Processing of Thermoset Composites

Joanna Wong
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Last week…

- Introduction to Thermoset Composites Processing
  - Pressure driven flow
  - Capillary driven flow
Also last week...

Fluid In → Porous Medium → Fluid Out

Darcy’s law: \[ Q = - \frac{AK}{\mu} \nabla P \]
Inside a composite: Computer Tomograph pictures highlighting the dual-scale nature of the porous media


ETH Zurich, Laboratory of Composite Materials and Adaptive Structures
Dual-scale structure is influencing the impregnation process

Mode 1 of the impregnation model of woven fabrics

Mode 2 of the impregnation model of woven fabrics

Mode 3 of the impregnation model of woven fabrics

The Straw Experiment

Which straw will have a higher column of water?
Fiber/Matrix interface development

- Fibre-wetting is a pre-condition for developing a 'good' interface!

![Diagram](image)

M. Connor, Consolidation Mechanisms and Interfacial Phenomena in Thermoplastic Powder Impregnated Composites, PhD-Thesis No. 1413, EPF Lausanne, 1995

ETH Zurich, Laboratory of Composite Materials and Adaptive Structures
Capillary pressure

<table>
<thead>
<tr>
<th>Wetting</th>
<th>No wetting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas phase (1)</td>
<td>Gas phase (1)</td>
</tr>
<tr>
<td>Liquid phase (2)</td>
<td>Liquid phase (2)</td>
</tr>
<tr>
<td>Solid phase (3)</td>
<td>Solid phase (3)</td>
</tr>
</tbody>
</table>

\[ 0 \leq \alpha \leq \frac{\pi}{2} \]

Capillary ascension

\[ \frac{\pi}{2} \leq \alpha \leq \pi \]

Capillary depression
Wetting of Fibres

“Surface tension”:

\[
\sigma = \frac{dW}{dA} \quad \left[ \frac{J}{m^2} = \frac{kg}{s^2} = \frac{N}{m} \right]
\]

Equilibrium condition:

\[
\sigma_{12} \cos \alpha = \sigma_{13} - \sigma_{23}
\]

Capillary height:

\[
h = \frac{2\sigma_{12} \cos \alpha \rho g r}{\rho g r}
\]

Capillary pressure:

\[
\Delta P_\sigma = -\frac{F_\sigma}{A} = -\frac{\sigma_{12} \frac{2\pi r \cos \alpha}{\pi r^2}}{r} = -\frac{\sigma_{12} \frac{2 \cos \alpha}{r}}{r}
\]
Straw Experiment
Contents

- Introduction
- Wet-Lamination Process
- Flow in porous media
- Resin curing kinetics
- Resin viscosity
The processing time is depending on the rheology properties of the matrix
Curing kinetics

- Addition polymerisation of epoxy systems is an exothermal reaction

  \[ \alpha = \frac{\int \dot{Q} \cdot dt}{H_{ges}} \]

- Kamal-Sourour model:

  \[ \frac{d\alpha}{dt} = \left( k_1 + k_2 \cdot \alpha^m \right) \cdot \left( 1 - \alpha^n \right) \]

  \[ k_i(T) = A_i e^{\left( \frac{E_i}{RT} \right)} \]

- Coefficients can be extracted from DSC-curves!
METHOD OF CALCULATING PARAMETERS FOR KINETICS MODEL

\[
\alpha = \frac{\Delta H_p}{\Delta H_T}
\]

\[
\frac{G_0}{G_W} = \frac{G + / G\alpha}{\Delta T}
\]
Method of calculating parameters for kinetics models

Epoxy-Amine Cure
DGEBA-PACM-20 (1:1)

Conversion ($\alpha$)

Time (minutes)

Wisniewski and Gillham,
Contents

- Introduction
- Wet-Lamination Process
- Flow in porous media
- Resin curing kinetics
- Resin viscosity
A simple viscosity model

- Viscosity model:

\[
\eta(\alpha, T) = Ae^{\left( \frac{B}{T} + C\alpha \right)}
\]

- Castro und Macosko:

\[
\eta(\alpha, T) = Ae^{\left( \frac{B}{T} \right) \left( \frac{\alpha_g}{\alpha_g - \alpha} \right)^{C+D\alpha}}
\]

With:
A, B, C, D: Constants
\(\alpha_g\): Curing degree of the resin at gelpoint
The complex viscosity as a function of time for isothermal cure at (○) 110, (□) 120, (●) 130, and (▲) 140°C. (—) The chemorheological model data.