CARBON COMPOSITES
IN AUTOMOTIVE STRUCTURAL APPLICATIONS.

EuCIA: Composites and Sustainability
19. March 2016, Brussels
TOPICS

– Motivation and Introduction
– Carbon Composites in the Life-Modul of the BMW i3 with aspects of the sustainability of The Brand BMW i
– Carbon Composites in Carbon Core of the BMW 7 series
– Summary of Carbon Composites in industrialized BMW products
– Actual Demands and Developments on Carbon Composites with aspects of its sustainability
THE FUTURE OF MOBILITY.
CHALLENGES.

Environment
Climatic Change and its subsequent Damage.

Urbanization
Until 2030 more than 60% of the world population will live in urban centers.

Politics
CO₂ legislation, fleet-legislation, driving restrictions in urban areas.

Drivers for: Sustainability, E-Mobility, Lightweight Design

Economy
Austerity of resources, fuel price increase.

Culture
Sustainable mobility as element of urban lifestyle, Adoption of social responsibility.

Customer Demand
Change of ideals.
DESIGN OF A MCV: LIFE-DRIVE CONCEPT. REALIZED IN BMW i3.

Holistic Life-Drive vehicle concept
- Weight reduction through lightweight design
- Specific structure to house the battery
- Thermoplastic exterior skin
- Horizontal split of materials
- Easy to create derivatives

Energy storage system in under floor section
- Low centre of gravity.
- Crash-protected area.
- Level floor in interior

Life:
Carbon fibre structure

Drive:
Aluminium space frame incl. energy storage system

The Life-Drive architecture allows a perfect integration of an electric powertrain.
THE PRODUCT HIGHLIGHTS OF THE BODY ARE DERIVED FROM THE REQUIREMENTS OF INDIVIDUAL MOBILITY IN MEGA CITIES.

- Max. interior space, light and airy
- No tunnel
- Full-fledged 4-seater
- Coach doors, no B-pillar
- Excellent all-round view
- Ideal weight distribution
THE PURPOSE-BUILT ELECTRIC BMW I3 HAS PERFECT DRIVING PROPERTIES FOR MEGA CITIES CONDITIONS.

• Unladen weight 1.195 kg
  => inversion of weight spiral successful
• Electric Range 130-160 km
  efficient mode up to 190 km
• CO₂ emissions 0 g/km
• Rex = Range extender available
tank capacity 9 l => up to 340 km
• Acceleration 0-60 km/h 3.8 s
  ~ BMW M3
• One pedal-feeling
  => high recuperation
THE BMW i3 MEETS ALL REQUIREMENTS ON PASSIVE SAFETY.
NO COMPROMISE ON PASSIVE SAFETY.

• Unladen weight 1.195 kg
• Electric Range 130-160 km
  efficient mode up to 190 km
• C0₂ emissions 0 g/km

• No compromise on passive safety.
The BMW i3 meets all requirements.

- FMVSS 216a Roof Crush Resistance
- Small Overlap
- FMVSS214 32km/h Oblique Pole
BMW i3 WITH ITS LIFE MODULE MADE OF CFRP MEETS ALL PASSIVE SAFETY AND REPAIR REQUIREMENTS LIKE A BMW 1 SERIES.

- Unladen weight: 1.195 kg
- Electric Range: 130-160 km (efficient mode up to 190 km)
- CO₂ emissions: 0 g/km

No compromise on passive safety. The BMW i3 meets all requirements.

Repair strategy:
Minor damage:
Exchange of thermoplastic skin parts.

Structural damage: CFRP parts, e.g. sill;
Same strategy as in conventional cars
(removal of defined repair sections and bonding using repair elements.)
### RETHINKING THE PRODUCTION PROCESS.
### SUSTAINABILITY: ECOLOGICAL, ECONOMIC & SOCIAL.

<table>
<thead>
<tr>
<th>Highly efficient production process</th>
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<tbody>
<tr>
<td>- 50% energy</td>
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<tr>
<td>100% renewable energy</td>
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<tr>
<td>- 50% time</td>
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<td>- 70% water</td>
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<td>- 50% noise</td>
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**CFRP**

- 50% greenhouse potential
### CFRP - ACCESS TO THE ENTIRE PROCESS CHAIN.

<table>
<thead>
<tr>
<th></th>
<th>Mitsubishi Rayon-SGL</th>
<th>SGL-ACF (JV)</th>
<th>BMW Group</th>
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<tbody>
<tr>
<td>Precursor</td>
<td>Otake, Japan</td>
<td>Carbon Fibre</td>
<td>Preforms</td>
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<td></td>
<td>Textile Fabric</td>
<td>Stacks</td>
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<td>CFRP parts</td>
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<td>Wackersdorf</td>
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<td>Body in White</td>
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<td>Vehicle Assembly</td>
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</table>
BMW i3 BODY MATERIALS.
CFRP COMPONENTS ACCOUNT FOR THE LARGEST SHARE OF THE BODY STRUCTURE WEIGHT.

Total ~ 140 kg
BMW i3.
OVERVIEW OF CFRP-PARTS.

34 CFRP parts in total
- 13 monolithic RTM parts
- 2 RTM braided profiles with supporting foam core (Flechtprofile)
- 19 monolithic fabric compression moulding parts (Nasspress-Teile)

CFRP Parts
Manufacturing technology and layup depending on requirements
- Geometrically complex components require RTM technology
- Multi-preform-parts allow for meeting widely varying requirements in one RTM-part
- High-volume production requires shell design

CFRP Body Shop
joining technology: gluing
- Total amount ~ 130 parts
  [1/3 of parts of a comparable BIW content]
Depending of the electricity-Mix less than about 30 to more than 50% CO₂ e Emissions.

E-Mobility is much more than only emission-free.

Efficient and no give up.

Simple and flexible.

New driving experience.

Sustainable.
SUMMARY BMW i3 (SOP 11/2013).

1. The BMW i3 as a small premium car for all important automotive markets demonstrates the potential for CFRP in a large volume vehicle.

2. Weight reduction is even more important for electric vehicles than in conventional cars.

3. Lightweight design of the Body-in-White with advanced topologies for different material mixes is a key-enabler for inverting the weight Spiral.

4. CFRP Technology is the next step in progressing into further weight reduction.

5. The CFRP Story has just begun.
NEW BMW 7 SERIES - DRIVING LUXURY.
SPECIFIC AIMS OF THE DEVELOPMENT.

The contemporary luxury experience for the performance elite.

Elegance, Comfort and Innovations at an outstanding level with typical BMW Driving Performance

Sustainable, Responsible and Leading.
NEW BMW 7 SERIES - DRIVING LUXURY. INNOVATIONS AT AN OUTSTANDING LEVEL.

BMW Laserlight

LED-Highbeam range 300m

BMW Laserlight outshines all other headlight technology

Remote Control Parking

BMW Display Key

NEW BMW 7 SERIES – DRIVING LUXURY. INNOVATIONS AT AN OUTSTANDING LEVEL.

740e: 240 kW - 400 Nm - 5,6 s ;  2,1 l - 49 g CO2/km
NEW BMW 7 SERIES - CARBON CORE.
SPECIFIC AIMS OF THE DEVELOPMENT.

The lightest car in the segment
with extensive use of CFRP
through technology transfer
from BMW i.
LIGHTWEIGHT APPROACH OF THE ALL NEW 7 SERIES.
FROM CUSTOMERS EXPECTATIONS TO LIGHTWEIGHT CONCEPTS.

What the customers expect:
- Best in Class Driving Performance
- Top of the Range Riding Comfort
- Luxury Acoustic Comfort
- Leading Efficiency Technology
- Leading Edge Innovations
- Elegant Styling with high Precision details
- Contemporary sense of Wellbeing

What did we achieve:
- Weight Reduction by up to 130 kg compared to Predecessor
- Centre of Gravity lower than in Predecessor
- Axle Load Distribution almost exactly 50:50
- CO2 Champion in its segment (4.5 L/100 km)
- Innovative Acoustic Concept for highly improved acoustics at reduced weight
- The most advanced and innovative car in the luxury segment

What did we focus on:
- Low Vehicle weight
- Low Centre of Gravity
- Optimized Axle Load Distribution
- Quiet and light
NEW BMW 7 SERIES – DRIVING LUXURY. 
THE LIGHTEST, THE MOST DYNAMIC AND MOST EFFICIENT LUXURY SEDAN IN THE SEGMENT.

Weight, unladen to DIN [kg, HerA]

1600kg 1600kg 1730kg 1805kg 1820kg 1725kg


* All cars six-cylinder in-line petrol engine - New 7 Series 740i
NEW BMW 7 SERIES - CARBON CORE.
WEIGHT REDUCTION BY UP TO 130 KG.

+70kg* Weight Increase

Reduction Target -130kg*

Measures Needed 200kg*

Body
- Carbon Core -40 kg
- Mounted Parts -10 kg
  -50 kg

Unsprung Masses
-40 kg

Acoustic Concept
-10 kg

Other Concepts
-40 kg

Optimization of Details
-35 kg

Supplier Selection
-25 kg

* The given example is valid for 750Li xdrive
NEW BMW 7 SERIES - CARBON CORE.
INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.
NEW BMW 7 SERIES - CARBON CORE.
INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.

Highlights

• First time to combine 3 Materials in the painted body
• 4 different CFRP technologies
• 3 different Alu technologies
• Carbon Fibre with 100% renewable energy
• Alu with 50% recycled material

Facts and Figures

Weight body structure: 323 kg (331 kg LWB, Pan.roof)
Weight reduction: 40 kg
CFRP parts numbers: 16
Alu part numbers: 11
CFRP parts per day: > 4000
NEW BMW 7 SERIES - CARBON CORE.
INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.

New Corrosion protection concepts:

Risk CFRP-Steel-Alu

CFRP only in dry areas

Galvanic separation with adhesives

Problems solved with 5 hardware prototype loops - >DyKo confirmed
NEW BMW 7 SERIES - CARBON CORE. INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.

New swimming CFRP-joining concept with increased thickness of adhesive:

**Joining concept „fixed“ Steel-Alu**
- Movement not possible

**Joining concept „swimming“ Steel-CFRP**
- Movement possible

Advantages:
- Relative movements are compensated
- No cracks in KTL oven process
- Elongation at rupture is increased

Risks:
- Stiffness and strength are reduced
- Adhesive mass is increased
- Corrosion prevention depends on filling of adhesive
NEW BMW 7 SERIES - CARBON CORE.
INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.

- 16 CFRP parts
- 4 different technologies
NEW BMW 7 SERIES - CARBON CORE.
WET COMPRESSION MOLDING AND RESIN TRANSFER MOLDING.

- CFRP Technologies

![CFRP Technologies Diagram]

CFRP Wet Compression Molding

CFRP Resin Transfer Molding
NEW BMW 7 SERIES - CARBON CORE.
RESIN TRANSFER MOLDING.

Highlights

- High stiffness and strength with minimal weight
- Variable cross section
- Twisting carbon fibre on a thermoplastic core
- Thermoplastic core filled with water
- Parts without lost core -> optimal weight reduction

Facts and Figures

<table>
<thead>
<tr>
<th>RTM parts:</th>
<th>3</th>
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<tbody>
<tr>
<td>Braiding machines:</td>
<td>6</td>
</tr>
<tr>
<td>RTM machines:</td>
<td>2</td>
</tr>
<tr>
<td>Level of material utilisation:</td>
<td>&gt; 90 %</td>
</tr>
<tr>
<td>RTM parts per day:</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>
NEW BMW 7 SERIES - CARBON CORE.
WET COMPRESSION MOLDING.

Highlights

- Wet Compression technology transferred from BMW i
- Improved processes with faster resins
- Milling instead of water-jet
- New CFRP hall in Dingolfing
- CFRP Tunnel is the backbone reinforcement of the body

Facts and Figures

- Wet Compression parts: 8
- Wet Compression machines: 5
- Length of tunnel: > 1500 mm
- Milling machines: 10
- Production area: > 19000 m²
NEW BMW 7 SERIES - CARBON CORE. INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.

- CFRP Technologies
NEW BMW 7 SERIES - CARBON CORE. CFRP STEEL HYBRID.

Highlights

- Direct pressing process
- CFRP and steel get an ideal connection
- CFRP hardened and glued with steel in one step
- B-Pillar with Press-Hardening Steel (PHS)
- Weight reduction with reduced thickness of steel

Facts and Figures

- CFRP Steel Hybrid parts: 2
- PHS-Steel: TRB with 6 thickness areas
- Thickness of steel: 1.3 – 2.2 mm
- Weight reduction: 2.8 kg
- CFRP Steel Hybrid machine: 1 with 2 parallel tools
NEW BMW 7 SERIES – CARBON CORE.
INTELLIGENT INTERPLAY OF CARBON FIBRE, STEEL AND ALUMINIUM.

- CFRP Technologies
NEW BMW 7 SERIES - CARBON CORE.
RECYCLED MATERIAL CF-SMC.

Dry waste material
  - Roving/Fabric
  - Stack
  - Preform waste

Fibre preparation
  - Punching/cutting of the material
  - Separating the fabric into fibres

Fleece production
  - Generating maximum fibre orientation
  - Fixation/stabilization

Multi-layer fleece
  - Processing of the fleece to a multilayer complex

Return of the recycled carbon fibres into CFRP parts in the vehicle
(e.g.: Reinforcement C-Pillar, Trunk partition wall upper)
NEW BMW 7 SERIES.
HIGHLIGHTS PRODUCTION CARBON CORE.

Overview Process Painted Body

Production Concept

Quality circle

Press shop

Body shop

Paint shop

Single part production

Logistic and supply process
TECHNOLOGY PAINT SHOP.

Highlights

- Multi-Material Dryer (KTL, Sealing, Top Coat)
- Application of painted Aluminium-roof
- Integrated Paint Process (IPP)

Multi Material Dryer

IPP

- Conditioning
- El-phoretic Dip Painting
- Underbody coating
- Filler coating
- Top coat
- Cavity preservation

Facts and figures

Employee: 1470
Production area: ~120,000m²
Automats/Rosbots: >250
Process time: 6h
Automation Level: 100%
Convey distance: ~4km
FROM SINGLE PART THROUGH BODY SHOP AND PAINT SHOP TO THE PERFECT BMW.

Quality Circle

- Offline measurement of mounted parts
- 100% Inline measurement Body Shop
- 100% measurement before delivery with Lasergauge
NEW BMW 7 SERIES.
CARBON CORE.
## BMW i3 and BMW 7 Series in Comparison by Aspects of CFRP

<table>
<thead>
<tr>
<th></th>
<th>BMW i3</th>
<th>BMW 7 Series</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production volume</strong></td>
<td>100 cars/day</td>
<td>&gt; 300 cars/day; &gt; 4000 CFRP p/d</td>
</tr>
<tr>
<td><strong>CFRP technologies</strong></td>
<td>Wet Compression Pressing; HP-RTM</td>
<td>Wet Compression Pressing; HP-RTM; Steel Hybrid; CF SMC</td>
</tr>
<tr>
<td><strong>Design concept</strong></td>
<td>LifeDrive =&gt; CFRP dominant in Life-Module</td>
<td>Carbon Core =&gt; Multi-Material (Steel, ALU, CFRP)</td>
</tr>
<tr>
<td><strong>Painting concept</strong></td>
<td>CFRP none Exterior thermoplastic parts (painted and mounted)</td>
<td>Classic also for CFRP (temperature of about 180 °C in EDP)</td>
</tr>
</tbody>
</table>
DEMANDS FOR A FUTURE LIGHTWEIGHT DESIGN WITH CFRP.

1. Decrease of material costs.
   - Raw material price, e.g. carbon fibre.
   - Cutting loss as production waste, e.g. carbon fibre.

2. Reduction of process costs ↔ Correct Design.
   - Right process with the necessary product properties at the right place.
   - Correct use of fibre orientation.
   - Less process steps.
   - Integration of additional function in one part ➞ less components.

3. Optimized composite properties.
   - Improvement of properties by weight for specific material & process, e.g. sizing.
   - Improved prediction by simulation; Composites properties are the junction between design and process due to they are created during the process.

4. Safe and stable process.
   - Further weight reduction.

Source: Roland Berger, Study 9/2012
Vision
• Ability to use CFRP in large-scale production
• 90% reduction of process costs (based on costs of 2010)
• 60% - 80% of added value will take place in Germany
• Establish an SME supplying industry
• Anchoring of CFRP in the public

Cost target has been précised in 2014 to:
Part cost in 2020 less than 18 €/kg

with assumption/targets:

<table>
<thead>
<tr>
<th>Level for automation</th>
<th>High; reduced to a few steps process steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time</td>
<td>~1 min</td>
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<tr>
<td>Cost for Carbon Fibre</td>
<td>~10 €/kg</td>
</tr>
<tr>
<td>Cutting loss</td>
<td>~10%</td>
</tr>
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</table>
Design and load path optimized roof bow in thermoplastic CFRP with less expensive materials in a skeleton design method

• Product properties exceed those of the actual BMW i3.
• Reduction of production cost by about 74%.
• Reduction of tooling cost by about 80%.
• Cycle time: 75s
• Thermoplastic injection material is reinforced with 100% recycled carbon fibres.
Pre-study for Life-Cycle-Analysis (LCA) with an eco-efficiency evaluation of relevant process chains for CFRP structural parts.
THANK YOU FOR YOUR ATTENTION.

"Premium will be defined by sustainability."

Dr. Norbert Reithofer, Former CEO of BMW
BACKUP
NEW BMW 7 SERIES - LIGHT AND QUIET. AT-SOURCE INSULATION CONCEPT.

**Highlights**

- Excellent interior acoustics coupled with weight reduction
- Innovative at-source insulation concept
- Use of Superabsorbers
- Absorbing sound energy near the source (light insulation materials)

**Facts and Figures**

- Weight reduction: 10 kg

Colored parts are adapted to the specific requirements that occur based on type of engine and transmission.