INTELLIGENT PROCESS MONITORING IN THE MANUFACTURING OF FML STRUCTURES

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DLR

FML structures

- combine the advantages of metals and reinforced plastics in a laminate structure
- Until now was used only at the Airbus A380 so slow processing time was not an issue

Challenge for FML structures

- Enhance significantly productivity for high volume production

Targets of the specific project

- Ensure product quality in FML curing/bonding stage
- Reduce curing cycle time

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

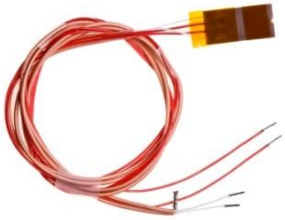
Optimold
Cure, viscosity, resin quality check

Real-time measuring of

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

Input of external signals e.g. pressure sensors

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

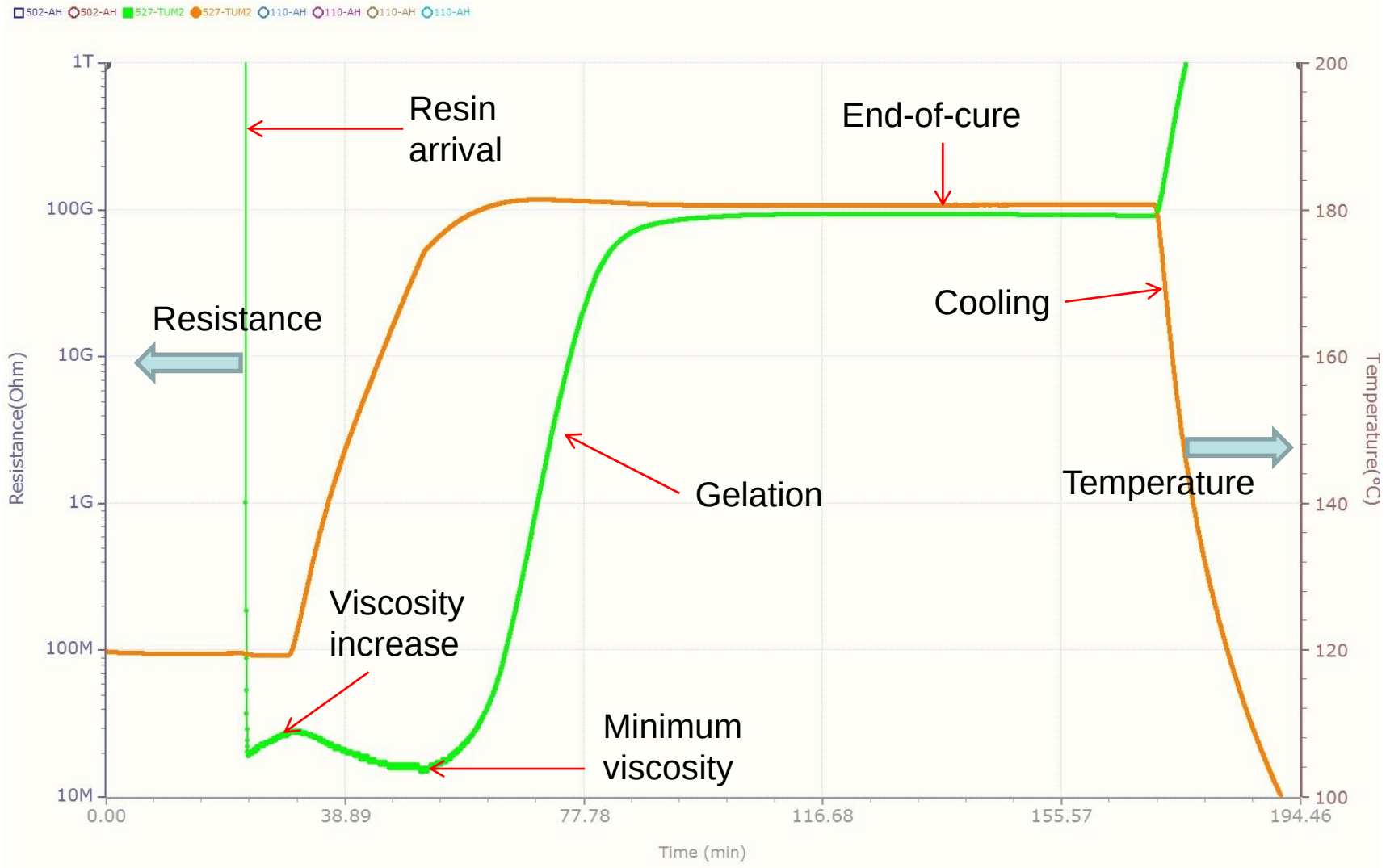
New

CF In-mould Durable

New

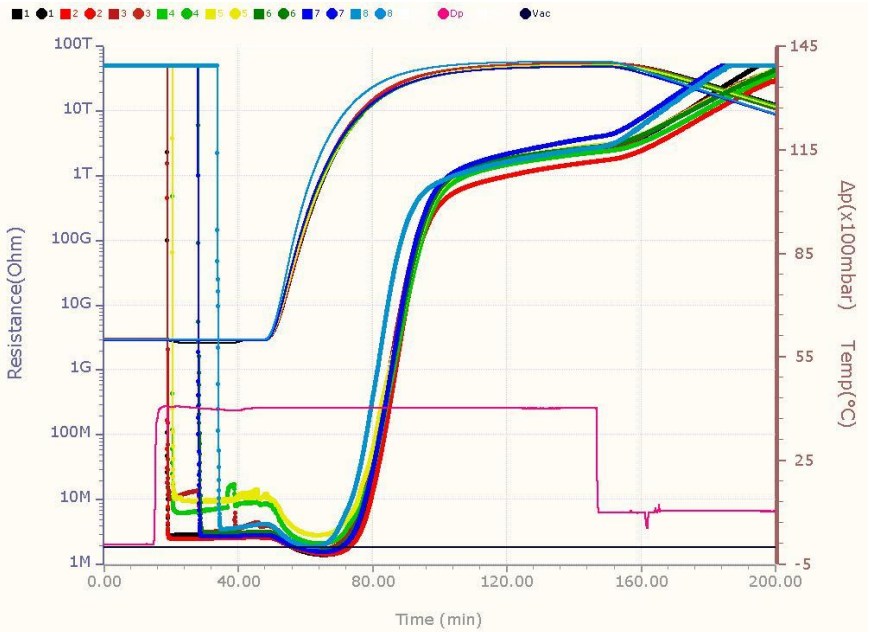
Vacuum Bag Sensor

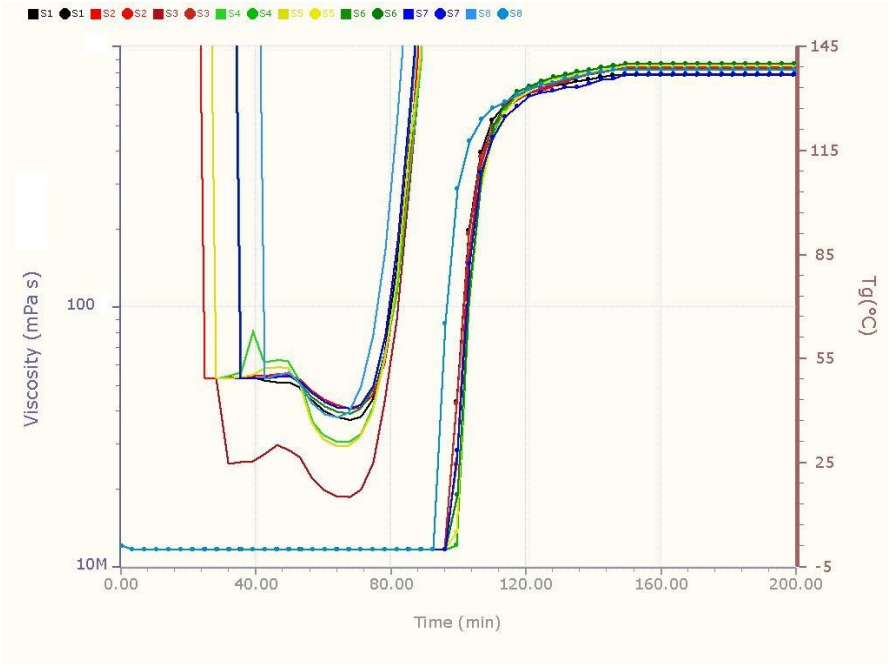
A typical RTM6 cure cycle as measured with Optimold



On-line Resin State (ORS software)

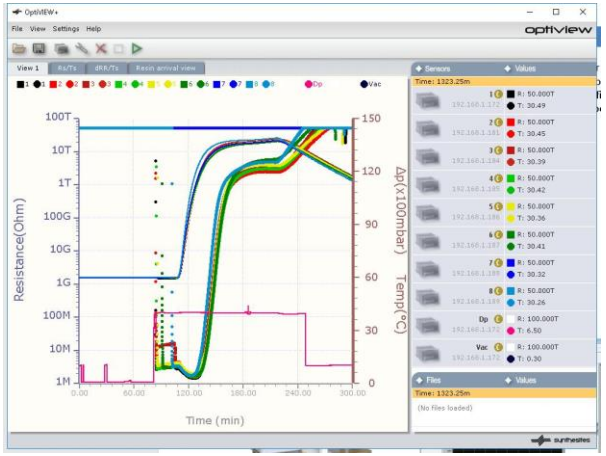
From Resistance and Temperature to Real-time viscosity and Tg estimation





More than 25 resins have been modeled in the whole range of composites manufacturing

Process control using the ORS

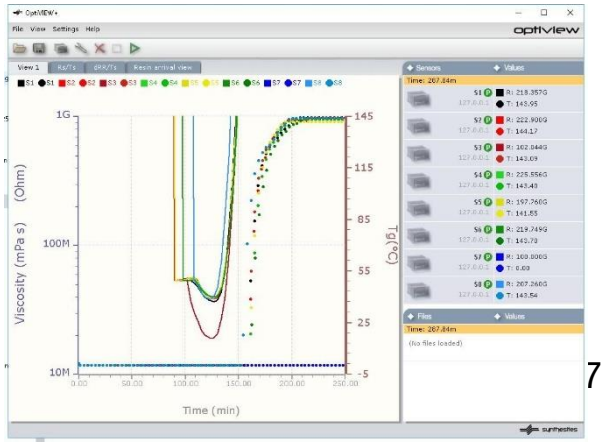


Online Resin State
And
Process Control

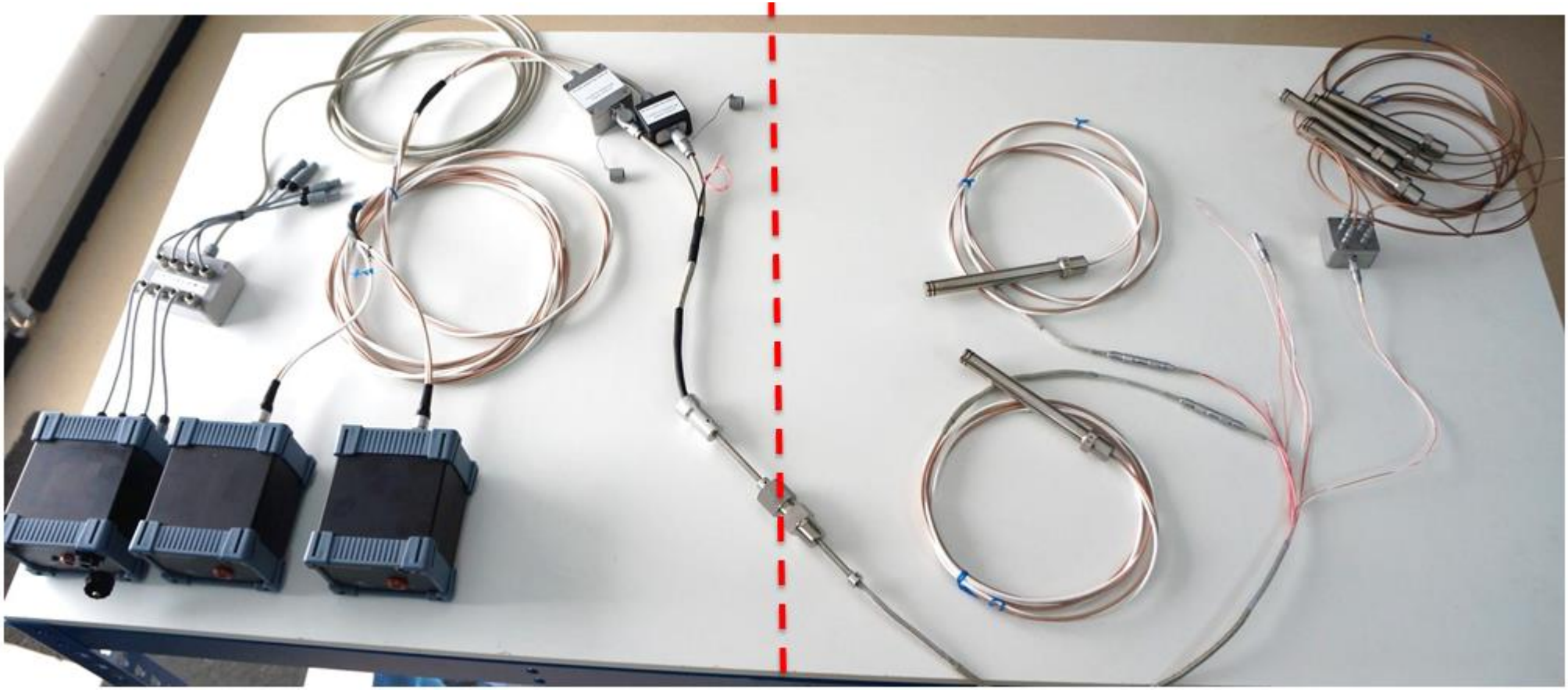
Injection machine

Temperature controller(s)

Valves



Autoclave application (Bombardier Belfast) ECOMISE R&D project



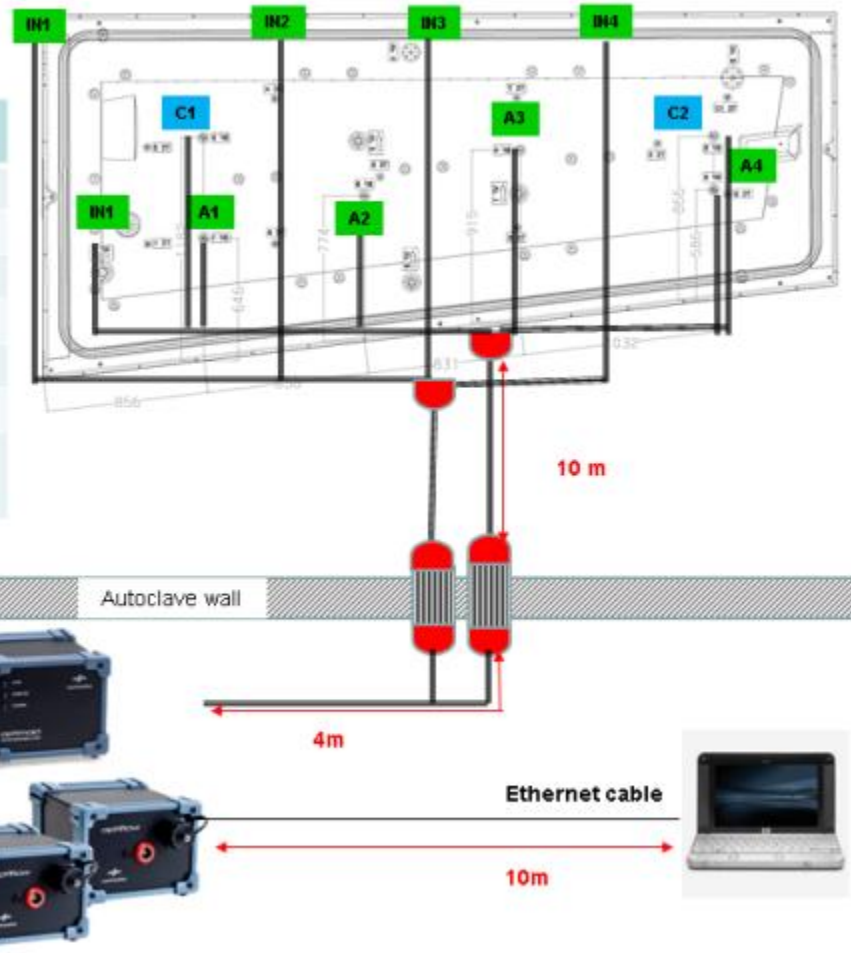
Outside of the autoclave

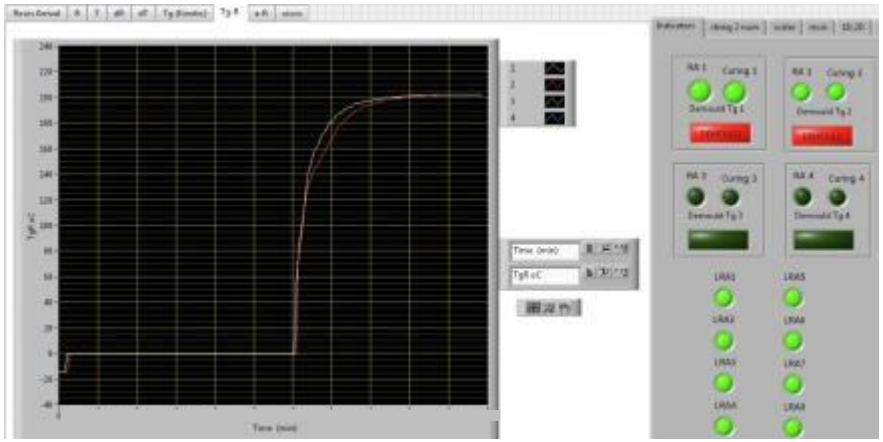
Inside of the autoclave

Demonstration @ WPU Bombardier Belfast ECOMISE R&D project

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

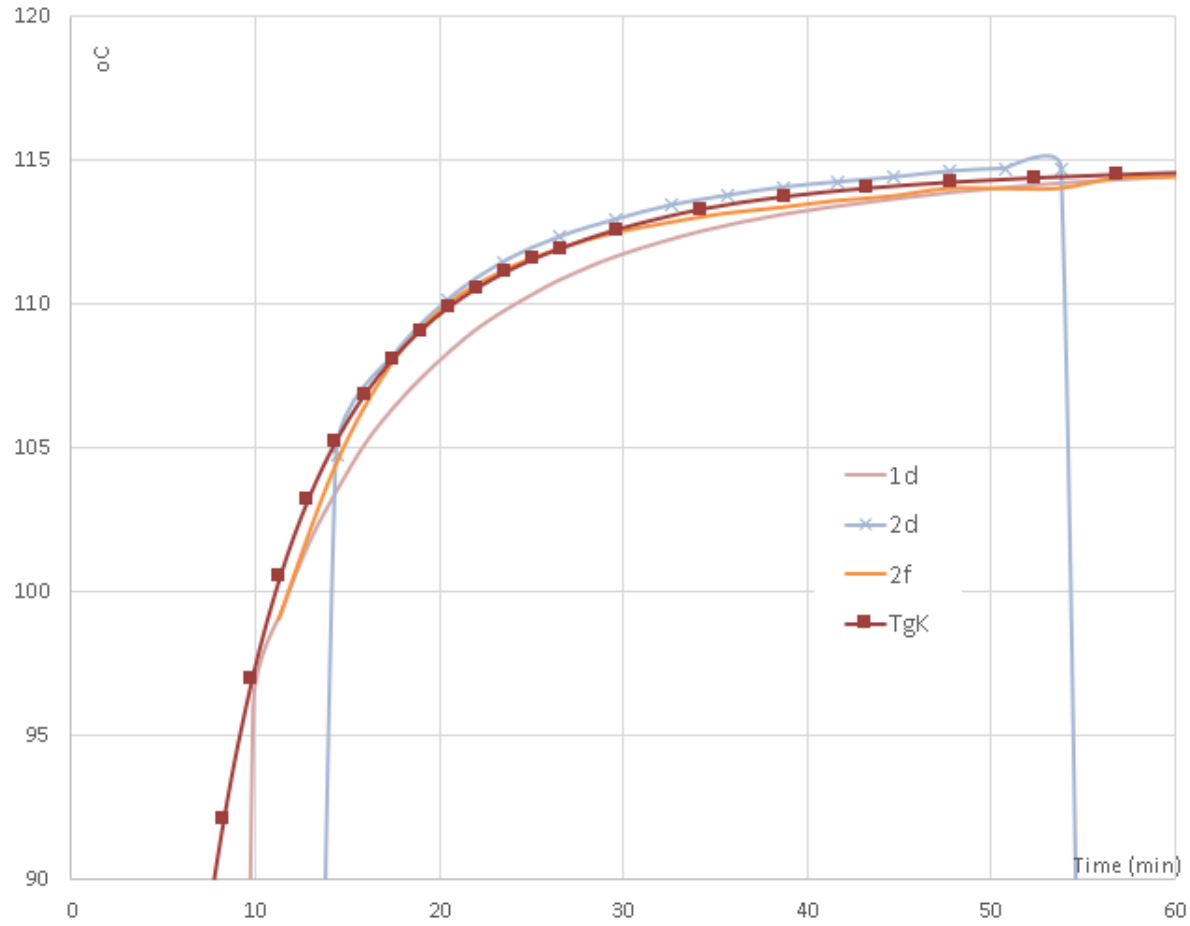
C = Cure sensor
A = Resin arrival and Temperature sensor





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

Kinetic model vs. ORS

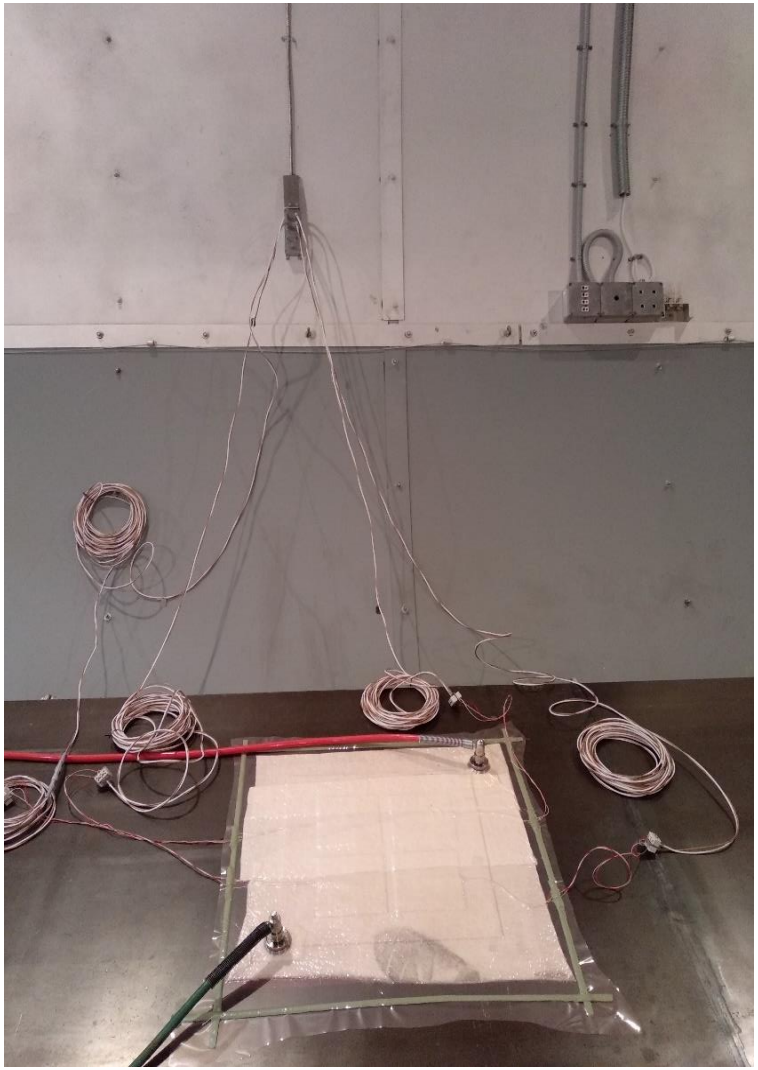


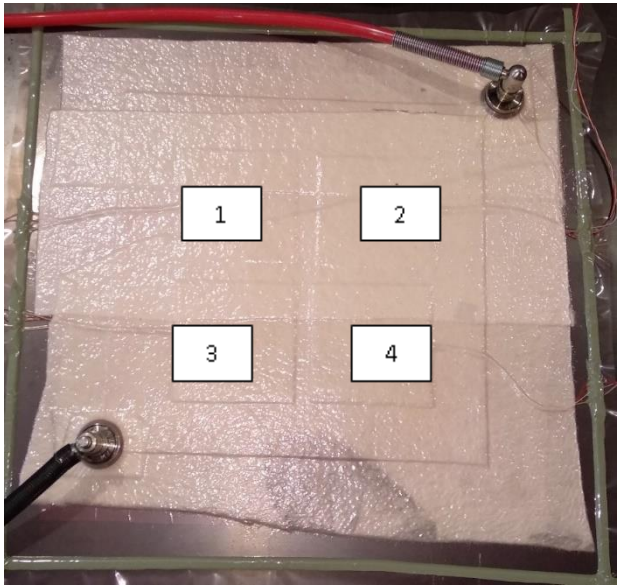
Correlation of Tg estimation between ORS and kinetic model

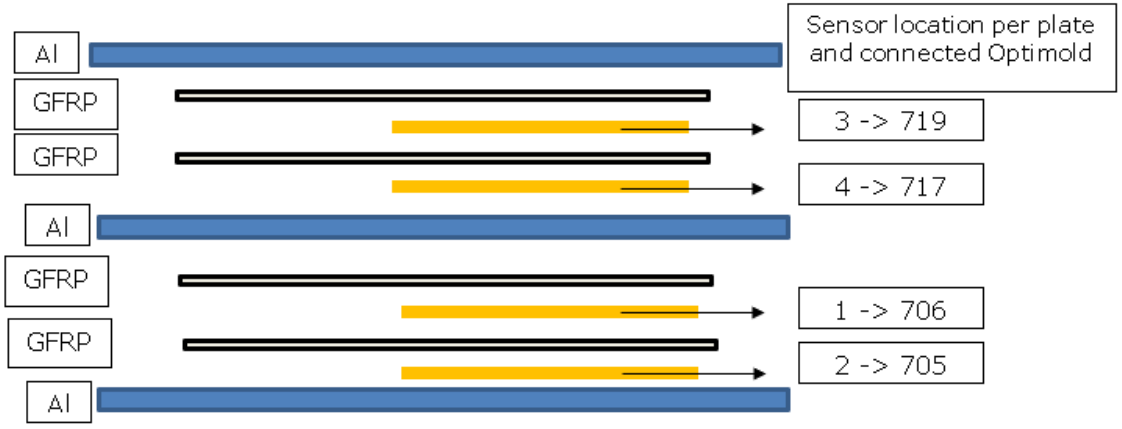
Challenges when using kinetic models online

- Kinetic models depend only on (measuring) temperature
- They are focused mainly at the end of cure
- Questionable accuracy for non-isothermal cases
- Questionable accuracy even for well established aerospace resins
- Questionable accuracy for the useful processing range
- Calculate only the degree of cure from which the calculation of the Glass Transition temperature may add significant errors
- Significant resources and knowledge to develop new kinetic models

Experimental Set-up @ BALU, DLR, Stade



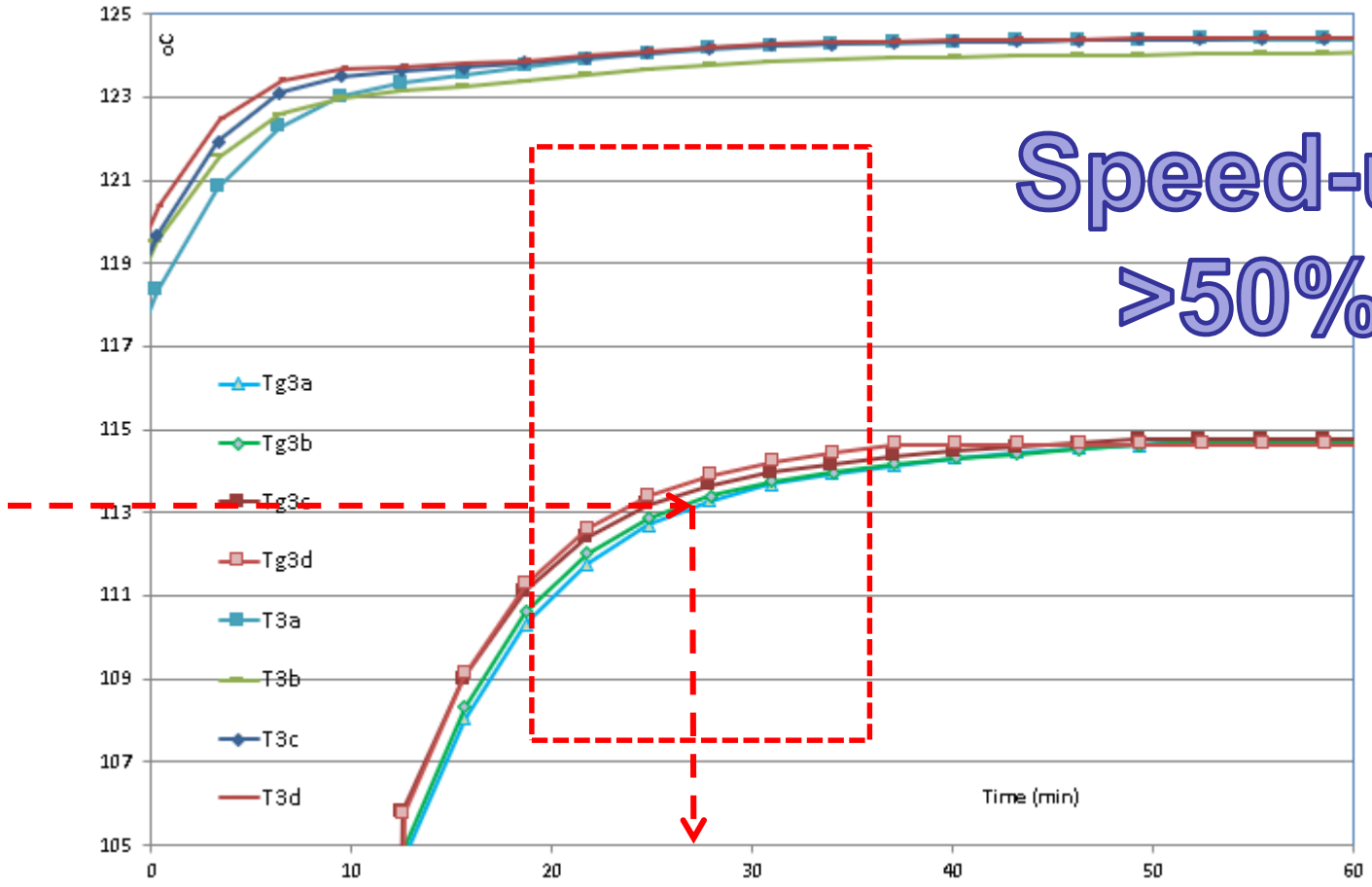




Results

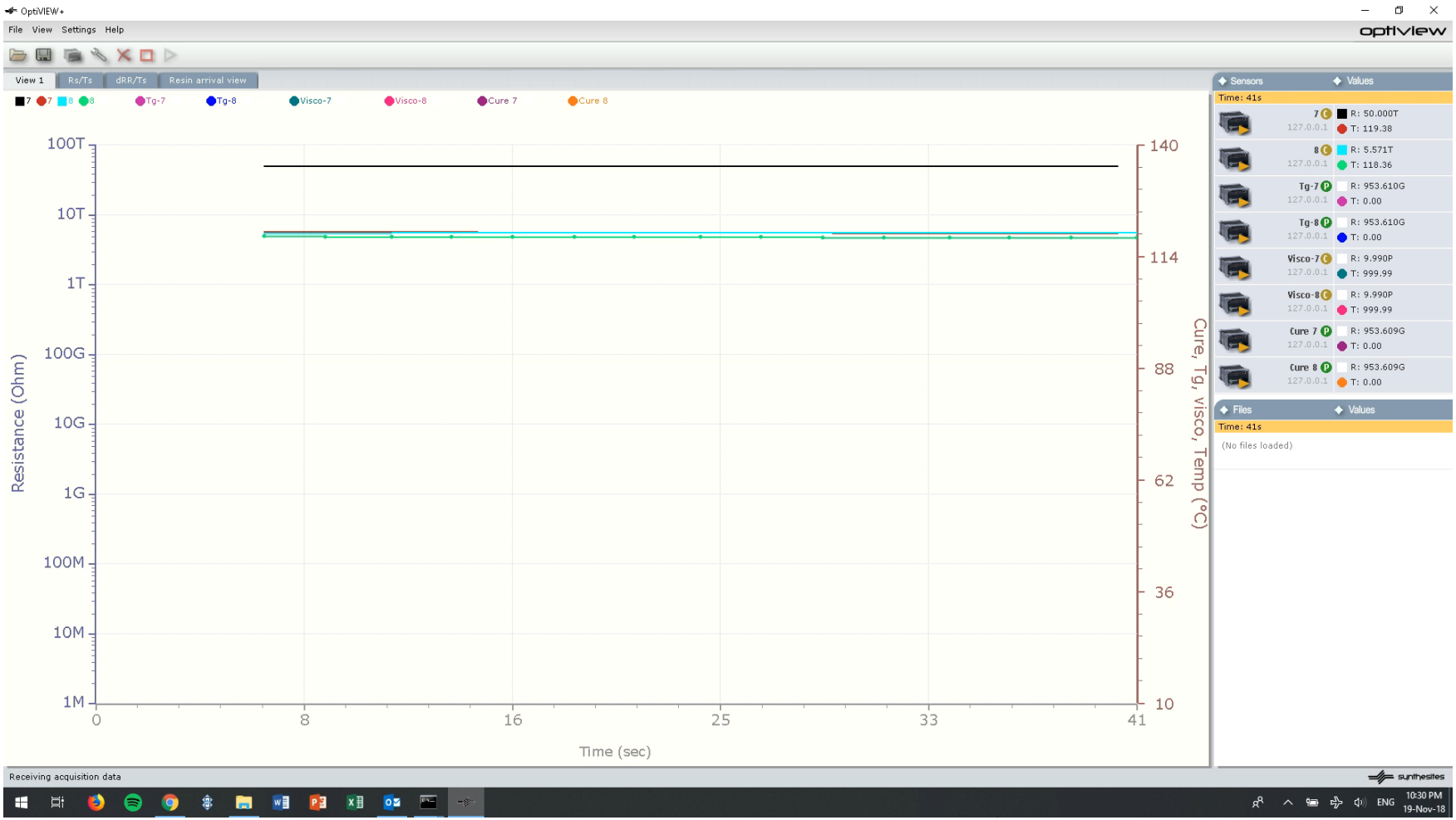
Recommended cure cycle: 60’ @ 125°C

Online Tg estimation helps to reduce curing time by more than 50% to reach 98% of maxTg



Speed-up >50%

Online viscosity, Tg and Degree of cure



Example of the ORS with a snap-curing resin

Conclusions

- Online quality control for FML curing/bonding stage was successfully applied and verified at autoclave conditions
- Reduction of curing cycle time by 50% was achieved in small scale trials
- And this performance was proven at larger scale trials where variability and need for process insight is paramount
- Similar performance has been demonstrated in many other applications in aerospace, automotive and wind energy.

We thank our project partners

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