Anisotropic Extensions of the SAMP-Model for the Simulation of UD-Composites and Organo Sheets

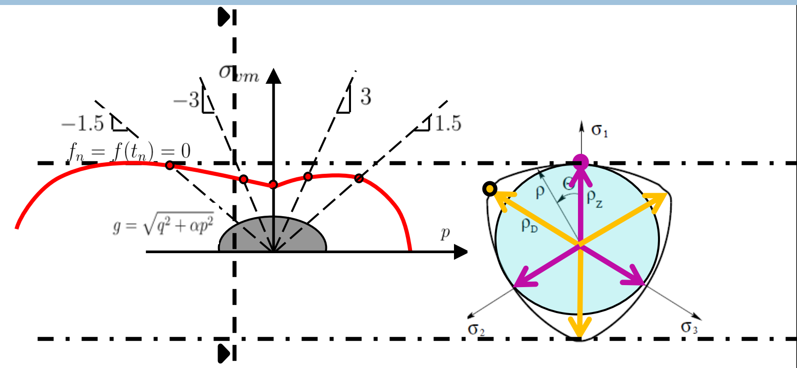
Matthias Vogler[1], Julian Schöpfer[2], Raimund Rolfes[3]

[1] Consulting Engineer, vogler.consulting@email.de

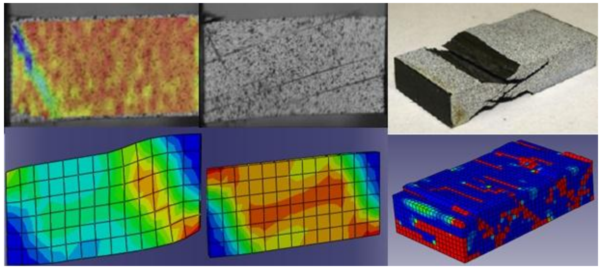
[2] Dr. Ing. h.c. F. Porsche AG

[3] Institut für Statik und Dynamik, Leibniz Universität Hannover

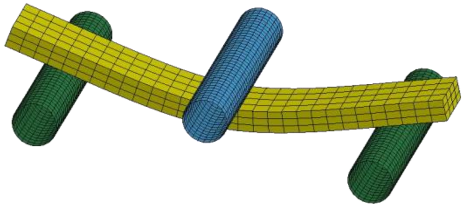
SAMP – Semi Analytical Models for Polymers

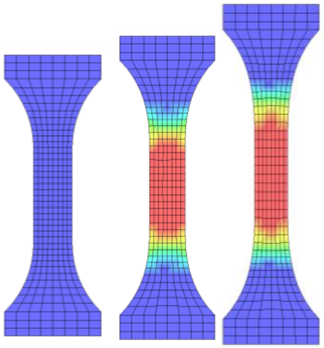


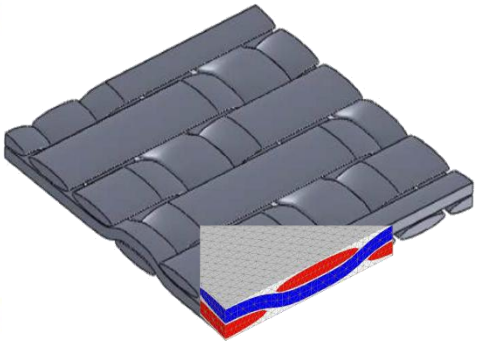
- **SAMP_isotropic**
  - **for unreinforced polymers, adhesives, epoxy resins**



- **SAMP_transversely-isotropic**
  - **for endless fiber UD-composites (carbon – epoxy, glass – epoxy)**
- **SAMP_orthotropic/anisotropic**
  - **Short fiber reinforced thermoplastics**
  - **Organic sheets, textile fabrics**

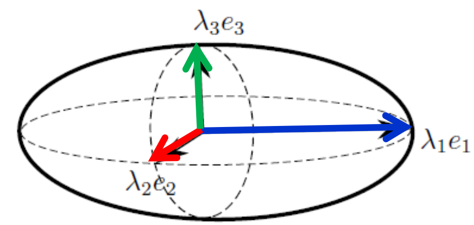




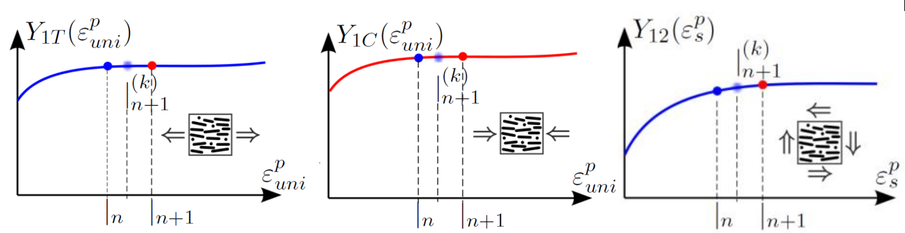


SAMP – Semi Analytical Models for Polymers

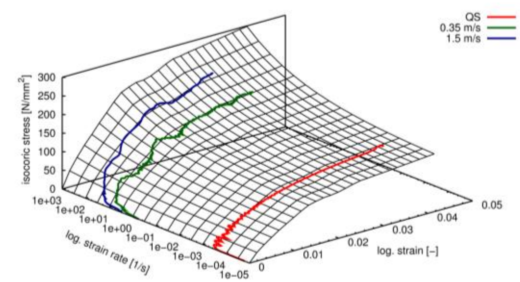
SAMP_isotropic SAMP_transversely-isotropic SAMP_anisotropic



- Anisotropy regarded by invariant formulation
  - ➡ structural tensor as additional arguments in yield surface
- Pressure dependent yielding:
  - ➡ Different yielding in compression, tension , shear and biaxial stress states



- Realistic prediction of volumetric plastic strains
- True viscoplastic formulation:
  - ➡ Parameter formulation/tabulated data
- Fully 3D formulation, applicable in shell and solid elements

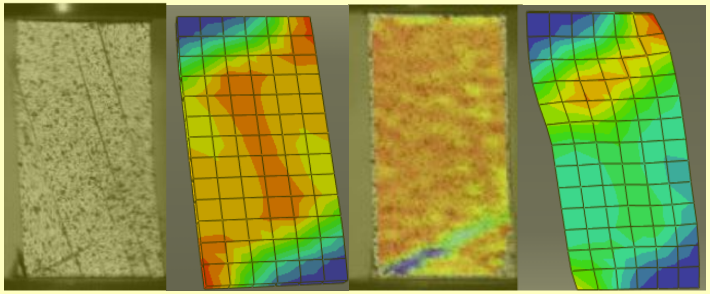


Anisotropic SAMP material models :

SAMP_transversely-isotropic / anisotropic

IM7-8552

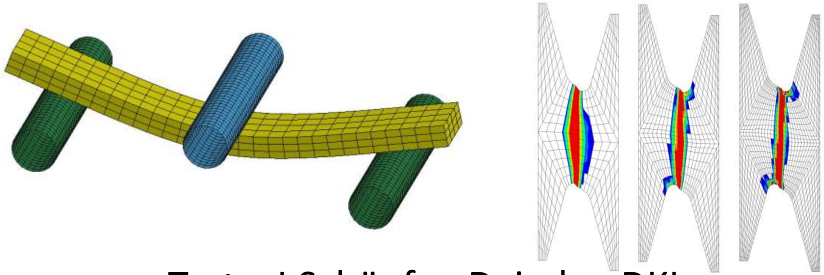
- UD carbon-epoxy
- Quasitstatic and dynamic off-axis compression tests
- High pressure tests



Tests: Camanho/Körber

PA6GF60

- Short fiber reinforced polymer
- Quasistatic tension, compression and shear tests
- Dynamic tensile tests
- Dynamic bending tests (4a Impetus)



Tests: J.Schöpfer, Daimler, DKI

SAMP transversely-isotropic: Yield surface formulation

- Decomposition of stress tensor $\boldsymbol{\sigma} = \boldsymbol{\sigma}^{\text{pind}} + \boldsymbol{\sigma}^{\text{reac}}$
- Reaction stress tensor and plasticity inducing stresses

$$\boldsymbol{\sigma}^{\text{reac}} = \underbrace{\frac{1}{2}(\operatorname{tr}\boldsymbol{\sigma} - \mathbf{a}\boldsymbol{\sigma}\mathbf{a})}_{p}\,\mathbf{1} - \underbrace{\frac{1}{2}(\operatorname{tr}\boldsymbol{\sigma} - 3\mathbf{a}\boldsymbol{\sigma}\mathbf{a})}_{T_a}\,\mathbf{A}$$

$$\boldsymbol{\sigma}^{\text{pind}} = \boldsymbol{\sigma} - \frac{1}{2}(\operatorname{tr}\boldsymbol{\sigma} - \mathbf{a}\boldsymbol{\sigma}\mathbf{a})\mathbf{1} + \frac{1}{2}(\operatorname{tr}\boldsymbol{\sigma} - 3\mathbf{a}\boldsymbol{\sigma}\mathbf{a})\mathbf{A}$$

- Deviatoric stresses $\boldsymbol{\sigma}^{\text{dev}} := \boldsymbol{\sigma} - \frac{1}{3}\operatorname{tr}\boldsymbol{\sigma}$
- Invariants

$$I_1 := \frac{1}{2}\operatorname{tr}\left(\boldsymbol{\sigma}^{\text{pind}}\right)^2 - \mathbf{a}\left(\boldsymbol{\sigma}^{\text{pind}}\right)^2\mathbf{a} \qquad I_3 := \operatorname{tr}\boldsymbol{\sigma} - \mathbf{a}\boldsymbol{\sigma}\mathbf{a}$$

$$I_2 := \mathbf{a}\left(\boldsymbol{\sigma}^{\text{pind}}\right)^2\mathbf{a} \qquad I_4 := \frac{3}{2}\mathbf{a}\boldsymbol{\sigma}^{\text{dev}}\mathbf{a} = T_a\mathbf{a}$$

- Transversely-isotropic yield surface

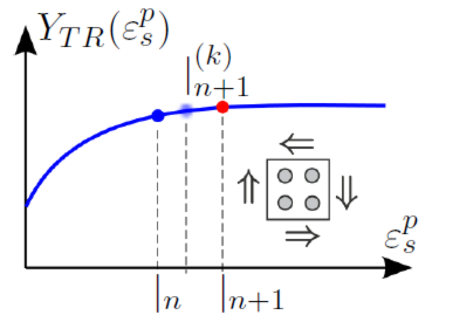
$$f = \alpha_1 I_1 + \alpha_2 I_2 + \alpha_3 I_3 + \alpha_{32} I_3^2 + \alpha_4 I_4 + \alpha_{42} I_4^2 - 1$$

6 yield parameters → 6 material tests necessary

SAMP transversely-isotropic: Parameter identification

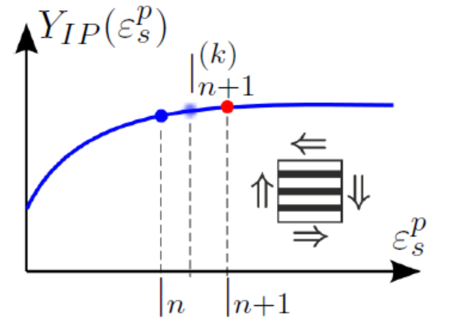
$$f = \alpha_1 I_1 + \alpha_2 I_2 + \alpha_3 I_3 + \alpha_{32} I_3^2 + \alpha_4 I_4 + \alpha_{42} I_4^2 - 1$$

transverse shear



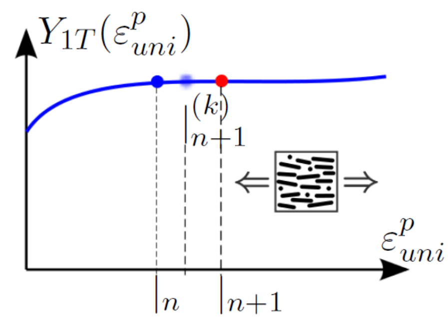
$\Rightarrow \alpha_1$

in-plane shear

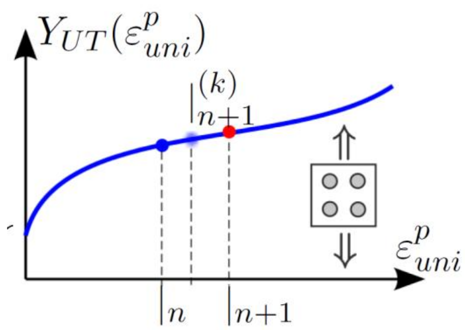


$\Rightarrow \alpha_2$

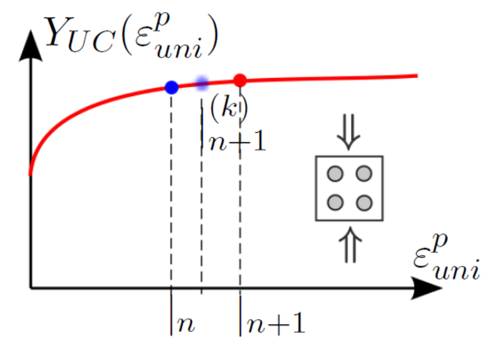
uniaxial tension



uniaxial tension

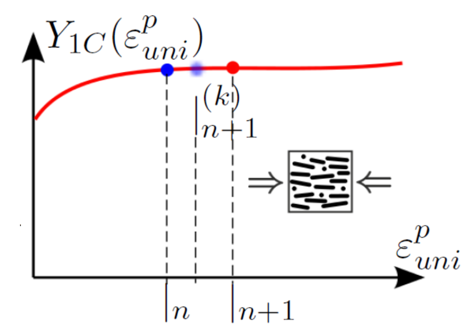


uniaxial compression



$\Rightarrow \alpha_{32}, \alpha_3$

uniaxial compression

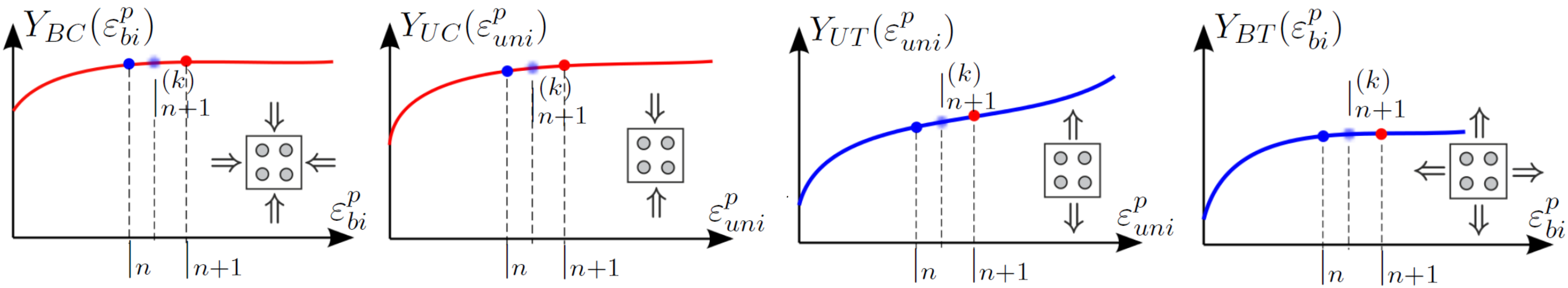


$\Rightarrow \alpha_4, \alpha_{42}$

SAMP transversely-isotropic: Parameter identification

$$f = \alpha_1 I_1 + \alpha_2 I_2 + \alpha_3 I_3 + \alpha_{32} I_3^2 + \alpha_4 I_4 + \alpha_{42} I_4^2 - 1$$

$$I_3 \leq 0 \qquad\qquad I_3 > 0$$



$$\alpha_{32}^c := \frac{1 - \frac{Y_T}{2Y_{BT}} - \alpha_1 \frac{Y_T^2}{4} - \alpha_{42}\left(\frac{Y_T^2}{4} - \frac{Y_{BT} Y_T}{2}\right)}{Y_T^2 - 2Y_{BT} Y_T}$$

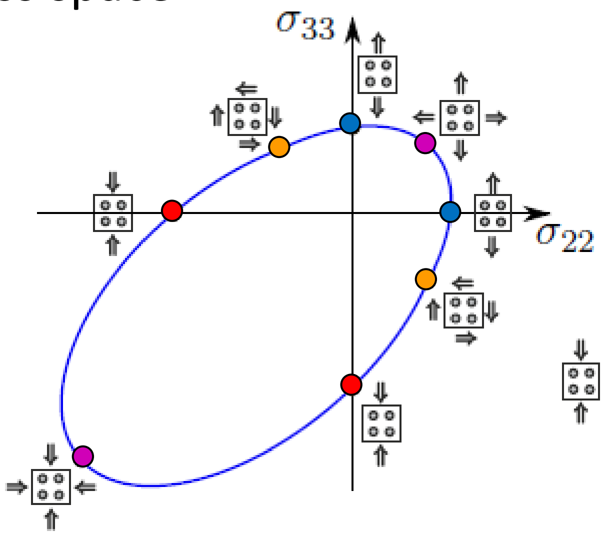
$$\alpha_{32}^t := \frac{1 - \frac{Y_T}{2Y_{BT}} - \alpha_1 \frac{Y_T^2}{4} - \alpha_{42}\left(\frac{Y_T^2}{4} - \frac{Y_{BT} Y_T}{2}\right)}{Y_T^2 - 2Y_{BT} Y_T}$$

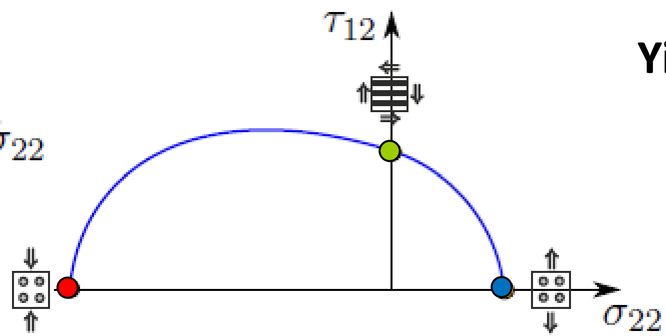
$$\alpha_3^c := -\frac{1}{2Y_{BT}} + 2\alpha_{32}^c Y_{BT} + \alpha_4 \frac{1}{2} + \alpha_{42} \frac{Y_{BT}}{2}$$

$$\alpha_3^t := \frac{1}{2Y_{BT}} - 2\alpha_{32}^t Y_{BT} + \alpha_4 \frac{1}{2} - \alpha_{42} \frac{Y_{BT}}{2}$$

SAMP transversely-isotropic: Representation of yield locus in..

.. Stress space

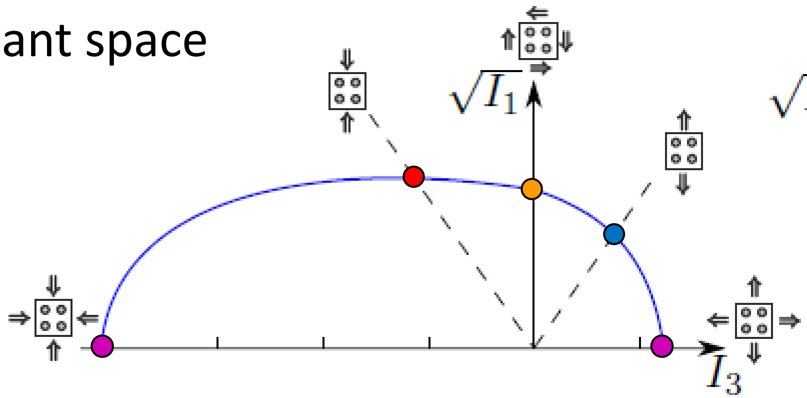


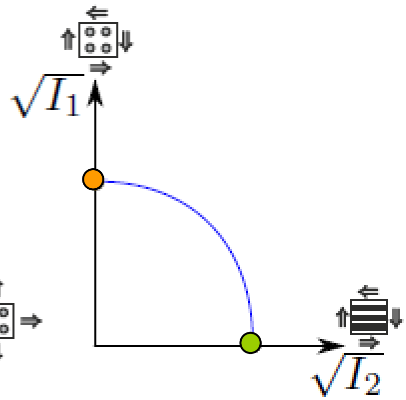


Yielding controlled in:

- Uniaxial tension transverse
- Uniaxial compr. transverse
- Transverse shear
- In-plane shear
- Biaxial tension transverse
- Biaxial compr. transverse

.. Invariant space





Uniaxial tension fiber direct.

Uniaxial compr. fiber direct

SAMP transversely-isotropic: Numerical treatment

- Yield surface

$$f = \alpha_1 I_1 + \alpha_2 I_2 + \alpha_3 I_3 + \alpha_{32} I_3^2 + \alpha_4 I_4^2 - 1$$

$$f = \frac{1}{2}\boldsymbol{\sigma} : \mathbb{A} : \boldsymbol{\sigma} + \mathbf{B} : \boldsymbol{\sigma} - 1$$

- Operator-Split

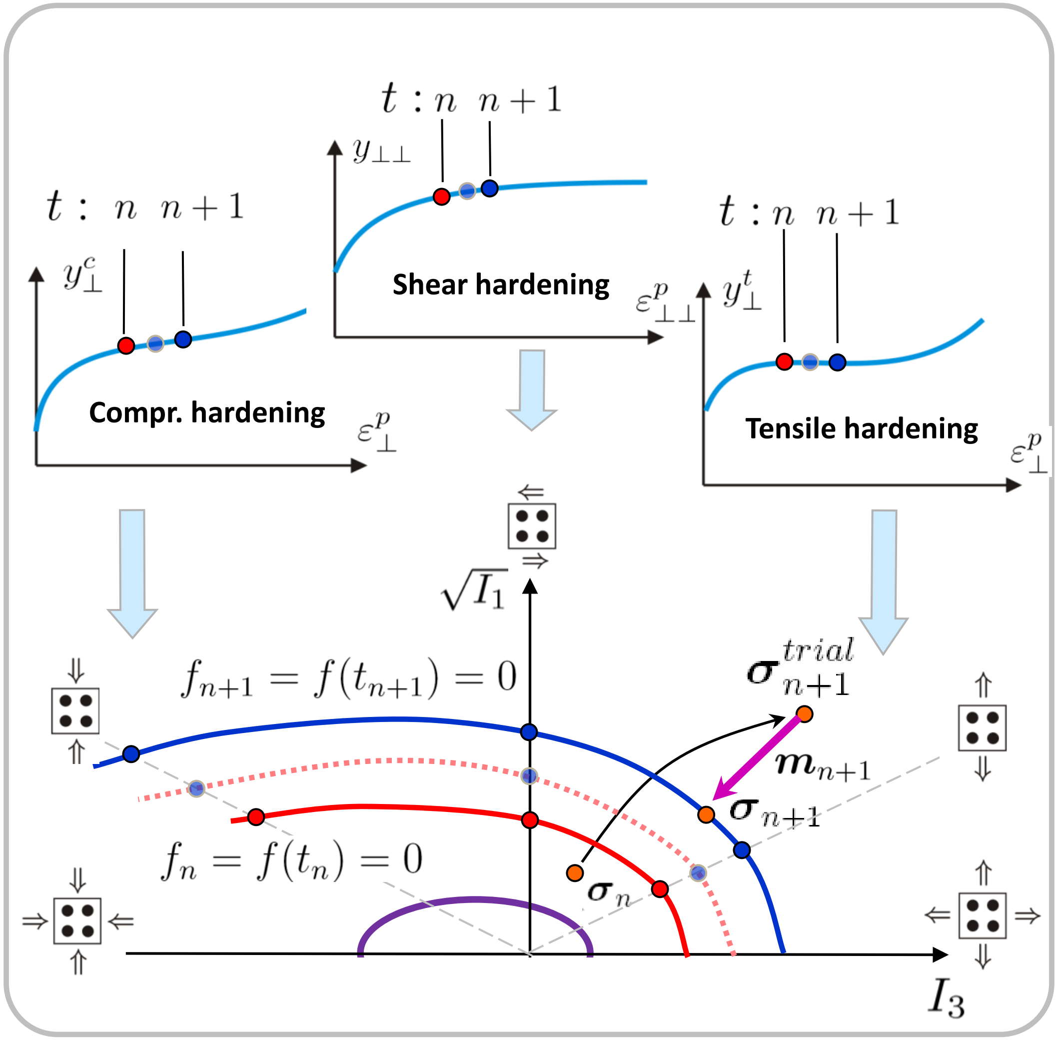
$$\begin{aligned} \boldsymbol{\sigma}_{n+1}^{tr} &= \mathbb{C}_e : \boldsymbol{\varepsilon}^{tr} \\ &= \boldsymbol{\sigma}_{n+1} + \gamma_{n+1}\mathbb{C}_e : \partial_{\boldsymbol{\sigma}} f \\ &= \boldsymbol{\sigma}_{n+1} + \gamma_{n+1}\mathbb{C}_e : [\mathbb{A} : \boldsymbol{\sigma} + \mathbf{B}] \\ &= [\mathbb{I} + \gamma_{n+1}\mathbb{C}_e : \mathbb{A}]\, \boldsymbol{\sigma}_{n+1} + \gamma_{n+1}\mathbb{C}_e : \mathbf{B} \end{aligned}$$

$$f_{n+1} = \frac{1}{2}\boldsymbol{\sigma}_{n+1} : \mathbb{A} : \boldsymbol{\sigma}_{n+1} + \mathbf{B} : \boldsymbol{\sigma}_{n+1} - 1 = 0$$

- Non-associated flow rule - plastic potential :

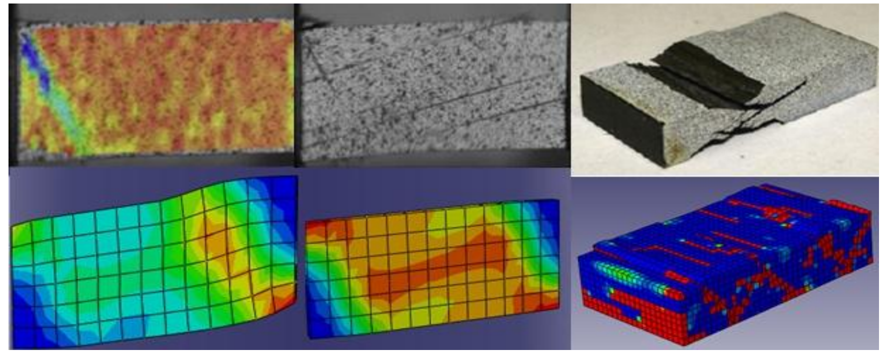
$$g = \beta_1 I_1 + \beta_2 I_2 + \beta_3 I_3 + \beta_{32} I_3^2 + \beta_4 I_4^2 - 1$$

$$\boldsymbol{\varepsilon}_{n+1}^p = \boldsymbol{\varepsilon}_n + \gamma_{n+1} \partial g(\boldsymbol{\sigma}_{\mathbf{n+1}}) / \partial \boldsymbol{\sigma}_{\mathbf{n+1}}$$



IM7-8552: Off-axis compression tests and triaxial tests

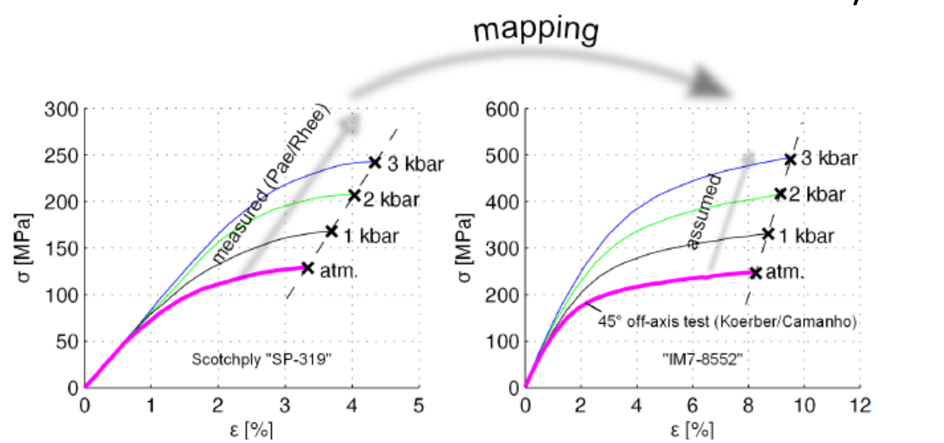
UD carbon-epoxy: IM7-8552



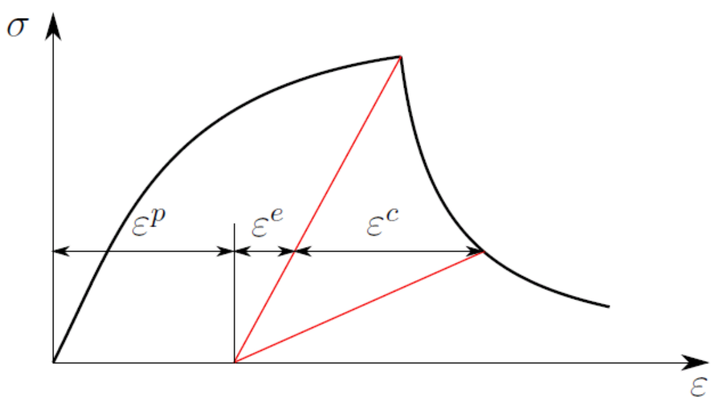
Tests: Camanho/Körber

•Quasi-static and dynamic off-axis compression tests

•Uniaxial compression tests under various levels of hydrostatic pressure



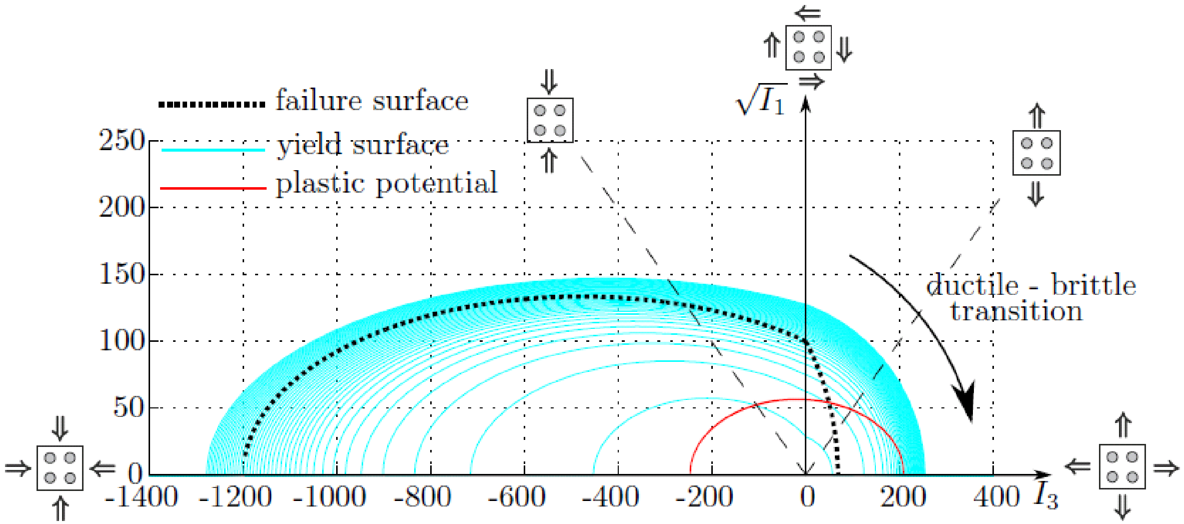
Tests: Pae/Rhee

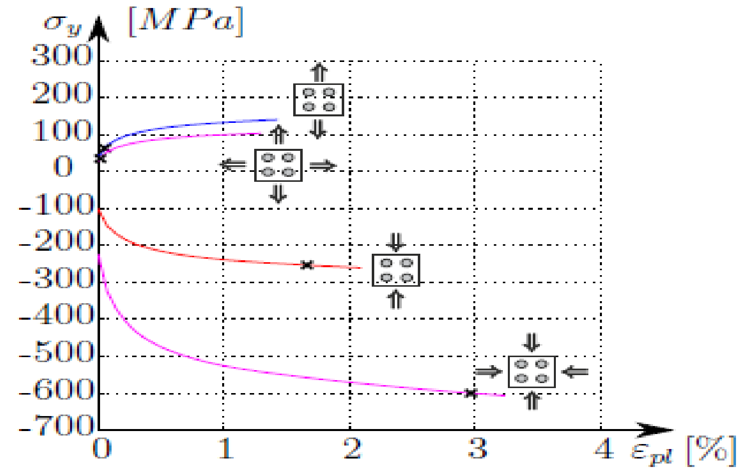


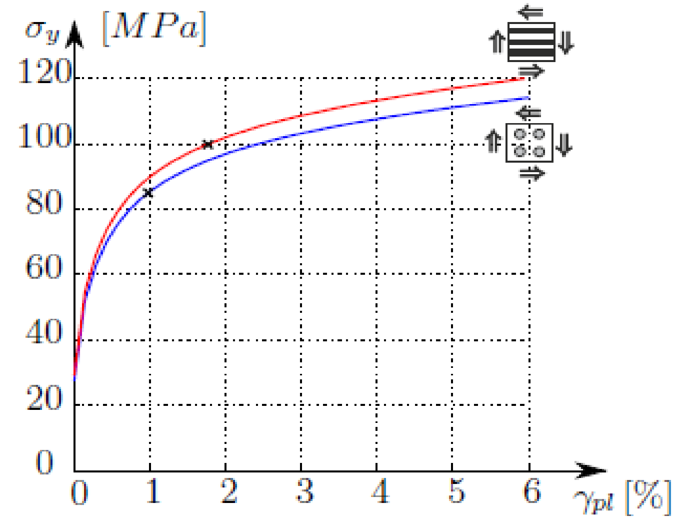
…..smeared crack model (collaboration with Pedro Camanho, Universidade do Porto)

SAMP_transversely-isotropic for UD composites

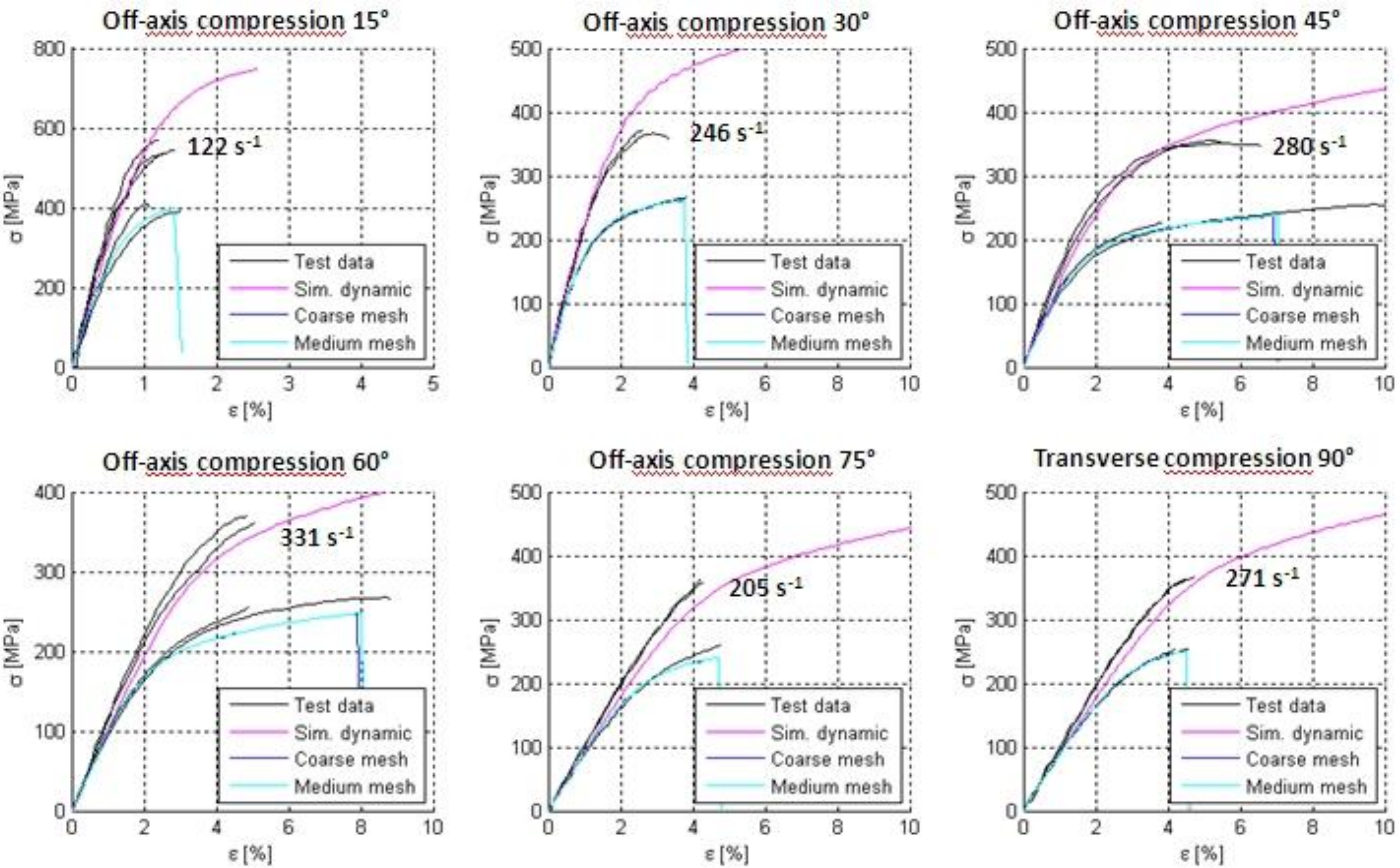
Hardening curves, feed into material law:





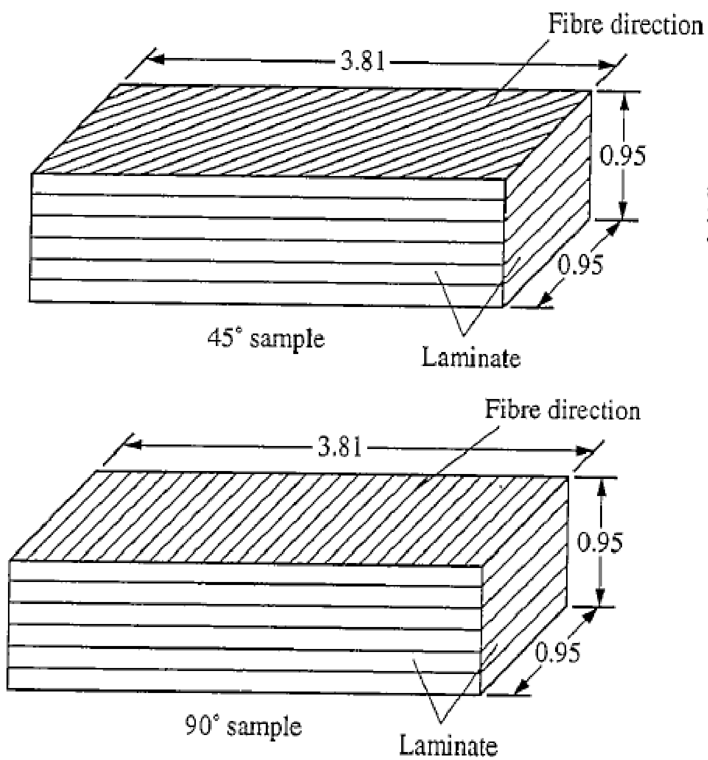


IM7-8552: Quasi-static and dynamic off-axis compression tests

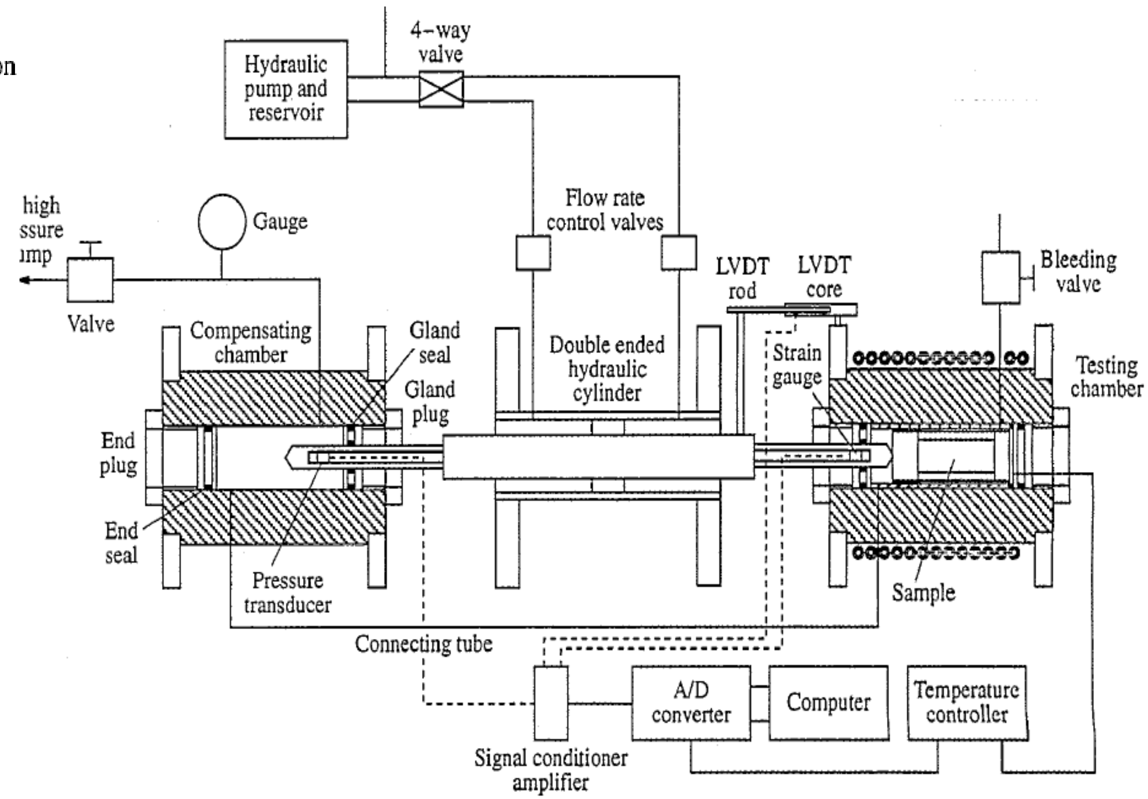


IM7-8552: Triaxial tests – Test set-up

Test specimen



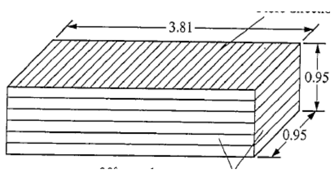
Test apparatus

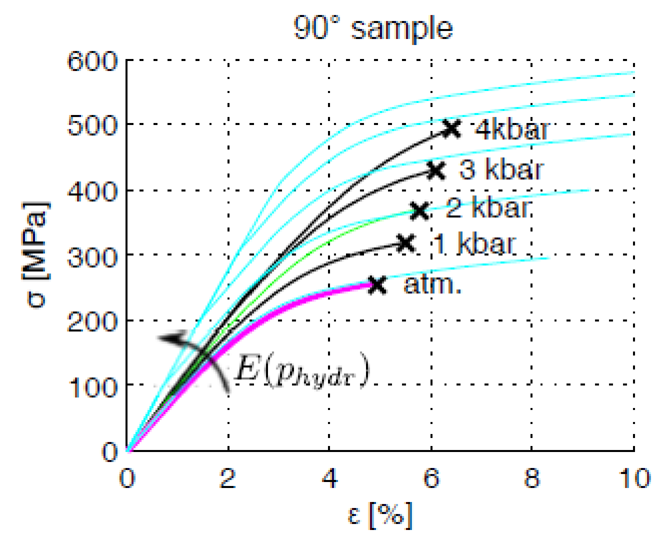


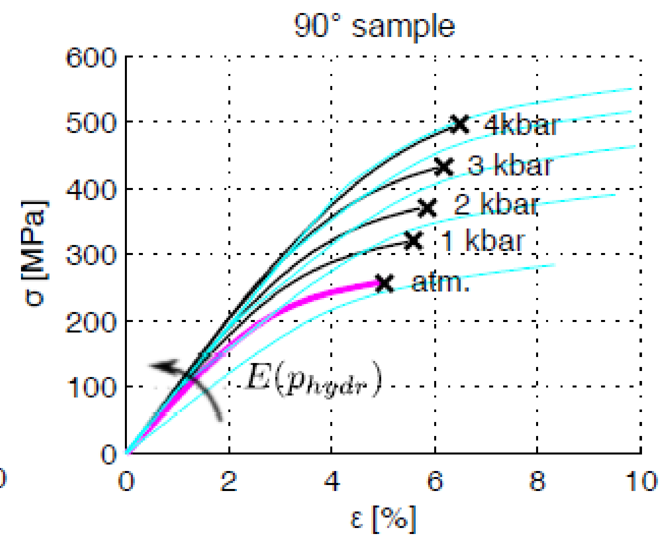
K.D. Pae & K.Y. Rhee : „Effects of hydrostatic pressure on the compressive behavior of thick laminated 45° and 90° unidirectional graphite-fiber/epoxy matrix composites“

IM7-8552: Triaxial tests

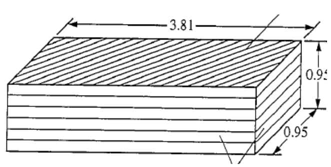
90° sample

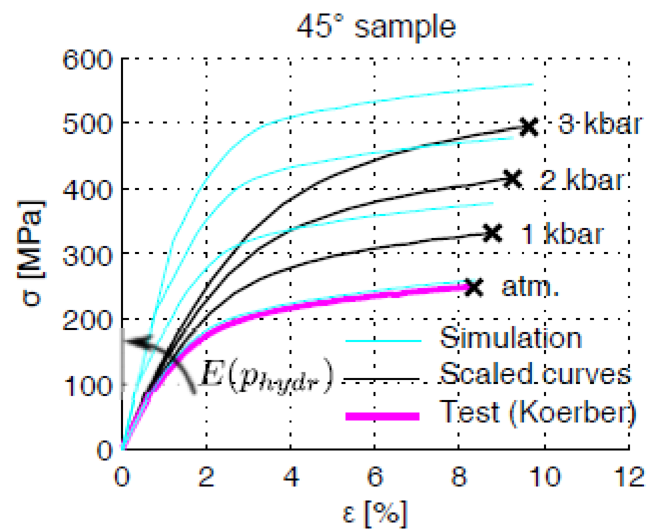


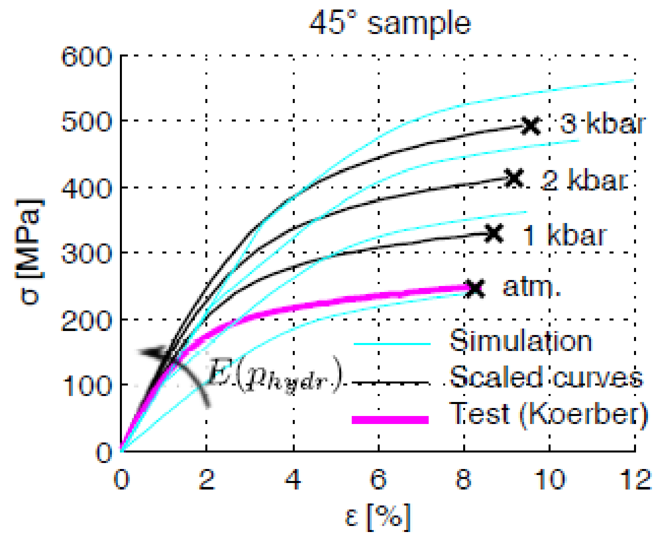




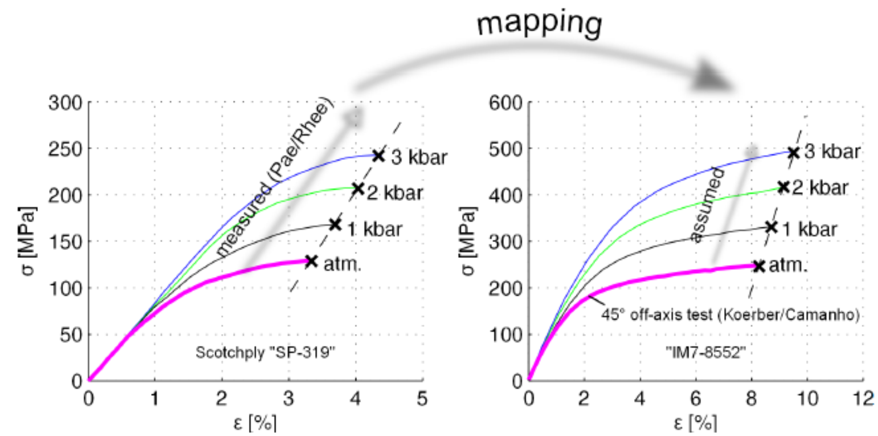
45° sample

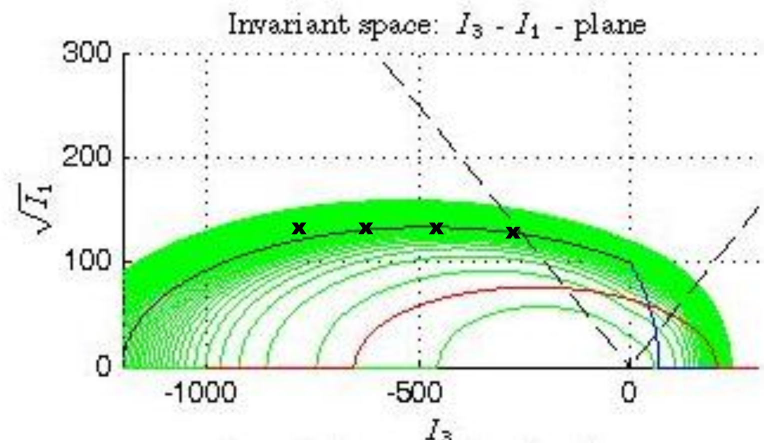


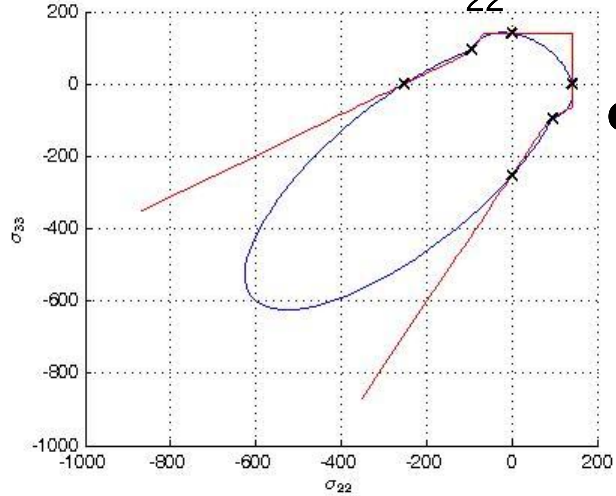


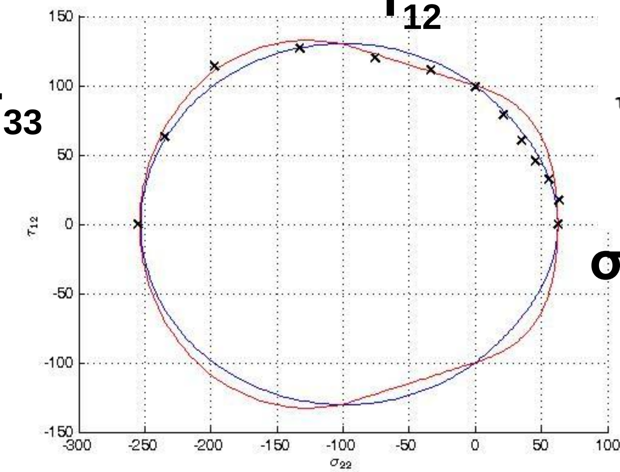


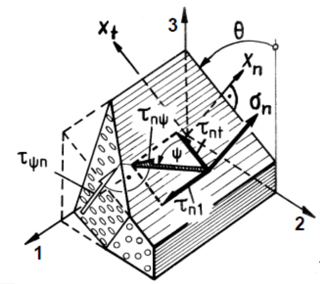
IM7-8552: Failure surface











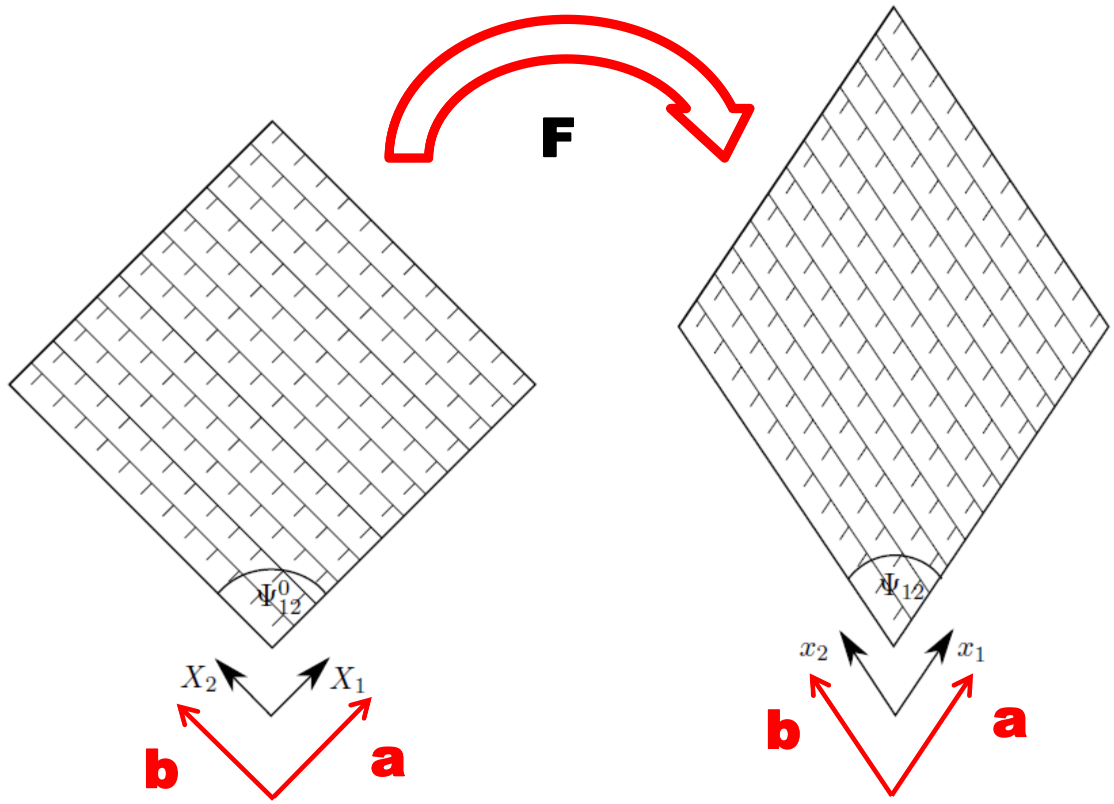
$$\begin{bmatrix}\sigma_n\\ \tau_{nt}\\ \tau_{n1}\end{bmatrix} = \begin{bmatrix} c^2 & s^2 & 2cs & 0 & 0\\ -sc & sc & \left(c^2-s^2\right) & 0 & 0\\ 0 & 0 & 0 & s & c\end{bmatrix} \cdot \begin{bmatrix}\sigma_2\\ \sigma_3\\ \tau_{23}\\ \tau_{31}\\ \tau_{21}\end{bmatrix}$$

Invariant based criterion

Puck

SAMP anisotropic: Modeling Fabrics

•Rotation of yarn directions can be modeled with SAMP_anisotropic



PART_FABRIC

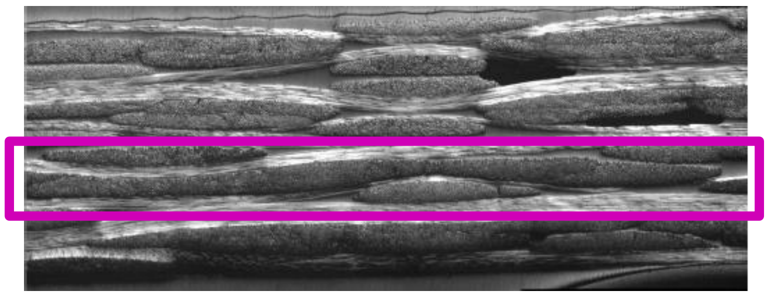
… for layerwise assembly of fabrics

Process chain :

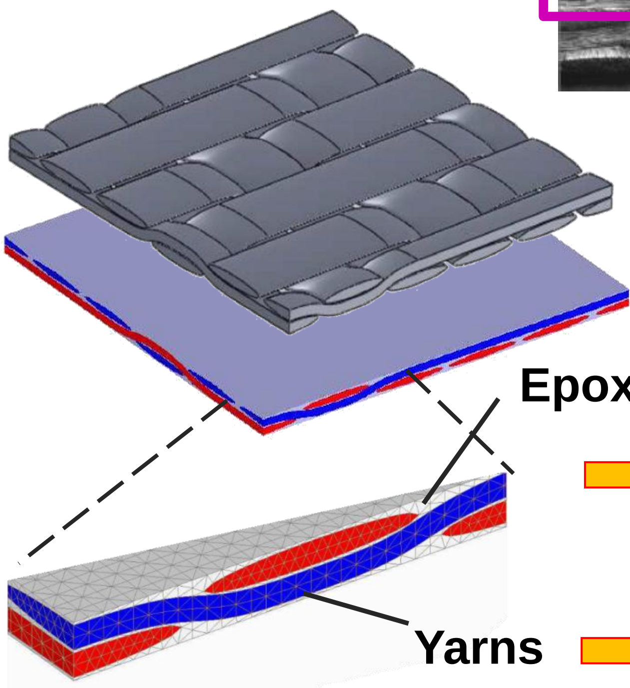
Drape simulation → Forming simulation → Crash Simulation

SAMP anisotropic: Modeling Fabrics

5 harness satin

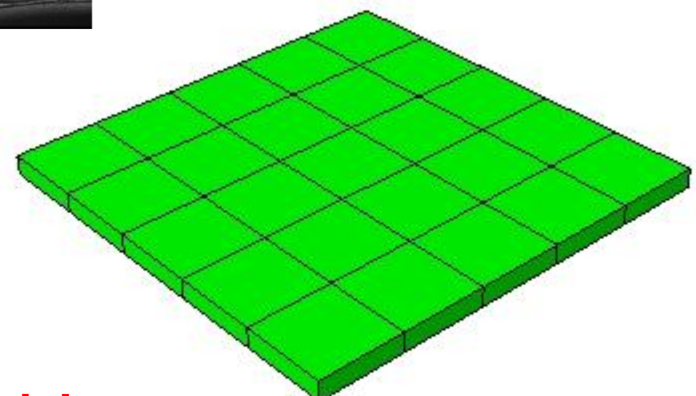


Meso level: RVE



Homogenization

Macro level



Homogenized layer

Isotropic SAMP model

Transversely-isotropic SAMP model

Anisotropic SAMP model

Collaboration with Antonio Melro and Pedro Camanho, Faculdade de Engenharia, Universidade do Porto

Summary

Objective: DYNA Implementation of anisotropic SAMP Material Models

- **SAMP_transversely-isotropic..**

  ..for UD composites :

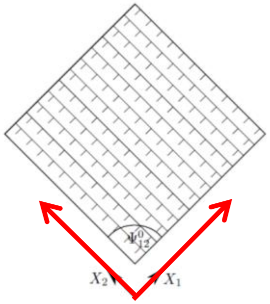
  - Coupling with failure criteria / degradation laws (Collaboration with Pedro Camanho, Faculdade de Engenharia da Universidade do Porto
  - Impact loading, regarding high dynamic fracture toughnesses

- **SAMP_anisotropic..**

  ..for fabrics:

  - ***PART_FABRIC** for a layerwise assembly of componentes

    ➡ Input of main directions of the yarns for each layer

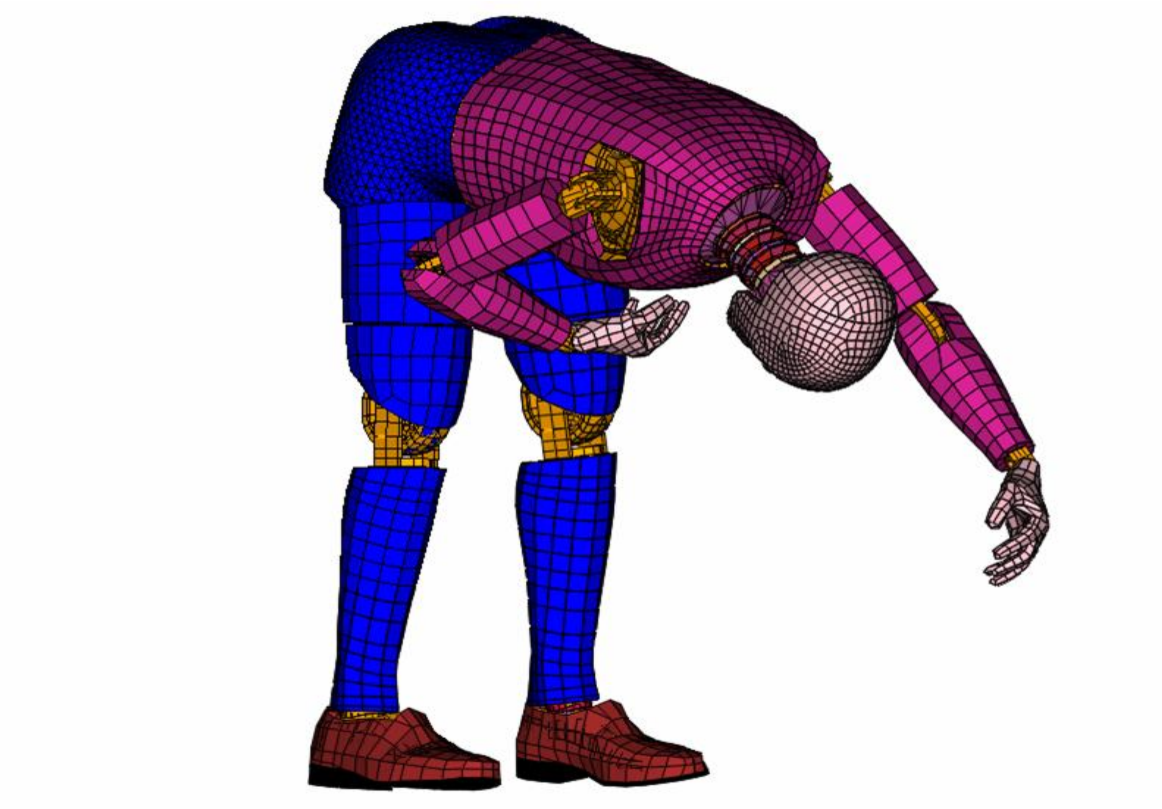


  - Simulation of loading induced rotation of yarns
  - Process chain: drape simulation –> forming simulation –> crash simulation

Acknowledgement

I would like to express my sincere thanks to

- Pedro Camanho and Hannes Körber for providing the test data for the IM7-8552 carbon-epoxy and for fruitful discussions
- DYNAmore GmbH for Support and providing the LS-DYNA licenses in the testing phase of the presented material models



Thanks for your attention!