Intelligent monitoring of the infusion of large carbon-fibre reinforced structural parts

Dr Nikos Pantelelis, (pantelelis@gmail.com) 
National Technical University of Athens, Greece

Anurag Bansal, Acciona Infrastructures, Spain

Dr Isabel Harismendy, Ricardo Mezzacasa, TECNALIA, Spain

Efthymios Bistekos, Synthesites, Greece

First International Symposium on Automated Composites Manufacturing 
April 11-12, 2013, Concordia University, Montreal, Canada
Process Automation

for RTM, Resin infusion, LRTM, Film infusion, Prepregs (in or out of autoclave)

- 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
The DC-based Process Monitoring System from Synthesites

Real-time measuring of
• Resin’s electrical resistance (from 0.1 MOhm up to 100 TOhm) and
• temperature (0.1°C accuracy)

Characteristics
– Non-intrusive
– Range of sensors
– Good Repeatability
– Fast Acquisition
– Compact design
– Wireless
– Quality and Process control
Optimold can help to

- Detect resin ageing or mixing ratio deviations before injection
- Detect resin arrival
- Detect viscosity changes
- Identify critical processing milestones in the cycle
  - minimum viscosity
  - gelation
  - vitrification
- Identify end of cure
- Monitoring Tg and degree of cure (depending on resin)
- Detect unexpected issues
- Automate production
Cure and Viscosity Sensors

Several models have been developed to fit in the range of composites processing

**process monitoring sensor** = electrical resistance + RTD sensors

<table>
<thead>
<tr>
<th>Durable sensor</th>
<th>Flexible sensor</th>
<th>Inline sensor</th>
<th>Pot sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Durable Sensor Image" /></td>
<td><img src="image2.png" alt="Flexible Sensor Image" /></td>
<td><img src="image3.png" alt="Inline Sensor Image" /></td>
<td><img src="image4.png" alt="Pot Sensor Image" /></td>
</tr>
</tbody>
</table>

**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
OptiFlow: The resin arrival and temperature monitoring system

- 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/ temperature sensors

**In-mould**
- Durable

**Gate sensor**
- flat areas
- possible mark
- ideal for oven/ autoclave vacuum infusion (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

- flexible disposable
Data acquisition software

OptiView software for Optimold and OptiFlow systems
Lab-scale trials (viscosity vs resistance)

Resistance and viscosity monitoring of Bakelite’s neat L20 epoxy resin at various temperatures
Real-time monitoring of resin ageing

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>R (MΩm)</th>
<th>Resistance vs mixing ratio of fresh and aged monocomponent resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>63 hrs @80°C %</th>
<th>fresh %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>75.2</td>
</tr>
<tr>
<td>2</td>
<td>50.5</td>
</tr>
<tr>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Detect resin ageing before injection

Viscosity, Resistance and temperature vs time for 4 resin batches

<table>
<thead>
<tr>
<th>Batch Nr</th>
<th>Batch Description (hrs@80°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>Mix of 51.9% Nr1 and 48.1% Nr3</td>
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Resin ageing effect during cure

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Resistance vs. aging
Tg real-time prediction

Correlation of resistance and Tg (iso-T)
Vacuum Infusion control case (CFRP bridge beam)

6 cure sensors (VI trial performed at Acciona Infrastructures in a 3x2x2 m part)

http://www.youtube.com/watch?v=m7iT_oGjp7I
Vacuum Infusion control case

6 cure sensors (VI trial performed at Acciona Infrastructures in a 3x2x2 m part)
Vacuum Infusion case
Control of the exotherm reaction and demoulding

cycle time reduction more than 50%
Tg-predictions validation

Results from two VI trials

Besides the sharp exotherms and the noisy environment, Tg real-time final predictions lie within ±5% of DSC values (DSC accuracy margin)
Industrial high-speed RTM
(CFRP automotive part @ Cemcat, France)
Tg-based press control

Real-time Tg prediction as calculated by the Tg-prediction algorithm for various mixing ratios (100:14, 100:15, 100:17 and 100:20)
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
Acknowledgments

Part of the presented results, were obtained during the iREMO project which was partially funded by the European Commission under contract NMP2-SL-2009-228662.

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