Intelligent Process Monitoring and Quality Control in Advanced Composites Manufacturing

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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

OptiSensors (durable/ disposable, flexible, outlet, custom)

Real-time calculation of Tg/ degree of cure/ viscosity/ resin quality

Automation, design and prototyping solutions
Indicative customers

- EADS
- BOMBARDIER
- Aircelle Groupe SAFRAN
- EUROCOPTER
- Audi
- faurecia
- schunk
- Krauss Maffei
- SIEMENS

Collaborators

- DLR
- TUM Technische Universität München
- FIBRE Bremen
- AIMPLAS INSTITUTO TECNOLÓGICO DEL PLÁSTICO
- tecnalia
- Fraunhofer
- ANADOLU UNIVERSITY
Completed

FP7 iREMO: intelligent Reactive Moulding (9/2009-8/2012)
RTM, Light RTM and Infusion
Glass and carbon fibre, epoxy and polyester
Automotive and infrastructure applications

On-going

FP7 Ecomise: Composites manufacturing (9/2013-8/2016)
Partners: DLR (CO), Faser I., Bombardier, Hutchinson, Airborne, Polyworx, Loop, Samtech, Dassault System, NLR
RTM and RTI, Glass and carbon fibre, epoxy
Aerospace, automotive and marine applications

FP7 MAC-RTM: Microwave curing (11/2011-10/2013)
ICT and Aimplas involved

FP7 Coaline: Injection pultrusion with mw and coatings (9/2013-8/2016)
ICT and Aimplas involved
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
Real-time measuring of
- Resin’s electrical resistance (from 0.1 MOhm up to 50 TOhm) and
- temperature (0.1°C accuracy)

**Characteristics**
- Non-intrusive
- Range of sensors
- Good Repeatability
- Fast Acquisition
- Compact design
- Wireless
- Quality and Process control
**Cure and Viscosity 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
- 4 temperature and resin arrival sensors
- Electrical resistance-based measurements and RTD temperature sensing
- Continuous connection checking
- One relay output for process automation
Resin arrival and temperature sensors

In-mould Durable

- flat areas
- possible mark

Gate sensor

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

Flexible disposable

- Curved surfaces
- Can be used in the laminate for development
- Remove with peel-ply
- Suitable for very long cables
- no need for extra protection
OptiView: DAQ software

OptiView software for both Optimold and OptiFlow systems
System check and calibration

Calibrators for Optimold and OptiFlow systems
Through-thickness cure simulation and optimisation

- Optimise temperature profile using 1-D or 2-D models based on targets and constraints
- Robust Optimisation: include statistical deviations
- Sensitivity analysis of the optimal case: Check the robustness of the optimal profile based on statistical deviations.
Resistance and viscosity monitoring of Bakelite’s neat L20 epoxy resin at various temperatures
Resistance (MOhm) vs. hardener percentage (100:0->100:34)
Resistance vs mixing ratio of fresh and aged monocomponent resin
Resin aging and viscosity build-up

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

Case 1

Case 2, 4

Case 3

Viscosity, Resistance and temperature vs. time for 4 resin batches
RTM6: Correlation between resistance and Tg
Resistance vs. Tg

Correlation between resistance and Tg (iso-T)
Vacuum Infusion Test Case
(Large CFRP)

6 cure sensors (VI trial performed at Acciona Infrastructures in a 3mx2mx2m part)
On-line Tg calculation

cycle time reduction higher than 50%
Besides the sharp exotherms and the noisy environment, Tg real-time final predictions lie within ±5% of DSC values (DSC accuracy margin).
High-Speed RTM

- Press
- Wifi
- In-line sensor
- 2 Monitoring systems
- Injection machine
- Punch
- Die
- In-mould sensor
Installation of in-mould sensor in a RTM Press

No direct contact with the part is necessary
Streamlining the resin flow at the sensor’s area
Temperature effect on injection time

Resistance (=> viscosity) vs. temperature
Mixing ratio effect on demoulding time

Real-time Tg prediction for various mixing ratios (100:14, :15, :17 and :20)
Quality control of CFRP RTM production

@Outlet gate
Carbon-fibre/Epoxy med temp RTM
No direct contact of the sensors with the part

@Inlet gate
Cycle time reduction using process monitoring

Non-isothermal curing: First, just monitoring then, fully optimised cure cycle and then decrease injection temperature.
Light-RTM (non-heated composite tools)

Seat production with process monitoring (UP/Glass, non-heated moulds)
Glass/UP in composite tool without temperature control

- Resin Arrival
- Peak exotherm
- Heating due to exotherm
- Curing (sharp exotherm)
- Demoulding
- Temperature increases during the day

Resistance (Mohm) vs. Time (min)

- 147' 103' 92'

Temperature (°C)

- 10.0 16.0 22.0 28.0 34.0 40.0
Light-RTM (non-heated composite tools)

Sandwich production with process monitoring (UP/Glass, non-heated moulds)
Optimise Demoulding time: not sooner nor later.
Glass/Epoxy in composite tool @ different locations of the part.
(Trials performed@ Fraunhofer/ICT for MAC-RTM project)
@ Acciona Infrastructures (iREMO EC-funded project)
Conclusions

- The Intelligent Process Monitoring and Control Platform is a reliable solution for automating composites manufacturing.
- The platform can provide reliable solutions for online and offline optimization of the process.
- The adaptation and tuning of the platform to the process-specific needs can be done on-site so no costly lab-scale trials are necessary.
- A speed-up of more than 30% with respect to resin manufacturers’ recipes can be achieved.
- Applications in Aerospace, Automotive, Wind Energy, constructions, marine etc. and large potential for customized solutions according to customers’ needs.
**How to Select the Best Sensor Location**

- Sensor’s sensing element should be in direct contact with the resin to be monitored.
- It is better that the sensor:
  - is flush-mounted on the surface of the mould
  - doesn’t directly touch the part
  - doesn’t come in direct contact with carbon fibres
- Take care of:
  - Heating/cooling channels
  - Gates/feeding lines
- Preferably the sensor should be placed at the upper tool.

*Overall the best location to place a cure sensor, is at the flash/trimming area closest to the inlet gate.*
Sensor’s locking plate
(for low injection pressures)

Sensor’s back side
Screw to secure the sensor to the locking plate

Screw to secure the locking plate to the tooling

MOULD

MOULD HOLES FOR SENSOR AND LOCKING PLATE
Tooling/sensor adaptors

- SWADGELOK FITTING FOR HIGH-PRESSURE INJECTIONS (EXAMPLE)
- CUSTOM-MADE ADAPTOR FOR METAL TOOL (EXAMPLE)
- CUSTOM-MADE ADAPTOR FOR COMPOSITE TOOL (EXAMPLE)
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