Intelligent process monitoring and control: Two industrial applications

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INTERNATIONAL CONFERENCE ON MANUFACTURING OF ADVANCED COMPOSITES (ICMAC 2015), 24-25 June 2015, Bristol, UK

ECOMISE Project

www.ecomise.eu

Enabling Next Generation COmposite Manufacturing by In-Situ Structural Evaluation and Process Adjustment

Objective

A breakthrough composite manufacturing system is being developed comprising probabilistic process prediction, online process monitoring, in-situ structural evaluation and in-situ process adjustment. By means of industrial applications the focus is laid upon preforming processes such as pick & place and dry fibre placement, as well as subsequent infusion and curing processes such as Resin Transfer Infusion (RTI) and Resin Transfer Moulding (RTM).

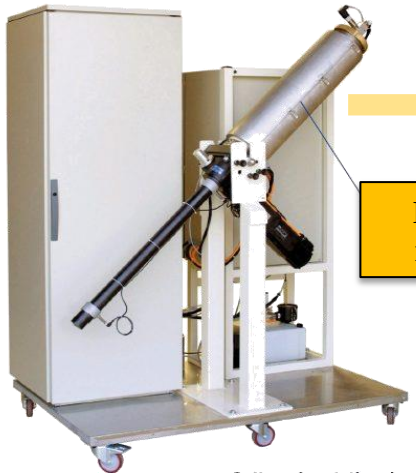
Industrial Demonstrators

- Aerospace (Bombardier)
- Automotive (Hutchinson)
- Marine (Airborne)

Partners

DLR, Airborne, Bombardier, Dassault Systemes, Faserinstitut Bremen, Hutchinson, LMS, 180, NLR, Polyworx, synthesites

Intelligent automation in composites moulding



Injection machine

Inline Sensors

Mould

Composite part

In-mould Sensors

Control Actions

Temperature controller(s)

DAQ + Control

Monitoring Systems

SEVENTH FRAMEWORK PROGRAMME

synthesites

PROJECT CONCEPT: INTELLIGENT MOULDING

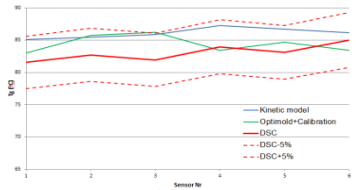
- Introduce new flow and cure sensors for minimum flow disturbance
- Advance the monitoring systems for improved process monitoring
- Advance the intelligence of the DAQ system to provide valuable information e.g. Tg.
- Develop a control system that will get the feedback from the sensors and provide real-time or offline optimised control actions
- Introduce an outer identification loop in the simulation task to adjust automatically specific process parameters in order to minimise the deviation between simulations and measurements
- Apply all the above to three industrial-oriented typical applications
- Advance the concept for industrial applications

Process monitoring and simulations

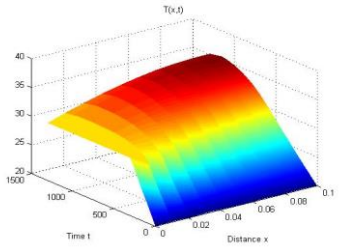
OptiMold system for monitoring resin cure, resin viscosity, mixing ratio quality and resin quality

OptiFlow system for optimising mould filling, process automation and simple process control

OptiSensors (durable/ disposable, flexible, outlet, custom)



Real-time calculation of Tg/ degree of cure/ viscosity/ resin quality



Simulations, Automation, Design and Prototyping solutions

Optimold: Cure, viscosity and resin quality check

Real-time measuring of

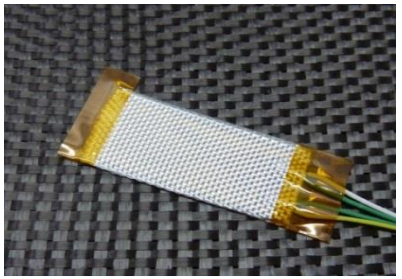
- Resin's electrical resistance (from 0.1 MOhm up to 50 TOhm) and
- temperature (0.1^{o}C accuracy)

Characteristics

- Non-intrusive (it depends)
- Range of sensors
- Good Repeatability
- Fast Acquisition
- Compact design
- Wireless
- Quality and Process control

Cure and Viscosity Sensors

process monitoring sensor = electrical resistance + RTD sensors

Durable sensor	Flexible sensor	Inline sensor	Pot sensor
			
High Temp RTM • Resin arrival • Viscosity rise • Gelation • End-of-cure	VI and RT cure • Resin arrival • Viscosity rise • Gelation • End-of-cure	• Avoid pipe cleaning • Adjust cycle • Mixing ratio check	• Mixing ratio • Resin Quality • Resin aging • Adjust cycle

OptiFlow: Resin arrival and temperature

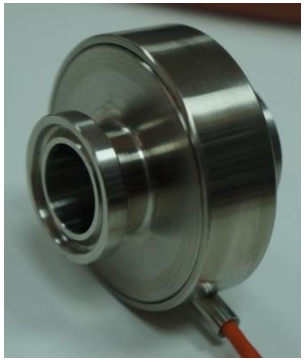
- 4 temperature and resin arrival sensors
- Electrical resistance-based measurements and RTD temperature sensing
- Continuous connection checking
- One relay output for process automation

Resin arrival and temperature sensors

In-mould Durable

- flat areas
- possible mark

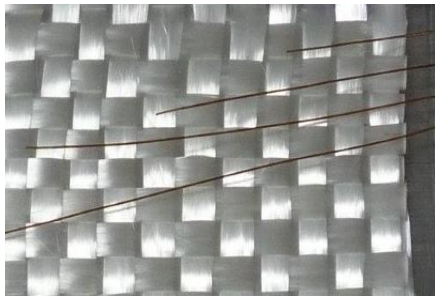
Gate sensor



- ideal for vacuum infusion in oven/ autoclave (gates, pipelines, pots etc.)

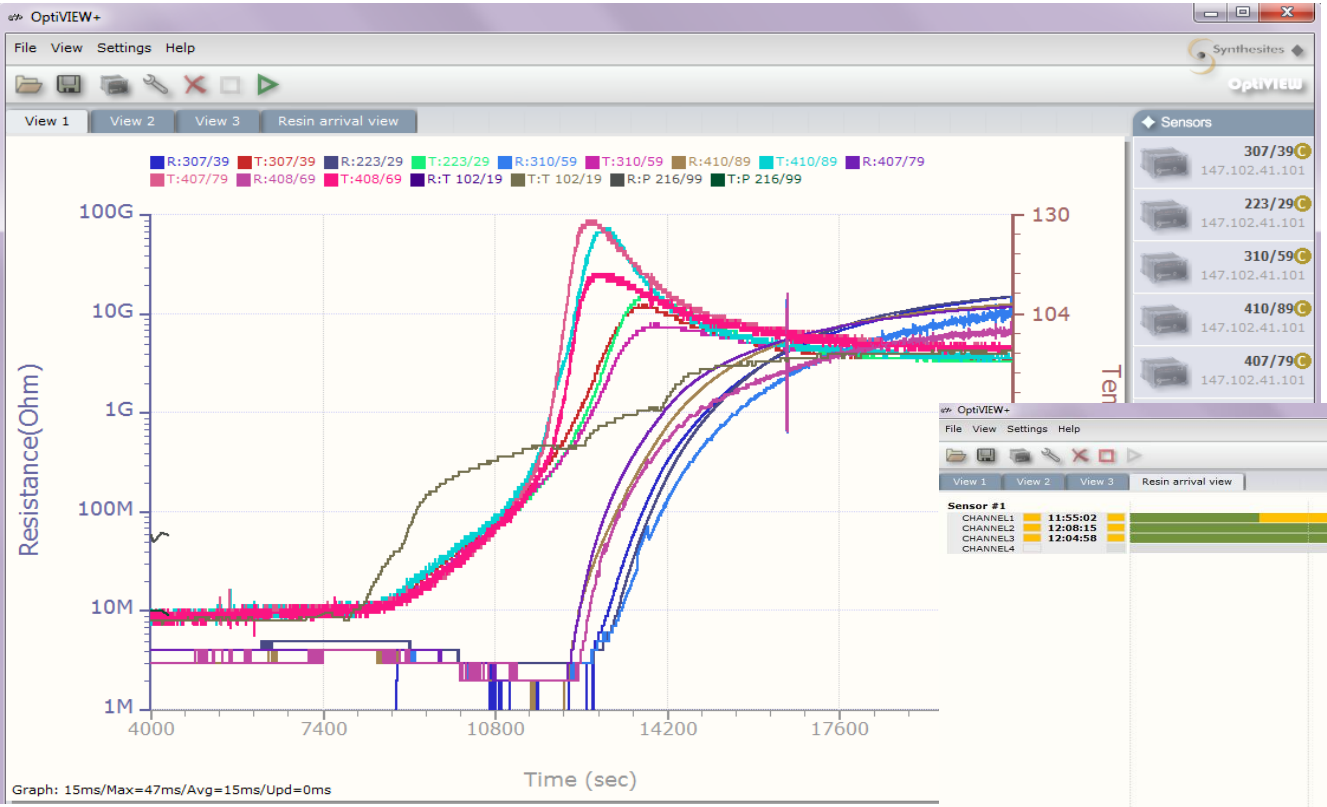
Flexible disposable

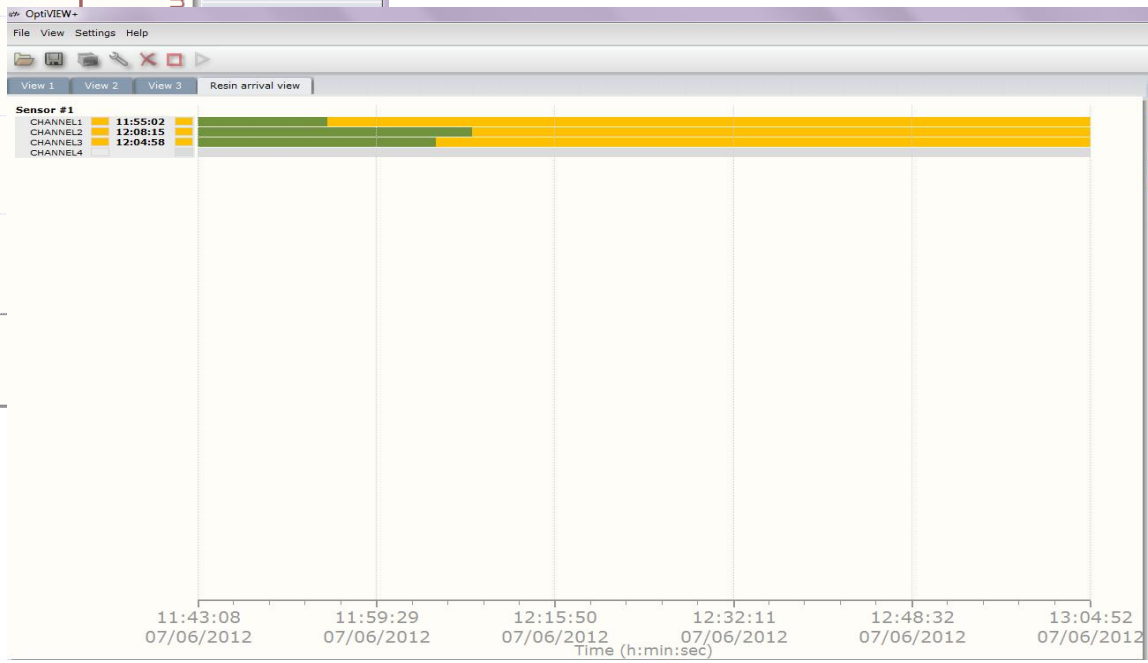
FloWire sensors



- Curved surfaces
- In the laminate for development
- Over the peel-ply
- Suitable for very long parts
- no extra protection for Carbon Fibre Preforms

Optiview: DAQ software





OptiView software for both Optimold and OptiFlow systems

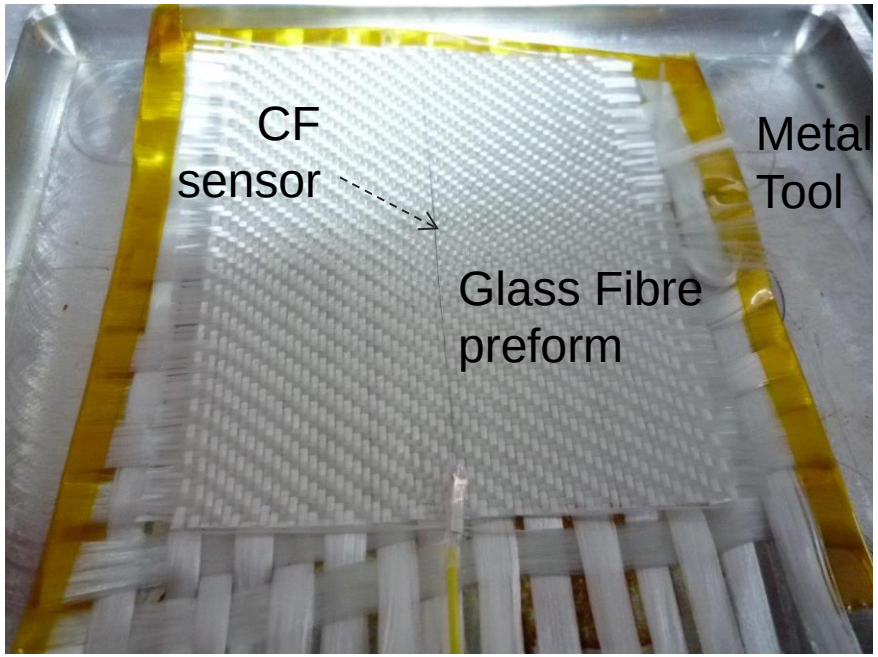
New sensors developed and tested

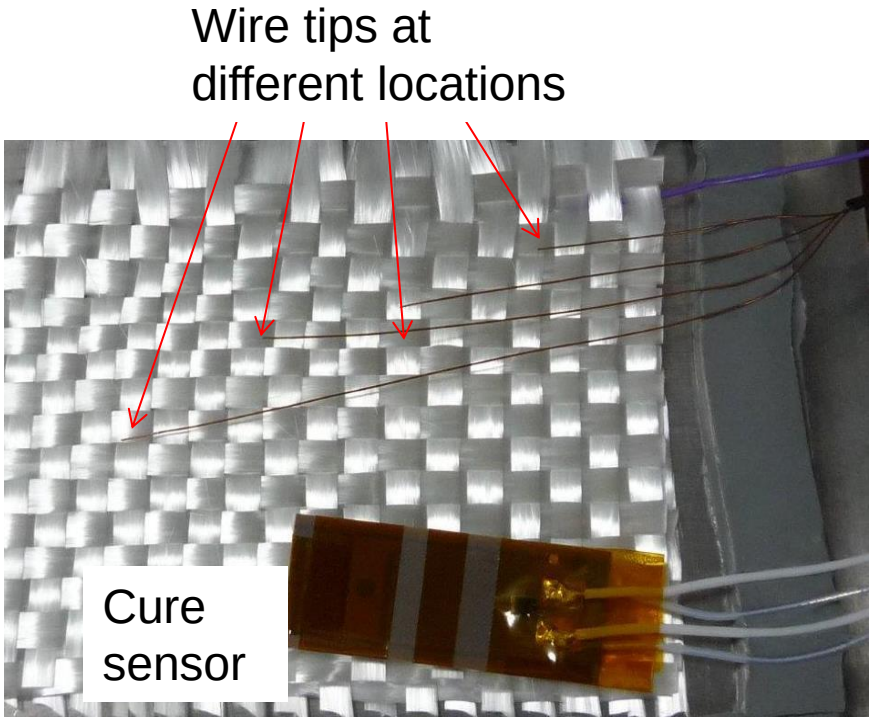
- Carbon fibre sensor (for glassfibre preforms)
  - CF or wire sensors can be used as lineal flow sensors and cure sensors when used with **Optimold** cure monitoring system
- Very thin wires (>0.2 mm) (for carbon fibre preforms)
  - In combination with Optiflow system
- New durable sensor for direct contact with CF
  - Without the need of glass-fibre protection

New Resin Arrival sensors

New disposable and, practically, non-intrusive sensors

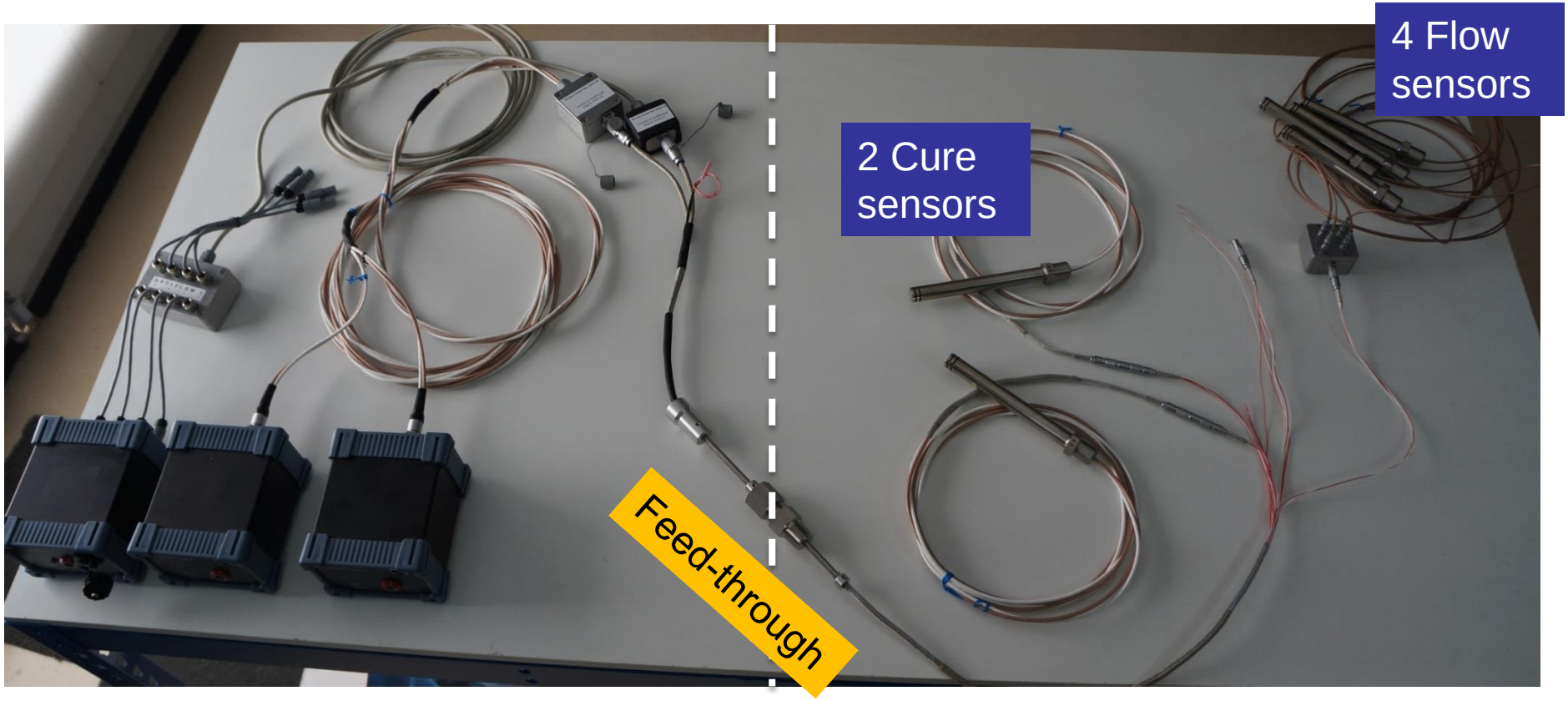
- Carbon Fibre Strands + metal tool





Thin wires (0.2-0.3 mm)
Carbon-fibre-proof

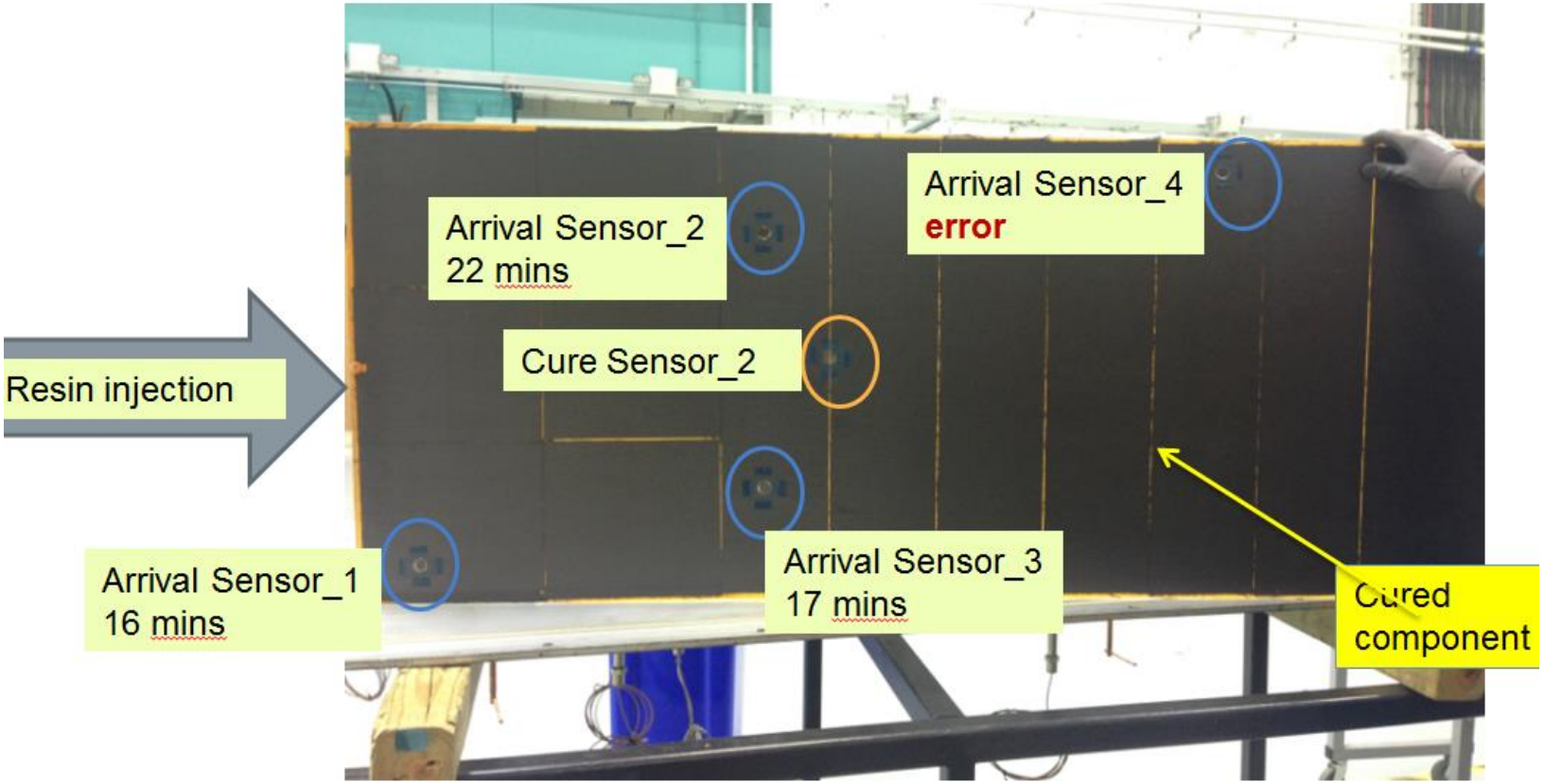
Bombardier test case
Process monitoring



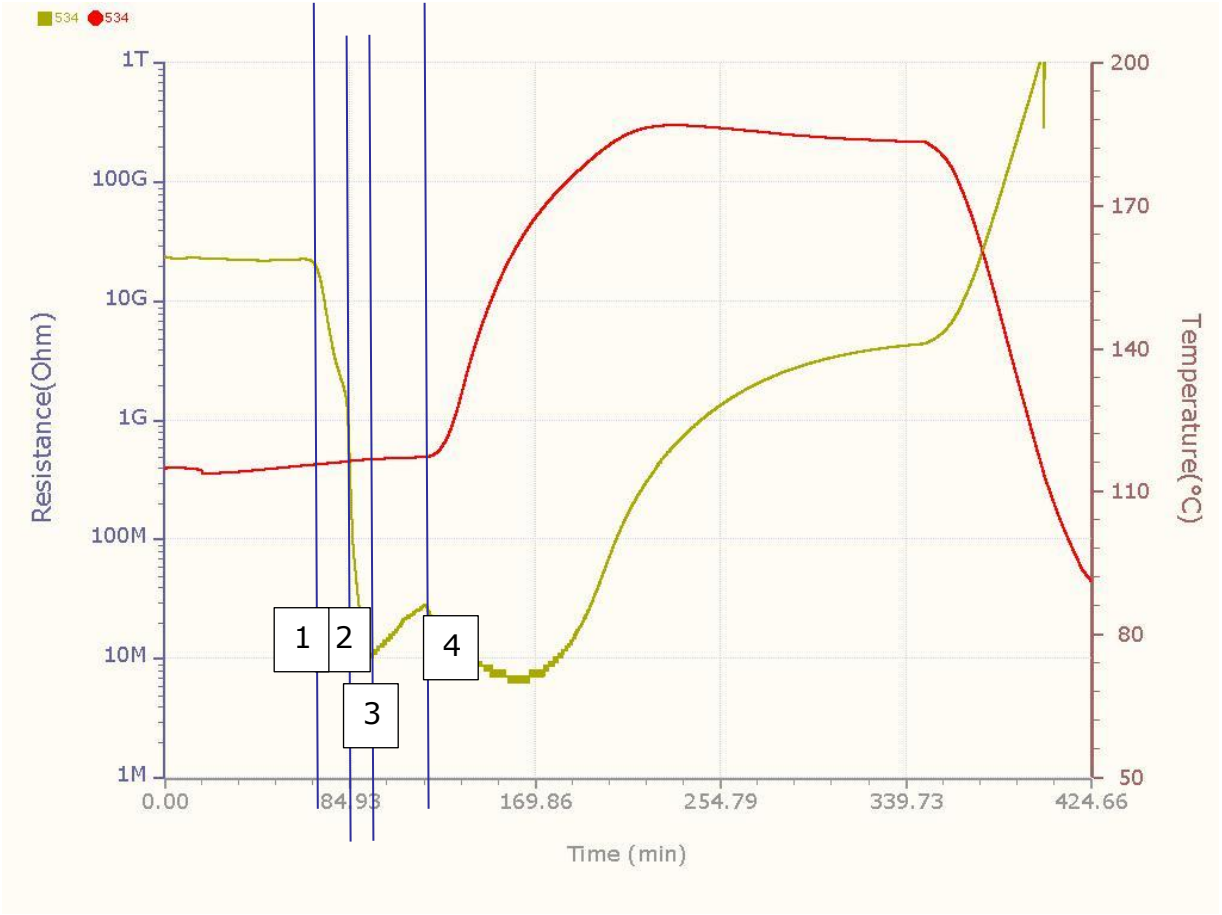
Outside the autoclave

Inside the autoclave

Bombardier Test case
1st trial

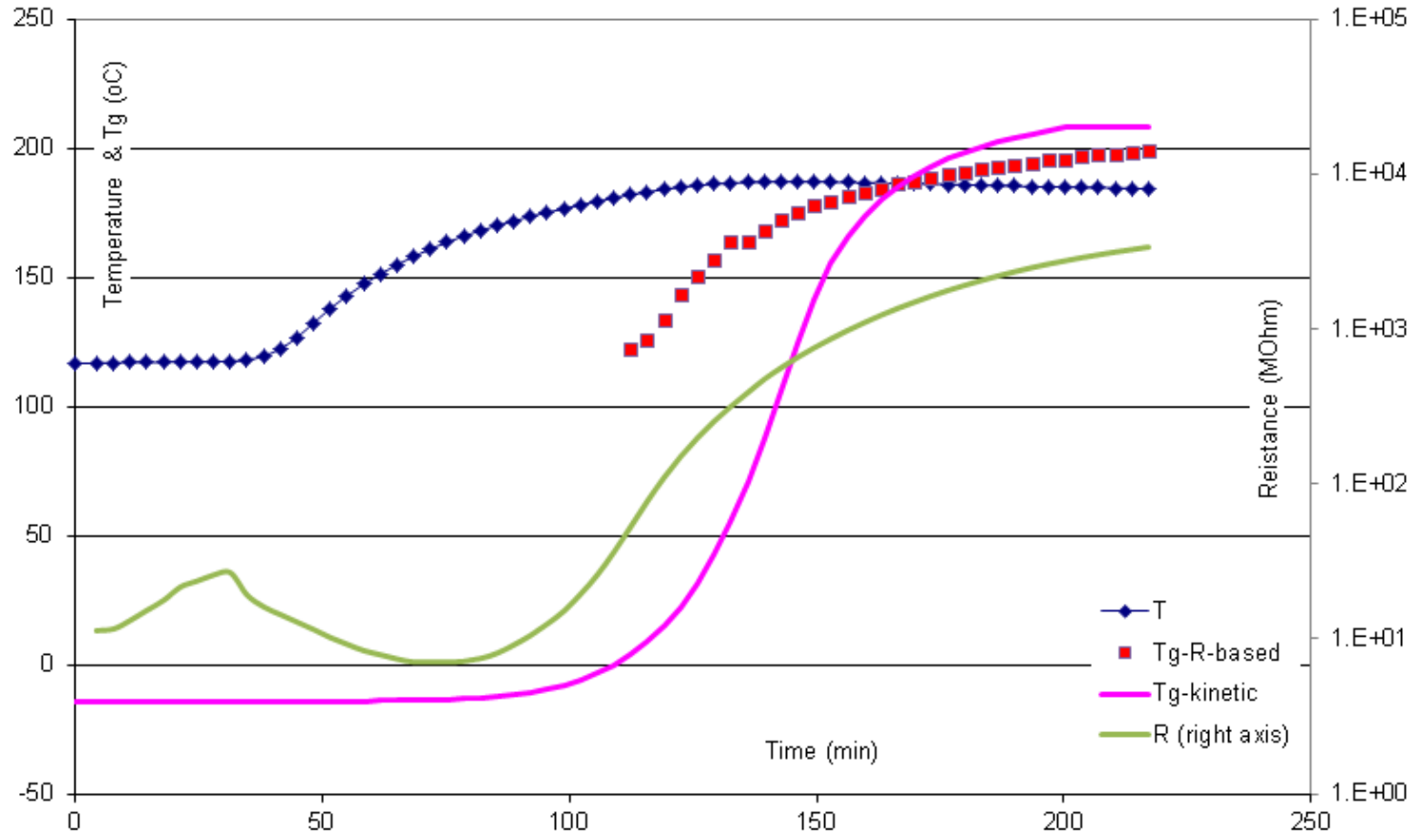


Bombardier Test case 2nd trial



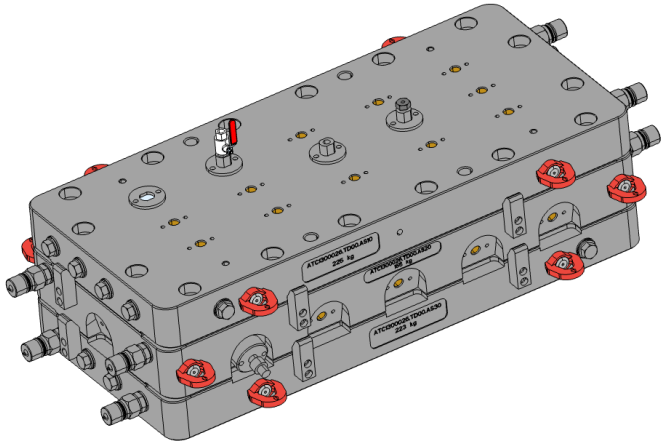
1: Very slow resin arrival;
2: pressure applied;
3: pressure released;
4: pressure re-applied

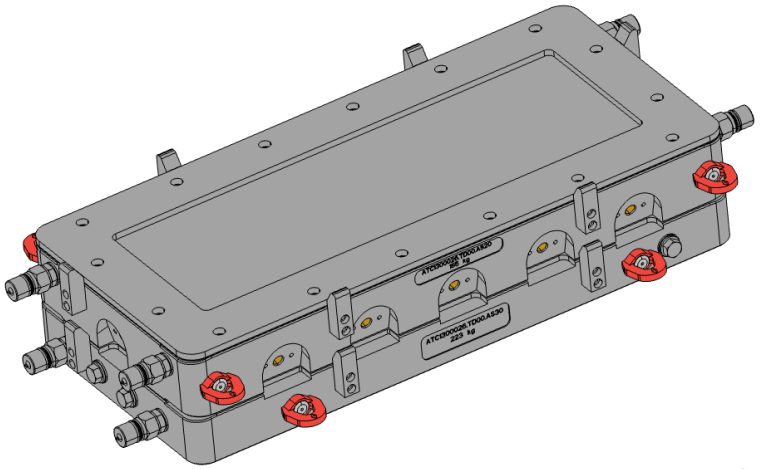
Bombardier Test case Resistance and Tg prediction

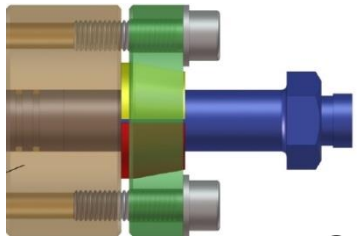


Cycom 890: Correlation between resistance and Tg real-time prediction

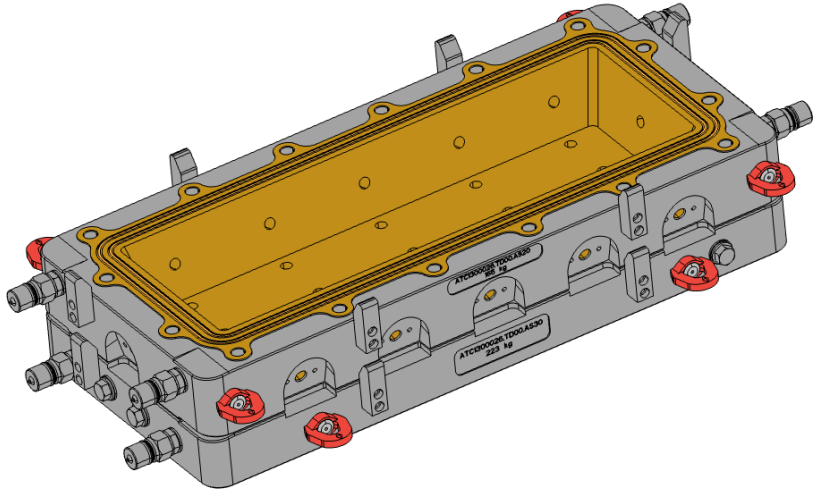
Airborne Test case
Test Mould for thick parts



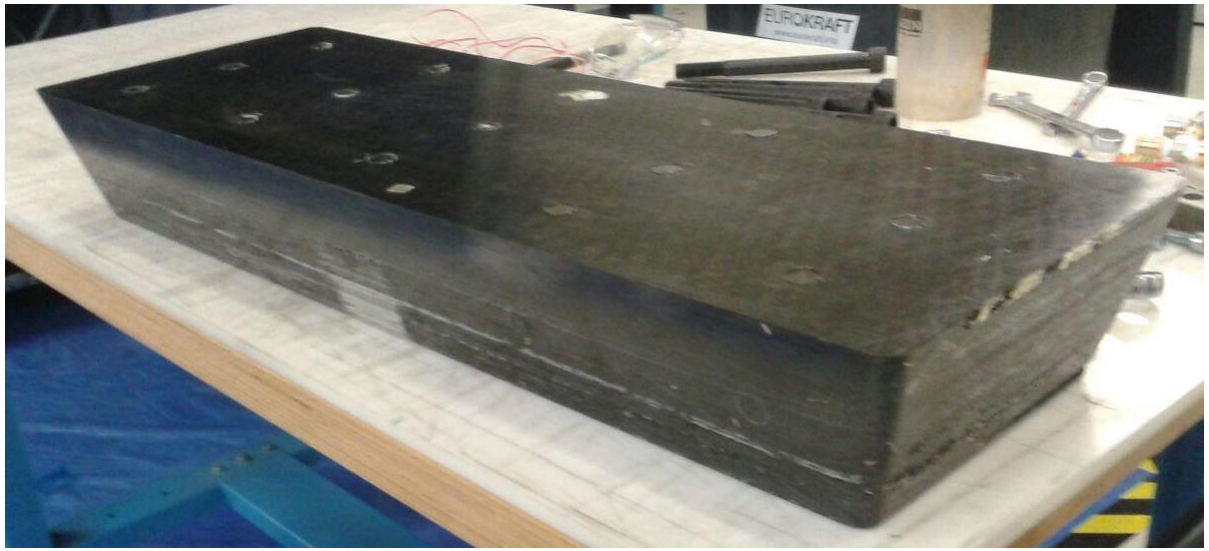




In-mould sensor with mould adaptor

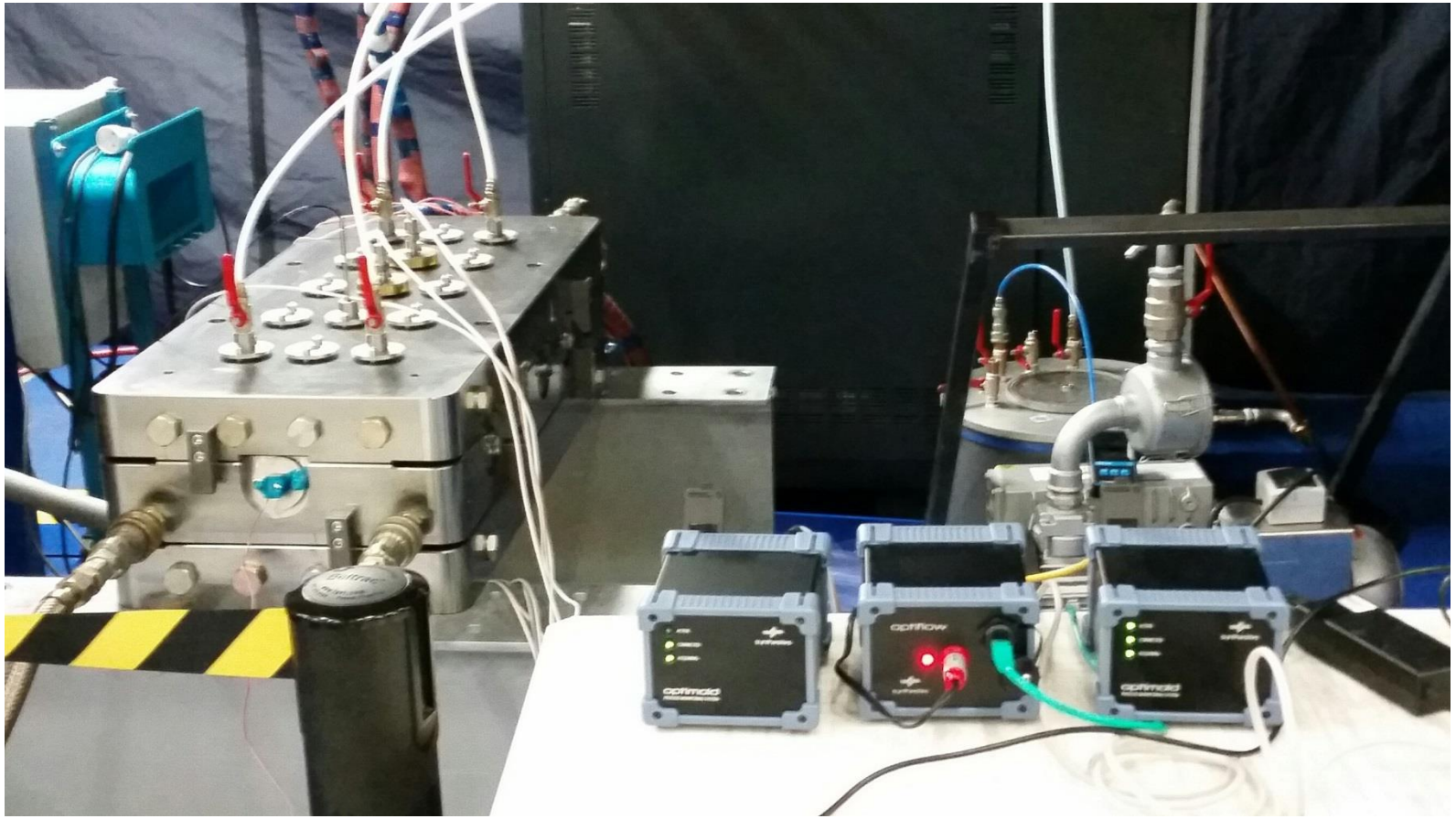


Airborne Test case (1st part produced)



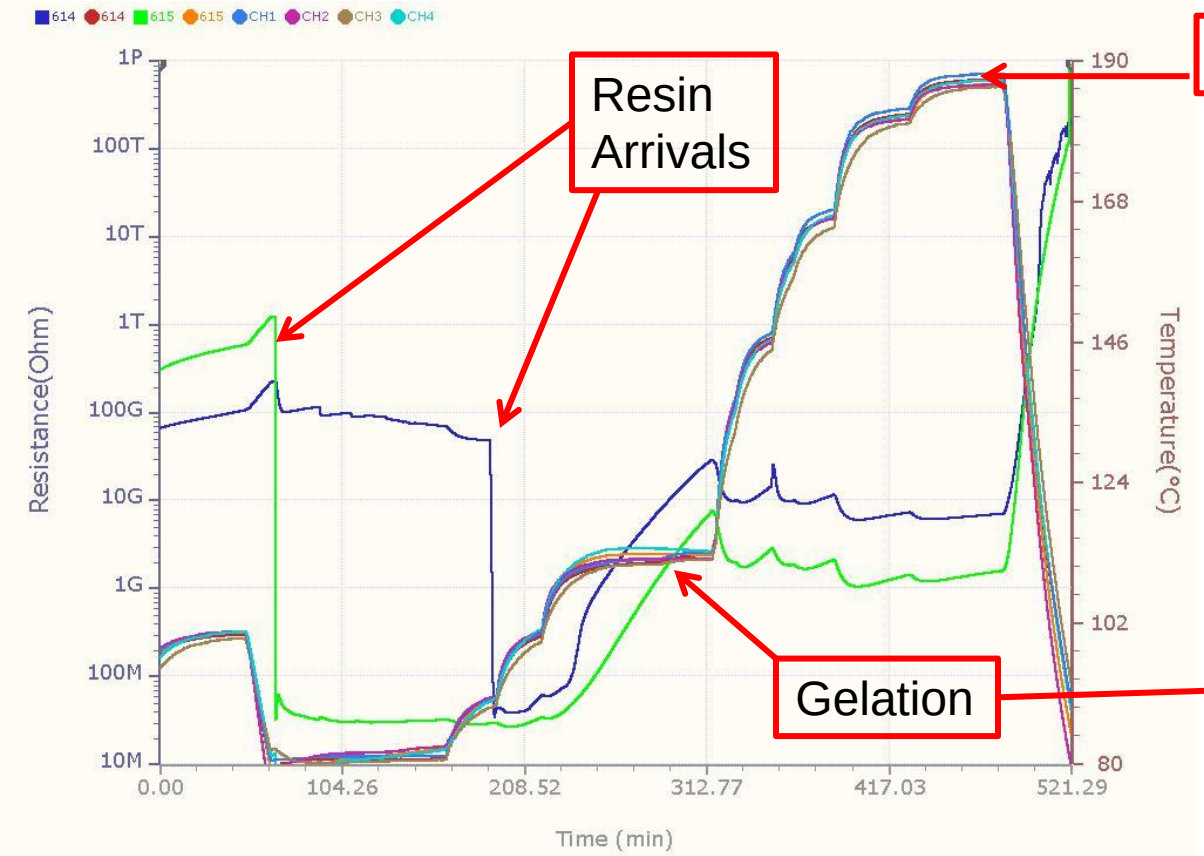
Cavity dimensions
Length and width at the Bottom mould: 700 x 200 mm
Length and width at the Top mould: 750 x 250 mm (draft angle of 15°)
Thickness: 100 mm
Total internal volume is 16 litres (approx.).

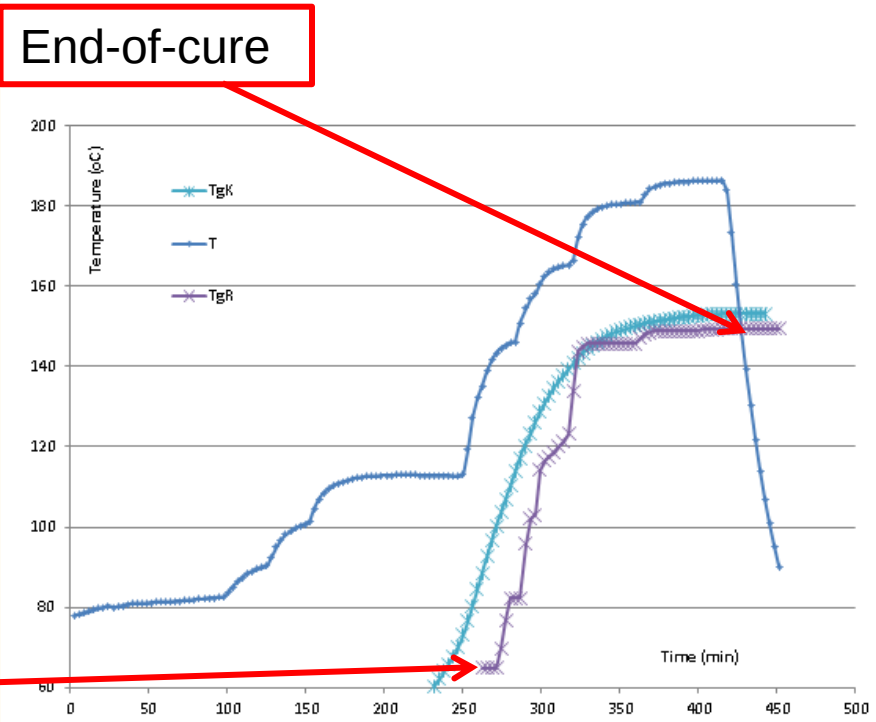
Airborne Test case
Trials set-up



8 Resin Arrival and 2 Cure durable sensors from Synthesites in addition to 1 pressure sensor and 6 thermocouples

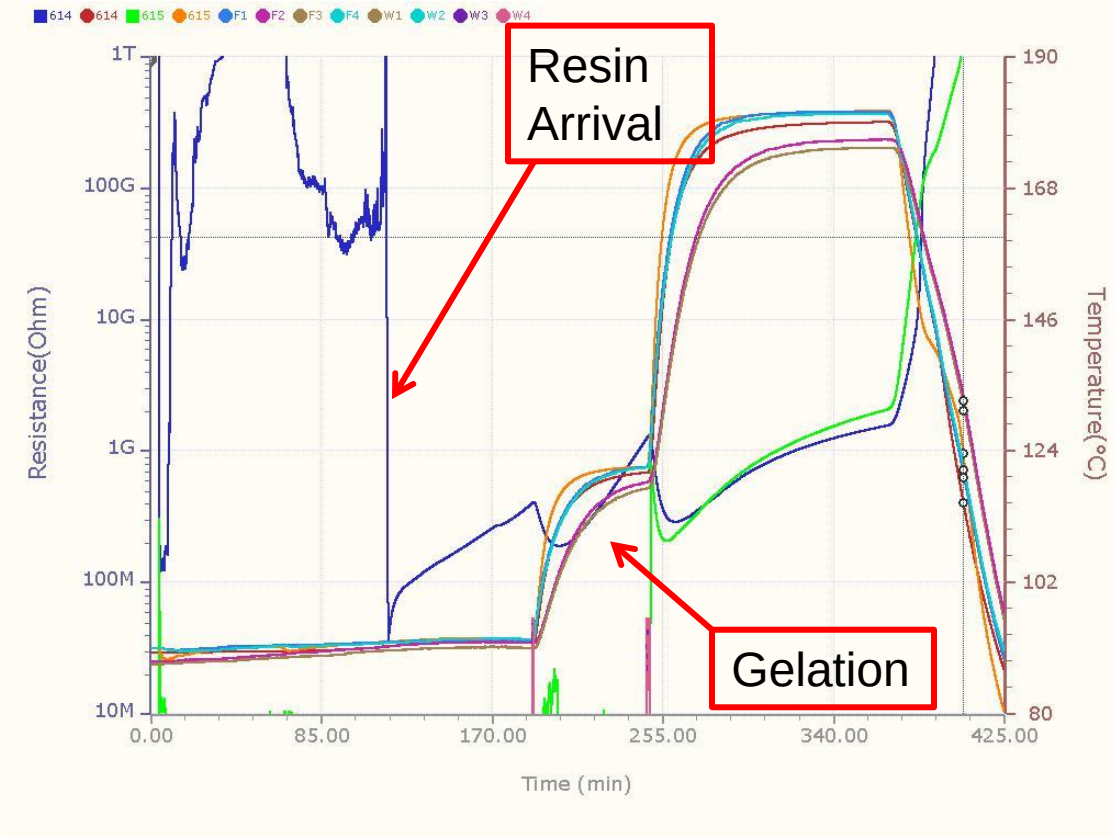
Airborne Test case
First Trial: results and Tg prediction

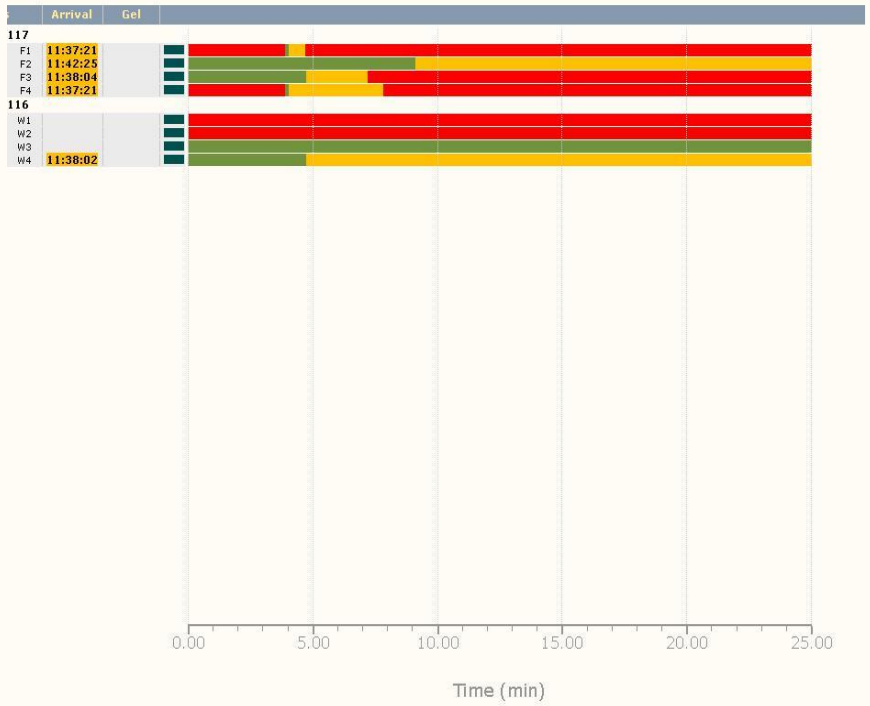




6 temperatures and 2 resistance curves (left figure) and Tg evolution as predicted by kinetic model (TgK) and measured resistance (TgR) (right figure).

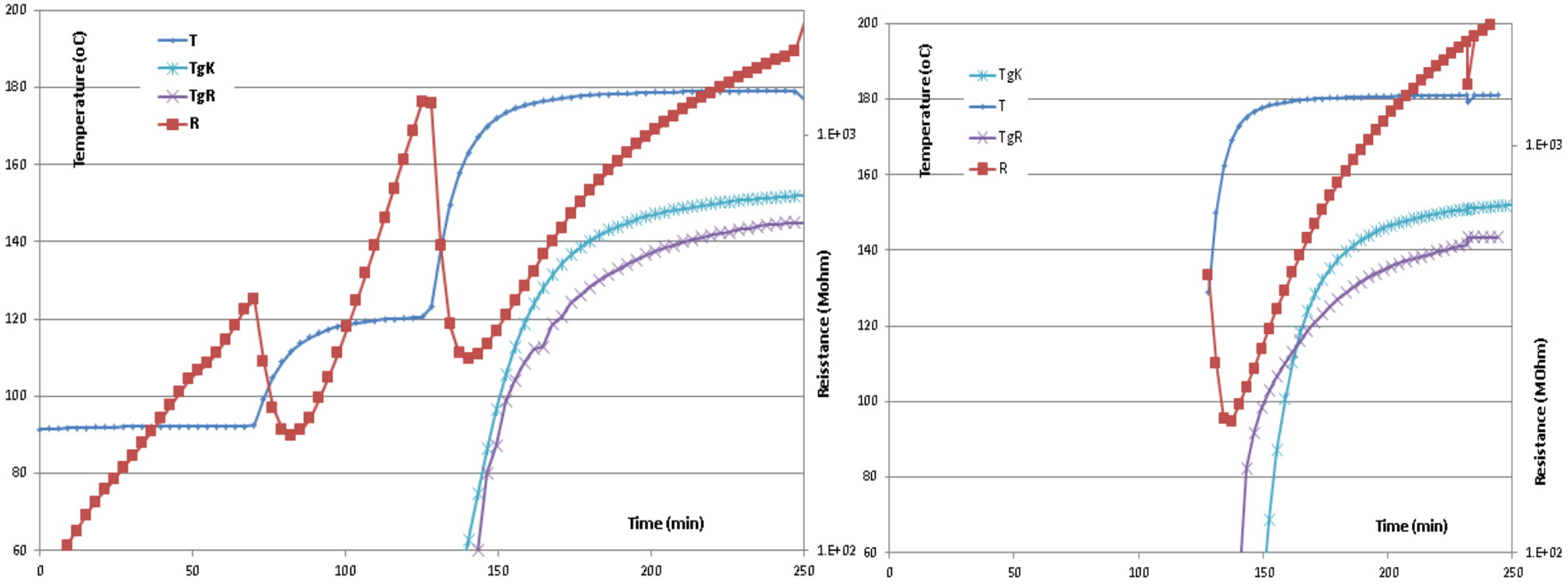
Airborne Test case
2nd Trial: Flow and cure





6 temperatures and 2 resistance curves (left figure) and 8 resin arrival sensors (right figure).

Airborne Test case
2nd Trial: Tg prediction



Tg prediction based on kinetic model and resistivity for cure sensor #1 (left figure) and cure sensor #2 (right figure).

Conclusions

- Real-time process monitoring has become more intelligent and matured towards industrial applications
- Within Ecomise project, considerable advancements have been achieved e.g. to complete the sensor series with flow sensors that can help significantly in the identification of the resin's flow paths
- Process monitoring can also provide reliable and quantified information about the Tg evolution so demoulding can be optimised
- Furthermore, the reliable and intelligent process monitoring combined with appropriate modelling and simulation tools can provide a unique platform for optimal control of the process ensuring product quality.

Acknowledgements

This work was partially supported by the European Commission FP7 programme under Grant NMP2-SL-2013-608667 (Enabling Next Generation Composite Manufacturing by In-Situ Structural Evaluation and Process Adjustment).

The paper clearance and collaboration with the partners of Ecomise project is gratefully acknowledged.

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Thank you