Material characterization of composites using micro mechanic models as key enabler

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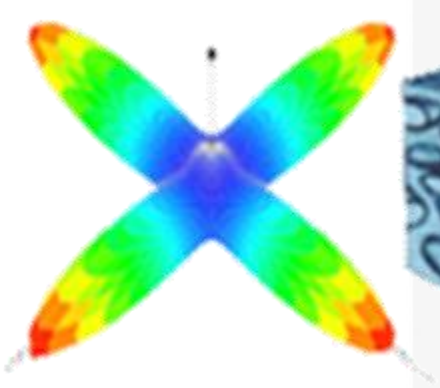
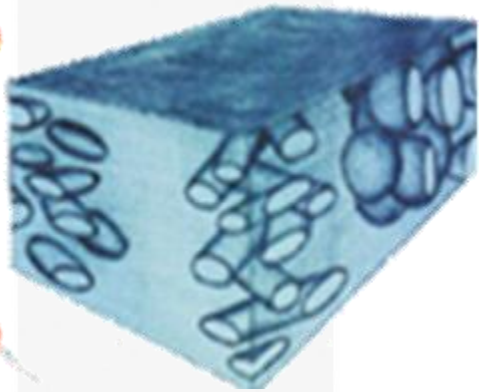
4a engineering GmbH





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Congress Park Hanau, Germany

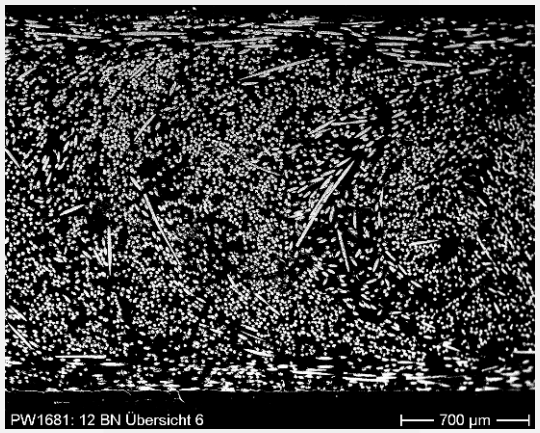
I N P H Y S I C S W E T R U S T

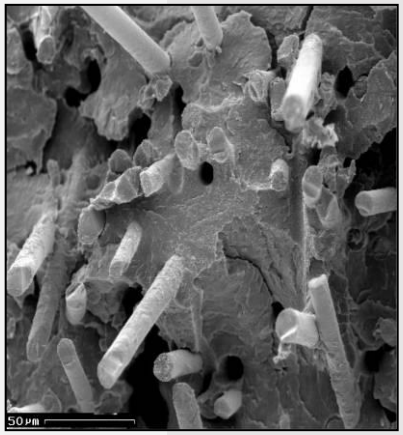
Content

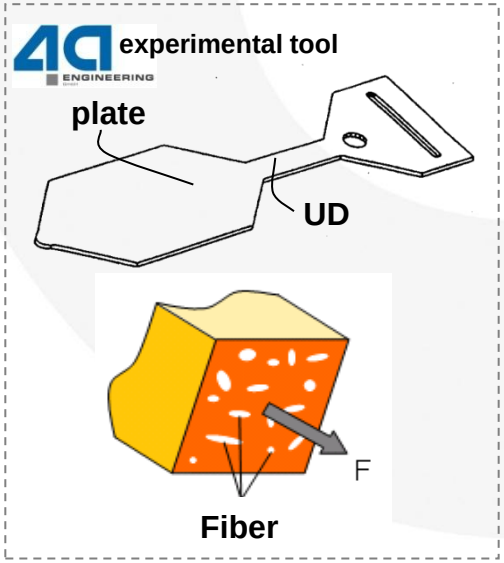
- Introduction
- Exemplary material behavior
  fiber orientation and content – strain rate - temperature
- *MAT_24 – typical approach
- Available material models in LS-DYNA
- Micro mechanic based model
- Simulation process chain
- Case studies
- Conclusion

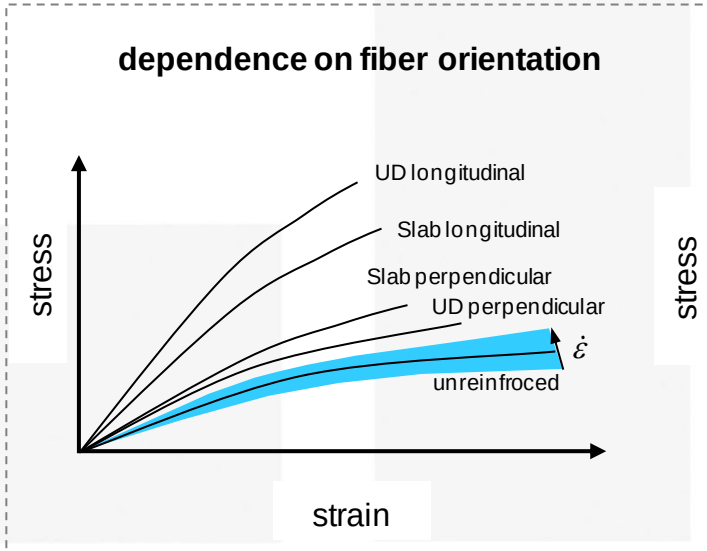
Introduction
Characteristic structure of reinforced plastics

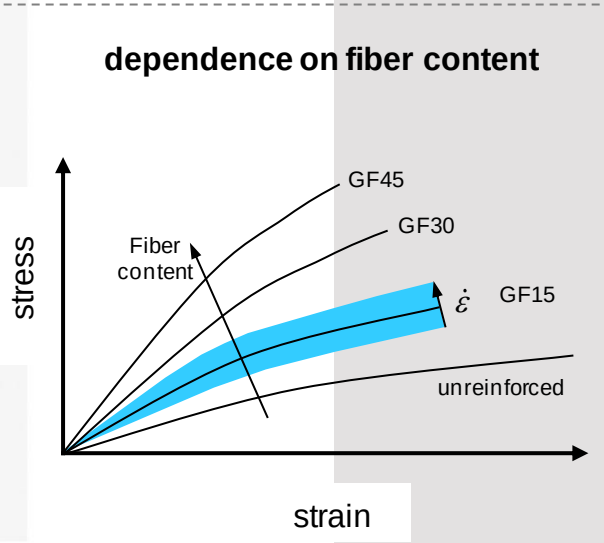
Fiber size and geometry →
significant influence on part performance
Increasing fiber content →
orthotropic properties increase & effect of strain rate diminishes (less content of matrix material)







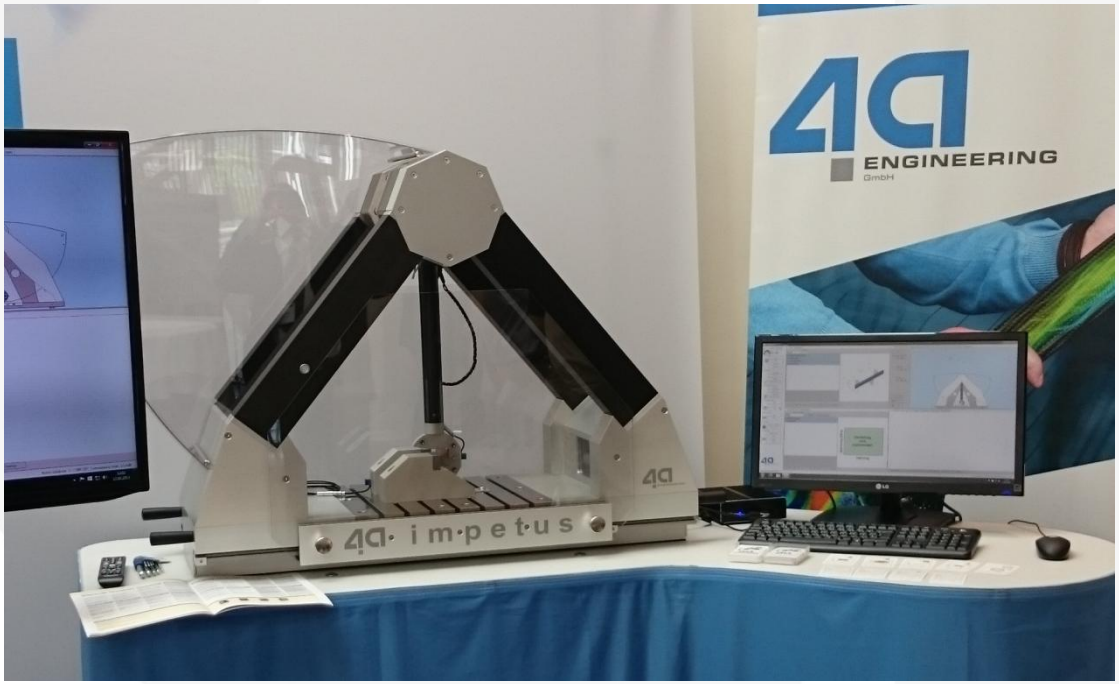




Introduction
4a impetus

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

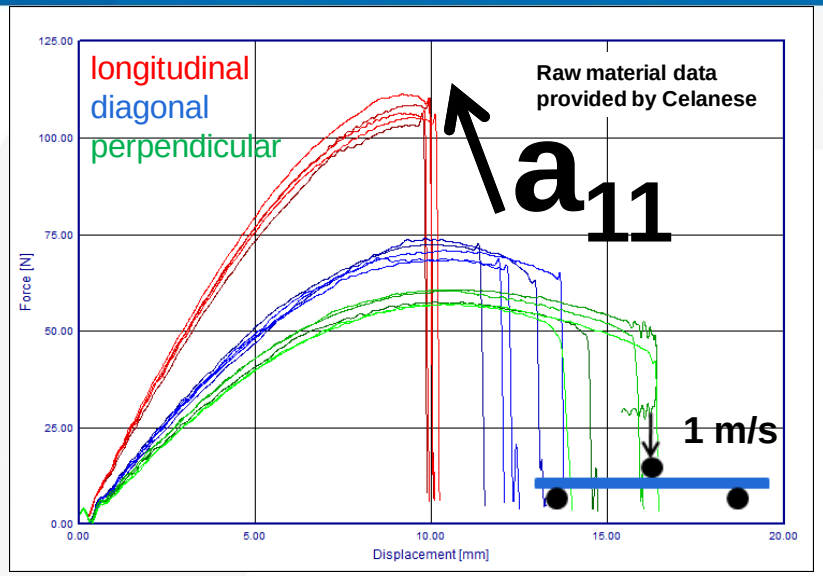
bending test on 4a impetus

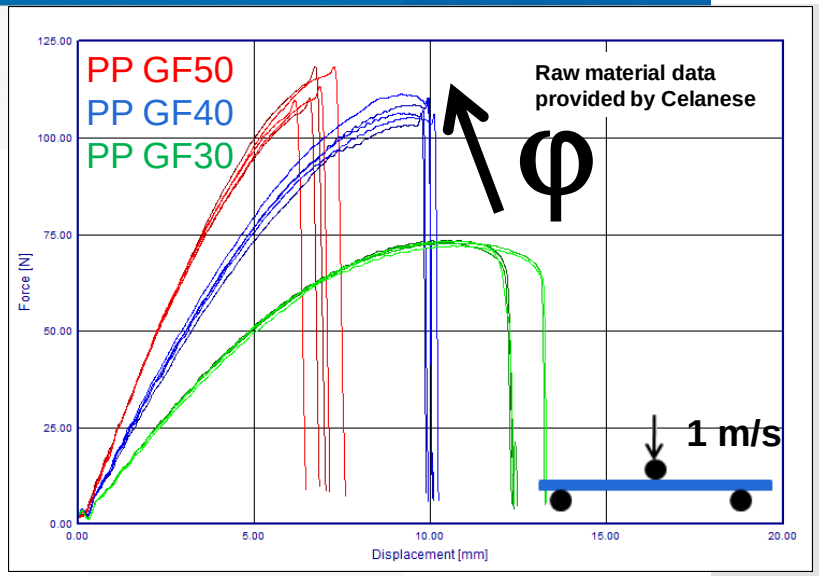


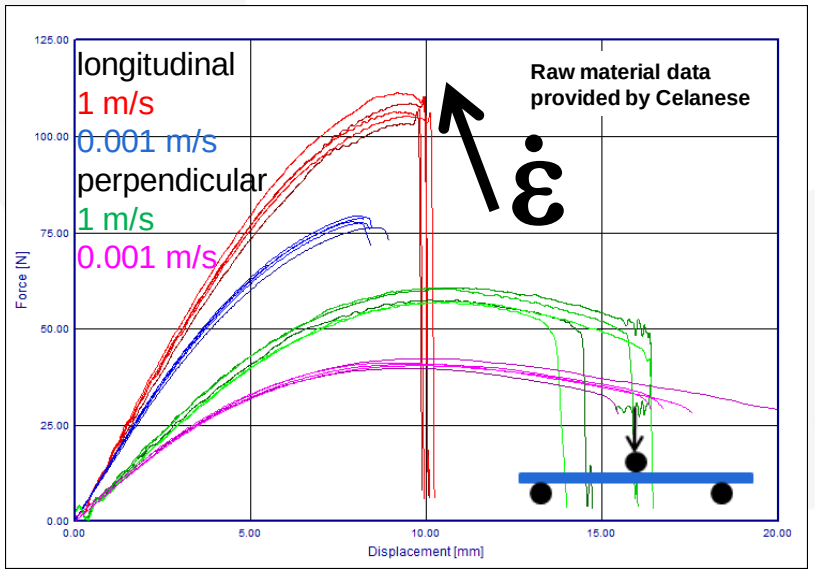
4a impetus - intelligent testing systems powered by 4a engineering GmbH

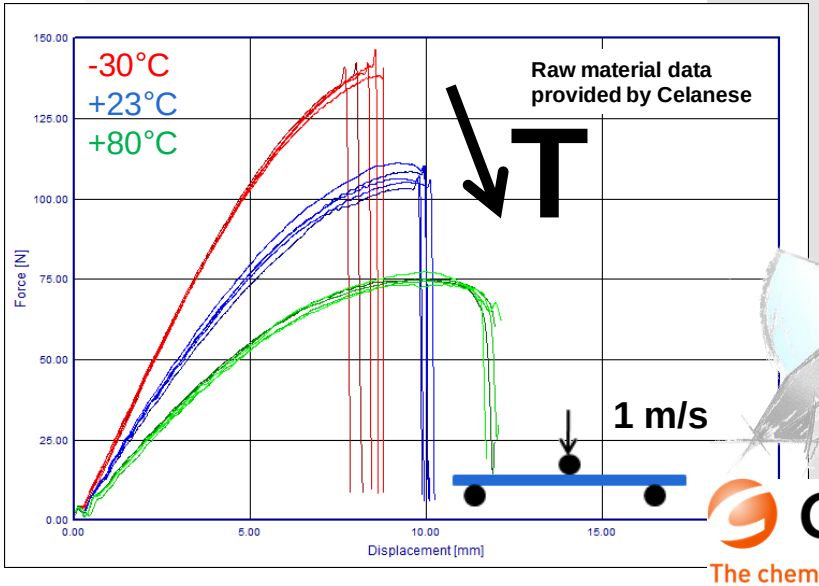
Fiber reinforced thermoplastics

3-point-bending, support distance 50 mm



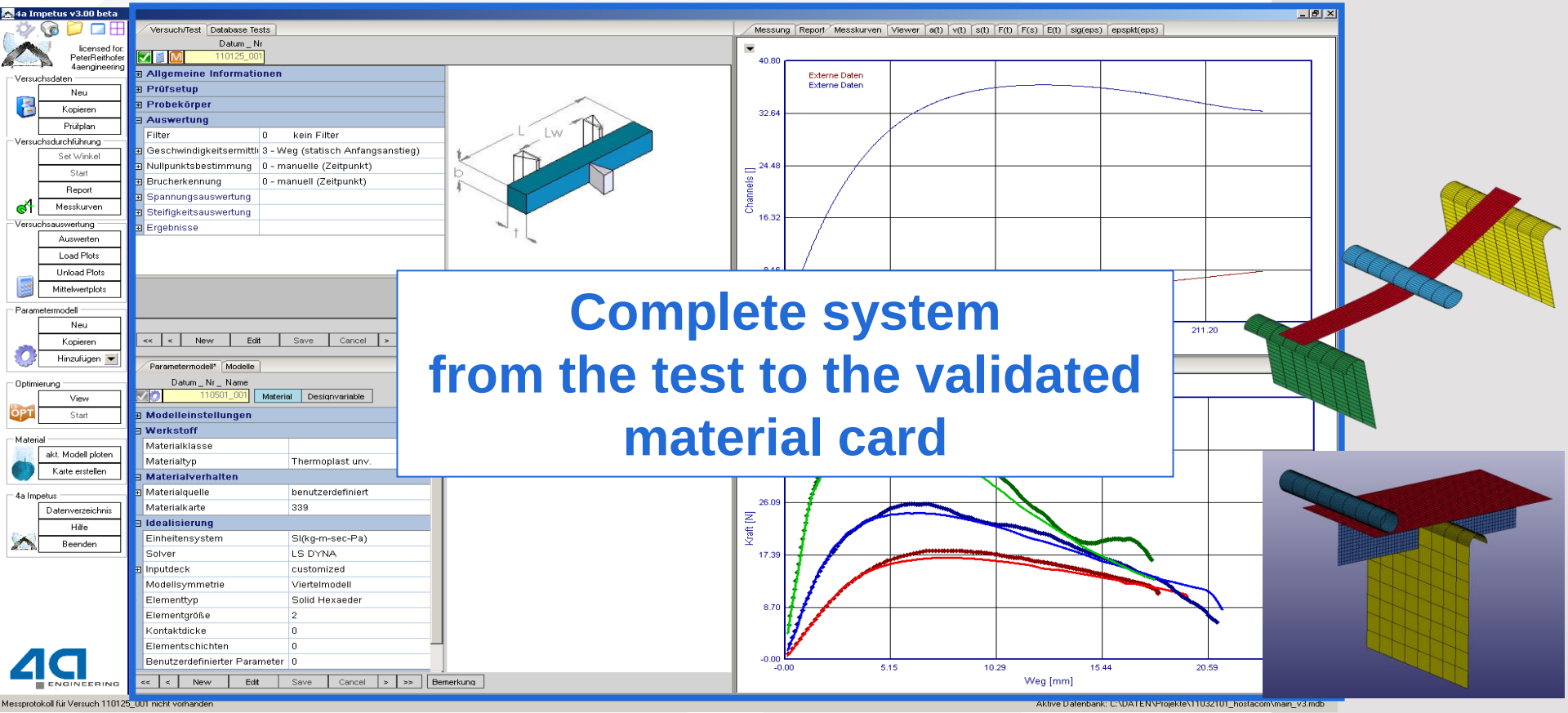




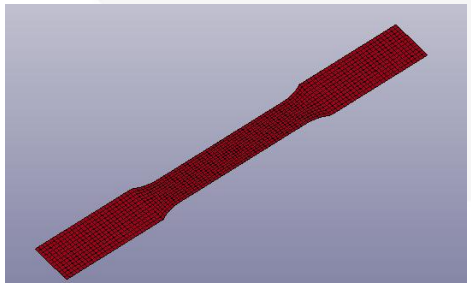


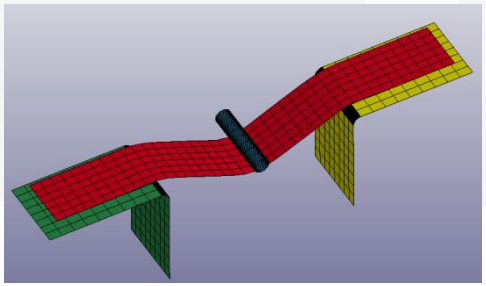
Celanese
The chemistry inside innovation™

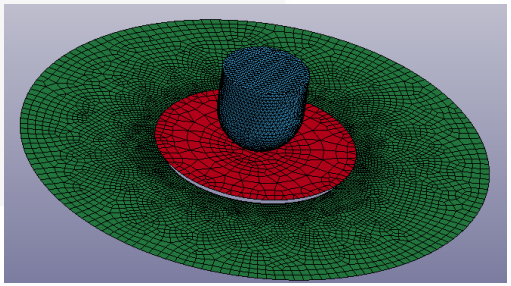
Introduction
4a impetus

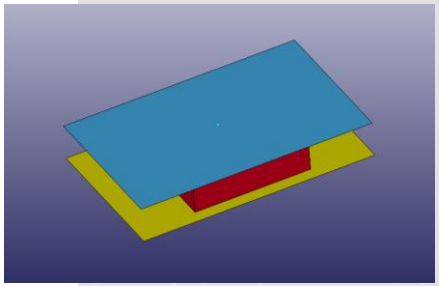


Complete system
from the test to the validated
material card







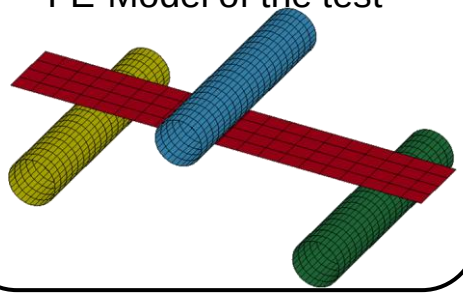


*MAT_24 – typical approach

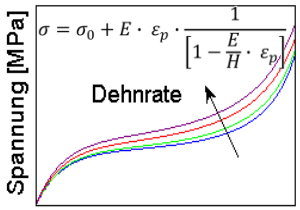
Separate for each direction

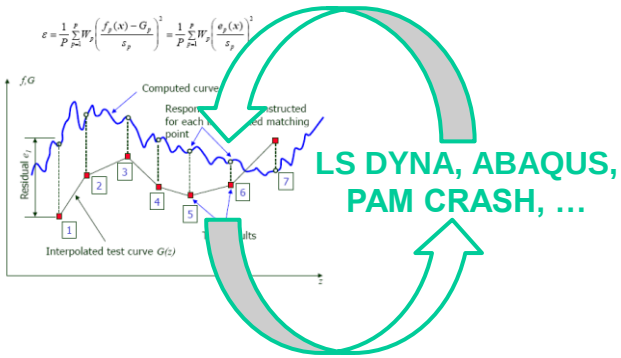
[2005Fritz]

FE-Model of the test



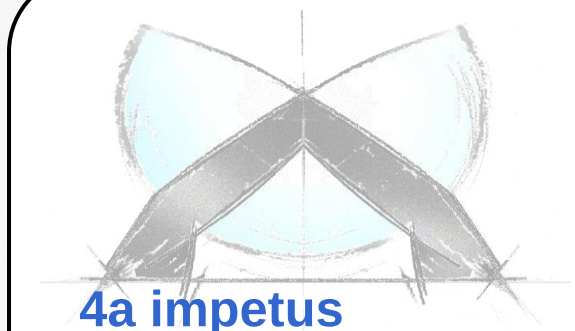
Parameterized materialcard





LS DYNA, ABAQUS,
PAM CRASH, …

Reverse Engineering



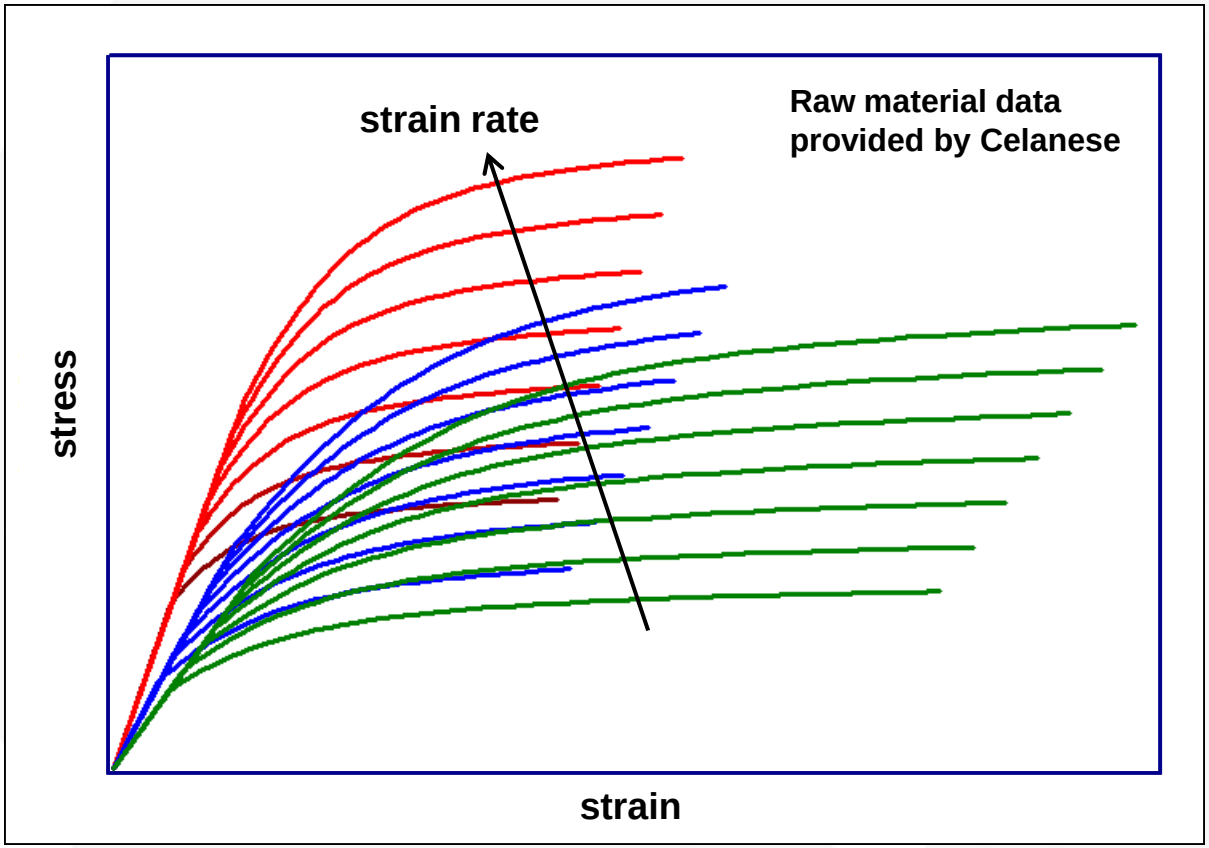
4a impetus

Hyperview, Animator,
LS PREPOST, …

DATABASE
measurement, models

*MAT_24 – typical approach

Separate for each direction



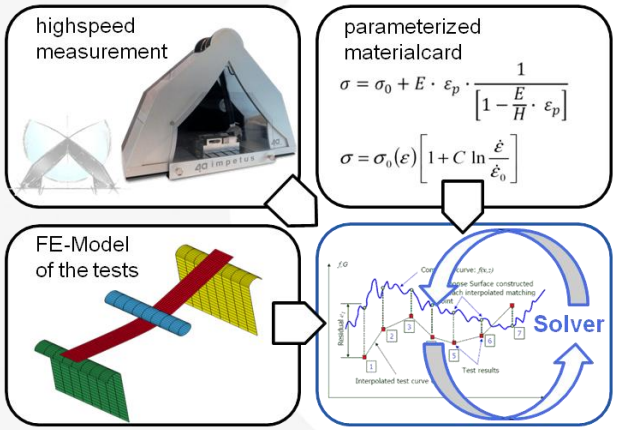
PP GF40

longitudinal
diagonal
perpendicular

Introduction
4a software tools - Overview

4a ENGINEERING GmbH

IMPETUS

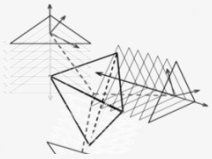


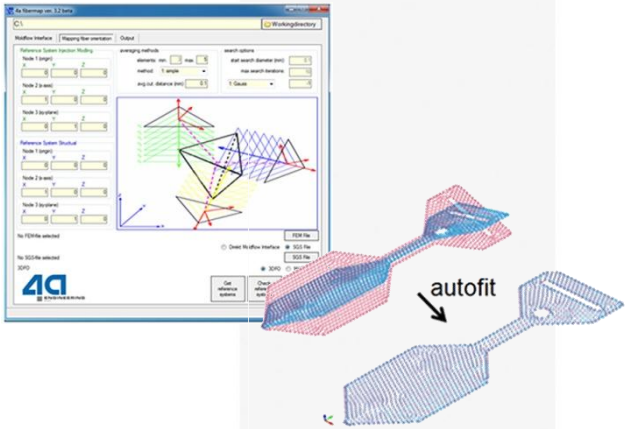
validated material cards

Virtual Performance Solution

LS-DYNA

FIBERMAP





individual mapping process information

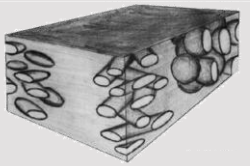
MOLDFLOW

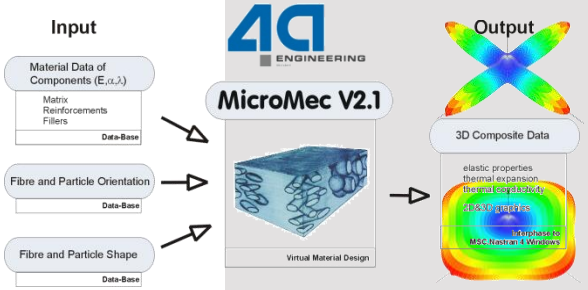
Moldex3D MOLDING INNOVATION

LS-DYNA

SIMULIA

MICROMEC





3D thermo elastic anisotropic material cards

NASTRAN

LS-DYNA

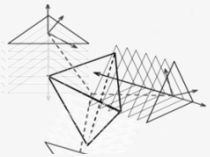
SIMULIA

Virtual Performance Solution

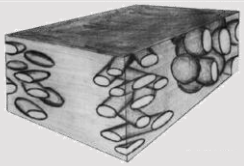
Introduction
4a software tools - Overview

4a ENGINEERING GmbH

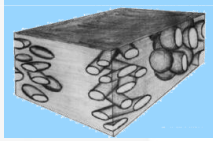
IMPETUS



FIBERMAP



MICROMEC



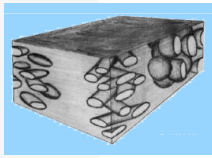
4a micromec Library

Orthotropic standard material cards elastic visco plastic (HILL plasticity)

Virtual Performance Solution

LS-DYNA

SIMULIA



User Material elastic visco plastic

LS-DYNA

SIMULIA

Micro mechanic based material models

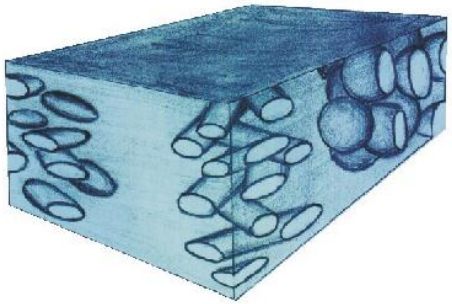
Stand-alone product - calculating the elastic values

since 1999

Input

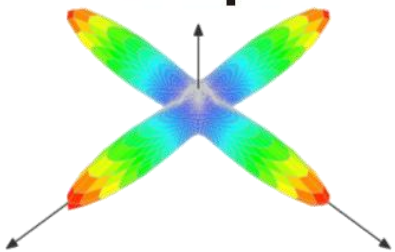
- Material Data of Components (E,α,λ)
  - Matrix
  - Reinforcements
  - Fillers
  - Data-Base
- Fibre and Particle Orientation
  - Data-Base
- Fibre and Particle Shape
  - Data-Base

4a micromec



Virtual Material Design

Output

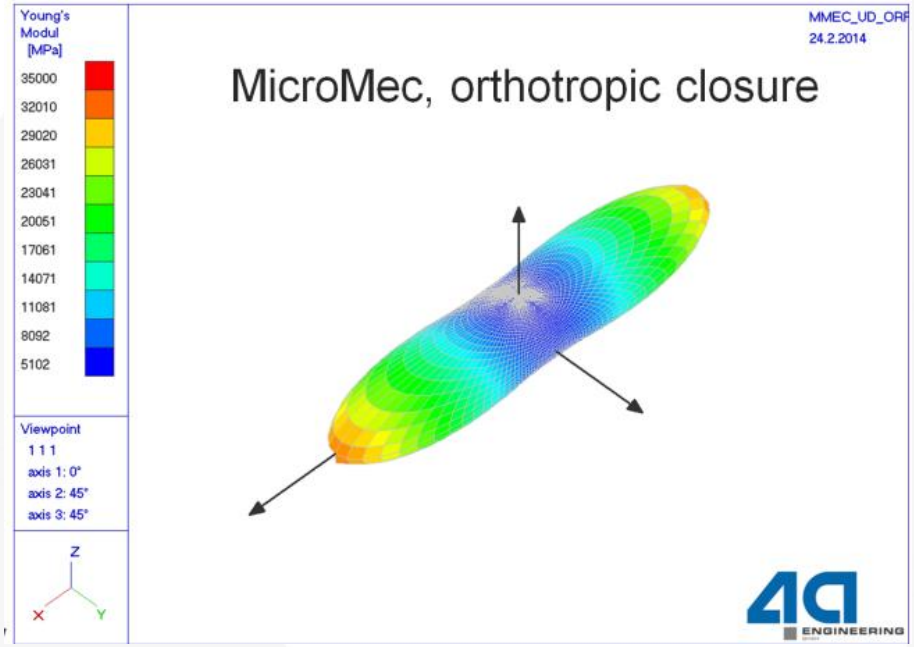


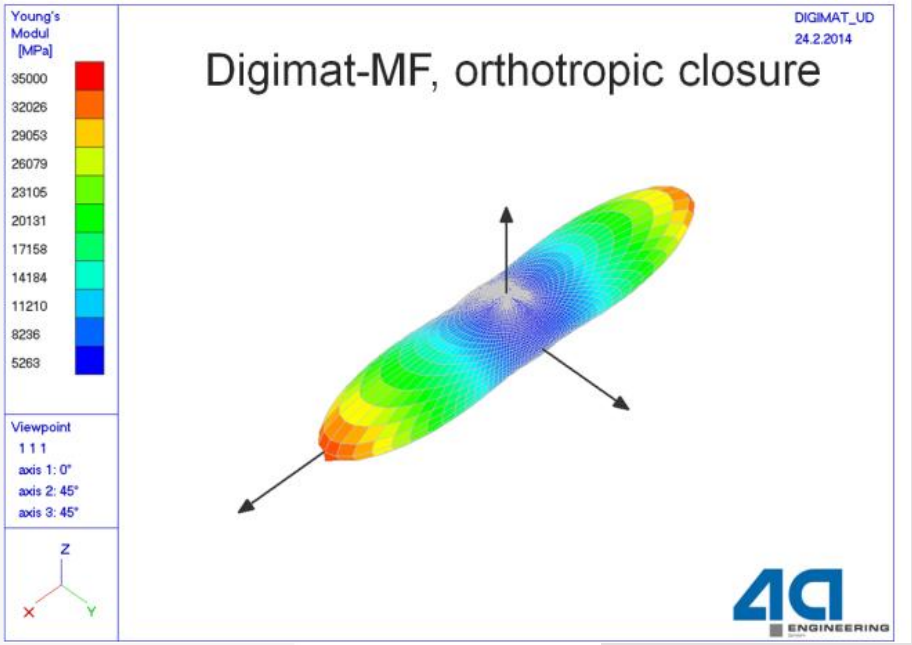
- 3D Composite Data
  - elastic properties
  - thermal expansion
  - thermal conductivity
  - 2D&3D graphics
  - Interphase to MSC.Nastran 4 Windows

- SFRT, LFRT, CFRP, GFRP, ….
- 3D thermo-elastic properties

Micro mechanic based material models

Stand-alone product - calculating the elastic values





- Comparison by University of Leoben between Digimat-MF and 4a micromec
- User material (orthotropic elastic visco-plastic including failure)

Material models in LS-DYNA

Overview

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	

USERMAT → Micro mechanic based material models

Micro mechanic based material models
LS-DYNA *MAT_215

- ***MAT_157** → phenomenological model **based on composites stresses**
- ***MAT_4a_micromec (*MAT_215)**
  - Current development / available Q4/2016
  - Based on 4a_micromec
  - In each simulation cycle
    - **Composite stress → matrix and fiber stress**
    - Matrix: isotropic elastic viscoplastic
    - Fiber: (transversal) isotropic elastic
  - Advantage
    - Material behavior **local** defined **through mapped fiber orientation**
    - Failure criteria based on matrix or fiber

Material models in LS-DYNA
*MAT_157

[2014SimuliaManual]

- Hill plasticity → „extended“ von Mises

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

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

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

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

Material models in LS-DYNA
*MAT_157 → *INITIAL_STRESS_SHELL(SOLID)

[2014Haufe]

*MAT_157: Selective mapping IHIS

FLAG	Description	Variables	#
a_0	Material directions	$q_{11}, q_{12}, q_{13}, q_{31}, q_{32}, q_{33}$	6
a_1	Anisotropic stiffness	C_{ij}	21
a_2	Anisotropic constants	F, G, H, L, M, N	6
a_3	Stress-strain curve	$LCSS$	1

*INITIAL_STRESS_SOLID: NHISV

- in addition to 6 stress values and eps NHISV history can be initialized
- NHISV must correspond to the a_i that define IHIS in *MAT_157

$$NHISV = 6a_0 + 21a_1 + 6a_2 + 1a_3$$

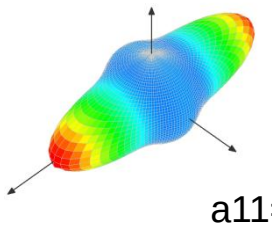
Material models in LS-DYNA
*MAT_157 material

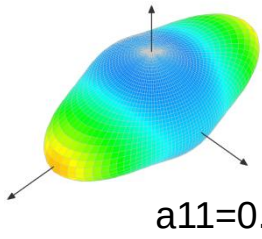
- material model based on **composites properties**

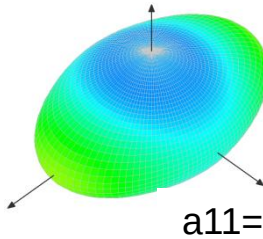
description	variables	Number of variables	dependencies
anisotropic stiffness	Cij	21	$C_{ij}\left(a_{ij},\varphi,C^M,C^F\right)$
Hill plasticity	3D: F, G, H, L, M, N 2D: r00, r45, r90	6	$f\left(a_{ij},\varphi,\sigma^M,\sigma^F\right)$
stress-strain curve	Loadcurve	3	$f\left(a_{ij},\varphi\right)$
failure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

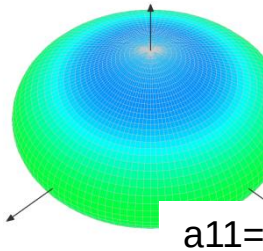
- Not possible to generate samples with **explicit defined and varying a_{ij}**
- **Hard to characterize, too many possibilities in a_{ij}**

→ Micro mechanical model is needed





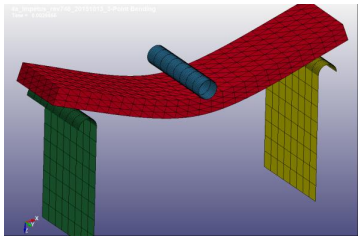




MAT_157 - micro mechanic models as key enabler

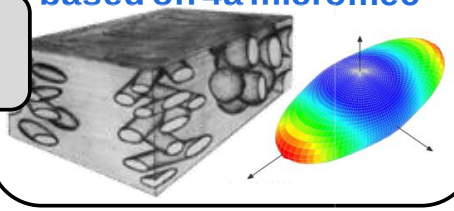
Consider each direction in one material model

FE-Model of the test

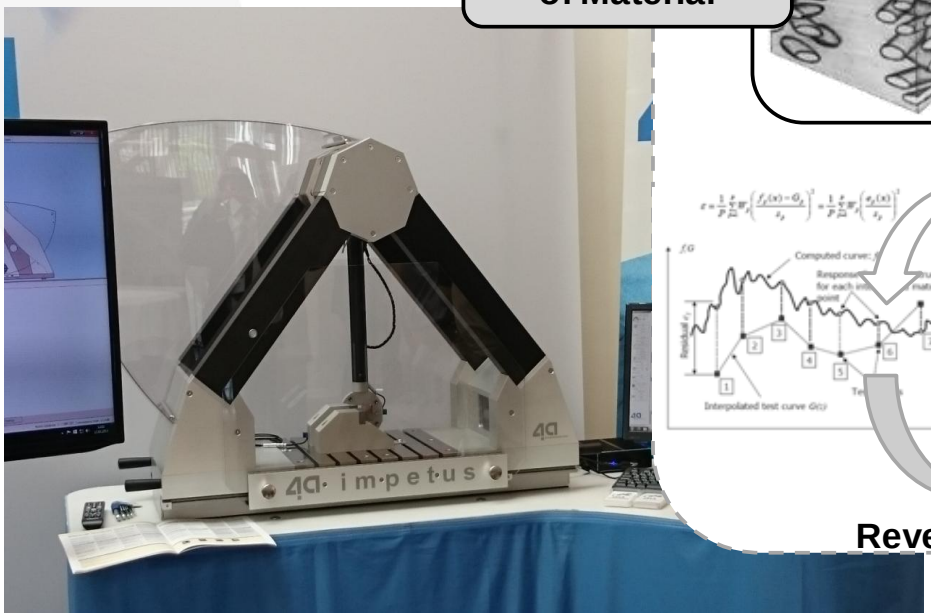


Orientation of Element

Parameterized materialcard based on 4a micromec



Orientation of Material



LS DYNA, ABAQUS, PAM CRASH, …

Reverse Engineering

DATABASE measurement, models

Orientation of test

MAT_157 - micro mechanic models as key enabler

Consider each direction in one material model

e.g. PP LGF30

- micro mechanics
  based on **Fiber & Matrix** properties

  Composite elasticity→ orthotropic E_1, E_2, E_3, ν_{12} , ν_{13} , ν_{23}, G_{12}, G_{13}, G_{23}

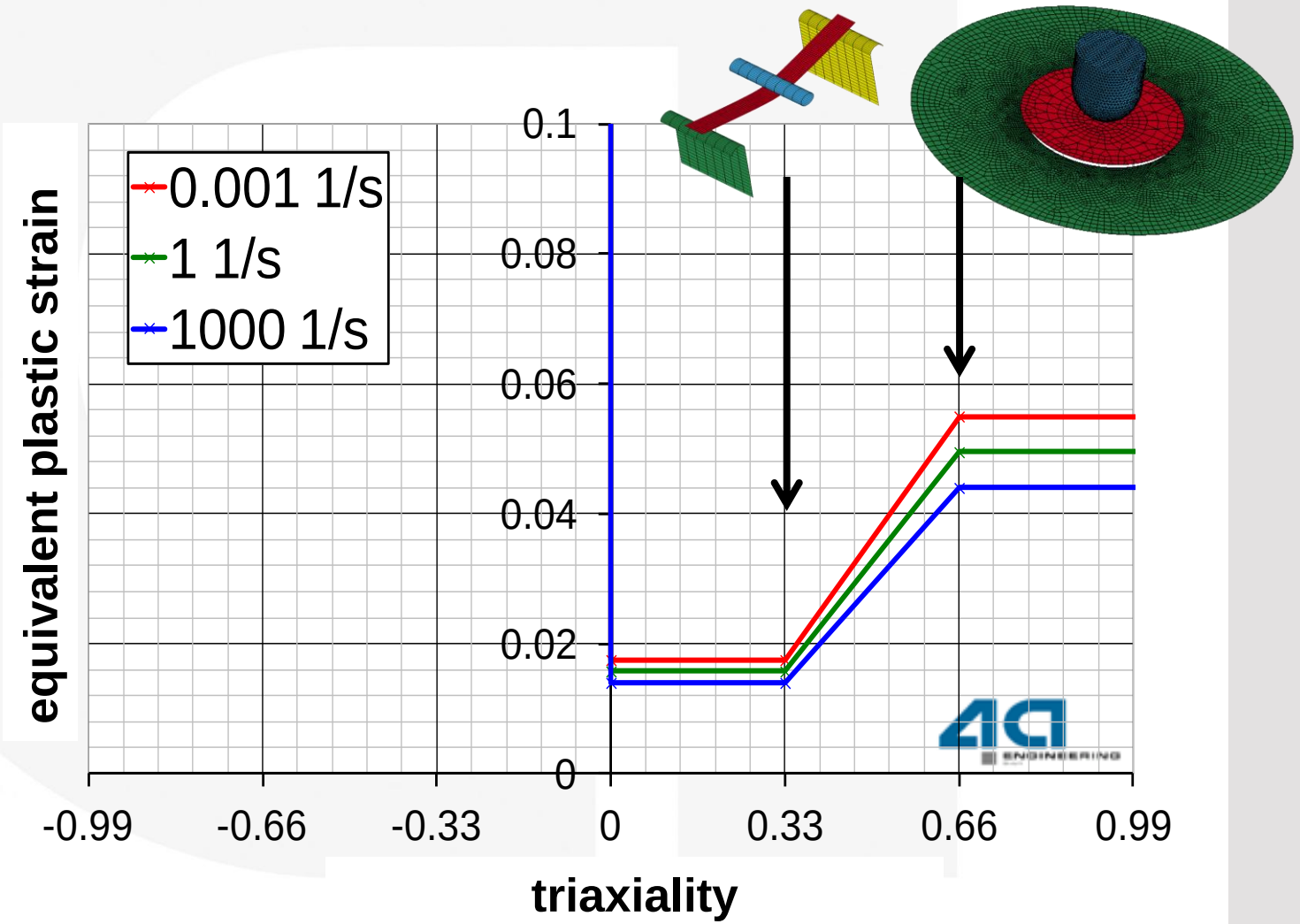
  Composite plasticity→ HILL coefficient F, G, H, L, M, N

- **Reverse Engineering**
  - hardening: Bilinear → **2 parameters**
  - strainrate: Johnson Cook → **1 parameter**
  - failure: DIEM → **equivalent HILL strain**

MAT_157 - micro mechanic models as key enabler

Consider each direction in one material model

MAT_ADD_EROSION: DIEM with DUCTILE CRITERION



MAT_157 - micro mechanic models as key enabler

Current 4a impetus 3.4 alpha version

160223_006 | Material | Designvariablen | Layers

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

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]

MAT_157 - micro mechanic models as key enabler

Current 4a impetus 3.4 alpha version

160223_006 | Material | Designvariablen | Layers

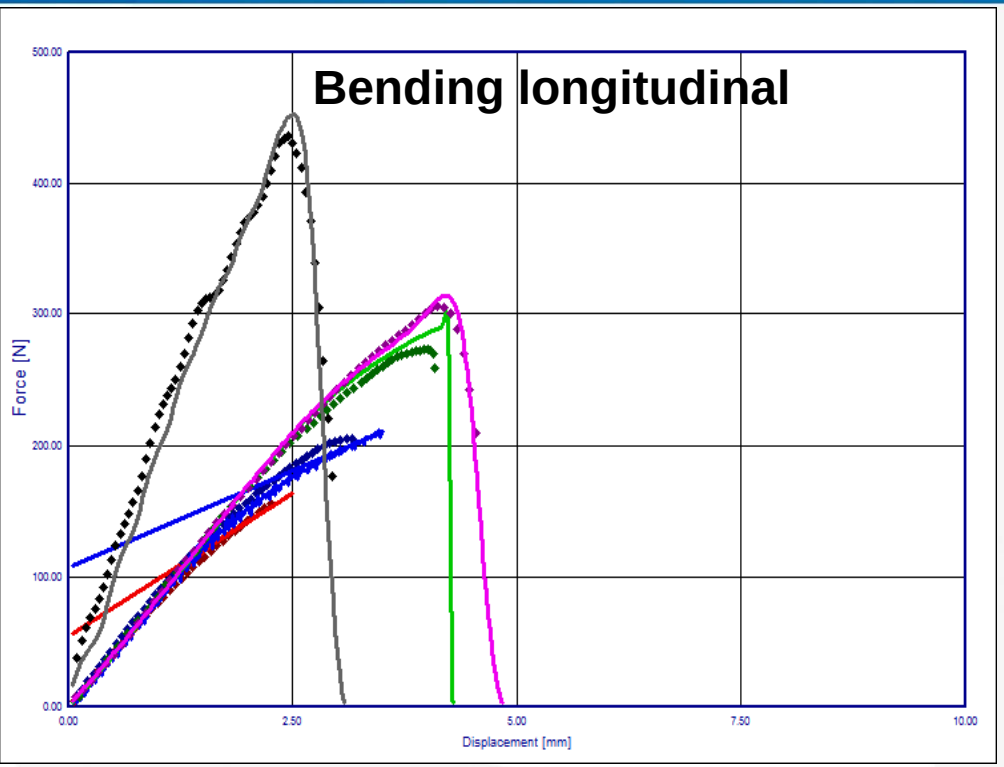
Name	Start	const...	Description
GroupName: 10_elasticity			
c_C11	MMEC	☑	constitutive matrix 11
c_C12	MMEC	☑	constitutive matrix 12
c_C13	MMEC	☑	constitutive matrix 13
c_C14	MMEC	☑	constitutive matrix 14
c_C15	MMEC	☑	constitutive matrix 15
c_C16	MMEC	☑	constitutive matrix 16
c_C22	MMEC	☑	constitutive 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
*	Click here to add a new row		

MAT_157 - micro mechanic models as key enabler

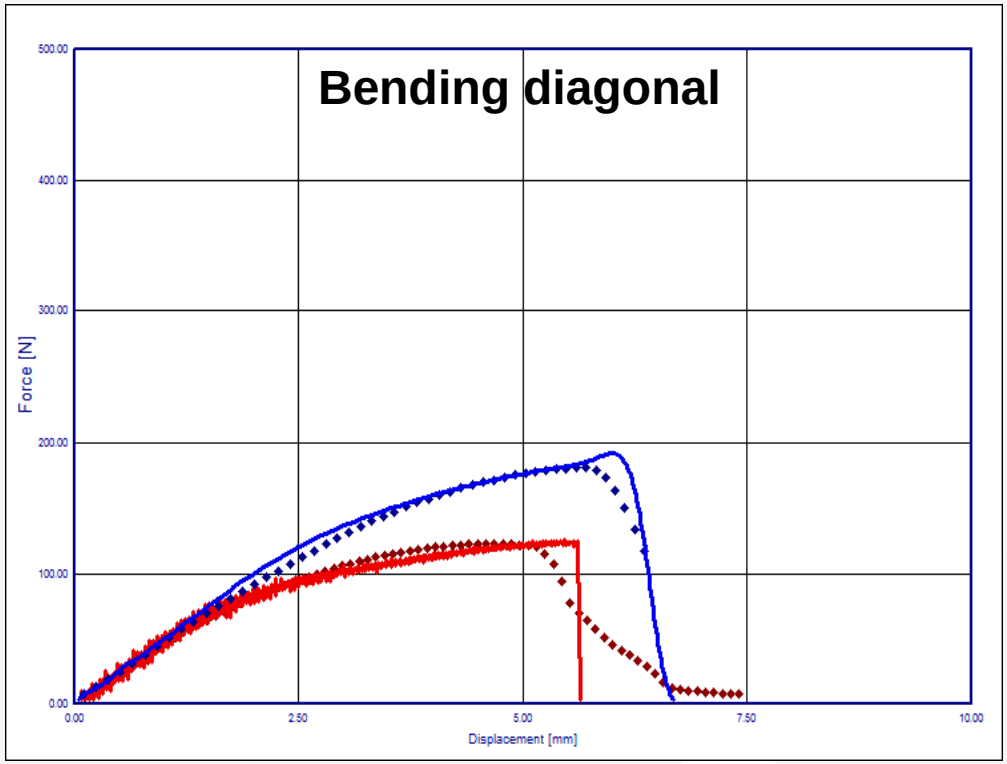
Consider each direction in one material model



Shell 2mm, Type 16, 5 IP

MAT_157 - micro mechanic models as key enabler

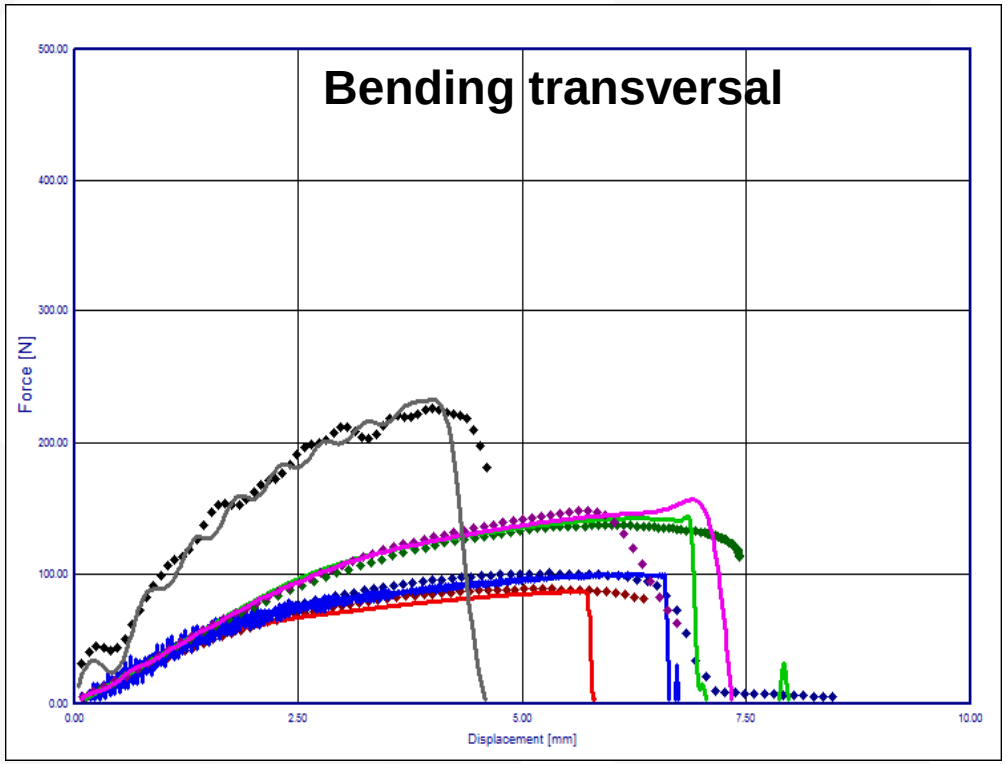
Consider each direction in one material model



Shell 2mm, Type 16, 5 IP

MAT_157 - micro mechanic models as key enabler

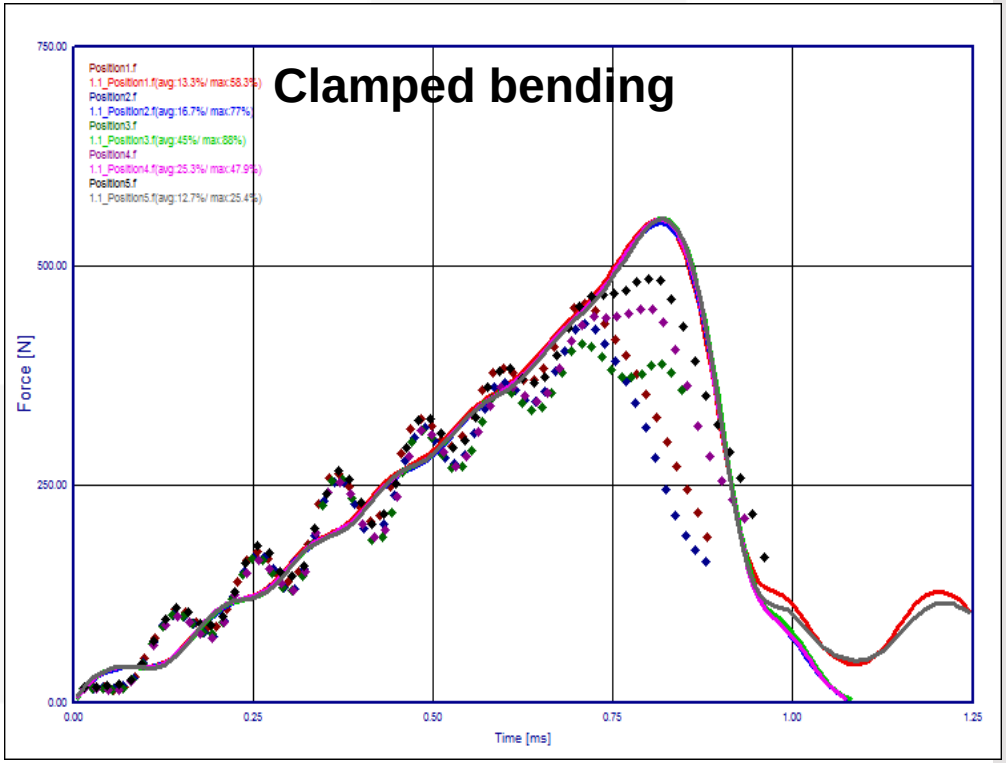
Consider each direction in one material model



Shell 2mm, Type 16, 5 IP

MAT_157 - micro mechanic models as key enabler

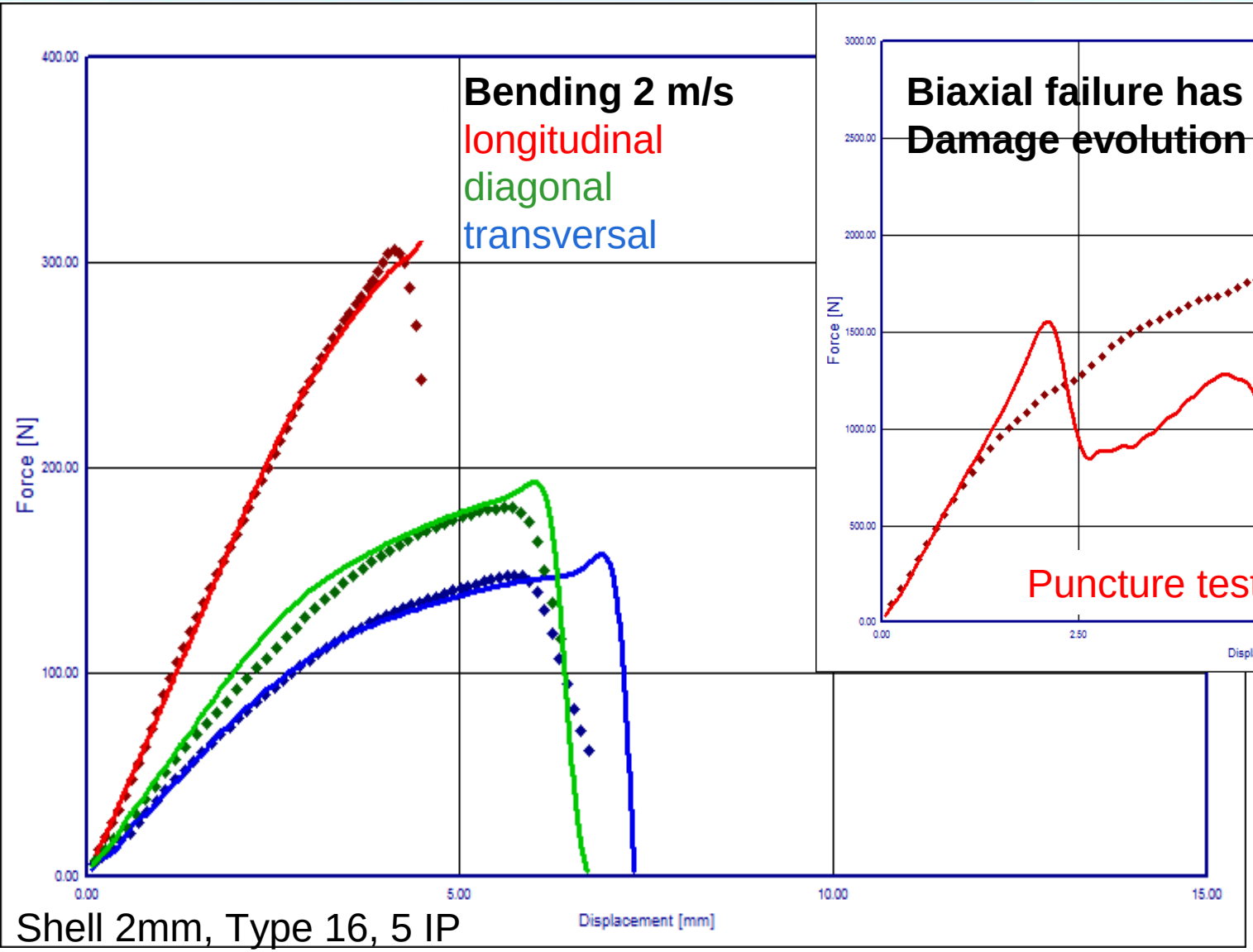
Consider each direction in one material model



Shell 2mm, Type 16, 5 IP

MAT_157 - micro mechanic models as key enabler

Consider each direction in one material model

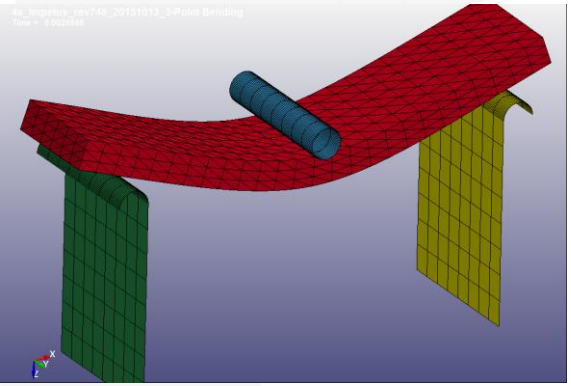


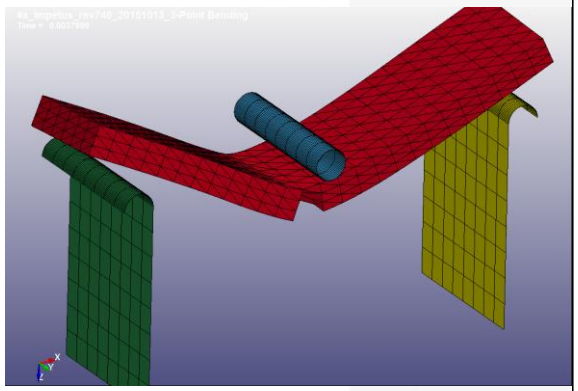
Shell 2mm, Type 16, 5 IP

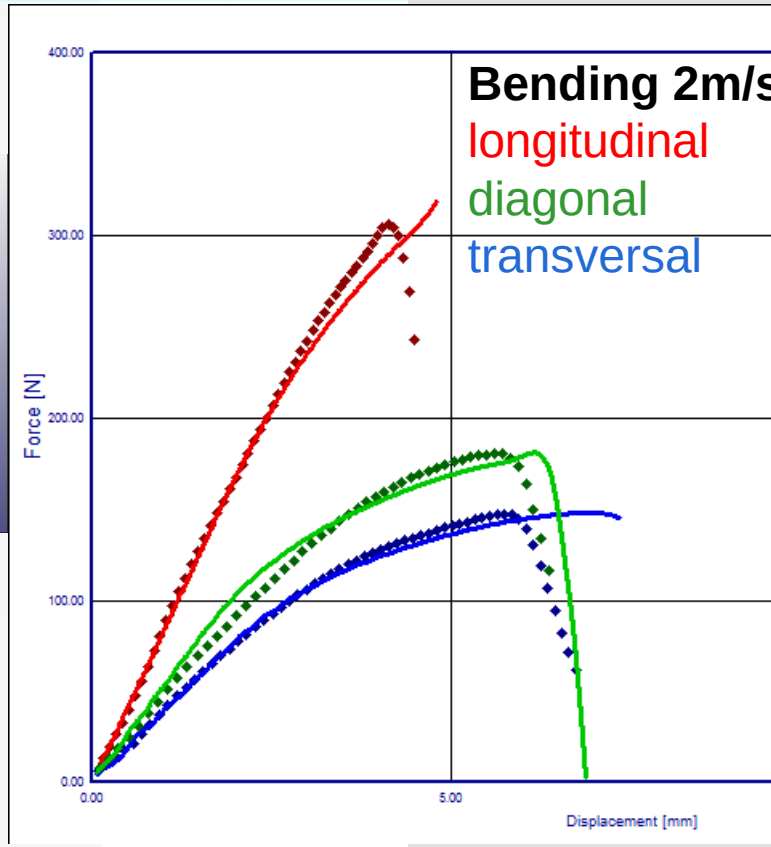
MAT_157 - micro mechanic models as key enabler

Consider each direction in one material model

Solid – TET10 (Type 16)



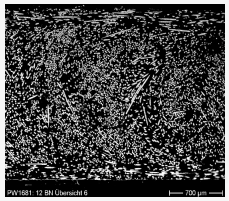




Simulation process chain
For injection molded parts

[2012Reithofer]

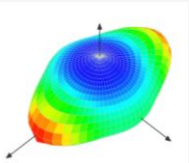
Injection molding (Moldflow, Moldex, ...)



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

fiber orientation

micromechanic modeling (4a micromec, ...)

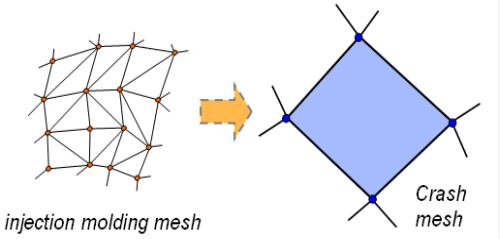


$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ & & C_{33} & C_{34} & C_{35} & C_{36} \\ & & & C_{44} & C_{45} & C_{46} \\ & & & & C_{55} & C_{56} \\ & & & & & C_{66} \end{bmatrix}$$

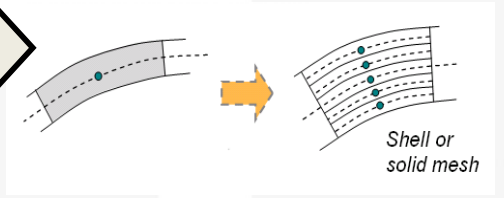
anisotropy

Mapping (4a fibermap, ...)

In plane mapping



Mapping in thickness direction



Crash Simulation (LS-DYNA)

orientations

*ELEMENT_SHELL_BETA

*ELEMENT_SHELL_COMPOSITE

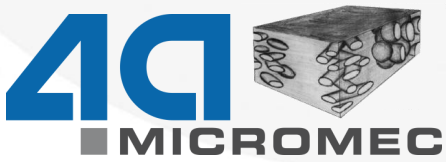
*INITIAL_STRESS_SHELL(SOLID)

*ELEMENT_SOLID_ORTHO

standard material models

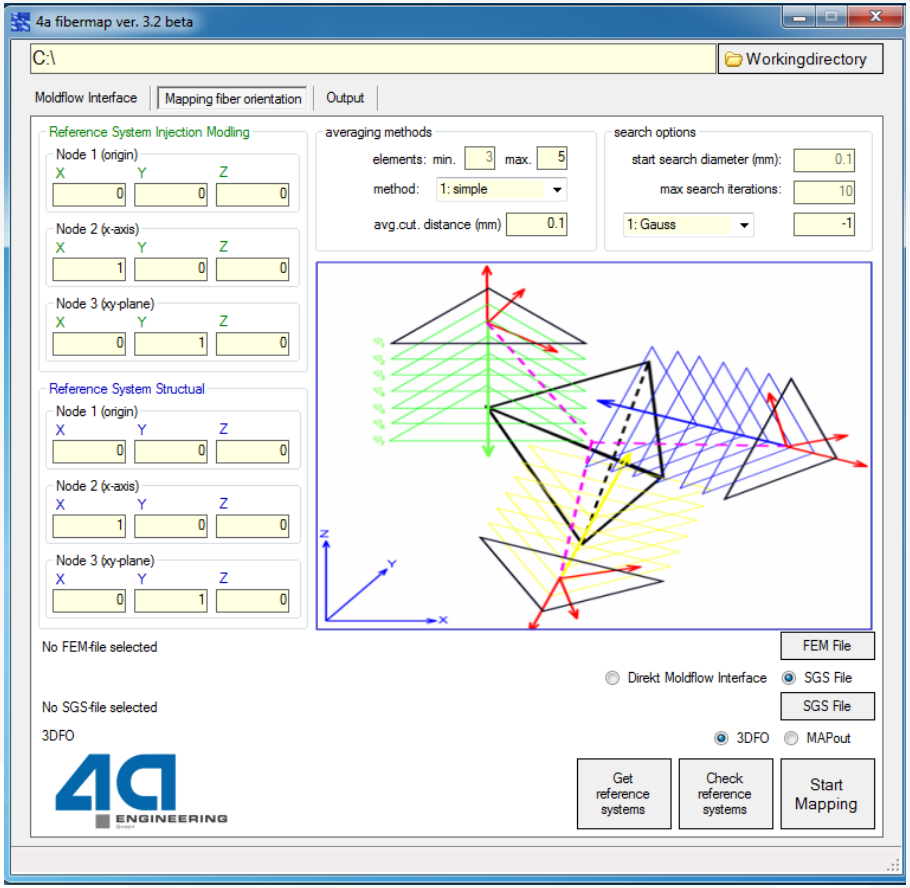
*MAT_(ANISO)TROPIC_ELASTIC

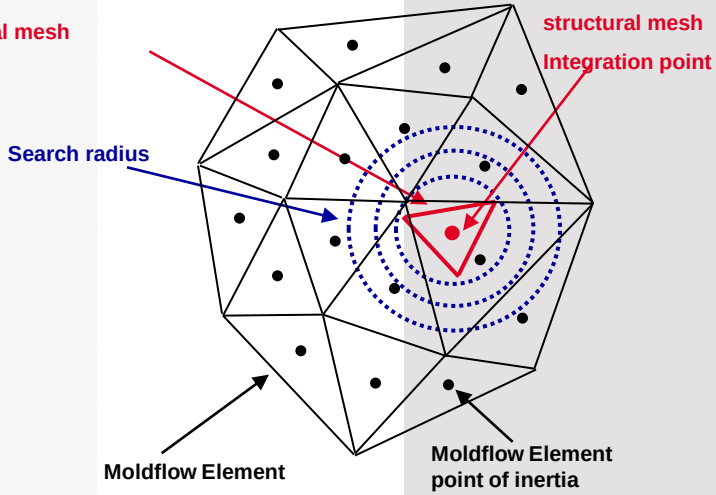
*MAT_ANISOTROPIC_ELASTIC_PLASTIC

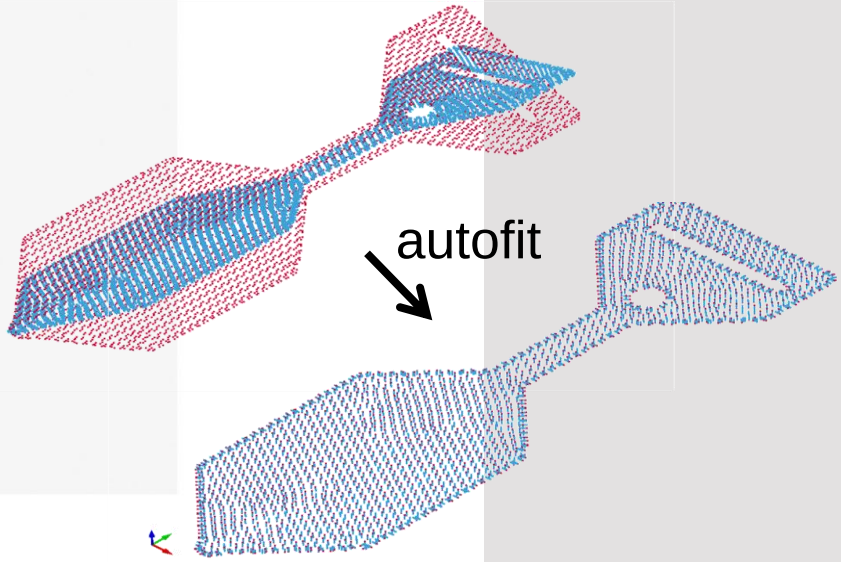


Simulation process chain

4a fibermap - mapping



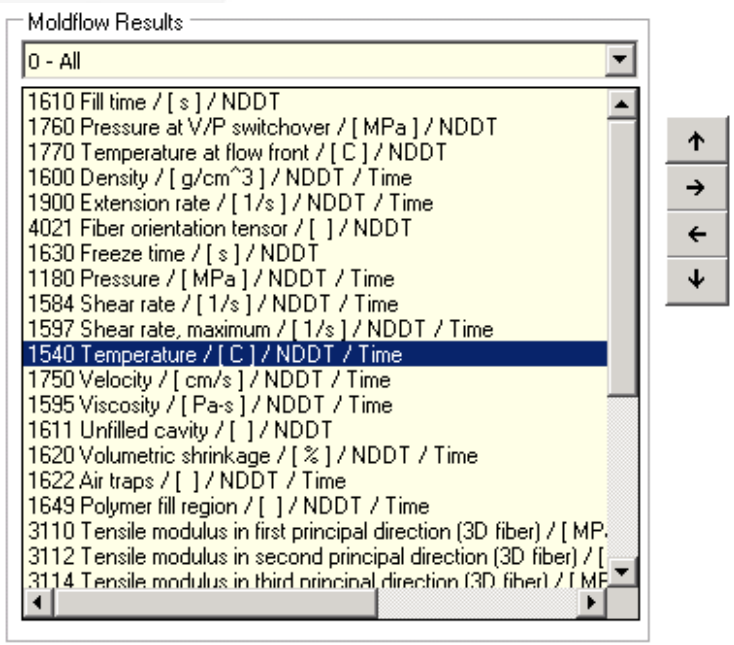


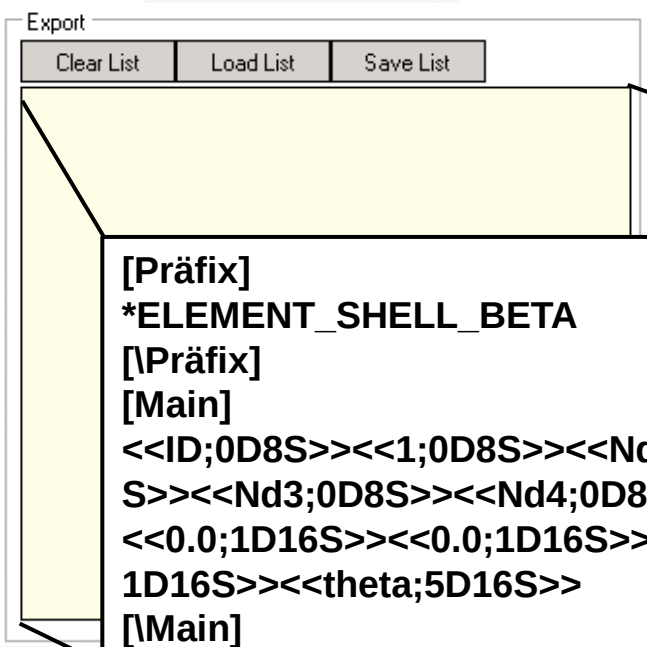


Simulation process chain
4a fibermap – interface

[2012Reithofer]

- Moldex3D®- fiber orientation
- Autodesk Moldflow® - fiber orientation and further results can be mapped





[Präfix]
***ELEMENT_SHELL_BETA**
[\Präfix]
[Main]
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<<0.0;1D16S>><<0.0;1D16S>><<0.0;1D16S>><<0.0;1D16S>><<theta;5D16S>>
[\Main]

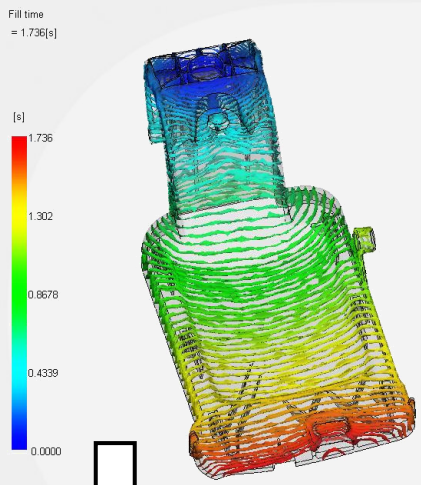
I N P H Y S I C S W E T R U S T

Case study (of Audi AG)
Integrative simulation

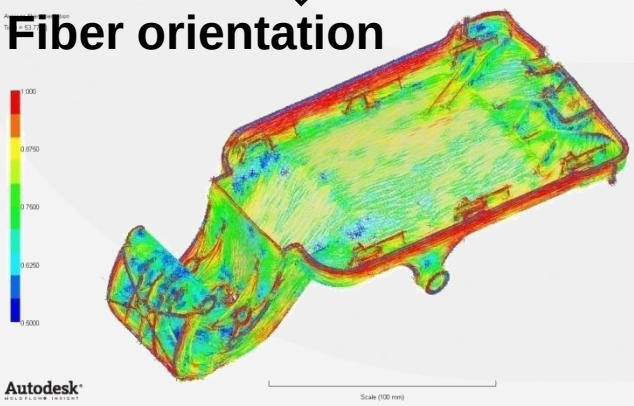
[2012Gramling]

Process simulation

Filling

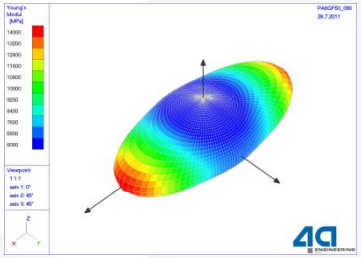


Fiber orientation



Mapping

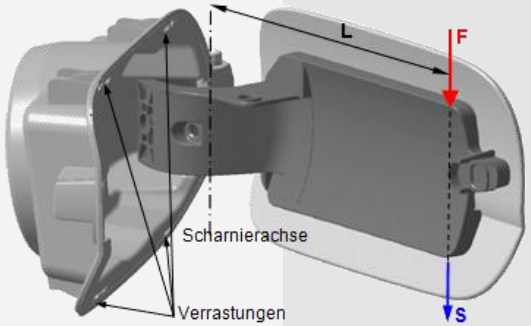
FIBERMAP

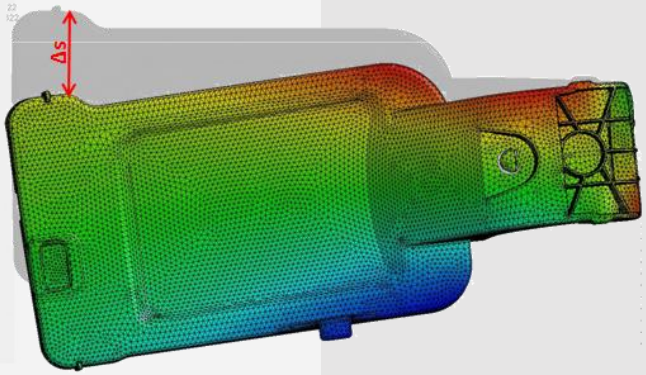


local anisotropy

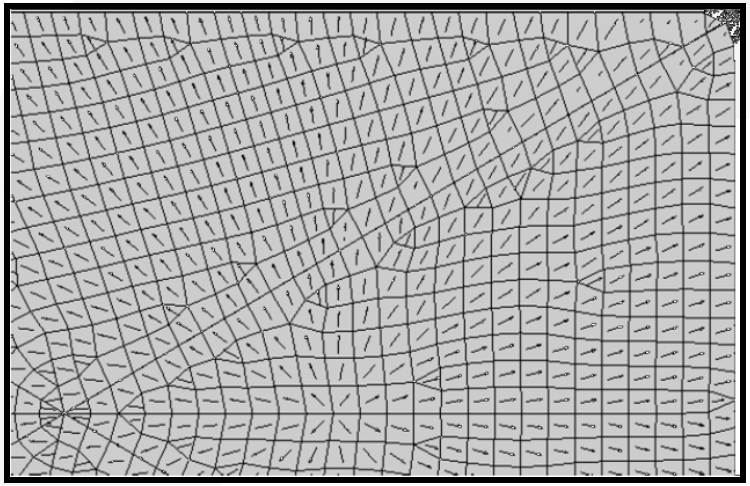
Structual simulation

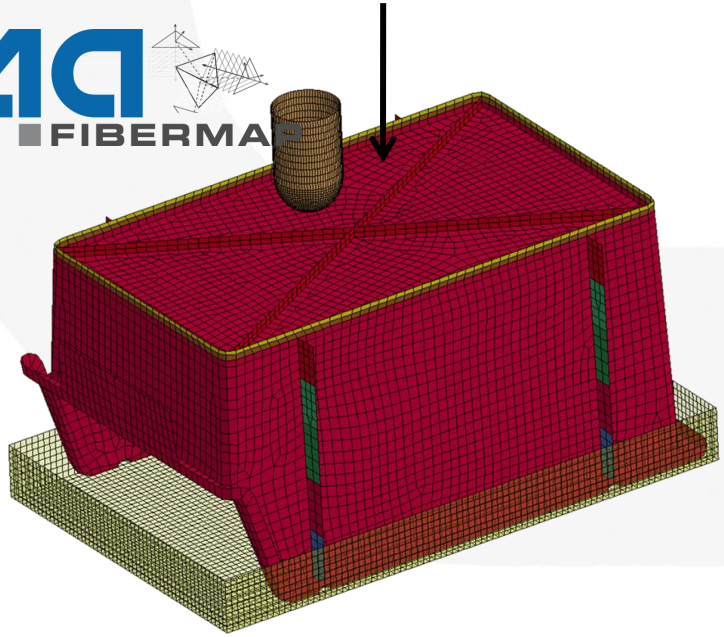
bending



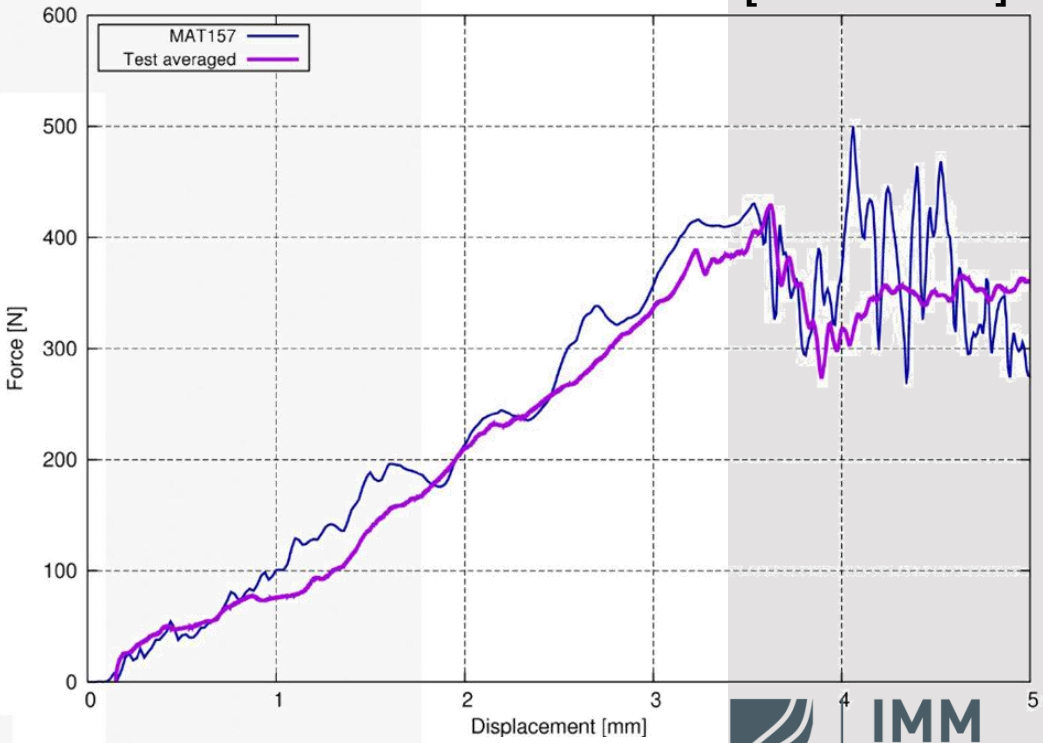


Case study Nutini Box
Using *MAT_157

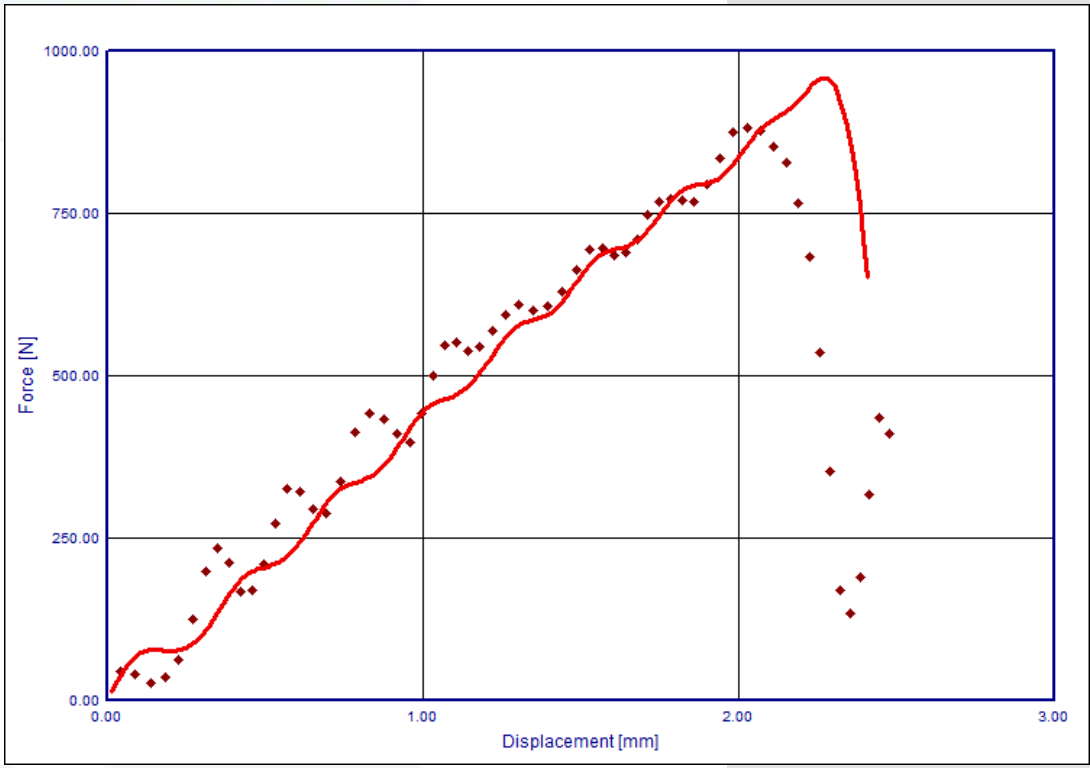




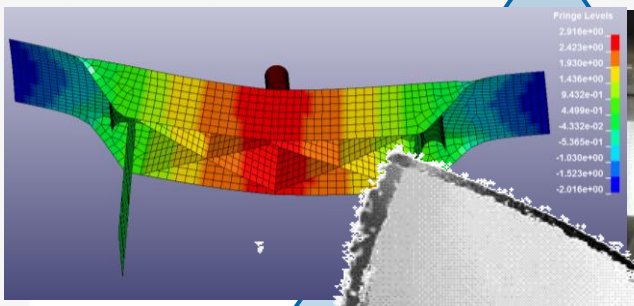
[2014Jennrich]

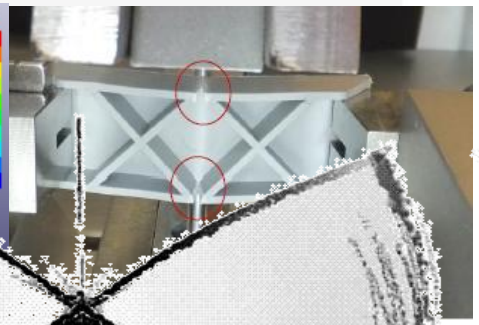


Case study Doublecrossrib
Using *MAT_215



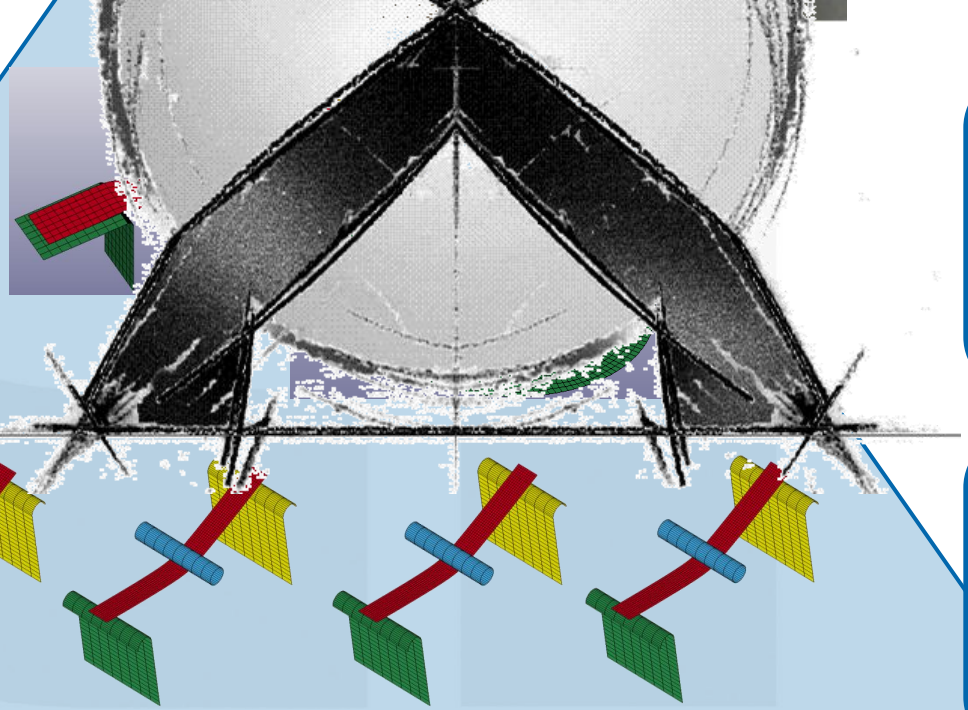
Conclusion characterization pyramid micro mechanic models as key enabler





FIBERMAP

MICROMEC



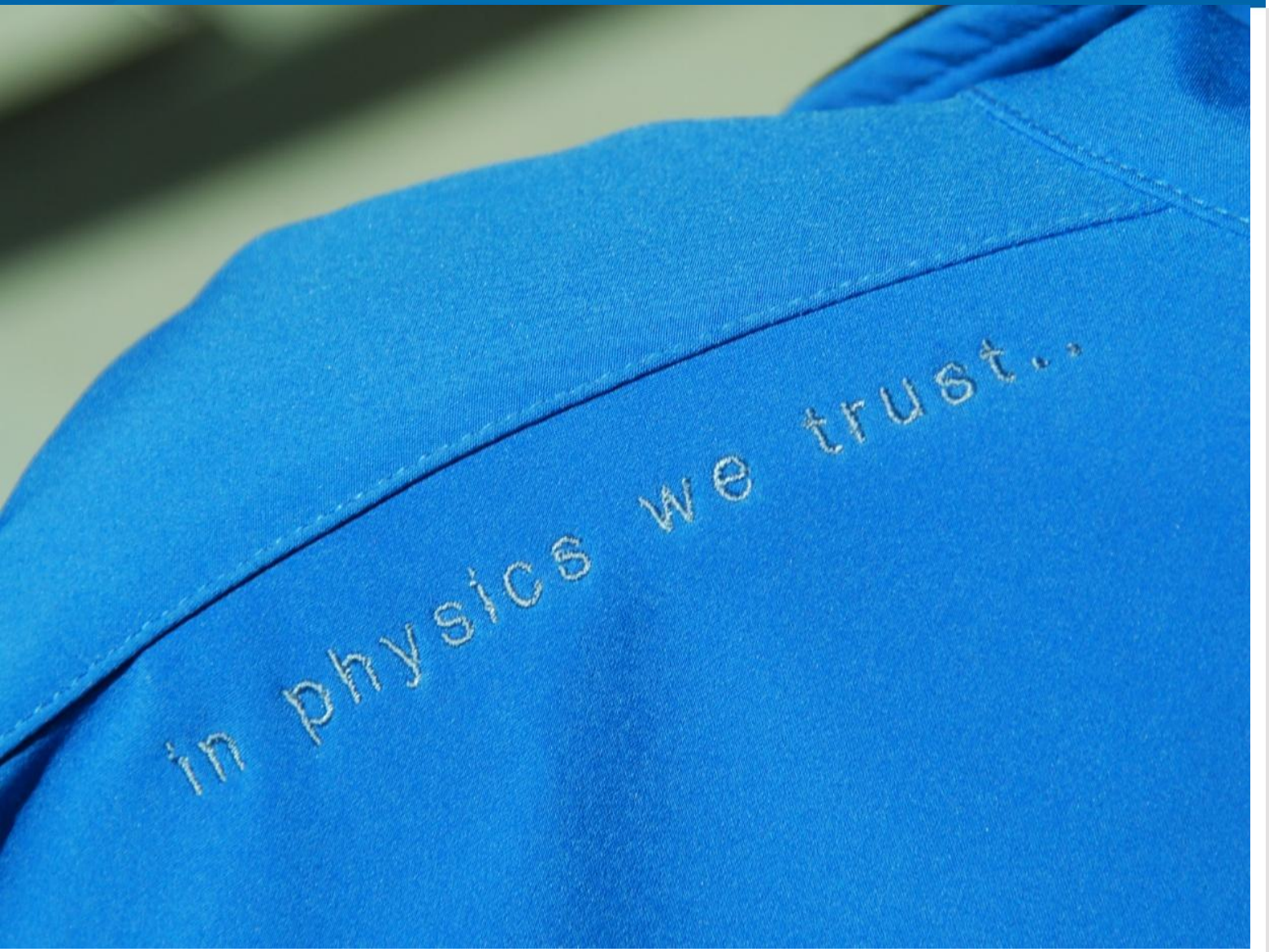
component validation

failure

elasticity
plasticity
strainrate

I N P H Y S I C S W E T R U S T

Thank you for your attention!



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