COST EFFECTIVE BONNET MANUFACTURING BY COMPRESSION RESIN TRANSFER MOLDING
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Overview of FAGOR ARRASATE
FAGOR ARRASATE

Overview of Fagor Arrasate

- Cooperative founded in 1957
- Member of Mondragon Corporation
- Headquarters: Arrasate (Basque Country)
- Three divisions:
  - Steel division
  - Home appliances division
  - Automotive division

- Staff: 850 people
- Turnover: 290M€
Overview of Fagor Arrasate

Production lines for lightweight design:

- AHSS & UHSS material stamping
- Steel & Aluminum hot stamping lines
- Composites forming lines
Production lines for lightweight design:

AHSS & UHSS material stamping
Overview of Fagor Arrasate

Production lines for lightweight design:

Steel & aluminum HF installation with Mechanical ServoPress **

Steel and aluminum hot stamping lines

** Patented solution
Production lines for lightweight design:

- SMC
- GMT-LWRT
- D-LFT
- X-RTM
- ...
RTM Variants Cost Analysis comparison
**PROJECT DRIVERS**

* CO$_2$ emission restrictions. The weight of vehicles affects directly in CO$_2$ emissions.

* The use of composites (CFRP) has the highest potential in.

  ✓ High weight reduction.
  ✓ High impact energy dissipation.
  ✓ High Specific stiffness and Strength.
  ✓ Excellent fatigue resistance.
PROJECT CHALLENGES

* Fast and robust manufacturing process.

✓ Short cycle time.
✓ Good quality.
✓ Repeatability.
✓ High automation level.

Cost structure of CFRP parts. SGL.
RTM Variants
Cost Analysis comparison

<table>
<thead>
<tr>
<th></th>
<th>RTM</th>
<th>HP-RTM</th>
<th>CRTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregnation Through</td>
<td>Plain</td>
<td>Plain</td>
<td>Thickness</td>
</tr>
<tr>
<td>Mixing Pressure</td>
<td>Low</td>
<td>Hi</td>
<td>Low</td>
</tr>
<tr>
<td>Impregnation Pressure</td>
<td>Low</td>
<td>Hi</td>
<td>Medium</td>
</tr>
<tr>
<td>Filling + Impregnation Time</td>
<td>Long</td>
<td>Short</td>
<td>Short</td>
</tr>
<tr>
<td>Curing Time</td>
<td>Long</td>
<td>Short</td>
<td>Short</td>
</tr>
</tbody>
</table>
Automotive Roof

- Part: Urban Electric car roof (1500 x 2000)
- Projected Area: 1,72m²
- Thickness in Steel: 0,7 mm
- CFRP Thickness: 2 mm
- Vf = %60
- Production Volume: 90,000 parts/year (7 years / 3 Shifts)
- Same Preform
- Material Cost not considered
**Resin and inlets.**

**Filling and impregnation time.**

**Clamping force.**

**Pressure distribution.**
**Cost Calculation steps**

- **Case Study**
  - Type of Part
  - N° of parts/year
  - Analyze part characteristics.

- **Process Simulation**
  - Timing
  - Resin
  - Inlets
  - Pressure

- **Cost Calculation**
  - Tooling + Equipment
  - Energy
  - Plant Cost

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**RTM Variants**

**Cost Analysis comparison**

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*Cell cost in each scenario considering:*

*Number of cells needed (Press, injection system, mold and robots).*

*Energy cost.*

<table>
<thead>
<tr>
<th>Process</th>
<th>RELATIVE TOTAL COST (per part)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTM</td>
<td>4,7</td>
</tr>
<tr>
<td>HP-RTM</td>
<td>2,2</td>
</tr>
<tr>
<td>CRTM</td>
<td>1,0</td>
</tr>
</tbody>
</table>

*Relative numbers.*
RTM Variants
Cost Analysis comparison

1. CRTM is the fastest process.
2. Investment level is the lowest.
3. Bigger Plant area for RTM and HP-RTM than for CRTM.
4. Part cost considering investment payback and energy consumption in CRTM is much lower.

1. CRTM has limitations for complex geometrical parts
CRTM process characterization
CRTM process characterization

**Raw materials**

- Epoxy (XB 3585 / Aradur 3475, HUNSTMAN)
- Biaxial fabric (HPT 610 C090, 50k, SGL)
- Binder (Araldite LT 3366 BD)

**Characterization**

- Curing kinetics
- Rheology
- Permeability
- Compressibility

\[ \nu = -\frac{1}{\mu} K \cdot \nabla P \]
CRTM process characterization

**Injection stage**

- Studied parameters:
  - Resin viscosity
  - Preform permeability
  - Gap thickness
  - Injection pressure
  - Injection flow-rate
  - Injected resin volume

**Simulation** + **Experimental analysis**

**Compression stage**

- Studied parameters:
  - Initial resin distribution
  - Compression speed
  - Compression pressure
Resin distribution depends mainly on:

- Gap thickness.
- Permeability of the preform through thickness.
Compression stage

Compression time and loads depend mainly on:

- Resin volume.
- Speed control of the compression phase.

Speed control:

* Gap stroke with fast speed.
* Preform stroke with slow speed.
Bonnet manufacturing
Bonnet manufacturing

Part Design

Upper Part: Lamination

<table>
<thead>
<tr>
<th>PLY ID</th>
<th>GSM</th>
<th>FABRIC TYPE</th>
<th>ANGLE (°)</th>
<th>note</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>Twill Weave</td>
<td>0/90</td>
<td>General Ply: Aesthetic Requirements</td>
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<tr>
<td>2</td>
<td>200</td>
<td>Twill Weave</td>
<td>0/90</td>
<td>General Ply</td>
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<td>3</td>
<td>200</td>
<td>Twill Weave</td>
<td>±45</td>
<td>Boundary Reinforcement – 60 mm</td>
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<tr>
<td>4</td>
<td>200</td>
<td>Twill Weave</td>
<td>0/90</td>
<td>General Ply</td>
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<tr>
<td>5</td>
<td>200</td>
<td>Twill Weave</td>
<td>±45</td>
<td>Boundary Reinforcement – 60 mm</td>
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<tr>
<td>6</td>
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<td>7</td>
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<td>Twill Weave</td>
<td>±45</td>
<td>Rib Reinforcement – 80 mm</td>
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Playbook definition
## Resin and hardener selection

*Tg superior to 120°C to assure part stability.
*Good resin transparency.

<table>
<thead>
<tr>
<th>Material</th>
<th>Aralith LY3585/3458</th>
<th>Aralith LY3585/3475</th>
<th>TRAC 06150</th>
<th>TRAC 06300</th>
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<tbody>
<tr>
<td>producer</td>
<td>Huntsman</td>
<td>Huntsman</td>
<td>Hexion</td>
<td>Hexion</td>
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<tr>
<td>T&lt;sub&gt;r&lt;/sub&gt; before aging</td>
<td>~120 °C</td>
<td>Up to 140 °C</td>
<td>Up to 130 °C</td>
<td>Up to 130 °C</td>
</tr>
<tr>
<td>T&lt;sub&gt;r&lt;/sub&gt; after aging</td>
<td>~113 °C</td>
<td>&gt;135 °C</td>
<td>To be tested</td>
<td>To be tested</td>
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<tr>
<td>Yellowing</td>
<td>Reference</td>
<td>Better than</td>
<td>Worse than</td>
<td>Better than</td>
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<tr>
<td></td>
<td>LY3585/3458</td>
<td>LY3585/3458</td>
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<tr>
<td>Processing</td>
<td>Reference</td>
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<tr>
<td>Compatibility with XB3566 binder</td>
<td>YES</td>
<td>YES</td>
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<td>To be checked</td>
</tr>
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</table>

**Tests for getting Tg**

**Selected resin and hardener:** XB3585- Aradur 3475
Bonnet manufacturing

Process window

Gel Point

Curing Degree

Process simulation

Gap Injection time [s] | 27
Mould closing time [s] | 5
Curing time [s] | 238
CRTM circle time[s] | 270 4,5min
Mold temp [°C] | 116,5
Injected resin and hardener[l] | 1,9
**Mold design**

Resin/Vacuum:

- **Absaugung**
- **Anguss**

Bonnet manufacturing
Bonnet manufacturing

Results

<table>
<thead>
<tr>
<th>Test number</th>
<th>Gap (mm)</th>
<th>Model temperature (°C)</th>
<th>Resin temperature (°C)</th>
<th>Injection strategy</th>
<th>Resin volume (l)</th>
<th>Injection pressure (bar)</th>
<th>Clamping velocity (mm/s)</th>
<th>Vacuum (psi)</th>
<th>Injection (s)</th>
<th>Compression (%)</th>
<th>Curing (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.3</td>
<td>82</td>
<td>60</td>
<td>Centre</td>
<td>1.8/1.8</td>
<td>5</td>
<td>1</td>
<td>-</td>
<td>20</td>
<td>5</td>
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<tr>
<td>2</td>
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<td>180</td>
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<td>30</td>
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<td>82</td>
<td>60</td>
<td>Centre</td>
<td>0.5/2.2</td>
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<td>1</td>
<td>-</td>
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<tr>
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<td>83</td>
<td>60</td>
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<td>5</td>
<td>1</td>
<td>Yes</td>
<td>30</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
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<td>3.3</td>
<td>80</td>
<td>60</td>
<td>Front</td>
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<td>75</td>
<td>60</td>
<td>Front</td>
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<td>20</td>
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<tr>
<td>7</td>
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<td>Centre</td>
<td>2.2/2.2</td>
<td>5</td>
<td>1</td>
<td>Yes</td>
<td>60</td>
<td>5</td>
<td>30</td>
</tr>
</tbody>
</table>

Adjusting of the process

PART MANUFACTURING VIDEO
New press architecture
New press architecture

- Reduced Height
- Integrated Parallelism Control
- Bolster Deformation Control
- Rapid Closing Speed of the Slide
- Short Pressure Build Up Time
- Reduced Energy Consumption
- Customized Control System for CRTM
New press architecture
Advanced Compression Resin Transfer Molding Line
Advanced Compression Resin Transfer Molding Line.

Adjusted to the real necessities of the CRTM process.

Included a specific control configuration for CRTM.

Flexible and ready for using for other processes.
Summary
✓ CRTM is the most suitable manufacturing process from cost, energy consumption and cycle time point of view.

✓ Specific CRTM process knowledge has been developed and has been implemented in our press and cell control.

✓ A tight cell solution has been defined for CRTM.
SHARING YOUR CHALLENGES

Thank you!

Project supported by: