POLYTECH NANTES

École d'Ingénieurs de l'université de Nantes

LTEN UMR 6607

LABORATOIRE DE THERMIQUE ET ÉNERGIE DE NANTES

Composite Forming
Characterization of thermophysical properties
2022-2023

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Coupling

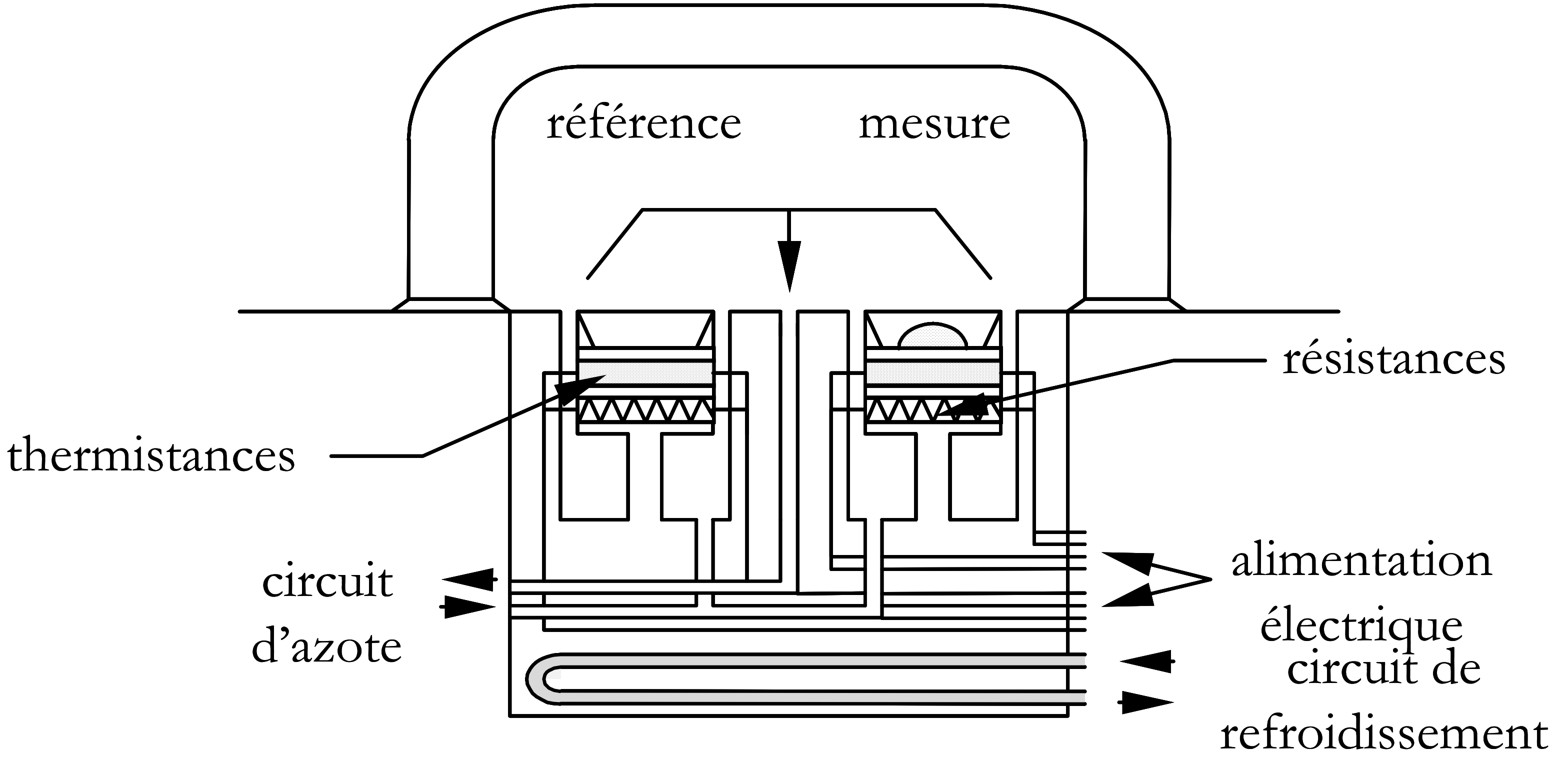
Heat transfer ⟷ **Chemistry**

$$(\rho_c Cp_c)\frac{\partial T}{\partial t} = \vec{\nabla}\cdot\left(\overline{\overline{\lambda_c}}\,\vec{\nabla T}\right) + (1-\phi)\rho_r \Delta H \frac{\partial \alpha}{\partial t}$$

$$\frac{\partial \alpha}{\partial t} = f(\alpha, T)$$

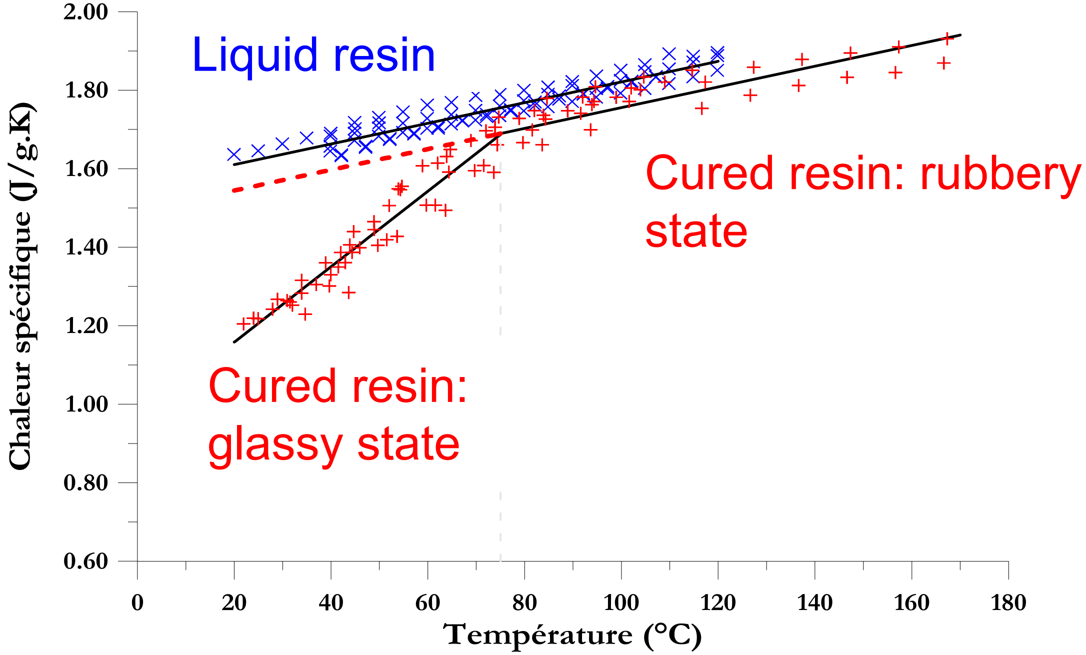
Parameters to determine ?

Differential Scanning Calorimeter



Thermophysical properties

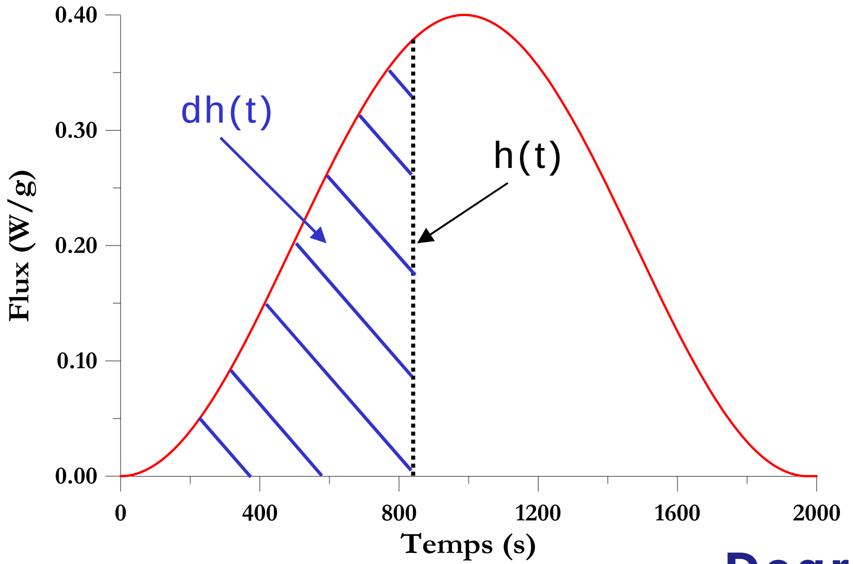
Example of Cp for a polyester resin

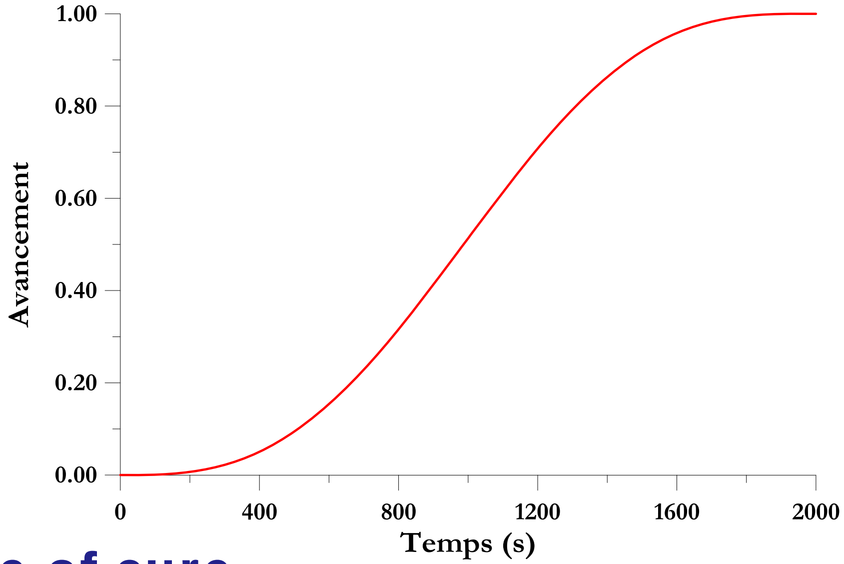


Dans ce cas, utilisation d'une DSC → facile…

$$Cp_{\text{résine}}(\alpha, T) = \alpha Cp_{\text{résine Caoutchoutique}}(1, T) + (1-\alpha) Cp_{\text{résine}}(0, T)$$

Crosslinking kinetics





Total enthalpy

$$\Delta H = \int \phi(t)dt$$

Degree of cure

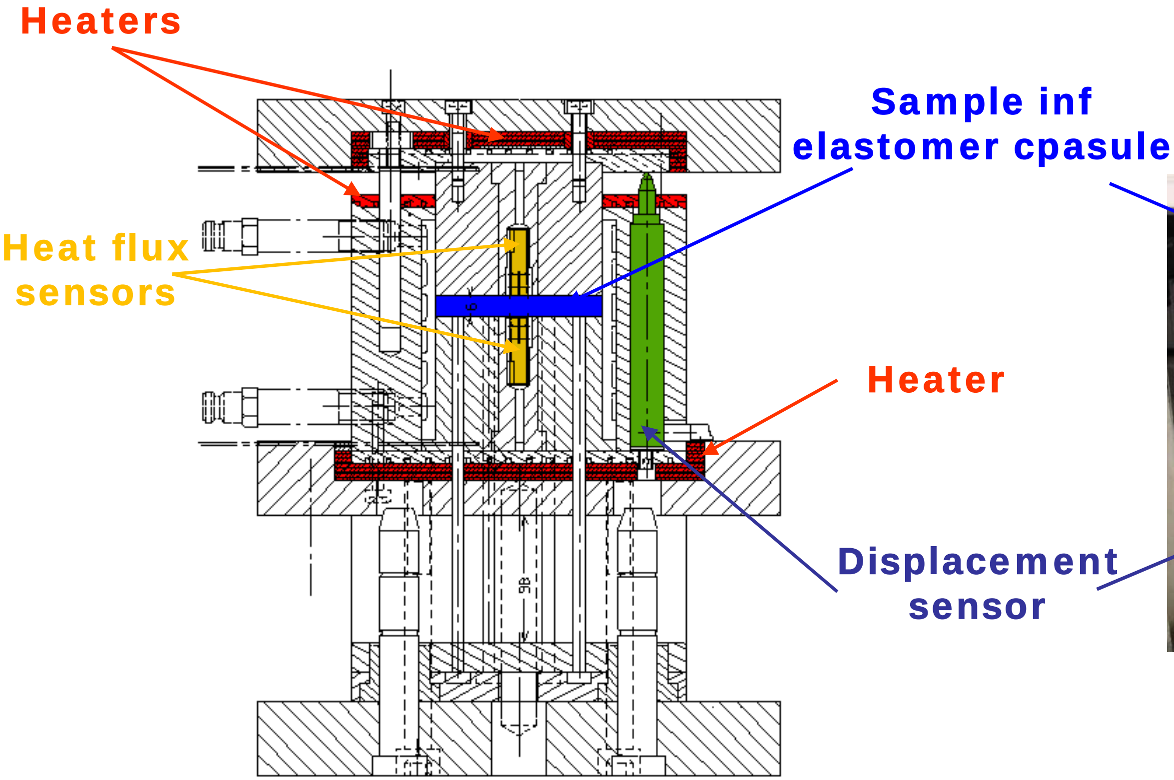
$$\alpha(t) = \int_0^{t_{max}} \frac{\partial \alpha}{\partial t} dt = \frac{dh(t)}{\Delta H}$$

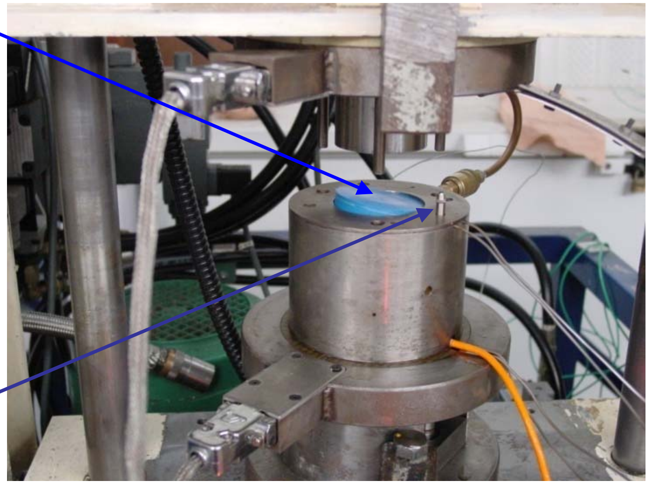
$$0 \leq \alpha \leq 1$$

Kinetics

$$\frac{\partial \alpha}{\partial t} = \frac{h(t)}{\Delta H}$$

Density: Thermal expansion and chemical shrinkage measurement





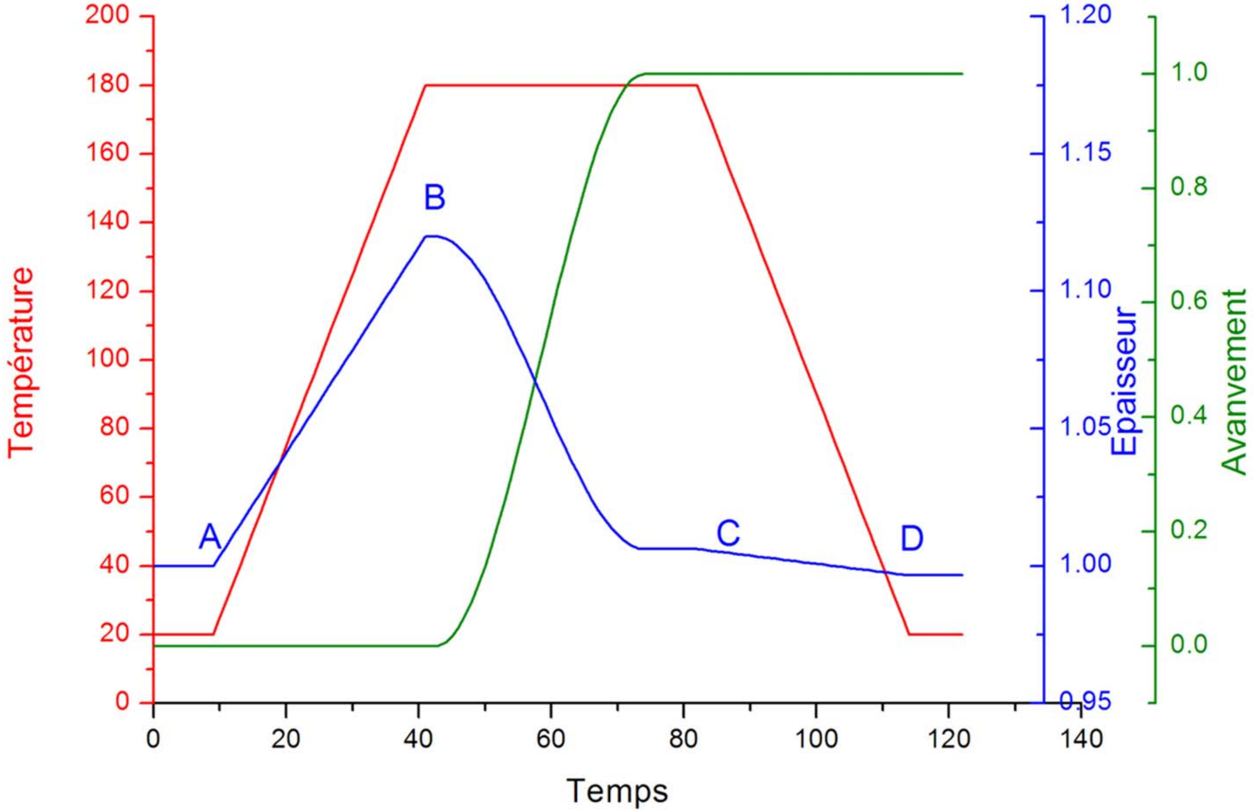
This apparatus allows to control:

- Pressure (P)
- Temperature (T)

It allows the simultaneous measurement of

- Volume (V)
- Degree of cure (α)

Volume modelling



Explanation of curves ?

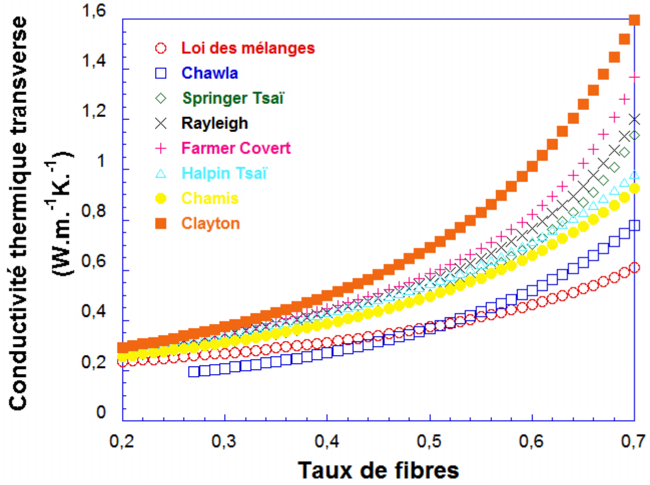
Thermophysical properties

Analytical models

$$Cp_{\text{composite}}(\alpha,T) = XCp_{\text{matrice}}(\alpha,T) + (1-X)Cp_{\text{fibre}}(T) \Rightarrow \text{ok}$$

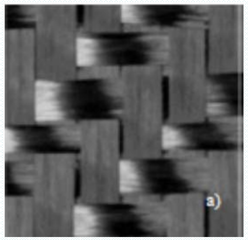
$$\rho_{\text{composite}}(\alpha,T) = (1-\tau_f)\rho_{\text{matrice}}(\alpha,T) + \tau_f \rho_{\text{fibre}}(T) \Rightarrow \text{ok}$$

Thermal conductivity

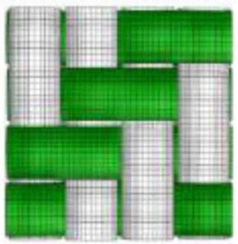


Numerical models

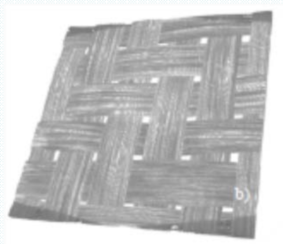
Hexcel G0986®, Carbon twill



Real structure



Numerical model



Tomography

Naour et al., Key Engineering Materials, Vols. 611-612 (2014), pp 316-323

→Require to characterize the structure

Experimental characterization

Thermal conductivity measurement

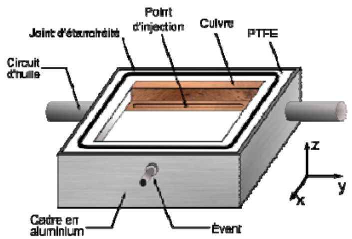
$$\bar{\bar{\lambda}} = \begin{bmatrix} \lambda_x & 0 & 0 \\ 0 & \lambda_y & 0 \\ 0 & 0 & \lambda_z \end{bmatrix}$$

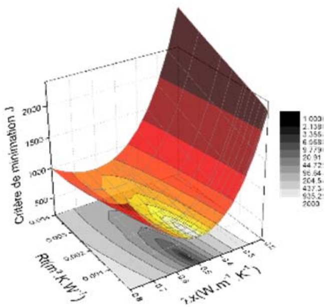
Dépends on

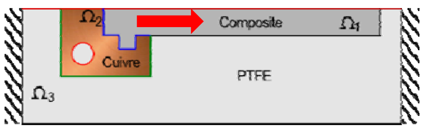
- State of the material: dry preform, impregnated preform, cured composite
- Structure of the preform: compressibility, shearing
- Temperature

Démarche: sollicitation thermique et mesure de la réponse

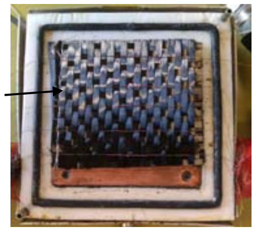
1D method: λ_x

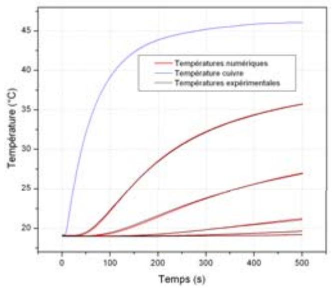






thermocouples

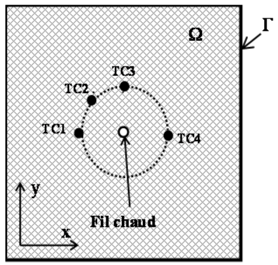




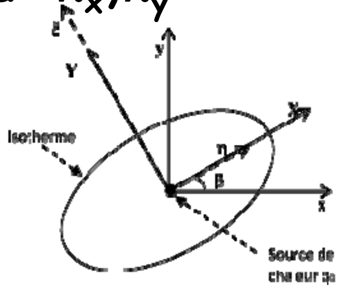
→ Allows the consolidation of the composite in situ

2D method: λ_x, λ_y

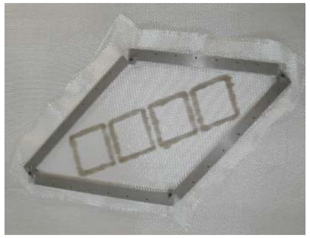
Hot wire method

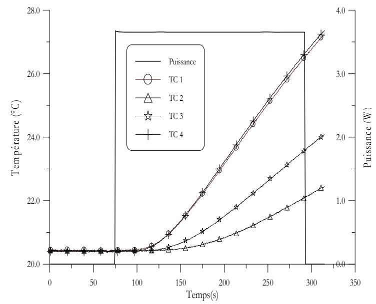


½ ∞



Ex.: renfort sec cisaillé





→Identification of main directions

Time consuming methods