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Systematic approach for an FE-based process simulation framework for wet compression moulding of continuously reinforced composites

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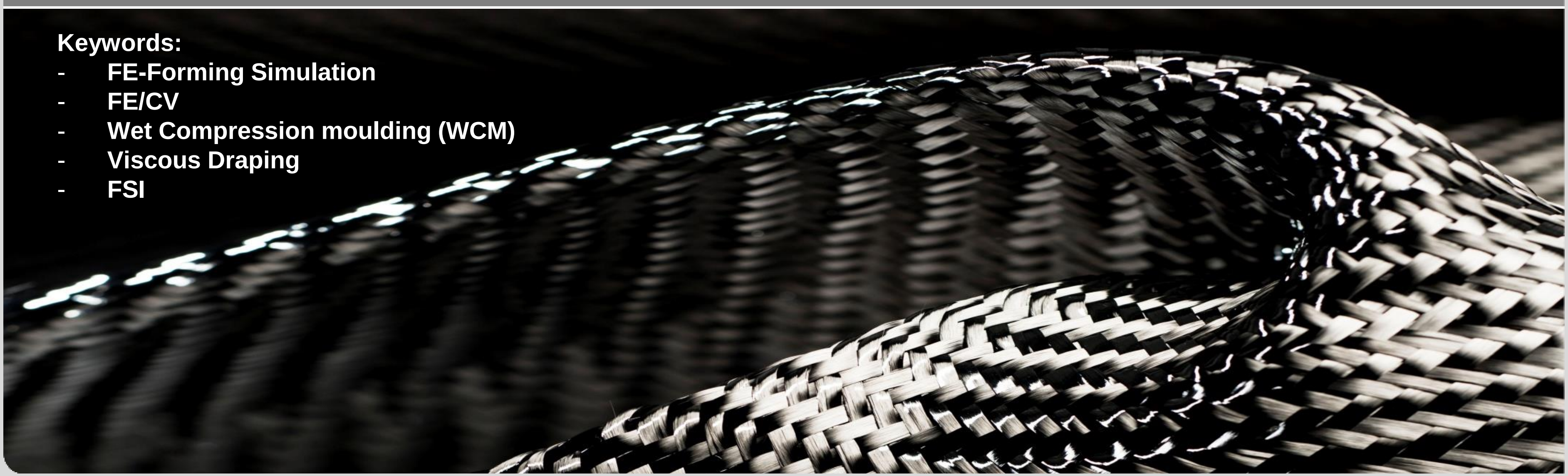
Keywords:
- FE-Forming Simulation
- FE/CV
- Wet Compression moulding (WCM)
- Viscous Draping
- FSI



Outline

- Introduction of Wet Compression Moulding Process ○
- Systematic Approach for an macroscopic FE-based ○ Framework
- Current research and findings ○ ○ ○ ○
- Recap and Conclusion ○
- Roadmap ○

Introduction of Wet Compression Moulding Process

Introduction & Motivation

Wet compression moulding process

Motivation

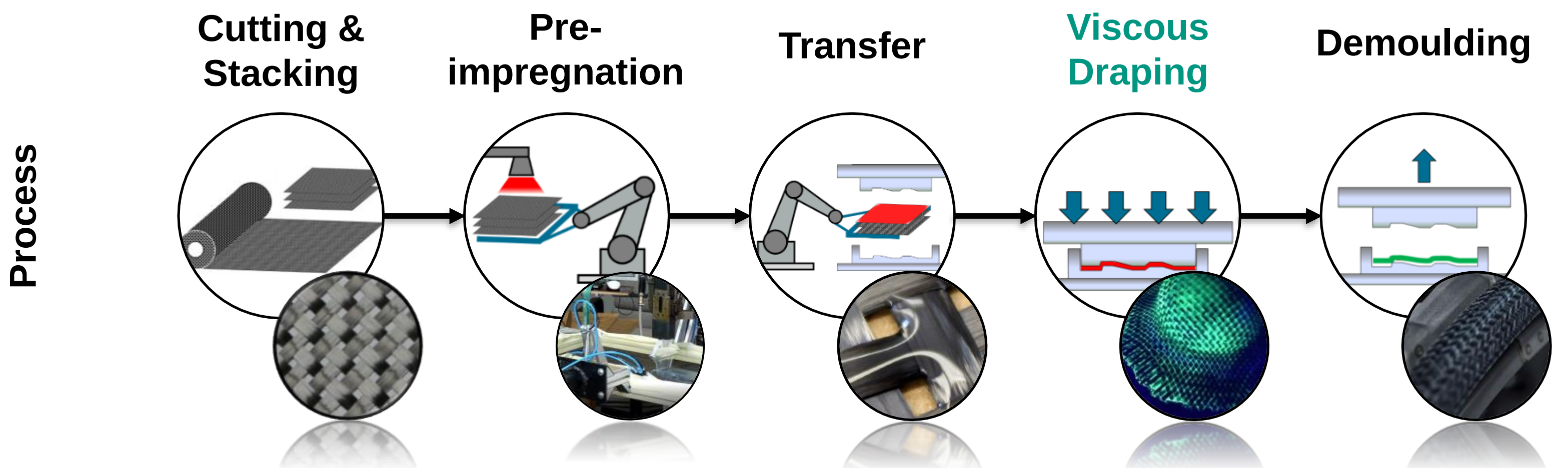
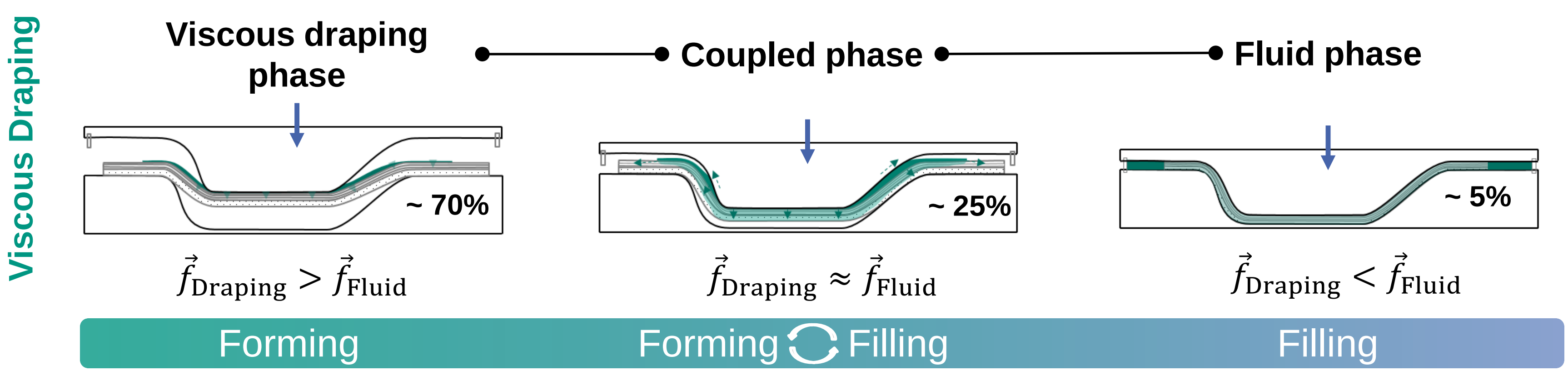


Figure 1: Illustration of the WCM-Process (adapted from [Pop18], based on [Ber16])

Figure 2: Subdivision of the viscous draping into process phases



Systematic Approach for an macroscopic FE-based Framework

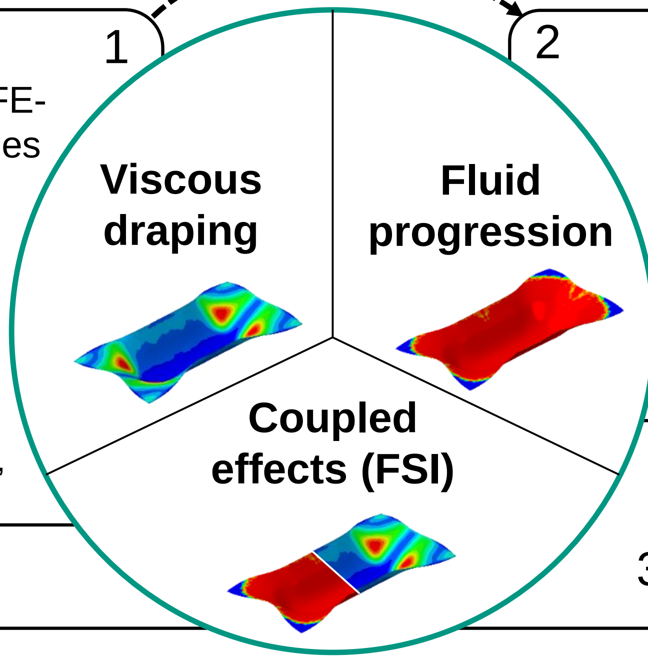
Systematic Approach

Applied macroscopic breakdown in terms of modelling

Approach

1

- Large deformations
- Lagrangian formulation in FE-based simulation approaches
- Intra-Ply & Interface mechanisms $f(\eta, v)$
- Several macro. modelling approaches in literature [Wil08, Haa13, Ger13, Boi15, Mac16, Boi16, Guz16, Dör17, Sch17, Boi18, Dör18a, Pop18a, Hen19]

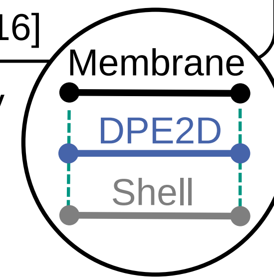


2

- Eulerian Formulations (FV)
- Lagrangian formulation with control volumes (FE/CV) [Bus90 Tru93, Jos00]
- Simultaneous fluid progression and forming simulation [Pop18b]
- Curing [Ber16]

3

Internal ply structure [Pop18b]



objectives

- infiltration-dependent draping behaviour
- Permeability-dependent fluid progression
- Accurate process boundary conditions
- Fiberwashing, Impregnation, Cavity pressure

➢ Which mechanisms require modelling?

Figure 3: Deviation of the main process mechanisms regarding modelling

Current research and findings
Viscous Draping

Current research and findings
Viscous draping

Intra-Ply & Interface mechanisms $f(\eta, v)$

Membran behaviour Bending behaviour Contact behaviour

- Experiments with a modified infiltrated bias-extension test (IBET) [Pop18a]

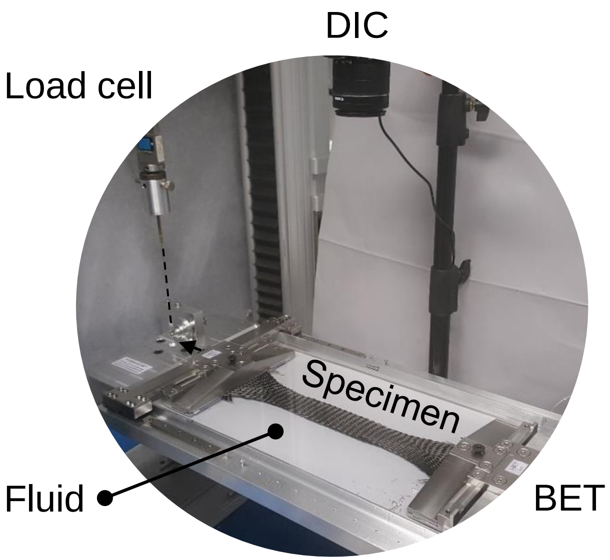


Figure 4: Test setup for the characterisation of infiltrated membrane behaviour

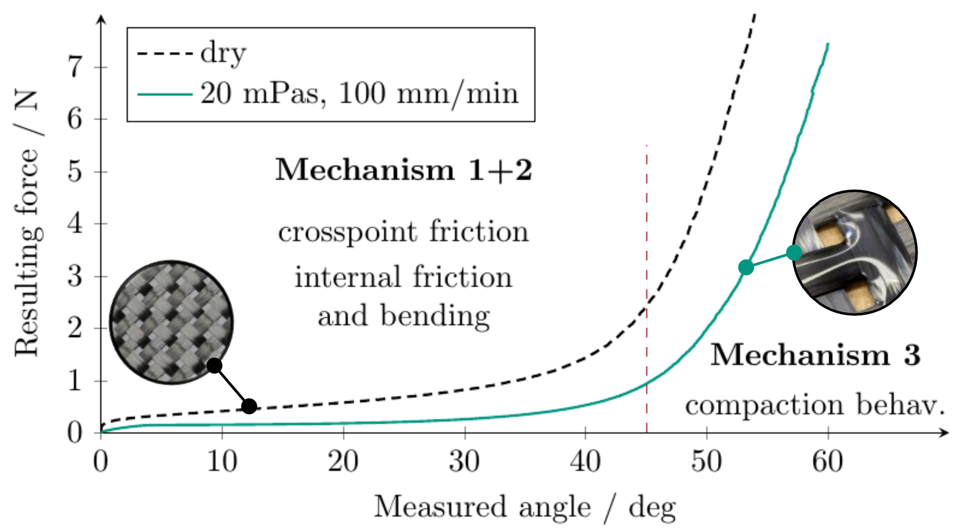


Figure 5: Exemplary result – dry vs. infiltrated membrane behaviour

Is this mechanisms worth modelling? Yes, shear response is viscosity- and rate-dependent!

Current research and findings

Viscous draping

Findings | Vis. Draping

Intra-Ply & Interface mechanisms $f(\eta, v)$

Membran behaviour | Bending behaviour | Contact behaviour

- Constitutive equations: → hyperviscoelastic model [Pop18a]

$$\Psi\left(I_1^{\mathrm{e}}, I_2^{\mathrm{e}}, I_{12}^{\mathrm{e}}, I_{12}^{\mathrm{v}} \right) = \Psi^{\mathrm{elong}}\left(I_1^{\mathrm{e}}, I_2^{\mathrm{e}} \right) + \Psi^{\mathrm{shear}}\left(I_{12}^{\mathrm{e}}, I_{12}^{\mathrm{v}} \right) \text{ with } G_{12}(I_{12}^{\mathrm{e}}) \;\&\; \eta(I_{12}^{\mathrm{e}}, I_{12}^{\mathrm{v}})$$

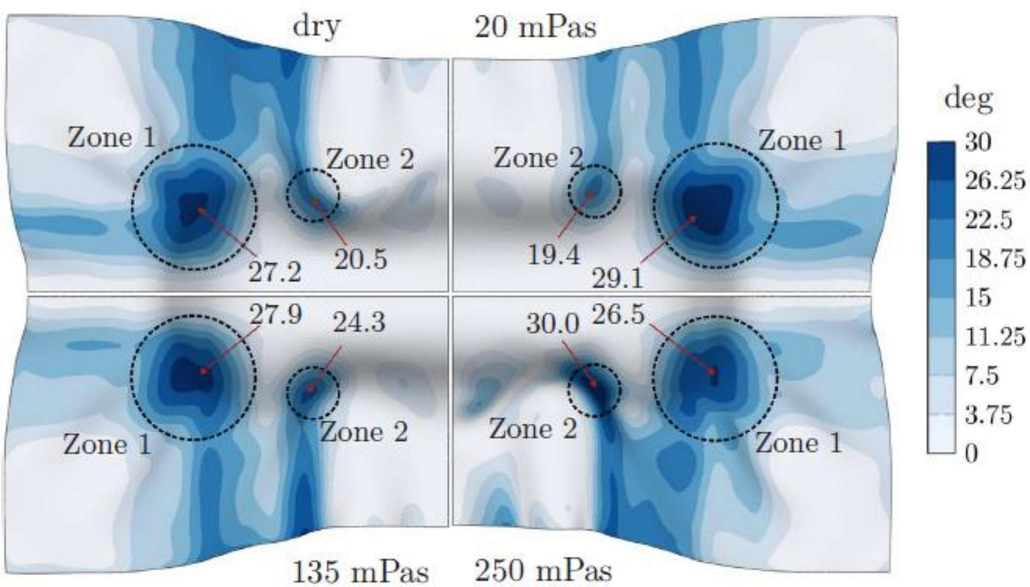


Figure 6: Exemplary result on component level in terms of shear angle distribution

Do this mechanisms require modelling? ▶ Yes, viscosity- and rate-dependent membrane behaviour with impact on component level!

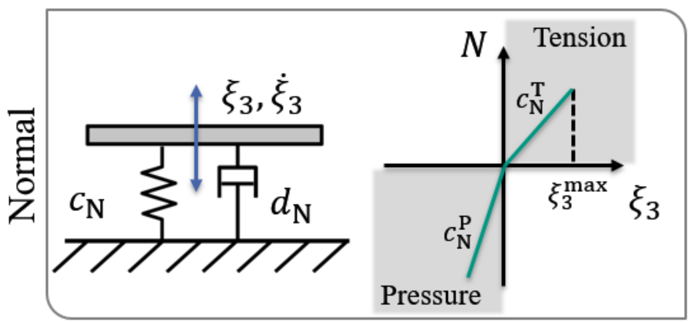
Current research and findings

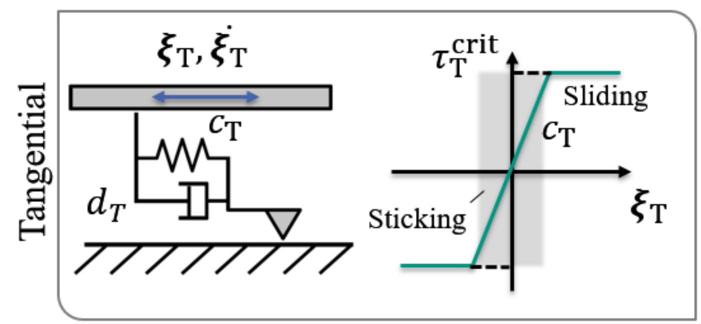
Viscous draping

Intra-Ply & Interface mechanisms $f(\eta, v)$

Membran behaviour | Bending behaviour | **Contact behaviour**

- Large macroscopic slip during forming
  (Lubrication between the single plies)
- Viscoelastic contact modelling required [Hüt17, Pop19 (accepted)]
- Numerical modelling approach using the penalty-method [Pop19a based on Dör18b]:





$$N = \begin{cases} 0 & , \xi_3 \geq \xi_3^{max} \quad \text{(no contact)} \\ c_N^T \xi_3 + d_N \dot{\xi}_3 & , 0 \leq \xi_3 < \xi_3^{max} \quad \text{(adhesion)} \\ c_N^P \xi_3 + d_N \dot{\xi}_3 & , \xi_3 < 0 \quad \text{(penetration)} \end{cases}$$

$$\boldsymbol{T} = \begin{cases} c_T \boldsymbol{\xi}_T + d_T \dot{\boldsymbol{\xi}}_T & , \Phi \leq 0 \quad \text{(sticking)} \\ \tau_T^{crit}(p, \eta, \dot{\boldsymbol{\xi}}_T) \dfrac{\dot{\boldsymbol{\xi}}_T}{\|\dot{\boldsymbol{\xi}}_T\|} & , \Phi > 0 \quad \text{(sliding)} \end{cases}$$

Iso. Yield function Φ

Current research and findings
Viscous draping

Intra-Ply & Interface mechanisms $f(\eta, v)$

Membran behaviour | Bending behaviour | **Contact behaviour**

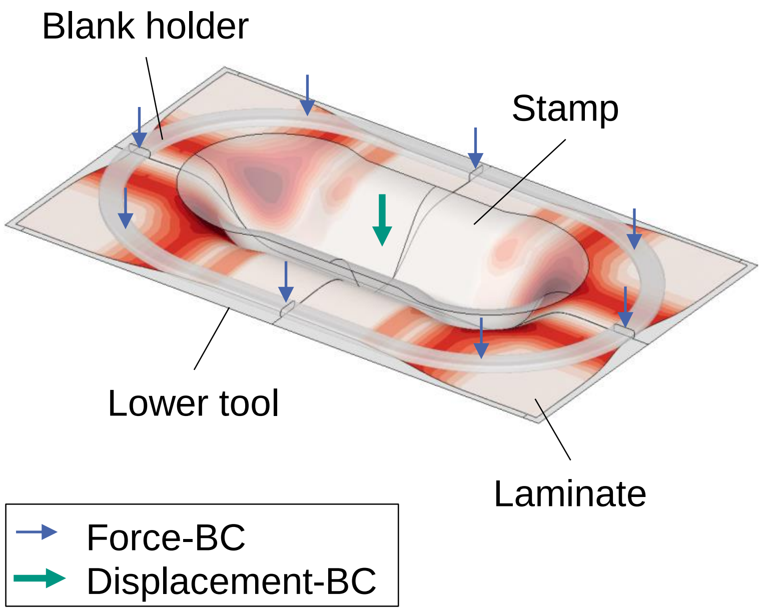


Figure 9: Exemplary simulation setup comprising 2 plies (0/90°,±45°) [Pop19a]

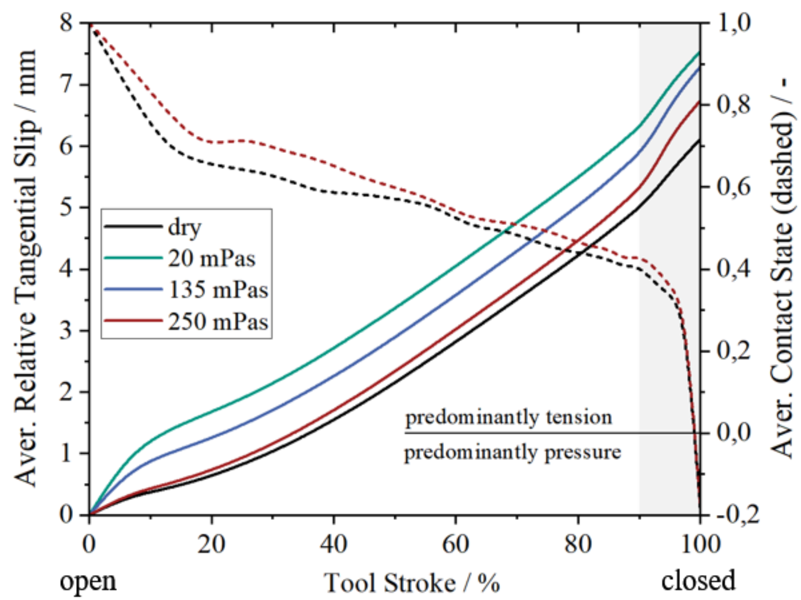


Figure 10: Results of the aver. Contact slip and state during forming [Pop19a]

Do this mechanisms require modelling?

Definitely. Beyond that, tangential with low transversal pressure and adhesion is currently investigated!

Recap and Conclusion ○

Recap and Conclusion

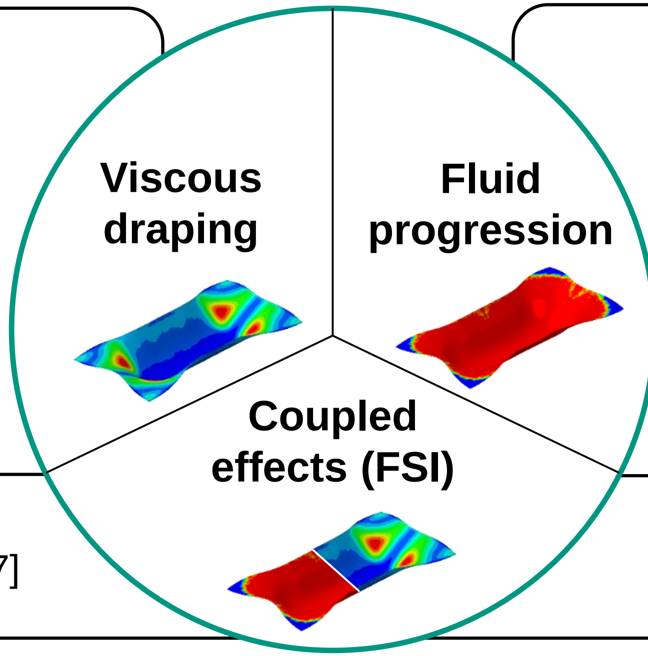
Applied macroscopic breakdown in terms of modelling

Recap

Current research and findings

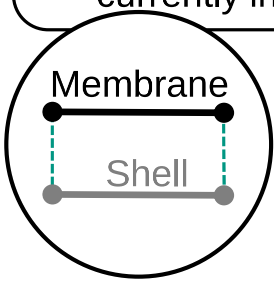
- Infiltration- and rate-dependent Intra-Ply & Interface mechanisms
  - Membrane
  - Bending
  - Contact

  $f(\eta, v)$
- Sensitivity analysis of combined mechanism currently investigated

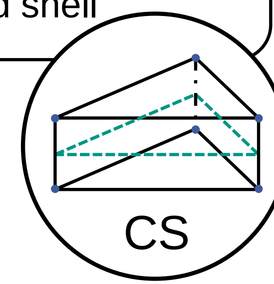


Current research and findings

- Lagrangian formulation with control volumes (FE/CV) within 2D Approach [Pop18b]
- 3D-Darcy approach required to account for suitable process boundary conditions
- Corresponding forming model required (compaction) → CS or Solid shell



Internal ply structure [Dör17]



Not covered yet

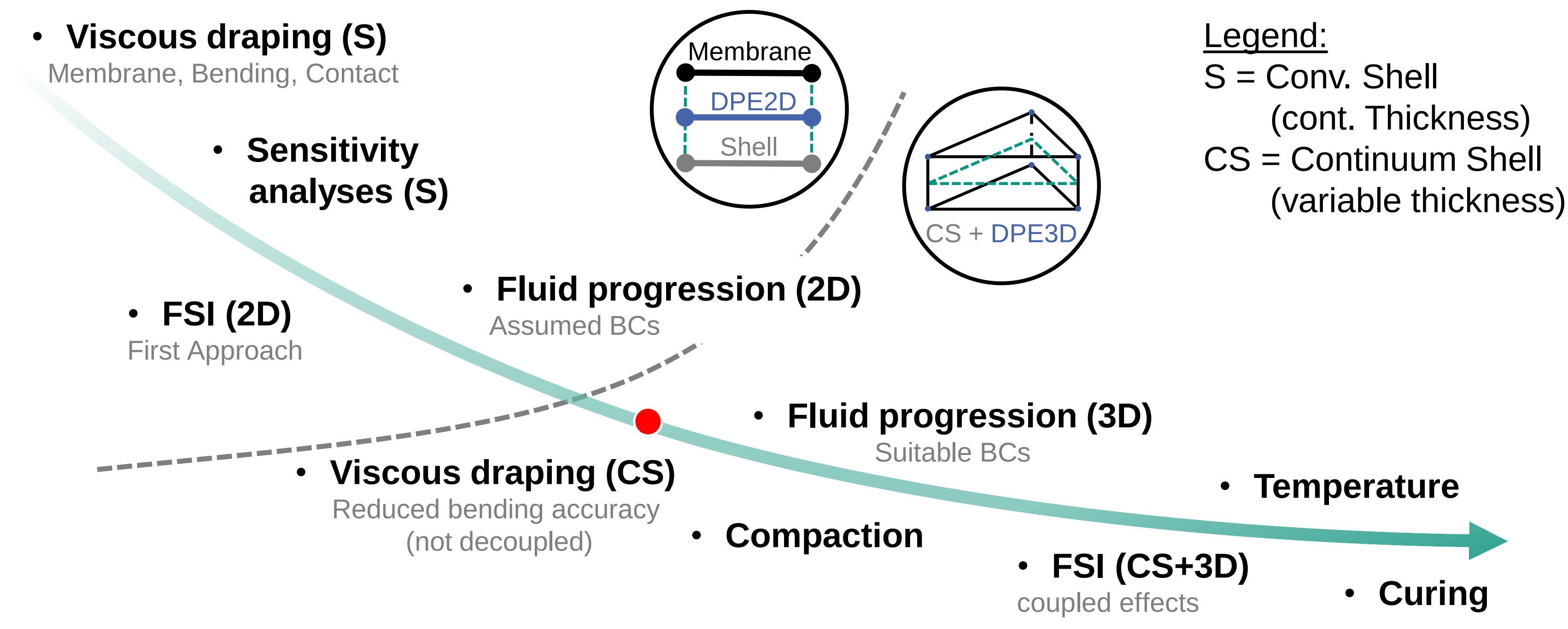
Figure 11: Recap and current conclusion

Roadmap ○

Outlook and Roadmap

Macroscopic WCM-process simulation model

Roadmap



- Research motivation in terms of process modelling
  - Which mechanisms require modelling?
  - Which mechanisms need accurate/effective modelling?
  - How sufficient are theses approaches?
  - How much effort has to be taken into material characterization?
  - Are we able to predict complex coupled process effects?

Objective

Wet compression moulding process simulation module (Abaqus)

Literature

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Pop19b Poppe et al: Comparative experimental and numerical analysis of bending behavior of dry and infiltrated woven fabrics, Composites Part A (under revision)

Thank you! Do you have any Questions?

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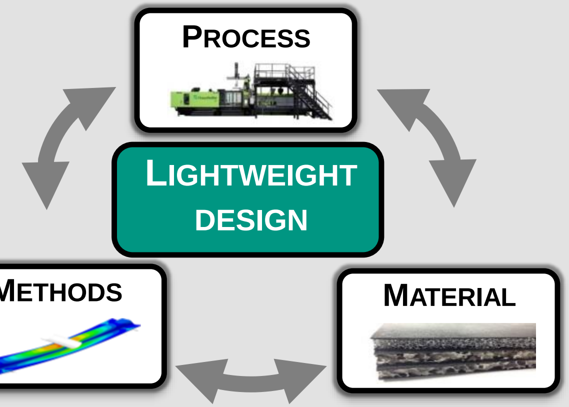

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