Great Automotive Designs Enabled By Advances in Adhesive Bonding

Mansour Mirdamadi and Greg Korchnak

Dow Automotive
• Classification of adhesive systems for body structure applications
• Industry trends
• OEM acceptance of adhesive bonding technology
• Benefits of structural bonding
• Case studies
Choice of Structural Adhesive

• Automotive industry criterion for structural adhesives
  ➢ Modulus: Above 1000 MPa
  ➢ Glass Transition Temperature: Above 80 °C
  ➢ Impact Resistance f(T): From -40 °C to 80 °C
  ➢ Oil Compatibility: Adhesion to oily substrates
  ➢ Wash-off resistance

• Epoxy based systems
  ➢ General purpose
  ➢ Standard grades
  ➢ Semi-fracture toughened
  ➢ Superior fracture toughened

One component toughened epoxy is the industry choice
Characterization of Adhesive Toughness

- **Wedge impact peel (ISO 11343)**
  - The wedge is driven between two bonded metal halves by the energy of a falling mass achieving impact speeds of 2 m/sec to 3 m/sec

- **Usable outputs**
  - Adhesive resistance to crack growth
  - Compatibility of the adhesives with substrate types and coatings
  - Influence of temperature -40 °C to 80 °C

![Wedge impact peel diagram](image-url)

**Typical load vs. time profile**

- **Stable crack growth**
  - Load sustained
- **Unstable crack growth**
  - Unable to carry load
Impact Peel Test Results

- Increased ductility at low temperatures

- Increased crash resistance
- Increased durability
- Increased flexibility to down gauge metal & reduce welds

<table>
<thead>
<tr>
<th>Strength (N/mm)</th>
<th>General Purpose Adhesive</th>
<th>Structural Adhesive</th>
<th>Semi Fracture Toughened</th>
<th>Fully Fracture Toughened</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40C</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>44</td>
</tr>
<tr>
<td>-20C</td>
<td>12</td>
<td>12</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>RT</td>
<td>7.5</td>
<td>6</td>
<td>12</td>
<td>35</td>
</tr>
</tbody>
</table>

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Wedge-Impact Peel Performance for Various Steel Types

Galvaneal Coating Evaluation

- Adhesive systems optimized for compatibility to galvaneal coatings

Steel Type Evaluation

- Adhesive systems optimized for full compatibility to new AHSS steels

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Adhesive systems optimized for compatibility to galvaneal coatings

Adhesive systems optimized for full compatibility to new AHSS steels
Trends and Needs for Innovation

- **External drivers**
  - Safety requirement and continuous demands to increase vehicle safety and crashworthiness
    - Frontal offset impact
    - IIHS side impact
    - Roof crush, rollover protection
    - Upgraded fuel integrity requirements
  - CAFE requirements (mass reductions)
  - Customer comfort
  - Consumer demand for frequent styling changes

- **OEM**
  - Cost reduction
  - Common architecture body structure design
  - Carry over components, assemblies, and sub-assemblies
  - Design theme variations
    - Coupe, sedan, convertible
  - Engine, and powertrain combinations
  - Import vehicles designed and manufactured from AP, and LA into US
  - Aggressive styling, while improving occupant compartment space
  - Plant utilization and capacity
Structural Bonding Usage Trends for Fracture Toughened Adhesives

A:
- Mercedes Benz S-Class

B:
- Range Rover
- VW Polo
- VW Touran
- Mercedes Benz E-Class
- Mercedes Benz S-Class
- Jaquar XJ
- BMW 7-Series

C:
- BMW 1-Series
- Skoda Octavia
- Audi A6

D:
- Audi Q7
- Mercedes Benz S-Class
Fracture Toughened Adhesives Contributes to Weld Reduction, Stiffness Improvement, and Weight Reduction

- Stiffness and weight comparison relative to baseline
  - 1st bending: 34% increase
  - Torsion: +20% increase
  - Mass: -7 kg reduction

<table>
<thead>
<tr>
<th></th>
<th>05’ AUDI A6</th>
<th>Previous AUDI A6</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of parts</td>
<td>345</td>
<td>287</td>
<td>+ 58</td>
</tr>
<tr>
<td>Spot welds</td>
<td>5102</td>
<td>6147</td>
<td>- 1045</td>
</tr>
<tr>
<td>Rivets</td>
<td>364</td>
<td>0</td>
<td>+ 364</td>
</tr>
<tr>
<td>Clinching</td>
<td>83</td>
<td>63</td>
<td>+ 20</td>
</tr>
<tr>
<td>Laser welds</td>
<td>4.5 m</td>
<td>3.5 m</td>
<td>+ 1 m</td>
</tr>
<tr>
<td>Laser solder</td>
<td>4.2 m</td>
<td>0</td>
<td>+ 4.2 m</td>
</tr>
<tr>
<td>MIG welds</td>
<td>5.9 m</td>
<td>2.5 m</td>
<td>+ 3.4 m</td>
</tr>
<tr>
<td>Weld pins</td>
<td>408</td>
<td>220</td>
<td>+ 188</td>
</tr>
<tr>
<td>Structural adhesives</td>
<td>122 m</td>
<td>36 m</td>
<td>+ 86 m</td>
</tr>
<tr>
<td>Inserts</td>
<td>22</td>
<td>5</td>
<td>+ 17</td>
</tr>
<tr>
<td>BIW robots</td>
<td>603</td>
<td>480</td>
<td>+ 123</td>
</tr>
</tbody>
</table>

Reference: EURO CAR BODY 2004
## Structural Bonding Usage Trends

<table>
<thead>
<tr>
<th>High</th>
<th>Replication mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Down gauging of sheet metal components</td>
</tr>
<tr>
<td></td>
<td>Reducing no. of spot welds</td>
</tr>
<tr>
<td></td>
<td>Investigating innovative ways to reduce total system cost</td>
</tr>
<tr>
<td></td>
<td>Optimizing joint designs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Realized full benefits of structural bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rely on other joining techniques in addition to adhesive bonding</td>
</tr>
<tr>
<td>Early adopters of technology, move cautiously</td>
</tr>
<tr>
<td>Have not established implementation strategies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low</th>
<th>Use adhesives to enhance corrosion resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use adhesives in areas where welding or other joining options are limited</td>
</tr>
<tr>
<td></td>
<td>Structural adhesives not aligned with long-term strategies</td>
</tr>
</tbody>
</table>

| Primary use adhesives for stiffness and durability improvements |
| Have not recognized the benefits of fully fracture toughened adhesives |

<table>
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<tr>
<th>Technology Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
</tr>
</tbody>
</table>
Why Structural Adhesives?

- Eliminates sudden change of stresses
- Significantly lowers stress acting across joined region
- Uniformly distributes the load
- Eliminates stress concentration

Why Structural Adhesives?

- Reduction of stress concentration, improves fatigue life significantly
- Higher loads can be sustained
- Enables down gauging of steel

Axial Crush Testing

Fracture toughened adhesives perform better than standard grades

- Improved stability to progressive crush
- Improved load-carrying capability

- Testing parameters
  - Drop tower weight - 33.3 kg
  - Material - 350 MPa yield steel
  - Thickness - 0.62 mm
  - Adhesive thickness - 0.25 mm
  - Test temperature - 14 °C

- Parameters studied
  - Weld spacing - 50 mm and 200 mm
  - Impact speed - 27.6 km/h to 42.2 km/h
Weight Optimization using Structural Adhesives

Objective

Assess the use of structural adhesives to improve NVH body structural response to:
- Improve global NVH body response
- Downgauge sheet metal panels
- Minimize use of steel reinforcements

Methodology

- Evaluate baseline performance by predictive CAE engineering analysis
- Develop adhesive pattern
- Perform design sensitivity analyses to optimize structural response and adhesive pattern
- Develop metal panel thin gauging approach and weight reduction estimates

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Optimized Structural Response using BETAMATE Adhesives

**Adhesive Treatment**

- BETAMATE* Adhesive: + 0.25 kg
- Steel Downgauging: - 23.0 kg (-10%)

**Weight Benefits**

- **Cost reduction**
- **Improved performance over the baseline**
- **Mass reduction**

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<table>
<thead>
<tr>
<th>Mode</th>
<th>Baseline BIW</th>
<th>Baseline BIW Adhesively Bonded</th>
<th>Optimized BIW Adhesively Bonded</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.24 Hz</td>
<td>32.22 Hz</td>
<td>32.23 Hz</td>
<td>Bending of lower radiator support cross member</td>
</tr>
<tr>
<td>2</td>
<td>33.17 Hz</td>
<td>35.32 Hz</td>
<td>35.05 Hz</td>
<td>1st Global bending</td>
</tr>
<tr>
<td>3</td>
<td>35.15 Hz</td>
<td>37.43 Hz</td>
<td>35.74 Hz</td>
<td>1st Global torsion</td>
</tr>
</tbody>
</table>

*Trademark of The Dow Chemical Company
Fracture Toughened Adhesives
For IIHS Side Impact

• Key questions
  ➢ Can structural bonding provide benefits in improving structural response during IIHS side impact
  ➢ What is the level of improvements that can be obtained
  ➢ What is the engineering approach in selecting adhesive location
  ➢ How could the benefits be further enhanced

• Baseline model
  ➢ Selected a full vehicle model having an “acceptable” structural rating
  ➢ Vehicle type: minivan

• Outputs
  ➢ B-Pillar intrusion
  ➢ Energy distribution

• Techniques
  ➢ LS-DYNA3D for full-vehicle analysis
Fracture Toughened Adhesives vs. Sheet Metal Thickness

Sheet Metal Thickness Sensitivity

Adhesive Location

B-Pillar intrusion improvement, mm

Sub-system

2.3 kg, 1.75 kg, 18.75 kg, 10.88 kg, 13.05 kg

B-Pillar intrusion improvement, mm

Adhesive location

BASE, FD, RD, SA, ALL, Optimum

0.6 kg

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Study Findings

• B-Pillar intrusion
  ➢ Fracture toughened adhesive provided 5.4 mm of B-Pillar intrusion over the baseline design
  ➢ Adhesive contribution to B-Pillar intrusion was independent of metal thickness, and grade of steel used
  ➢ Further improvements are viable with optimum sheet metal and joint design

• Adhesive contribution to body stiffness
  ➢ Match boxing – 0.2 Hz improvement
  ➢ 1st bending – 1.0 Hz improvement
  ➢ Torsion – 0.5 Hz improvement
  ➢ 2nd bending – 1.6 Hz improvement
Successful Integration and Execution

Additional tools to be added
- Joining technologies
  - Weld bonding
  - Optimized joint design
- Materials technologies
  - Superior fracture toughened adhesives
  - Robust processing
  - Robust adhesion to accommodate various metallic substrates and coatings
  - Robust curing window
  - Polymeric hybrid inserts
- Engineering analysis tools for predicting
  - Stiffness
  - Crashworthiness
  - Fatigue and durability

- Design
  - Cross section
  - Joint design
  - Reinforcement
  - Gage increase
- Materials
  - Cold rolled steel
  - High strength steel
  - Dual phase steel
  - TRIP
  - Bake hardenable
- Manufacturing/process
  - Welding (laser welding)
  - Hydroforming
  - Tailor welded blanks