A Multiscale Strategy for the Simulation of Braided Composites with ENVYO

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ARENA2036 DigitPro: Digital Prototype

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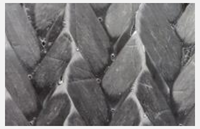
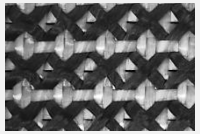
DigitPro – Digital Prototype

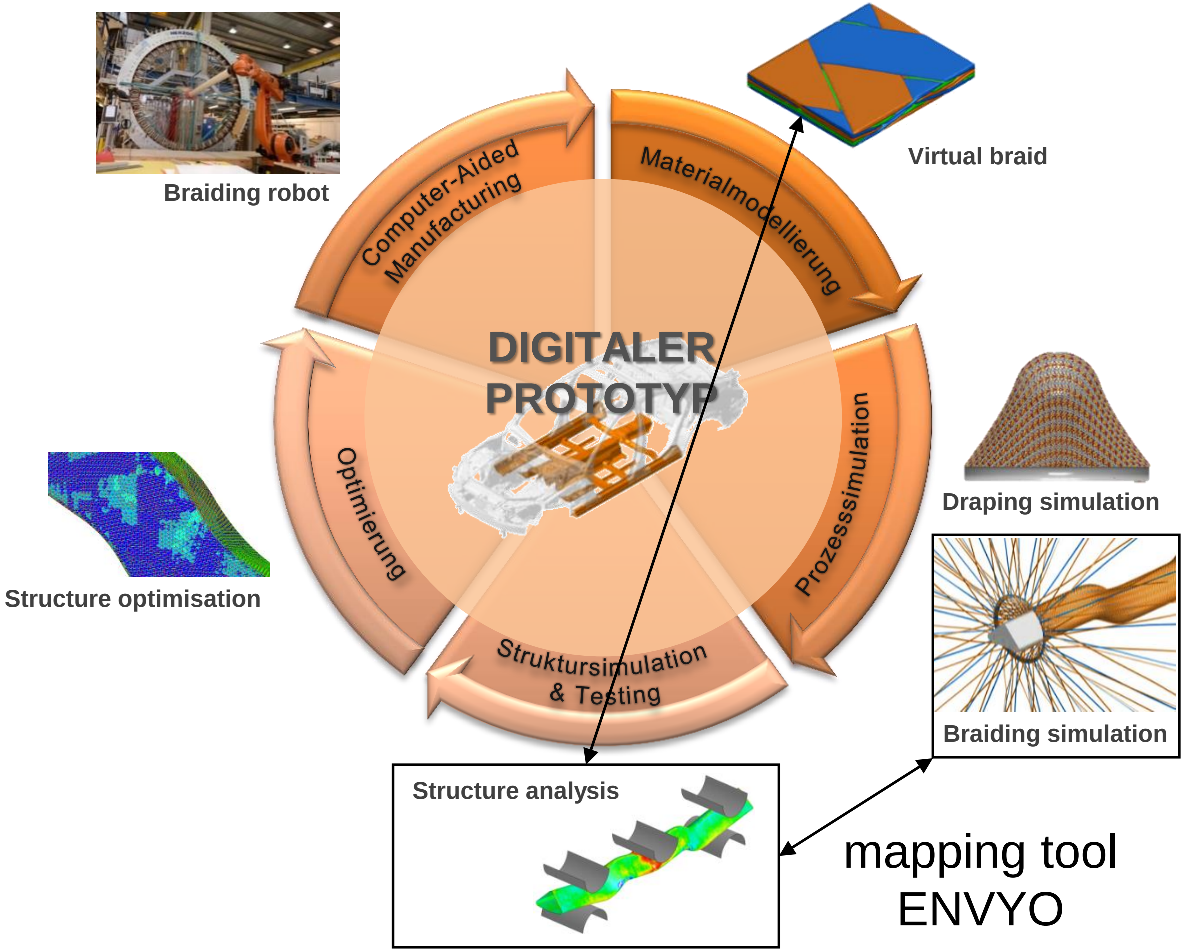
- closed, numerical process chain
- from the presizing to the final product
- simulation on the meso and macroscale
- various simulation tools
- HDF5 format

– braided structures
– **O**pen-**R**eed-**W**eaving parts





-50% development time
min. -10% weight



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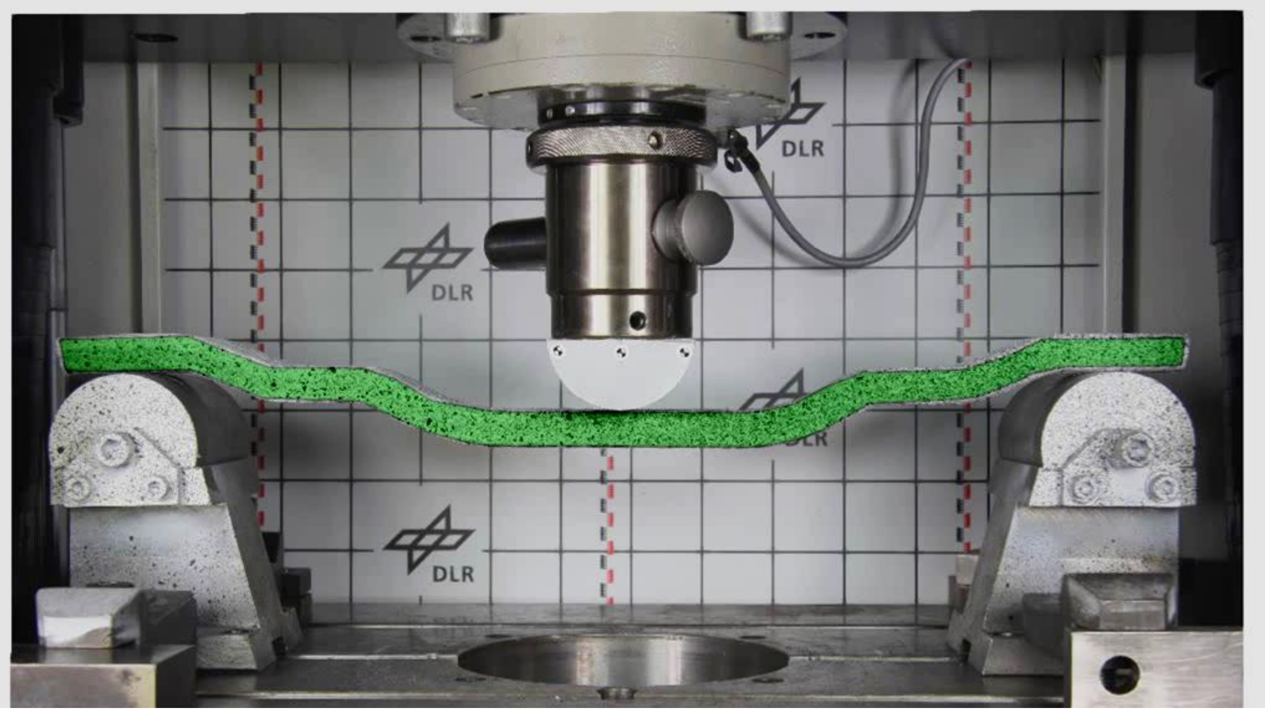
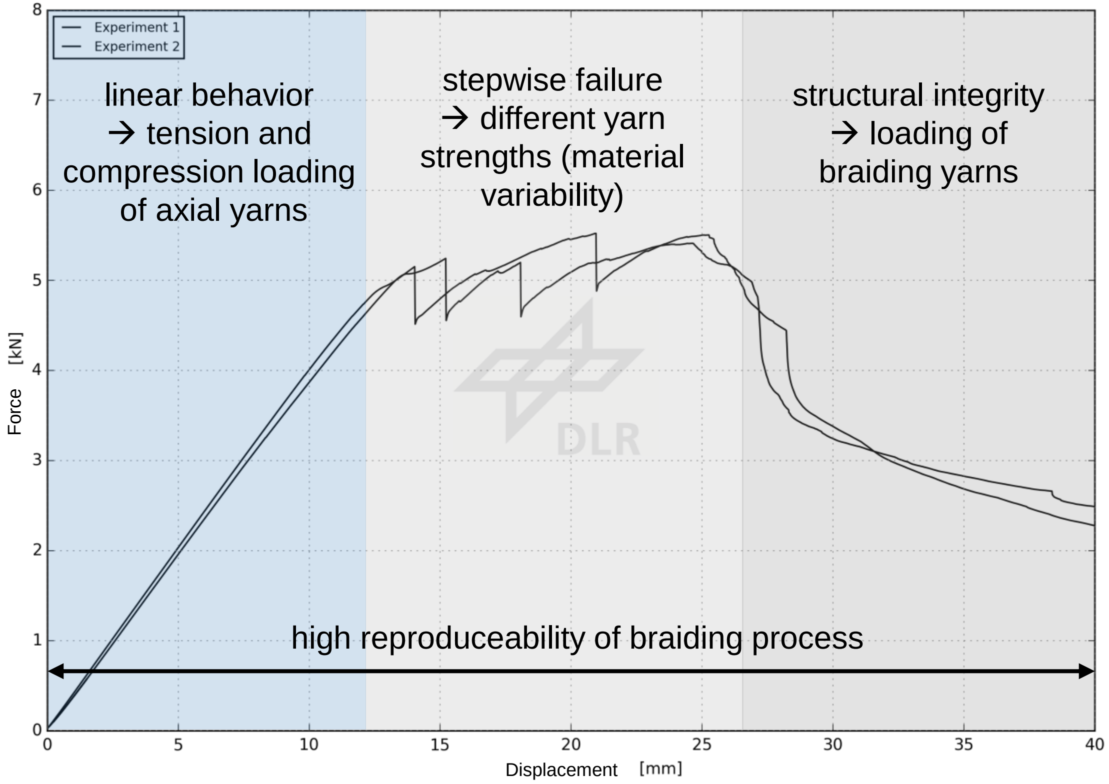
Investigation of a braided reinforcement structure under quasistatic 3-point bending

- complex structure geometry → potential deffects due to manufacturing conditions
- use as reference for the investigation of different modelling approaches





- transfer of test condition in the simulation (impactor and support displacement, testing speed etc.)

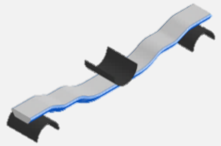
$$E_{\ell 11} = k_f E_{f11} + k_m E_m$$

$$E_{\ell 22} = \frac{E_m}{1 - \sqrt{k_f}\,(1 - E_m / E_{f22})} = E_{\ell 33}$$

1 – Standard approach

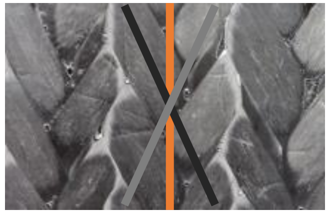
$$E_{\ell 11} = k_f E_{f11} + k_m E_m$$

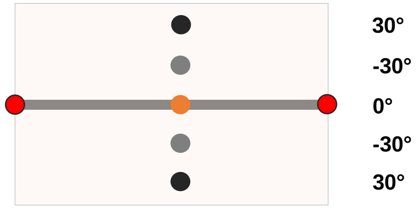
$$E_{\ell 22} = \frac{E_m}{1 - \sqrt{k_f}\,(1 - E_m / E_{f22})} = E_{\ell 33}$$



Principle of the approach

1. Modelling with UD-plies





2. Calculation of yarns stiffness and strength

   – Use of material properties from datasheets

Matrix →

Fibre →

FVC →

Yarn ←

LONGITUDINAL MODULUS:	$E_{\ell 11} = k_f E_{f11} + k_m E_m$
TRANSVERSE MODULUS:	$E_{\ell 22} = \frac{E_m}{1 - \sqrt{k_f}\,(1 - E_m/E_{f22})} = E_{\ell 33}$
SHEAR MODULUS:	$G_{\ell 12} = \frac{G_m}{1 - \sqrt{k_f}\,(1 - G_m/G_{f12})} = G_{\ell 13}$
SHEAR MODULUS:	$G_{\ell 23} = \frac{G_m}{1 - \sqrt{k_f}\,(1 - G_m/G_{f23})}$
POISSON'S RATIO:	$\nu_{\ell 12} = k_f \nu_{f12} + k_m \nu_m = \nu_{\ell 13}$
POISSON'S RATIO:	$\nu_{\ell 23} = \frac{E_{\ell 22}}{2G_{\ell 23}} - 1$

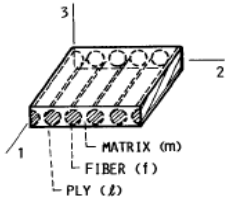
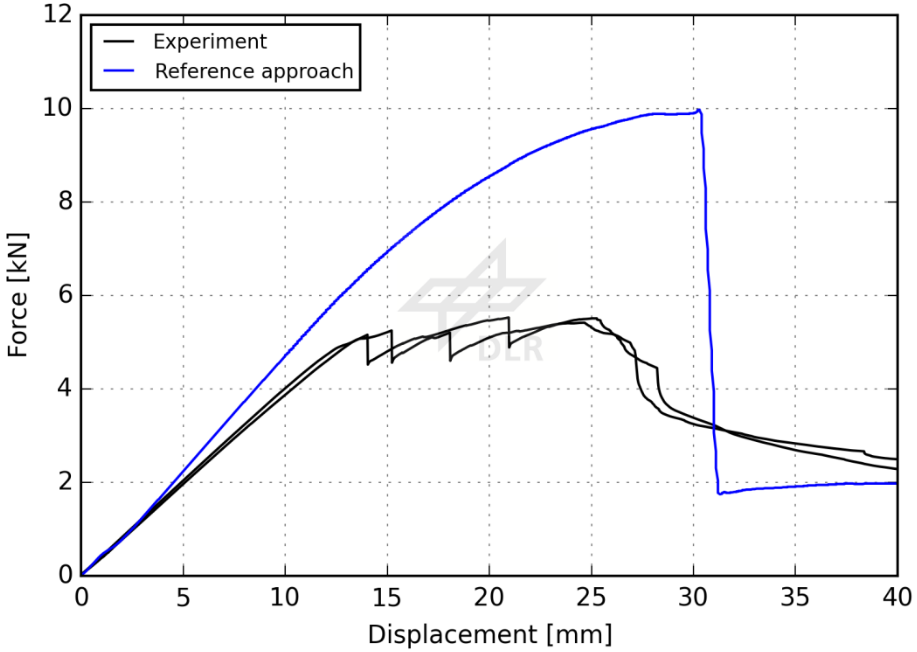


FIGURE 4. - COMPOSITE MICROMECHANICS, MECHANICAL PROPERTIES.

Analytical calculation according to Chamis „Mechanics of composite materials: past, present, and future, NASA TM-100793, 1984"

3. Structure simulation **without tuning**



→ **Overprediction** of structural strength

4. Changes of material parameters → try-and-error
→ no predictive simulation, only a post-test simulation

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Principle of the approach

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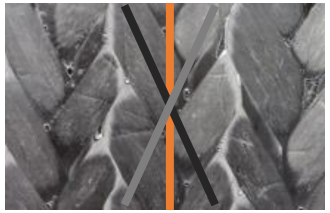

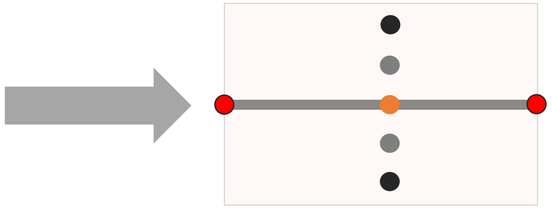

2. Calculation of yarns stiffness and strength

   – Use of material properties from datasheets

LONGITUDINAL MODULUS: $E_{\ell11} = k_f E_{f11} + k_m E_m$

TRANSVERSE MODULUS: $E_{\ell22} = \frac{E_m}{1-\sqrt{k_f}\,(1-E_m/E_{f22})} = E_{\ell33}$

SHEAR MODULUS: $G_{\ell12} = \frac{G_m}{1-\sqrt{k_f}\,(1-G_m/G_{f12})} = G_{\ell13}$

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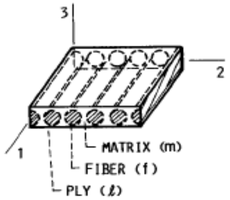

FIGURE 4. - COMPOSITE MICROMECHANICS, MECHANICAL PROPERTIES.

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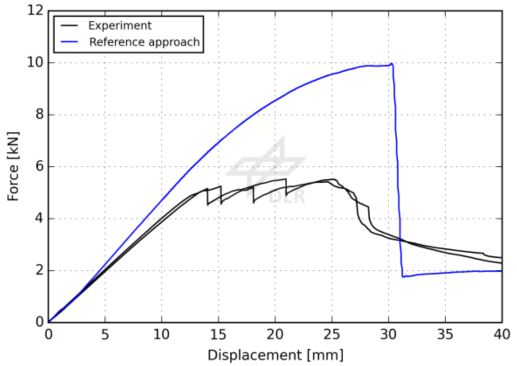
3. Structure simulation



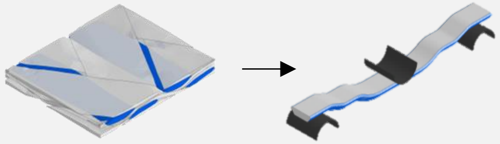
Drawbacks

– local effects are not considerated
– fibre architecture is not reproduced
– adjustment cycles necessary
– overpredictive if not tuned

Advantages

– „universal" approach (weave / UD...)
– fast model generation
– low computing time

2 – Multiscale approach



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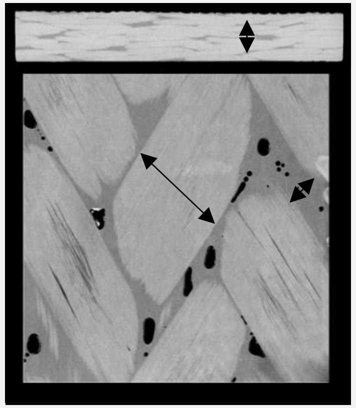
Example of a 30°-triaxially braided laminate – compaction simulation

CT-Scan



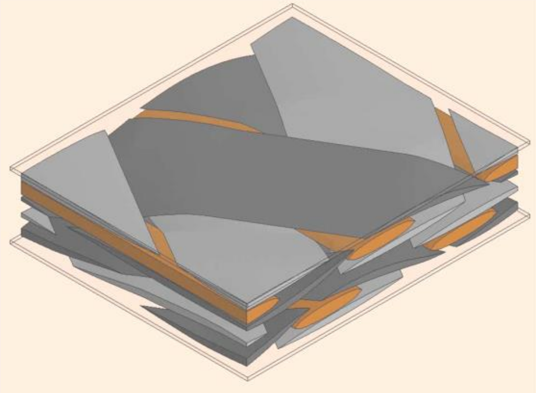
Braiding angle

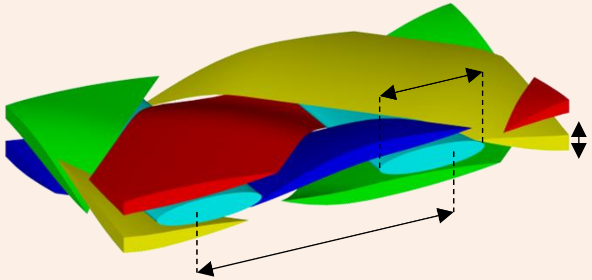
Braiding core diameter

$$\text{Breite} = f_1(\theta, d, k, \eta)$$
$$\text{Länge} = f_2(\theta, d, k, \eta)$$
$$\text{Lücke} = f_3(\theta, d, k, \eta)$$

FVC

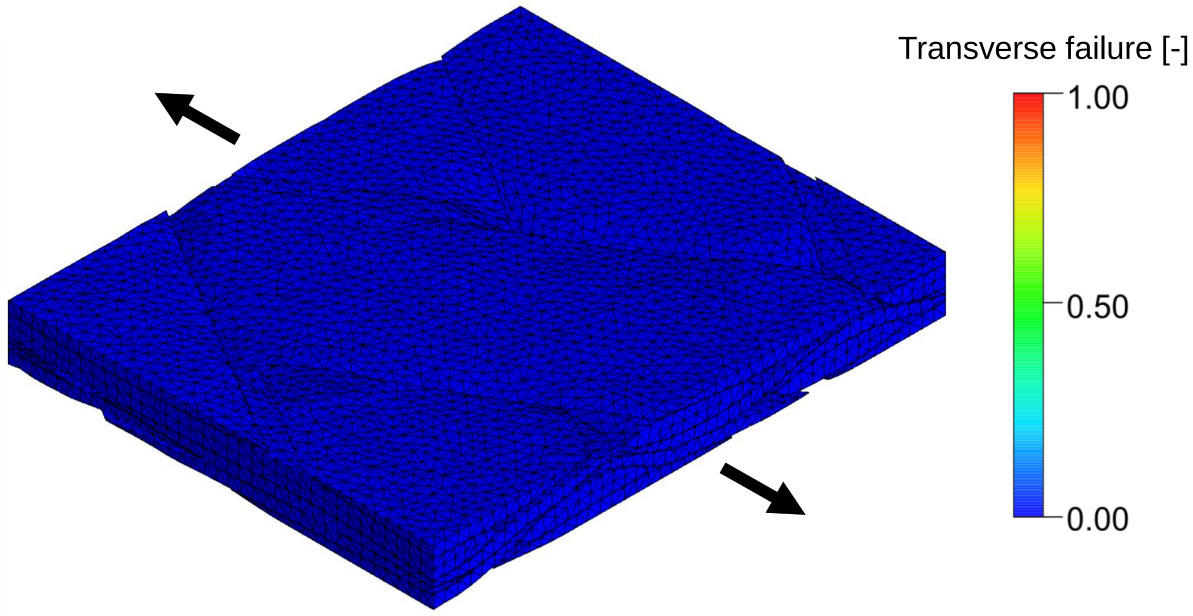
Size of yarn

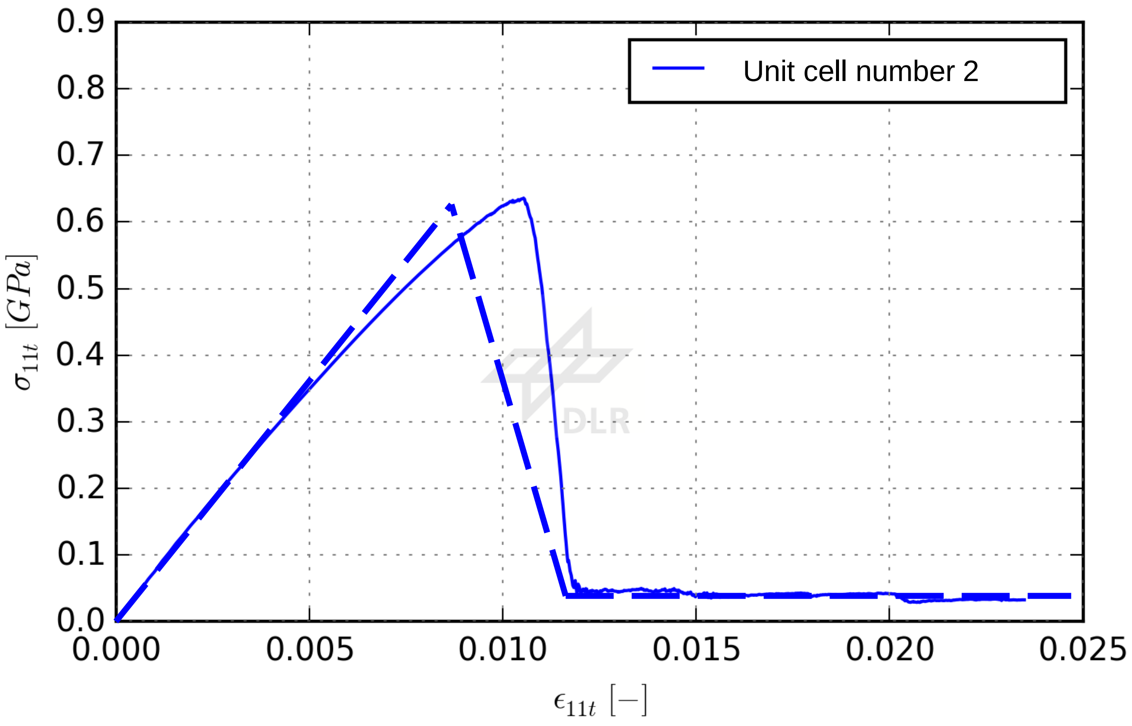




Parametric model of the dry textile

Example of a 30°-triaxially braided laminate – tension simulation

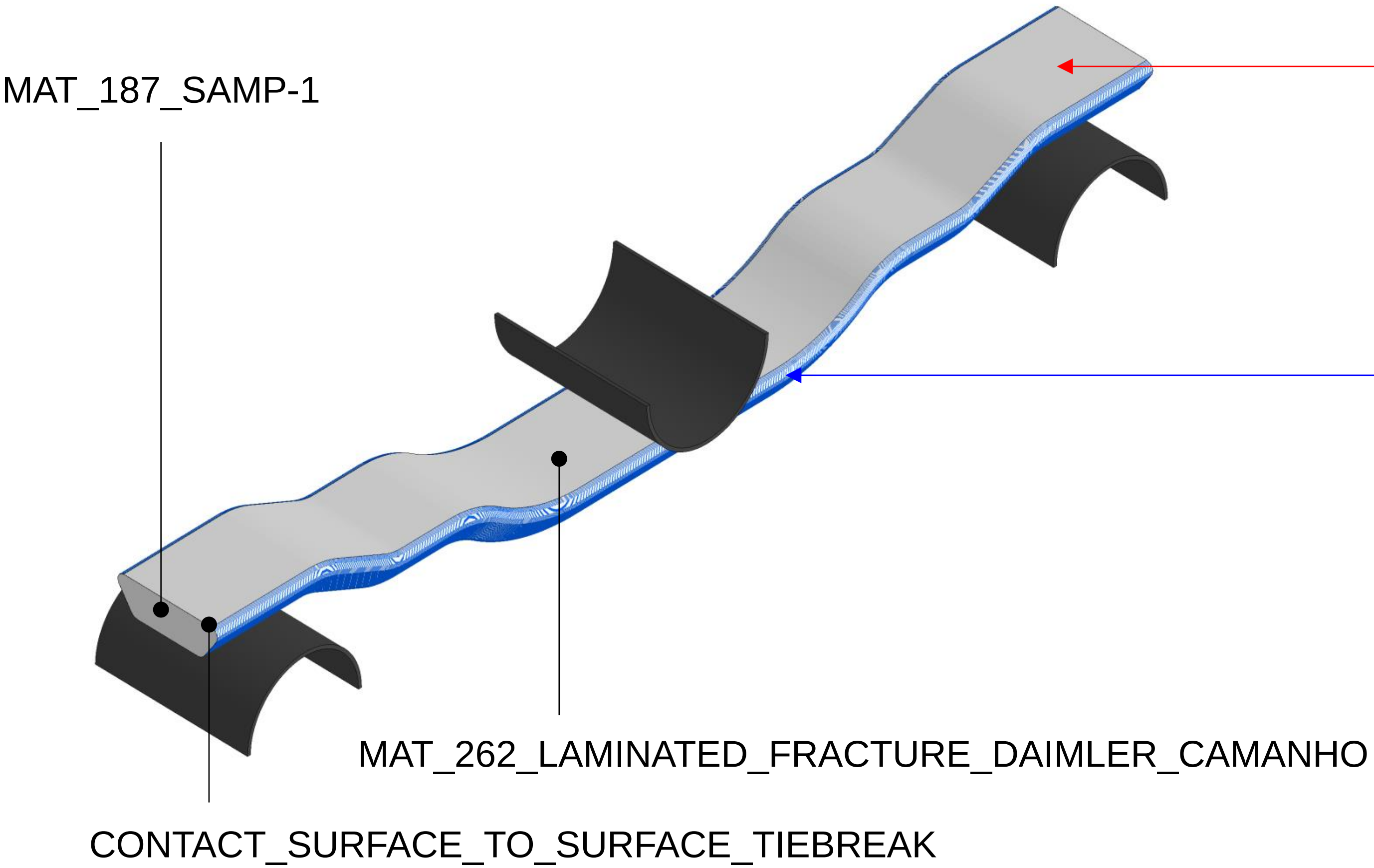




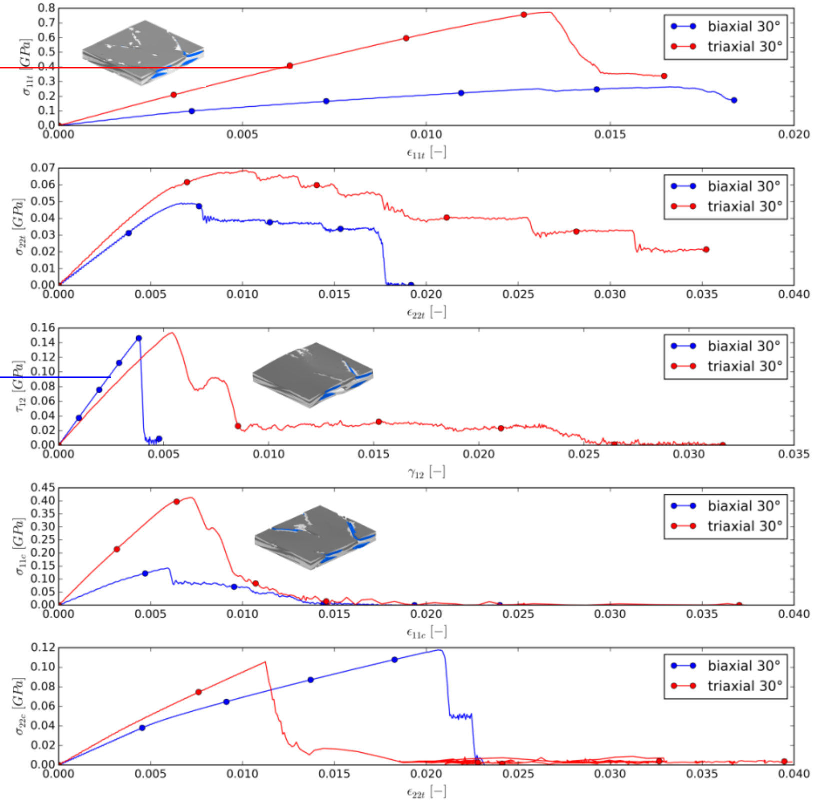
→ Data for generation of a material card (E_{11}, E_{22}, S_{11}, S_{22}...)

Structure simulation of the reinforcement structure

- automatic postprocessing of unit cell results with ENVYO
- generation of material cards for the different textile types



Virtual material data



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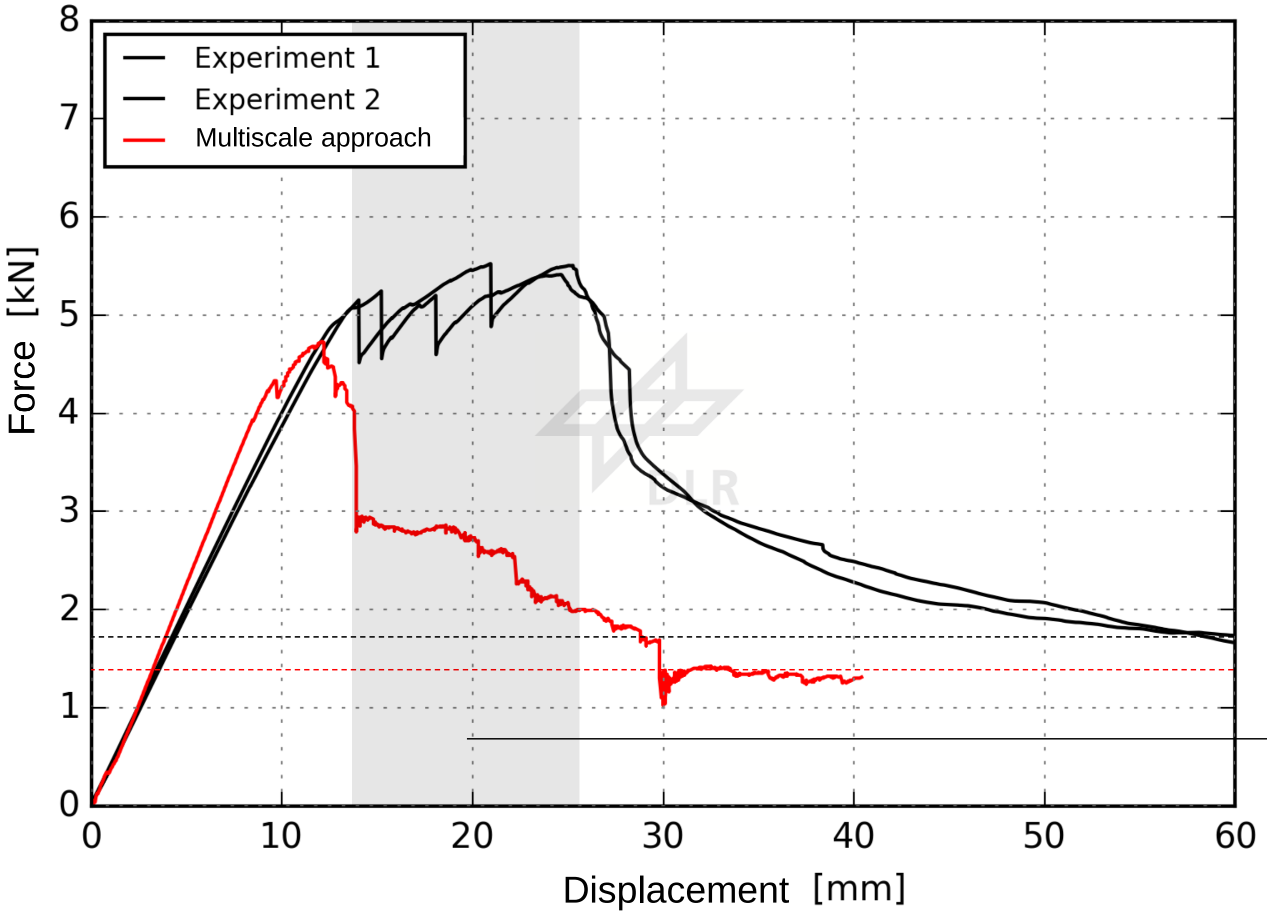
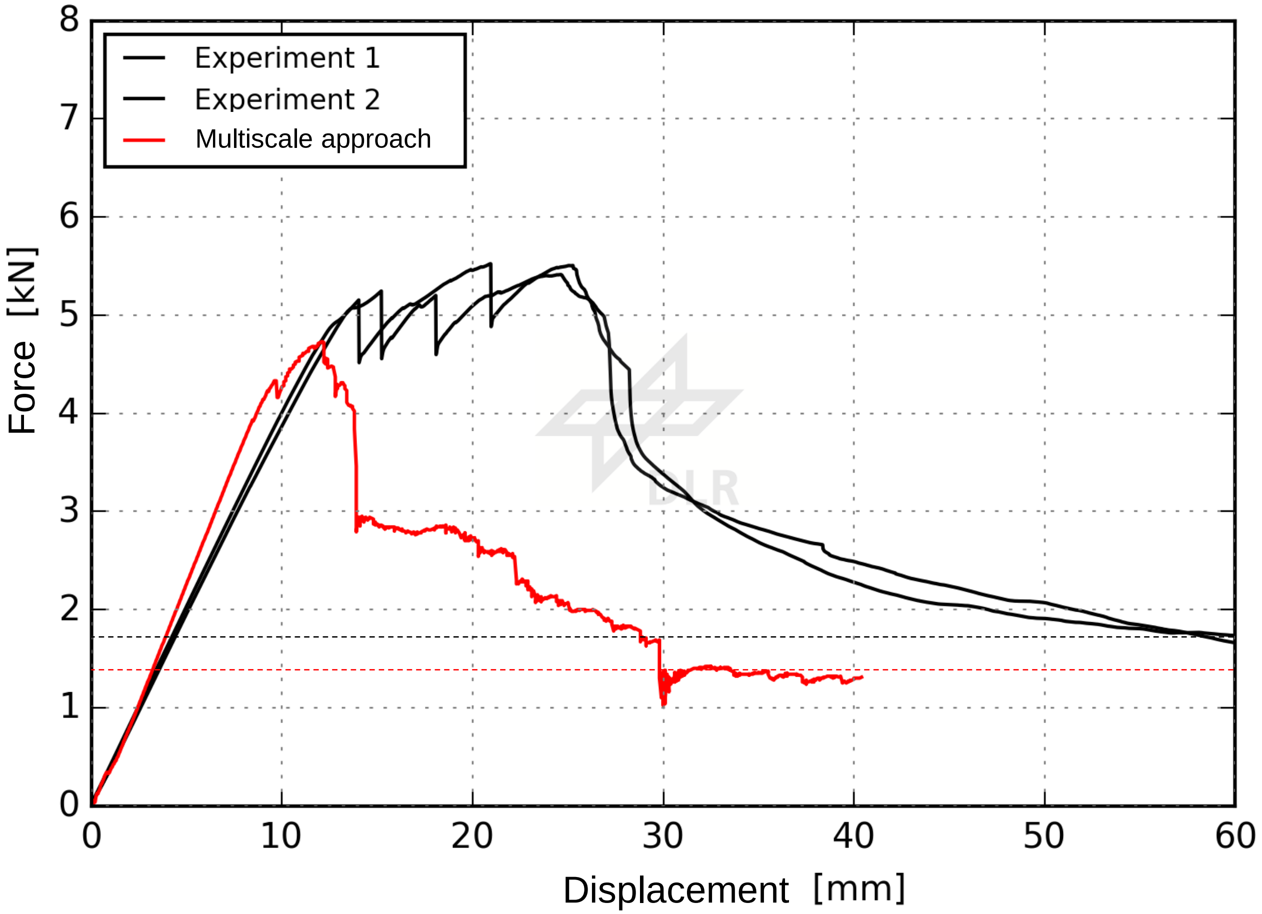
Predictive structure simulation of the reinforcement structure



- Stiffness prediction ✓
- Strength prediction ✓
- Prediction of residual strength ✓

delayed failure of axial yarns ✗

Structure simulation of the reinforcement structure

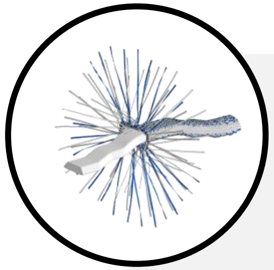


Advantages

- consideration of textile architecture
- realistic textile behaviour in simulation
- automatisation possible
- predictive simulation, no tuning

Drawbacks

- increased computing times
- more complex model generation



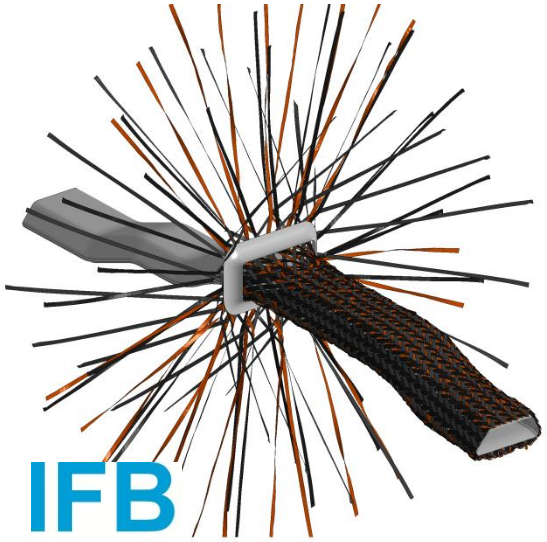
3 – Process chain approach

Braiding simulation

Machine parameters

- Number of bobbins
- Fibre typ
- Yarn pretension
- Braiding Speed
- Robot path

Digital Twin



Simulation model

- Manufacturing effects
  - ✓ Orientation
  - ✓ Ondulation
  - ✓ Dry spots
  - ✓ Gaps to core
- Opt. machine parameters

<u>Original textile architecture after braiding simulation</u>

Gaps in the braided textilte

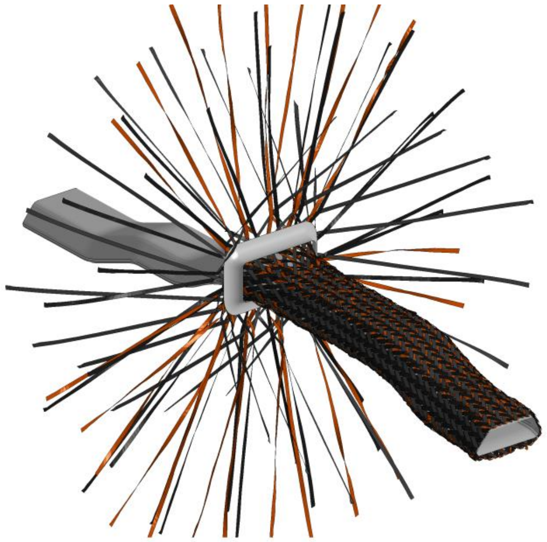
Gap between yarn and braiding core → matrix-rich zones

Braiding simulation

Machine parameters

– Number of bobbins
– Fibre typ
– Yarn pretension
– Braiding Speed
– Robot path

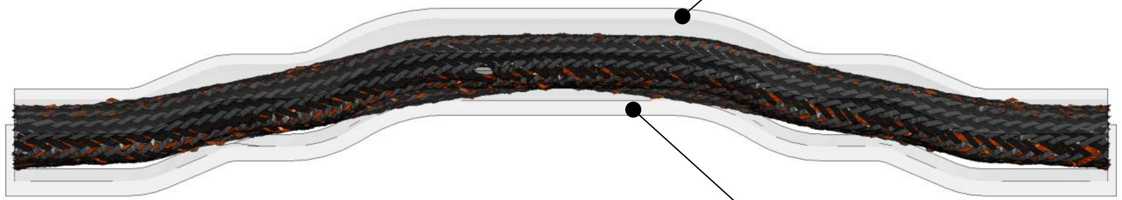
Digital Twin



Simulation model

– Manufacturing effects
  - ✓ Orientation
  - ✓ Ondulation
  - ✓ Dry spots
  - ✓ Gaps to core
– Opt. machine parameters

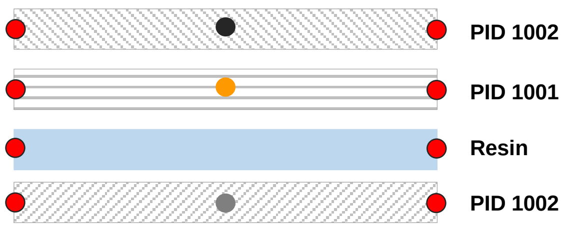
Closing of the gaps

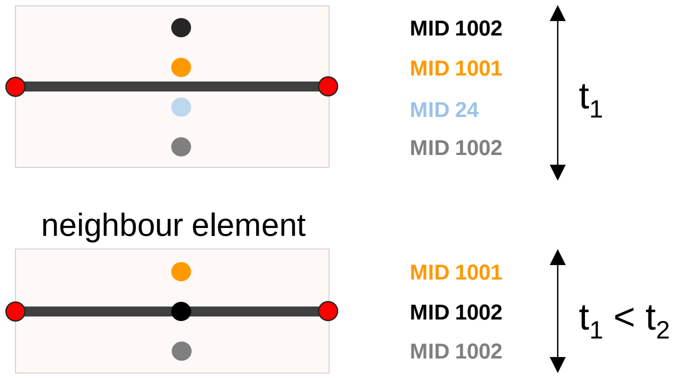


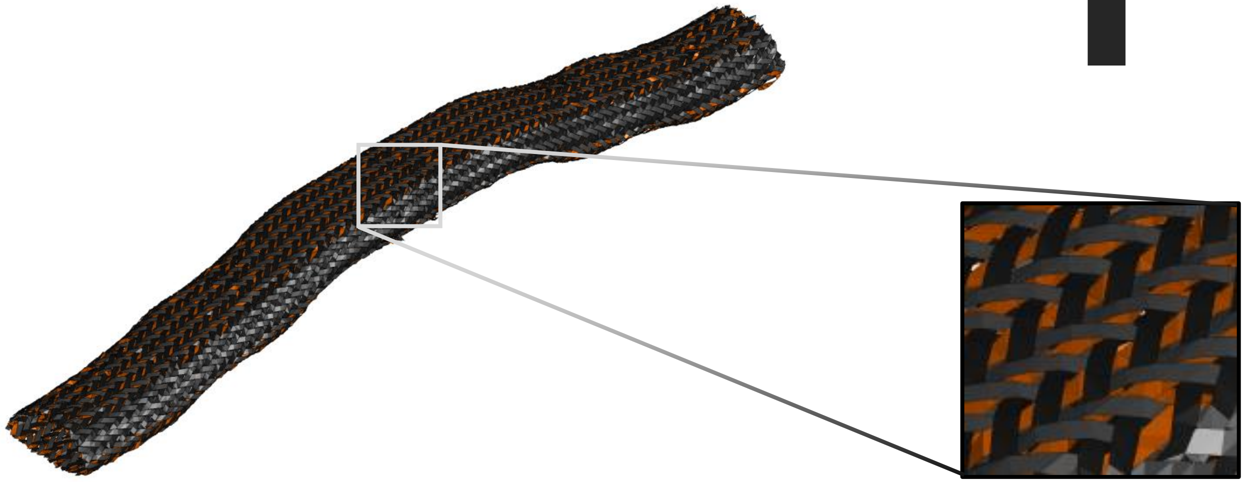
Information mapping to structure mesh

Mapping of:

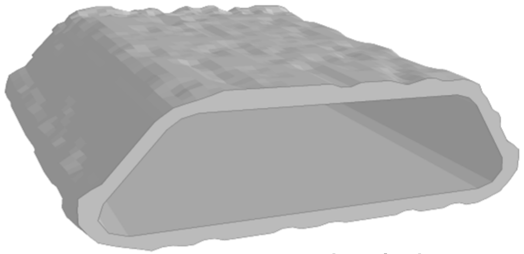
- Yarn orientations
- Ondulation
- Dry spots
- Yarn geometry (width/thickness)





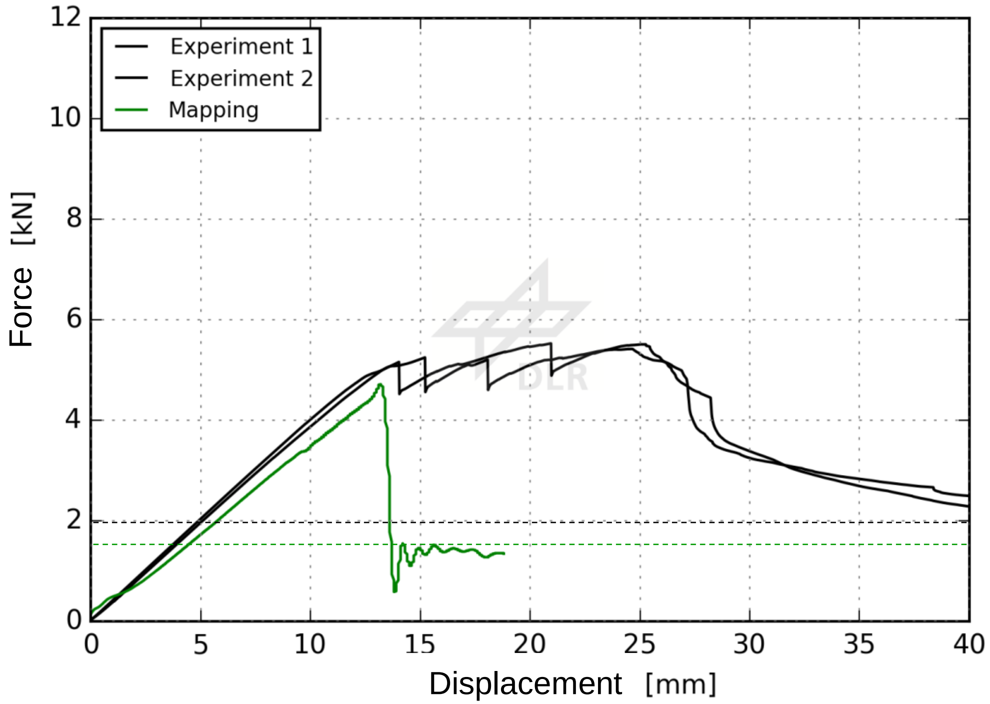


Model from the braiding simulation

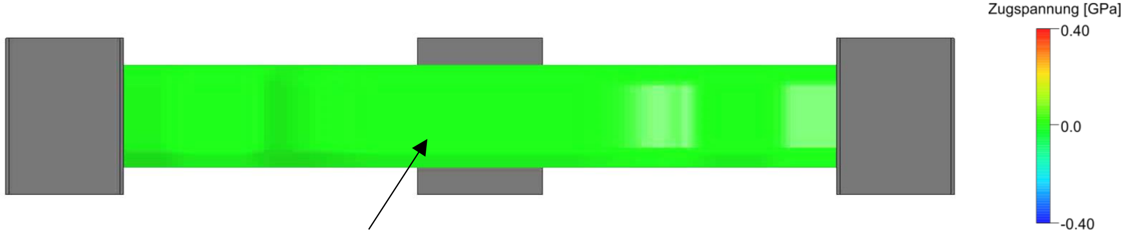


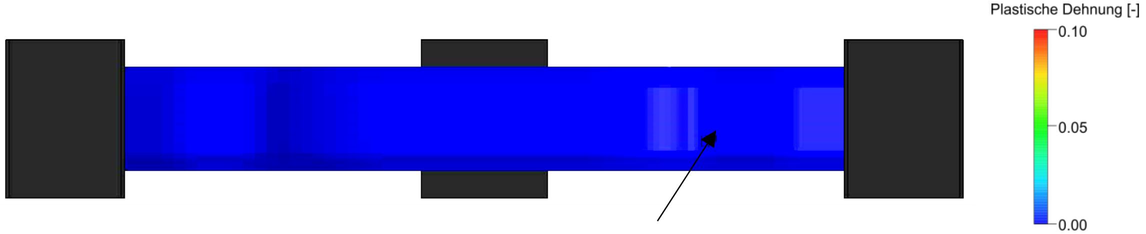
Simulation

Structure simulation with mapped information

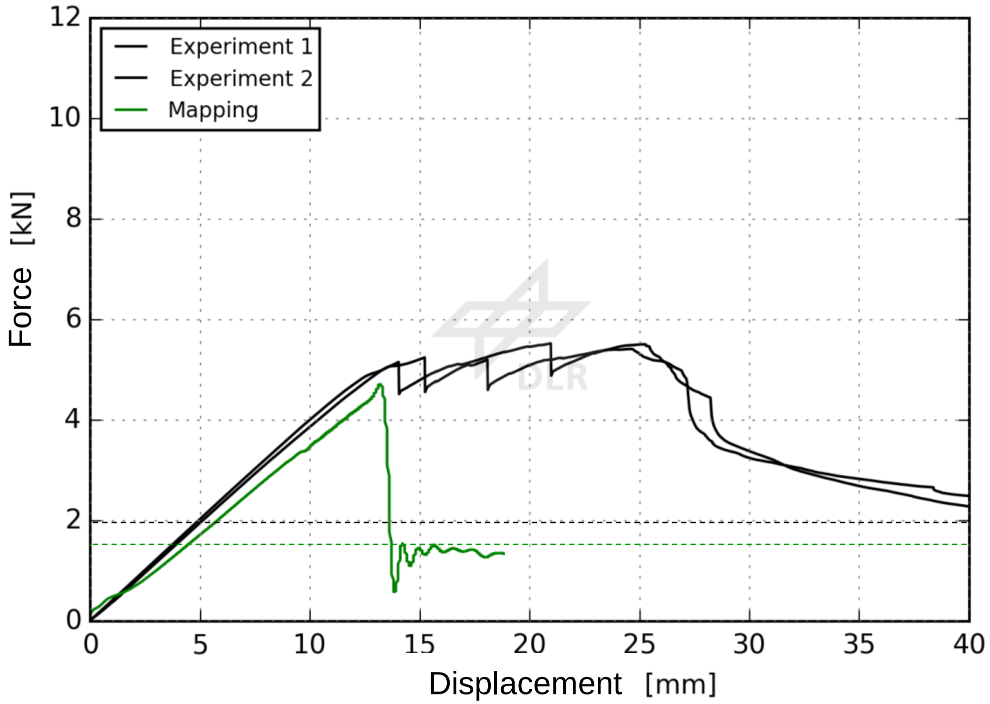


- Stiffness prediction
- Strength prediction
- Prediction of residual strength
- Prediction of yarn influence on local strain field





Structure simulation with mapped information



- Stiffness prediction ✔
- Strength prediction ✔
- Prediction of residual strength ✔
- Prediction of yarn influence on local strain field ✔

Advantages

- consideration of textile architecture
- realistic textile behaviour in simulation
- automatisation possible
- local strain field can be predicted

Drawbacks

- increased computing times
- more complex model generation
- investigation of information mapping with ENVYO is necessary

- mapping tool as link between process simulations and structure simulations
- transfer and simplification of information from the mesoscale to the macroscale
- a sensitivity analysis have to be performed before starting the structure simulation
- increase of prediction capabilities of structure simulation

Mesoscale

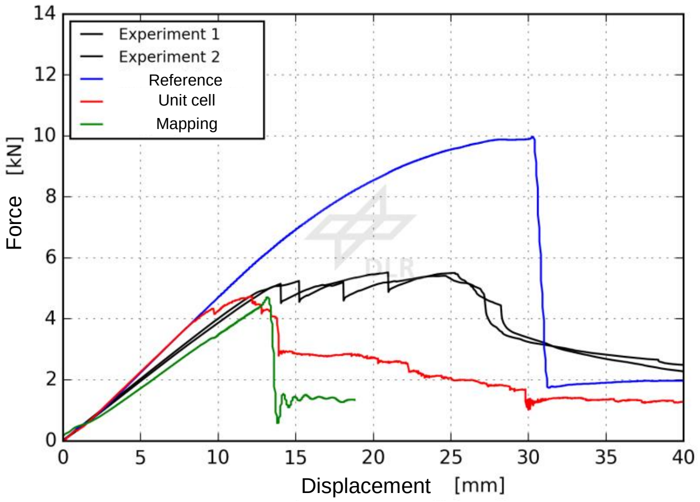
- process simulation
- reduction of experimental effort
- increased structure quality through optimisation loops

Envyo ⟷

Macroscale

- structure simulation
- consideration of manufacturing effects
- relative low CPU time

HDF5 format



Thank you very much for your attention

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öffentlich-private Partnerschaft für Innovationen

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