Numerical Modelling of the Mechanical Response of Triaxial Braided Composites

Tobias Wehrkamp-Richter
Silvestre T. Pinho
Roland Hinterhölzl

„A Comprehensive Approach to Carbon Composites Technology“ Symposium on the occasion of the 5th anniversary of the Institute for Carbon Composites

Research Campus Garching, September 11th – 12th 2014
Agenda

1. Motivation and Strategy
2. Modelling Framework
3. Conclusion and Outlook
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1. Motivation and Strategy
2. Modelling Framework
3. Conclusion and Outlook
Introduction to Braiding Technology

- **Braiding technology**
  - Counter-rotating orbital spools with carbon fibres
  - Mandrel is guided through braiding centre by robot
  - Fibres deposit on mandrel
  - Complex geometries possible
  - Low waste, high throughput

- **Process flexibility**
  - Biaxial and triaxial braids possible

- **High volume production**
- **Mechanical in-plane properties**
Overall Strategy

Material Modelling

MATERIAL CHARACTERIZATION
- MECHANICAL PROPERTIES
- TEXTILE ARCHITECTURE
- FAILURE MECHANISMS AND MORPHOLOGY

MATERIAL MODELING
- MESO-Scale MODELING
- NUMERICAL APPROACHES
- PREDICTION OF NON-LINEAR MATERIAL BEHAVIOR
- ASSESSMENT OF KEY PARAMETERS

MATERIAL MODELING
- MACRO-Scale MODELING
- ANALYTICAL/SEMI-ANALYTICAL APPROACHES
- FOCUS ON REDUCED COMPUTATIONAL COST
- APPLICABILITY TO STRUCTURAL ANALYSIS/SIZING

Final failure of a triaxial braid
Unit cell simulation
Braided structure
Agenda

1. Motivation and Strategy
2. Modelling Framework
3. Conclusion and Outlook
Simulation Framework

**LEVEL I: Geometry Pre-processor**

- 3D surface mesh generation
- Preliminary geometry assessment
- Selection of unit cell size
LEVEL I: Geometry Pre-processor

- Parametric 3D geometry model
  - Instant build in MATLAB
  - Sinusoidal superposition to create yarn surfaces
  - Assembly of phase-shifted cross-sections to model non-orthogonal yarn intersections
- Geometry export to Abaqus

\[ z_{surf} = \pm \frac{t_{len}}{2} \cdot \cos\left(\frac{y \cdot \pi}{b}\right)^{n_{sec}} + t_h \cdot \sin\left(x - \frac{\kappa \cdot \pi}{L_s}\right) + t_s \cdot \frac{t}{2} \]

\[ \kappa = \chi \cdot y \cdot \tan\left(\frac{\pi}{2} - 2 \cdot \theta\right) \cdot \cos\left(\frac{x \cdot \pi}{L_s}\right)^2 \]
Simulation Framework

**LEVEL I: Geometry Pre-processor**
- 3D solid representation
- Automatic periodic meshing and boundary conditions
- Property and contact assignment

**LEVEL I: Meso-Model**
LEVEL I: Meso-Model

Derivation of Reduced Unit Cell

\[
T_1 = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{bmatrix},
T_2 = \begin{bmatrix}
-1 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & 1 \\
\end{bmatrix},
T_3 = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{bmatrix},
T_4 = \begin{bmatrix}
-1 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & -1 \\
\end{bmatrix}
\]

N.V. De Carvalho et al.: Reducing the domain in the mechanical analysis of periodic structures with application to woven composites. Compos Sci Technol 2011;71:969-979
LEVEL I: Meso-Model

Periodic Meshing

- Automatic periodic meshing in Abaqus
- Periodic mesh refinement in contact zones

- Hex-dominated yarn mesh
- Material orientations from mesh
Simulation Framework

**LEVEL I: Geometry Pre-processor**
- Fictitious thermal loading to resolve interpenetrations
- Fabric compaction to desired fibre volume fraction

**LEVEL I: Meso-Model**

**LEVEL I: Forming Simulation**
LEVEL I: Forming simulation

Interpenetration correction

- Geometric interpenetrations exist in the model due to the nominal geometry model
- Correction using orthotropic thermal expansion step with contact
- Full periodic boundary conditions to avoid geometric coupling effects
LEVEL I: Forming simulation

Compaction simulation

- Out-of-plane BCs to implicitly consider nesting of plies
- Axial yarns shifted by half of spacing

\[ T_5 = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \]

\[ T_6 = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \]
LEVEL I: Forming simulation
Compaction simulation

- Compaction using soft membrane to achieve desired fibre volume fraction
- Periodicity remains throughout simulation
- Top and bottom membrane nodes can be used for matrix mesh
**LEVEL I: Forming simulation**

Compaction simulation

- Effect of neighbouring plies taken into account during nesting
- Computationally efficient

![Diagram showing rUC uncompacted and compacted states](image_url)
Simulation Framework

**LEVEL I: Geometry Pre-processor**

**LEVEL I: Meso-Model**

**LEVEL I: Forming simulation**

**LEVEL II: Meso-Model**

- Yarn geometry reconstruction from deformed mesh
- Determination of matrix pocket geometry
- Periodic boundary conditions
Simulation Framework

LEVEL I: Geometry Pre-processor

LEVEL I: Meso-Model

LEVEL I: Forming simulation

LEVEL II: Meso-Model

LEVEL II: Mechanical Simulation
Agenda

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Conclusion and Outlook

- Framework for meso-scale simulation of braided composites proposed

- **High fidelity**
  - Detailed stress fields available, full continuum unit cell
  - Representation of typical composite failure modes
  - Realistic representation of geometry, intra-yarn FVF and global FVF

- **Efficiency**
  - Reduction of modelling domain through advanced PBCs
  - Hex-mesh in the yarns
  - Implicit consideration of nesting using out-of-plane PBCs

- **User friendliness**
  - Parametric modelling framework
  - ‘One click’ input file, no manual model generation required

**Next steps:** Matrix mesh and validation of geometry
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