Experimental/Numerical Characterisation of Hygrothermal Ageing in Laminate Composites

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Iuri Rocha

R.P.L. Nijssen

F.P. van der Meer

L.J. Sluys

Knowledge Centre WMC

Wind turbine Materials and Constructions

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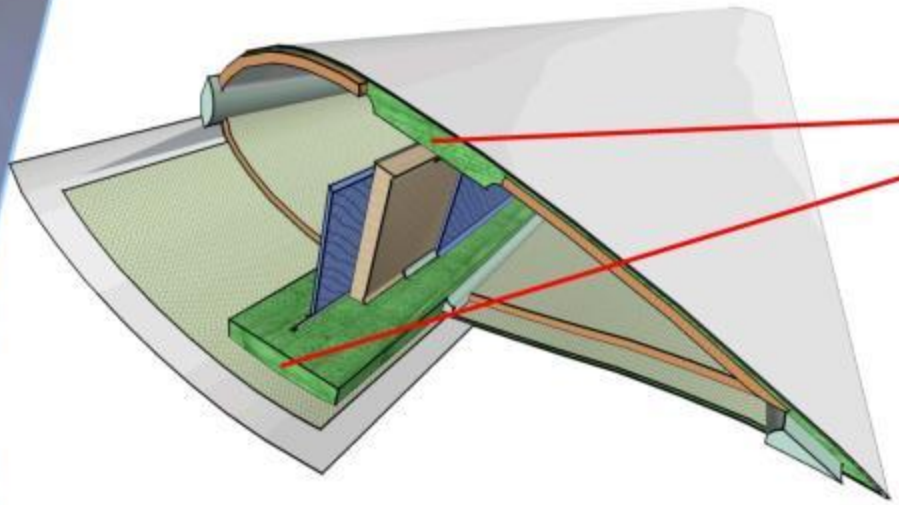
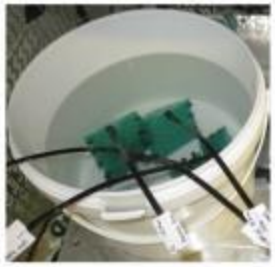
Environmental Loads on Blades



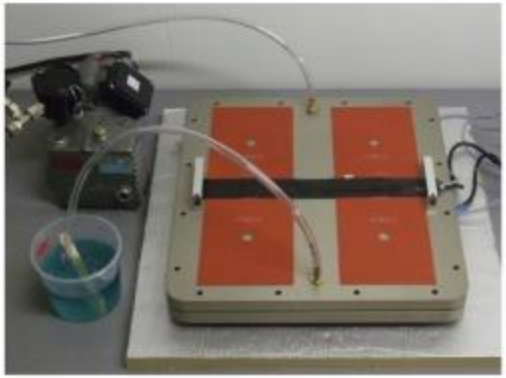
50°C
4800 h



- High/low temperatures
- Moisture ingression
- UV radiation
- Erosion
- Biologic attack

Experimental Investigation

- Manufacturing

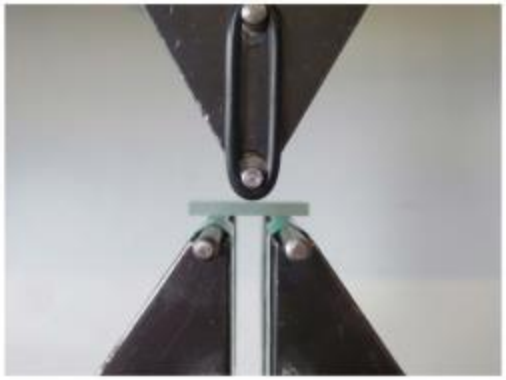


- RIMR135/RIMH1366 epoxy system
- Unidirectional E-Glass fabric
- Vacuum infusion molding
- Short beams for interlaminar shear

- Conditioning

- Demineralised water at 50°C
- Moisture-free reference specimens
- Ageing durations from 250h to 2000h
- Sets tested wet and after being redried

- Mech. testing

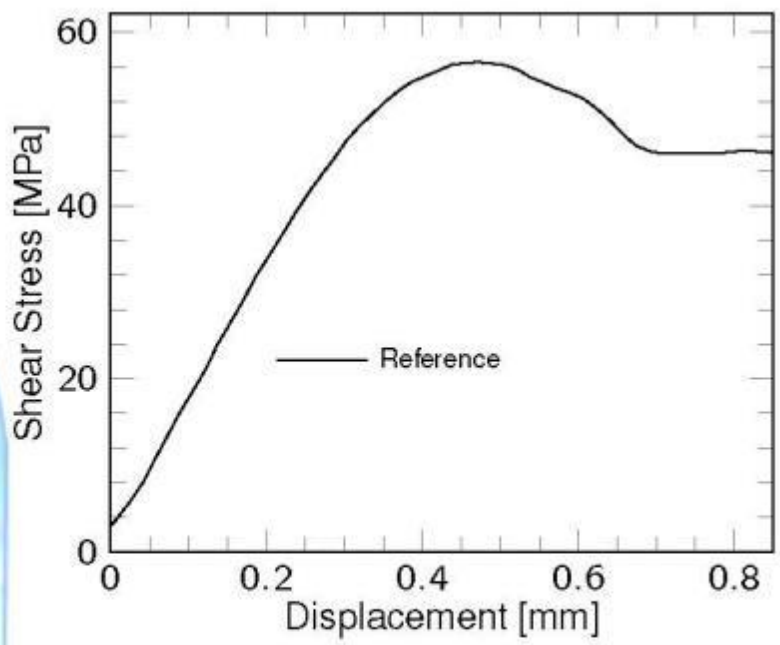


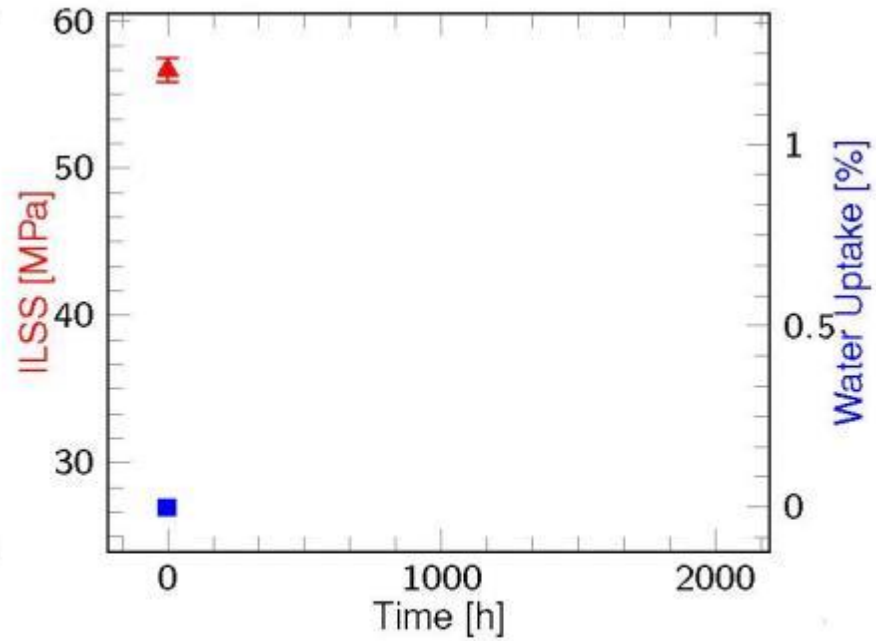
- 3-point bending at 1 mm/min speed
- Sets of 10 tests for each condition
- Interlaminar shear stress calculated as:

$$\tau = \frac{3}{4} \cdot \frac{F}{b \cdot h}$$

Experimental Investigation

- **Results from mechanical tests:**
  - Up to 50% strength decrease after immersion
  - Strength decreases linearly with water uptake
  - Permanent material degradation was observed





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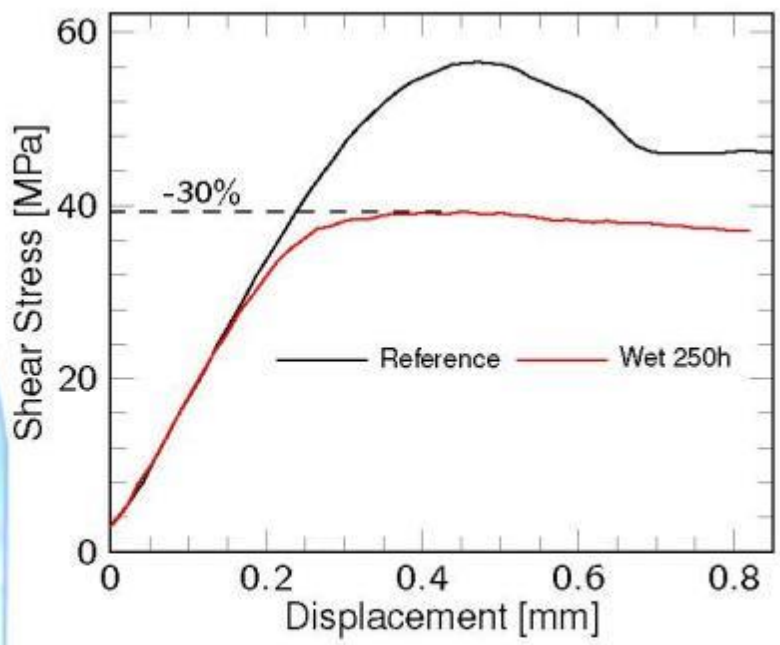

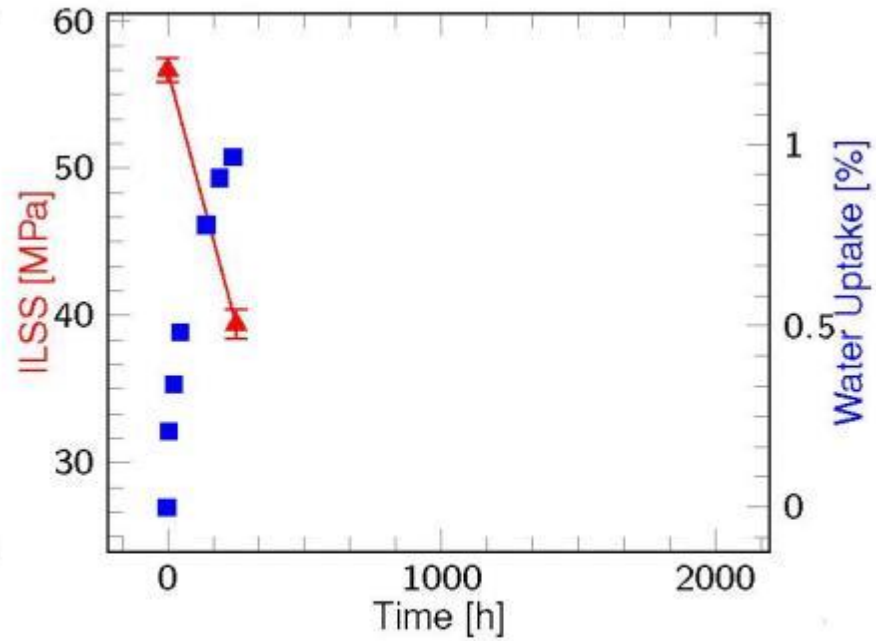

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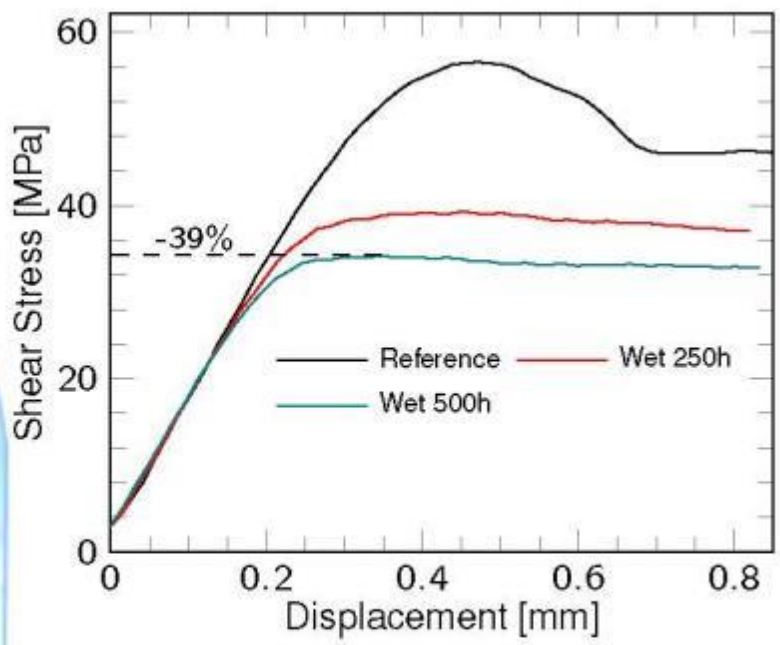

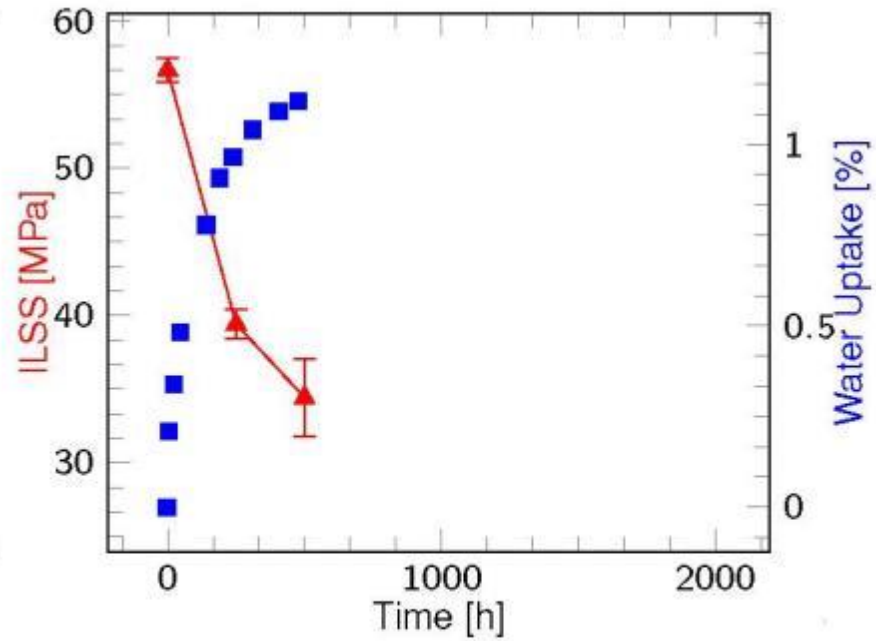

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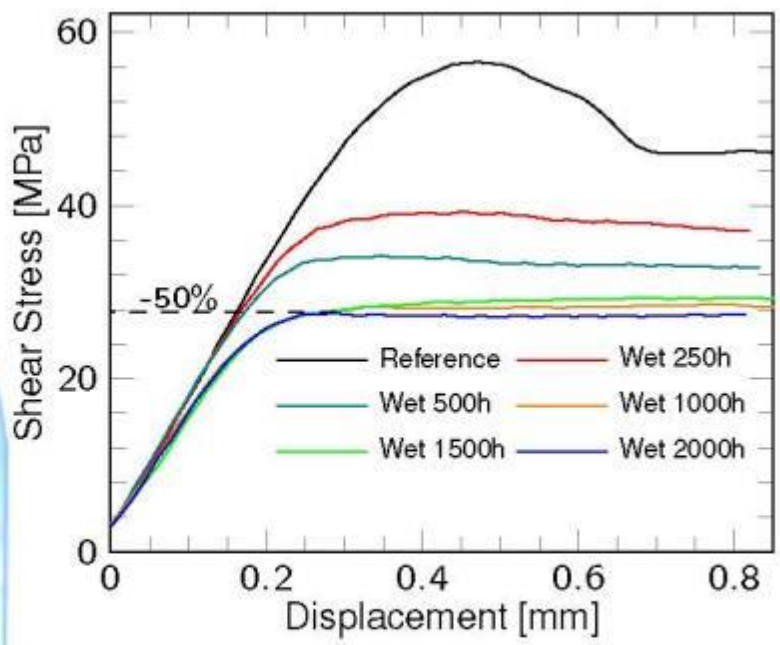

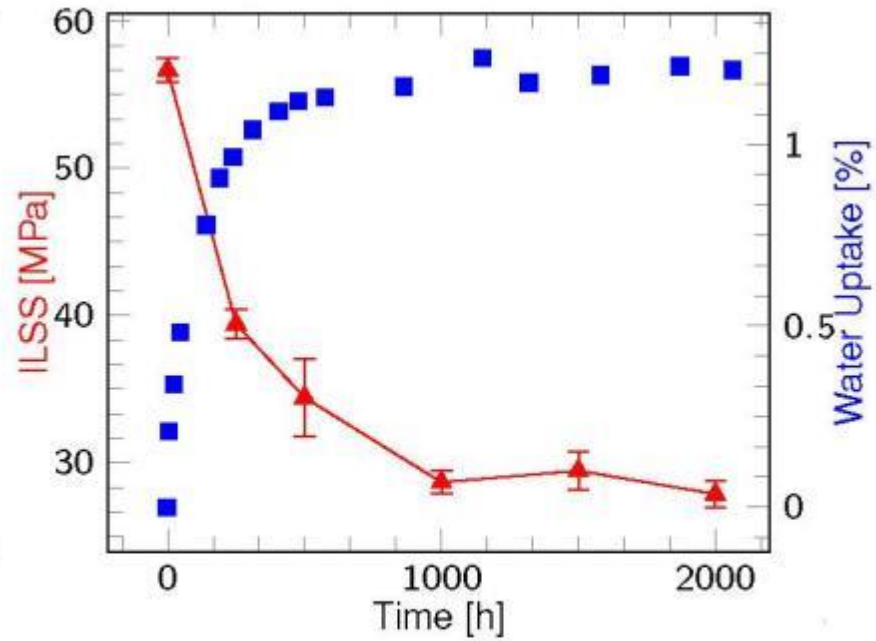

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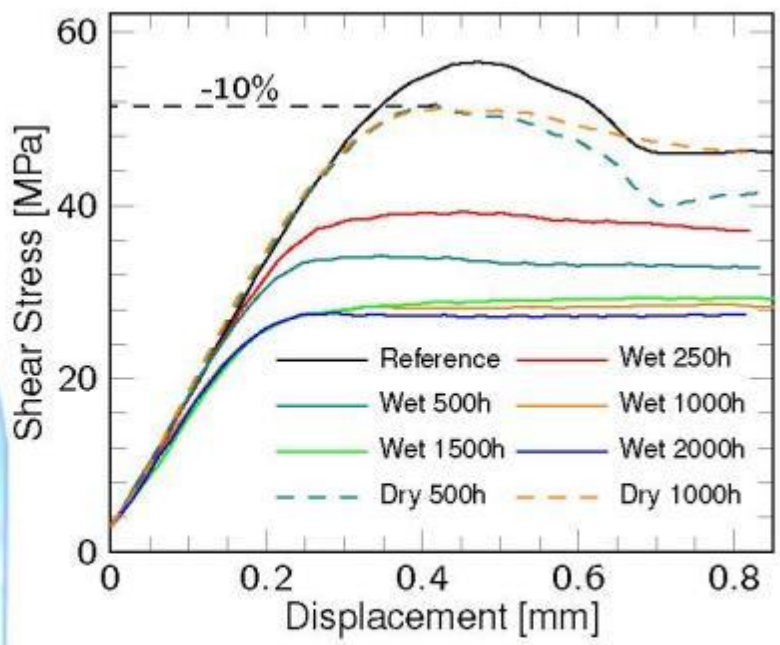
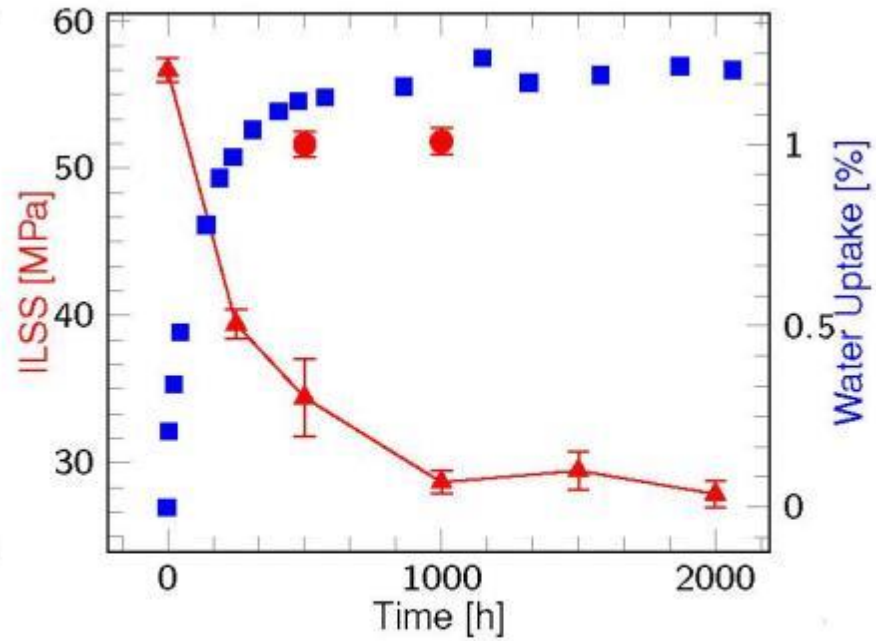
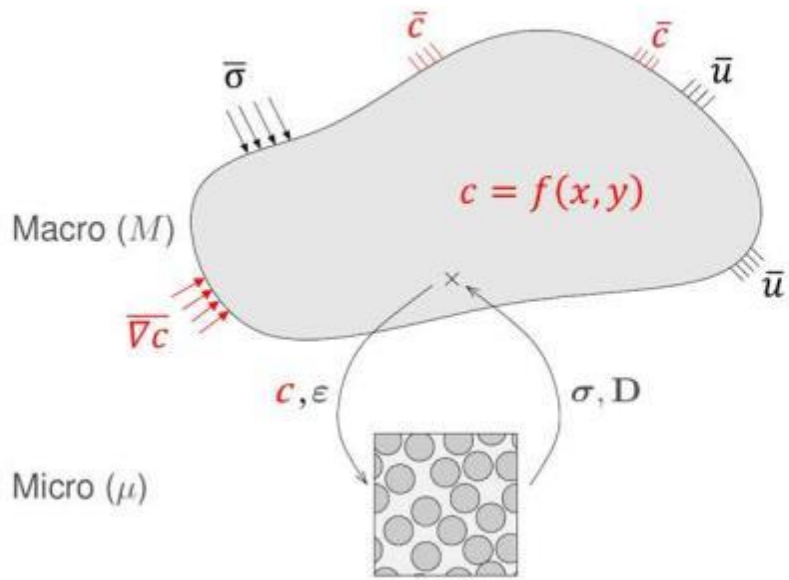




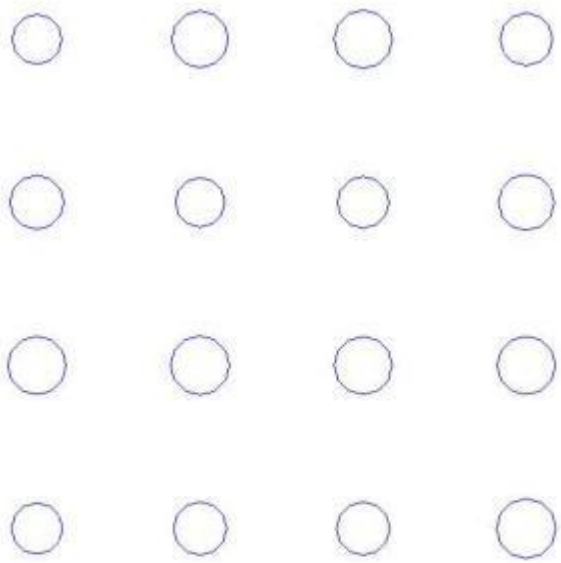
Multiscale Analysis

- **Concurrent (FE^2) homogenization:**
  - Micro-BC's obtained from macro-scale strain
  - Macroscopic local response obtained from RVE
  - Embedded FE model at each integration point
  - Multiphysics $\rightarrow$ Modification of classic FE^2:
    - Macro diffusion $\rightarrow$ micro swelling $\rightarrow$ macro stresses



Micromechanical Model

- **Representative Volume Element (RVE):**
  - 2D with fibres oriented out-of-plane
  - Random fibre distribution with periodicity
  - Interface elements around every fibre



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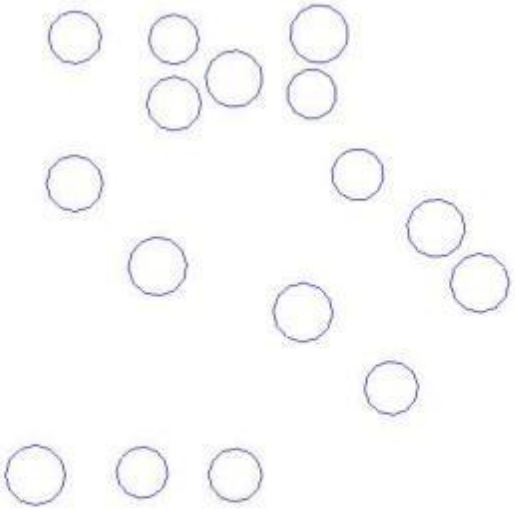

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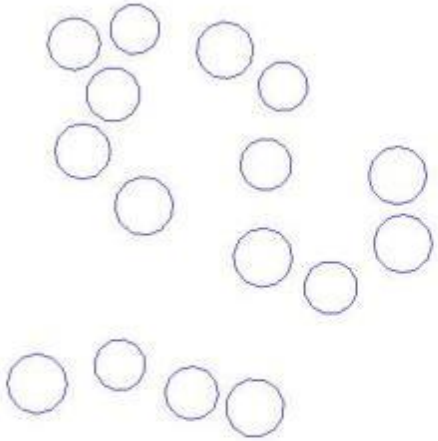

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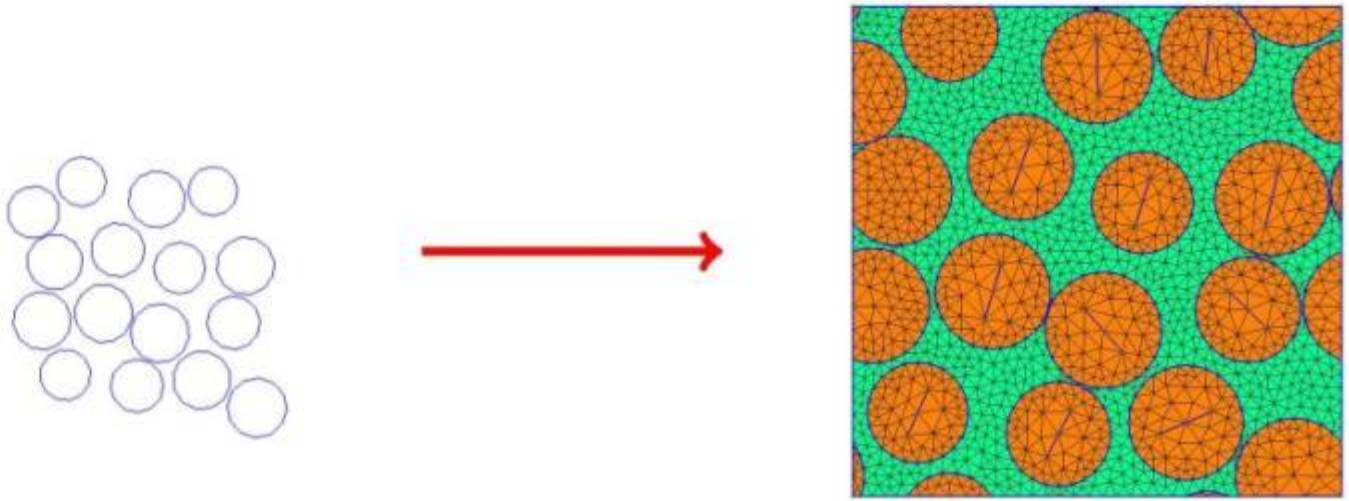
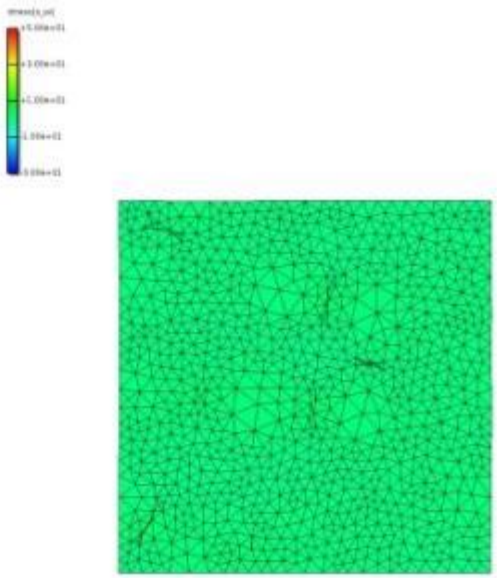


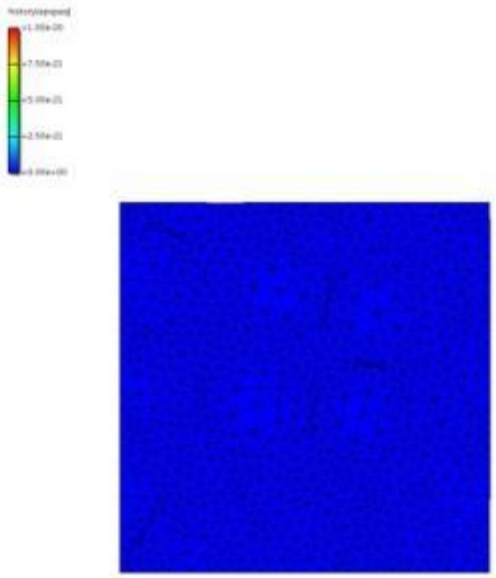
Micromechanical Model

- **Loads and boundary conditions:**
  - Periodic boundary conditions
  - Macroscopic strain applied at corner nodes
  - Swelling strain at every resin point

σ_x[MPa]



ϵ^p_{eq}[-]



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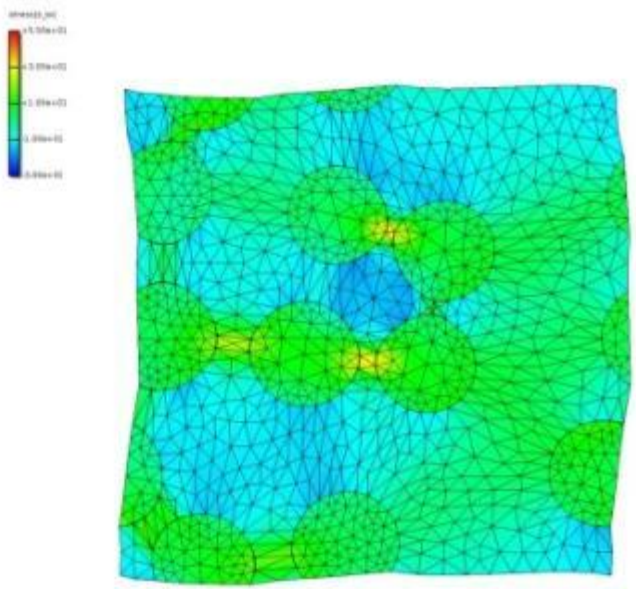

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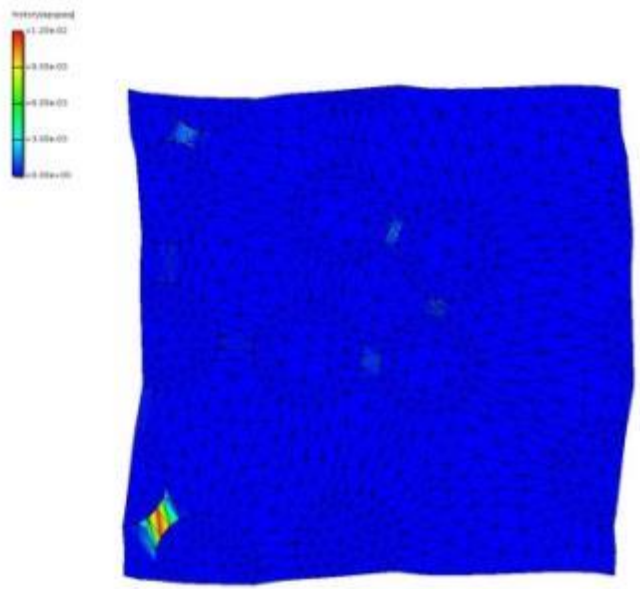

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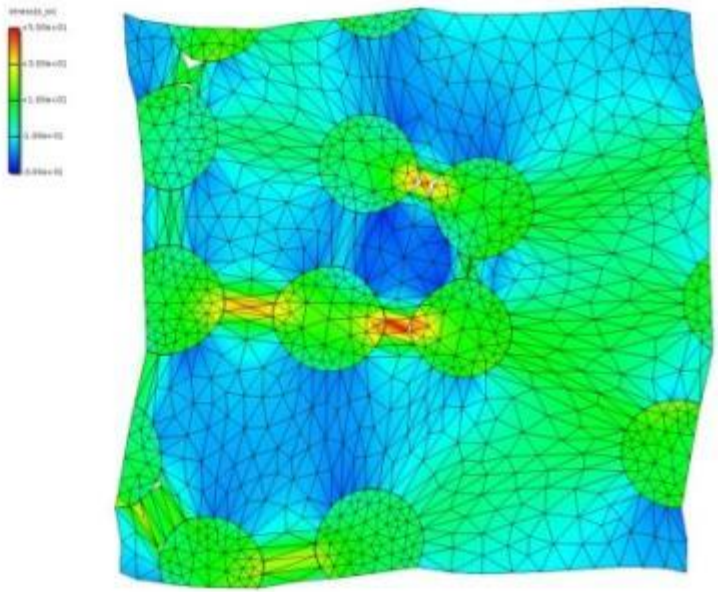

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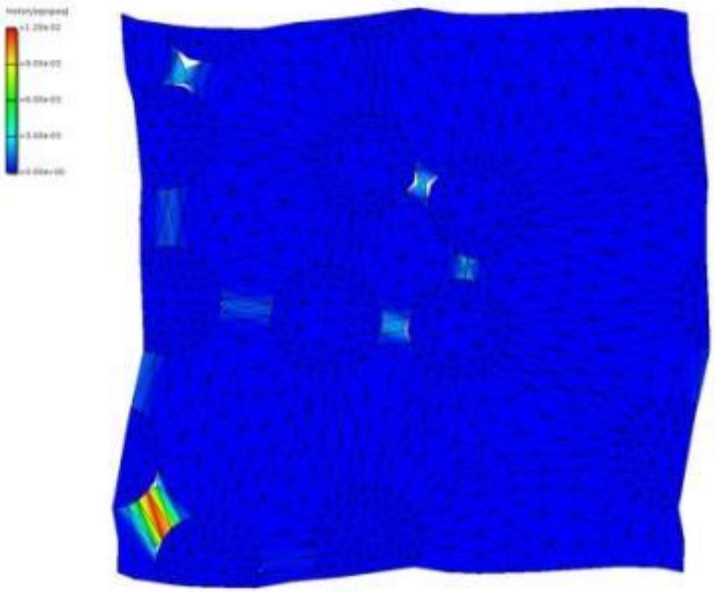
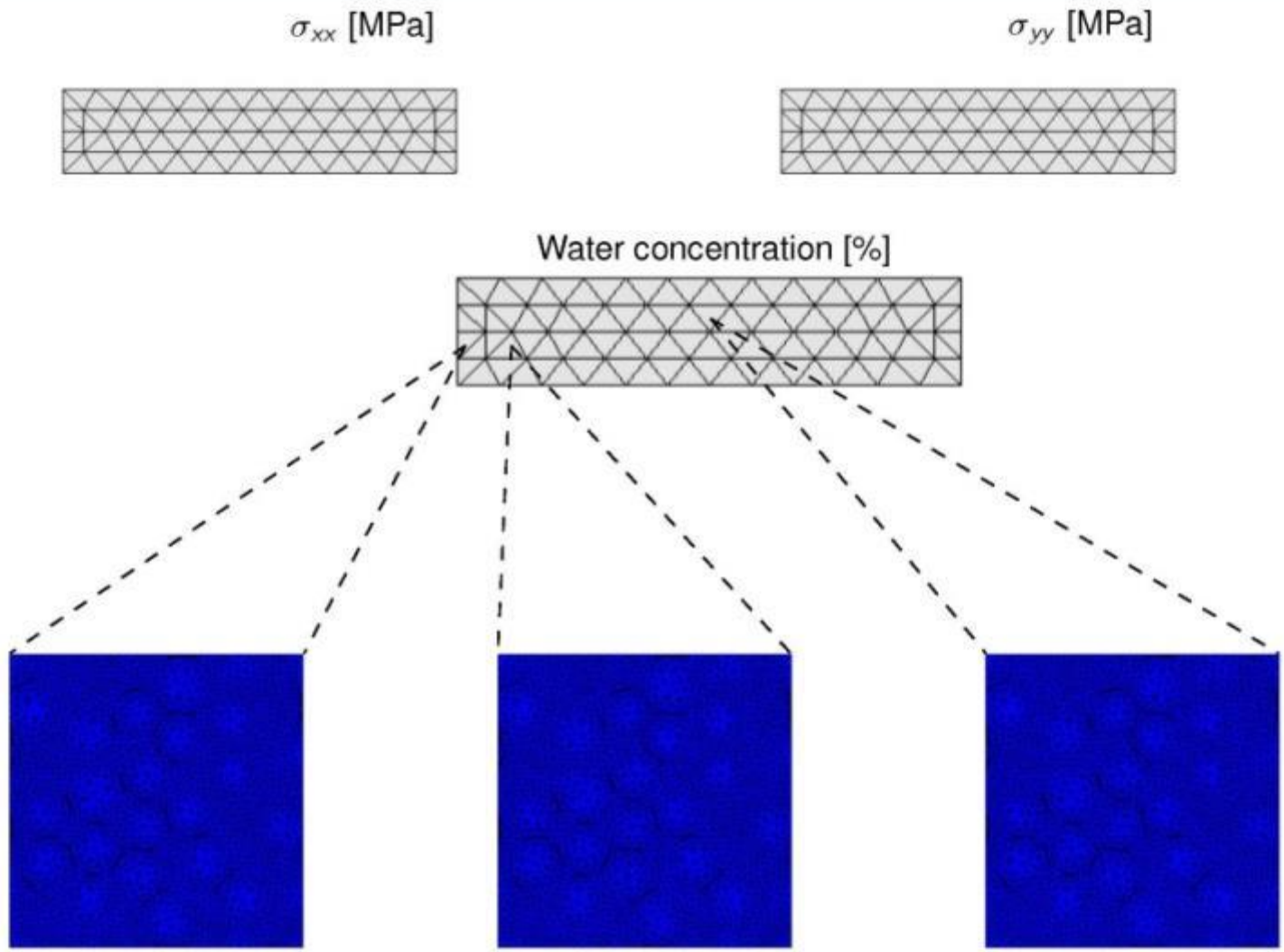


FE^2 Example



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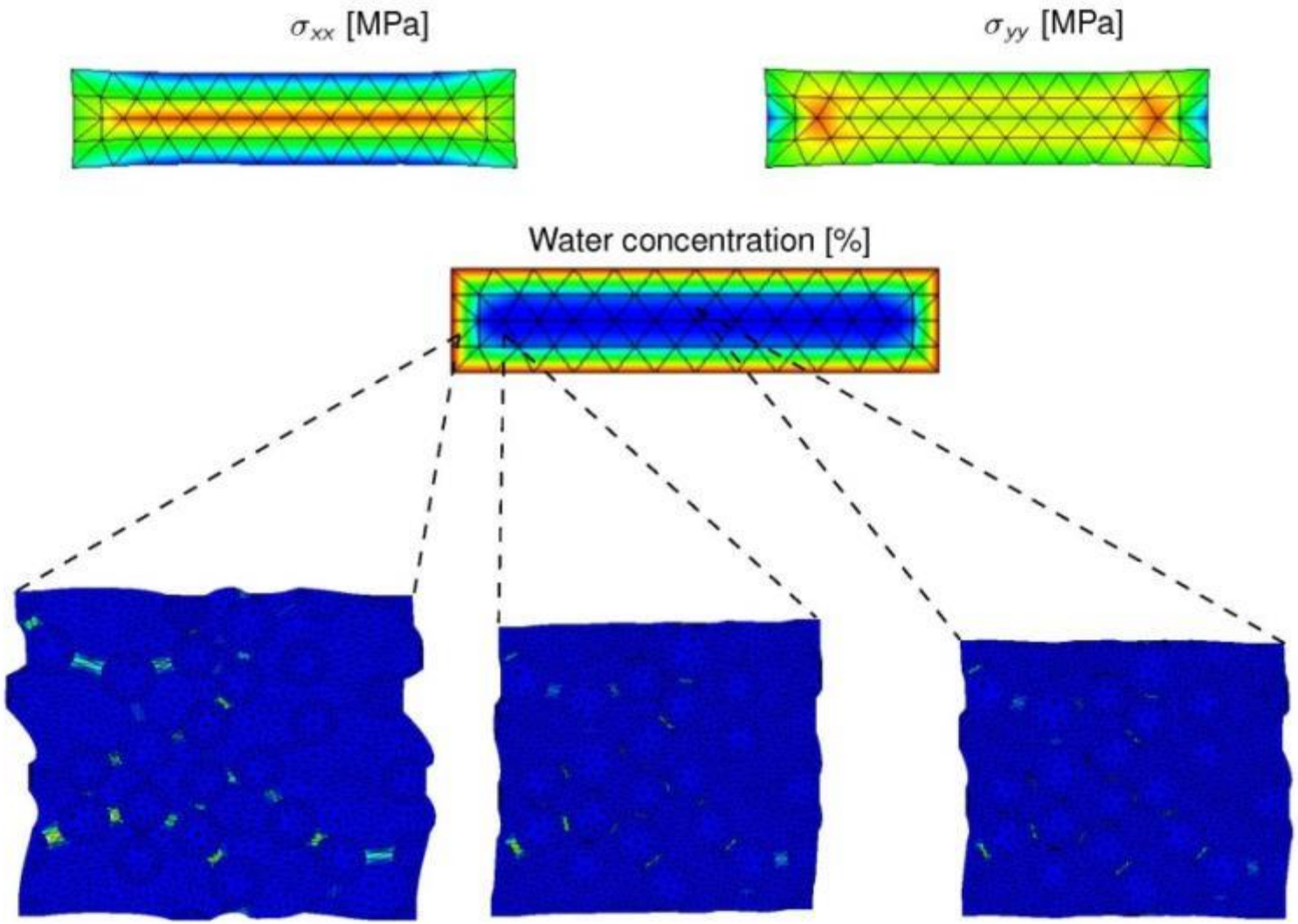

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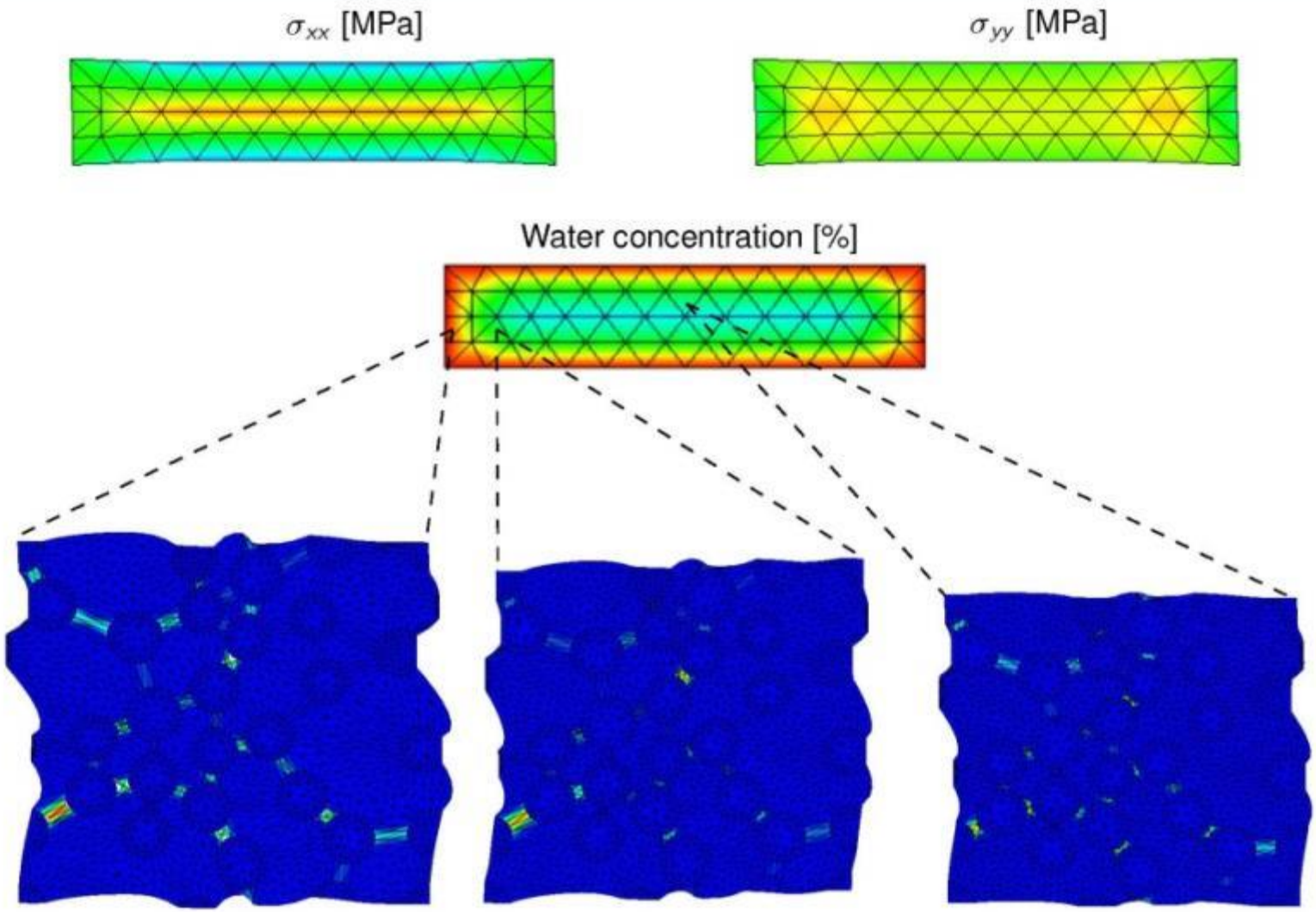

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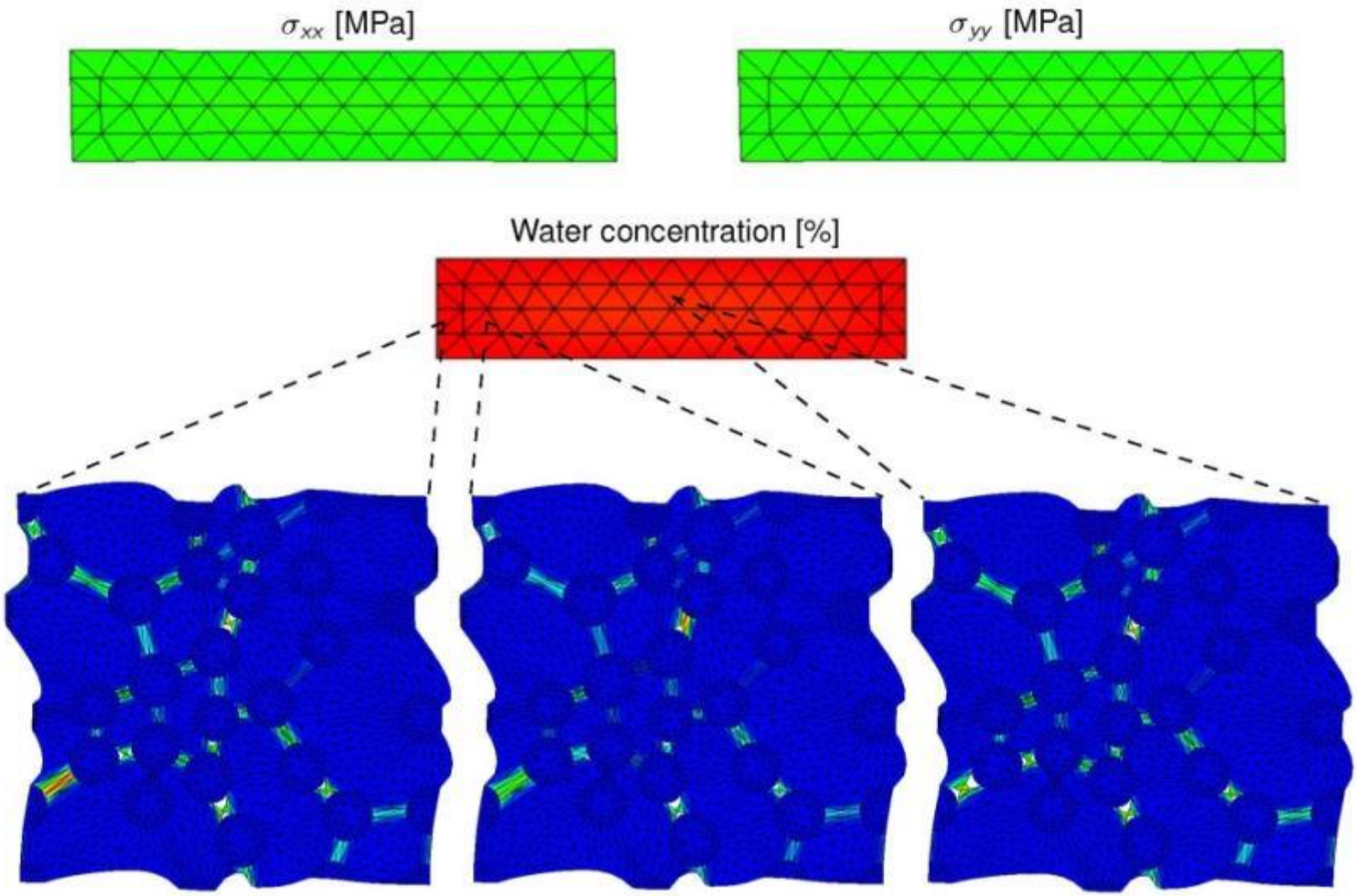
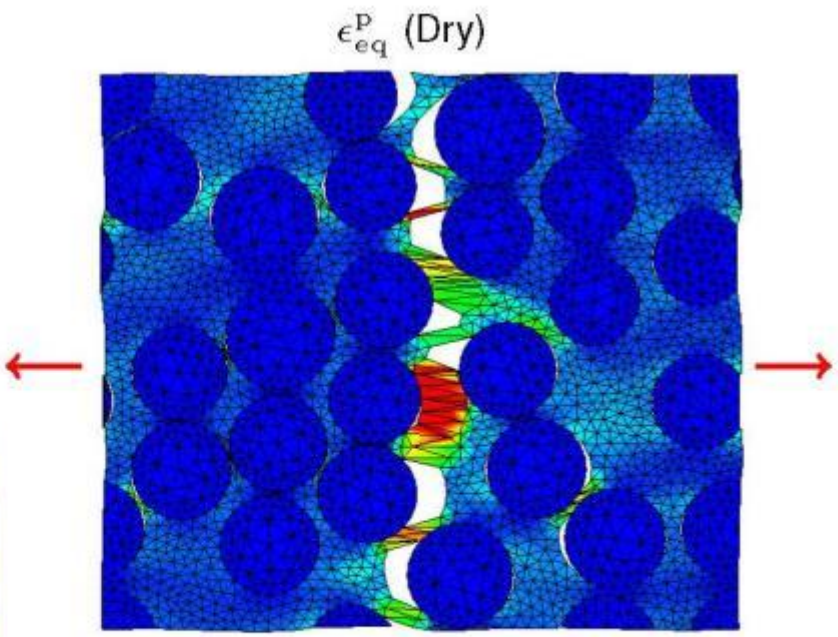
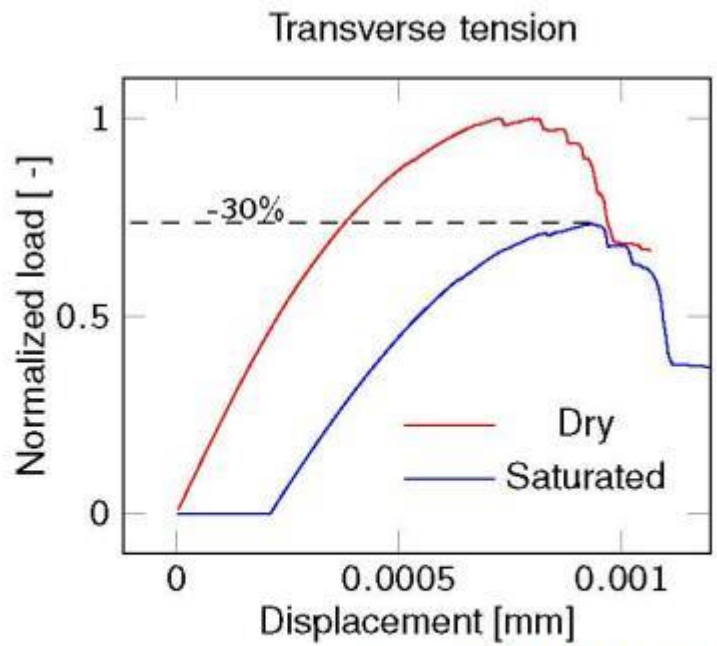


Strength Degradation

- **Loading the final diffusion RVEs:**
  - After saturation, mechanical loads can be applied to the RVEs
  - Crack location changes after immersion





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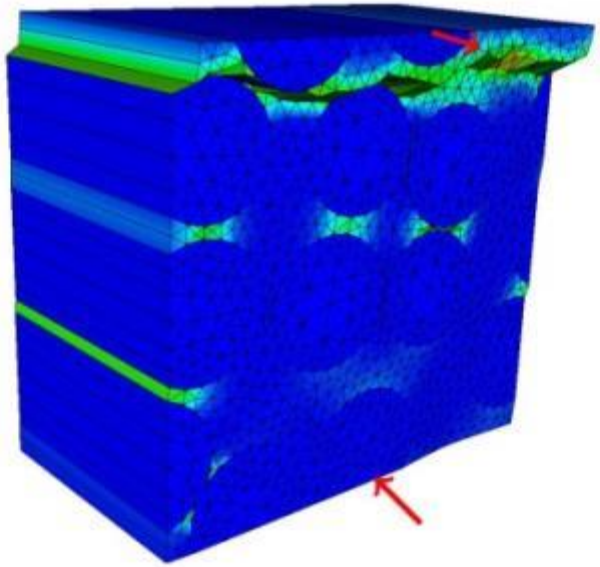
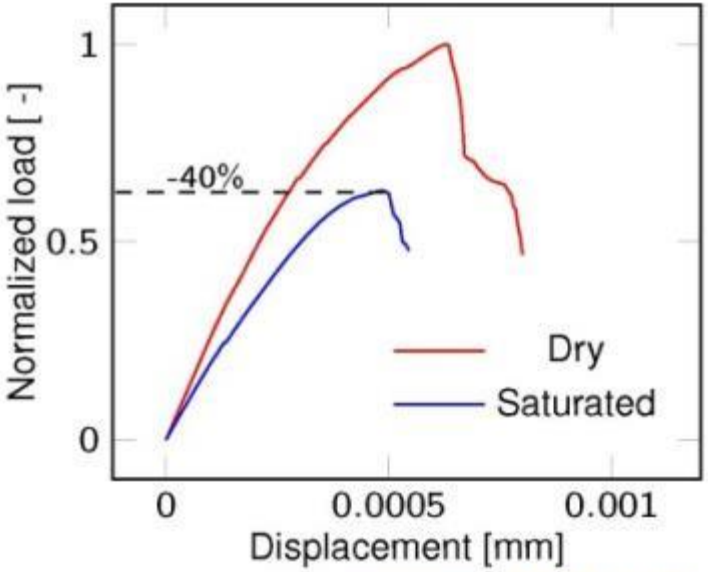
ϵ^{P}_{eq} (Saturated)



Out-of-plane shear