Intelligent Process Monitoring and Control in Composites Manufacturing

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Customers

Companies

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R&D Centres and Universities

DLR

NATIONAL COMPOSITES CENTRE

n|w University of Applied Sciences and Arts Northwestern Switzerland

nlr Dedicated to innovation in aerospace

Fraunhofer IWES

FIDAMC

AIMPLAS INSTITUTO TECNOLÓGICO DEL PLÁSTICO

aimen TECHNOLOGY CENTRE

Ulster University

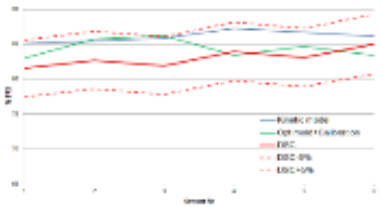
PURDUE UNIVERSITY

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 solutions

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optimold
Cure, viscosity and resin quality

Real-time measuring of

- Resin's electrical resistance (from 100 Kohm up to 100 Tohm) and
- temperature (0.1^{o}C accuracy)

Characteristics

- Non-intrusive
- Range of sensors
- Operational indicators
- Fast Acquisition
- Compact design
- Wireless
- Quality and Process control

Optimold Sensors

process monitoring sensor = electrical resistance + Temperature (RTD) sensors

Durable sensor

High Temp RTM

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

Durable bag sensor

Vacuum Infusion

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

Flexible sensor

VI and RT cure

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

Inline sensor

- Adjust cycle
- Avoid resin purging

Resin pot sensor

Check of

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

Optiflow
Resin arrival and temperature

- 4 channels for resin arrival sensors and valves
- 4 channels for temperature
- Electrical resistance-based measurements and RTD temperature sensing
- Continuous connection check between sensor and Optiflow
- 1-4 relay outputs for process automation

optiflow (resin arrival and temperature) sensors

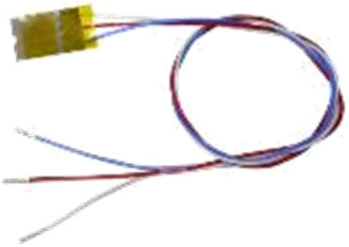
In-mould
Durable

- High Temp RTM

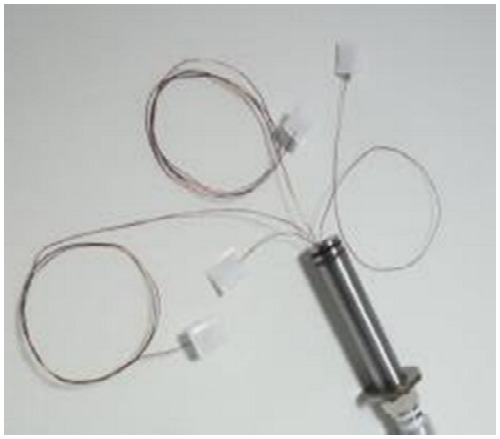
Gate
Durable

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

Flexible
Disposable



FloWire
Disposable



Infusion and RTM

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

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CF sensors
The durable sensor for CFRP

- The durable CF cure sensor allows to measure at CFRP applications without the need of any protection
- Trials with a prototype sensor in a HP RTM press have shown very good results and confirms that the use of that sensor in CFRP production is feasible
- Extensive trials at IRT M2P in France and NCC in the UK with industrial RTM presses and pressures up to 220 bar have proven that the CF cure sensor is performing well and is very robust
- New CF resin arrival sensor for industrial production

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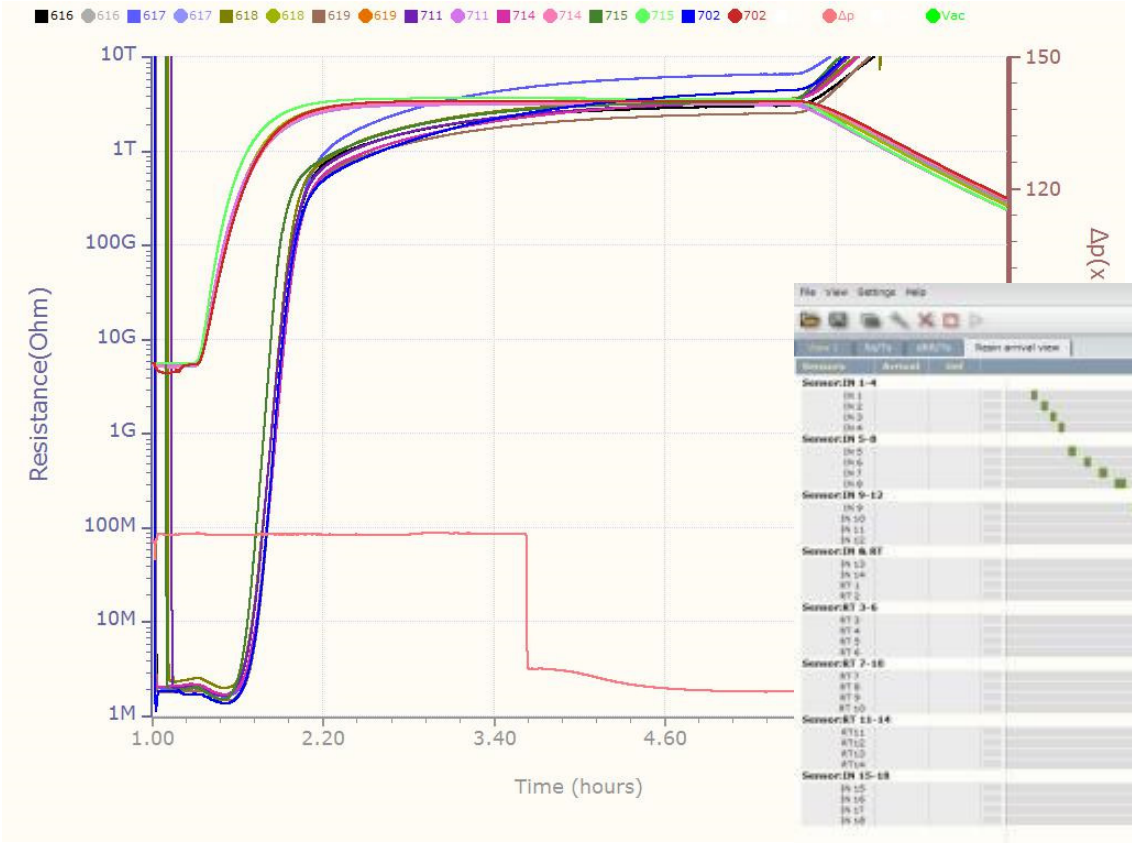
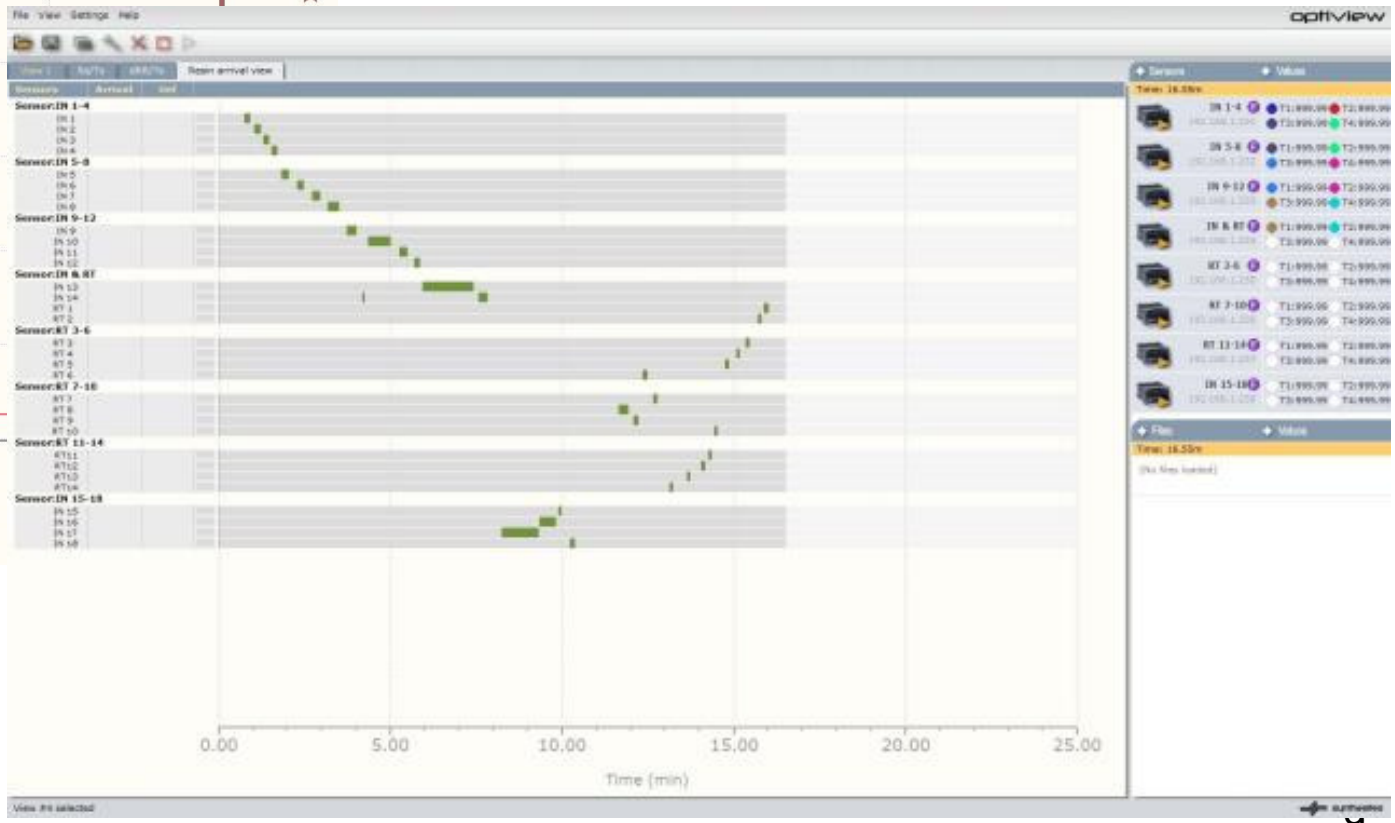
optiview
DAQ software

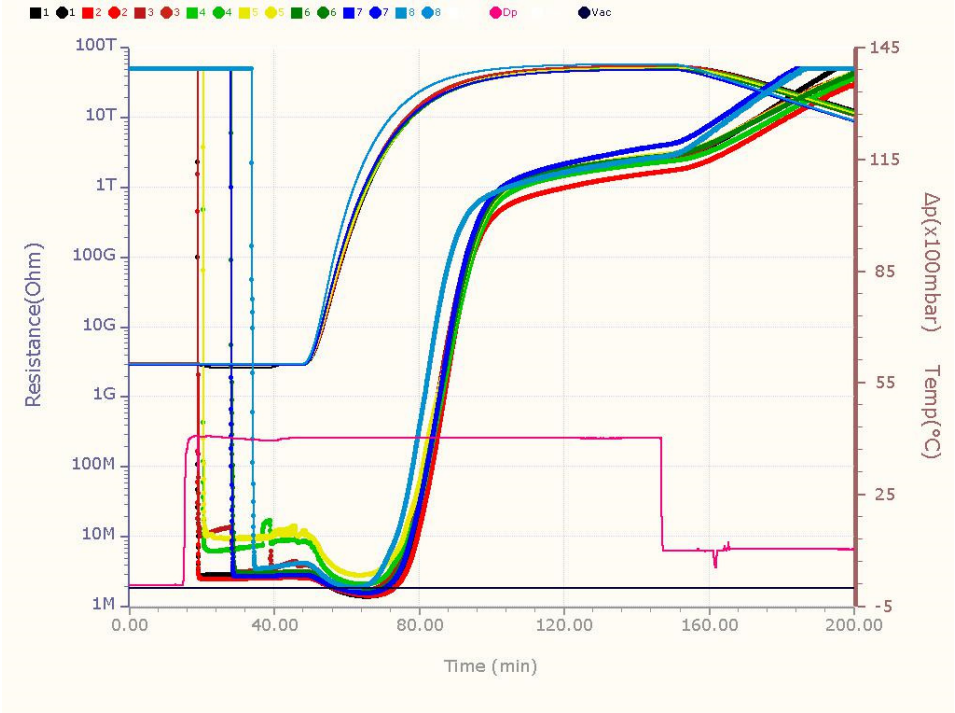


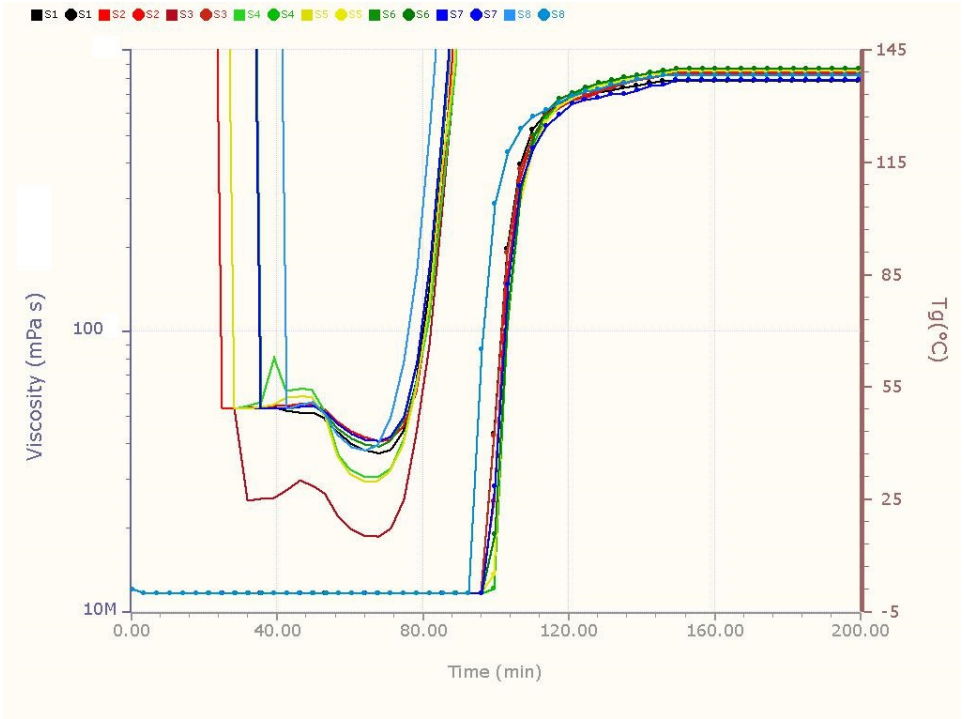


optiview DAQ software for optimold and optiflow systems

On-line Resin State (ORS software)

From Resistance and Temperature to Real-time viscosity and Tg





Curing time potential reduction over 30%

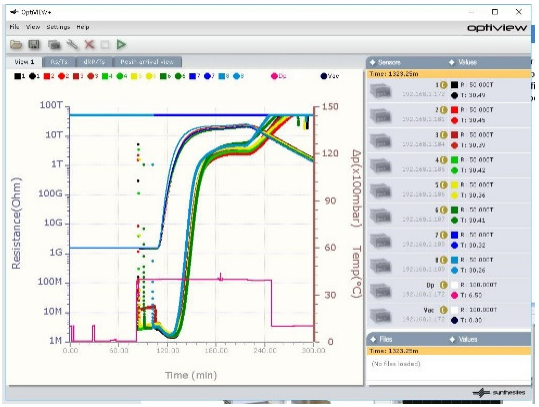
New Opticure system

Opticure mobile system includes:

- Up to 3 Optimold
- Industrial windows-based PC
- Touch screen IP65
- Online Resin State software
- User-Interface (HMI)
- Alarms
- Several connectivity options including connection to PLC

Intelligent Process control

resistance, temperature



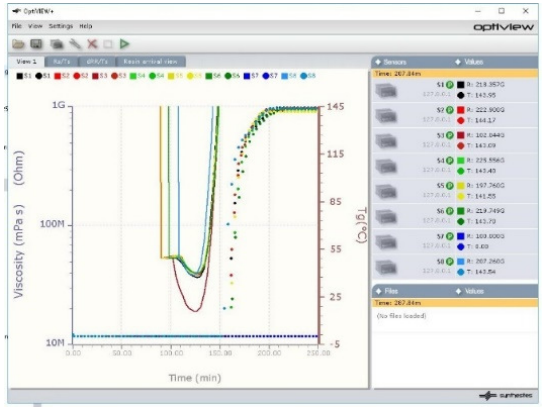
Tg, viscosity, degree of cure

Valves

Temperature controller(s)

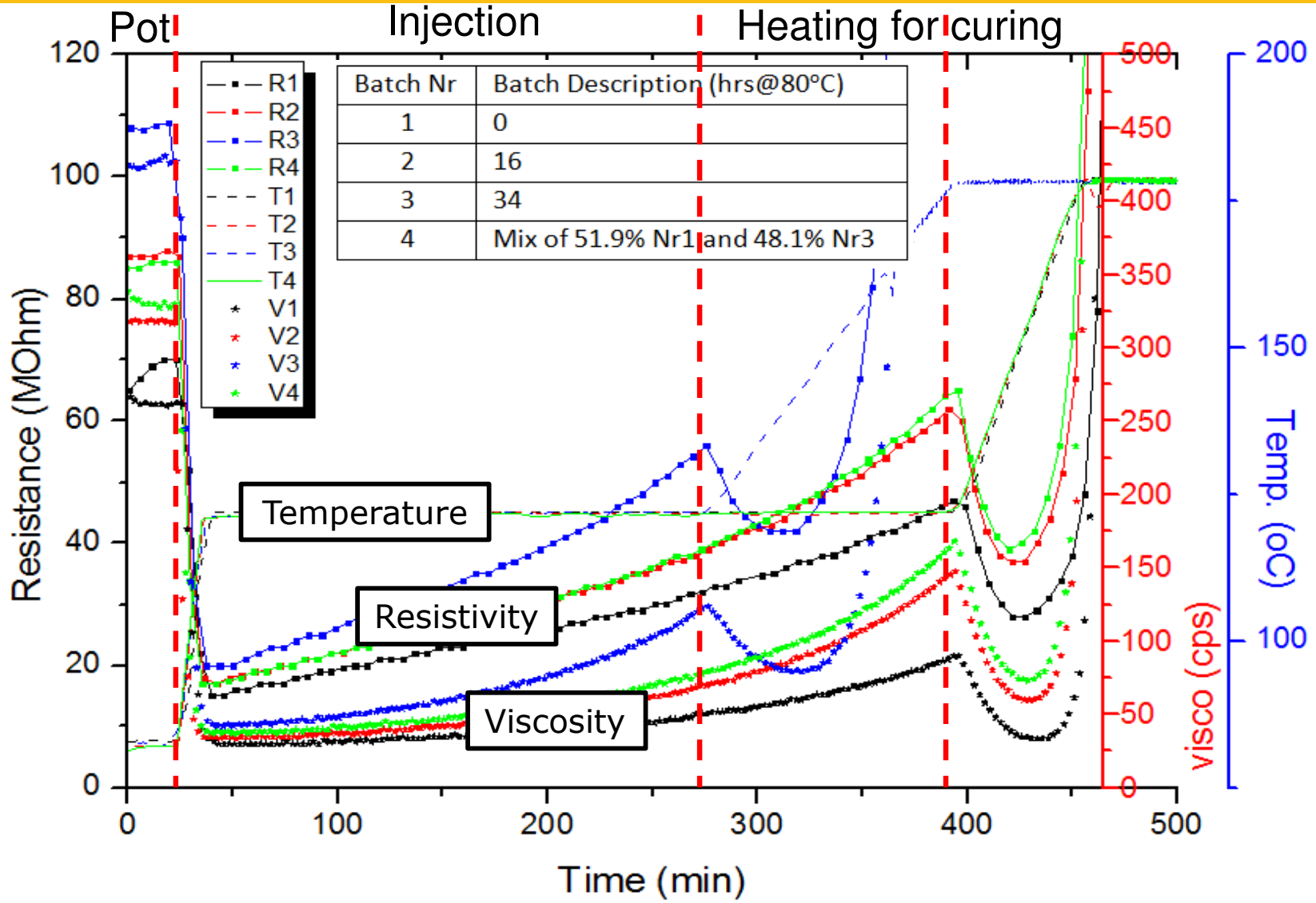
Press controller

Controlling temperature, time etc.



Monitoring Resin aging and viscosity

Simulating the injection process of a mono-component resin of various age (fresh, 16 hrs@80°C, 34 hrs@80°C, and mixture)



Viscosity, Resistance and temperature vs. time for 4 Cycom 890 batches of different age

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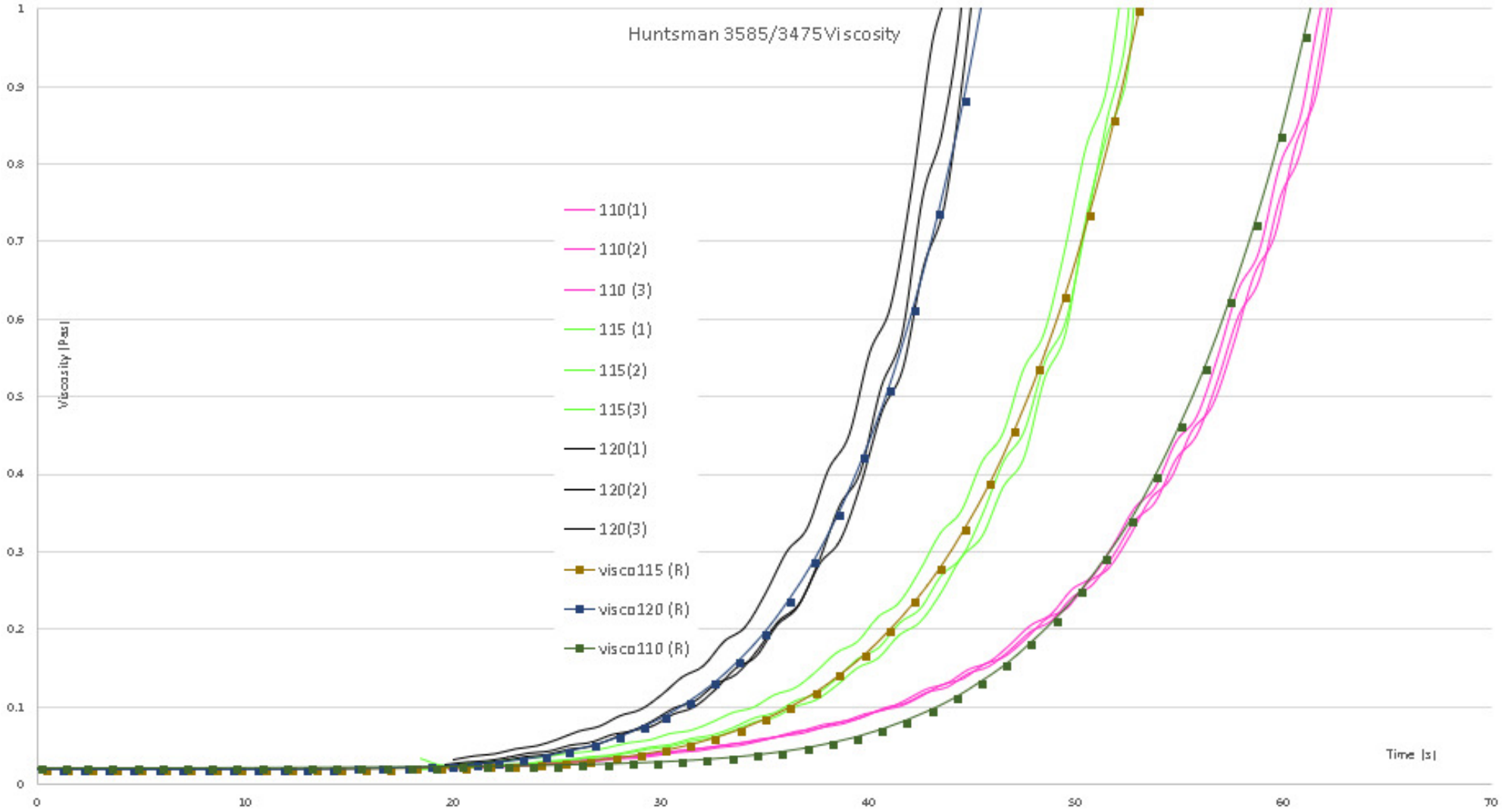
Resistance vs. viscosity



Correlation between resistance and viscosity (iso-T)

Online Tg estimation at DMA/DSC accuracy

DMA/ Autoclave

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

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) by Spirit Aerostructures, Belfast

Presented at SAMPE Europe 2021, ICMAC and NDT in Aerospace 2021

DSC/ RTM

Tool Temperature (°C)	Cure Time (s)	DSC T_g (°C)	DC T_g (°C)	Error Compared with DSC Values (%)
110	600	122	123	1.2
115	180	112	112	<1
115	240	118	118	< 1
115	600	123	126	1.9
120	600	127	128	< 1

Table 2: Overview of the various cure cycles and the difference between DC-Tg measured by the Optimold CF sensors and DSC-Tg measured using DSC after demoulding.

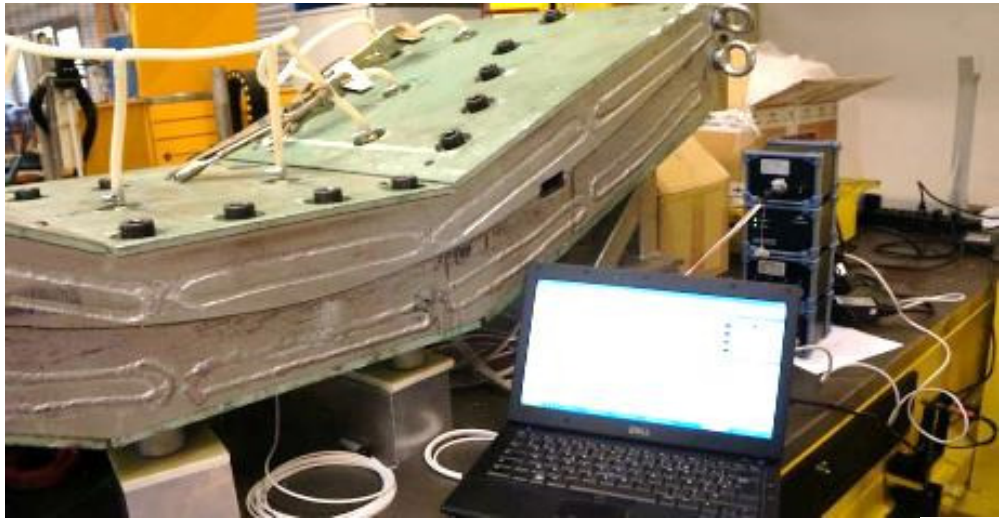
Trials and DSC performed by

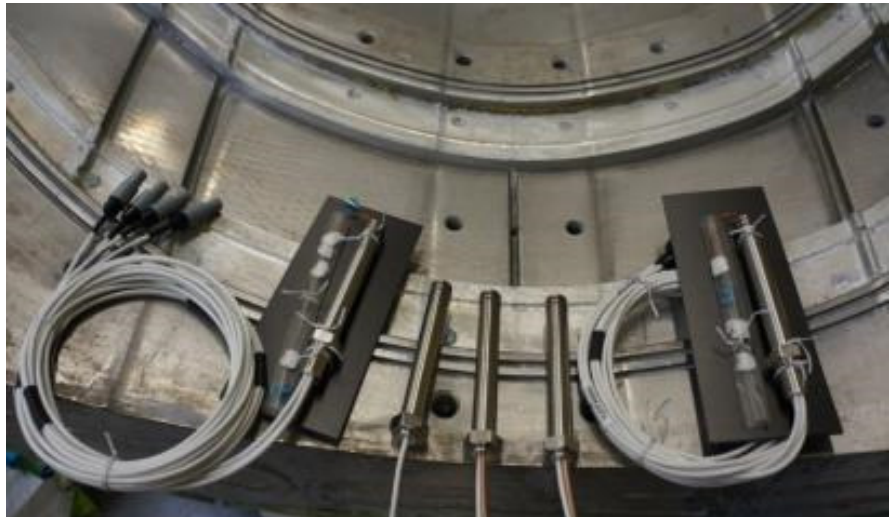
NATIONAL COMPOSITES CENTRE

presented at SAMPE Europe Conference, Nantes France, 2019

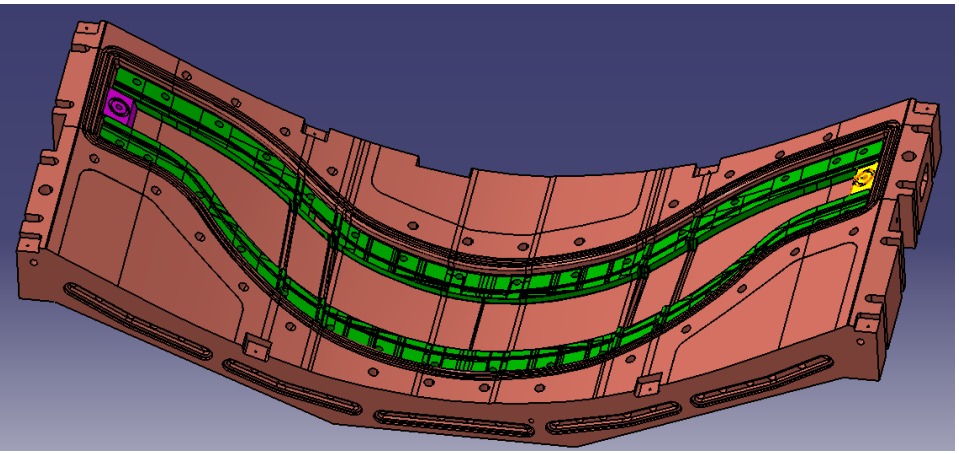
RTM/Infusion Applications

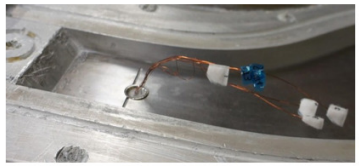
RTM application (Hutchinson FR) ECOMISE R&D project





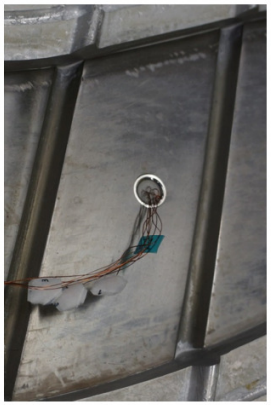
Sensors' Placement in the mould cavity



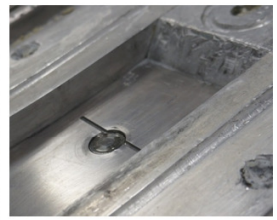


Embedded sensors (through-thickness) SET2

Flow and cure sensors @ inlet



Embedded sensors (through-thickness) SET1



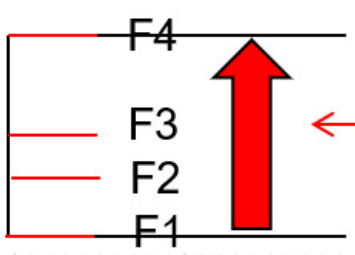
Cure sensor Nr2

RTM application (Hutchinson FR) ECOMISE R&D project

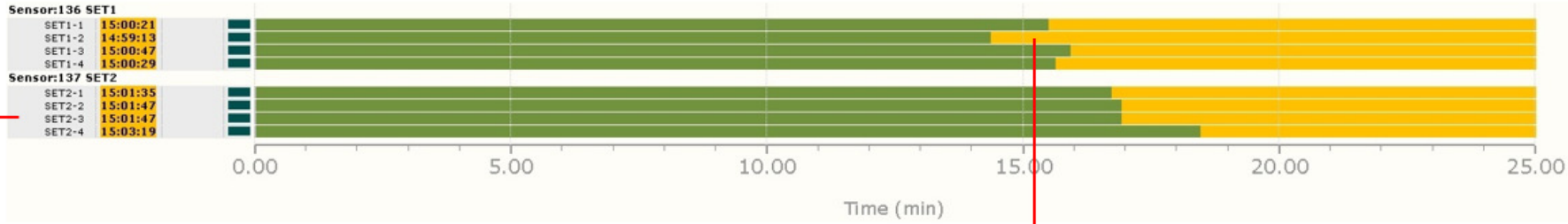
- 8 Resin Arrival (Flowire) connected to 2 Optiflow systems

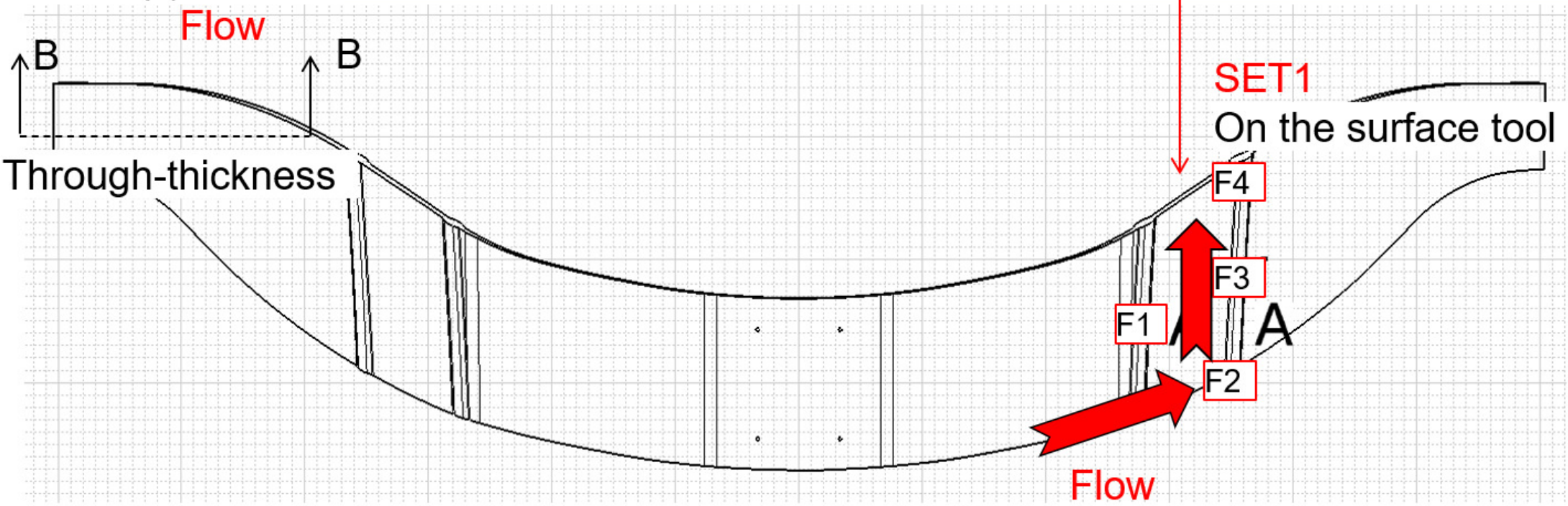
Through-thickness

B-B SET2

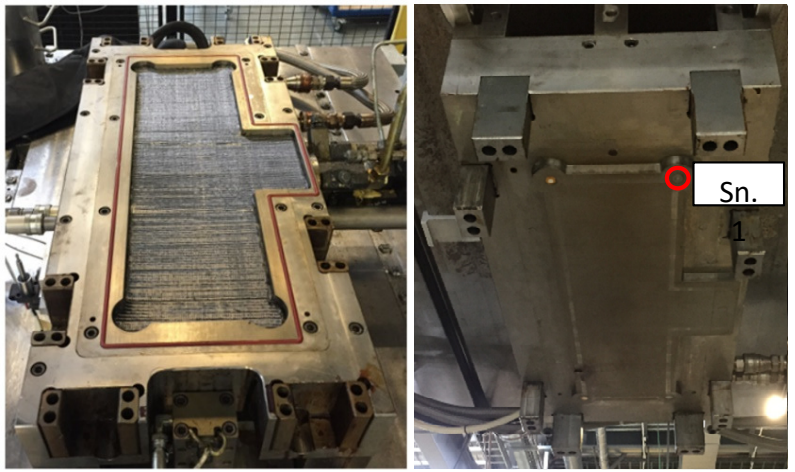


Resin arrival time stamps





HP-CRTM automotive application, 2018, NCC, UK



A durable CF (carbon-safe) cure sensor working in direct contact with Carbon fibres was extensively tested at NCC in a HP-CRTM process with pressure reaching 200 bar. Online Tg estimation was also proved accurate comparing to the Tg measured by DSC afterwards.

Tool Temperature (°C)	Cure Time (s)	DSC T_g (°C)	DC T_g (°C)	Error Compared with DSC Values (%)
110	600	122	123	1.2
115	180	112	112	<1
115	240	118	118	< 1
115	600	123	126	1.9
120	600	127	128	< 1

Table 2: Overview of the various cure cycles and the difference between DC-Tg measured by the Optimold CF sensors and DSC-Tg measured using DSC after demoulding.

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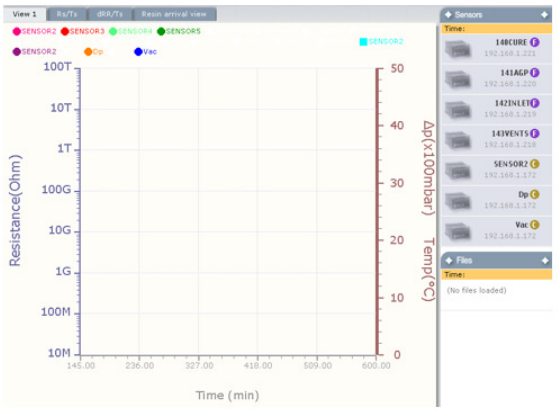
RTM Closed-loop Automation
CLAMPS Project (@NCC UK)

ALPHA PC: 192.168.1.14: OPTIVIEW SERVER



192.168.1.14 : 26500
SensorName arrivaltime (s)

192.168.1.14 : 26702: Dp
Time (s), dummy, Px0.1 (bar)

192.168.1.14 : 26703: Vac
Time (s), dummy, Vacx0.1 (bar)

CFMS PC:
192.168.1.XX
(Surrogate model)

VALVES
192.168.1.14 : 26499
Open INLET1: **1 1**
Close INLET1: **1 0**
Open INLET2: **2 1**
Close INLET2: **2 0**
Open VENT1: **3 1**
Close VENT1: **3 0**
Open VENT2: **4 1**
Close VENT2: **4 0**
Allow 5'' before sending a new command

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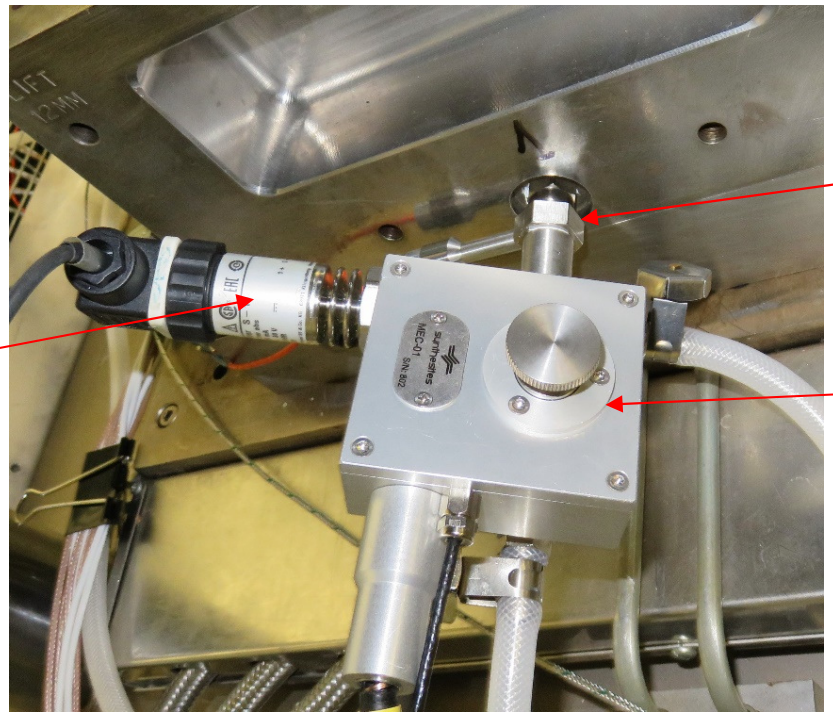
Inline sensor and valve automation

Combining Inline sensors with automatic outlet valves

- Suitable for High Temp applications
- Part of CLAMPS project (NCC UK)

Inline Sensor



Pressure Transducer

Automatic valve

Nikos

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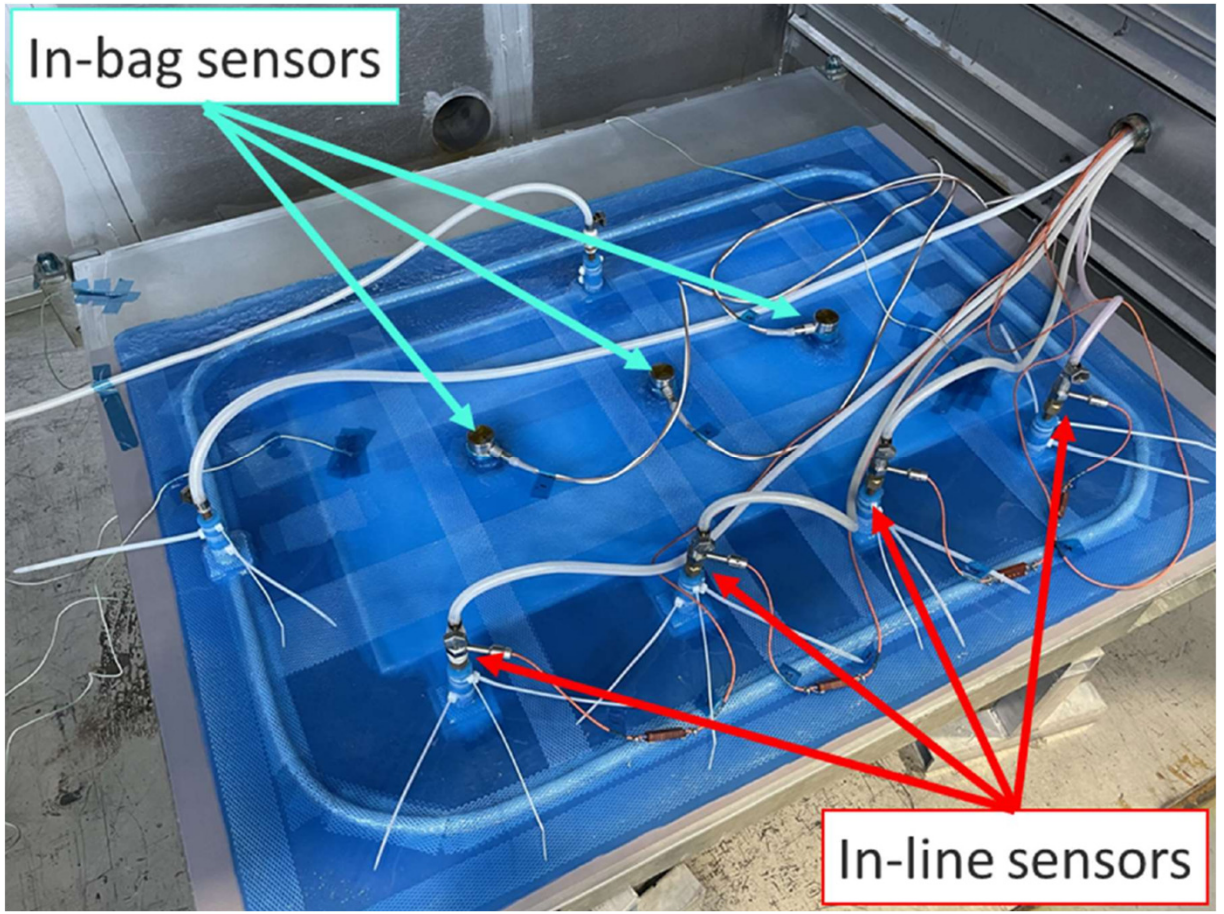
CLAMPS 2 project

Combining Inline sensors with automatic outlet valves and bag sensors

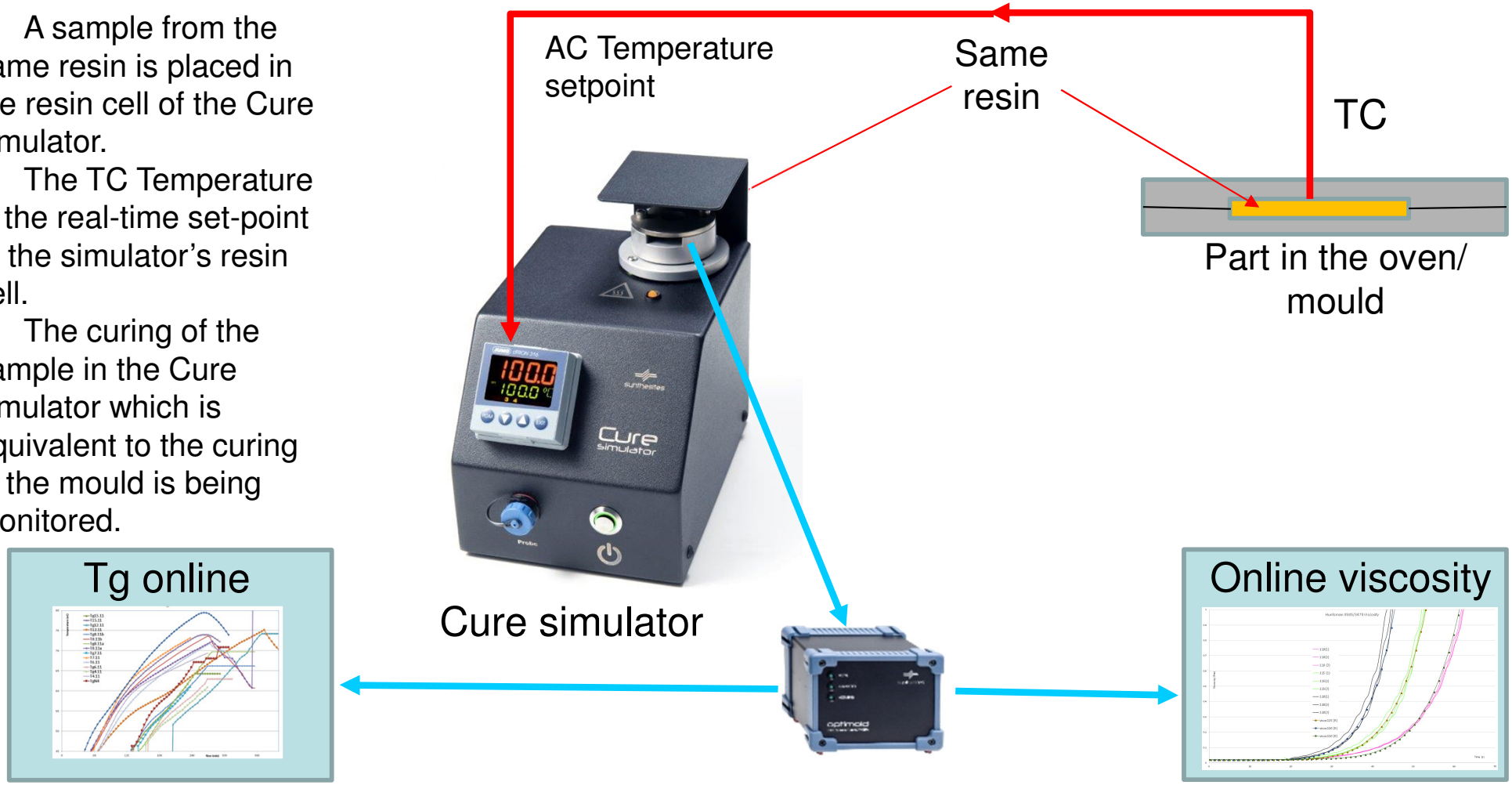
- Suitable for High Temp aerospace OoA applications
- Part of CLAMPS2 project (NCC UK)



Valve Control system (left) and silicon-bag infusion in an oven with 4 bag and 4 inline sensors (top)

Cure simulator Concept for OoA applications

- A sample from the same resin is placed in the resin cell of the Cure simulator.
- The TC Temperature is the real-time set-point at the simulator's resin cell.
- The curing of the sample in the Cure simulator which is equivalent to the curing in the mould is being monitored.



Morpho Project with Safran (2022)

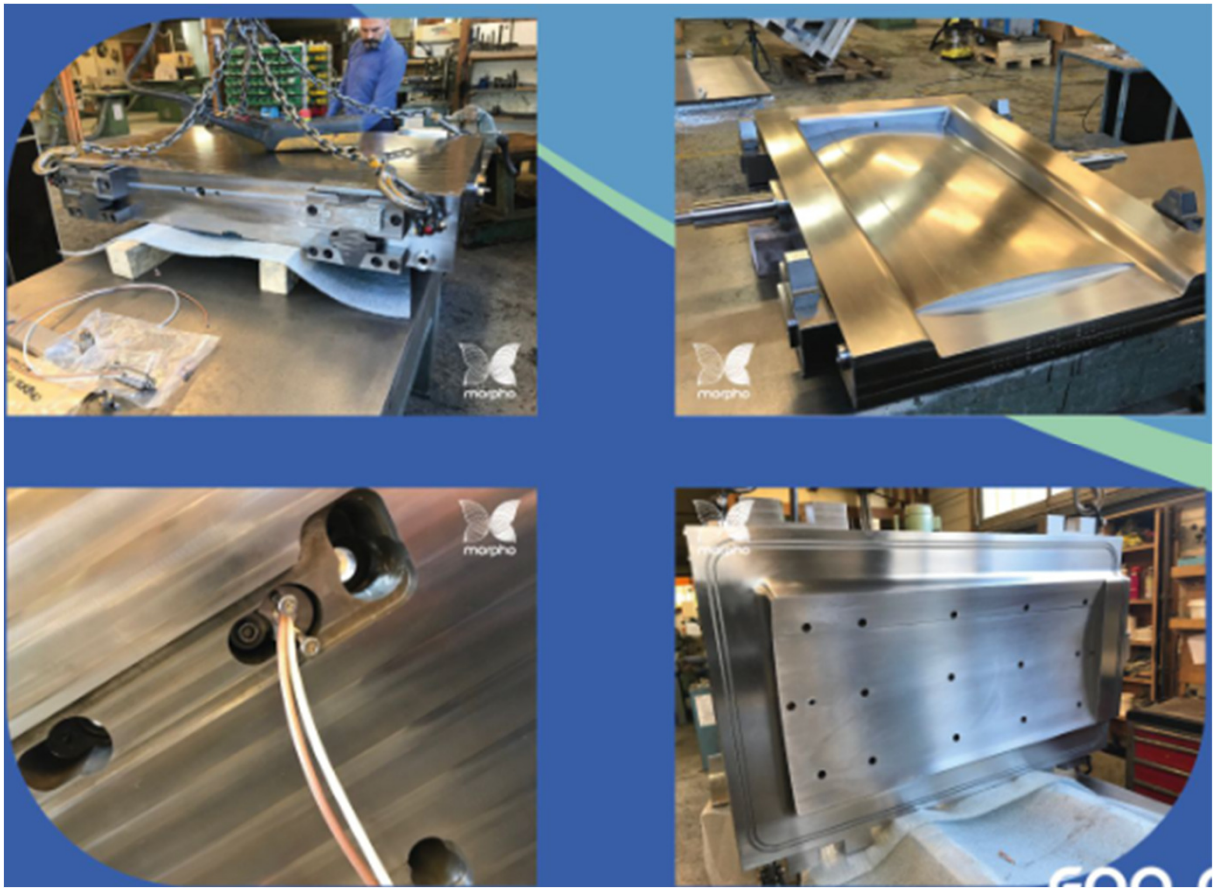
A fully sensorised RTM mould with aerospace standards with:

- 13 Resin arrival sensors
- 3 flow speed and Tg sensors
- 2 Inline gate sensors
- 1 viscosity sensor
- 1 pressure sensor at the inlet

for the completer monitoring of the injection and curing of a cfrp/epoxy aerospace part

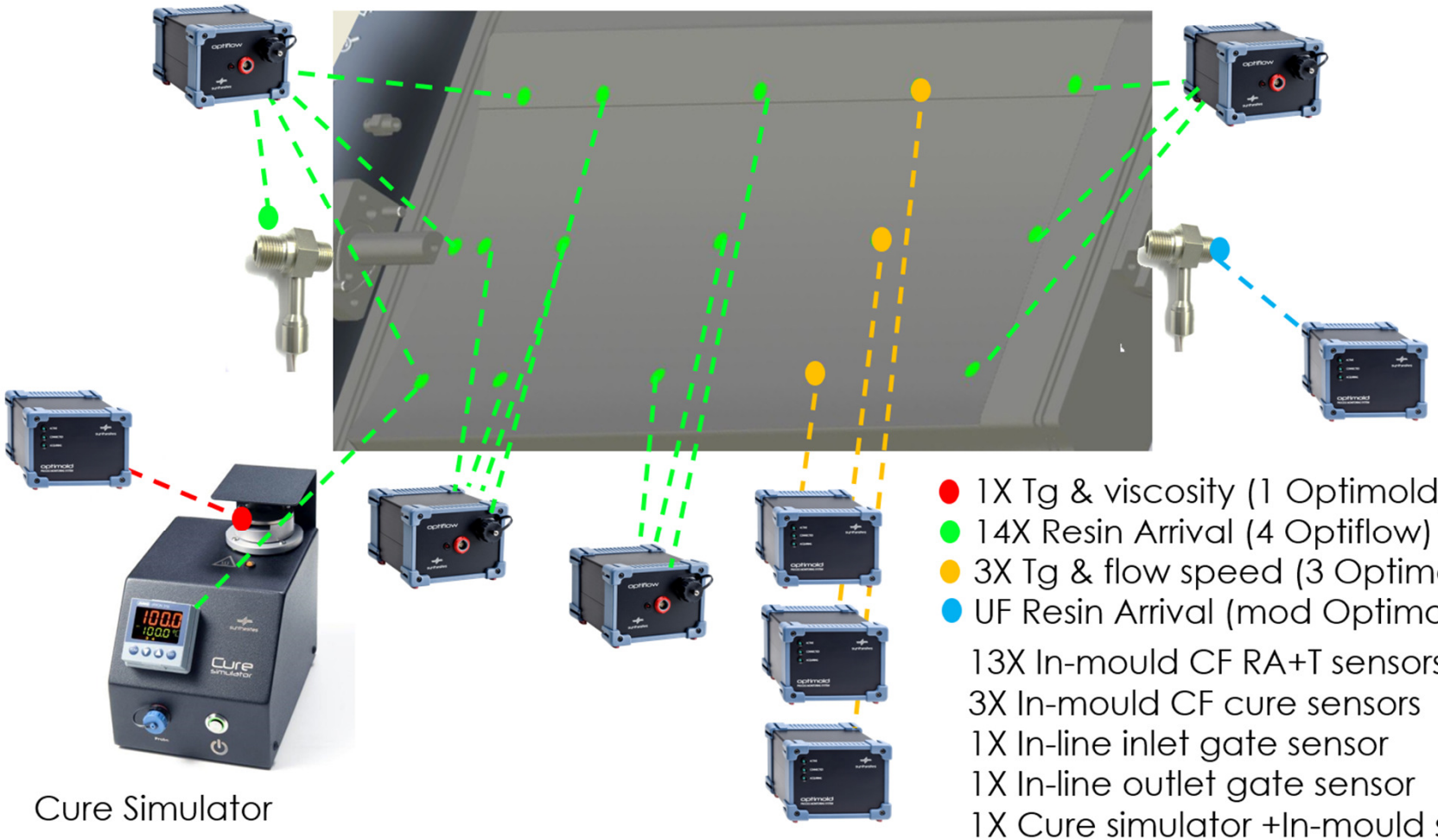
All sensors do not need a carbon fibre protection

Ultimate target is the full process control through hybrid twin



Full process monitoring

Sensors/Units at the mould



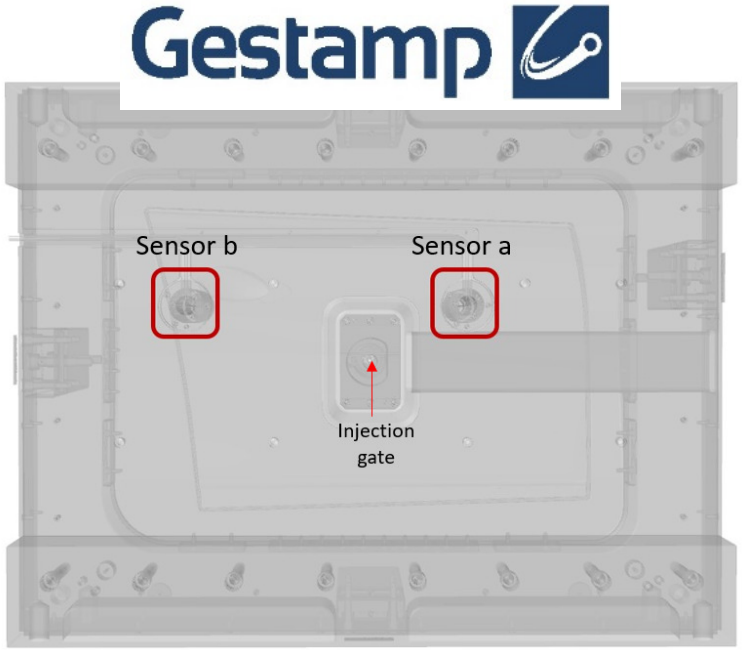
- 1X Tg & viscosity (1 Optimold)
- 14X Resin Arrival (4 Optiflow)
- 3X Tg & flow speed (3 Optimold)
- UF Resin Arrival (mod Optimold)

13X In-mould CF RA+T sensors
3X In-mould CF cure sensors
1X In-line inlet gate sensor
1X In-line outlet gate sensor
1X Cure simulator +In-mould sensor

Automotive demonstrator
Gestamp@IRT M2P

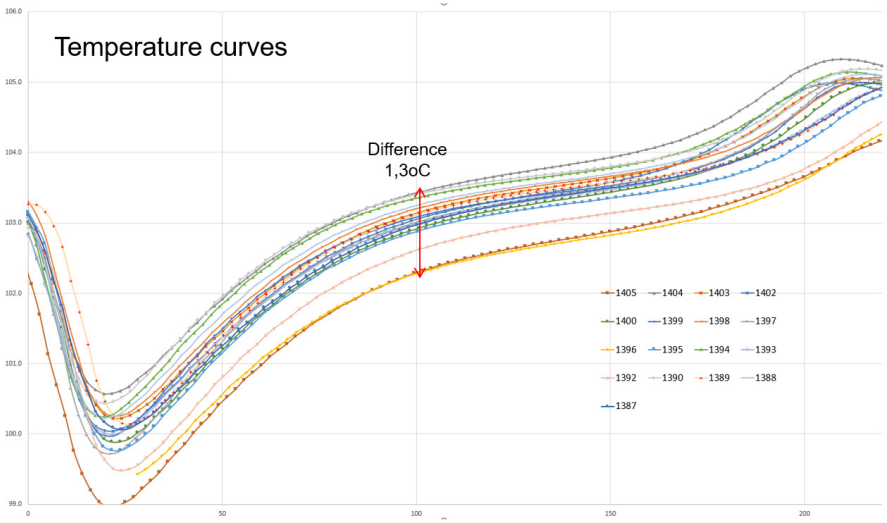
Low-pressure injection (max 10 bar) / compression (max 90 bar) moulding

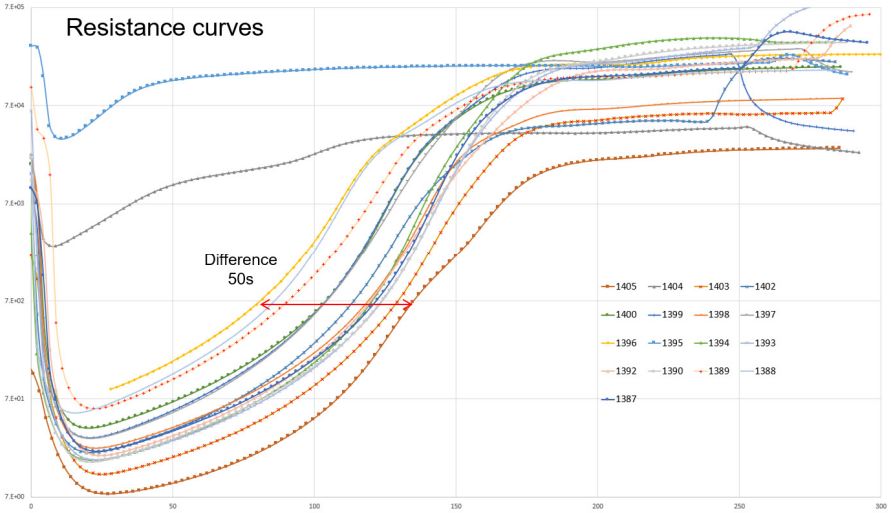
Thin hybrid preform from recycled carbon fibres and continuous glass mats.



Automotive demonstrator
Gestamp @IRT M2P

Process fluctuation





Video demonstrator

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Applications in Autoclaves

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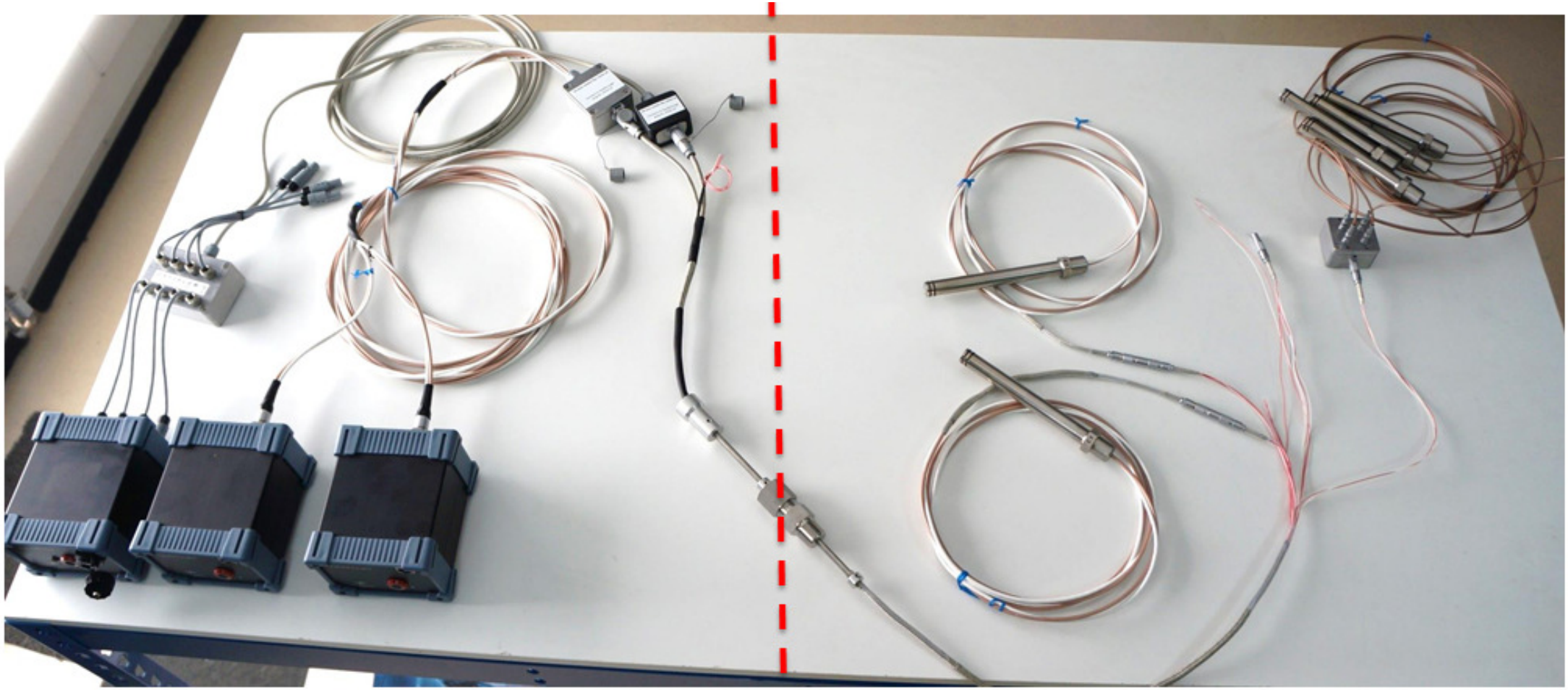
Autoclave application (Bombardier Belfast) ECOMISE R&D project



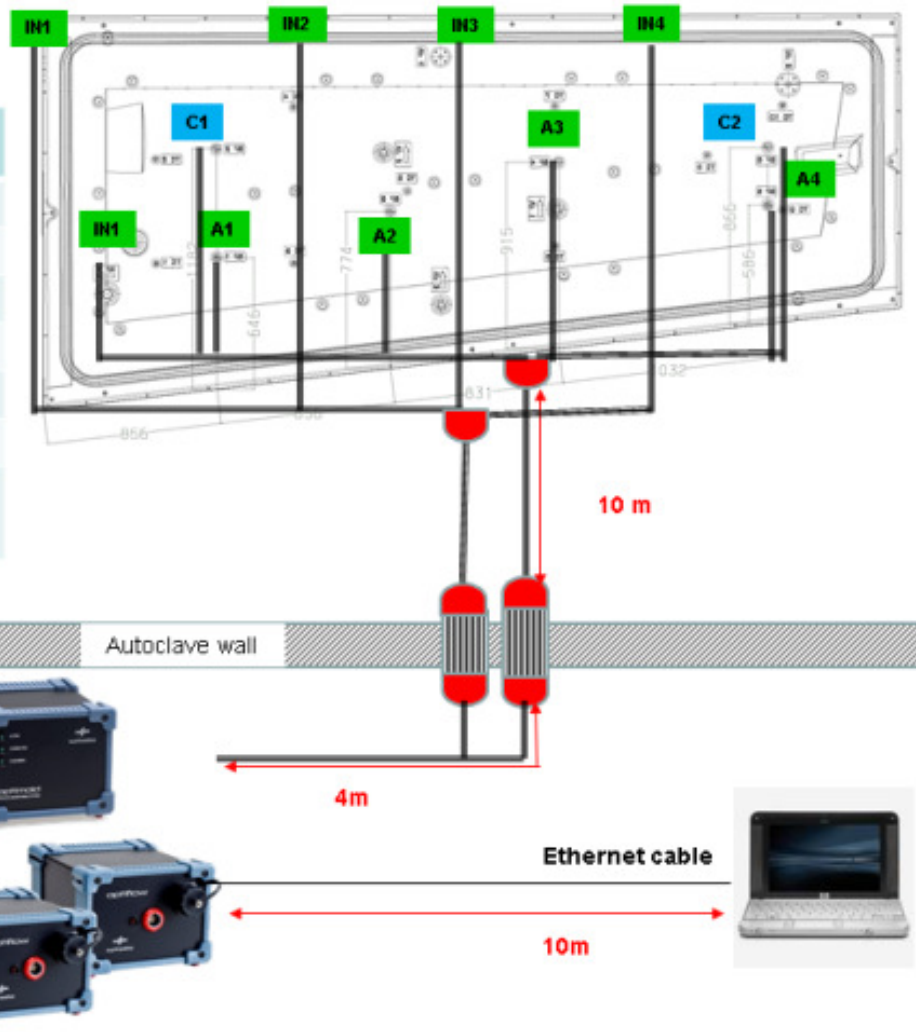
Outside of the autoclave

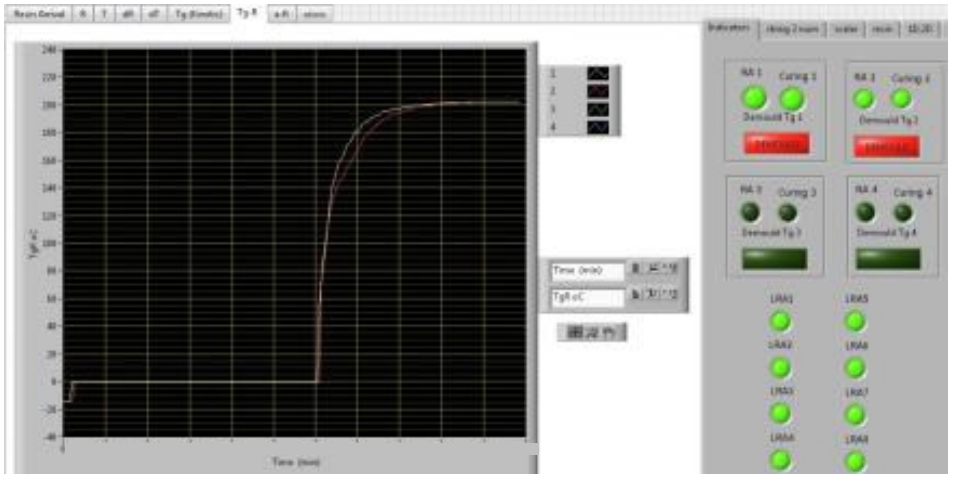
Inside of the autoclave

Demonstration ECOMISE project 2016, Bombardier Belfast, UK

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

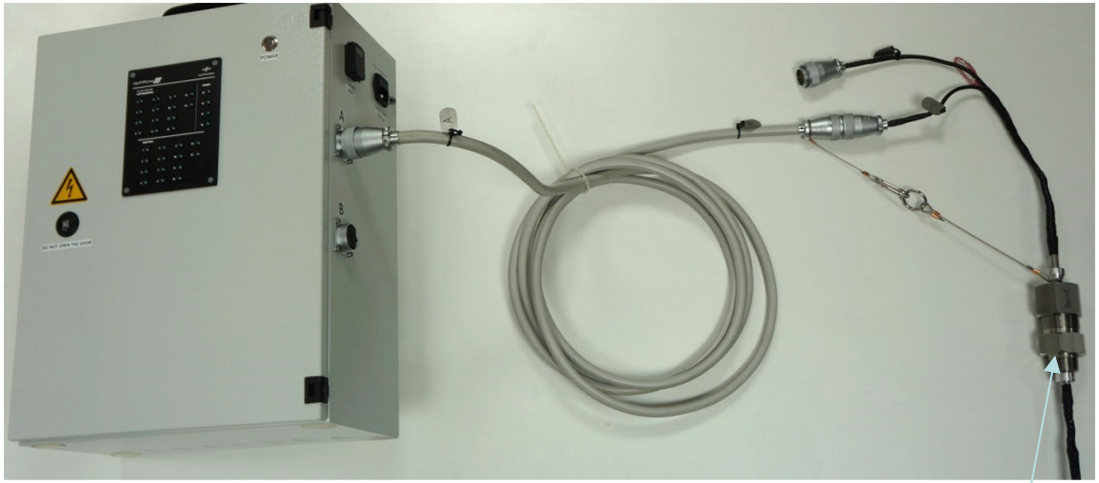


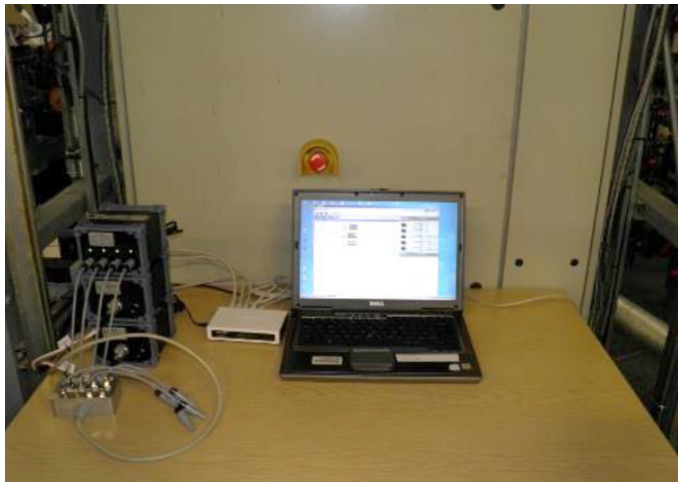


Real-time Tg prediction and demoulding decision based on targeted Tg.

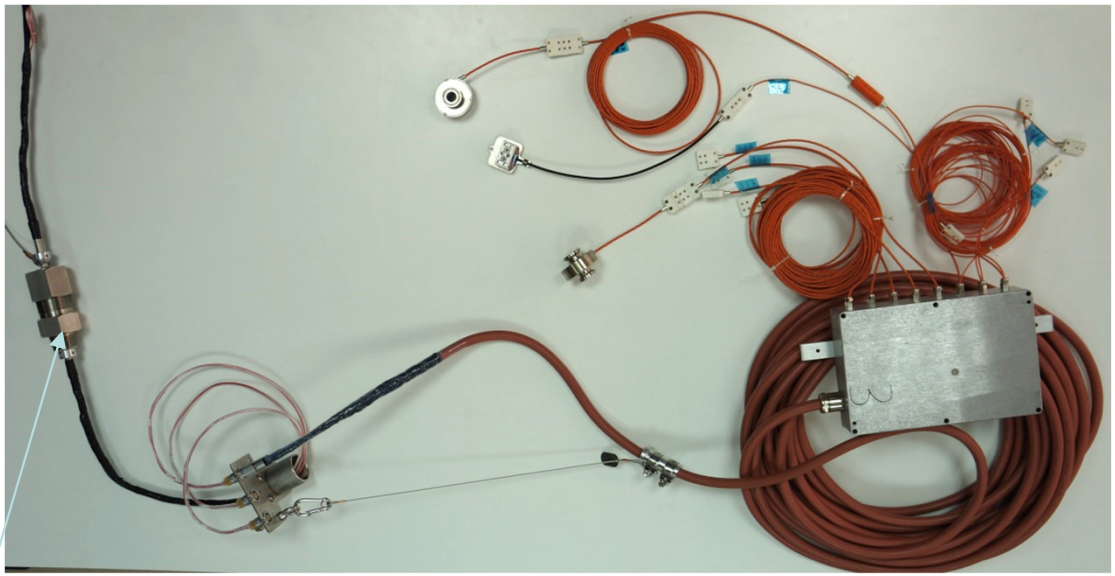
Optiflow32
Flow monitoring in Autoclave

Components outside of the autoclave

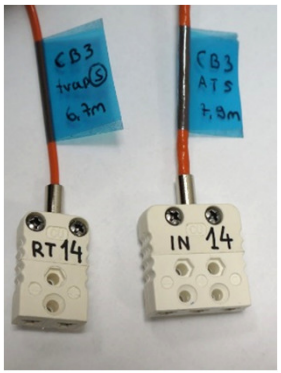




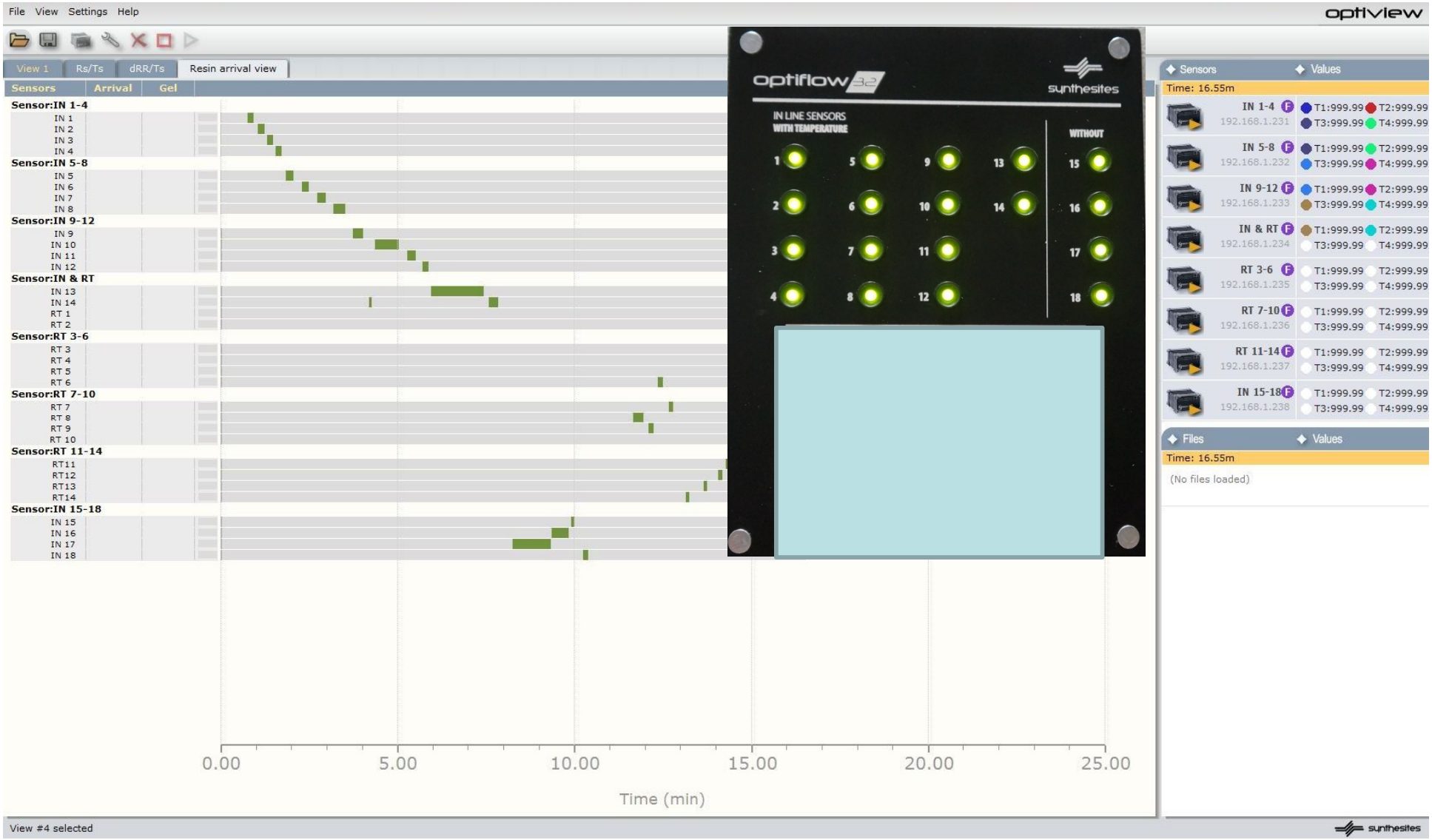
Components inside the autoclave



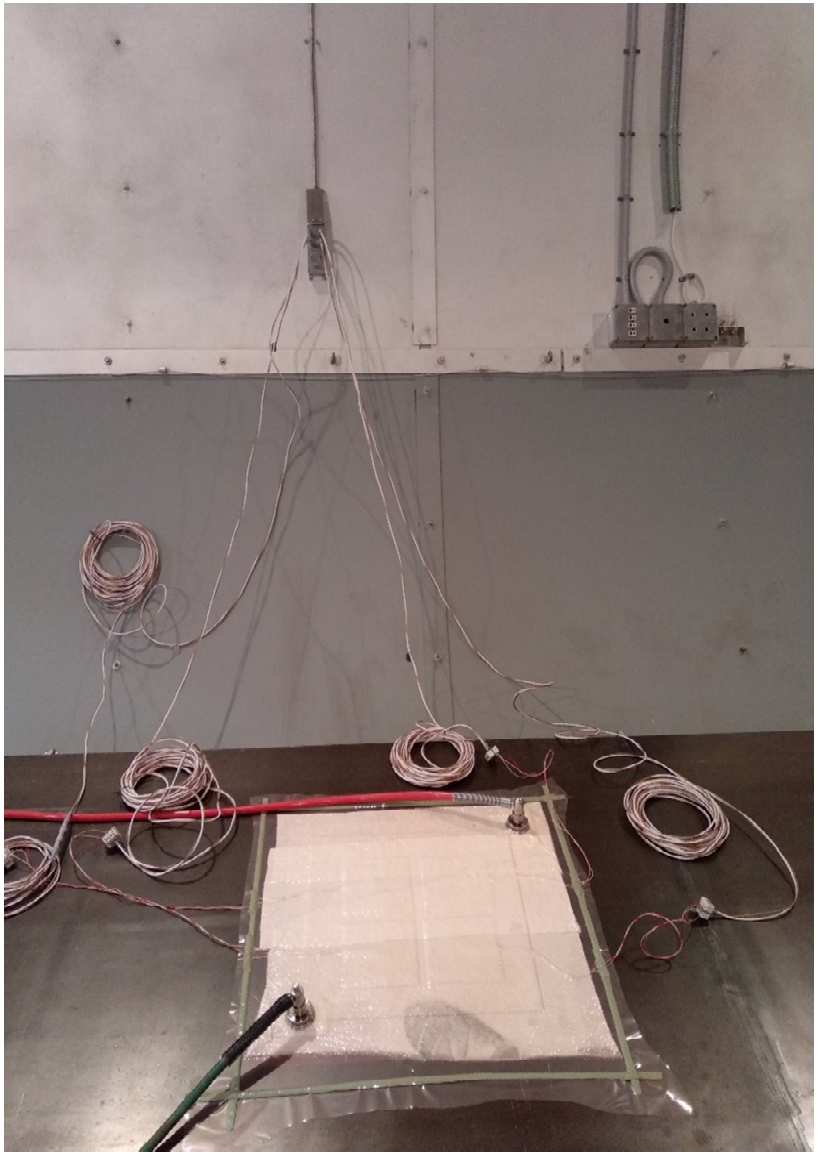
Feedthrough gland



Optiview32
Resin Arrival screen



Cure monitoring FML
DLR, Stade, DE



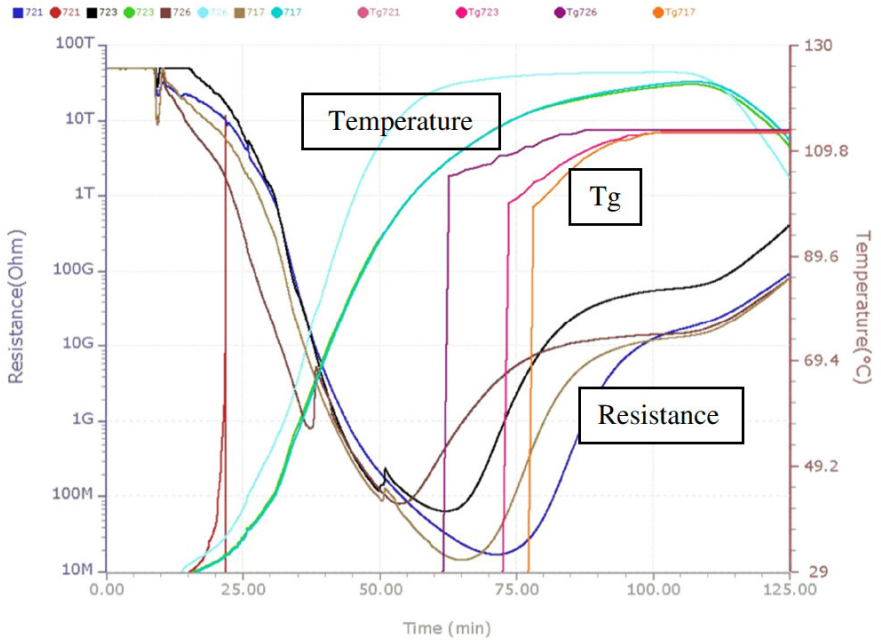
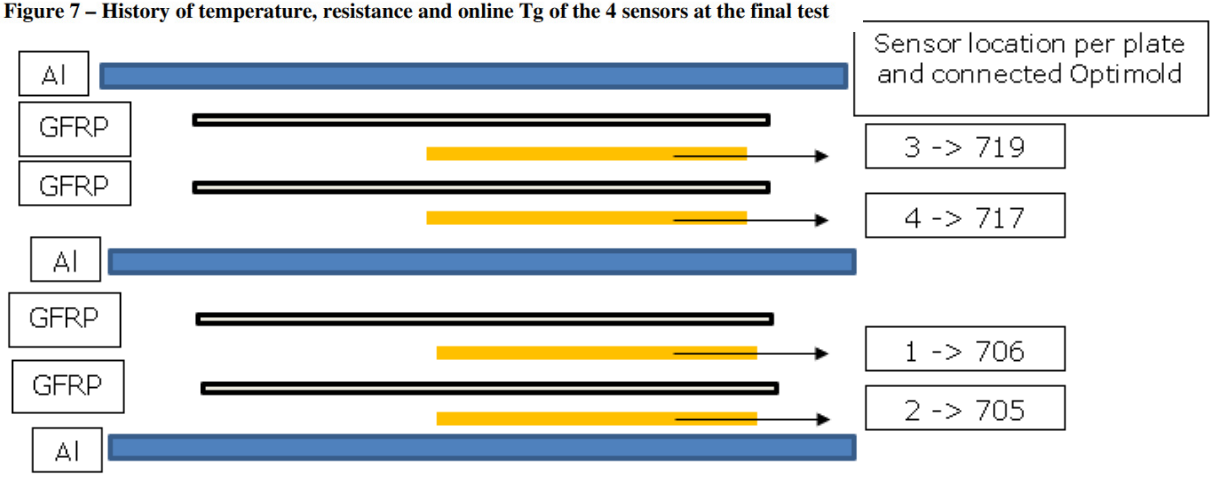
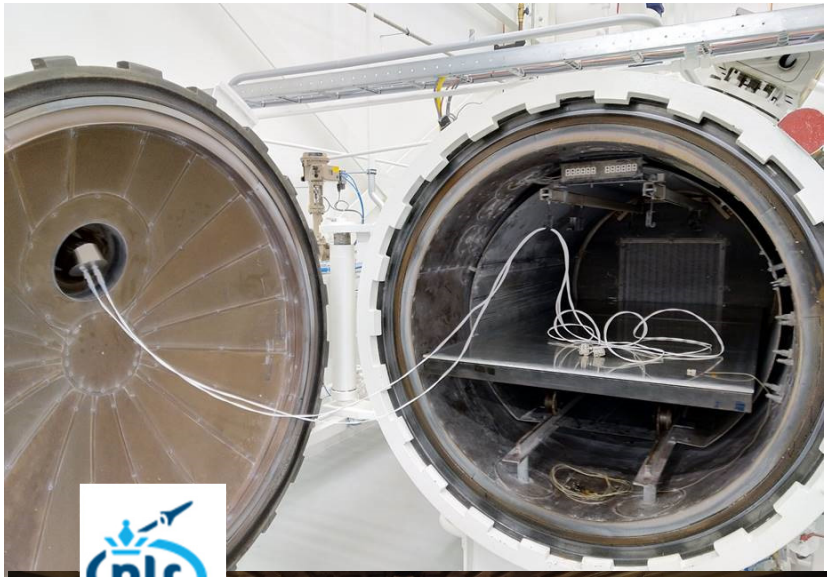


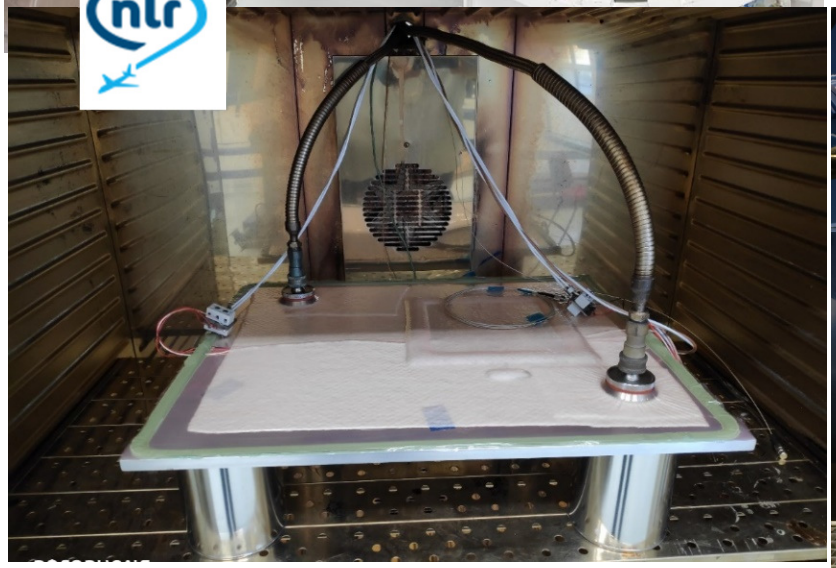
Figure 7 – History of temperature, resistance and online Tg of the 4 sensors at the final test



Cure monitoring, SUCOHS project

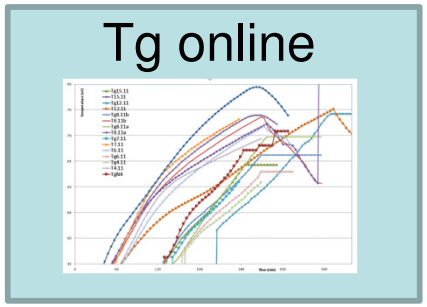
Autoclave and Oven installations @ NLR, Spirit and Fokker

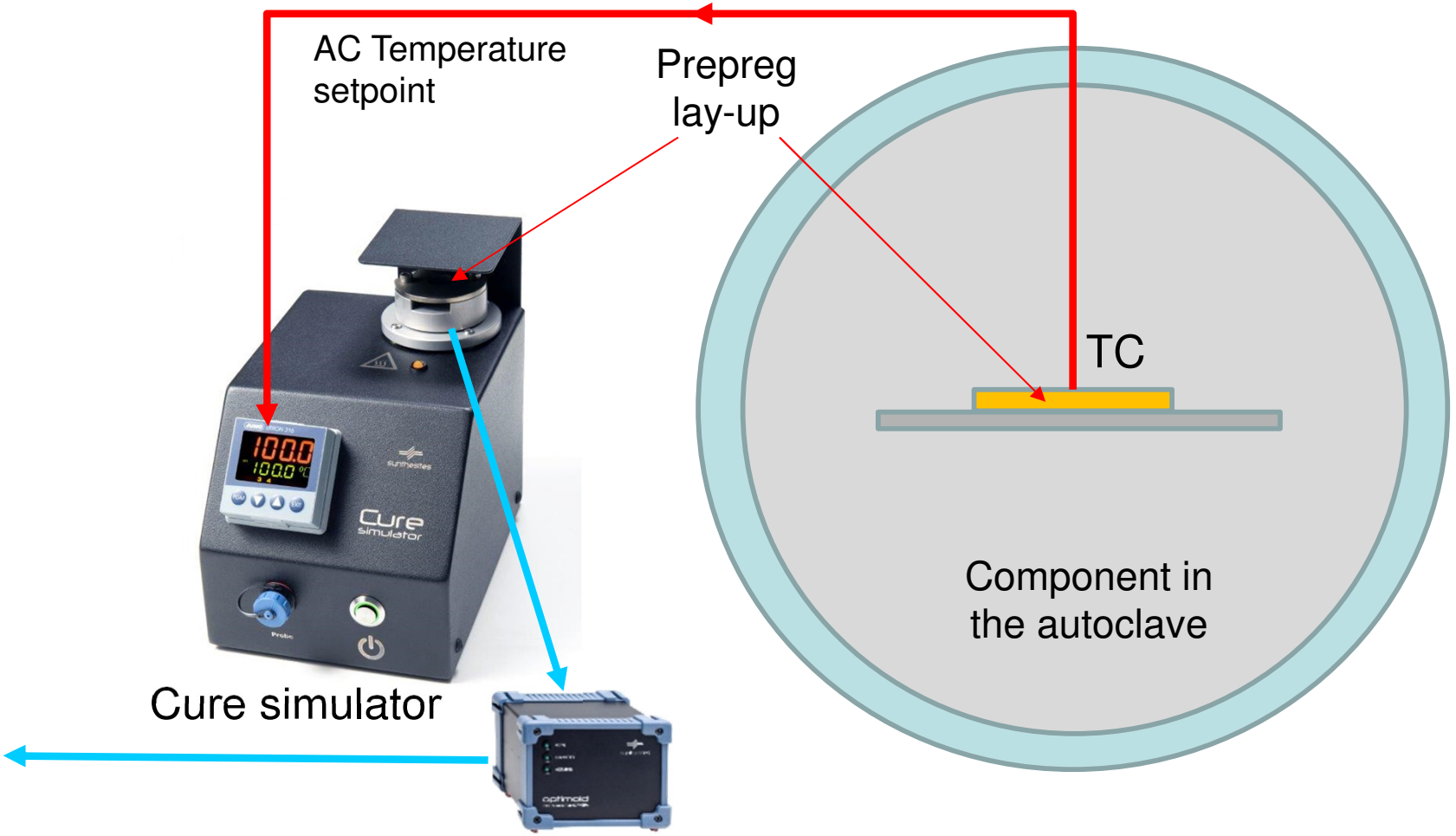




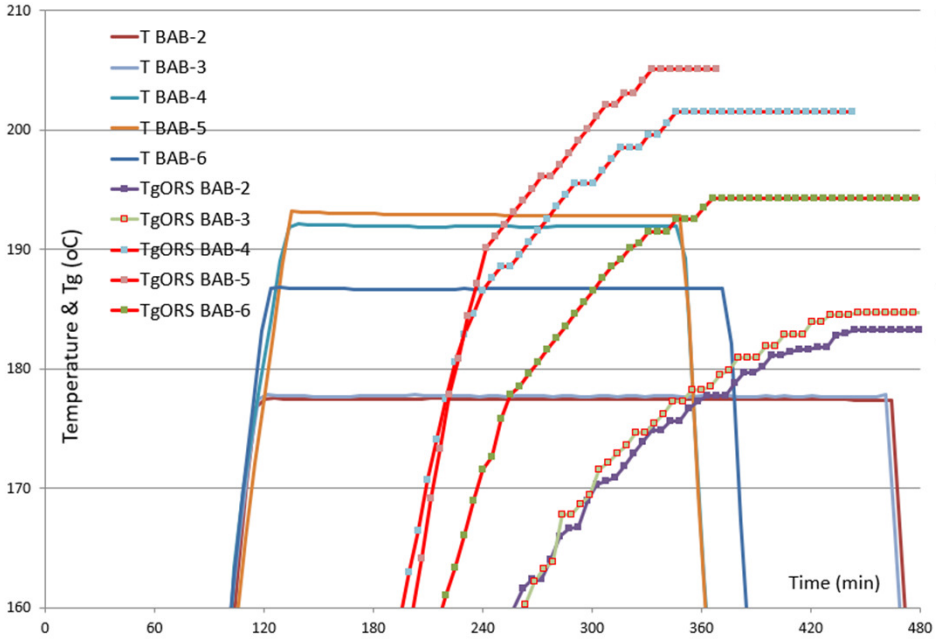
Cure monitoring without extra sensors?

- A sample from the same prepreg is placed in the resin cell of the Cure simulator.
- The AC Temperature is imposed in real-time at the simulator's resin cell.
- The curing of the sample in the Cure simulator which is equivalent to the curing in the autoclave is being monitored.





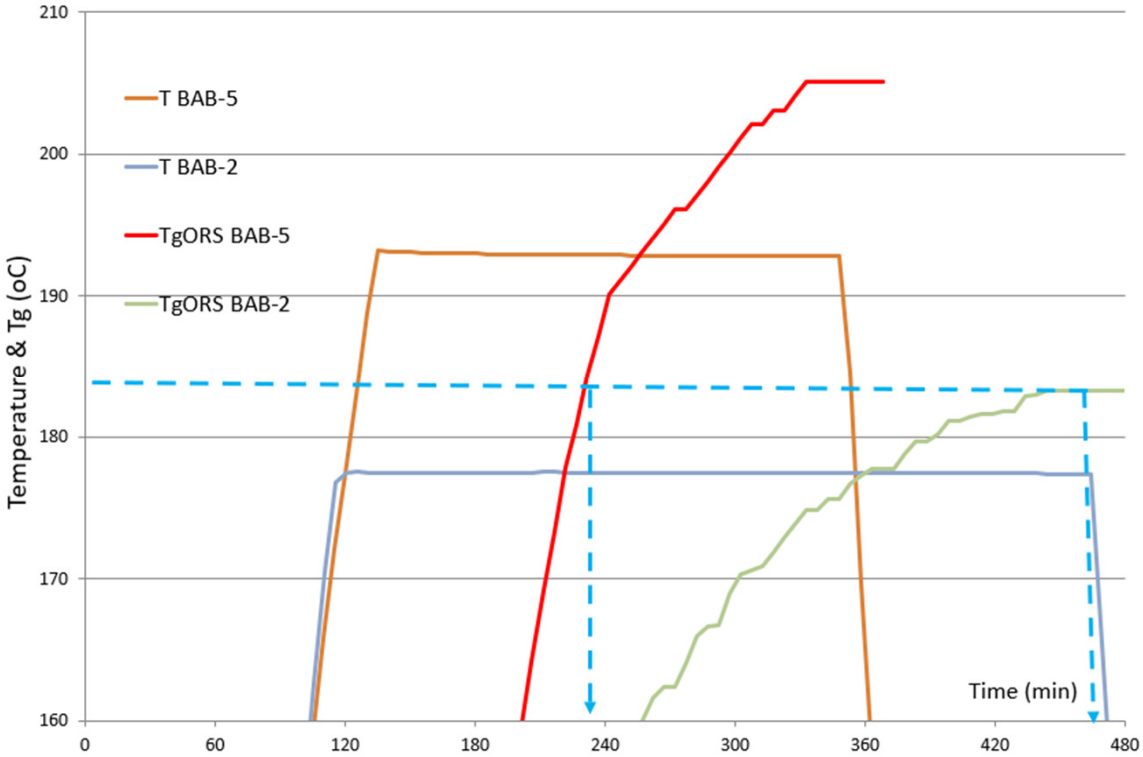
Five trials performed by Spirit in the NIACE autoclave with the Cure Simulator



Comparison of Tg estimated online (Tg ORS) and measured afterwards by DMA (Tg DMA)

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

50% cure cycle time reduction can be achieved to achieve the same Tg by raising the curing temperature from 177°C to 191°C



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).

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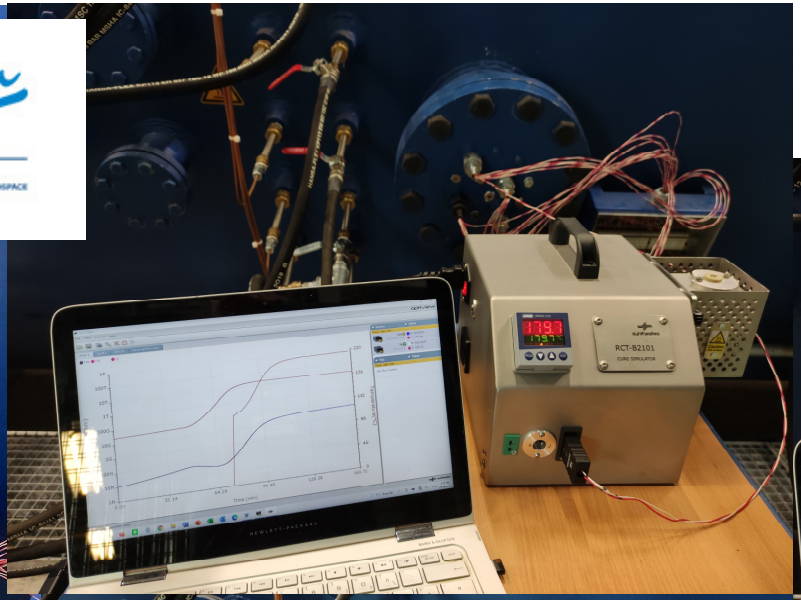
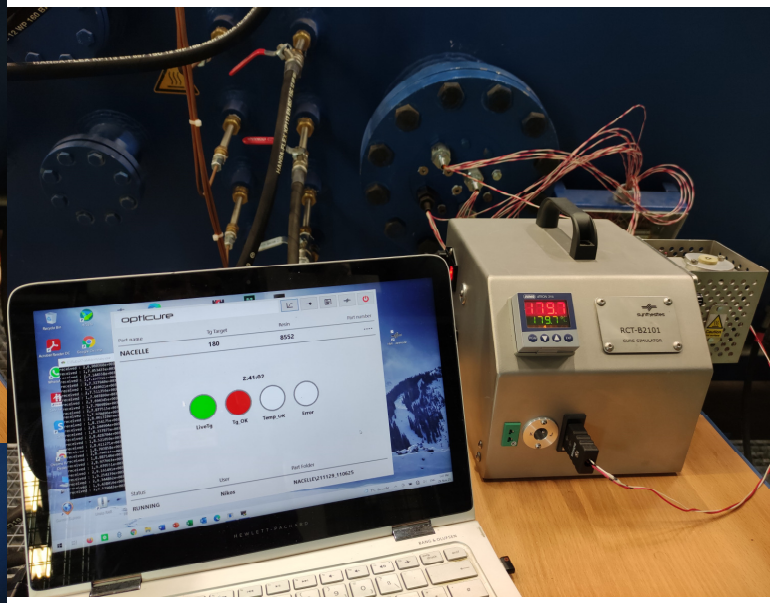
Cure monitoring, SUCOHS project

GKN Fokker Demo

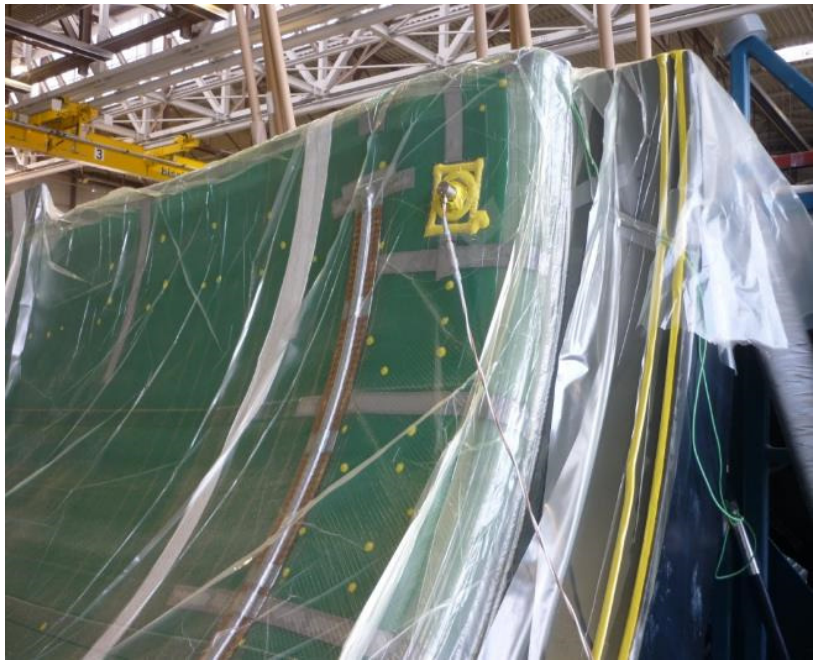


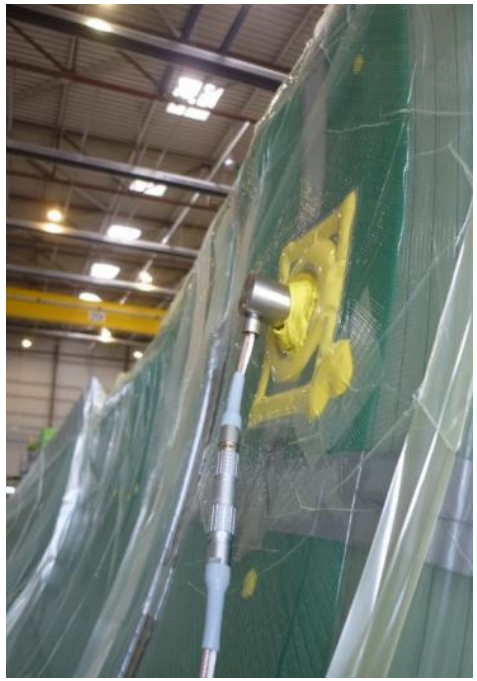


Applications in wind turbine blades

Real Production

Placing the sensor on top of the laminate on the vacuum bag where there is no direct heating from the mould and it is the last point to cure

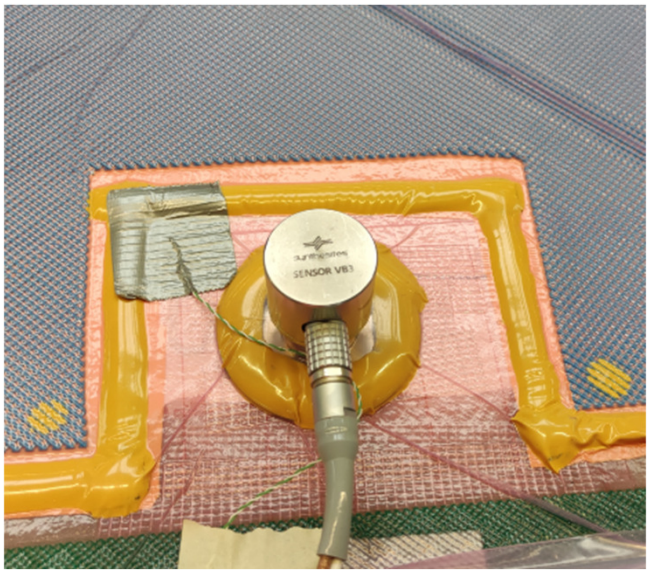


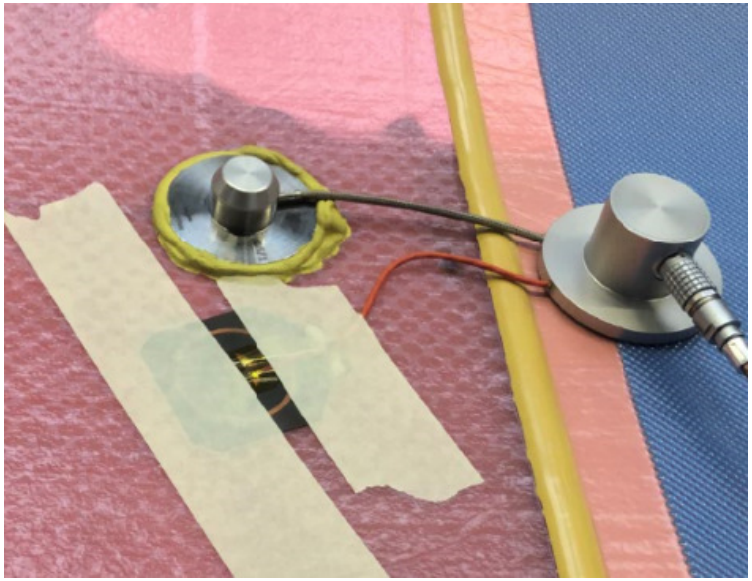


2017: In collaboration with CARBON ROTEC COMPOSITE TECHNOLOGY

Vacuum-bag
durable sensor

Vacuum-bag
Heated durable
sensor





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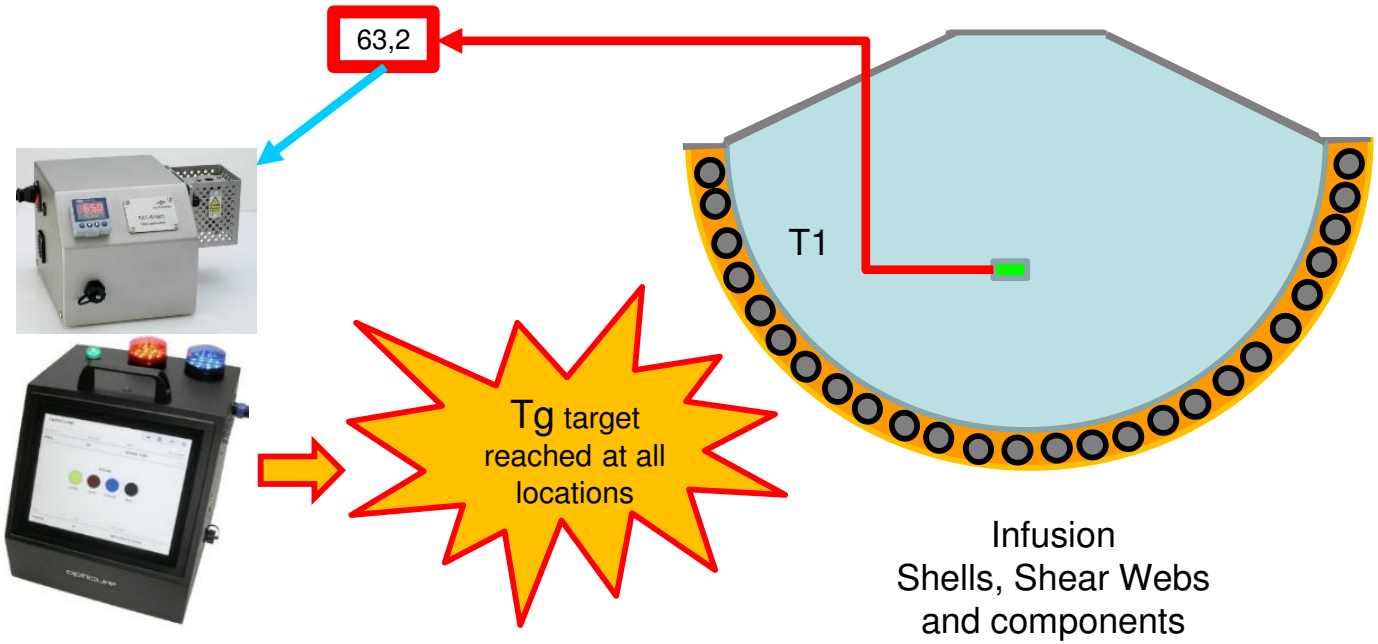
OnlineQC system: Infusion



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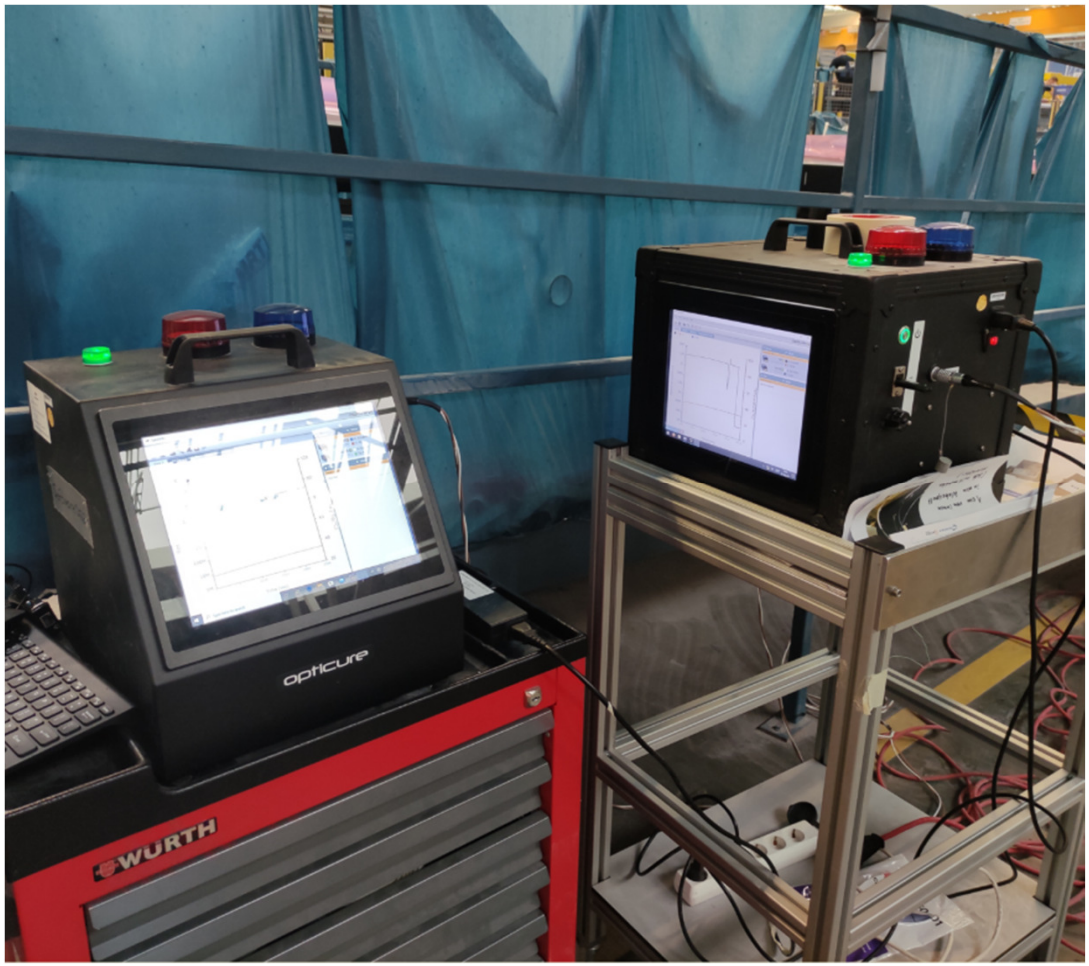
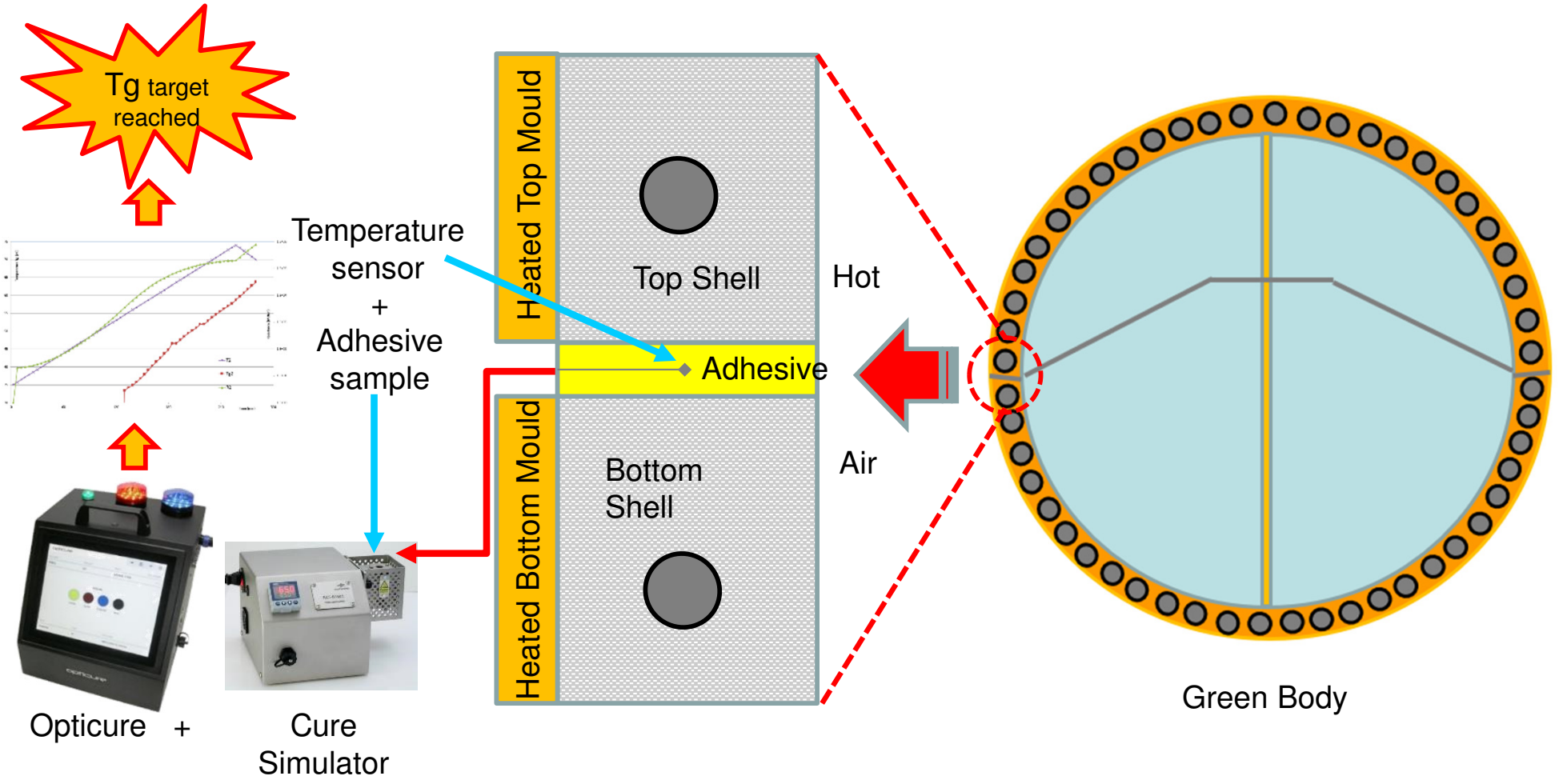
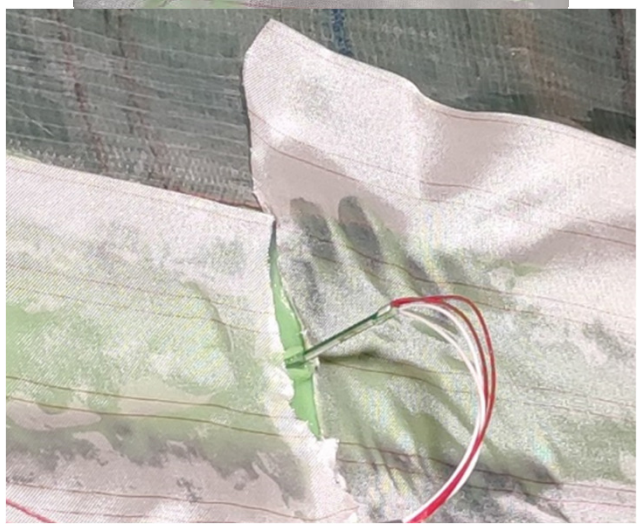
Production @ Nordex Infusion



2 OptiCure systems
and a Cure Simulator


Tg target reached
Temperature sensor + Adhesive sample
Heated Top Mould
Top Shell
Hot
Adhesive
Air
Bottom Shell
Heated Bottom Mould
Opticure +
Cure Simulator
Green Body

Adhesive bonding monitoring and connection to the PLC



Initially placing a thin film cure sensor in the bondline

Now placing a tiny temperature sensor in the bondline in combination with the Cure Simulator and the Opticure systems

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External links & videos

Company and system video presentation

Presentation

Graphic representation of how the intelligent monitoring works

How it works

Online Tg Demos (from real applications)

RTM6 Cure cycle RTM CFRP injection
(fast forward video, 1s=1min)

Wind blade (shell) Cure cycle (v. infusion, epoxy glass, two sensors)
(fast forward video, 1s=1min)

High Pressure Compression RTM (CFRP, snap curing epoxy, two sensors)

Contact

Belgium

SYNTHESITES SRL

Av. du Lycée Français 5B, b9
1180, Uccle
Phone: +32 (0) 472 201 382
e-mail: be@synthesites.com

Greece

SYNTHESITES INNOVATIVE TECHNOLOGIES Ltd

Kyprion Agoniston 33,
GR-185 41, Piraeus
Phone: +30 210 42 00 885,
e-mail: info@synthesites.com

www.synthesites.com

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