Assessment of different meso-modelling techniques for 2D woven composites

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Introduction

Shift away from the test-intensive classical approach by more simulation
Virtual Material Characterization (VMC) Concept

Main objective: efficiently generate mechanical material data by simulation replacing tests (coupon-tests)

Key technology elements:
- Covers micro (yarn-level) to meso (textile/UD-level) to macro (application-level)
- CAD interface to geometry modeler WiseTex (KULeuven MTM)
- Fast homogenization method by TexComp (KULeuven MTM) for stiffness predictions
- Advanced FE-based homogenization by ORAS (UGent MMS)
Virtual Material Characterization

Generic framework

Composite geometry definition

- WiseTex
- CAD
- Composite geometry definition
- woven (2D and 3D)
- braids
- weft-knits
- NCF
- laminates

Fast analytical homogenization

- Macro-level
- Stiffness

FE-based homogenization

I. Virtual Material Characterization

II. Composite geometry definition

- CAD

III. FE preprocessing

- Mesh process
- Material data (orientations,..)
- Constraints (PBC,..)

iii. FE preprocessing

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ORAS

Universiteit Gent

SIEMENS

nafems.org/americas

Multiscale and Multiphysics Modeling & Simulation - Innovation Enabling Technologies

March 28th-29th, 2017 | Columbus
Case study: 2D woven composite

3 Models evaluated:

- Model based on μ-CT (UGent)
- Idealized model based on WiseTex (VMC ToolKit, Simcenter)
- Model using Mesh Superposition Technique (KU Leuven)

Input data

- Matrix/ Fiber: experimentally measured
- Yarns: micro-scale homogenization (Chamis)

Model based on μ-CT (MESI)

Benchmarking
Homogenized elastic properties

Idealized model (VMC ToolKit)

Model with Mesh Superposition Technique (MSP) technique
MESI Model based on $\mu$-CT
Variation of cross sections

- Measurement-based RUC construction
- Reliably captures variation of cross sectional shape of yarns with understandable shape functions

**MESI Model based on μ-CT CAD**

- Shape function calibration with measured data → Avoids geometrical interpenetrations upon RUC assembly → Easier meshing
- Includes nesting effects (2-ply RUC!)

MESI Model based on $\mu$-CT

Preliminary results

- Compared to Idealized RUC, correctly captures yarn cross sectional area
- $\Rightarrow$ more realistic local stress prediction

Idealized model (VMC ToolKit)

File | Home | Results | View | Application | VMC ToolKit 1.2

Geometry | TexComp | Chamis | Random Packing | Mesh Process | Material Definition | Contact and Kinematic Definitions | Periodic Boundary Conditions | Cohesive Layer | Cohesive Wrapper | Homogenization | Default Parameters

Model in WiseTex -> Import to CAD of one fabric ply -> Nesting -> Meshing the model

Idealized model
Local material orientation

Assign Materials

Material autocorrection
• To account for change in local Vf in yarns
Idealized model
Periodic boundary conditions (PBC)

**Challenge:** periodic non-conformal and non-symmetrical meshes

**Solution:** set of constraints/equations on the different faces that creates from a non-periodic mesh a periodic unit cell

[PhD Stefan Jacques, UGent, 2014]
Idealized model
Homogenization

I. 6 load cases
   - 3 tensile load cases
   - 3 shear load cases

Tensile load case 1 $e_x=0.1\%$

II. Volume averaging of stresses

III. Build stiffness matrix (automatized process)
MSP model (mesh superposition)

MSP model

- Reinforcement parts or “guest” meshes are placed inside the matrix part or “host” mesh.
- A “superimposing equation” is created for defining a relation between the degrees of freedom (DOF's) of the two meshes.

Main challenges in meso-FEM of textile composites using MSP:

1) **Volume redundancy**.
2) **Interpenetration of reinforcements**
MSP model
Volume redundancy

1. Embed guest region (yarns) in the host (matrix)
2. Assign material properties to the matrix
3. Assign material properties in yarns: \( C'_R = C_R(x) - C_M \).
4. Run the Homogenisation
5. Calculate strain fields \( \varepsilon(x) \) separately for the yarns and the matrix
6. Keep stress fields in the matrix. The stress fields in the yarns must be recalculated: \( \sigma(x) = C_R \varepsilon(x) \).
MSP model

Resolving interpenetrations

Adjustment of interpenetrated nodes using contact algorithm

Interpenetrated yarns after geometry generation!

Results

MSP model vs MESI model

Strain profiles from the tensile load case: along the weft direction (-x)
Results
MSP model vs MESI model

- Good correspondence between strain profiles!
- Extra noise in MSP model
**Results**

**Homogenized elastic properties**

<table>
<thead>
<tr>
<th></th>
<th>(E_{xx})</th>
<th>(E_{yy})</th>
<th>(E_{zz})</th>
<th>(G_{xy})</th>
<th>(G_{xz})</th>
<th>(G_{yz})</th>
<th>(\nu_{xy})</th>
<th>(\nu_{xz})</th>
<th>(\nu_{yz})</th>
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</thead>
<tbody>
<tr>
<td><strong>MESI-RUC</strong></td>
<td>60.527</td>
<td>59.918</td>
<td>7.47</td>
<td>3.442</td>
<td>2.53</td>
<td>2.581</td>
<td>0.07</td>
<td>0.46</td>
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<tr>
<td><strong>Idealised model (VMC)</strong></td>
<td>63.997</td>
<td>63.667</td>
<td>7.056</td>
<td>5.096</td>
<td>2.212</td>
<td>2.106</td>
<td>0.04</td>
<td>0.463</td>
<td>0.4512</td>
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<tr>
<td><strong>MSP</strong></td>
<td>59.487</td>
<td>58.512</td>
<td>7.215</td>
<td>3.439</td>
<td>2.654</td>
<td>2.7</td>
<td>0.067</td>
<td>0.459</td>
<td>0.464</td>
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<td><strong>Experiment</strong></td>
<td>58.1</td>
<td>56.7</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

- **<10%** difference in **Young’s moduli** between 3 models and experiments
- **<5%** difference in **all moduli** between MSP and MESI
- **\(G_{xy}\)** is **45%** higher in idealised model (increased local \(vf\) in yarns due to interpenetration correction)
- **60-70%** difference in **Poisson’s coef** between MSP/MESI and experiments (difficult to measure \(\nu\) experimentally)
Conclusions

**MESI model:** improved RVE based on $\mu$CT
- Variability of the structure based on the in-situ measurements
- Correction of yarn interpenetrations using *shape functions*
- Good agreements with experiments

**Preprocessing:** slow ($\mu$CT analysis)
**Computation:** fast

**VMC model:** industry-ready simulation framework
- (Semi)automated process for meshing, material orientation, PBC, homogenization
- Fast model generator of textiles (link to WiseTex)
- Too high in-plane shear moduli

**Preprocessing:** fast and automated
**Computation:** fast

**MSP:** an efficient method for meshing meso-level models
- The problem of redundant volumes is resolved
- Inter-yarn interpenetrations are corrected using *contact* algorithm
- Strain profiles in a good agreement with MESI model, but have additional noise
- Good agreements with experiments

**Preprocessing:** fast and efficient
**Computation:** slow (x10 vs MESI) (due to MSP constraints)
Acknowledgements

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