Automotive Composites Consortium:

Focal Project 4: Structural Automotive Components from Composite Materials

Advanced Materials and Processing of Composites for High Volume Applications

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May 12, 2011

Project ID #LM046

Focal Project 4: Overview

AUTOMOTIVE COMPOSITES CONSORTIUM

Timeline

- Start – October 2006
- Finish- September 2011
- 90% complete (based on time)

Budget

- Total project funding
  - DOE share: $9,235K
  - Contractor share: $5,800K
- Funding received in FY10
  - $1,200K
- Funding for FY11
  - $700K

Barriers

- Barriers addressed
  - The cost-effective mass reduction of the passenger vehicle, with safety, performance, and recyclability;
  - Performance, reliability, and safety comparable to conventional vehicle materials;
  - Development and commercial availability of low cost structural composites, with lifecycle costs equivalent to conventional steel.

Partners

- Interactions/ collaborations
  - Multimatic
  - Continental Structural Plastics (CSP)
  - Century Tool and Gage
  - ORNL
  - U Mass Lowell
  - IBIS and Camanoe
- Project leads
  - Libby Berger
  - John Jaranson

Focal Project 4

AUTOMOTIVE COMPOSITES CONSORTIUM

Milestones

Month/ Year	
Nov 2007	Structural Composite Underbody: Selection of a Material and Process System
Mar 2010	Structural Composite Underbody: Full Design of Underbody, Including Manufacturing and Analysis Scenarios
Dec 2010	Structural Composite Underbody: Fabrication of Testable Underbodies
July 2011	Structural Composite Underbody: Assembly Testing and Correlation with Analysis
Mar 2008	Lightweight Composite Seat: Initial Design and Structural Analysis
Aug 2009	Lightweight Composite Seat: Design for a Cost-effective Seat
Feb 2011	Lightweight Composite Seat: Fabrication and Testing of Seat

Objectives

Focal Project 4: Structural Automotive Components from Composite Materials (ACC007)

The objective of this project is to use composite materials to decrease the mass of high-volume automotive structures, at acceptable cost. The project goals are:

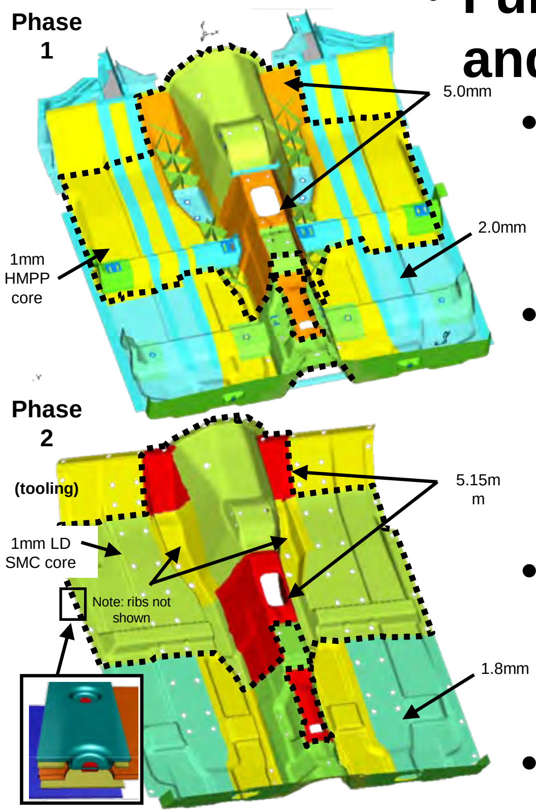
•Guide, focus, and showcase the technology research of the ACC working groups.
•Design and fabricate structural automotive components with reduced mass and cost, and with equivalent or superior performance to existing components.
•Develop new composite materials and processes for the manufacture of these high volume components.

Focal Project 4

Approach

- This project targets two automotive structures, a structural composite underbody and a lightweight composite seat, as well as the materials and processes required to produce them.
- The underbody project will design, analyze, fabricate, and test a structural composite underbody for a large rear-wheel-drive vehicle. The primary research outcomes of this project are:
  - A 2 ½ minute cycle time (100k vehicles per year, 2 shift operation)
  - Methods of joining and assembly of the underbody to the vehicle
  - Processes for fabricating oriented reinforcement within the time window
- The seat project focuses on a second row seat which combines the functions of a seat (both with and without an integrated restraint system) and a load floor. The seat must save mass, be cost competitive at volumes from 20k to 300k, and the seat back must fold flat to create a load floor.

Structural Composite Underbody: Technical Accomplishments (previous years)



- Full design of underbody, including manufacturing and assembly scenarios
  - Design composite underbody with high elongation material (patent granted in 2010), combining 16 steel parts
  - Develop glass fabric/vinyl ester SMC with low density SMC core
    - Glass selected over carbon since part is strength limited instead of stiffness limited.
  - Mass savings 11.5 kg + enabling 3.3 kg mass savings from front rails, due to greater stiffness (31% of underbody and rail savings)
  - Composite to steel weld bond joint (patent granted in 2010)

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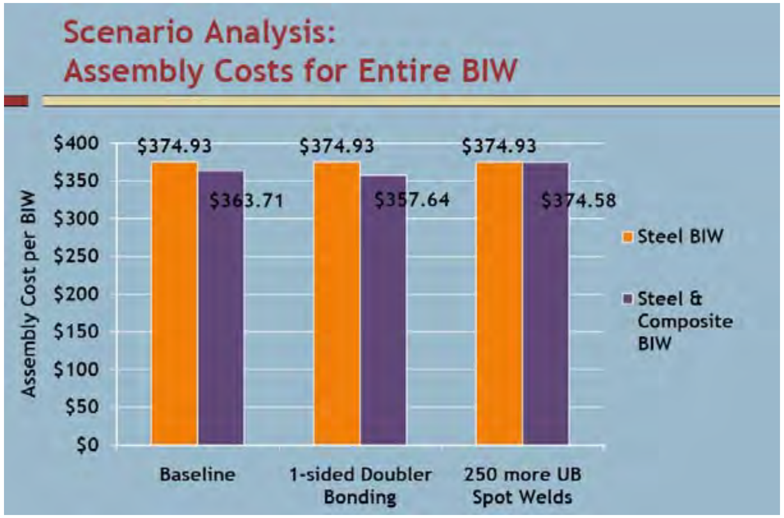
Structural Composite Underbody: Technical Accomplishments

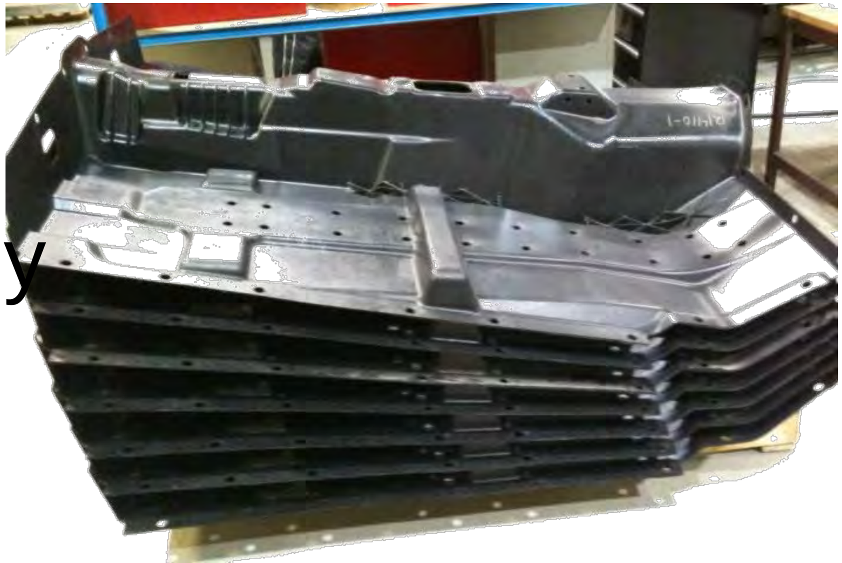
- Demonstrate full underbody molding with fabric SMC
- Load fabric preform into tool 40 seconds
- Cure time 3.0 min
- Path forward for 2.5 min cycle with 3-piece tool

Structural Composite Underbody: Technical Accomplishments

- Technical Cost Model
  - Manufacture and Assemble Underbody for $5/kg saved, based on TCM of steel and composite systems



- Successfully molded and delivered over a dozen Underbodies for assembly and testing



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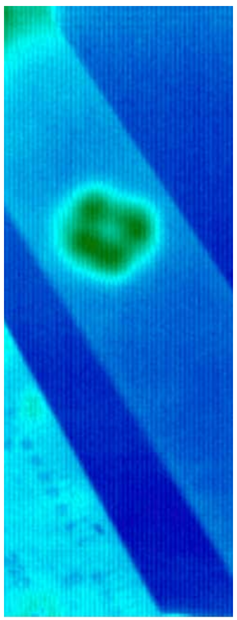
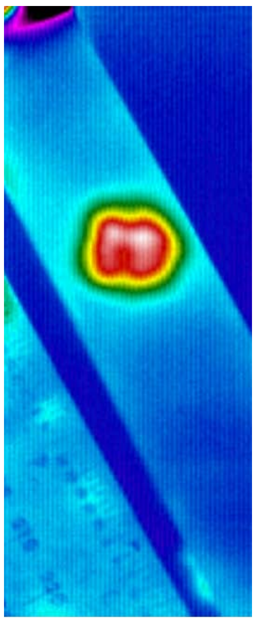
Structural Composite Underbody: Technical Accomplishments

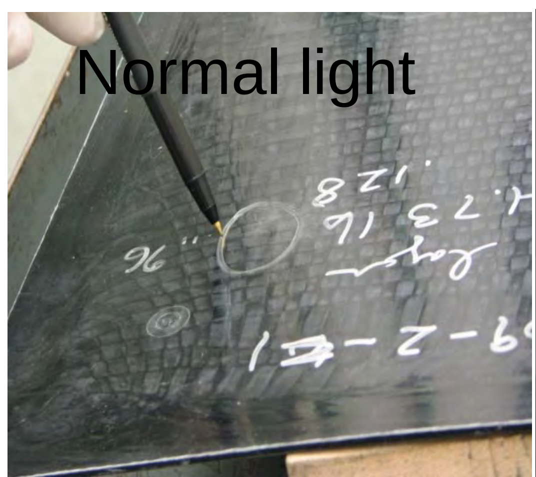
- Non-destructive evaluation of impact damage from steel ball drops shown
  - Vibrothermography
  - UV florescent dye penetrant

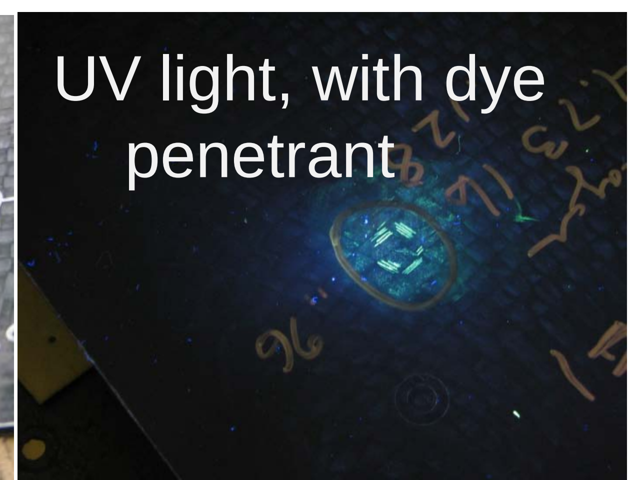


Impact side



back side





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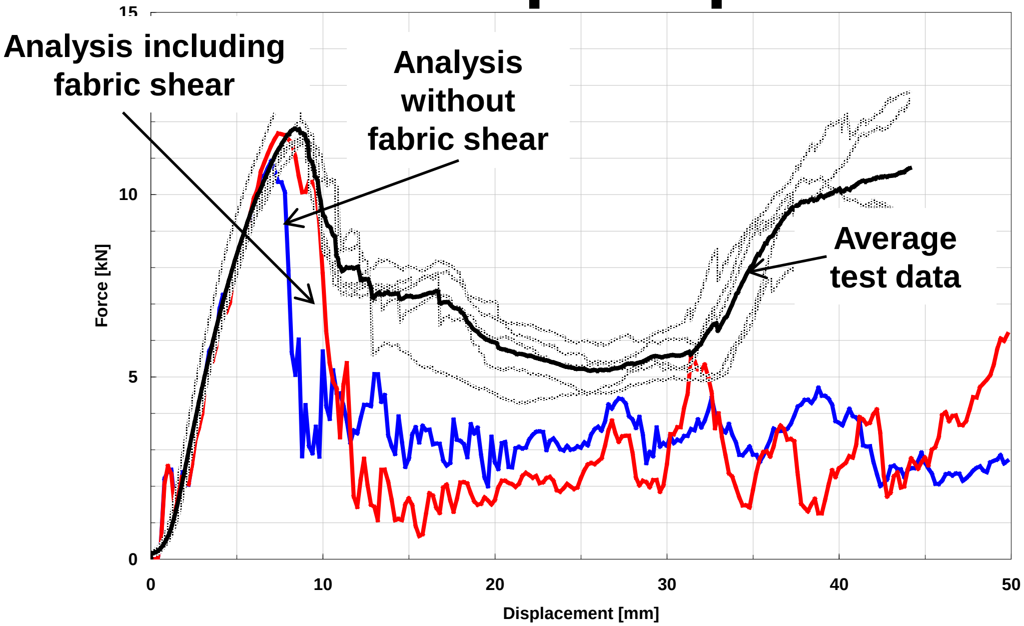
Structural Composite Underbody: Technical Accomplishments

As-molded double dome

FEA models quasi-static crush of surrogate double dome sample well through peak loads, and is conservative post-peak.



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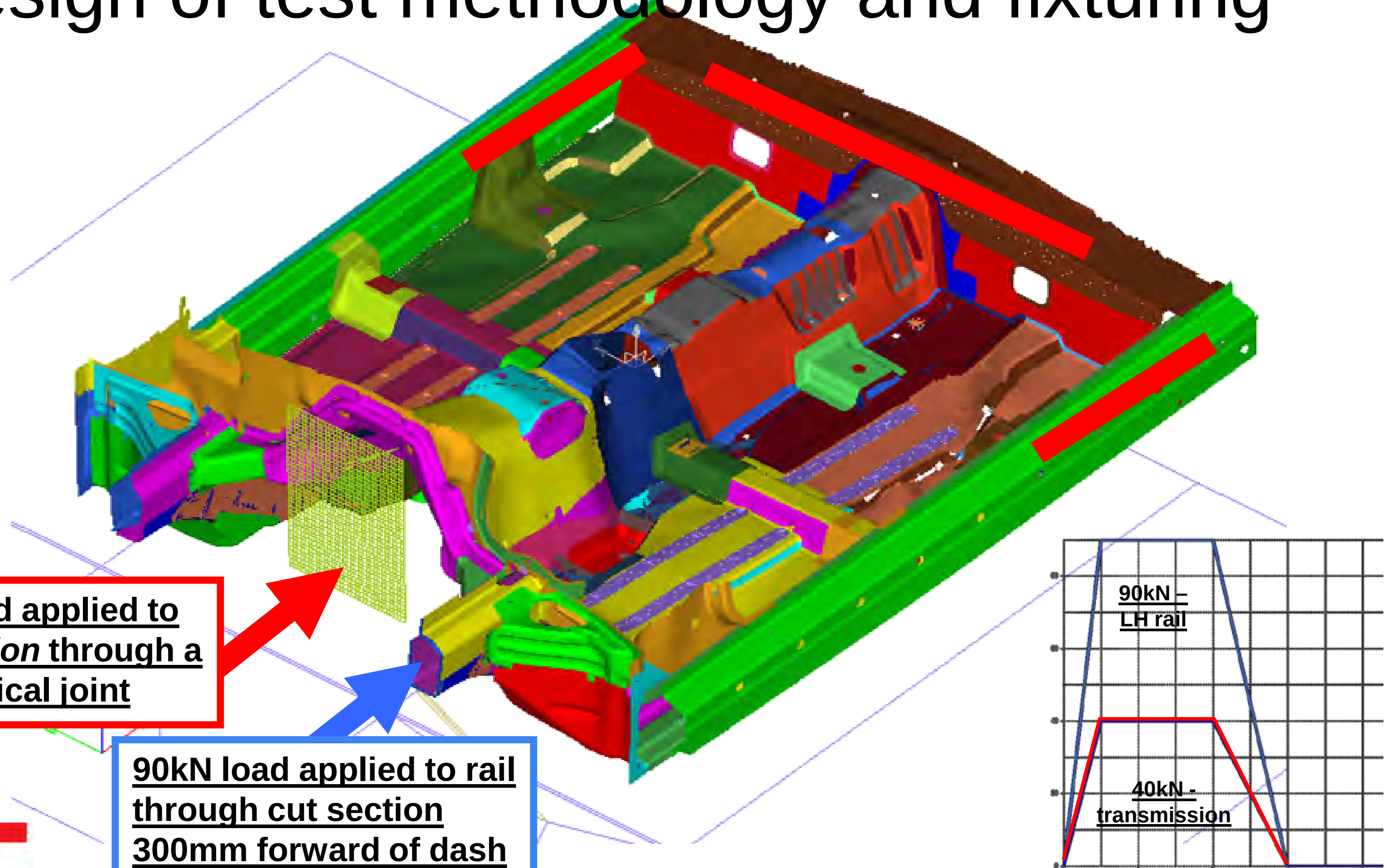
Structural Composite Underbody: Technical Accomplishments

- Design of test methodology and fixturing



40kN load applied to *transmission* through a spherical joint

90kN load applied to rail through cut section 300mm forward of dash panel

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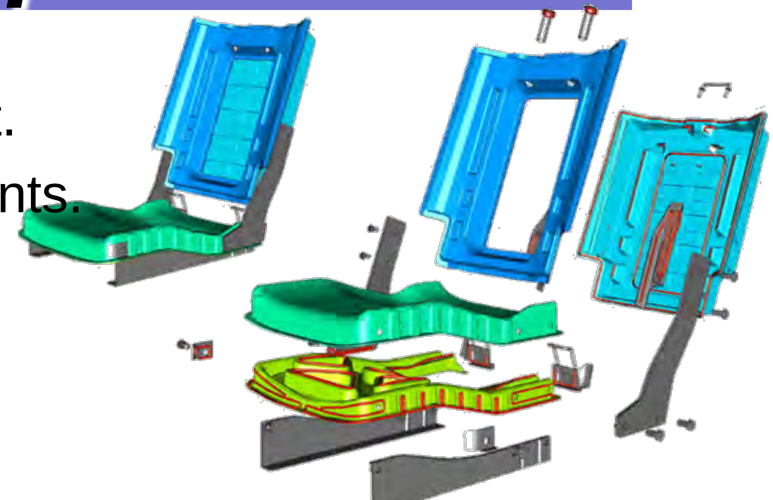
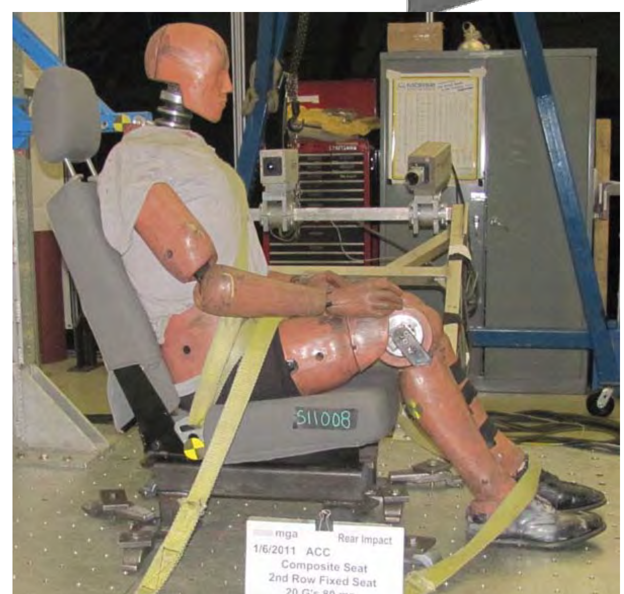
Composite Seat
Technical Accomplishments



- Completed final design of composite seat.
- Completed CAE for all loading requirements.
- Completed molding and assembly of 30 sets of seats.
- Tested 22 seats.



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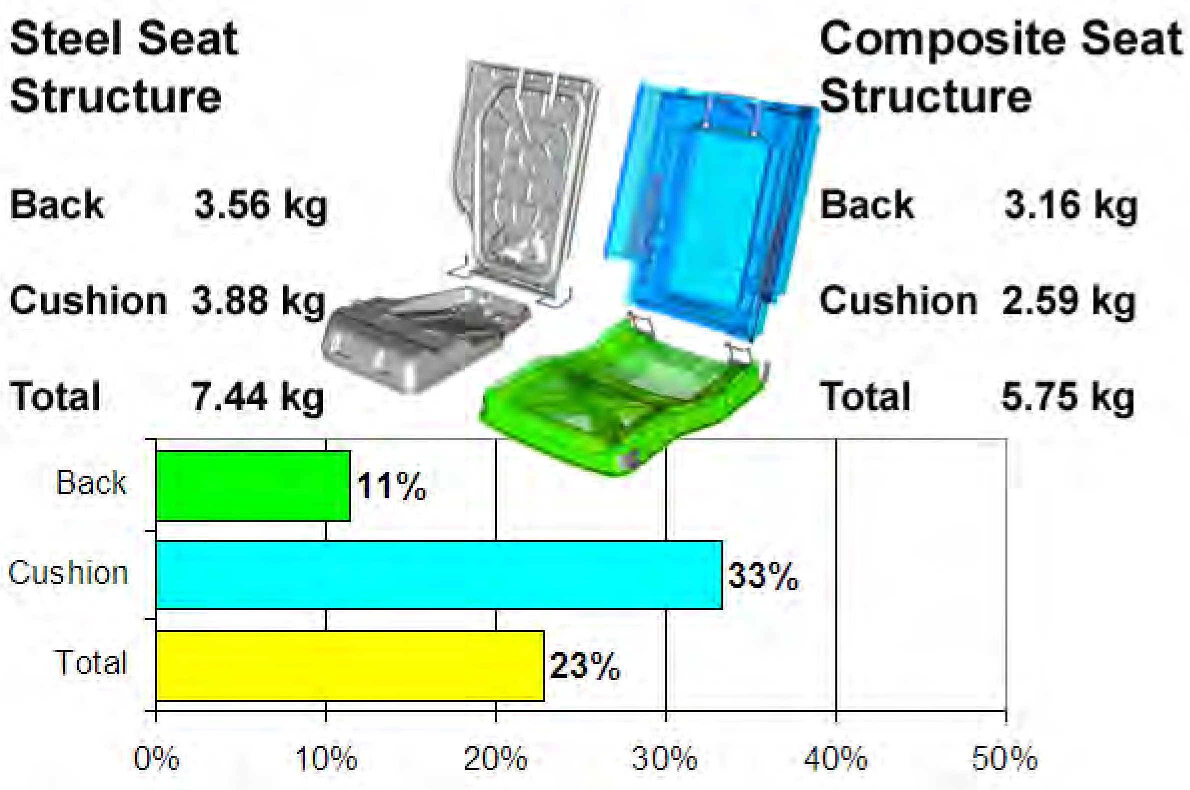
Composite Seat Technical Accomplishments

- Achieved a 23% weight reduction for the seat structure compared to a typical steel seat structure.



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Focal Project 4: Collaborations

- **Partners**
  - Multimatic
  - Continental Structural Plastics (CSP)
  - Century Tool and Gage
  - ORNL
  - U Mass Lowell
  - IBIS & Camanoe
  - Composite Products, Inc
  - Altair Engineering
  - Chelexa Design
  - RCO Engineering
  - MGA Research

- **Technical Transfer**
  - OEM's to determine opportunities for future implementation

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Focal Project 4: Future Efforts

1. Molded underbodies will be assembled and tested in static and dynamic modes, with the results compared to the analysis.
2. Develop a realistic automation scenario for efficient high volume preform preparation.
3. Complete comparison of test results and analysis of the composite seat.
4. Develop and carry-out work plan for additional testing and verification as needed for automotive integration.

Summary

- Structural Composite Underbody
  - Molding of full underbody part, which replaces 16 steel parts, saving 11.5 kg mass (31%)
  - Development of a high strength glass fabric SMC
  - Weld bonding assembly scenario demonstrated
  - Technical cost model indicates $5/kg mass saved
  - Design methodology demonstrated for crush of surrogate part
  - Test methodology and fixturing designed
- Composite seat
  - Final design, CAE, molding and assembly of seats, showing 23% mass savings relative to steel seat
  - Static and dynamic testing of seat assemblies

Advanced Materials and Processing of Composites for High Volume Applications (ACC932)

Project Leader: Dan Houston
Presenter: Libby Berger

Automotive Composites Consortium (ACC)

May 12, 2011

Project ID #LM046

ACC 932 : Objectives

Advanced Materials and Processing of Composites for High Volume Applications

1: Carbon Fiber Sheet Molding Compound SMC – Develop high-performance, cost-effective, carbon fiber SMC materials and associated processing techniques for high-volume automotive components. This will allow OEM's a chance to implement both Class-A and structural applications that allow significant weight savings coupled with superior mechanical performance.

2: Bond-Line Read-Through BLRT – Enable implementation of minimum thickness composite closure panels to eliminate weight added for appearance by developing a validated finite element (FE) model that can predict, and therefore allow design optimization of, the severity of BLRT distortions based on part design. This will allow OEMs to implement minimum thickness composite closure panels while still meeting customer expectations for surface quality.

3: Direct Long Fiber Technology DLFT & Long Fiber Injection LFI Thermoplastics – Determine processing parameters, customize master batch formulations for Nylon material, establish composite material properties, investigate processing equipment and tooling design and develop Tier-1 supplier interface.

Overview – CF SMC

Timeline

- Start – May 2007
- End – December 2012
- 65% Complete

Budget

- Total project funding
  - DOE share
  - Contractor share
- $75,000 in FY10 (excluding C. Knakal)
- $174,000 in FY11

Barriers

- Barriers addressed
  - Technical; Fiber Compatibility and Surface Treatments, Resin Development and High Volume Manufacturability
  - Market: Fiber Cost, Inadequate Supply Base and Understanding of Automotive Requirements

Partners

- Continental Structural Plastics, a Tier One supplier
- Zoltek, carbon fiber manufacturer
- Huntsman, epoxy resin system

Carbon Fiber SMC

Milestones

Month/ Year	
May/2008	Install carbon fiber SMC compounding equipment modification.
Dec/2010	Develop a resin system compatible with carbon fiber reinforcement. Fiber bundle spreading is a critical component for proper wet-out of the carbon fibers.
Jun/2011	A low cost structural carbon fiber will be incorporated with an optimized resin system and compounding process to produce a cost effective carbon fiber SMC package.
Sep/2012	Structural carbon fiber SMC will be refined to provide a class “A” surface appearance material system for automotive applications
Dec/2012	Documentation to allow Tier-1 suppliers to use carbon fiber SMC for OEM usage.

Carbon Fiber SMC

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Approach

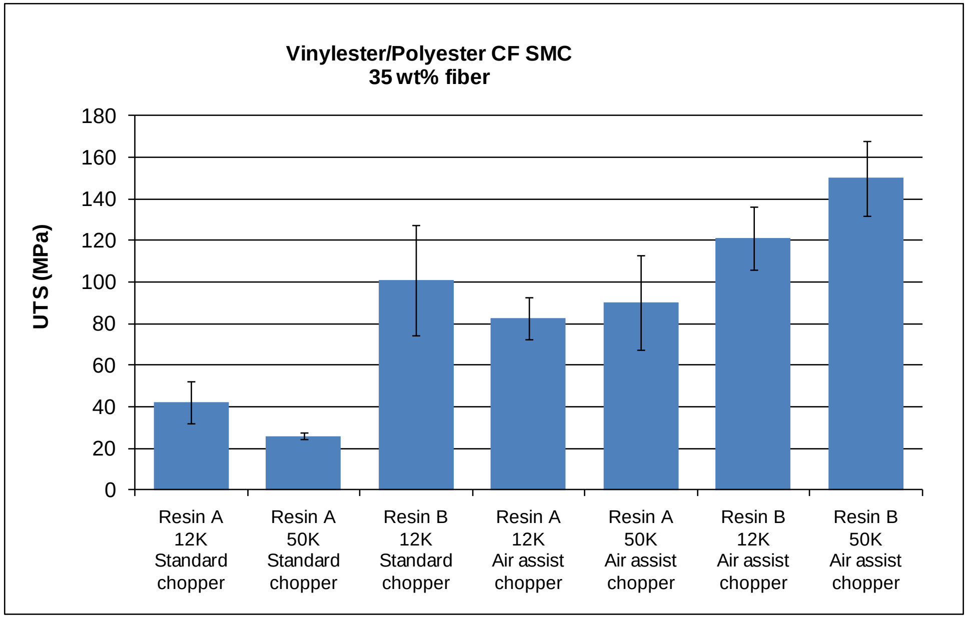
- Initiate studies with Tier-1 and 2 resin and fiber supply base to understand their capabilities and what they are able to add to the project objectivities.
- Compound carbon fiber SMC and characterize mechanical properties to compare against current state-of-art systems.
- Modify SMC compounding machine/process to allow for improved wet-out of SMC composite.
- Develop and start carbon fiber bundle spreading experiments to maximize mechanical properties.
- Investigate optimizing the compounding process for enhanced consistency and cost effectiveness.
- Focus on optimizing the structural compound to enhance its appearance for visible automotive applications.

Carbon Fiber SMC

AUTOMOTIVE COMPOSITES CONSORTIUM

- In 2008 equipment was modified, materials were evaluated, and preliminary fiber “sizing” studies were made.
- In 2009 the “air knife” concept was explored to enhance de-bundling of the carbon fibers. De-tensioning the bundle seems to be a crucial element.
- In 2009 multiple trials indicate very fine lines between having dry fiber bundles, wetting out the carbon fiber bundles, and losing bundle integrity during compounding.
- In 2010 design of experiments were conducted using epoxy and vinylester resins, 6K, 12K, and 50K carbon fibers, standard and elevated temperature/pressure compounding, and standard and air assisted choppers:
  - SMC compounds made with both resin systems showed near target performance, but compounding process window for epoxy was narrow.
  - Promising SMC materials were successfully made with “de-bundled” large tow carbon fibers using air assisted chopper.

Carbon Fiber SMC



- Air de-bundled carbon fibers produced higher tensile strength SMC from both vinylester resin systems.
- Vinylester resin B seemed to be more compatible with carbon fibers than vinylester resin A.

Carbon Fiber SMC

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Collaborations

- **Partners**
  - Continental Structural Plastics (CSP); resins and compounding
  - Zoltek; carbon fibers and sizing
  - Huntsman; alternative resins
  - National Composite Center; compounding
- **Technical Transfer**
  - Collaborate with CSP, Huntsman, and Zoltek to implement into high volume applications
  - OEM’s to define prototype component for full prove out
  - OEM’s to determine opportunities for future implementation

Carbon Fiber SMC

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Future Efforts

1. Continue to refine understanding of critical compounding variables; such as compaction pressure, resin viscosity, and resin/fiber ratios.
2. Using lower cost carbon fibers, evaluate low cost methods to “de-bundle” the carbon fibers; such as bundle spreading, air blasts, de-tensioning, and an alternative chopper system.
3. Study additives and resin modifications to enhance the surface appearance of the molded material.
4. Mold developmental parts for potential OEM applications.

Overview – Bond Line – Read Through

Timeline

- Start – March 2005
- End – March 2011
- 100% Complete

Budget

- Total project funding
  - DOE share
  - Contractor share
- $305,000 in FY10
- $40,000 in FY11

Barriers

- Barriers addressed
  - Technical; designed, built and qualified system to measure BLRT.
  - Technical; developed models to predict BLRT.
  - Market: developed weight reduction opportunity

Partners

- Continental Structural Plastics, a Tier One supplier
- Multimatic, Finite Element Modeling Development Source

Bond-Line Read-Through

AUTOMOTIVE COMPOSITES CONSORTIUM

Milestones

Month/ Year	
5/2008 **Complete**	Phase 1: Develop a measurement system capable of quantifying the visual severity of BLRT-induced distortions
8/2010 **Complete**	Phase 2: Experimentally determine the material and process factors that are the root cause of BLRT. Completion of all experiments, including part validation experiment.
1/2010 **Complete**	Phase 3: Determine material models required to correctly predict BLRT-induced distortions using finite element modeling.
9/2010 **Complete**	Phase 3: Establish design and manufacturing guidelines for eliminating visible distortions in production parts and methodologies for updating those guidelines upon adoption of new materials (i.e. Class "A" carbon fiber SMC).
2/2011 **Complete**	Project Documentation: Peer reviewed journal papers summarizing the material and process factors that contribute to BLRT and the design and manufacturing guidelines for eliminating visible distortions.

Project is Complete

Bond-Line Read-Through

FY10 Technical Accomplishments

- ***Phase 2 – Determine BLRT Root Cause***
  - Completed Final Two Factor Evaluation Experiments
    - Dam Design and Hard Hit Experiment
      - Any feature that can be molded into an inner panel will cause a visible distortion in the outer above it
      - It is the presence of adhesive that causes visible distortions not differences in paint thickness
    - Fixture Type Experiment: Hot Air vs. Electric Heat
      - The method of applying heat to the panel does not affect the severity of the distortion
  - Completed Final Validation Experiments
    - Bead Shape Experiment
      - Completed to provide data for CAE validation
      - Found that for thickness changes that occur gradually, only the thickness is important (the fact that it has changed is not important)
    - Mustang Decklid Validation Experiment
      - Lessons learned in this project can be implemented on a part.
      - Manufacturing processes need to be more tightly controlled!

Bond-Line Read-Through

FY10 Technical Accomplishments

- ***Phase 3 – Analytical Model for Predicting BLRT***
  - Validated that Model Predicts Distortion within Measured Experimental Data Variation
    - CAE to Experimental Correlation Study
      - Demonstrated correlation between prediction and experimental data within the noise
    - CAE Bead Shape Study
      - Showed that if the thickness of the bead changes gradually only the actual thickness (not the fact that it has changed) matters
      - Confirmed all prior experimental findings
    - Influence of Global Part Geometry Study
      - BLRT is a localized distortion and is not affected by the global shape of the part
    - Influence of Local Part Geometry Study
      - Abrupt changes in the local part geometry (character lines) will create local BLRT (it may appear as a circular “divot”!)
    - Completed a series of single factor studies to support final reports

Overview – DLFT & LFI Thermoplastics

AUTOMOTIVE COMPOSITES CONSORTIUM

Timeline

- Start – March 2009
- End – December 2011
- 66% Complete

Budget

- Total project funding
- $131,000 FY10
- $130,000 FY11

Barriers

- Barriers addressed
  - Technical; Performance and Manufacturability
  - Market: Cost

Partners

- Continental Structural Plastics, a Tier One supplier
- National Composite Center
- DuPont, BASF, PPG and University of Western Ontario

Affordable Vehicle Weight Reduction through Direct Compounding

AUTOMOTIVE COMPOSITES CONSORTIUM

Month/ Year	2010 & 2011 Milestones
5/2010 – 9/2010	Completed injection molding trials of direct compounded PA66 materials formulations to validate material rheology while manufacturing ISO and ASTM test samples for subsequent testing. Completed a parallel set of studies to validate use of the same formulation for direct compression molding.
7/2010- 12/2010	Completed mechanical testing of compression and injection molded panels to determine short and long term heat ageing performance. Demonstrated equivalent performance against conventional material systems.
1/2011- 2/011	Completed processing studies to determine effect of compounder process setup on fiber chopping and fiber length attrition. Completed loss by ignition and mechanical testing of excised samples to quantify performance benefits of compression vs. injection molding

Month/ Year	Future Work
3/2011 – 7/2011	Compounding trials are planned to investigate the effect of compounder screw element design and configuration on constituent dispersion, distribution and fiber length attrition.
5/2011 – 7/2011	Fiber processing studies will be performed to confirm processing capability of low cost carbon fibers using the direct compounding approach.