Study of the hygro-mechanical coupling in composite materials

ICCS23 - 23rd International Conference on Composite Structures

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Q. Dezulier[(1)], F. Jacquemin[(1)], P. Davies[(2)], A. Clement[(1)], M. Arhant[(2)], B. Flageul[(2)]

(1): Research Institute in Civil and Mechanical Engineering, CNRS UMR 6183, University of Nantes
(2): Marine Structures Laboratory, IFREMER Centre Bretagne

This work was carried out within the framework of the WEAMEC, West Atlantic Marine Energy Community, and with funding from the CARENE

Composite materials in marine environment

- Good resistance to marine corrosion
- Lightening of marine structures
- Saving energy (fuel/electricity)

Sensitivity to water
Hydrophilic property of the matrix

+

Various mechanical loadings
Creep or fatigue

→

Durability ?
Lifetime > 25 years

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Hygromechanical coupling

Water absorption

Diffusive behaviour

Physico-chemical and mechanical behaviour

Mechanical loading

Overview – On the study of hygromechanical coupling

I. **Experimental procedure**

II. **Uncoupled approach**

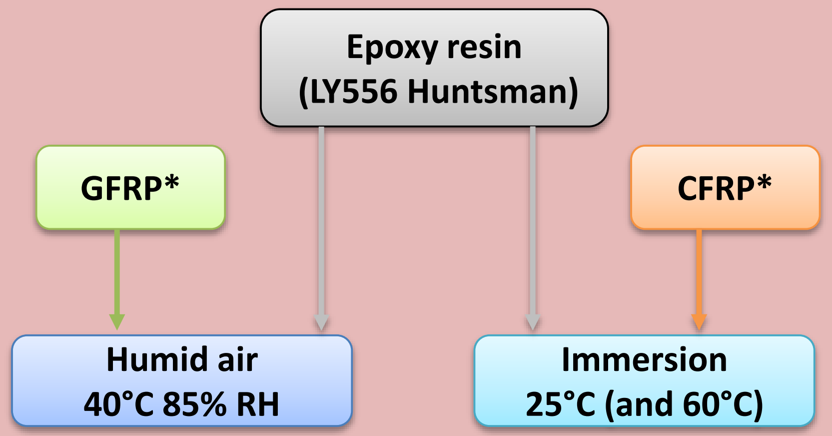
1) Diffusive and hygro-elastic behaviour
2) Quasi-static uncoupled test

III. **Hygromechanical coupling**

1) Design of specific coupled creep test
2) Simulation of coupled creep test with a water content field

IV. **Conclusions & ongoing work**

- **3 types of materials**



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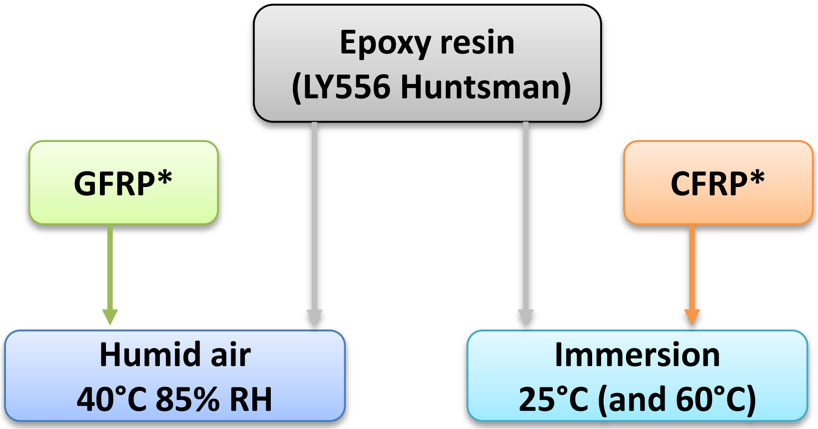

- **3 stacking sequences for composites**

*GFRP: glass fiber reinforced polymer

*CFRP: carbon fiber reinforced polymer

- **$[+/-45]_6$**
- **$[+/-45/0/+/-45]_s$**
- **$[+/-45/90/+/-45]_s$**

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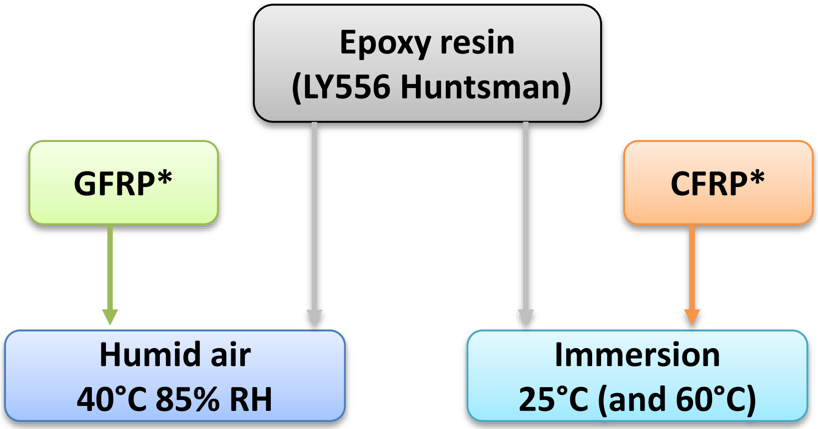

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1

Identification of diffusive properties

- **Gravimetric test**
- **Hygroscopic swelling**
- **DVS**

3 types of materials

Epoxy resin (LY556 Huntsman)

GFRP*

CFRP*

Humid air 40°C 85% RH

Immersion 25°C (and 60°C)

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1 Identification of diffusive properties

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- DVS

2 **Identification of mechanical properties at different state of ageing**

- **Tensile test**
- **Creep test**
- **DMA**

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1 Identification of diffusive properties

- Gravimetric test
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3 **Hygro-mechanical coupling**

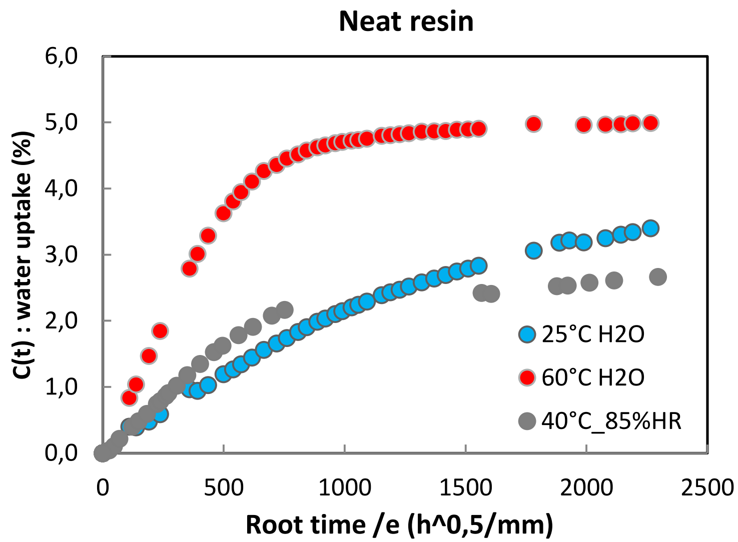
- **Coupled creep test**
  - **Humid air / immersion**

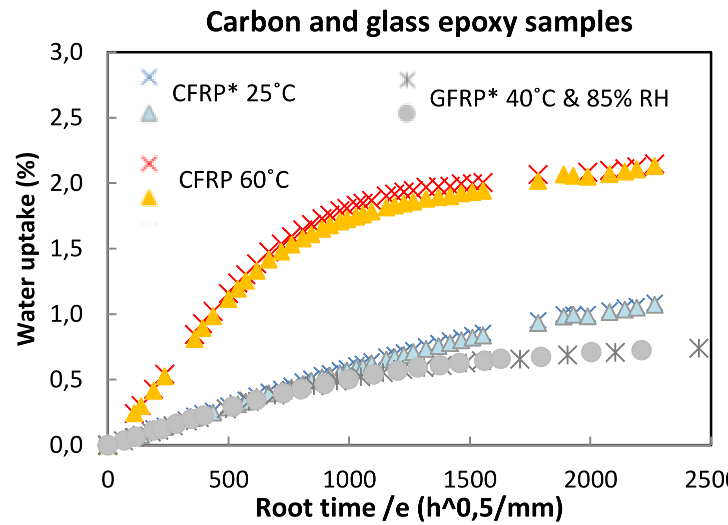
2 Identification of mechanical properties at different states of ageing

- Tensile test
- Creep test
- DMA

Gravimetric tests

- Evaluation of the **diffusive behaviour of resin and composite samples** through gravimetric tests



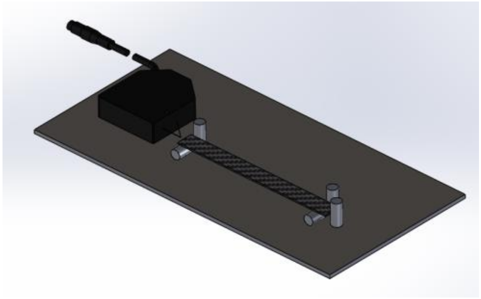


$$C(t) = \frac{m(t) - m_0}{m_0}$$

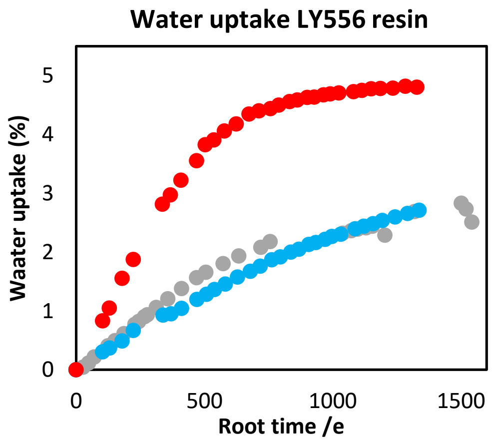
C(t) : global water content
m(t) : mass at t time
m_0 : initial mass

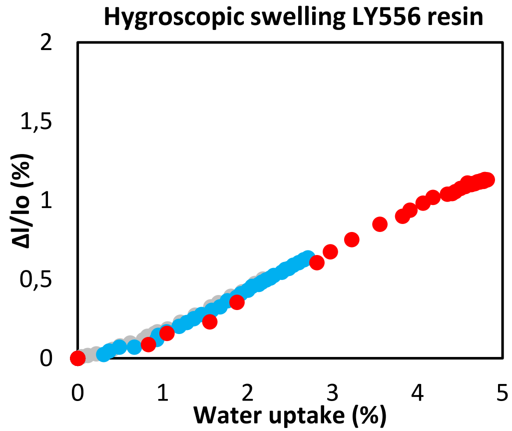
Hygroscopic swelling

- **Experimental test** : Measurement of the longitudinal strain in accordance with the global water uptake content.
- Predict **internal stresses** due to water absorption.



Laser swelling measurement device





- Immersion 60˚C
- Immersion 25˚C
- Humid air 40˚C & 85% RH

➢ **Same swelling behaviour** regardless the **hygro-thermometric** condition

➢ **Temperature** only **accelerates** the **diffusion** phenomenon and thus the **hygroscopic swelling**

➢ **Linear** identification for $\boldsymbol{\beta_h}$

Hygroscopic swelling coefficient β_h (neat resin)

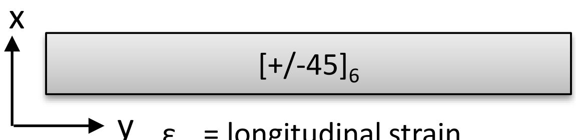
	25°C	60°C	40°C / 85%HR
β_h (avg) %	0,20	0,24	0,22

$$\varepsilon_h = \beta_h \cdot c(x,t)$$

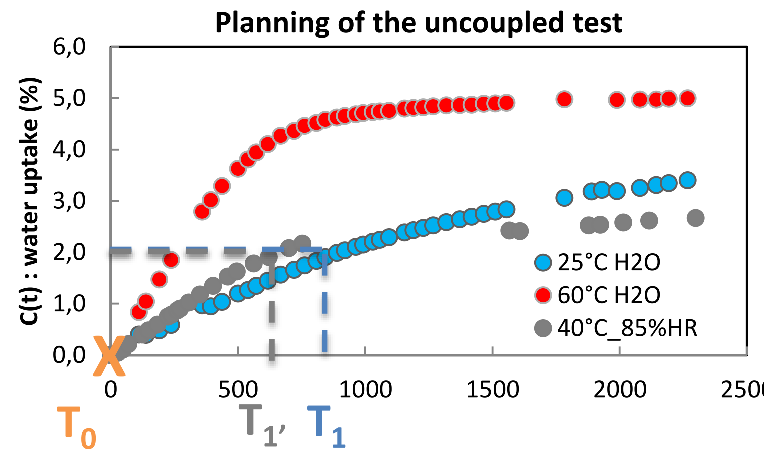
Uncoupled test: ex-situ test at different ageing states
Coupled test: in-situ test during ageing

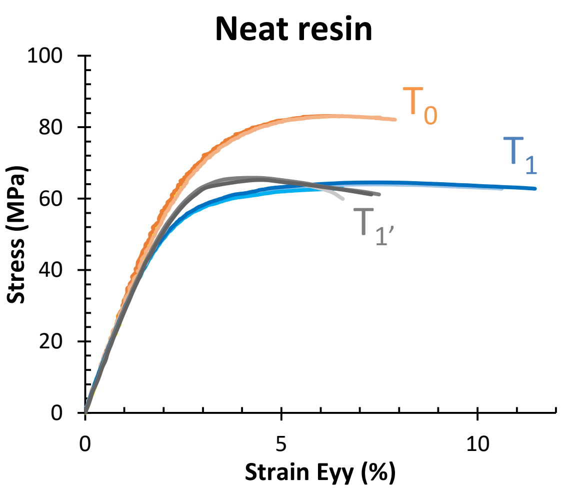
Tensile tests

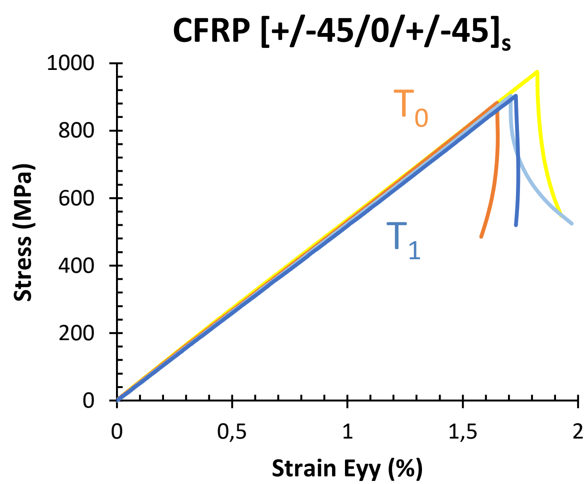
- Evolution of **mechanical properties** versus **global/local water content**
- Analysis of the **sensitivity** of the different **stacking sequences** towards **humid ageing**

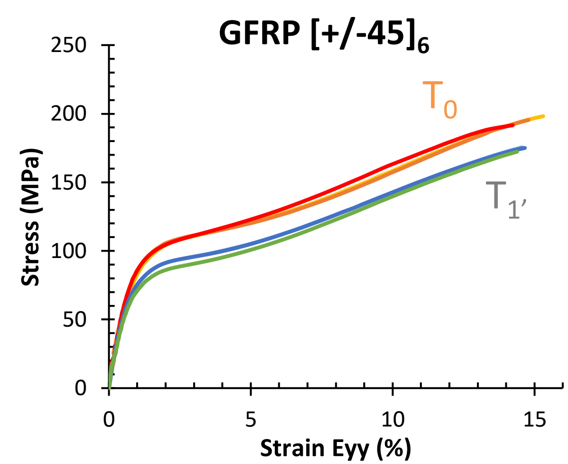


ε_{yy} = longitudinal strain

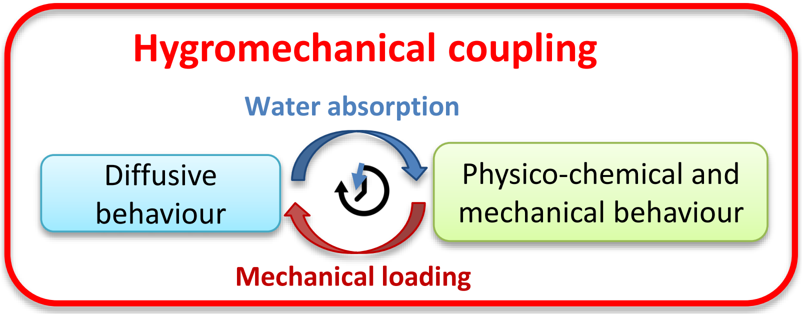








<u>Objectives</u>: perform **numerical** and **experimental** tests that take into account the **diffusive** and **mechanical** behaviour at the same time



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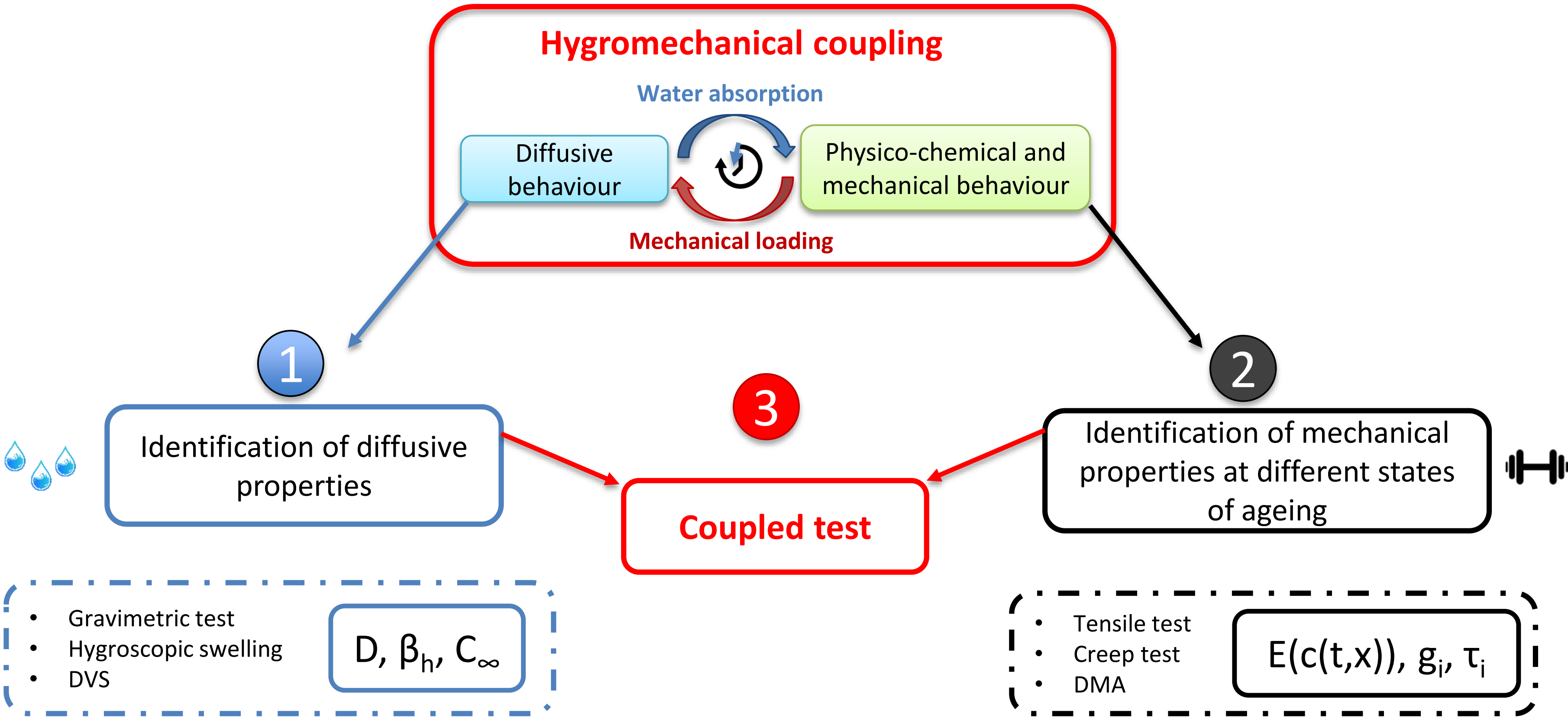


Diffusive behaviour and mechanical states

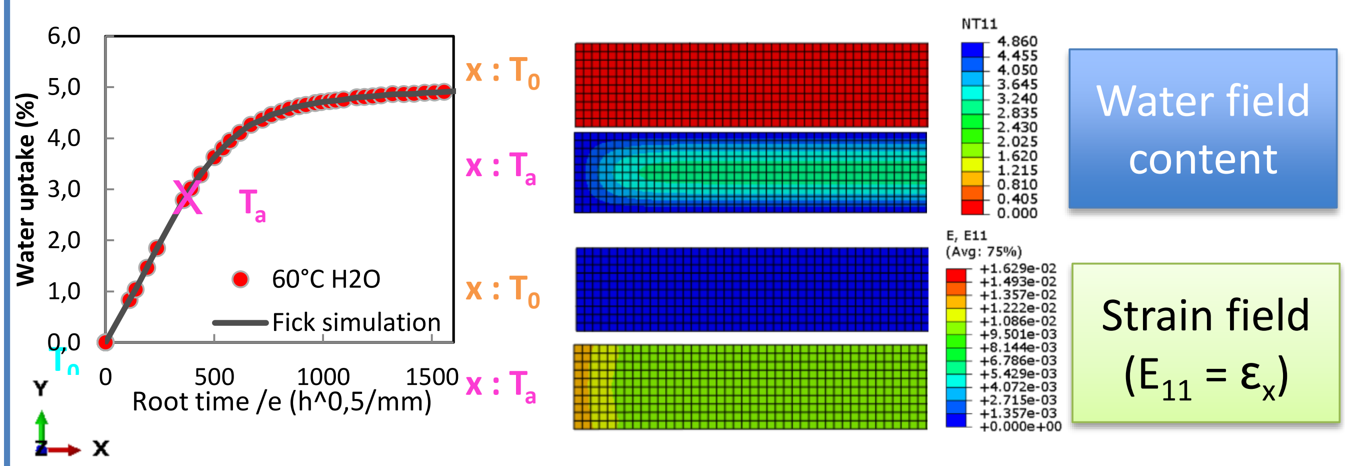
- Numerical simulation based on a **Fick law** for the **diffusive behaviour**
- **Mechanical states** obtained with an **uncoupled elastic model**
- Simulation performed with **Abaqus©**

Physical parameter inputs

Diffusion
- D = 5.07E-13 m²/s
- **C_inf = 4.95 % (BC)**
- T_a = 115 days

Elasticity
- E: 3,39 GPa
- v: 0.35
- **β_h = 0.2%**

Water diffusion & hygroscopic swelling associated without mechanical loading



Viscoelastic behaviour

- Add of **viscoelastic constitutive equations** with generalized Maxwell model through **Prony series**, identified with experimental **creep data**

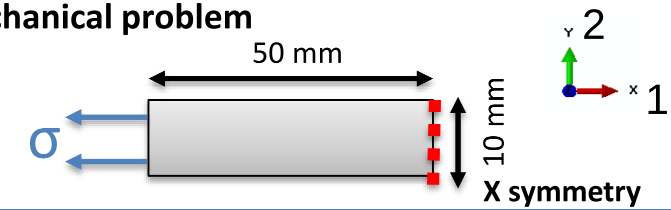
Viscoelastic model

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

Mechanical problem

__Creep test__

- 3 steps (1h creep / 3h relaxation)
- 5 / 7.5 / 10 MPa
- Elastic domain = no plasticity



Physical parameter inputs

__Elasticity__

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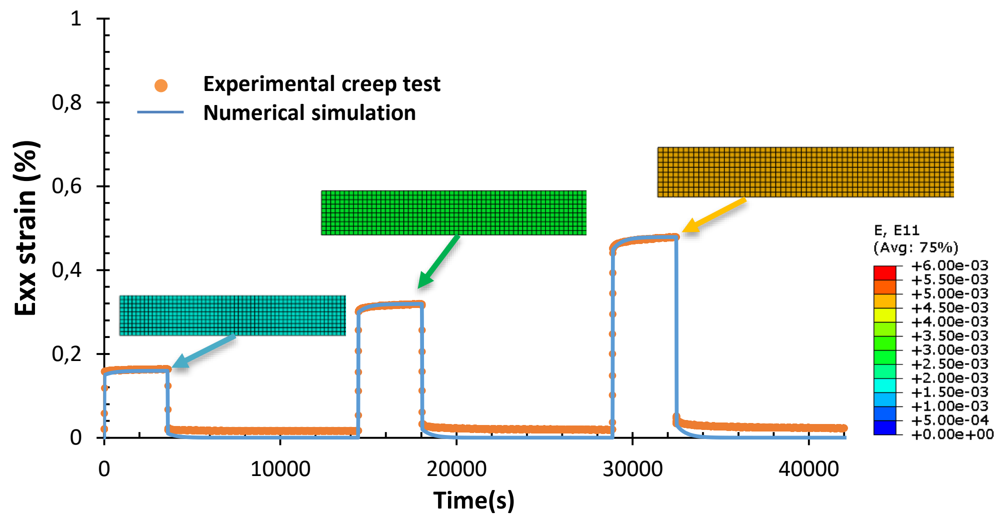
__Viscoelasticity__

g_1 = 0.001 **τ_1=100**

g_2 = 0.08 **τ_2=500**

Results

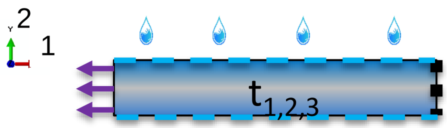


Discussion

- Uniform strain field
- Good accordance with creep data

Hygro-viscoelastic behaviour

➢ Creep simulation with hygroscopic strain due to water uptake



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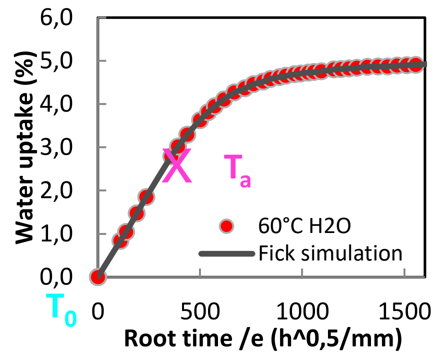
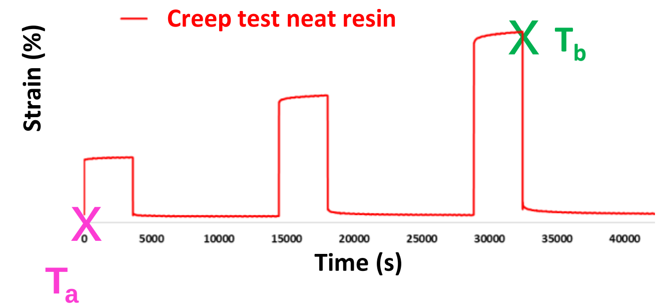
Creep test associated with water diffusion (at T_a for diffusion and T_a + T_b for creep test)





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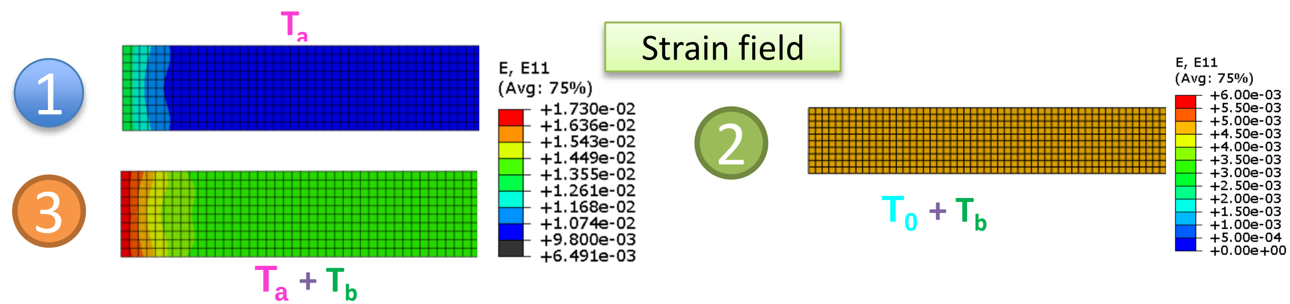

1) Strain induced by water diffusion only
2) Homogeneous strain field for creep only
3) Strain field resulting from creep + water diffusion

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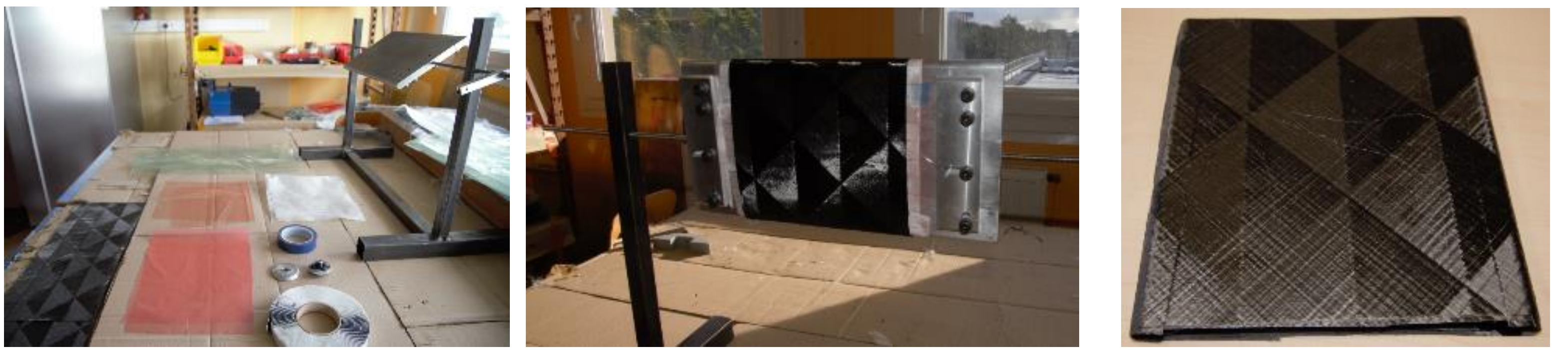
- **Objective:** perform **creep tests** in **humid environment** (immersion/humid air) during a long period of time (> week) so that diffusion can affect the overall mechanical behaviour.

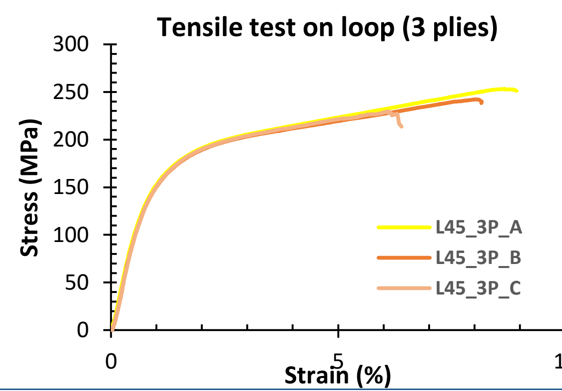
- Manufacturing of specific samples called « **loop** » - *Meier et al.(2001)*

Manufacturing process of loop samples



- Advantages:
  - Avoid slipping in grips
  - Easy to remove from creep bench

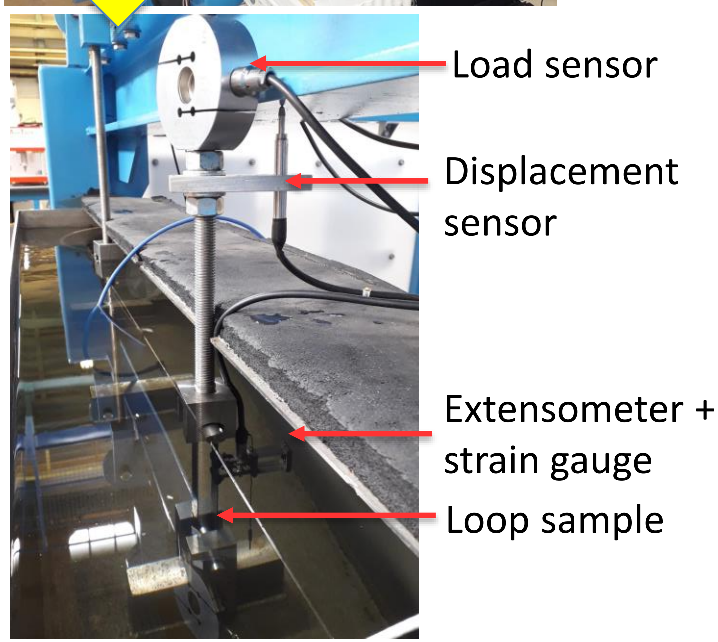
- Process: CFRP Prepreg $[+/-45]_3$



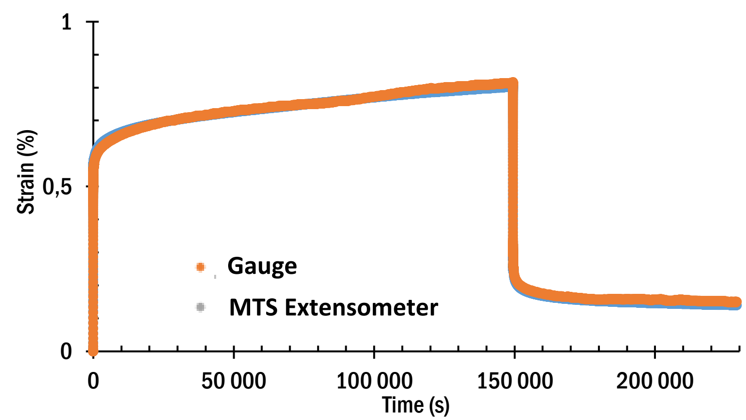
Acknowledgments to Prof. P. Casari

Design brief

- Follow the strain evolution during a creep test in humid condition
- Possibility of testing up to 5 samples with different loads at the same time



Creep test (air) for 41h, 1500N on **loop sample** [+/-45]$_3$



Following in situ creep test…

Conclusion

Experimental

- An experimental procedure to study **hygromechanical coupling** has been set up.
- **Uncoupled test** have been realized and showed evolution of some properties after less than 6 months

Modelling and simulation

- A **viscoelastic Maxwell** model combined with hygro-elastic properties was used to simulate a creep test in hygro-elasticity

Ongoing work

Experimental

- Perform uncoupled tests at **further ageing states**
- Carry out **coupled creep test** (right now)

Modelling and simulation

- Introducing a **dependency to ageing** for elastic and viscoelastic properties

Thanks for your attention and take care

quentin.dezulier@univ-nantes.fr

Quentin DEZULIER

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This work was carried out within the framework of the WEAMEC, West Atlantic Marine Energy Community, and with funding from the CARENE