VORAFORCE™ RTM Resin Systems
Mass Reduction for Mass Production

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Agenda

• Brief Introduction to Dow Chemical
• Need for lightweighting in the automotive industry
• Affordable lightweighting with composites
• VORAFORCE™ Systems for RTM and wet compression processes

• Thick glass composite springs
• Processing of thick glass composite parts in HP-RTM
• Performance of VORAFORCE™ Systems
• Conclusions
Dow: An Innovation Company

• Founded in 1897
• 119 years of growth
• Largest chemical company in the U.S.
• Ranked 48th in the S&P Fortune 500
• ~ 49500 employees worldwide
• $49 billion in annual revenue in 2015
• Integrated value chains aligned to high-growth sectors
• 6000 product families manufactured at 179 sites in 35 countries across the globe
Dow Automotive Systems
Setting the Pace

• We provide OEM, tier, aftermarket and commercial transportation customers with world-class solutions

• Our portfolio includes:
  – Polyurethanes
  – Epoxy Systems
  – Elastomers
  – Films
  – Brake fluids and lubricants
  – Glass, structural and specialty adhesives
  – Acoustic management materials
Material Solution Addressing Valued Market Needs

MACRO DRIVERS

- CO₂ regulation
- Fuel efficiency
- Globalization
- Performance expectation
- Sustainability
- Safety regulation

KEY TRENDS

- Lightweighting
- Powertrain downsizing and electrification
- Global specification
- Functionalization
- Automated, connected, autonomous drive
- Life cycle analysis

MATERIAL SOLUTIONS

Adhesives
- High volume manufacturing
- Mixed substrate bonding

Composites
- High volume/fast cycle times

Elastomers & Foams
- UTH thermal/acoustic
- Low density/low emissions/comfort

Adjacencies and new business platforms
## Products

<table>
<thead>
<tr>
<th>NEW BUSINESS PLATFORMS</th>
<th>PERFORMANCE SOLUTIONS</th>
<th>ADHESIVES</th>
</tr>
</thead>
</table>
| • VORAFORCE™ composite resins  
• VORAFUSE™ composite systems | • ENGAGE™ elastomers  
• SPECFLEX™/SPECFLEX™ Activ foams  
• BETAFOAM™/BETAFOAM™ Renue structural & acoustic foams  
• Brake Fluids & Lubricants | • BETAMATE™ structural adhesives  
• BETAFORCE™ structural adhesives  
• BETASEAL™ glass bonding adhesives  
• ROBOND™ bonding agents  
• THIXON™ bonding agents  
• MEGUM™ bonding agents |

Our portfolio includes: Polyurethanes, Elastomers, Films, Brake fluids and lubricants, Glass, structural and specialty adhesives, Acoustic management materials, Epoxy Systems

™Trademark of The Dow Chemical Company
Dow Automotive Systems
Composite Solutions

- Dow is long experienced in producing large structural composite component solutions

1990

BMW Z1 Horizontal Body Panels
Manufactured: Dow Tägerwilen
Glass Fiber Epoxy RTM
Demold Time: 1 hour

2012

VORAFORCE™ 5200 Rear seat shell
(145 x 65 cm, 2.4 mm thickness)
Carbon Fiber Epoxy HP-RTM
Epoxy 2.46 kg, fiber 50.2 vol.-%
Demold time <5’

2013

VORAFORCE™ 5300
<60 s cure time!
Dow Composite Center for RTM & Wet Compression

Objectives

- Resin development
- Simulation, testing
- Process development
- OEM
European Composite Technical Center Capabilities

Resin Transfer Molding (RTM) Press & tools
- High pressure 3 component RTM machine
- Low pressure Isojet Injection equipment
- 2 composite processing presses (120 & 400 ton)
- RTM, 3D “torture tool”, wet compression panel tool
  Opening force measurement
  Process data logging capabilities
  Injection point and gate adjustable
  Water heated tool - top and bottom heated independently
  Evacuation equipment for RTM (and Wet Compression) tools
  XY robot-table for reproducible resin application
Analytical equipment (DSC, DMA, rheology, “low” force mech)
  … + Large range of mech and analytical testing in other sites
20kg mixing equipment
Chemistry lab for formulation development
Co-location with Engineering Simulation team, TS&D, and Adhesive R&D team (validated RTM infusion simulation tool)
Market Driver: Efficiency / Emissions Reduction

Europe (gCO₂/km) 2015: 135, 2021: 95, 2025: 65?
Dow Vision: Affordable Lightweighting

- **Legislative Penalties**
- **Material Efficiency**
  - Durable, Stable Matrix Material
  - Fast Cure Resins
  - High Efficiency Processes
- **Processing Efficiency**
- **Assembly Efficiency**
- **Mass Decompounding**
- **Part Consolidation & Adhesive optimisation**
- **Secondary Value**
- **Material Characterisation**
- **Engineering Simulation**

- **Required Thickness Increase**
  - 80°C CF PA6
  - 80°C CF Epoxy

- **00:59s**
Mass Reduction for Mass Production

Multi-Piece Stamped & Welded Steel Floorpan

>95% part integration

>Dow VORAFORCE™ One-Piece Carbon Fiber Epoxy Floorpan

>50% weight reduction
Dow Automotive Lightweight Solutions

- **Dow VORAFORCE™** Epoxy Matrix Materials
  - Optimised substrate-adhesive interface
  - Minimised composite overdesign
  - Minimised substrate surface preparation
  - Minimised required carbon fibre content via optimised resin-fibre interface

- **DowAksa AKSACA™** Carbon fibre JV
  - Minimised carbon fibre content via local foam core reinforcement

- **Dow BETAMATE™** and **BETAFORCE™** Structural Adhesives
  - Cavity sealing and Acoustic optimisation

- **Dow BETAFOAM™** Structural Foam
Automotive Composites Applications

Class A applications

- Integration into Vehicle (module)
- Medium mass reduction potential
- Surface Quality challenges
- Cost (low part consolidation)

Structural applications

- High mass reduction potential
- High part consolidation (cost down)
- No surface quality concerns
- Integration into Vehicle (body shop?)
Why Epoxy for Structural Composites?

**Superior Performance in Structural Composites**
- Low shrinkage or residual stress
- Durable / fatigue resistant
  - *long aerospace history*
- Minimised overdesign versus other matrix resins
  - *Excellent thermal stability (chemistry formulated for the application)*
  - *Excellent moisture stability*
  - *Excellent chemical / environmental resistance*

**Improved Processing**
- Extremely low viscosity (10-15 mPa·s) enabling
  - *fast/long infusion (latency)*
  - *excellent fiber wet-out*
  - *minimized void content*
- Cure times <1 min now possible, even with long infusion times
- Excellent carbon fiber sizing compatibility
- Recycling route via pyrolysis
  - *recovers useful high-value carbon fiber content*
VORAFORCE™ Fast-Cure Epoxy Systems

• VORAFORCE™ solutions focus on reducing composite part cost, providing mass-production alternatives to structural metal.

• VORAFORCE™ epoxy system formulations are suitable for Resin Transfer Molding (RTM) or Wet Compression high-volume processing.

• The VORAFORCE™ range is designed to meet elevated temperature requirements, either for assembly or in-service operation.

Special for springs: VORAFORCE™ 5500
VORAFORCE™ 5300 offers industry-leading ultra-fast molding cycle times, enabling a single molding press to produce hundreds of thousands of parts per year.
RTM Technology

Insert CF pre-form

RTM PRESS

Close RTM mold

Epoxy
Resin

Inject Epoxy Resin System

< 60 sec

Curing

Open mold Remove part

RTM Technology Diagram

Viscosity

Time

Max infusion viscosity

200 mPa·s

Dow
VORAFORCE™ 5300 combines ultra-fast cure with

- Low processing viscosity down to 10 mPa·s
- Designed to be non-aggressive towards HP-RTM equipment
- Not classified as toxic according to REACH 2015

Tuneable processing via tool temperature to lengthen infusion time / latency
**VORAFORCE™ 5300: Mech data**

<table>
<thead>
<tr>
<th>Process: HP-RTM</th>
<th>Unit</th>
<th>Standard</th>
<th>VORAFORCE™ 5300</th>
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</thead>
<tbody>
<tr>
<td>Neat Resin Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>%</td>
<td>ISO 527-2</td>
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</tr>
<tr>
<td>Elastic Modulus</td>
<td>GPa</td>
<td>ISO 527-2</td>
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<tr>
<td>Tensile Strength</td>
<td>MPa</td>
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<tr>
<td>Fracture Toughness $K_{IC}$</td>
<td>MPaVm</td>
<td>ASTM D5045</td>
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<tr>
<td>Composite Data (DowAksa A42 CF, 50 vol.-%)</td>
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<td></td>
<td></td>
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<tr>
<td>$T_g$ Midpoint (DSC)</td>
<td>°C</td>
<td>ASTM E1356</td>
<td>120</td>
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<tr>
<td>0° Tensile Modulus (0 / 90° fabric)</td>
<td>GPa</td>
<td>ISO 527-4</td>
<td>63</td>
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<tr>
<td>0° Tensile Strength (0 / 90° fabric)</td>
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<td>ISO 527-4</td>
<td>960</td>
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<tr>
<td>90° Tensile Strength (UD fabric)</td>
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<td>ISO 527-4</td>
<td>59</td>
</tr>
<tr>
<td>Composite Density</td>
<td>g/cm³</td>
<td></td>
<td>1.49</td>
</tr>
</tbody>
</table>

*Data as molded, including IMR; no post cure needed*
A VORAFORCE™ Resin System for Composite Springs

VORAFORCE™ 5500
Critical Performance for Springs

- Modulus to provide stiffness (can be compensated via thickness)
- Strength: will determine to first failure on the surfaces, where highest stress level is reached
- Elongation: provide bending flexibility – especially on surfaces
- Shear strength: important to transfer to load from layer to layer. Without shear strength: interlaminar failure
- Dynamique fatigue resistance
Fatigue test setup

ISO 14130 for ILSS
R1 = 5 mm and R2 = 2 mm
No difference noted in static values between electromechanical and servo-hydraulic test frames
ILSS Fatigue Data
For VORAFORCE™ (developmental + commercial) products
20 mm Glass Composite Panels

Glass UD fabric, 1200 gsm per ply

Red lines are stitching

Part weight 7 kg
Thermocouples in a 20 mm sample

61% Glass FVF, Mold Temperature 90° C
Resin injection 1640 g @ 70 g/s

$\Delta T_{\text{max}} = 100° \text{ C}$
Surface Tc and Pressure Sensors on Thick Panel Mold

- Tool pressure depends on position in tool
- Tool surface temperature increases notably
Summary

• VORAFORCE™ 5300 Resin System is well suited for high volume production via RTM or Wet Compression

• VORAFORCE™ 5300 matrix system has been demonstrated on a variety of composite parts
  - Many glass and carbon fiber fabrics, UD, twill, chopped
  - Many components, from a few hundred grams to over 10 kilogram

• VORAFORCE™ products exist to cover Tg ranges up to 190°C
  - Concept of: right product for right application
  - All designed for high volume/short cycle time (<4'/5’)


Thank You