Integrated Modeling of Manufacturing and Structural Performance of Carbon Fiber Composites

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Outline

• Composites in Automotive
• Challenges for Composites in Automotive
  - Material Processing Prediction
  - Performance Prediction
• Complex Interplay Between Manufacturing and Performance
• Structural Carbon Fiber (CF) Supply Chain
• Barriers for Large Scale CF Implementation in Automobiles
• Technology in Development
• Conclusions
Composites in Automotive

Helps to achieve following beyond current metals:

- Light-weighing
- Parts consolidation
- Complex geometry
- Variable thickness parts
- Hybrid material construction (CF/Glass)
GM- Corvette – Stringray – Light-Weighing

Carbon Fiber Components – Hood Outer, Hood Inner, Roof

Lowering the center of gravity has considerable increase in ride and handling of the vehicle
Part Consolidation

Single Composite Floor Replacing 14 Steel Parts

Courtesy ACC Project
Solstice Rear Compartment Panel

Draw depth = 11”
2014 GM – Spark EV – Battery Tray Enclosure

12” depth

Significant CARB ZEV Credits for GM from Spark EV
Challenges for Composites in Automotive - Material Processing Prediction

- Engineering the material processing for
  - Maximizing throughput
  - Maximizing quality
  - Minimize the defects
  - Minimize the scrap
  - Minimize the tooling costs
  - Certification protocol for buyoff

Technologies to address above challenges are needed urgently for each of the high volume composite manufacturing processes to be at par with metals.
Challenges for Composites in Automotive – Material Performance Prediction

Accurate predictive tools needed for

• Crush performance
• Durability/Fatigue
• Design for damage during service life

Current technologies are phenomenological and methods are not adaptable between different architectures.

Multi-scale technologies considering the architecture in the unit cell are promising
Interplay Between Processing and Performance

• Material processing has a huge influence on the performance (complex interplay)
• Taming the material processing using computational tools is the key in predicting the performance accurately
Samples cut from plaque show wide scatter in stiffness. Considering the worse stiffness makes design overly conservative.

Steep drop for CF compared to Glass
Performance with Defect

Buckling strength including delamination

Graph showing nondimensional buckling load as a function of a/L, b/L for different interface delaminations: 0/-45 and -45/45.
OEM’s have to comprehend the work flow between each of the Suppliers for continuity.
Barriers for Large Scale CF Implementation in Automobiles

• Non-availability of material processing modeling
• Non-availability of performance prediction
• Non-availability of technology to predict the effect of processing on the performance
• Non-availability of mapping methods from processing to performance
Technology in Development – GM-DOE Project Proposal

• GM has strategic interest in eliminating the roadblocks for large scale CF composite implementation of structural composites in automobiles.
• GM Proposed a DOE project partnering with leading domain experts in the relevant fields:
  
  CSP – Material supplier, molder
  ESI – Software company owner of composite manufacturing simulation
  Altair – Expert in composite structural performance prediction using multi-scale approach
  USC – Expert in stochastic model development
Project Information

• DOE- DE-FOA-0000991
• DOE Funding: $6,000,000; in-kind: 2,576,967 (30%);
• Total: $8,576,967

• Start Date: March 1, 2015
• End Date: Feb 28, 2019
## Project Objectives

### Mass savings and cost targets from DOE

<table>
<thead>
<tr>
<th>Vehicle System</th>
<th>System Definition</th>
<th>Weight Reduction</th>
<th>Cost per Pound Saved ($/lb saved)</th>
<th>Additional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body</td>
<td>Body-in-White, Closures, Windows, Fenders, &amp; Bumpers</td>
<td>≥35%</td>
<td>≤$4.32/lb</td>
<td>Replacement Technology must achieve Function and Packaging Requirements of Technology to be Replaced</td>
</tr>
<tr>
<td>Chassis</td>
<td>Suspension, Steering, Wheels, &amp; Underbody Structural Components</td>
<td>≥25%</td>
<td>≤$4.27/lb</td>
<td>Function and Packaging Requirements of Technology to be Replaced</td>
</tr>
</tbody>
</table>
## Project Objectives

<table>
<thead>
<tr>
<th>Model</th>
<th>Manufacturing Phase</th>
<th>Modeled Elements</th>
<th>Percent Error (Compared to Experimental)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constituent material (fiber/interphase/resin and assembly of such)</td>
<td></td>
<td>Robust, accurate and reliable constitutive models for each constituent material as well as the composite assembly under expected service conditions including high-strain rates utilizing physics based model</td>
<td>≤15%</td>
</tr>
<tr>
<td>Part Properties</td>
<td>During and After Molding</td>
<td>Microstructure morphology</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Optimized cycle time, and local thickness, fiber length and orientation of the final part</td>
<td>≤15%</td>
</tr>
<tr>
<td>Assembly Properties</td>
<td>After Joining/assembly</td>
<td>Load to failure, failure location, and failure mode, stiffness/deflection, dynamic performance, energy absorption/crashworthiness</td>
<td>≤15%</td>
</tr>
</tbody>
</table>
Predictive Tools for Integrated Manufacturing and Structural Performance

Manufacturing process for structural composites
- RTM, C-RTM, HP-RTM
- Prepreg compression molding

Multi-scale crash performance prediction
- Unit cell microstructure linking micro-scale to macro-scale

Stochastic Methods
Optimization for mass, cost, etc.
Potential Impacts of Technology Development

• Optimum material process development
• Design to maximize the processing potential
• Optimum design for structural performance
• Lower material and manufacturing costs
Example – Time and cost in material characterization

Drawback: Current practice does not include support from predictive models from both manufacturing and performance.

Tools developed during the project will potentially minimize the experiments – reduce cost and time.
Multi-scale technologies will be developed in this project to include Manufacturing defects such as Voids, angle changes, etc.
Manufacturing and Performance - Model Linkage

Material Processing Prediction Model → Map → Structural Performance Prediction Model

Output
a) Voids
b) Angle Changes

Material Property Prediction With voids and angle changes

Mapping procedure need to account domain discretization (mesh size), parametric unit cell generation, etc.
Stochastic modeling allows us
• transform experimental data to probabilistic models
• design based on confidence levels and reduce the safety margins
• model some of the uncertainty in predictive modeling (material allowable, finite element errors, etc.)
Having composite material curriculum in universities to include all the above topics will better prepare the workforce to solve these complex problems in the area of composite materials.
Conclusions

• GM is placing a lot of efforts in developing state of art computational tools for predicting material processing and performance of composites—cradle to grave
• Expectation is to eliminate significant barriers in large scale implementation of CF structural composites in automobiles