Closed Mould Systems

- Why closed mould systems?
- Types of closed mould systems
- Theory
- Materials
- How to change from open to closed moulds
Why Closed Mould Systems

- Limits in MAC values in the workshop
- Less styrene exposure to labourers
- Less pollution of the atmosphere
- Better quality and piece to piece reproducibility
- More cost effective in bigger series
Why Closed Mould Systems

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European MAC values of styrene monomer are more stringent.

Will be followed by other countries
Why Closed Mould Systems

- Limits in MAC values in the workshop
- Less styrene exposure to labourers
- Less pollution of the atmosphere
- Better piece to piece reproducibility
- More cost effective in bigger series versus HLU and SU

- Exposure to styrene can affect health
- Improved cleanliness
- No unpleasant odors
The committee for risk assessment (RAC) agreed to classify styrene as causing damage to the hearing organs through prolonged or repeated exposure via inhalation and as a substance suspected of damaging the unborn child (Repr. 2).

For both effects the RAC opinion deviated from the proposal from Denmark who had orginally proposed to classify styrene as causing damage to the nervous system through prolonged or repeated exposure via inhalation and as a substance which may damage the unborn child.
Why Closed Mould Systems

- Limits in MAC values in the workshop
- Less styrene exposure to labourers
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- Better quality and piece to piece reproducibility
- More cost effective in bigger series versus HLU and SU

- Better for environment
- Reduces or prevents complaints of neighbours
- Prevents measures imposed by the government
Why Closed Mould Systems

- Limits in MAC values in the workshop
- Less styrene exposure towards labourers
- Less pollution of the atmosphere
- Better quality and piece to piece reproducibility
- More cost effective in bigger series versus HLU and SU

- Better control of reinforcement distribution
- Controlled wet-out of the reinforcement
- Potential for higher percentage reinforcement
  - Reduced product weight by same strength
  - Stronger product by same weight
Better wet-out
Why Closed Mould Systems

- More cost effective in bigger series (compared with HLU and SU)

Source: Rovicore
Closed Mould Systems

- Compression Moulding
- Wet press moulding
- SMC and DMC

- RTM

- VARTM
- Light RTM
- Resin Infusion
<table>
<thead>
<tr>
<th>ACRONYM</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIRTM</td>
<td>co-injection RTM</td>
</tr>
<tr>
<td>CRYSTIC VI</td>
<td>vacuum infusion (Scott Bader)</td>
</tr>
<tr>
<td>DRDF</td>
<td>double RIFT diaphragm forming</td>
</tr>
<tr>
<td>LRI</td>
<td>liquid resin infusion</td>
</tr>
<tr>
<td>MVI</td>
<td>modified vacuum infusion (Airbus)</td>
</tr>
<tr>
<td>RFI</td>
<td>resin film infusion</td>
</tr>
<tr>
<td>RFIT</td>
<td>resin infusion under flex. Tooling</td>
</tr>
<tr>
<td>RIRM</td>
<td>resin injection recirculation moulding</td>
</tr>
<tr>
<td>SCRIMP</td>
<td>Seeman composite resin inf. moulding</td>
</tr>
<tr>
<td>VAIM</td>
<td>vacuum assisted injection moulding</td>
</tr>
<tr>
<td>VAP</td>
<td>vacuum assisted processing</td>
</tr>
<tr>
<td>VARIM</td>
<td>vacuum assisted resin injection moulding</td>
</tr>
<tr>
<td>VARTM</td>
<td>vacuum assisted resin transfer moulding</td>
</tr>
<tr>
<td>VRTM</td>
<td>vacuum resin transfer moulding</td>
</tr>
<tr>
<td>VIMP</td>
<td>vacuum injection moulding process</td>
</tr>
<tr>
<td>VIP</td>
<td>vacuum infusion process.</td>
</tr>
</tbody>
</table>

Source: John Summerscales
Requirements for closed mould systems

- More accurate handling
- Better skilled operators
- Adapted reinforcement material needed
- Critical mould design
What is Infusion

- Resin injection with standard bottom mould + extra flange for hermetic closure by a foil
- Top mould is a flexible foil
- Top and bottom mould are sealed together by a gum tape. (tacky tape)
- Resin injection by 50 – 90% vacuum
What is Light RTM?

- Resin injection with standard bottom mould + extra flange for vacuum closing border
- Top transparent mould (semi rigid) ca 4 mm thick UP/glass laminate with flange provided with seals for vacuum
- Resin injection by vacuum supported by pressure on the resin inlet (0.3 – 1.5 bar)
Pressure and injection technology

<table>
<thead>
<tr>
<th>Pressure inlet</th>
<th>Pressure outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTM</strong></td>
<td>Overpressure</td>
</tr>
<tr>
<td></td>
<td>(Max 8 bar)</td>
</tr>
<tr>
<td><strong>Light RTM</strong></td>
<td>Overpressure</td>
</tr>
<tr>
<td></td>
<td>(1,2 bar)</td>
</tr>
<tr>
<td><strong>Infusion</strong></td>
<td>Atmospheric</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Darcy's Law

\[ t = \frac{l^2 \cdot \eta}{2 \cdot k \cdot \Delta P} \]

- \( t \) = injection time
- \( l \) = injection length
- \( \eta \) = viscosity resin
- \( k \) = permeability
- \( \Delta P \) = pressure difference
Injection length \( \ell \)

Length of resin transport through the reinforcement

\[
t = \frac{\ell^2 \cdot \eta}{2 \cdot k \cdot \Delta P}
\]
- Resin viscosity $\eta$

Low viscosity decreases injection time

Take care: increased amount of styrene reduces the mechanical properties and increases shrinkage

Solid content below 50% must be avoided.
• Permeability $k$

Higher permeability decreases injection time

• Resin inlet hoses
• Reinforcement material
• Core material for sandwich constructions
• Permeability $k$

(Comparative values)

**Inlet hoses**
- 5 mm diameter 300
- 15 mm diameter 3000

**Reinforcement**
- Fabric < 1
- Chopped strand mat 5
- Rovicore 50

**Core material**
- Balsa wood 30
Pressure difference $\Delta P$

Bigger difference decreases injection time

- Take care: too high vacuum:
- can reduce the permeability of the reinforcement material
- can cause collapsing the vacuum hoses
Factors influencing injection speed

- Resin Viscosity
- Permeability reinforcement
- Permeability hoses
- Gravity
- Pressure
- Injection strategy

(Show Movies)
Injection strategy & combination of materials

Sandwich laminate
- Woven roving
- Balsa wood with flow channels
- Woven roving

Laminate with flow aid
- Flow aid
- Woven Roving
Analytical Solutions

- Filling time:
  \[ t_{\text{fill}} = C \frac{\eta L^2 \phi}{\Delta p \cdot K} \]
  with \( C \) the 'strategy' factor

- Basic methods
  
  \[ C = \frac{1}{2} \]
  
  - Edge injection:
  
  \[ C = \frac{1}{16} \] (0.0625)
  
  - Peripheral injection:
  
  \[ C = \frac{1}{16} \left( \epsilon^2 + 2 \ln \left( \frac{1}{\epsilon} \right) - 1 \right) \]

<table>
<thead>
<tr>
<th>( \epsilon (d/L) )</th>
<th>( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100</td>
<td>0.23</td>
</tr>
<tr>
<td>0.010</td>
<td>0.51</td>
</tr>
<tr>
<td>0.005</td>
<td>0.60</td>
</tr>
<tr>
<td>0.001</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Source: Polyworks
Important properties of reinforcement materials

- Good conformability
- High permeability
- No loose fibers

- CSM not really suitable: low permeability, loose fibres
- Woven roving often combined with flow aids
- Often used mats: Rovicor, Multimat
  - Continuous fiber mat
  - Combinats WR + stitched CSM
Flow simulation for defining injection strategy

Source: Polyworks
Cost comparison production techniques

Processes: HLU – SU- Light RTM

- Raw materials amount
- Raw material costs
- Labour costs
- Final product price
# Materials

<table>
<thead>
<tr>
<th>RAW MATERIAL</th>
<th>LIGHT RTM</th>
<th>SPRAY UP</th>
<th>HAND LAY UP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gel coat</td>
<td>1,1 kg</td>
<td>1,1 kg</td>
<td>1,1 kg</td>
</tr>
<tr>
<td>Resin</td>
<td>6 kg</td>
<td>6 kg</td>
<td>6,1 kg</td>
</tr>
<tr>
<td>Rovicore</td>
<td>1,9 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSM</td>
<td></td>
<td></td>
<td>2,5 kg</td>
</tr>
<tr>
<td>Spray roving</td>
<td></td>
<td></td>
<td>2,3 kg</td>
</tr>
<tr>
<td>Filler</td>
<td>2 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initiator</td>
<td>0,2 kg</td>
<td>0,2 kg</td>
<td>0,2 kg</td>
</tr>
<tr>
<td>Glass veil</td>
<td>1,5 sqm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top coat</td>
<td></td>
<td>1,3 kg</td>
<td>1,3 kg</td>
</tr>
<tr>
<td>Others</td>
<td>1 kg</td>
<td>1 kg</td>
<td>1 kg</td>
</tr>
</tbody>
</table>
Raw material costs
Price comparison finished product
Important points (1)

- No vacuum leakage
- Equal diameters inlet hoses
- Do not change vacuum level too much
- Injection vacuum often between 0.5 and 0.8 bar
- Mould closing vacuum => maximum
- Polished top mould makes release easy.
- Peak exotherm in top mould max. 65°C
- When filler is used, avoid lumps
Important points (2)

- Temperature resin, mould and reinforcement
- Adapt curing speed on workshop temperature
- Gel time approx 10 minutes longer than injection time
- Wait a few minutes after mixing resin and catalyst for de-airation
- Use stiff hoses to prevent collapsing by vacuum
- Closing resin inlet only allowed when the system is 100% tight
Runners in the laminate give marks in the final product
Stitch mats give better surface than woven roving
Wait with vacuum till the resin channel is filled (LRTM)
Core materials

Resin channels

Avoid sharp angles
Surface quality

- Correct degree of cure of gelcoat before start positioning reinforcement and injection.
- High degree of cure of laminate before release
- Use barrier coat and/or tie coat
- Use veils
- Use low tex CSM for first two layers
- Avoid double overlapping
- Use stitched mats in stead of woven roving
- Use polished and low waviness moulds
Remarks

- Constant temperature in workshop is required
- Relatively low investment, but much more attention and dexterity
- Make notes of every handling, in order to write or update a standard operation procedure
Important facts that must be monitored

Climate in the work place

- 1 degree celcius colder (warmer) will reduce (increase) the gel time by 10%
- 1 degree celcius colder (warmer) will increase (reduce) the viscosity of the resin by 5 – 10 %

Temperature of the mould

- Equal to the work place temperature to avoid condens (to cold surface) or pre-gel of the gelcoat.

Right curing time of the gelcoat

- Too fast curing results in high peakexotherm which may cause melting and dissolving the applied wax, resulting in bad release
- Too slow curing may cause dissolving of the applied wax in the styrene monomer coming out of the gelcoat, that also results in bad release.
Resin Viscosity

Resin viscosity in function of the temperature

Viscosity mPas

Degree C
Future of closed mould techniques

- Stronger environmental requirements
- Development of better techniques
- Increasing number of users generates more invents
- Better support by material suppliers