



The Society for the Advancement of Material and Process Engineering

Advanced monitoring and control for CFRP
RTM in Aerospace without compromises





Advanced process monitoring and control for CFRP RTM in aerospace without compromises

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Speaker info

- Dr Nikos Pantelelis
- Synthesites, Greece and Belgium
- Co-founder and Director
- Brief bio
 - MSc and PhD in mechanical engineering
 - 25 years in composites manufacturing and intelligent process monitoring and control

Synthesites- Customers

Companies



R&D Centres and Universities



Synthesites- Products



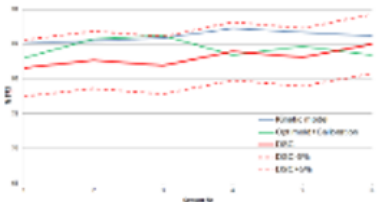
optimold system for monitoring resin cure, resin viscosity, mixing ratio quality and resin quality



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)



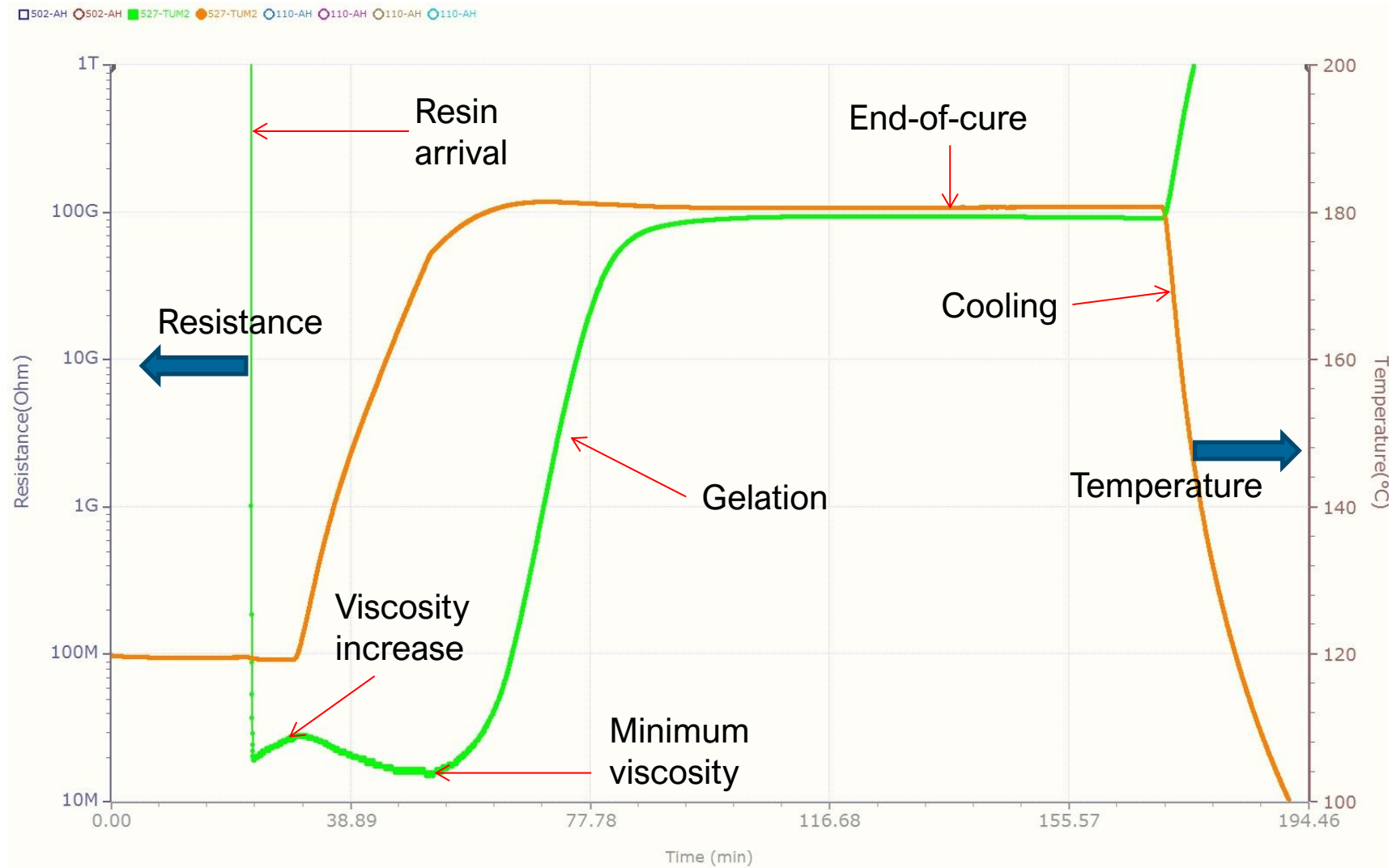
Automation, design and prototyping

New CF sensors

- ④ The durable CF cure sensor allows to measure at CFRP applications without the need of any protection
- ④ 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
- ④ 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
- ④ New CF resin arrival sensor for industrial production



Typical Cure Cycle



Cure monitoring- Sensors and unit

Real-time measuring of

- Resin's electrical resistance (from 0.1 MOhm up to 100 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



- 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



Flow monitoring - Sensors and unit

Real-time measuring of

- 4 Resin Arrival channels
- 4 temperature (pt100 sensor with 0.2°C accuracy)

process monitoring sensor = electrical resistance + RTD sensors

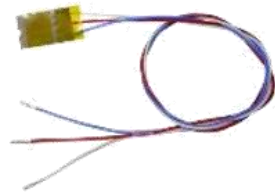


Durable
sensor



- 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

New

CF In-mould
Durable



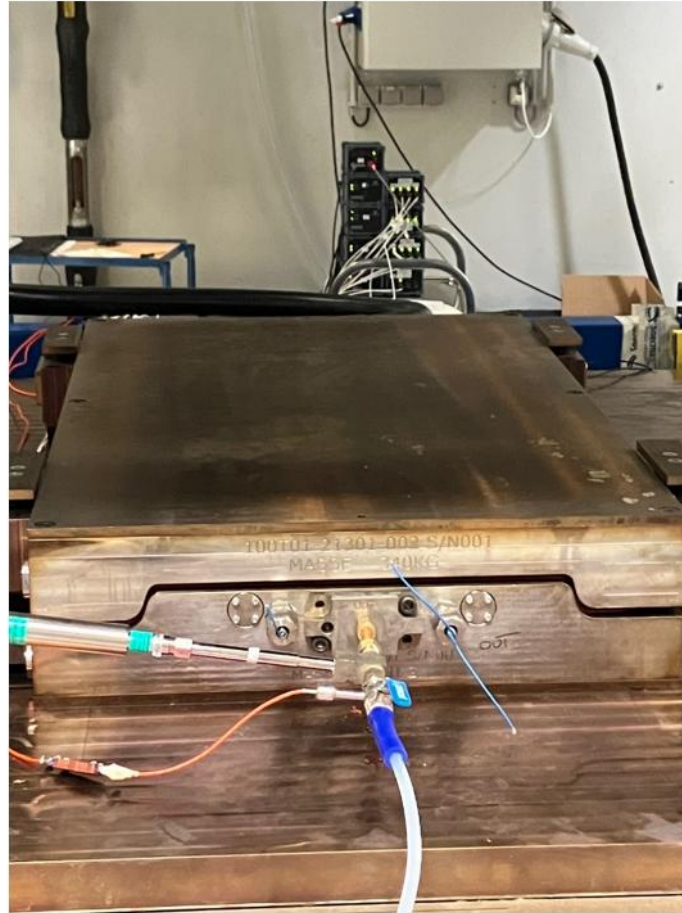
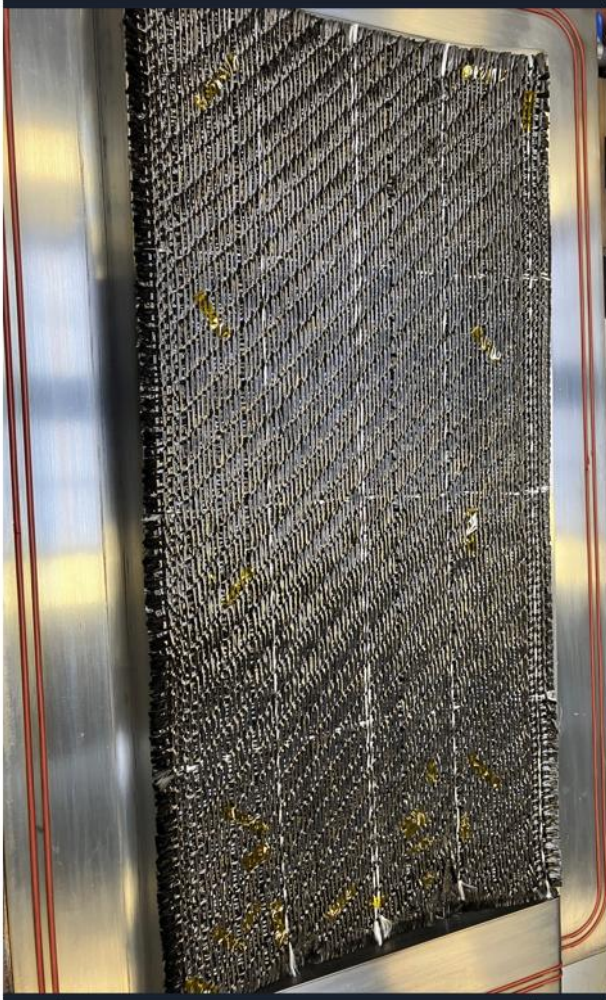
CF Vacuum Bag
Sensor

New

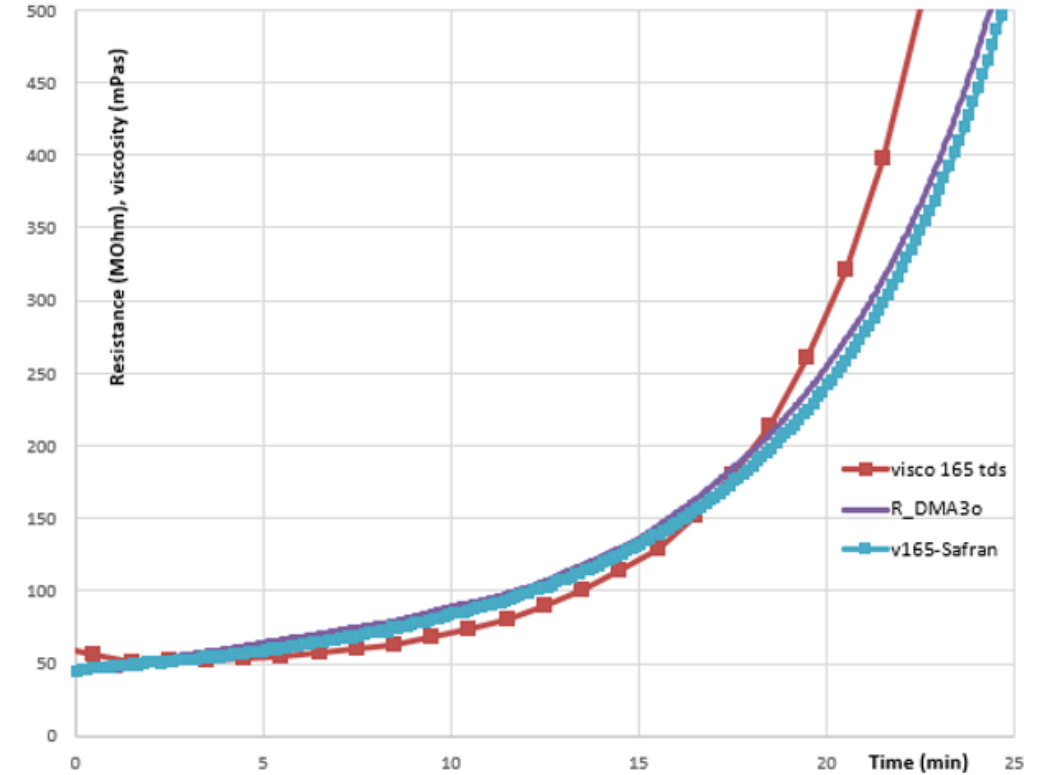
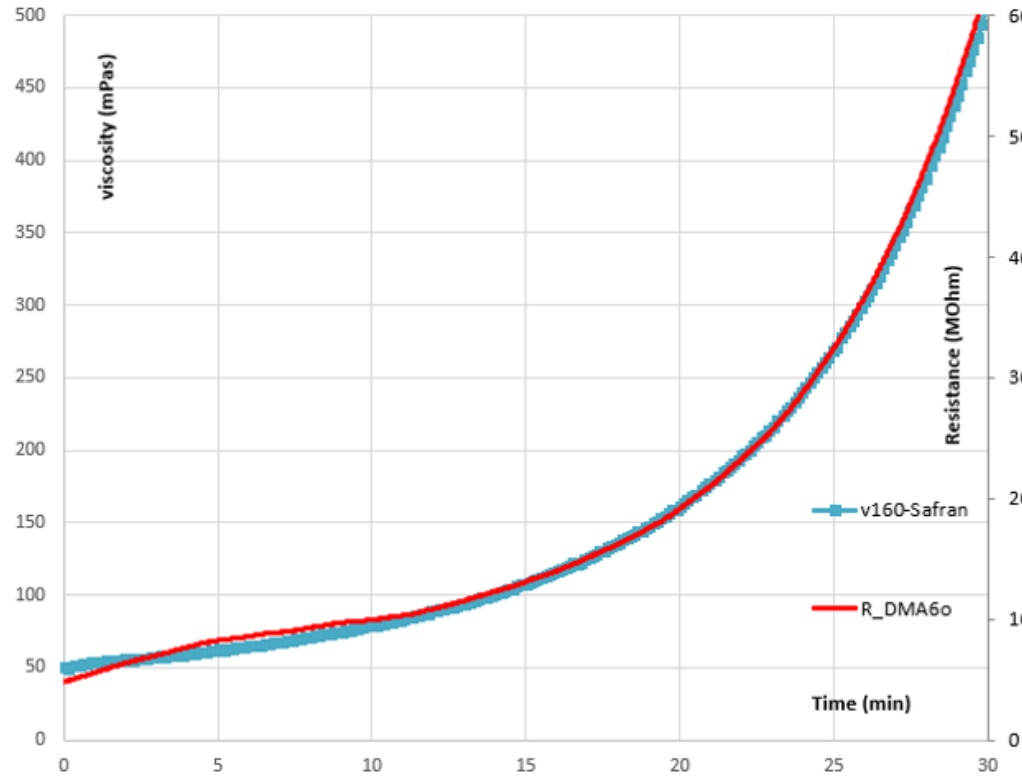


Results

Test Case: @Safran Composites, FOD panel with 3D-woven carbon-fibre preform
High-pressure, high-temp RTM



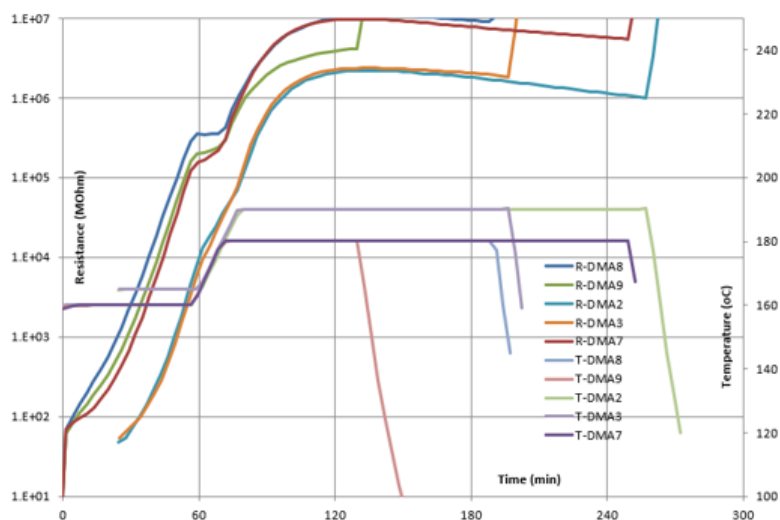
Viscosity correlation



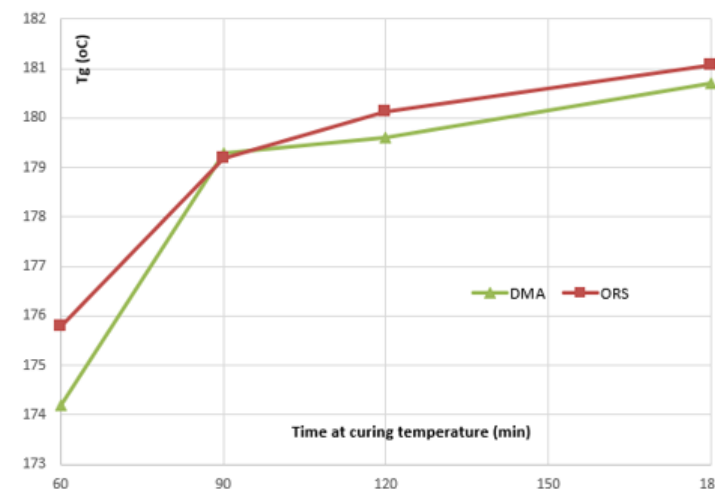
Correlation between viscosity and resistance @160 and 165°C

Calibration

- DMA coupon production



	Temp (time)/Heating rate/ Temp (time)/ Cooling rate	T _g (DMA)
DMA1	160(60)/2/190(180)/1	178.0
DMA2	165(40)/2/190(180)/1	180.7
DMA3	165(40)/2/190(120)/1	179.6
DMA4	165(60)/2/190(90)/1	179.3
DMA5	165(60)/2/ 190(60) /1	174.2
DMA6	165(60)/2/ 190(45) /1	179.5 ?
DMA7	160(60)/2/180(180)/1	177.7
DMA8	160(60)/2/180(120)/1	179.6
DMA9	160(60)/2/ 180(60) /1	175.2



Resistance vs T_g (DMA)

injection@160 or 165°C, curing@180 or 190°C for 45',60',90', 120' and 180'

Sensors' deployment

- 1X Tg & viscosity (Cure Simulator)
- 15X Resin Arrival (3 Optiflow)
- 3X Tg & viscosity (3 Optimold)
- UF Resin Arrival (mod Optimold)

Monitoring equipment



Cure Simulator



Sensors and HMI

- 16X In-mould CF sensors
- 1X In-line inlet gate sensor
- 1X In-line outlet gate sensor
- 1X Cure simulator +cure sensor
- 1X Pressure sensor



Resin Arrival+Temp



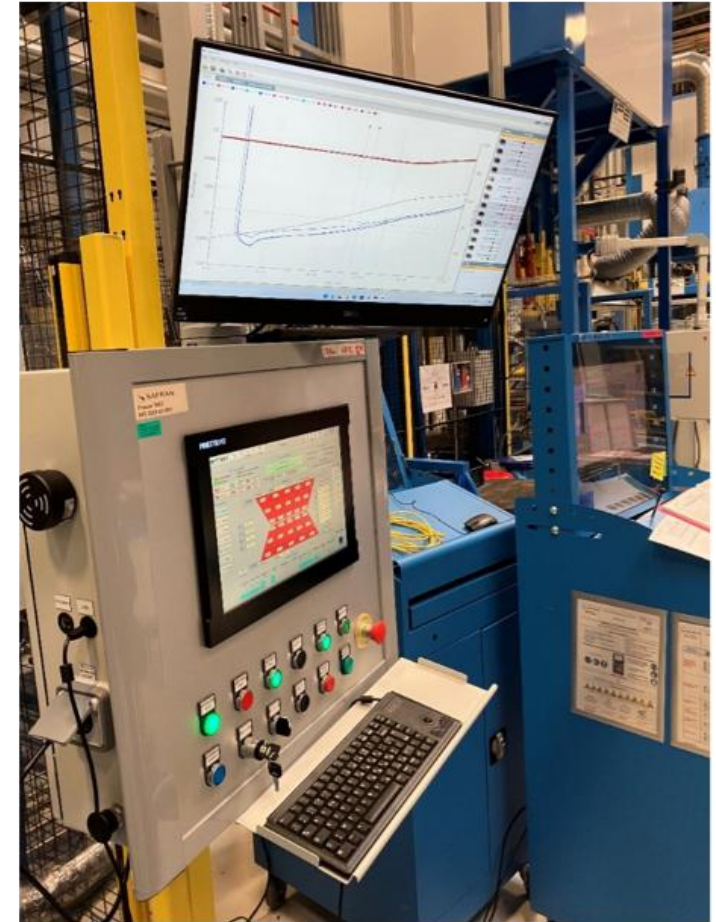
Resistance+Temp



Inline



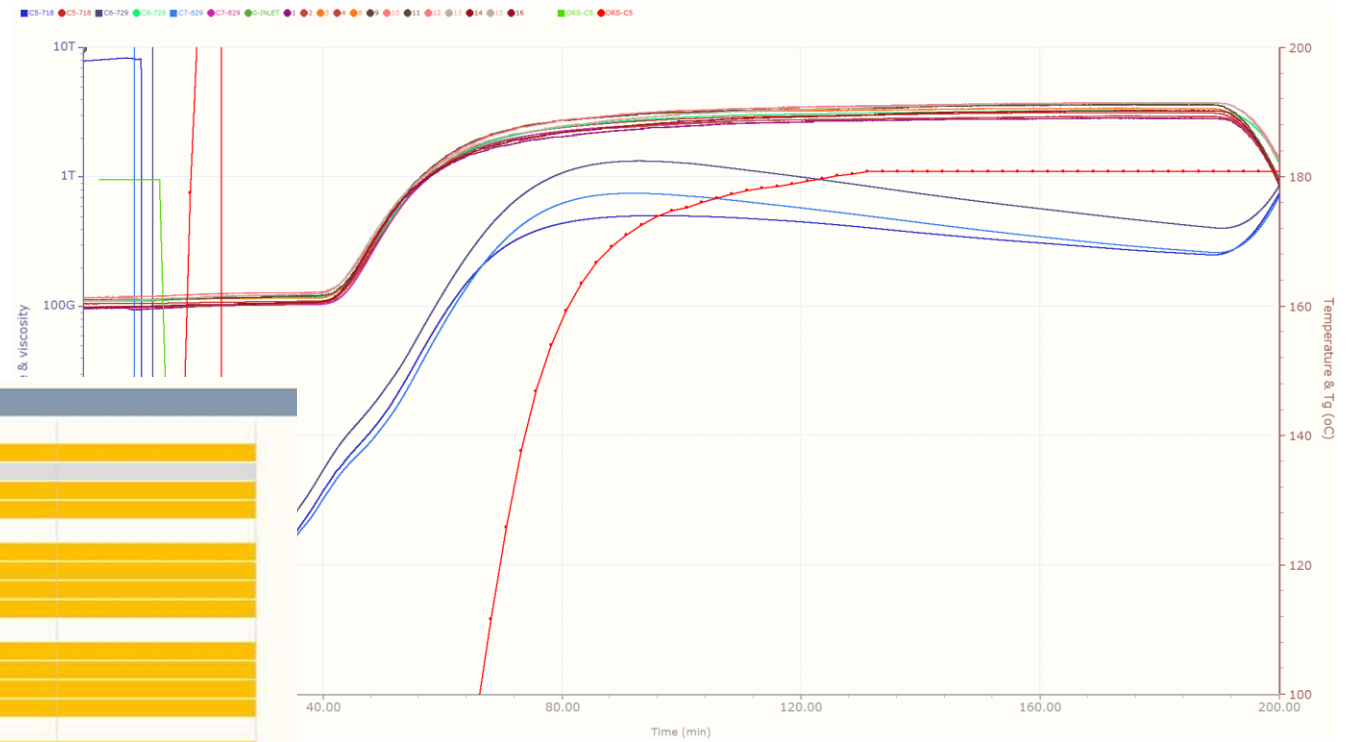
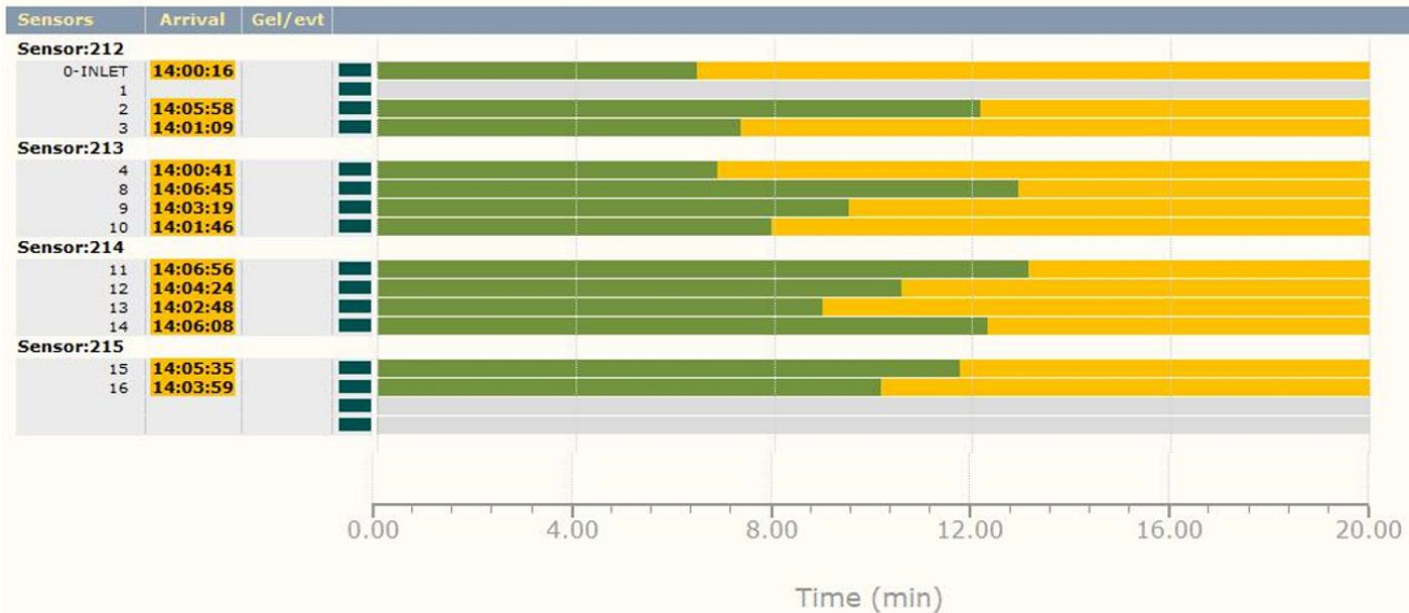
Pressure



Resin arrival and curing

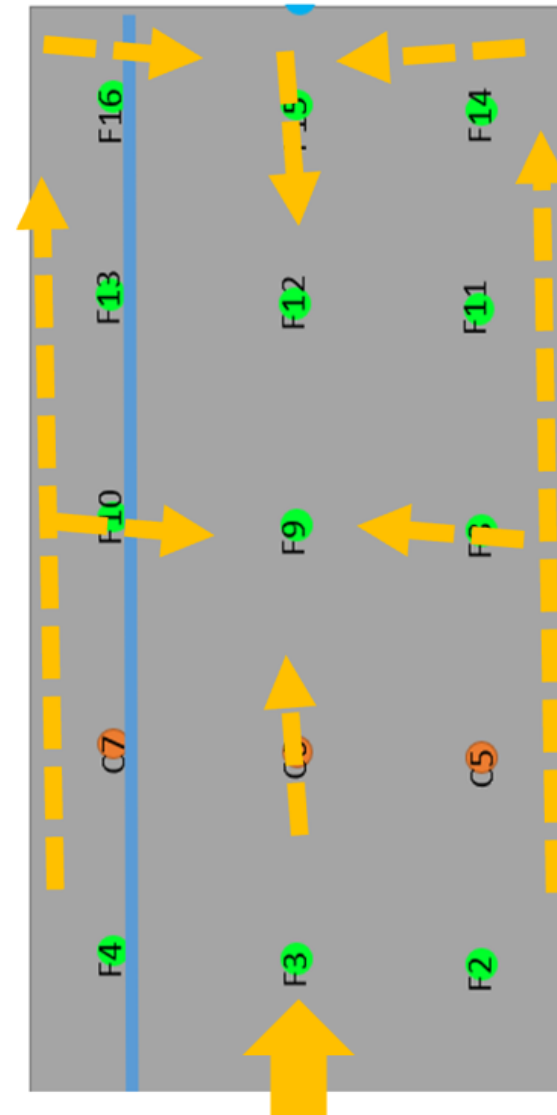
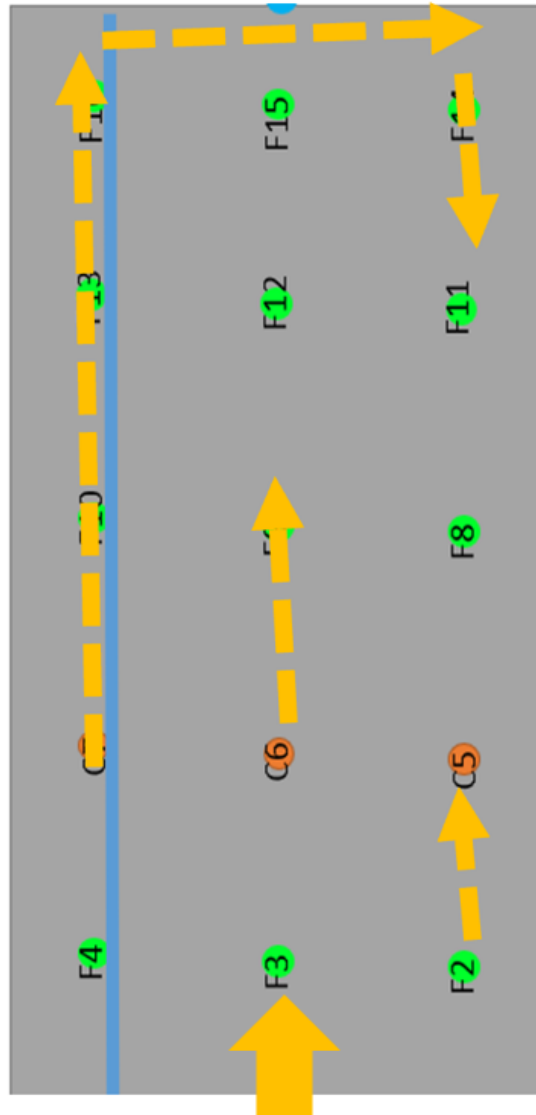
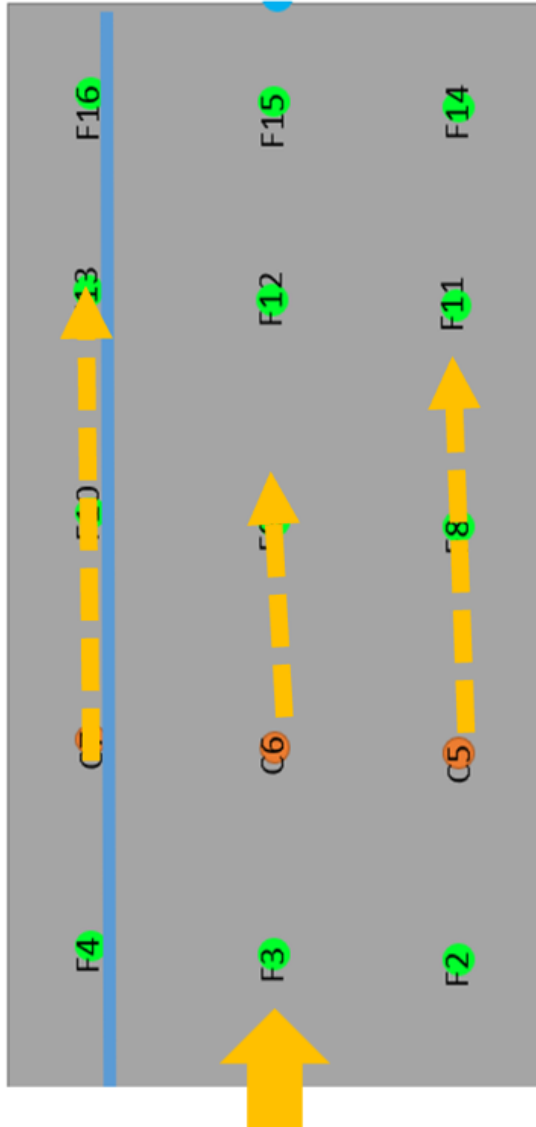
Typical results

Resin Arrival timeline

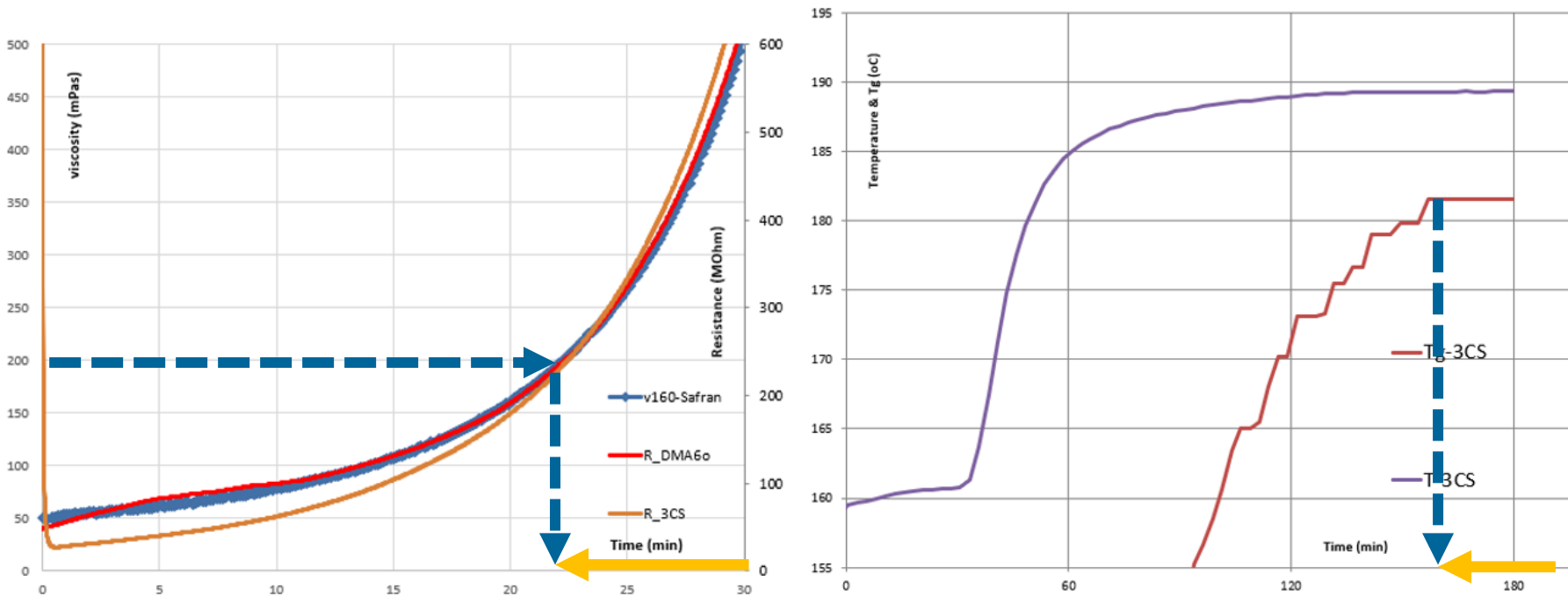


Resistance and temperature

Indicative Flow patterns



Process Optimisation

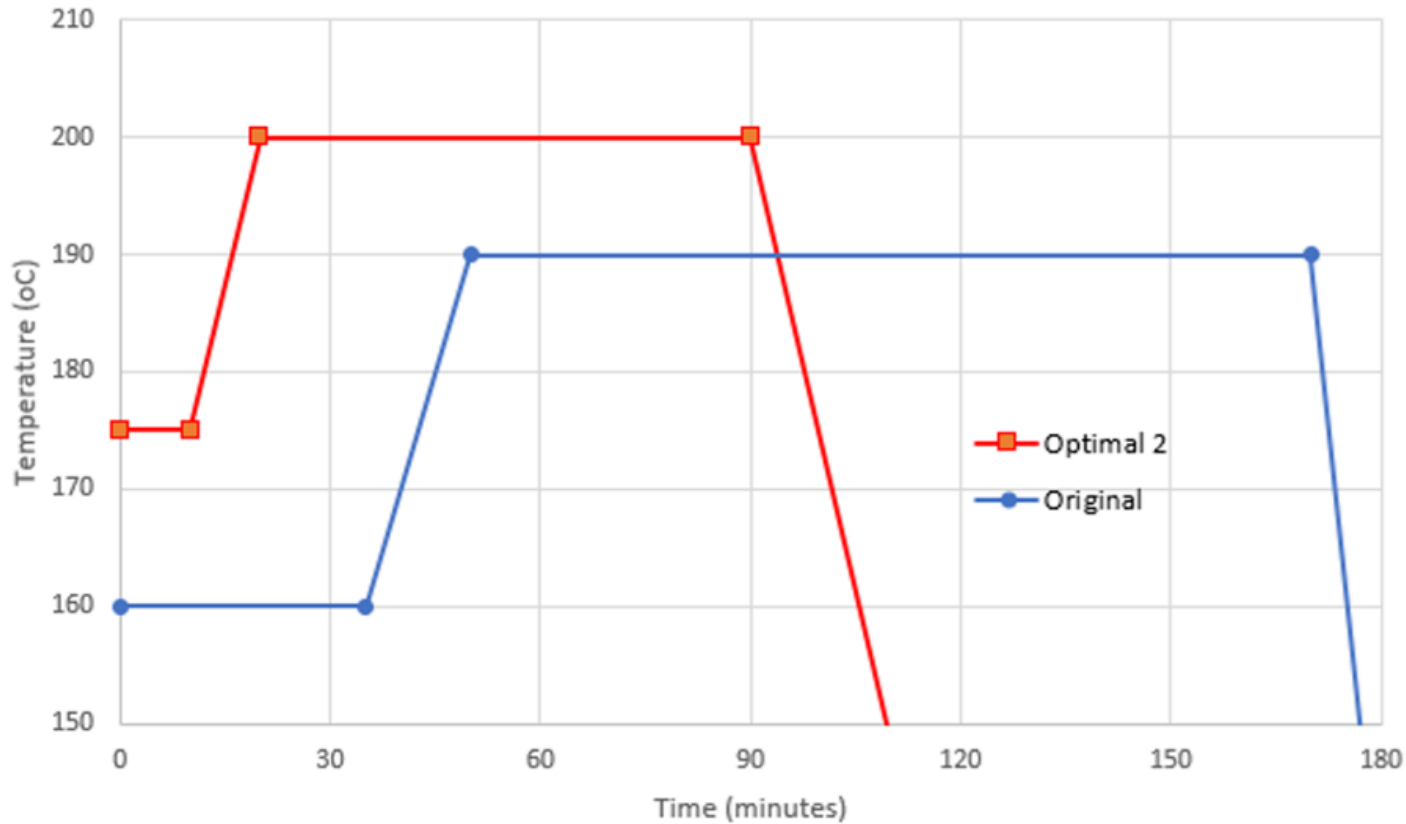


Start heating when all sensors are wet and viscosity is high

Stop heating when Tg is reached

- ✓ Optimising the injection stage (left) and the curing stage (right) based on the feedback from the sensors

Real-time Control



- ✓ More than 60 minutes can be saved in a 180' cycle i.e. saving 33% from the current cycle time for the same result

Conclusions- Next steps

- ✓ The new CF Resin Arrival sensors have been used successfully for the monitoring of aerospace-grade RTM manufacturing of CFRP parts close to industrial conditions.
- ✓ The use of the new CF cure sensors and calibration methods can lead in a significant reduction of the cycle time ensuring part quality.
- ✓ The introduction of the Cure Simulator can considerably facilitate the implementation of this technology in everyday production, eliminating the modifications in the existing infrastructure.
- ✓ This complete online process control technology is being implemented in serial production in wind turbine blades (on-going) and aerospace (under preparation) production lines.

Acknowledgements



Thank you!