AUTOMOTIVE COMPOSITES CONFERENCE & EXHIBITION.

MASS PRODUCTION OF CFRP IN AUTOMOTIVE APPLICATIONS – POTENTIALS AND CHALLENGES IN IMPLEMENTING LOCAL REINFORCEMENTS.

Stanglmaier Stefan
Detroit, September 10th 2015
AGENDA.

1. Structural Carbon Fibre Reinforced Polymers at the BMW Group.
   - The roadmap of CFRP at the BMW Group and the idea of BMW i.
   - BMW Group – high pressure RTM process chain.
   - Aspects to optimize in large scale CRFP production.

2. Local Reinforcements within Structural Shells.
   - Motivation for and potentials of local reinforcements.
   - Methodology and parameters of testing procedure.
   - Example results from the project local reinforcements.
STRUCTURAL CFRP AT THE BMW GROUP. ROADMAP.

Unites per life cycle

Mass-production

Industrialisation

Transient

Application

Concept State

Timeline

Surface-Applications

Structural-Applications

1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 ...

BMW Z8 BMW X5 BMW Series 6 (ragtop) BMW Z8 BMW X5 BMW Series 6 (ragtop) BMW M3 BMW M6 BMW M5 BMW M3 GTS BMW M6 (Gran) Coupe BMW i3 BMW i8 BMW M3 / M4 Coupe BMW P-Typ Z22 BMW P-Typ Z29 BMW M3 CSL BMW M3 BMW M5 BMW Hydrogen 7 BMW M3 GTS

ACCE 2015, Stefan Stanglmaier, CFRP Mass Production at BMW – Today and Tomorrow, 9/10/2015
The holistic approach of the BMW Group is unique.

**Motivation**
- Environment
- Politics
- Urbanisation
- Customers

**BMW i**
- Innovative technologies
- Future portfolio
- Differentiation from the market
- New customer groups
- Sustainable approach
STRUCTURAL CFRP AT THE BMW GROUP.
THE IDEA OF BMW i - LIFE AND DRIVE MODULE CONCEPTS.

BMW i3 - Electrical driven

BMW i8 - Hybrid driven

[URL 15a]
STRUCTURAL CFRP AT THE BMW GROUP.
THE IDEA OF BMW i - RTM AND WET PRESSING PARTS OF THE i8.

Wet Pressing - 34 parts
RTM - 21 parts
## STRUCTURAL CFRP AT THE BMW GROUP.
### WET PRESSING AND HIGH PRESSURE RTM PROCESSES.

<table>
<thead>
<tr>
<th>Process</th>
<th>Resin Transfer Moulding</th>
<th>Wet Pressing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preforming</td>
<td><img src="#" alt="Preforming Diagram" /></td>
<td><img src="#" alt="X Mark" /></td>
</tr>
<tr>
<td>External Resin Application</td>
<td><img src="#" alt="Mark" /></td>
<td><img src="#" alt="Preforming Diagram" /></td>
</tr>
<tr>
<td>Impregnation and Curing Process</td>
<td><img src="#" alt="Impregnation Diagram" /></td>
<td><img src="#" alt="Curing Diagram" /></td>
</tr>
</tbody>
</table>

*Image descriptions omitted due to text formatting constraints.*
STRUCTURAL CFRP AT THE BMW GROUP.
HP RTM PROCESS CHAIN - STACKING PROCESS.

**System description:**
- Modular design
- Automated stacking
- Optimised nesting
- Automated cutting
- Automated labeling
- Automated US-joining

**Stacking Catalogue**

<table>
<thead>
<tr>
<th>Stack Li-C-Saele below outside</th>
<th>Code 11 Tool-Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack designation</td>
<td>i8 Project</td>
</tr>
<tr>
<td>Doc.-Nr. SCK00011 F01</td>
<td>Index: 02</td>
</tr>
<tr>
<td></td>
<td>Page 2 of 3</td>
</tr>
</tbody>
</table>

**Layup - Stacking**

<table>
<thead>
<tr>
<th>Mat 4</th>
<th>Binder below</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat 3</td>
<td>Binder below</td>
</tr>
<tr>
<td>Mat 2</td>
<td>Binder below</td>
</tr>
<tr>
<td>Mat 9</td>
<td>Binder below</td>
</tr>
<tr>
<td>Mat 8</td>
<td>Binder below</td>
</tr>
<tr>
<td>Mat 2</td>
<td>Binder below</td>
</tr>
<tr>
<td>Mat 4</td>
<td>Binder below</td>
</tr>
<tr>
<td>Mat 3</td>
<td>Binder above</td>
</tr>
</tbody>
</table>

**Stacking floor**

[URL 15b]

[Pas 14]
STRUCTURAL CFRP AT THE BMW GROUP.
HP RTM PROCESS CHAIN - PREFORMING PROCESS.

**Preforming:**
- 100% automation.
- Isothermal heating field.
- Isothermal draping tools.
- One step draping.
- Cycle time <1 minute.
- Fast tool changing.

NCF-Stack → Melting binder → Draping → Trimming

[Pas 14]
STRUCTURAL CFRP AT THE BMW GROUP.
HP RTM PROCESS CHAIN – IMPREGNATION PROCESS.

**Machine specification**

Hydraulic sliding table presses
- Closing force: 3600 t (3 cylinder)
- Cylinder pressure: 250 bar
- Engine power: 200 kW
- Mounting plate: 3600 x 2400 mm
- Pusher swing: 1600 mm
- Machine weight: 320 t
- Tool weight: 85 t

**Technical Challenge:**
- RTM process with two lower tools
- Cycle time << 10 min
- Tailored Parts

[Pas 14]
€/Part = Material Efficiency [%] · Material Costs [€/kg] · Part Weight [kg/part]

Costs per CFRP Part [%]

- Textile Structure: 44%
- Injection: 10%
- Curing: 36%
- Add-On: 10%

Construction/Process Chain

Purchasing

Process Chain
LOCALLY REINFORCED COMPOSITES. MOTIVATION AND APPROACH.

Stacking Sequence

Base Laminate + Local Reinforcement = Tailored Layup

Potential of Local Reinforcement

State of the Art → Potential → Target Geometry

Potential of weight reduction compared to aluminium: 52 %
Potential of cost reduction compared to the State of the art: 22 %
# LOCAL REINFORCEMENTS.
## TEST PARAMETERS FOR INJECTION STUDIES.

### Glass Plate-, RTM-, Wet Pressing- Tool

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic geometry</td>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td>Patch position</td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Patch transient region</td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td>Patch fibre orientation</td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>Position of inlet channel</td>
<td><img src="image5" alt="Diagram" /></td>
</tr>
</tbody>
</table>
**LOCAL REINFORCMENTS. TEST PARAMETERS FOR INJECTION STUDIES.**

**Glass Plate-, RTM-, Wet Pressing- Tool**

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<tr>
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</tr>
<tr>
<td>Patch transient region</td>
<td><img src="image5" alt="Variation" /> <img src="image6" alt="Variation" /></td>
</tr>
<tr>
<td>Patch fibre orientation</td>
<td><img src="image7" alt="Variation" /> <img src="image8" alt="Variation" /></td>
</tr>
<tr>
<td>Position of inlet channel</td>
<td><img src="image9" alt="Variation" /> <img src="image10" alt="Variation" /></td>
</tr>
</tbody>
</table>
# LOCAL REINFORCEMENTS.
# IMPREGNATION PROCESS.

<table>
<thead>
<tr>
<th>Time intensity</th>
<th>Method</th>
<th>Indicator</th>
<th>Pictogram</th>
</tr>
</thead>
</table>
| **Textile**    | Compaction measurement | - Maximum force at defined fibre volume fraction (FVF)  
- Relaxation at defined FVF | |
| **Textile**    | Permeability measurement | - Average permeability in plain direction $\sqrt{K_1K_2}$  
- Permeability in thickness direction $K_3$ | | ![Pictogram](image1.png) |
| **Process**    | Flow front visualisation | - Flow front progression (qualitatively)  
- Flow front quotient (quantitatively)  
- Injection data of filling | | ![Pictogram](image2.png) |
| **Simulation** | | - Filling simulation HP-RTM | | ![Pictogram](image3.png) |
| **Laminate/ Part** | HP-RTM | - Prozess data  
- Ultra sonic  
- Sections and micro sections  
- Mechanical properties | | ![Pictogram](image4.png) |
| **Product relevance** | Computer-tomography | - Laminate quality  
- Ondulations  
- Fibre orientations  
- Entrapped air | | ![Pictogram](image5.png) |
<table>
<thead>
<tr>
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<th>Indicator</th>
<th>Pictogram</th>
</tr>
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|                | Permeability measurement | ▪ Average permeability in plain direction $\sqrt{K_1 K_2}$  
▪ Permeability in thickness direction $K_3$ | K12, K3 |
| **Process**    | Flow front visualisation | ▪ Flow front progression (qualitatively)  
▪ Flow front quotient (quantitatively)  
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▪ Ondulations  
▪ Fibre orientations  
▪ Entrapped air | |
LOCAL REINFORCEMENTS.
FLOW FRONT PROGRESSION – VISUALISATION TOOL DESIGN.

Camera

Inlet

Tailored Blank

Pocket for local reinf.

Acrylic insert

Laminated glass

100 mm
LOCAL REINFORCEMENTS. FLOW FRONT PROGRESSION - INSERT DESIGNS.

Untapered case

Cavity Loc reinf. Base laminate

Tapered case

Untapered transient region

Tapered transient region
LOCAL REINFORCEMENTS.
FLOW FRONT PROGRESSION – RESULTS.

Local reinforcement outside 90°, untapered

Upper side

Lower side

100 mm

Inlet channel
Transient region

ACCE 2015, Stefan Stanglmaier, CFRP Mass Production at BMW – Today and Tomorrow, 9/10/2015
LOCAL REINFORCEMENTS.
FLOW FRONT PROGRESSION – RESULTS.

Local reinforcement outside 0°, untapered

Upper side

Lower side

100 mm

Dry spots

Inlet channel

Transient region
LOCAL REINFORCEMENTS. FLOW FRONT PROGRESSION – RESULTS.

Local reinforcement outside 0°, tapered

Upper side

Lower side

Inlet channel

Transient region
LOCAL REINFORCEMENTS.
FLOW FRONT PROGRESSION – RESULTS.

Local reinforcement outside 90°, untapered

Upper side

Lower side

Dry spots

100 mm

Inlet channel

Transient region

Dry spots

100 mm
LOCAL REINFORCEMENTS.
FLOW FRONT PROGRESSION – RESULTS.

Local reinforcement outside 90°, tapered

Upper side

Lower side

Inlet channel
Transient region

100 mm
LOCAL REINFORCEMENTS. MECHANICAL PROPERTIES – 4-POINT BENDING TEST.

**Frame conditions:**
- Measurement of the relevant transient region.
- Measurement possible without sensitivity to positioning.
- Distances of loading pins according to DIN 14125 not possible.
- Measurement speed: 5 mm/min.
- Measurement and analysis via the GOM-Aramis-System.
LOCAL REINFORCEMENTS.
MECHANICAL PROPERTIES – 4-POINT BENDING TEST.

90° outside, tapered

90° inside, tapered

Shear Angle [°]

Sample position [mm]

~50 %

Shear Angle [°]

Sample position [mm]
**Conclusion:**

- Optimization of the costs of CFRP components is strongly focused at the BMW Group.
- Local reinforcements have obvious potentials, but there are challenges to implement them to large scale production.
- The process relevant parameters were analysed at different production levels to make an implementation of local reinforcements possible in a large scale production.
- Example results from the baseline investigations were presented:
  - Impact of tapering on RTM filling behaviour.
  - Influence of the vertical position of local reinforcements to the properties under bending load.

**Outlook:**

- Knowledge transfer from presented 2D studies, into 3D parts.
- Industrialisation of the process technology for local reinforcements in large scale production.
- Presentation of the new 7 series car.
ACKNOWLEDGEMENTS.

Prof. Dr.-Ing. Frank Henning
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Prof. Dr.-Ing. Simon Bickerton
„The University of Auckland“

Dale Brosius
„Institute for Advanced Composites Manufacturing Innovation“
WELCOME TO THE CARBON AGE.
LIST OF REFERENCES.


Packaging of sub-preforms:
- Minimize waste material.
- Different mechanical properties within the final part.
- Different thicknesses within the final part (1.5 to 5.0 mm).
- Tailored parts.

[Pas 14]
LOCAL REINFORCEMENTS.
HIGH-PRESSURE RTM – SHORT SHOTS.

Local reinforcement outside 0°, untapered

Short shots – Resin Injection

Flow front visualisation

Upper side

Lower side

Dry spots

100 mm
### Mechanical Properties

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Max. Bending Force</th>
<th>Energy Absorption</th>
<th>Max. Tension Force</th>
<th>Energy Absorption</th>
<th>Undulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°-Fibre-Orientation</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>90°-Fibre-Orientation</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Loc. Reinf. Outside</td>
<td></td>
<td></td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Loc. Reinf. Central</td>
<td>+++</td>
<td>+++</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Tapered Trans. Reg.</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Untapered Trans. Reg.</td>
<td></td>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Explanation:**
- +: Positive influence
- -: Negative influence