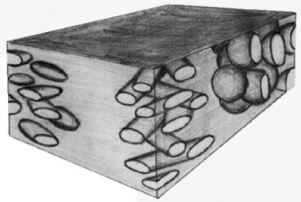


*MAT_4A_MICROMEC
micro mechanic based material model

P. Reithofer[1], A. Erhart[2], A. Fertschej[1], S. Hartmann[2], B. Jilka[1]
[1]4a engineering GmbH, [2]Dynamore GmbH

automotive CAE GRAND CHALLENGE 2017

5. – 6. April 2017, Hanau

4a engineering GmbH
Industriepark 1
A-8772 Traboch
reithofer@4a.co.at
++43 (0) 664 80106 601

Content

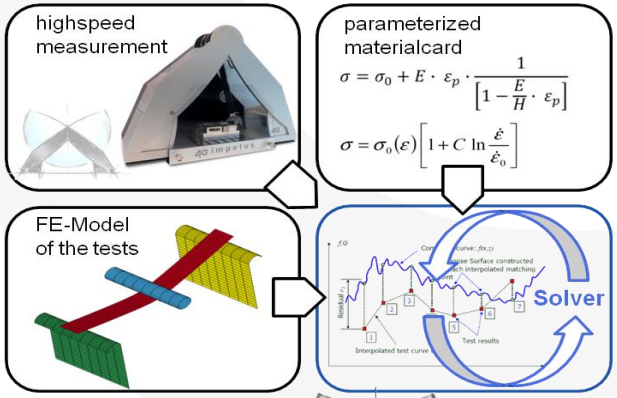
- Introduction
- Simulation process chain
- Constitutive material models in LS-DYNA
- **`*MAT_215 - *MAT_4A_MICROMEC`**
  - mean field homogenization
  - Keyword format
  - verification
  - validation
  - CPU time
  - Case studie
- Conclusion

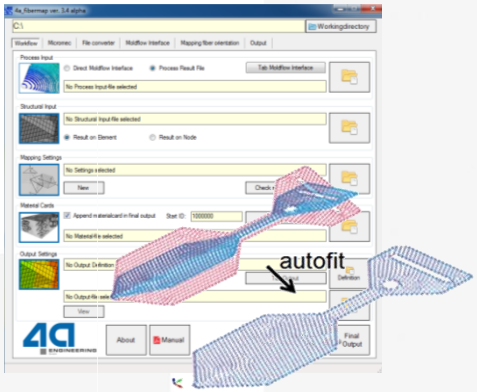
Introduction
4a engineering GmbH

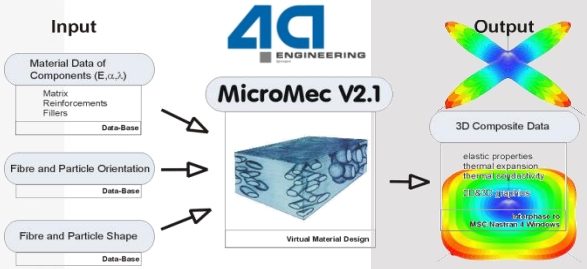
- polymer and materials science
- numerical simulation methods
- fiber reinforced plastics and composites
- method and software development
- material characterization
- product development

strut bar:

LH_2 – tank mounting:

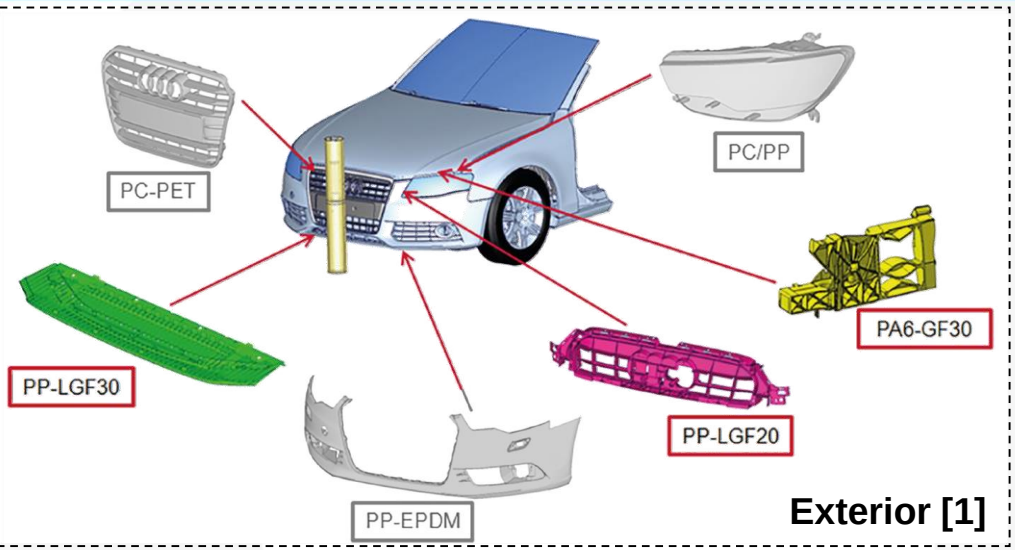




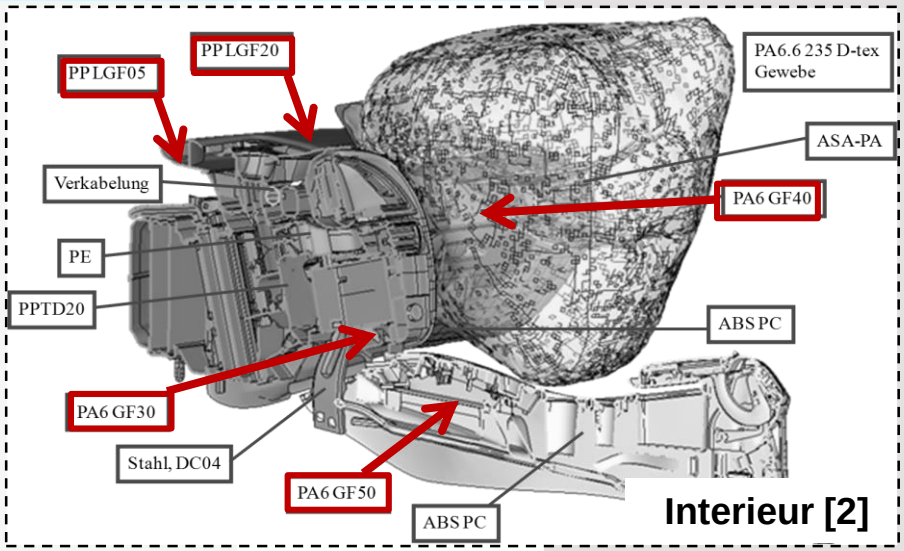


IMPETUS FIBERMAP MICROMEC

Introduction
plastics in typical automotive applications



Exterior [1]

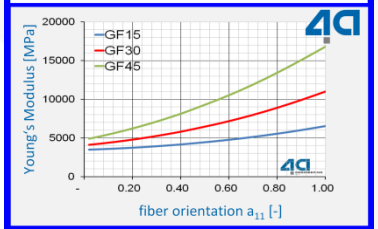


Interieur [2]

H1

PA6GF30

polyamide short glass fiber reinforced

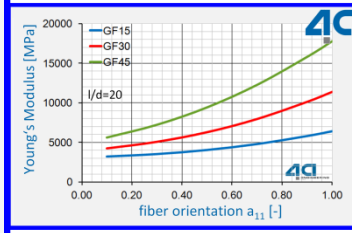


P: 3.4 €/kg	ρ: 1.4 g/cm³
E_1: 9700 MPa	α_l: 64·10⁻⁶ 1/K
σ_y: 140 MPa	ε_B: 4%
T_G: 50 °C	a_c: 100(15) kJ/m²

H2

PBTGF30

polybutylene terephthalate short glass fiber reinforced

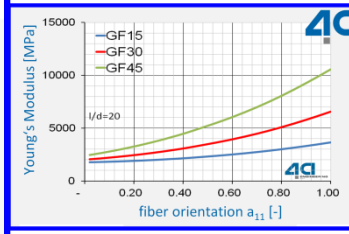


P: 3 €/kg	ρ: 1.5 g/cm³
E_1: 9500 MPa	α_l: 25·10⁻⁶ 1/K
σ_y: 92 MPa	ε_B: 3%
T_G: 30 °C	a_c: 67(11) kJ/m²

H3

PPGF30

polypropylene short glass fiber reinforced

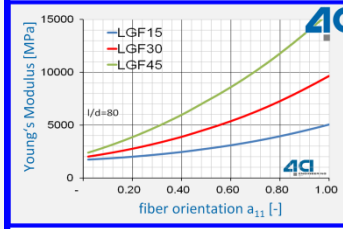


P: 2.3 €/kg	ρ: 1.1 g/cm³
E_1: 6000 MPa	α_l: 38·10⁻⁶ 1/K
σ_y: 70 MPa	ε_B: 4%
T_G: -10 °C	a_c: 20(5) kJ/m²

H4

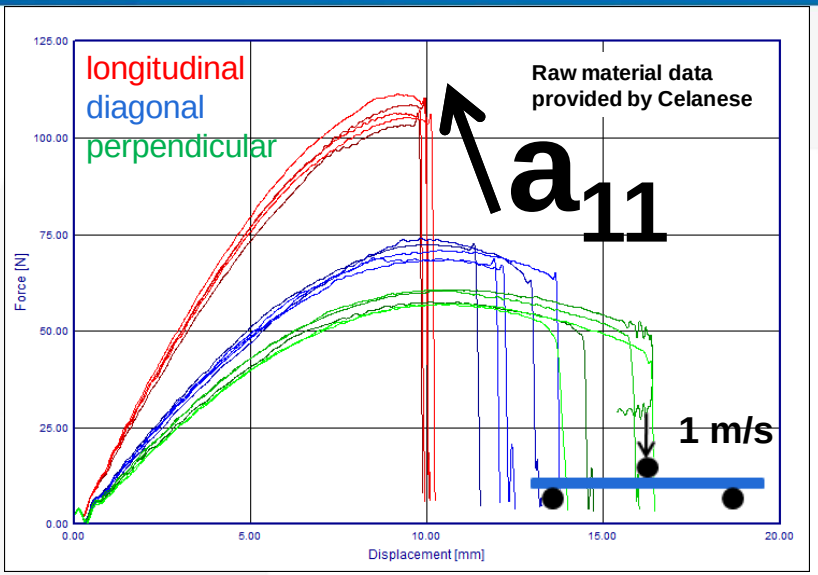
PPLGF30

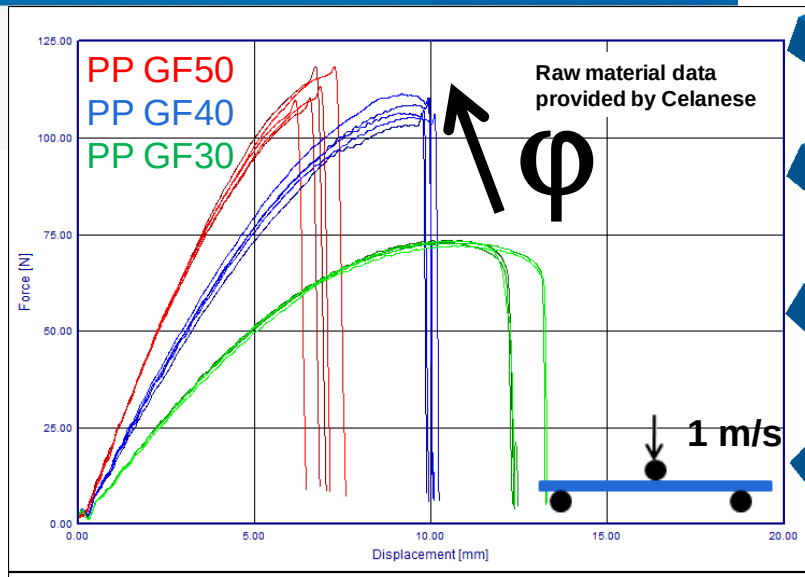
polypropylene long glass fiber reinforced

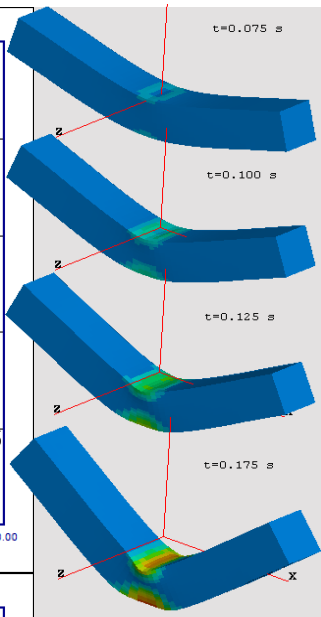


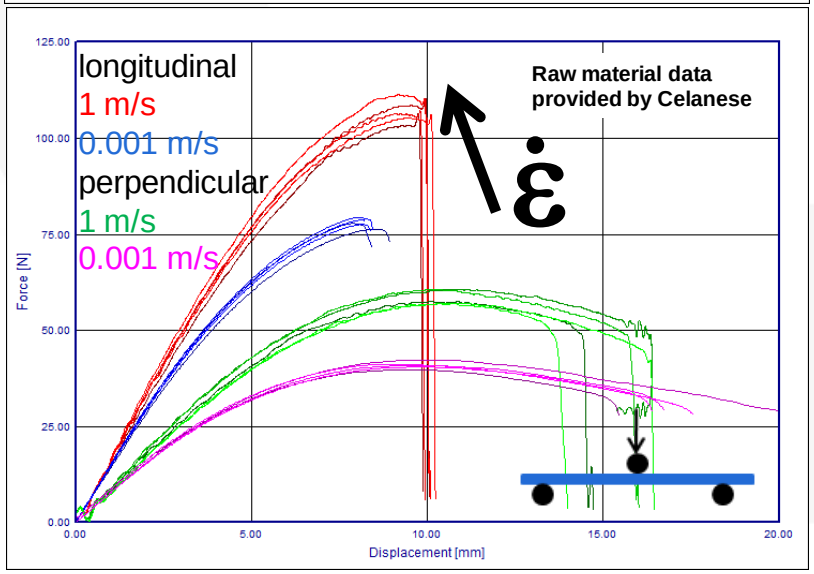
P: 2.5 €/kg	ρ: 1.1 g/cm³
E_1: 6900 MPa	α_l: 40·10⁻⁶ 1/K
σ_y: 76 MPa	ε_B: 5%
T_G: -10 °C	a_c: 70(18) kJ/m²

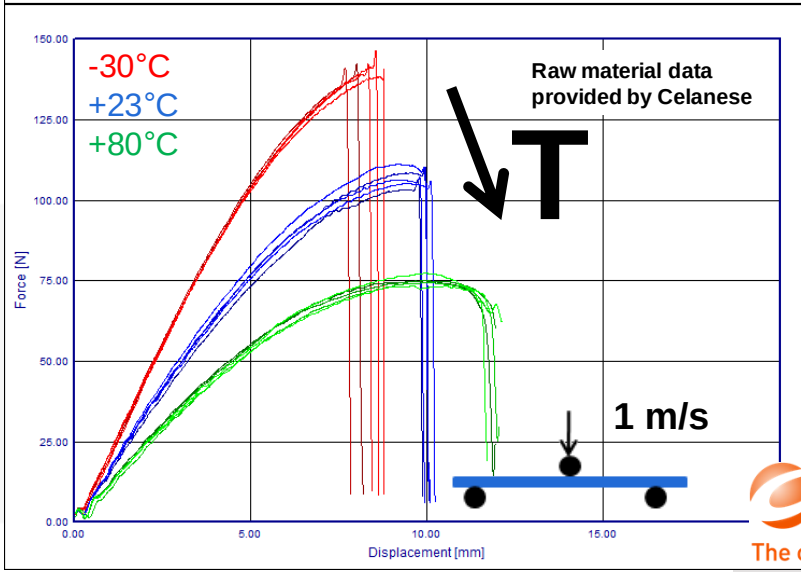
Introduction
typical behavior – bending test







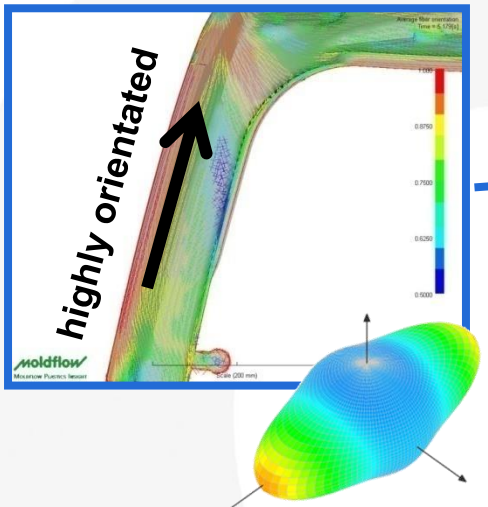




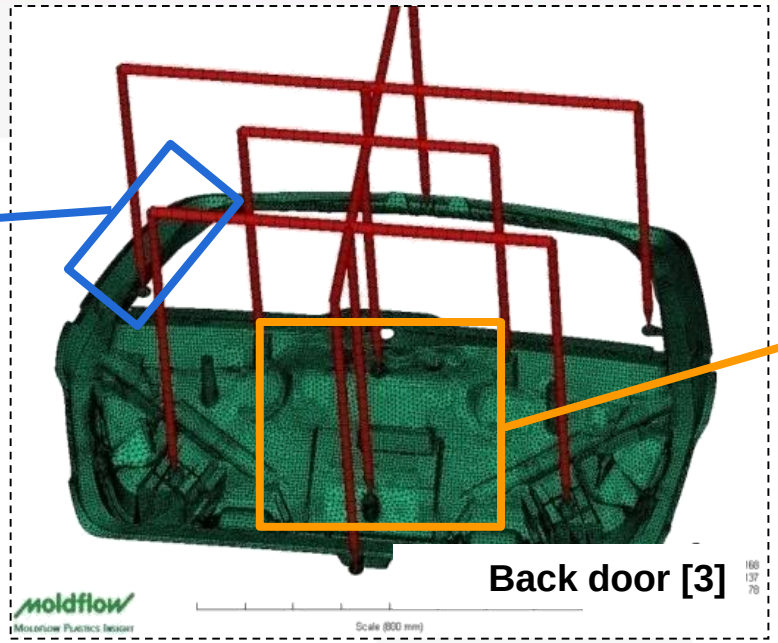
IMPETUS

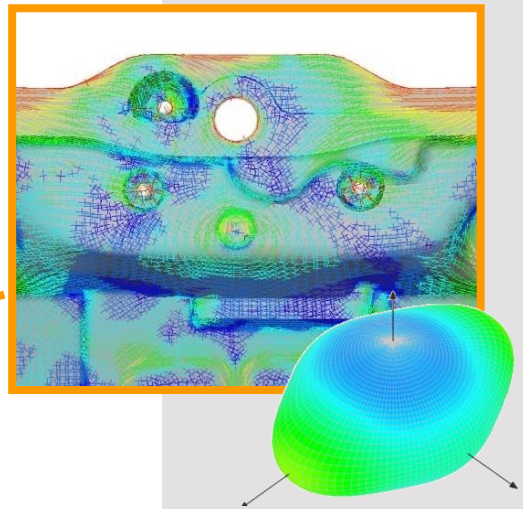
Celanese
The chemistry inside innovation™

Introduction
typical SFRT

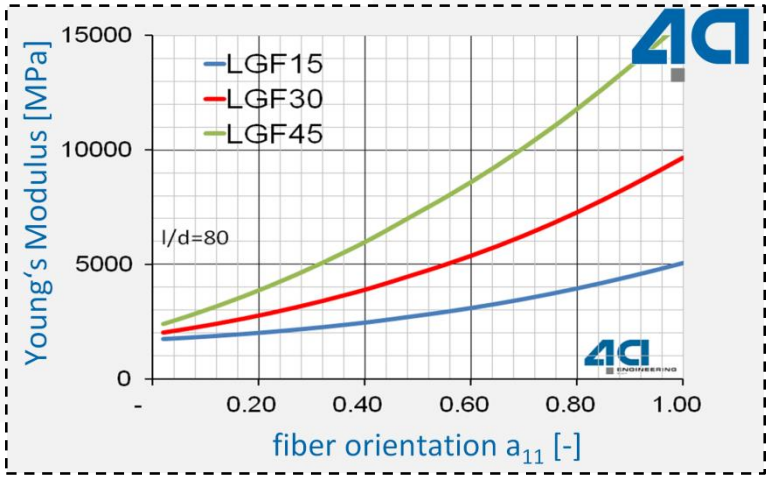


$$a_{ij} = \begin{bmatrix} 0{,}87 & 0 & 0 \\ 0 & 0{,}11 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$



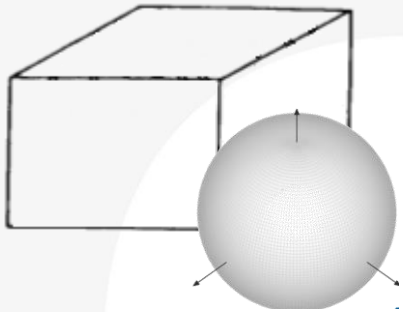


$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

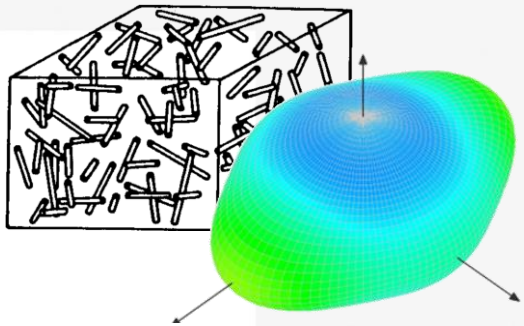


Material models in LS-DYNA
constitutive approach

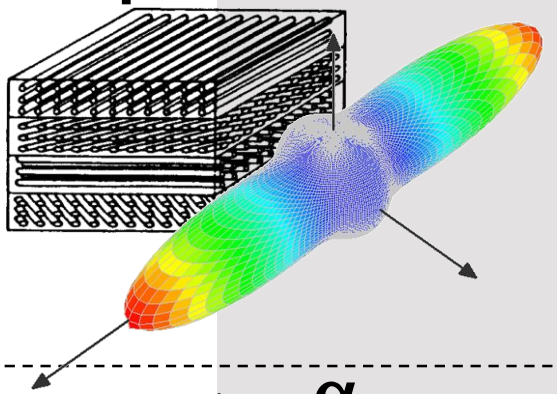
Plastics



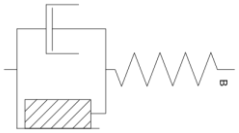
SFRT / LFRT



Composite

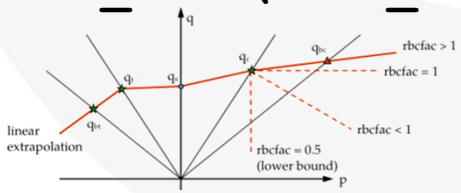


***MAT_024**



- quick & dirty
- Mises plasticity

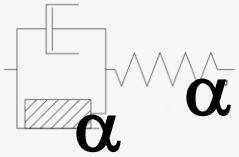
***MAT_187 (*MAT_124)**



***MAT_002**

- orthotropic elastic

***MAT_157**



- orthotropic
- elastic viscoplastic
- Hill plasticity

***MAT_022/**

***MAT_054/058**

- orthotropic elastic
- Damage

SHELL or TET10

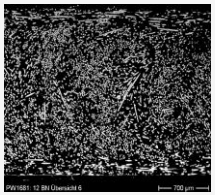
INITIAL_STRESS

COMPOSITE (PLY)

α – orientation dependent

Simulation process chain
For injection molded parts

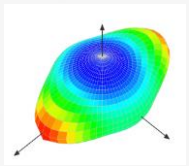
Injection molding (Moldflow, Moldex, ...)



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

fiber orientation

micromechanic modeling (4a micromec, ...)

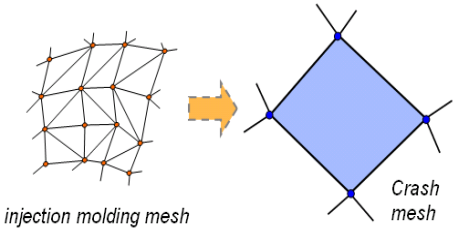


$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ & & C_{33} & C_{34} & C_{35} & C_{36} \\ & & & C_{44} & C_{45} & C_{46} \\ & & & & C_{55} & C_{56} \\ & & & & & C_{66} \end{bmatrix}$$

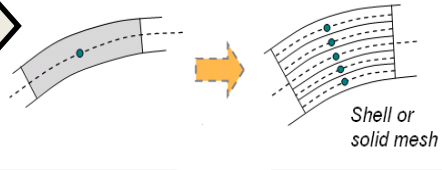
anisotropy

Mapping (4a fibermap, ...)

In plane mapping



Mapping in thickness direction



Material Model

Mean Field homogenization

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

*MAT_215

Standard Material Model

Hill Plasticity

*MAT_157

Structural Simulation

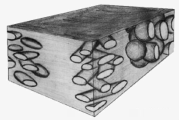
MICROMEC

FIBERMAP

LSTC Livermore Software Technology Corp.

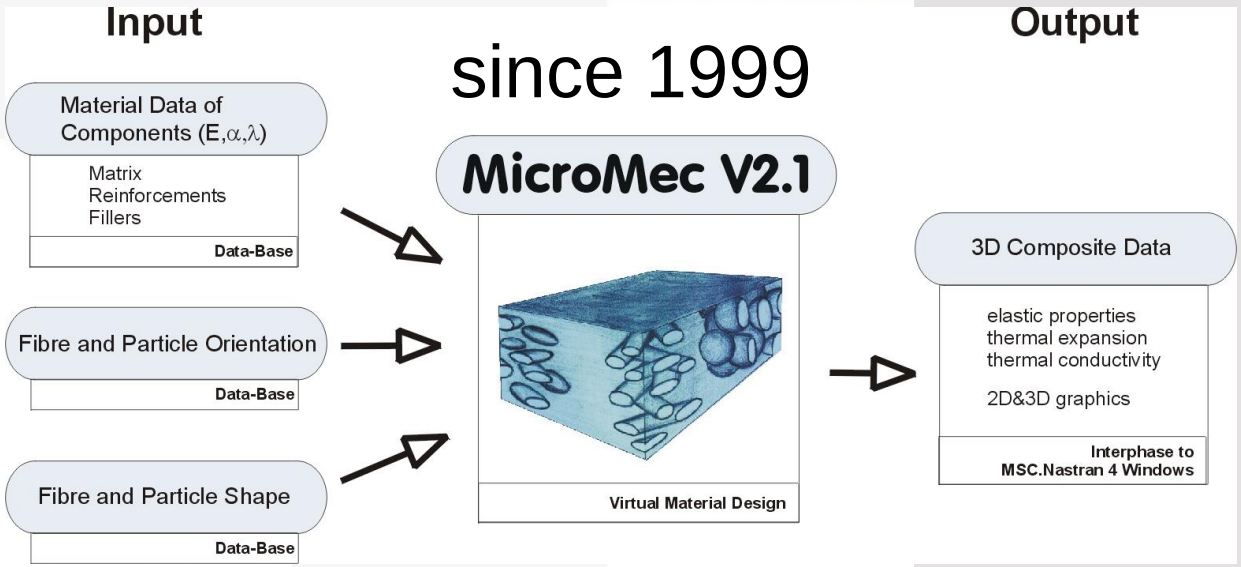
LS-DYNA®

*MAT_215 - *MAT_4A_MICROMEC
mean field homogenization



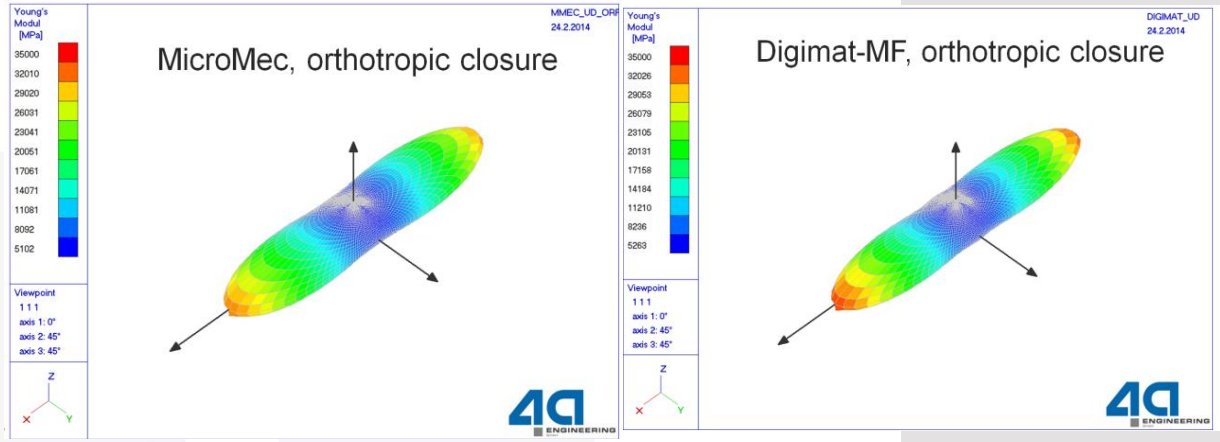
MICROMEC

Standalone product



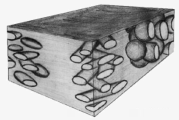
$$\bar{\sigma}^{C} = \varphi\bar{\sigma}^{F} + (1-\varphi)\bar{\sigma}^{M}$$

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



Comparison by University of Leoben **[4]**

*MAT_215 - *MAT_4A_MICROMEC
mean field homogenization



Standalone product

Library

***MAT_157**

calculate parameter for constitutive law

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

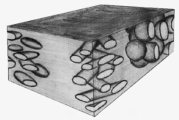
C...composite, F...fiber, M...matrix

160223_006 | Material | Designvariablen | Layers

Strain rate dependency	Table
Strain rate dependency	Johnson Cook
Micromec	User defined
Matrix	
Density of the matrix	900
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_215 - *MAT_4A_MICROMEC
mean field homogenization



Standalone product

Library → 4a impetus

usermaterial

Main Framework
Mori Tanaka Mean Field Theory

Composite stresses, strains (i)

↓

Matrix stresses, strains

↓

Fiber stresses, strains

↓

Failure, Damage Criteria

↓

Composite stresses, strains (i+1)

plug able
possible extensions other plasticity formulations, ...

→ **Yield condition**

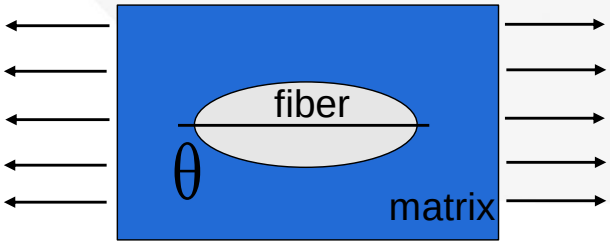
→ J2 Plasticity
Isotropic Harding

Table Lookup or Parameter Setup

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

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

assumption elliptical inclusion
(Eshelby Tensor)



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

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

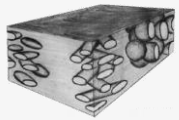
$$\Delta\varepsilon^{M} \Rightarrow E_M^T, \Delta\varepsilon^{M}{}_{pl}, \Delta\sigma^{M}$$

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

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

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

*MAT_215 - *MAT_4A_MICROMEC
mean field homogenization



MICROMEC

Standalone product

Library → 4a impetus

usermaterial

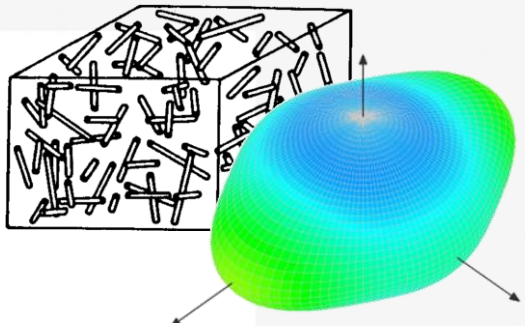
***MAT_4A_MICROMEC**

LSTC Livermore Software Technology Corp.

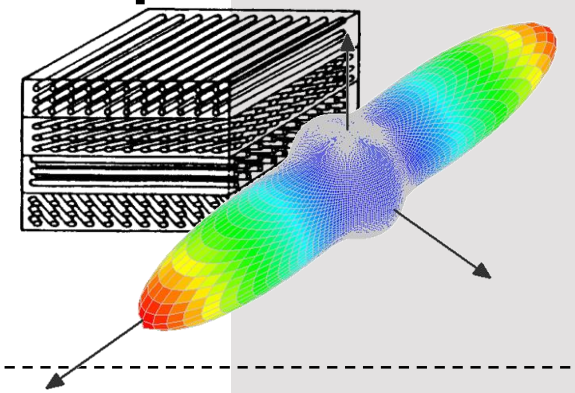
LS-DYNA®

DYNA MORE

SFRT / LFRT

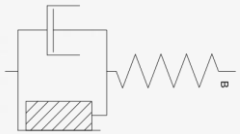


Composite



***MAT_215**

matrix:



- isotropic elastic viscoplastic (like ***MAT_024**)

fiber:

- isotropic elastic

***MAT_215**

matrix:

- isotropic elastic

fiber:

- transversal isotropic elastic

INITIAL_STRESS

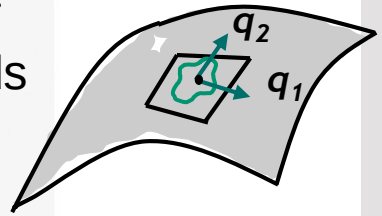
COMPOSITE (PLY)

*MAT_215 - *MAT_4A_MICROMEC
Keyword format

CARD 1: General Options / Parameter

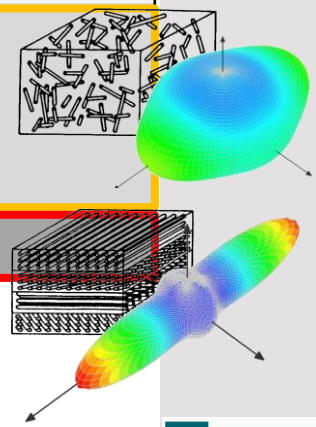
CARD 2-3: Element orientation*

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`

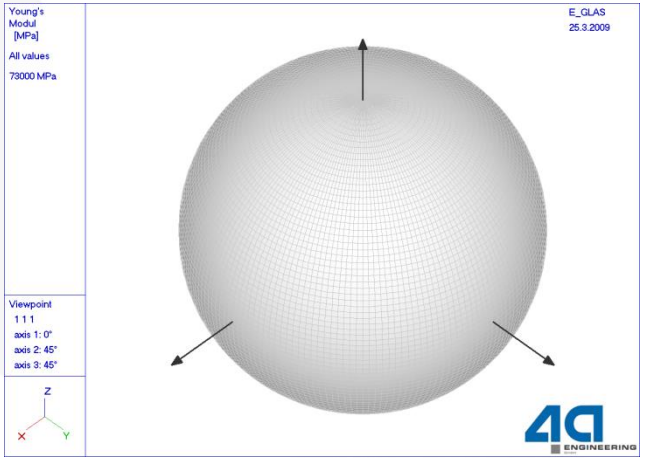
exemplary values without any warranty

CARD 5: fiber material

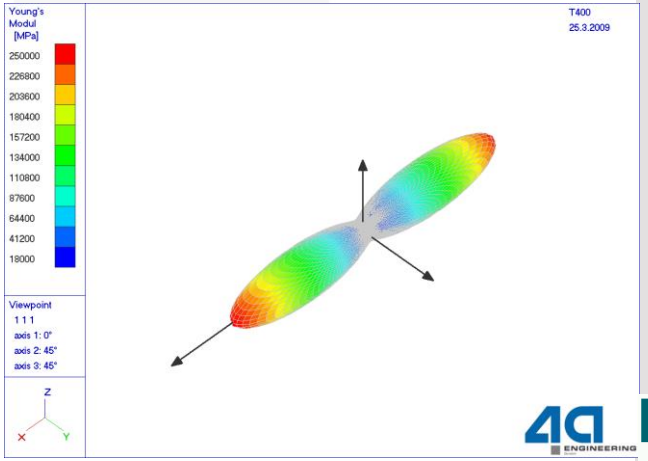
Standard values from literature

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

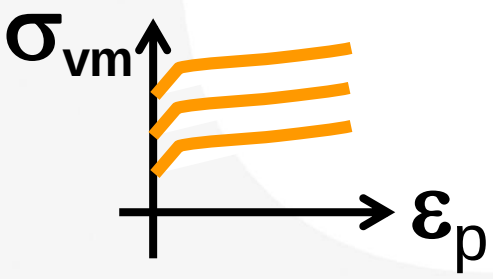
exemplary values without any warranty

CARD 9: matrix material tables

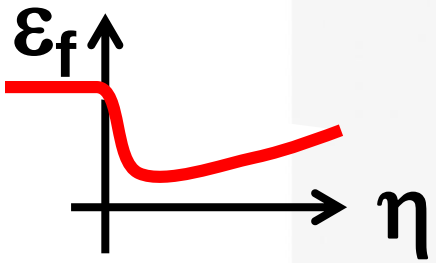
Card 9	1	2	3	4	5	6	7	8
Variable	LCIDT				LCDI	UPF		
Type	F				F	F		
Default	0				0	0.0		

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

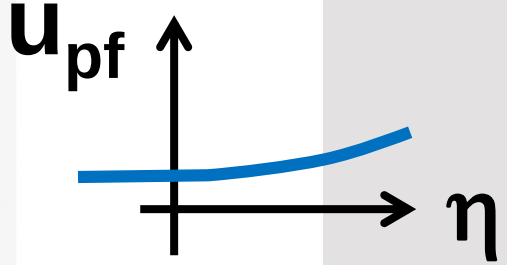
Hardening



Damage Initiation

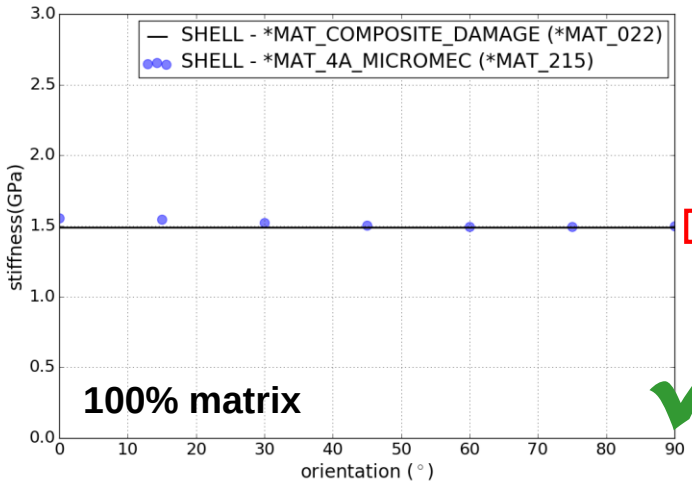


Damage Evolution

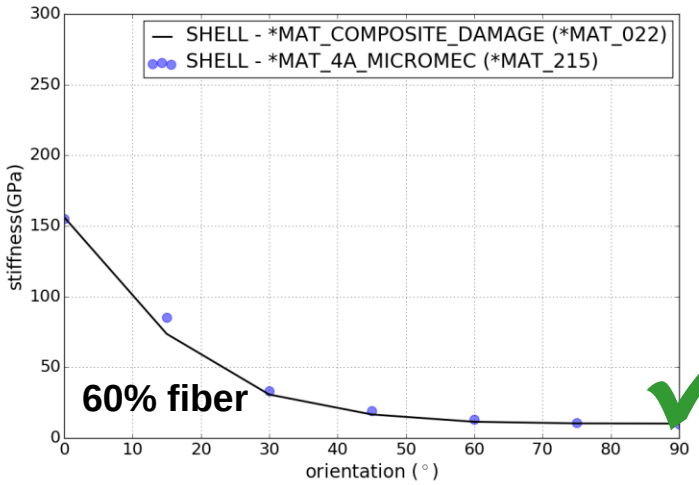


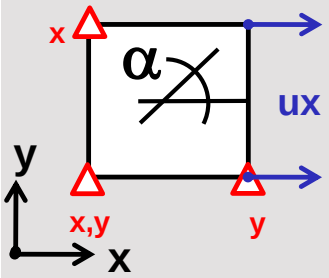
*MAT_215 - *MAT_4A_MICROMEC
Verification – 1-Element tension test

PP

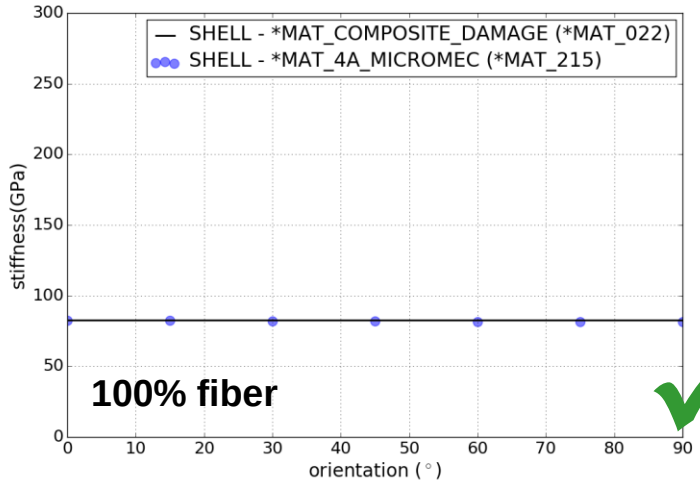


PP CFK 60vol%

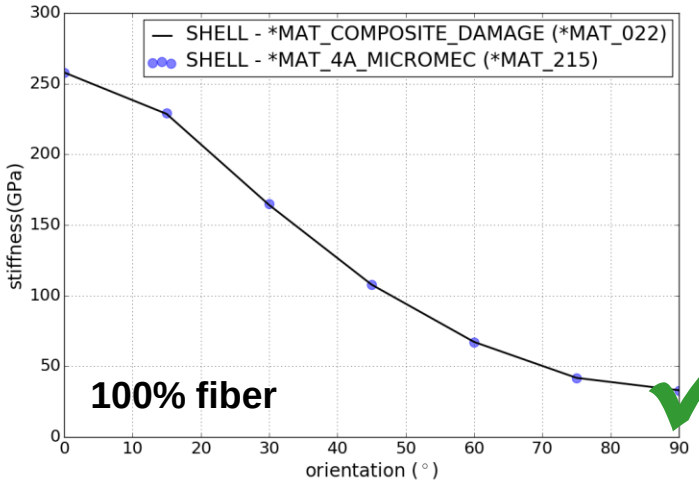




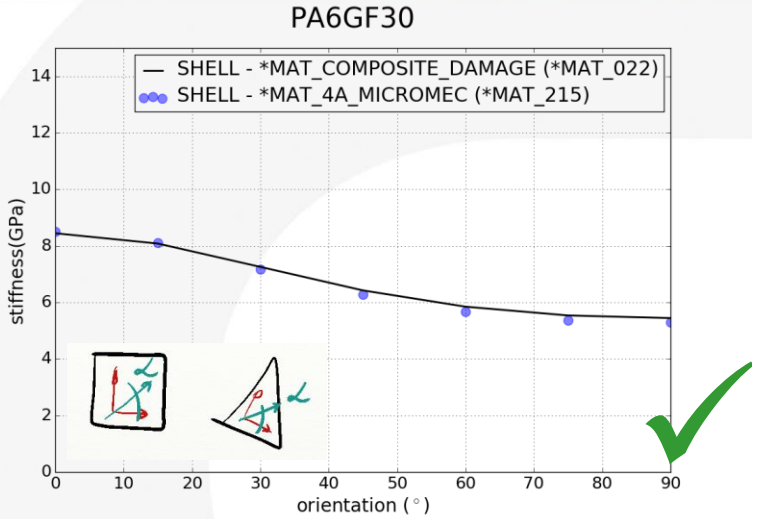
GLASS

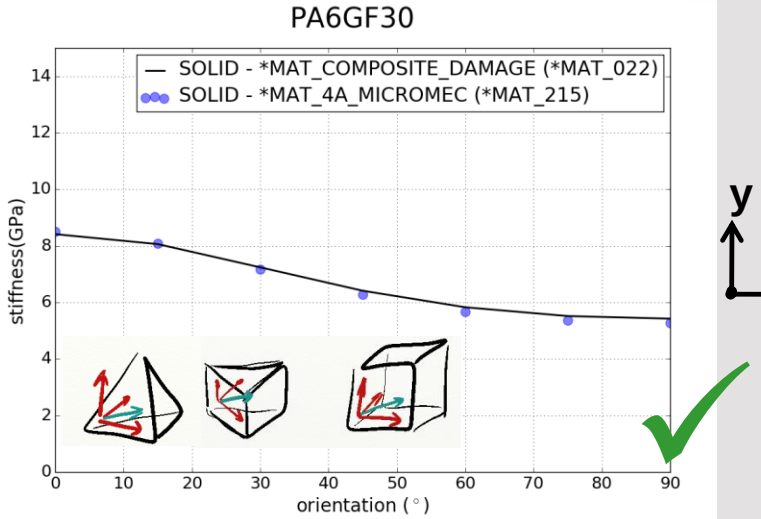


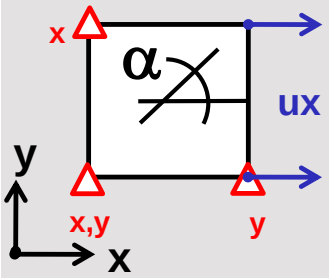
T300

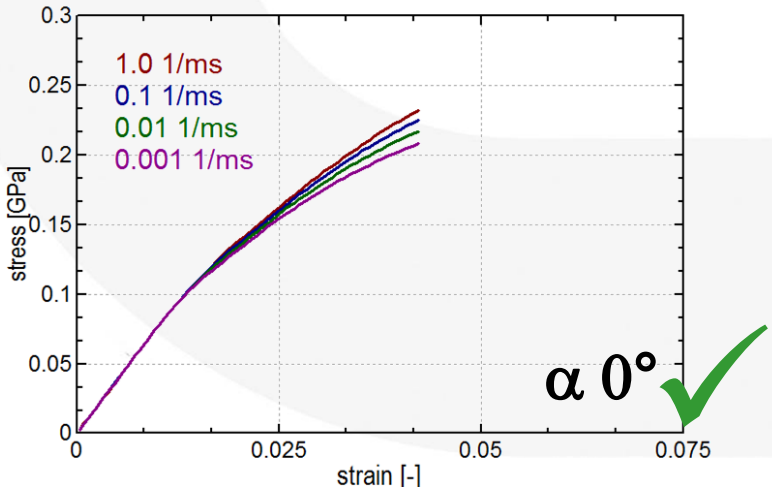


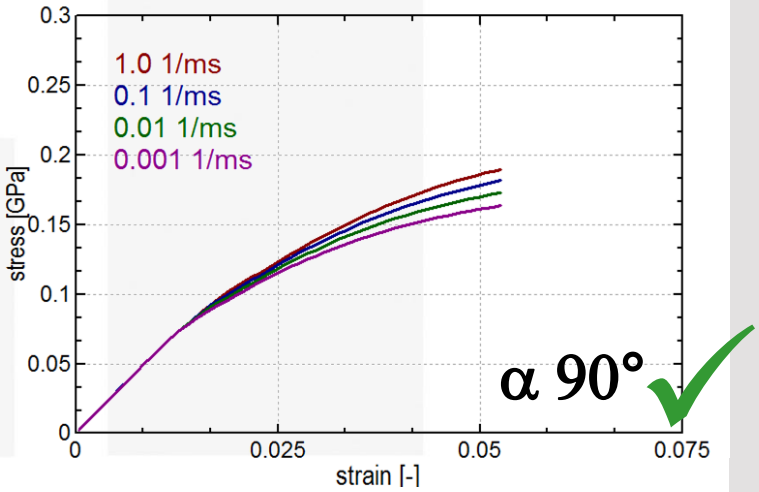
*MAT_215 - *MAT_4A_MICROMEC
Verification – 1-Element tension test



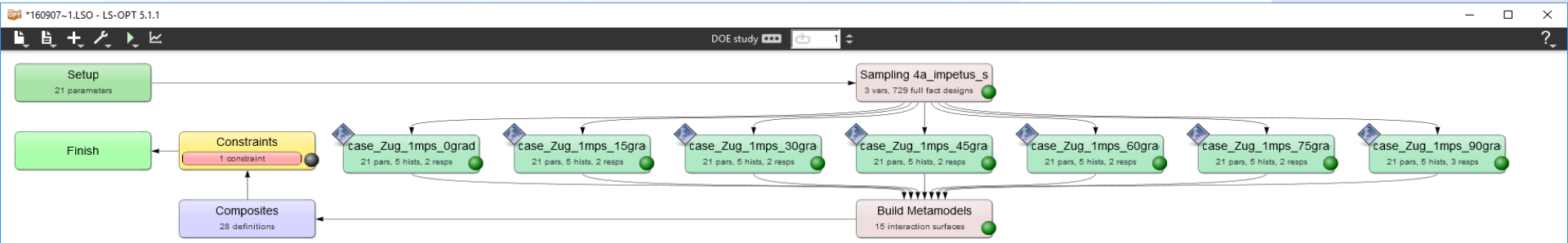








*MAT_215 - *MAT_4A_MICROMEC
Verification – 1-Element tension test



DOE with LS-OPT:

MATRIX: PP

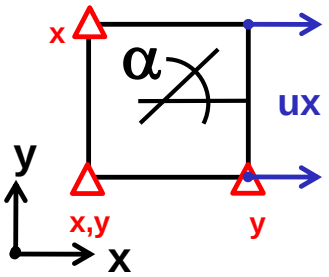
FIBER: GLASS

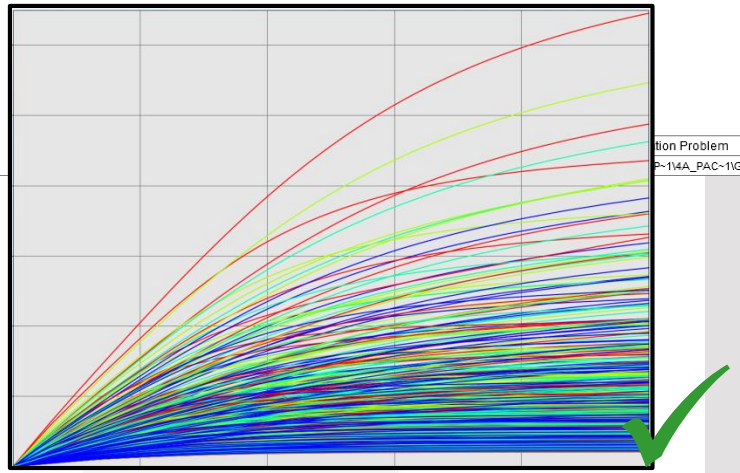
FVF: -0.05;-0.15;-0.20;-0.25;-0.30;-0.35;-0.40;-0.50;-0.60

FL: 100;200;500;1000

A11: 0.6;0.7;0.8;0.9

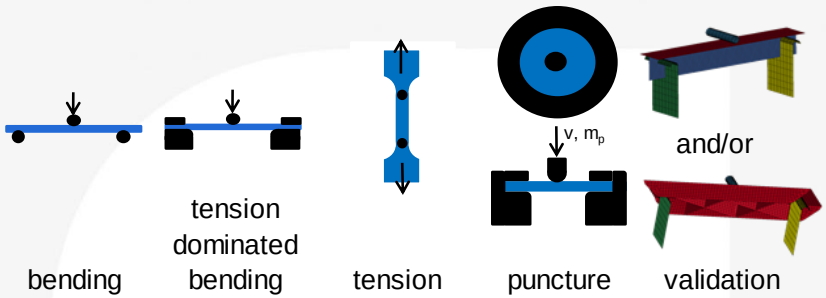
α: 0°;15°;30°;45°;60°;75°;90°

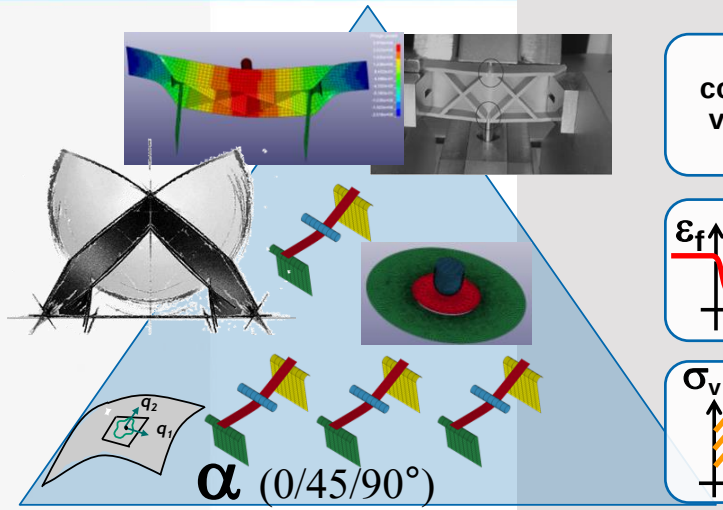




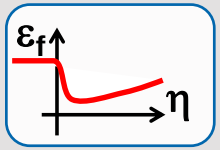
RUNS without an Error

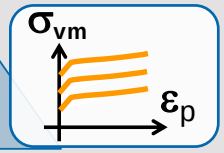
*MAT_215 - *MAT_4A_MICROMEC
Material characterization





component validation

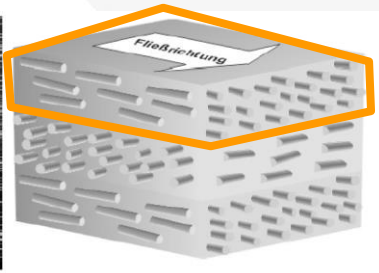


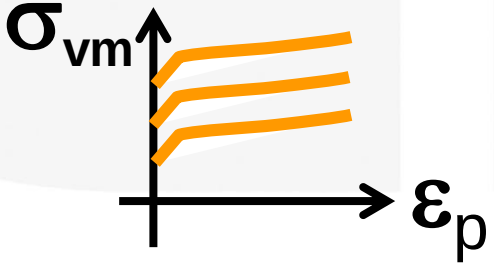


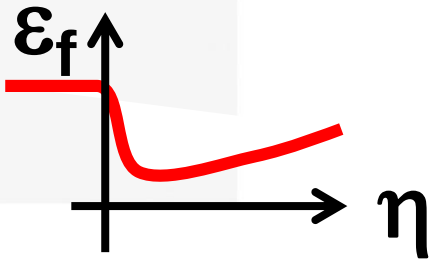
	static	dynamic	dynamic	static	dynamic	static	dynamic	static	dynamic	comment
*MAT_024	☑	☑								Materialcard for each direction
*MAT_157 *MAT_215	☑	☑		☑	☑		☑	☑	☑	☑	µCT

Upcoming ISO
Plate 120 x 80 x 2 mm

injected samples

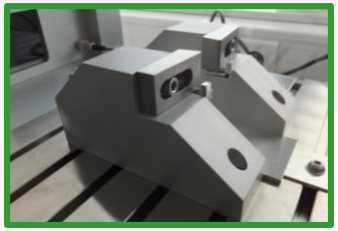


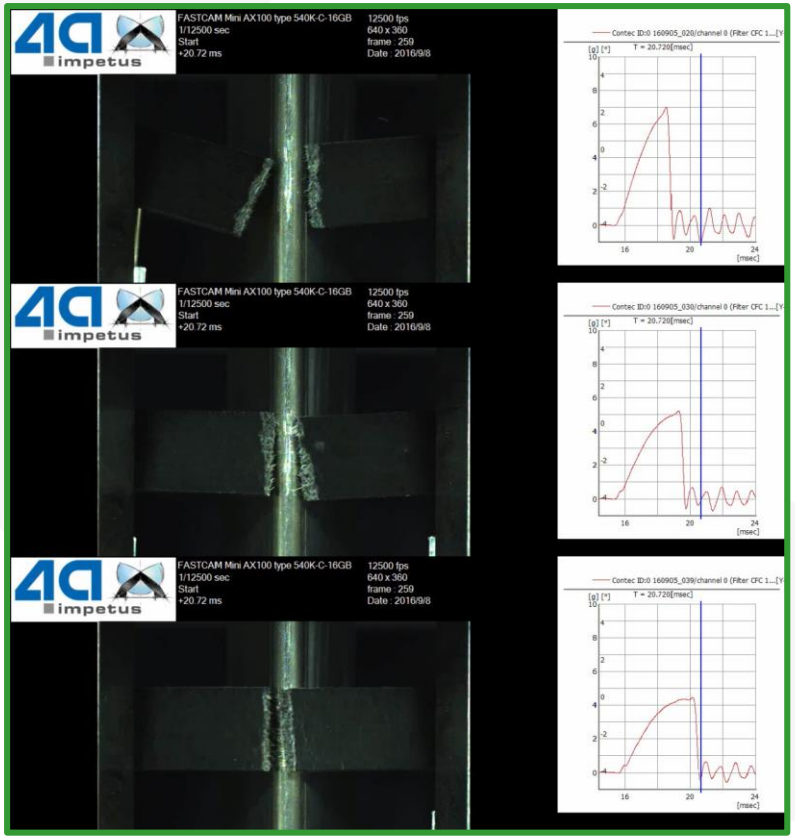


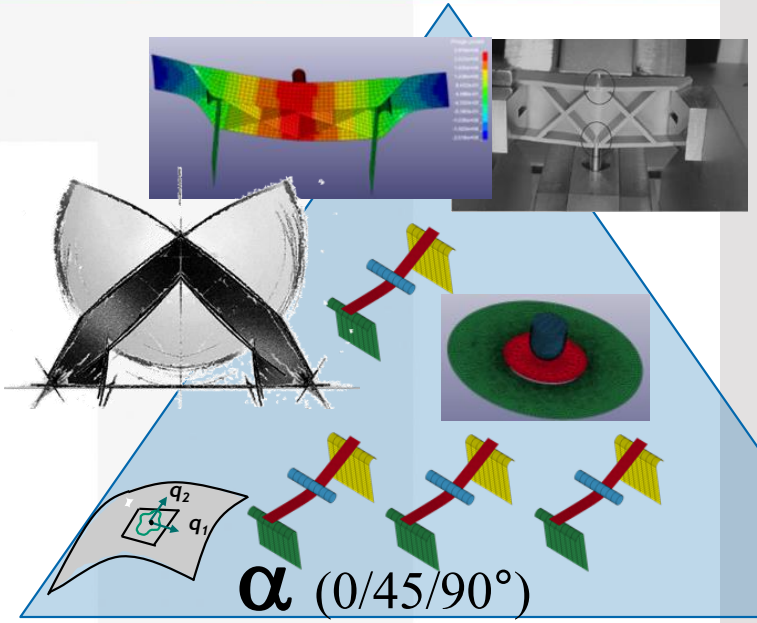


*MAT_215 - *MAT_4A_MICROMEC
Material characterization

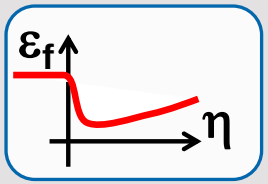
Bending

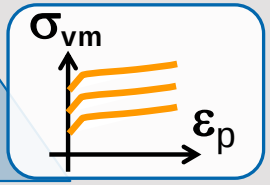


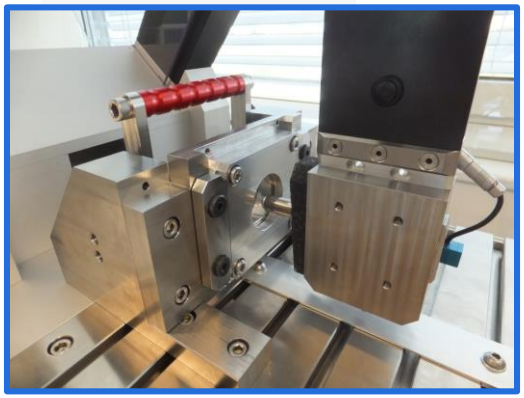


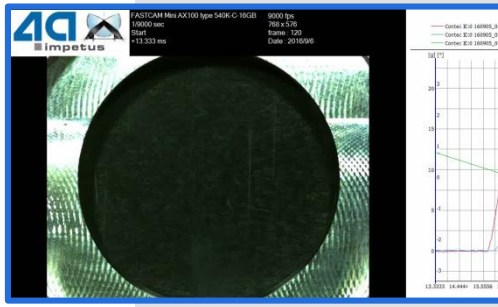


component validation



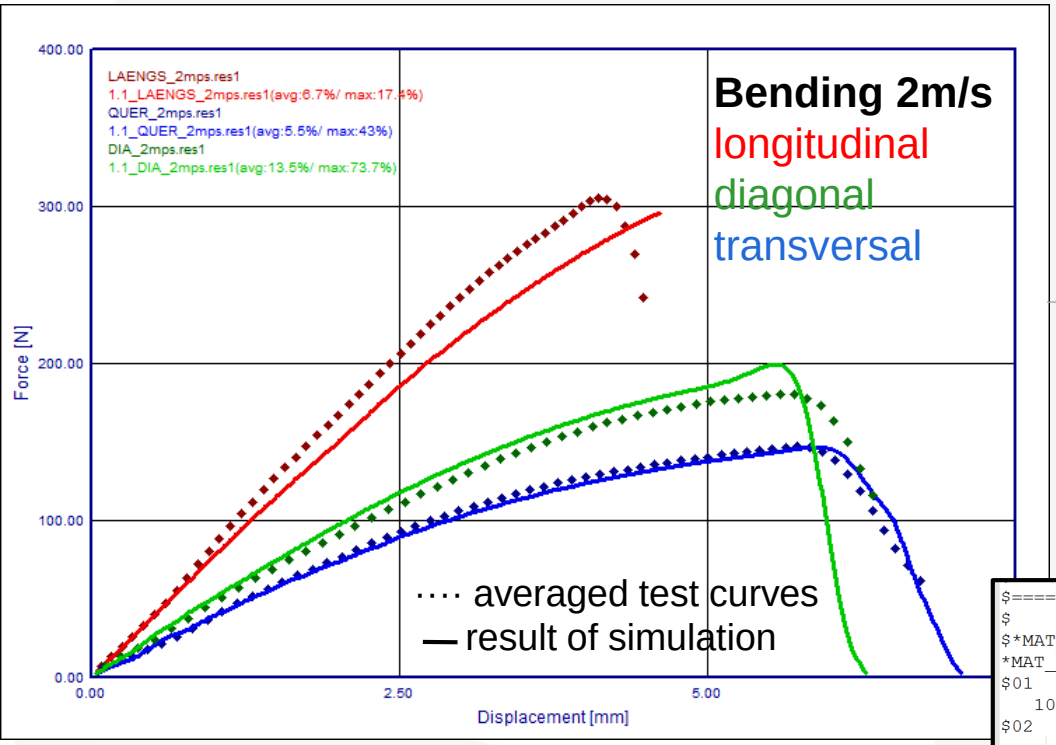


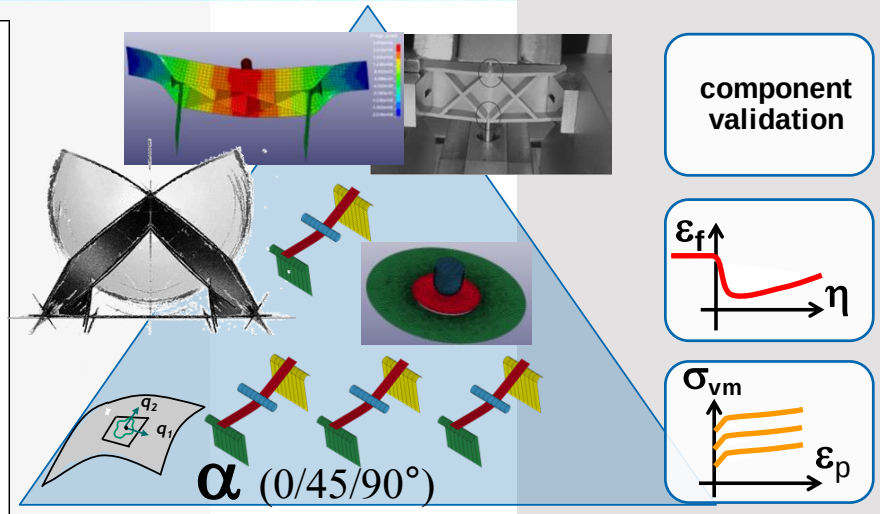




Puncture

*MAT_215 - *MAT_4A_MICROMEC
Material characterization



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$
$*MAT_215
*MAT_4A_MICROMEC
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   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
$=========================================================================
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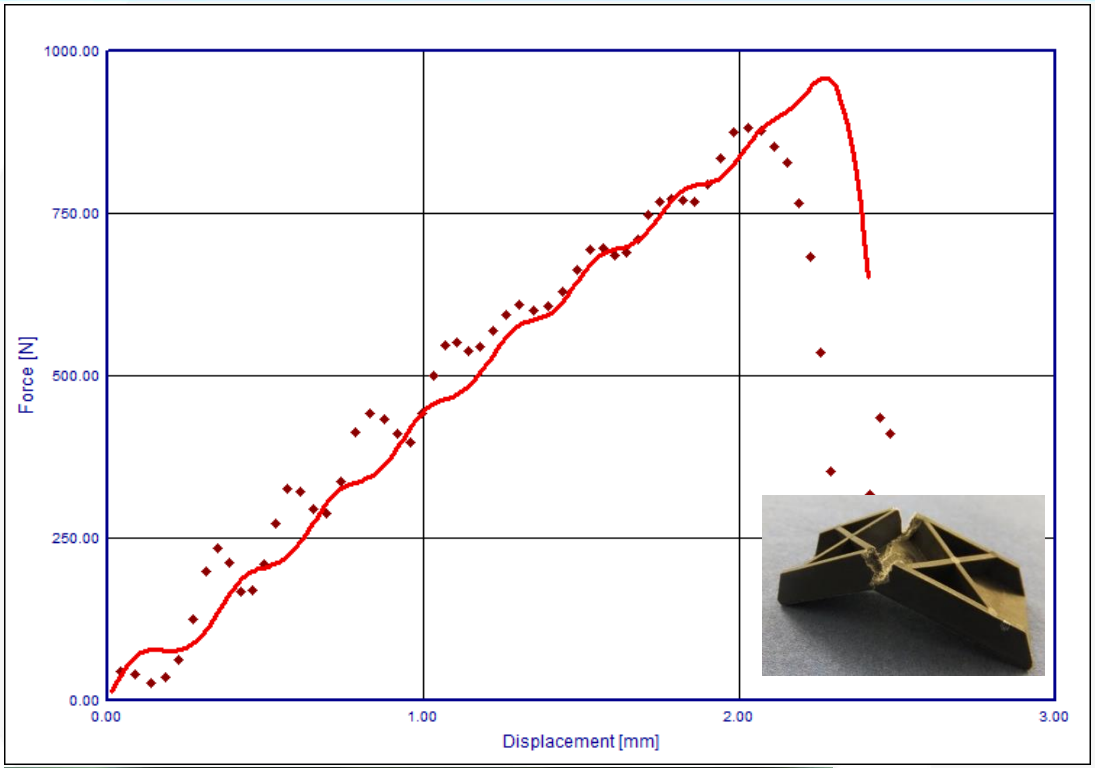
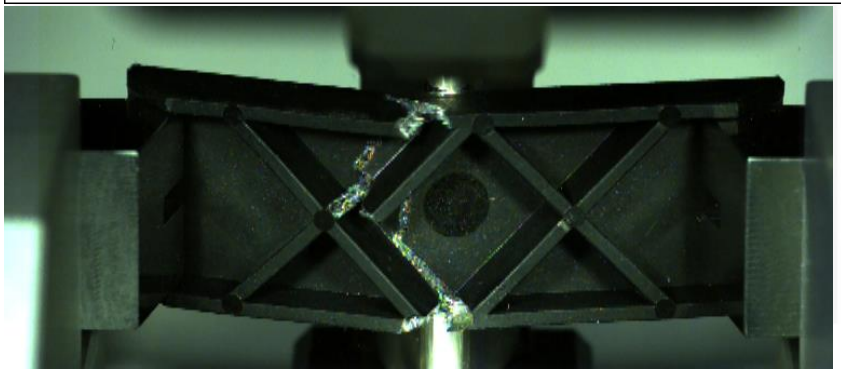
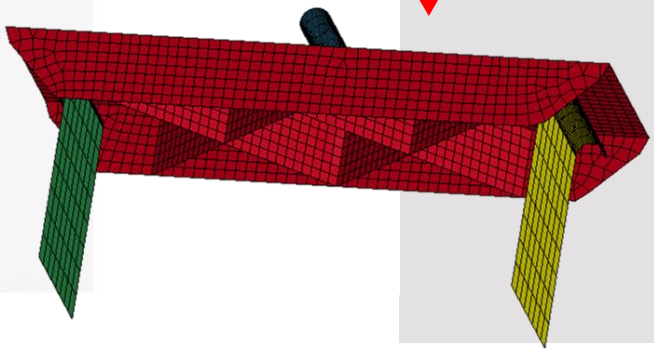
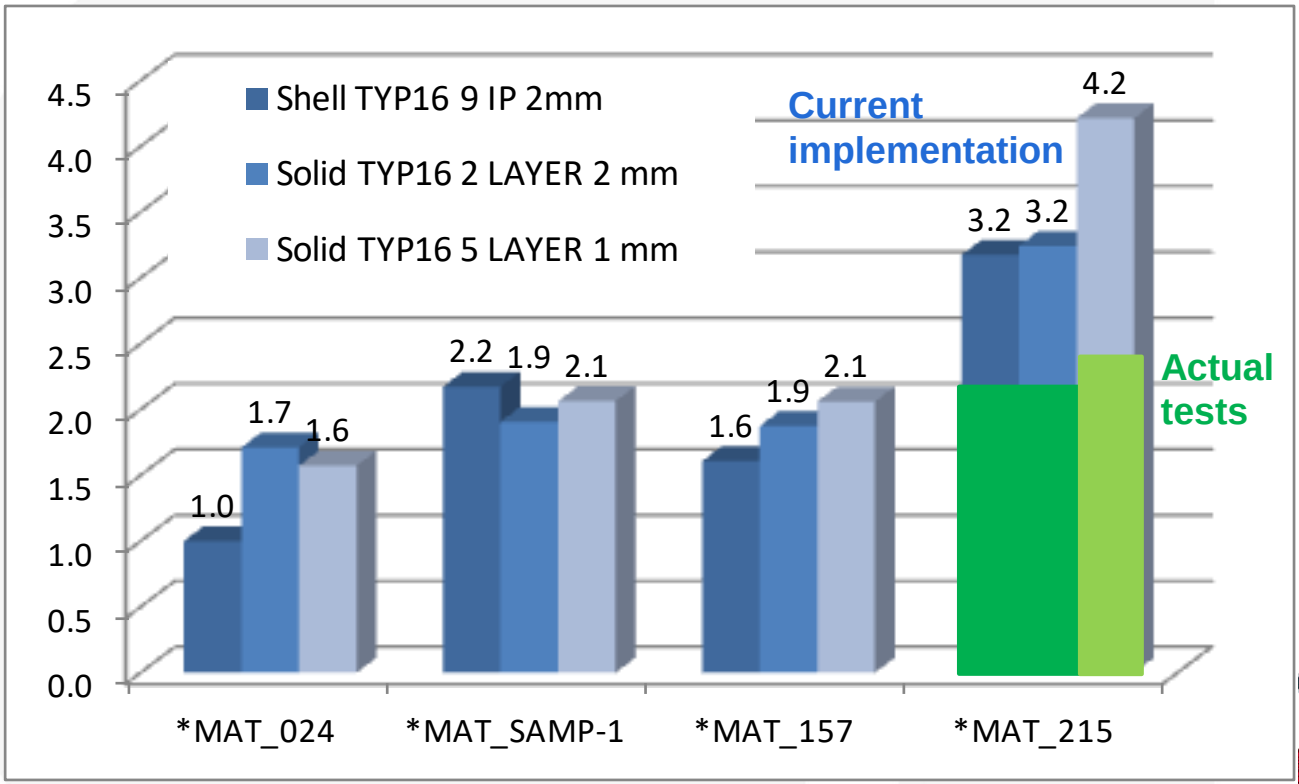
Case study Doublecrossrib
Using *MAT_215

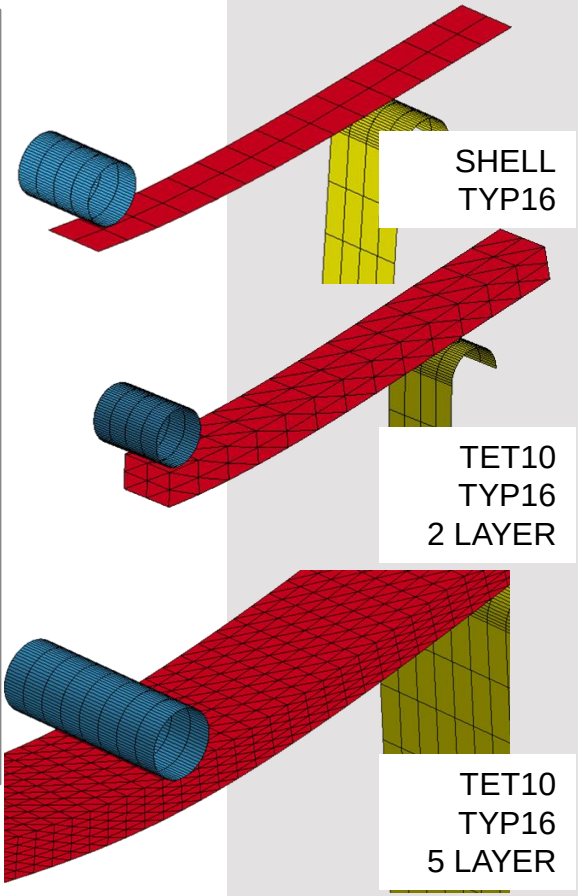






*MAT_215 - *MAT_4A_MICROMEC
CPU TIME per integration point (SMP 1 CPU)





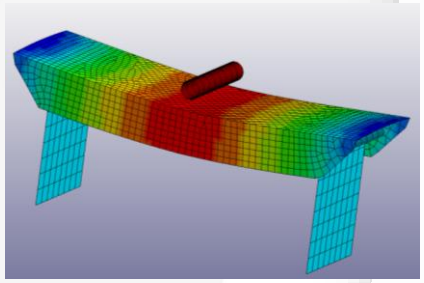
- ***MAT_215 - possible improvements**
  - timestep calculation (conservative implementation)
  - compiler options – Optimizations for Cluster
  - …

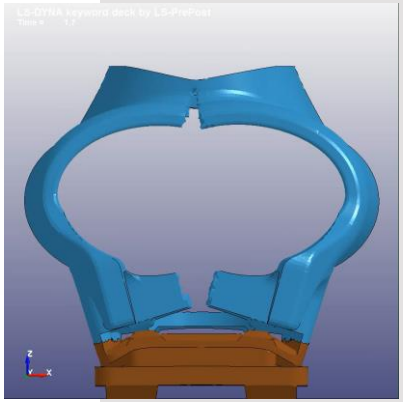
Summary

	*MAT_157	*MAT_215
Solver	implicit/explicit R9/R8	Explicit R10
CPU TIME vs. *MAT_024	2x slower	4x slower ongoing improvement (2x)
Material model	Composite (HILL)	Mean Field Homogenization
Material model parameters	at least 20	at least 10
Failure/Damage	Composite properties	Matrix and Fiber criteria
Mapping	Material properties	Fiber orientation & content, aspect ratio
Ease to use	-*	+

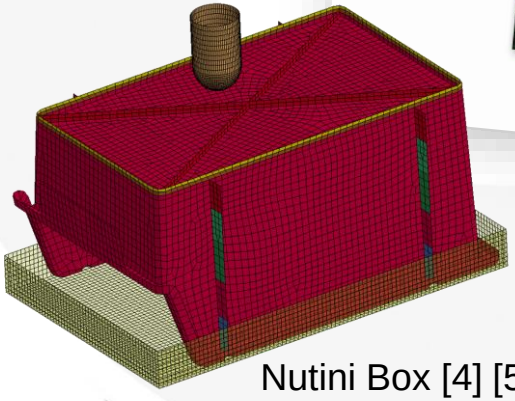
*** Check input not really possible**

Outlook
ongoing testing / validations





Hirtenberger Automotive Safety GmbH & Co KG



Nutini Box [4] [5]

Bosch Automotive Products (Suzhou) Co., Ltd

and hopefully many of your applications …

Thank you for your attention!

„in physics we trust”

Literature

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

[2] H. Staack, A. Koukal (Audi AG) – *Anforderungsgerechte Materialund Bruchmodellierung für die Fahrzeugsicherheit,* 4a Technologietag 2016 (Link)

[3] P. Reithofer, B. Jilka, A. Fertschej (4a engineering GmbH) – *4a micromec für die integrative Simulation faserverstärkter Kunststoffe,* NAFEMS Deutschsprachige Konferenz 2014, Bamberg (Link)

[4] Ch. Bodor[1], R. Brunner[2], R. Jördis[2], D. Tscharnuter[3], H. Erlach[4]; ([1]Lehrstuhl für Spritzgießen, Montanuniversität Leoben, [2]Materials Center Leoben, [3]PCCL GmbH, Leoben, [4]Mahle Filtersysteme Austria GmbH) - *Kopplung µCT und FEM Berechnung,* 4a Technologietag 2014 (Link)

[5] R. Jennrich, M. Roth, Prof. S. Kolling (Technische Hochschule Mittelhessen), C. Liebold (DYNAmore GmbH),G. Weber (Celanese GmbH) – *Experimentelle und numerische Untersuchung eines kurzglasfaserverstärkten Kunststoffes*, 13. LS-DYNA Forum 2014, Bamberg (Link)

[6] P. Reithofer , B. Jilka, S. Hartmann (4a engineering GmbH), T. Erhart, A. Haufe (DYNAmore GmbH) - *Short and long fiber reinforced thermoplastics – material models in LS-DYNA,* 10th European LS-DYNA Conference 2015, Würzburg (Link)