Experimental characterization and modelling of the coupling between water diffusion and mechanical behaviour of composite materials

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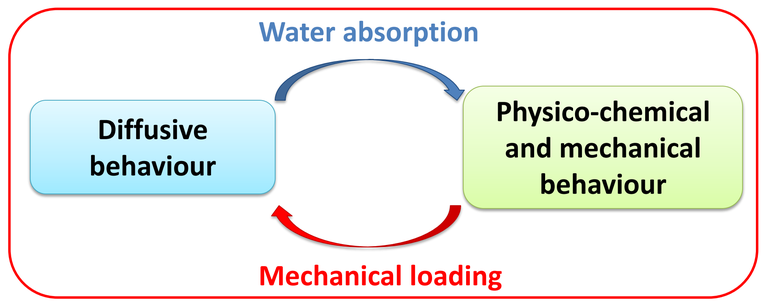
INDUSTRIAL & SCIENTIFIC ISSUE

Marine renewable energy and naval structures are subjected to severe environmental conditions (seawater or humid air) and continuous mechanical loadings. These factors are reducing the lifetime of these structures by accelerating the damage development. However, at the current state, there is no predictive model taking account of the coupled phenomena

OBJECTIVES

- Understand the coupling between the two physical phenomena:
  - ➡ diffusion & mechanical behaviour
- Perform creep tests in specific environment (humid air / immersion)
- Develop numerical models to simulate this coupling.

HYGROMECHANICAL COUPLING

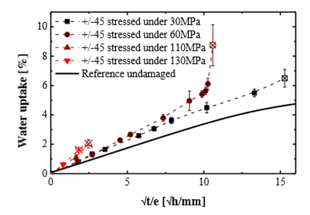


METHODOLOGY

1. **Diffusive properties**
   - Gravimetric analysis
   - DVS
   - Hygroscopic swelling
2. **Mechanical properties**
   - Uniaxial tension test
   - Shear test
3. **Long term viscoelastic properties**
   - DMA
   - ➢ Master curves
   - ➢ Viscoelastic properties
4. **Hygromechanical coupling**
   - Creep test
   - ➢ Air / RH/ Immersion

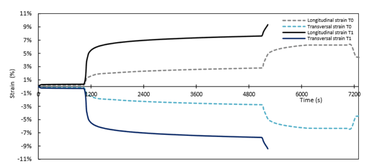
STATE OF ART

Diffusion under mechanical loading



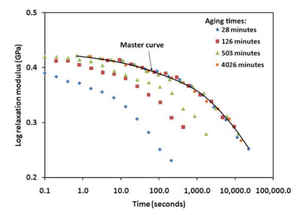
Humeau [1]

Creep and ageing



Tual [2]

Time-temperature-ageing superposition

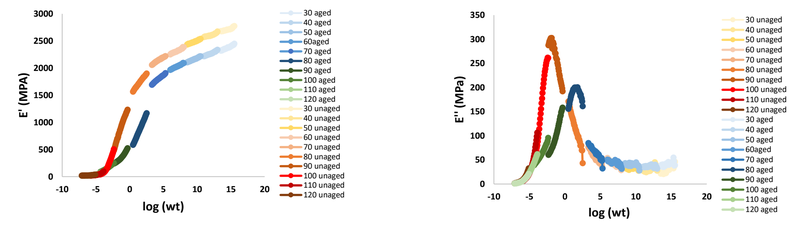


Tanks & al [3]

CREEP AND AGEING

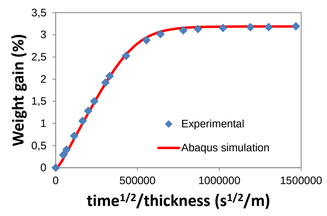
AGEING AND VISCOELASTIC PROPERTIES

Time temperature superposition of aged/unaged resin : Evolution of elastic (E') and loss (E'') modulus



- DMA experiments: traction from 30 to 120°C of aged/unaged samples
- Decrease of elastic modulus (E') of 15% at glassy state for aged sample
  - ➢ Direct impact on $\varepsilon_{viscoelastic}$
- Increase of loss modulus (E'') with ageing
  - ➢ Delay of relaxation time
- Decrease of glass temperature for aged samples

Gravimetric test performed on neat epoxy resin sample at 60°C

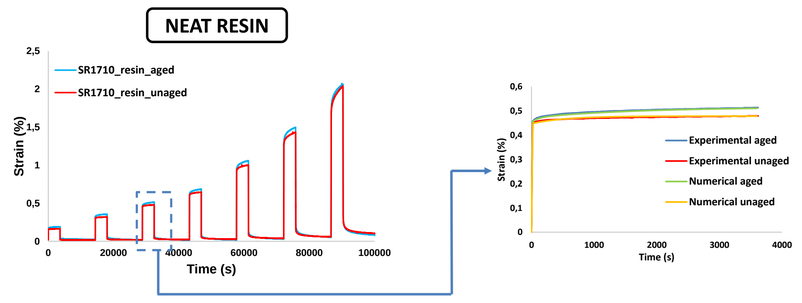


Determination of viscoelastic parameters to model creep behaviour with generalized Maxwell model

$$g_R(t) = 1 - \sum_{i=1}^{N} \bar{g}_i^P \left(1 - e^{-t/\tau_i^G}\right)$$

INFLUENCE OF AGEING ON CREEP BEHAVIOUR

NEAT RESIN



- Creep recovery test on unaged and aged resin/composite samples
- 7 creep / recovery steps (1h) / (3h)
- $\varepsilon_{aged} > \varepsilon_{unaged}$

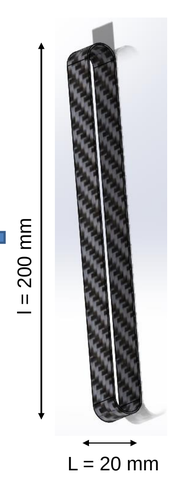
EXPERIMENTAL DEVELOPMENT

CREEP TEST IN SPECIAL ENVIRONMENT ON NEW SAMPLE DESIGN

Perform creep test in humid air / immersion

CREEP TEST BENCH

CREEP SAMPLE GEOMETRY



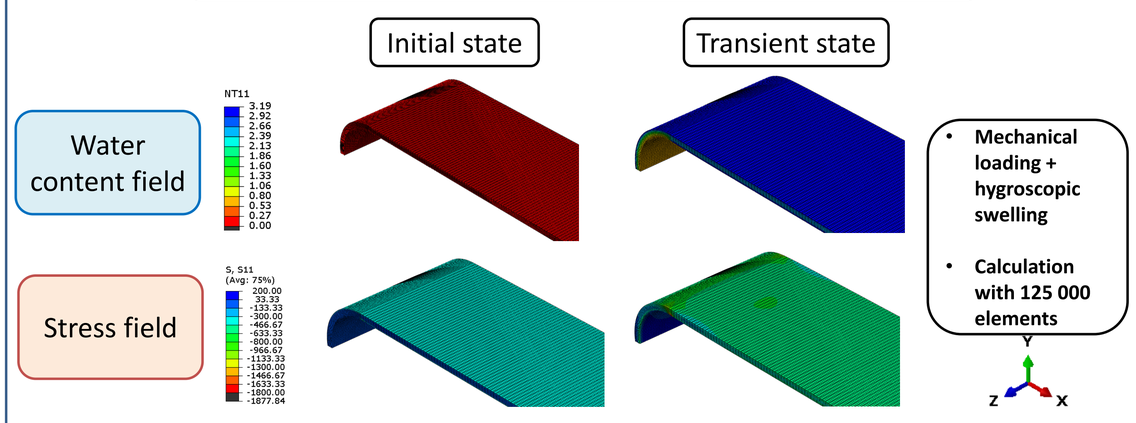
SPECIFICITY

- Obround samples
- No need for grips, which can slip in wet conditions
- Easier to remove for weight measurement and temporary characterization
- Prepreg or wet lay up

FINITE ELEMENT ANALYSIS

ANALYSIS OF DISTRIBUTION OF STRESS FIELD ON OBROUND SPECIMEN

Simulation of a traction test under water diffusion



- Higher stress level for transient diffusion states
- Uniform distribution of stresses regardless the water field content

ONGOING WORK

- Performing creep test in humid environment (humid air / immersion) on composites [±45] on the creep bench.
- Simulating creep test with Abaqus taking into account the hygromechanical coupling

BIBLIOGRAPHY

[1] N. Tual, "Durabilité des matériaux composites carbone/époxy pour applications pales d' hydroliennes," 2015
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[3] J. Tanks, K. Rader, S. Sharp, and T. Sakai, "Accelerated creep and creep-rupture testing of transverse unidirectional carbon/epoxy lamina based on the stepped isostress method," *Compos. Struct.*, vol. 159, pp. 455–462, Jan. 2017.

PARTNERSHIPS