# Liquid Composite Molding – process simulation chain to structural analysis


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## 2026-07-01


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Sustainable solutions for upgraded smart wearables

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WP5 – Development of digital tools for textile process & products

T5.1 Multiscale FE for textile & composite

T5.3 Development of ANN tools

Develop ANN reduced models for FE prediction to reduce the model size developed in T5.1 especially for simulations involving 3D imaging

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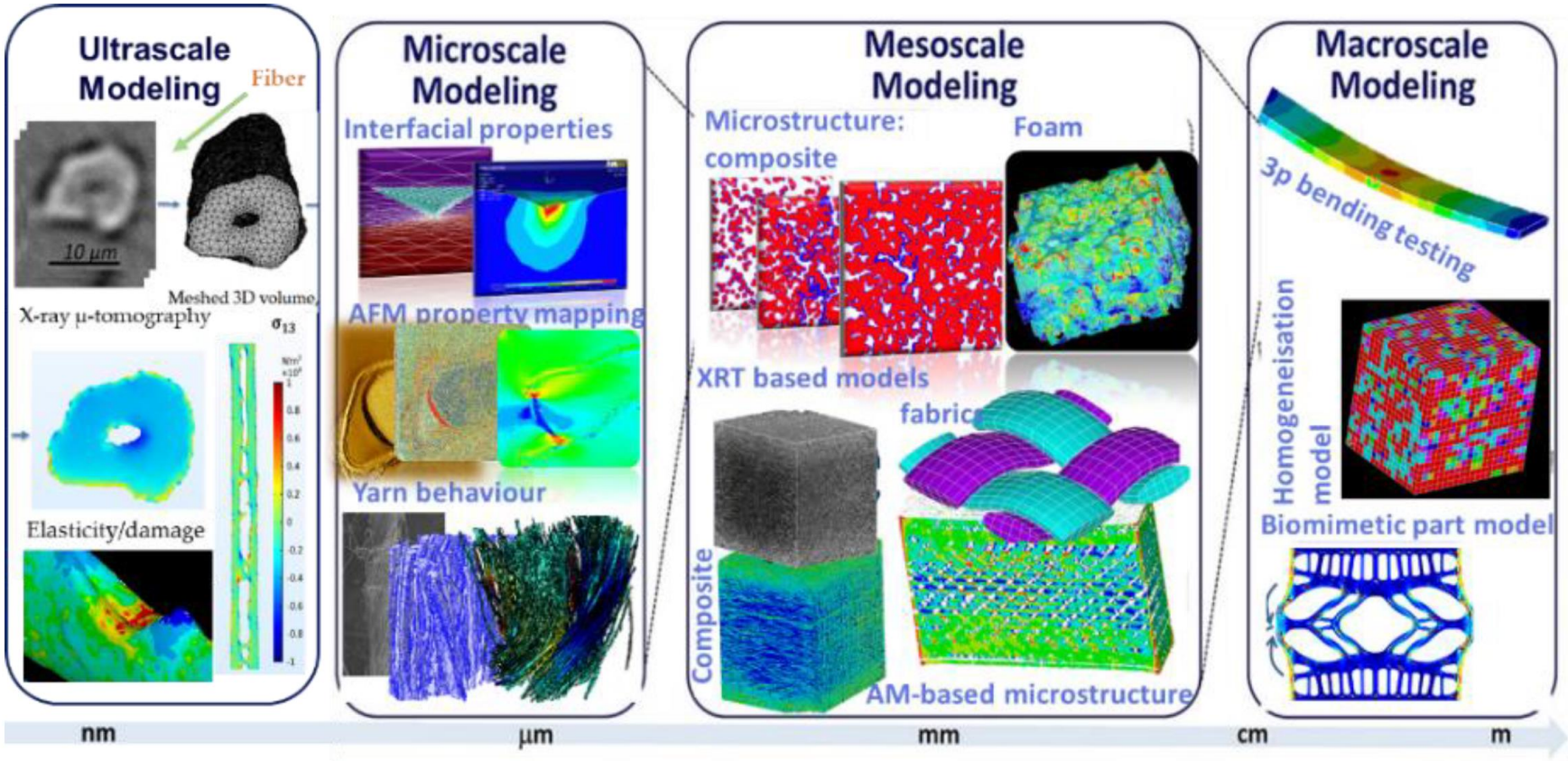
# Task 1 Multiscale FE for textile & composite

- FE-based multi-scale and multi-physics structural analysis
- Constitutive models between micro-meso, meso-macro scale





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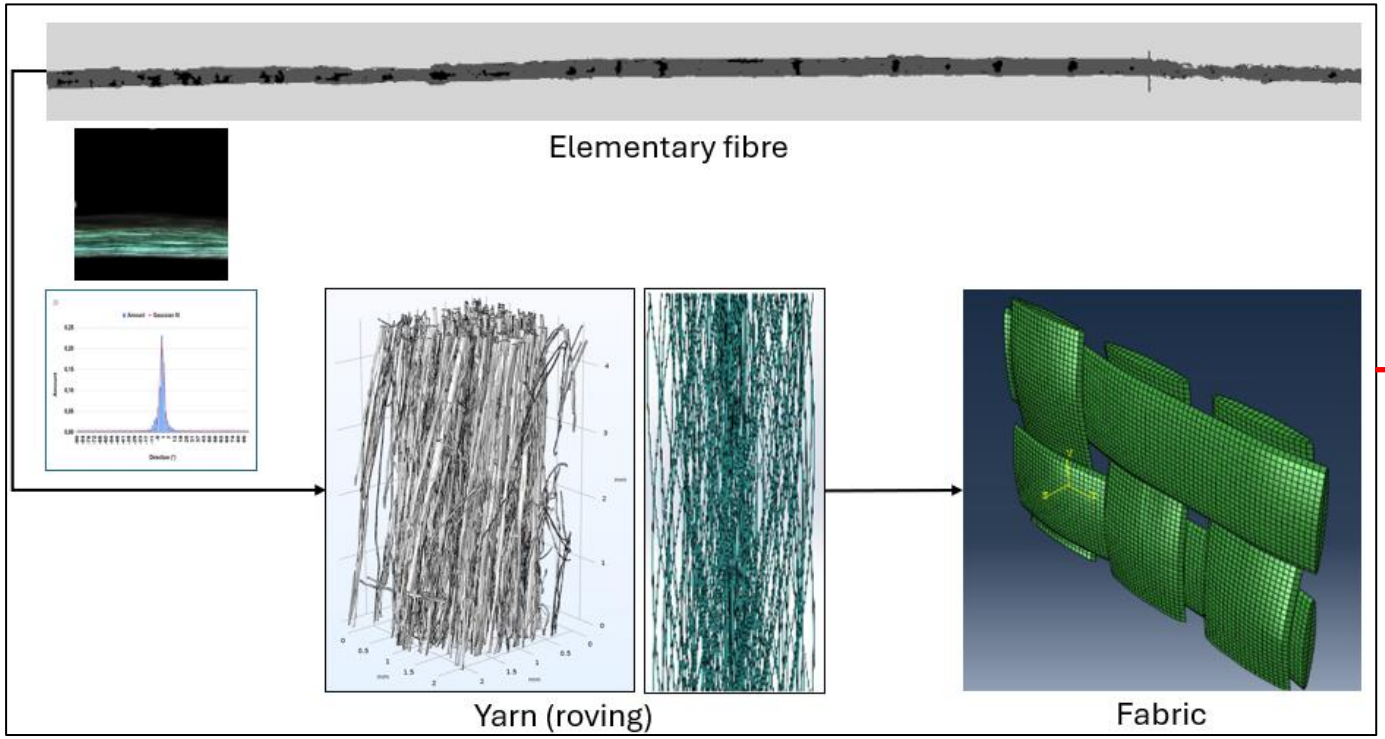
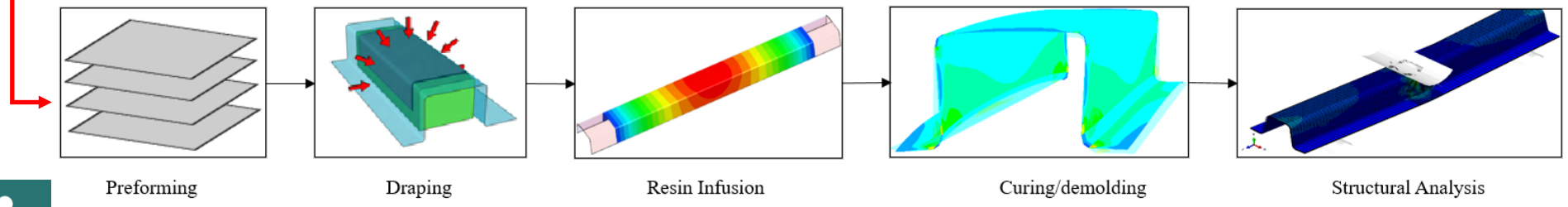
# Multi-scale modelling progress




- Experimental data for fibres & rovings
- Semi-analytical homogenisation of fibre properties (Python)
- Script based generation of idealised yarns in Abaqus (Python)
- Models for idealised fabric geometries

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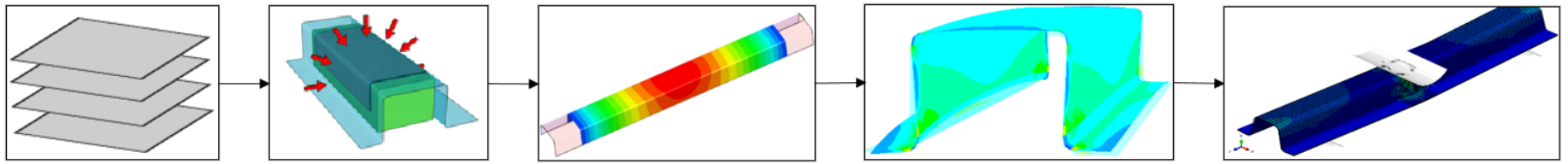
# RISE (former SICOMP) tools for composite simulations

- Liquid Composite Molding
- Path-dependent cure simulation
- Residual stresses and distortion
- Damage and failure of composites
- Physically-based model for kink-band growth and longitudinal crushing



Preforming | Draping | Resin Infusion | Curing/demolding | Structural Analysis

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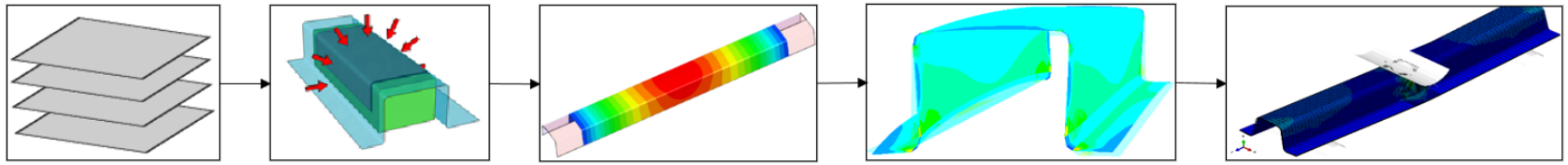
# Composite Process Simulation



| Preforming | Draping | Resin infusion | Curing/Demolding | Structural Analysis |
|---|---|---|---|---|
| Compaction | Forming | Flow Front | Cure Kinetics | Damage Initiation |
| Configuration | (Co) Bonding | Deformation | Distortion/Warpage | Damage Propagation |
| Lamination | Squeeze flow | Saturation | Residual stress | Delamination |
| | Volume Fraction | Volume Fraction | Tool-Part Interaction | Failure |
| | | | Adhesive Cure | Mechanical Performance |

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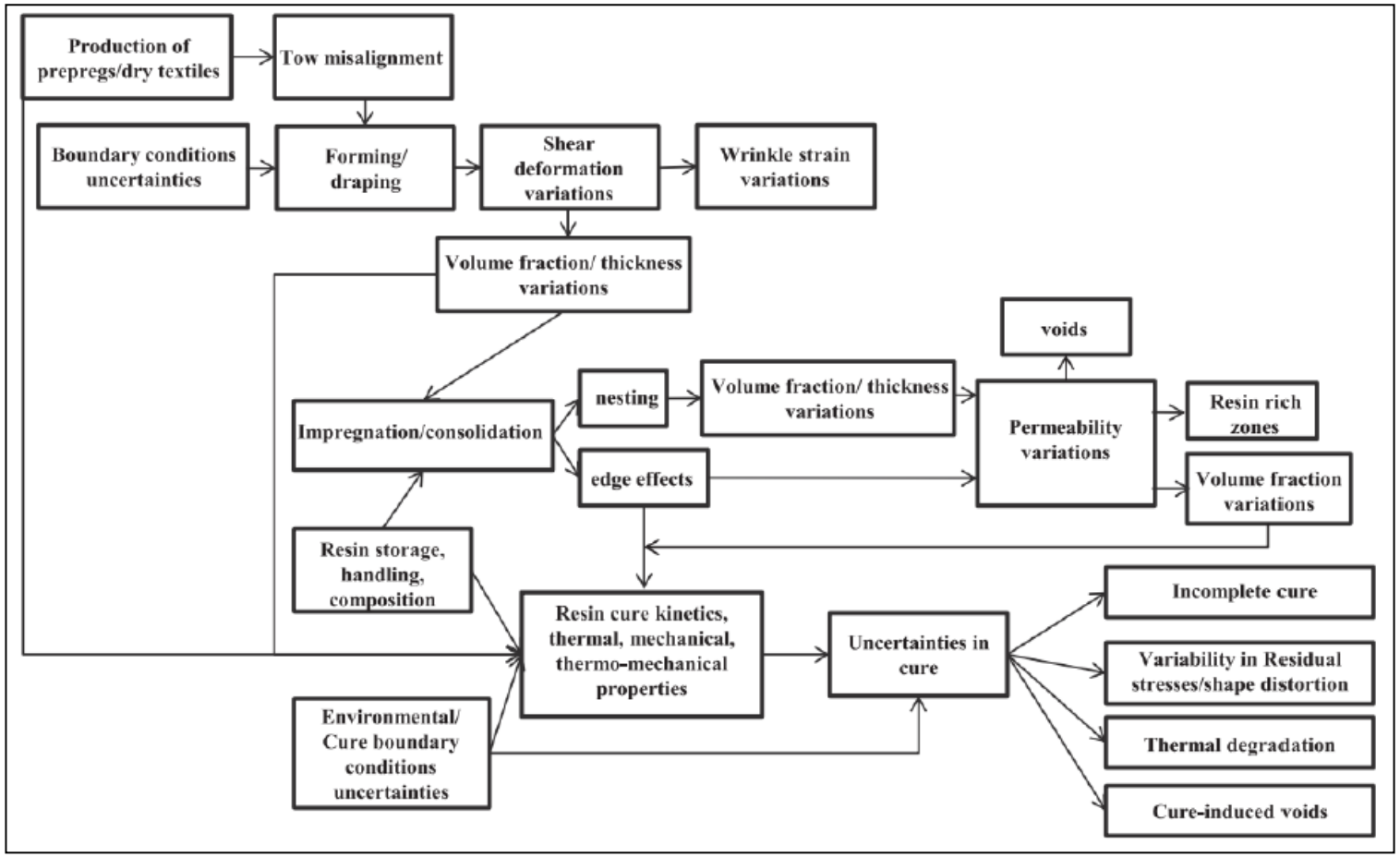
# Can we model all these defects?




T.S. Mesogitis, A.A. Skordos, A.C. Long, Uncertainty in the manufacturing of fibrous thermosetting composites: A review, Composites: Part A 57 (2014) 676–75.

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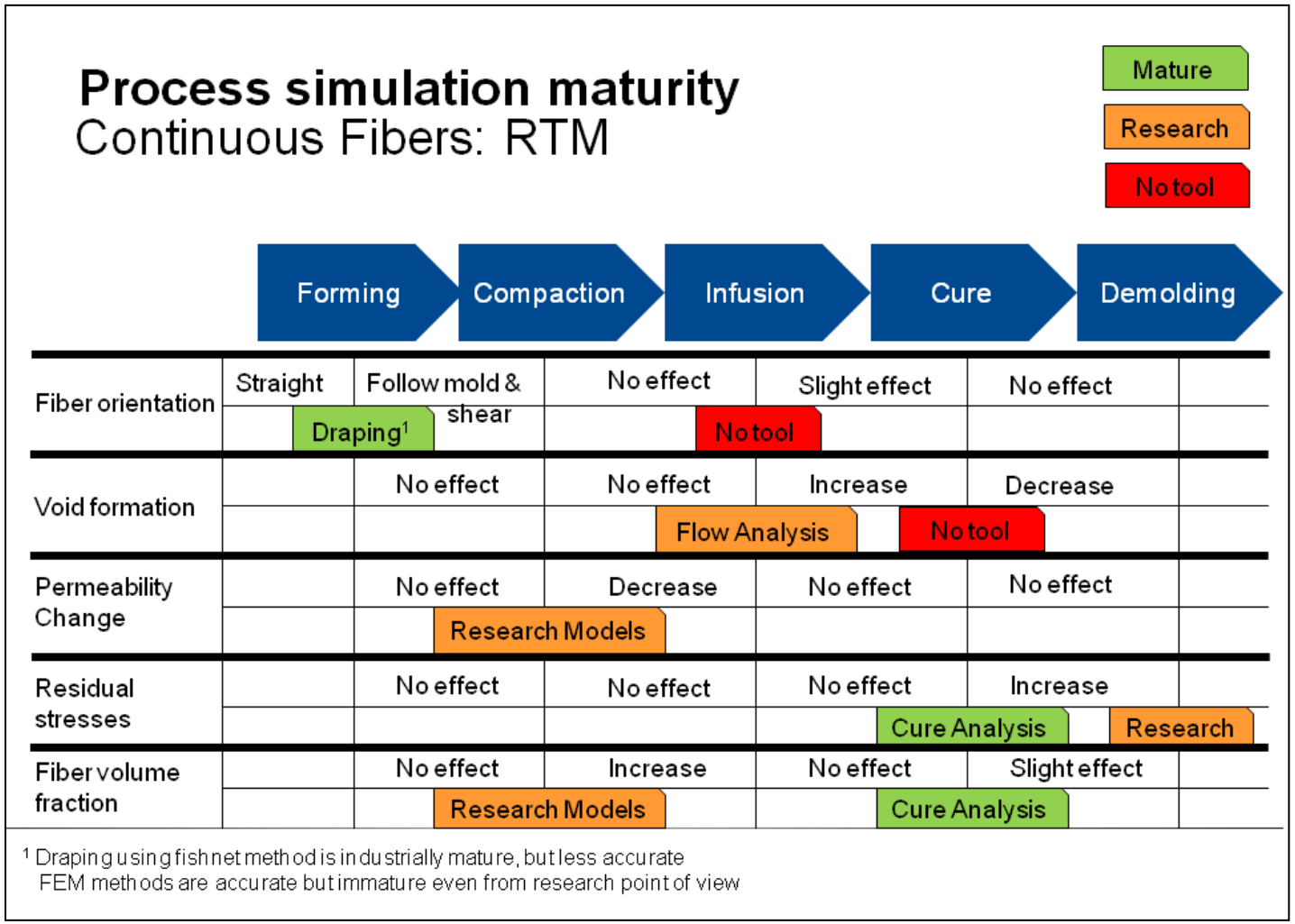
# Design methodology (2018)

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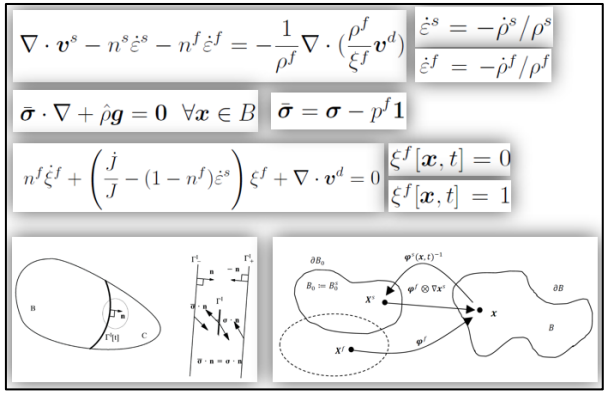
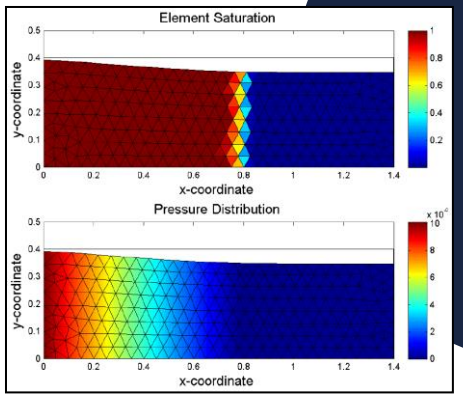
# Established Models

**Resin infusion**

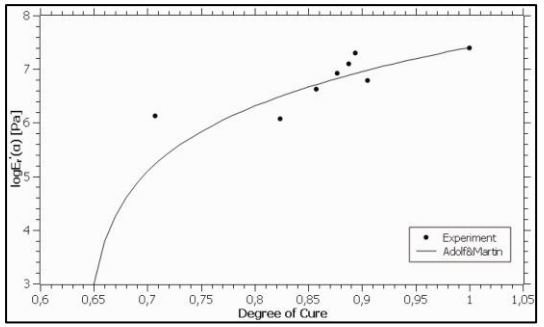
- RISE codes (Mohammad Rouhi)
- https://doi.org/10.1016/j.euromechsol.2011.06.015
- https://doi.org/10.1016/j.compositesa.2012.11.002

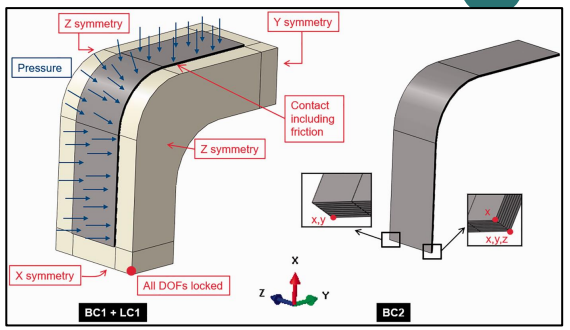





**Curing/Demolding**

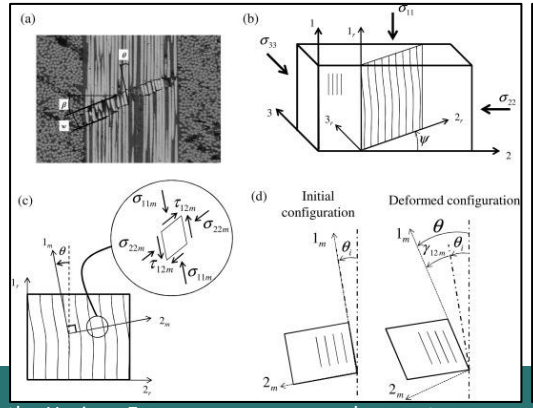
- RISE codes (Sibin Saseendran)
- https://doi.org/10.1080/09243046.2017.1310076
- https://doi.org/10.1177/00219983211024341

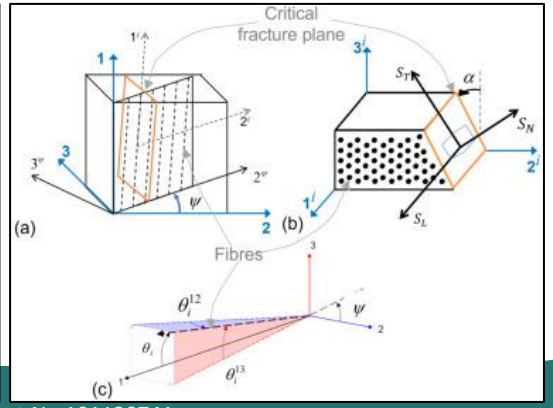



**Structural Analysis**

- RISE codes (Sergio Costa)
- https://doi.org/10.1016/j.compscitech.2016.09.002
- https://doi.org/10.1016/j.compositesa.2022.107103





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# Simulation Workflow

## Sequential multi-step framework

| Coupled Flow-Deformation | Cure/residual stress | | Damage&Failure |
|---|---|---|---|
| UEL<br>UEXTERNALDB<br>UVARM | HETVAL | UMAT<br>UEXPAN | VUMAT |
| Pressure, Saturation Degree, Volume Fraction | Heat Flux, Temperature, Degree of Cure | Cure Shrinkage, Thermal Expansion, Stiffness Evolution | Damage Initiation & Evolution, Failure |

**Key idea: Transfer physical state variables, not just geometry**

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Transferred variables:
- $\xi$ → resin presence
- $v_f$ → fiber fraction

Used in cure model:
- Heat generation scaled with $\xi$
- Density & material properties from $v_f$

Transferred variables:
- $\alpha$ → degree of cure
- $T$ → temperature

Used to compute:
- Glass transition temperature Tg = f($\alpha$)
- Material state: Glassy vs rubbery

Transferred variables:
- Stress field (σ)
- Strain state

Used in damage model:
- Failure initiation criteria
- Damage evolution

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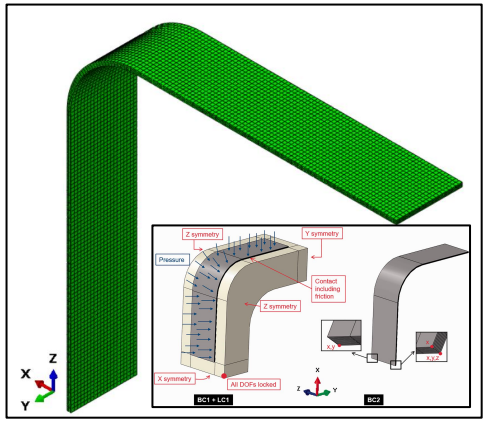
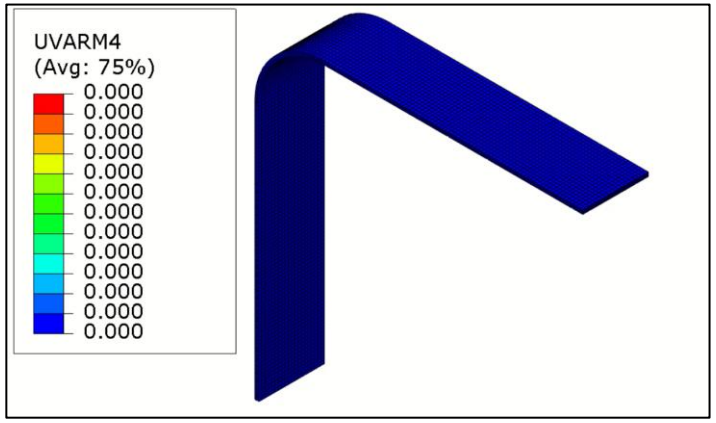
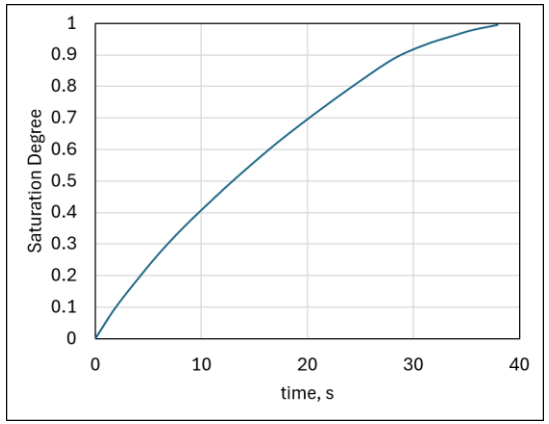
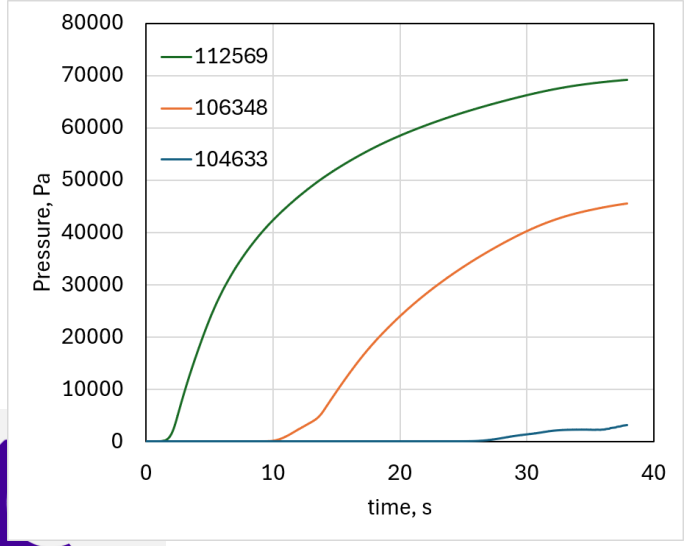
# Flow simulation

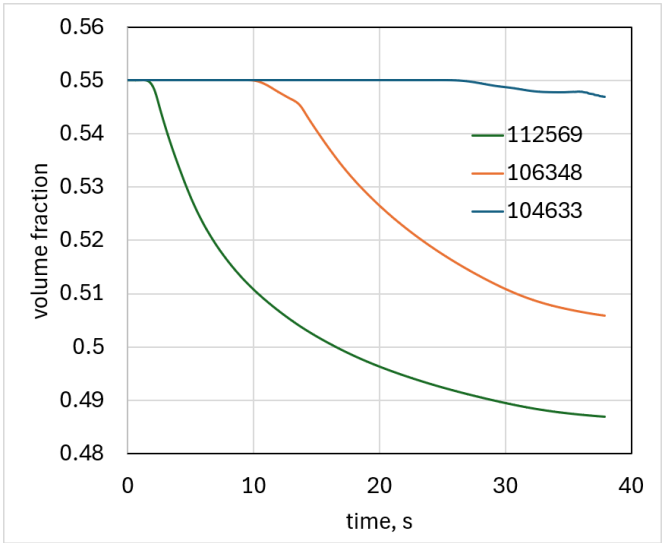


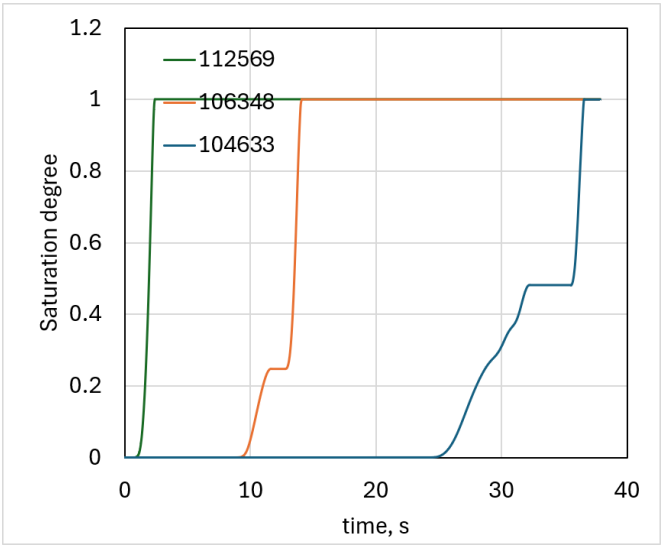




Width 100 mm
Height 100 mm
Length 20 mm
Radius 20 mm
Ply Thickness 0.3
Orientation [0,45,-45,90]

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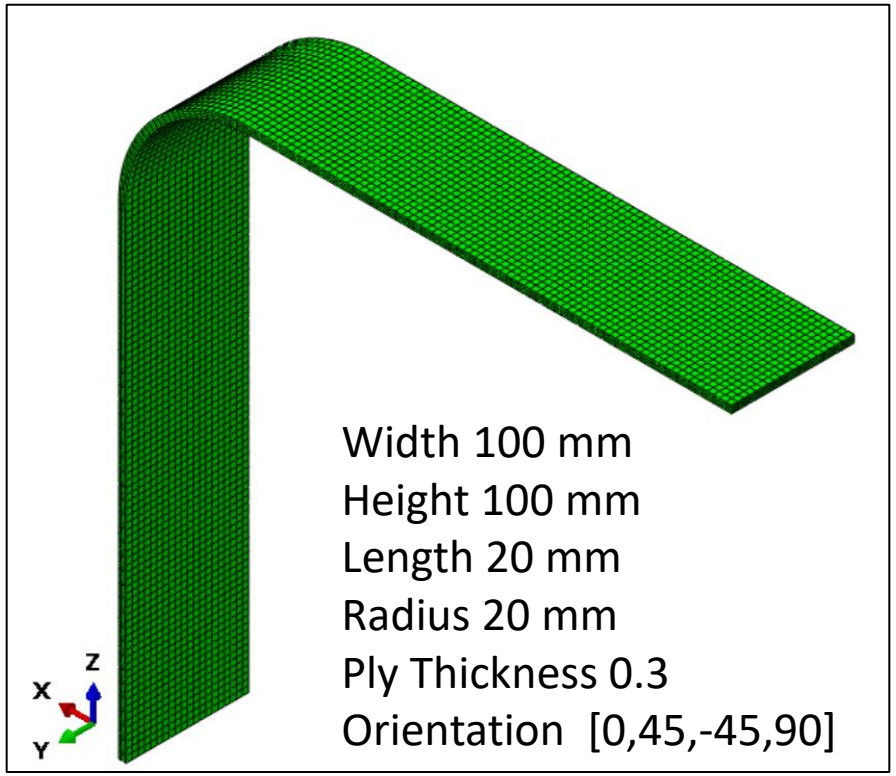
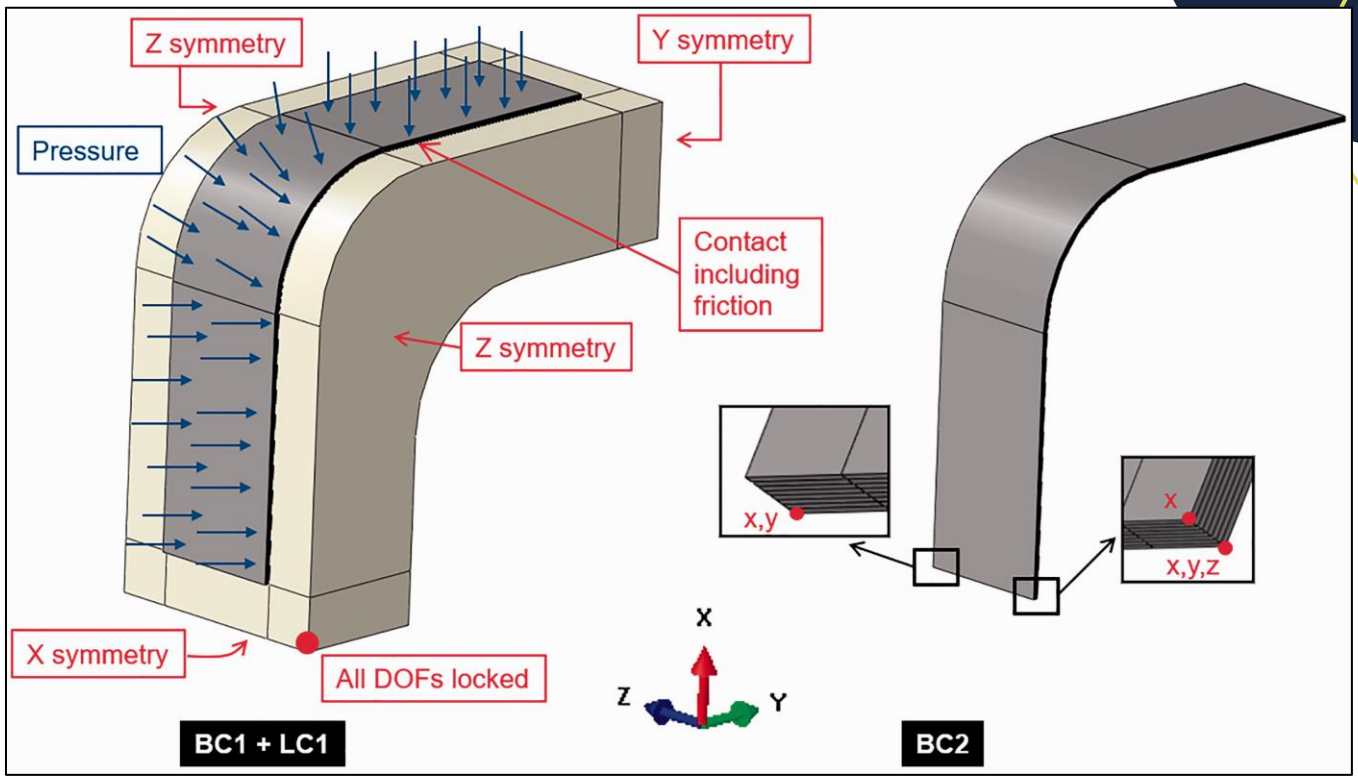
# Cure simulation setup




Cameron CJ, Saseendran S, Stig F, Rouhi M. A rapid method for simulating residual stress to enable optimization against cure induced distortion. *Journal of Composite Materials*. 2021;55(26):3799-3812. doi:10.1177/00219983211024341

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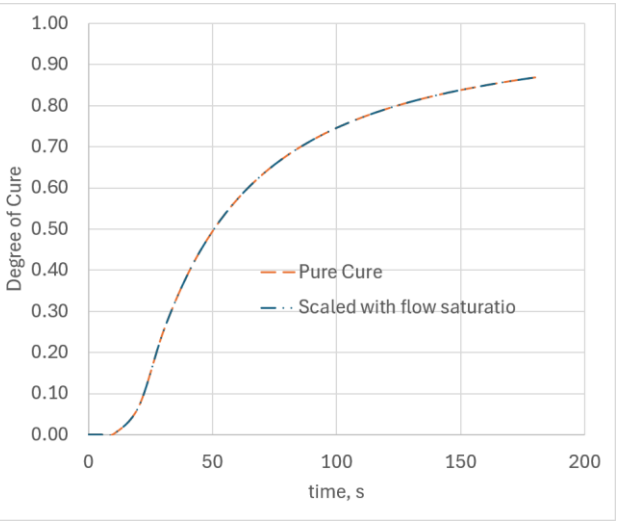
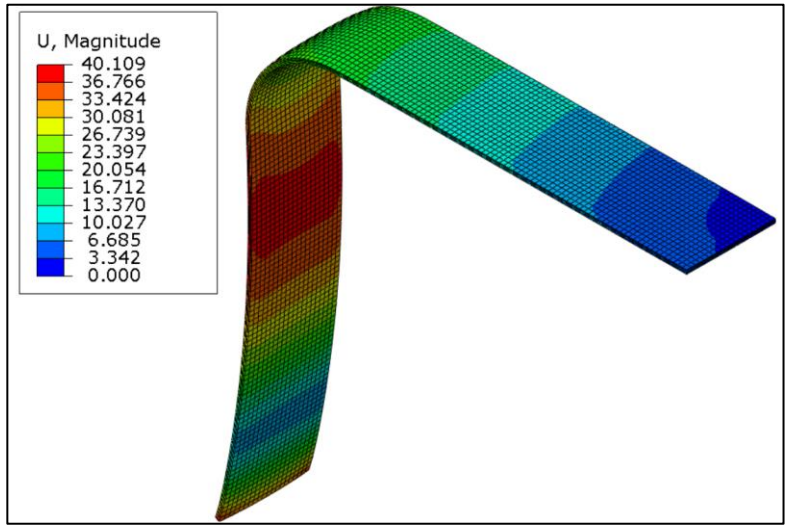
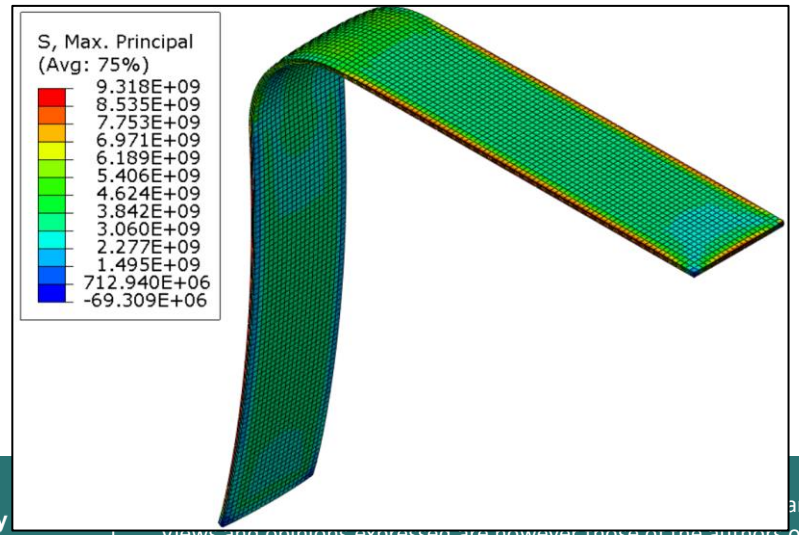
# Cure simulation results

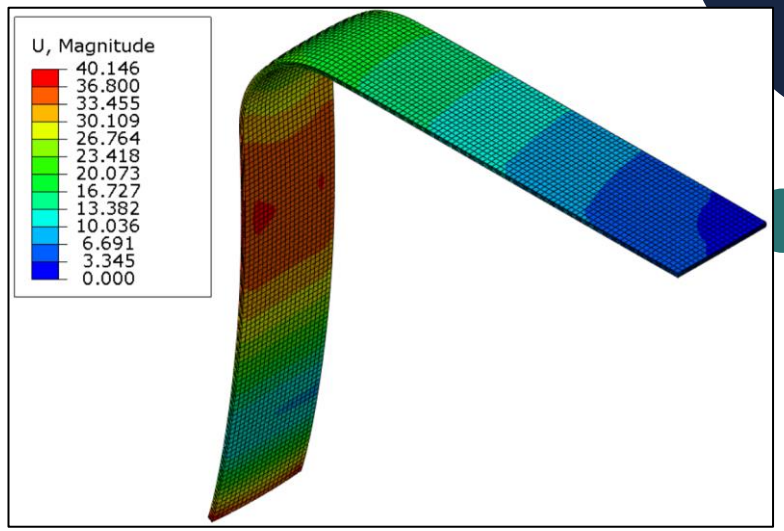


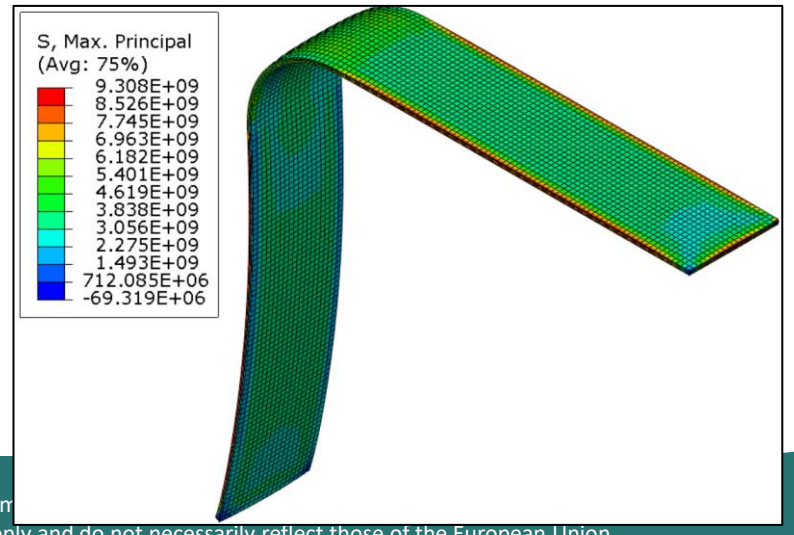

Scaled with flow saturation




Pure Cure

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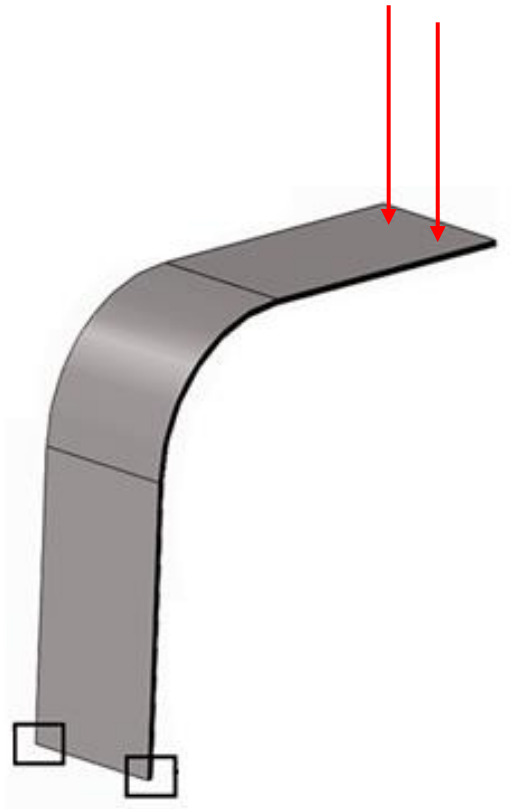
# Structural simulation



## Ongoing
## Damage Initiation & Evolution, Failure

Transferred variables:
- Stress field (σ)
- Strain state

Used in damage model:
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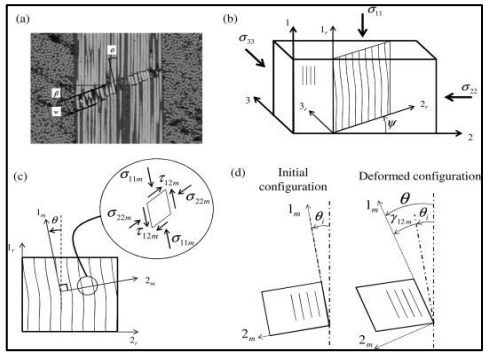


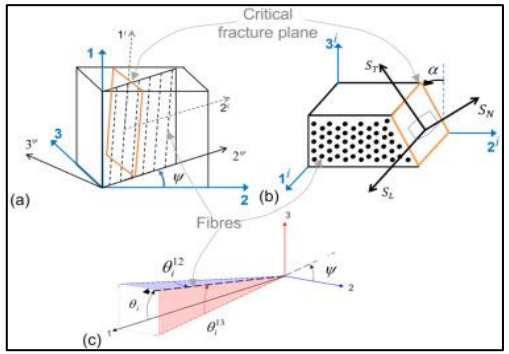


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# ANN tool development

Ongoing

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