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Polymer Composites Research in the LM Materials Program Overview

*Photo Courtesy of Ford Motor Company

20 May 2009

*Photo Courtesy of Freightliner

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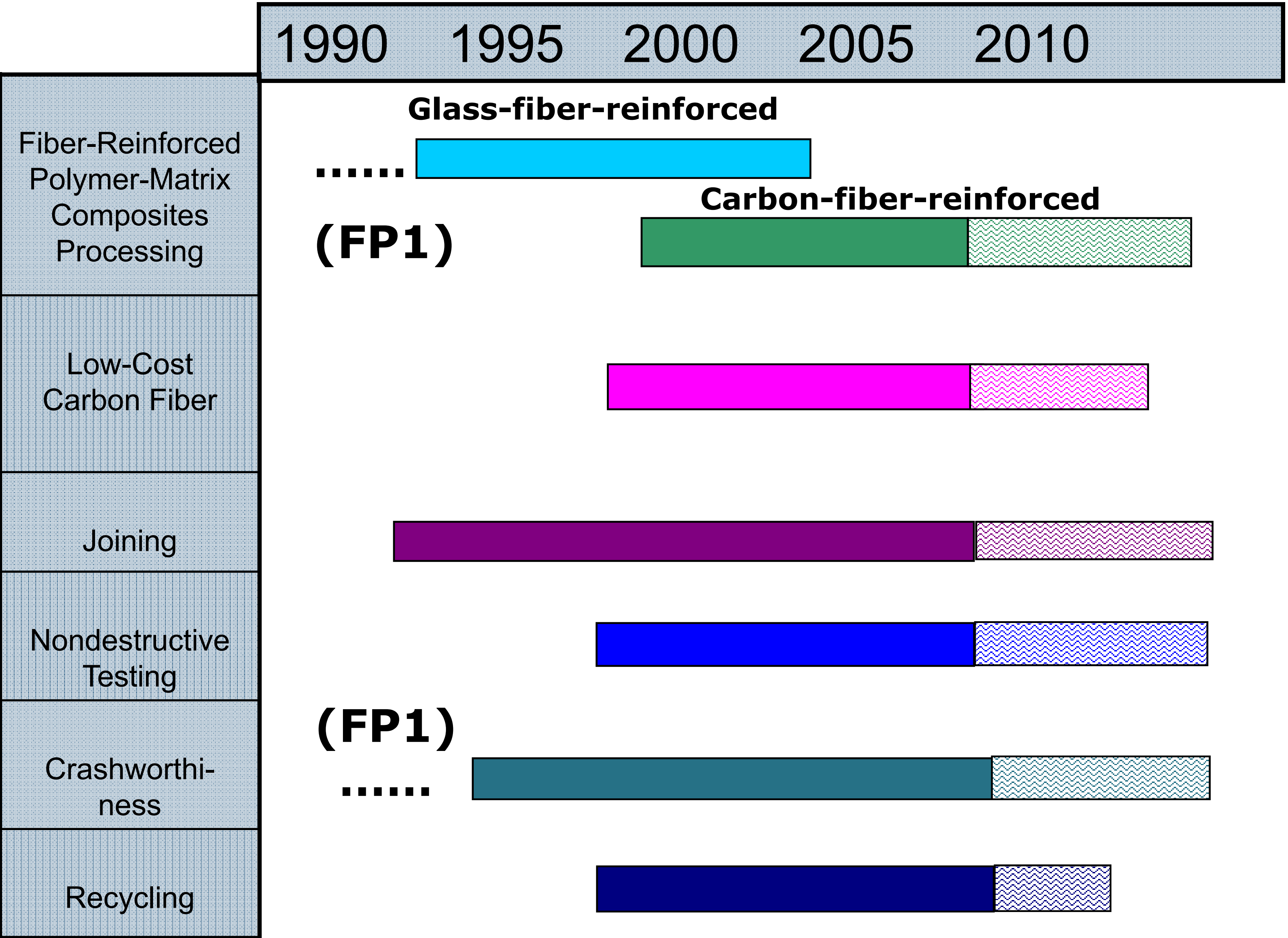
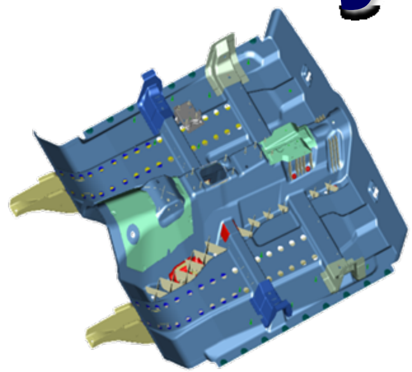
ALM Historical Timeline – Composites



ACC Key Deliverables

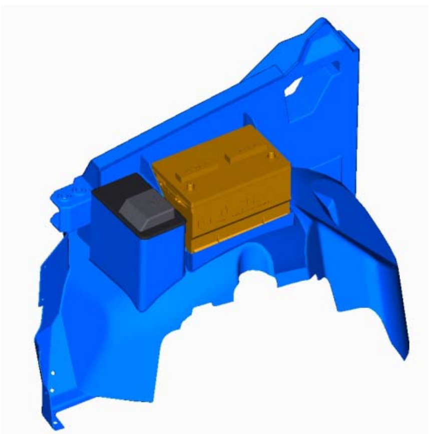


Composite Underbody

Low Cost Carbon Fiber

Carbon Fiber SMC Hood

2008 2010 2012 2014



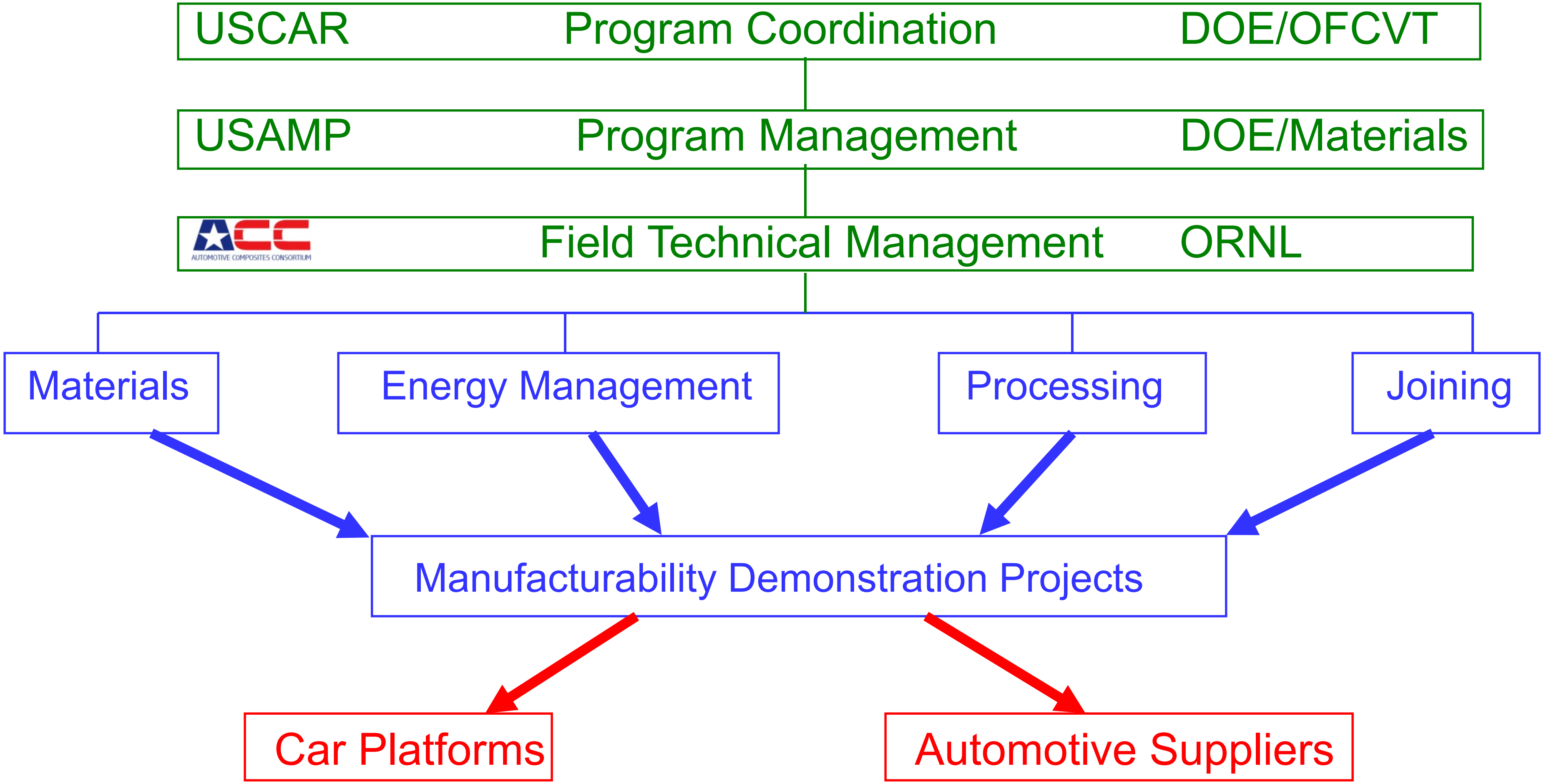
Polymer Encapsulated Mega-Module

Composite Seat

EMWG Composite Front Structure

*Slide provided courtesy of Automotive Composites Consortium

Automotive Research Program Old Organization



What we were Doing --- Carbon Fiber Composites

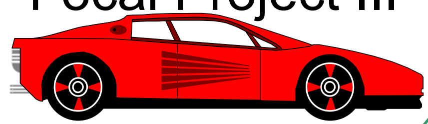
Processing
P4 Carbon Fiber
High Vol Process of Composites **(4)**
Next Generation P4
Optimal CF for P4
Chassis Support Structures
Chassis Structures
Body and Door Structures

Joining
Advanced Joining
Joint Energy Absorption
NDE Techniques
Heavy Vehicle Joining

Other
Cost Modeling – Program
Composites Conference

21st Century Truck
Automotive Lightweighting Materials

Focal Project III



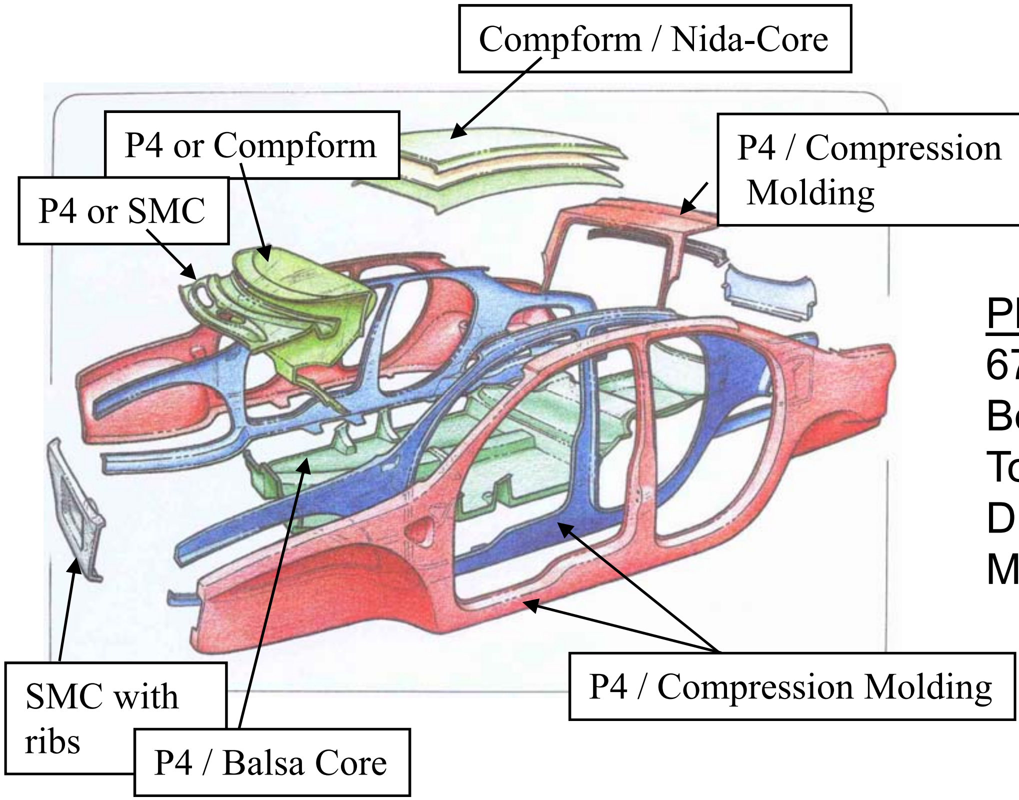
FreedomCar & 21Century Truck Goals

Low Cost Carbon Fiber
Lignin Based Precursors
Microwave Processing
Carbon Fiber Two Splitting
Advanced *Oxidation*
Advanced Stabilizaton
LCCF Integration Line

Materials
CF Comp Durability
Compressive Creep
Materials Dev & Screening
Recycling PMCs
CF SMC Structures
Development of CF SMC

Energy Management
Crash Adsorp of Bonded Structures
Crash Energy Management **(7)**
Testing Machine for Auto Crash
Crash of Sandwich Structures

Composite (Carbon) Intensive Body-In-White



Vehicle package
(based on DC JA)

Phase 1 Results:
67% mass savings over baseline
Bending stiffness exceeded 20%
Torsional stiffness exceeded 140%
Durability and abuse load cases satisfied
Manufacturing strategy developed

Courtesy of:
AUTOMOTIVE COMPOSITES CONSORTIUM

Materials / Mass Distribution:
Chopped carbon - 54.8 kg
Carbon fabric - 17.7 kg
Core - 3.2 kg
Adhesive - 1.6 kg
Inserts - 8.8 kg

ACC Reorganization

AUTOMOTIVE COMPOSITES CONSORTIUM

Board of Directors

Chrysler	General Motors	Ford
Doug Peterson	Hamid Kia	Jim deVries
Khaled Shahwan	Matt Carroll	David Wagner

ACC 007
Composite Structures Technology Demonstration
Focal Project IV
(Libby Berger)

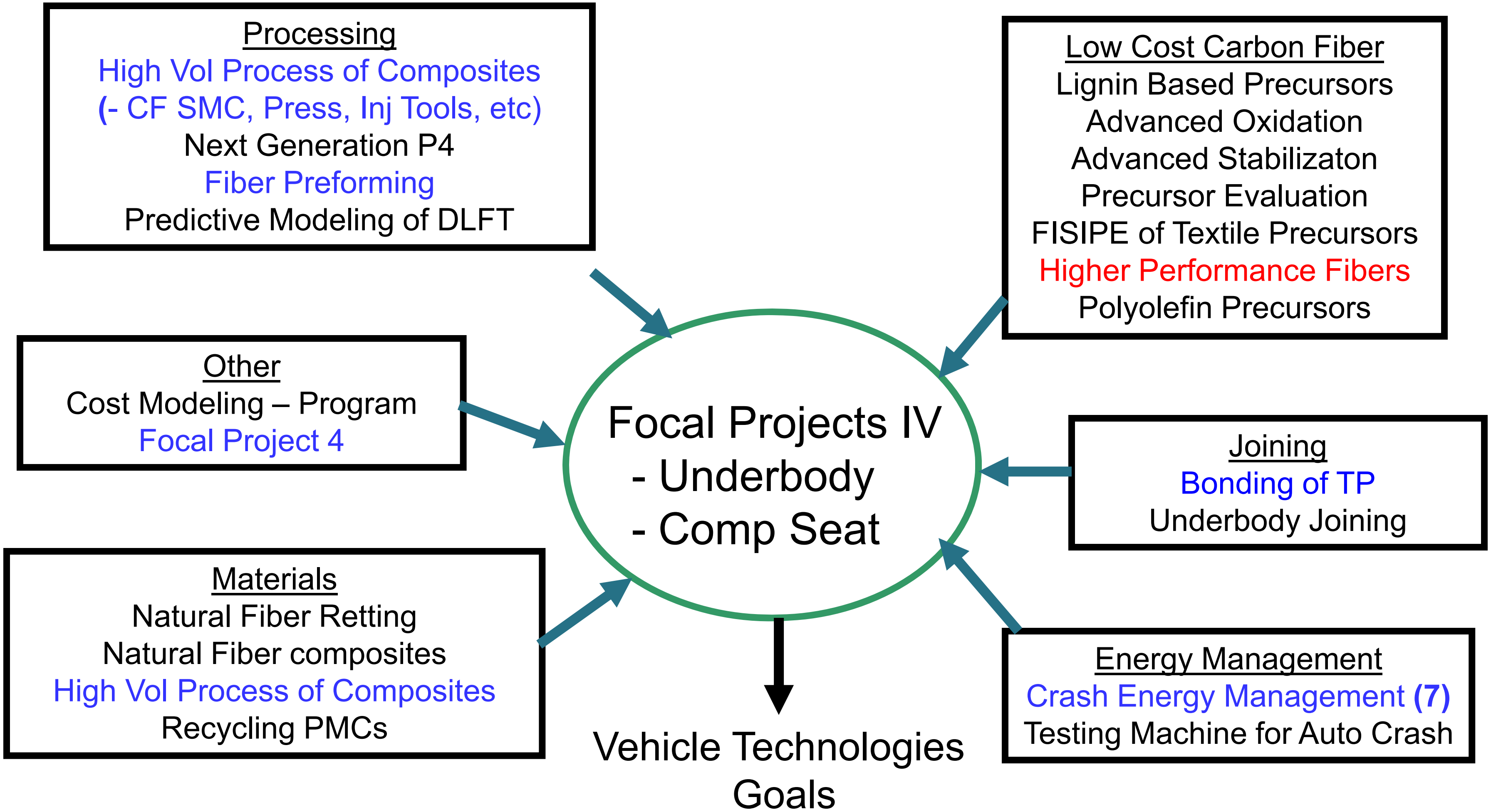
ACC 932
Materials and Processes Technology Development
(Dan Houston)

ACC 100
Predictive Technology Development
(Khaled Shahwan)

ACC Mission

To conduct joint research programs on structural and semi-structural polymer composites in pre-competitive areas that leverage existing resources and enhance competitiveness.

What we are Doing --- Carbon Fiber Composites

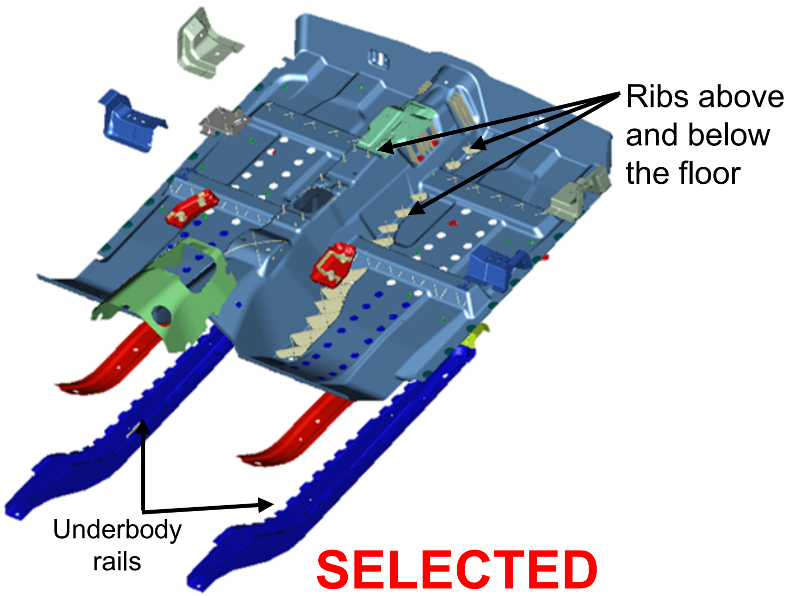


Coordinated with Hydrogen Program
Cooperative Agreement
Direct Funded

Focal Project 4 – Composite Underbody

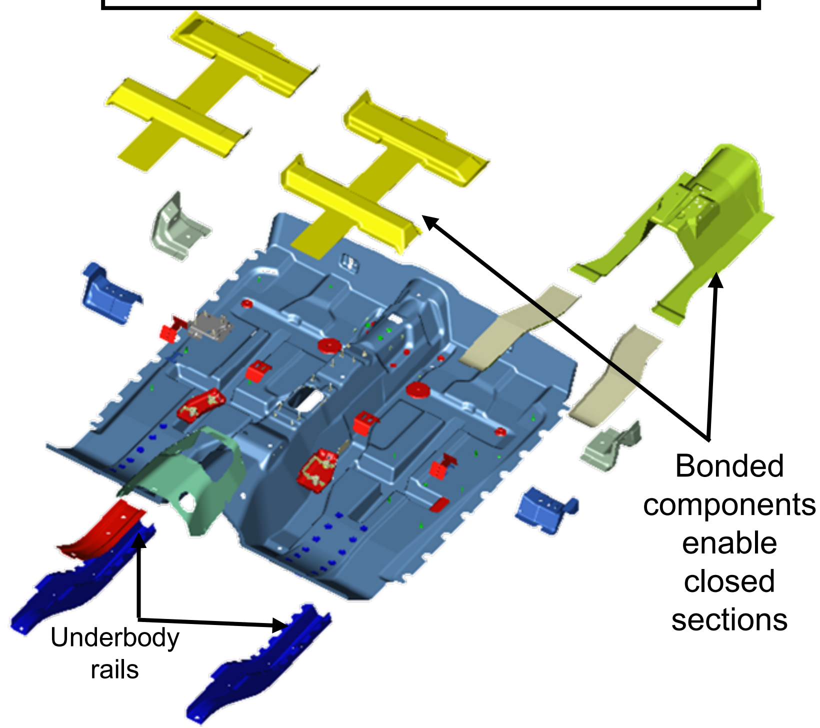
<u>Ribbed Composite:</u>
Components: ~55% reduction
Reinforcements: ~17% reduction

<u>Bonded Composite:</u>
Components: ~41% reduction
Reinforcements: ~17% reduction



SELECTED

Ribbed Design Concept



Bonded Design Concept

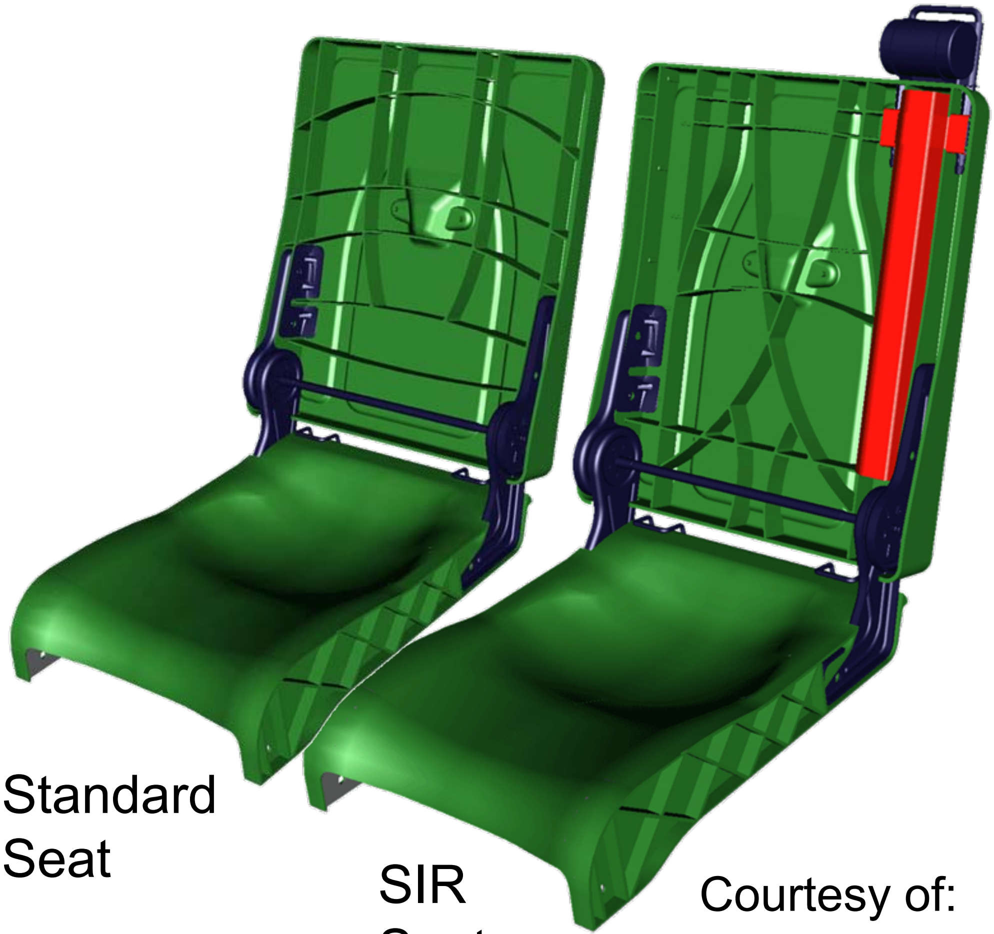
Courtesy of:

ACC
AUTOMOTIVE COMPOSITES CONSORTIUM

Focal Project 4 - Composite Seat

- **Structures Level**
  - Back Frame and Cushion Frame only
  - Carry-over Headrest Design
  - Mechanisms and legs not included (except as related to attachments and joints)
  - Seat Integrated Restraint to be included.

- **Materials Level**
  - Thermoplastics and Thermosets included
  - Glass reinforcement with local carbon as required
  - Metal reinforcements included.



Standard Seat

SIR Seat

Courtesy of:

ACC AUTOMOTIVE COMPOSITES CONSORTIUM

Presentations

Time	Agreement Number	**Technical Presentation**	**Briefing**	**Presenter(s)**	**Funding ($) FY 09**
4:15 – 4:25		Overview of Polymer Composites	LM - 06	Dave Warren	
4:25 – 4:45	17241	Composite Underbody Joining		Bob Norris	325,000
4:45 – 5:15	ACC 932	High-Volume Processing of Composites	LM – 07	Hamid Kia	510,420
5:15 -5:45	ACC 007	Focal Project 4 --Composite Underbody and Seat	LM – 08	Hamid Kia	789,060
8:30 – 9:00	ACC 100	Composite Crash Energy Management	LM - 09	Hamid Kia	824,500
9:00 – 9:10	8992	Testing Machine for Automotive Composites (TMAC)	LM - 10	Bob Norris	75,000
9:10 – 9:30	9223	Development of Next Generation P4		Bob Norris	250,000
9:30 – 10:00	11131, 11130	Predictive Modeling of Polymer Composites	LM - 11	Mark Smith	1,000,000
10:00– 10:30	16313	Natural Fiber Composite Retting, Preform Manufacturing and Molding	LM – 12	Mark Smith	400,000

Composite Underbody Attachment

B. J. Frame

Oak Ridge National Laboratory

May 18-22, 2009

Project ID #17241

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OAK RIDGE National Laboratory

Overview

- **Timeline**
  - Start: May 2008
  - Finish: March 2011
  - ~25% Complete

- **Budget**
  - Total project funding
    - DOE: $1,075K
  - Funding received in FY08
    - $200K
  - Funding for FY09
    - $325K baseline + $75K plus-up = $400K total
    - Plus-up for additional super lap shear testing

- **Barriers**
  - Barriers addressed
    - Multi-material joint durability
    - Multi-material joint design and analysis
    - Vehicle weight reduction

- **Partners**
  - Oak Ridge National Laboratory (ORNL)
    - Project lead
  - Automotive Composites Consortium (ACC)
    - Joining Group
  - Multimatic, Inc.

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Background

- Technologies for attachment, or joining, of PMC parts to the vehicle's other (metallic) components enables the wide-spread integration of structural composites into vehicle design and manufacture – REDUCING VEHICLE WEIGHT
- Issues associated with multi-material joint design include long-term reliability (durability) and manufacture
- Generic tools for predicting the performance of any composite joint design do not exist
- Validated modeling tools must be created to allow OEMS to predict the durability of composite structures with the same level of confidence as metal structures
- The joint and materials to be used in the PMC underbody must be studied for this particular application
- The methodology can be made applicable to other types of multi-material joints, including other material combinations
- This project is the first step toward achieving these goals

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Objectives

Develop a methodology that will enable prediction of the effects of environmental exposures and mechanical loadings on the durability of a composite/adhesive/metal (multi-material) joint

Focus application: The joining of a polymer matrix composite (PMC) underbody to the rest of the vehicle structure

Milestones

- Demonstrate and initiate durability testing of multi-material joint specimens using super lap shear weld bonded coupons – July 2009 (ORNL)
- Demonstrate and initiate durability testing of multi-material joint specimens using surrogate tool specimens – January 2010 (ORNL)
- Validate durability model using multi-material joint surrogate tool specimen data – March 2011 (ACC/Multimatic, Inc.)

Technical Approach

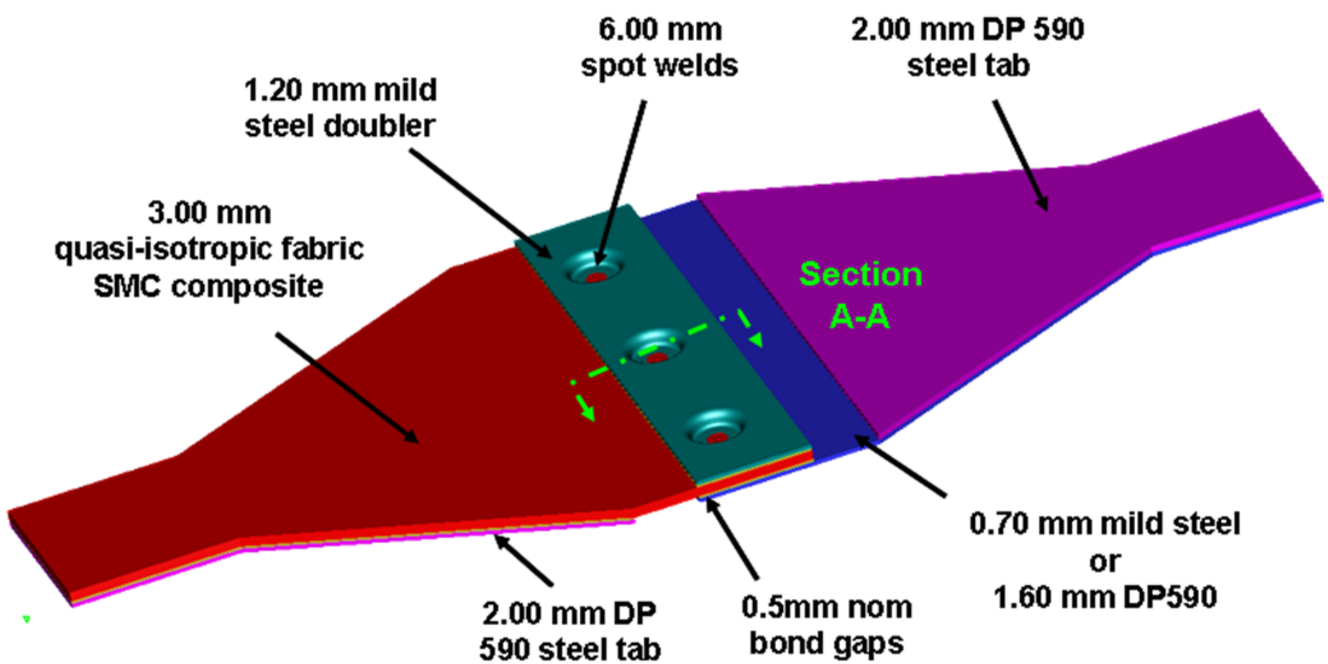
- Validate and develop the analytical models and tools capable of predicting multi-material joint performance and durability under multiple loading scenarios
- Generate an experimental data base of the multi-material joint's performance and durability under various loading and environmental conditions to support and validate the modeling approach
- Establish and define the bounds of validity for the methodology
- Combination approach
  - Modeling and analysis
  - Physical testing

Two Phases

- Phase 1: Simple load cases with small coupons
  - "Super lap shear" weld bonded specimen
    - Tensile loading (shear stress-dominated)
    - Cantilever bending (peel stress-dominated)
    - Torsion (combination peel-and-shear stress)

- Phase 2: Replicate and combine load cases with larger sub-structural specimen
  - "Surrogate tool" composite
    - Identified by GM personnel as a suitable substitute for providing molded composite constituent of joint specimen
    - Design of surrogate specimen and tests are on-hold pending results of Phase 1 effort

Super Lap Shear Specimen



Schematic is courtesy of Multimatic, Inc

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Experimental Test Parameters

- Quasi-static tests
  - Test method validation
  - Establish ultimate loads
  - Failure mechanisms
- Fatigue tests
  - Durability
  - S-N curves
  - 10% to peak load at 3 Hz
- Environmental conditions
  - ~+25°C (ambient/room temperature conditions)
  - +80°C
  - -40°C
  - +50°C and 85% RH

Model Validation and Development

- Multimatic, Inc.
  - Identify how best to model this material/structure
  - Validate current automotive models ability to predict durability for mixed material structures
  - Experimental test data to be used for validations
- Both Phase 1 (“simple”) and Phase 2 (“complex”)
  - Two or more single load cases
  - Combination load conditions (stress and environment)
  - Iterative process between analysis-and-test

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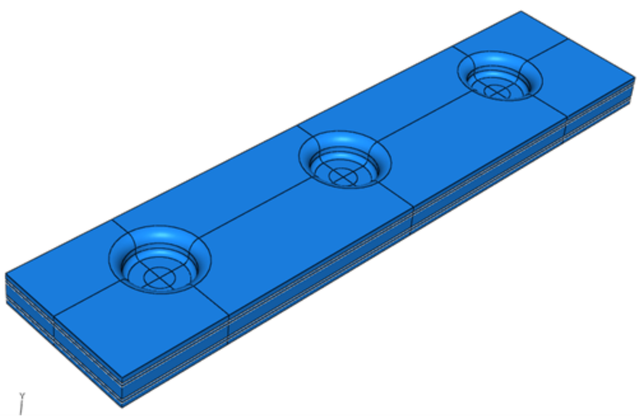
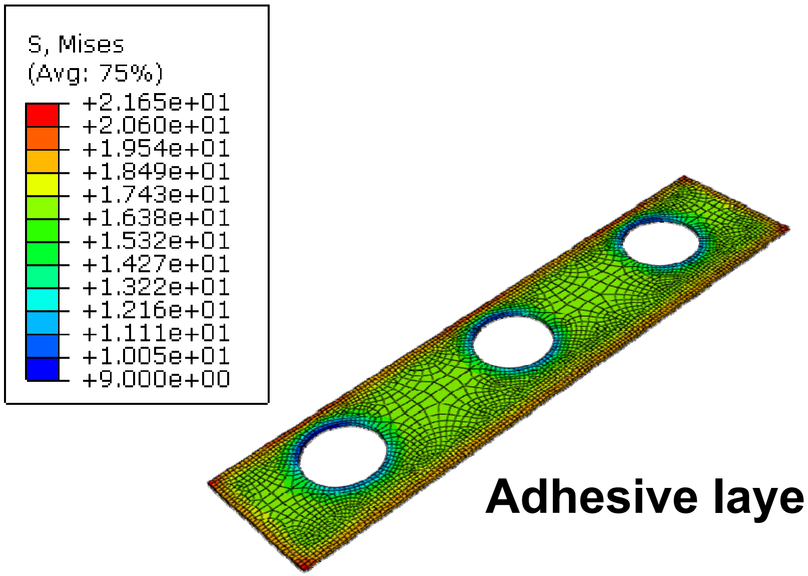
Manufacturing Stress Analyses

Linear finite element analysis employed to estimate the residual stresses in the composite-to-metal joint due to cooling after cure and spot welding





Adhesive layer

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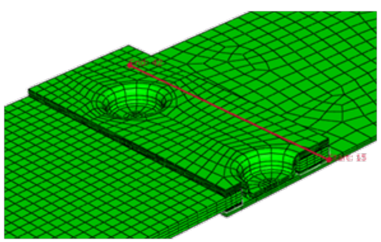
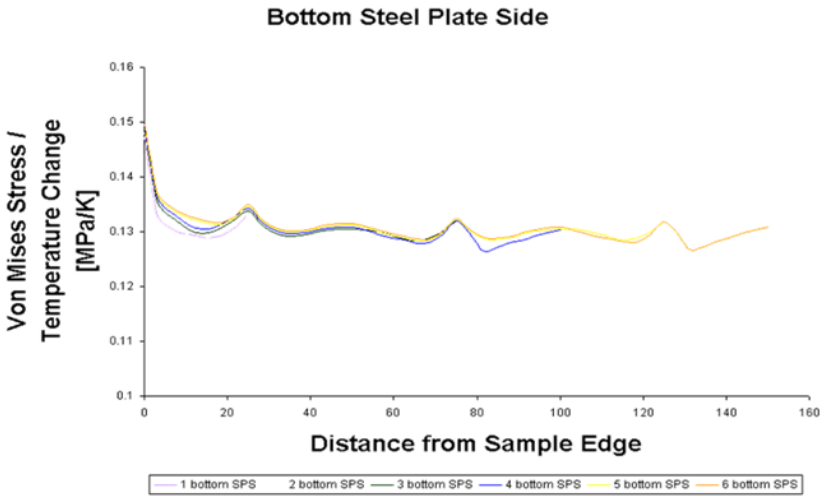
"Minimum Length" Analysis

- Established the minimum specimen dimension required in order to represent thermally driven stresses in a long weld bonded composite-to-metal joint
- Two or more welds minimum experienced virtually identical stresses along the edges of the joint





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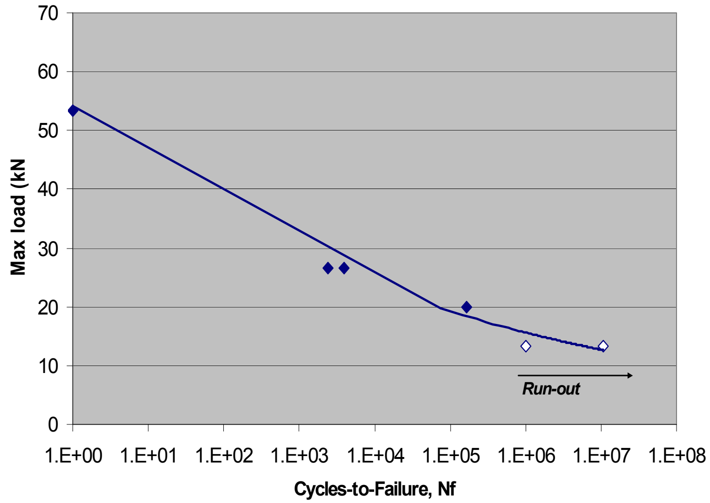
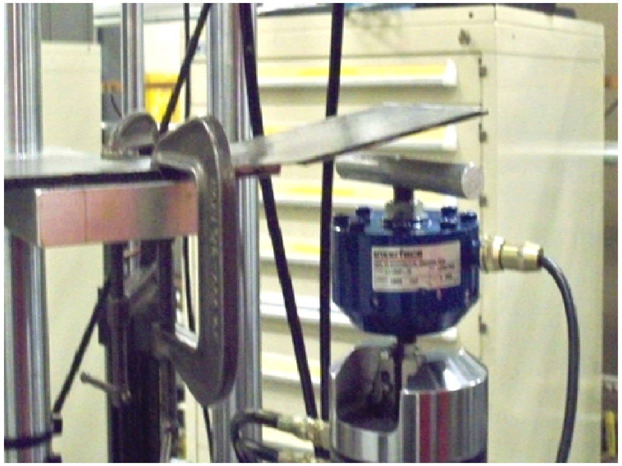
Physical Testing

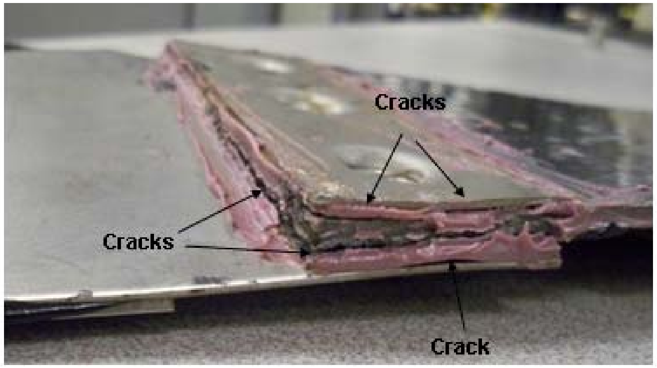
Tensile cyclic fatigue



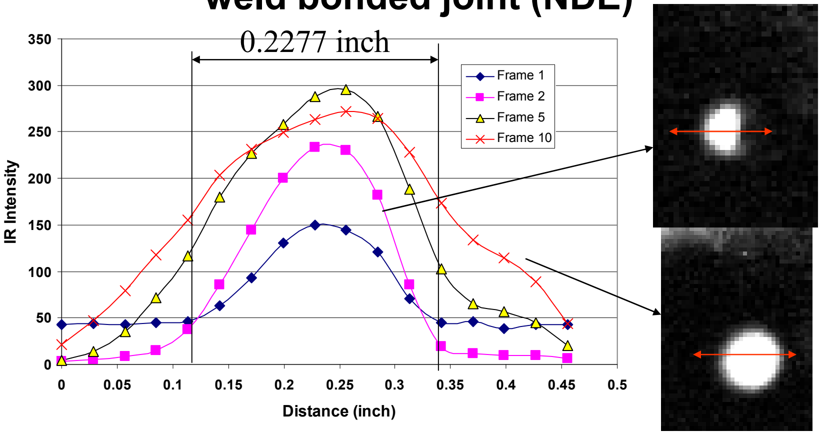
Cantilever bending



Crack initiation following torsion test



Infrared thermograpy of composite–to-metal weld bonded joint (NDE)



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Accomplishments
FY08-FY09

- Identified critical load cases for evaluation in joint durability tests and model validation efforts
- Defined the durability cycle and environmental conditions (temperatures, humidity) for durability testing
- Identified weld bonded “super lap shear” specimen geometry for initial joint durability test and model validation efforts
- Initiated cantilever bend and torsion test development for evaluating durability of weld bonded joint
- Conducted analyses to identify minimum specimen dimension necessary to capture thermal loading effects
- Constructed analytical model to estimate stresses in super lap shear weld bond geometry arising from manufacturing process temperatures
- Identified “surrogate tool” for the manufacture of the composite of the multi-material joint specimens in the second phase of this project

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Future Work

- Conduct durability tests with super lap shear specimens tested in tensile mode
- Evaluate super lap shear specimen geometry tested via cantilever bend and torsion tests for suitability/applicability to program goals
- Evaluate validity of durability analytical models with weld bonded specimen test data and make modifications to models as appropriate
- Design specimen, tests, fixtures and equipment for evaluating multi-material joint durability using composite molded from surrogate tool
- Continue validation and development of durability analytical models using test data from surrogate tool specimens as input

Summary

- **Project objectives**
  - Develop a methodology to enable prediction of the effects of environmental exposures and mechanical loadings on the durability of a composite/adhesive/metal (multi-material) joint
  - Enables the wide-spread integration of structural composites into vehicle design and manufacture – REDUCING VEHICLE WEIGHT
  - Focus application - The joining of a polymer matrix composite (PMC) underbody to the rest of the vehicle structure
- **Combination approach**
  - Modeling and analysis
    - Validate and develop the analytical models and tools capable of predicting multi-material joint performance and durability under multiple loading scenarios
    - Establish and define the bounds of validity for the methodology
  - Physical testing
    - Generate an experimental data base of the multi-material joint's performance and durability under various loading and environmental conditions to support and validate the modeling approach
- **The methodology can be made applicable to other types of multi-material joints, including other material combinations**