CURE MONITORING OF HIGH-TEMPERATURE RESINS FOR ENHANCING THE MANUFACTURING OF ADVANCED COMPOSITES

Dr N. Pantelelis, Synthesites SNC, Belgium
W. Gerrits, R. Klomp-de Boer, NLR, The Netherlands
A. Johnston, S. Wilson, A. McKibbin, Bombardier Aerospace, UK
C. Brauner, F. Schadt, L. Amirova, M. Grob, FHNW, Switzerland

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Customers
(non exhaustive list)

Companies

R&D Centres and Universities

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Funded R&D projects

On-going

Recotrans: (2017-2020) Multimaterial recyclable manufacturing for the transportation industry
RTM and pultrusion, Glass fibre, reactive thermoplastic for automotive and rail applications
Partners: Aimplas (CO), Fraunhofer, Daimler, Far UK, Stadler, INEA, Istanbul University, Arkema

SuCoHS: (2018-2020) Sustainable and Cost Efficient High Performance Composite Structures demanding Temperature and Fire Resistance
Partners: DLR (CO), Bombardier, Aernnova, NLR, ONERA, Apodius, Rockwell Collins

Completed

Ecomise: First-time right composites manufacturing (2013-2016)
Partners: DLR (CO), Faser I., Bombardier, Hutchinson, Airborne, Loop, Dassault Systemes, NLR
RTM and RTI, Glass and carbon fibre, epoxy

Coaline: Injection pultrusion with microwave curing and injection of coatings (2013-2017)
Fraunhofer ICT, Aimplas, Resoltech, Rescoll, Acciona

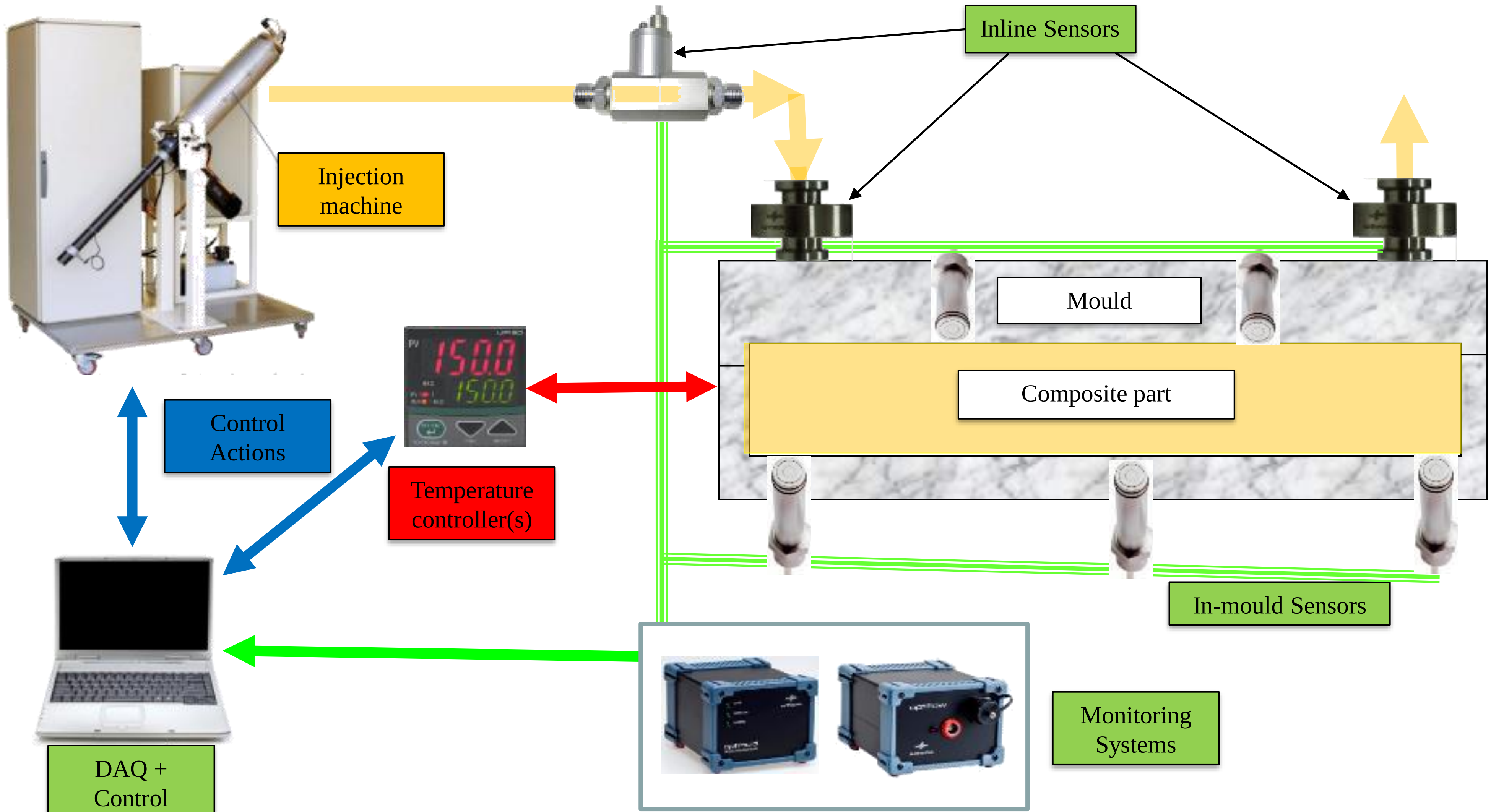
iREMO: intelligent Reactive Moulding (2009-2012)
RTM, Light RTM and Infusion, Glass and carbon fibre, epoxy and polyester

MAC-RTM: Microwave curing (2011-2013), Fraunhofer ICT and Aimplas

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

Intelligent automation in composites processing



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

In-mould Durable

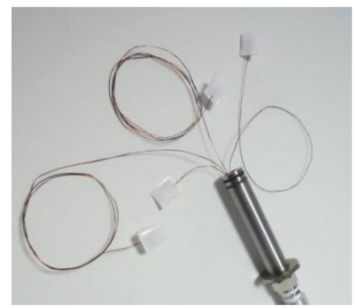
- flat areas
- possible mark

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

New

Curved Durable

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

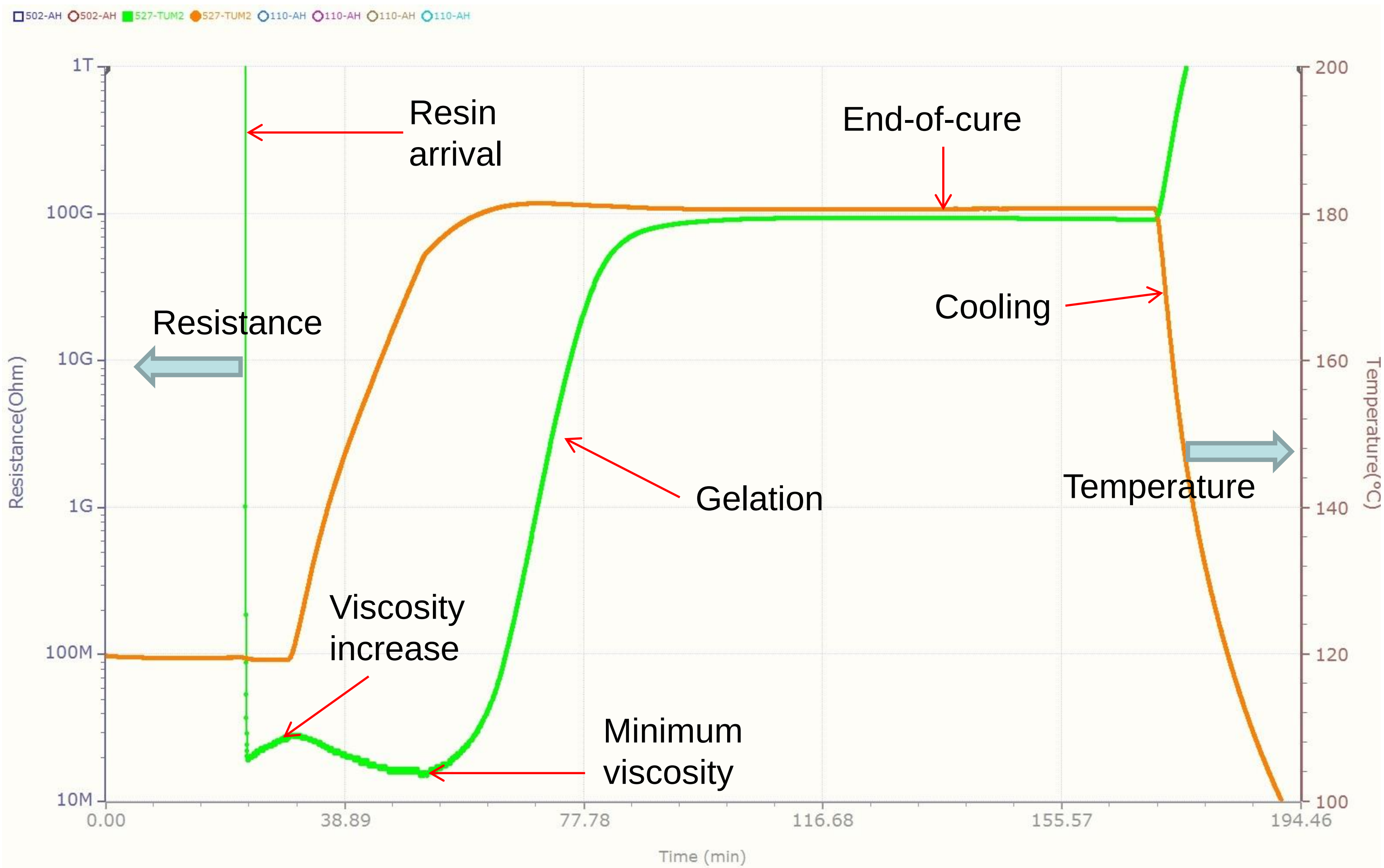
New

CF In-mould Durable

New

Vacuum Bag Sensor

A typical RTM6 cure cycle as measured with Optimold



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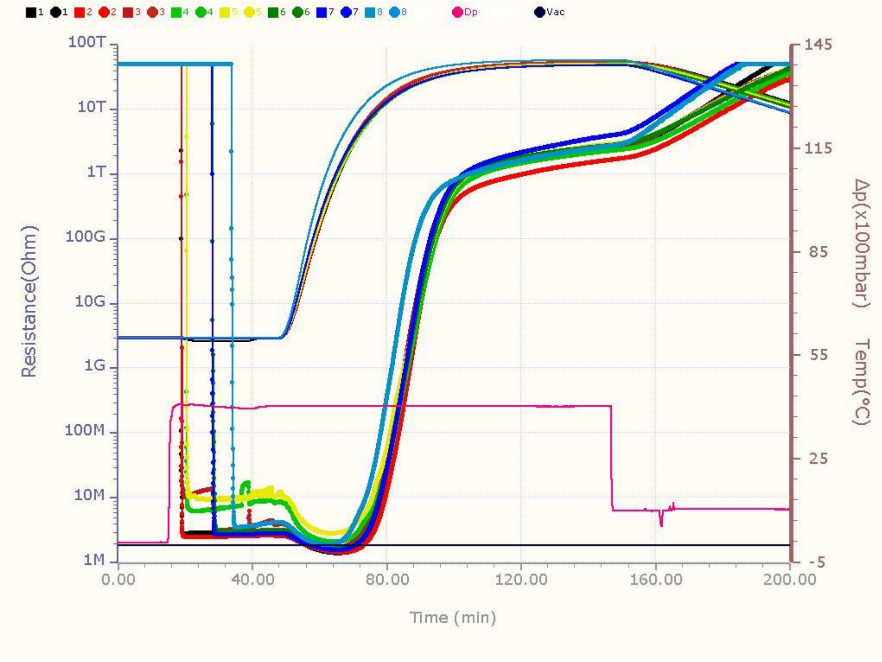
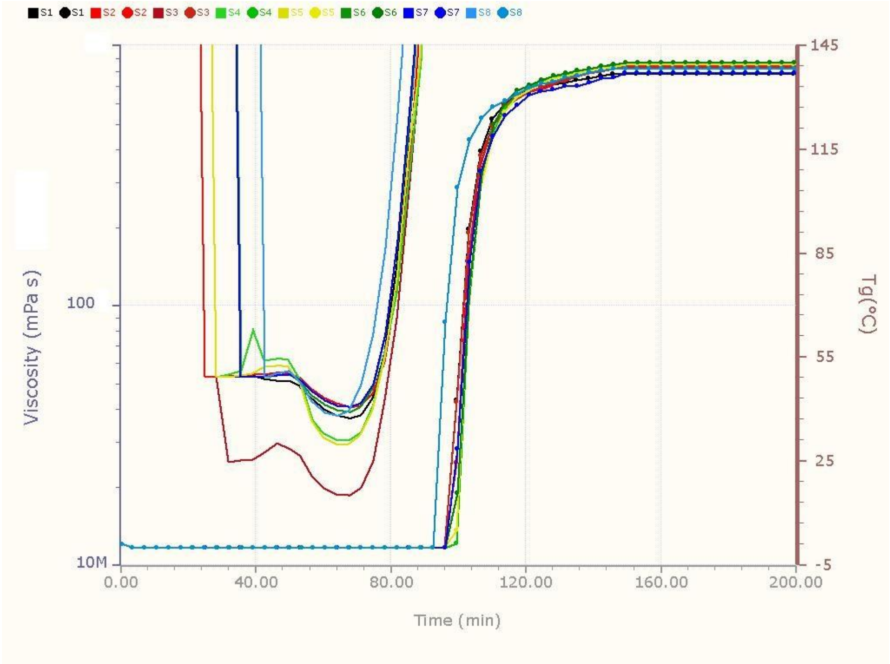
On-line Resin State (ORS software)

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

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

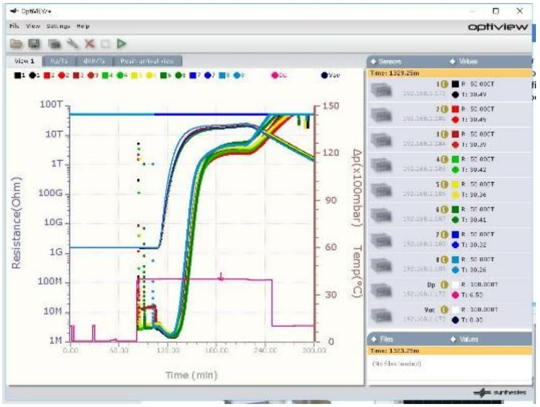
CARBON ROTEC COMPOSITE TECHNOLOGY

published at SAMPE Journal, v.53/6, Nov/Dec 2017, pp. 6-10

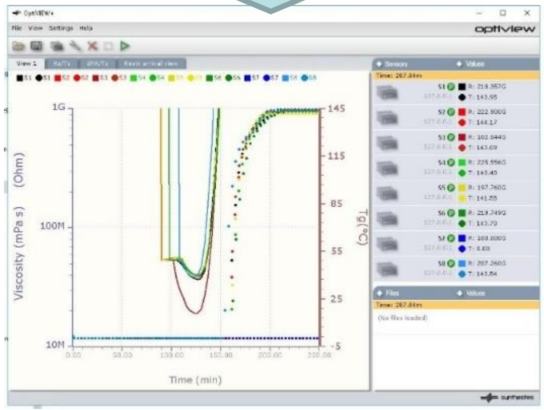
	Trial	Duration [h]	T_g-ORS (°C)	T_g- DSC (°C)	Difference (°C)
Isothermal	80DV1	3	73.17	73.34	-0.17
	80DV3	2.5	70.30	70.91	-0.61
	80DV4	2.5	73.45	72.49	0.96
	80-120'	1.92	66.96	66.02	0.94
	80-90'-1	1.50	62.04	61.80	0.24
	80-90'-2	1.50	65.52	65.21	0.31
	80-D2-2	1.50	61.88	60.59	1.29
	60-260'	4.33	55.02	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

Measuring resistivity, temperature, pressure



Online Estimating Tg, viscosity, degree of cure



Intelligent Process Control

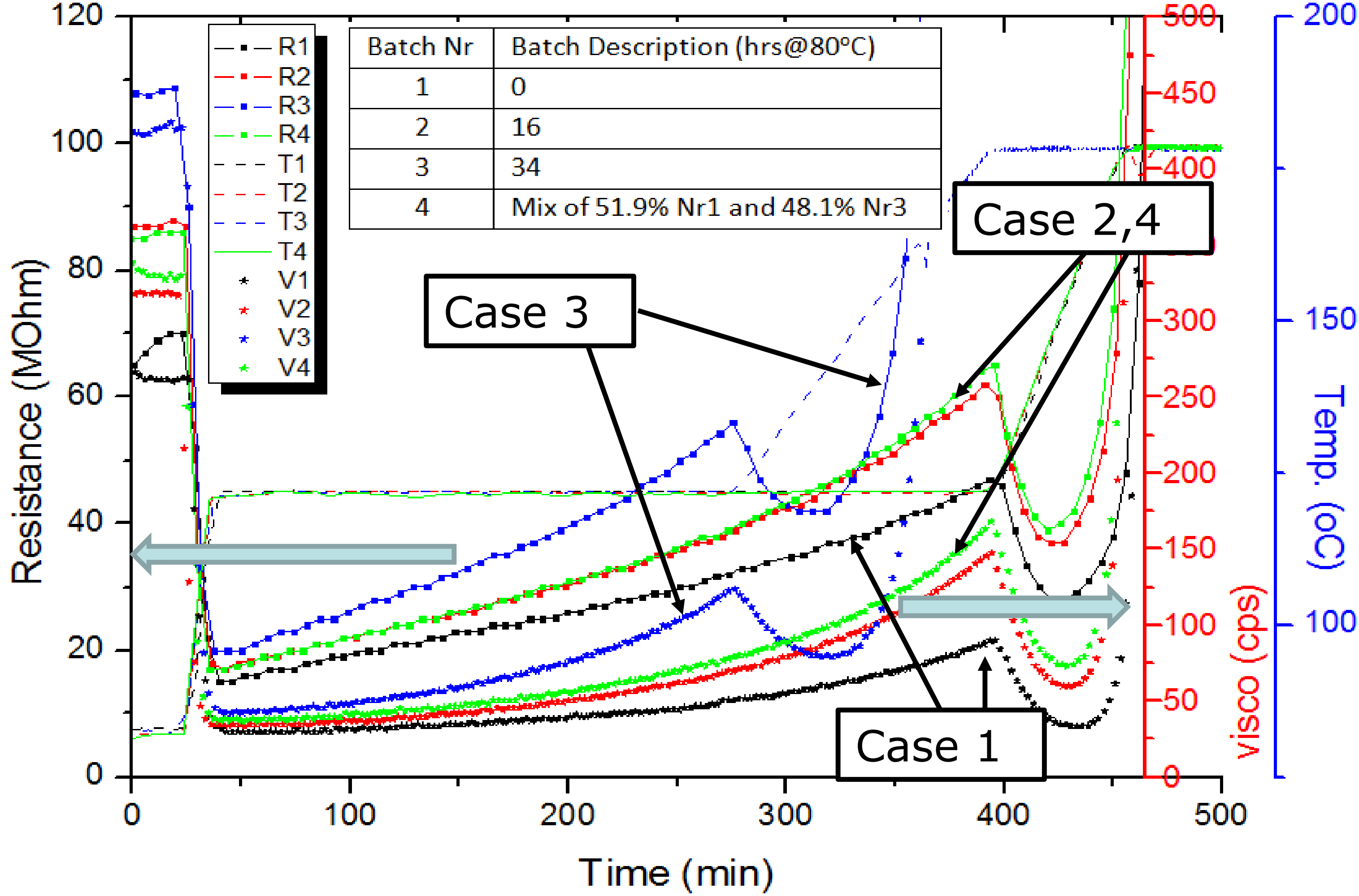
Controlling temperature, demoulding time etc.

Injection machine

Press controller

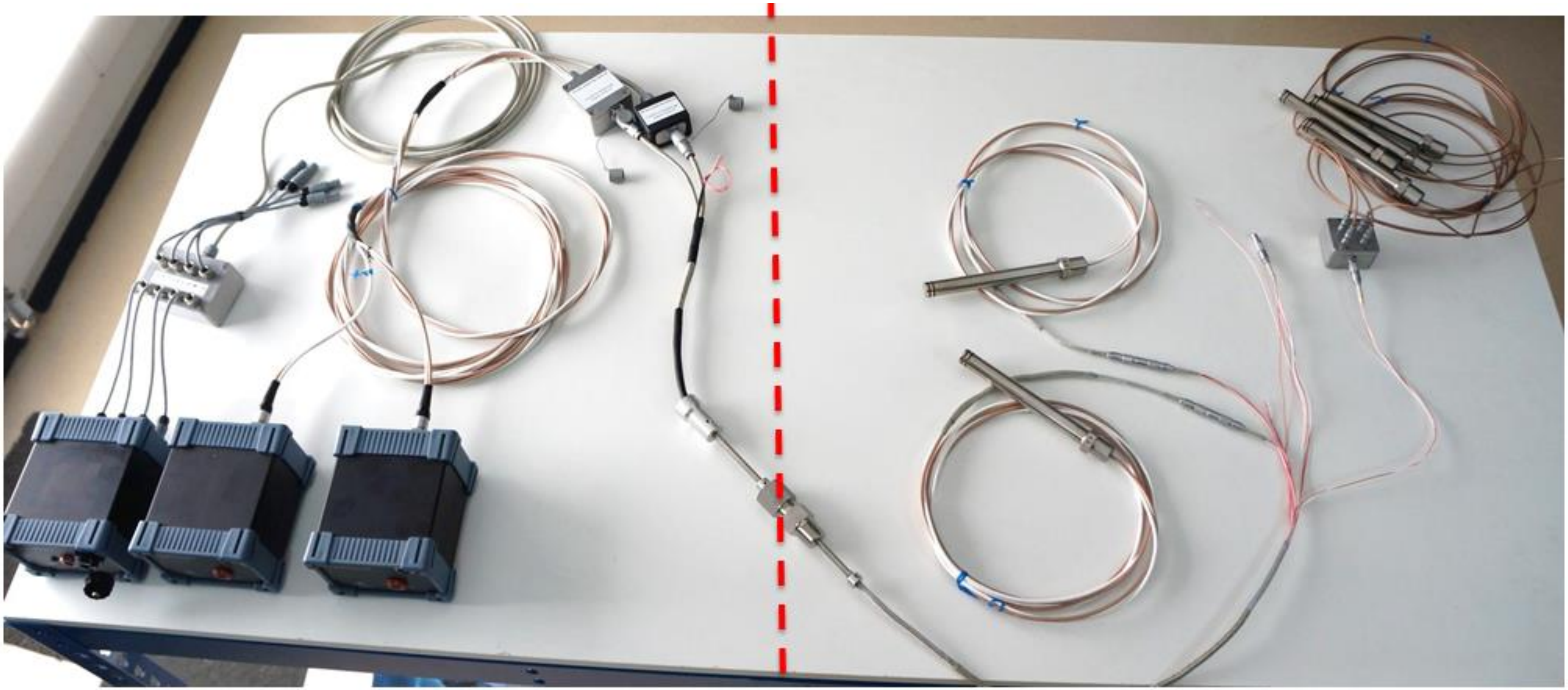
Temperature controller(s)

Sensing online Resin aging and viscosity



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

Autoclave system
(Bombardier Belfast)
ECOMISE R&D project

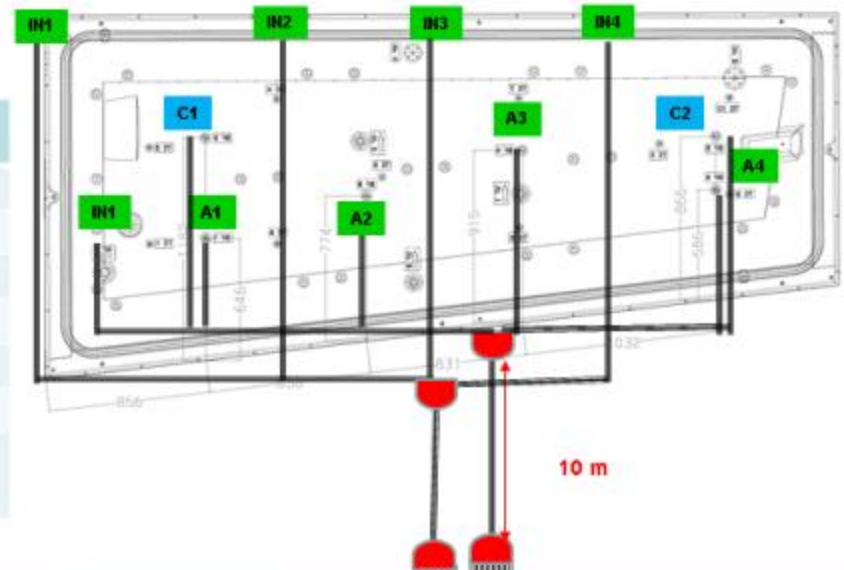


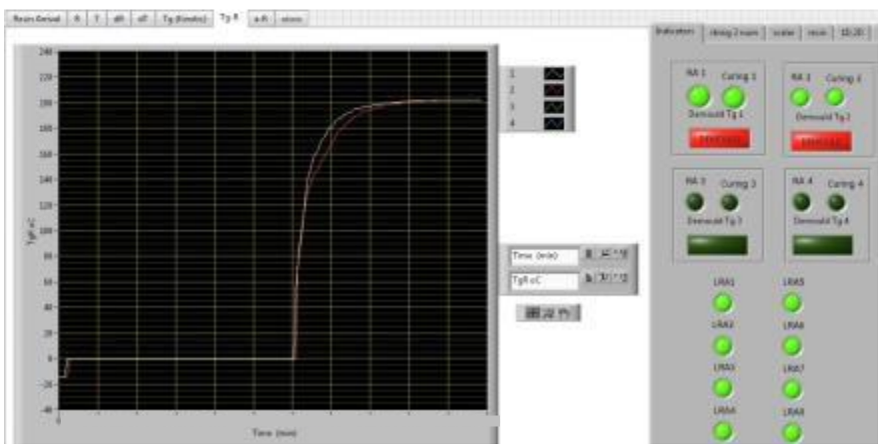
Outside of the autoclave

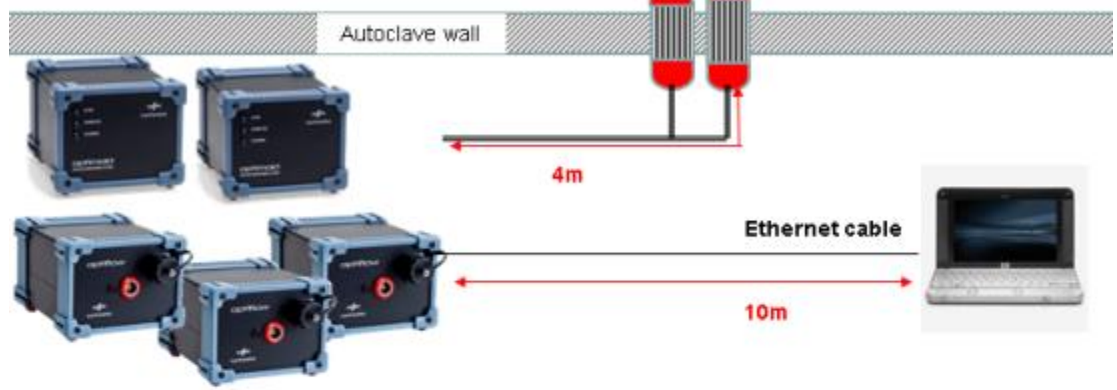
Inside of the autoclave

Demonstration
@ WPU Bombardier 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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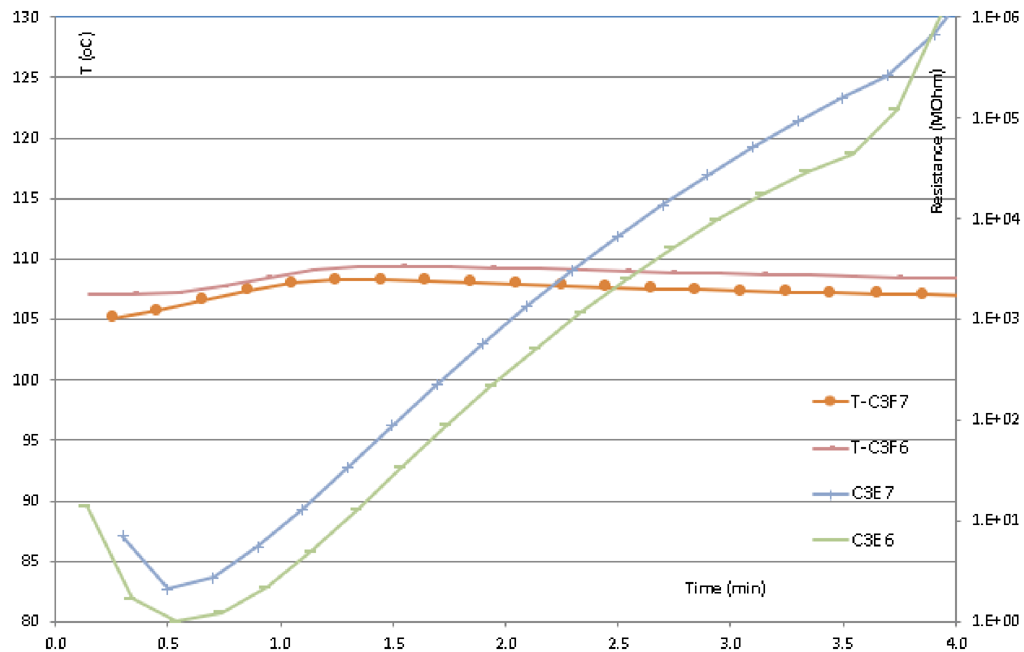
New durable sensor for cfrp production



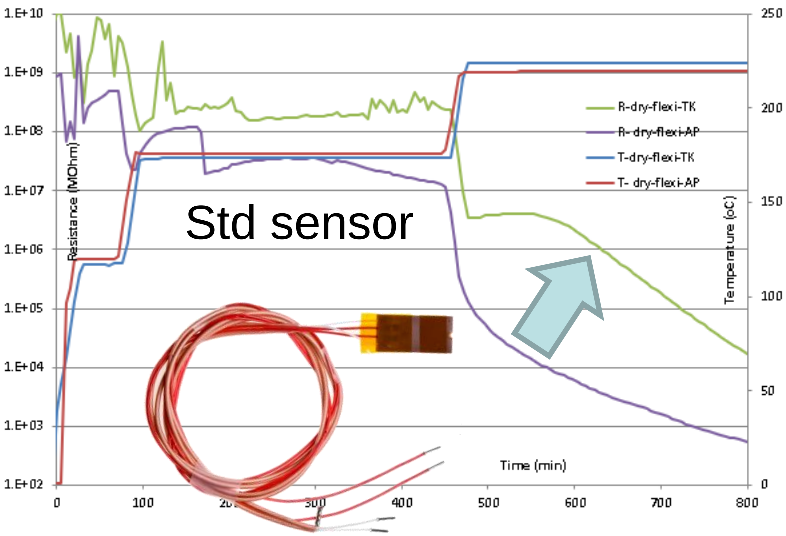
A new durable sensor was developed to allow to measure CFRP production without the need of any extra protection e.g. glass fibre

- Due to the unique surface measurement of the DC-based sensor no coating but specially shaped electrodes were used

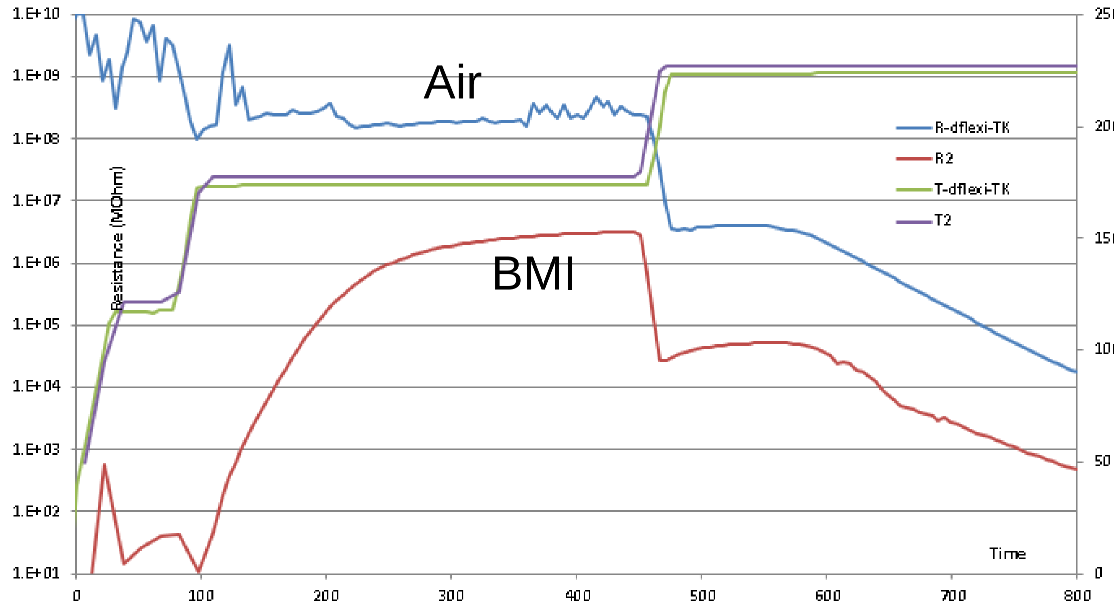
Extensive trials in a C-HPRTM application have shown very good results confirming that the use of this sensor in CFRP production is feasible

New higher temp sensor (max 250ºC)

@Air



Air vs. BMI

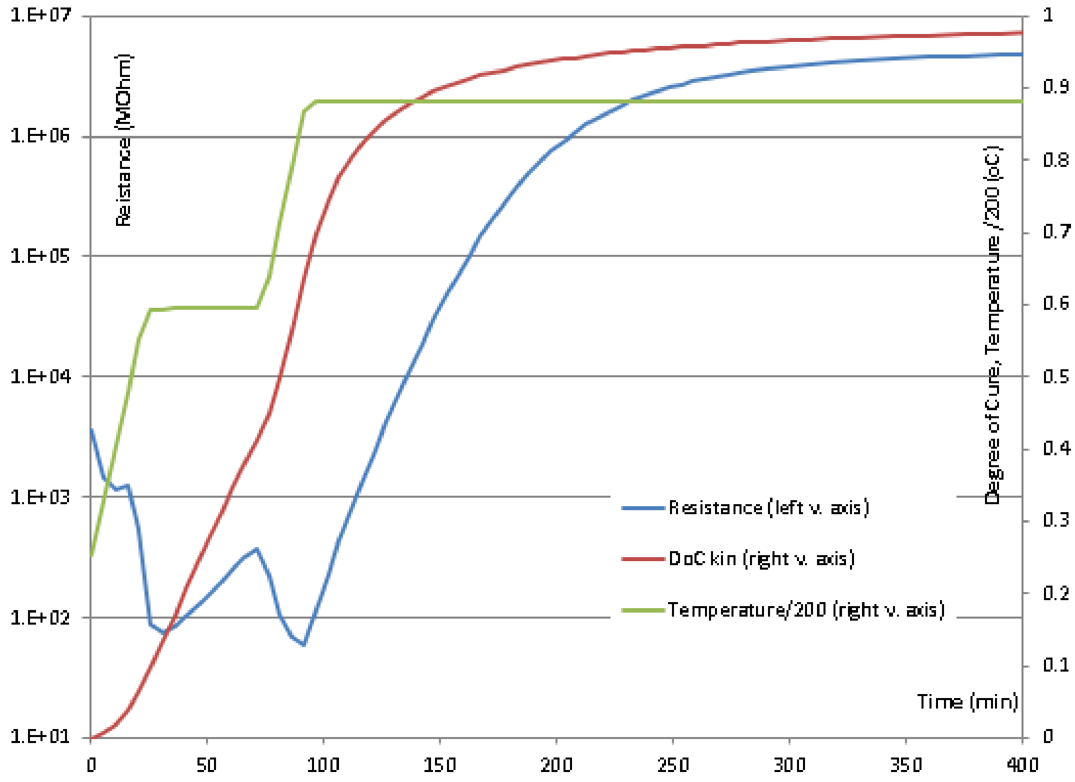


Resistance and temperature

A new higher-temp material was introduced in the disposable sensor to improve the high-temp performance of the sensor

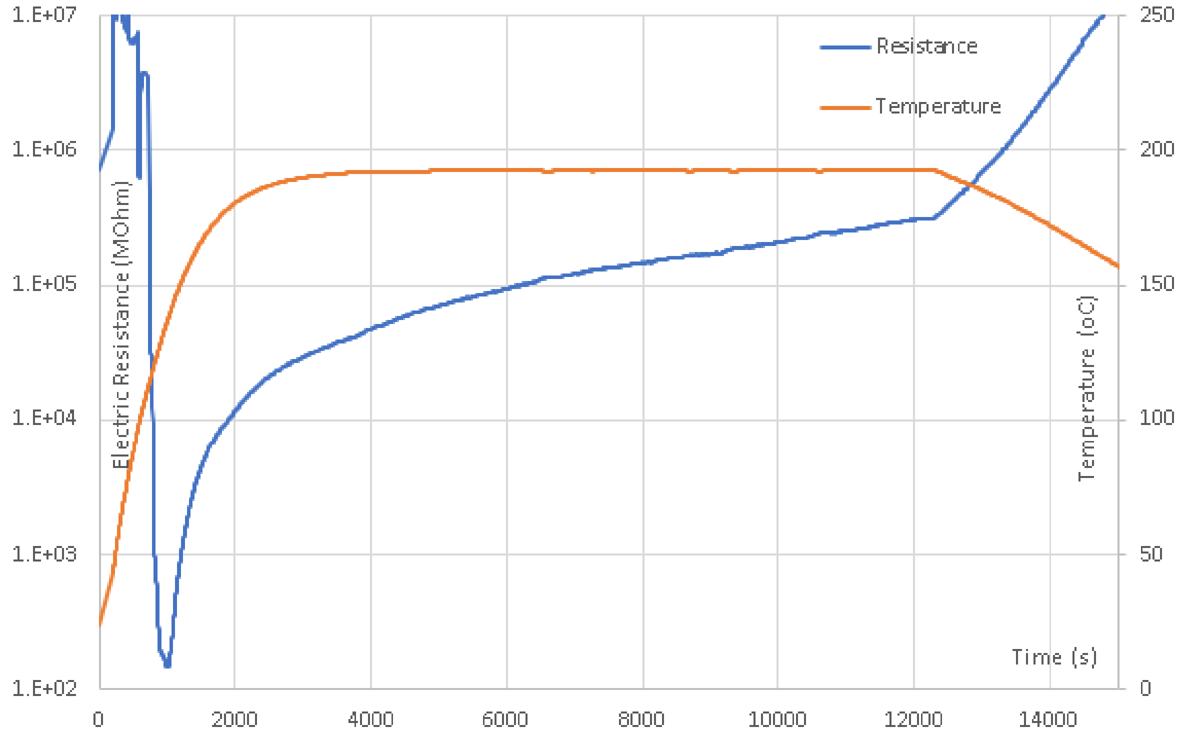
First trials with a prepreg BMI sample sent by BAB demonstrated the improved performance of the sensor

Correlation between Cure and Resistivity



BMI Cytec 5250: Correlation between the expected Degree of Cure as simulated by a kinetic model and the recorded resistance during for the recommended temperature profile.

Cure monitoring of a Cyanate ester resin



Within SuCoHS, Cyanate ester resins were also monitored for the first time successfully by FHNW

Conclusions

- ✓ The online cure monitoring and quality control for high temperature resins was applied and verified successfully.
- ✓ The development of new high temperature sensors and calibration methods will lead to significant reduction of the curing time of advanced aerospace resins ensuring cure quality.
- ✓ Further development with SuCoHS project will allow disposable and durable sensors to work at temperatures up to 300^{o}C (first step) and ultimately at 350^{o}C.

SuCoHS

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

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www.sucohs-project.eu

https://www.linkedin.com/company/sucohs-project/

Contact

Belgium

SYNTHESITES SNC

Av. du Lycée Français 5, Bte9
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 12 274,
e-mail: info@synthesites.com

UK

SYNTHESITES UK LTD

31 Arden Close,
Bristol, BS32 8AX
Phone: +44 333 01 2468 1
e-mail: uk@synthesites.com

www.synthesites.com