 version

Material behaviour	
Material source	Implemented
Elasticity	Not isotropic elastic
Plasticity	Not selected
Failure/Damage	Not selected
Material card	*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)
Deformation	*MAT_COMPOSITE_DAMAGE (*MAT_022)
Damage/Failure	*MAT_ENHANCED_COMPOSITE_DAMAGE (*MAT_054)
Materialcard id	*MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
Density	*MAT_RATE_SENSITIVE_COMPOSITE_FABRIC (*MAT_158)
Plasticity	*MAT_LAMINATED_FRACTURE_DAIMLER_PINHO (*MAT_261)
Function (Hardening, Elastic curve form)	*MAT_LAMINATED_FRACTURE_DAIMLER_CAMANHO (*MAT_262)
Strain rate dependency	*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)
Micromec	*MAT_MICROMEC (*MAT_215)
Fracture	*MAT_MICROMEC (*MAT_215)+Carbon
Postfracture	None

Measurement curves | Viewer | a(t) | v(t) | s(t) | F(t) | F(s)

variable | Layers



	Implemented
	*MAT_COMPOSITE_DAMAGE (*MAT_022)
	7500_MAT22
	Chang Chang
	1000000
	1480
	None
	None
Micromec	Endless fiber reinforced plastics
Matrix	
Density of the matrix	1093
E-Modulus	3000
Poisson's ratio	0.3
Yield strength	50
Strength at Break	70
Failure strain	0.05
Fiber	
Fillerlength	20000
Fillerdiameter	20
Phi or Psi	φ
Phi	58
Psi	71.7
Fillermaterial	T300
Orientation	
Fillerorientationtype	UD
Strength	
Strength evaluation	Fiber strength
XT	2300
XC	2000
Fracture	Composite
Postfracture	None

Matrix properties

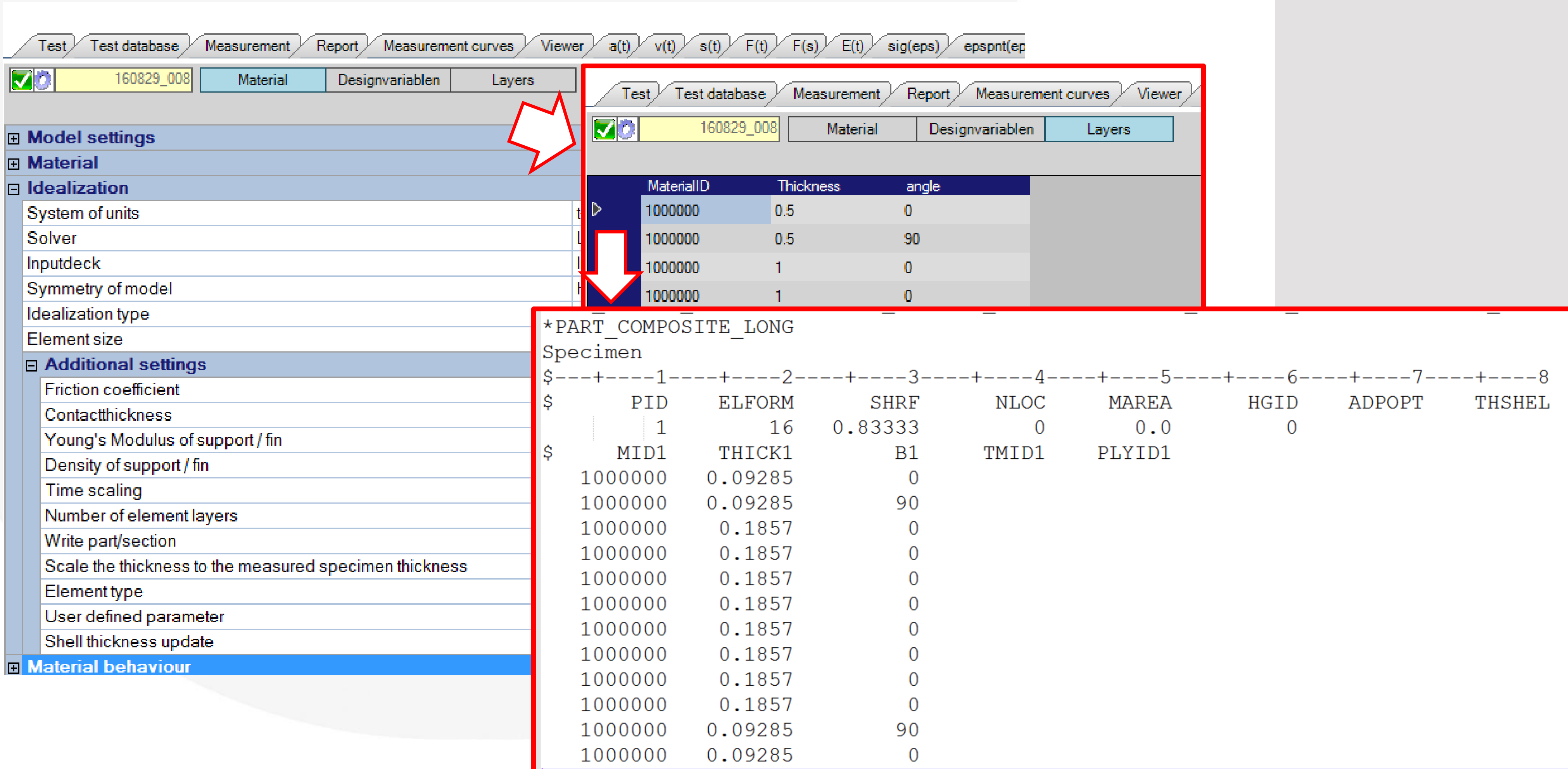
Filler properties

Orientation

Strength

Material micromec implementation *MAT_022

Idealization – *Part_Composite



Typical Design Variables for *MAT_022

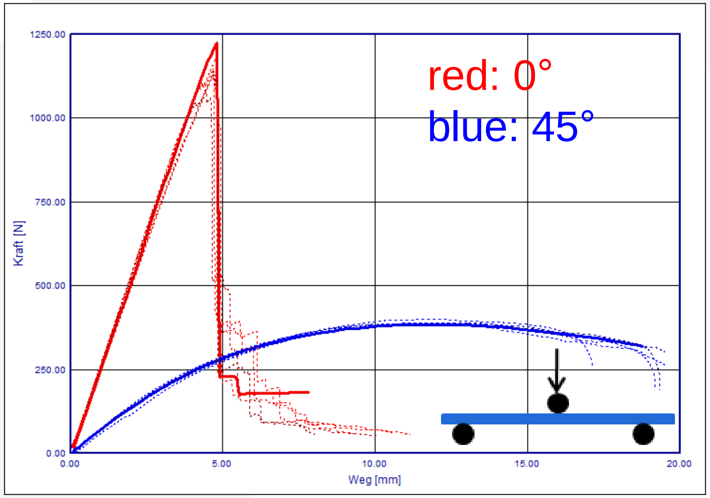
160826_004 | Material | Designvariablen | Layers

Name	Start	const...	from	to	Variance	Condi...	Description
GroupName: 10_elasticity							
c_E11	MMEC	☐	100000	180000	(NULL)		young modulus tensile in 1 direction
c_E22	MMEC	✓	(NULL)	(NULL)	(NULL)		young modulus tensile in 2 direction
c_E33	MMEC	✓	(NULL)	(NULL)	(NULL)		young modulus tensile in 2 direction
c_nue21	MMEC	✓	(NULL)	(NULL)	(NULL)		poisson ration in 21 plane
c_nue31	MMEC	✓	(NULL)	(NULL)	(NULL)		poisson ration in 31 plane
c_nue32	MMEC	✓	(NULL)	(NULL)	(NULL)		poisson ration in 32 plane
c_G12	MMEC	✓	(NULL)	(NULL)	(NULL)		shear modulus in 12 plane
c_G23	MMEC	✓	(NULL)	(NULL)	(NULL)		shear modulus in 23 plane
c_G31	MMEC	✓	(NULL)	(NULL)	(NULL)		shear modulus in 31 plane
GroupName: 51_failure							
fc_R11T	MMEC	✓	(NULL)	(NULL)	(NULL)		
fc_R11C	MMEC	✓	(NULL)	(NULL)	(NULL)		
fc_R22T	MMEC	✓	(NULL)	(NULL)	(NULL)		
fc_R22C	MMEC	✓	(NULL)	(NULL)	(NULL)		
fc_R12	MMEC	✓	(NULL)	(NULL)	(NULL)		

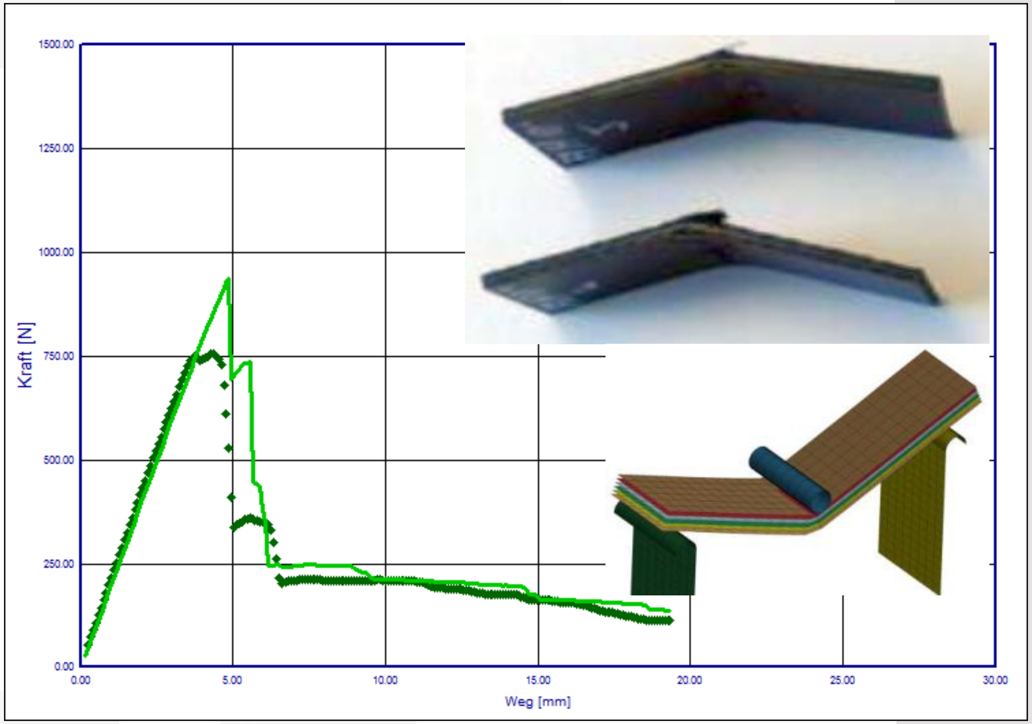
Composites
Verification of measurements - Compression

ENGINEERING GmbH

Orientation

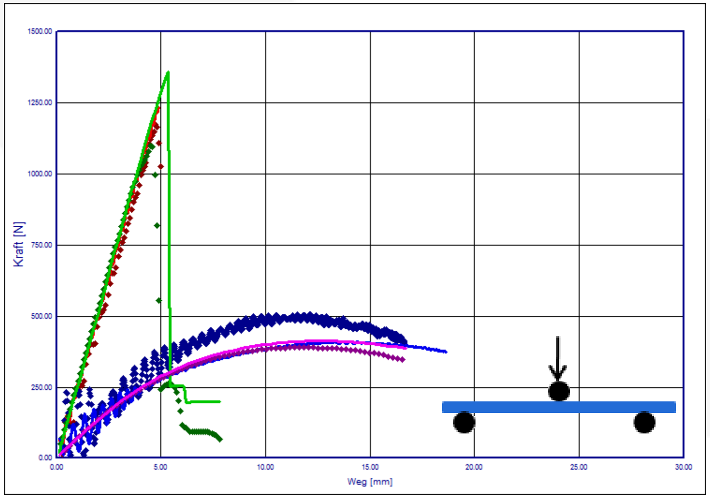


Multilayer Setup



.... test
— simulation

Dynamic 4a impetus



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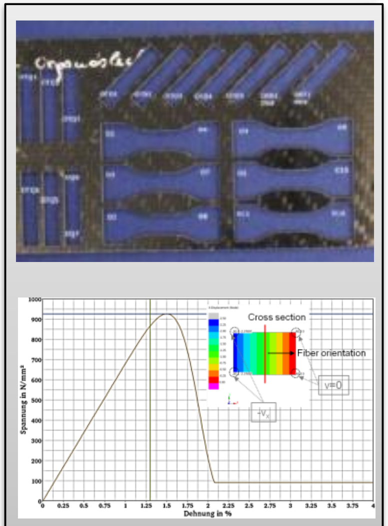
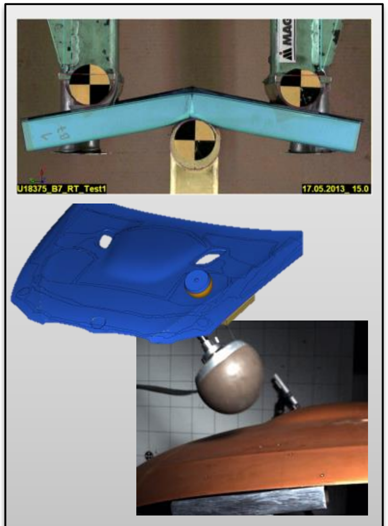
Composites – method development
Vehicle safety - crash

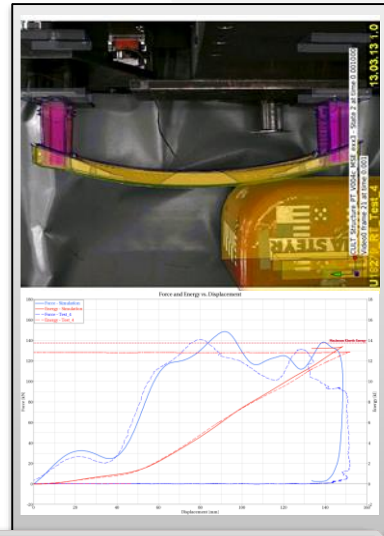
Mehrstufiger Ansatz



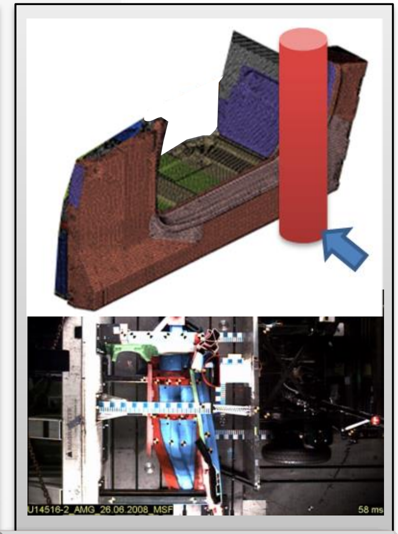
Werkstoff



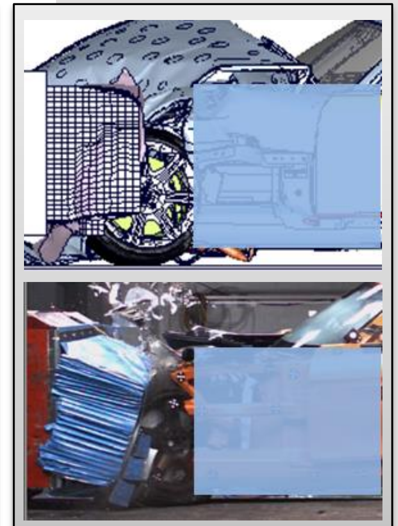
Bauteil



Modul



Fahrzeug Teilbereich



Gesamt-fahrzeug

MAGNA

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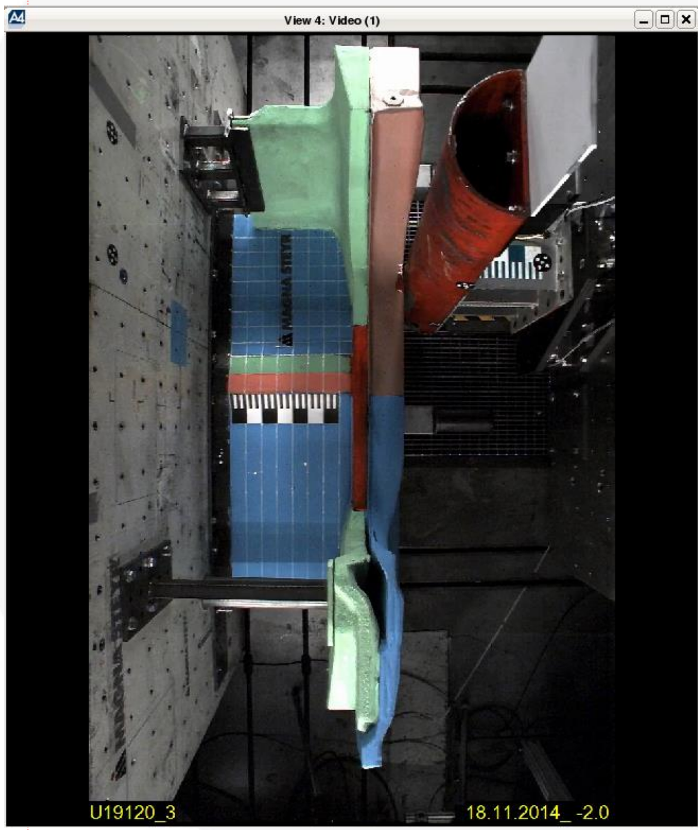
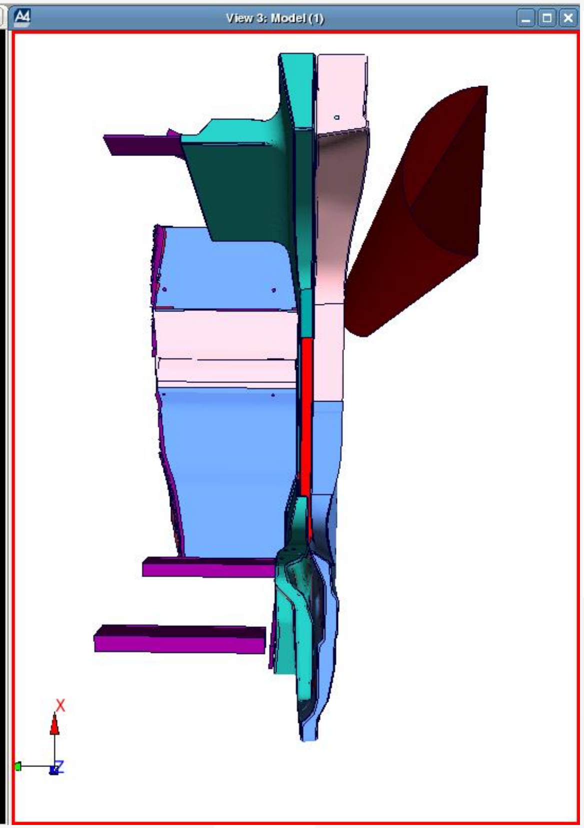
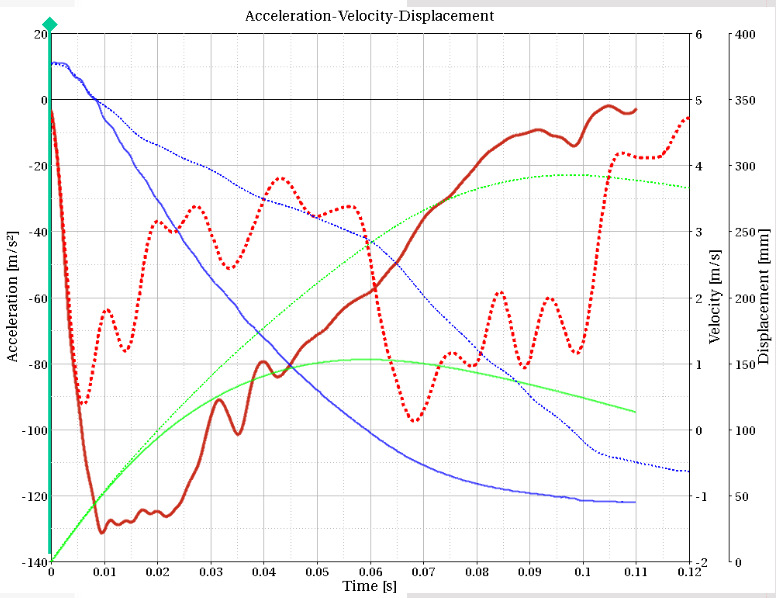
Composites – Validation

Composite Life Cell

Fahrzeugteilbereich – Crash







Simulation	Beschleunigung
Test 3	Geschwindigkeit
	Weg

MAGNA

Werkstoff → Bauteil → **Modul** → **Fahrzeug Teilbereich** → Gesamtfahrzeug

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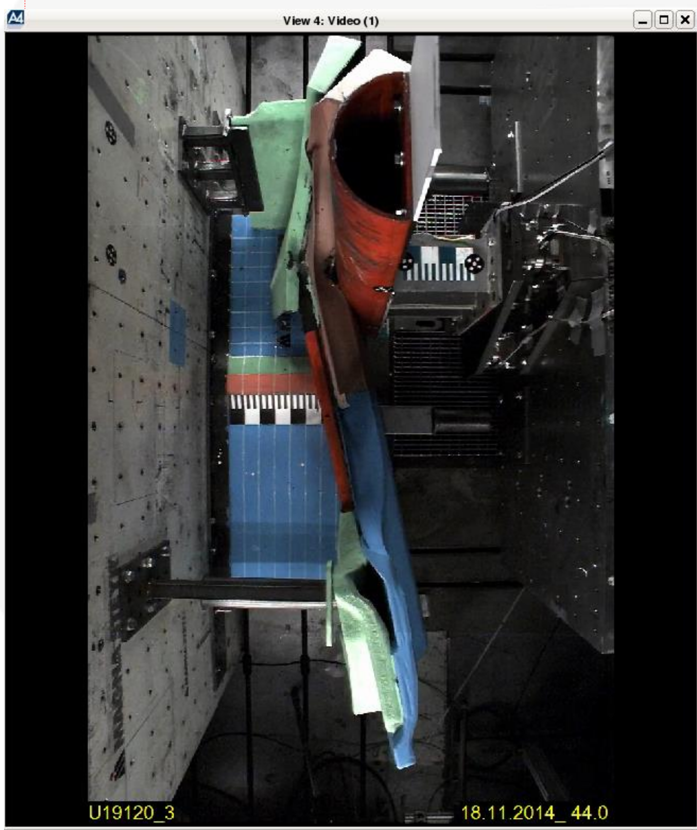
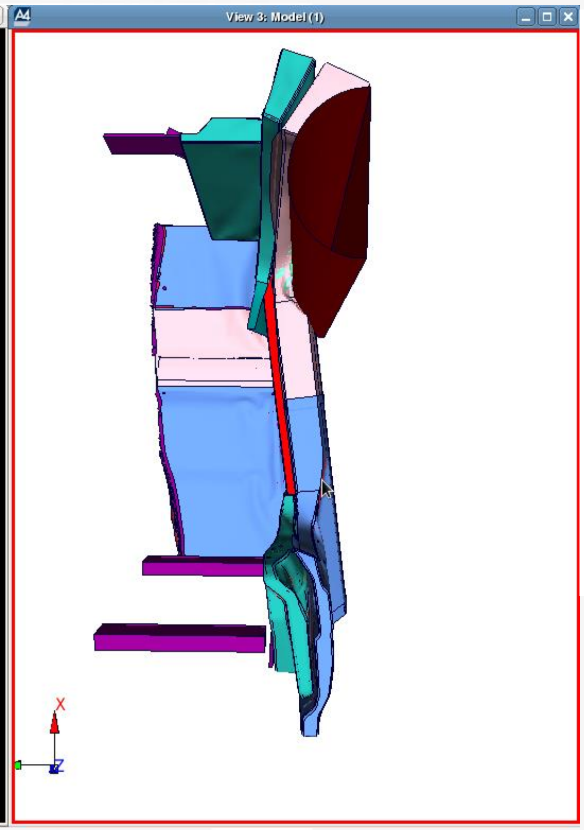
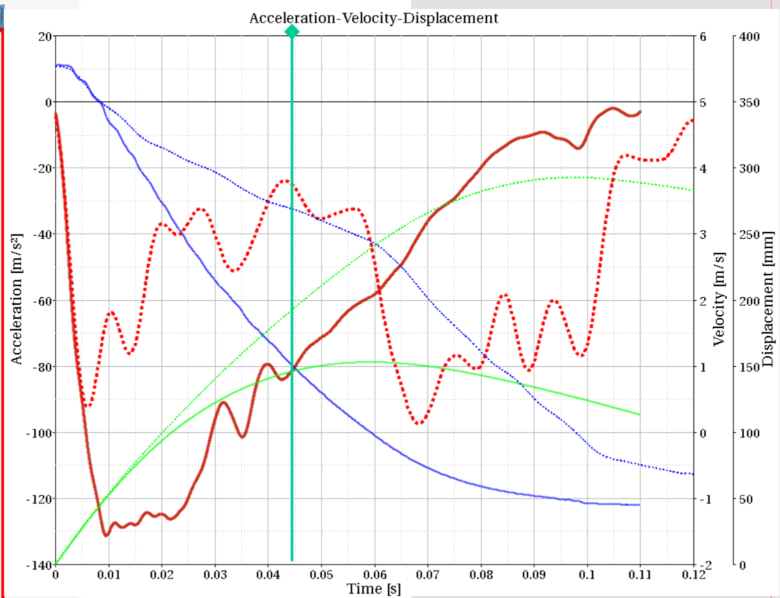
Composites – Validation

Composite Life Cell

Fahrzeugteilbereich – Crash







Simulation	Beschleunigung
Test 3	Geschwindigkeit
	Weg

Werkstoff → Bauteil → Modul → Fahrzeug Teilbereich → Gesamtfahrzeug

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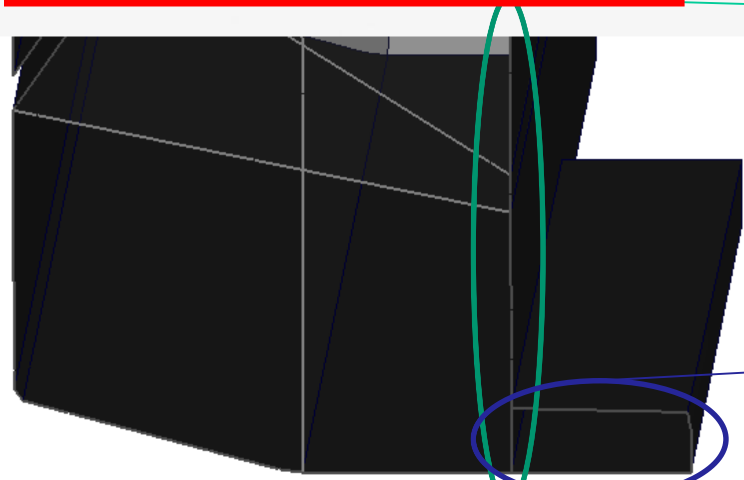
Composites – Simulation expertise

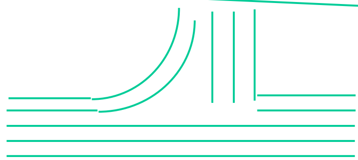
Composite Life Cell

Detail Analyse

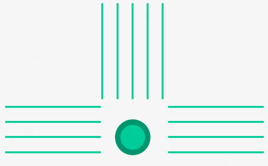


Schwellerprofil - Schnitt

Schwellerprofil deformiert



Real fiber structure



FE-model

Layered thin shell element reicht nicht aus.
Stacked Shell Modell lokal wieder notwendig

Fiktives Beispiel:

Werkstoff → Bauteil → Modul → Fahrzeug Teilbereich → Gesamt-fahrzeug

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Summary & Outlook

Summary & Outlook

Numerical support – key enabler

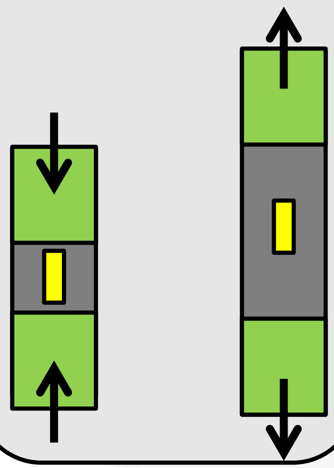
Effort
Costs
Time

Testing
different directions
0°, 45°, 90°

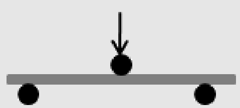
Virtual methods
Homogenization

detailed – standard
tensile, compression
strain measurement
(strain gauge or
optical)

→ $E_{||}$, $E_{\perp}$, $\sigma_{(\varepsilon)}$



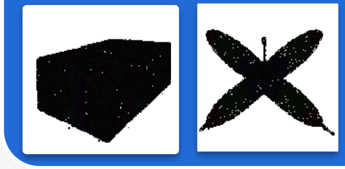
Engineering approach
Bending
$E_{||}$, $E_{\perp}$, F(w)



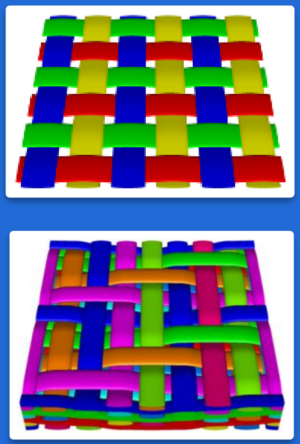
$$\overline{\underline{\sigma}}^{V} = (1-\varphi)\cdot\overline{\underline{\sigma}}^{M} + \varphi\cdot\overline{\underline{\sigma}}^{F}$$

$$\overline{\underline{\sigma}}^{F} = \underline{\underline{B}}^{\sigma}\,\overline{\underline{\sigma}}^{M}$$

Micro mechanics

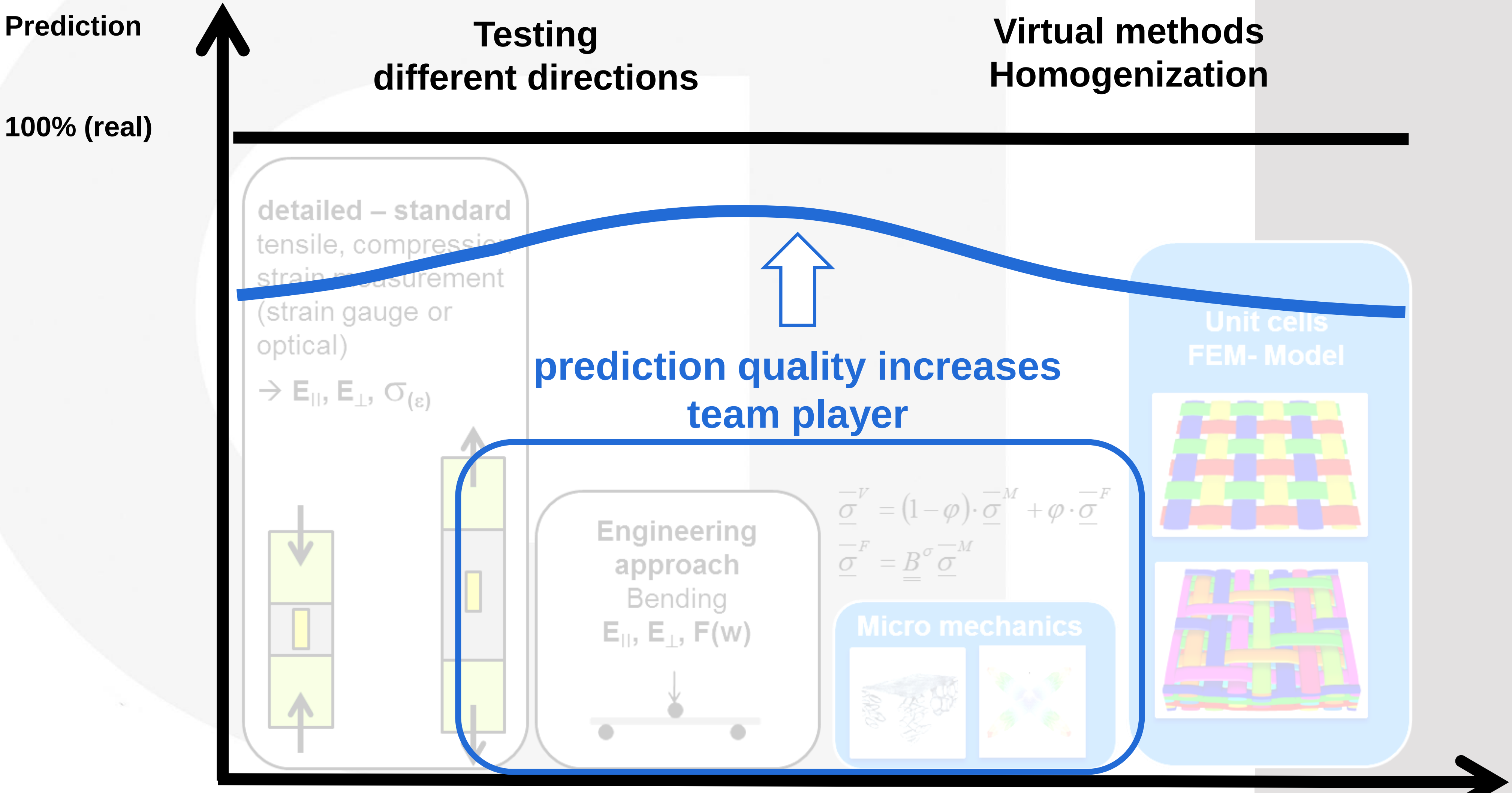


Unit cells
FEM- Model



Summary & Outlook

Numerical support – key enabler

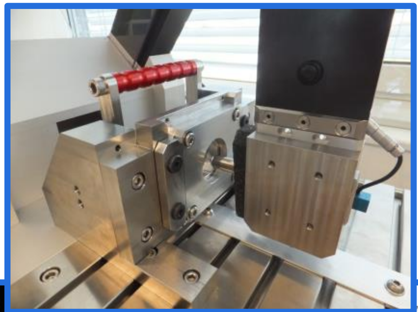


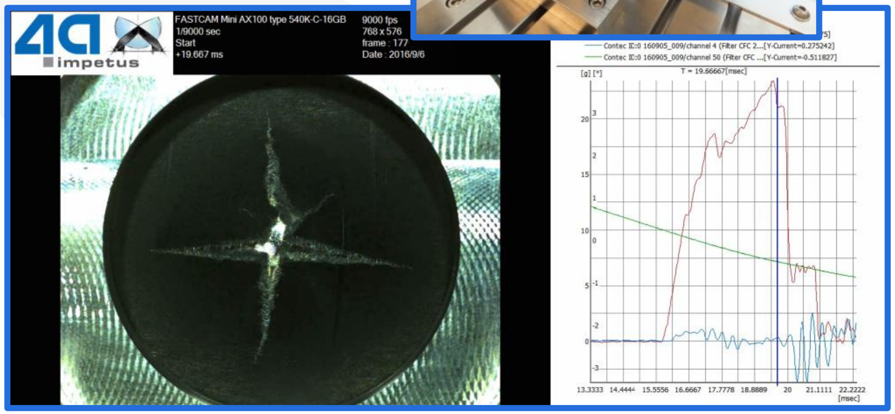
Summary & Outlook

4a impetus Hardware

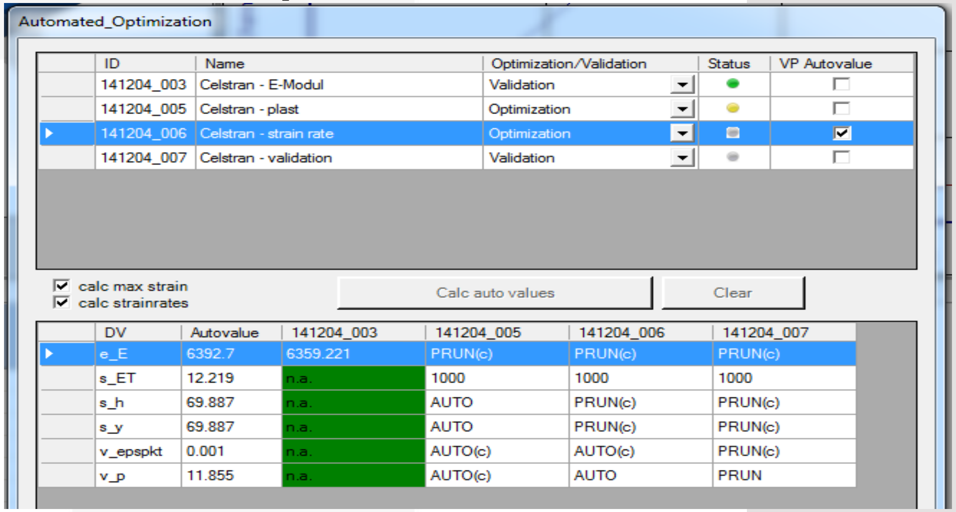
Spezifikationen	
Pendelarmlänge	500 mm
mögliche Prüfgeschwindigkeiten	0,5-4,4 m/s
maximal zulässige Zusatzmassen	4000 g
maximal zulässige Prüfenergie	50J

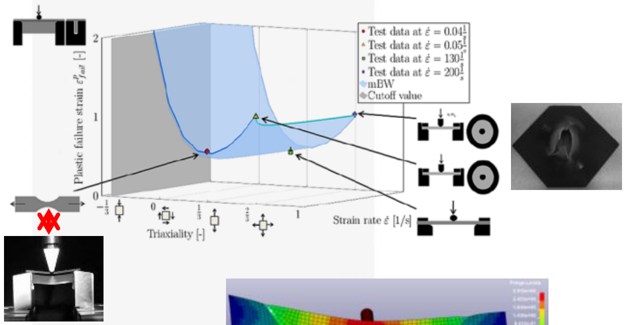
Highspeed Video
Composites
Puncture test
Component testing

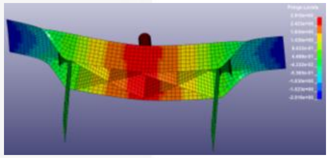


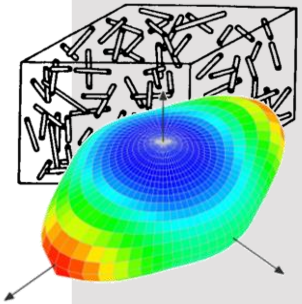


Workflow - process automation



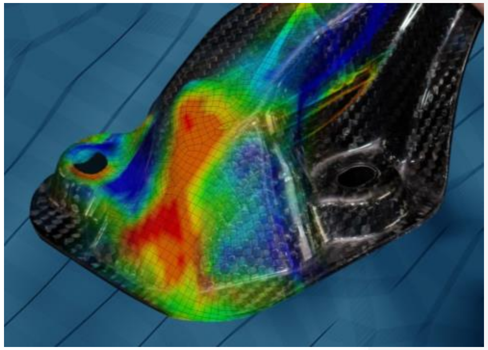






Failure
Anisotropy
Validation

Thank you for your attention!



14th 4a TECHNOLOGIETAG

23.- 24. March 2017
in Schladming, Austria

„Light weight applications & Composites"
More information: *http://technologietag.4a.co.at/*