

# Intelligent process monitoring and control to reduce defects and cycle times in composites serial production



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Seattle, US

# Welcome

- Dr-Ing Nikos Pantelelis
- Synthesites Srl, Belgium
- Managing Director
- More than 25 years in advanced composites manufacturing, DEA monitoring, simulations and control

# Synthesites

Leaders in intelligent process monitoring and control in composites manufacturing in aerospace, automotive, wind energy and industrial applications

## Highlights

- Monitoring the production of the unique CFRP wing skin for the Airbus A220 by Spirit (Bombardier), Belfast.
- Monitoring the cure in production for a leading wind blade OEM
- Collaboration with leading R&D centres in Germany, UK, US and Spain for composites process automation



- Collaboration with 4 Global OEMs and tool manufacturers towards the intelligent production in wind turbine blades, automotive and aerospace



# Cure monitoring

Real-time measuring of

- Resin's electrical resistance (from 0.1 MOhm up to 100 TOhm)
- Resin's temperature (pt100 sensor with 0.1°C accuracy)

**process monitoring sensor** = electrical resistance + Temperature sensors

Durable sensor



- High Temp RTM
- Resin arrival
  - Viscosity
  - Gelation
  - End-of-cure

Durable bag sensor



- Vacuum Infusion
- Resin arrival
  - Viscosity
  - Gelation
  - End-of-cure

Flexible sensor



- VI and RT cure
- Resin arrival
  - Viscosity
  - Gelation
  - End-of-cure

Inline sensor



- Resin arrival @ gate

CF In-mould Durable



Vacuum Bag heated Durable



# Flow and temperature monitoring



- 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

Resin's arrival and temperature at four points

In-mould  
Durable



- High Temp RTM
- Vacuum Infusion

Gate  
Durable



- Resin arrival at gates, pipelines, pots etc.

Flexible  
Disposable



- Infusion and RTM
- Curved surfaces
- In the laminate
- Over the peel-ply
- Suitable for very long parts

# Cure Simulator

## New Cure Simulator

- Follows in real-time the temperature set-point
- Input of any TC, pt or 4-20mA as a set-point
- Includes a cure sensor to measure the curing of the resin/adhesive/prepreg sample
- Up to 200°C

**New**

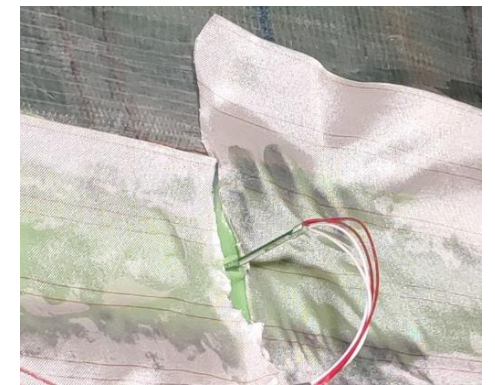
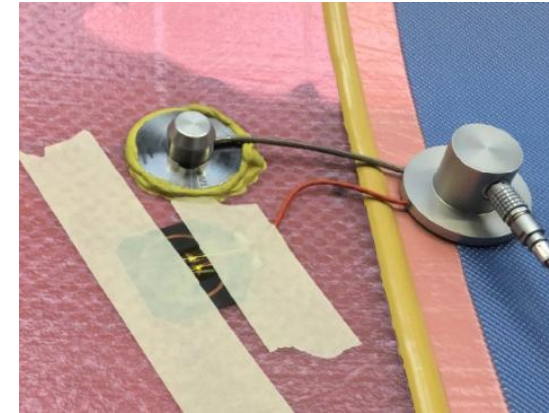
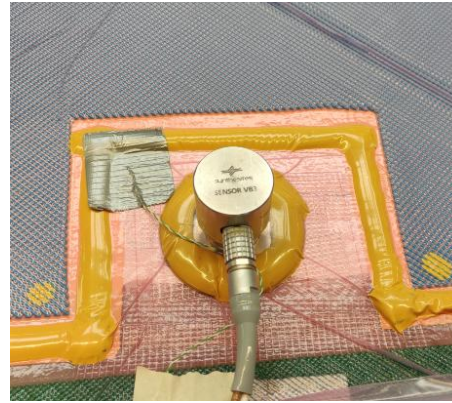
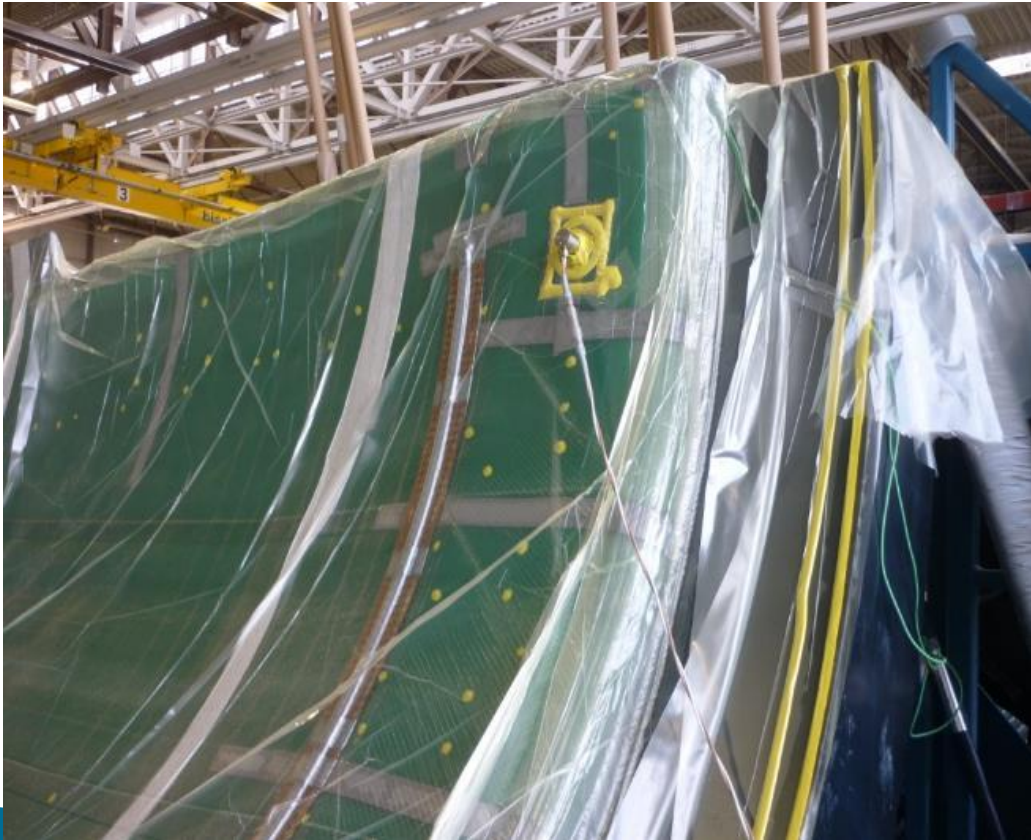


# PLC Communication

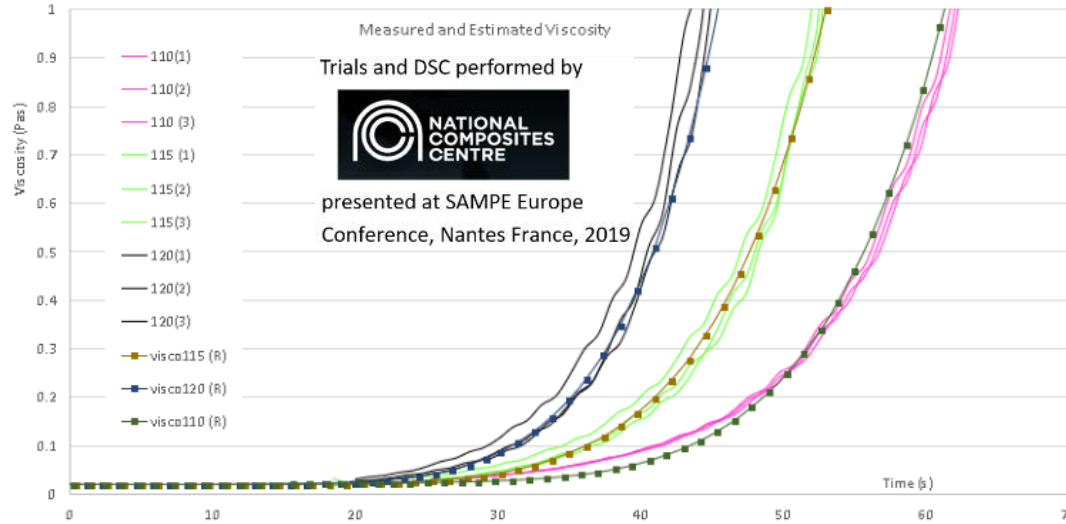


# Sensors in Production

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



# Online viscosity and Tg validation



**Figure 6.** Comparison between the measured viscosity development at three different curing temperatures (110, 115 and 120°C) and the viscosity estimated by the Optimold system.

Left: Correlation between resistance and viscosity for a snap-curing epoxy resin  
 Right: Correlation between resistance and Tg for a wind turbine blade epoxy resin

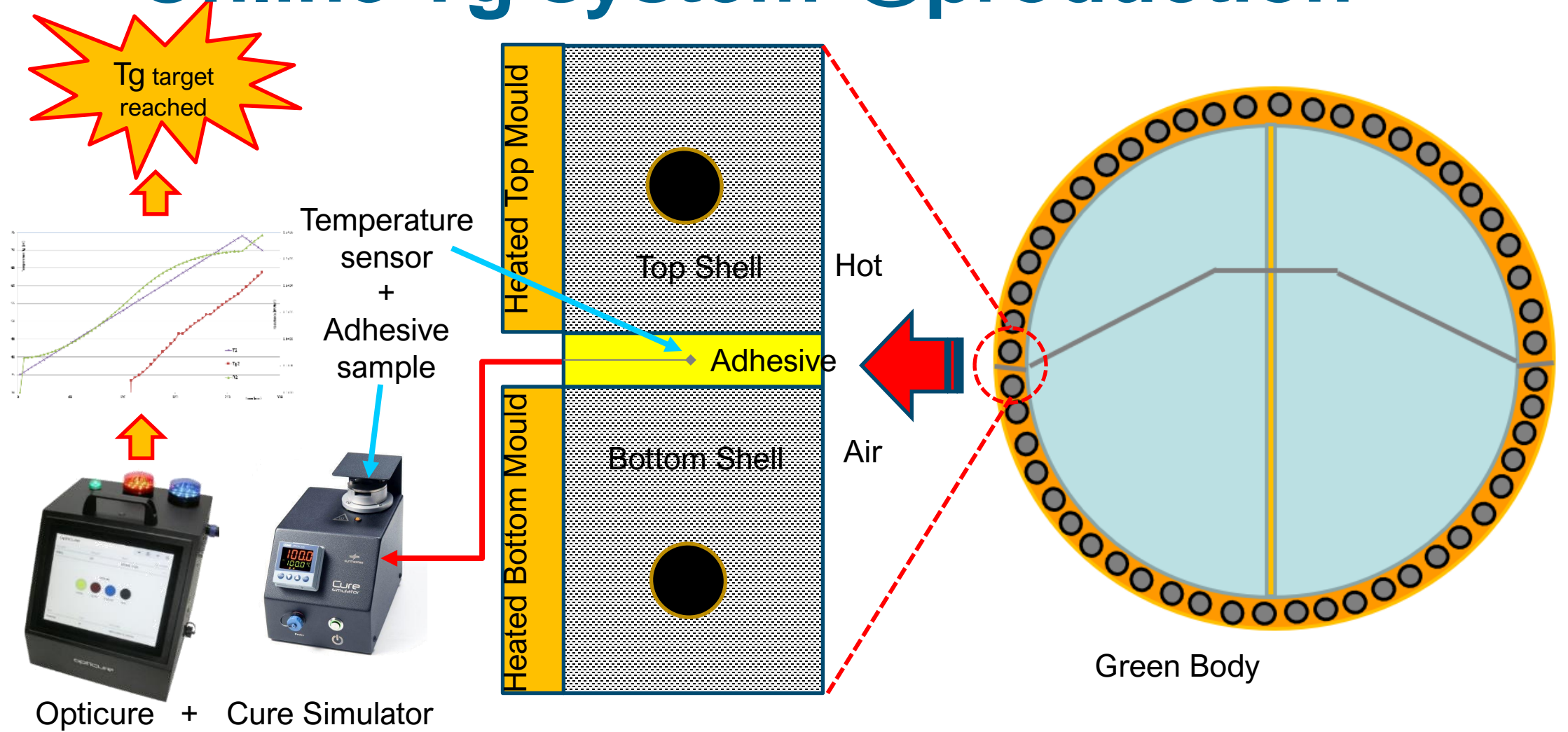
	Trial	Duration [h]	T <sub>g</sub> -ORS (°C)	T <sub>g</sub> -DSC (°C)	Difference (°C)
Isothermal	80DV1	3	73.17	73.34	-0.17
	80DV3	2.5	70.30	70.91	-0.61
	80DV4	2.5	73.45	72.49	0.96
	80-120'	1.92	66.96	66.02	0.94
	80-90'-1	1.50	62.04	61.80	0.24
	80-90'-2	1.50	65.52	65.21	0.31
	80-D2-2	1.50	61.88	60.59	1.29
	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

Trials and DSC executed by

**CARBON ROTEC**  
 COMPOSITE TECHNOLOGY

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

# Online Tg system @production

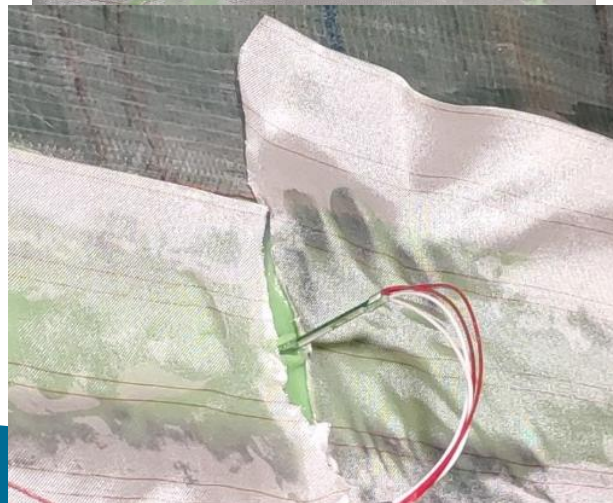


# Online Tg system @production

Initially, placing a disposable thin film cure sensor in the bondline



Then, placing a tiny temperature sensor in the bondline and feeding to the Cure Simulator



Now, getting the temperatures online from the PLC and feeding them to the Cure Simulator

# Turbo project

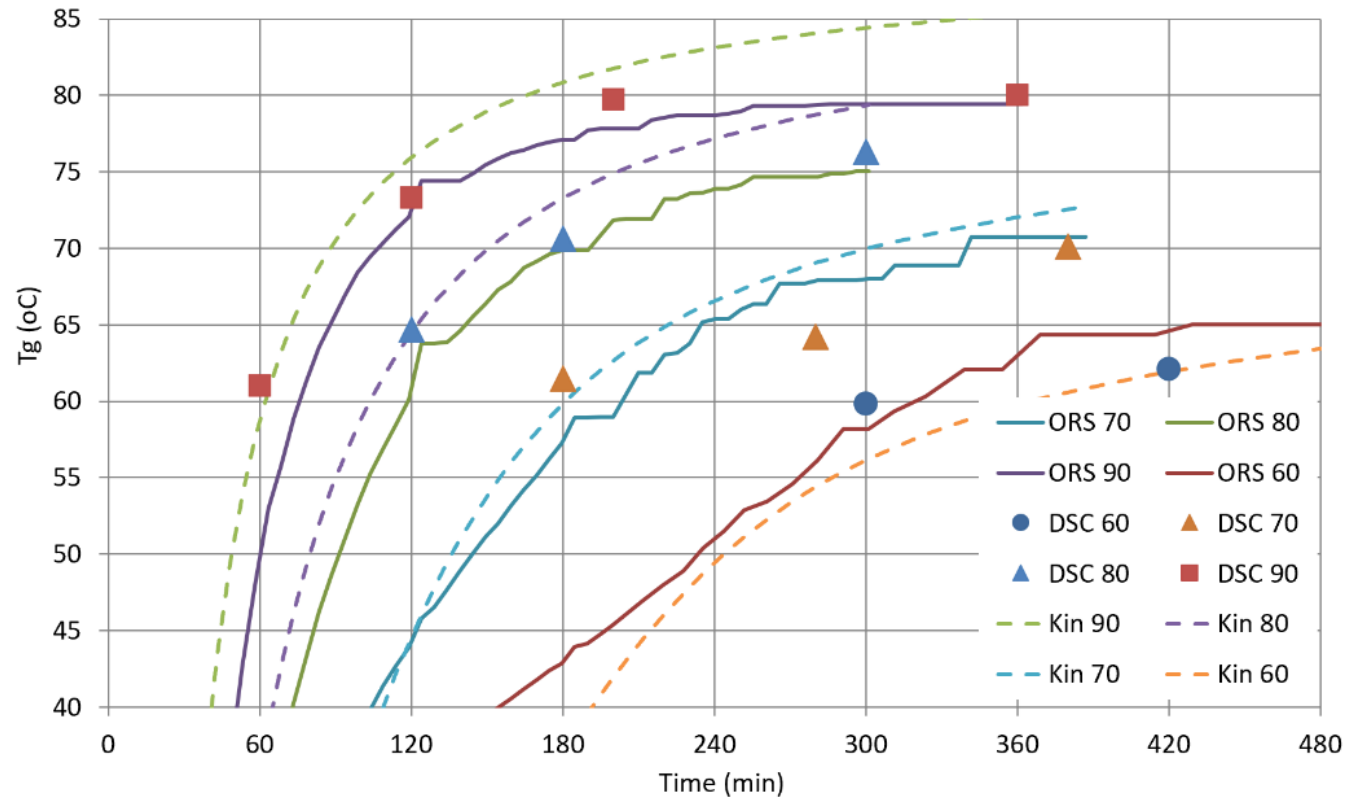
Synthesites role: monitoring and control of the infusion process

- Effective process monitoring with Resin Arrival, Online viscosity and Tg evolution
- Non-intrusive sensing
- Integrating with ML and simulations
- Effective flow and cure control
- Real-time injection control
- Combining numerous and multiple-type sensors in an innovative control strategy to:
  - Reduce scrap rate
  - Reduce injection time
  - Reduce curing time
  - Improve quality control

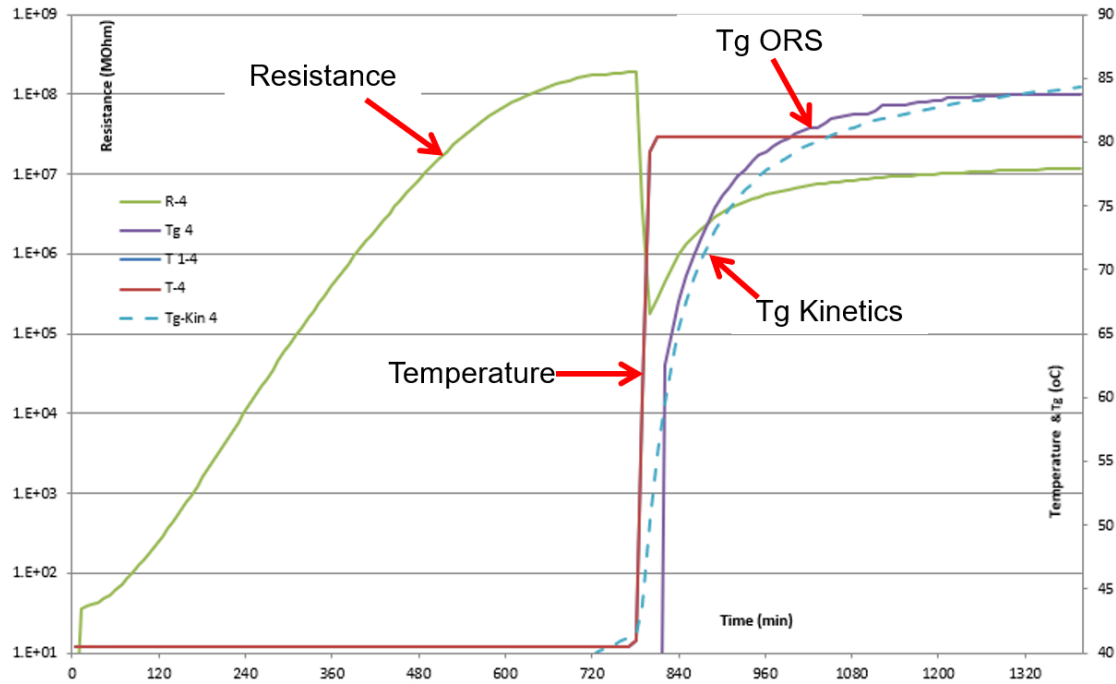


# Online Tg vs Kinetic model

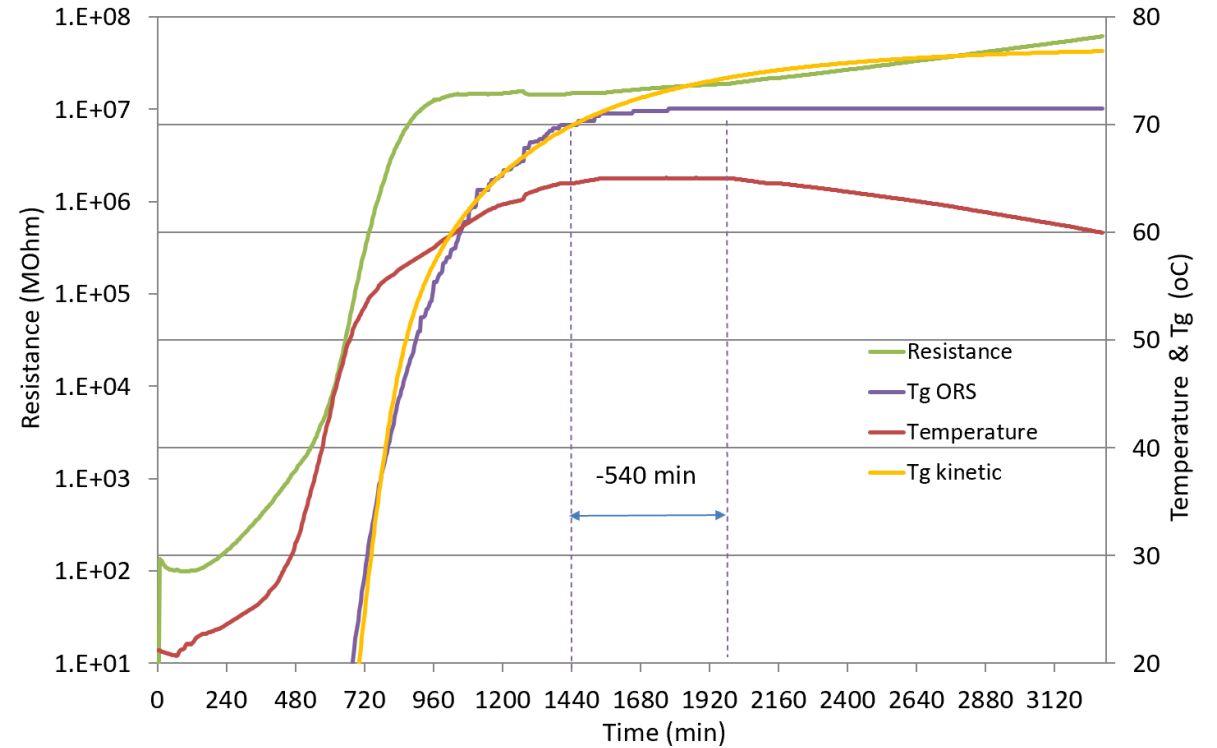
Comparison of kinetic model (DTU), OnlineTg (ORS) and DSC



# Comparison of non-isothermal cases

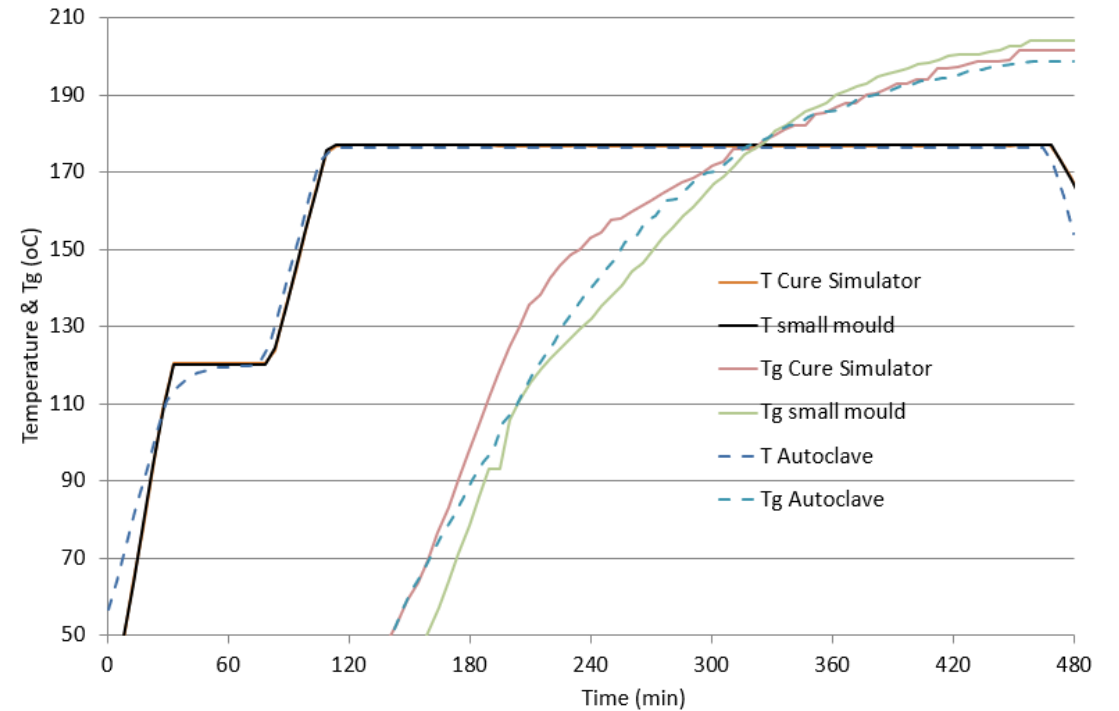
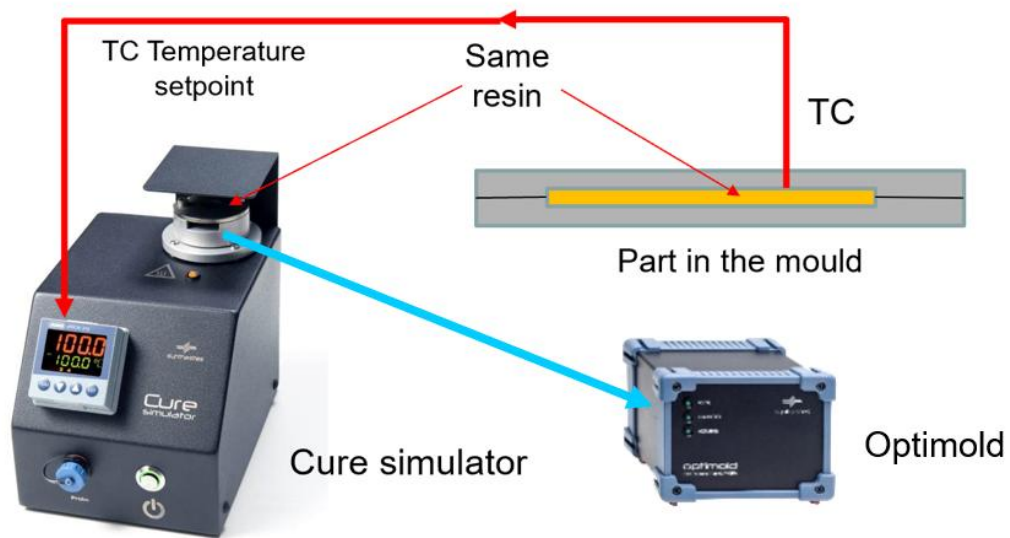


Tg comparison of ORS and Kinetics of isothermals 40/80°C



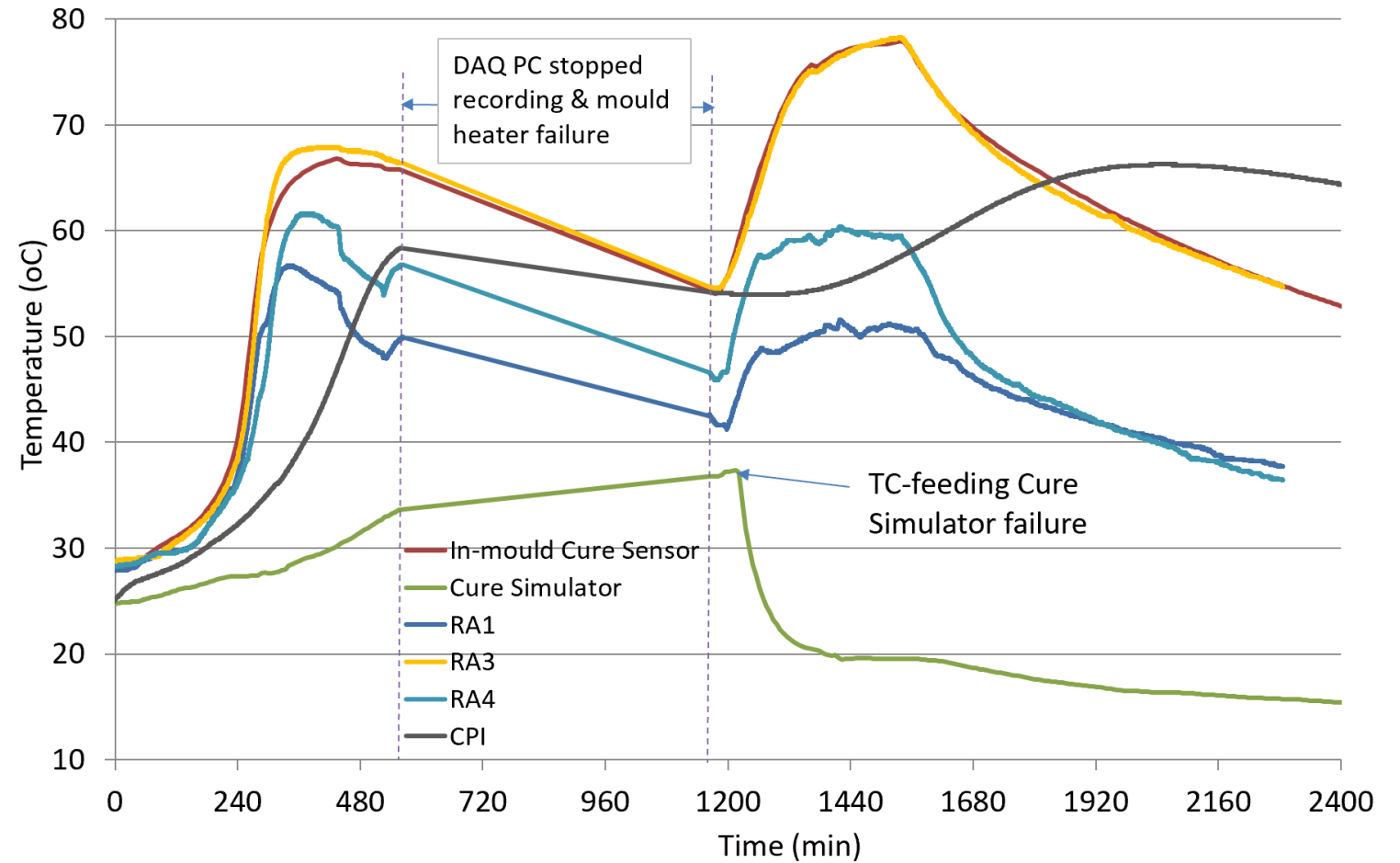
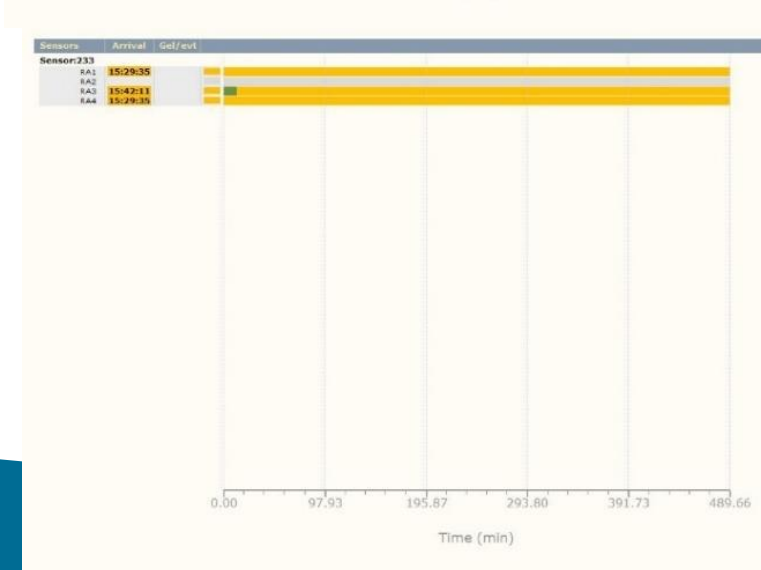
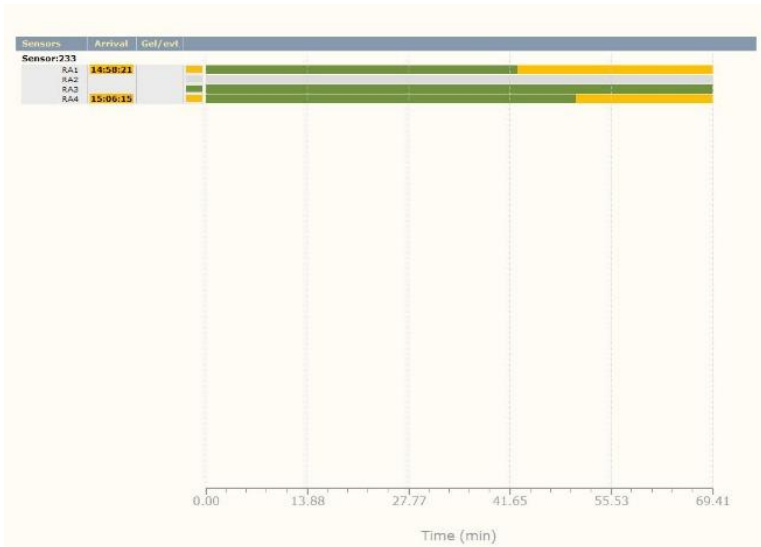
Tg comparison of ORS and Kinetics of a real curing cycle

# Cure Simulator: The “Sensorless” concept

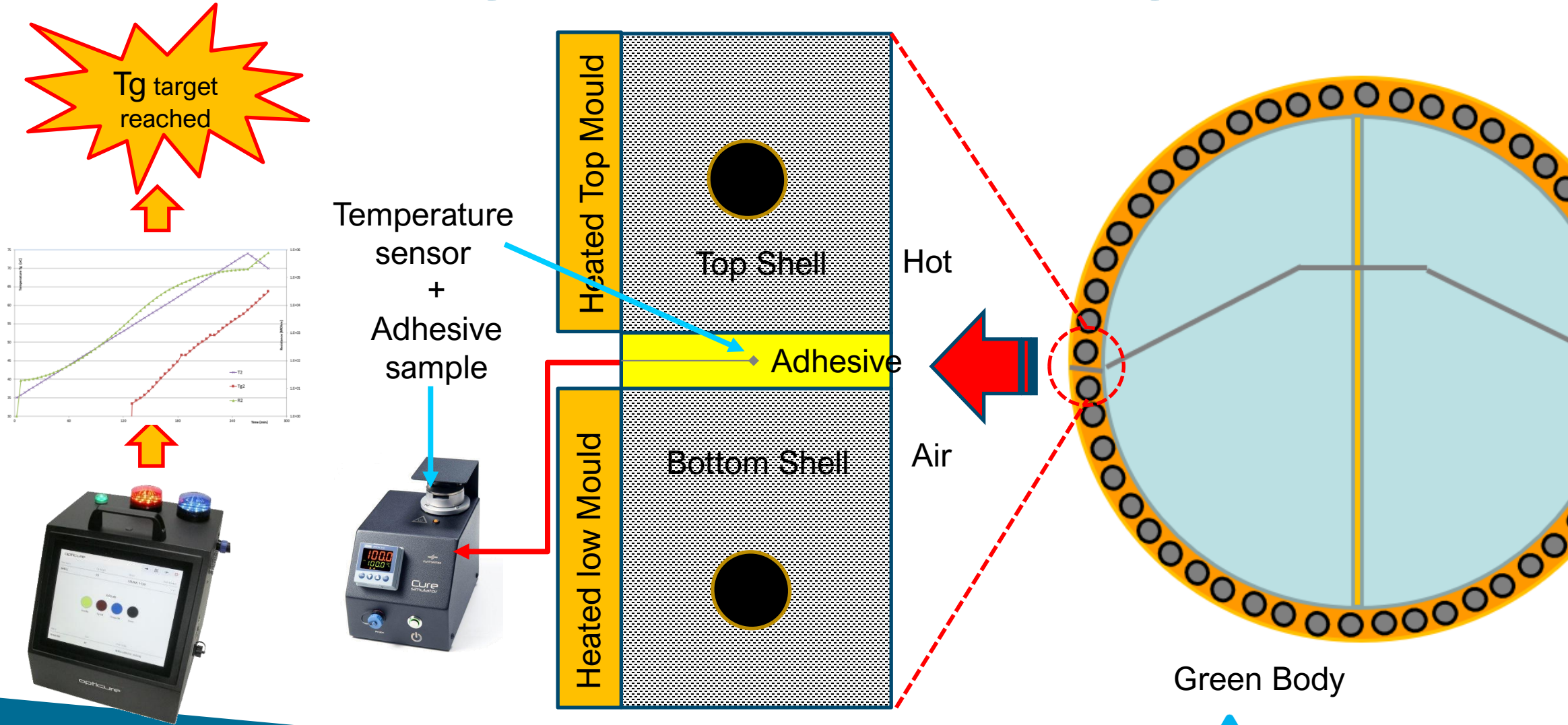




# Baseline Trial: Results



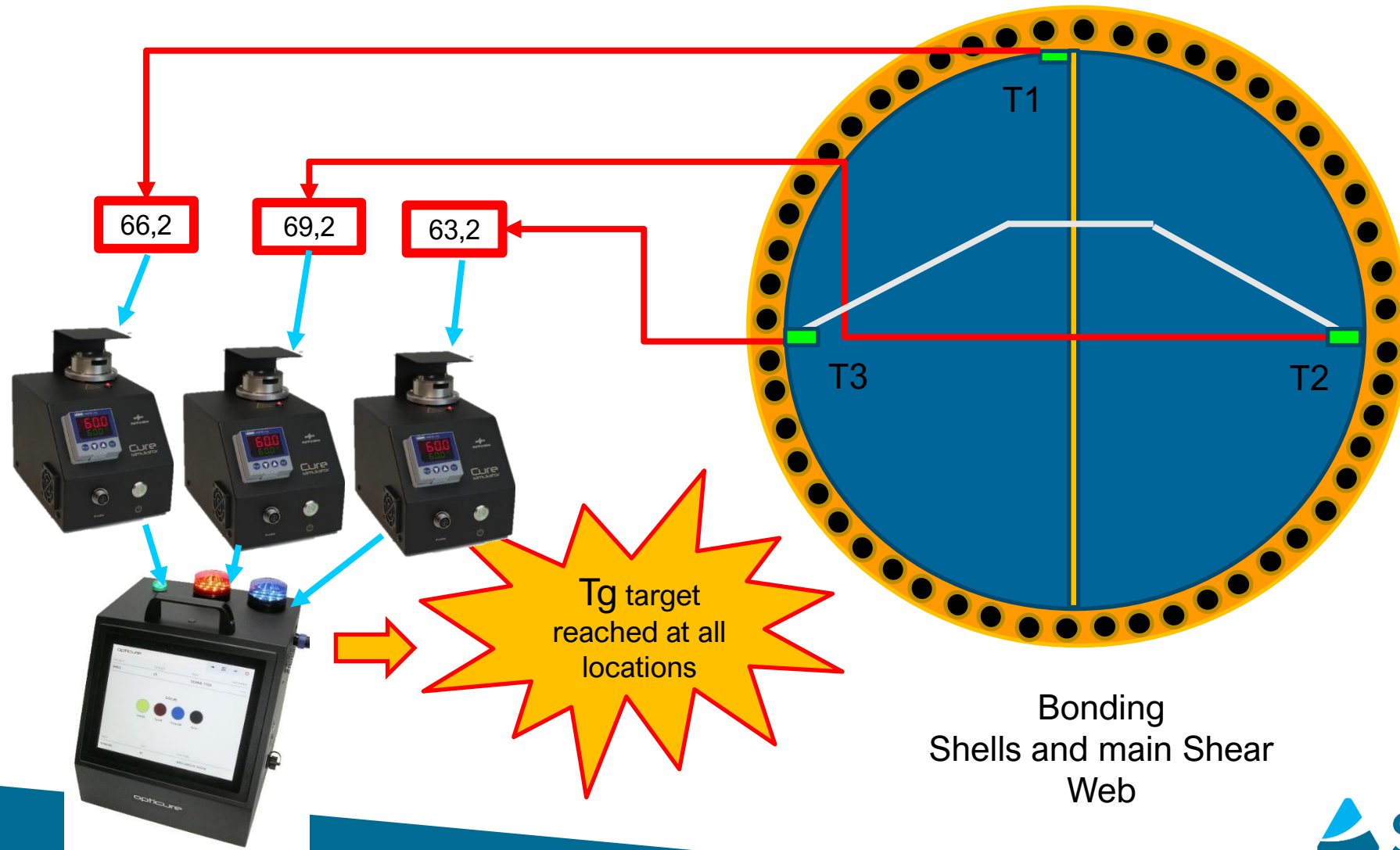
# OnlineTg system: Bonding



Opticure+ Cure Simulator

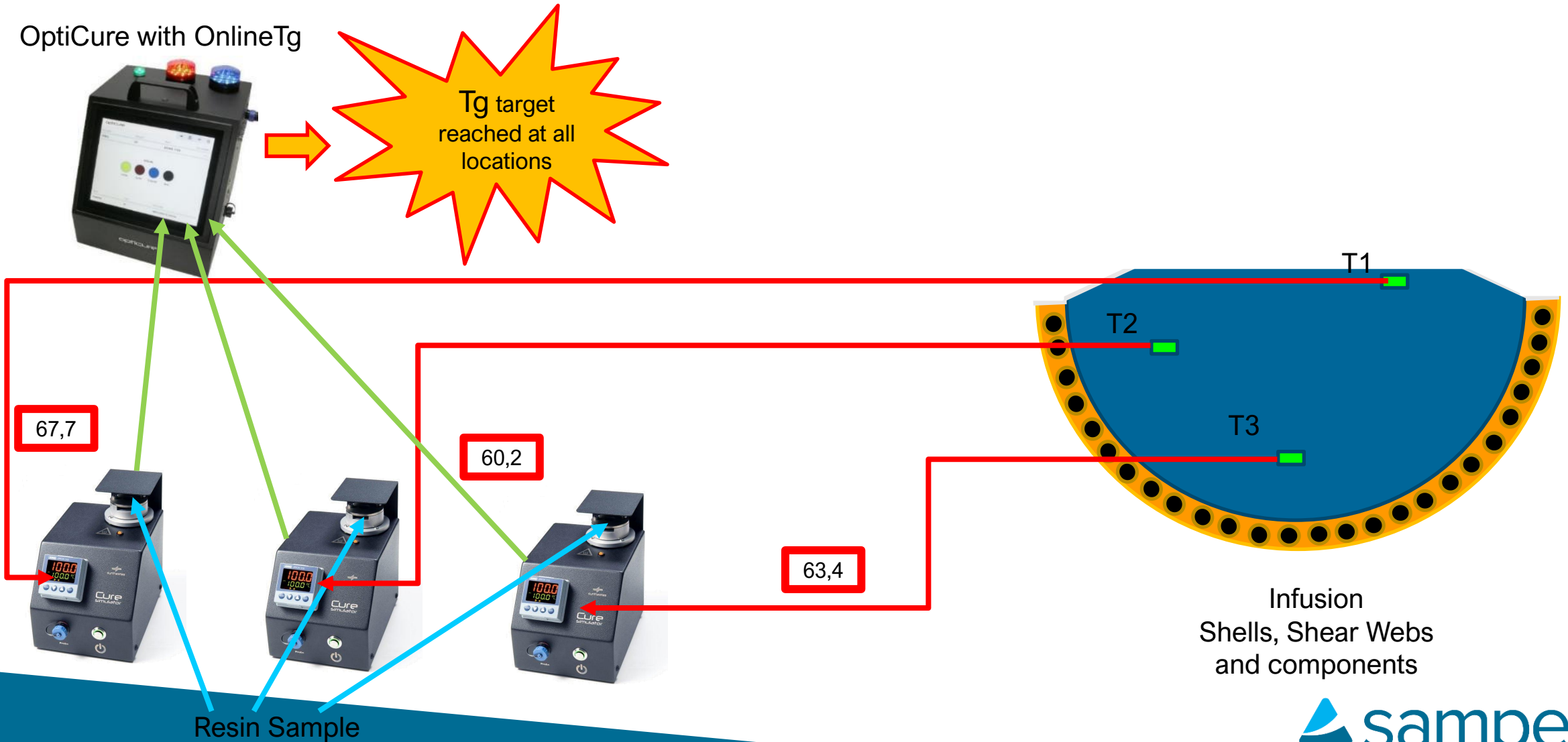
Green Body

# Sensorless Online Tg for bonding

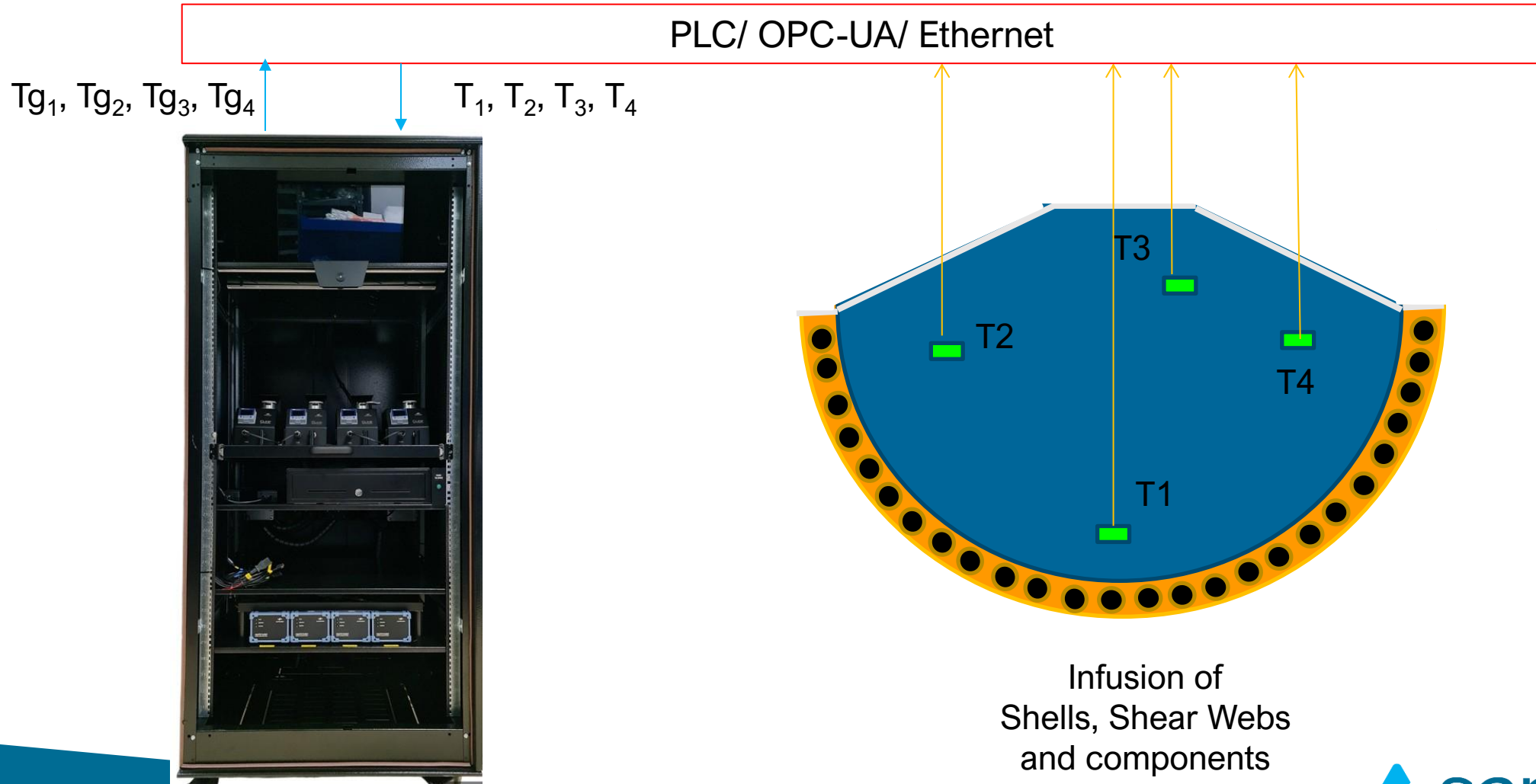


# Sensorless OnlineTg for infusion

OptiCure with OnlineTg



# Online Tg system: Infusion



# Benefits in production

## Reduce curing time

- Webs, Girder, prefabs: stop heating when resin's Tg reaches e.g. 65°C
- Half Shell: stop heating when resin's Tg reaches e.g. 70°C at lagging areas
- Blade: stop heating when adhesive's Tg reaches e.g. 80°C at lagging areas

## Ensure part quality

- Independent of the outside temperature, the Tg target is always achieved at the minimum time and DSC accuracy

## Check resin quality

- Mixing ratio deviations may not be revealed on-time and/or by DSC.

## Reduce filling time

- Half Shell infusion: start heating as soon as resin reaches the mould at thickest areas.

## Reduce process development time

- All fabrication steps: gain real process insight and optimize basic set-up

# Conclusions/ Next steps

## Conclusions

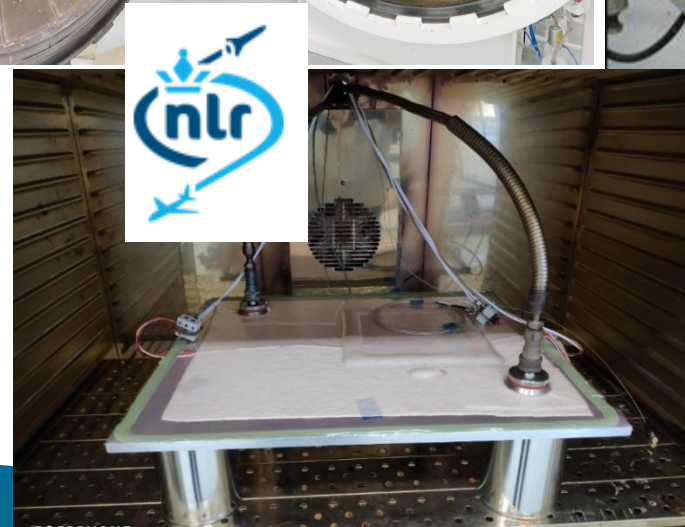
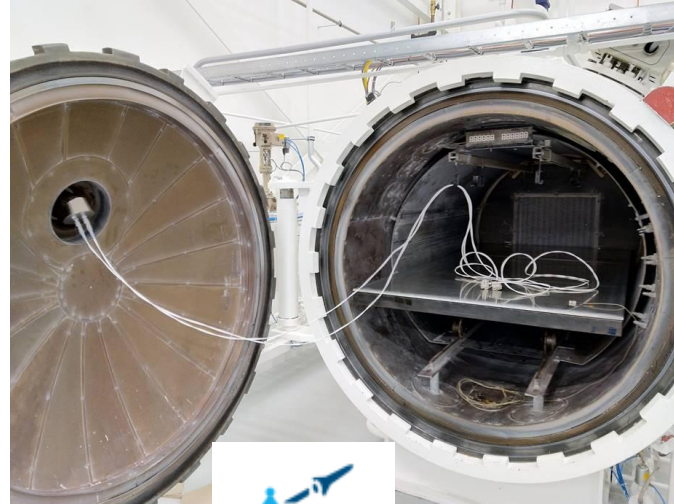
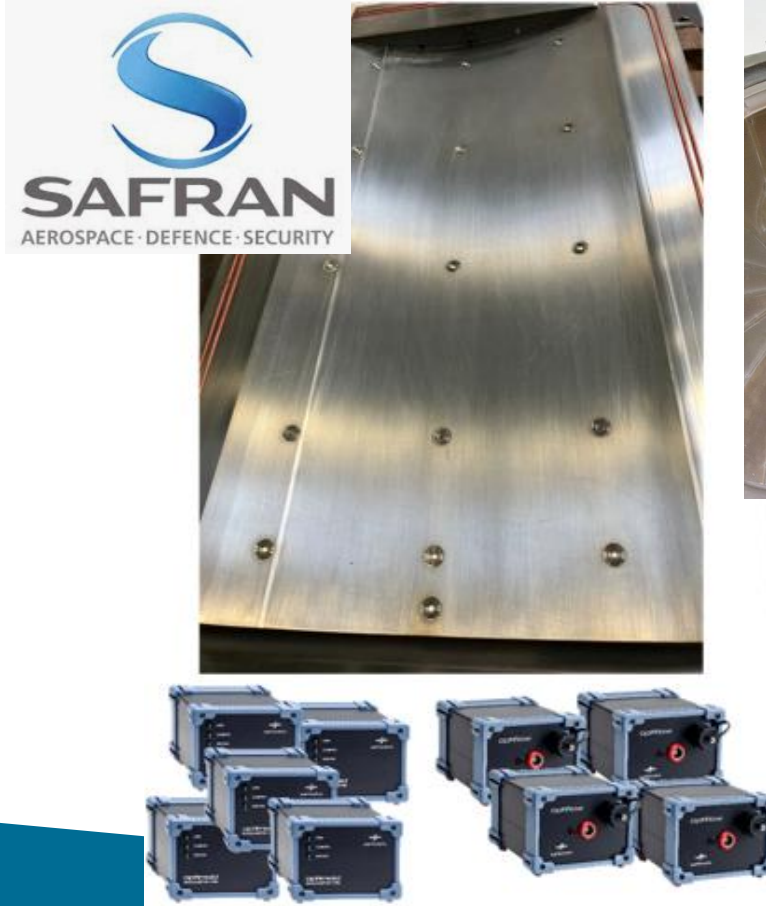
- A complete process monitoring system has been developed for wind blade production
- The online Tg estimation has been used and validated in production at several cases
- Interfaces with PLCs and other systems to transfer information in real-time
- Large OEMs have been using this technology in development and everyday production.

## Next steps

- Apply and demonstrate the intelligent flow control system (Turbo)
- Convince more blade manufacturers towards online monitoring and process control to save time and ensure quality

# More Applications

Currently, a lot of interest from major aerospace OEMs to integrate this technology in RTM, OoA and autoclave production



One-shot wind turbine blade production



**Thank you for your attention!**



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the European Union

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