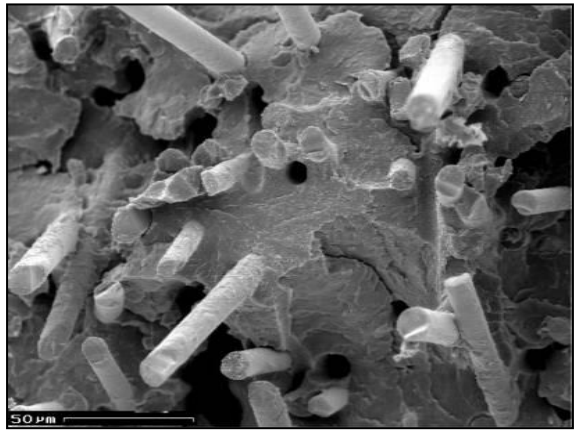


failure criteria SFRT and LFRT

Peter Reithofer
contact: peter.reithofer@4a.at

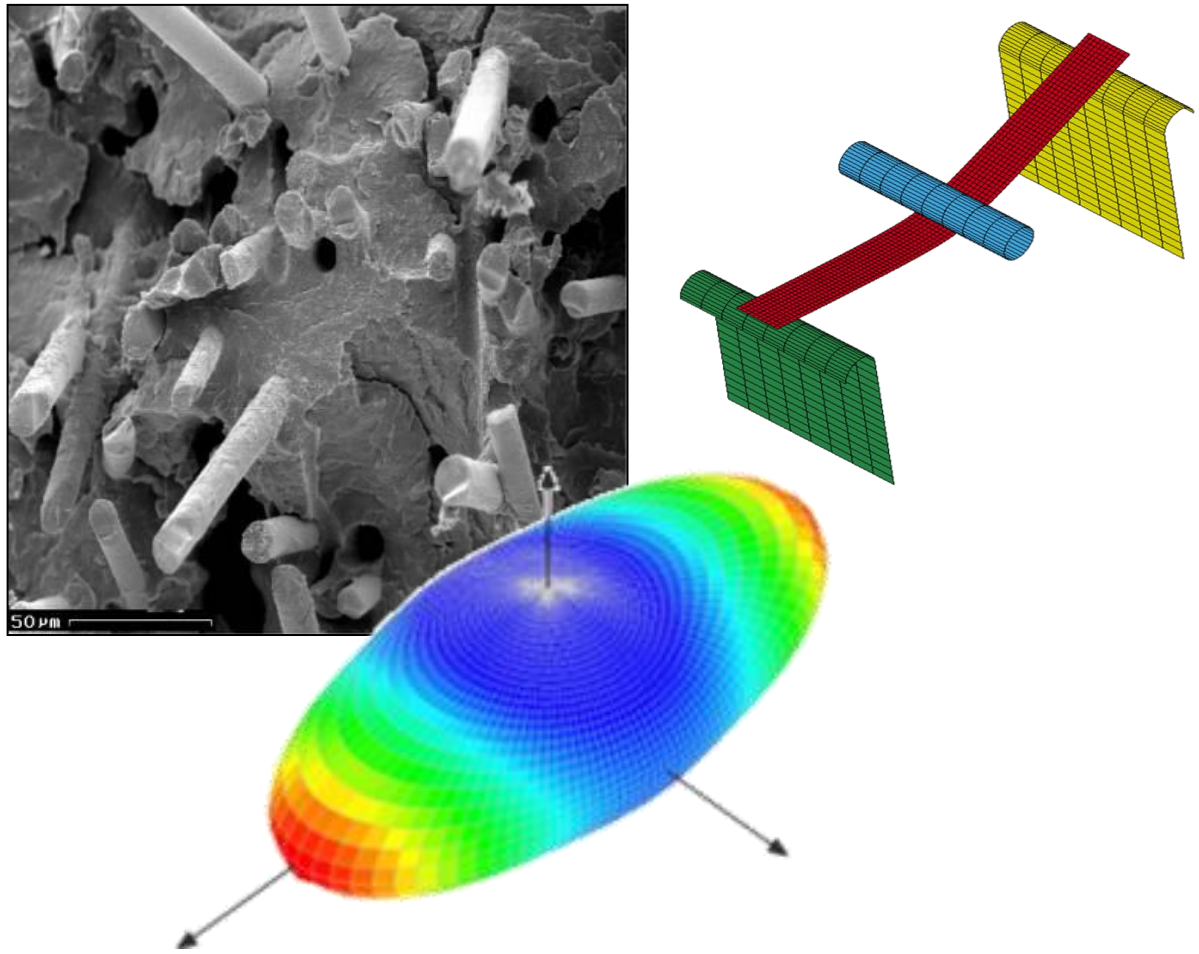
IMM
Institute of Mechanics and Materials

THM
TECHNISCHE HOCHSCHULE MITTELHESSEN

ISM+D
Institute of Structural Mechanics and Design
Institut für Statik und Konstruktion

Content

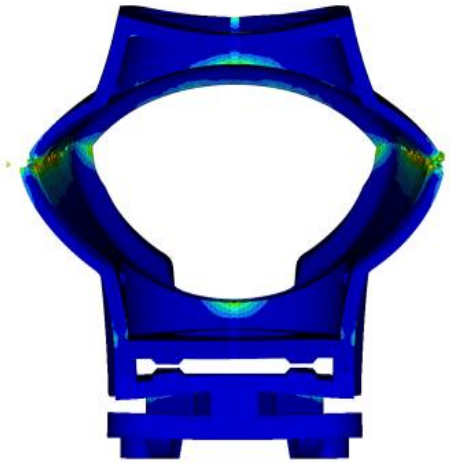
- Introduction & Motivation
- Questions / Aims
- Material model approaches
- Material characterization - Status
- Integrative simulation
- New investigations



Motivation

test

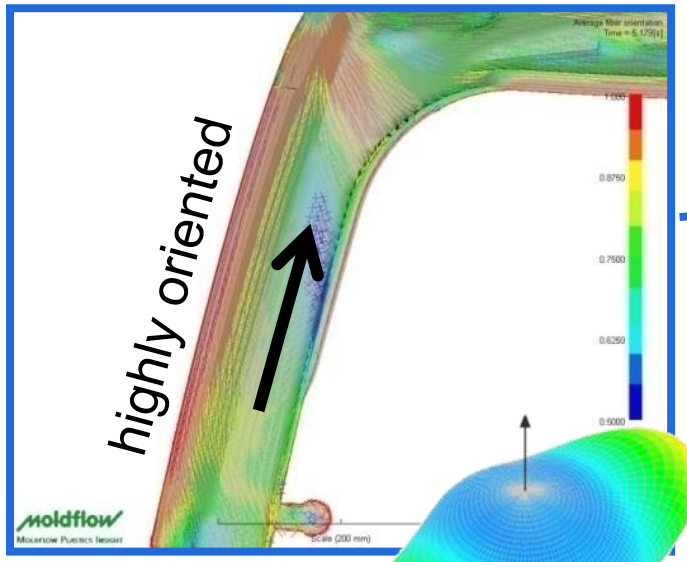
Isotropic
****MAT_24***



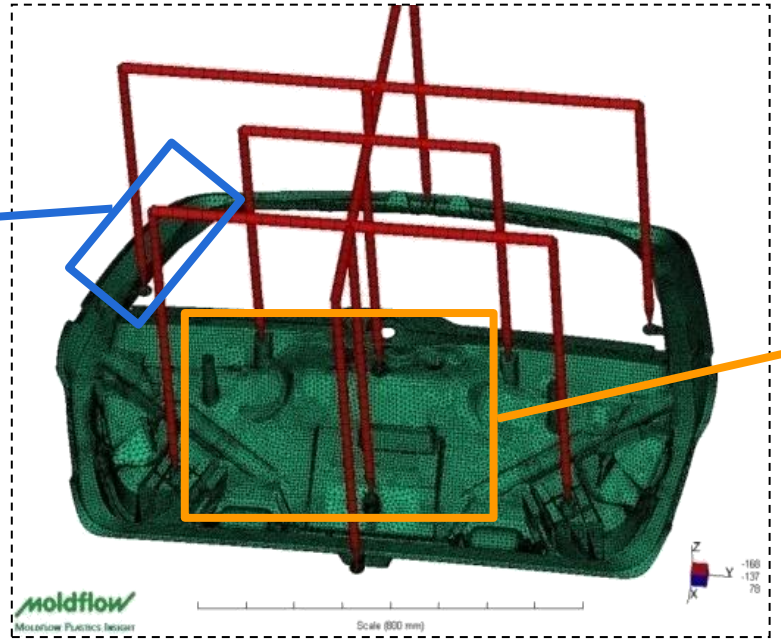
Questions

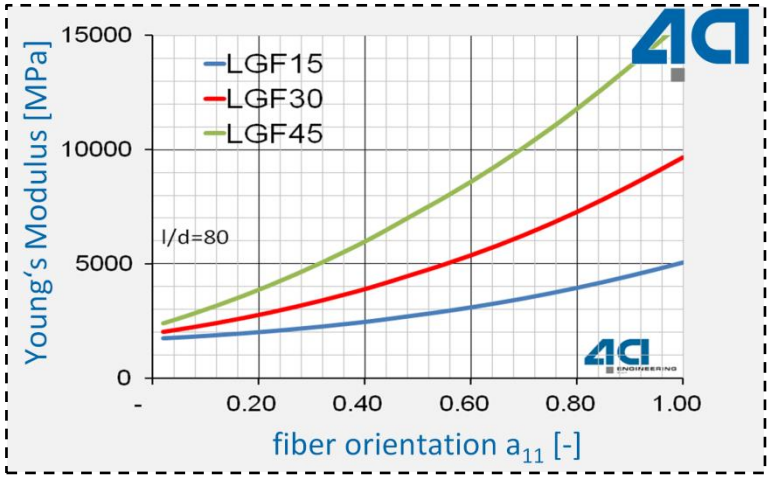
- **How good are current material models ?**
  - Deformation prediction
  - Failure prediction
  - **broader range of materials**
    (PBT GF30, PP LGF30, PA6 I GF30)
- What steps are needed ?
  - CAE Workflow (Mapping) –Simplification
  - **material characterization**
- Improvement of failure models ?
  - stress / strain / energy
  - fiber / matrix / composite

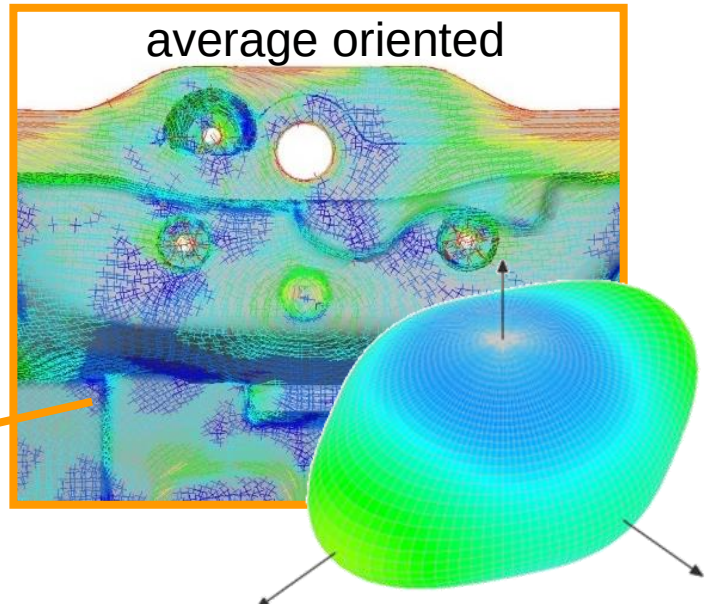
fiber orientation – development in typical part



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





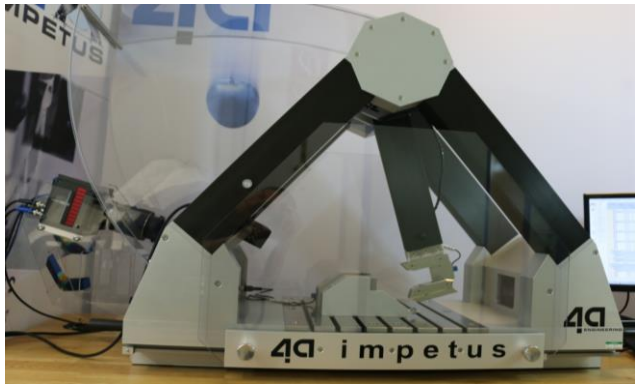


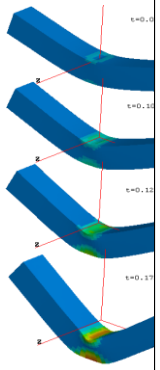
$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

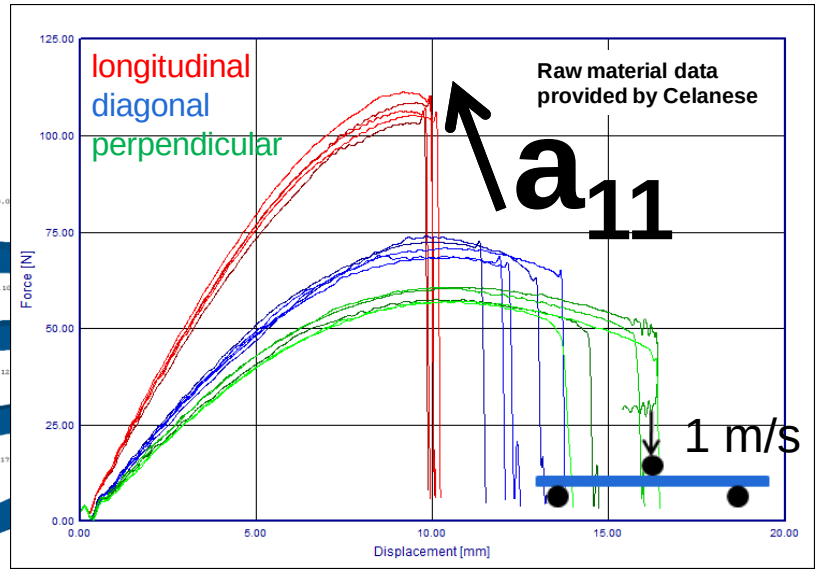
Source: P. Reithofer - *Integrative Simulation – Berücksichtigung der prozessbedingten Anisotropie*, 4a Technologietag 2011

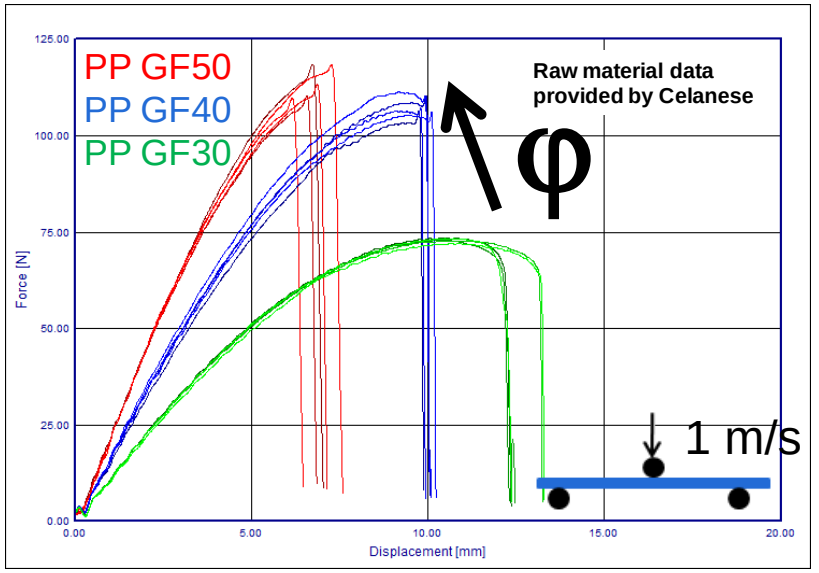
typical material behavior – SFRT / LFRT

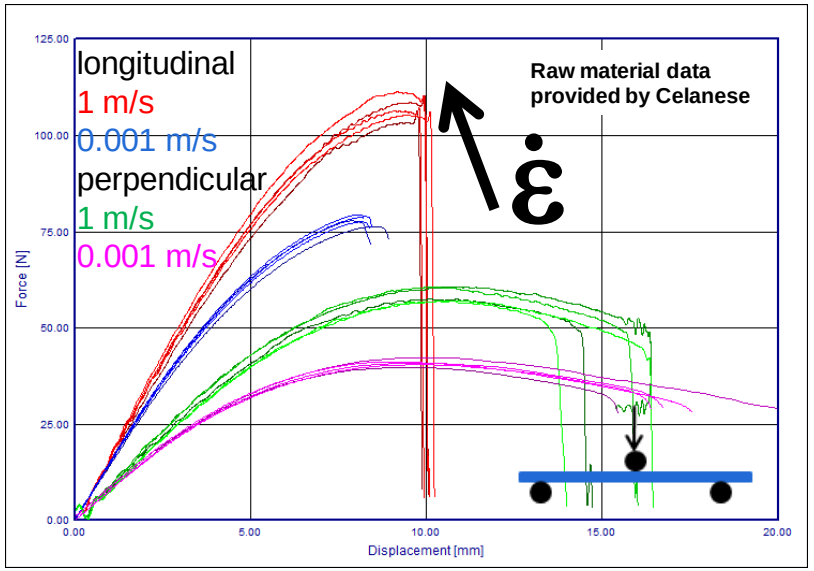
IMPETUS

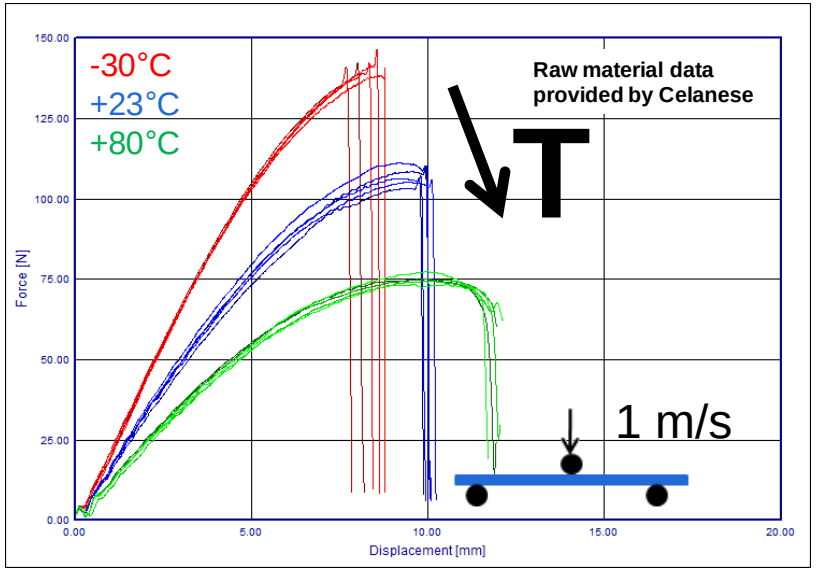




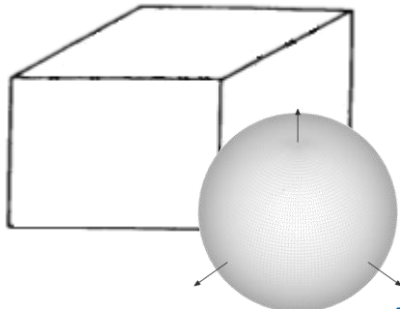


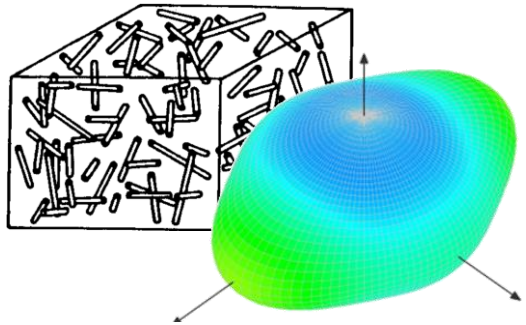




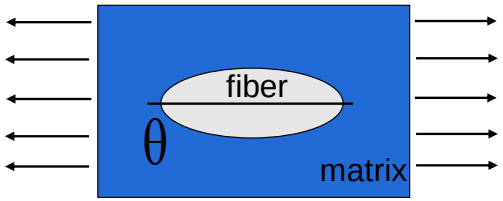


typical material models in LS-DYNA





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



Eshelby Tensor

macro scale

constitutiv law → composi

micro scale

homogenizat

Mises plasticity

- quick & d
- criti g
  t
  orientation

elastic

- orthotro
- aniso

elastic tic

- city

M… matrix

- isotropic elas
  viscoplast

F… fiber

- iso tic

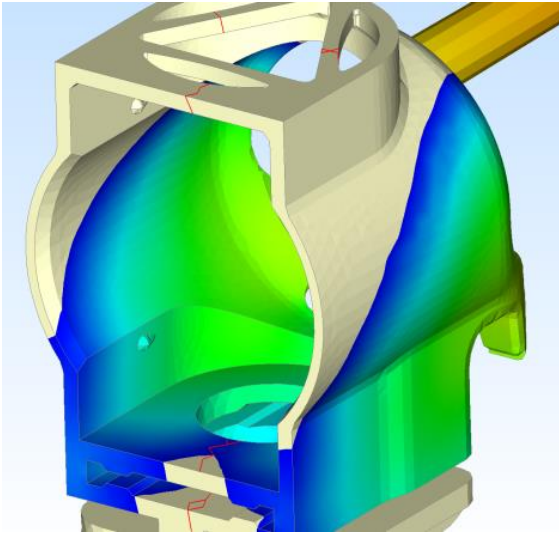
*MAT_024

*MAT_157

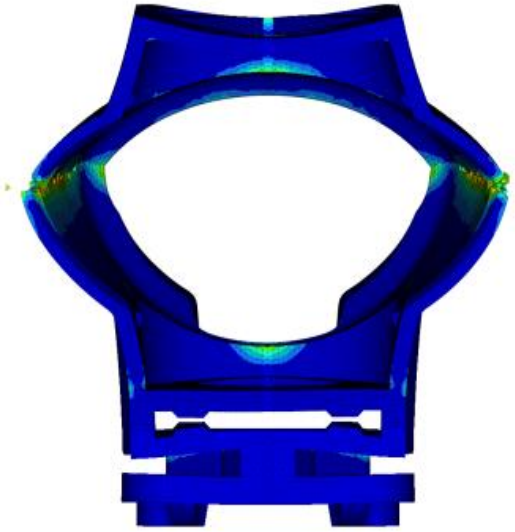
*MAT_215

α – orientation dependent

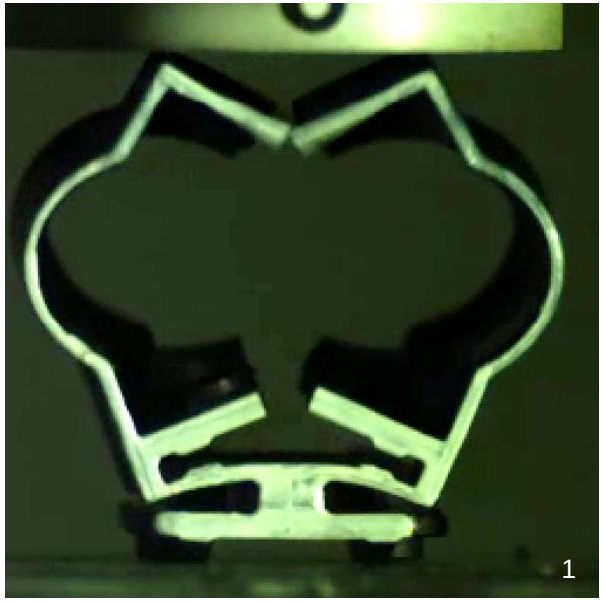
Case study - sleeve



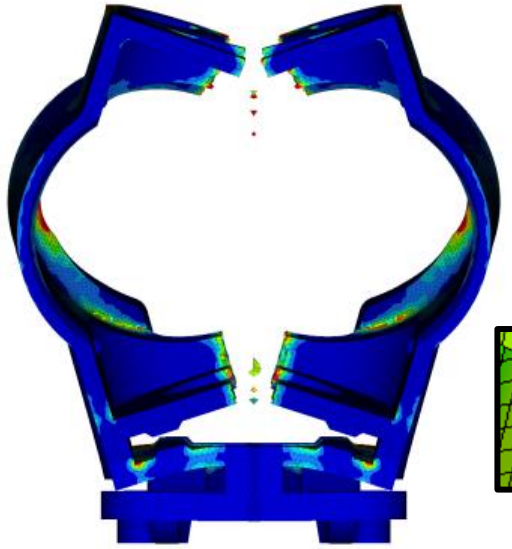
isotropic
***MAT_24**



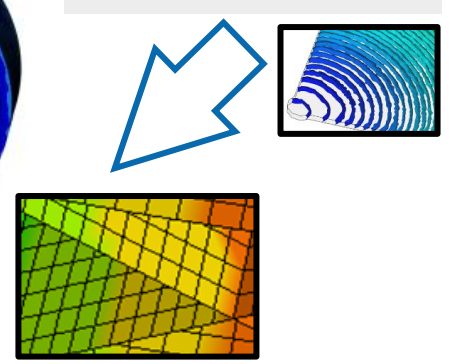
test



local anisotropy
***MAT_157/215**



FIBERMAP

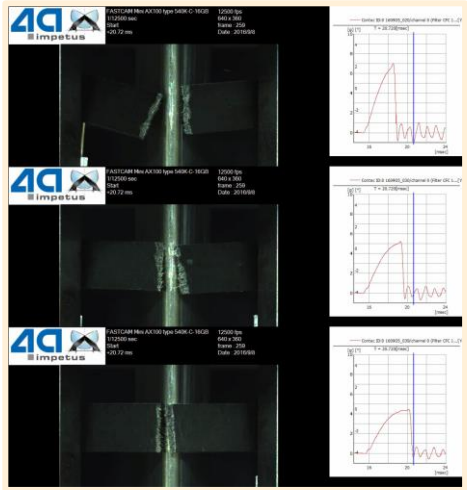


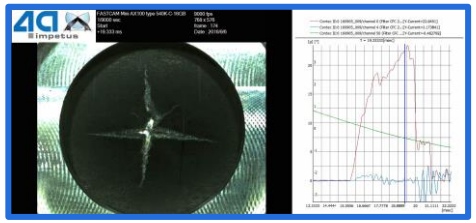
See more: R. Steinberger, et.al. Hirtenberger Automotive Group – *Considering the Local Anisotropy of Short Fiber Reinforced Plastics, European Dynaforum 2017*

hirtenberger
Automotive Safety

Material characterization for different materials

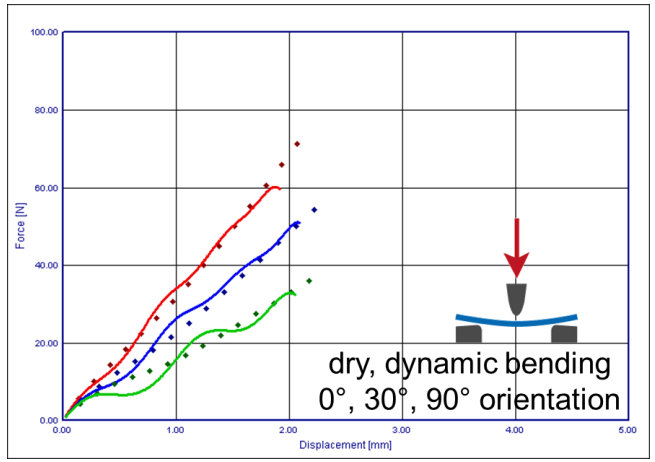
	Fiber	Tensile	Bending	Puncture
PP LGF30	**LFRT l/d ~ 50**	$\dot{\varepsilon}$; α reduced	$\dot{\varepsilon}$; α	$\dot{\varepsilon}$
PBT GF30	**SFRT l/d ~ 20**	$\dot{\varepsilon}$; α reduced	$\dot{\varepsilon}$; α	$\dot{\varepsilon}$
PA6 GF30 impact modified	**SFRT l/d ~ 30**		$\dot{\varepsilon}$; α reduced moisture	dynamic moisture



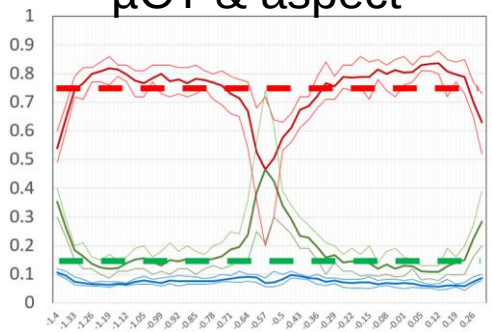


PA6 GF30 I – material characterization for *MAT_215

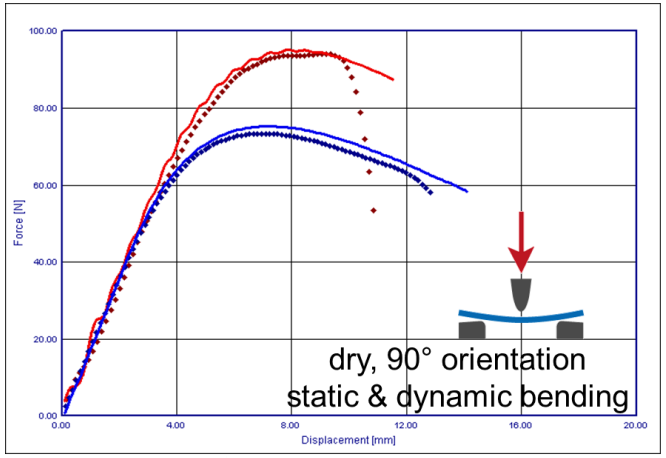
1st step: set up the composite



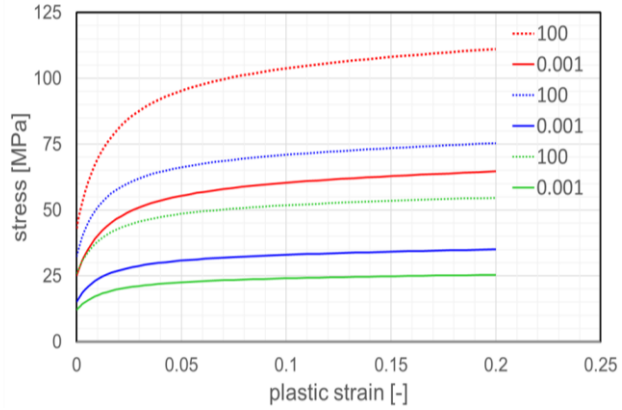
µCT & aspect



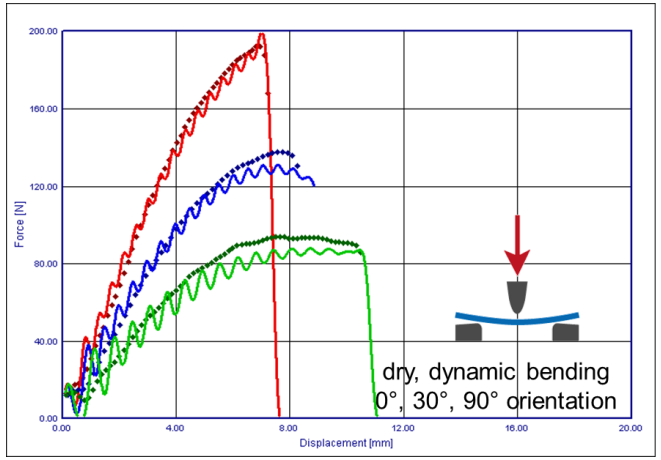
2nd step: matrix hardening



Young's Mod.	dry	cond.	wet
[MPa]	2500	1600	1450



3rd step: validation

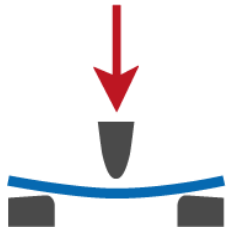


4th step: failure strains

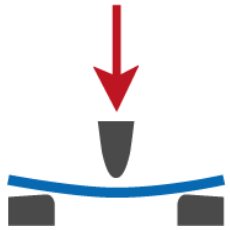
Source: P Reithofer, et.al., failure criteria SFRT and LFRT

PA6 GF30 I – validation different moisture contents

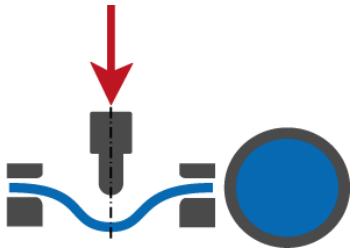
VALIMAT



90° orientation
static & dynamic bending

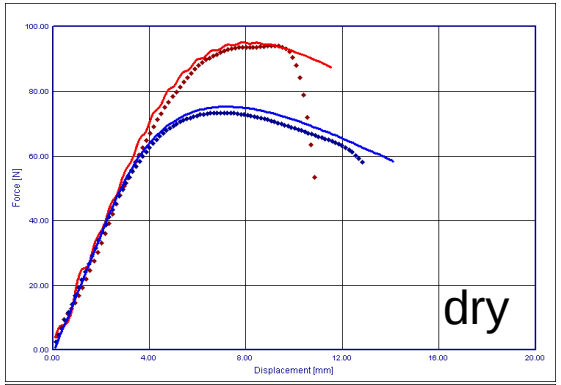


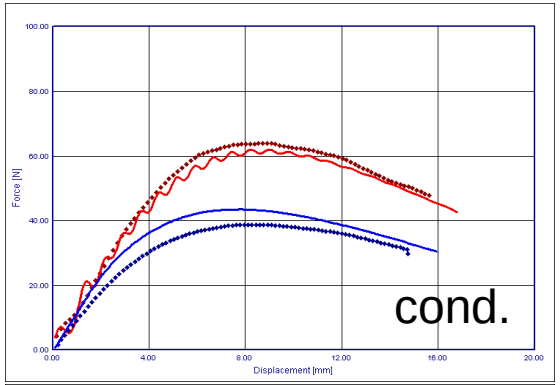
dynamic bending
0°, 30°, 90° orientation

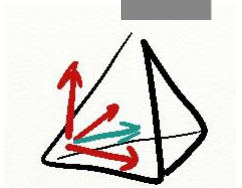


dynamic puncture test

Source: P Reithofer, failure criteria SFRT and LFRT

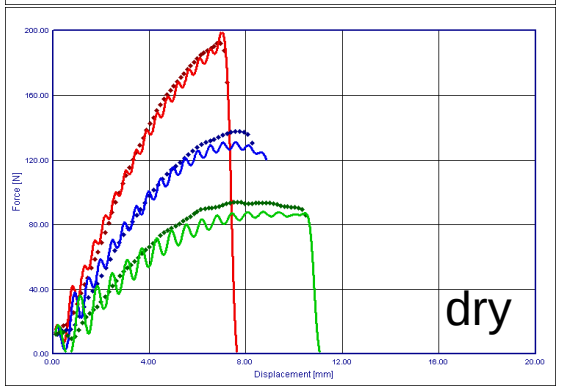


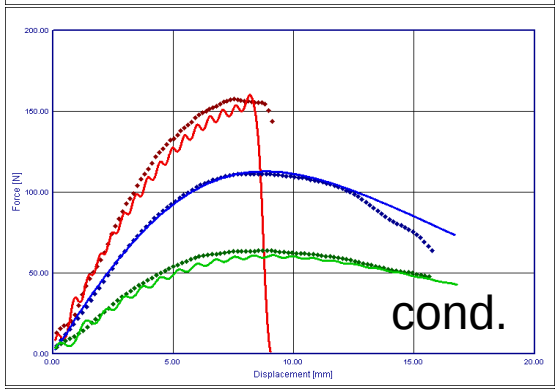


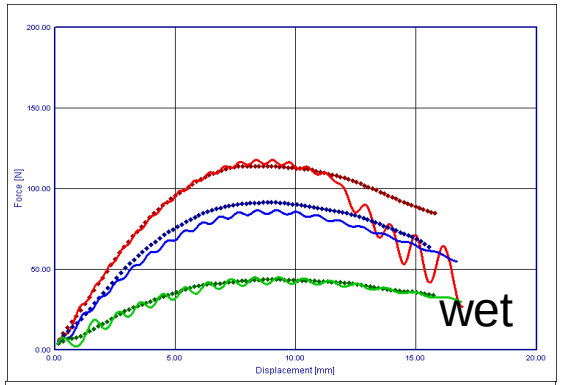


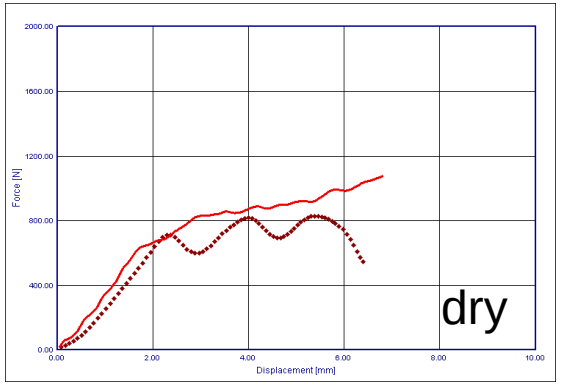
ELTYP4
0.5 mm

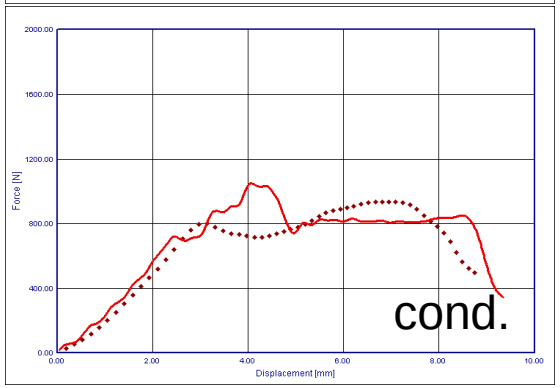
···· averaged test curves
— result of simulation

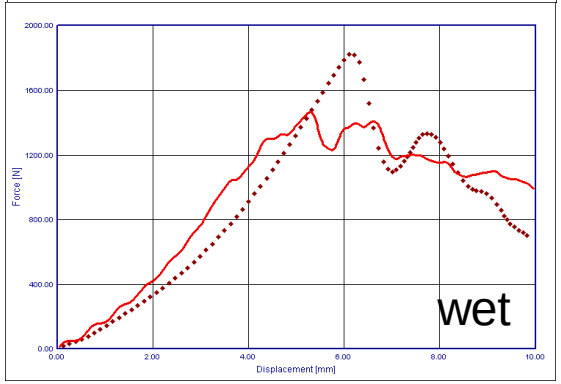






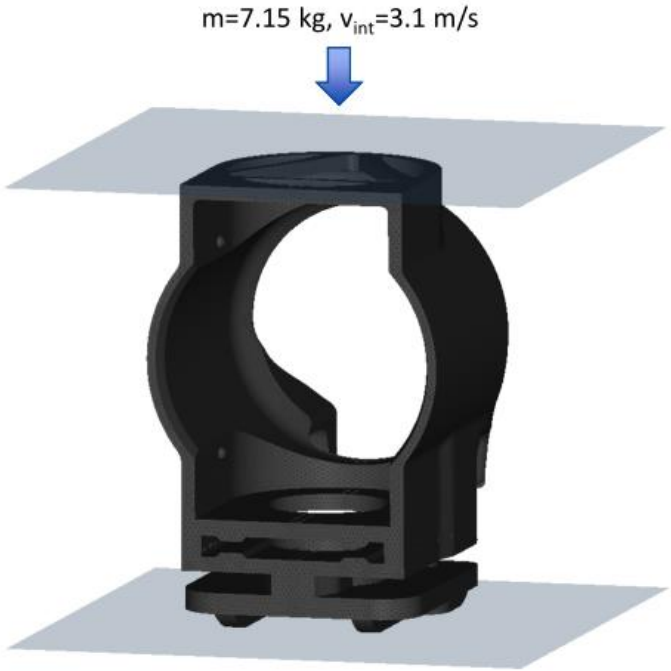


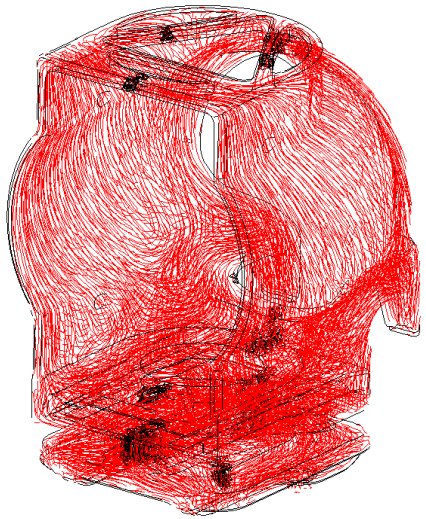


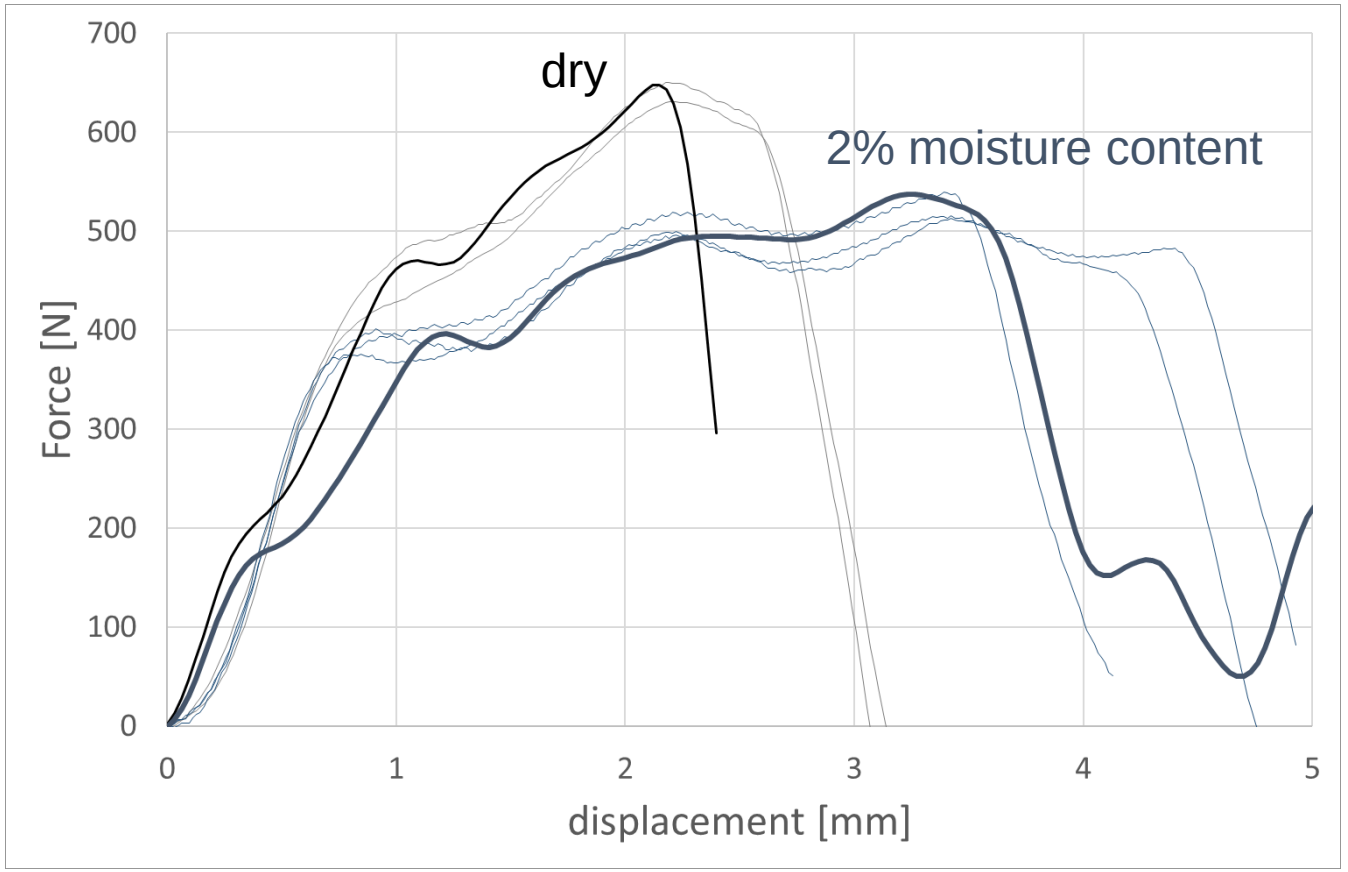


Case study - sleeve

Validation component test



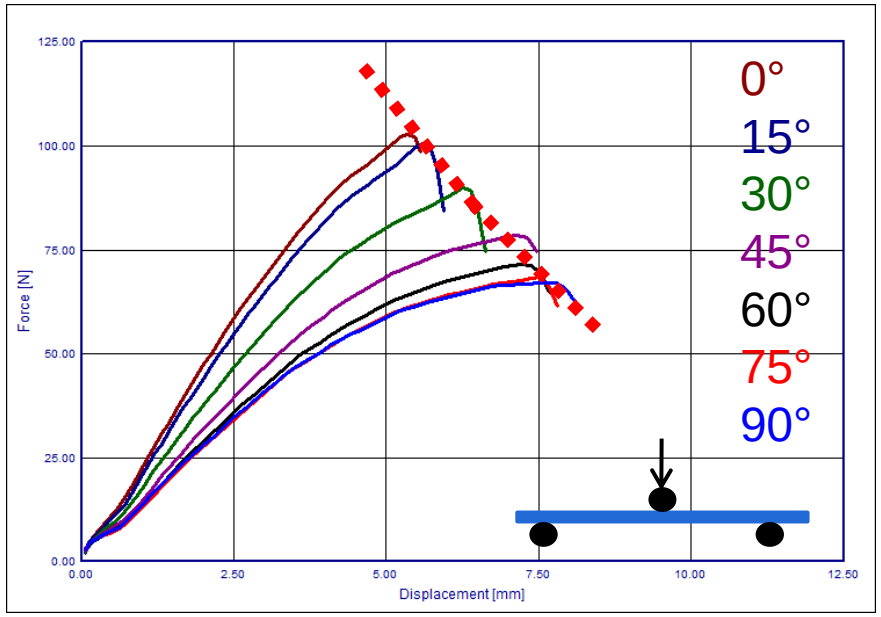


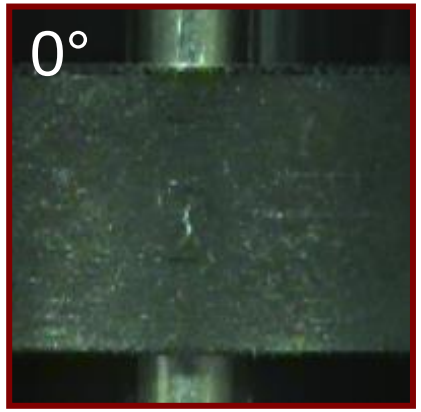


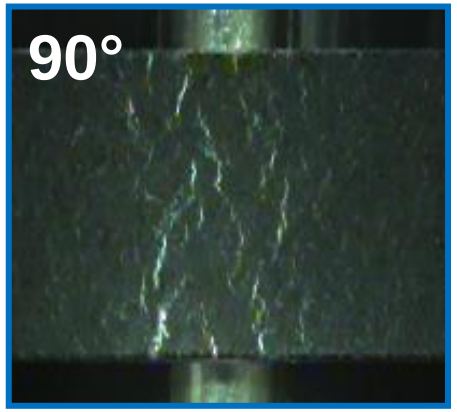
Typical element size : 0.25 mm
Element type : Tetrahedron Type 10
Number of elements : 469470

—— material cards based on mapped FOT
—— test curves

Questions







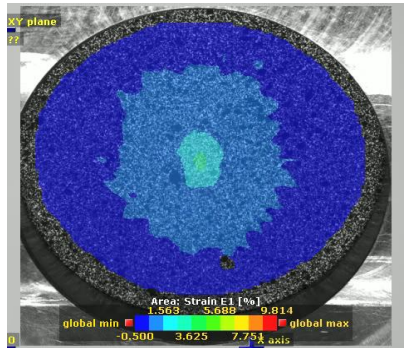
- How good are current material models ?
  - Deformation prediction
  - Failure prediction
  - broader range of materials
    (PBT GF30, PP LGF30, PA6 I GF30)
- What steps are needed ?
  - CAE Workflow (Mapping) –Simplification
  - material characterization
- **Improvement of failure models ?**
  - **stress / strain / energy**
  - **fiber / matrix / composite**

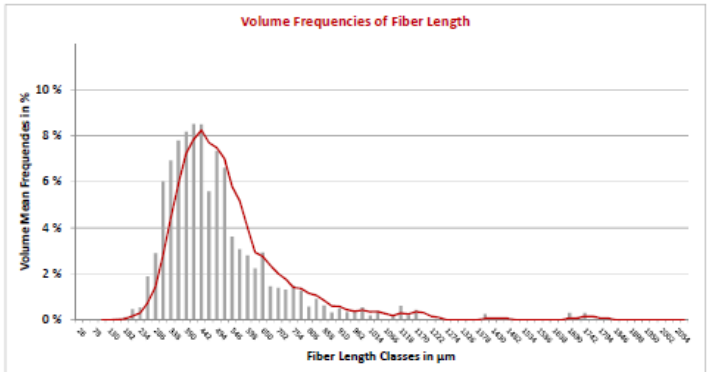
additional investigations

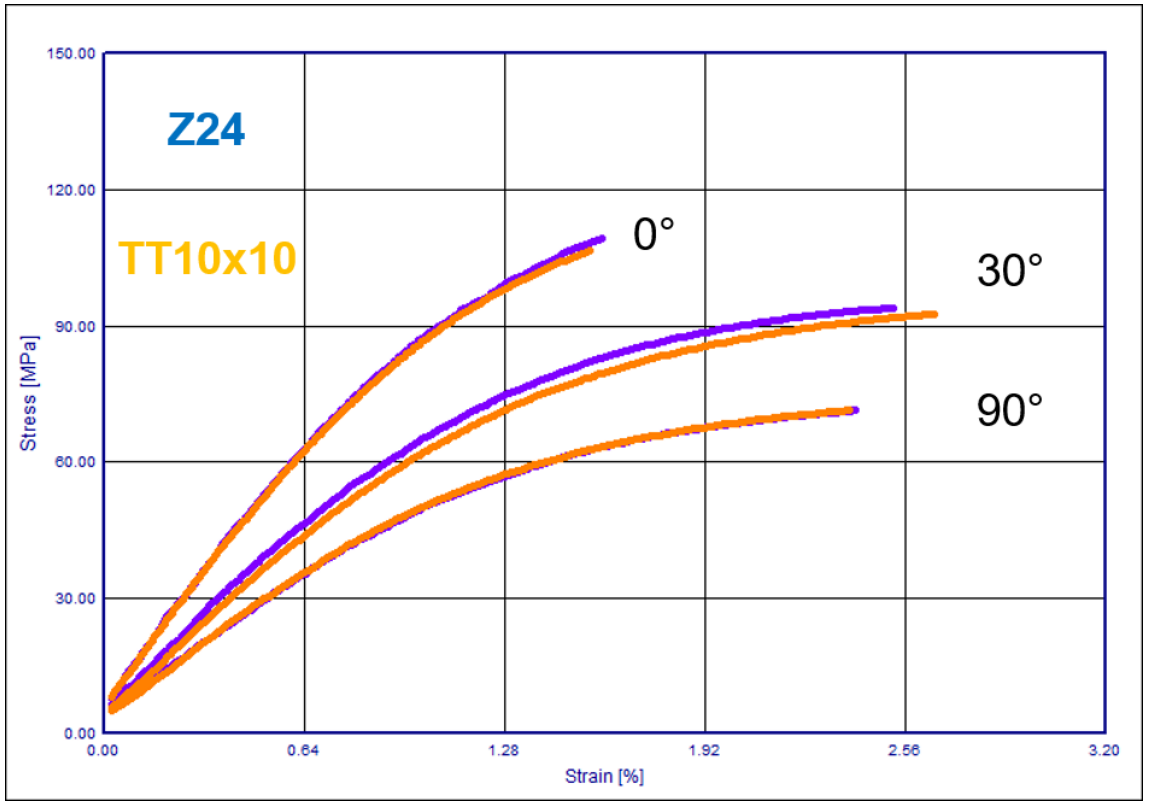
- fiber length measurement
- fiber orientation measurement µCT

- **static and dynamic tensile tests**

- **3D DIC**
  - **Bending tests**
  - Puncture test **(Master Thesis Christine Jantos)**



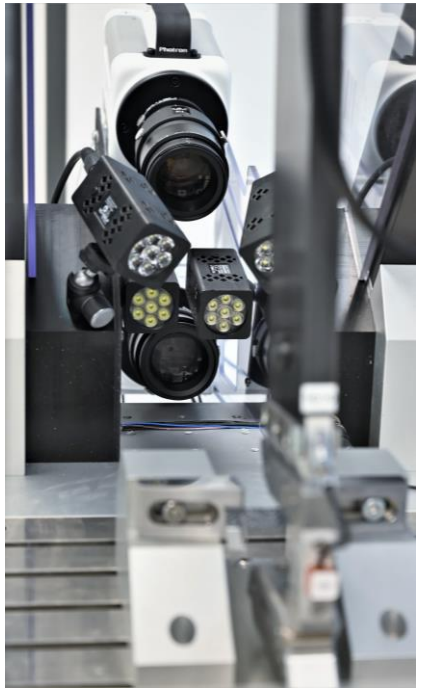




PBTGF30

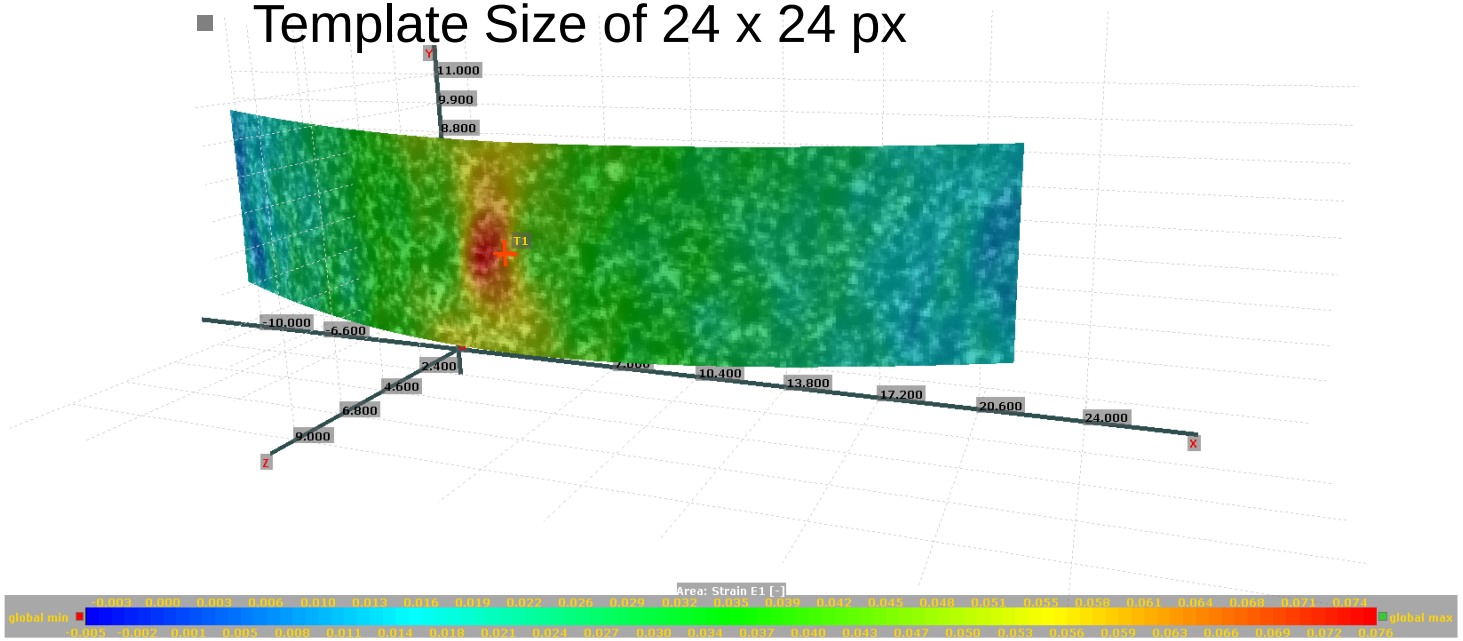
IMPETUS® - 3D DIC Setup

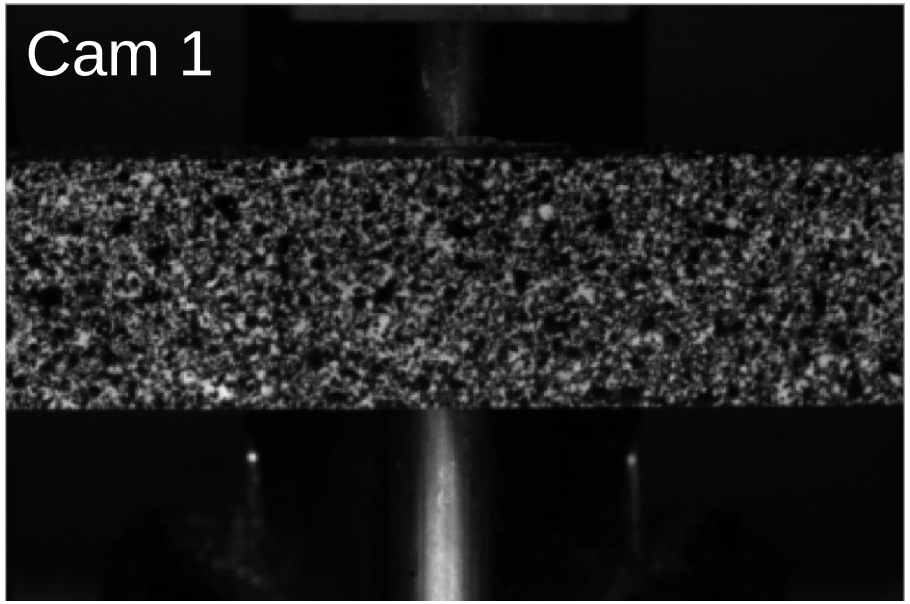
- 3PB Test setup
  - 2 x Photron FASTCAM NOVA S9
  - Camera 1 from above tilt angle 20°
  - Camera 2 from below tilt angle -5°

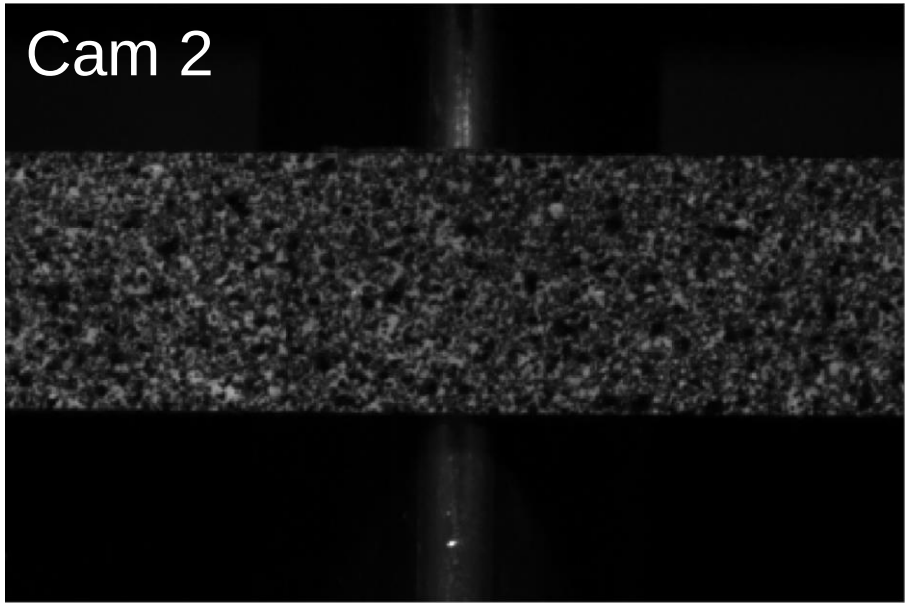


IMPETUS® - 3D DIC Setup

- DIC settings
  - Resolution of 384x256 px
  - Recorded frame rate of 15.000 fps
  - Strain measuring with a Full-Field Area
    - True Strain E1maximum
    - Template Size of 24 x 24 px

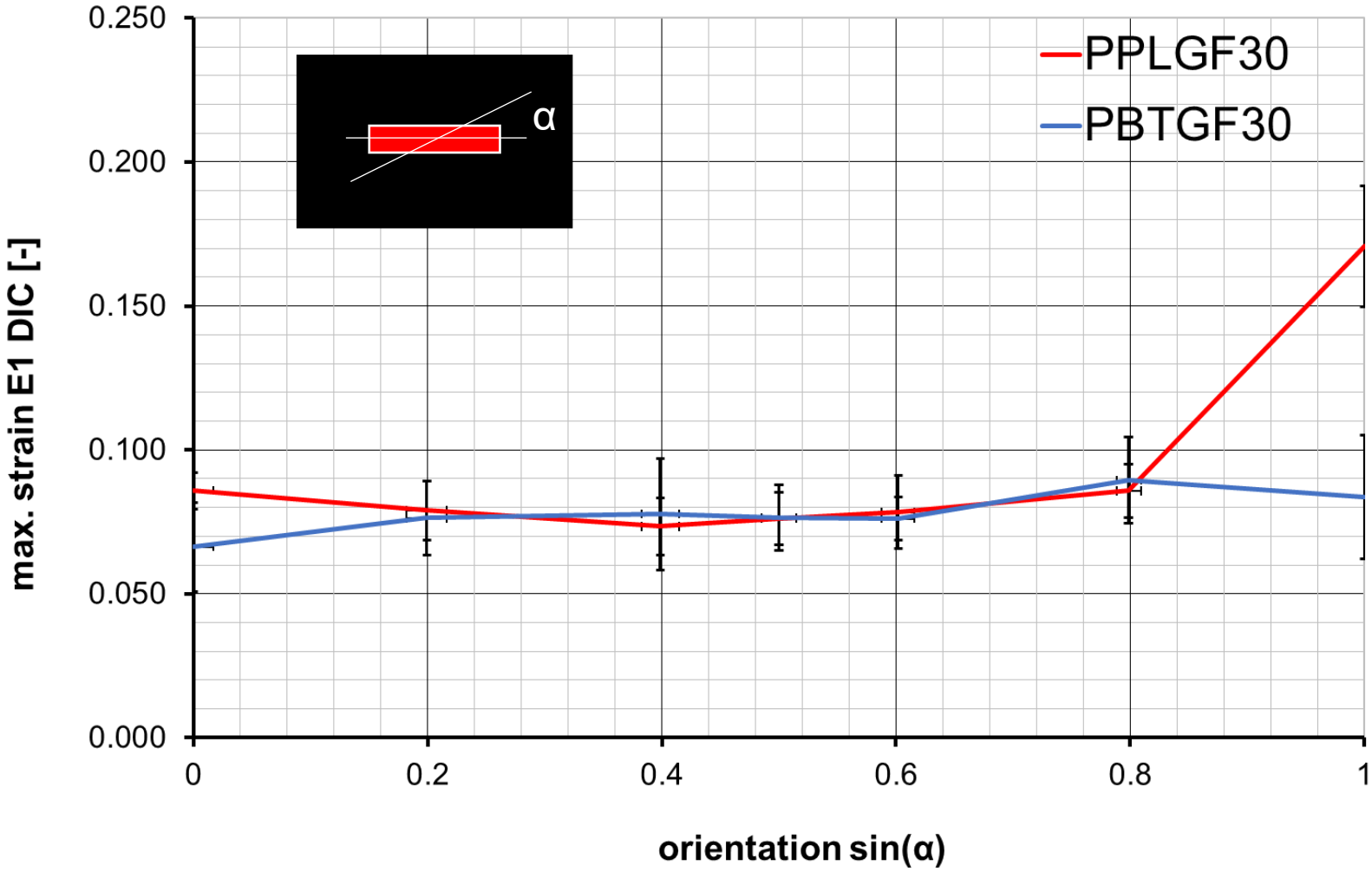






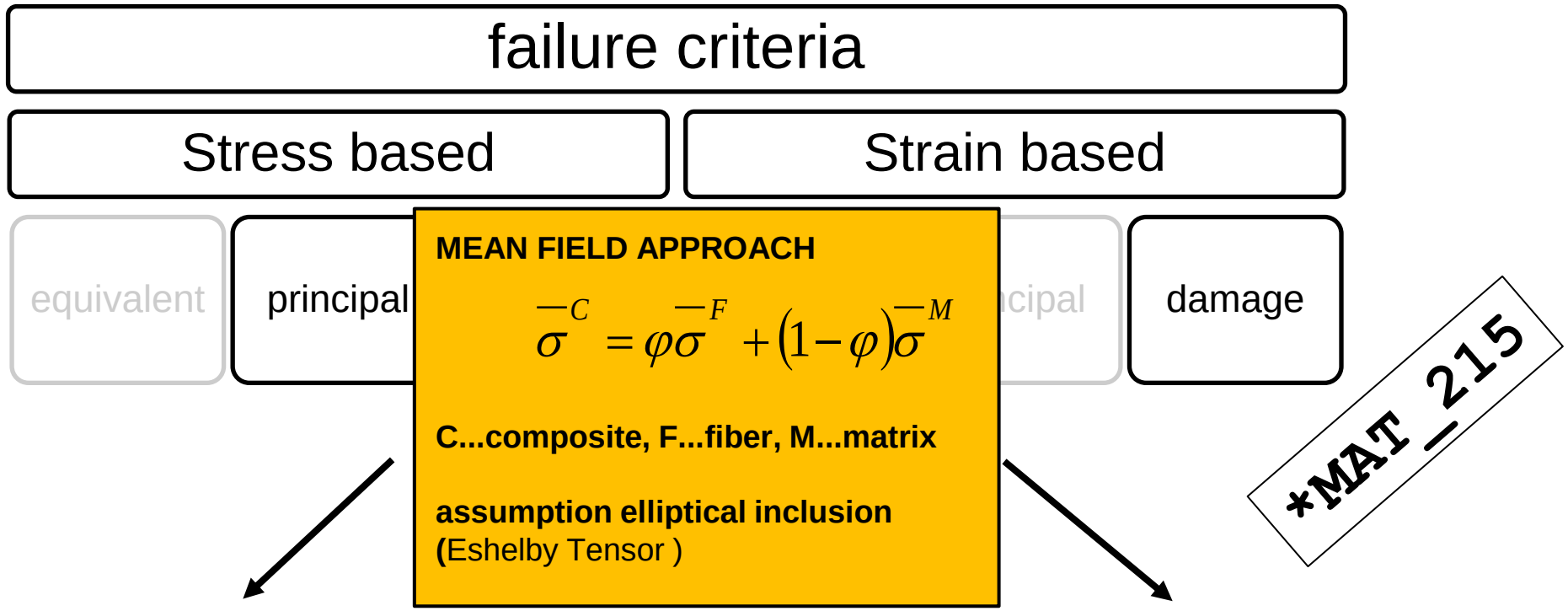
Source: P Reithofer, failure criteria SFRT and LFRT

first results



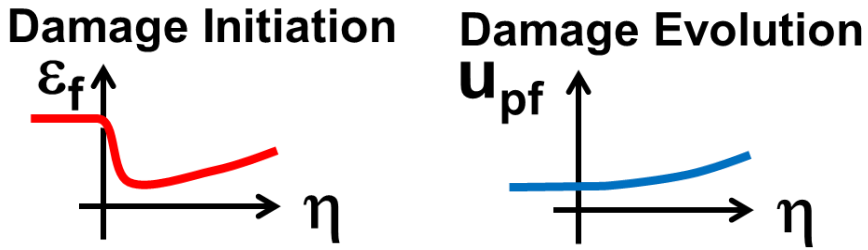
Source: P Reithofer, failure criteria SFRT and LFRT

micro mechanical motivated failure

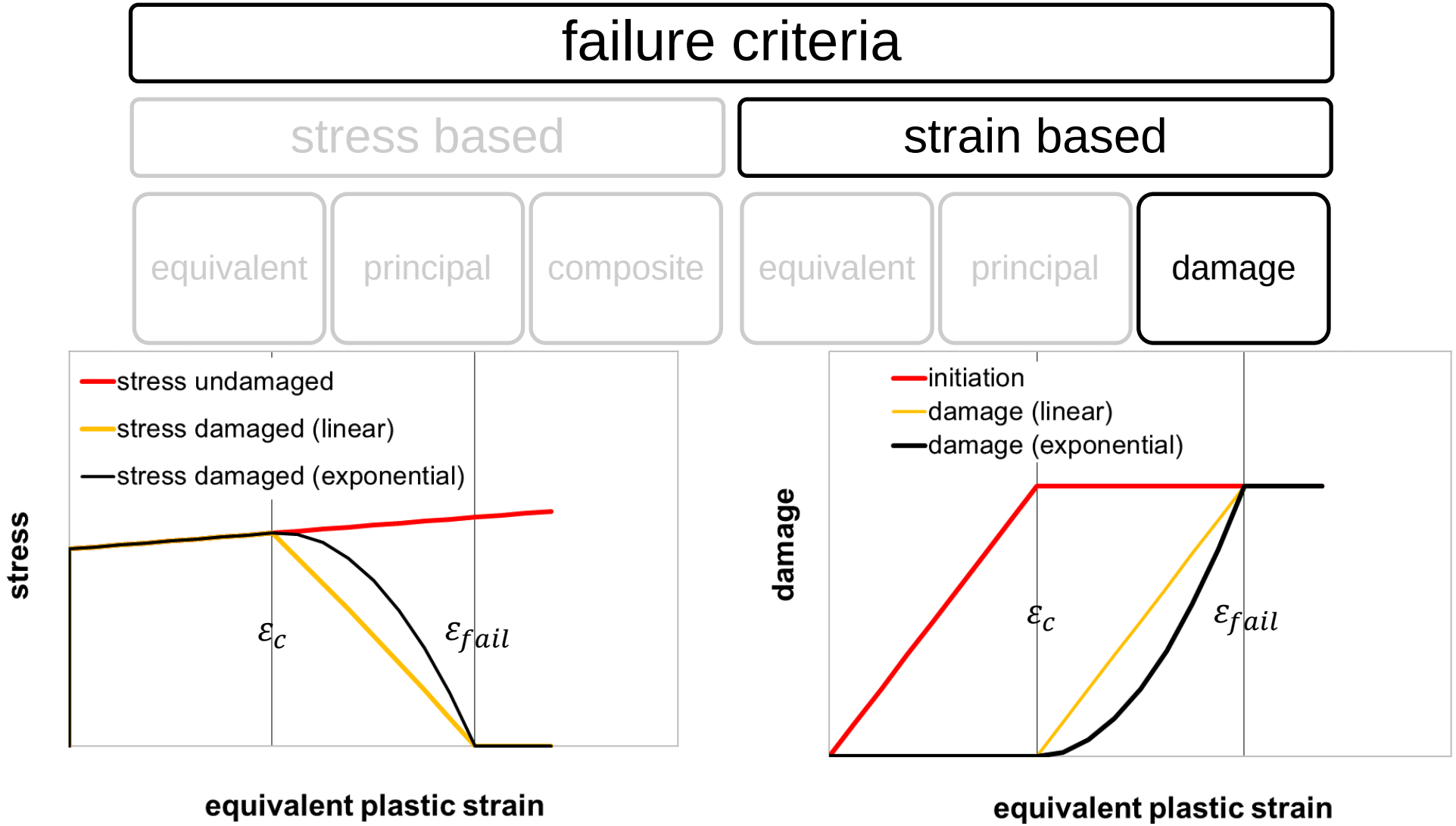


FAILF: Fiber failure

FAILM: Matrix failure – ductile DIEM-Model



incremental damage formulation

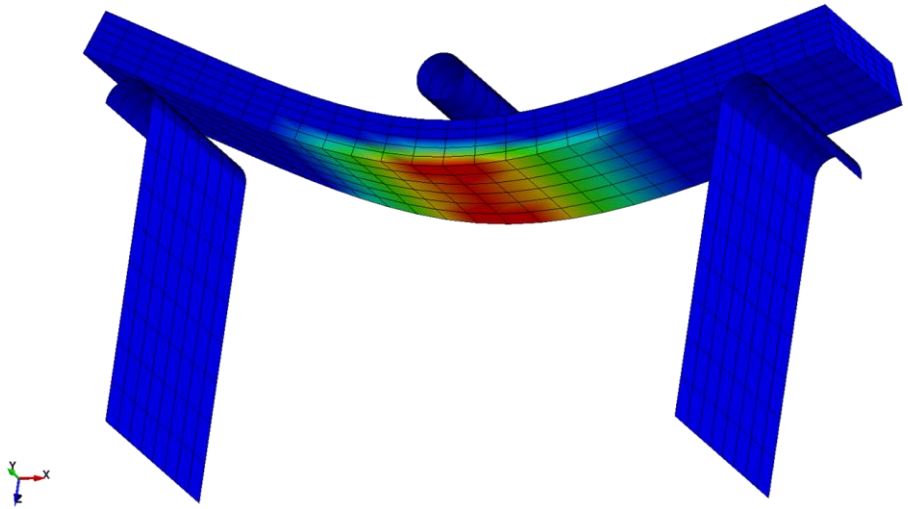


micro mechanical motivated failure

CARD 1: General Options / Parameter

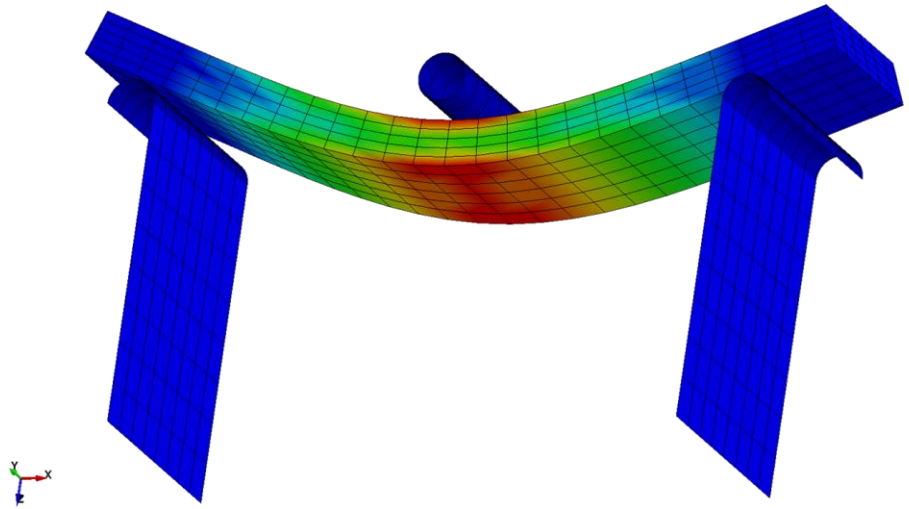
*MAT_215

Card 1	1	2	3	4	5	6	7	8
Variable	MID	MMOPT	BUPD			FAILM	FAILF	NUMINT
Type	A8	F	F			F	F	F
Default	**none**	**0.0**	**0.01**			**0.0**	**0.0**	**1.0**



History#4 (step8: 0-0.81):

dm - matrix damage init.

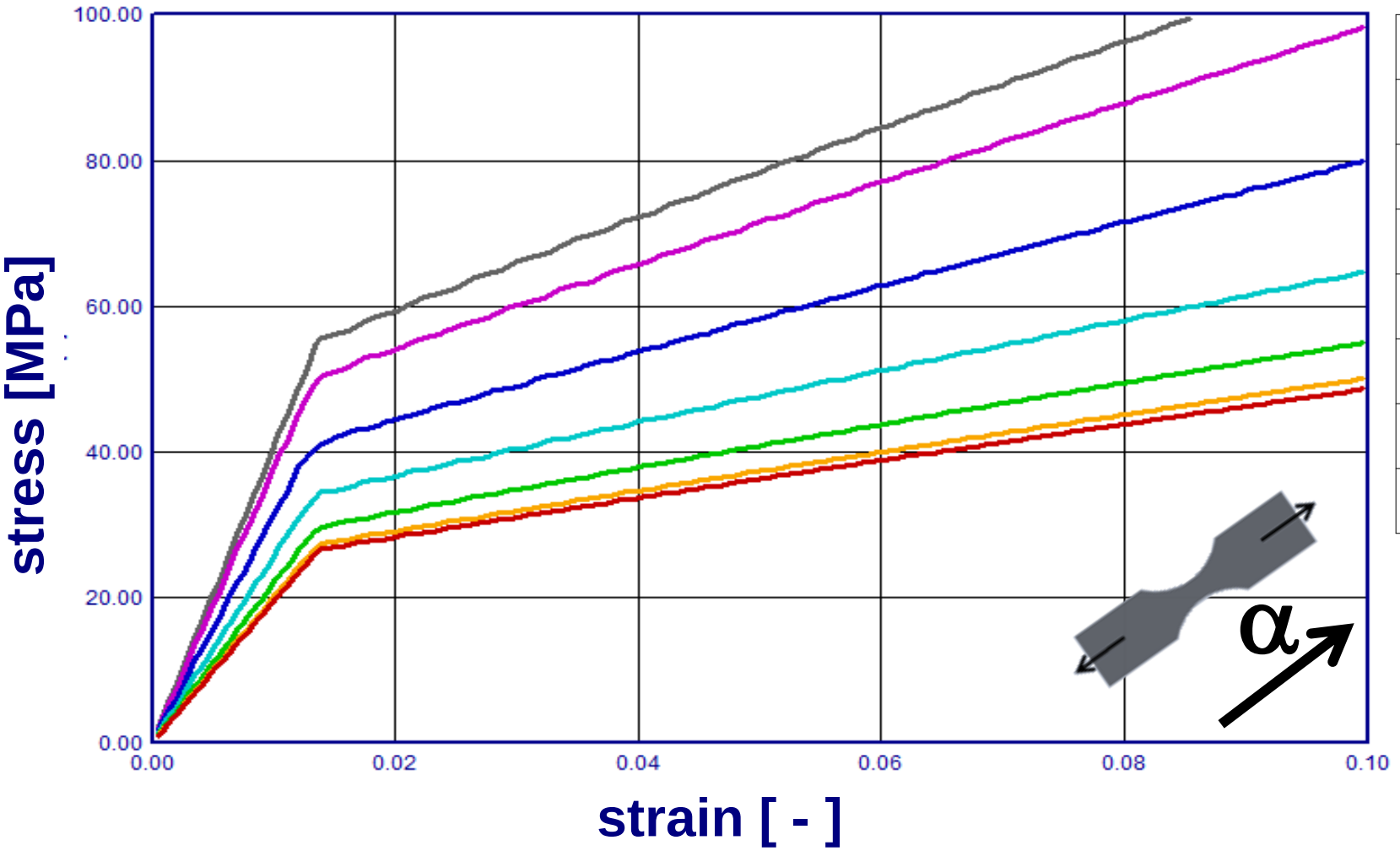


History#6 (step8: 0-0.13):

Fiber damage init.

Simple mind model → 1- Element tension test different directions

no – failure model used



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

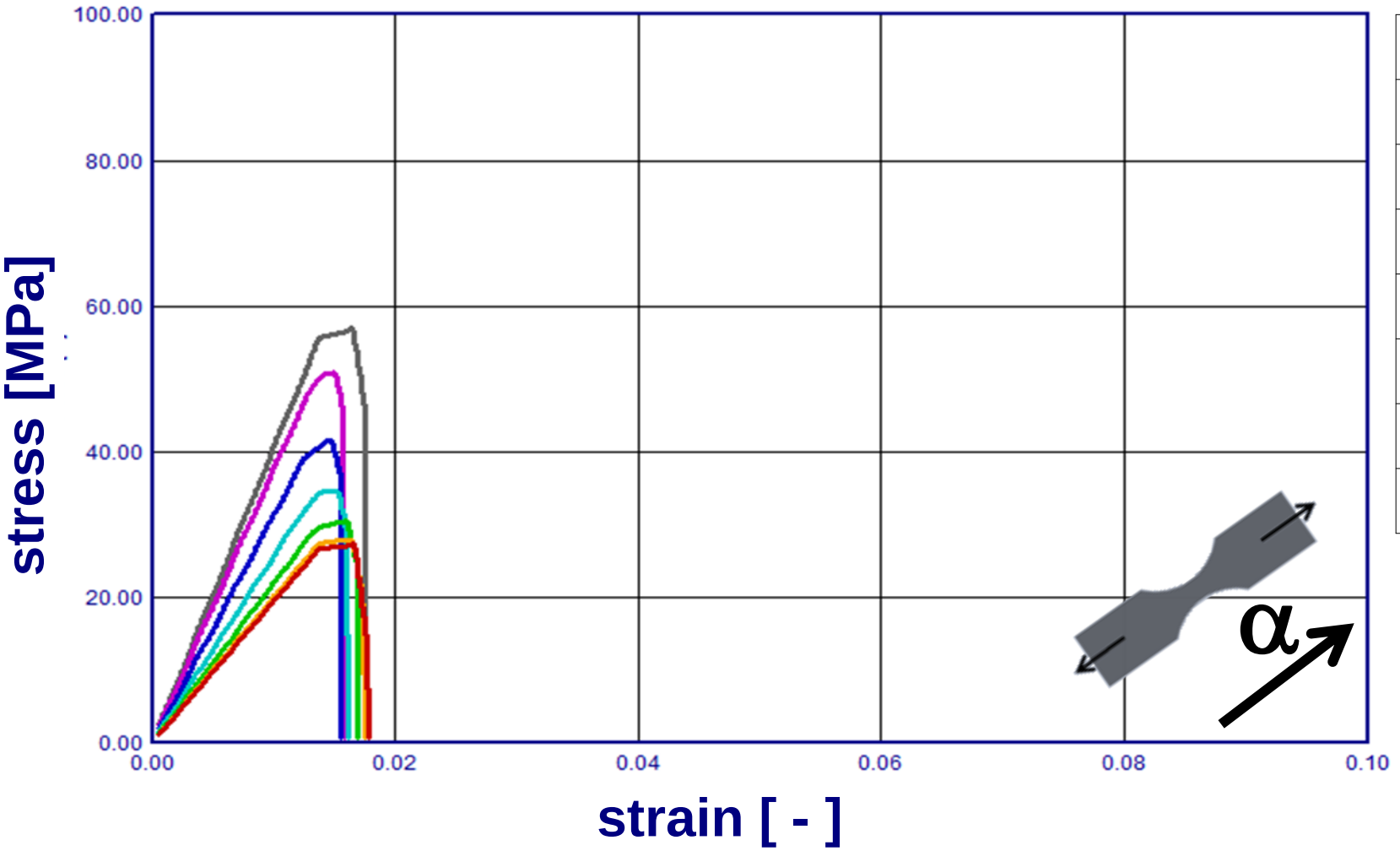
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

Simple mind model → 1- Element tension test different directions

0,3% pl. failure strain



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

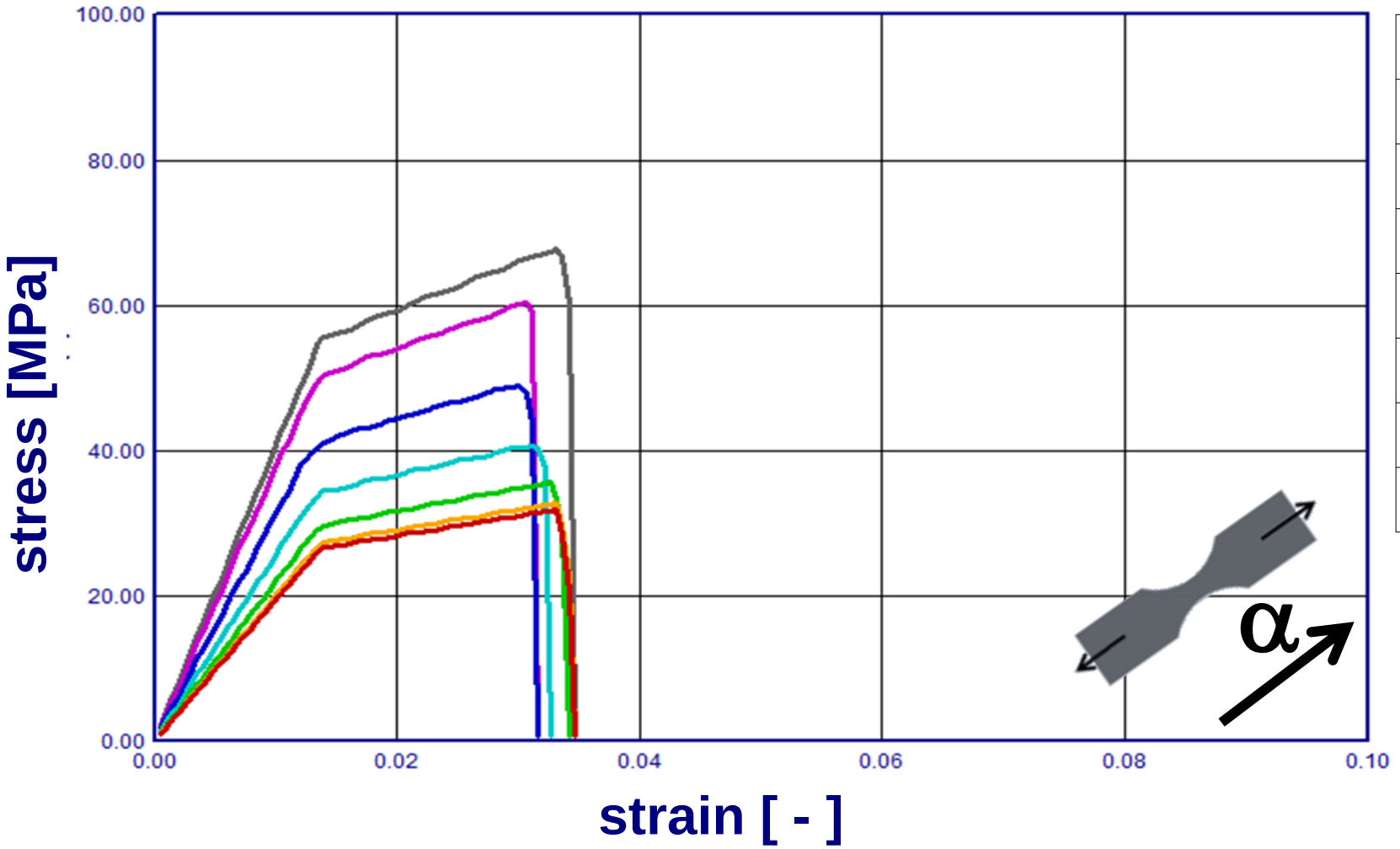
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

Simple mind model → 1- Element tension test different directions

2% pl. matrix failure strain



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

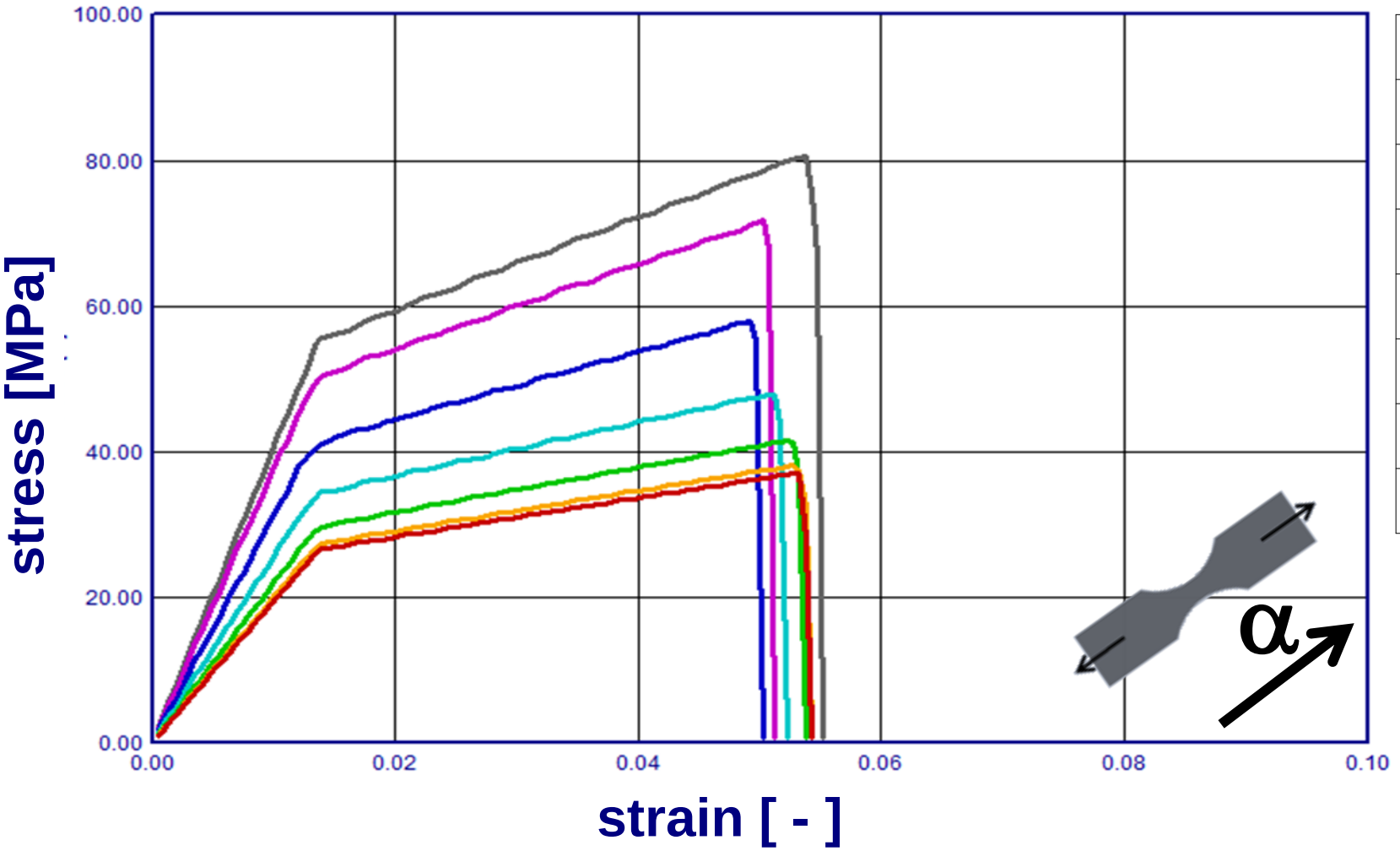
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

Simple mind model → 1- Element tension test different directions

4% pl. matrix failure strain



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

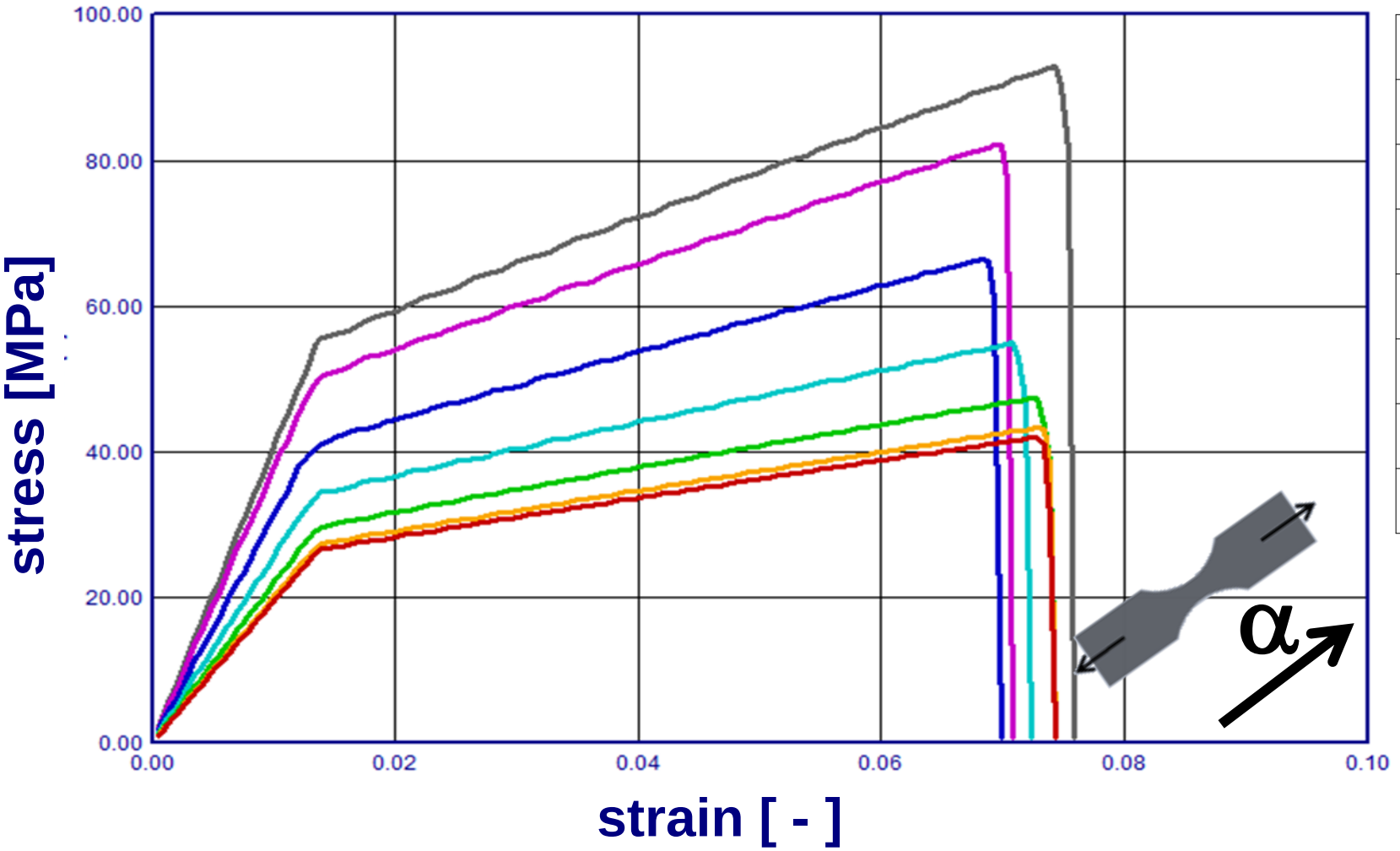
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

Simple mind model → 1- Element tension test different directions

6% pl. matrix failure strain



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

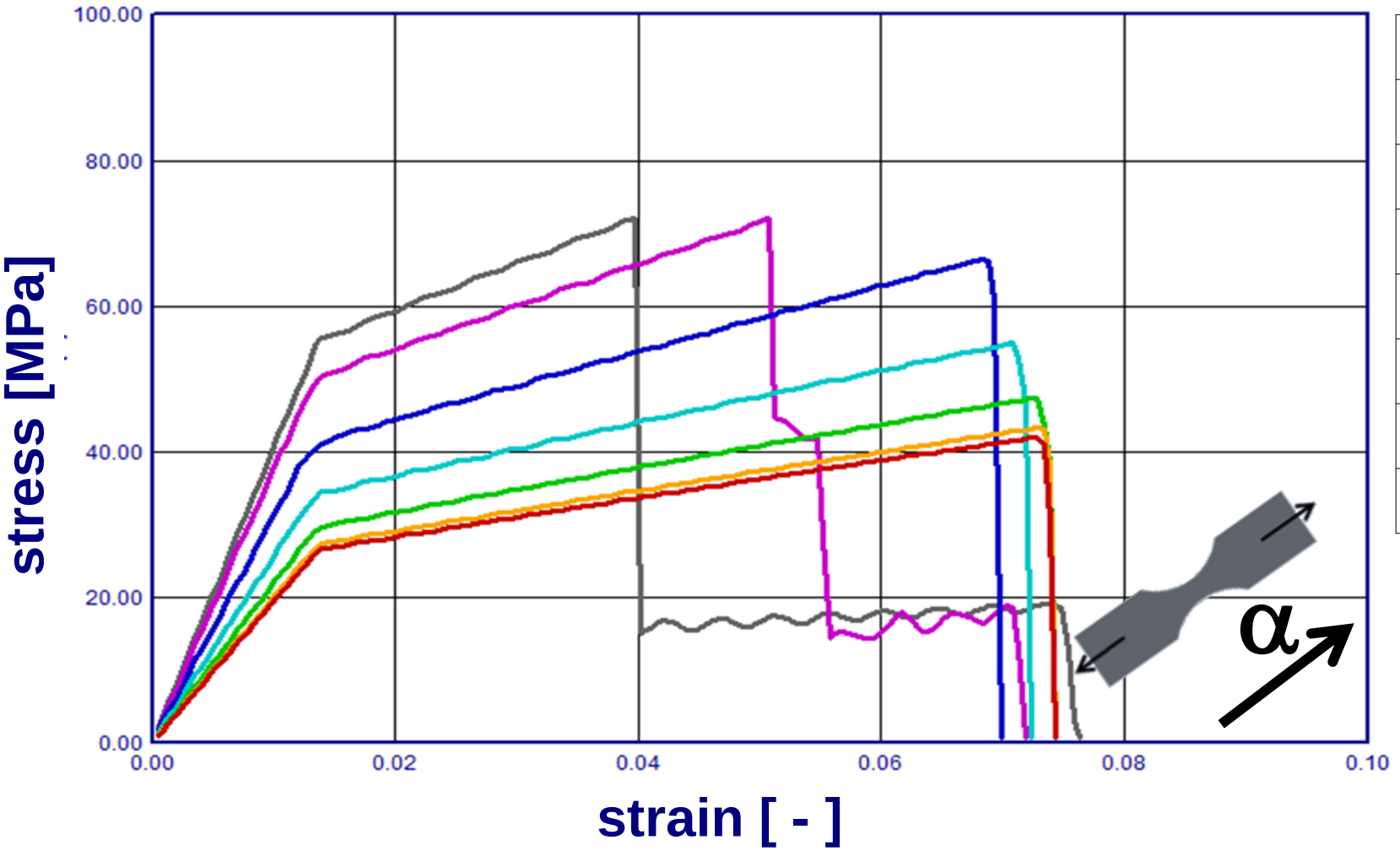
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

Simple mind model → 1- Element tension test different directions

6% pl. matrix failure strain + fiber failure (XT = 450 MPa)



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

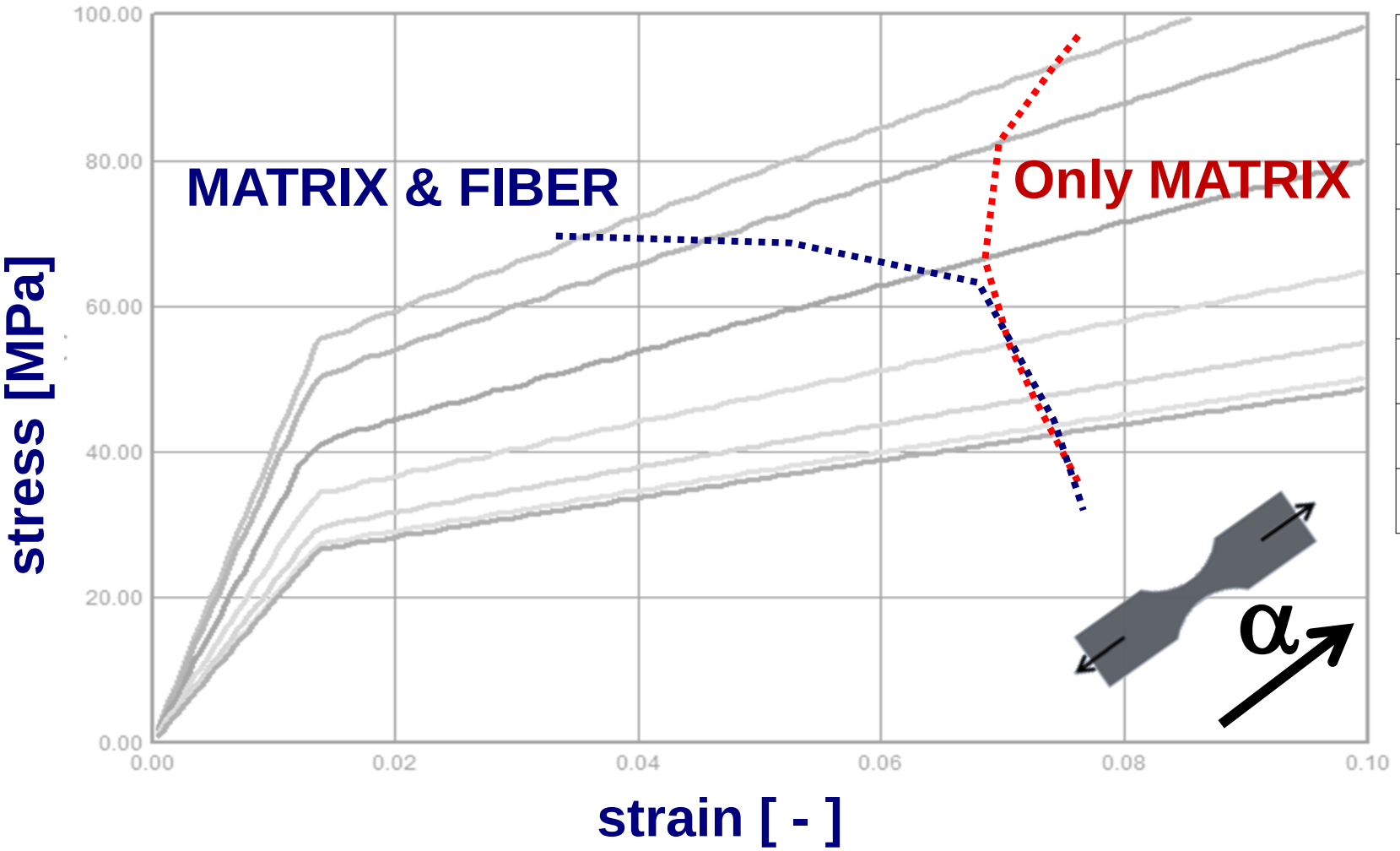
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

Simple mind model → 1- Element tension test different directions

active failure flags



α
0°
15°
30°
45°
60°
75°
90°

***MAT_215**

matrix – PP simplfied

$E_M = 1000\ MPa,$

$Y_{M,0} = 15\ MPa,$

$E_{M,T} = 100\ MPa,$

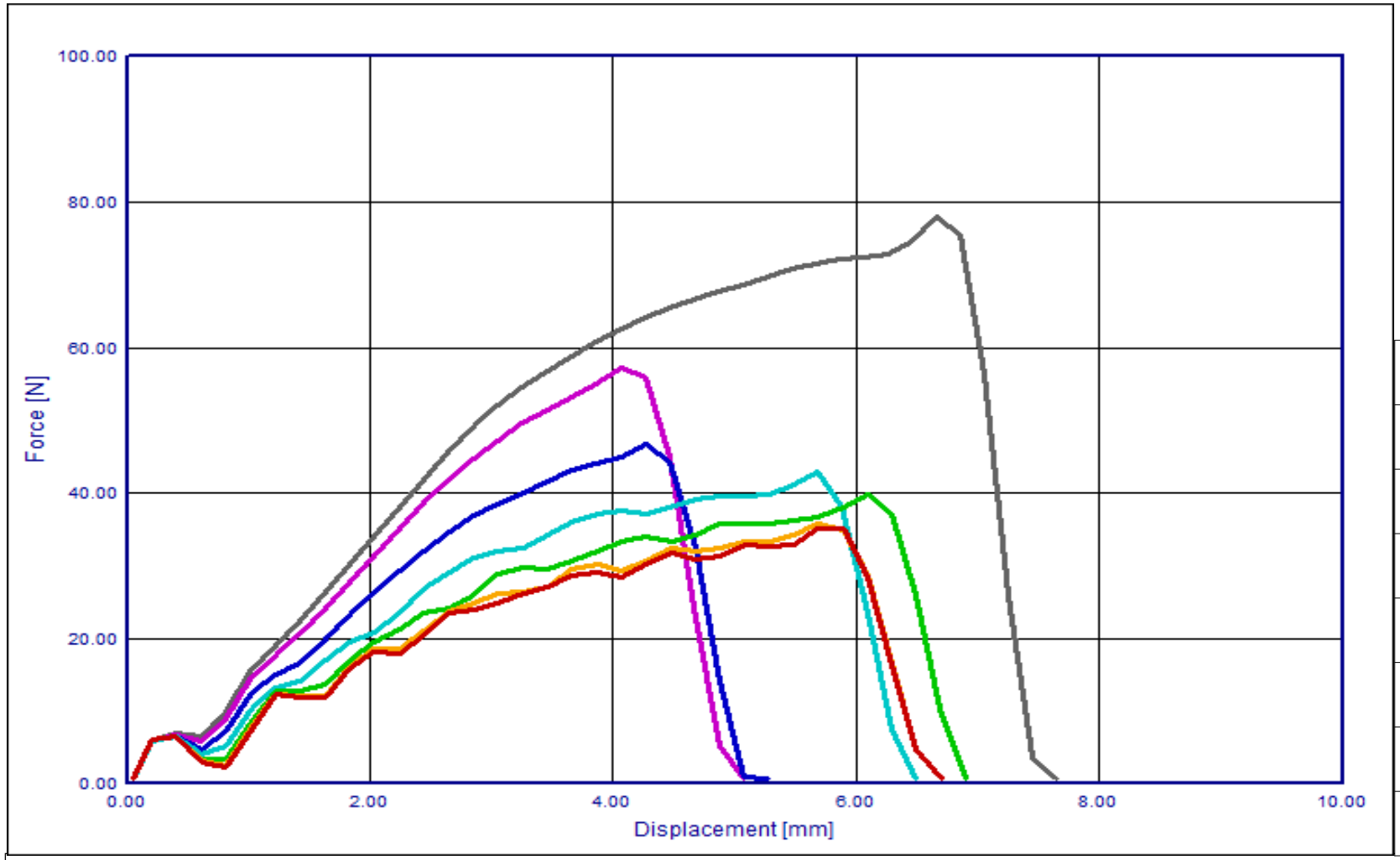
fiber - glass

$\varphi = 13\%, \frac{l}{d} = 25,$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

3point bending different directions

5% pl. matrix failure strain



α
0°
15°
30°
45°
60°
75°
90°

model 211004_035 LS DYNA LSDYNA_TEST_v1 STUDY BEND FD FAIL MAT215 FD0.05 a11k7 Bend 3mps ORIENT

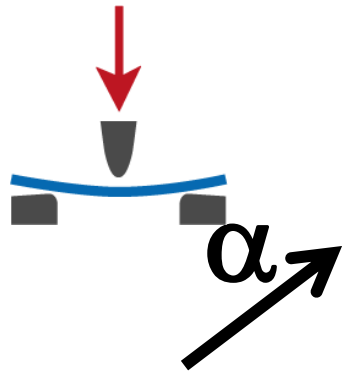
matrix – PP simplfied

$$E_M = 1000\ MPa,$$
$$Y_{M,0} = 15\ MPa,$$
$$E_{M,T} = 100\ MPa,$$

fiber - glass

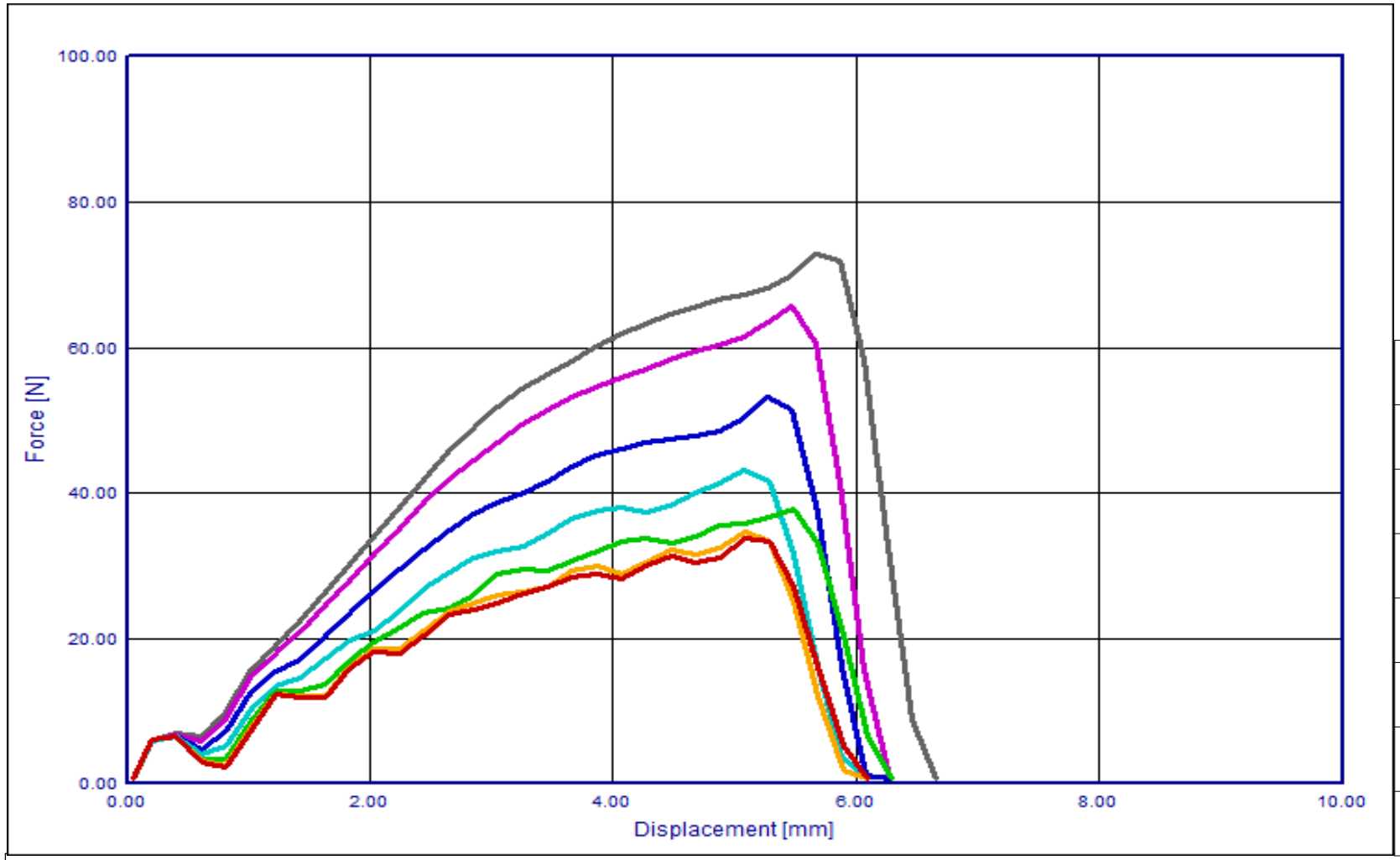
$$\varphi = 13\%, \frac{l}{d} = 25,$$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$



3point bending different directions

5% pl. matrix failure strain



α
0°
15°
30°
45°
60°
75°
90°

model 211004_036 LS DYNA LSDYNA_TEST_v1 STUDY BEND FD FAIL MAT215 FD0.05 a11k7k7 Bend 3mps ORIENT

matrix – PP simplfied

$$E_M = 1000\ MPa,$$
$$Y_{M,0} = 15\ MPa,$$
$$E_{M,T} = 100\ MPa,$$

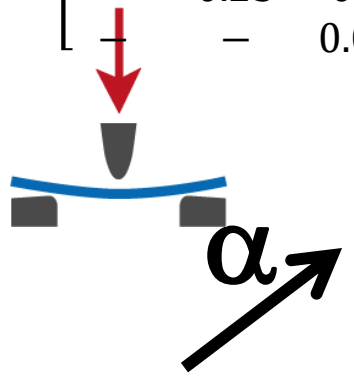
fiber - glass

$$\varphi = 13\%, \frac{l}{d} = 25,$$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

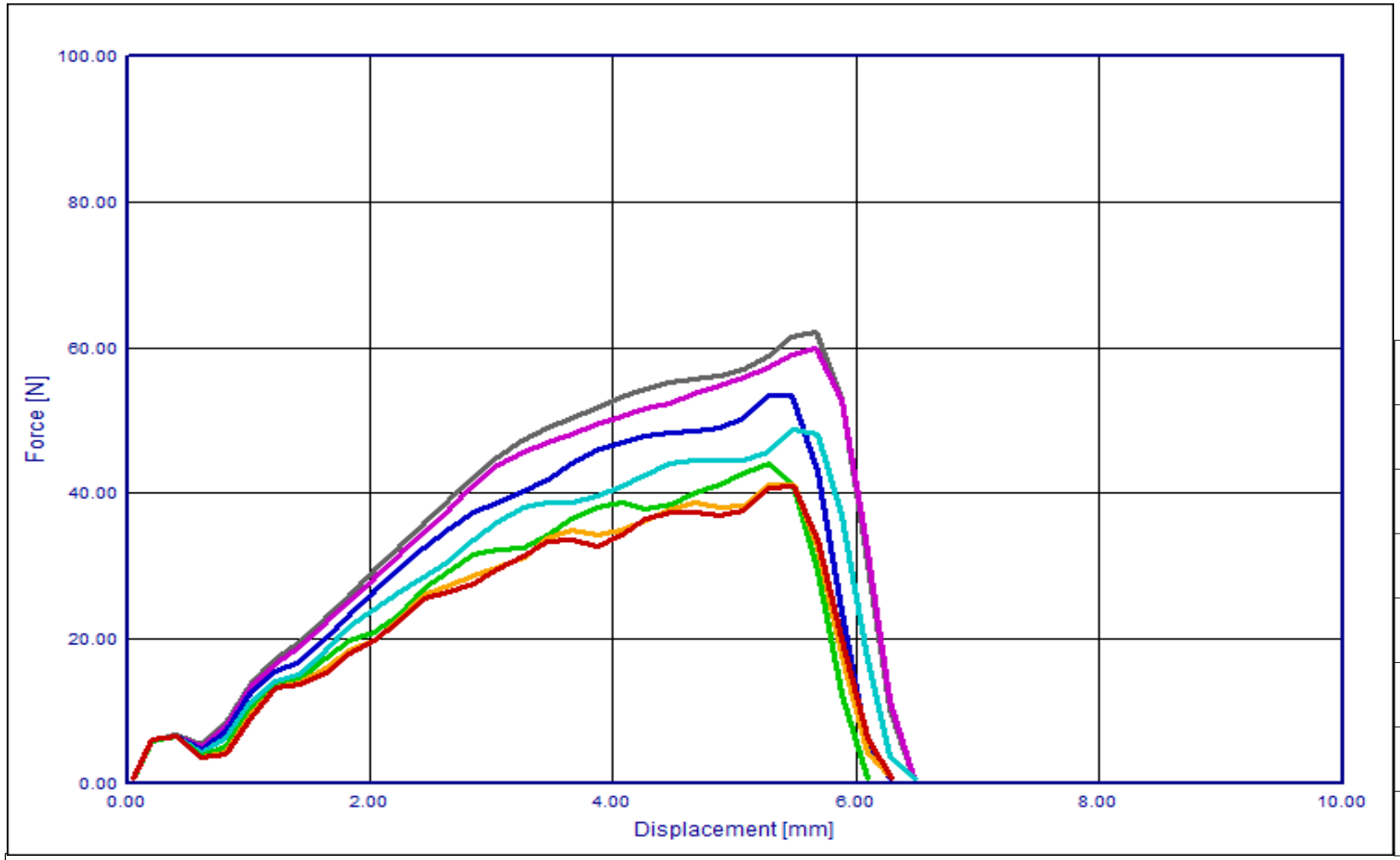
$$a_{ij} = \begin{bmatrix} 0.25 & - & - \\ - & 0.70 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$



3point bending different directions

5% pl. matrix failure strain



α
0°
15°
30°
45°
60°
75°
90°

model 211004_037 LS DYNA LSDYNA_TEST_v1 STUDY BEND FD FAIL MAT215 FD0.05 a11k6k8 Bend 3mps ORIENT

matrix – PP simplfied

$$E_M = 1000\ MPa,$$
$$Y_{M,0} = 15\ MPa,$$
$$E_{M,T} = 100\ MPa,$$

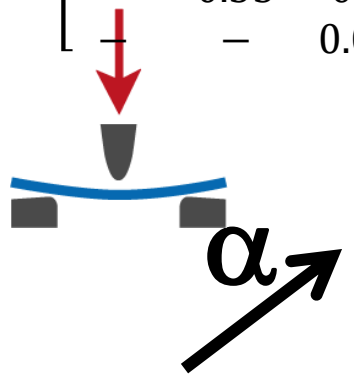
fiber - glass

$$\varphi = 13\%, \frac{l}{d} = 25,$$

$$a_{ij} = \begin{bmatrix} 0.60 & - & - \\ - & 0.55 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

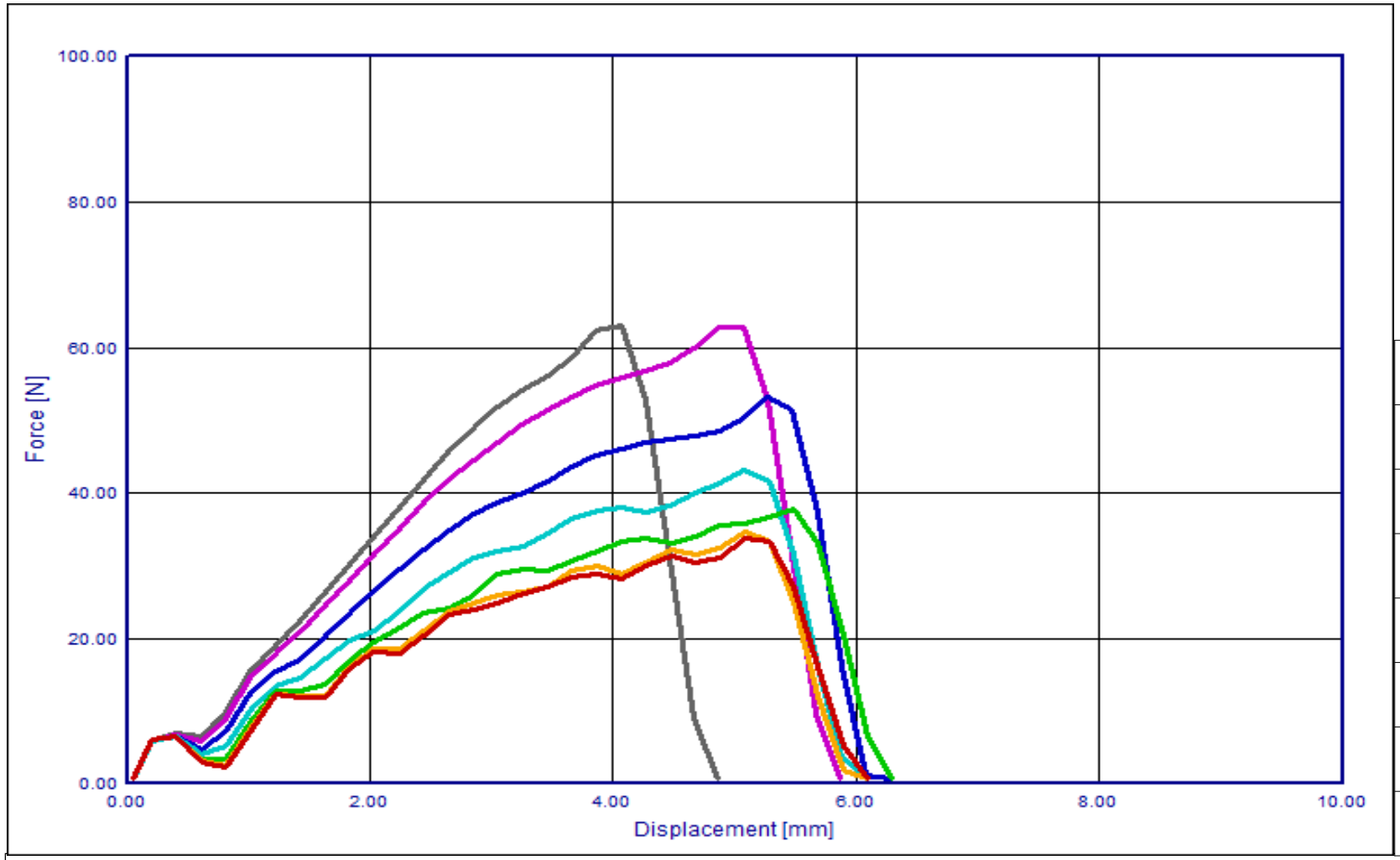
$$a_{ij} = \begin{bmatrix} 0.15 & - & - \\ - & 0.80 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

$$a_{ij} = \begin{bmatrix} 0.60 & - & - \\ - & 0.35 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$



3point bending different directions

5% pl. matrix failure strain + fiber failure (XT = 450 MPa)



α
0°
15°
30°
45°
60°
75°
90°

model 211004_038 LS DYNA LSDYNA_TEST_v1 STUDY BEND FD FAIL MAT215 FD0.05 a11k7k7 XT Bend 3mps ORIENT

matrix – PP simplfied

$$E_M = 1000\ MPa,$$
$$Y_{M,0} = 15\ MPa,$$
$$E_{M,T} = 100\ MPa,$$

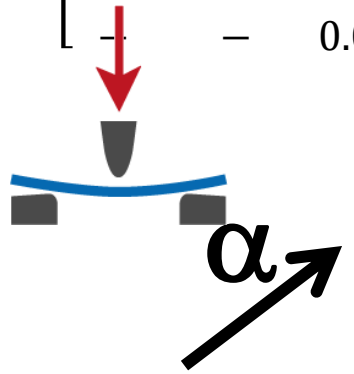
fiber - glass

$$\varphi = 13\%, \frac{l}{d} = 25,$$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

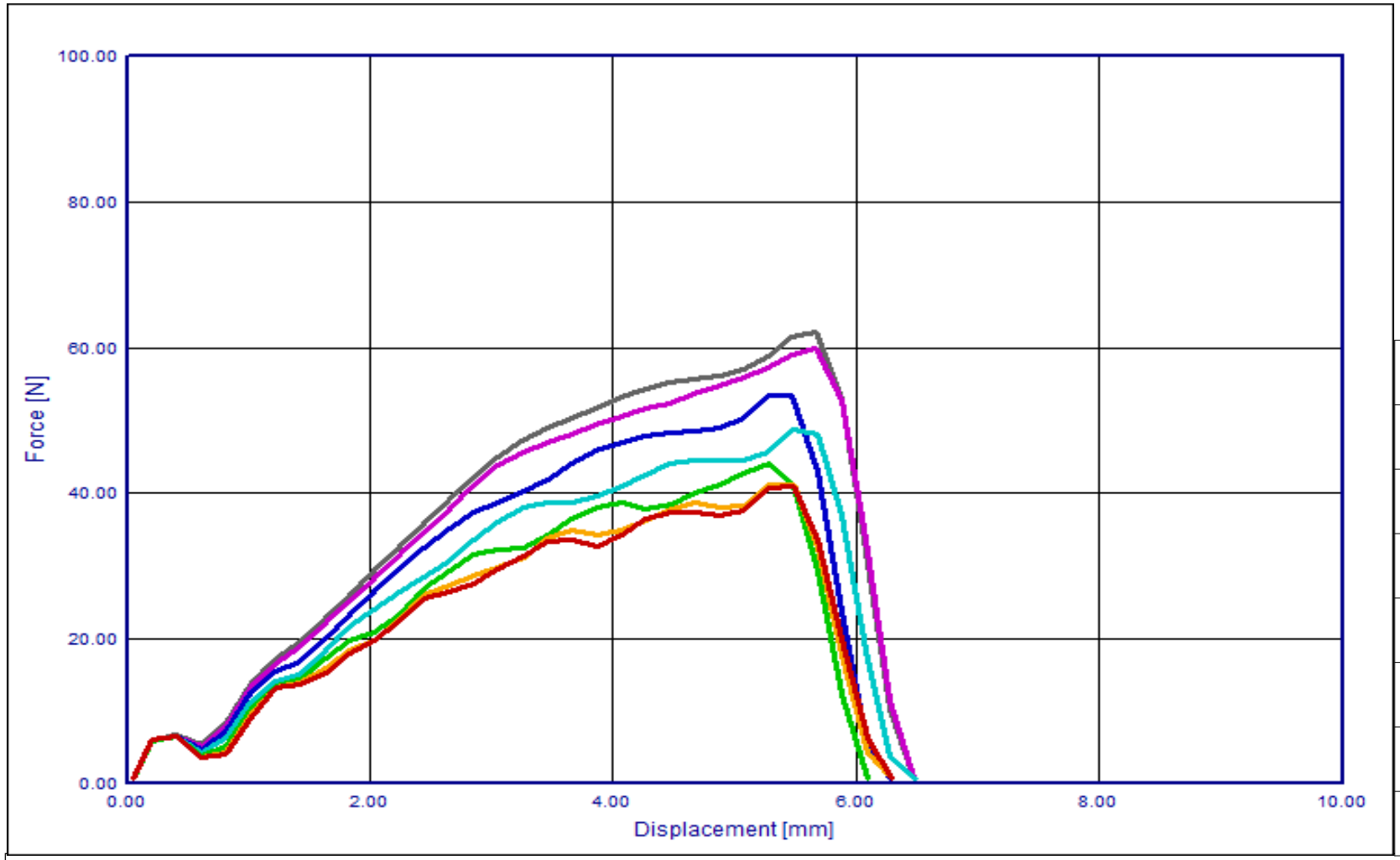
$$a_{ij} = \begin{bmatrix} 0.25 & - & - \\ - & 0.70 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

$$a_{ij} = \begin{bmatrix} 0.70 & - & - \\ - & 0.25 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$



3point bending different directions

5% pl. matrix failure strain + fiber failure (XT = 450 MPa)



α
0°
15°
30°
45°
60°
75°
90°

model 211004_039 LS DYNA LSDYNA_TEST_v1 STUDY BEND FD FAIL MAT215 FD0.05 a11k6k8 XT Bend 3mps ORIENT

matrix – PP simplfied

$$E_M = 1000\ MPa,$$
$$Y_{M,0} = 15\ MPa,$$
$$E_{M,T} = 100\ MPa,$$

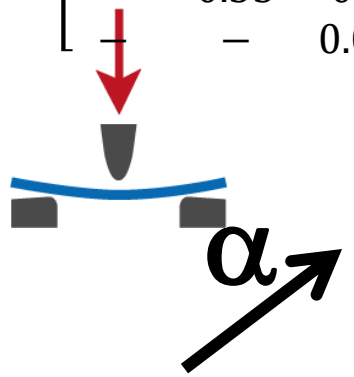
fiber - glass

$$\varphi = 13\%, \frac{l}{d} = 25,$$

$$a_{ij} = \begin{bmatrix} 0.60 & - & - \\ - & 0.55 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

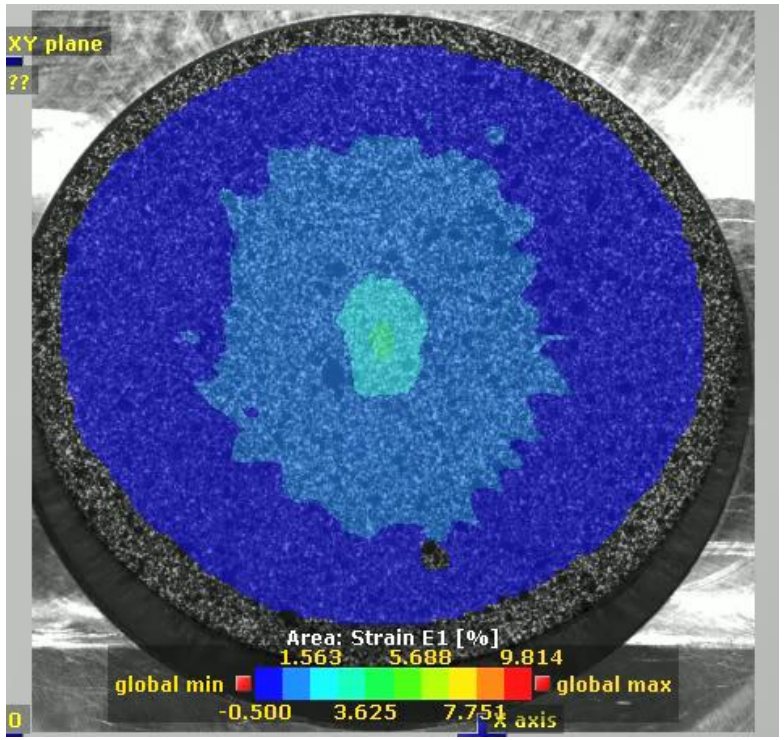
$$a_{ij} = \begin{bmatrix} 0.15 & - & - \\ - & 0.80 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$

$$a_{ij} = \begin{bmatrix} 0.60 & - & - \\ - & 0.35 & 0.0 \\ - & - & 0.05 \end{bmatrix}$$



Summary & Outlook

- advantages micro mechanical approach
  - model understands → ***fiber orientation, aspect ratio***
  - simulation process chain considering local anisotropy ***process → structural***
- Validation results (coupon and component level)
  - Good correlation in deformation behavior
  - promising results in capturing failure
    → improvement post failure especially shells
- Outlook
  - failure/damage → further research
  - DIC measurement – biaxial behavior
  - Usage for endless fiber reinforced materials



See more: Master Thesis, Christine Jantos - THM