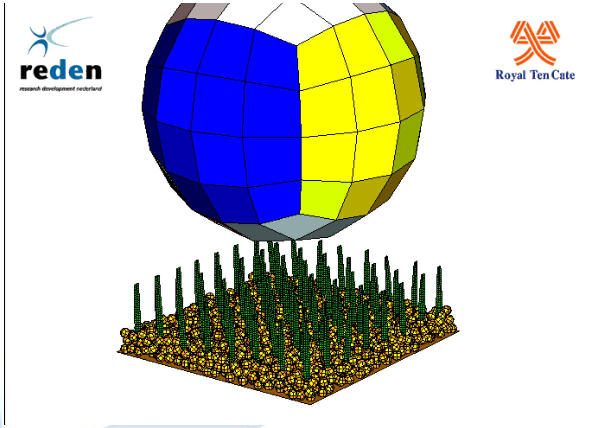
From braiding simulations towards structural analyses

Fachkongress Composite Simulation
2013

Contents

Introducing Reden

Reden is an abbreviation for: **Re**search & **De**velopment **N**ederland



Mission:

Initiate a *break-through in product development* for our customers. By bringing state of the art scientific knowledge to clients on a commercial basis.

Method:

Providing profound insights for the product developers using *validated simulation models of the product and/or the production process*.

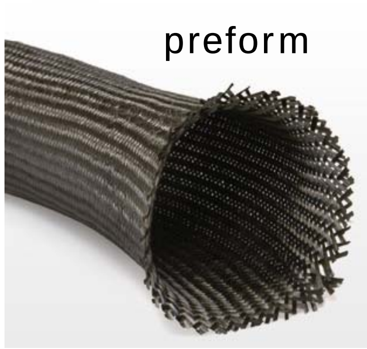
Introduction

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

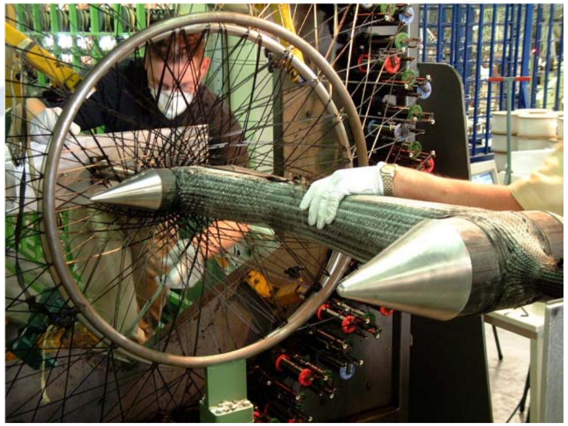
Required input to predict the composite product mechanical properties:

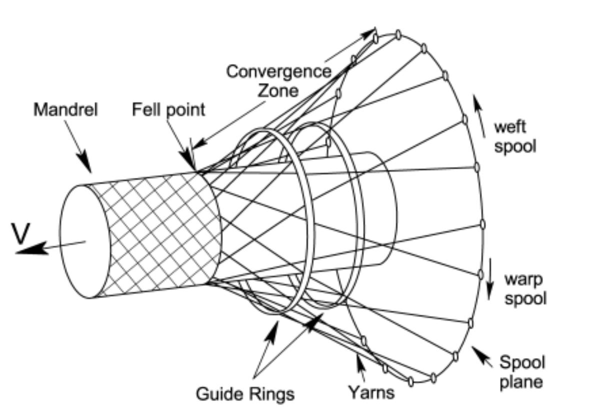
- fibre directions
- Material properties (fibres, resin)
- Lay-up
- Processing

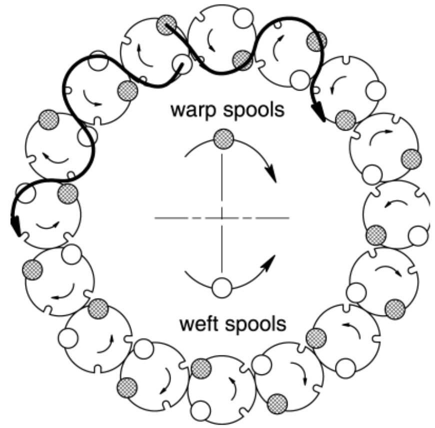


Introduction

- 2D Braiding
  - Bobbins travel in spool plane
  - Dry fibres are braided on mandrel
- Add resin and cure
  - Process
  - Resin properties
- Structural properties
  - Combination of all above

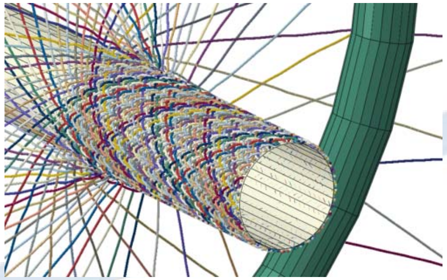






Prediction of mechanical properties

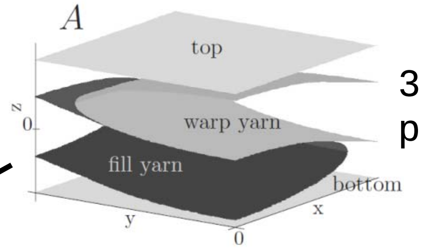
FEM braiding



Braiding parameters
+
FEM mesh

Fibre direction, coverage

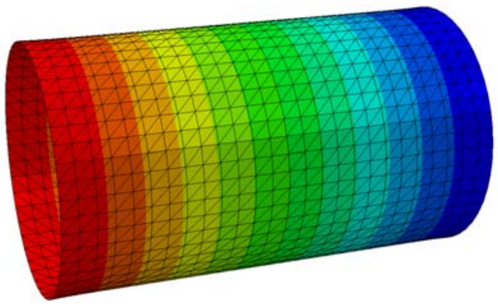
Processing parameters



3D weave properties

E, G, etc

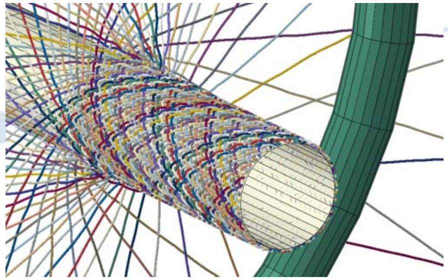
Structural analysis



Stresses, strains

Braiding

- explicit FEM (ABAQUS explicit)
- Conditionally stable: O(10^6) increments
- Contact and friction included
- Mass scaling
- Yarns are truss elements, length O(1 mm) (i.e. no bending stiffness)
- Yarns are tensioned
- Yarns cross-section circular
- CPU costly
- Spoolplane with 96 bobbins (48 cw, 48 ccw)



Braiding

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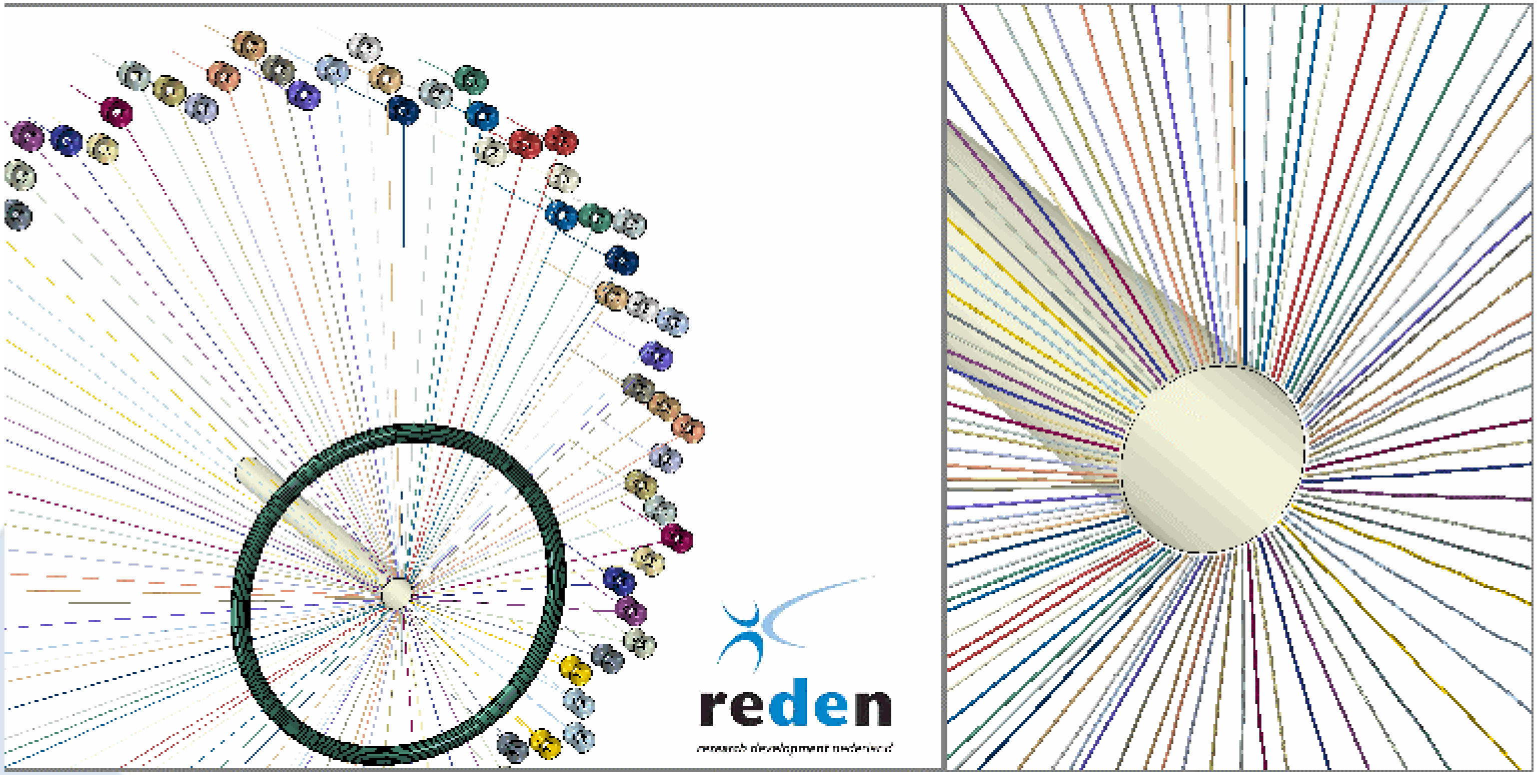
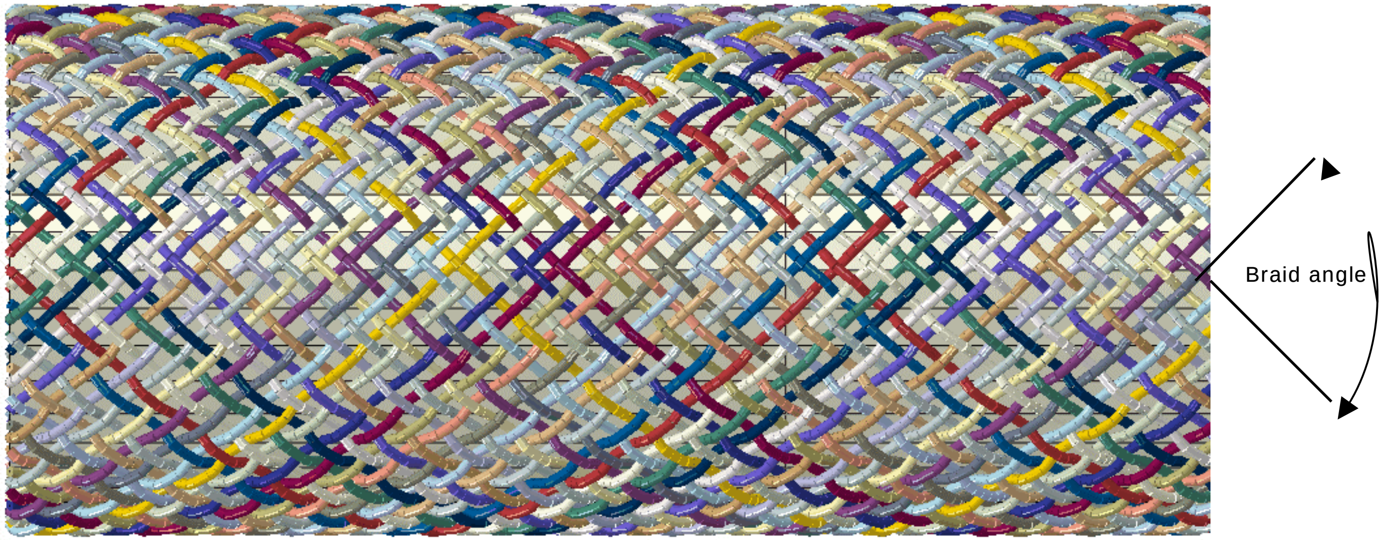


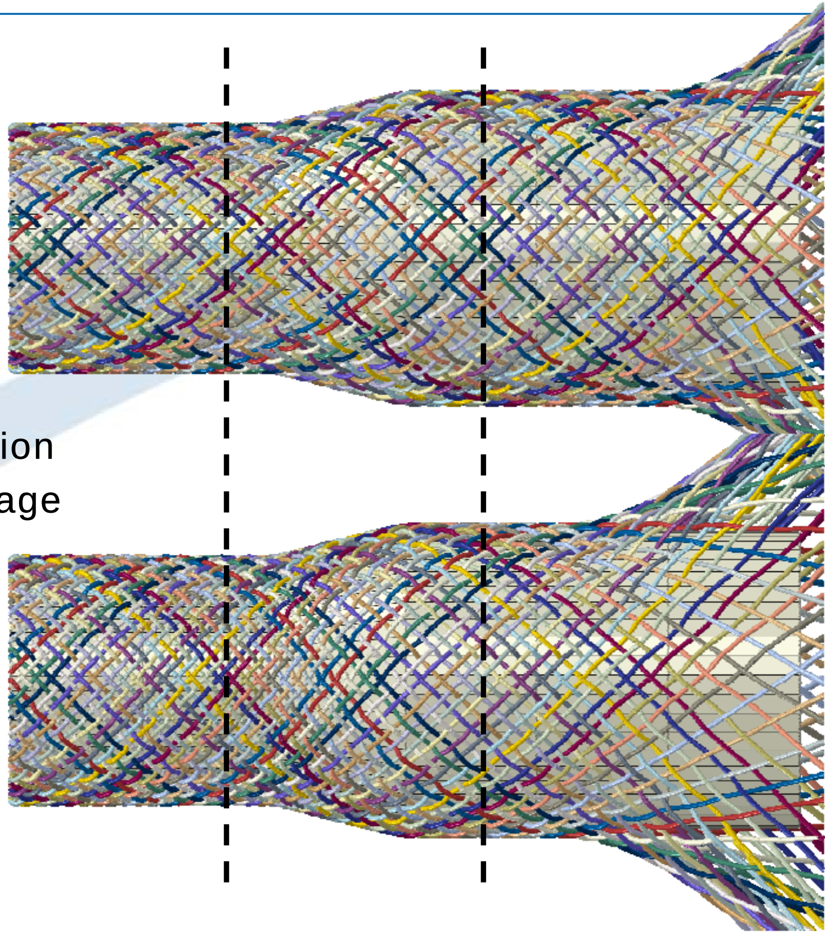
Braiding

- Validation against analytical models (steady state)
- 3K Toray T300 JB carbon yarn
- Tube diameter 35 mm, length 500 mm
- Steady state angle @ 90 degrees in model vs. 90 degrees analytically



Braiding

Effect of friction



no slip on mandrel

Can be compared with geometrical braid simulations

Change of fibre direction

Change in fibre coverage

Slip on mandrel

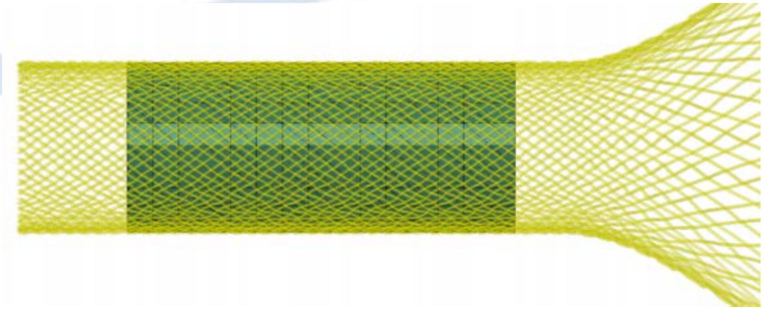
Little friction on mandrel

Tube diameter from
35 to 45 mm at
angle of 10 degrees

Mapping

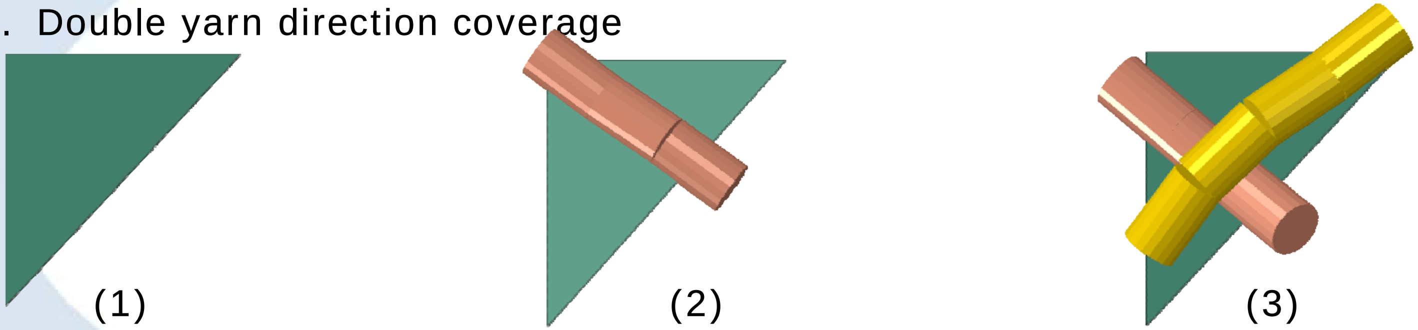
Per element the:

- Undulated fibres are projected onto the mesh
- Local fibre directions are determined
  - With respect to local element axis
- Local coverage is determined
  - Distance between yarns

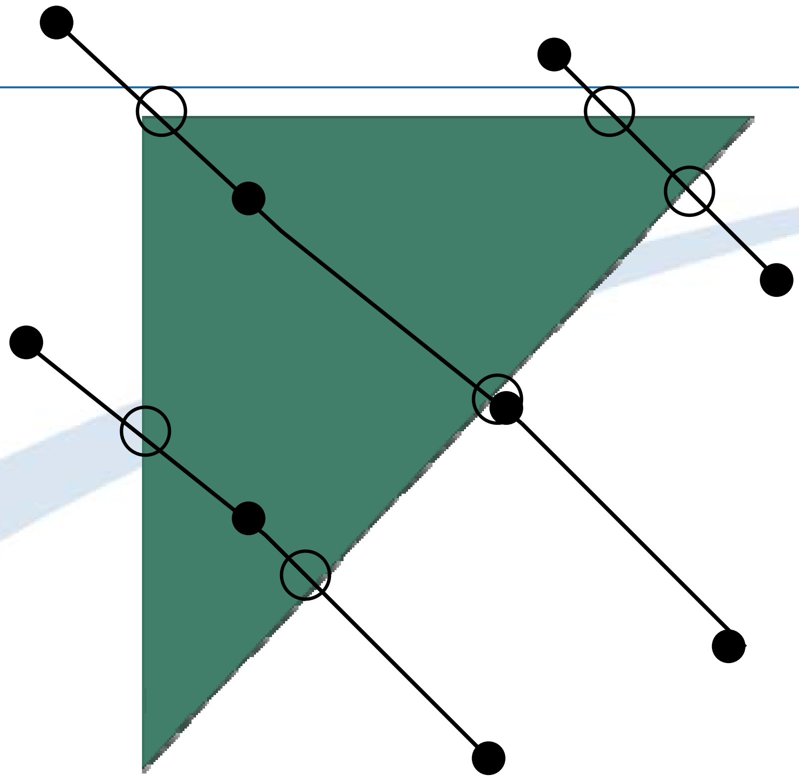


3 cases

1. No coverage
2. Single yarn direction coverage
3. Double yarn direction coverage



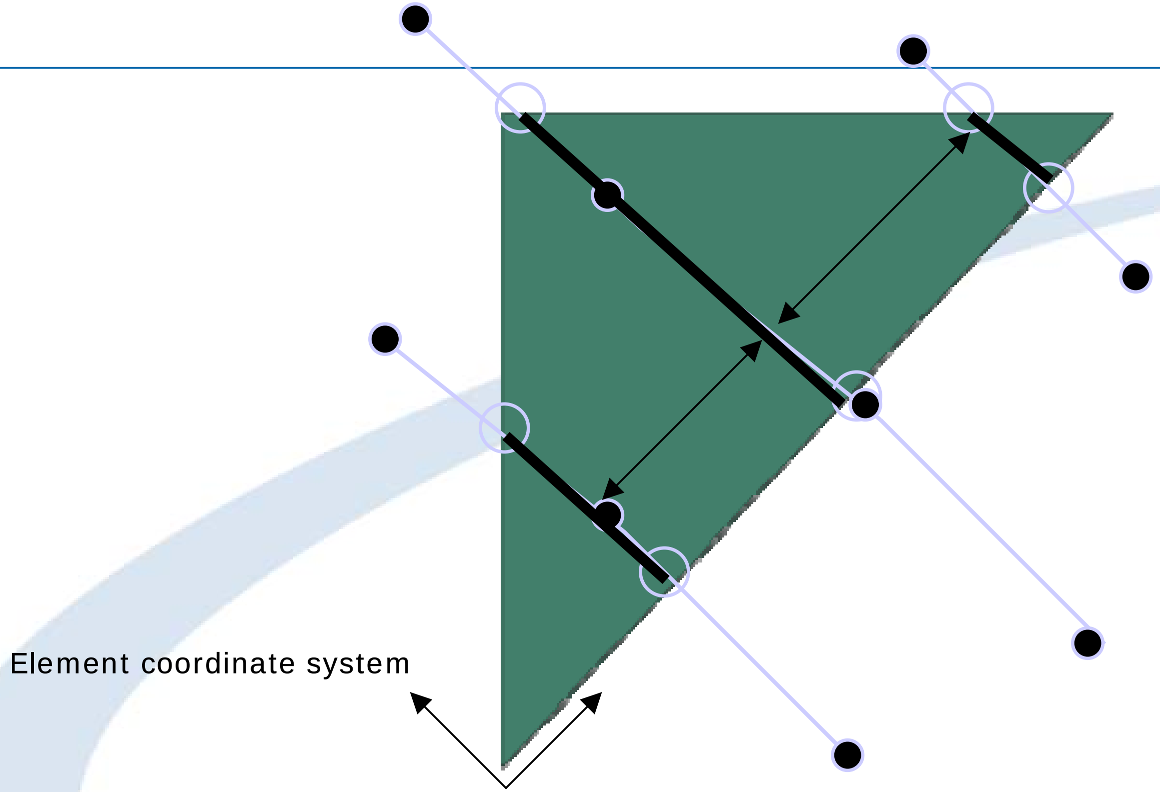
Mapping



Find acceptable crossings per element for each yarn at element edges

- 3D line section projections
- For each yarn and yarn direction

Mapping



With crossings

- Distance between yarns (by averaging with covered lenght and area)
- Local yarn angle (in element coordinate system)

Local 3D properties

Input:

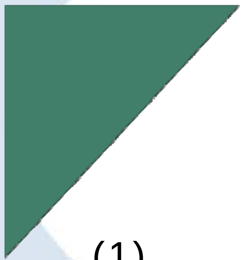
- Minimum resin layer thickness (0.1 mm)
- Maximum fibre volume fraction (50%)
- 3D fibre properties
- Matrix properties

For the 3 mapping cases:

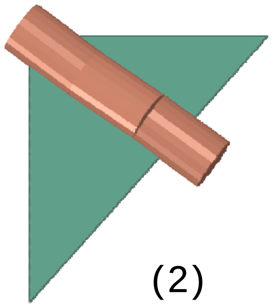
Case 1: pure resin properties

Case 2: UD properties (although not implemented)

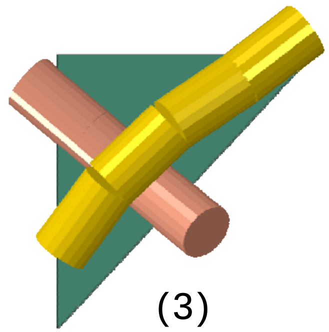
Case 3: plain weave properties



(1)



(2)



(3)

3D weave properties

Fibre properties

- Modulus
  - $E_1 = 230$ GPa, $E_2 = E_3 = 40$ GPa
  - $G_{12} = G_{13} = 24$ GPa, $G_{23} = 14$ GPa
- Poissons ratio
  - $\nu_{12} = \nu_{13} = 0.26$, $\nu_{23} = 0.38$

Yarn properties

- 3K bundle, average fibre diameter 7 microns
- Density 1780 kg/m^3

Resin properties (Epoxy)

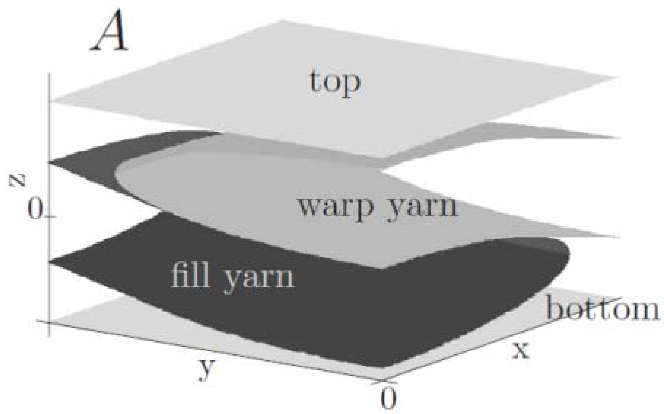
- Modulus E = 3.2 GPa
- Poissons ratio $\nu = 0.37$

Minimal resin layer thickness 0.1 mm (process dependent)

3D weave properties

3D weave properties based on Wijskamp [1]

- Yarns are undulated, i.e. twill weave
- Micromechanics based



3D properties implemented in U20MM [2]

- called at each element
- Iso strain configuration

Returns:

- Homogenised properties (i.e.E1, E2, E3, G12, G13, G23, etc)
- Local thickness (i.e. Element thickness)

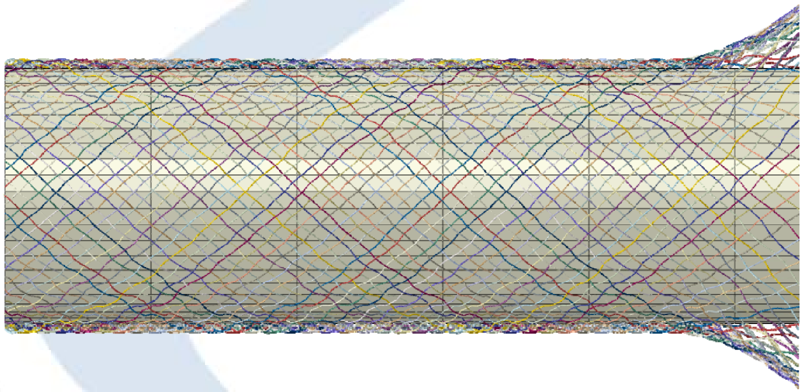
[1] Shape distortions in composites products, Sebastiaan Wijskamp, PhD Thesis, University of Twente, 2005
[2] U20MM, http://www.utwente.nl/ctw/pt/research/Tools/

Structural analysis

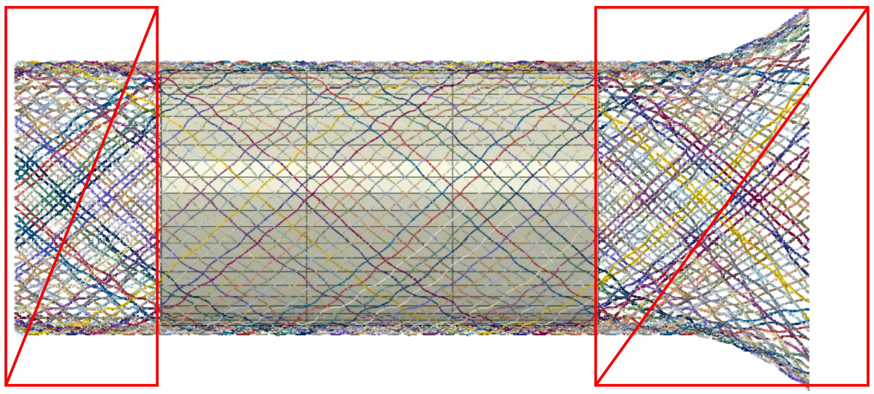
- Results from braiding and U20MM combined
- Part trimmed to appropriate size

- implicit FEM (ABAQUS standard)
- Linear triangular shell elements (S3), 5 integration points through thickness

Tensile test upto 1% axial strain, on tube of 60mm long



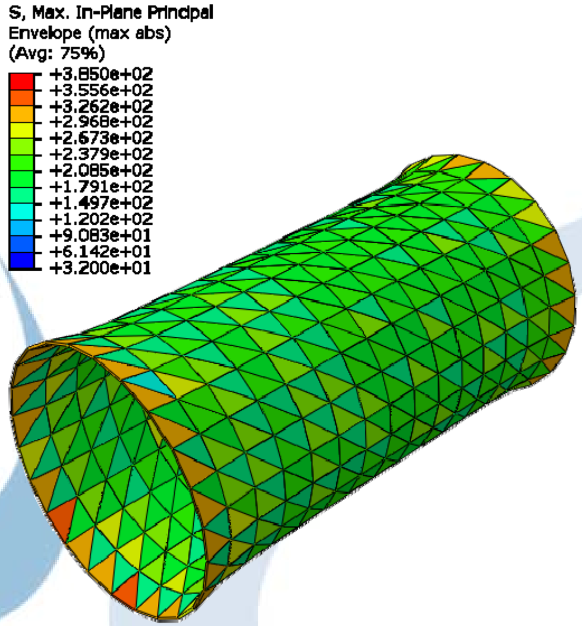
Braided mesh



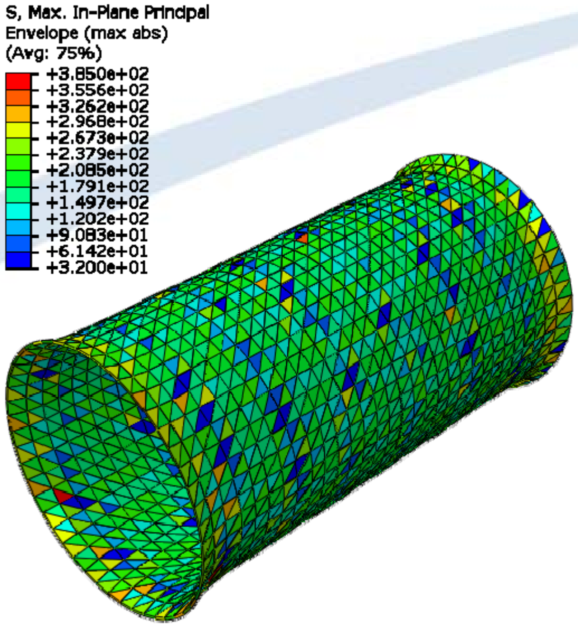
Braid for structural analysis

Discussion

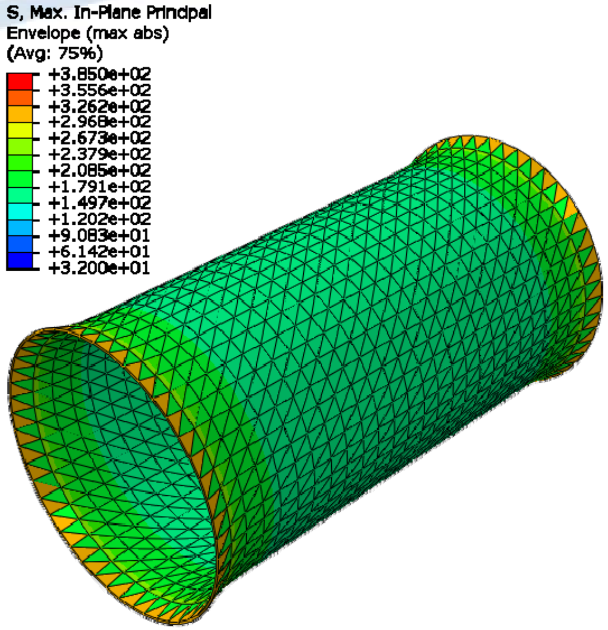
Discretisation, stress distribution [MPa] (max - principal)



Coarse mesh



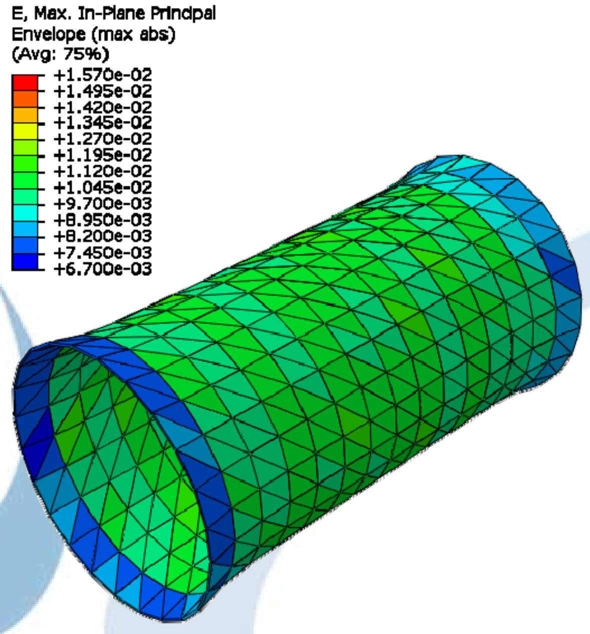
fine mesh



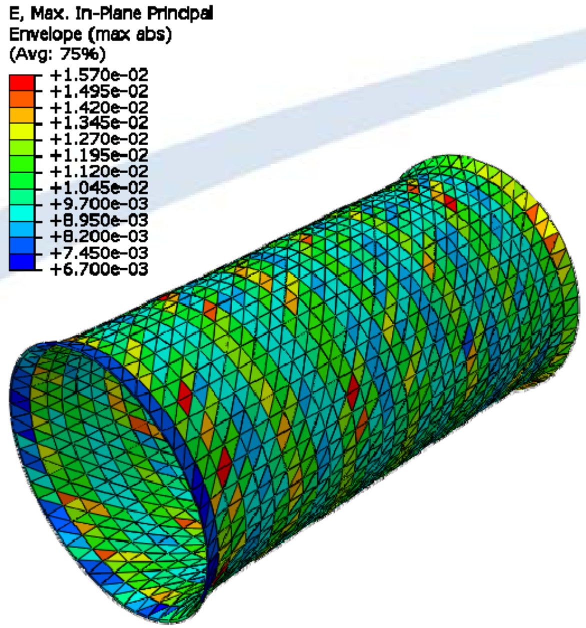
homogenised properties

Discussion

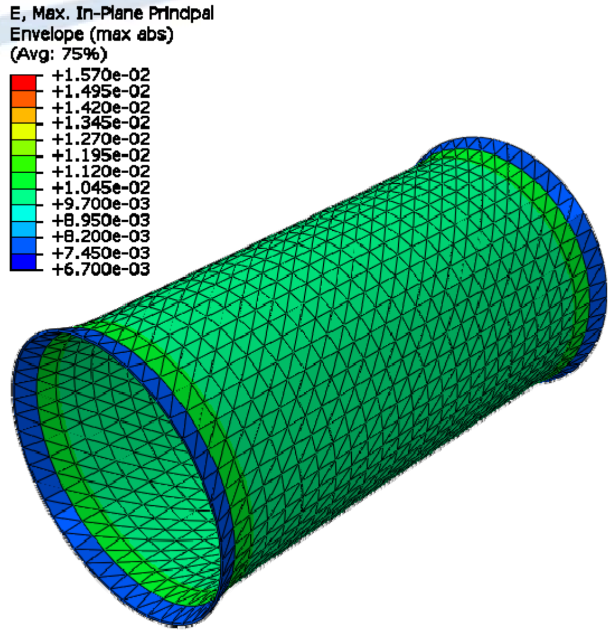
Discretisation, strain [-] max principal



Coarse mesh



fine mesh



homogenised properties

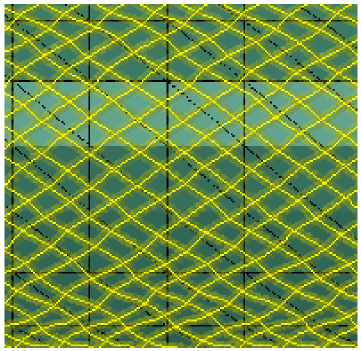
Discussion

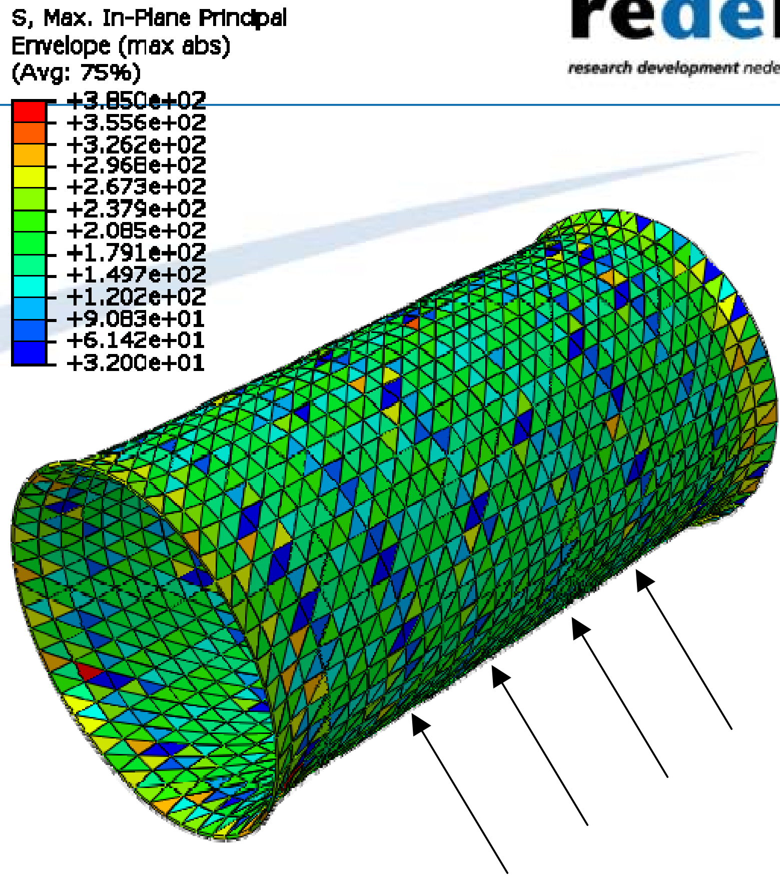
stress banding

Mesh is fine compared to distance between yarns

Elements coverage becomes inhomogeneous

3D properties not homogeneous across elements





Repetitive crossing of structural mesh and fibre directions

Conclusion

- Braiding simulations were performed and validated against analytical models
- A mapping method of the braiding results was developed for shell meshes
  - Fibre directions
  - Fibre coverage on mandrel
- The results of the mapping method were used to predict 3D Engineering constants properties of composite materials
- A shell based structural analysis was done with the predicted properties, and validated against analytical solutions
- Results depend on homogenisation, mesh dependency

Future work

- Braiding of multiple layers
  - Include cohesive elements between layers
- Quad meshes
- Validation of complex shapes, including inserts
- Include UD properties into prediction
- Determine if smoothing of the directions or coverage is required

Acknowledgements

- MapiCC3D, Research project co-founded by the European Commission under GA 263159

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