On the Meso-structure Spatial Variability Characterizing and Geometric Modelling of Textile-Based Composite via Volume Imaging

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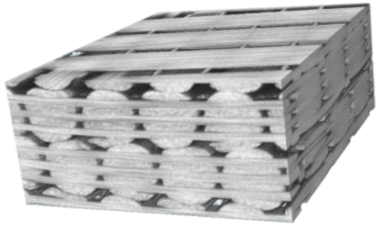
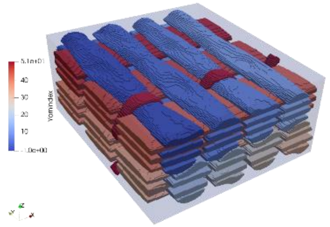


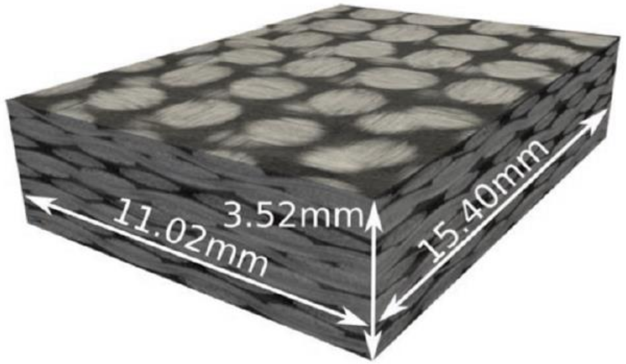
August 2, 2023



Digital Material Twin (DMT) - Virtual Lab

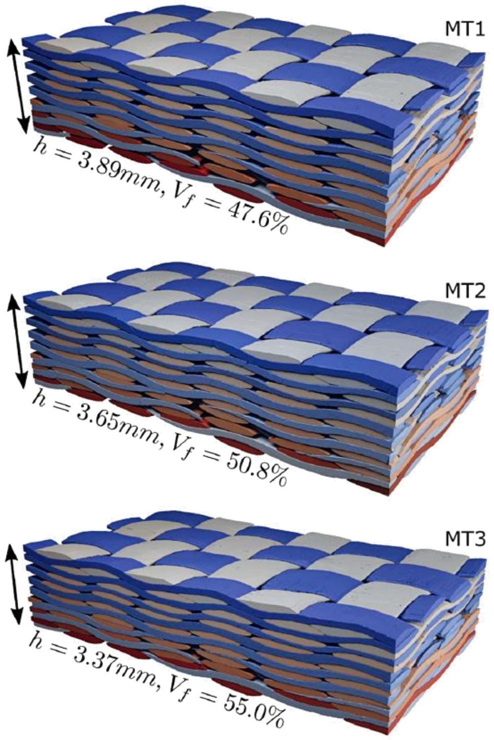
DMT = *Collection of **actual physics-based** models reflecting the **exact** structure of the physical part and operating conditions.*

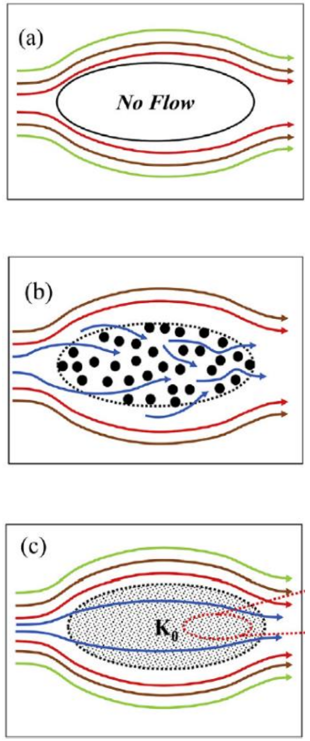
- **detailed and accurate** geometrical modelling and meshing
- automatic tools to evaluate **quality**
- robust **numerical analysis**
- **multiscale** analysis
- real-time data from sensors in its physical implementation

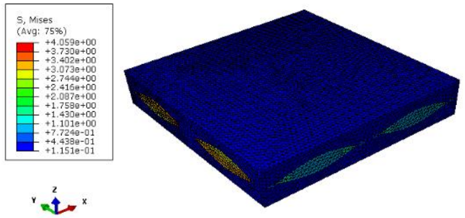


Digital Material Twin in composites

- Preform Digital Physics
  - Compressibility
  - Flow
- Digital Composite Physics







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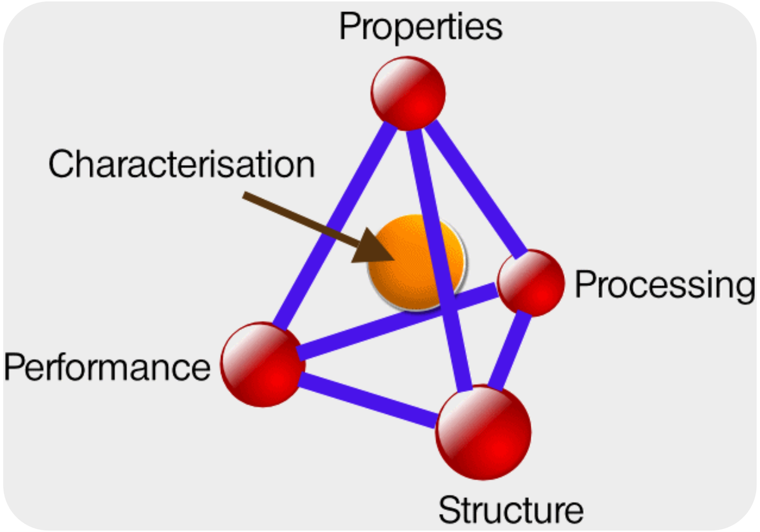
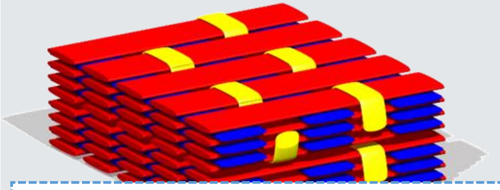


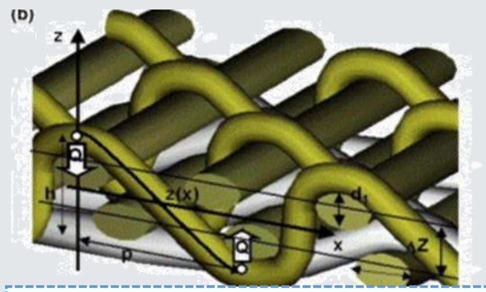
Mesoscopic modelling technique



[1] Zeng et al., Compos Part A Appl Sci Manuf. 2015

Geometrical simplification:

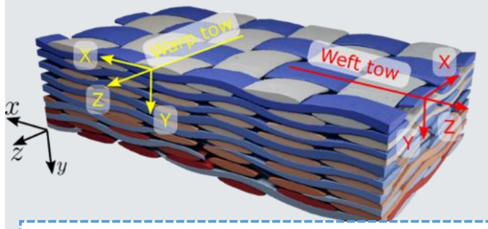
- General-purpose CAD software
- TexGen [1], etc.



[2] Verpoest et al., Compos Sci Technol. 2005

Mechanical prediction:

- WiseTex (minimum energy) [2]
- beam elements / digital element chain
- et cetera…



[3] Huang et al., Compos Part A Appl Sci Manuf. 2019

Image-based modelling:

- Commercial: VG studio, Avizo …
- Open source: ImageJ, Scikit-image …
- In-house code

Objective

Develop a geometry modeling algorithm incorporating stochastic geometrical analysis and considering the local variation of materials.

- ❑ Morphological representation of **fiber tow**
  - **Tow representation** fibrous reinforcement
  - **Statistical analysis** of geometrical features

- ❑ Geometrical modeling and meshing of **fibrous preform**
  - **3D reconstruction fabric**
  - **Conformal and non-conformal meshing**

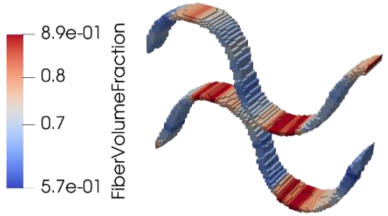
Outline

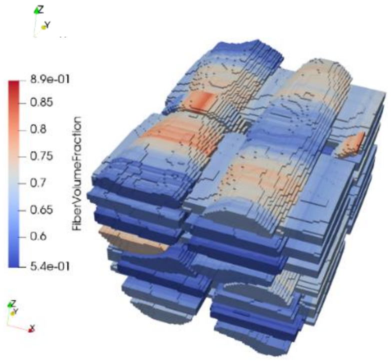
Experimental charaterization

Fiber tow representation

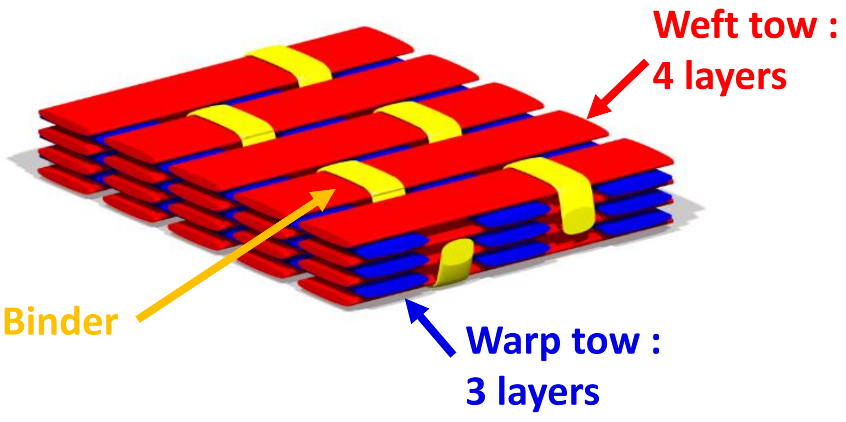
3D preform reconstruction

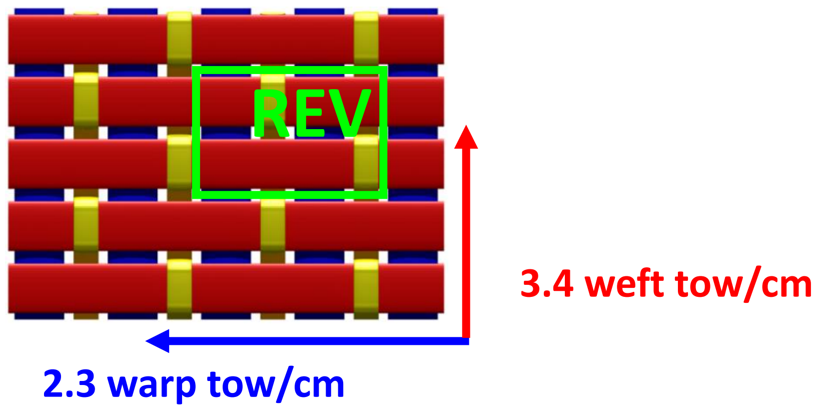
Conclusion

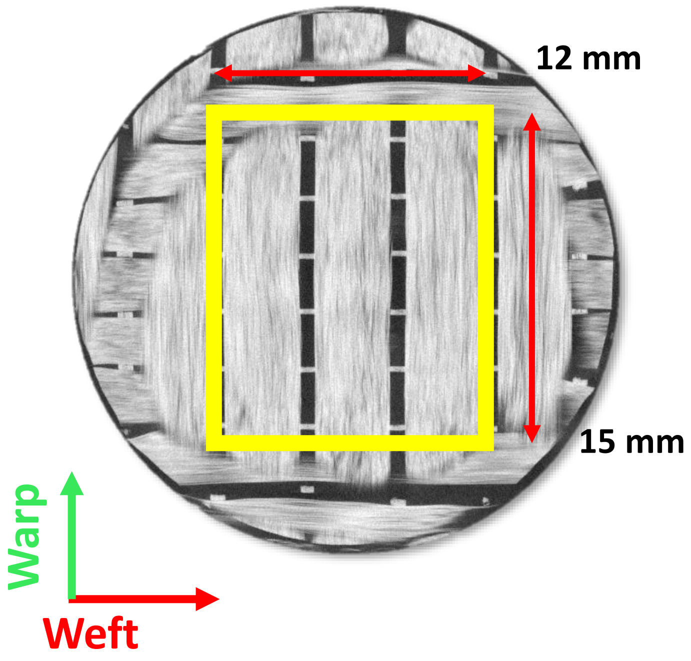


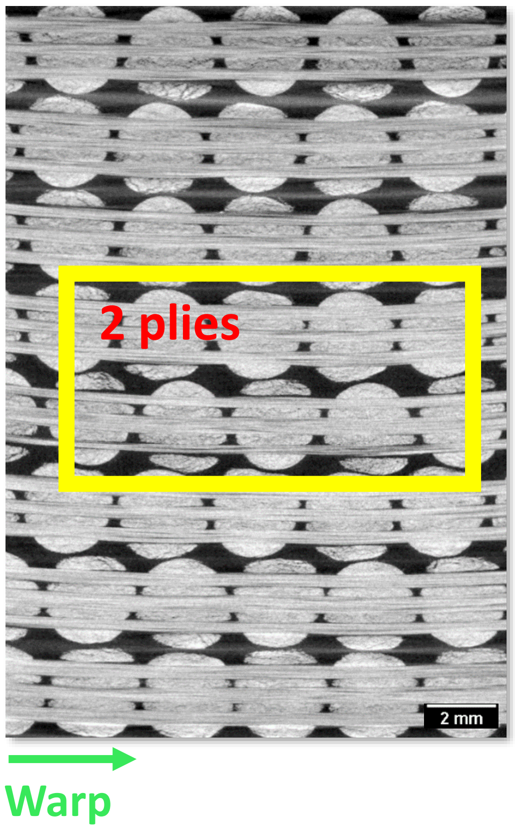


Fibrous reinforcements investigated









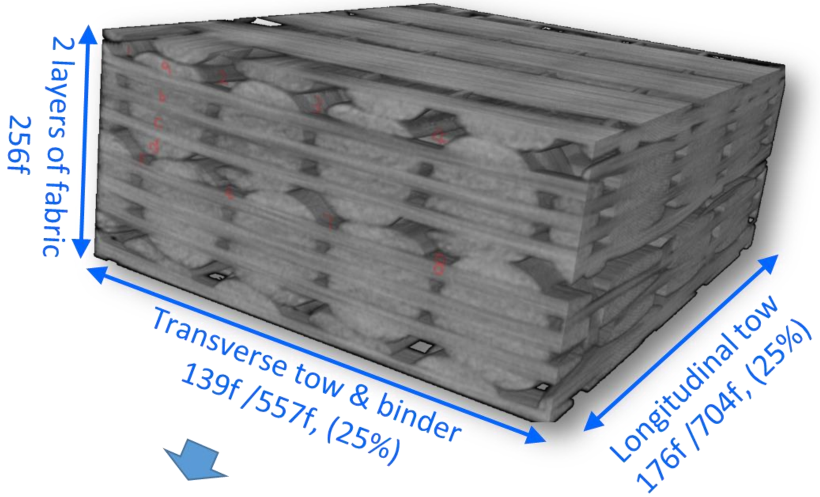
8 dry circular plies

Diameter : 25.4 mm

Plies with the same orientation

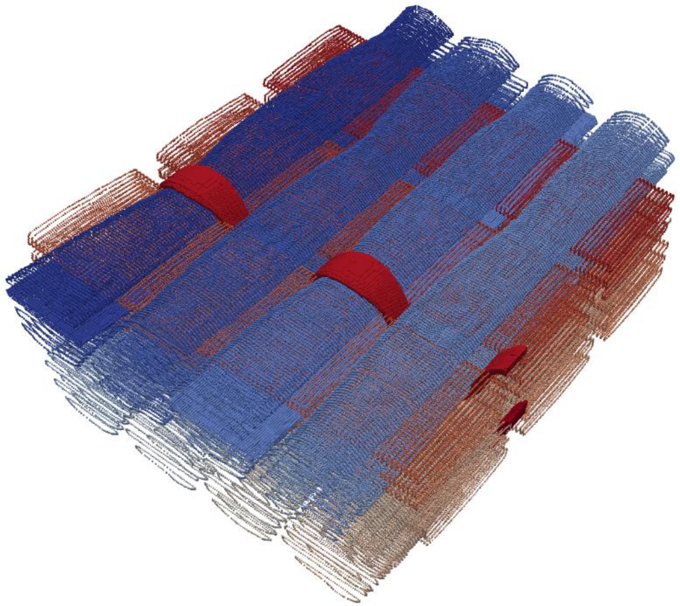
Segmentation

Raw data



- Size: 12.25 mm × 15.55 mm × 5.63 mm
- Fiber volume fraction: 57 %

Point cloud



Semi-automated workflow:

Manual segmentation on key slices → Interpolating the segmented contour → Manual refinement

Outline

Experimental method

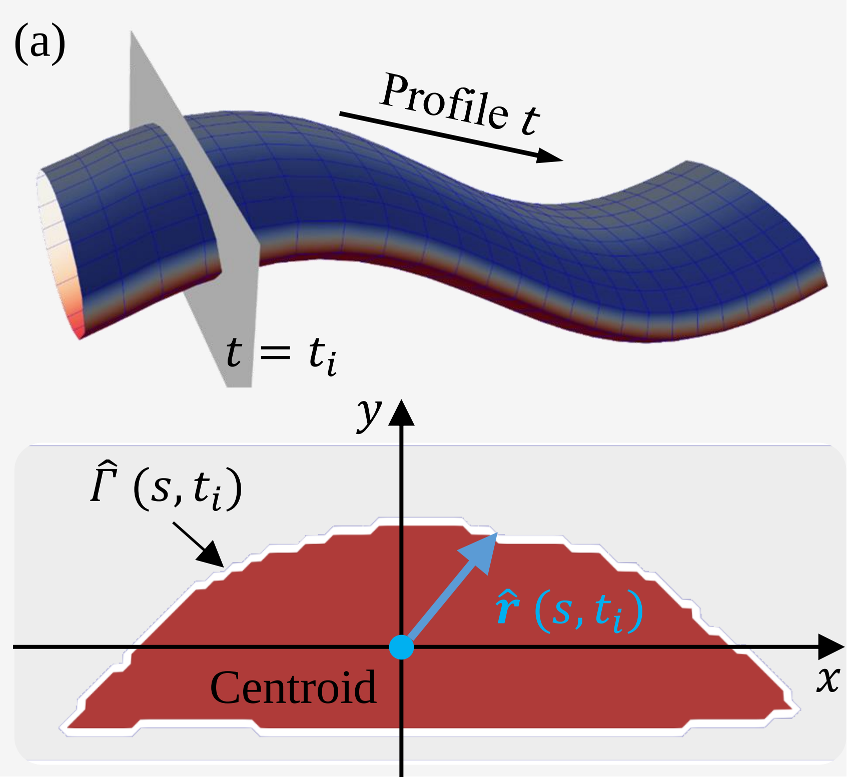
Fiber tow representation

- Tow surface
- Tow trajectory
- Accuracy control

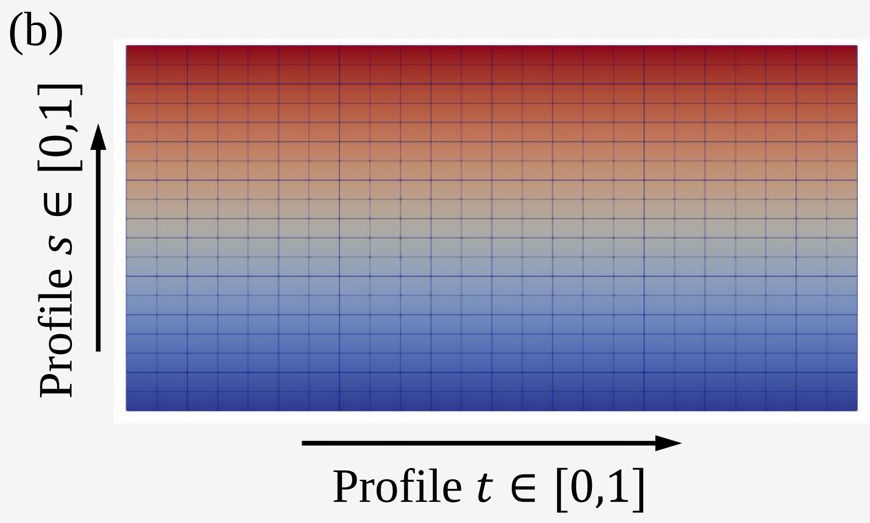
3D preform reconstruction

Conclusion

Parametric representation of tubular tow surface



(s, t): normalized geodesic distance in **radial** and **axial** direction



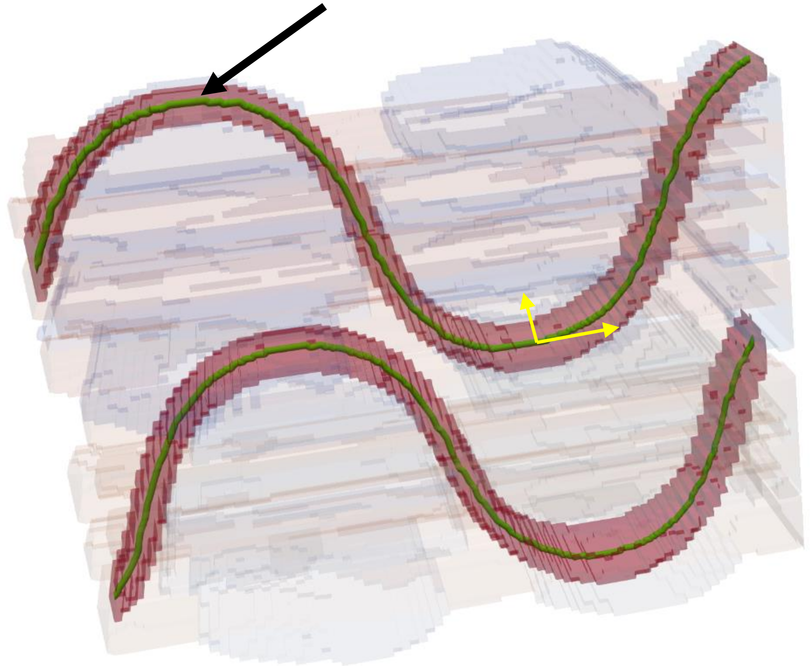
Tow tubular surface

$$\hat{\Gamma}(s, t_i) = (X(s, t), Y(s, t), Z(s, t))$$

Reduced to 2 dimensions

Extraction of tow trajectory

Trajectory $\gamma(t) = (x(t), y(t), z(t))$



1D parametric Kriging:

$$\gamma(t) = a(t) + W(t, \sigma^2)$$

- t: parameter
- σ^2: nugget effect

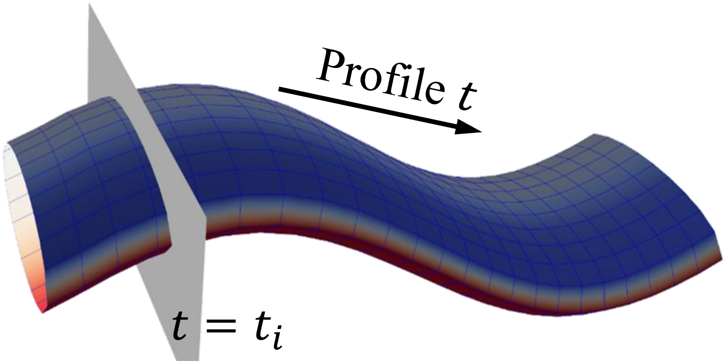
Tangent vector

$$\gamma(t) = (x(t), y(t), z(t)) \rightarrow \gamma'(t) = (x'(t), y'(t), z'(t))$$

Cross-section identification

1. Parametric equation of tow surface:

$$\begin{cases} x(s_i,t) = k_1(s_i)^T \cdot S^{-1} \cdot P_x \cdot T^{-1} \cdot k_2(t) \\ y(s_i,t) = k_1(s_i)^T \cdot S^{-1} \cdot P_y \cdot T^{-1} \cdot k_2(t) \\ z(s_i,t) = k_1(s_i)^T \cdot S^{-1} \cdot P_z \cdot T^{-1} \cdot k_2(t) \end{cases}$$

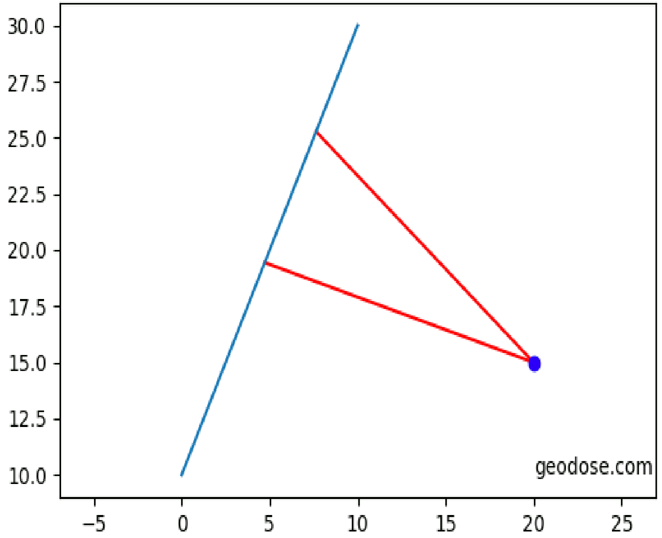


Intersection between an implicit object and a parametric object

2. Implicit equation of the plane:

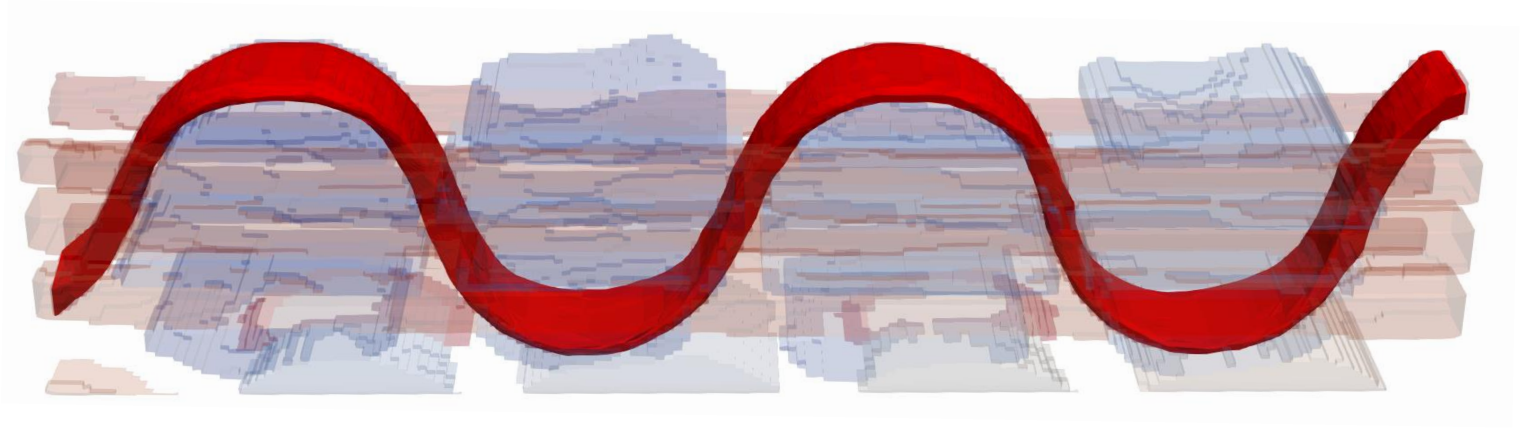
- Centroid $P = (x_c,\ y_c, z_c)$
- Normal vector $\vec{n} = $ (a,b,c)

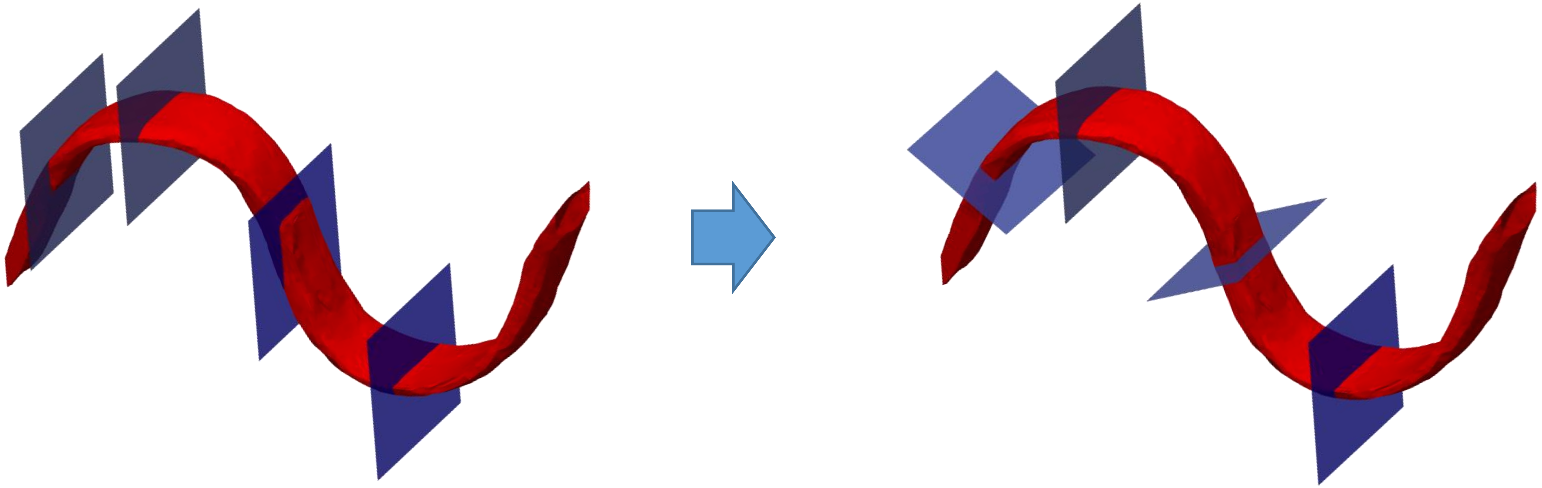
$$a(x - x_c) + b(y - y_c) + c(z - z_c) = 0$$



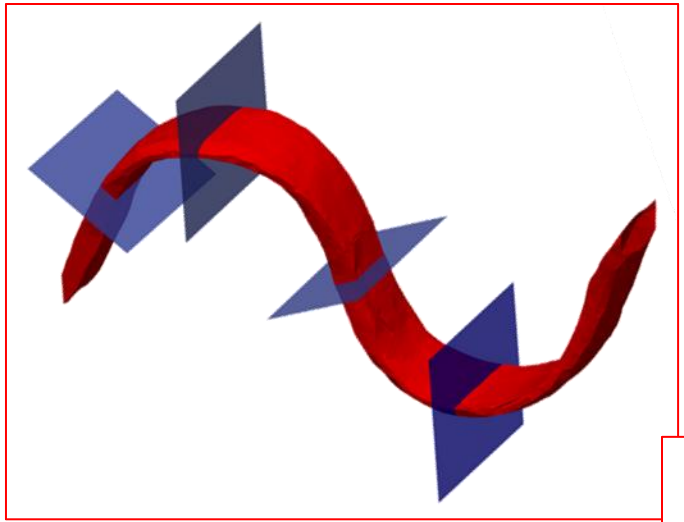
Accelerated by **Golden Section Search**

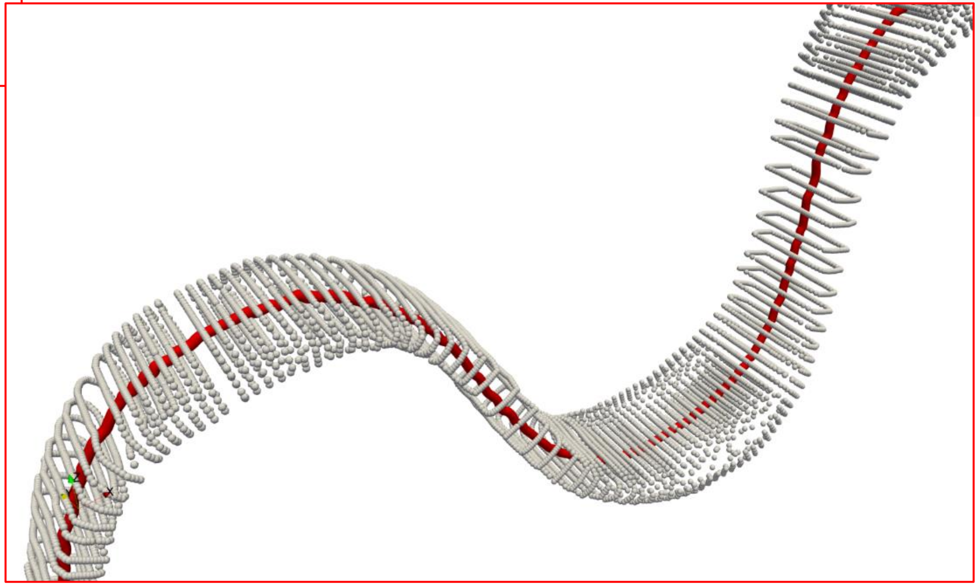
Cross-section identification

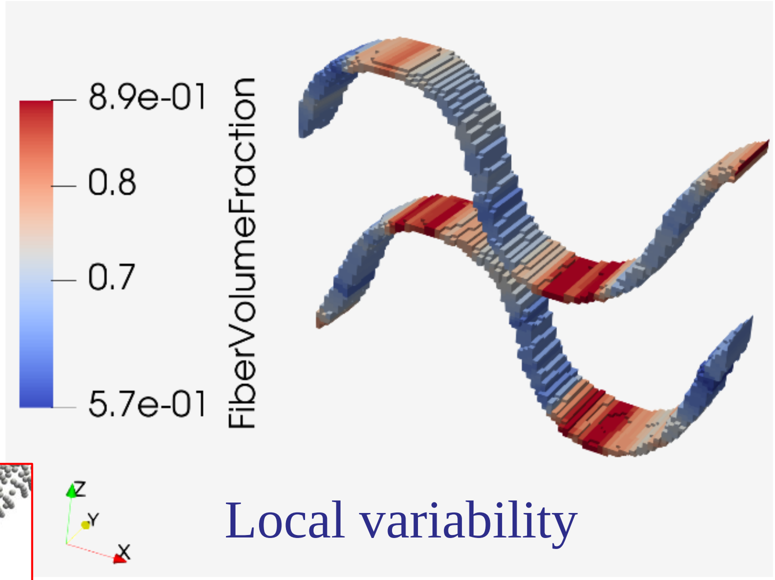




Cross-section identification







Advantages

For each tow an analytical equation is provided:

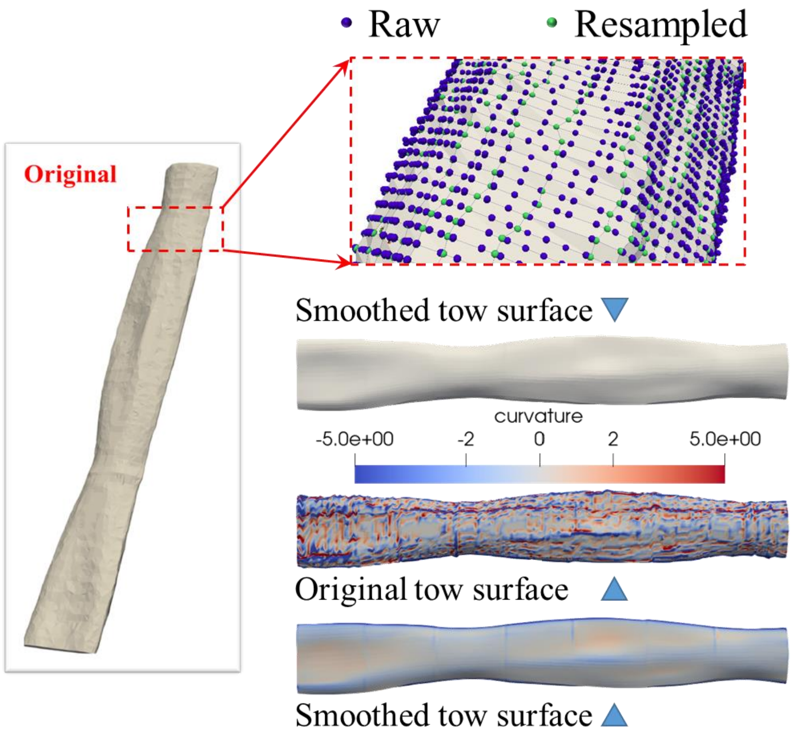
- morphological operations
- reduce the data stored

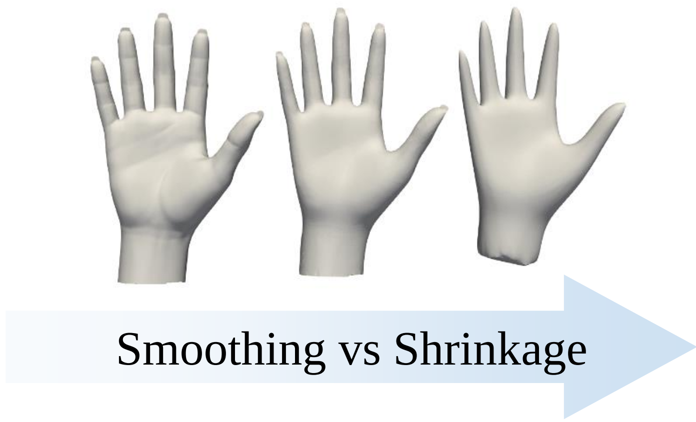
Shrinkage induced by smoothing is avoided because:

- the estimator is constructed by minimizing variance ("best")
- estimated values are weighted linear combinations of knowns
- it searches the combination with zero mean estimation error ("unbiased")

Anisotropic smoothing:

- allows specifying different smoothing factors in axial and radial direction to attain anisotropic smoothing





Outline

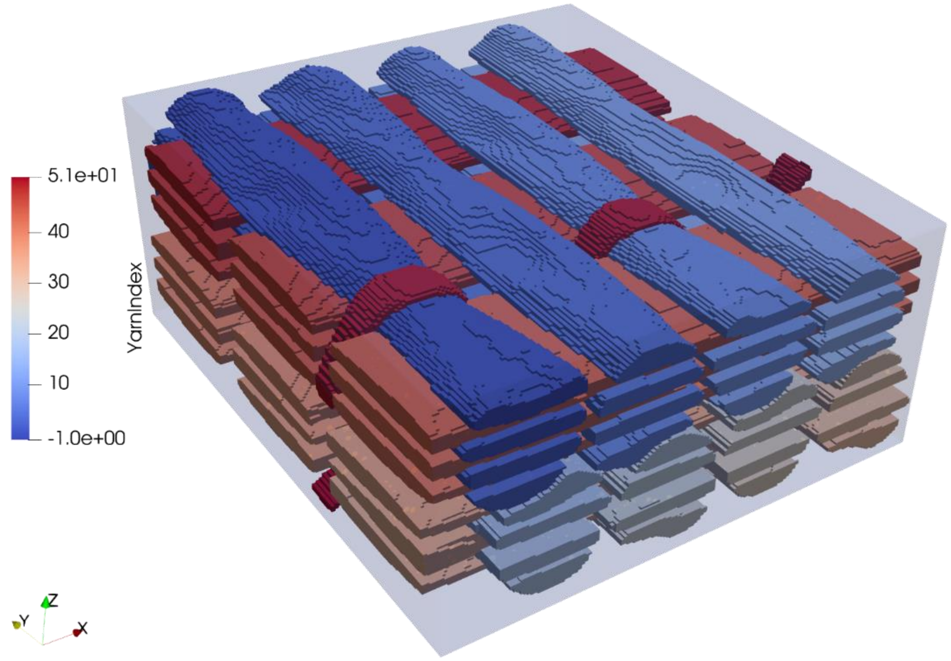
Experimental method

Tow representation reinforcement

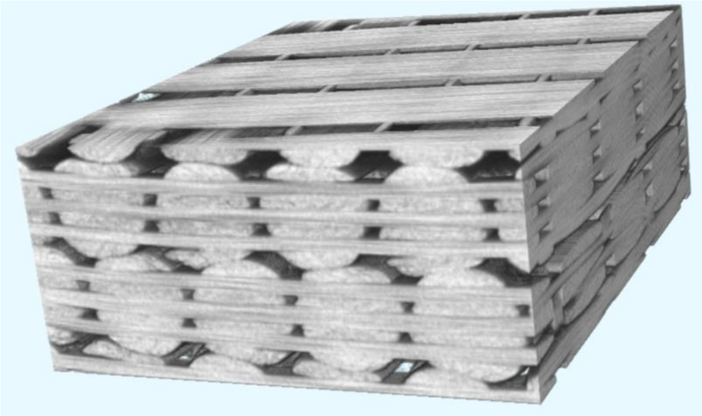
3D reconstruction reinforcement

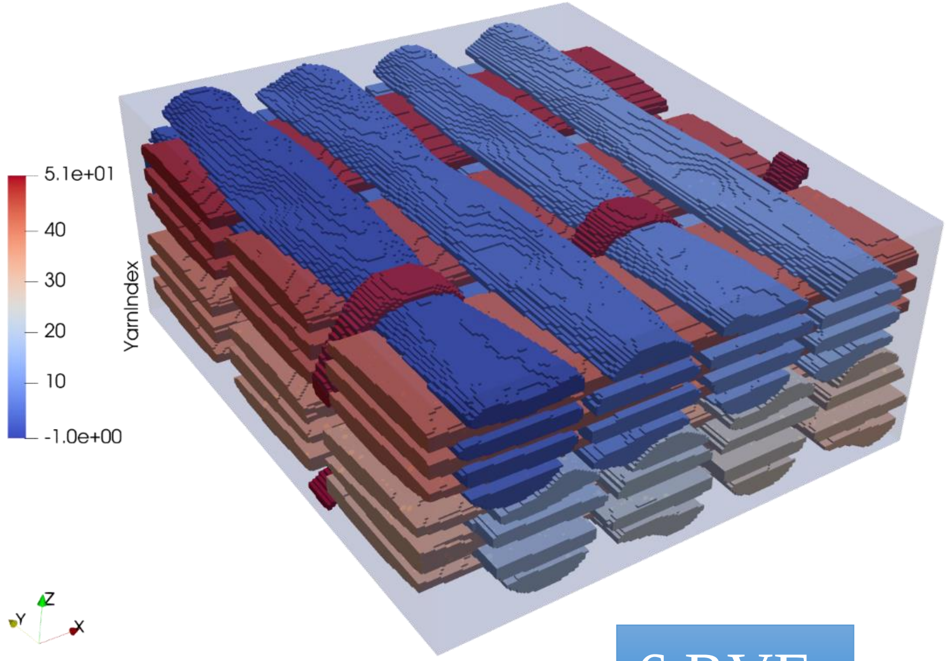
- **Fiber tow assembling**
- **Mesopores distribution**

Conclusion



Labelled fiber tows



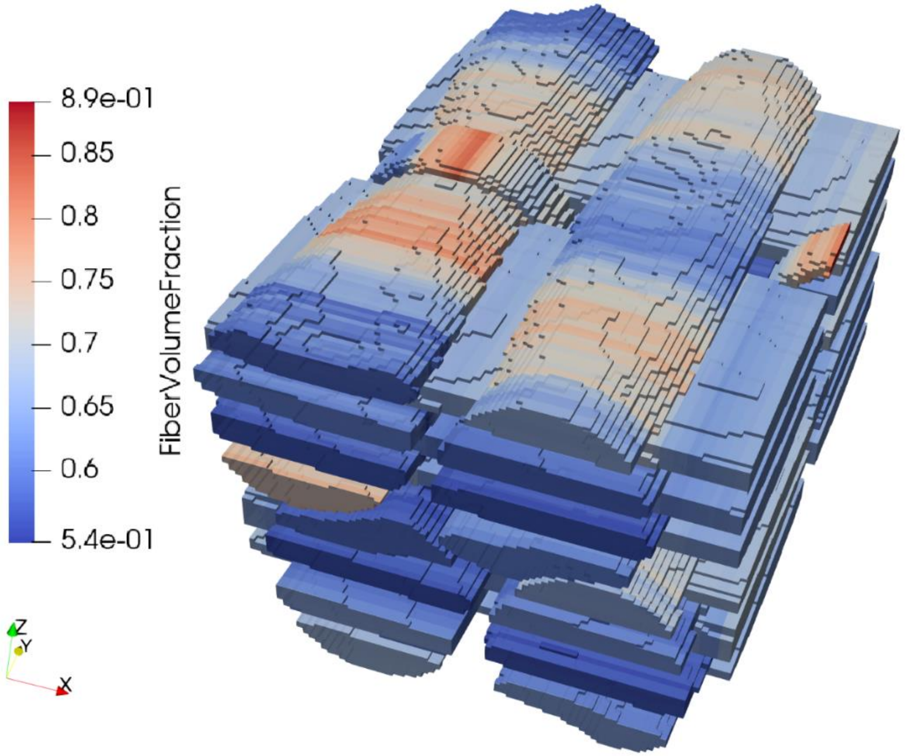


6 RVEs

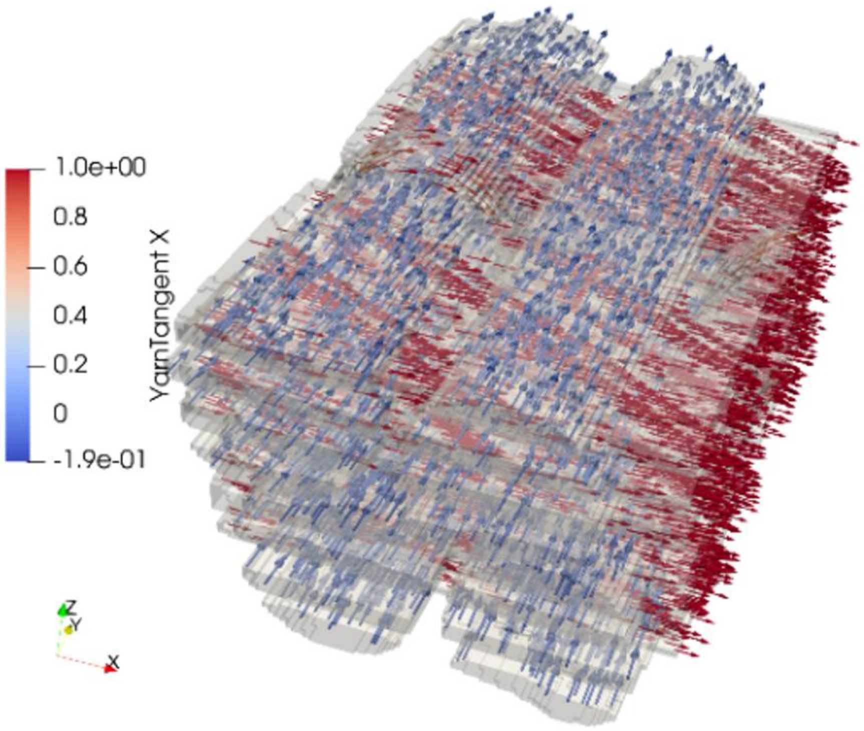
Flow and void formation simulation in a dual scale structure:

- Fiber volume fraction (V_{f})
- Fiber tow orientation
- Local variability and global conservation (V_{f})

Spatial variability and vector information



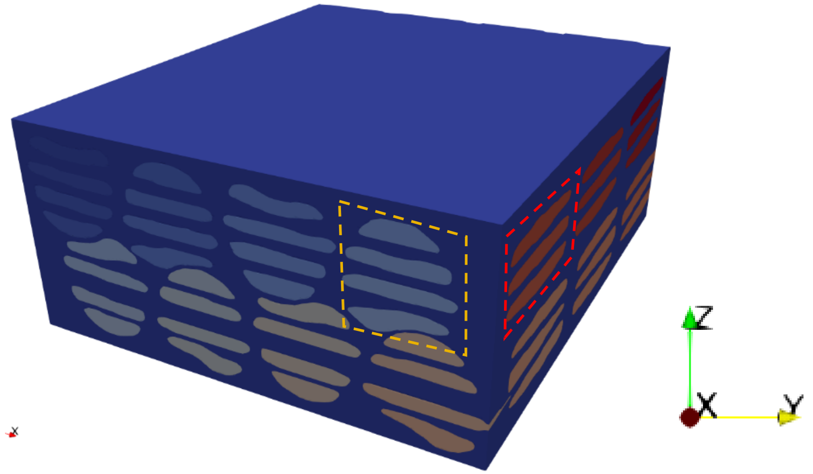
Fiber volume fraction



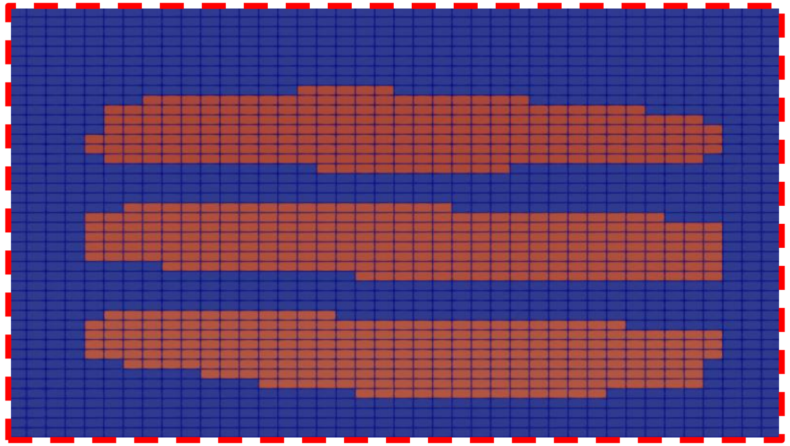
Tangent vectors

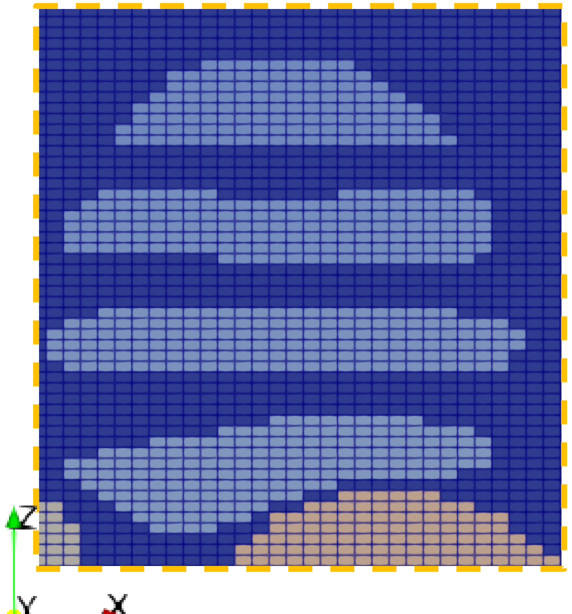
In progressing: interpenetration between tows

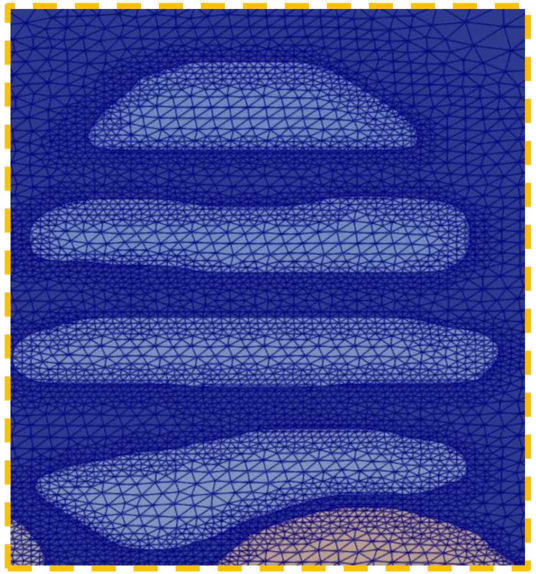
Conformal & non-conformal meshes

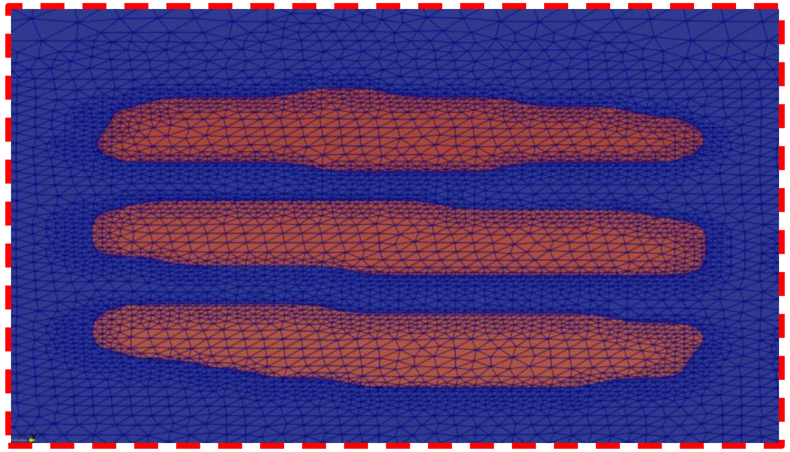


$(\mathrm{d}x = 0.088 \text{ mm}, \mathrm{d}y = 0.11 \text{ mm}, \mathrm{d}z = 0.055 \text{ mm})$









Issue: too many elements → simplification!

Outline

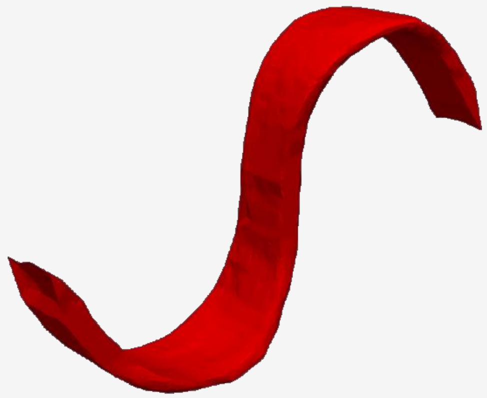
Experimental method

Tow representation reinforcement

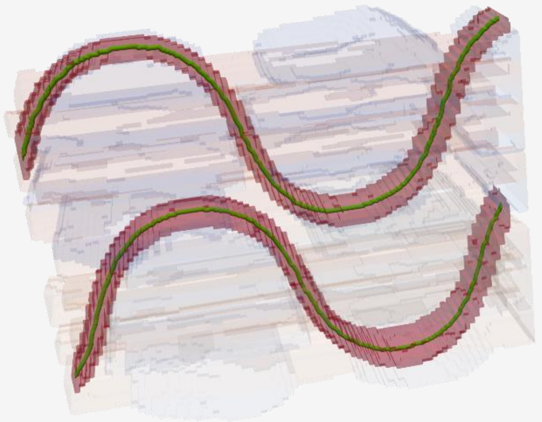
3D reconstruction reinforcement

Conclusion

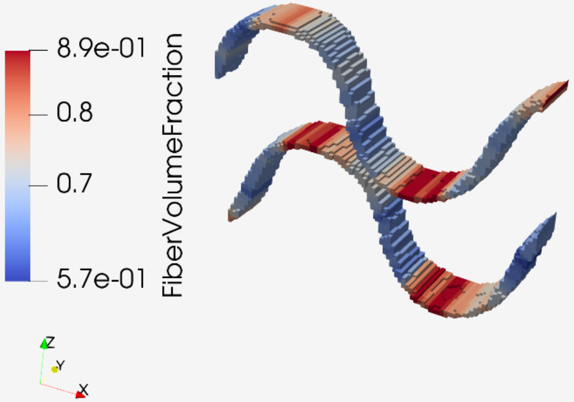
Conclusion



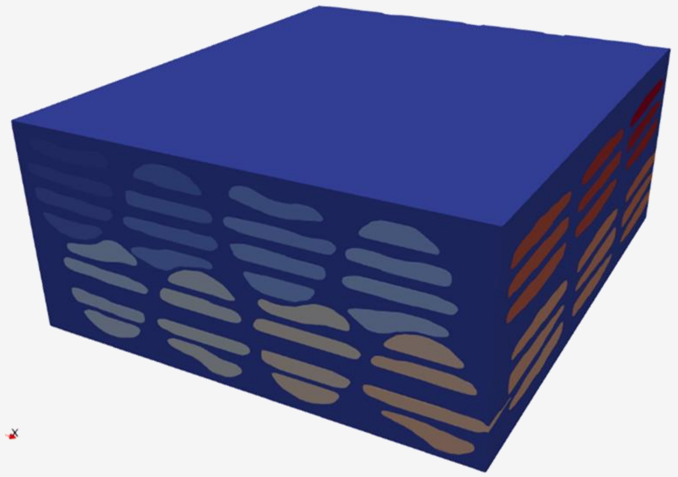
Tow contour



Tow trajectory



Local variability



Digital Material Twin

A basis for future numerical work based on high-fidelity models

One more thing …

Composites: Part A 169 (2023) 107524

Contents lists available at ScienceDirect

Composites Part A

journal homepage: www.elsevier.com/locate/compositesa

Performance evaluation of unidirectional molds used for measuring saturated transverse permeability of engineering textiles

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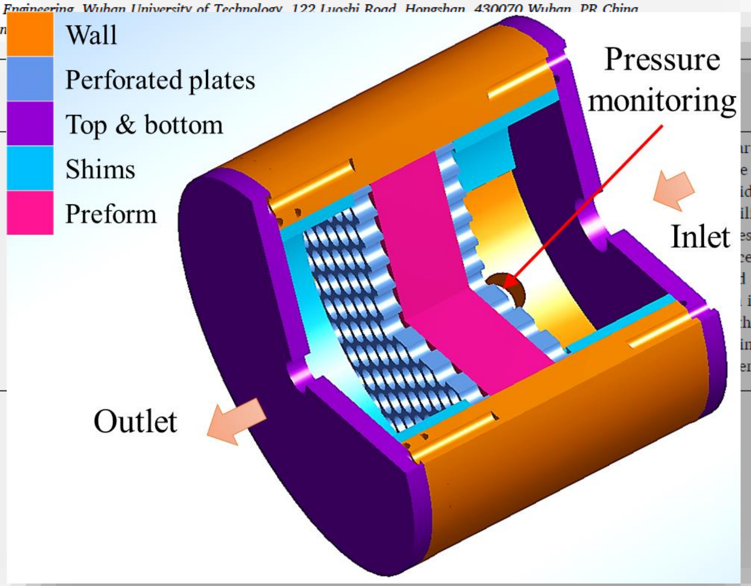
ARTICLE INFO

Keywords:
Engineering textiles
Transverse permeability
Mold performance
Iterative framework

…rt approaches revealed consider-
…e analysis protocols makes quan-
…iding approaches for evaluating
…ility from conventional saturated
…es affect flow capacity and lead to
…e performance, a dimensionless
…d on mold geometry and sample
… intrinsic transverse permeability
…h actual textiles. The first under-
…inconsistency. Comparatively, the
…ency for both molds.



Findings:

- support plate affects the measurement
- accuracy varies along material properties (thickness & anisotropy)
- potential underestimation of K_z

Discharge coefficient, an indicator for:

- evaluation of mold performance
- comparison of different molds
- K_z correction (from apparent to intrinsic)

Thank you!

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