Non-intrusive intelligent cure monitoring for enhancing the manufacturing of high-temp composite structures

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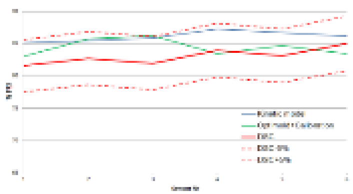
Products and Services

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



Sensors (durable/ disposable, flexible, gate, custom)



Real-time calculation of Tg/ degree of cure/ viscosity/ resin quality (ORS software)

Automation, design and prototyping

Optimold
Cure, viscosity, resin quality check

Real-time measuring of

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

Input of external signals e.g. pressure sensors

process monitoring sensor = electrical resistance + RTD sensors

Durable sensor

High Temp RTM

- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

Flexible sensor

VI and RT cure

- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

Inline sensor

- Avoid pipe cleaning
- Adjust cycle
- Mixing ratio check

Pot sensor

- Mixing ratio
- Resin Quality
- Resin aging
- Adjust cycle

New

CF In-mould Durable

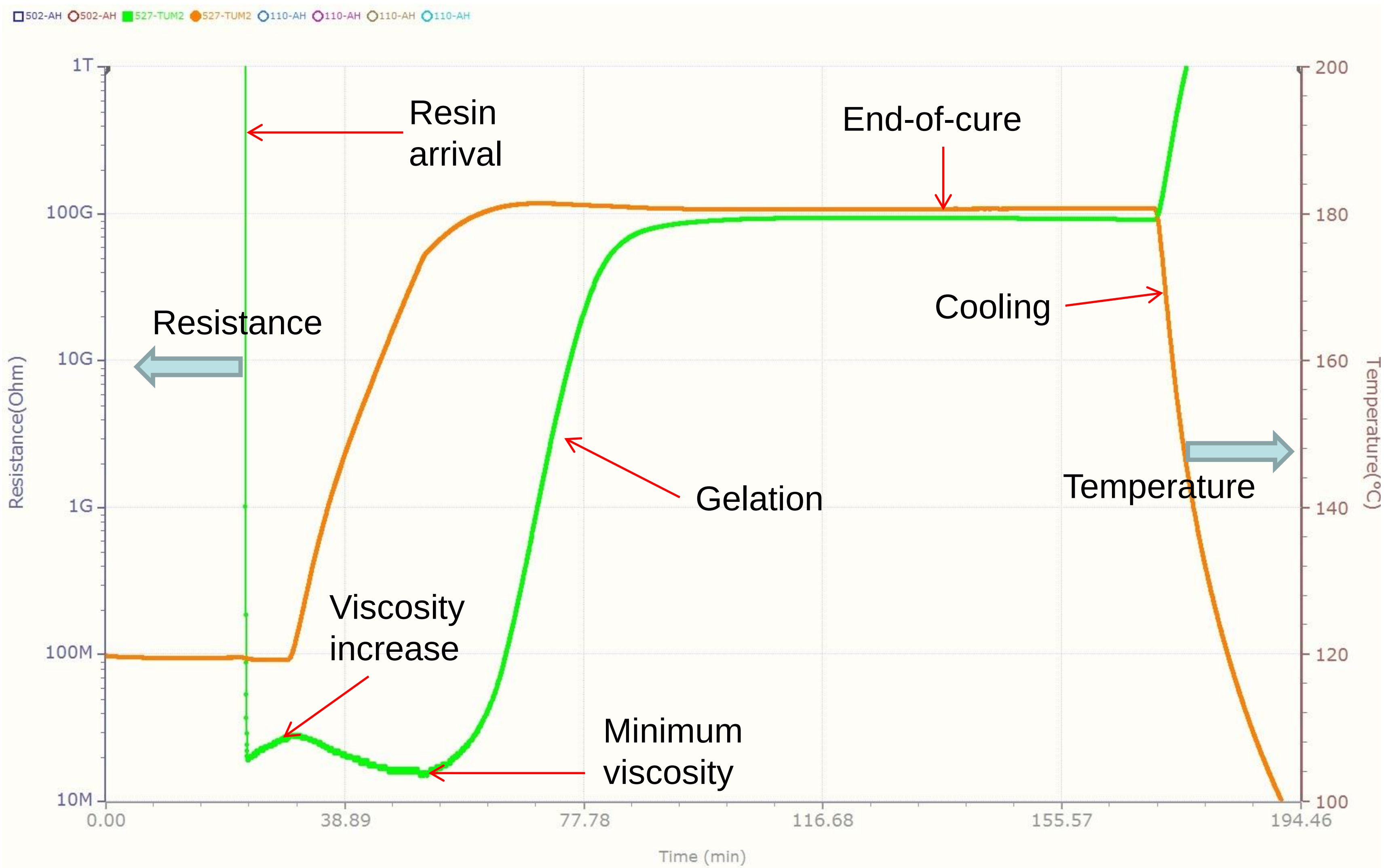
New

Vacuum Bag Sensor

Advantages of Process Monitoring in composites manufacturing

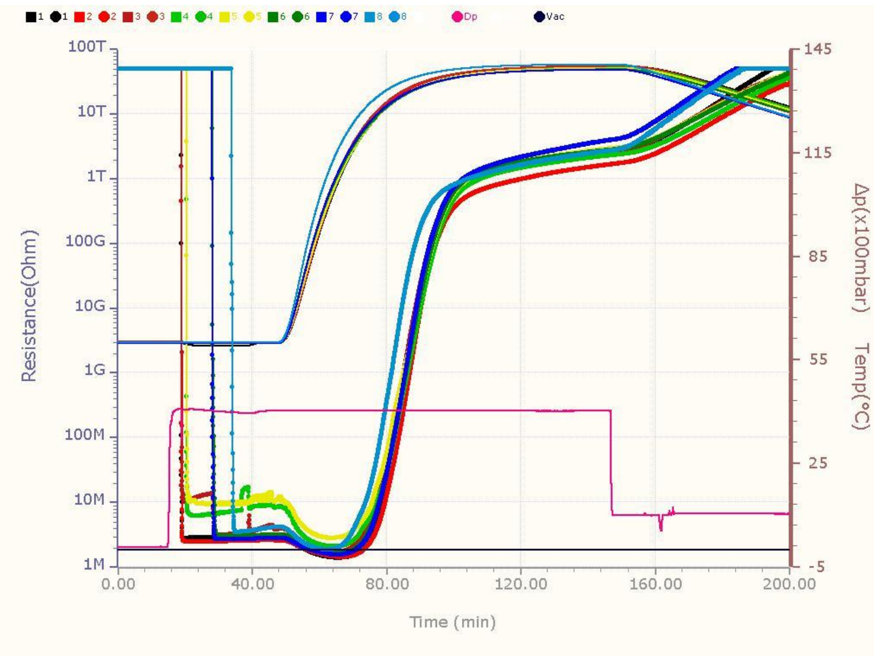
- **Check resin quality and adjust process accordingly**
- **Detect accurately resin arrival at critical locations**
  - **Open/close valves based on sensors' feedback**
- **Monitor viscosity changes and decide when start heating**
- **Identify minimum viscosity and decide about pressure**
- **Detect 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**

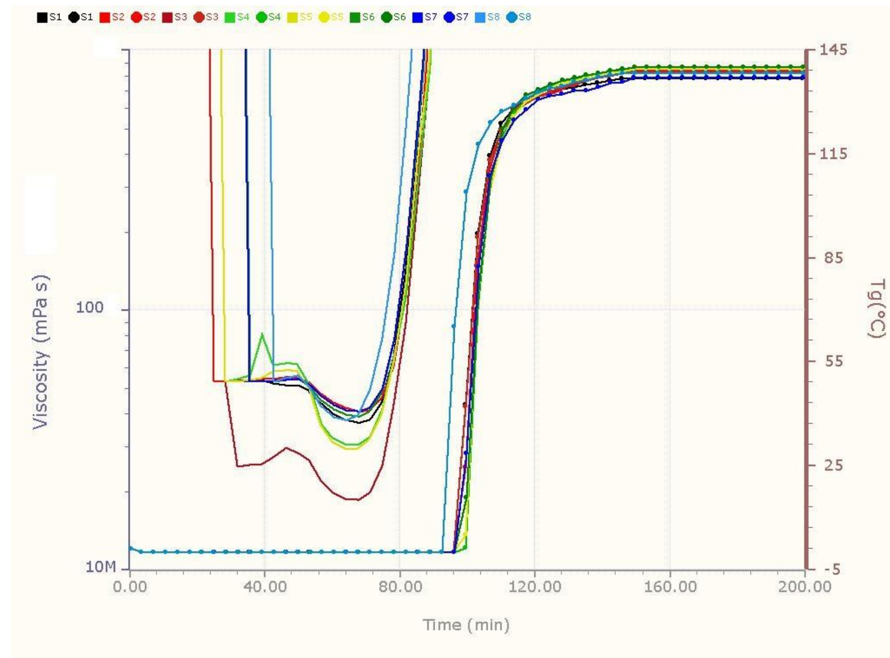
A typical RTM6 cure cycle as measured with Optimold



On-line Resin State (ORS software)

From Resistance and Temperature to Online viscosity and Tg estimation





More than 25 resins have been calibrated for the whole range of advanced composites manufacturing

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Verification of the real-time estimated Tg

Overview of the Tg estimated online with the ORS software and T_g measured right after demoulding by DSC and the difference between them for several isothermal and realistic test cases which shows that

the Tg online estimation is within the DSC accuracy

Trials and DSC performed by

CARBON **ROTEC**
COMPOSITE TECHNOLOGY

published at SAMPE Journal,

v.53/6, Nov/Dec 2017, pp. 6-10

	Trial	Duration [h]	T_g-ORS (°C)	T_g- DSC (°C)	Difference (°C)
Isothermal	80DV1	3	73.17	73.34	-0.17
	80DV3	2.5	70.30	70.91	-0.61
	80DV4	2.5	73.45	72.49	0.96
	80-120'	1.92	66.96	66.02	0.94
	80-90'-1	1.50	62.04	61.80	0.24
	80-90'-2	1.50	65.52	65.21	0.31
	80-D2-2	1.50	61.88	60.59	1.29
	60-260'	4.33	55.02	56.51	-1.49
	70-190'	3.17	64.92	65.39	-0.47
Isothermal cases, mean difference					1.61
Isothermal cases, standard deviation					2.42
Non-isothermal	TEB1-1		61.37	59.54	1.83
	TEB1-2		69.36	70.93	-1.58
	TEB2-1		60.00	58.64	1.36
	TEB2-2		70.02	70.30	-0.28
	LESW1-1		76.97	74.35	2.62
	TESW1		71.34	69.18	2.16
	Shell1-1		80.36	78.92	1.44
	Shell1-2		75.72	77.83	-2.12
	Shell2-1		79.60	77.70	1.89
Non-isothermal cases, mean difference					2.15
Non-isothermal cases, standard deviation					1.26

Intelligent Process control

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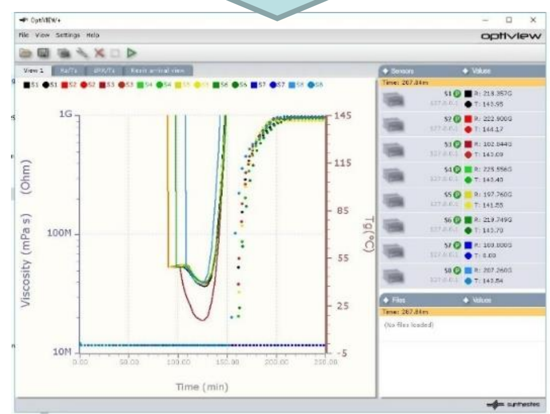
Measuring resistivity, temperature, pressure

Intelligent Process Control

Online Estimating Tg, viscosity, degree of cure

Injection machine



Controlling temperature, demoulding time etc.

Press controller

Temperature controller(s)

SuCoHS project: Consortium

40 Researchers and engineers

14 Partners

36 Months

7 European Countries

571.5 person-months

EU contribution 6 638 939 €

Project name:
Sustainable and Cost Efficient High Performance Composite Structures demanding Temperature and Fire Resistance

Project acronym: SuCoHS

Funding scheme: Research and Innovation Action (RIA)

Project Coordinator: Dr. Tobias Wille (DLR)

Contact: tobias.wille@dlr.de

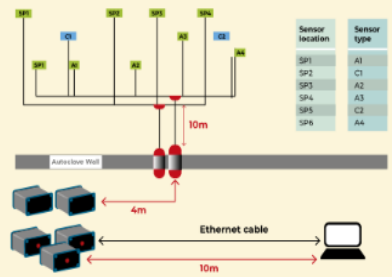
Project start date: 01/09/2018

Project end date: 31/08/2021

SuCoHS
SUSTAINABLE & COST EFFICIENT HIGH-PERFORMANCE COMPOSITE STRUCTURES DEMANDING TEMPERATURE AND FIRE RESISTANCE

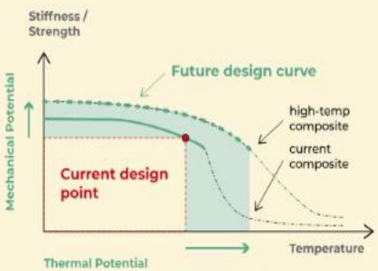
SuCoHS project: Concept and Methodology

- Concept providing key technologies for
  - Design
  - Manufacturing
  - Operation



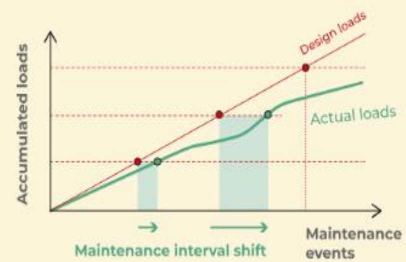
Manufacturing

- Tailored multifunctional preforms
- Advanced hybrid manufacturing technologies
- Zero-defect manufacturing



Design

- New composites materials
- Reliable multidisciplinary analysis tools and allowable
- Robust multifunctional structural concepts

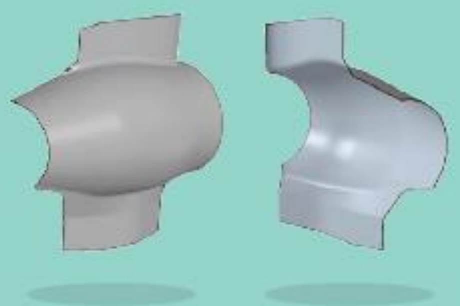


Operation

- Reliable multifunctional sensors
- Efficient tools for structural usage evaluation
- Enhanced maintenance scheduling

SuCoHS project: Pilot Demonstrators

High temperature nacelle component
(Bombardier)



- Reduce part complexity
- Multidisciplinary loading
- Reduce number of subparts
- Use of composites Tg<335°C

Tail cone panel substructure
(Aernnova Engineering)

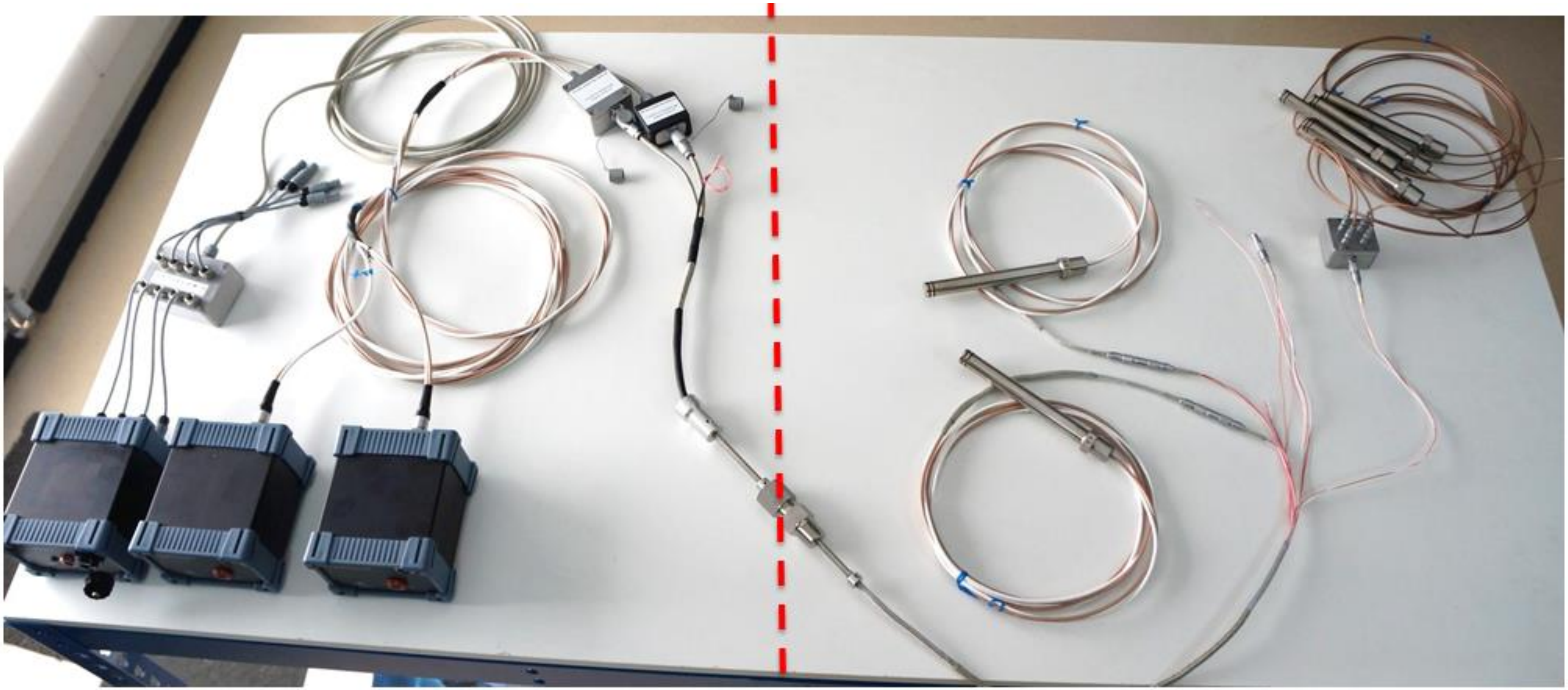
- Avoid titanium APU housing
- Use of composites Tg<300°C
- Ensure fire resistance
- Ensure damage tolerance

Composite aircraft interior shell
(Collins Aerospace)

- New structural concepts and materials for improved performance at reduced costs
- Flammability and FST requ.

SuCoHS
SUSTAINABLE & COST EFFICIENT HIGH-PERFORMANCE COMPOSITE STRUCTURES DEMANDING TEMPERATURE AND FIRE RESISTANCE

Autoclave system (Spirit Belfast) ECOMISE R&D project



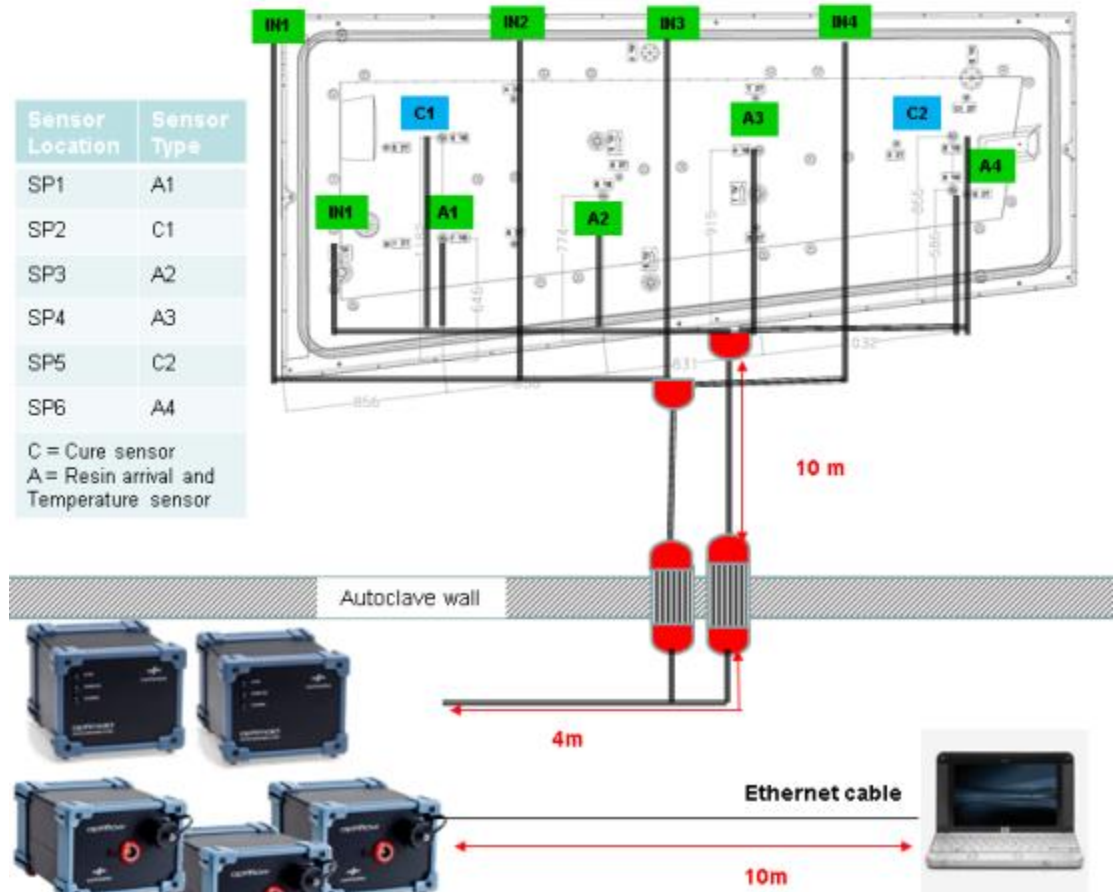
Outside of the autoclave

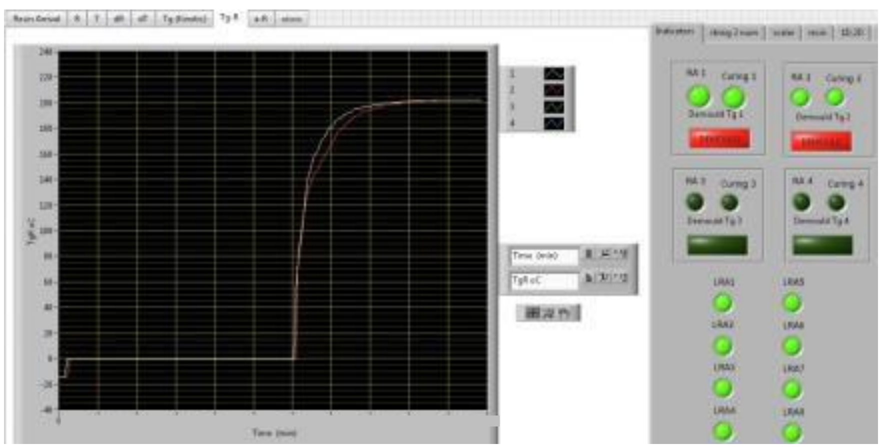
Inside of the autoclave

Demonstration
@ WPU Spirit Belfast
ECOMISE R&D project

Sensor Location	Sensor Type
SP1	A1
SP2	C1
SP3	A2
SP4	A3
SP5	C2
SP6	A4

C = Cure sensor
A = Resin arrival and Temperature sensor





Real-time Tg prediction and demoulding decision based on targeted Tg.

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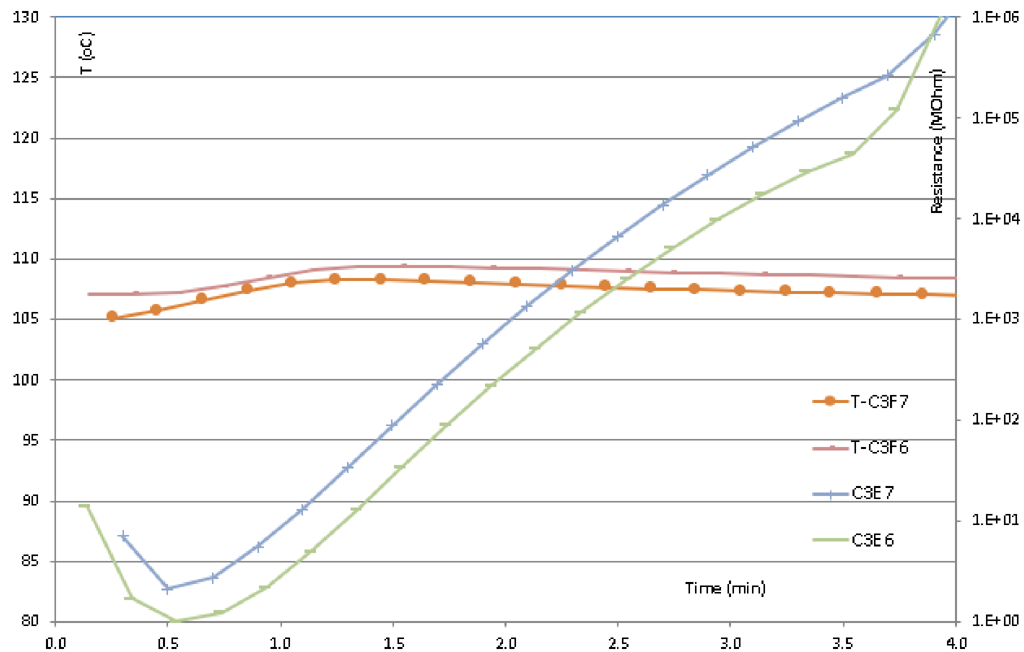
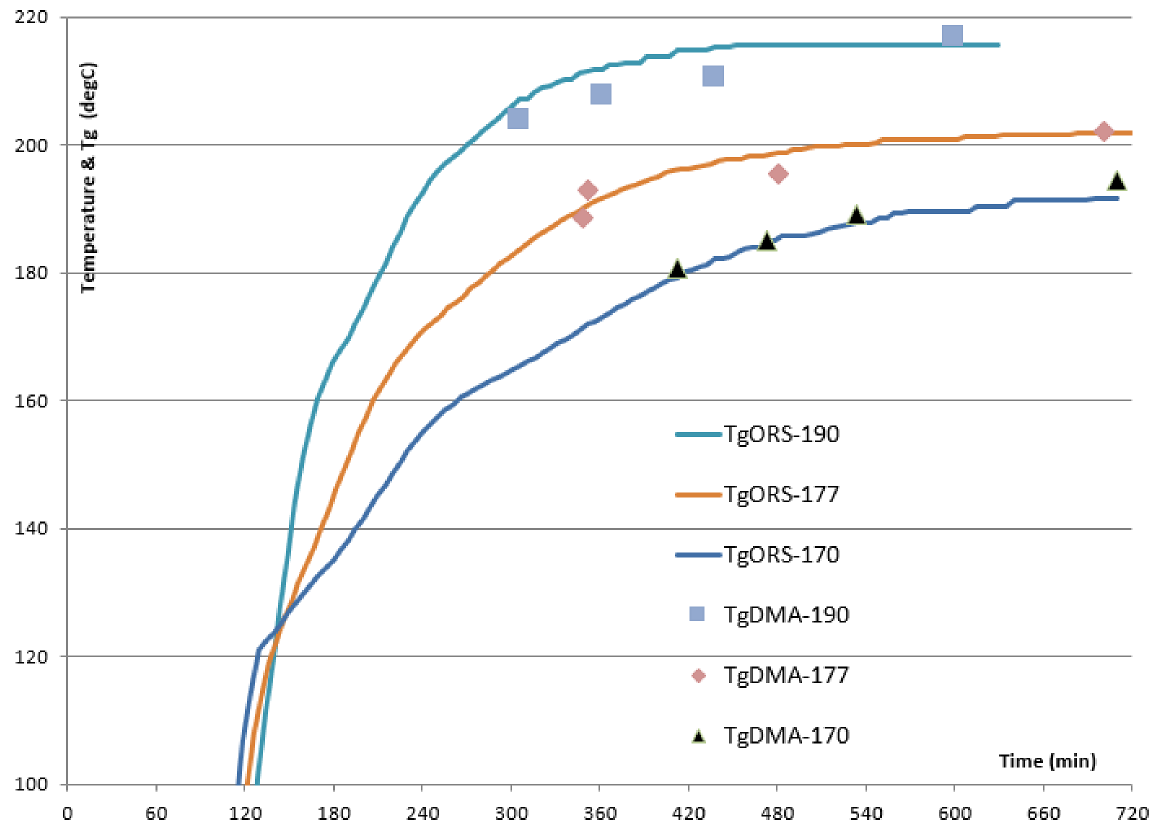
New durable sensor for cfrp production



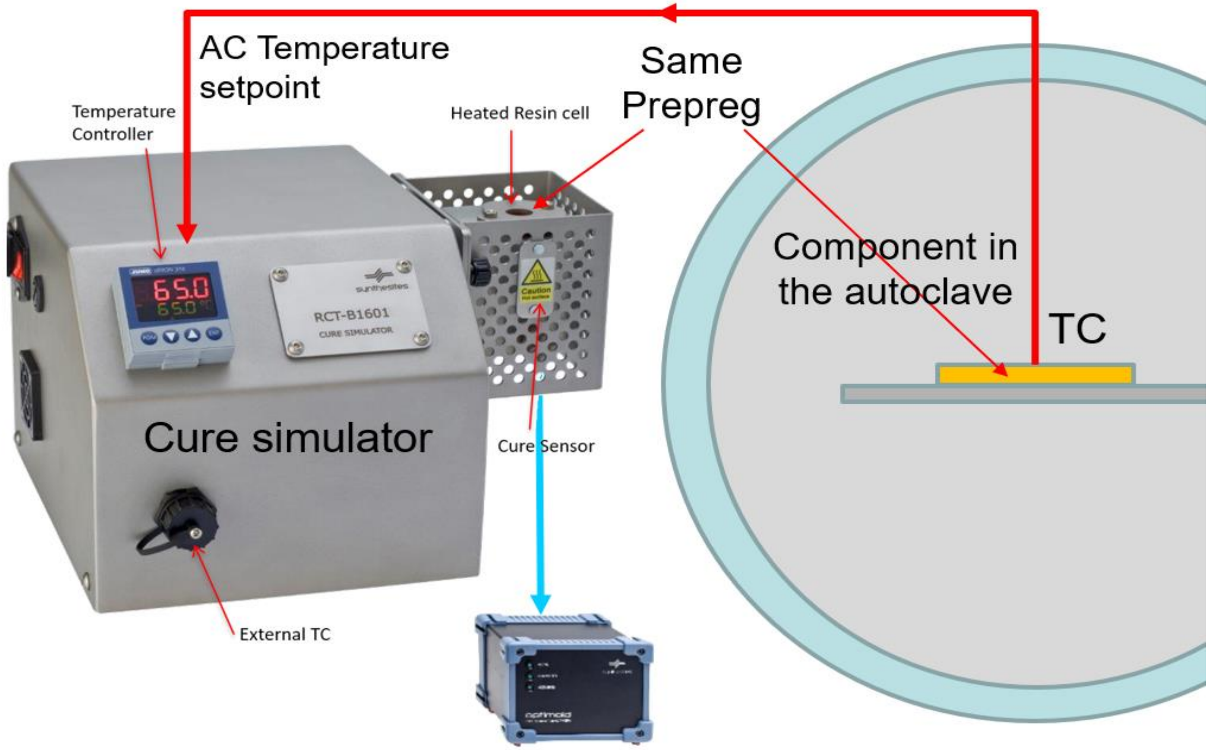
A new durable sensor was developed to allow to measure CFRP production without the need of any extra protection e.g. glassfibre

Sensor Calibration for BMI-5250-4



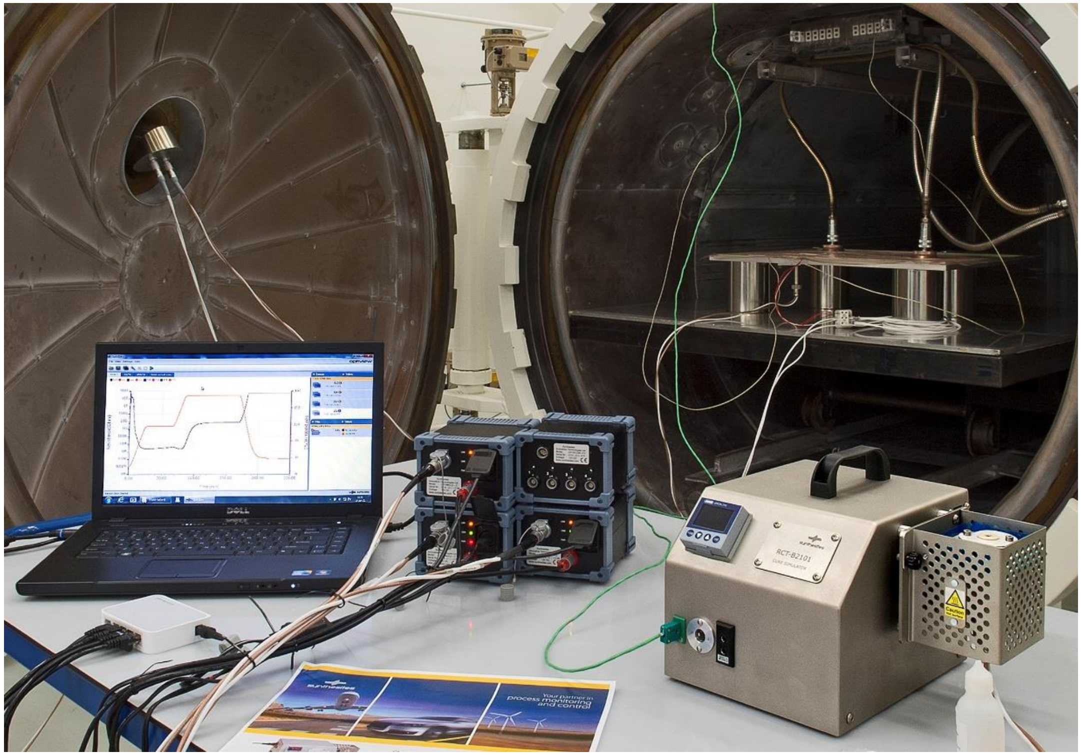
Correlation between Tg measured by DMA (symbols) and online estimation by ORS in isothermal cure cycles at 170ºC, 177ºC and 190ºC after calibration

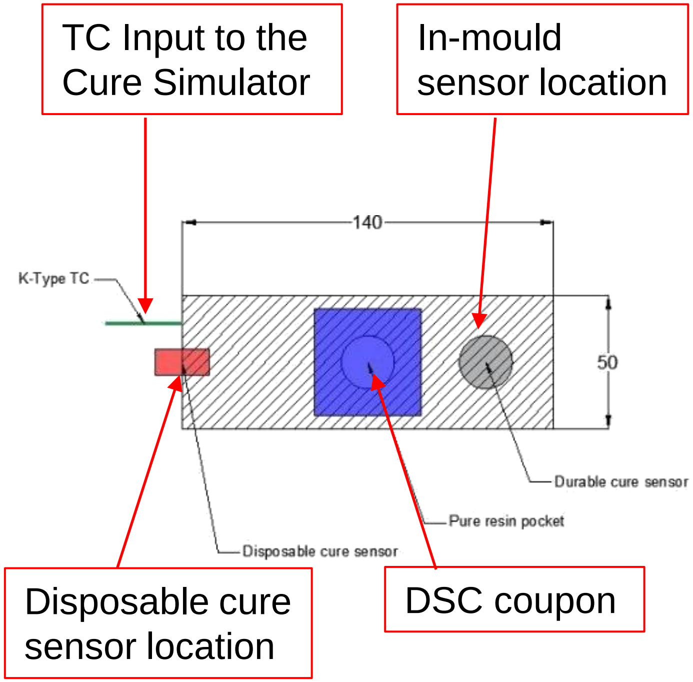
The Cure Simulator concept



The Cure Simulator concept for autoclaves

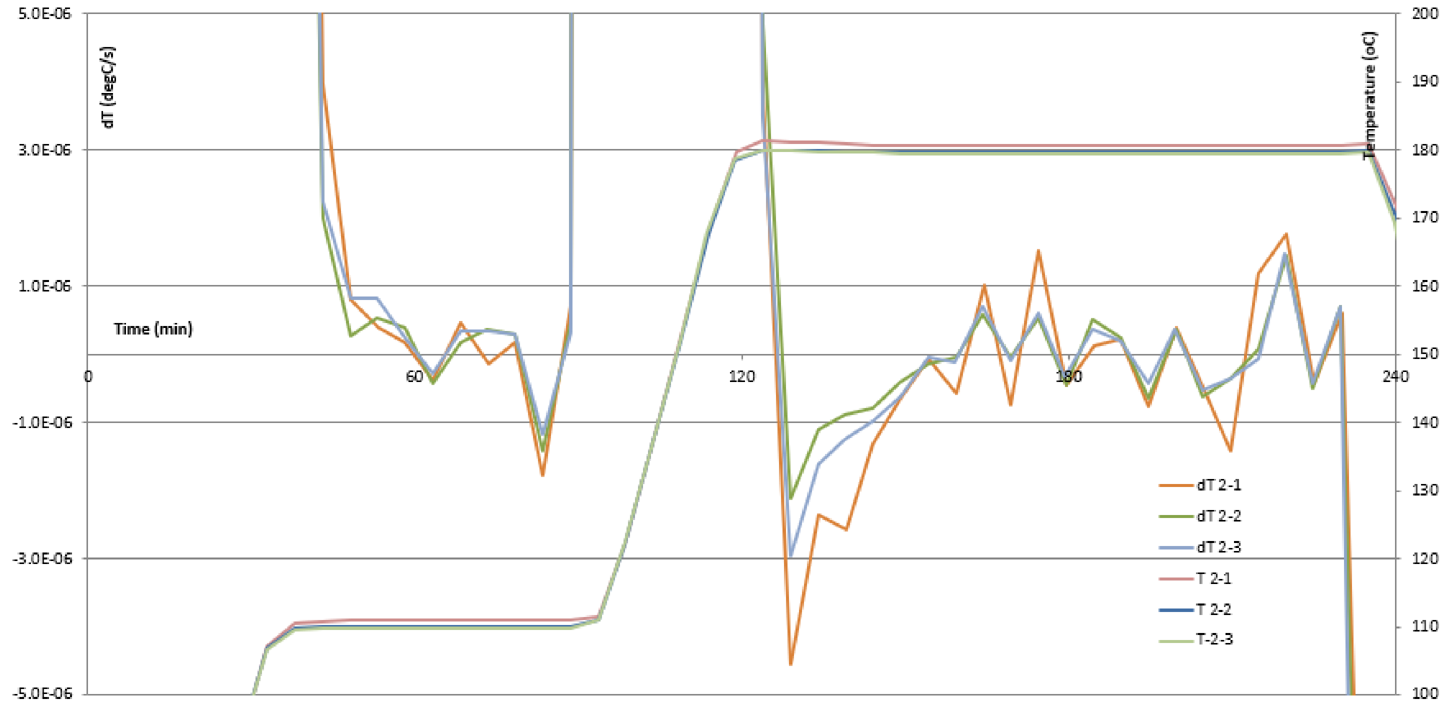
Installation at NLR





The Cure Simulator system together with 3 standard cure sensor at the R&D autoclave at NLR, Marknesse (left) and configuration of the test coupon (right)

Correlation between Cure and Resistivity

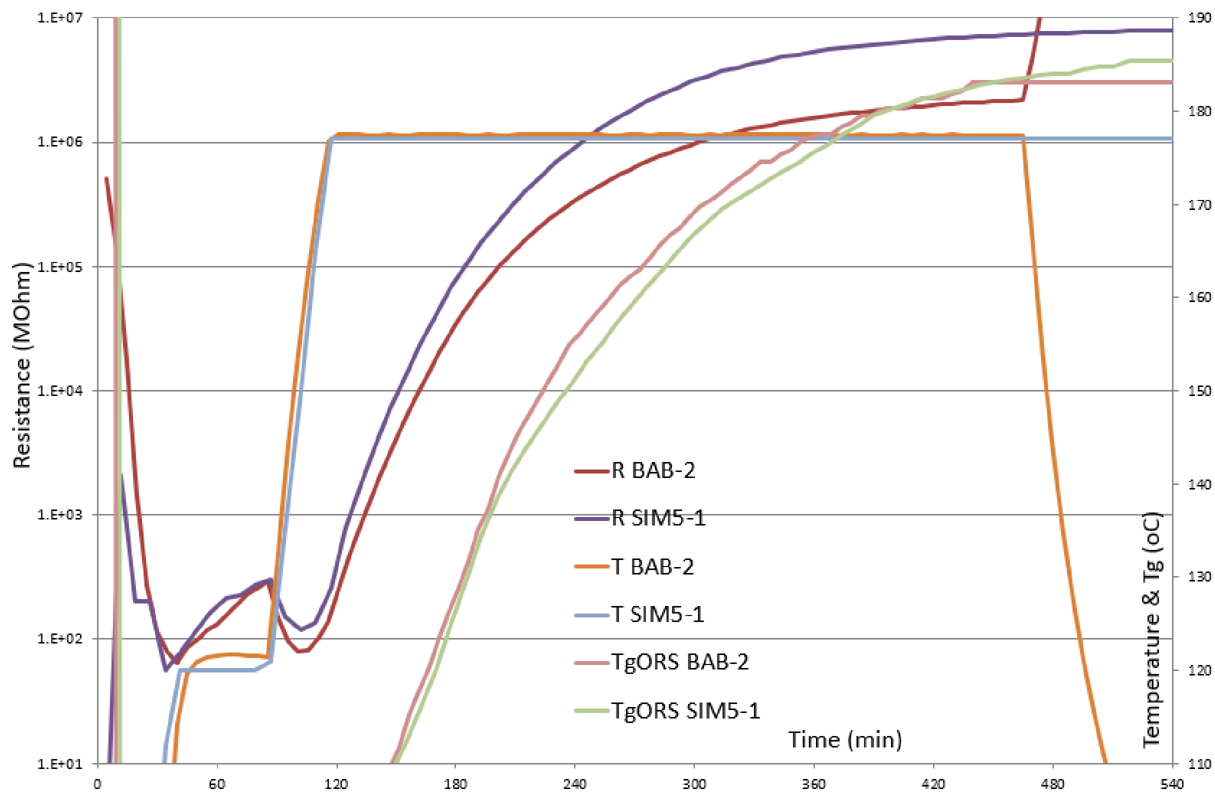


Temperature (T) and temperature rate (dT) during a trial at NLR’s autoclave for three cure sensors: 2-1 for the durable sensor at the Cure Simulator, 2-2 and 2-3 for the Disposable and the Durable cure sensors in autoclave.

Installation at Spirit Belfast

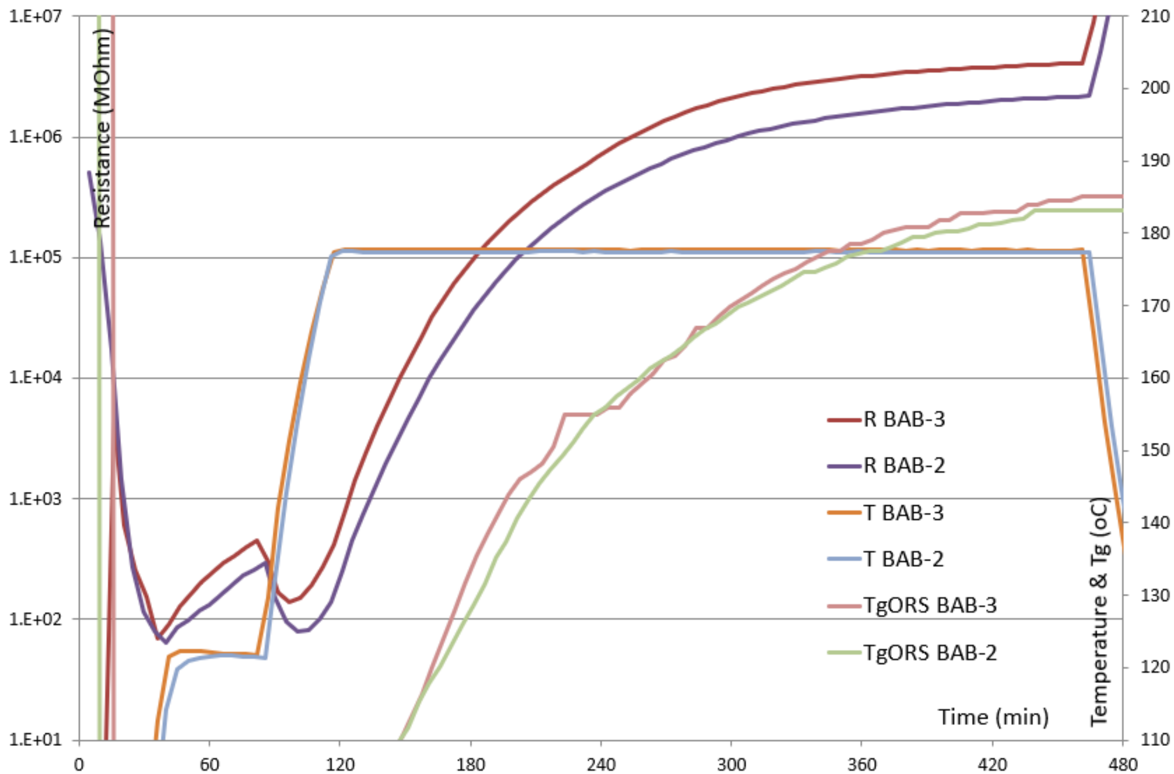
Left: The Cure Simulator system at the R&D autoclave at NIACE, Belfast,
Right: The flat mould with the preform installed in the autoclave.

Repeatability



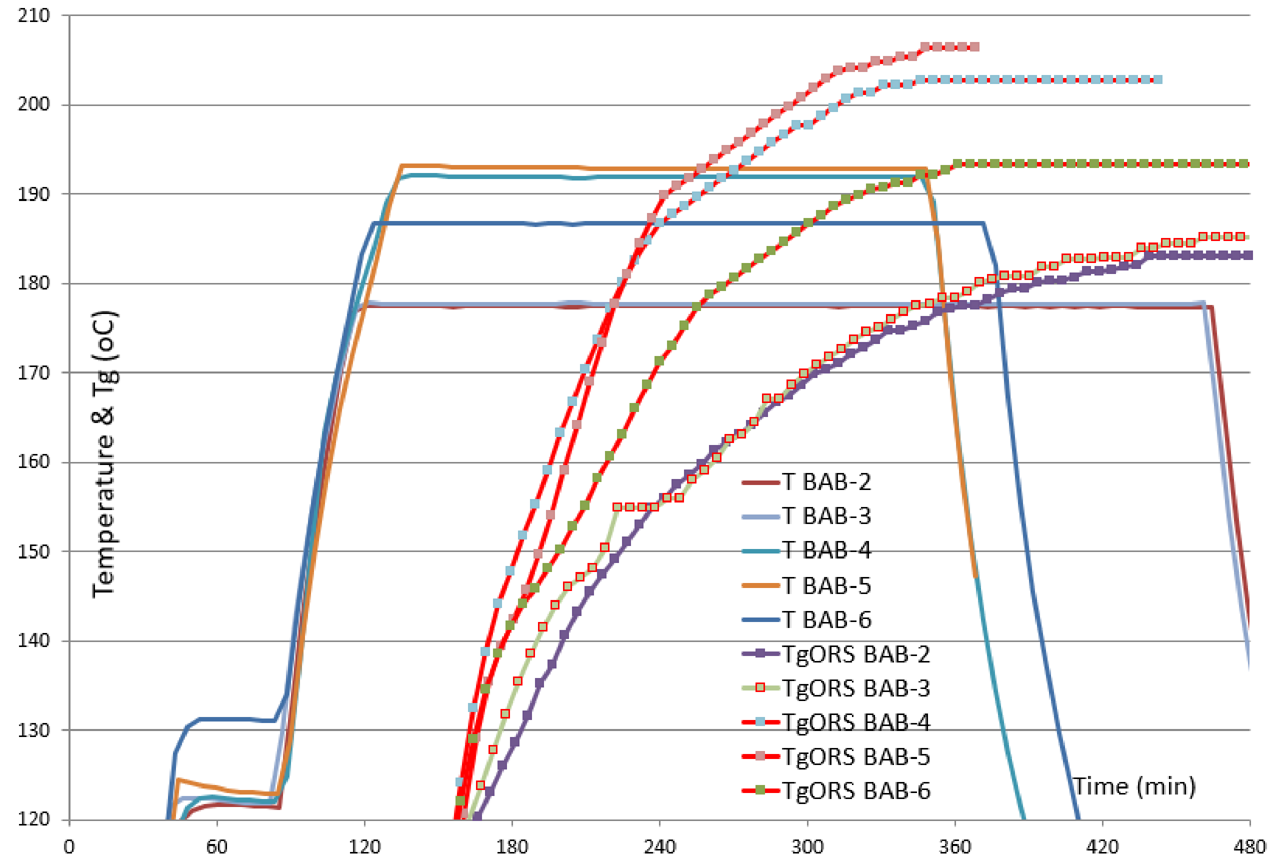
Temperature (T), resistance (R) and online Tg estimation for two similar cure cycles cured at a small mould in the lab (SIM5-1) and in the autoclave (BAB-2) both using the Cure Simulator.

Repeatability at autoclave



Temperature (T), resistance (R) and online Tg estimation for two similar cure cycles at autoclave (BAB-2 and BAB-3).

5 panels produced



Temperature (T) and online Tg estimation of the cure cycles for all panels produced at Spirit using the Autoclave with the Cure Simulator

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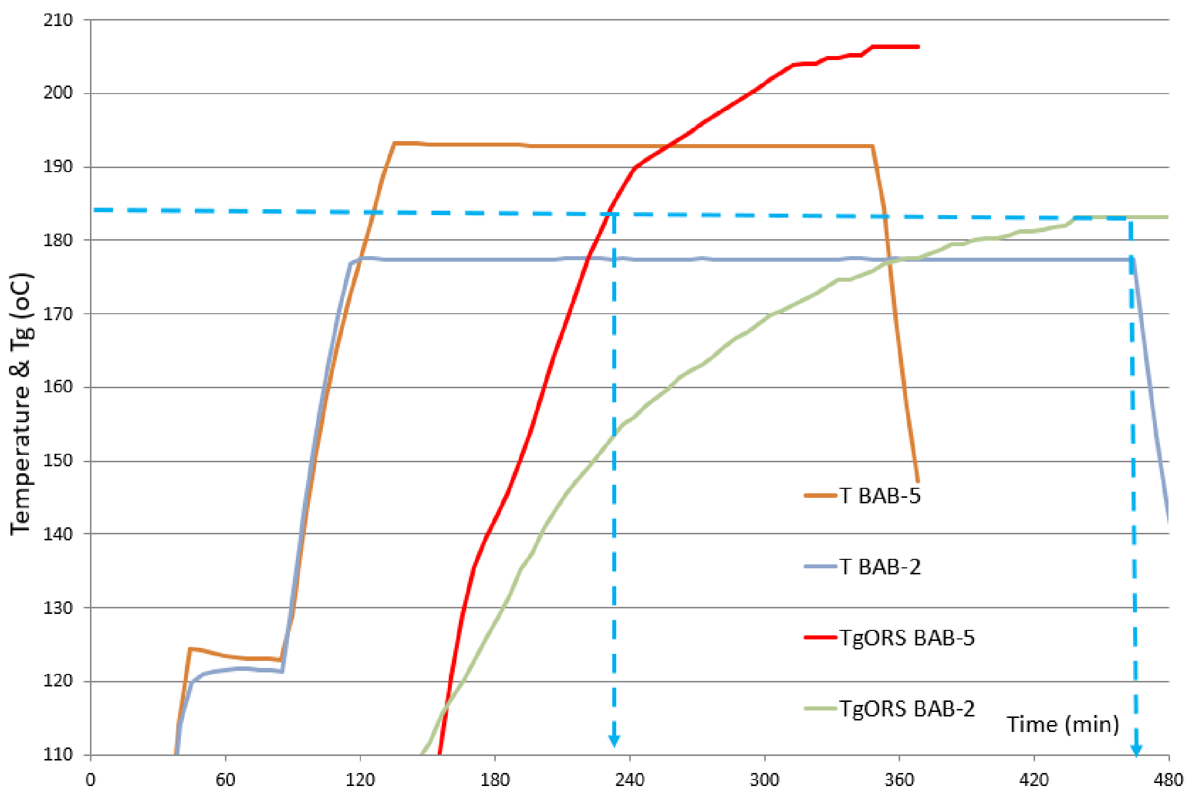
Tg Validation

Final Tg of the five trials performed by Spirit in the NIACE autoclave with the Cure Simulator as estimated online (Tg ORS) and measured afterwards by DMA (Tg DMA)

Trial	Cure Temp (°C)	Tg DMA (°C)	Tg ORS (°C)	Diff (°C)	Diff (%)
BAB-2	177	184.51	183.11	1.40	0.8
BAB-3	177	185.11	185.13	-0.02	-0.0
BAB-4	191	205.46	202.66	2.80	1.4
BAB-5	191	206.59	206.31	0.28	0.1
BAB-6	185	190.75	193.29	-2.54	-1.3%

50% speed-up is possible



Comparison of Temperature (T) and online Tg estimation for two different cure cycles with curing at 177°C (BAB-2) and 191°C (BAB-5).

Conclusions and next steps

- ✓ The online cure monitoring and quality control for high temperature resins was applied and verified successfully.
- ✓ The development of new CF sensors and calibration methods can lead to a significant reduction of the curing time ensuring cure quality.
- ✓ The introduction of the Cure Simulator can considerably facilitate the implementation of this technology in everyday production, reducing considerably the modifications to the existing infrastructure.
- ✓ This new technology should be further implemented in serial production to validate its performance and to evaluate its benefits.

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