# Towards the intelligent RTM system


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# Background

- **Resin Transfer Molding (RTM) is a 'blind' and complex process**

**Furthermore**

- **Process monitoring in composites production is very 'primitive' even in aerospace**
  - **No real feedback from the cavity until demoulding**
  - **Only Temperature is being monitored (and in most cases far from the part)**

**This eliminates the possibility to track and solve problems during production but also the possibility to solve the problems later (since no relevant data exist)**

# The Resin monitoring system

- **Check resin quality and adjust process accordingly**
- **Detect accurately resin arrival at critical locations**
  - **Open/close valves based on sensors' feedback**
- **Monitor viscosity changes and decide when start heating**
- **Identify minimum viscosity and decide about pressure**
- **Detect unexpected events and follow alternative routes**
- **Improve simulation accuracy and design intelligent strategies**
- **Real-time decision of the cure cycle based on Tg and degree of cure (depends on the resin) rather than time**

# ECOMISE Project

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)

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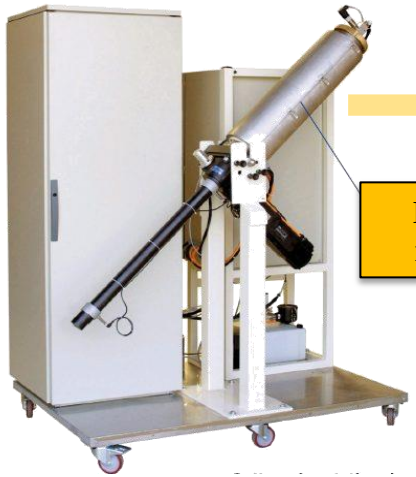
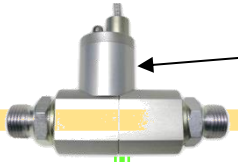
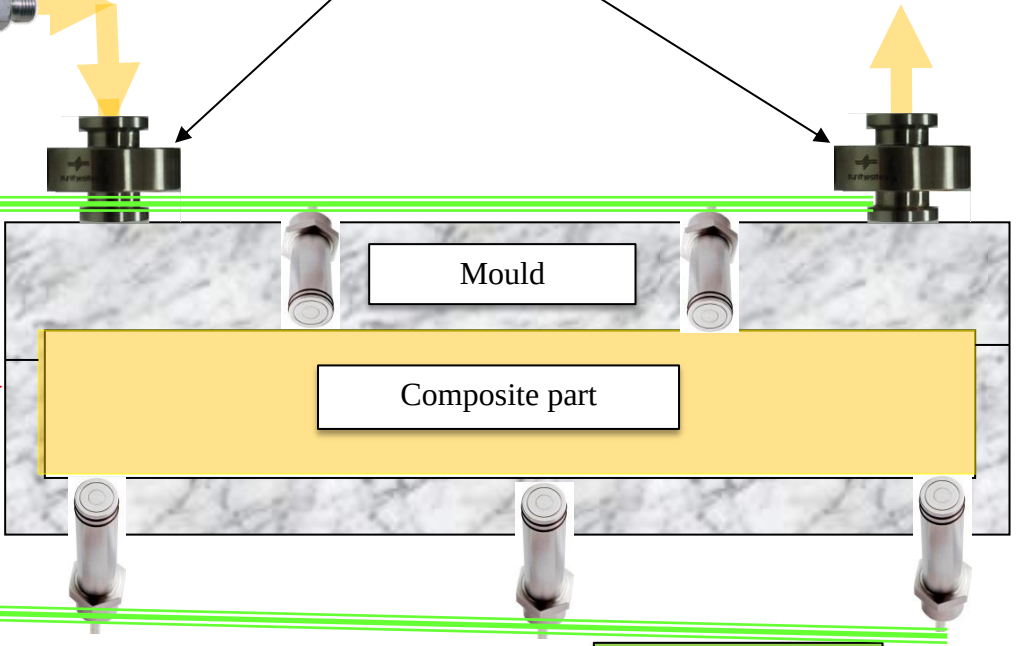
# Intelligent Closed Moulding



Injection machine



Inline Sensors




In-mould Sensors


Control Actions

Temperature controller(s)

DAQ + Control


Monitoring Systems

# Process Monitoring Systems used

## OptiFlow
## Resin arrival, temperature

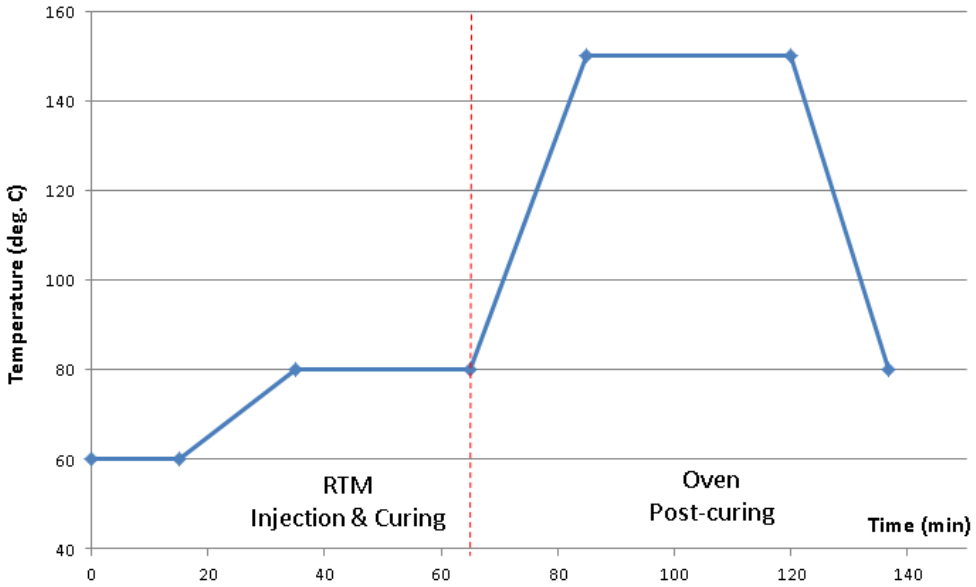

- 4 temperature and resin arrival sensors
- Resistance-based measurements and RTD temperature
- Continuous connection checking
- One relay output for process automation

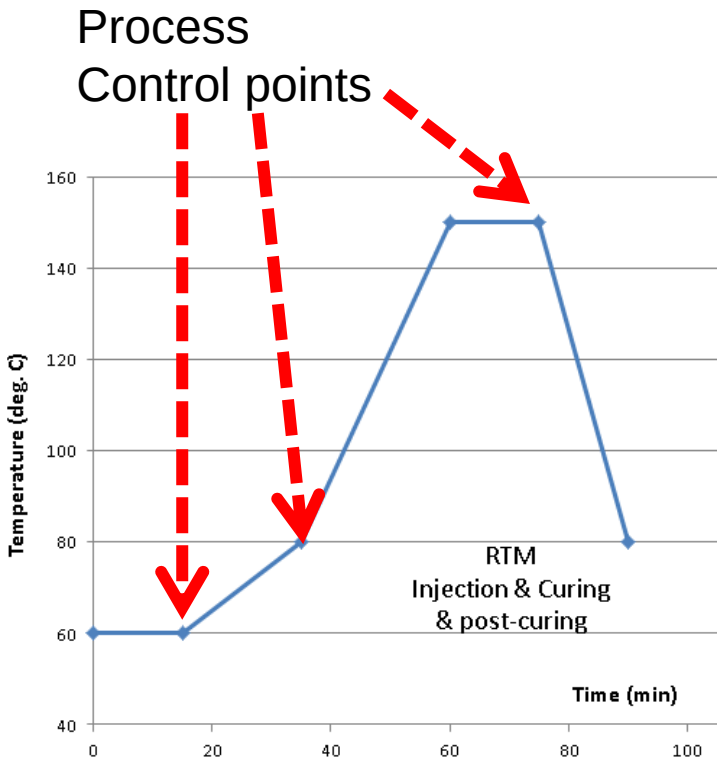
## Optimold
## Cure, viscosity, resin quality


Real-time measuring of

- Resin's electrical resistance (from 0.1 MOhm up to 50 TOhm)
- temperature (pt100 sensor with 0.1°C accuracy)

# Intelligent monitoring and control




Measured temperature (*TC1, TC2)*, *r*esistance-based calculated Tg *(TgR1, TgR2)* and the theoretical Tg (*TgK1, TgK2)* for the C1 and C2 sensors together with the Tg targets

# Off-line and On-line Optimisation Strategies

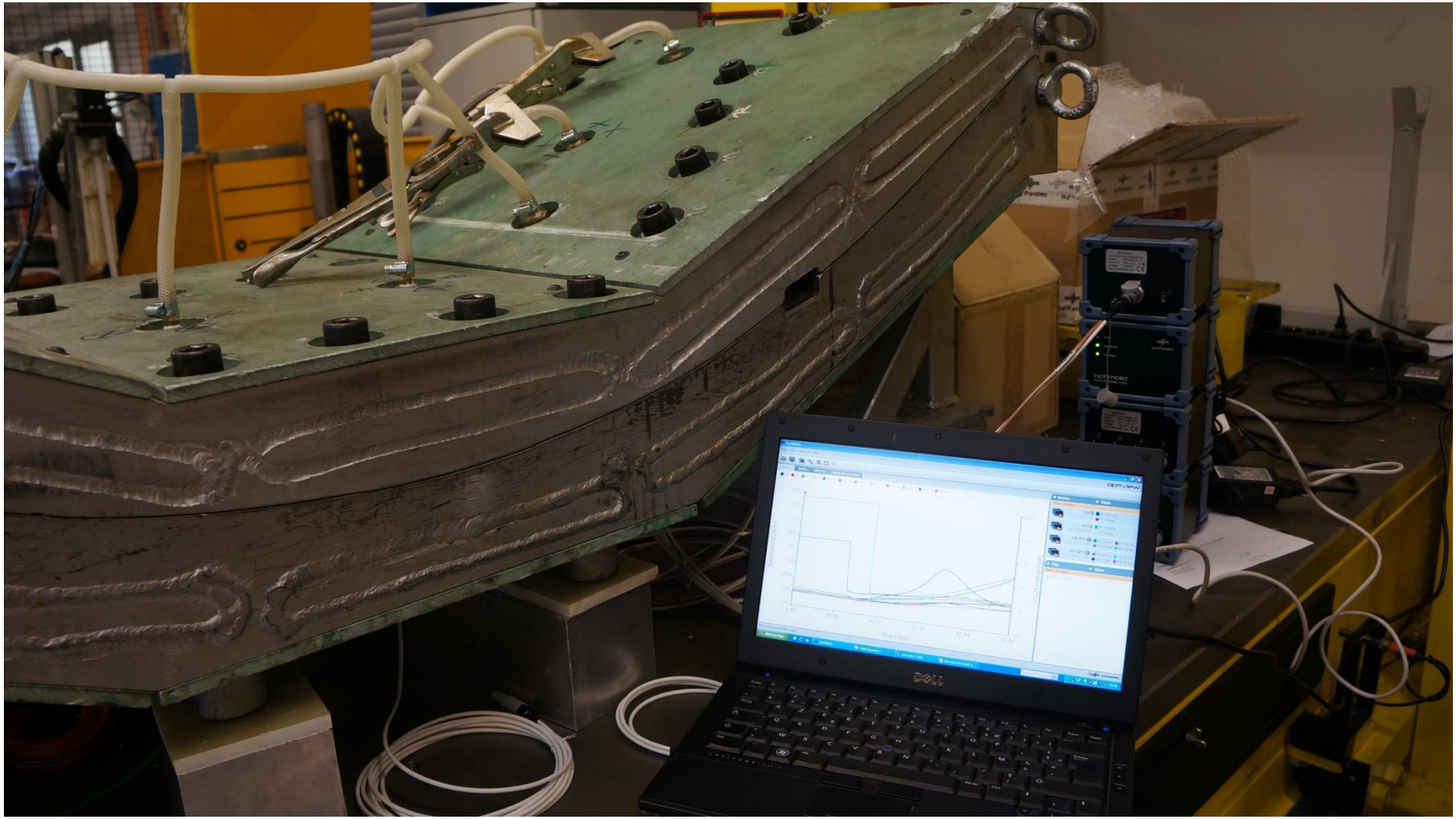
Off-line Optimisation Strategy (Using the 1D-heat transfer model and the robust optimisation tool)

1. Prescribed filling time
2. Calculate the minimum necessary temperature to achieve the targeted degree of cure from the di Benedetto equation $a_{max} = f(T_{max}) \rightarrow T_{max} = f^{-1}(a_{max})$
3. Set heating ramp = max heating rate (in case of high heating rates exotherms might be also considered).
4. Calculate necessary time at $T_{max}$

On-line Optimisation Strategy

1. Completion of the filling stage based on sensors and start the first heating ramp
2. Completion of the curing stage based on Tg-prediction and start the second heating ramp
3. Completion of the post-curing stage based on Tg-prediction and start cooling or demoulding

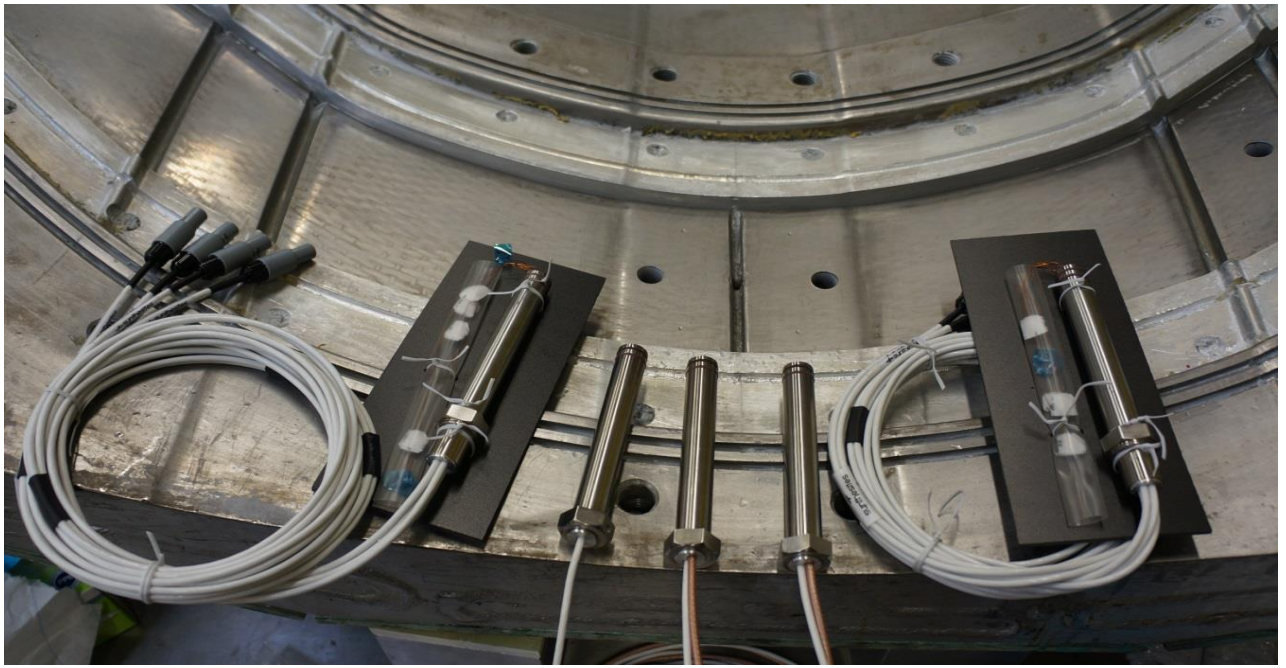
# RTM mould and process monitoring systems



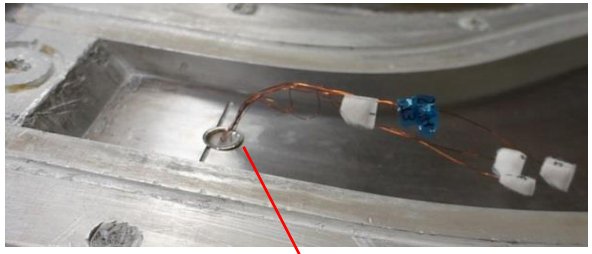
# Cure, Flow and Temperature sensors
# Durable and embedded sensors

Durable Sensors
- 2 Cure
- 1 Flow+Temperature

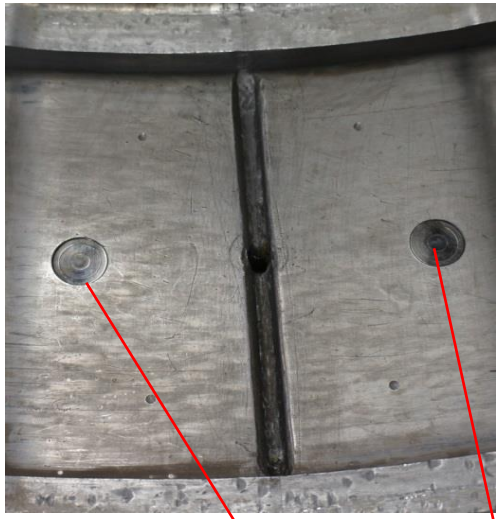
Embedded Sensors
- 8 Arrival
- 8Temperature



# Hutchinson Demo
# suspension blade Glassfibre/ epoxy with RTM



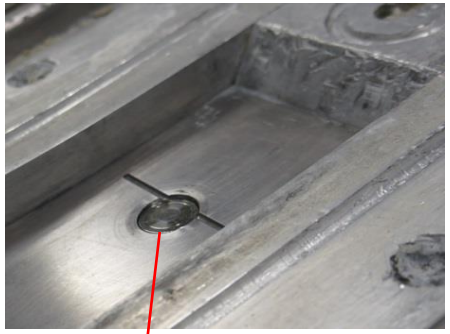
8 Embedded sensors (through-thickness) SET2



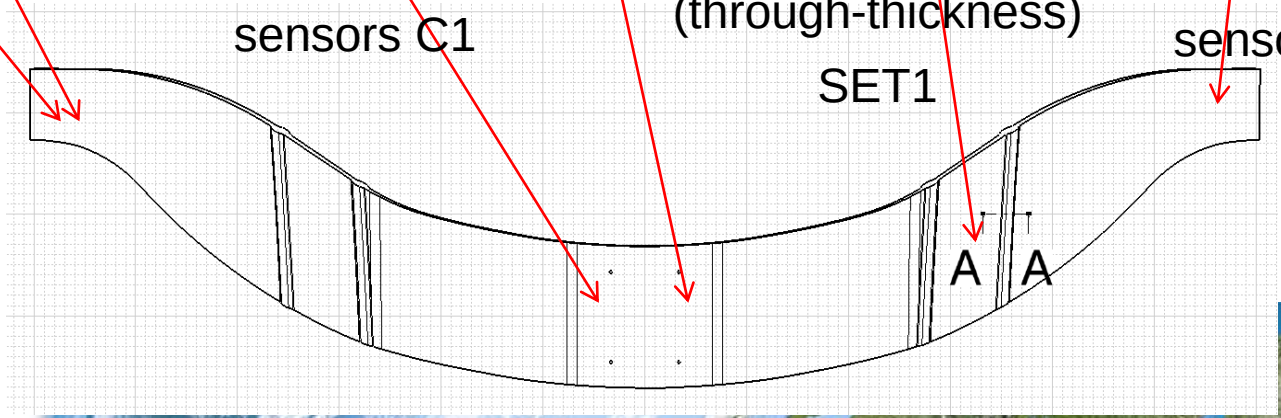
Durable Sensors

Flow F1 and cure sensors C1

8 Embedded sensors (through-thickness) SET1



Durable Cure sensor C2

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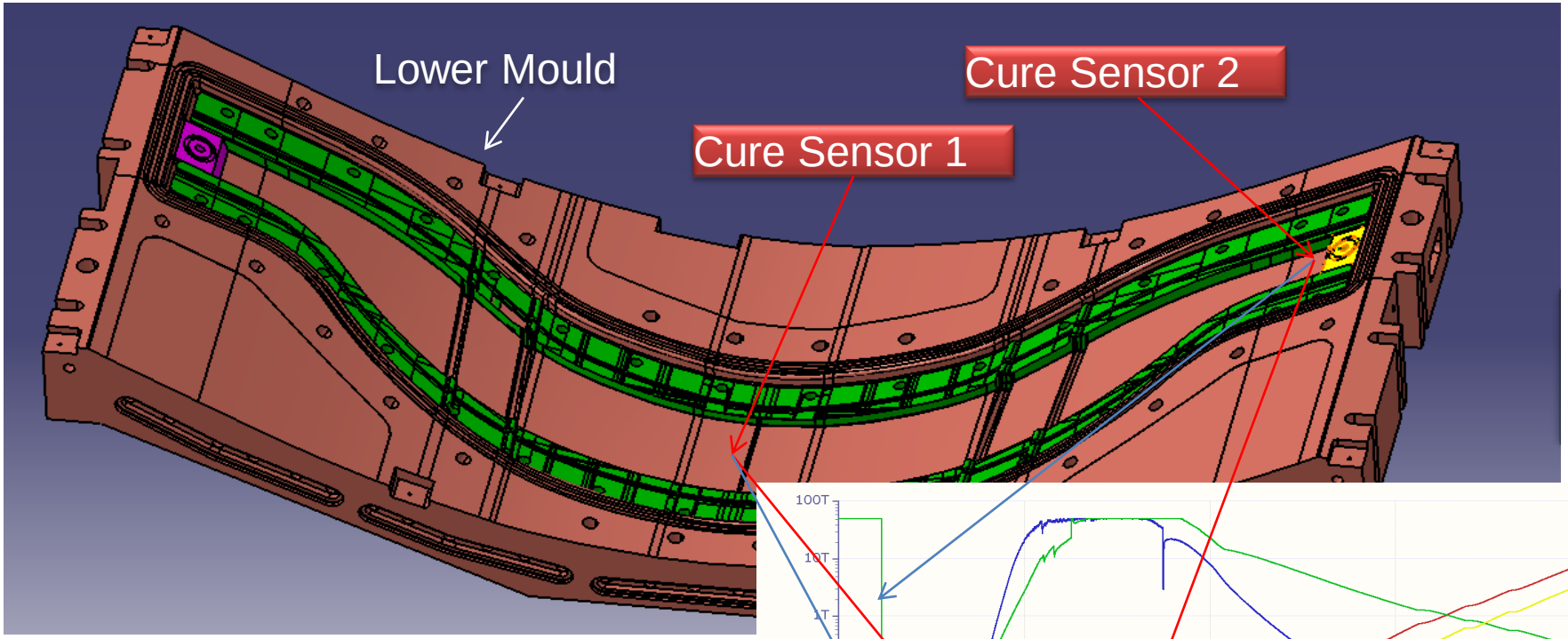
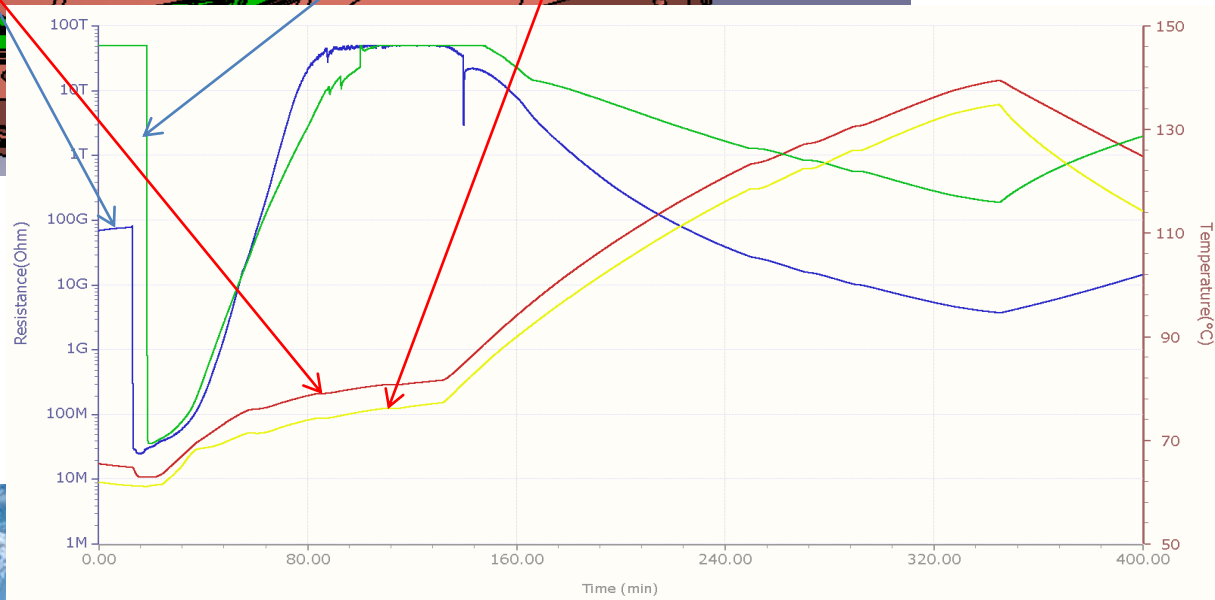
# Cure sensors position

- 2 cure sensors (cure sensor 1 close to injection point)



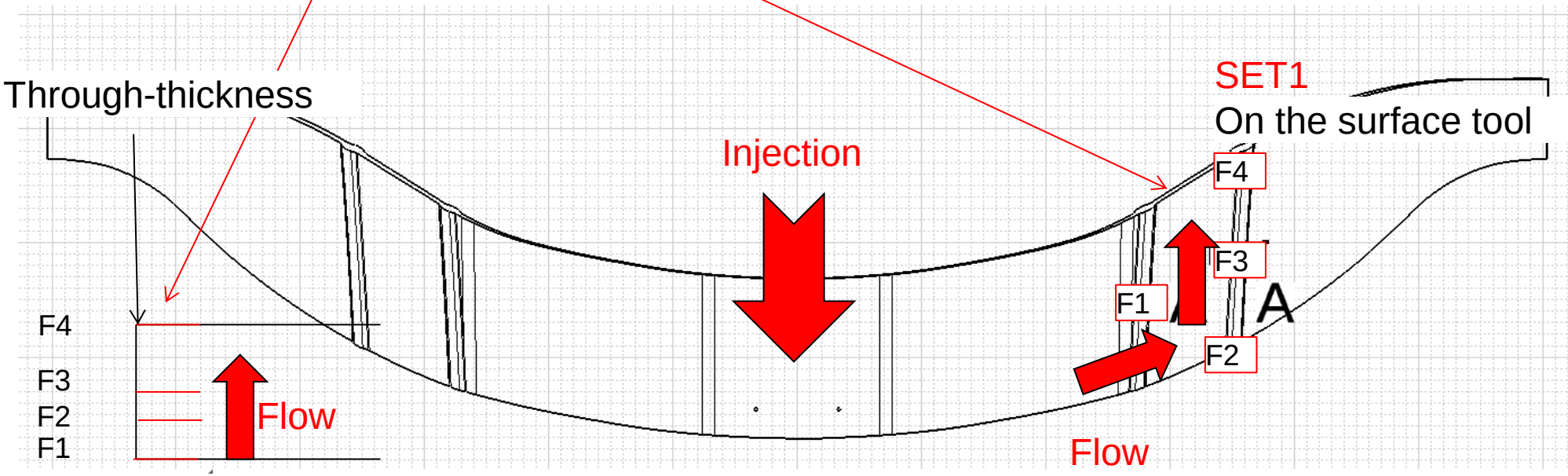



# Flow sensors

- 8 Resin Arrival (Flowire) connected to 2 Optiflow systems

Through-thickness

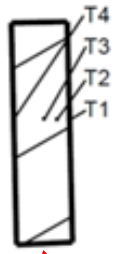
Resin arrival time stamps

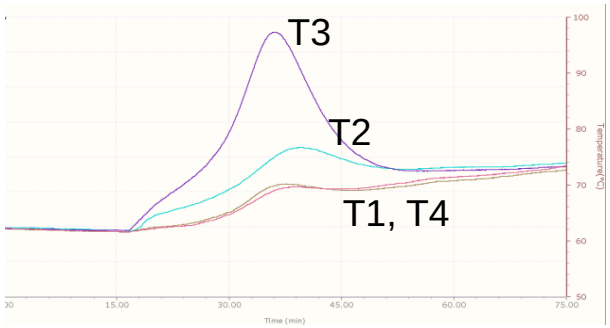



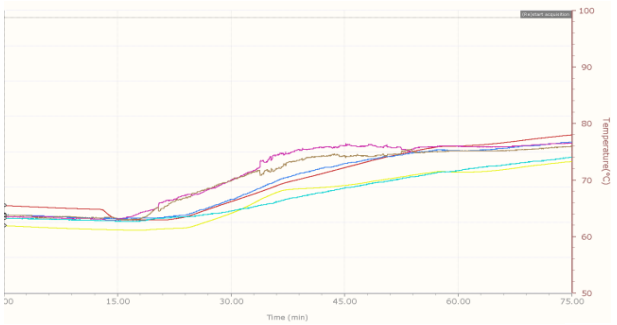
# Temperature sensors

- 8 embedded temperature sensors connected to 2 Optiflow systems

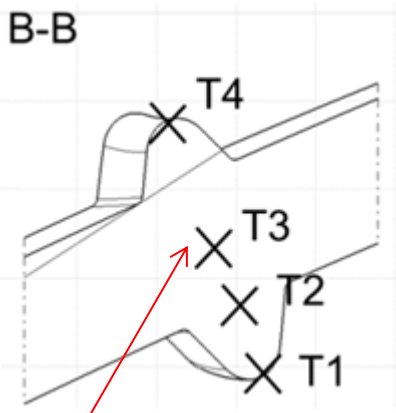
Through-thickness



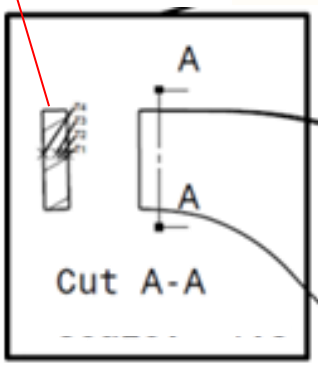



Through-thickness

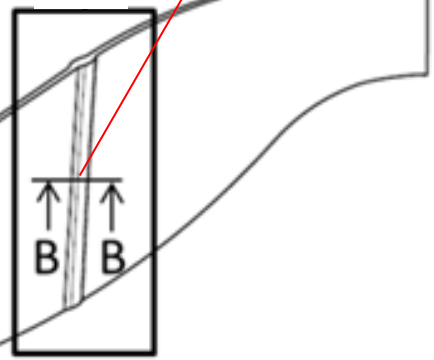



SET2

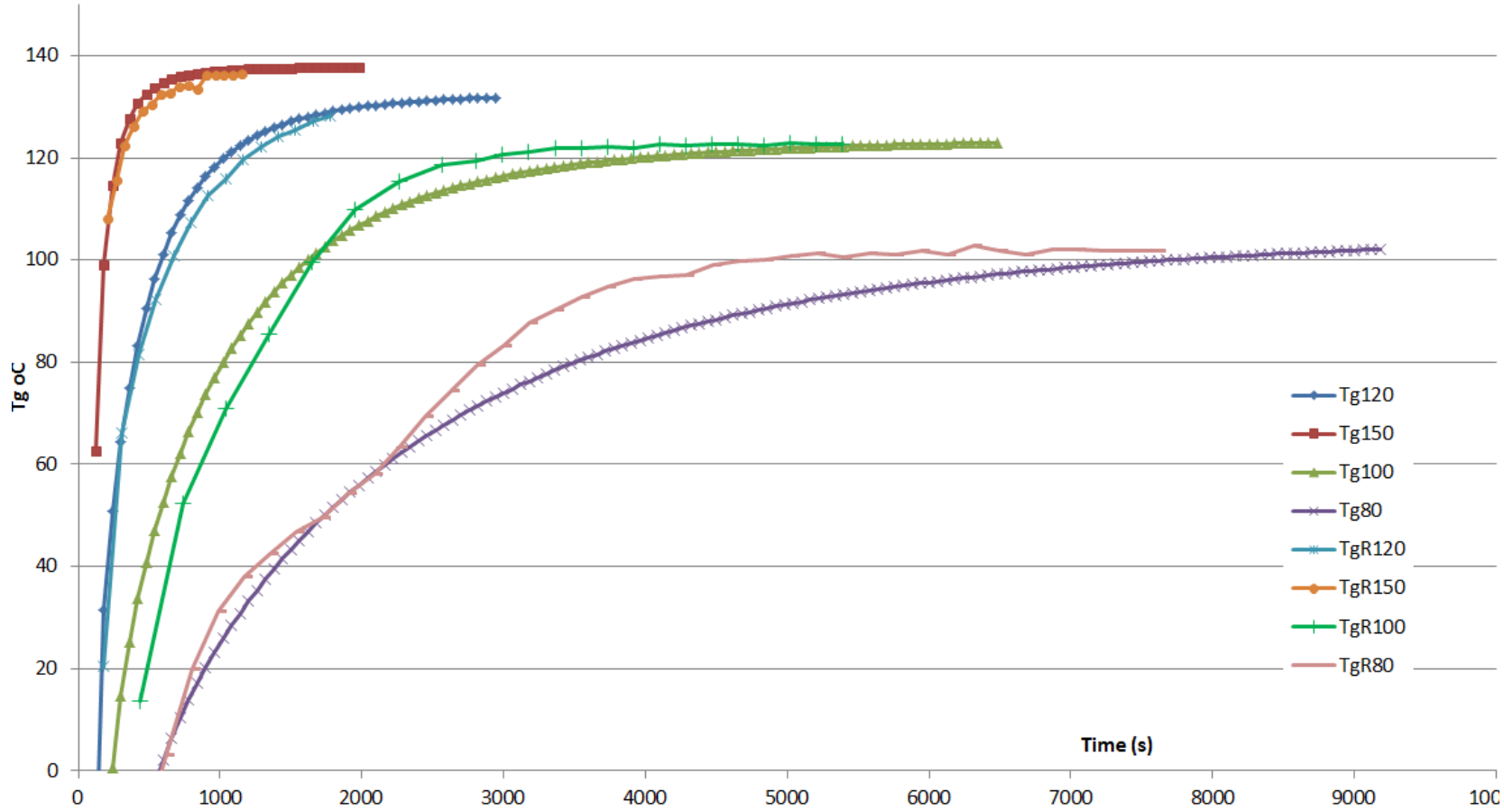



SET1

Premature exotherm just after injection due to resin reach area

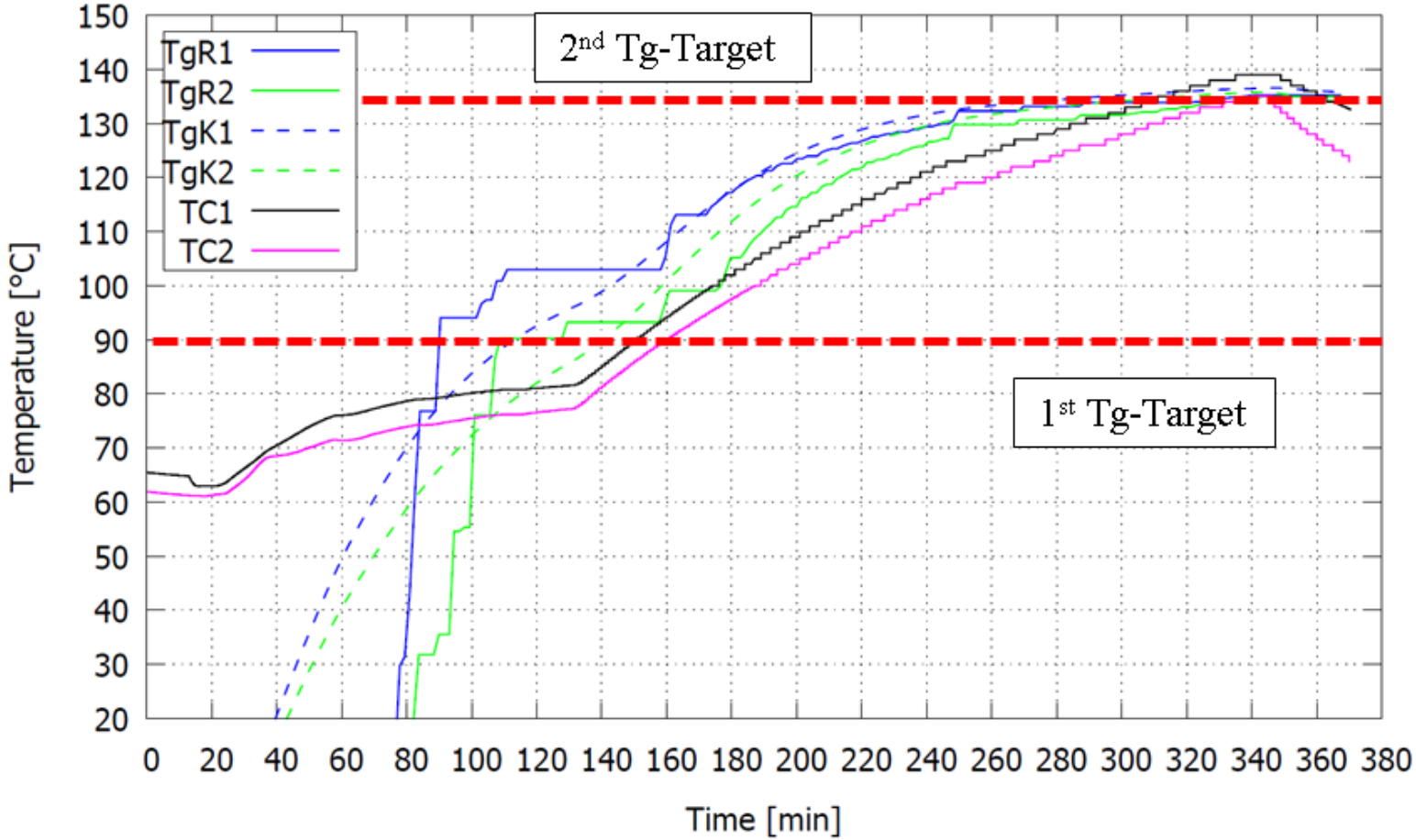


# Predicting Tg in real-time



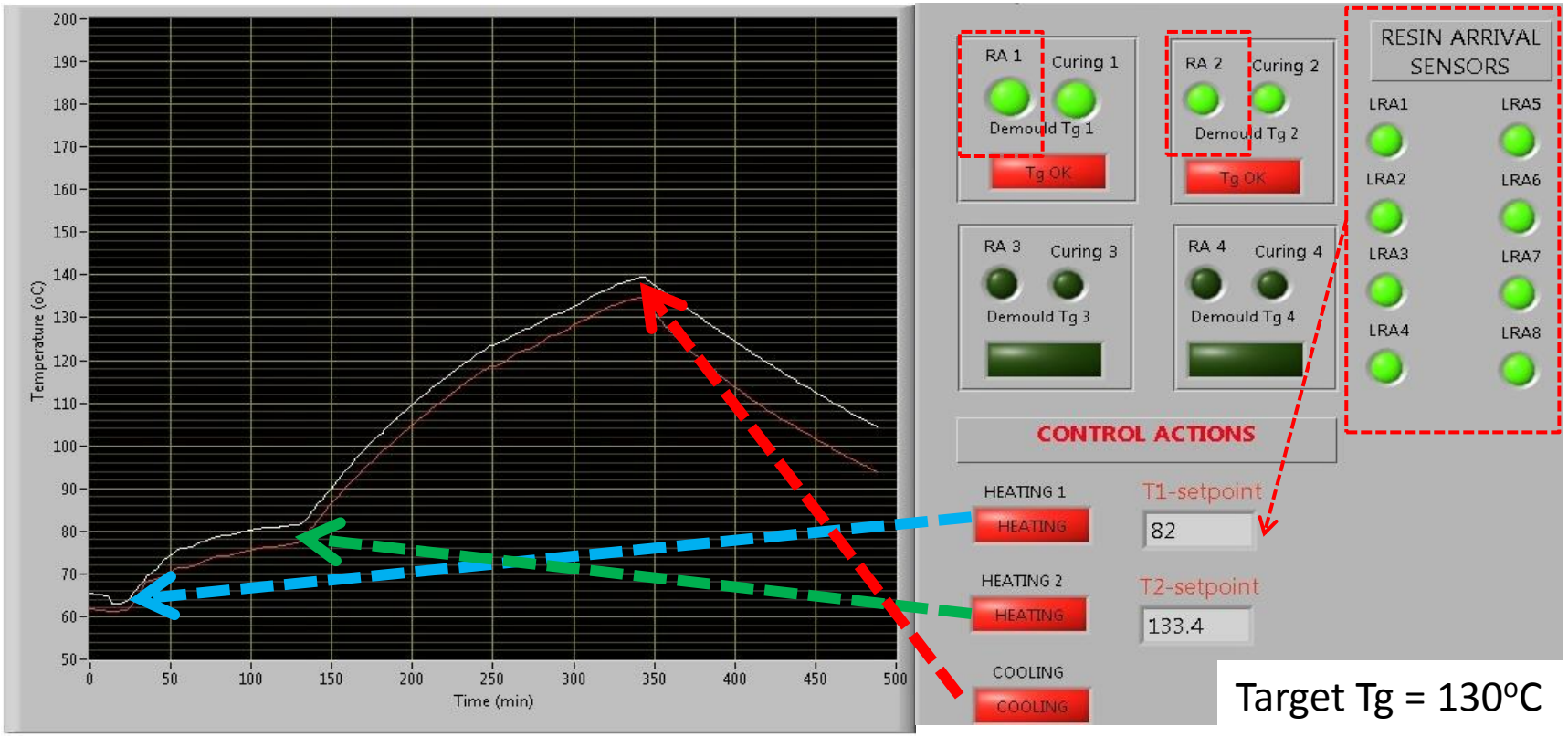

Tg prediction based on resistivity (TgR*) and on kinetic models (Tg*) for 4 isothermal cycles at 80°C, 100°C, 120°C and 150°C.

# Intelligent monitoring and control



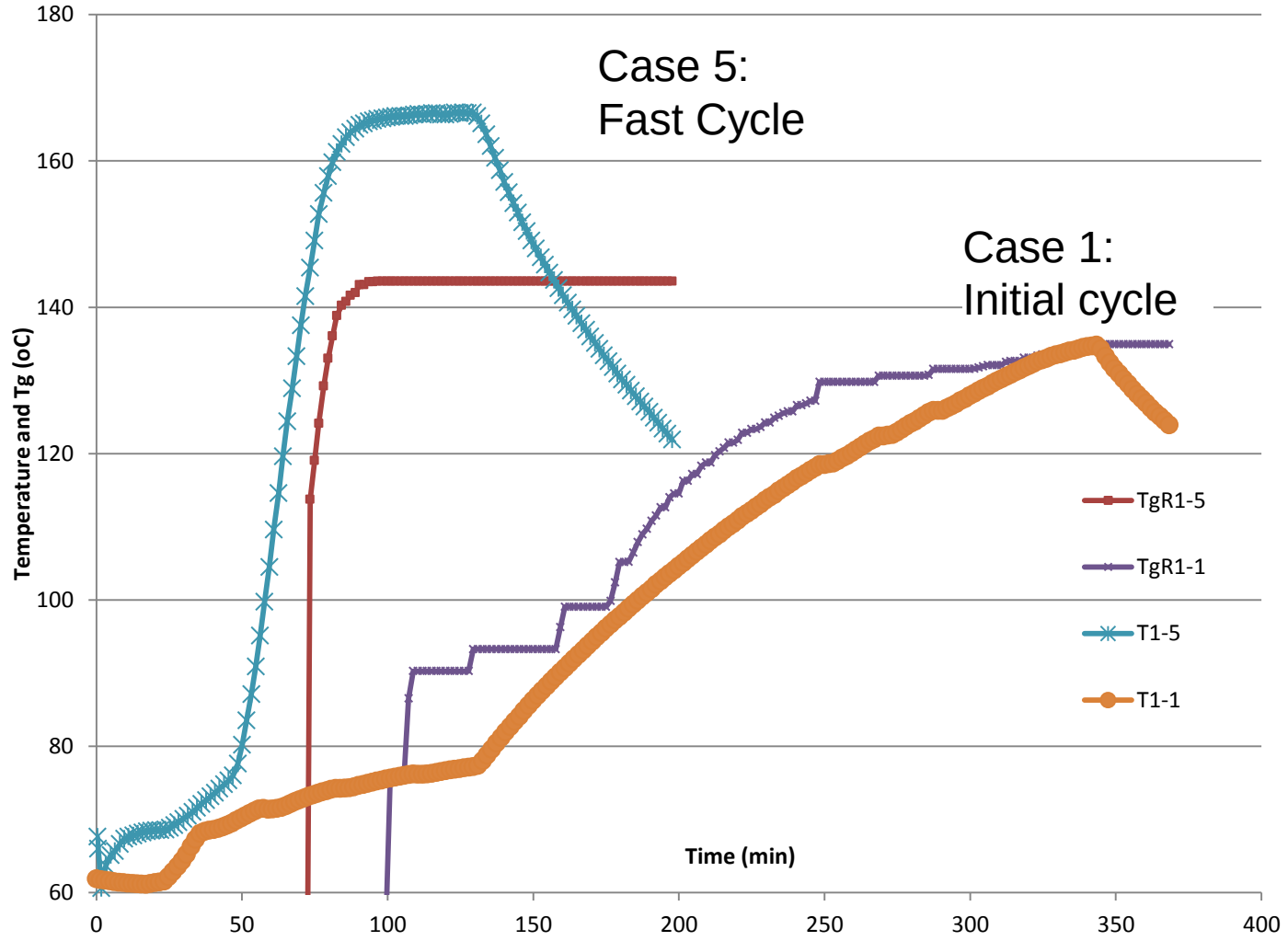

Measured temperature (*TC1, TC2)*, *r*esistance-based calculated Tg *(TgR1, TgR2)* and the theoretical Tg (*TgK1, TgK2)* for the C1 and C2 sensors together with the Tg targets

# Intelligent RTM process control




Real-time Tg calculation and demoulding decision based on targeted Tg (target Tg = 130°C)

# Optimized cycle



# Conclusions

- The Intelligent Process Monitoring and Control Platform developed in ECOMISE is a reliable solution for automating and optimising composites manufacturing
- The platform can provide reliable solutions for online and offline optimization of the process
- The adaptation and tuning of the platform to the process-specific needs can be done on-site so no costly lab-scale trials are necessary.
- A speed-up of more than 30% with respect to conventional processing can be achieved.
- Further benefits from the use of this technology from the development phase.
- Industrial applications in Aerospace, Automotive, Energy and potential for customized solutions according to customers' needs.

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SEVENTH FRAMEWORK PROGRAMME