Modelling the Microstructure of Multilayer Woven Fabrics

Fachkongress Composite Simulation 2014

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Outline

- Introduction
- Weaving model set-up
  - Simulating the weaving process
- Validation
  - Yarn shape
- Mechanical analysis model set-up
  - Validation
- Summary
- Next steps

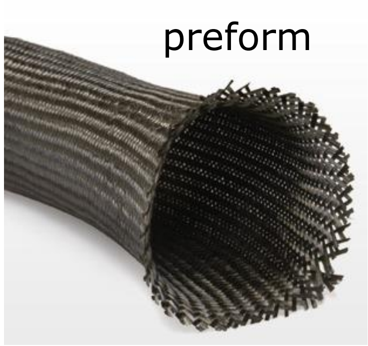
Introduction

Composites

- (highly) anisotropic material
- Advanced composites generally consist of continuous fibres in combination with a resin material
- Difficult to predict properties on beforehand
- Generally a costly material

Required input to predict the composite product mechanical properties:

- fibre directions
- Material properties (fibres, resin)
- Processing
- composite structure



preform

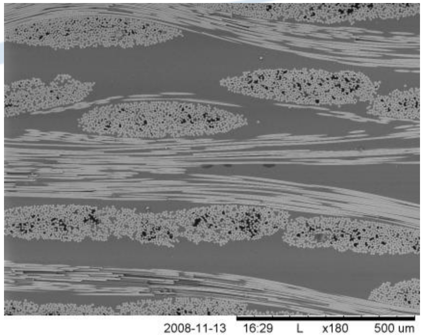
product

Introduction

- Many properties depend on the composite structure
  - Permeability
  - Mechanical properties
  - Thermal properties (expansion, conduction etc.)

- The “general” approach is to use a multi-level approach
  - Micro level (intra-yarn)
  - Meso level (inter-yarn)
  - Macro level (ply level)
  - Structural level (complete parts)

- At each level assumptions are used to include properties



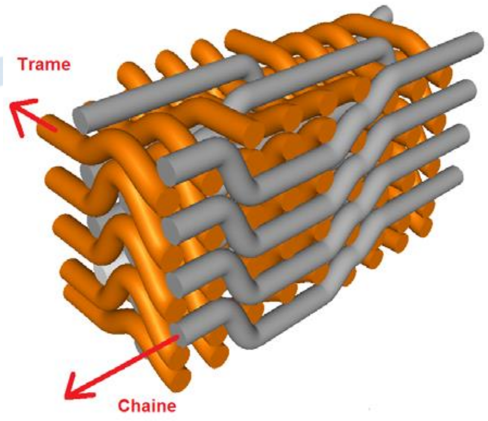
Introduction

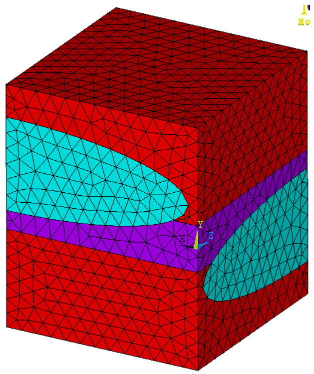
- Micro level
  - Fibre Volume Fraction
  - Packing
  - Constituent properties

- Meso level (inter-yarn)
  - Weave structure (bi-axial, multi-layer, knitting, etc)
  - Yarn shape (elliptical, fish-eye, etc)
  - Micro-level properties (stiffness, thermal, etc)

- Macro level
  - Properties from meso

- Structural level
  - Geometry of part
  - Properties from macro





Introduction

Here, the objective is to gain more insight in the (micro) structure of the (multilayer) weave by including:

Process parameters

- weave type (layer-to-layer, orthogonal, non-orthogonal)
- fibre properties
- Yarn tension

In order to

- Predict mechanical properties at meso level
- Give input to permeability modelling
- Find the local structure of the fabric at corners / holes / edges
- etc

Introduction

Weaving parameters

FEM weaving

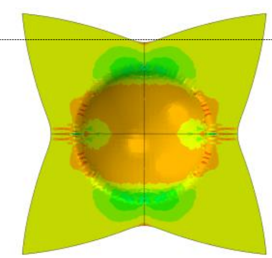
Experimental input

(bias extension, tensile, etc)

Elementary tests

E, G, t, etc

Stamping



Geometrical input

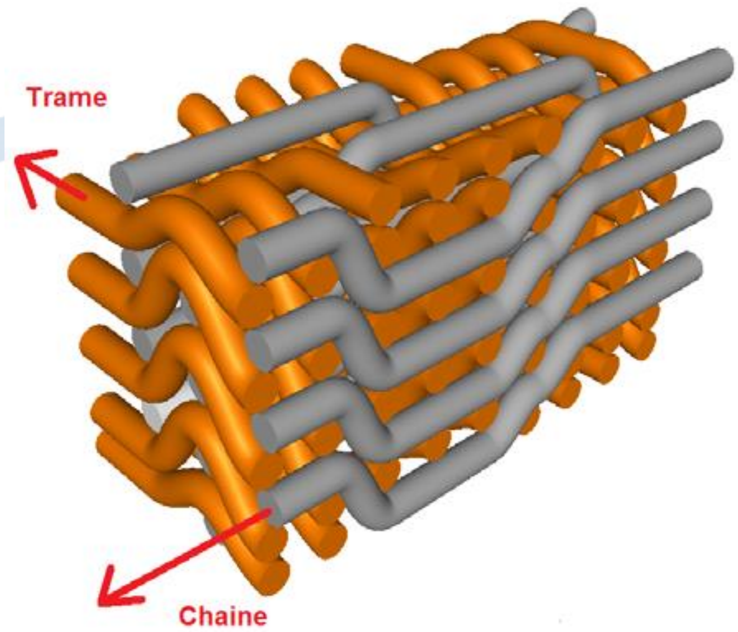
(shape, size)

Structural analyses

Model set-up
weave

Modelling of a warp interlock fabric

- Unit cell approach
- 45 weft yarns, 12 warp yarns
- 6 weft yarn layers
- 3360 dtex para-aramid yarns

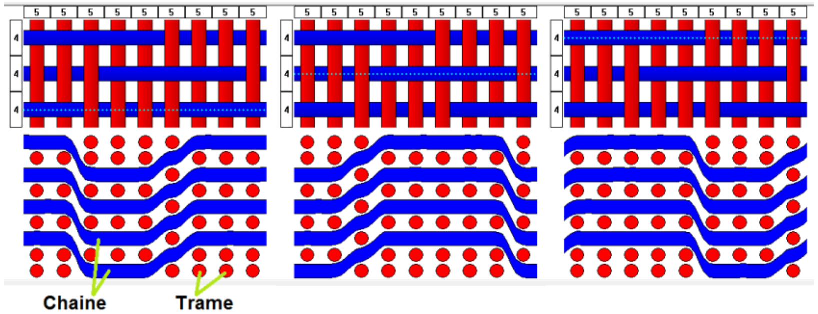


Measurements and weaving done by Ensait

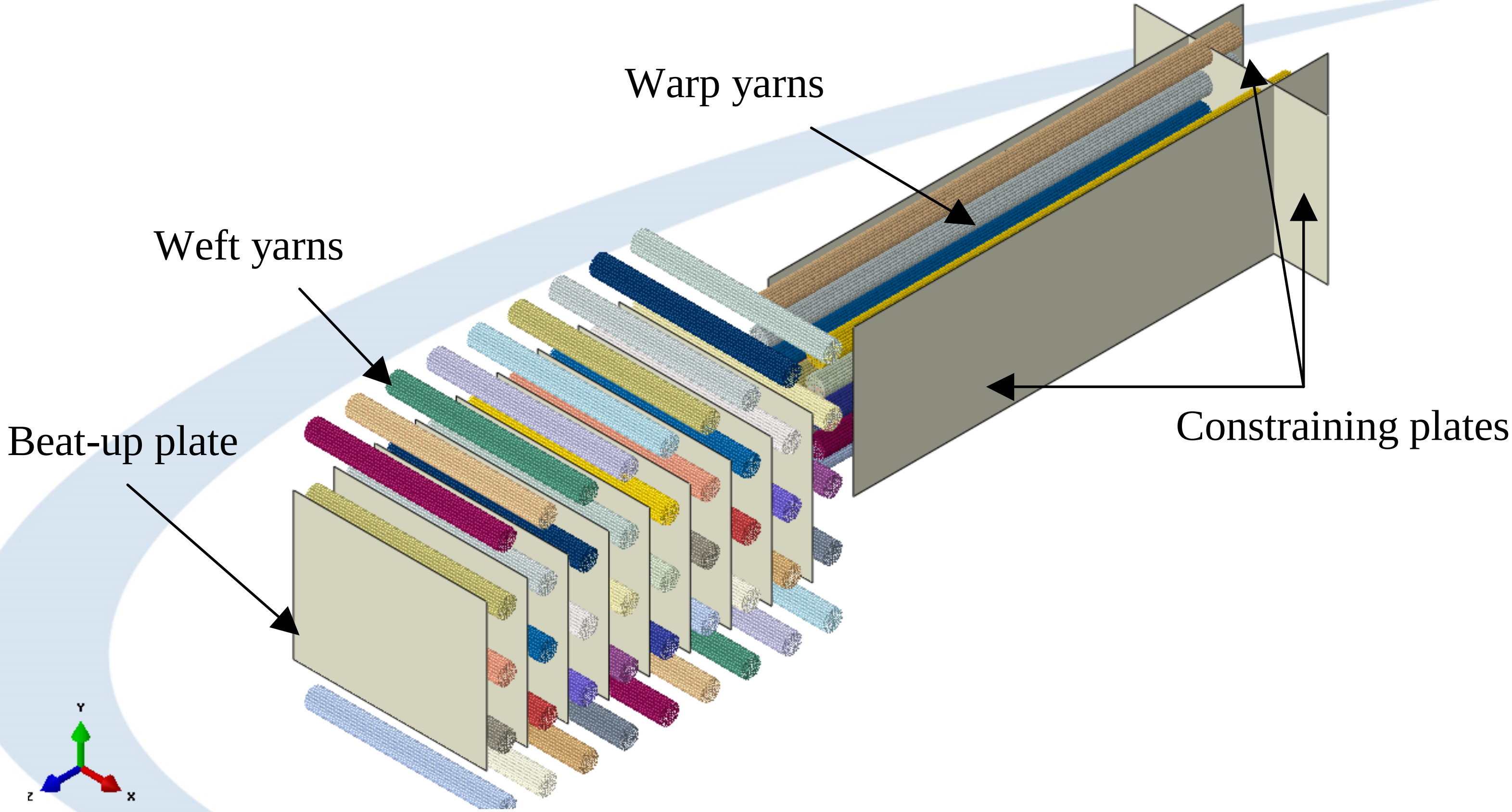
Model set-up

- Follow machine kinematics
- Yarns build out of several ‘fibres’. These fibres represent multiple ‘real‘ fibres
- Yarns initial shape is circular
- The model is Finite Element Method based (beams)
- The model includes contact and friction

Elementary weave diagram

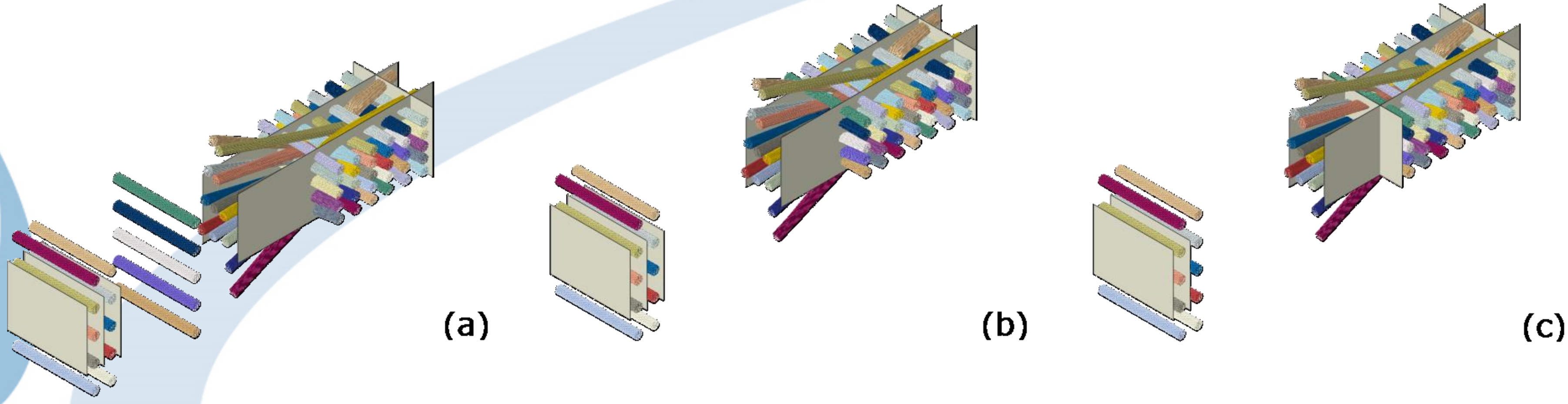


Model set-up
BC's

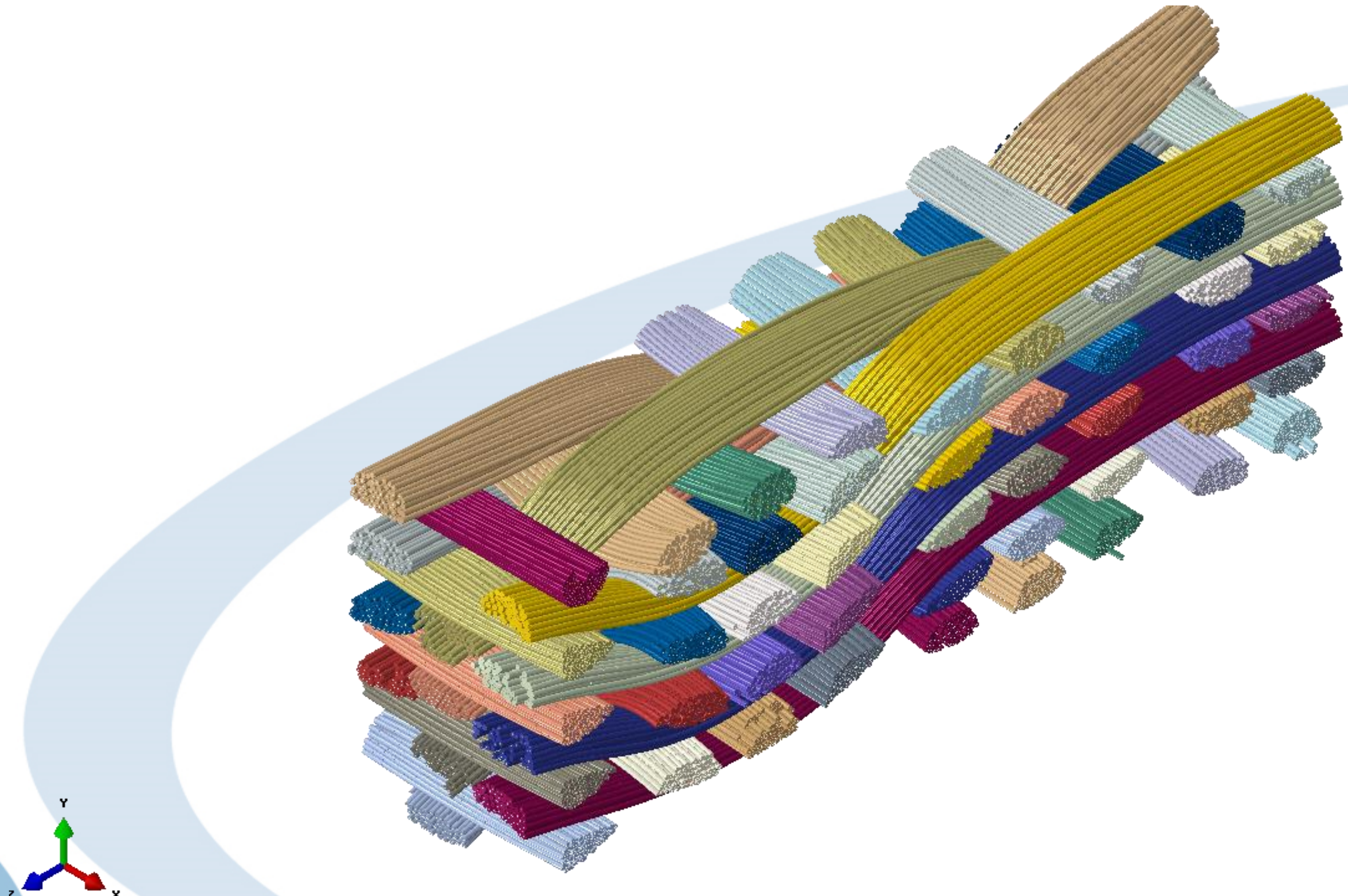


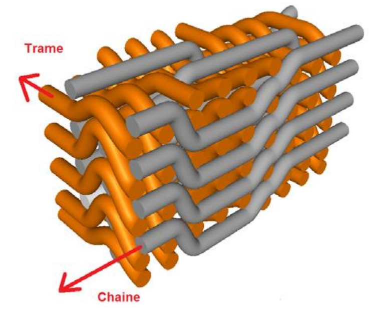
Warp interlock weaving
model results

Stages during weaving



Warp interlock weaving
model results

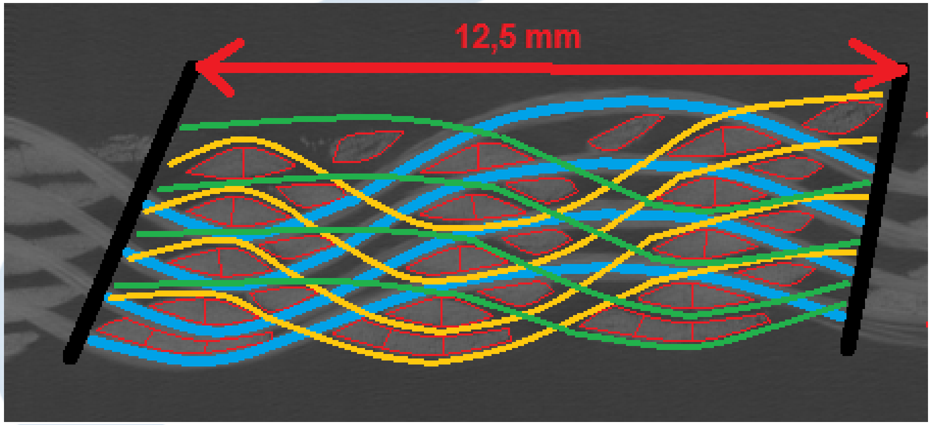




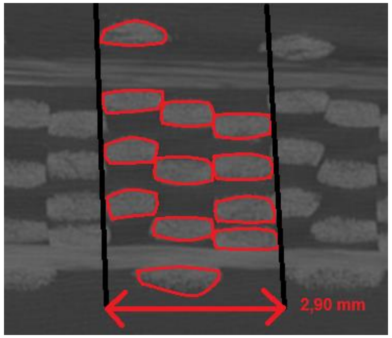
Warp interlock weaving
experimental results

Experimental results

- Size of unit cell (12.5 x 2.9 x 4.8 mm^3)
- X-ray tomography



Weft cross-sectional view

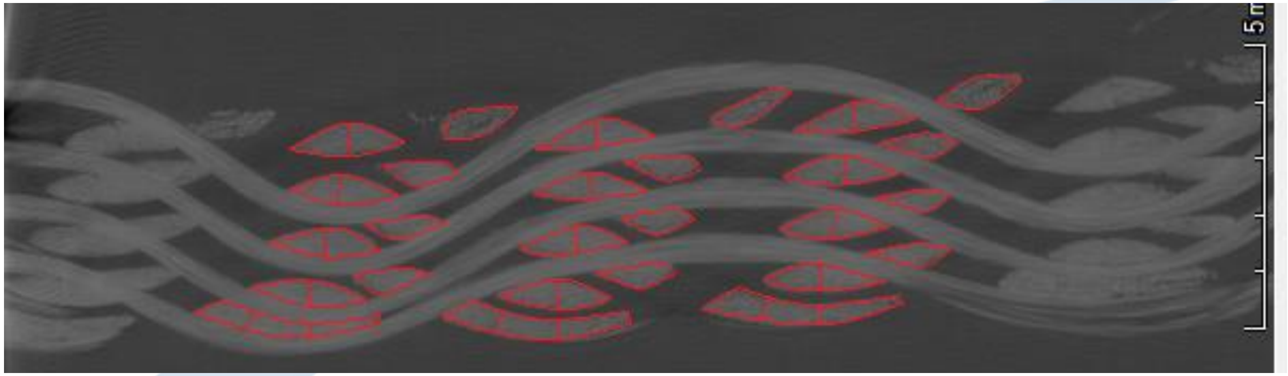


Warp cross-sectional view

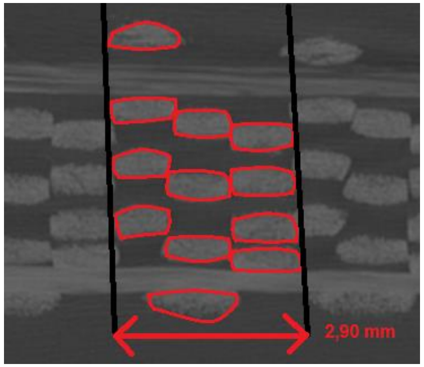
Warp interlock weaving
validation

model results

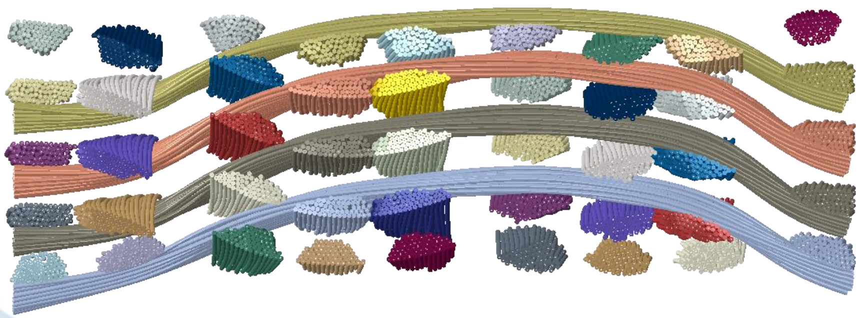
- Size of unit cell (12.5 x 2.8 x 4.3 mm^3)



Weft cross-sectional view

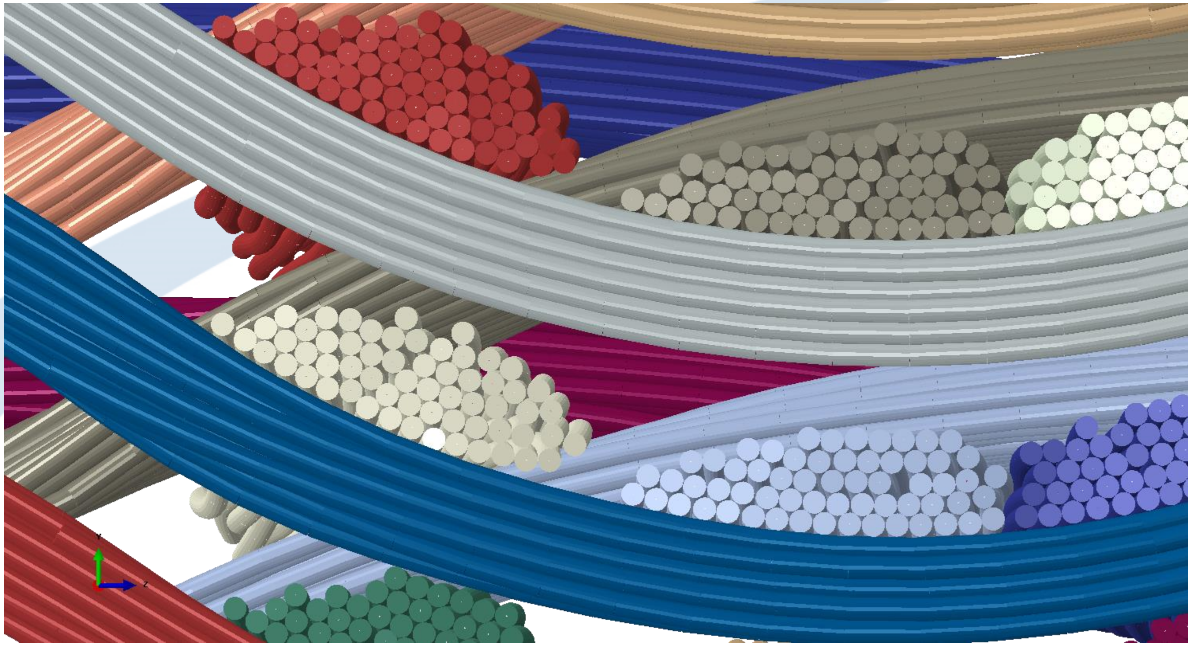


Warp cross-sectional view



Yarn shape

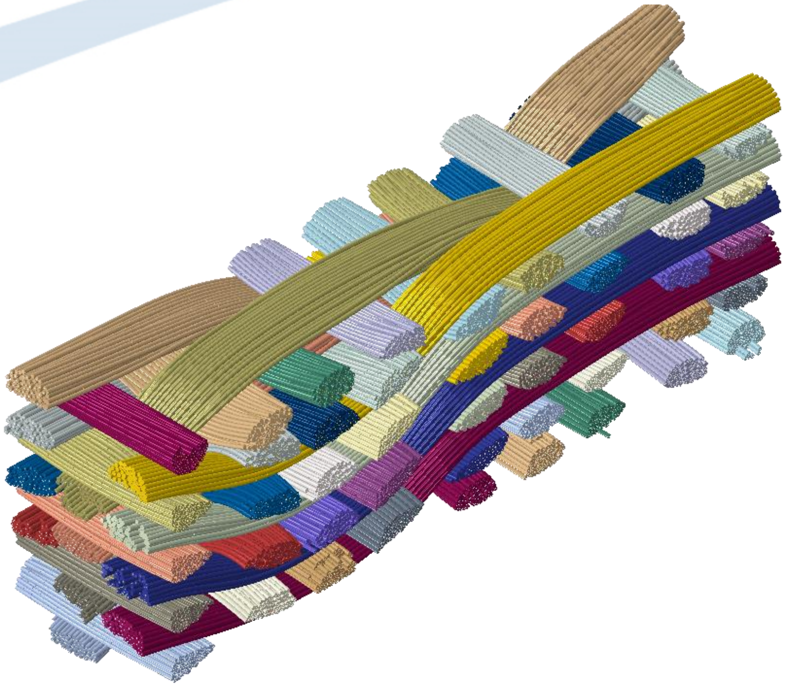
Change in cross-section of weft yarns



Weft cross-sectional view

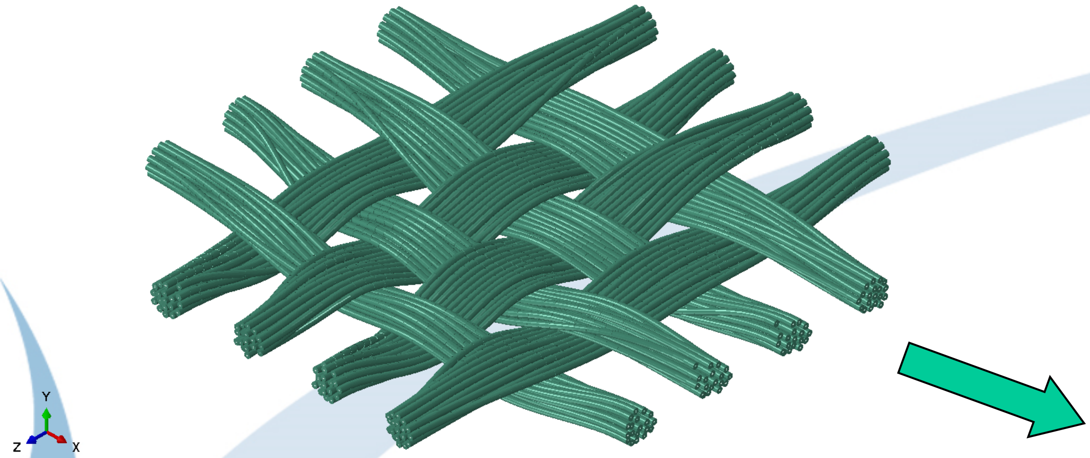
Structural modelling

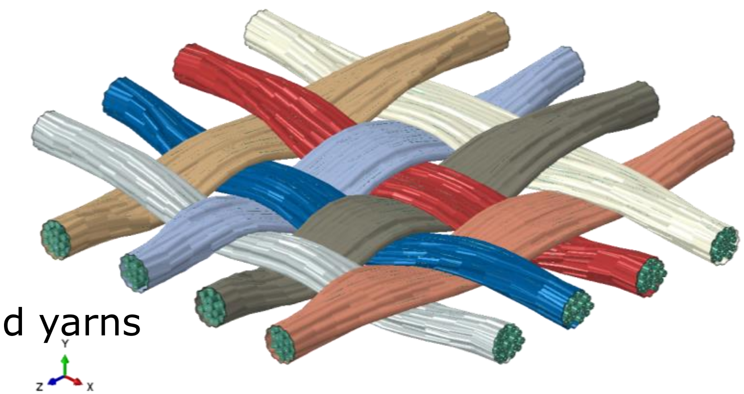
- Complex structure after weaving
  - Meshing -> no option
- Use of embedded elements
  - too much material
- Find areas of resin and fibres
  - remove “double” areas
  - Assign fibre orientations
- Perform mechanical analysis



Methodology
Plain weave example

A plain weave has been created with yarns, existing out of filaments

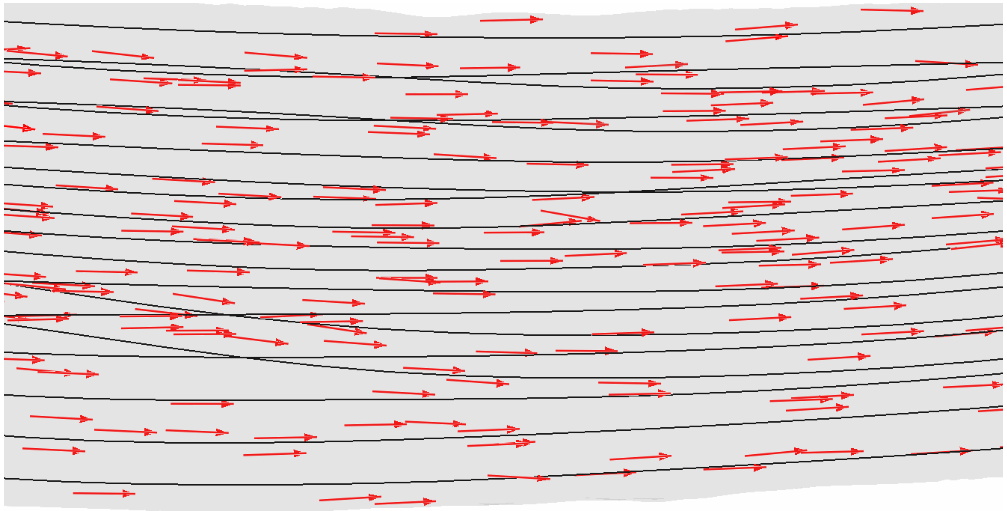




Create surfaces around yarns
&
Define yarn volumes

Material properties of the yarns
Orientation of the material

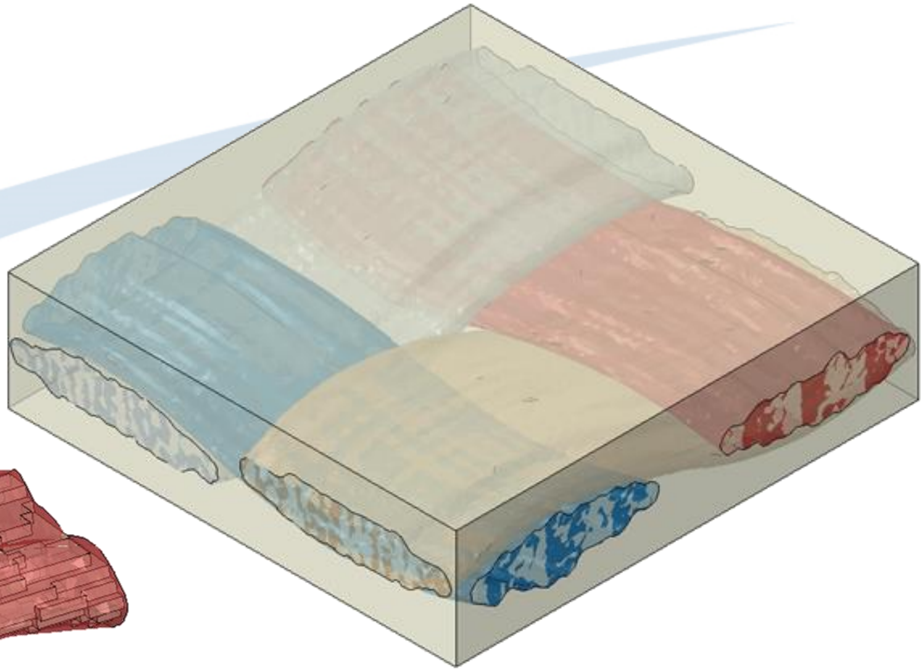
- Material orientation can be assigned using the beam orientation of the weft (see next slide for details)
- The orientation is assigned using the surface of the yarn and the beam edges (discrete option in orientation).
- Then using the keyword block, one can create a discrete field with the orientation per element.
- This is used in the model, since the beams are then not needed anymore.
- See figure at the side how orientation(red) follows the beams (black).

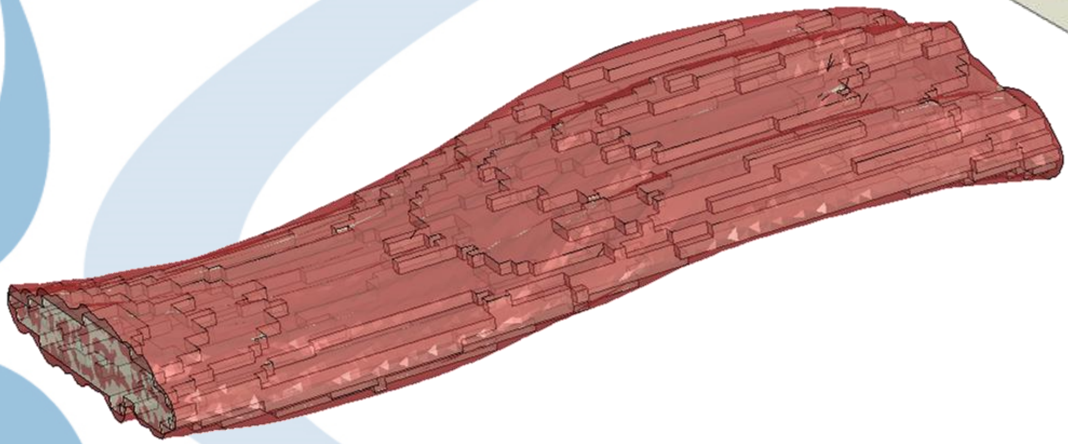


Composite creation

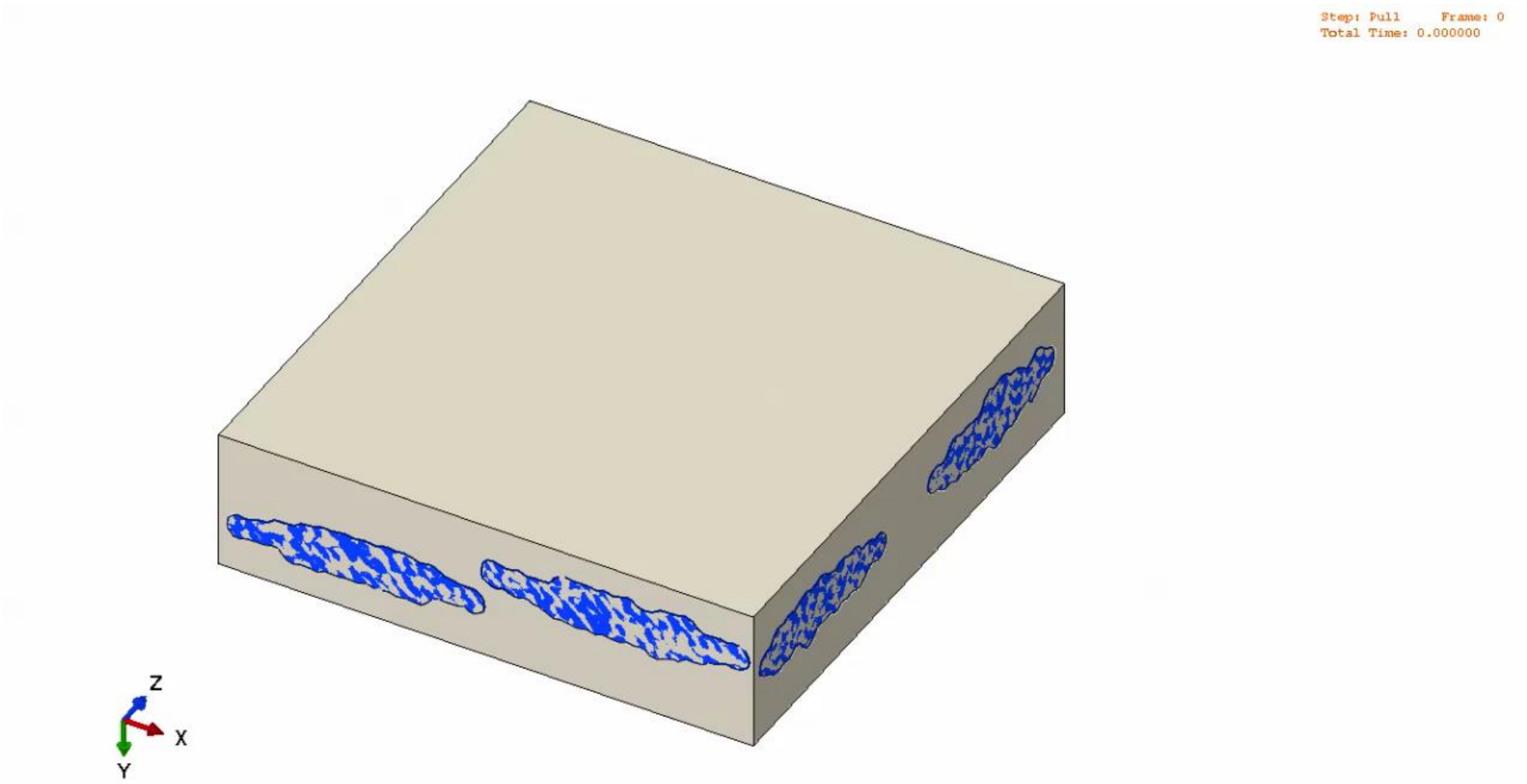
- See for example the plain weave composite at the side.

- The figure at the bottom shows the elements which are softened to improve the accuracy of the simulation; only elements that are fully within the yarn are softened.





Results mechanical testing
Model impression; A movie of the Ex testing



Results mechanical testing

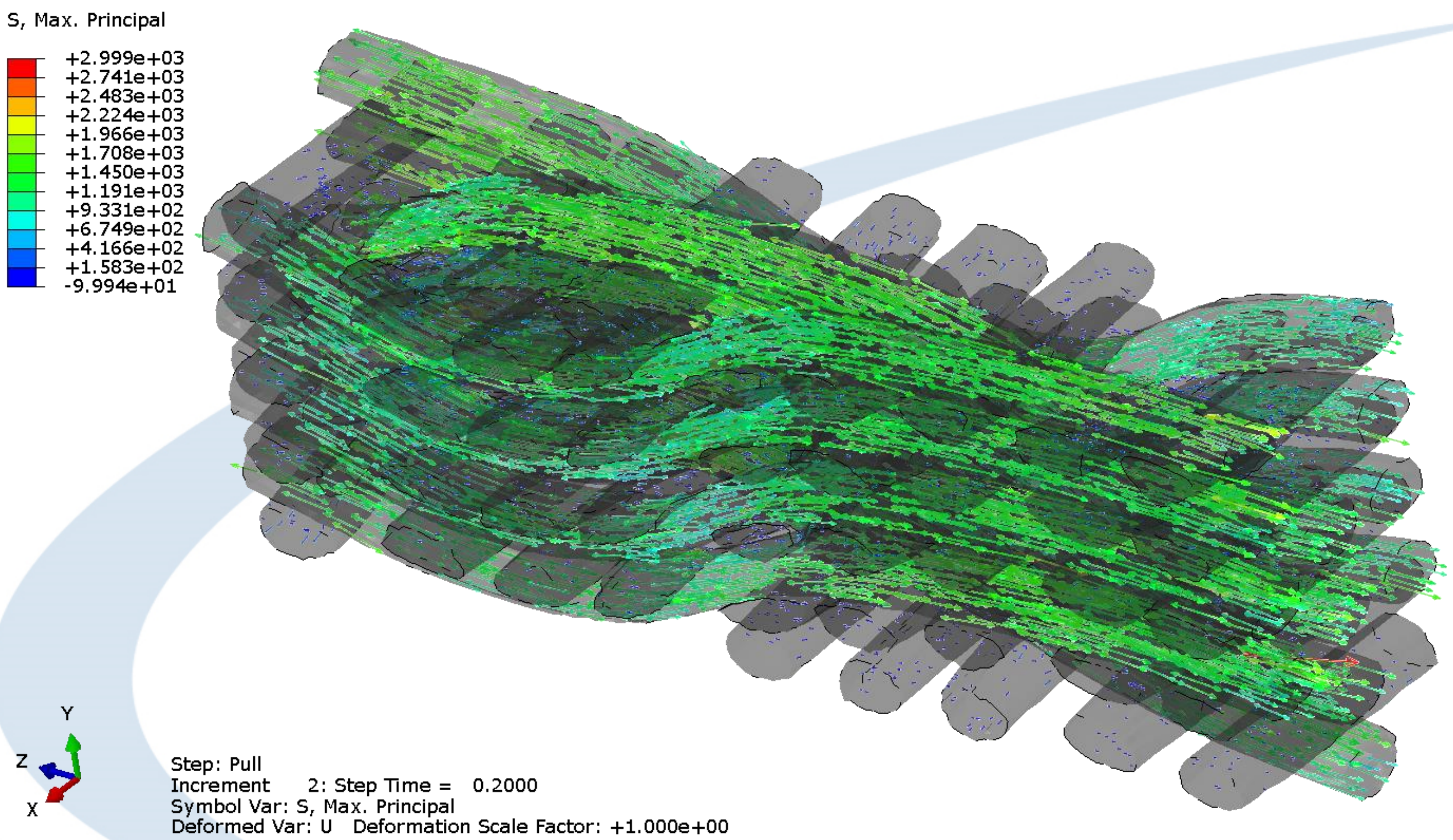
- Find the values for the unit cell, based on the micromechanical tool as well as on the simulation:

Property	U20MM	Simulation	Error [%]
Ex [Gpa]	16.44	16.59	0.95
Ez [Gpa]	7.36	7.65	4.00
Gxy [Gpa]	2.92	3.16	8.10

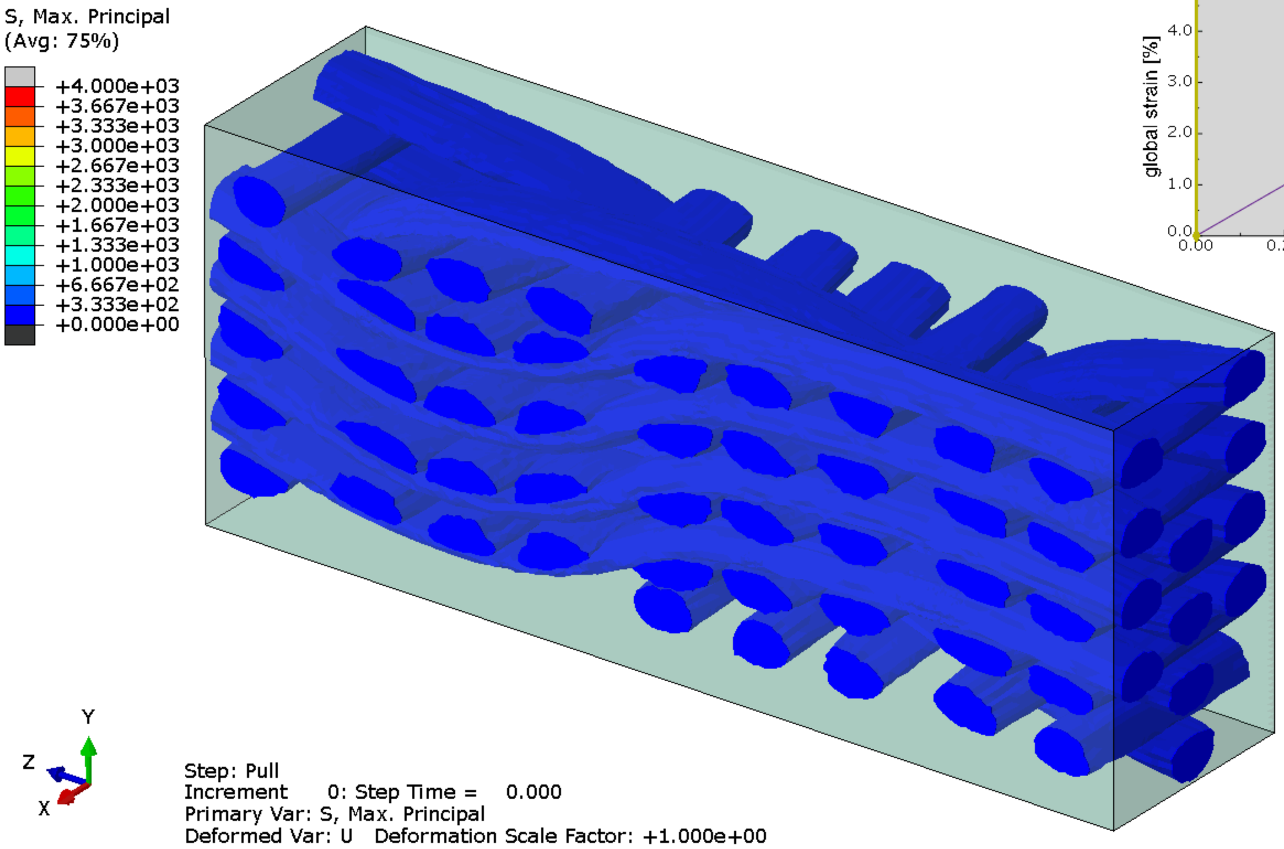
- The error on the Gxy is relatively large. This value is also very sensitive to the height of the yarns in the composite. As the height is difficulty to measure exactly, the error of the Gxy can be 8%, but also easily 15% if a different yarn height (for instance; 68% vs 75% fibre height does this) is used in comparison with the micromechanical tool!

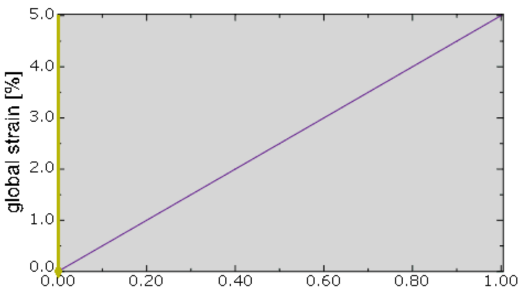
- The other errors are less dependent and are also < 5% compared to the micromechanical tool.

Warp interlock



Warp interlock





Summary

- A finite element model has been made to address the weaving process:
  - In which the fabric is built out of fibres and yarns.
  - In which the production process is included.
  - That predicts the geometry of the fabric
- The model agree well to the experiments
- The shape and local fibre volume fraction within the yarn changes slightly

- The results of weaving are used as input for a mechanical analyses
  - The method was validated against simple plain weave results
  - Errors were within 8%
- Method was applied for more complex warp interlock fabric

Next steps

Validation on different types of warp interlock fabrics

Perform unit cell based elementary tests
- tensile
- shear

Apply method to “real” products
Validation on “real” products

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AND YOUR ATTENTION