

Composite Underbody Attachment

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Presenter: R. E. Norris

Oak Ridge National Laboratory

June 7-11, 2010

Project ID #LM024

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Overview

- **Timeline**

- **Start: May 2008**
- **Finish: September 2011**
- **~35% Complete**

- **Budget**

- **Total project funding**
 - **DOE: \$1,075K**
- **Funding received in FY09**
 - **\$400K**
- **Funding for FY10**
 - **\$320 baseline**

- **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)**
 - **Composite Underbody Project, Focal Project 4**
- **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

This project is a collaborative effort on the Composite Underbody project (Focal Project 4) between the Automotive Composite Consortium (ACC), Multimatic, Inc and ORNL

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Milestones

Month/Year	Milestone
Jul-09	Develop and demonstrate durability testing of multi-material joint specimens using super lap shear weld-bonded coupons (completed by July 2009)
Sep-10	Complete tensile fatigue tests of super lap shear specimens fabricated both with and without spot welds at ambient, 80°C and -40°C. Note: These data will be used for the joint model validation and development effort.
Mar-11	Complete modifications of super lap shear specimen geometry and test methodologies to enable evaluation of joint durability via cantilever bending and torsion test methods. Note: These test methods will enable bend and torsion durability data to be generated for joint model validation and development effort.
Sep-11	Design specimen, tests, fixtures, and equipment for evaluating multi-material joint durability using three-dimensional (3D) composite molded from “surrogate tool.” Note: The durability data produced in these tests will be the final confirmation in this project of the developed joint model(s) validity and applicability.

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Approach/Strategy

- 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

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Interactions/Collaborations

- ORNL: Project lead, test method development, durability testing, TMAC dynamic tension testing
- ACC: Technical consultation regarding automotive industry needs and requirements, material characterization, test specimen fabrication
- Multimatic, Inc.: Joint finite element (FE) analyses, CAE model validation and development

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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

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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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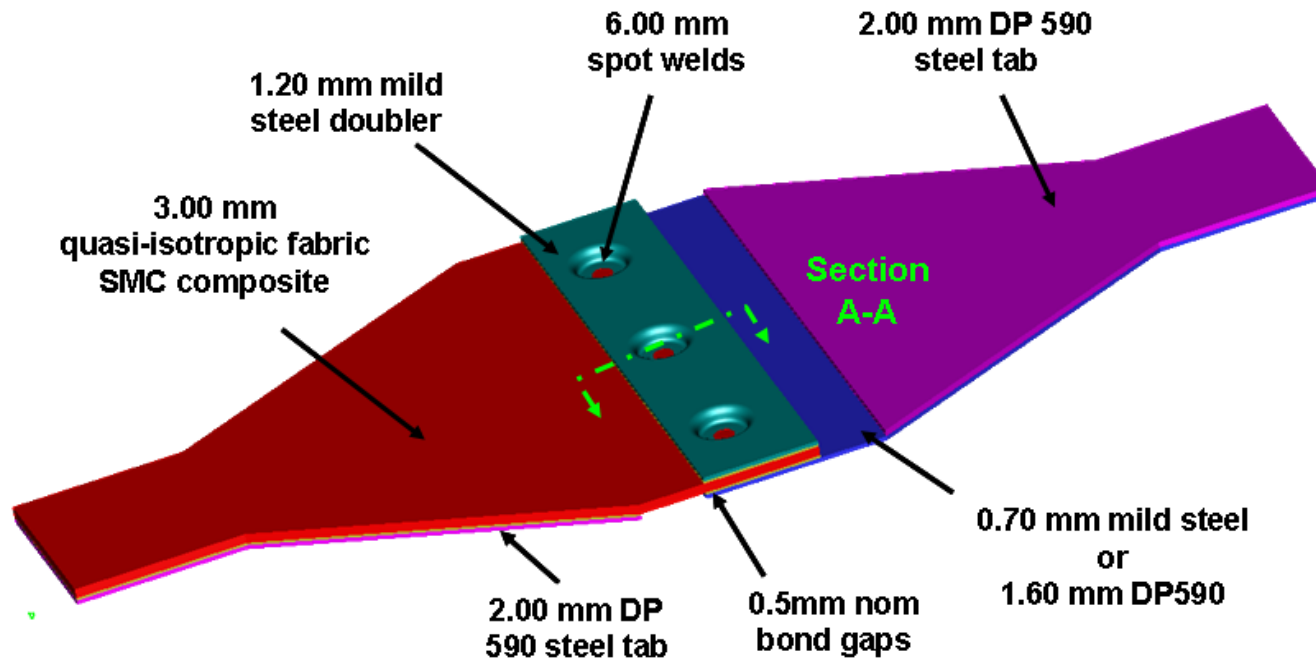
Accomplishments

FY09-FY10

- Milestone: Develop and demonstrate durability testing of multi-material joint specimens using super lap shear weld-bonded coupons (completed by July 2009)
- Conducted tensile fatigue tests of super lap shear specimens fabricated with and without spot welds at ambient, 80°C and -40°C. Data files, photos, plots and videos forwarded to Multimatic, Inc
- Prepared test fixtures and equipment to evaluate weld bonded specimens via cantilever bending and torsion test methods.
- Designed grips and generated software drive files to enable dynamic (high strain rate) tensile tests of joint specimens using the Test Machine for Automotive Crashworthiness (TMAC). (The TMAC is part of the ORNL User Facility.)
- Conducted failure analyses of weld bonded composite-to-steel torsion specimens using infrared (IR) thermography method. (IR thermography is a capability of the ORNL User Facility)

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Super Lap Shear Specimen



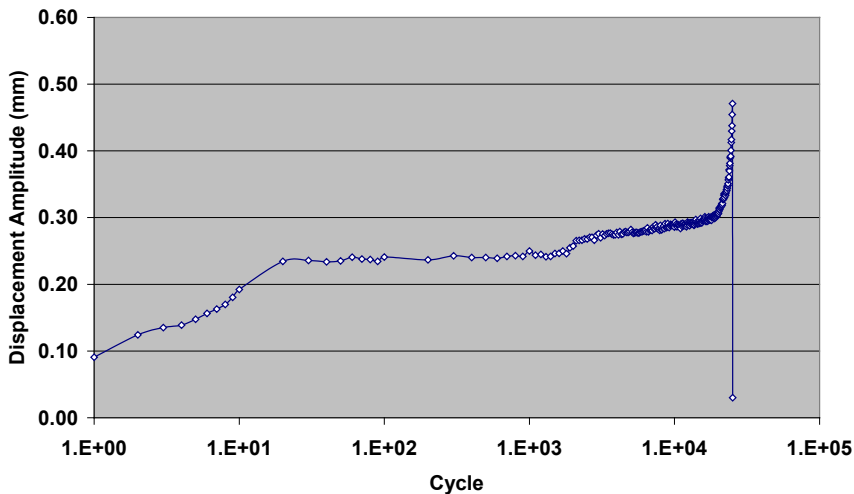
Schematic is courtesy of Multimatic, Inc

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Tensile Fatigue



Damage progression during fatigue test of weld bonded specimen (video)



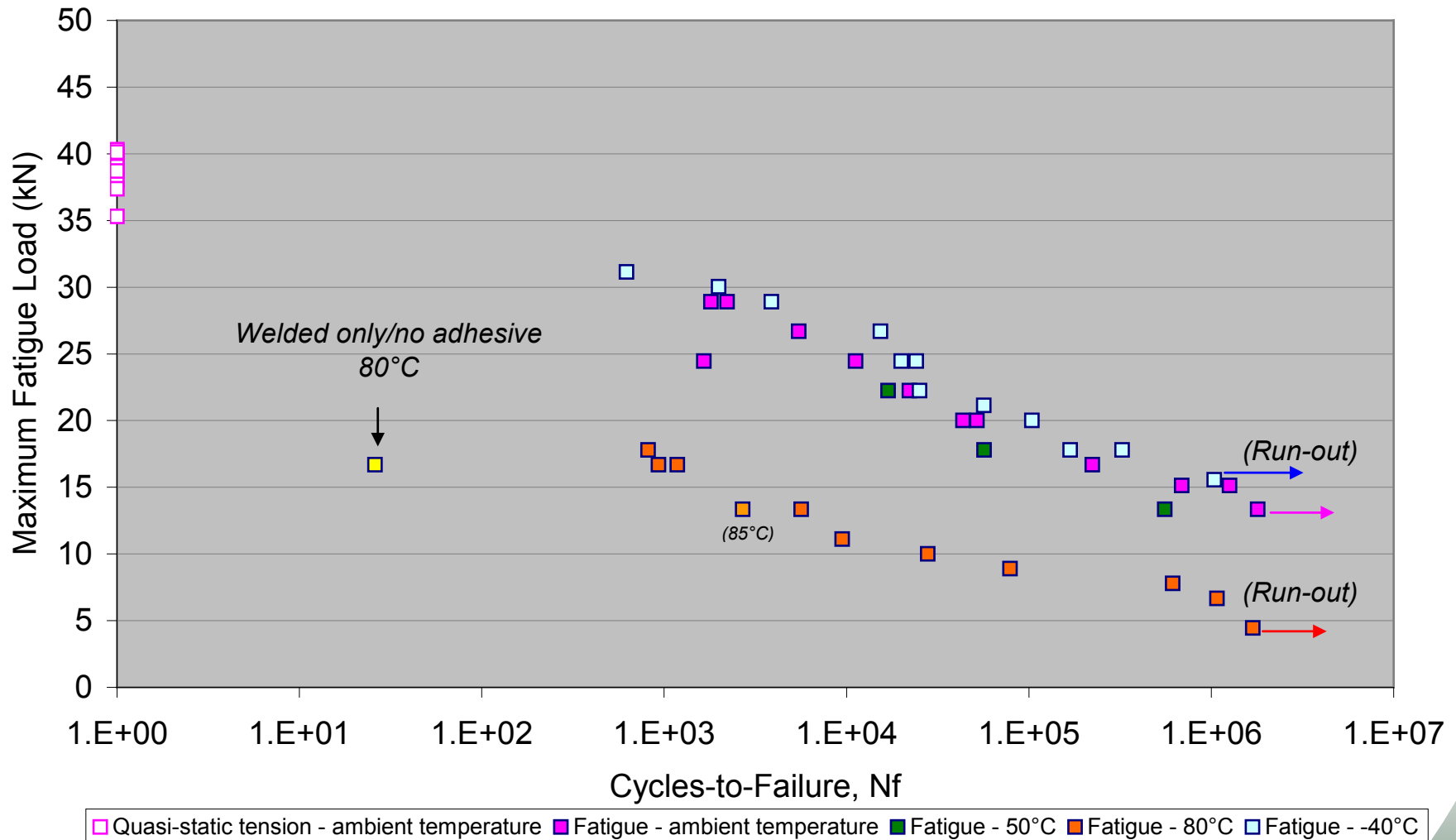
Displacement amplitude versus cycle
(weld bonded/-40°C)



Fatigue failure
“adhesive bond only” (80°C)

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Weld Bonded Specimen S-N Data



Project Activities

ORNL User Facility

Tensile fatigue
MTS test machine/Oven chamber
 (elevated temps, LN₂cooling)



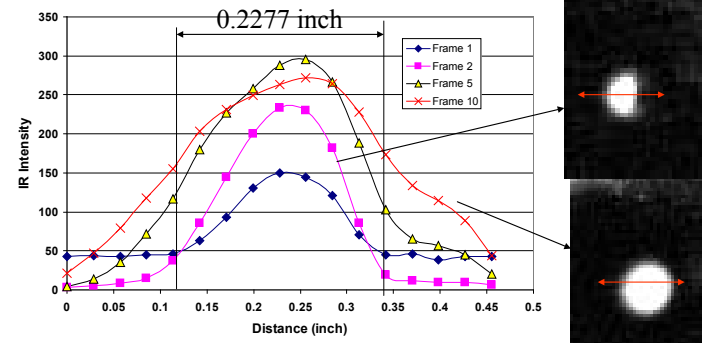
Torsion test
MTS axial-torsional test machine



Dynamic tensile test development
Test Machine for Automotive
Crashworthiness (TMAC)



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



Future Work

- Complete tensile fatigue tests of super lap shear specimens fabricated with and without spot welds at ambient, 80°C and -40°C. These data will be used for the joint model validation and development effort. Milestone: September 2010
- Continue and complete modifications to super lap shear specimen geometry and test methodologies to enable evaluation of joint durability via cantilever bending and torsion test methods.
- Evaluate validity of durability analytical models with weld bonded and adhesively bonded specimen test data and make modifications to models as appropriate
- Conduct dynamic tensile tests of composite-to-steel joint specimens using the TMAC.
- Design specimen, tests, fixtures, and equipment for evaluating multi-material joint durability using three-dimensional (3D) composite molded from surrogate tool.
- Continue validation and development of durability analytical models using test data from surrogate tool specimens as input

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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**
- The methodology can be made applicable to other types of multi-material joints, including other material combinations
- 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

- **This project is a collaborative effort on the Composite Underbody project (Focal Project 4) between the Automotive Composite Consortium (ACC), Multimatic, Inc and ORNL**

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Advanced Preforming and Related Processes for Manufacturing Low Cost Composites

DOE 2010 Annual Merit Review

R. E. Norris, PI

Oak Ridge National Laboratory

June 7-11, 2010

Project ID: LM-024-Norris

Agreement Number: 9223

Advanced Preforming Overview

Timeline

- Phase I – FY 2004 to FY 2009
- Phase II – FY 2009 to FY 2013
- Percent complete – ~65%

Budget

- \$250K new for FY 2010
- \$250K received in FY 2009
- ~\$6.2M Total Funding to Date
- ~\$3.1M in Capital

Barriers

- Vehicle Weight Reduction
- Lower Cost /Low Cycle Time Manufacturing of Composites
- Lower Cost Materials and Alternate Material Forms in Manufacturing (e.g. carbon fiber, hybrids, DRIFT, etc.)

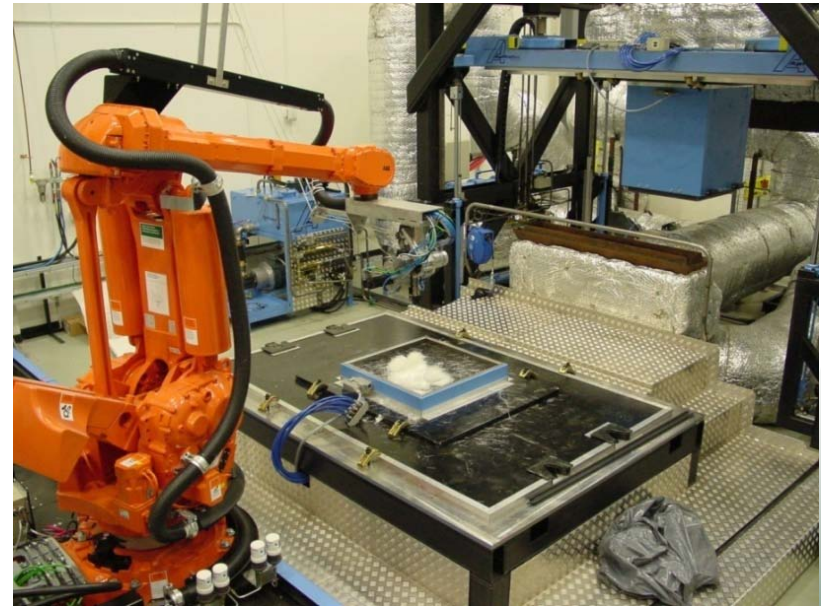
Partners

- ACC Materials/Processing Groups and EPFL – Composite Seat Focal Project
- Materials Suppliers (Polycomp, CF suppliers, Fiber Science)
- Blade Coating Developers (C3 and Swagelok)
- Discussions with others ongoing (Plasticomp, Fiberforge, etc.)

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Objectives and General Approach

- **Achieve significant reduction in vehicle mass with advanced directed fiber preforming and related processes:**
 - Lower cycle time (cost) and enhance structural efficiency via high rate robotic fiber disposition and associated molding processes
 - Introduce and evaluate lower cost materials and alternate material forms in manufacturing (e.g. carbon fiber, hybrids, DRIFT, etc.)
- **Focus on reinforced thermoplastics, carbon fiber, and hybrid glass-carbon fiber materials providing**
 - New materials and material forms
 - Machine improvements and alternative process developments
 - Supporting technologies such as modeling and preform characterization techniques



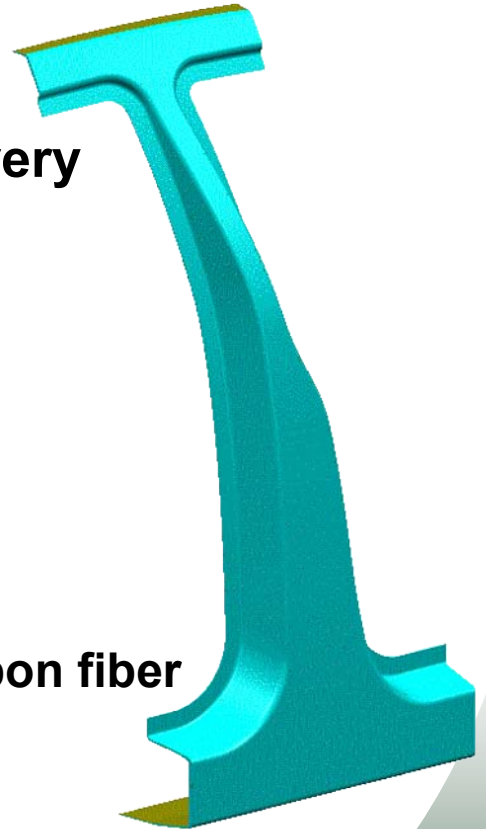
Approach – One Interaction Model

	ORNL	ACC
Objectives/ Purpose	Fundamental research to early/small-scale process development	Process development/optimization and prototype demonstration
Activities	<p>Integrated equipment suite for rapid determination of how materials and architecture characteristics affect composite articles</p> <p>Highly instrumented experiments for process characterization and modeling</p> <p>Resin/sizing screening, selection, evaluation and development of processing envelope</p> <p>Definition of matrix interactions</p> <p>Prove-out of LCCF and related technologies (DRIFT, etc.)</p> <p>Characterization standards and practices</p>	<p>SMC, thermoplastics compression molding</p> <p>Verification of new technologies on production-intent components</p> <p>Integration of pre-molding processes (e.g. P4, extrusion, etc.)</p> <p>Realistic representation of sizes, reliability, controls, data acquisition, etc. available for scaleup</p> <p>Determination of achievable process economics and robustness for eventual production</p>
Sizes and Capacities	Plaques and small components of limited complexity and features	Plaques and larger components with more complexity and full features
Utilization of Results	Supports and Fulfills enabling research and technology needs	Evaluates and Demonstrates technologies for implementation on a pre-competitive basis

- **Target – precompetitive technology development and demonstration(s) resulting in implementation similar to path followed for pickup box (FP2)**

Preforming Technical Issues/Drivers

- **Focal Project 3 analysis had indicated:**
 - >60% mass savings for minimum thickness of 1.5mm
 - Carbon fiber utilization is critical to overall objectives
 - 15% greater mass savings potential for 1mm min. thickness
- **Liquid molding applicable, but problematic for very thin sections**
- **Thermoplastic preforms offer:**
 - Potential for thinner sections – mass savings
 - Potential for increased recycling opportunities
- **Glass and Carbon hybrids offer:**
 - Cost-saving potential
 - “Synergistic” properties
 - Ability to introduce and gain experience with carbon fiber at lower quantities than for all-carbon parts
- **Many fundamental issues not understood, e.g.,**
 - Anisotropy
 - Optimal product form

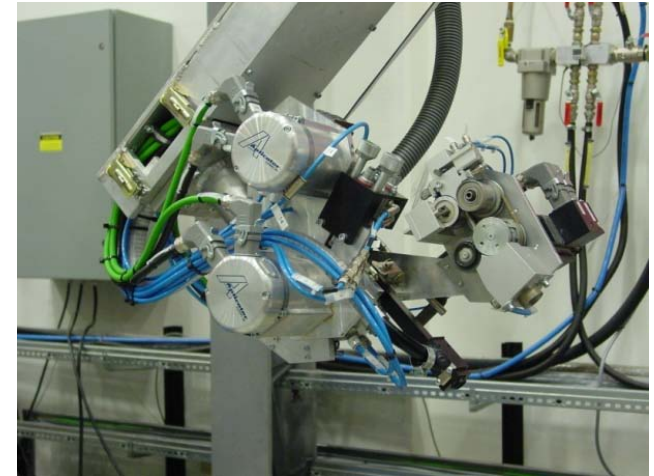


Milestones

Month/Year	Milestone
May 2009	Mounting of the modified Wolfangel chopper on the ORNL preforming machine has been completed and output capacity meeting target performance (~ 6X performance of the baseline Aplicator chopper) has been demonstrated at rates simulating liftgate manufacturing with the chopper mounted on and controlled by the robot system.
March 2010	Manufacture an initial set of 15 thermoplastic preforms for ACC evaluation in the Focal Project 4 Composite Seat Program.
June 2010	Complete new oven installation, mold, and test 5 panels from preforms representative of those provided to the ACC supporting composite seat project.
September 2010	Preform, mold, and test 5 panels using in-situ blended carbon fiber and glass hybrid materials to determine feasibility of continuing developmental work on the in-situ blending process.

Chopper Gun Development Drivers

- Results of ACC, EPFL, ORNL collaboration: thermoplastic preforming *technically and economically attractive versus competitive technologies at high deposition rates – 12-15 kg/min*
- Chopping of Twintex on baseline P4 equipment is feasible, but inconsistent and not economically attractive
 - Low material outputs possible (~1.4 kg/min) due to fiber jamming processing 4 tows
- Wolfangel prototype chopper selected for evaluation and further development
 - Designed for 5 ends of glass fiber and claims of 0-12 kg/min (relatively constant)
 - Baseline could achieve only <5 kg/min in with rapid speed change

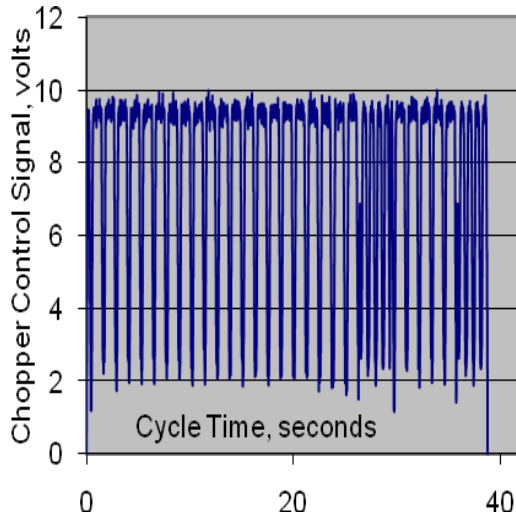


Baseline Applicator Chopper



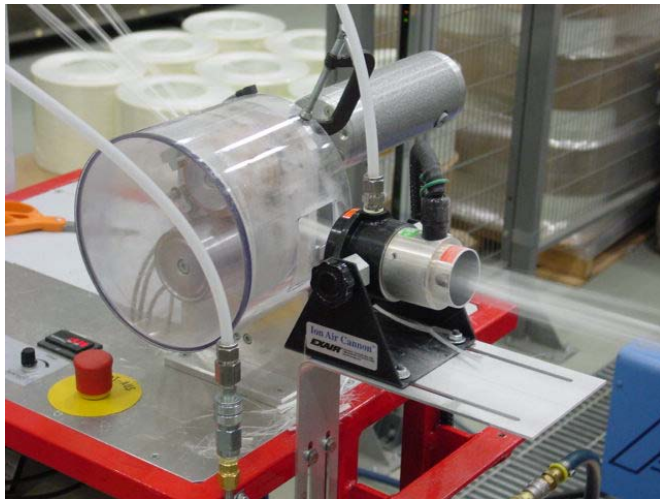
Unmodified Prototype
Chopper

Chopper Upgraded Meet Output Targets



Representative Duty Cycle
for Liftgate Preform

- Utilized ORNL –implemented control features to simulate liftgate preforming via numerous hardware and process configuration iterations to achieve higher speeds and more consistent operation
- With 9 strands of Twintex, we achieved ~18 kg/min top speed and consistent chopping in representative off-robot testing



Hardware
Modifications to
Improve Speed and
Consistency



Chopping Process was Characterized and Adjusted for Robotic Deposition

Output %	# of Tows → Cut Length →	3		5		7		9	
		25mm	75mm	25mm	75mm	25mm	75mm	25mm	75mm
30	Poor						x		x
	Needs Improvement				x			x	
	Marginal					x			
	Acceptable		x						
50	Good	x		x					
	Poor								x
	Needs Improvement				x		x		
	Marginal								
70	Acceptable		x			x			
	Good	x		x				x	
	Poor								
	Needs Improvement						x		x
90	Marginal				x				
	Acceptable		x						
	Good	x	x	x	x	x		x	
	Poor								
100	Needs Improvement								x
	Marginal								
	Acceptable						x		
	Good	x	x	x	x	x		x	

Tests run at 10 bar roller/cutter interface actuation pressure



High Output Robotic Deposition Requires Significant Tow Spacing and Air Tensioning in Addition to Guides Implemented Previously



- Additional hardware and controls were completed to mount modified chopper on robot and use 9 strands
- Preform deposition quality vs speed was evaluated in stationary deposition and on representative large sections like the liftgate

Deposition Uniformity Appears Good

Chopper Speed	Robot Speed	100%	75%	50%
100%	Section Length	Mass	Mass	Mass
	m	kg	kg	kg
	1.5	2.656	3.531	5.464
	1	1.734	2.325	3.619
	0.5	0.860	1.145	1.792
75%	Section Length	Mass	Mass	Mass
	m	kg	kg	kg
	1.5	2.057	2.771	4.193
	1	1.334	1.820	2.800
	0.5	0.669	0.896	1.389
50%	Section Length	Mass	Mass	Mass
	m	kg	kg	kg
	1.5	1.404	1.886	2.737
	1	0.925	1.251	1.829
	0.5	0.476	0.617	0.921

Measured Out put as a Function of Size, and
Programmed Robot Speed and Chopper Speed

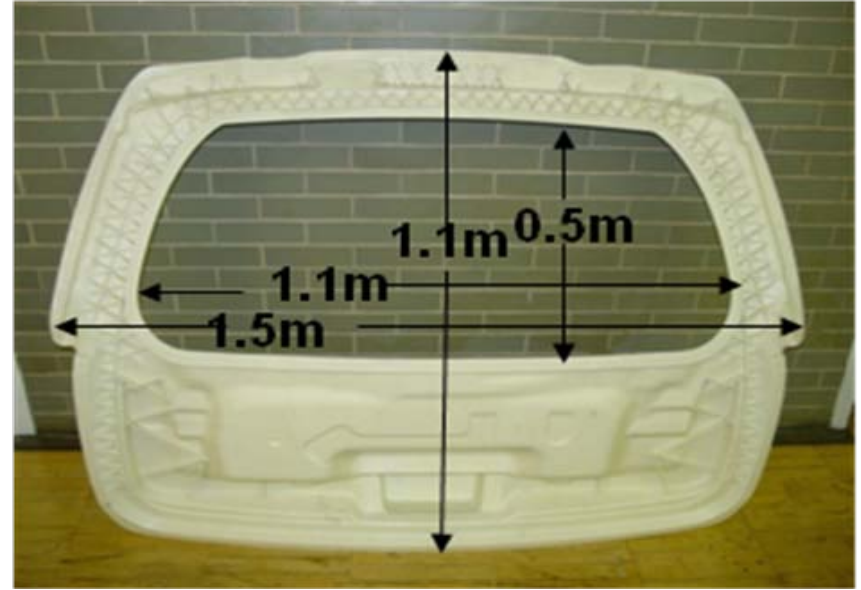
Chopper Speed	Robot Speed	100%	75%	50%
100%	Section Length	Mass	Mass	Mass
	m	kg	kg	kg
	1.5	-2.7%	-3.0%	0.1%
	1	-4.7%	-4.2%	-0.6%
	0.5	-5.5%	-5.6%	-1.5%
75%	Section Length	Mass	Mass	Mass
	m	kg	kg	kg
	1.5	0.5%	1.5%	2.4%
	1	-2.3%	0.0%	2.6%
	0.5	-2.0%	-1.6%	1.8%
50%	Section Length	Mass	Mass	Mass
	m	kg	kg	kg
	1.5	2.9%	3.6%	0.3%
	1	1.6%	3.1%	0.5%
	0.5	4.6%	1.7%	1.2%

Deviation from “Expected” Output

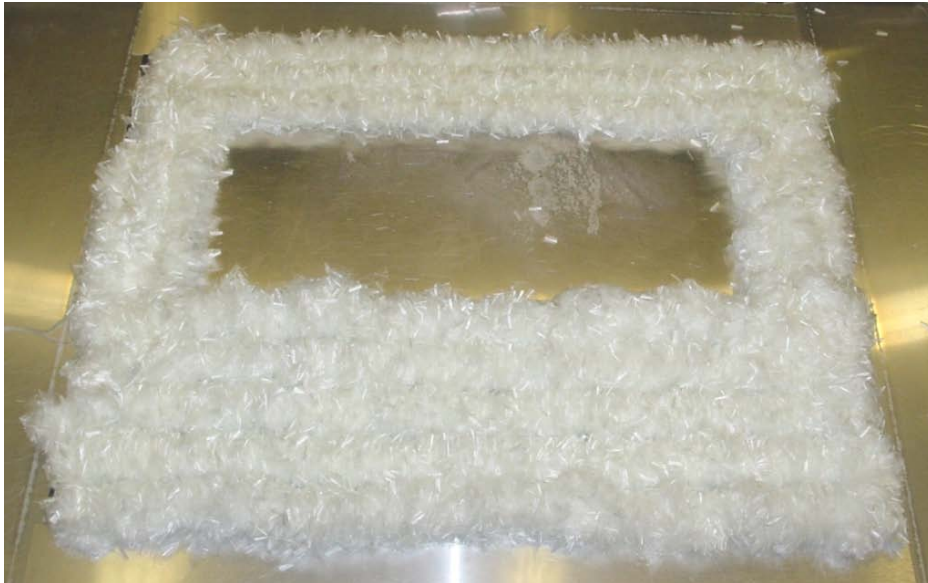
- Data normalized to 75% chopper speed and 75% robot speed
- Deposition rates tend to be relatively consistent within typical ranges; i.e. at highest chopper speed, deposition is slightly low, at lowest rate slightly high with the effect magnified by robot speed
- Software adjustments for robotic controls are possible

Demonstrated Liftgate Preforms in Less than 30 secs

- Met the objective of 12-15 kg/min deposition rate and deposition of a complete liftgate preform in the 30 seconds assumed in the earlier process comparison and economic study.



- Capabilities exceed the deposition rate assumed for the upper limit of a single robot/chopper system and the lower end of a dual system as assumed in this study.



Liftgate Preforming Video



- Primary Demo 2010 01 29 09 40 07.avi

Advanced Preforming Partnerships

- ORNL has been partnering with the ACC and EPFL in developing the technology and demonstrating applicability in high rate thermoplastic preforming for liftgates, seats, etc.
- ORNL has demonstrated some success in utilizing blade coatings developed by C³I for durability improvements
- ORNL has been partnering with Polycomp as potential low cost, high quality “pre-impregnated tow” supplier that might be applicable to preforming and could be added to LCCF line
- ORNL is working informally with Plasticomp and Fiberforge to evaluate related manufacturing technologies for automotive applications
- ORNL has proposed and is exploring partnerships to introduce variants of preforming to wind blade applications and military vehicles to further develop and exploit the technology in other areas to facilitate implementation and drive availability of broader material forms

Advanced Preforming Conclusions

- New high speed chopper upgraded and mounted on robot, control modifications implemented, and *demonstrated deposition of preforms for liftgate in under 30 seconds at greater than 12 kg/min for economic feasibility*
- Continued improvements in in-situ blending. Procured and installed combined IR and convection charge heating to mitigate molding limitations.
- Manufactured preforms for evaluation in comparison with DLFT for FP4 Composite Seat initiative.
- Near-term plans to complete initial feasibility determination for in-situ blending as primary pathway to hybrid materials development and LCCF evaluation. Alternate pathway is to complete installation of SRIM.
- ORNL is developing partnerships for development of related technologies that have potential to facilitate implementation of preforming for automotive applications.

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My apologies to those I have left off or whose name I misspelled!

Technical contributors to current/recent activities

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