Evaluating Different Techniques for Joining Carbon Fiber Composite Parts

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High Volume Forming Symposium
Carbon Fiber Composites (CFC): The base resin

<table>
<thead>
<tr>
<th>Thermoplastics</th>
<th>Thermosets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast forming (~ &lt; 5min)</td>
<td>Slow forming (≥ 20 min)</td>
</tr>
<tr>
<td>“Re-formable”/”De-formable”</td>
<td>Set shape</td>
</tr>
<tr>
<td>Low(er) strength</td>
<td>High(er) strength</td>
</tr>
<tr>
<td>Ductile</td>
<td>Brittle</td>
</tr>
<tr>
<td>Single layer construction</td>
<td>Laminate construction</td>
</tr>
<tr>
<td>Recyclable</td>
<td>Not easily recyclable</td>
</tr>
</tbody>
</table>

→ The selection of the joining techniques largely depends on the material properties
Polymer & composite Joining Techniques

- Adhesive
- Mechanical – Metal fasteners
  - Riveting (pop, SPR, etc.)
  - Flow drill screw
  - Staking
  - Co-molding of fasteners
- Mechanical – Plastic/composite fasteners
  - Riveting/staking (heat, IR, laser, Ultrasonic)
- Welding
  - Mechanical force (Ultrasonic)
  - Frictional force (Vibration, Spin)
  - Energy source:
    - Conduction (heat)
    - Radiative (laser, IR)
    - Induction (EM)
From Development to Implementation

COMPANY VISION, MANUFACTURING STRATEGY & ENGINEERING REQUIREMENTS

Technology Development – R&D, Supplier, Collaborations, etc.
• Evaluation (applicability, performance & product requirement, math modeling)
• Process development
• Technology transfer

Process Validation - Manufacturing & Engineering
• Tool selection for manufacturing environment
• Process & quality monitoring (Fault/No fault, Good/Bad)
• Process development and optimization on selected tools based on product engineering performance requirements.

Process Manufacturing Integration
• Validate assembly process in a scaled-down manufacturing environment with selected process and selected tools
• Math model development and validation
• Production readiness evaluation
Selection Factors

- **Manufacturing integration**
  - Performance
  - Cost
  - Time

Knowing the material, design and manufacturing implications is crucial for technology implementation.

- **Material**
  - Type and properties
  - Manufacturing processes (e.g., co-molding)

- **Application**
  - Use requirement
  - Performance requirements
## Joining Techniques: Advantages and Limitations

<table>
<thead>
<tr>
<th>Joining methods</th>
<th>Resistance Spot Welding</th>
<th>Adhesive</th>
<th>Welding</th>
<th>Mechanical Fastening</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time</td>
<td>≤ 5 s</td>
<td>≥ 20 min</td>
<td>≤ 5 s</td>
<td>≤ 10 s</td>
<td>≥ 20 min</td>
</tr>
<tr>
<td>Joint Performance</td>
<td>+ +</td>
<td>Ref.</td>
<td>≈</td>
<td>≈</td>
<td>++</td>
</tr>
<tr>
<td>Assumptions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Comparable joint design</td>
</tr>
<tr>
<td>Cost - Inv.+ maint.</td>
<td>++</td>
<td></td>
<td></td>
<td>++</td>
<td>Comparable cycle time</td>
</tr>
<tr>
<td>Cost - Labor</td>
<td>++</td>
<td></td>
<td></td>
<td></td>
<td>Robotic/Manual</td>
</tr>
<tr>
<td>Design Flexibility</td>
<td>≈</td>
<td></td>
<td></td>
<td></td>
<td>Part geometry, accessibility, etc.</td>
</tr>
<tr>
<td>Appearance</td>
<td>-</td>
<td>Ref.</td>
<td>≈</td>
<td>≈</td>
<td>--</td>
</tr>
<tr>
<td>Corrosion</td>
<td>++</td>
<td>Ref.</td>
<td>≈</td>
<td>≈</td>
<td>--</td>
</tr>
<tr>
<td>Recyclability</td>
<td>+</td>
<td>Ref.</td>
<td>+</td>
<td>+</td>
<td>≈</td>
</tr>
<tr>
<td>Added weight</td>
<td>+</td>
<td>Ref.</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Implementation requirement</td>
<td>NA</td>
<td>NA</td>
<td>Development</td>
<td>Development</td>
<td>Development</td>
</tr>
</tbody>
</table>

### Mixed Technology Solution:
- Compounds advantages
- Alleviates limitations
Mixed Technologies: An Example

- **Sealing + Dissimilar material joining:**
  - **Geo-Setting + Strength:** Self-Piercing rivets
  - **Sealing + Dissimilar material joining:** Adhesive bonding
  - **Composite joining:** Ultrasonic Welding

When adhesive bonding is necessary, SPR offers geo-setting capabilities and alleviates adhesive bonding long cycle time.

Limitations: material type, stack up, part design/dimension

Rapidity, strength, corrosion prevention, cleanliness, weight reduction, recyclability for all other composite joints.

In “Joining Tomorrow’s cars,” Autospeed, Issue 144, 2001

In “Corvette’s carbon hood creates shock and awe,” Composites Technology, 2009
Mixed Technologies Example: Development Needs

- **Self Piercing rivets**
  - Material: Thermoset/Thermoplastic, substrate thickness, rivet material type
  - Joint Design: Stack-up, material gage, rivet material type
  - Design allowances for manufacturing implementation
  - Joint Performance

- **Ultrasonic Welding**
  - Manufacturing implementation: Flexible tooling
  - Process development: Specificity
    - Welding schedules
    - Process/quality monitoring
  - Joint performance

- Ultrasonic Welding:
  1. Pressure & high frequency vibrations
  2. Heat generation, melting & molecular diffusion
  3. Pressure & weld consolidation

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Conclusions

- There is no “ONE” answer
  - Mixed technologies appear to be the best approach

- Fast technologies adapted to composite joining are not mature enough for OEM’s
  - Require extensive development efforts to:
    - Understand the technology and its implications relative to:
      - Joint performance
      - (Automotive) Manufacturing needs
    - Model and predict the joint performance
    - Evaluate each technology business case for best implementation