Towards the intelligent RTM system

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Background

- Resin Transfer Molding (RTM) is a ‘blind’ and complex process

Furthermore

- Process monitoring in composites production is very ‘primitive’ even in aerospace
  - No real feedback from the cavity until demoulding
  - Only Temperature is being monitored (and in most cases far from the part)

This eliminates the possibility to track and solve problems during production but also the possibility to solve the problems later (since no relevant data exist)
The Resin monitoring system

• 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
ECOMISE Project

Enabling Next Generation COMposite 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)

www.ecomise.eu
Intelligent Closed Moulding

In-mould Sensors

Inline Sensors

Injection machine

Temperature controller(s)

Control Actions

DAQ + Control

Mould

Composite part

Monitoring Systems
Process Monitoring Systems used

**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

**Optimold**
Cure, viscosity, resin quality

- Real-time measuring of
  - Resin’s electrical resistance (from 0.1 MOhm up to 50 TOhm)
  - temperature (pt100 sensor with 0.1°C accuracy)
Intelligent monitoring and control

Measured temperature ($TC_1$, $TC_2$), resistance-based calculated Tg ($TgR_1$, $TgR_2$) and the theoretical Tg ($TgK_1$, $TgK_2$) for the C1 and C2 sensors together with the Tg targets.
Off-line and On-line Optimisation Strategies

**Off-line Optimisation Strategy (Using the 1D-heat transfer model and the robust optimisation tool)**

1. Prescribed filling time
2. Calculate the minimum necessary temperature to achieve the targeted degree of cure from the di Benedetto equation \(a_{max} = f(T_{max}) \rightarrow T_{max} = f^{-1}(a_{max})\)
3. Set heating ramp = max heating rate (in case of high heating rates exotherms might be also considered).
4. Calculate necessary time at \(T_{max}\)

**On-line Optimisation Strategy**

1. Completion of the filling stage based on sensors and start the first heating ramp
2. Completion of the curing stage based on Tg-prediction and start the second heating ramp
3. Completion of the post-curing stage based on Tg-prediction and start cooling or demoulding
RTM mould and process monitoring systems
Cure, Flow and Temperature sensors
Durable and embedded sensors

Durable Sensors
• 2 Cure
• 1 Flow+Temperature

Embedded Sensors
• 8 Arrival
• 8 Temperature
Hutchinson Demo

Suspension blade Glassfibre/epoxy with RTM

8 Embedded sensors (through-thickness)
SET2

Durable Sensors
Flow F1 and cure sensors C1

8 Embedded sensors (through-thickness)
SET1

Durable Cure sensor C2
Cure sensors position

- 2 cure sensors (cure sensor 1 close to injection point)
Flow sensors

- 8 Resin Arrival (Flowire) connected to 2 Optiflow systems

Through-thickness

Resin arrival time stamps

Through-thickness

Injection

SET1
On the surface tool

Flow
Temperature sensors
• 8 embedded temperature sensors connected to 2 Optiflow systems

Through-thickness

Premature exotherm just after injection due to resin reach area
Predicting Tg in real-time

Tg prediction based on resistivity ($T_{gR}^*$) and on kinetic models ($T_{g}^*$) for 4 isothermal cycles at 80°C, 100°C, 120°C and 150°C.
Intelligent monitoring and control

Measured temperature ($TC1$, $TC2$), resistance-based calculated Tg ($TgR1$, $TgR2$) and the theoretical Tg ($TgK1$, $TgK2$) for the C1 and C2 sensors together with the Tg targets.
Intelligent RTM process control

Real-time Tg calculation and demoulding decision based on targeted Tg (target Tg = 130°C)
Optimized cycle

Case 5: Fast Cycle
Case 1: Initial cycle

Temperature and Tg (°C) vs Time (min)

- TgR1-5
- TgR1-1
- T1-5
- T1-1
Conclusions

- The Intelligent Process Monitoring and Control Platform developed in ECOMISE is a reliable solution for automating and optimising 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 conventional processing can be achieved.
- Further benefits from the use of this technology from the development phase.
- Industrial applications in Aerospace, Automotive, Energy and potential for customized solutions according to customers’ needs.
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