ADVANCED PROCESS CONTROL FOR HIGHER PRODUCTIVITY AND ONLINE QUALITY CONTROL

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Carbon Rotec GmbH and Synthesites SNC

Wind Turbine Blade Manufacturer 2017

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Project Overview and Objectives

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Advanced process control for higher productivity and online quality control

Molds and processes

Develop and validate theoretical models

- Simulation of heat flow
- Prediction of resin reactivity and glass transition temperature

Optimize manufacturing processes

- Designed resin flow, heating, curing and cooling cycles depending on blade layup and environmental conditions

Sensor systems

Online Tg monitoring with a robust sensor system

- Tests under laboratory and production conditions
- Software should be capable of estimating the on-going Tg at an accuracy similar to DSC

Intelligent molds and processes

Outlook: Industry 4.0 for Rotor Blade Manufacturing

- Integration of models, sensors and software into mold, heating and process control
- Implementation of resin flow simulation

PROJECT PARTNERS

Carbon Rotec

Blade manufacturing and advanced production equipment

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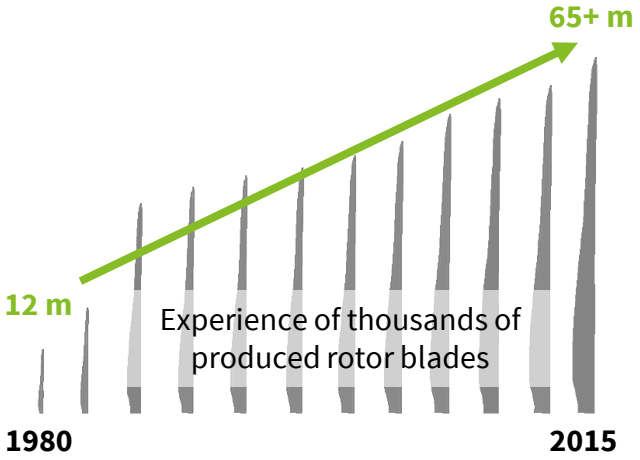
Intelligent monitoring and sensor systems for composite manufacturing

CARBON ROTEC:
35 Years of Expertise with Composites

CARBON ROTEC is one of the largest independent producers of rotor blades for wind turbines of the multimegawatt-class in Europe. For over 35 years, high-quality composite structures have been developed, manufactured and maintained.

- Headquarter in Lemwerder near Bremen
- Total area: 1.4 km^2
- Production area: 47,000 m^2
- Own research and development department inculding an application laboratory



- Production capacity of approximately 1,000 blades p. a.
- Experience in the realization of rotor blades, molds, commercial vehicle parts, aircrafts, bridges, covers for sewage treatment plants and various prototypes

CARBON ROTEC:
Product and Service Portfolio

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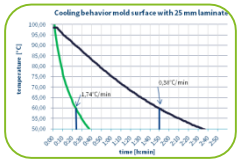
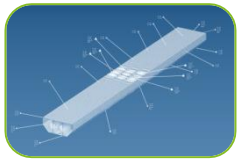
CARBON ROTEC
COMPOSITE TECHNOLOGY

Our expertises along the value chain of fiber composite plastic structures

- Design and Development



- Construction and Calculation



- Production Equipment

- Manufacturing and Testing

- Installation and Assembly

- Service and Maintenance

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Company Profile

World leader in intelligent process monitoring and control in composites manufacturing for aerospace, automotive, wind energy and industrial applications

HQ: Greece , **2 branches:** Belgium and the UK

Recent Achievements

- Involvement in the manufacturing of the most advanced CFRP wing for the C-Series at Bombardier, Belfast.
- Online Tg module with 8 cure sensors installed at NCC, UK.
- Involved in the online cure monitoring of the Elium TP resin with Arkema

R&D References

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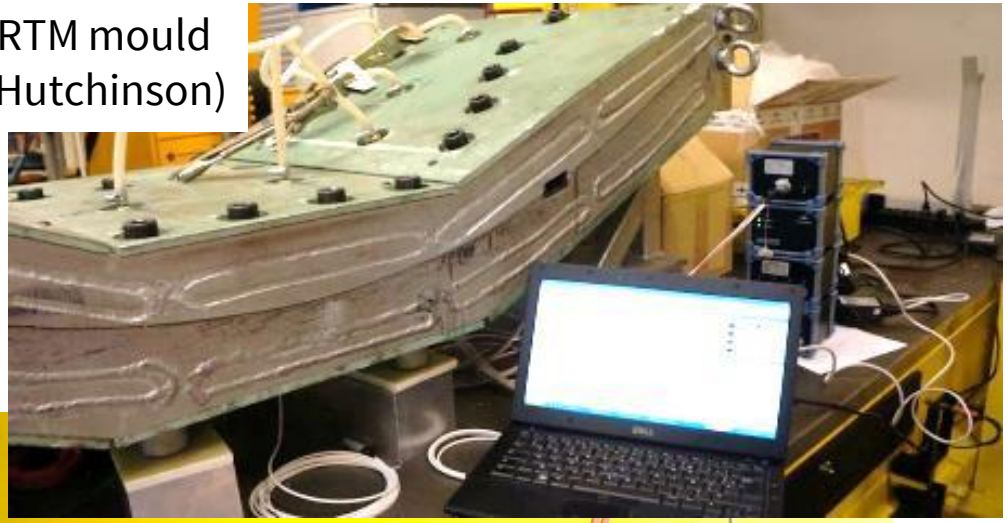
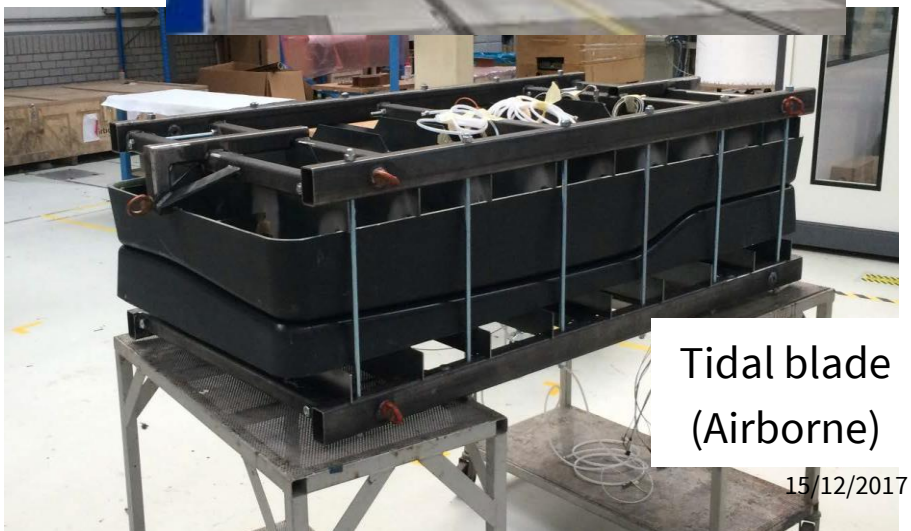
Indicative applications

RTM mould
(Hutchinson)



WPU autoclave
(Bombardier)

RTM mould
(Sotira)



Tidal blade
(Airborne)

OPTIMIZED BLADE MANUFACTURING PROCESSES
BY DESIGN OF HEATING, CURING AND COOLING CYCLES

Approaches for Process Optimizations

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Cycle times | **Costs** | **Robustness** | **Quality**

Infusion Processes

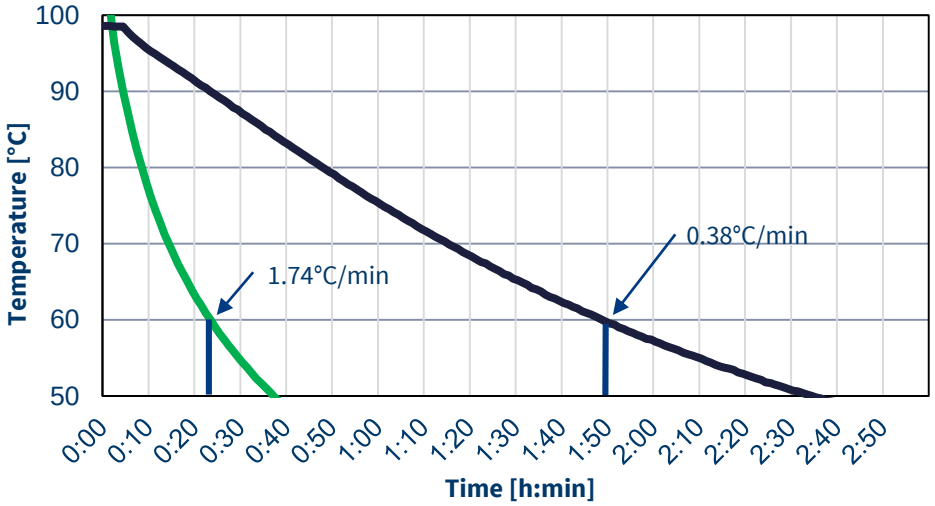
- Optimization of infusion strategies
- Reduction of waste, e. g. green mesh
- Development of flow biax
- Advanced sensor technologies

Curing Cycles

- Achieve proper glass transition temperatures in short cycle times
- Models for resin reactivity
- Designed heating and cooling cycles

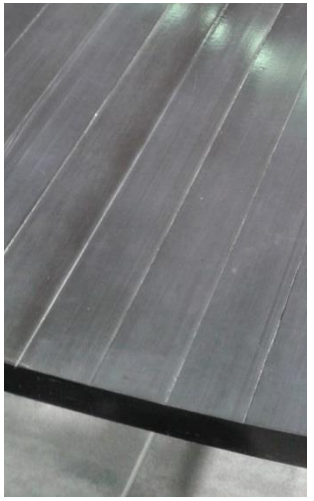
Materials/Structures

- Infused carbon girders
- Carbon girders made of pultrusion profiles
- Prefab components



Cooling behaviour of a mould surface with 25 mm thick laminate

Optimized infusion process



Infused carbon pultrusion profiles

Requirements towards Temperature Management

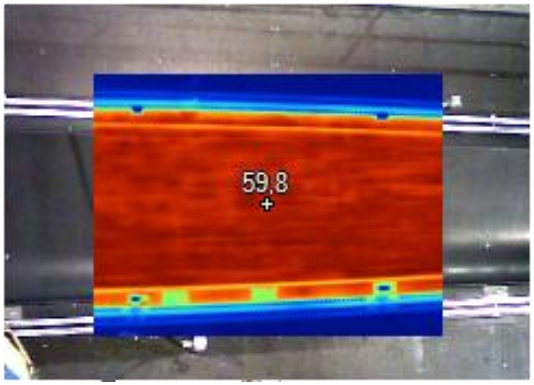
In general:
- High heating rates and high temperatures on mould surface
- Individual heating areas according to blade design
- Individual curing program for each heating area
- Optimized insulation regarding to energy efficiency

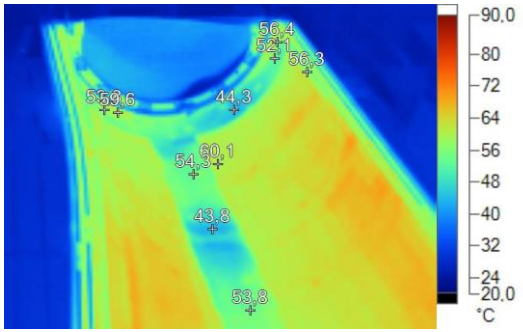
During infusion:
- Homogeneous temperature distribution
- Proper temperature / heat depending on layup
- Short time to achieve infusion temperature

During curing:
- Individual heat up ramps, temperatures, staring times and duration of heating depending on layup and exothermal reaction
- Fast reaction and short time to achieve curing temperature

During bonding operations and demolding:
- Fast heat up and cool down of layup in bonding zones
- Moderate temperature in other areas (no-bonding zones)
- Homogenous temperature distribution in the blade during demolding

Advanced production equipment is the basis for high an efficient and high quality blade production





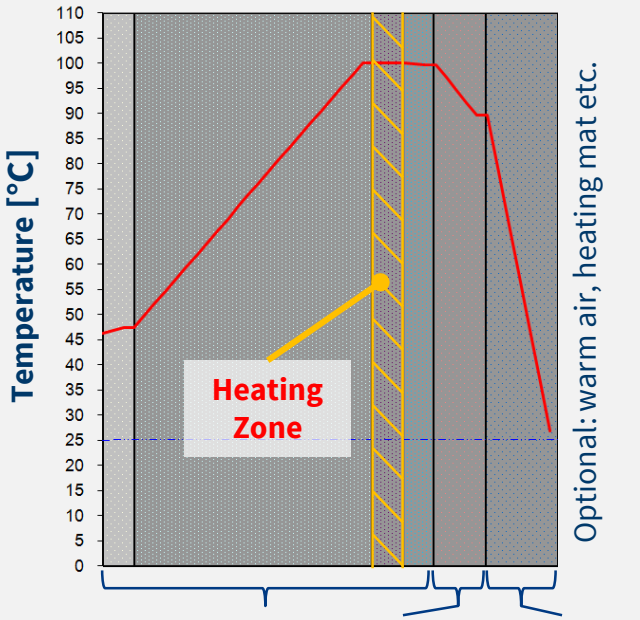
Advanced Theoretical Models

Material characterizations

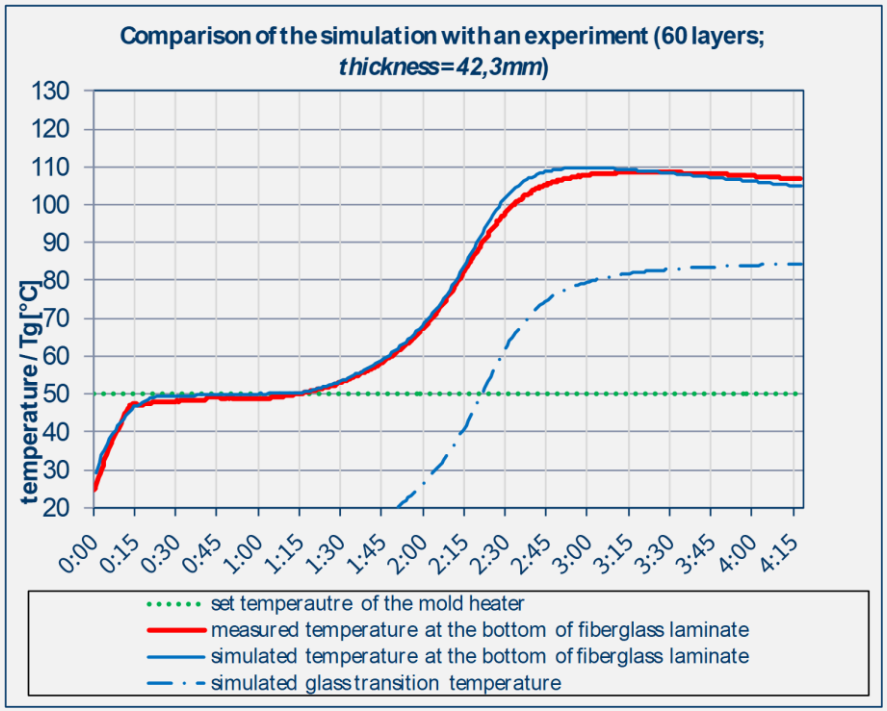
Theoretical models for resin reactivity

$$\frac{dp}{dt} = A \cdot e^{-\frac{E}{RT}} \cdot f(p,n,a)$$

Calculation of the temperature distribution in mould and lay-up



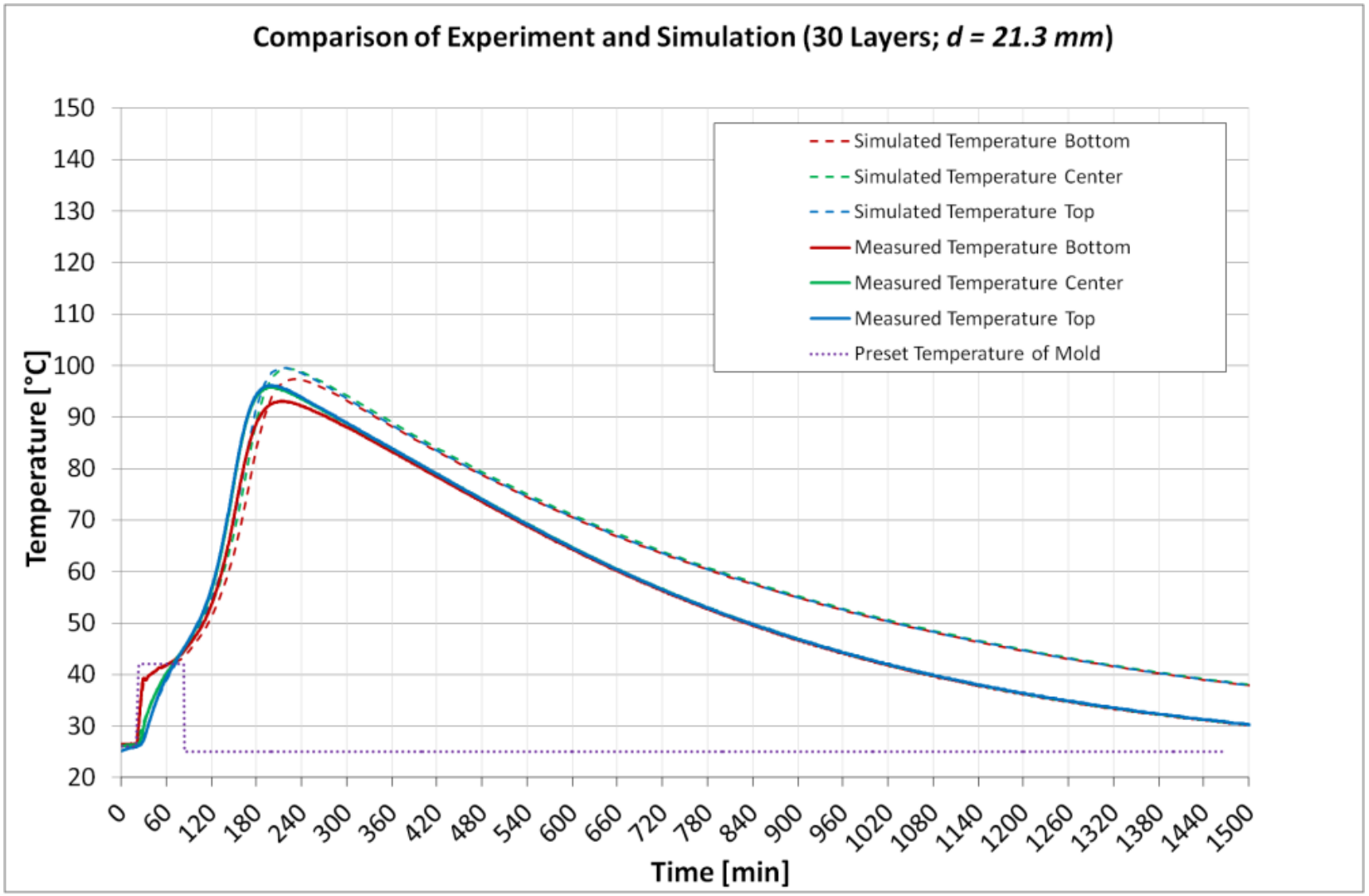
Application of the model



Position	T_G-Measurement	T_G-Simulation
Bottom	82,2	84,3
Top	84,6	84,8

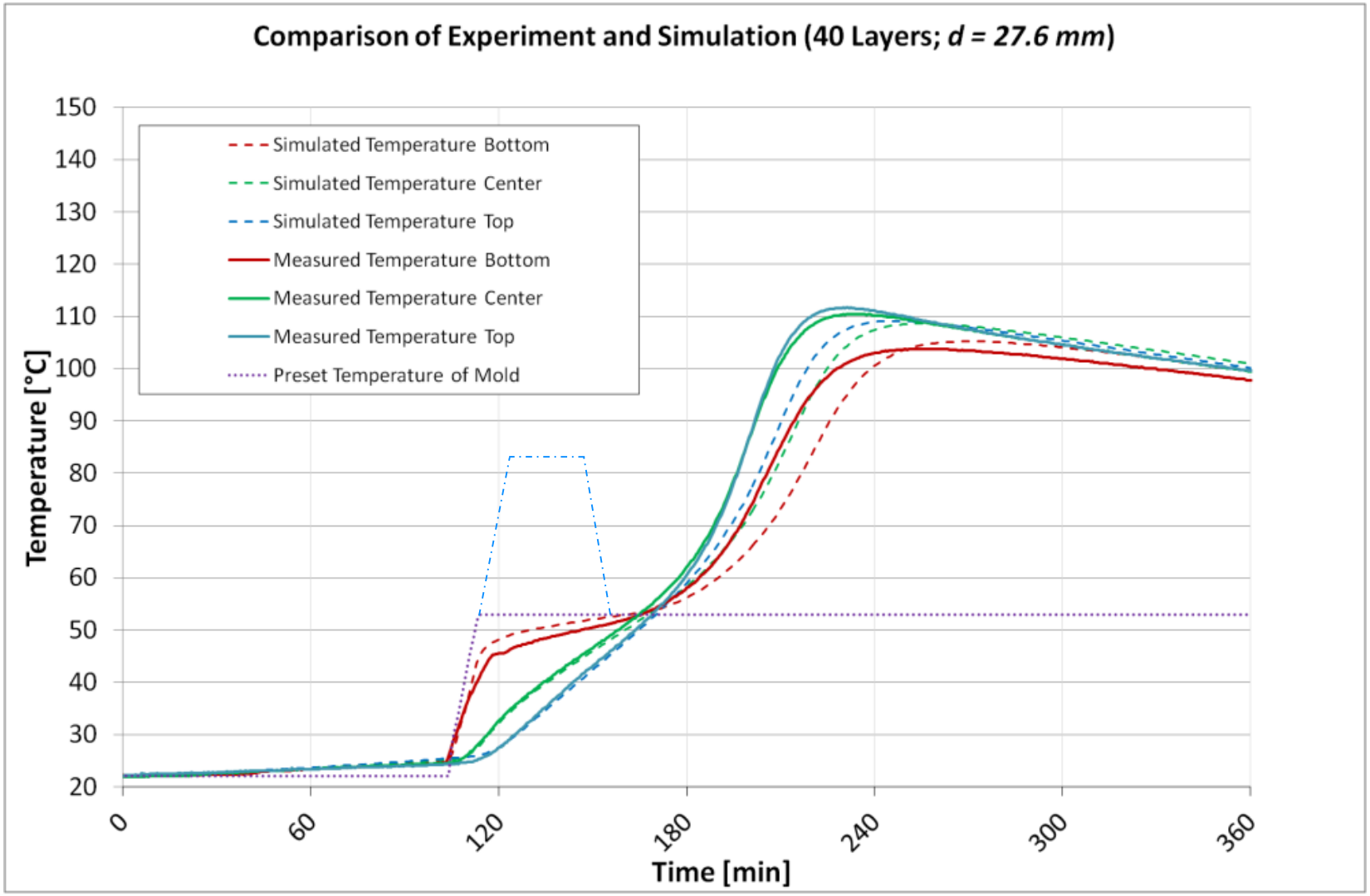
Design of curing procedures including resin reactivity leads to optimized curing cycles

Optimization of Heating up and Curing Cycles



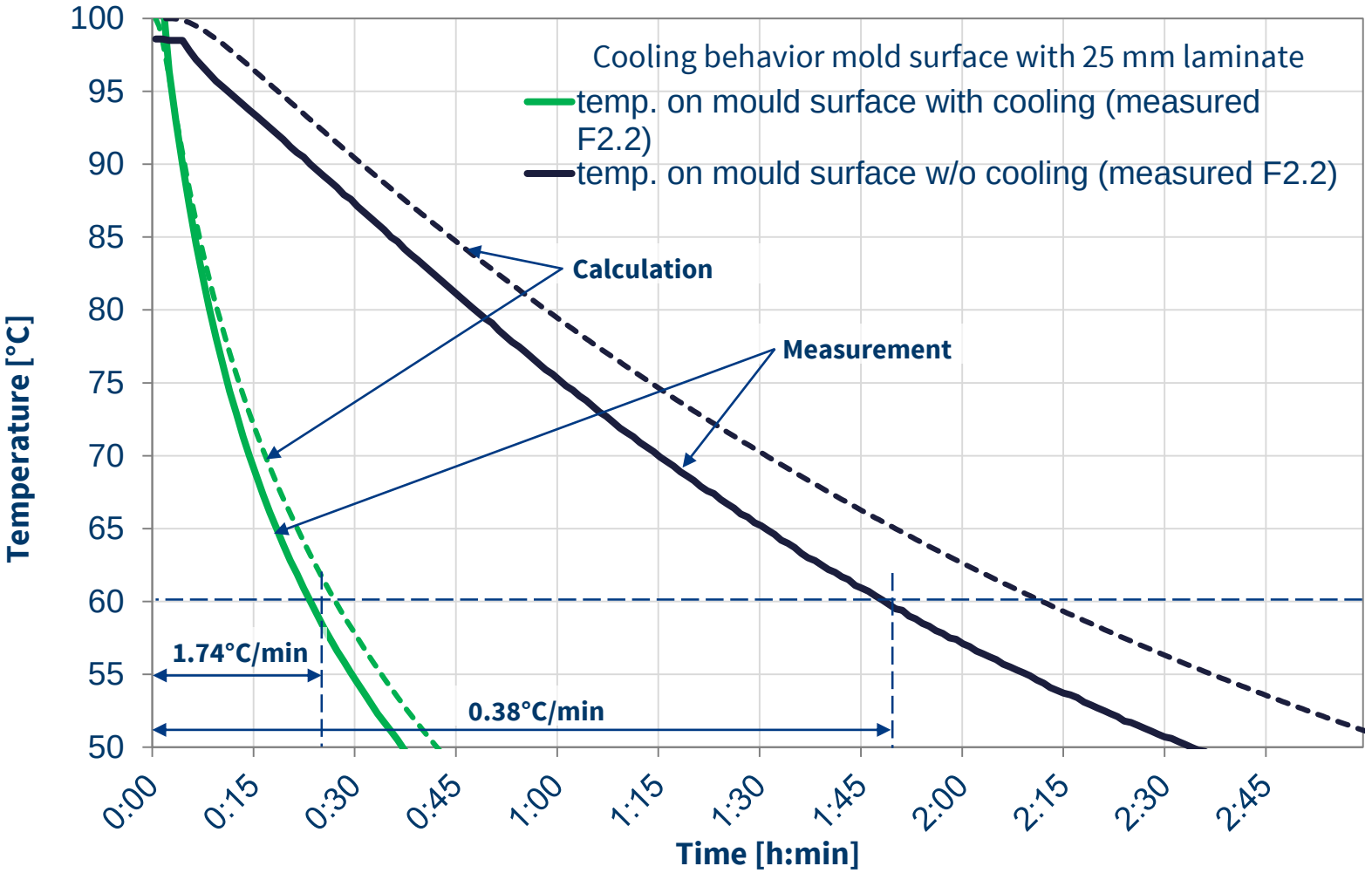
Simulations cover mold and blade layup, greenmesh, insulation materials etc.

Optimization of Heating up and Curing Cycles



Prediction of individual heat flow depending on local blade layup

Optimization of Cooling down Cycles



Reduction of cycle time by appr. 1.5 hours by designed cooling cycles

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IMPLEMENTATION OF ADVANCED SENSOR SYSTEMS

Optimold
Cure, viscosity, resin quality check

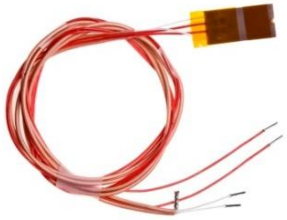
Real-time measuring of

- Resin's electrical resistance (from 0.1 MOhm up to 50 TOhm)
- temperature (pt100 sensor with 0.5°C accuracy)

Input of external signals e.g. pressure sensors

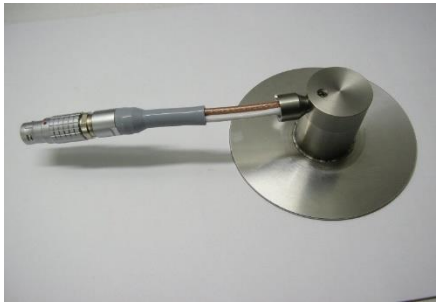
New

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

New

Vacuum Bag Durable Sensor



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

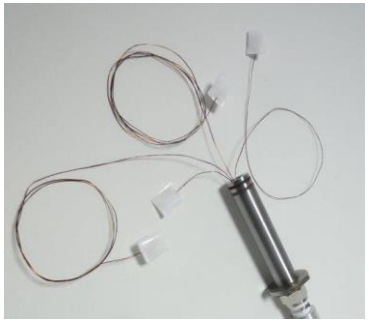
- flat areas
- possible mark

New Gate sensor

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

Flexible
disposable

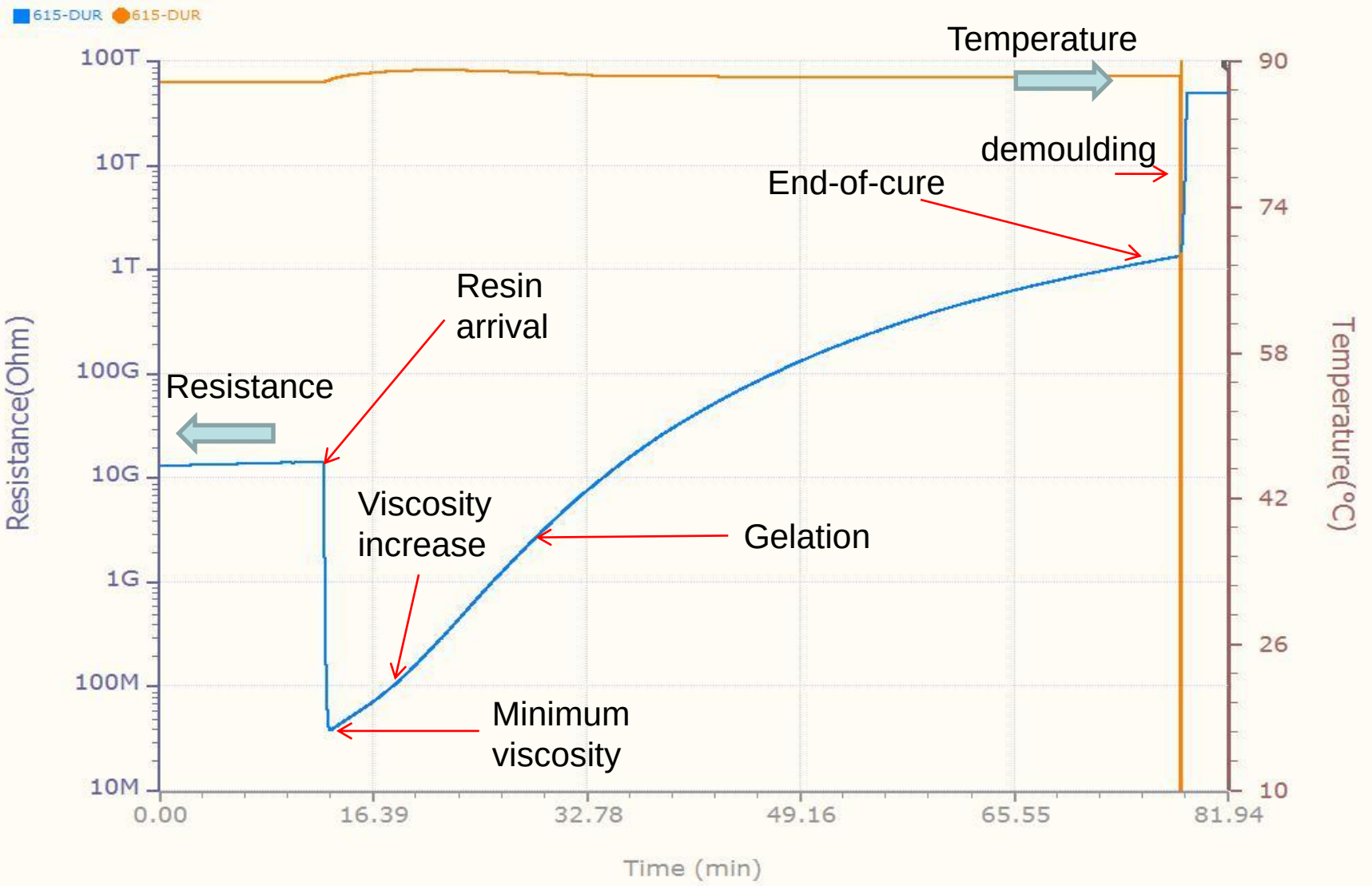
New FloWire sensors



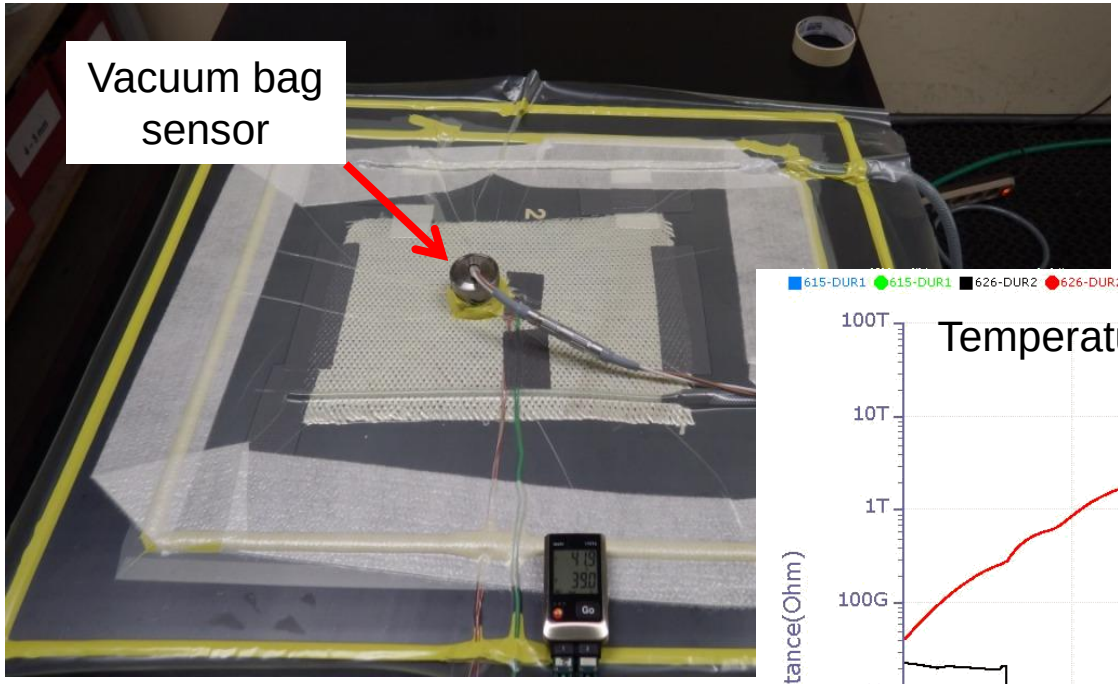
- Curved surfaces
- In the laminate for development
- Over the peel-ply
- Suitable for very long parts
- no extra protection for Carbon Fibre Preforms

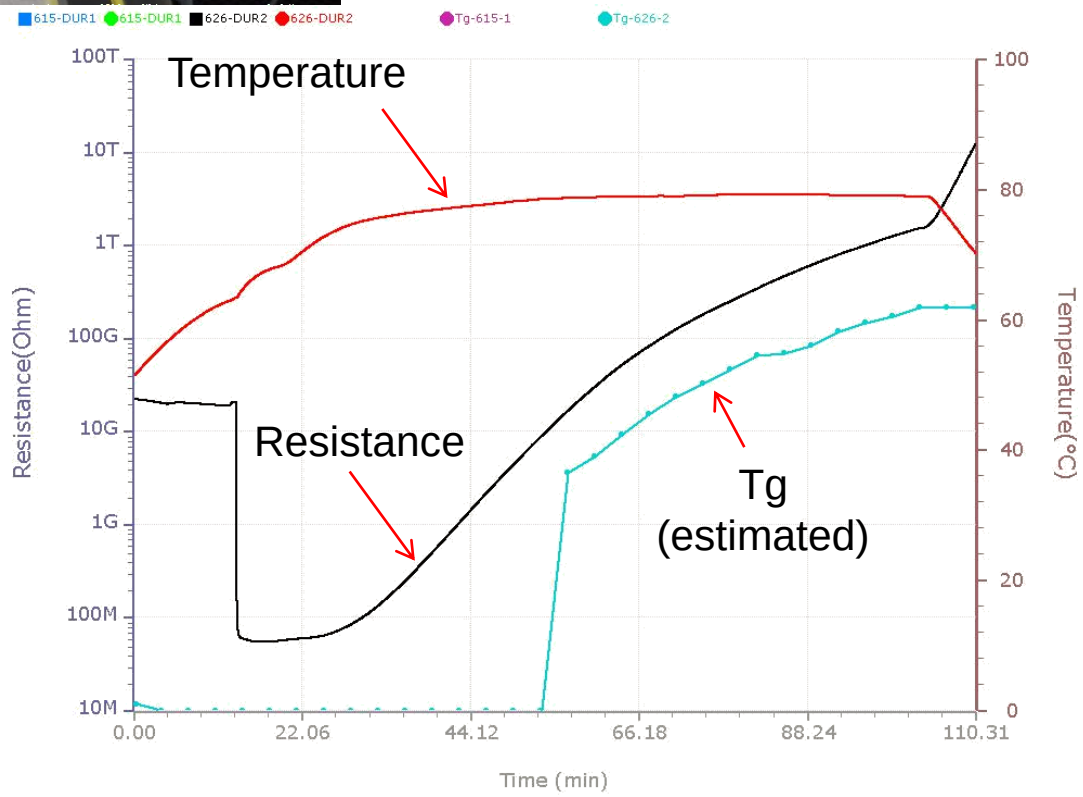
New
Curved
Durable

RIM035-RIMH037 cure cycle @90°C as measured with Optimold



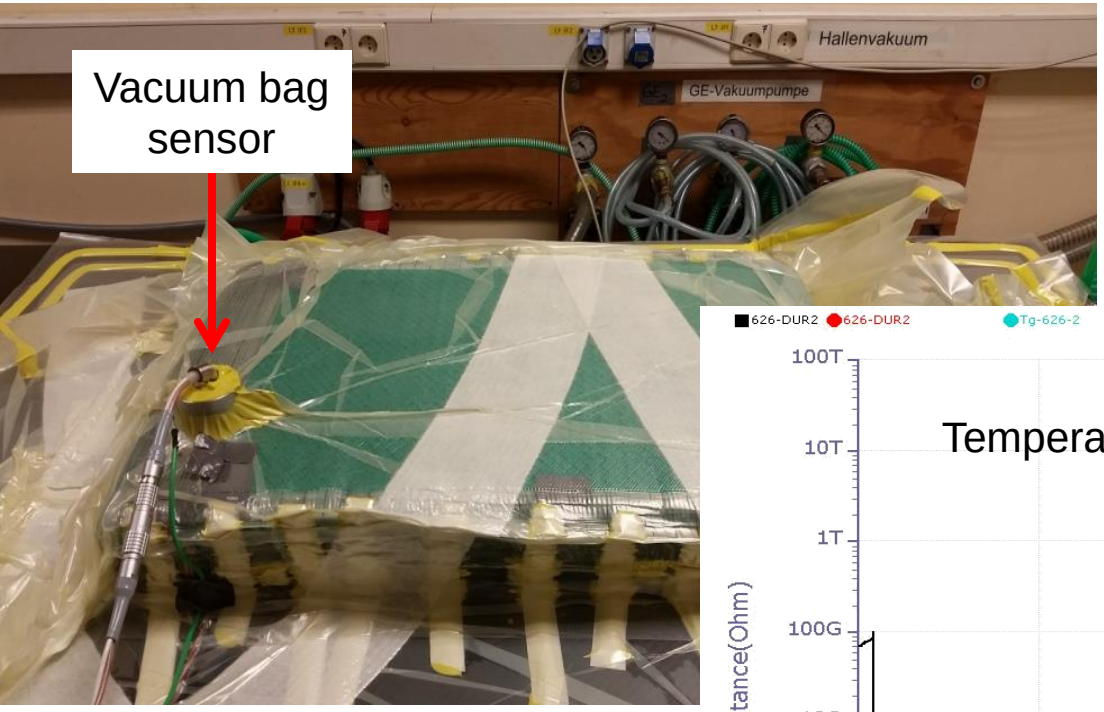
Lab scale production simulation trials

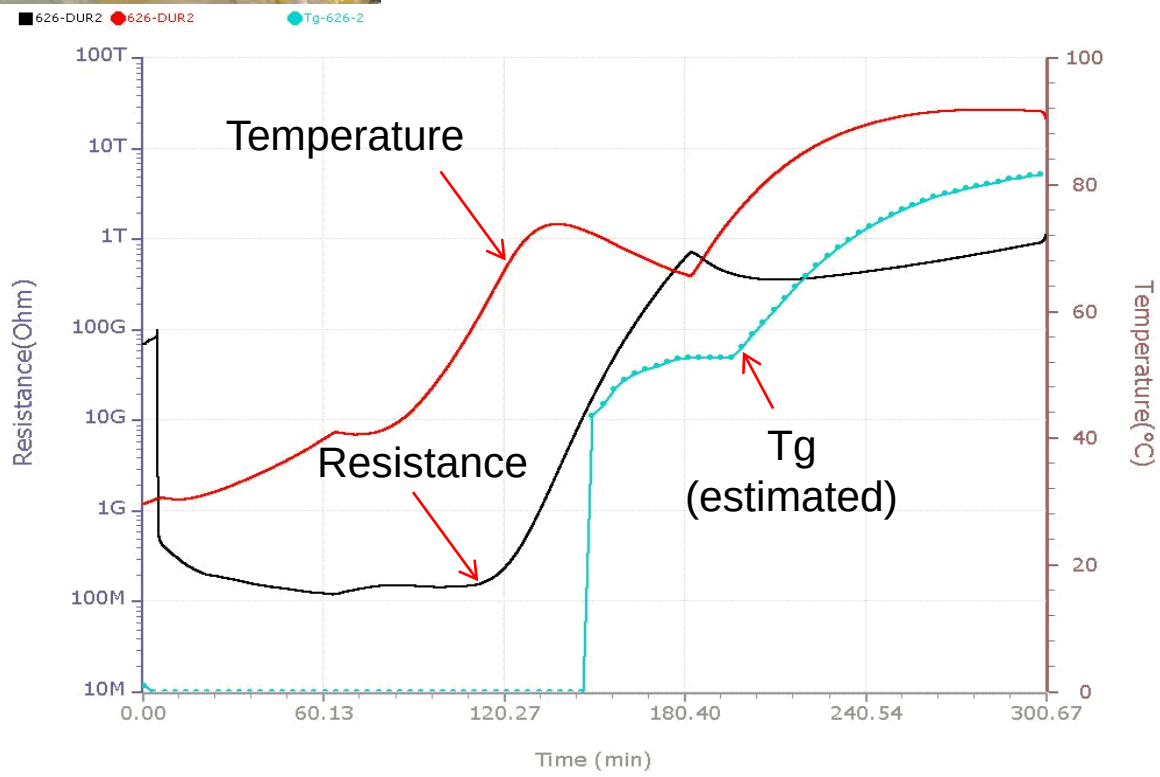




Simulating Isothermal cure cycles in the lab

Lab scale production simulation trials

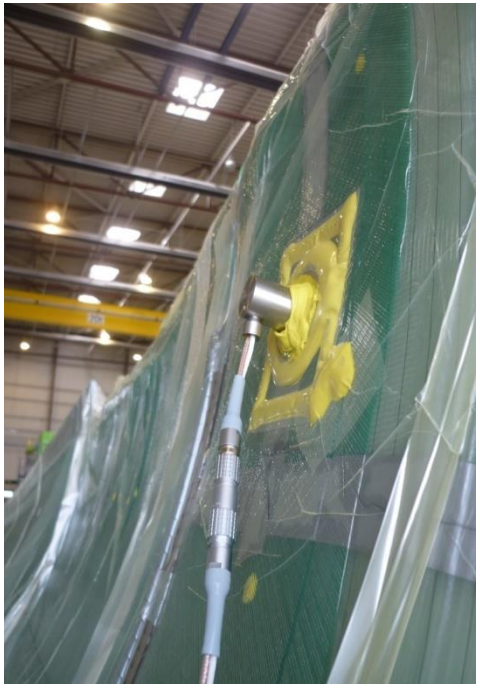


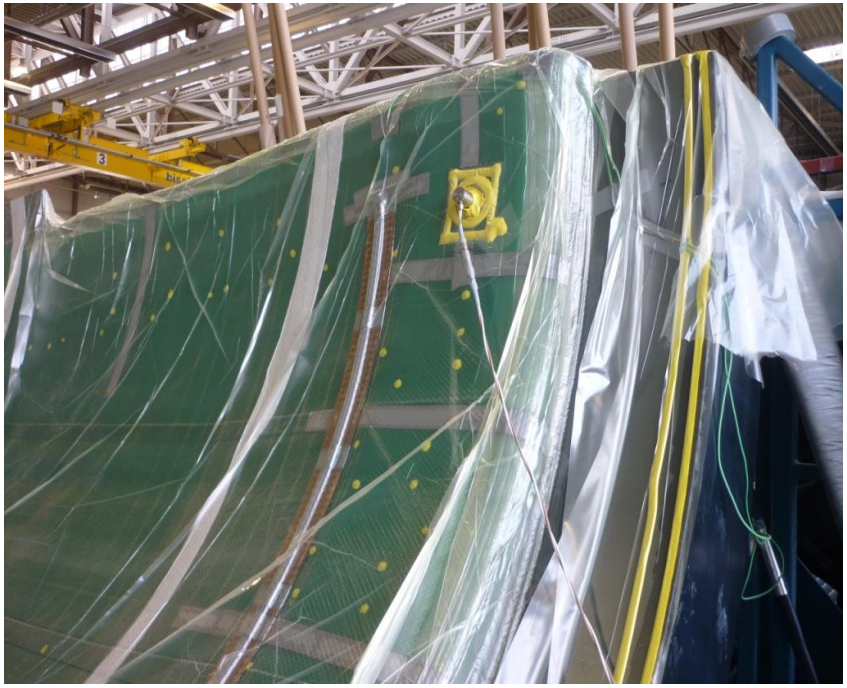


Simulating non-Isothermal realistic cure cycles in the lab

Field Trials

New vacuum-bag
durable sensor





Online Tg estimation at DSC accuracy

Overview of various isothermal and realistic test cases and the difference between Tg estimated online with the ORS software and T_g measured right after demoulding by DSC

Tg online estimation is within the DSC accuracy

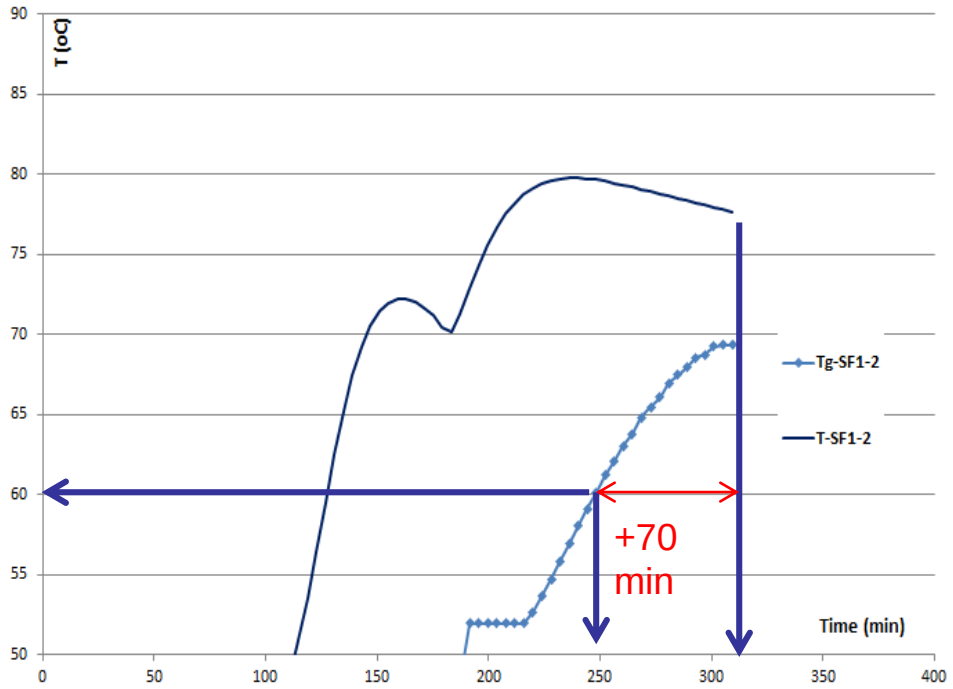
	Trial	Duration [h]	T_g-ORS (°C)	T_g- DSC (°C)	Difference (°C)
Isothermal	80DV1	3	73.17	73.34	-0.17
	80DV3	2.5	70.30	70.91	-0.61
	80DV4	2.5	73.45	72.49	0.96
	80-120'	1.92	66.96	66.02	0.94
	80-90'-1	1.50	62.04	61.80	0.24
	80-90'-2	1.50	65.52	65.21	0.31
	80-D2-2	1.50	61.88	60.59	1.29
	60-260'	4.33	55.02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

Shorter Cure Cycles

Using the new sensor shorter cycles were achieved at the lab-scale trials

Curing Temp °C	Time to cure (min)	**New** Time to cure (min)	Reduction (%)
60	360	260	28
70	240	190	21
80	150	120	20
Real case	320	250	22

But also in strongly non-isothermal production cases



Checking Resin quality and Mixing Ratio

Just before injection to identify resin problems

Steps:

1. Fast curing of resin samples

@110^{o}C and 140^{o}C

1. identify resin problems automatically
2. Proceed with injection safely

SUMMARY AND OUTLOOK

Summary and Outlook

Theoretical models build the basis for a holistic process and mold development

- Simulation of heat flow in the mould with dry fabrics and wet /stiff laminates
- Prediction of resin reactivity and behavior
- Development of degree of curing and glass transition temperature during the process

Advanced production tools enable significant cost and time savings

- Designed heating, curing & cooling cycles depending on blade layup and environmental conditions
- Individually controlled and tempered heating fields

Online Tg monitoring with a robust sensor system

- Tested successfully under laboratory and production conditions and environment
- Online Resin State software is capable of estimating the on-going Tg at an accuracy similar to DSC

The **sensor system** allows the wind blade manufacturers to:

- Shorten cure cycles
- Enhance quality control and production traceability
- Optimize the production in real-time

Further developments towards a comprehensive **Industry 4.0** approach

- Full integration of models, sensors and software into mold and heating control
- Implementation of resin flow simulation

Mold and process design

Sensor systems

Intelligent molds

Thank you for your attention!