Intelligent process monitoring and control: Two industrial applications

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INTERNATIONAL CONFERENCE ON MANUFACTURING OF ADVANCED COMPOSITES (ICMAC 2015),  
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ECOMISE Project

Enabling Next Generation CComposite Manufacturing by In-Situ Structural Evaluation and Process Adjustment

Objective
A breakthrough composite manufacturing system is being developed comprising probabilistic process prediction, online process monitoring, in-situ structural evaluation and in-situ process adjustment. By means of industrial applications the focus is laid upon preforming processes such as pick & place and dry fibre placement, as well as subsequent infusion and curing processes such as Resin Transfer Infusion (RTI) and Resin Transfer Moulding (RTM).

Industrial Demonstrators
• Aerospace (Bombardier)
• Automotive (Hutchinson)
• Marine (Airborne)

Partners
Intelligent automation in composites moulding

- Injection machine
- Control Actions
- Temperature controller(s)
- DAQ + Control
- Inline Sensors
- Mould
- Composite part
- In-mould Sensors
- Monitoring Systems
Introduce new flow and cure sensors for minimum flow disturbance

Advance the monitoring systems for improved process monitoring

Advance the intelligence of the DAQ system to provide valuable information e.g. Tg.

Develop a control system that will get the feedback from the sensors and provide real-time or offline optimised control actions

Introduce an outer identification loop in the simulation task to adjust automatically specific process parameters in order to minimise the deviation between simulations and measurements

Apply all the above to three industrial-oriented typical applications

Advance the concept for industrial applications
Process monitoring and simulations

**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

Simulations, Automation, Design and Prototyping solutions
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 (it depends)
• Range of sensors
• Good Repeatability
• Fast Acquisition
• Compact design
• Wireless
• Quality and Process control
**process monitoring sensor** = electrical resistance + RTD sensors

**Durable sensor**
- High Temp RTM
  - Resin arrival
  - Viscosity rise
  - Gelation
  - End-of-cure

**Flexible sensor**
- Vl 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
In-mould
Durable

- flat areas
- possible mark

Gate
sensor

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

Flexible
disposable

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

FloWire
sensors

ICMAC 2015, 24 June 2015, Bristol, UK
OptiView software for both Optimold and OptiFlow systems
New sensors developed and tested

- Carbon fibre sensor (for glassfibre preforms)
  - CF or wire sensors can be used as lineal flow sensors and cure sensors when used with **Optimold** cure monitoring system
- Very thin wires (>0.2 mm) (for carbon fibre preforms)
  - In combination with Optiflow system
- New durable sensor for direct contact with CF
  - Without the need of glass-fibre protection
New Resin Arrival sensors

New disposable and, practically, non-intrusive sensors

- Carbon Fibre Strands + metal tool

Wire tips at different locations

Thin wires (0.2-0.3 mm)
Carbon-fibre-proof
Outside the autoclave

Inside the autoclave

2 Cure sensors

4 Flow sensors

Feed-through
1: Very slow resin arrival;
2: pressure applied;
3: pressure released;
4: pressure re-applied
Cycom 890: Correlation between resistance and Tg real-time prediction
Airborne Test case
Test Mould for thick parts

In-mould sensor with mould adaptor
Cavity dimensions
Length and width at the Bottom mould: 700 x 200 mm
Length and width at the Top mould: 750 x 250 mm (draft angle of 15°)
Thickness: 100 mm
Total internal volume is 16 litres (approx.).
8 Resin Arrival and 2 Cure durable sensors from Synthesites in addition to 1 pressure sensor and 6 thermocouples
6 temperatures and 2 resistance curves (left figure) and Tg evolution as predicted by kinetic model ($T_{gK}$) and measured resistance ($T_{gR}$) (right figure).
6 temperatures and 2 resistance curves (left figure) and 8 resin arrival sensors (right figure).
Tg prediction based on kinetic model and resistivity for cure sensor #1 (left figure) and cure sensor #2 (right figure).
Conclusions

• Real-time process monitoring has become more intelligent and matured towards industrial applications

• Within Ecomise project, considerable advancements have been achieved e.g. to complete the sensor series with flow sensors that can help significantly in the identification of the resin’s flow paths

• Process monitoring can also provide reliable and quantified information about the Tg evolution so demoulding can be optimised

• Furthermore, the reliable and intelligent process monitoring combined with appropriate modelling and simulation tools can provide a unique platform for optimal control of the process ensuring product quality.
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Thank you