

# Mise en œuvre de composites thermoplastiques. *Méthodologie de caractérisation de la déconsolidation et de l'adhésion.*

Arthur Levy  
[arthur.levy@univ-nantes.fr](mailto:arthur.levy@univ-nantes.fr)

# Arthur Levy

Grew up in Paris

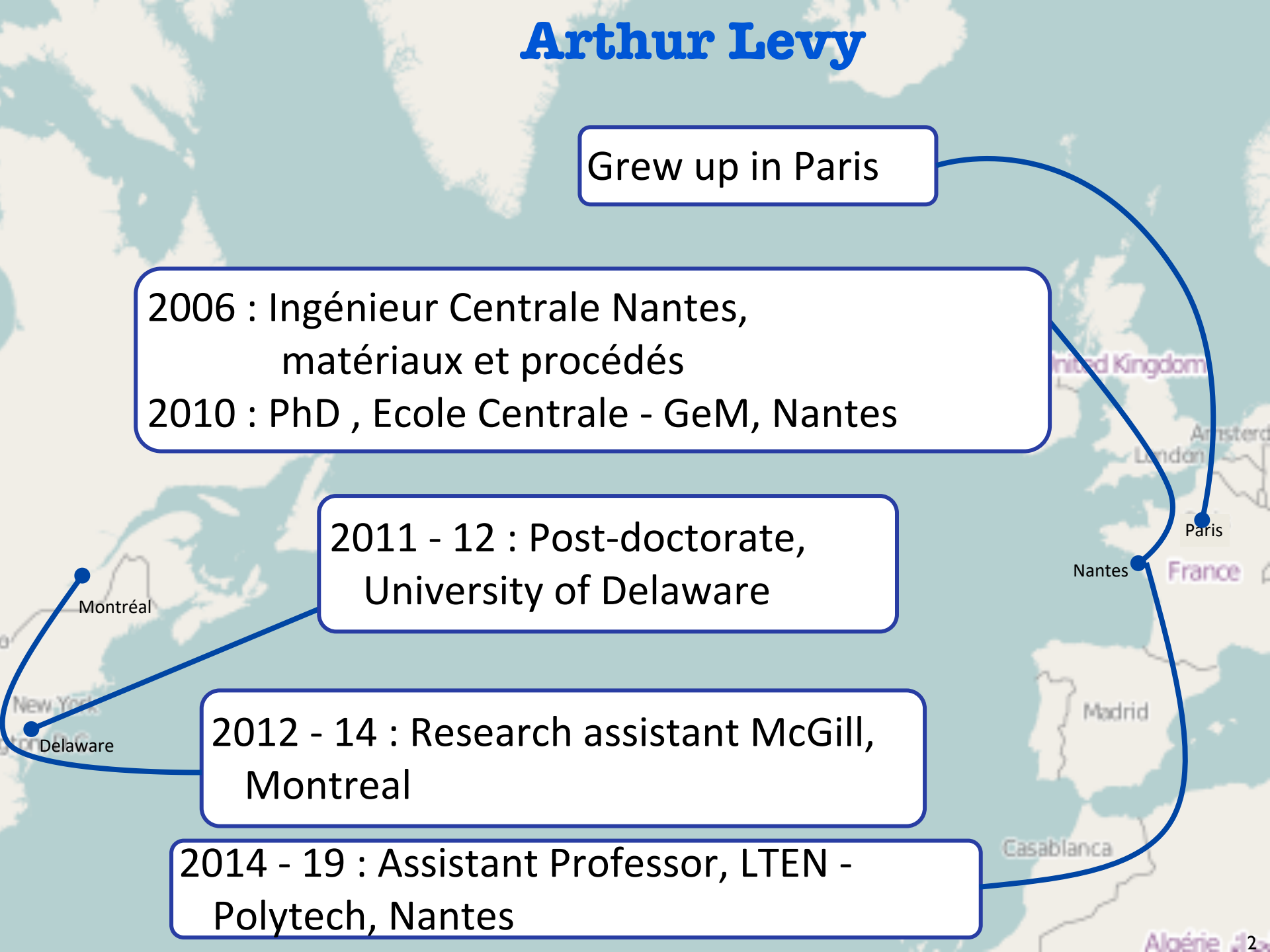
2006 : Ingénieur Centrale Nantes,  
matériaux et procédés

2010 : PhD , Ecole Centrale - GeM, Nantes

2011 - 12 : Post-doctorate,  
University of Delaware

2012 - 14 : Research assistant McGill,  
Montreal

2014 - 19 : Assistant Professor, LTEN -  
Polytech, Nantes



# Outline

- Nantes, France,
  - Nantes Université / Polytech
  - Laboratoire de Thermique et Energie de Nantes
  - Procédé polymères et composites
- Composite manufacturing
  - Deconsolidation
  - Adhesion



# Nantes

# Nantes (600 000 inhab.)

Région PAYS DE LA LOIRE

main campus



Chantrerie



# A Composite hub in France

## Industries

**AIRBUS**  
GROUP

**ARKEMA**  
INNOVATIVE CHEMISTRY

**DAHER**

**OP**  
PLASTIC OMNIUM

**SOLVAY**

**CORIOLIS**  
composites

PSA PEUGEOT CITROËN

## Academics

**Nantes**  
Université

**cnrs**  
Département de Nantes

**IMT Atlantique**  
Bretagne-Pays de la Loire  
Ecole Mines-Télécom

**CENTRALE**  
NANTES

**icam**

## Institutes

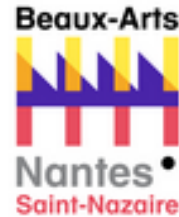
**IRT**  
JULES  
VERNE

**EMC2**

**Technocampus**  
Composites  
Innovative manufacturing for composite structures

# Nantes Université

Created in 2022.



Second biggest university in France by number of students.

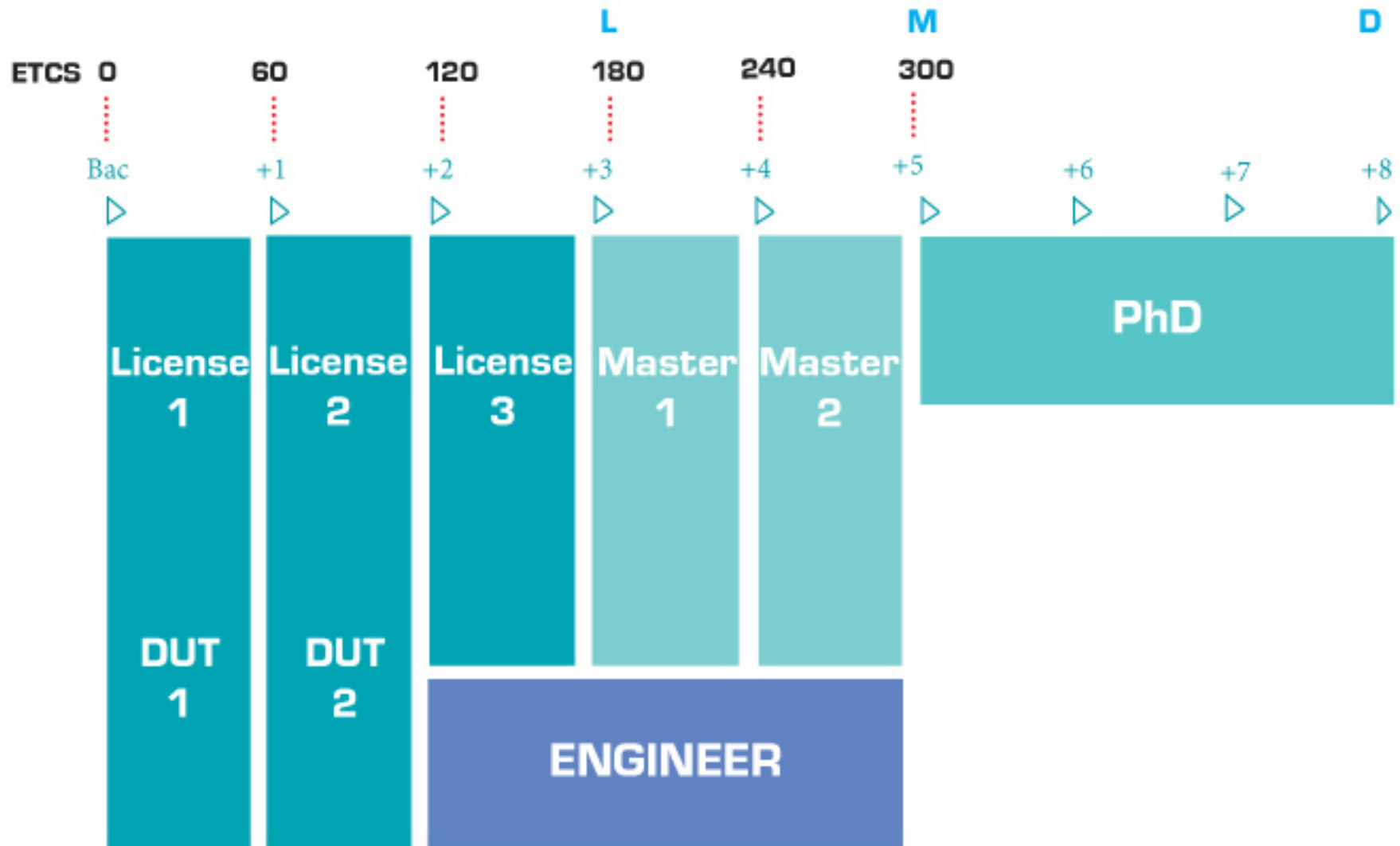
The largest University and second most important centre for research in the West of France.

# Nantes Université

- 43,000 students, including 5,000 international students (License - Master – Doctorate)
- 7,800 members of staff including:
  - 4,600 support staff and technicians
  - 3,257 lecturers, lecturer-researchers
- 20 faculties, schools or institutes
- 1,500 (approximately) PhD students
- 42 research structures



# Engineering Curriculum



# Polytech Network



## THE NETWORK OF FRENCH GRADUATE SCHOOLS OF ENGINEERING

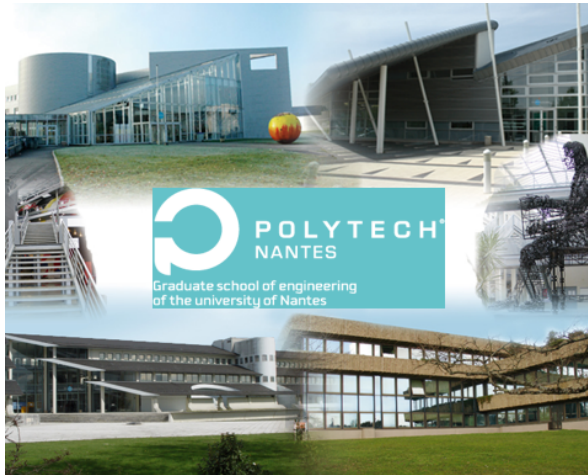
- **15** public graduate engineering faculties
- an alliance with **4** partners schools
- **12** different scientific fields
- **17 500** students
- **90 000** alumni
- **100** partner universities around the world
- **2 000** Masters and Ph.D students



POLYTECH®

[www.polytech-reseau.org](http://www.polytech-reseau.org)

# Polytech' Nantes



## 7 engineering specialities

ETN	Electronic and Digital Technologies
GC	Civil Engineering
GE	Electrical Engineering
GPB	Process and Bioprocess Engineering
INFO	Computer Science
MAT	Materials Sciences
TE	Thermal and Energy Sciences

400  
Graduates every year

1500  
Engineering  
students

250  
Master's and  
PhD students

7100  
Alumni

120  
Professors and  
assistants professors

+ joint degree ETS

# Laboratoire de Thermique et Energie de Nantes (LTEN)



~70 people



 Nantes  
Université





Transferts Thermiques dans les Matériaux et aux Interfaces

Transferts aux interfaces et dans les micro-systèmes

Transferts thermiques dans la mise en forme des polymères et composites

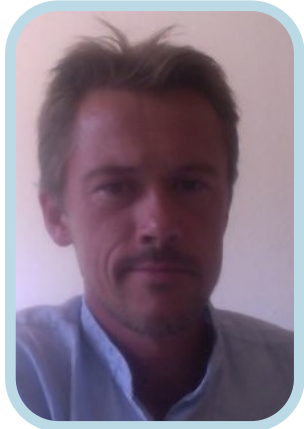
Caractérisation et fonctionnalisation des propriétés radiatives des matériaux

Transfert dans les Fluides et Systèmes Energétiques

Transferts dans les fluides et écoulements complexes

Transferts dans les Systèmes Energétiques

# Composite team



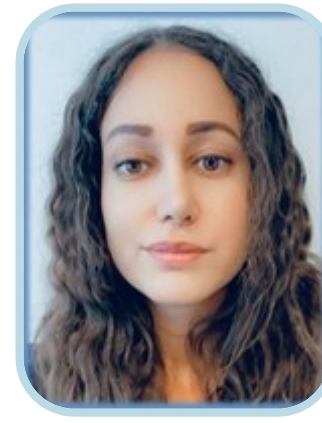
Steven Le Corre



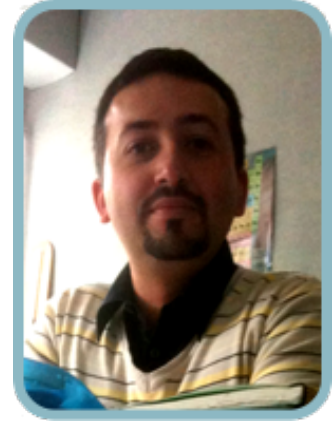
Jean-Luc Bailleul



Vincent Sobotka



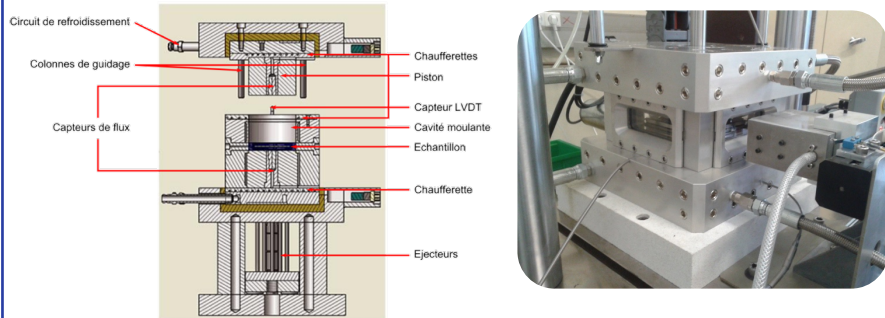
Elissa El Rassy



Nicolas Boyard

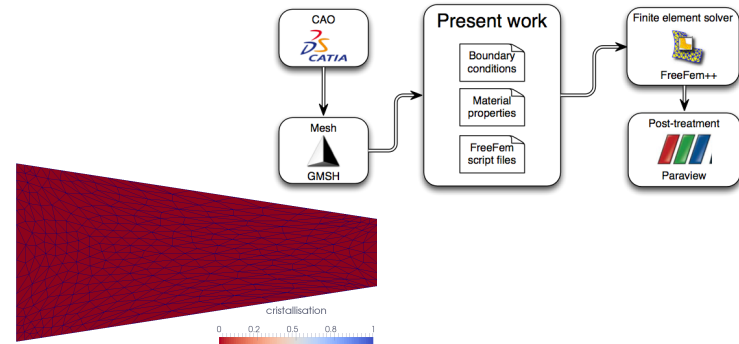
# LTEN expertise

## Characterization Under process conditions



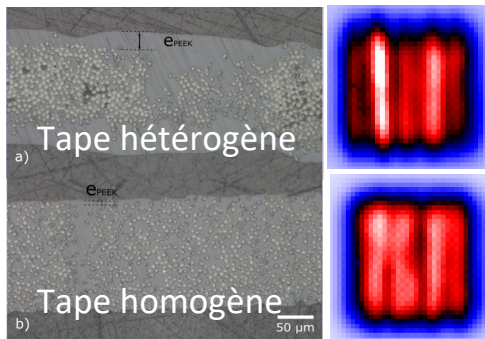
PVT series

## Simulation multiphysical

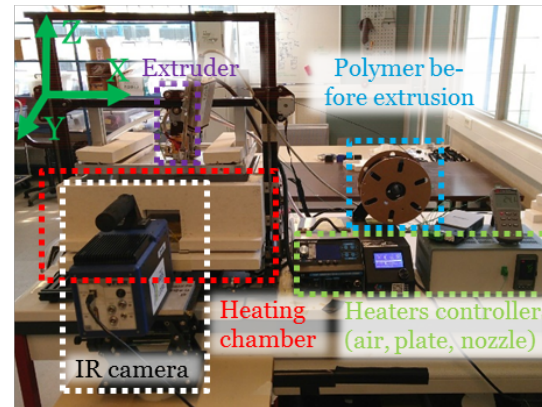


Thermoplastic solidification


## Instrumentation



AFP thermal study



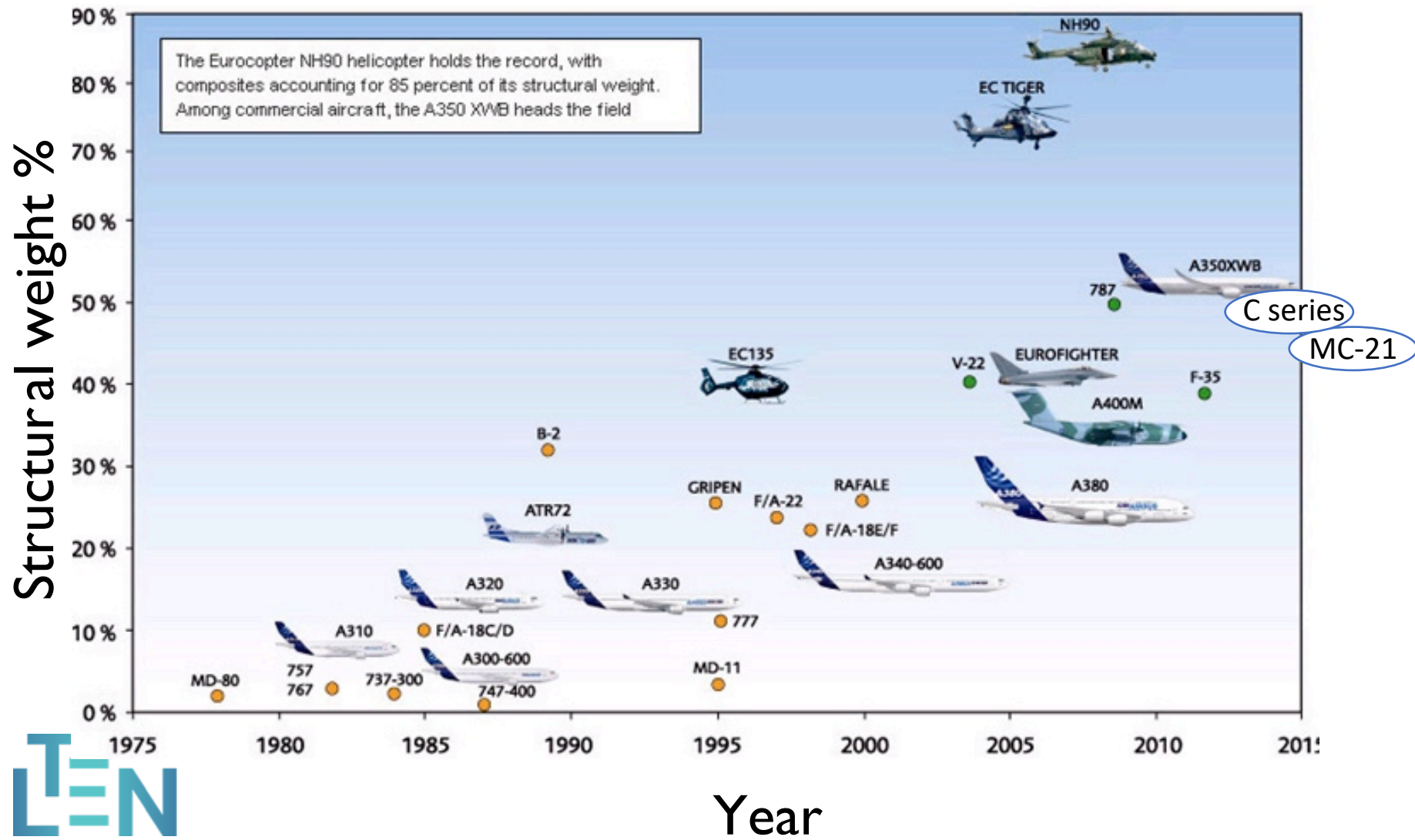
Instrumented 3D printer



# Composite manufacturing processes



# Composite use in aeronautical industry



# Today's challenges

## Increase part complexity



Pylone MATCH project



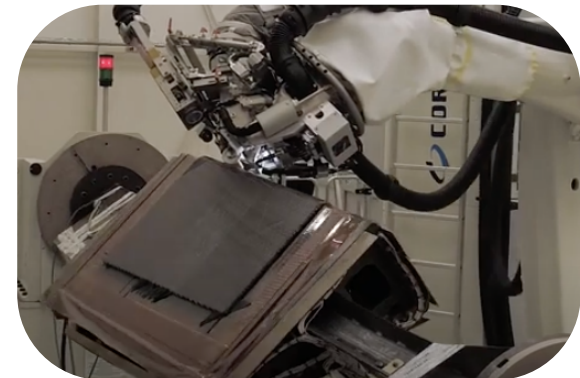
Boeing assembly line

- Intricate / thick parts
- Large parts
- Assembly

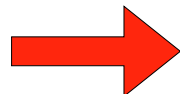
## Cheap / sustainable



[www.sabca.be](http://www.sabca.be)



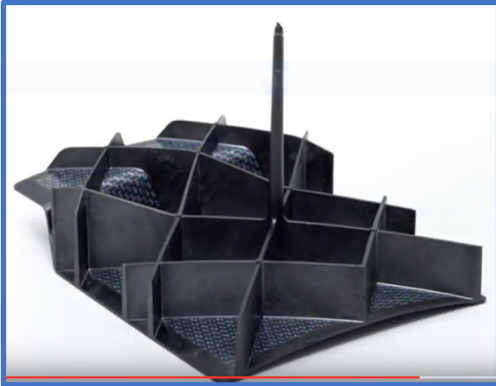
- Fast and efficient cycles
- Out-of-autoclave
- Defect free



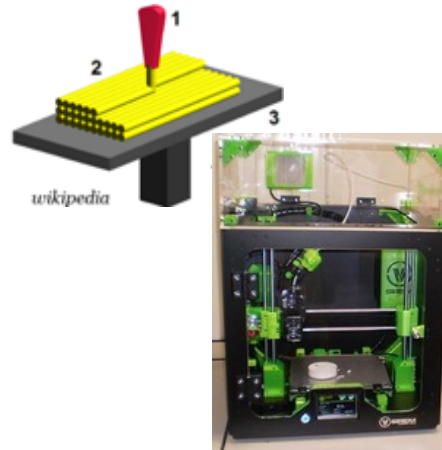
TP composites / robust forming processes

# TPC manufacturing processes

Overmoulding



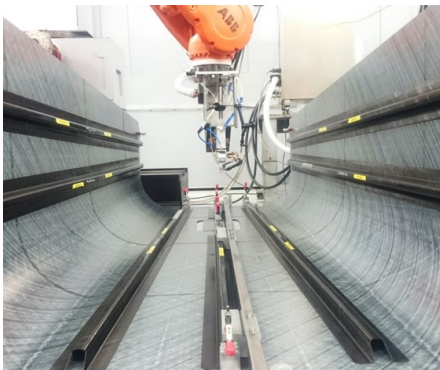
3D printing



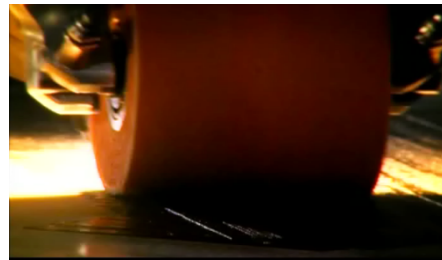
Thermo-compression



Induction welding



AFP



Thermo-stamping

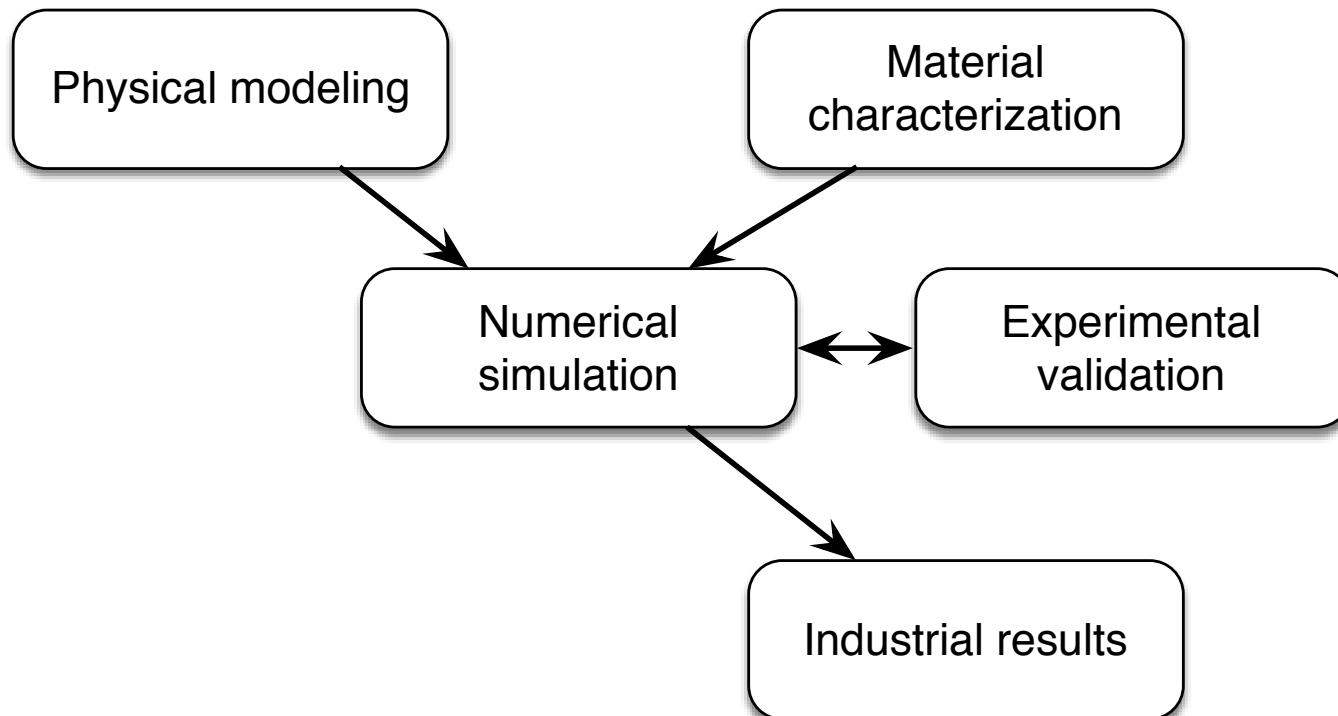


# Motivation

**Industrial goal:** control and optimize forming/assembling processes.

**Scientific aim :** develop predictive tools (simulation).

## Method:



# Outlines

Modelling and characterization of the leading phenomena during :

I – Deconsolidation

II - Adhesion

# I – Deconsolidation

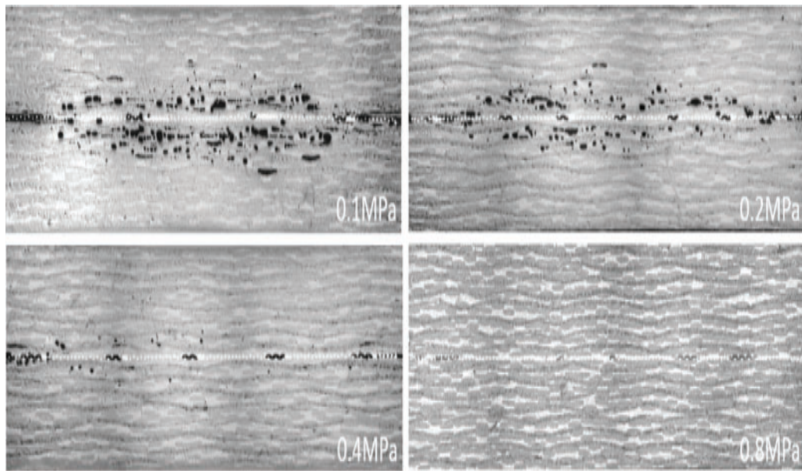


Luc Amedewovo, Arthur Levy, Steven Le Corre,  
Laurent Orgeas, Basile de Parscau



# Industrial context

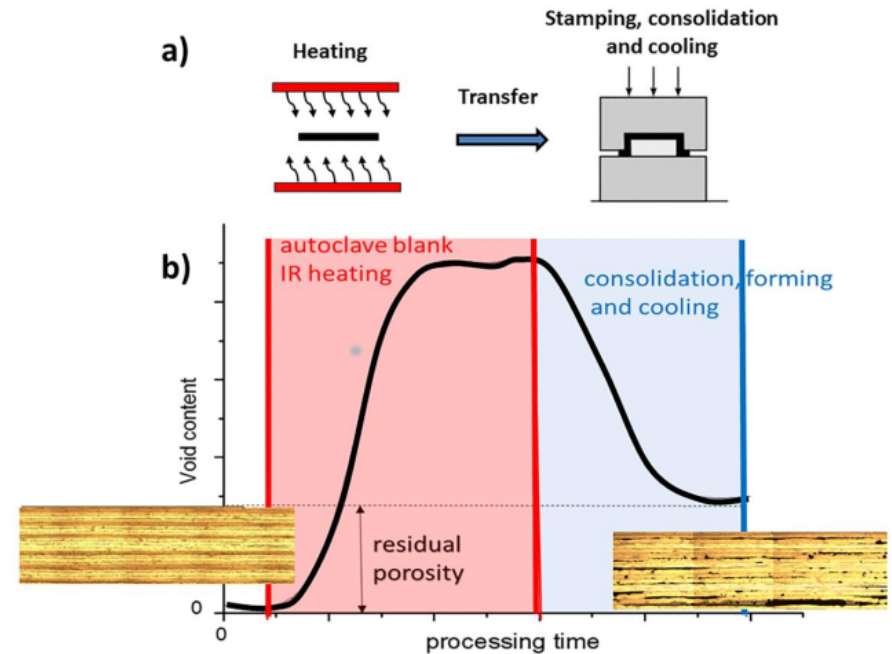
## GF / PEI resistance welding



GF/PEI resistance welding

[Shi et al. 16]

## Thermo stamping



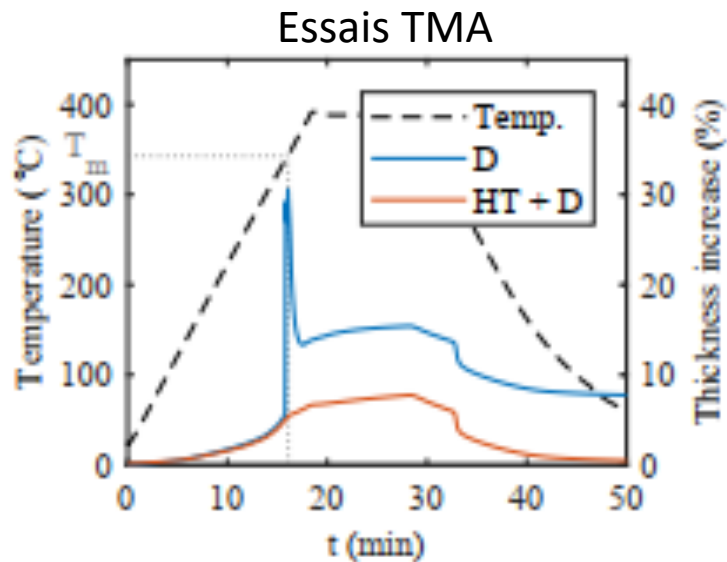
[Donnadei et al. 18]



Need for prediction and control

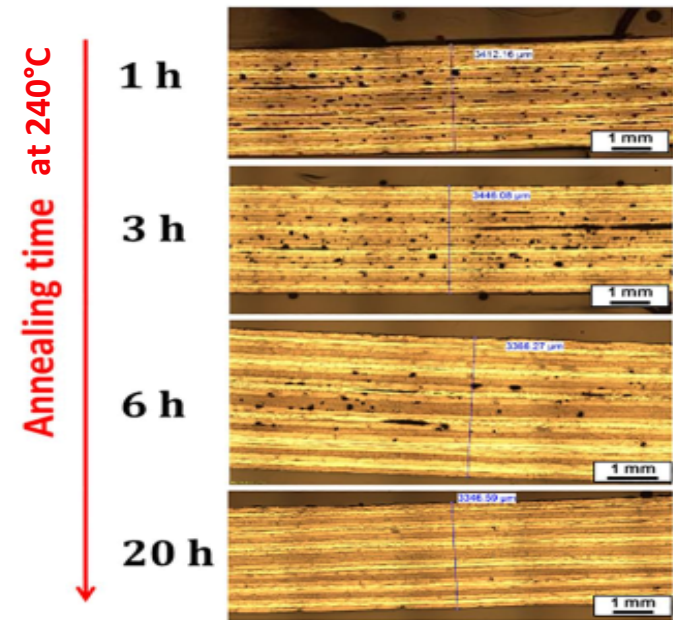
# State of the art hypothesis

## Moisture



[Slange et al. 18]

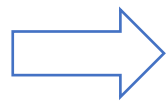
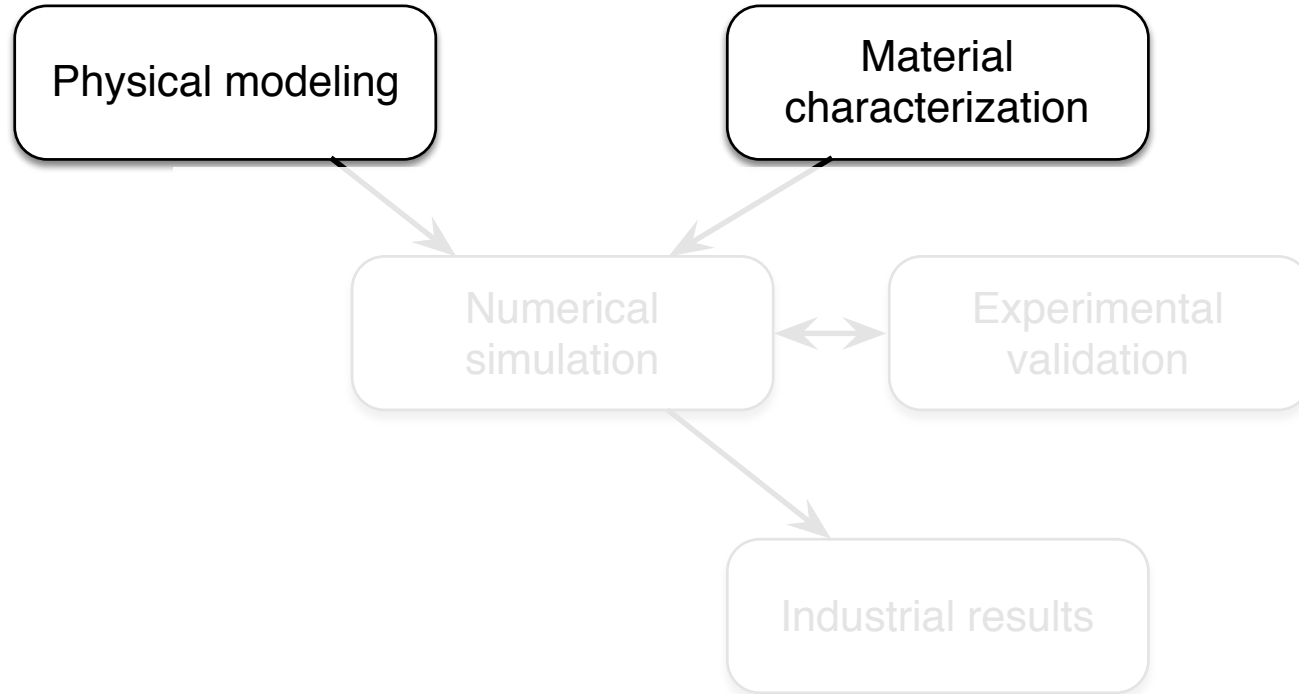
## Thermo-mechanics



[Donadei et al 18]



# Scientific approach



Development of a characterization bench under processing conditions

# Existing methods

## Post-process)

Thickness measurement (caliper)

Density measurement

Microscopy

Infrared thermography

Ultrasounds

Micro-tomography

## On line measurements

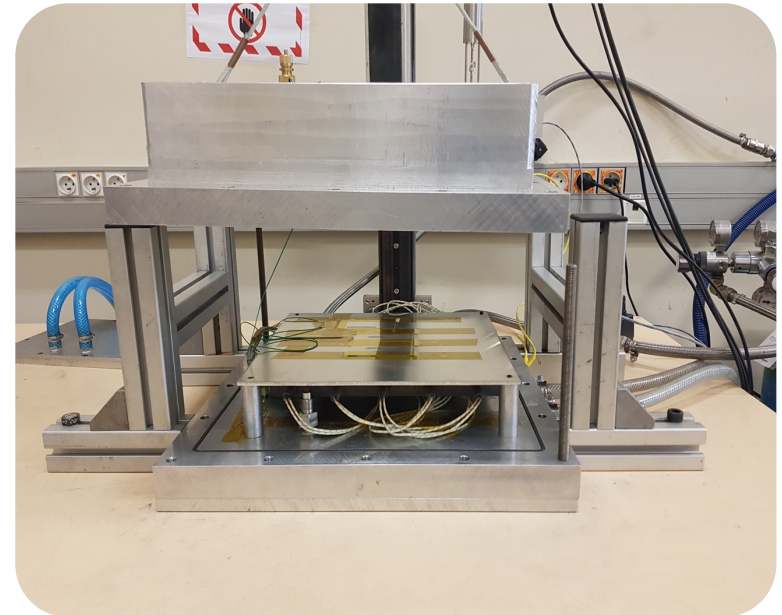
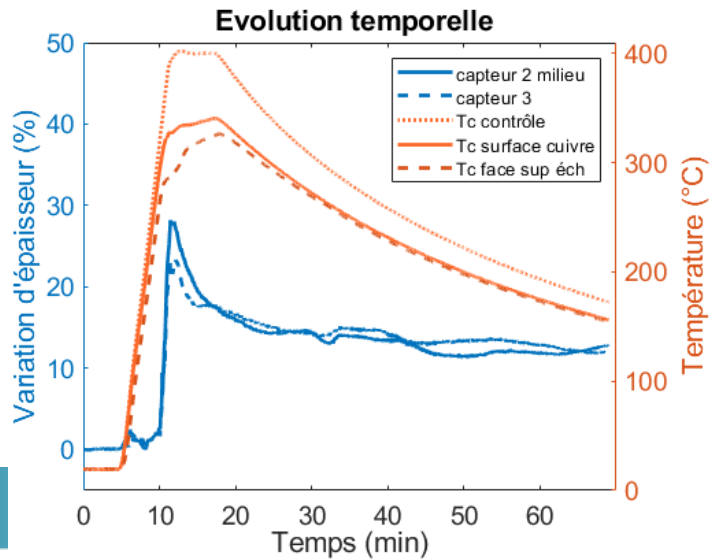
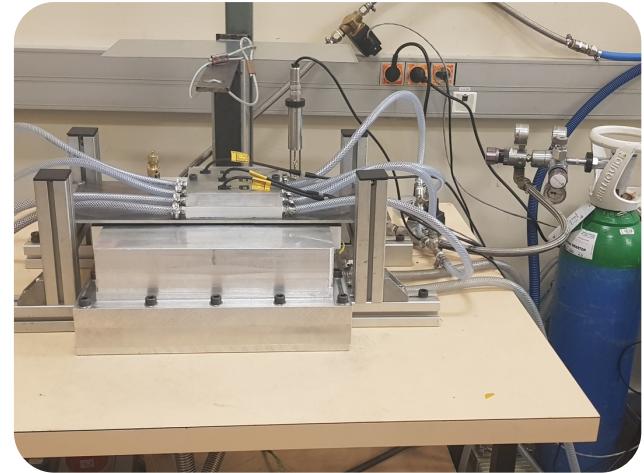
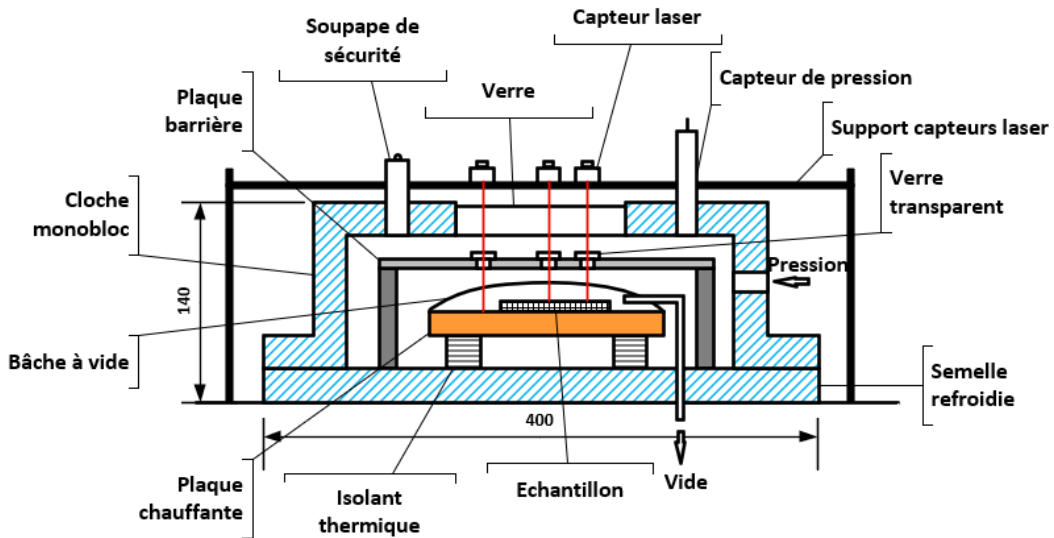
ThermoMechanical Analysis (TMA)

Optical measurement (image correlation)

# CODEC bench

[Amedewovo et al. 22]

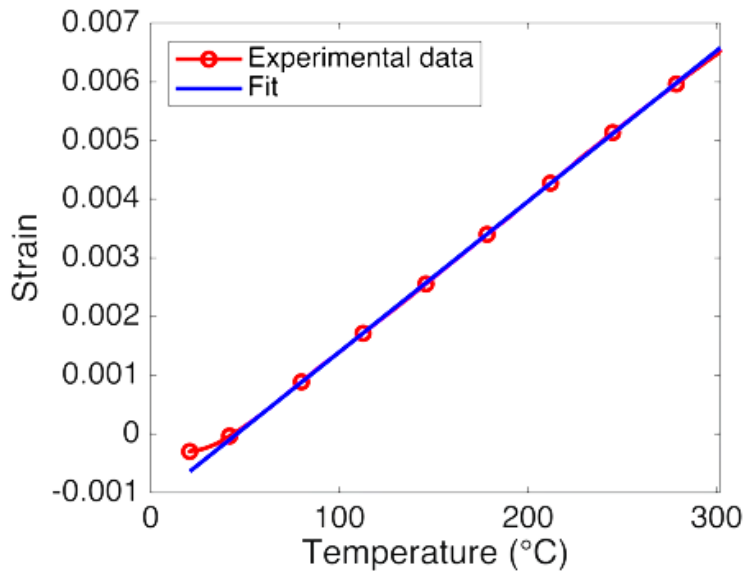
# CODEC bench



# Validation

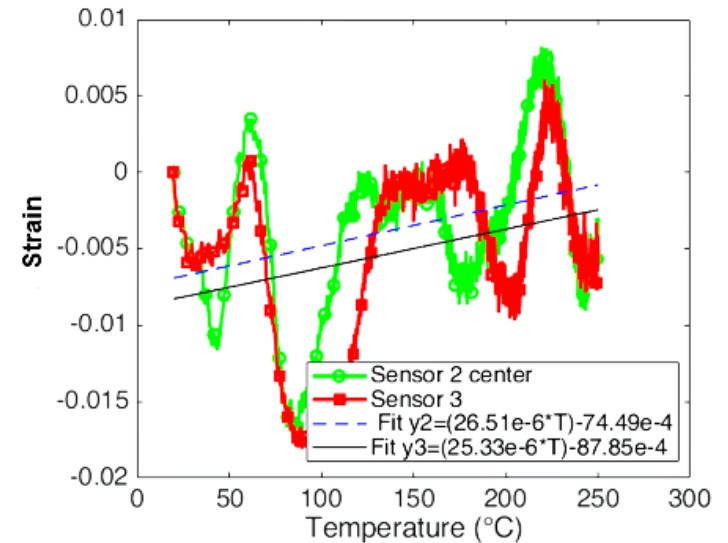
## Standard dilatometry

Sample size : 10 mm x 10 mm x 2,98 mm



## CODEC setup

Sample size : 125 mm x 25 mm x 2,98 mm



CODEC bench resolution :  $\pm 36 \mu\text{m}$

# First results

# Test procedure

## Material

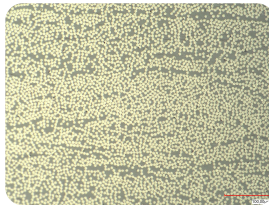
CF/PEKK (Toray Composites)  
348 \* 348 mm\*2,90 mm  
16 plis UD à 0°

## Consolidation

• Press



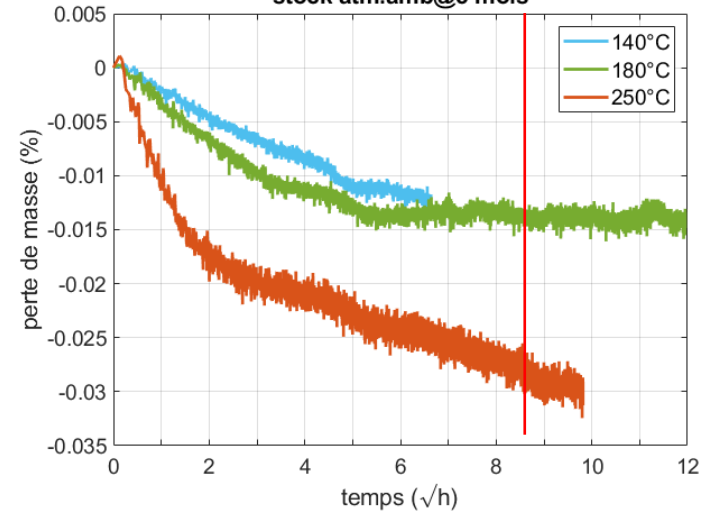
• Oven (VbO)



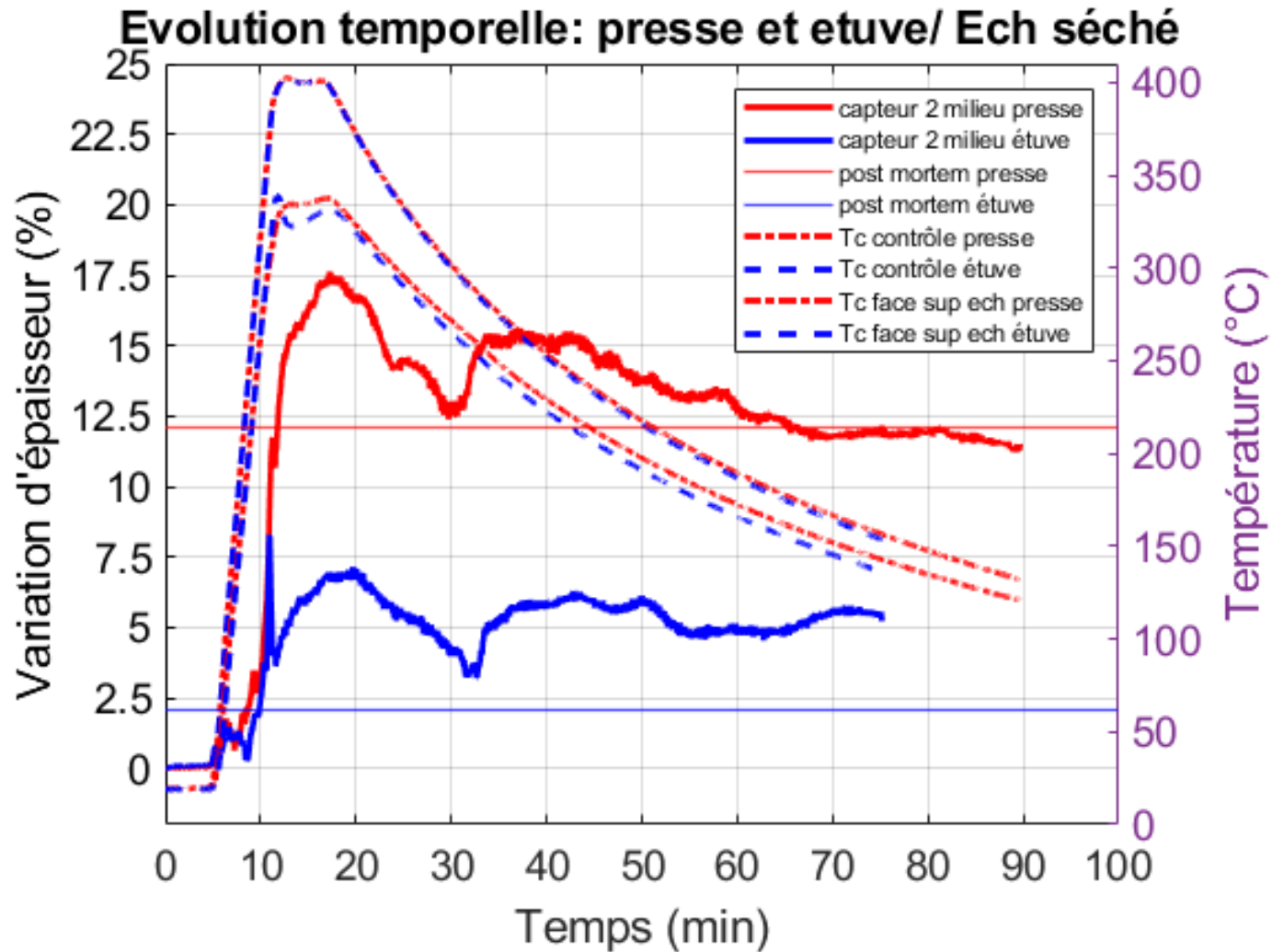
## Pre-conditionning

- Drying 180°C / 72h
- Ambient storage 5 months

courbe désorption sur des plaques de 80mm\*80mm\*16plis  
stock atm.amb@5 mois

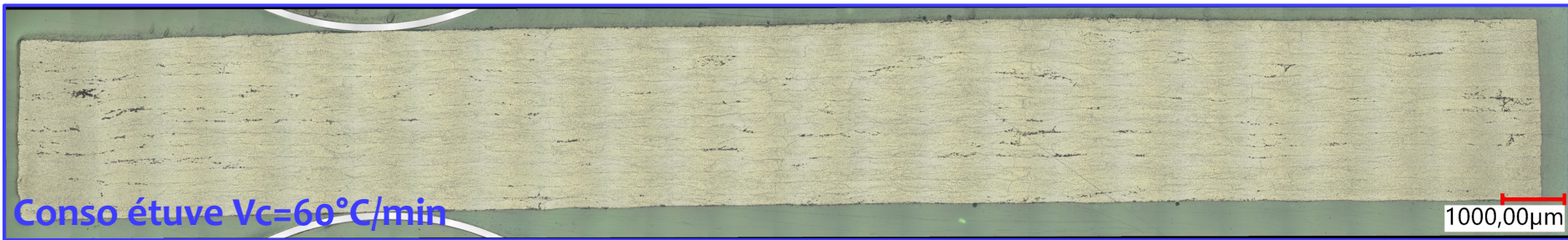
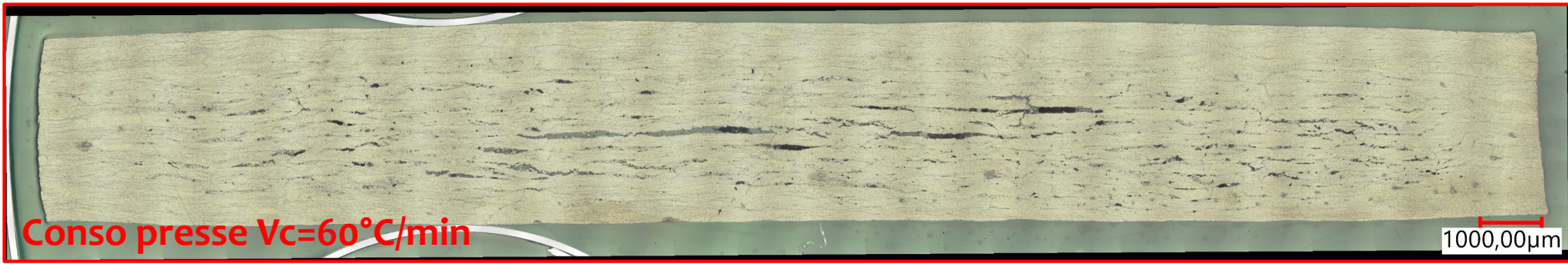


# Results press/oven

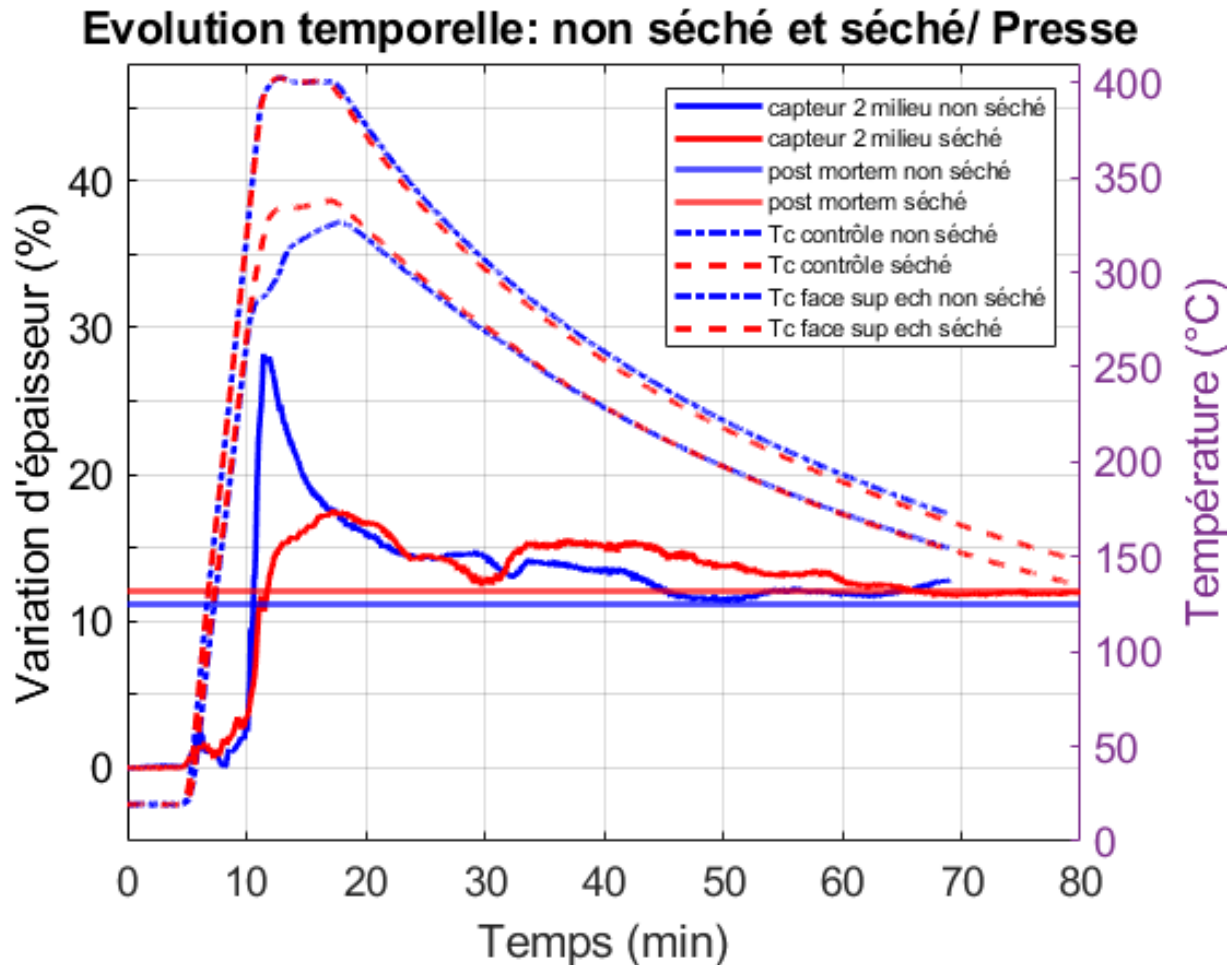




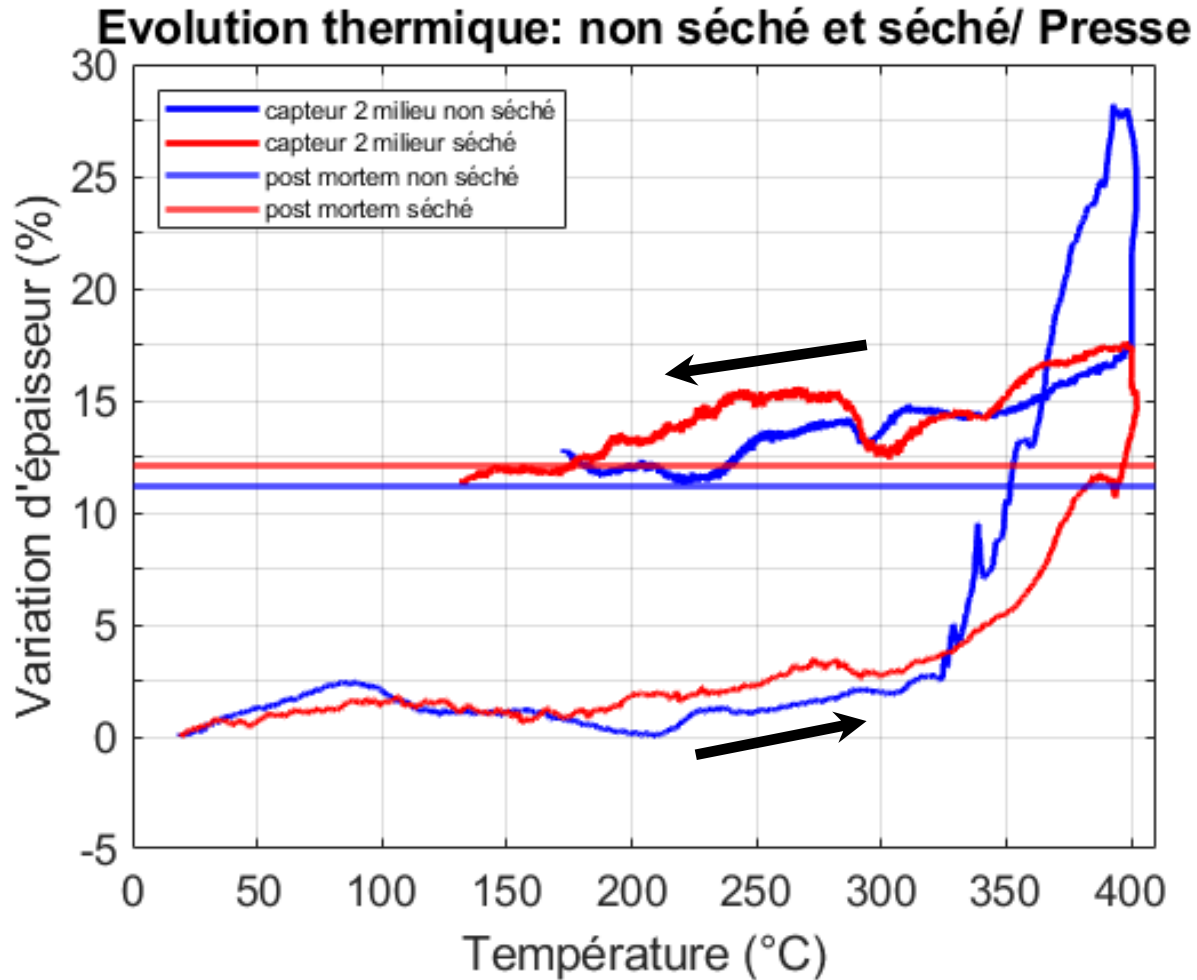
# Results press / oven



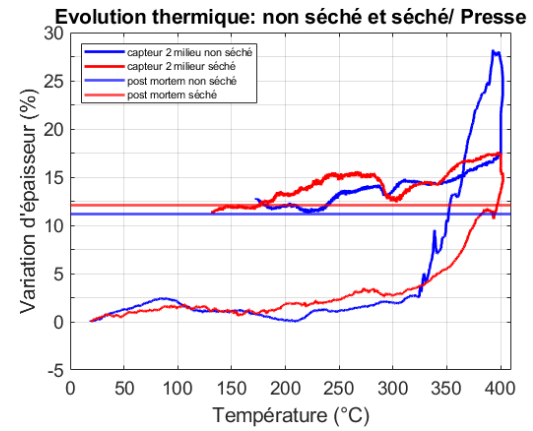
# Results dry/wet



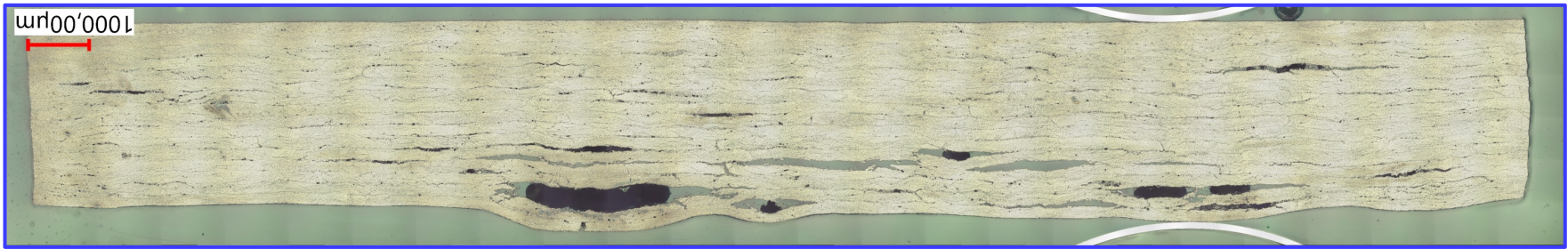
# Results dry/wet



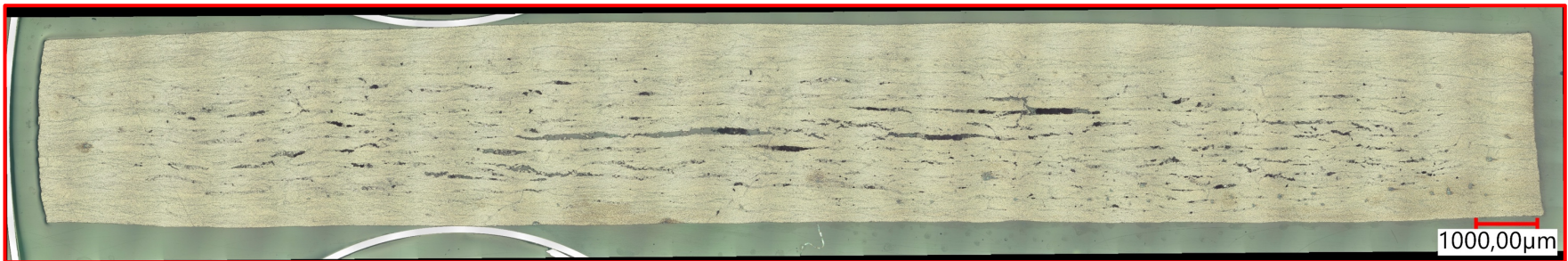
# Results dry/wet



Non séché Vc=60°C/min



Séché Vc=10°C/min



# Conclusion

## Development of CODEC

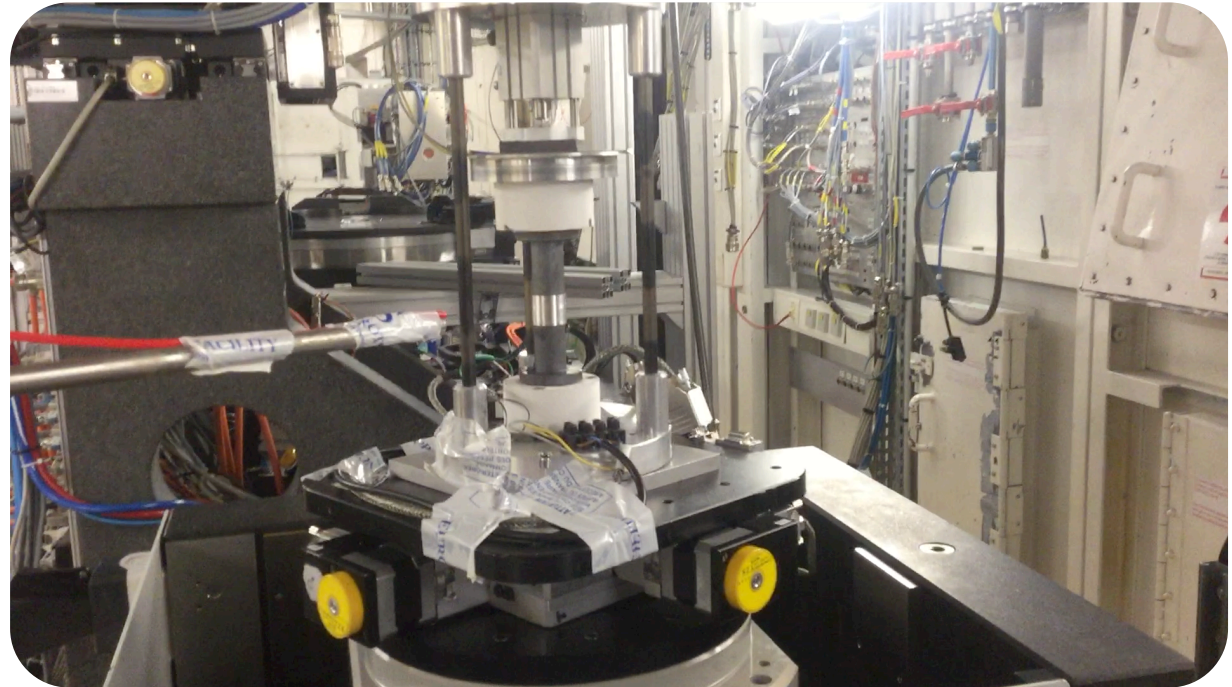
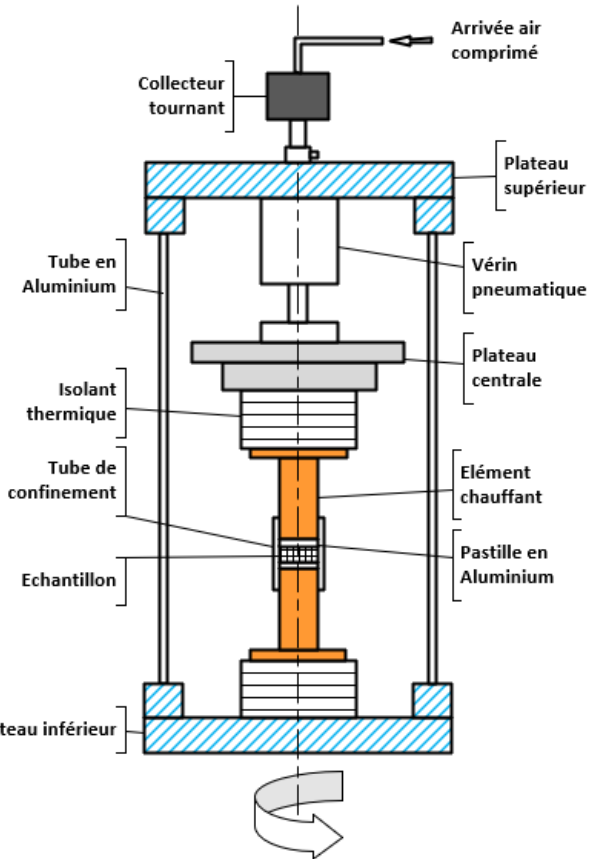
Lab scale deconsolidation  
Representative of manufacturing conditions  
In situ continuous measurement

## First results on Carbon/PAEK

Effect of moisture  
Effect of residual stress

# Ongoing work

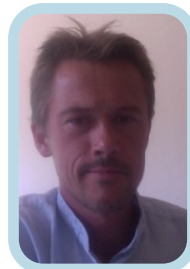
## In-situ observation in synchrotron (ESRF)



# II – Adhesion kinetics in thermoplastic composite manufacturing



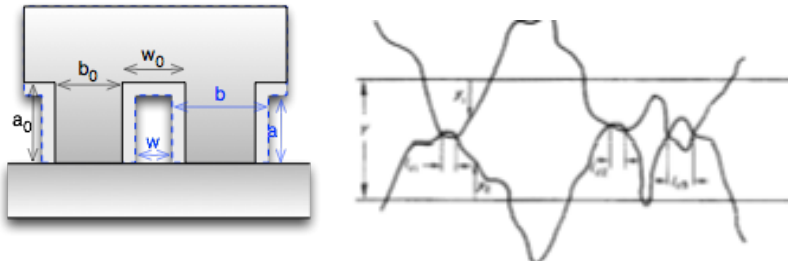
Julien Avenet, Thomas Cender, Arthur Lepoivre,  
Jean-Luc Bailleul, Steven Le Corre, Arthur Levy



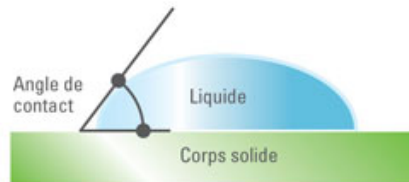
# Thermoplastic composite adhesion

[Doi & Edwards 78, Wool & O'Connor 81, Lee and Springer 87, Benatar 89]

## Geometrical contact



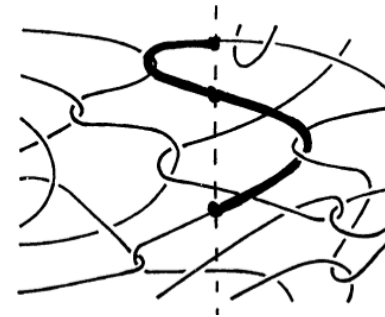
Intimate contact



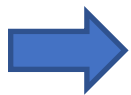
Wetting

## Bonding

Attraction force



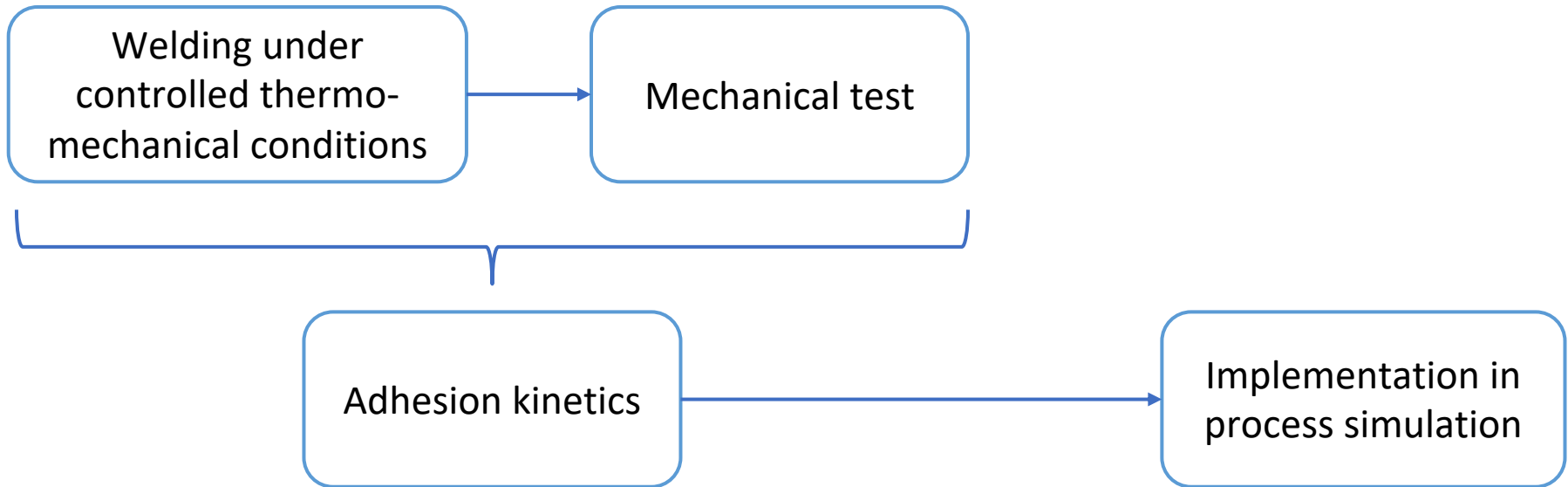
Healing



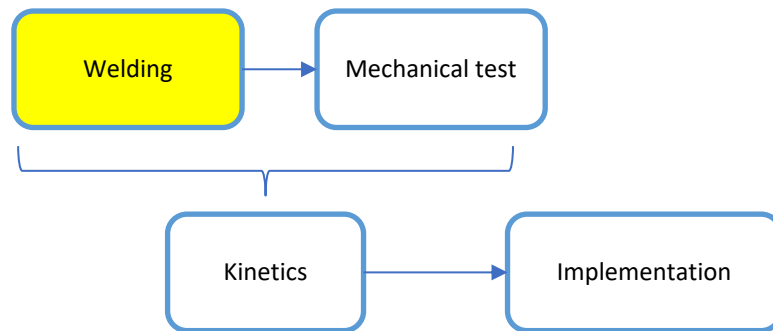
Goal : predict mechanical property of interface  
Under processing conditions (high temp., **short times**)



# Scientific approach

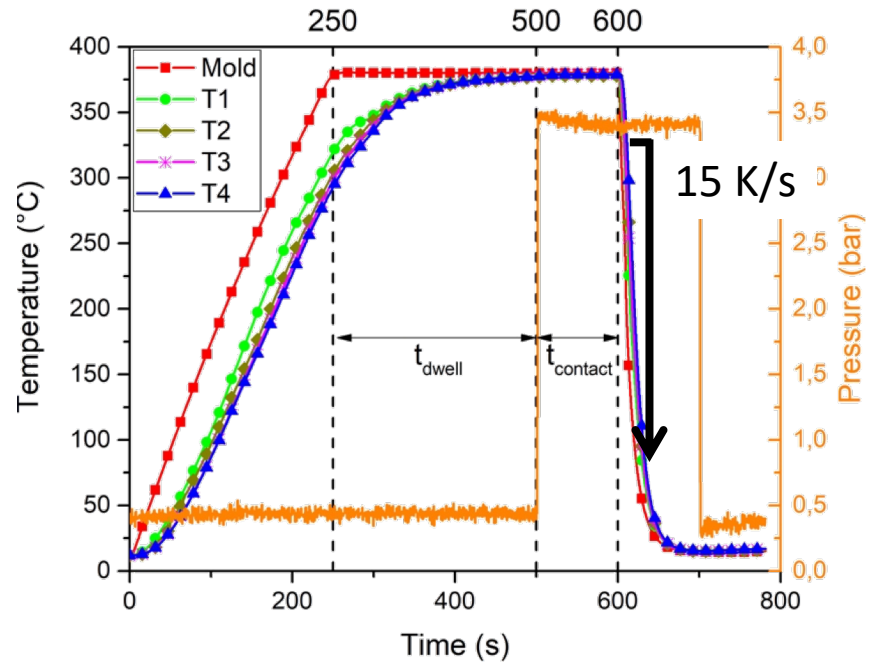
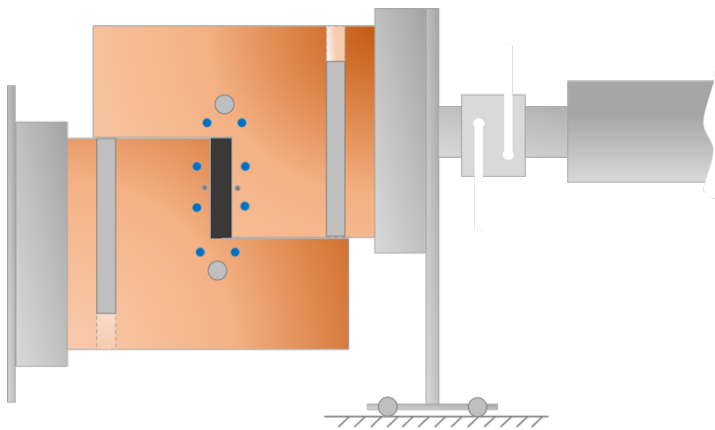
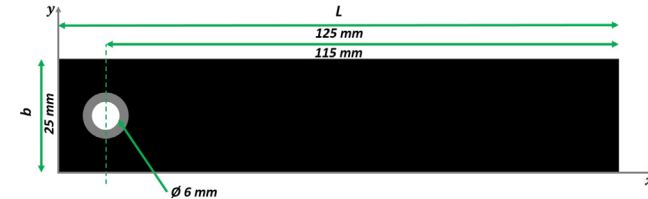
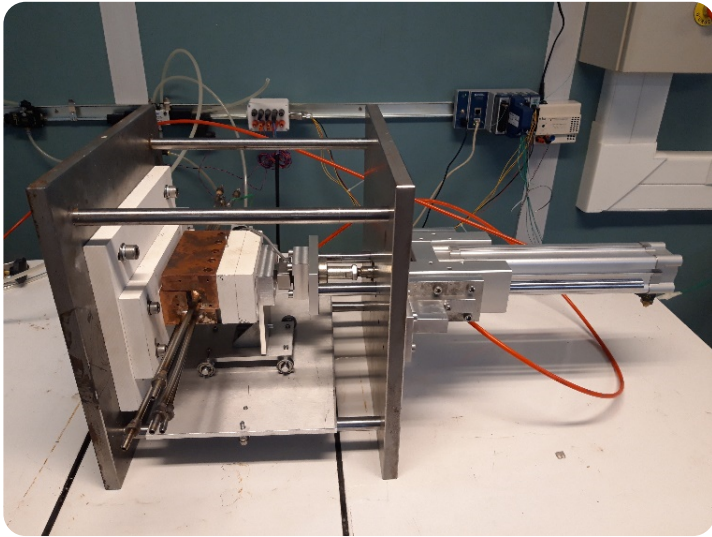


# TACOMA welding bench



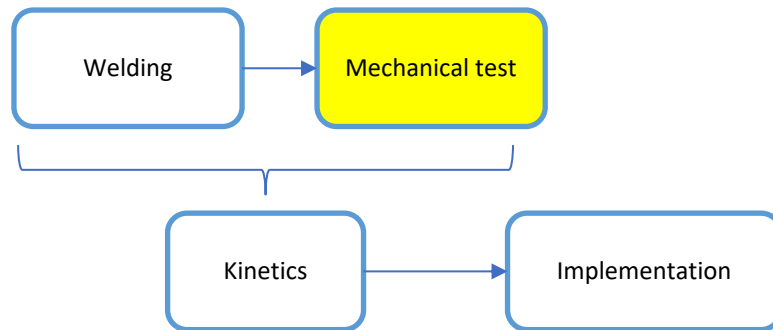
[Avenet et al, 20]

# TACOMA welding bench

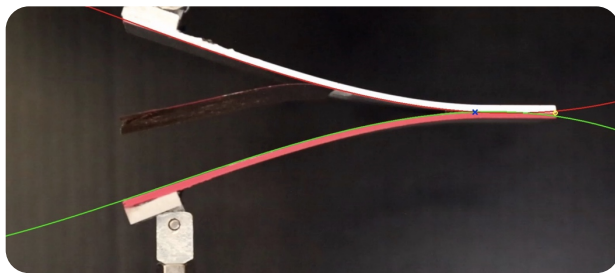
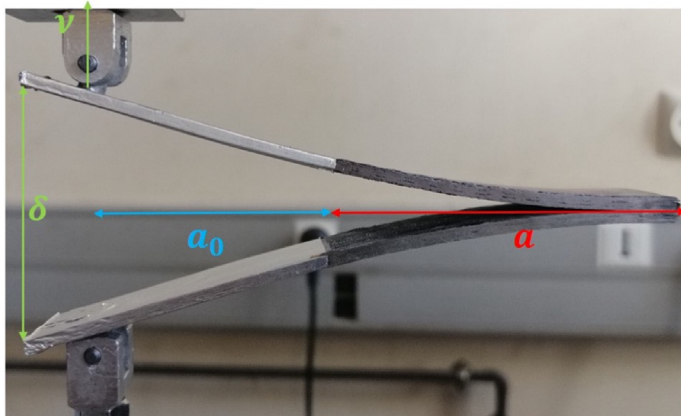
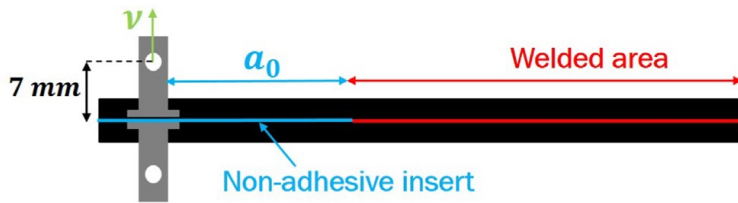


Stopped homogeneous welding test

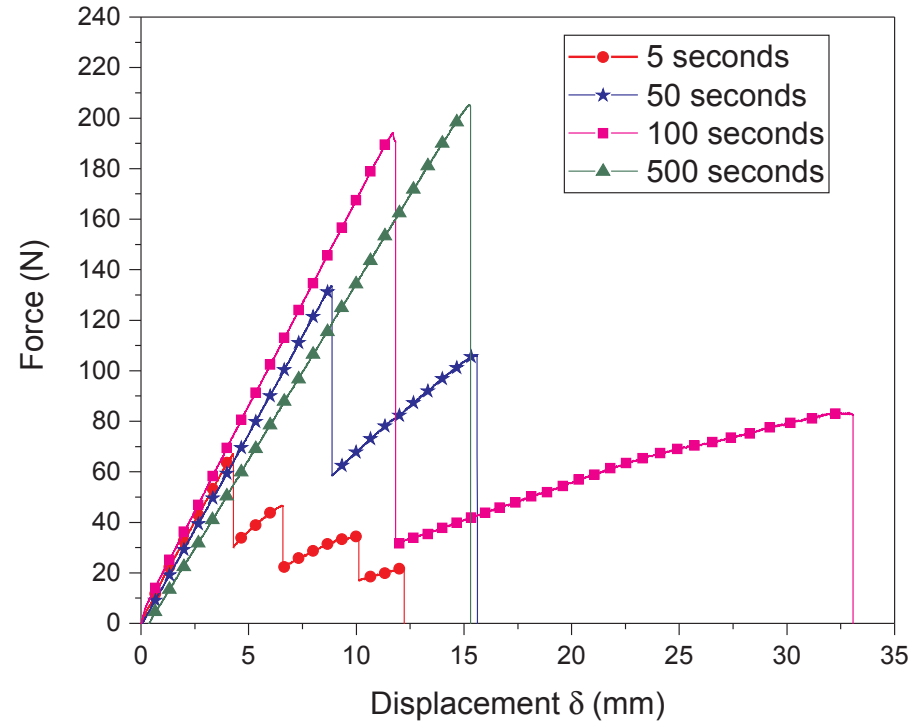
# Mechanical characterization



# DCB test



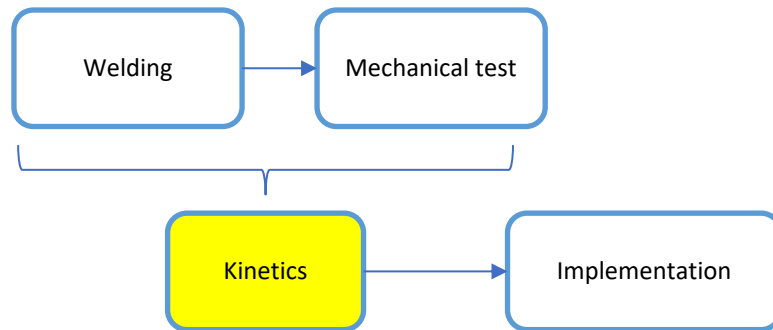
Automatic crack tip tracking



$$G_{IC,initiation} = \frac{3P_c\delta}{2ba_0}$$

➔ Mechanical adhesion quality quantification

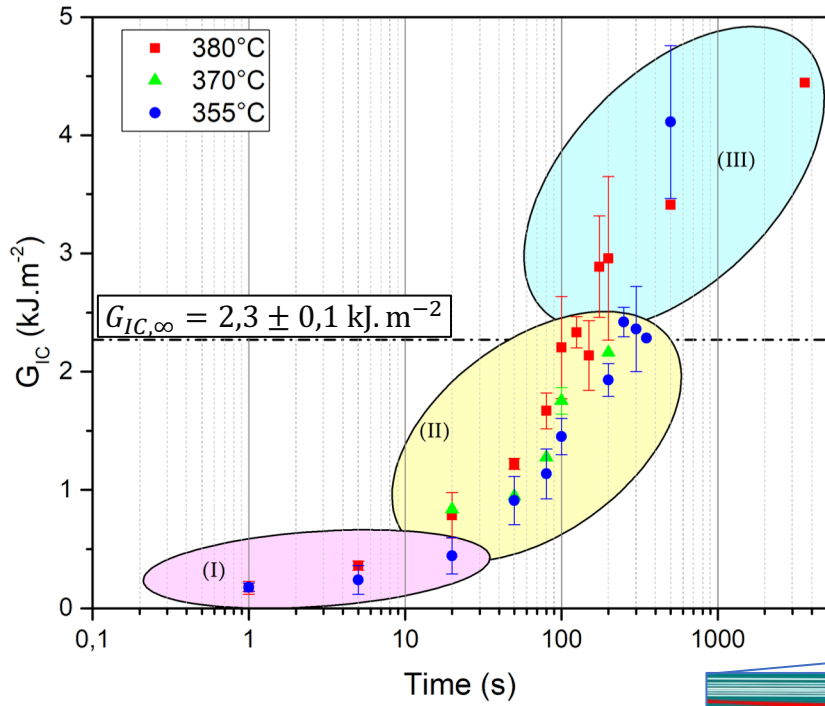
# Kinetics identification



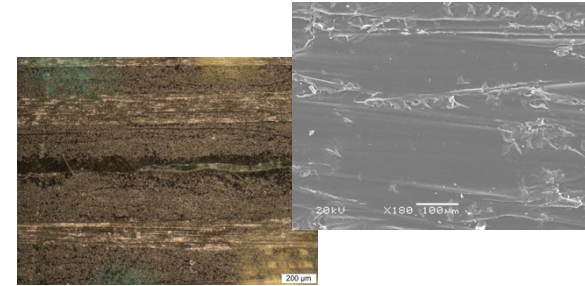
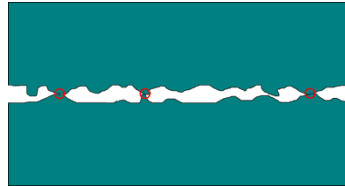
[Avenet et al, 21]

# Adhesion regimes

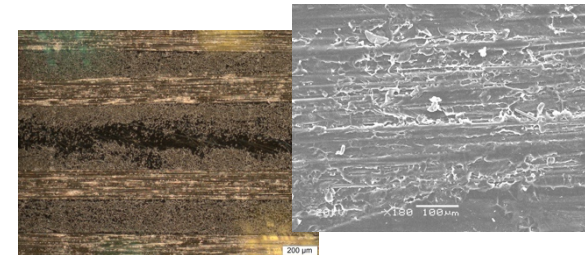
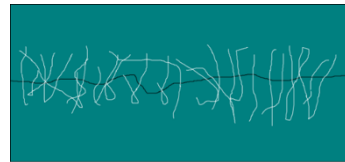
Carbon / PEKK 7002



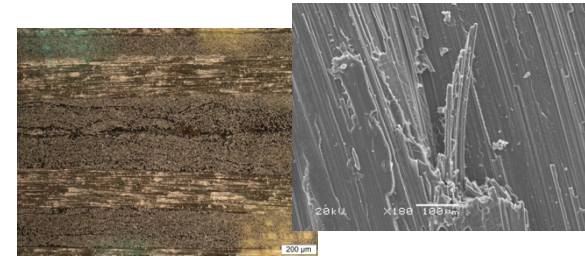
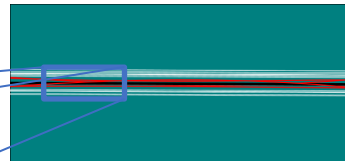
**I. Coupled regime:** Intimate contact is not fully achieved



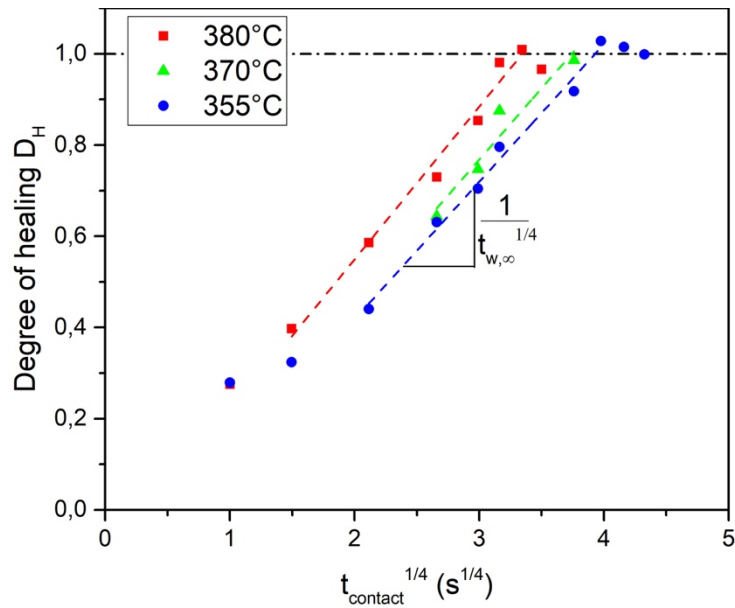
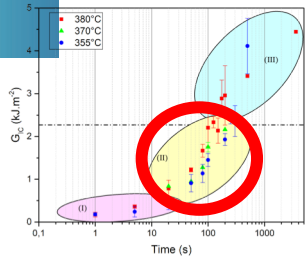
**II. Pure healing regime**



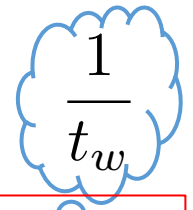
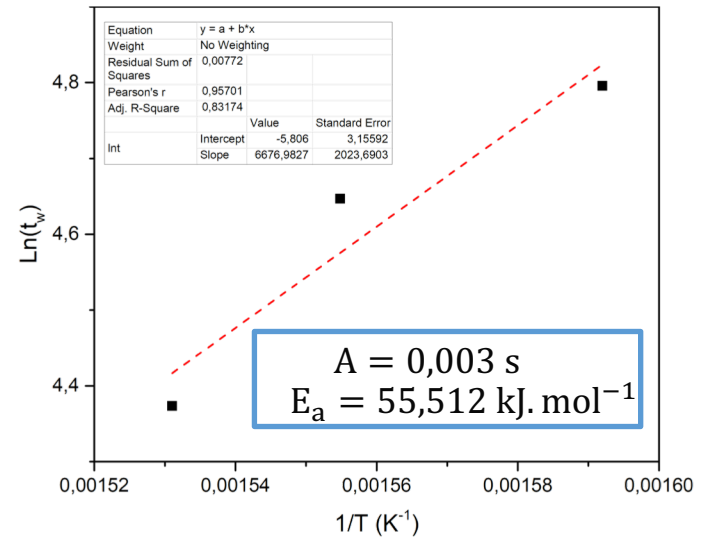
**III. Terminal regime:** Other adhesion phenomena



# Healing regime



T (°C)	380	370	355
$t_{w,\infty}$ (s)	79	104	121

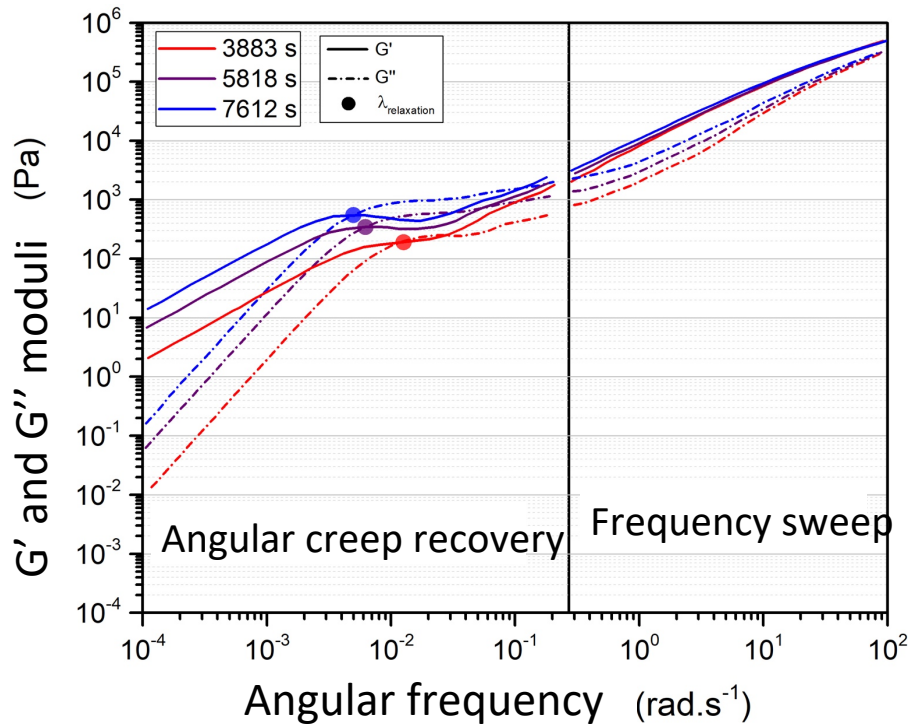


$$\frac{d(D_h)}{dt} = f(T)$$

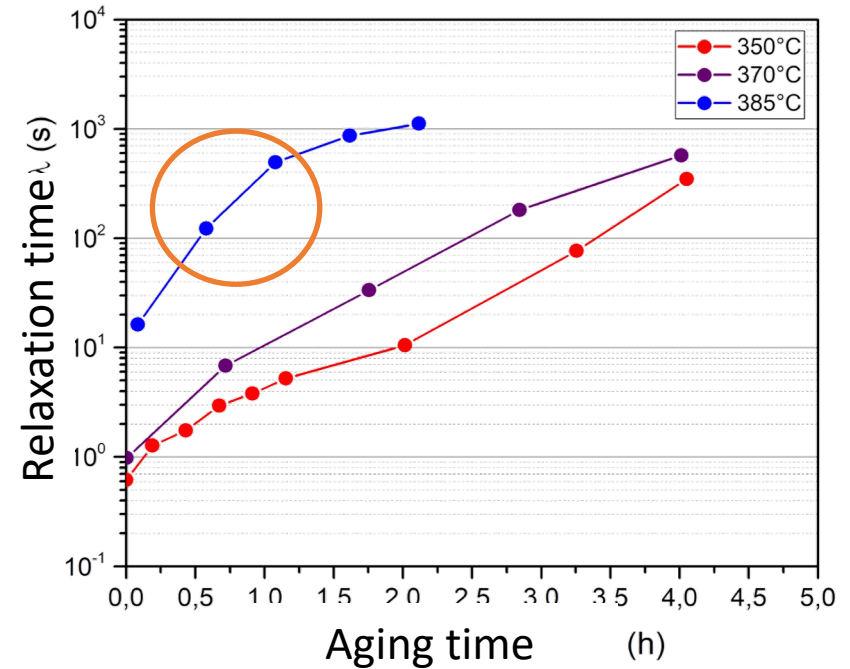


# Correlation with rheological time

## Relaxation time identification

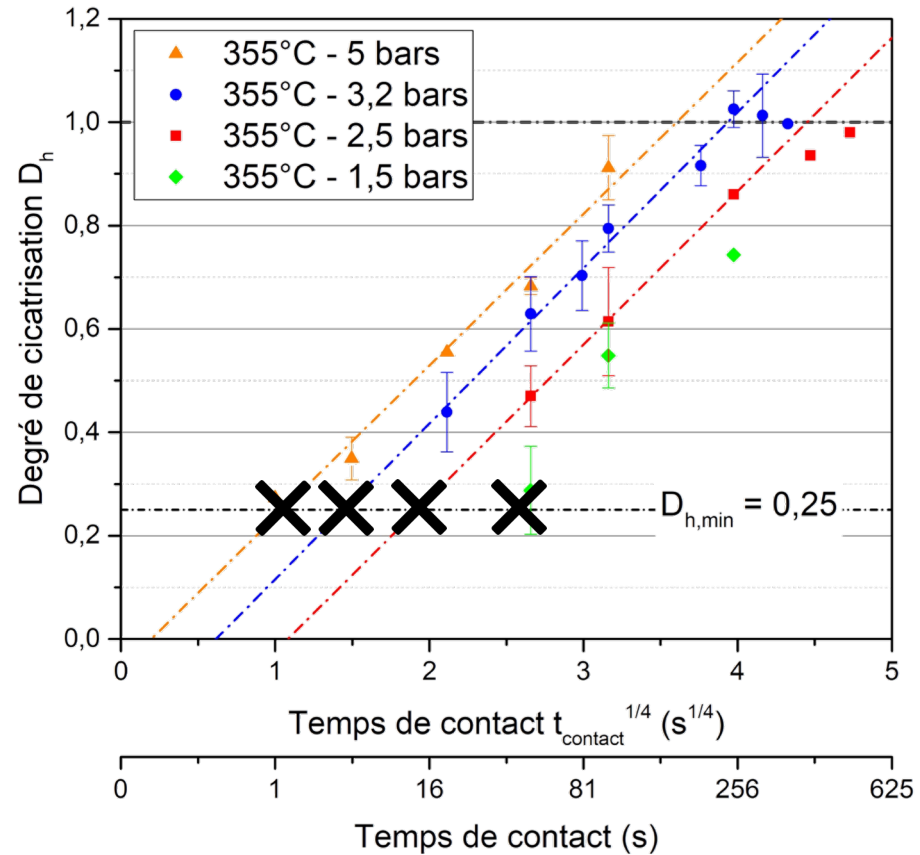
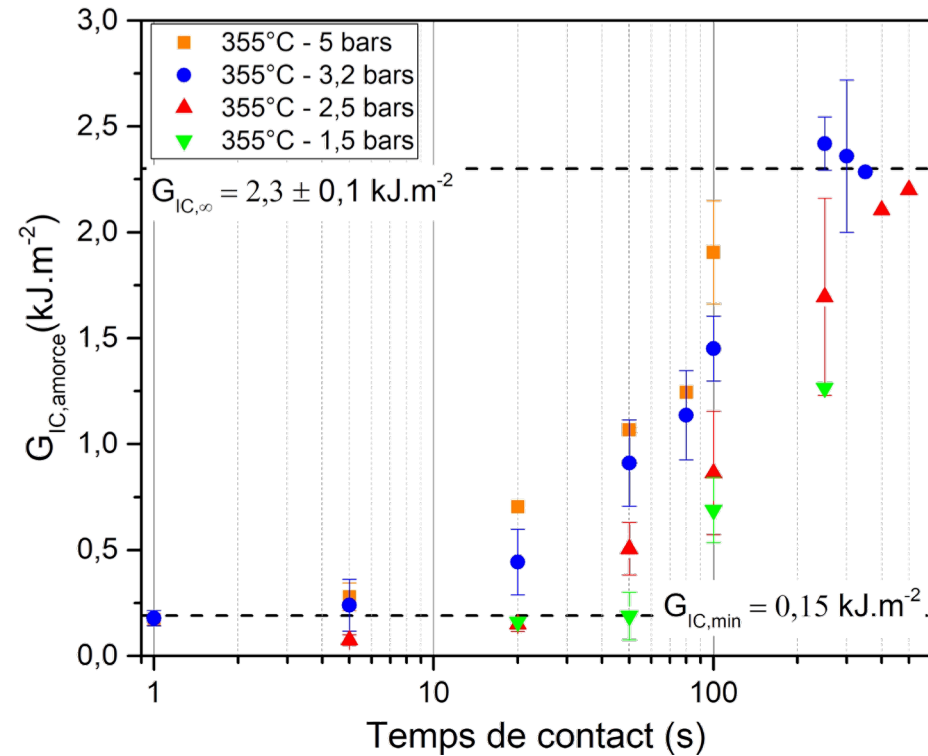
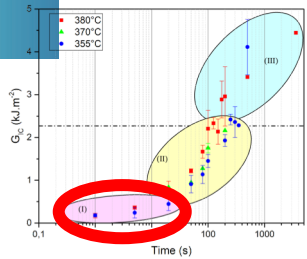


## Aging effect

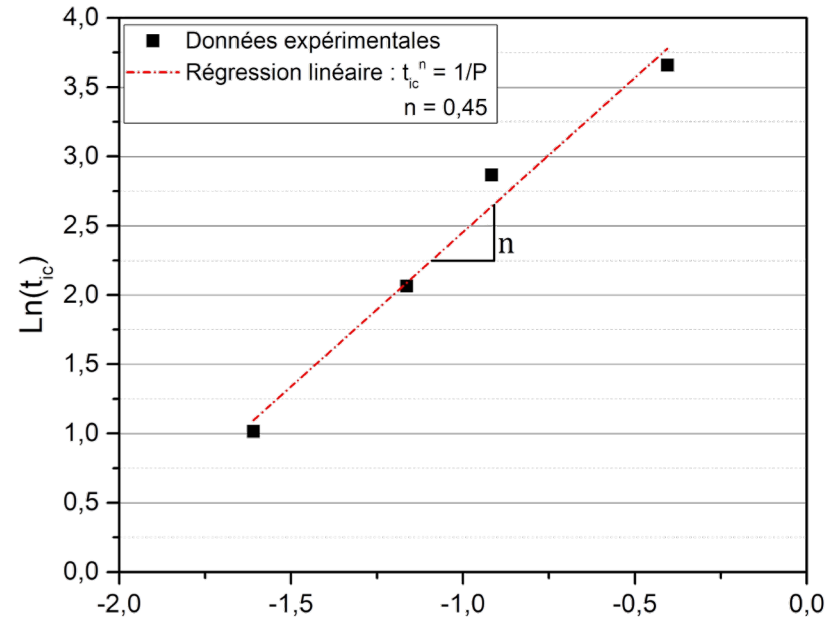
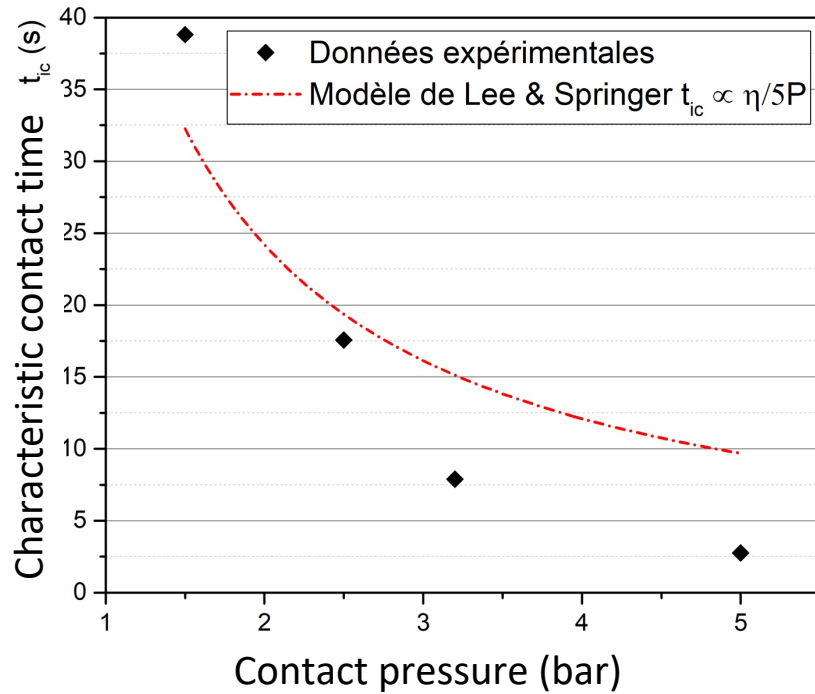
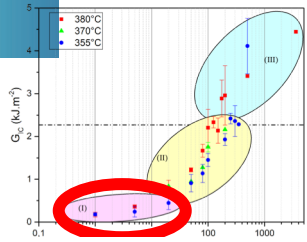


Preprocessing influences weldability

# Effect of pressure 1



# Effect of pressure 2



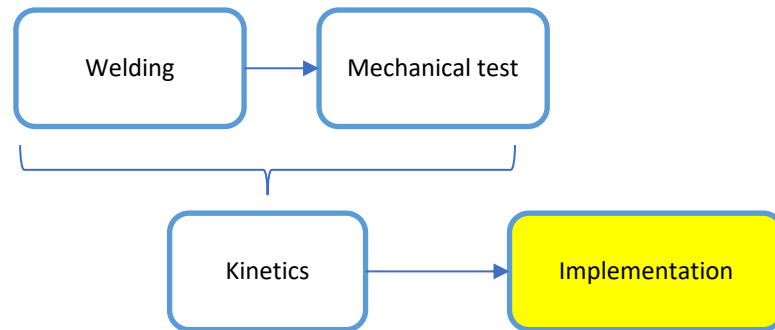
$$\tau = K \dot{\gamma}^n$$

$$P = \frac{K}{t_{ic}^n} \Rightarrow t_{ic} = \left(\frac{K}{P}\right)^{1/n} \propto \left(\frac{1}{P}\right)^{1/n}$$



Intimate contact is non-Newtonian

# Implementation



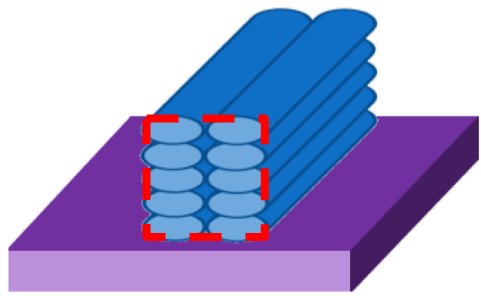
[Lepoivre, PhD, 2021]

# 3D printing application

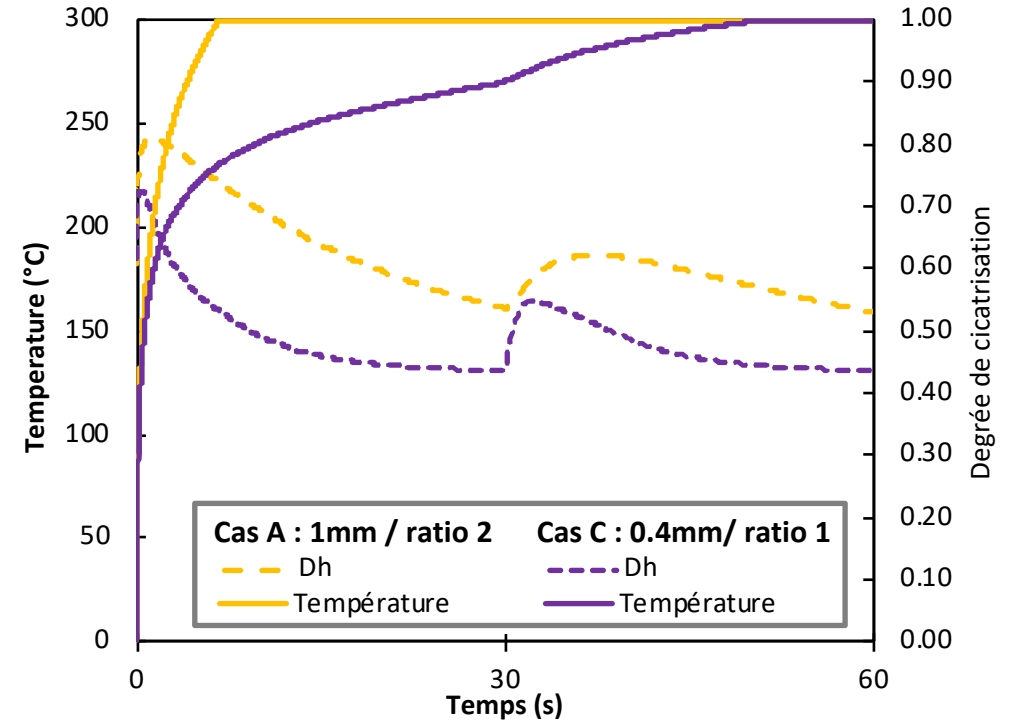
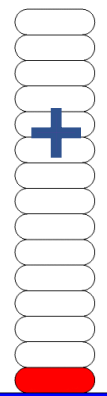
$$\frac{1}{t_w}$$

PEEK 6004

$$\frac{d(D_h)}{dt} = f(T)$$



Temps=0 s



[Lepoivre PhD, 21]



Parametric study, processing window

# Conclusion

Novel welding bench

Procedure for adhesion kinetics  
identification

Healing can be implemented in simulation  
tools



# Perspectives

# Sustainability

## **Material**

End of life

Recyclability

Low tech / footprint

## **Manufacturing**

Energy efficiency

Scraps

Consummable



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Polytech Nantes, Martine Dubé and Pascal Hubert  
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[arthur.levy@univ-nantes.fr](mailto:arthur.levy@univ-nantes.fr)