Thermoplastic Composites for LATW Laser Automated Tape Winding

6th International Carbon Composites Conference

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6th IC3 Conference, Arcachon, June 4-6, 2018

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- Part 4 – Test
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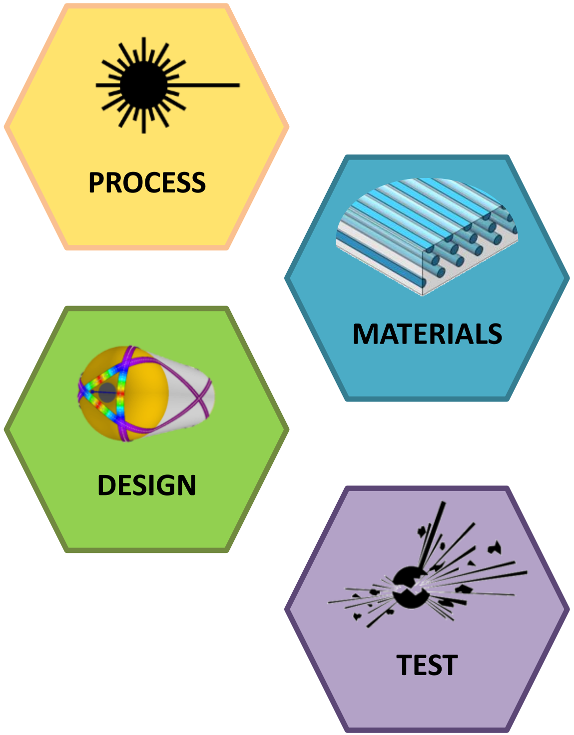
  - To burst test

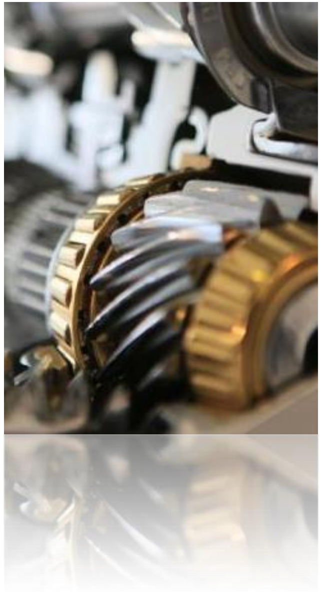


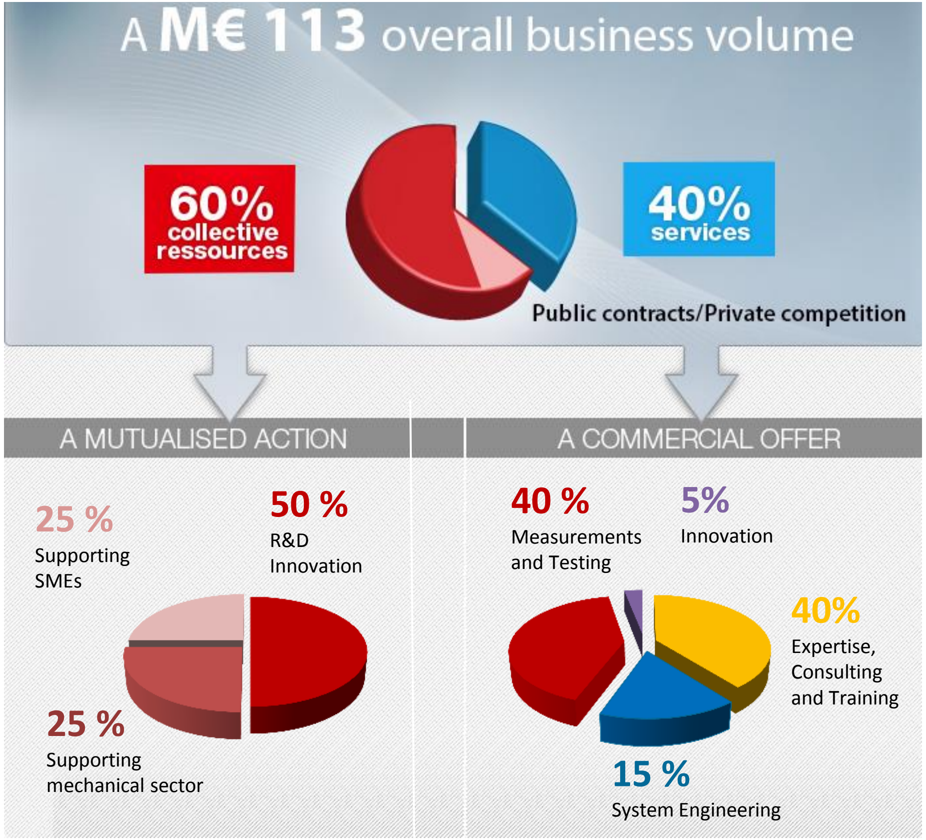
Introduction

Technological institute of mechanics

Steered by mechanical industrialists under the State’s supervision

Régi par les articles L521.1 à L521.13 du code de la recherche





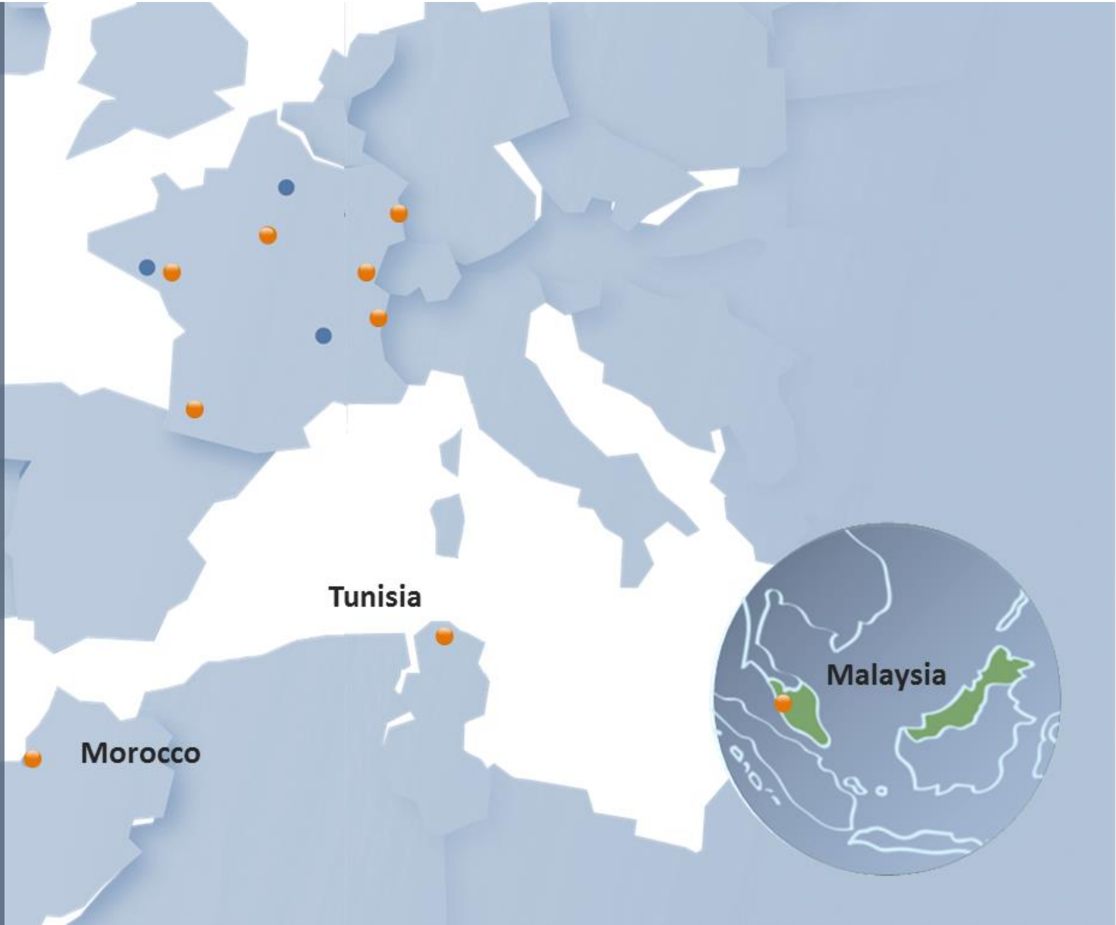
CETIM: Technical Centre for Mechanical Industry

established in 1965 to improve companies' competitiveness

- 1st French research institute in mechanical engineering
- Main technology partner for Industry 4.0 roll out

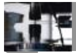
Main figures

- 1,000 employees
- 127 M€ turn over
- More than 4000 customers WW



Breakdown into activity divisions


Metallic materials and surfaces

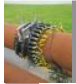

Mechanical components fatigue


Power transmission


Measurement - Mechatronics Acoustic Vibration


Sustainable industrial performance


Polymers and composite engineering


Pressure equipment and instrumentation engineering

Strategic and technological intelligence

Failure analysis and expertise

Training and knowledge management

Software

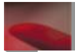

Simulation


Assembly Technologies


Innovative and Efficient processes


Sealing technologies


Fluid and flows techniques


Metrology and calibration expertise

CETIM - Polymer and Composites division

From innovation, through manufacturing, to implementation:

develop product performance

while controlling quality, cycles and costs

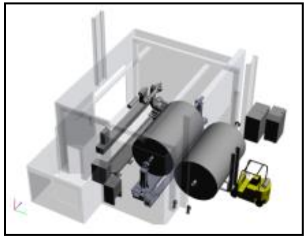
- Polymer Material expertise for 40 years
- +120 PhD, Engineers and Technicians
- 18M€ turn over in composite activity
- Scientific partnership with:
  - ECNantes,
  - ENSCachan,
  - Onera,
  - Imperial College of London
- Industrial partnership with
  - AFPT for Spide TP
  - Pinette, Loiretech and Compose for QSP

CETIM Laser Tape Winding Plateform

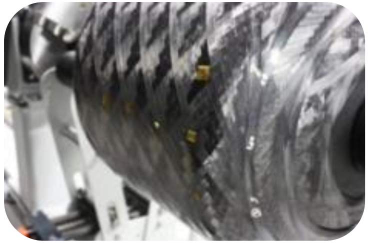
SPIDE TP Development Platform

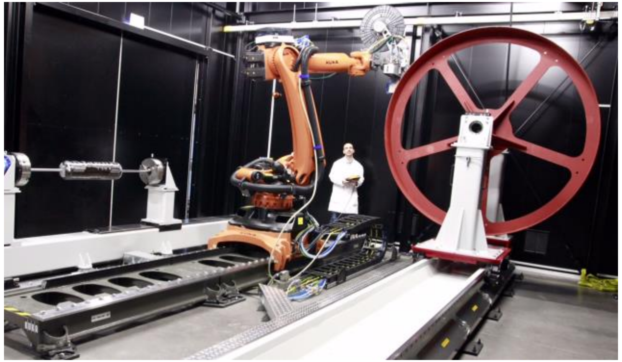
Technocampus Composites (Nantes)

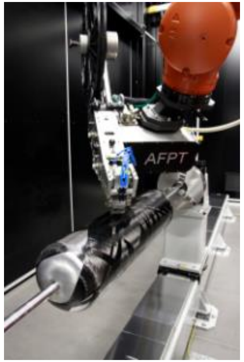
- 2013



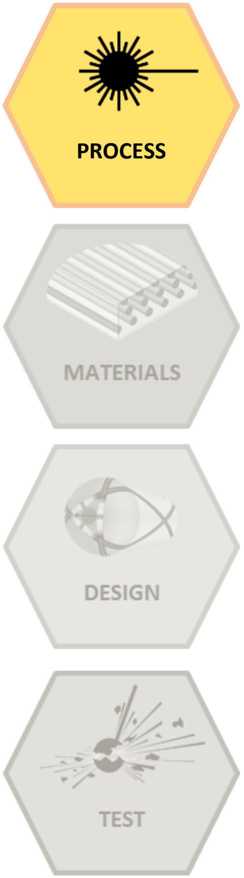
- Since 2014





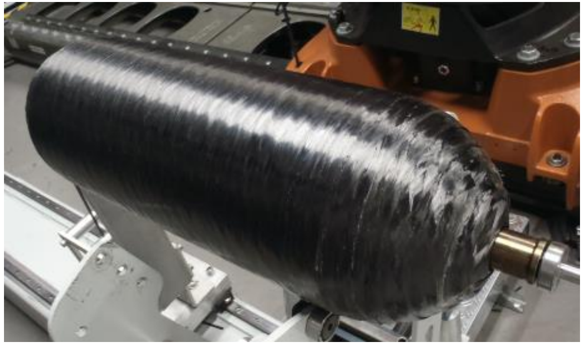


Part 1 – LATW Process



1. LATW Process

Pressure vessel manufacturing: Objectives



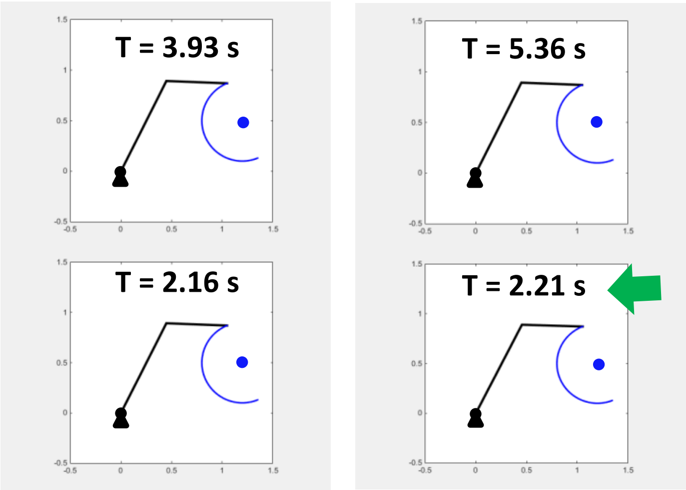
- Productivity
  - Production throughput
    - Robot & Automation science
- Composite Quality
  - Mechanical Performance
    - Mechanical & Material sciences

1. LATW Process

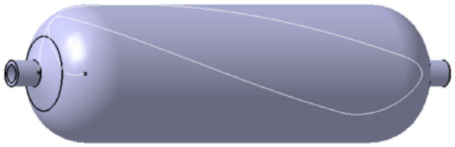
Productivity : Kinematics and motion improvement

- *Optimization of the robot and positioner motion in a redundant fiber placement work cell,*
  (PhD by J. Gao, Ecoles des Mines de Nantes, 2017)
  - *Allow more freedom to the post processor*
  - *Find the optimal motion*

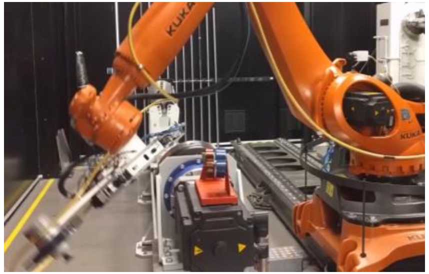
ECOLE DES MINES DE NANTES



- Implementation on a test case (D Shah, Master Ecole Centrale Nantes, 2017)



BEFORE / AFTER



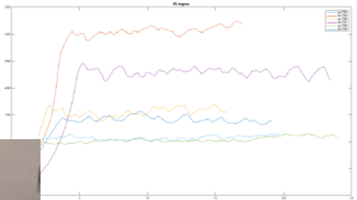
BEFORE : 14 seconds (standard post-processor test case)

AFTER : 7 seconds (optimized)

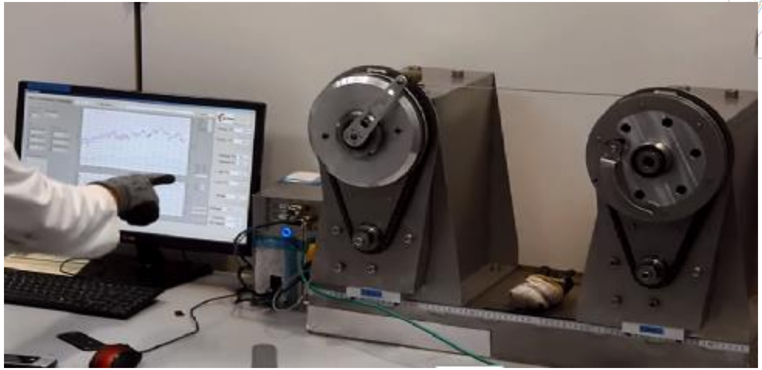
1. LATW Process

Parameters investigation

- Multi-parameters
  - thermal, mechanical, combined
- Design of Experiments method
  - Double Drum Peel test
  - Mechanical tests
  - Natural frequency
  - Void content



Peel energy (J/m²) vs tape length



Double Drum Peel Test

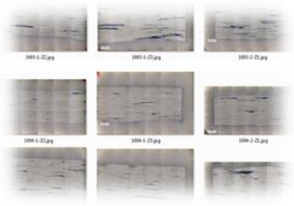
1. LATW Process

Design of experiment objectives

- Identify factors of influence
- Search for min-max values

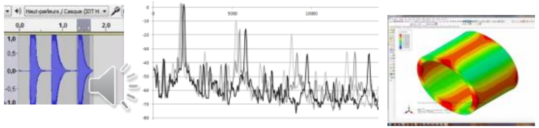
Samples production

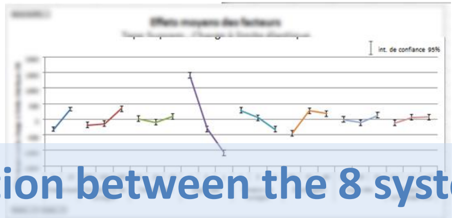
Micrographs



Mechanical tests

Natural frequencies



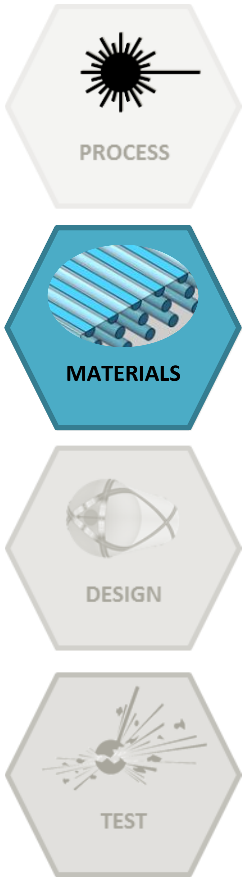


→ Very good correlation between the 8 system responses (publication coming)

1. LATW Process

Question : what happened?

Specimen after Double Drum Peel (DDP) test

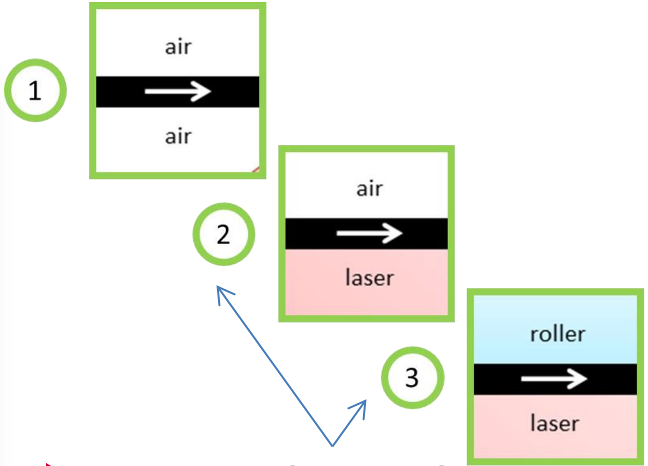


Part 2 – Thermoplastic Composite (TPC) Tapes

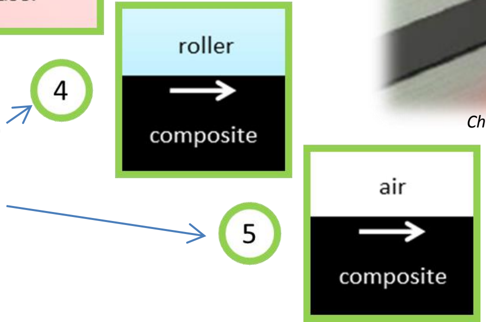
2. TPC Tapes for LATW

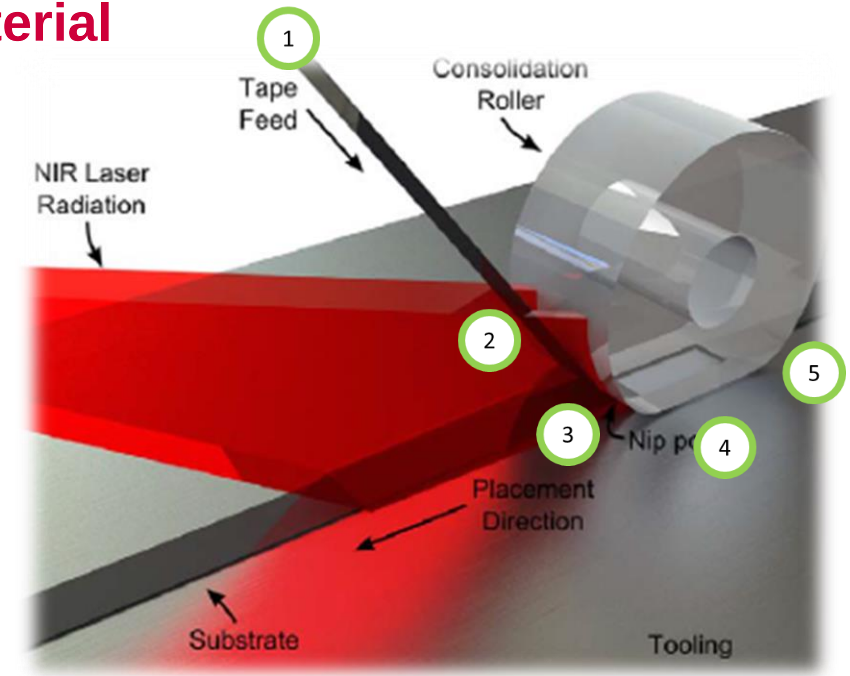
Process cycle applied to TPC material

- Temperature & pressure cycle



- Heat up (500ms)
- Compaction (200ms)
- Cool down (1sec)





Christopher M. Stokes-Griffin, A Combined Optical-Thermal Model for Laser-Assisted Fibre Placement of Thermoplastic Composite Materials, PhD thesis, 2015

2. Thermoplastic Composites (TPC) for LATW

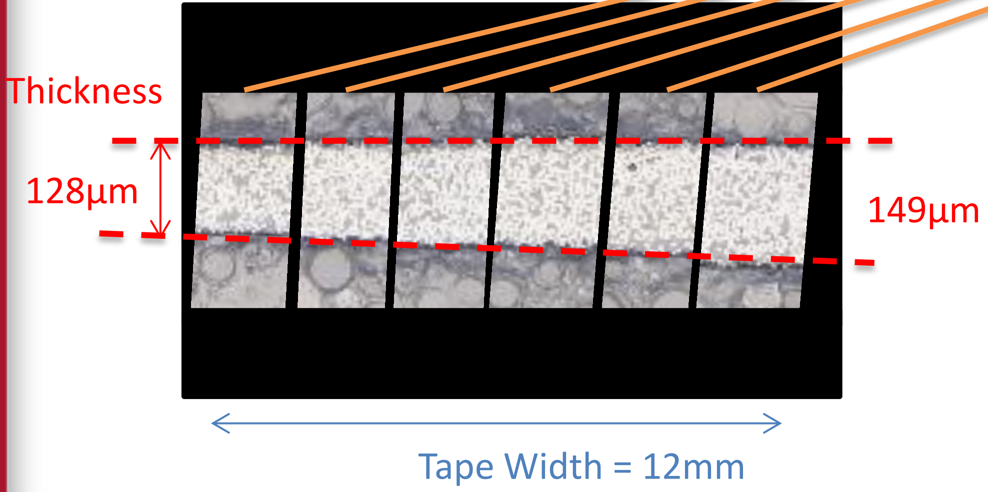
→ A typical thermal-related problem

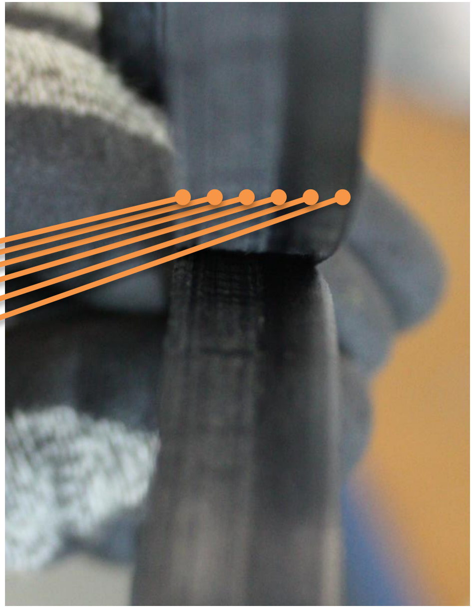
Specimen after Double Drum Peel (DDP) test

2. TPC Tapes for LATW

Thickness vs thermal behavior

- 15% thickness variation along the width
- However, a tolerance of 138+/-10µm seems “reasonable”



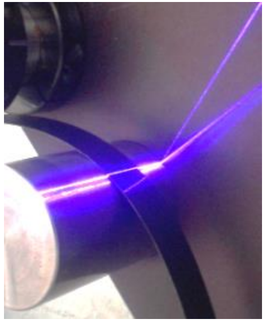


Specimen after Double Drum Peel (DDP) test

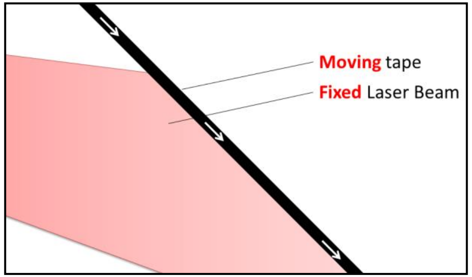
2. TPC Tapes monitoring

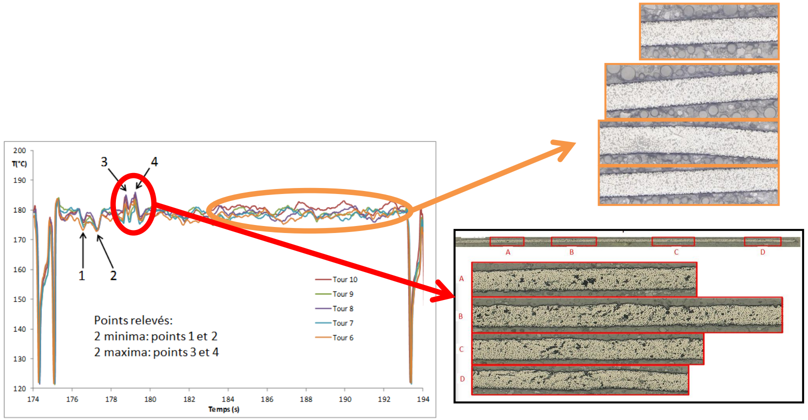
Quality control of TPC tapes

- Tape dimension
  - Laser profiler
  - Width inspection
  - Thickness inspection



- Tape thermal response
  - Thickness and void content inspection





Part 3 – Design

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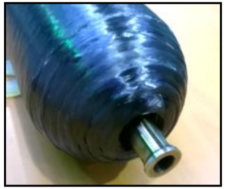
3. Design of TPC pressure vessels

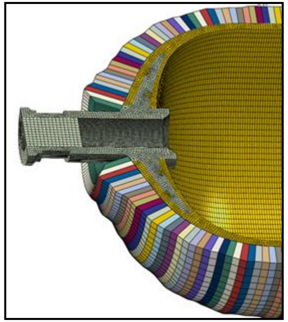
Increasing PV performance

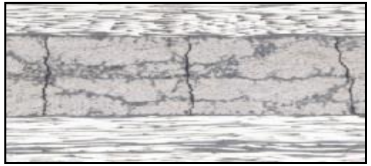
- Improved design
  - Vessel 1 (8,83kg)
    - Burst at 836 bar
    - Performance index 95

  - **Vessel 2** (8,76kg)
    - Burst > 931 bar
    - Performance index > 106

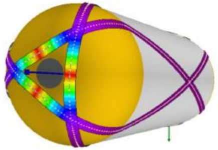


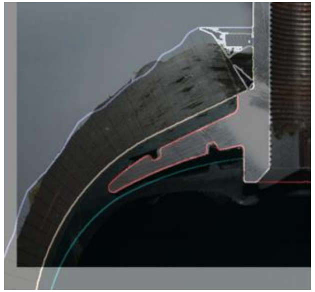
- Optimization levers
  - Model accuracy
  - Design efficiency
  - Product / Process adequacy
  - Material knowledge
    - Design criteria
    - Damage mechanism





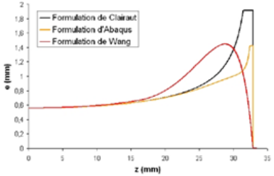
3. Design of TPC pressure vessels

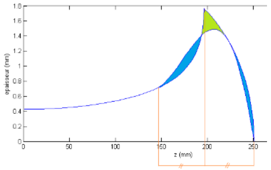


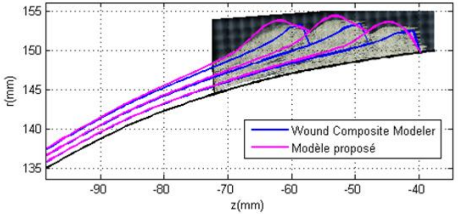


Increasing PV performance

- Model accuracy
  - Vessel 1 showed potential improvements on
    - Thicknesses
    - Angles prediction
  - Software benchmark (Composicad, WCM, Abaqus)
  - Literature review on existing models
- Selection of Vasiliev model
- Validation on real products

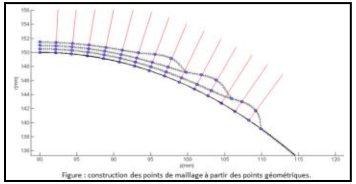






→House-made tool for **laminated automated modelling and meshing** (thickness/angle)

→ FEM model generated and post-processed by Matlab (~10s computing time)



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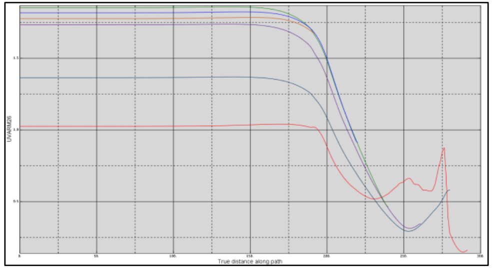
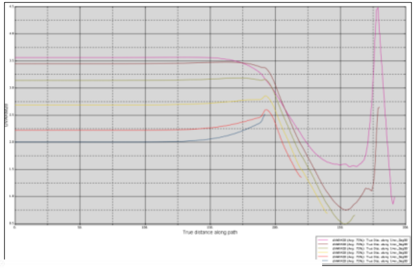
3. Design of TPC pressure vessels

Finite element analysis on Abaqus

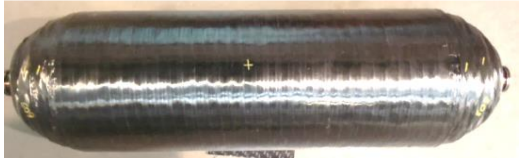
- Selection of Hashin criteria for more representative damage mechanisms in the domes and in the cylindrical portion
- Optimization of the layers thickness and orientation (Abaqus-Composicad)

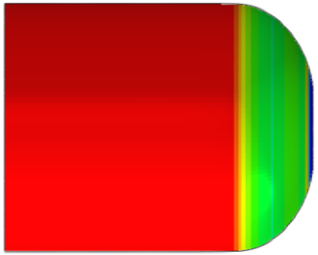




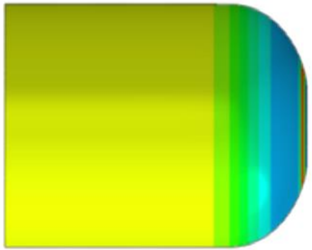
Angle	Epaisseur
Hélicoïdal 1	5,1
Hélicoïdal 2	1,8
Hélicoïdal 3	1,2
Hélicoïdal 4	1,2
Hélicoïdal 5	1,2
Radial	2,1
total	12,6

Filament winding



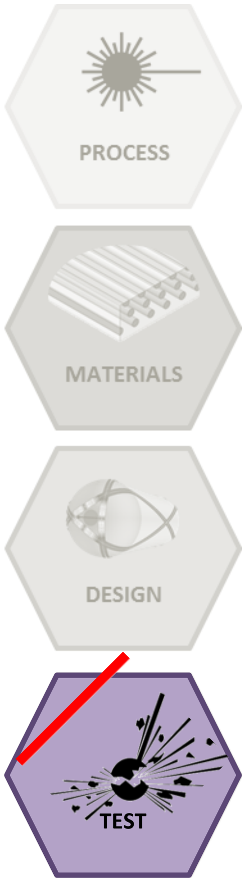


Hashin (tensile fiber failure)



Hashin (Tensile matrix failure)

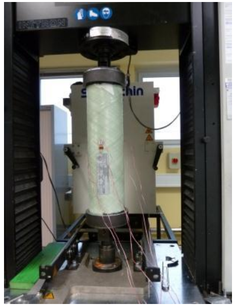
Part 4 – Tests

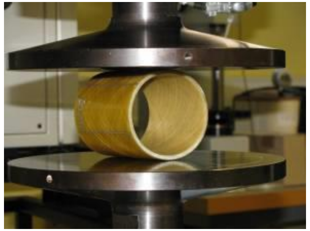


4. Tests for Mechanical properties

Predicting the right property (tensile, compression, shear)

- Testing
  - Flat samples
    - Easy to compare with datasheets
    - Difficult to wind
  - Curved samples
    - Easy to wind
    - Difficult to test a “simple” stress state
    - How to extract inputs for FEA ?

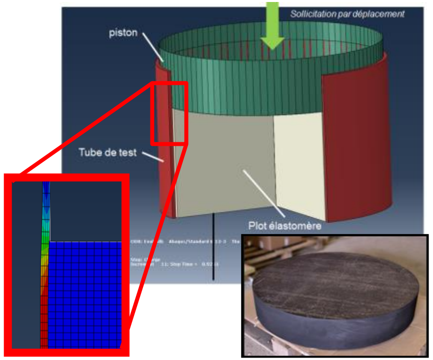




After production – Mechanical performance

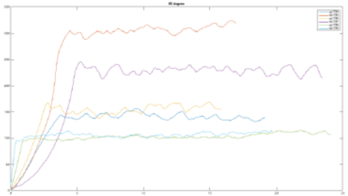
Mechanical properties = performance of the structure

- Tensile strength – **Pipe Burst Test**

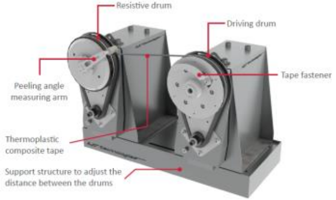


- Interlaminar strength – **Double Drum Peel** test

Double Drum Peel Test



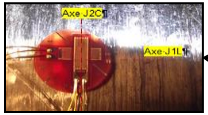
Peel energy (J/m²) vs tape length

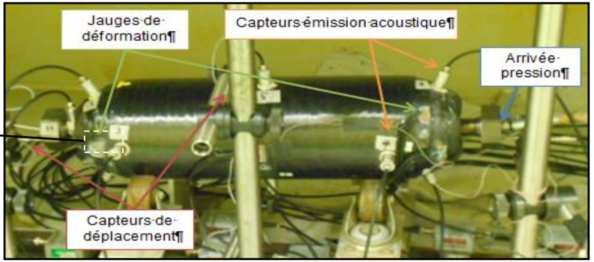


4. Burst tests

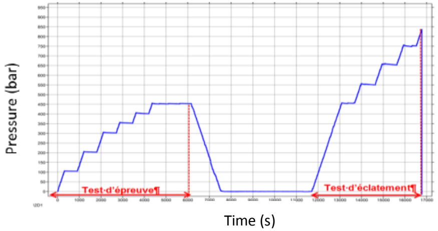
Experimental qualification by burst and fatigue testing

- Recording of strains by gauges and displacements by LVDT
- Recording of damages by acoustic emission

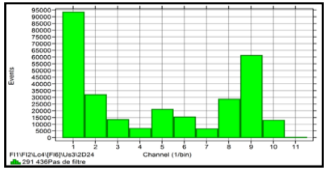


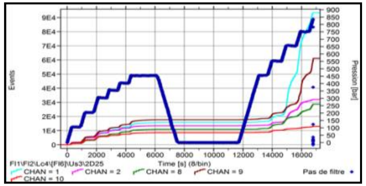


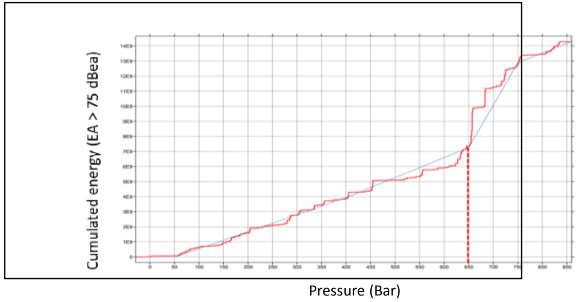
Pressure cycle



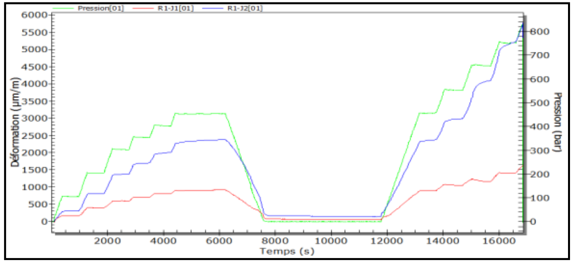
Acoustic emission







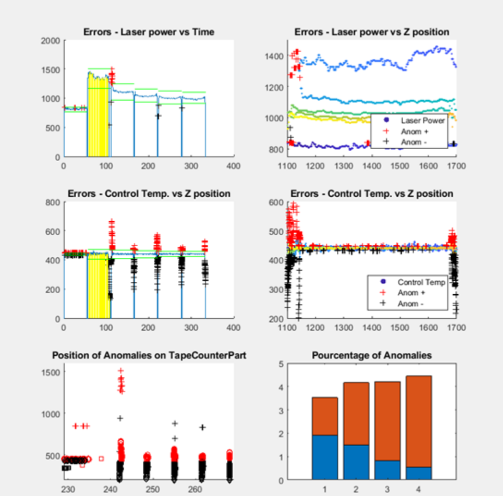
Strain gauges



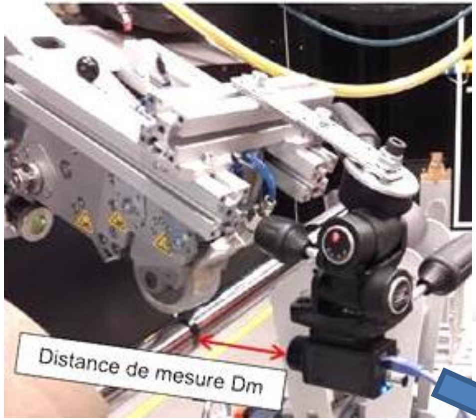
4. Burst tests

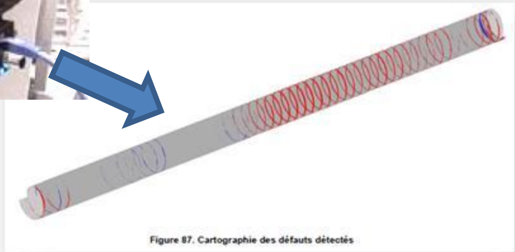
Finally, **compare experiments and process monitoring**

- From machine sensors
  - Repeatability
  - Error detection
  - Automated report for each layer



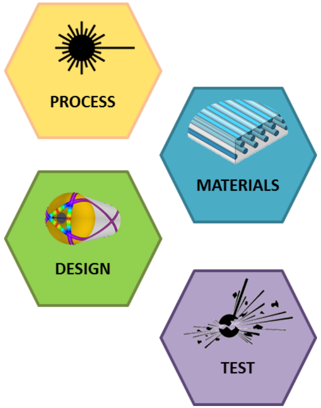
- From process monitoring
  - Online Infrared Thermography





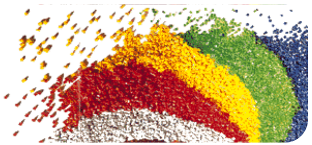
Conclusion

Conclusion



Key takeaways

- LATW Process is highly dynamic
    - >1000°C/s heating ramps
    - <1s under pressure
    - Requires new approach compared to classical pressure and temperature cycles
- Material variability must be considered
    - TPC tape controls are available (laser profile, IR thermography)
- Thermoplastic design is not thermoset design
    - Promising optimization tools have been developed
- New tests for wound samples
    - DDP: Double Drum Peel
    - PBT : Pipe Burst Test
- Increased performance with process monitoring



Thank you for your attention

Any questions?

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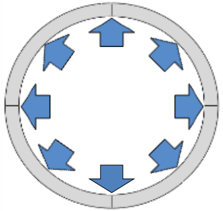
+33 272 741 023

Vers le futur

Thermoplastic Composites Vessels

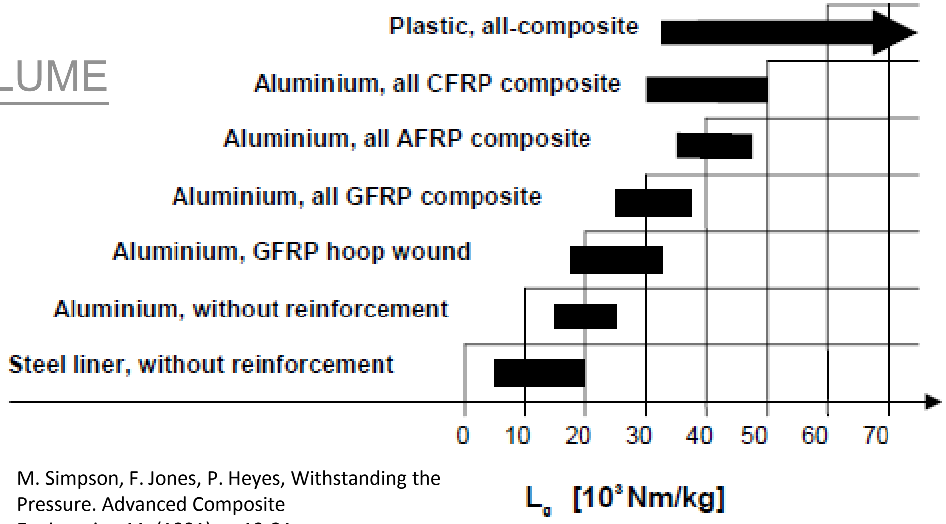
Why using composites for PV application ?

- Benefits of “pure” tensile strength of fibers



- Optimizing performance index

  - Perf. index= $\frac{\text{PRESSURE x VOLUME}}{\text{MASS}}$



“Virtual Pipeline”

M. Simpson, F. Jones, P. Heyes, Withstanding the Pressure. Advanced Composite Engineering 11, (1991), p. 19-21

2. TPC Tapes for LATW

Material subjected to dynamic **effects**

- High thermal gradient
- Very fast conduction through the thickness
- Local TP welding

HEAT

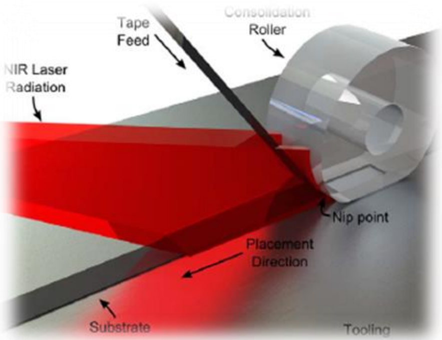
700 to 200ms

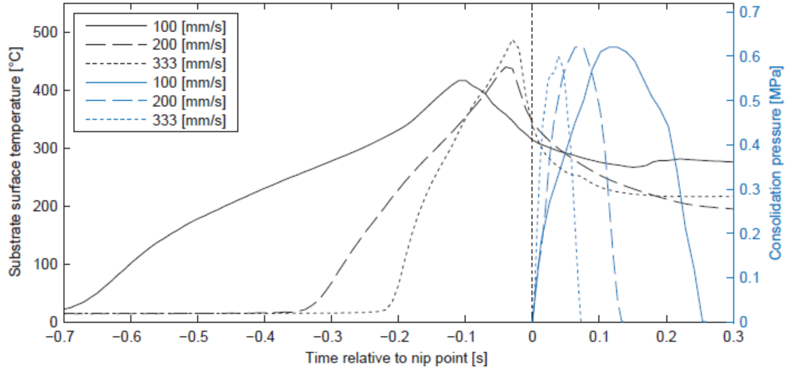
80ms to 250ms

PRESSURE

500 to 2000 °C/s

6 bar





(c) Silicone roller for consolidation force of 500 N.

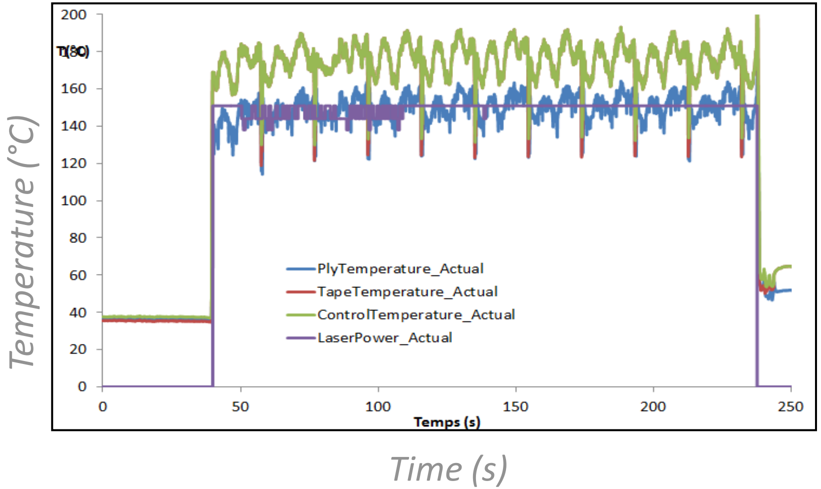
Figure 4.17 – Experimentally measured temperature and pressure histories relative to the nip point for the extended lap shear placement trials.

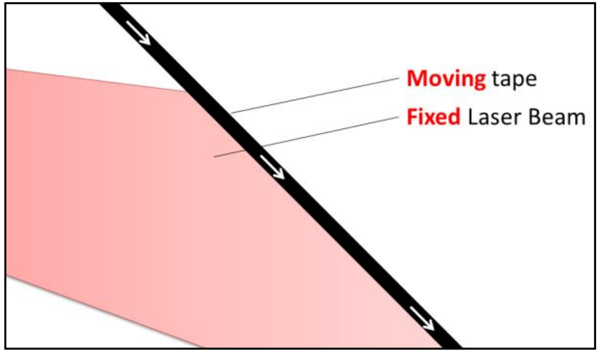
Christopher M. Stokes-Griffin, A Combined Optical-Thermal Model for Laser-Assisted Fibre Placement of Thermoplastic Composite Materials, PhD thesis, 2015

2. TPC Tapes for LATW

Quality control of TPC tapes

- Control based on IR thermography
- Repeatability proven
- “Thermal variation” means “process variation”

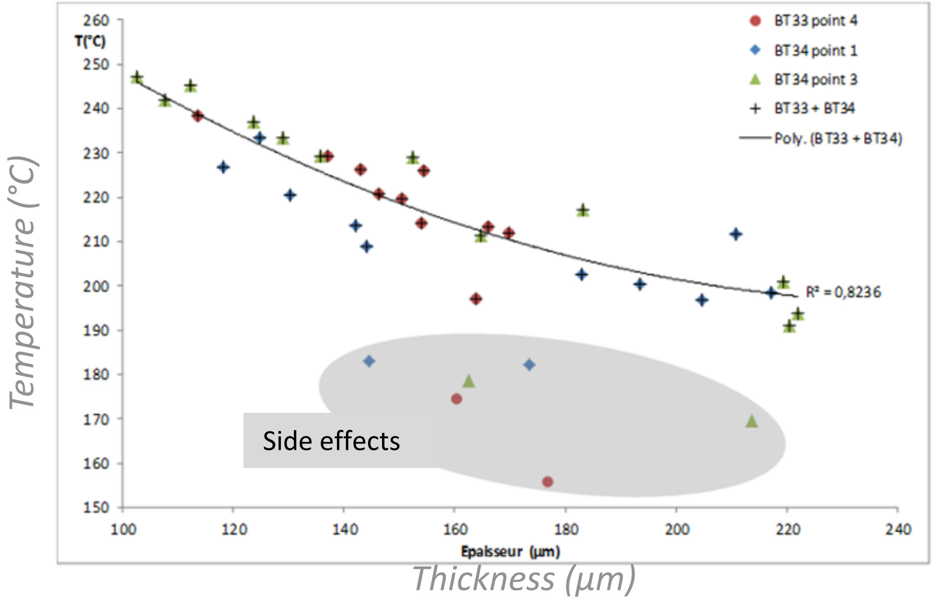


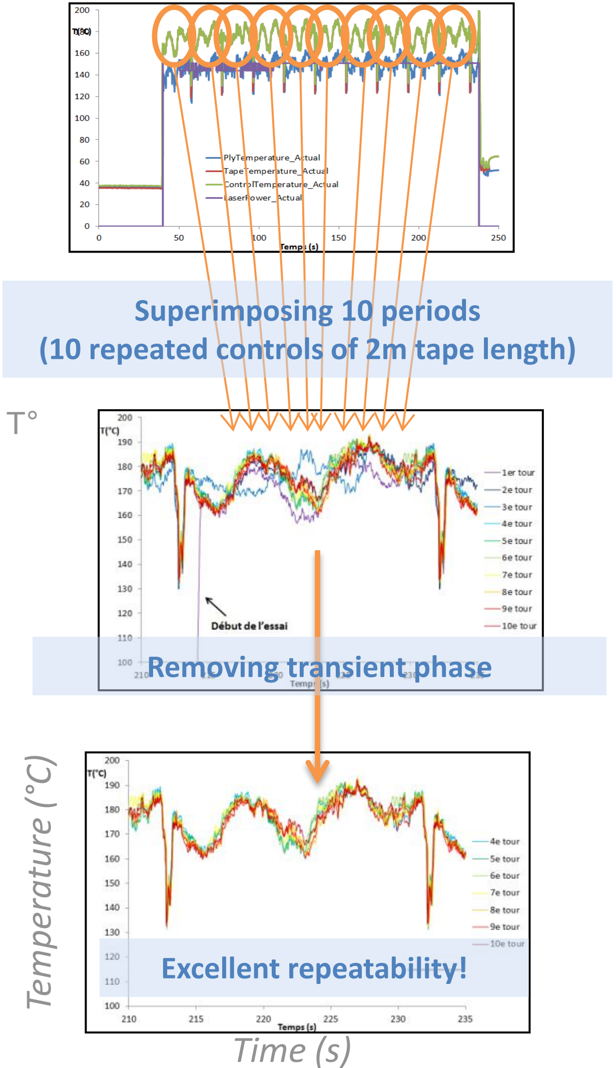


2. TPC Tapes for LATW

Quality control of TPC tapes

- Correlation between thickness and temperature
  - Variation of 100µm in thickness → Variation of 100°C in process T°

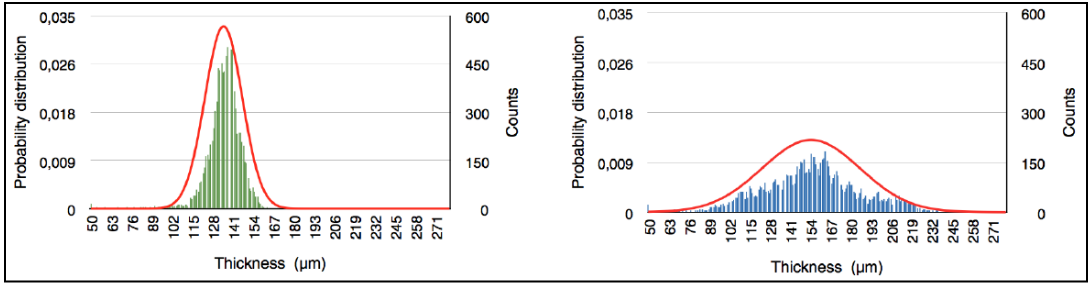




2. TPC Tapes for LATW

Quality control of TPC tapes

- Variability study on 2 types of C-PEEK tapes (local thickness and fiber distribution – experimental measures)



- Statistical thermal simulation shows that the 95% temperature range is:
  - 383°C < T < 423°C for tape A (green)
  - 360°C < T < 444°C for tape B (blue)

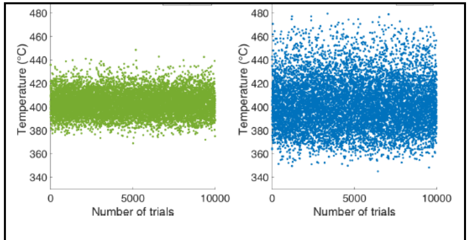


Fig. 8. Monte Carlo thermal simulations for ring setup.

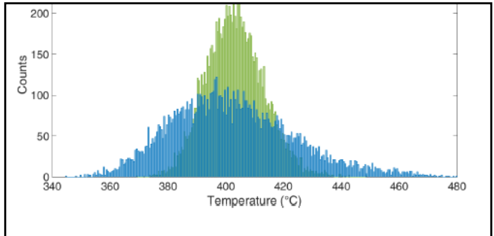


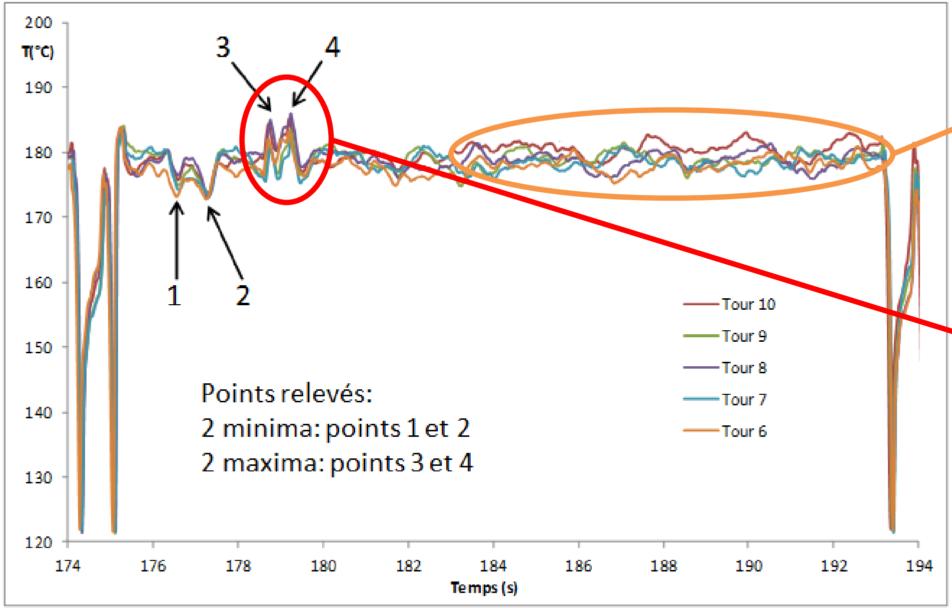
Fig. 9. Histograms for ring simulations.

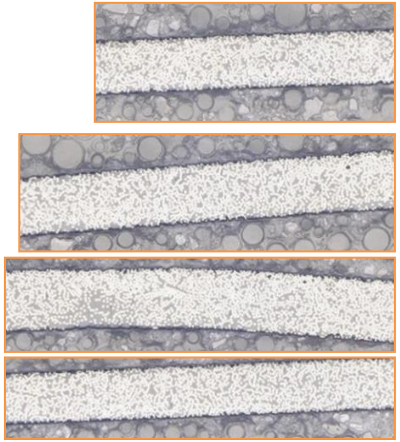
- Further information on tape variability → post-doctorate *Marta Perez (ECN)*, [*Thermal simulation of the laser-assisted tape placement process*], *JNC 2017.*

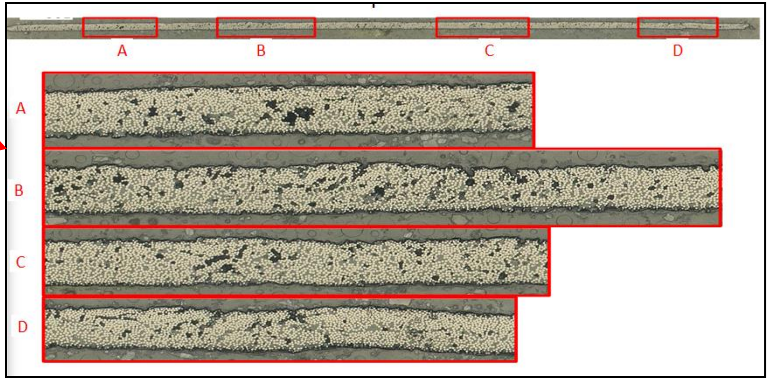
2. TPC Tapes for LATW

TPC tape quality control

- Local porosities detected
  - Very unlikely on this high quality tape



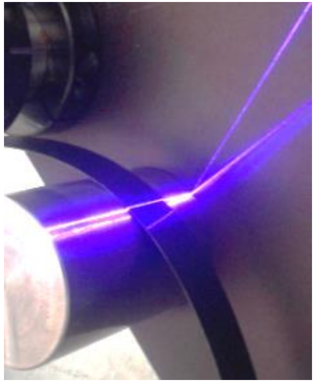




2. TPC Tapes for LATW

Quality control of TPC tapes

- Other controls under study
  - Tape dimension
    - Laser profiler
    - Width inspection
    - Thickness inspection



  - Current project : US control on tape production