DEMYSTIFYING AUTOMOTIVE COMPOSITES TO EVALUATE FULL POTENTIAL FOR SIGNIFICANT MASS SAVING

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AGENDA

LIGHT WEIGHTING

INTRODUCTION TO AUTOMOTIVE COMPOSITES

MATERIALS AND PROCESSES SELECTION

CHALLENGES AND OPPORTUNITIES

SUMMARY
DESPITE HEAVIER VEHICLES, AVERAGE FUEL ECONOMY OF PASSENGER VEHICLES IS STEADILY IMPROVING OVER PAST DECADE

Do we really need Light-weighting?
AVERAGE FLEET FUEL ECONOMY TARGET OF 54.5 MPG IN 2025

Less than 5% of 2014 vehicles meet 2025 CO$_2$ emission targets

Light-weighting is a key enabler to achieve these targets
LIGHT-WEIGHTING DOES NOT MEAN COMPROMISING CUSTOMER EXPECTATIONS FOR SAFETY, RIDE AND HANDLING CHARACTERISTICS, USER SPACE, AND QUALITY
LOSING WEIGHT NEEDS MOTIVATION, COMMITMENT, AND DISCIPLINE

- **Healthy Diet** (Lightweight Materials and Processes)
- **Exercise to get in shape** (Efficient Design)
- **Low Stress** (Minimize Risks – Technical/Commercial)
DOMINANT LOAD CASES DRIVING BODY STRUCTURE DESIGN

Material Property needs:

1. Stiffness dominant
2. Strength dominant
3. Energy absorption
4. Close out panels - lower strength and stiffness requirements
MATERIAL PROPERTY NEEDS

Cadillac ATS BIW structure

- Highest ultimate strength
- High strength & ductility
- Primarily stiffness dominant
- Minimum gauge closeouts contribute some strength, stiffness & Danner performance.
LIGHTWEIGHT MATERIAL SELECTION?

• Steel - Primary material of choice for automotive body for over a century

• Alternate materials such as Aluminum, Magnesium, and polymer composites have challenged its dominance in recent years.
WHY COMPOSITE?

Composites have higher specific strength and specific modulus compared to conventional automotive materials

- Potential for mass savings
  - Up to 70% over steel
  - Up to 30% over Aluminum

- Design flexibility

- Parts consolidation: less assembly time

- Can be reinforced locally, mixed with other materials

- Low tooling cost and short lead times

1953 Chevrolet Corvette

Image Source: Motortrend.com
COMPOSITES HAVE BEEN IN USE IN THE AUTOMOTIVE INDUSTRY SINCE EARLY 1950s

Saturn Sky

Chevrolet Corvette

Hummer H2

Cadillac XLR

Pontiac Fiero

Chevrolet Silverado
AUTOMOTIVE COMPOSITES 101

One of the key advantages of composites is that they can be tailored for a given application.

- Potential combinations of material compositions and processes are countless
COMPOSITE MATERIAL 101

Matrix

Thermoset
Epoxy, Vinyl Ester, Polyurethane, Polyester, etc.

Thermoplastics
Nylons, Polypropylene, PPS, PEEK

Additives
Processing Aids
Fillers
UV Stabilizers
Fire Retardants
Etc.

Reinforcement

Glass
Carbon
Aramid
Natural Fibers

Chopped Fiber
Fiber Tows
Woven fabric
Braided Fibers

Fiber Orientation
Fiber Length
Fiber Content

Toughness; Weatherability; Fire Resistance;
Moisture absorption; Permeability

Mechanical Properties
CARBON FIBER REINFORCEMENTS

CF Tow (1K-50K)

Unidirectional Prepreg

Chopped Fiber

Woven Fabric

Braiding

3D Fabric
MANUFACTURING PROCESSES

Dry Fiber
Chopped fiber
Continuous fiber tows
Mat/Weave/Braiding

Resin

SMC, BMC, LFT, TP mats

Pre-preg, Fabric SMC

Shaping
Wet Pre-forms, lay up, roll wraps

Cure/Molding
Ambient cure
Oven/heat Cure
Autoclave
Press molding
Injection molding
Thermoforming

Resin

Dry Pre-forms

Resin

RTM, Infusion
MATERIAL PROPERTIES: SPECIFIC STRENGTH VS SPECIFIC MODULUS
UNLIKE METALS, COMPOSITES ARE ANISOTROPIC MATERIALS.
TYPICAL TENSILE PROPERTIES OF RTM MOLDED CF REINFORCED EPOXY COMPOSITE

Adding layers in multiple directions improves isotropy but reduces overall properties
MATERIAL AND PROCESS SELECTION EARLY IN THE PROGRAM DEVELOPMENT IS ESSENTIAL

The ability of customized formulations is also the cause of frustration for many automotive engineers.

• Design guidelines
• Material cards for FEA
• Process simulations
• Understanding of failure modes and damage tolerance
• Joining methods
Material substitution for equal tensile load

- CF SMC
  - (200MPa/25GPa)
- RTM
  - (400MPa/40GPa)
- Biaxial Prepreg
  - (820MPa/65GPa)
Material substitution for equal tensile load
(CFRP Flat Panel vs 0.7 mm thick Steel Panel)
MATERIALS AND PROCESS SELECTION AND POTENTIAL MASS SAVINGS

Material substitution for equivalent stiffness

<table>
<thead>
<tr>
<th>Steel</th>
<th>CFRP (40GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Steel Diagram" /></td>
<td><img src="image" alt="CFRP Diagram" /></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>CFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t = 0.7 mm</td>
<td>t = 1.2 mm</td>
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<td></td>
<td><img src="image" alt="Steel Diagram" /></td>
<td><img src="image" alt="CFRP Diagram" /></td>
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<tr>
<td></td>
<td>t = 0.7 mm; d = 50 mm</td>
<td>t = 2.5 mm; d = 59 mm</td>
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<td><img src="image" alt="Steel Diagram" /></td>
<td><img src="image" alt="CFRP Diagram" /></td>
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<tr>
<td></td>
<td>t = 0.7 mm; d = 107 mm</td>
<td>t = 1.5 mm; d = 75 mm</td>
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<td><img src="image" alt="Steel Diagram" /></td>
<td><img src="image" alt="CFRP Diagram" /></td>
</tr>
<tr>
<td></td>
<td>t = 3.4 mm; d = 50 mm</td>
<td></td>
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- Is there enough packaging space for larger section?
- Process limitations
  - Wall thickness
  - Features such as ribs
  - Overmolding
## MANUFACTURING PROCESSES

Process selection based on the strength, shape/size, material choices and cycle time requirements

<table>
<thead>
<tr>
<th>Process</th>
<th>Fiber Content (%)</th>
<th>Strength</th>
<th>Cycle Time</th>
<th>Shape</th>
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</thead>
<tbody>
<tr>
<td>Compression Molding</td>
<td>20-50</td>
<td>Medium</td>
<td>1-20 min</td>
<td>Simple to complex</td>
</tr>
<tr>
<td>Injection Molding</td>
<td>10-50</td>
<td>Low - Medium</td>
<td>0.5 – 2 min</td>
<td>Small complex parts</td>
</tr>
<tr>
<td>RTM</td>
<td>20-50</td>
<td>Medium</td>
<td>3-40 min</td>
<td>Simple to complex</td>
</tr>
<tr>
<td>SRIM</td>
<td>20-50</td>
<td>Medium</td>
<td>2-20 min</td>
<td>Simple to complex</td>
</tr>
<tr>
<td>Autoclave</td>
<td>40-60</td>
<td>High</td>
<td>60 – 180 min</td>
<td>Simple to complex</td>
</tr>
<tr>
<td>Pultrusion</td>
<td>60</td>
<td>High (longitudinal direction)</td>
<td>Fast</td>
<td>Constant cross section</td>
</tr>
<tr>
<td>Filament Winding</td>
<td>60-70</td>
<td>High</td>
<td>Slow - Fast</td>
<td>Cylindrical, axis symmetric</td>
</tr>
<tr>
<td>Roll Wrapping</td>
<td></td>
<td>High</td>
<td>Medium - Fast</td>
<td>Tubular</td>
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</tbody>
</table>
CURRENT STATE OF CFRP MOLDING TECHNOLOGIES

How can we get here?
SEVERAL TECHNICAL CHALLENGES NEED TO BE ADDRESSED TO EXPAND COMPOSITE USAGE IN MAINSTREAM VEHICLES

• Cycle time reduction and process automation
• Improved confidence in analytical capability
  o Efficient predictive computational tools
  o Reliable material properties database for modeling and simulations
  o Material and tests standardization
• Low cost diagnostics and repair: NDE
• Dissimilar materials joining
• Cost effective recycling
VALUE PROPOSITION

• Composites must demonstrate competitiveness against benchmark in terms of mass, performance and cost

• Each program has different weighting for these metrics based on customer expectations

• Weakness in one or more areas must be compensated by added benefits in other areas
  • One off customized solution for a specific applications where one of the three elements have significantly higher weighting
  • Weak business case for broader applications
$/KG MASS SAVED: KEY METRIC FOR LIGHT WEIGHTING

Threshold may vary based on
- Brand, Architecture
- Program requirements
- Distribution of mass in vehicle

Higher Dollars/kg tolerance
FAVORABLE TRENDS GOING FORWARD

• Light-weighting
  o Stringent fuel economy requirements means lighter and more aerodynamic vehicles which favor composites
  o 0-60 performance improvement, offset for additional contents in vehicle

• Growing competition demands faster product updates with unique styling and designs, both factors in favor of composites

• Diverse consumer demand globally leading to more fragmentation of the market which means lower volume build variants, positive for composites

• End of risk averse culture. More willingness to accept composites as an alternative to metals

• Consolidation in the supplier base in a weak economy. Stronger and stable supply base will emerge
SUMMARY

- Plenty of opportunities to grow composite usage in the automotive industry. However they will not replace metals completely. Future automotive body will most likely be made of multi-materials.

- OEMs will select right materials for right applications. Composites need to demonstrate competitiveness for each application in terms of performance, cost and light-weighting potential

- Selecting the material composition and process early in the development is essential to realize the full value proposition
ACKNOWLEDGEMENT

- Mark Voss
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