TMAC User Program

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Oak Ridge National Laboratory

Project ID: lm_10_norris

Agreement Number: 8992

Overview

Timeline

- Equipment operational in FY 2003
- DAQ and diagnostics FY 2003-2007
- User programs initiated in FY 2007
- Est. end date: FY 2010

Barriers

- Predictive modeling capability for carbon fiber/polymer matrix composites and their crashworthiness (or ability to absorb energy)

Budget

- ~$1M in capital equipment
- FY07 - $100k
- FY08 - $75K

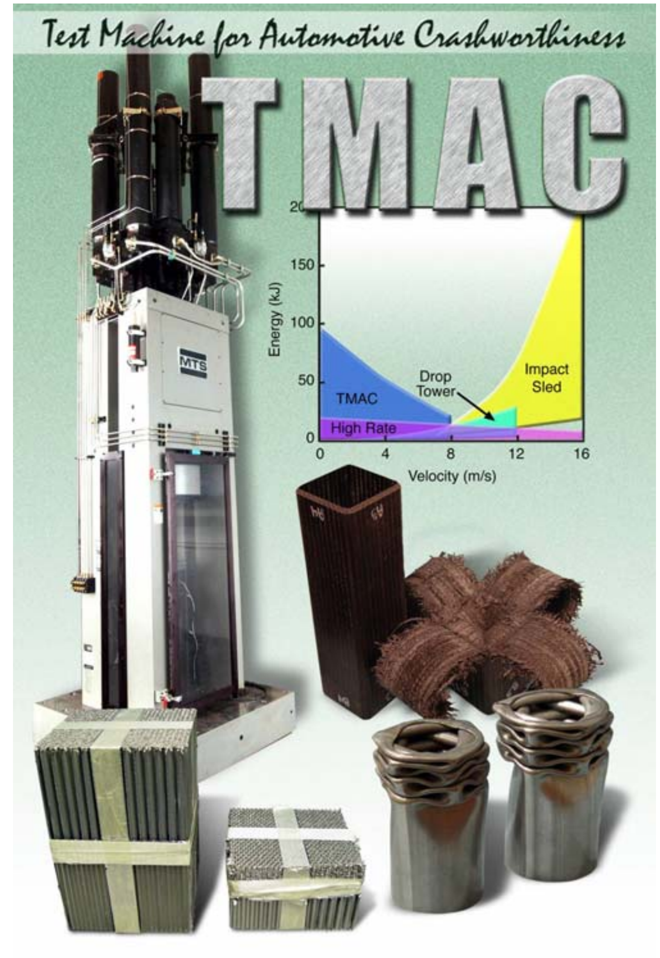
Partners

- Automotive Composites Consortium (ACC)

Objectives

1. **Develop unique characterization facility for controlled progressive crush experiments, at intermediate rates, of automotive materials (polymer composites, high-strength steels, and aluminum) and structures.**

2. **Provide access to unique test capability to university, industry, and government users for collaborative research.**

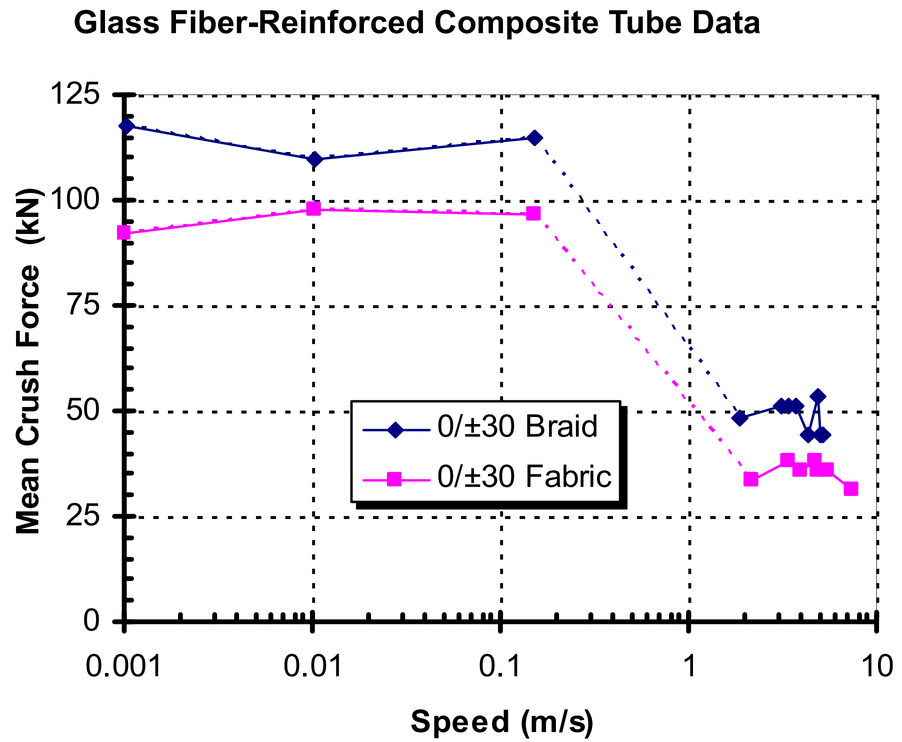


Milestones

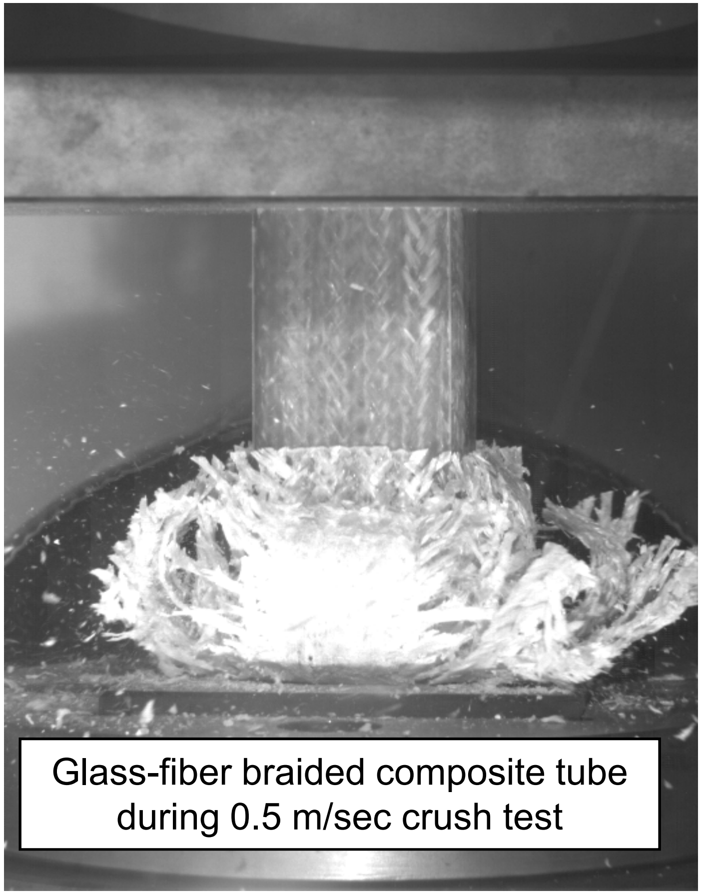
- **Complete 3-5 user programs/year**
  - **Sample of Previous Users and Others in Discussion:**
    - Virginia Tech
    - Stanford University
    - Rutgers University
    - University of Michigan
    - University of Knottingham
    - Imperial College, London
    - Monash University, Australia
    - Autokinetics, Inc.
    - Ford Scientific Research Lab
    - General Motors
    - MIRA, UK
    - Merkle Composites
    - South Dakota School of Mines and Technology
    - University of Utah

Approach

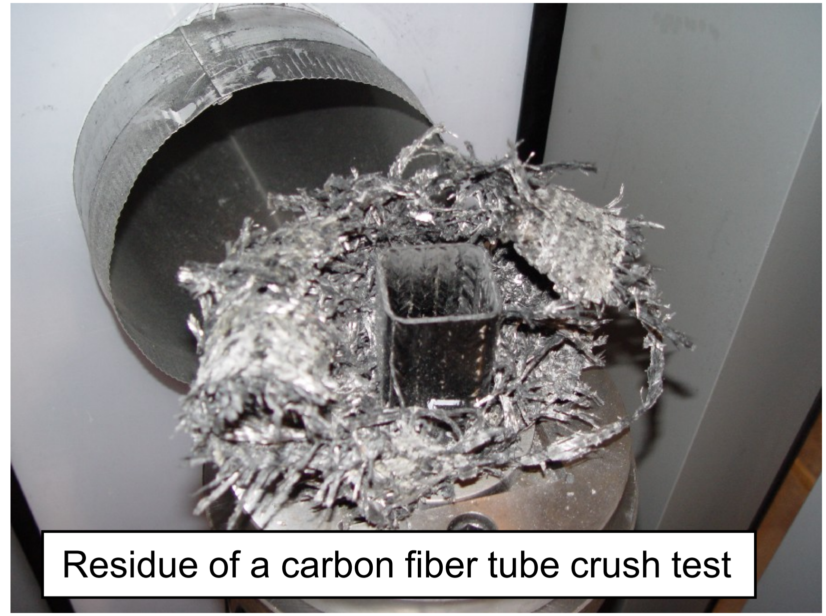
- **Develop an experimental capability that addresses:**
  - **Materials may respond differently when subjected to different rates of loading (e.g., impact velocity)**
  - **Transition between quasi-static and high rates not understood**
  - **Data is needed to develop reliable analytical models for predicting material response and structural performance during crash events**
  - **Drop tower and sled tests do not give constant velocity especially at lower velocities**
  - **Provide external users access to dynamic testing capabilities for nonproprietary work with results published in the open literature**
  - **Participate in user community development to facilitate understanding and utility of dynamic test results**



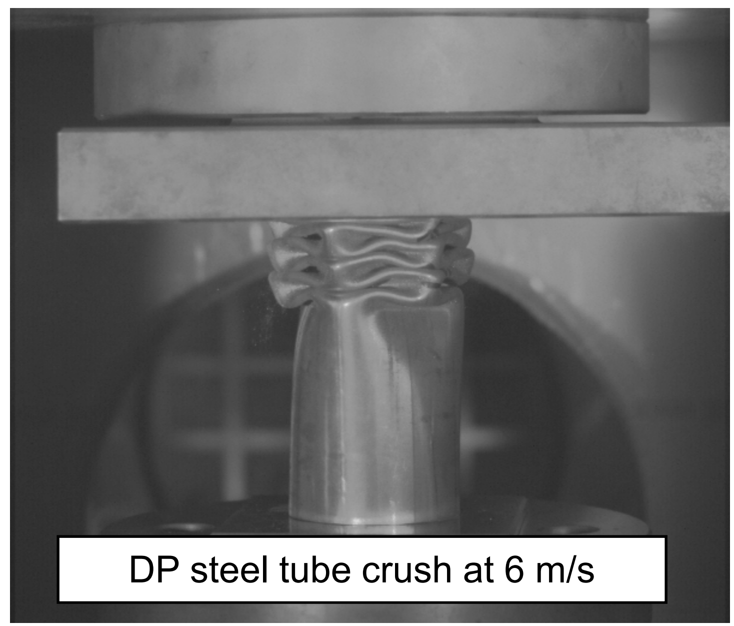
Examples of progressive crushing of tubes tested on TMAC



Glass-fiber braided composite tube during 0.5 m/sec crush test



Residue of a carbon fiber tube crush test



DP steel tube crush at 6 m/s

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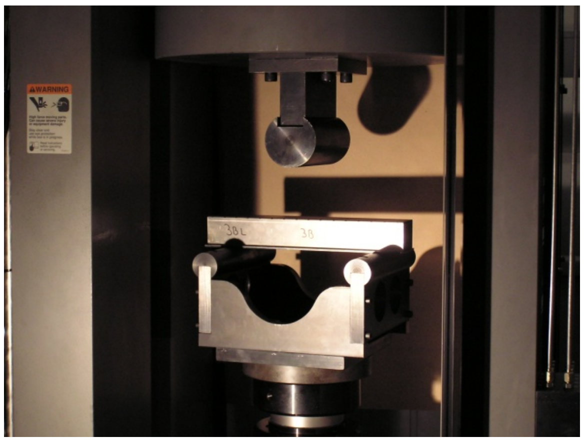
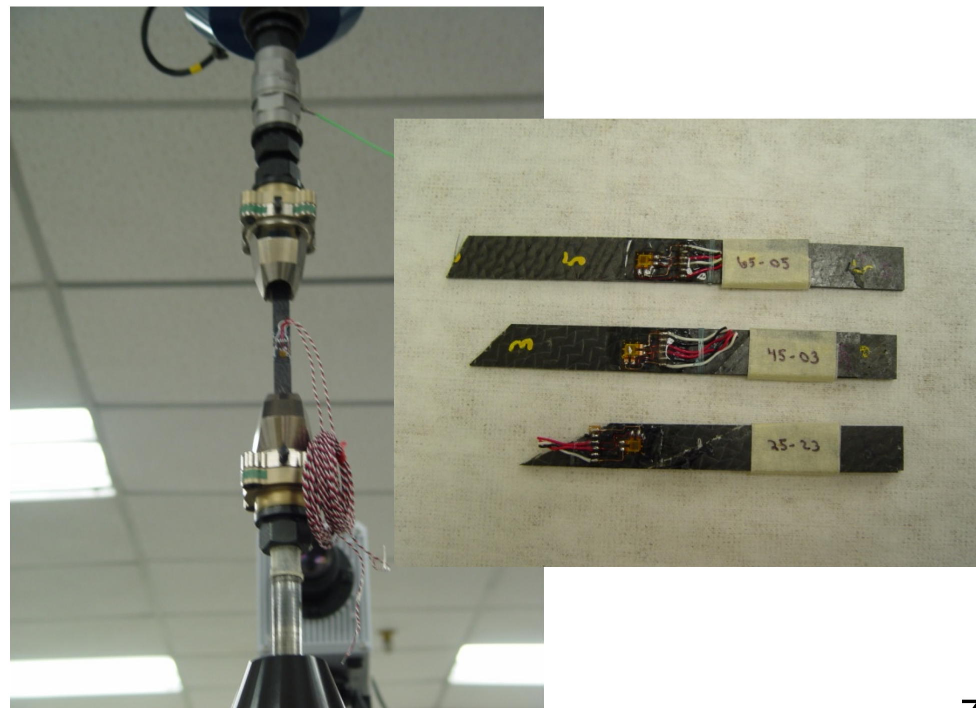
Technical Accomplishments/ Progress/Results

- L&L Products User Project – energy absorption in beams



  – GM User Project – rate dependent plasticity parameter for Stanford University's crashworthiness model



Future Work

- **Maintain involvement in CMH-17 crashworthiness effort**
- **Continue to support the ACC Energy Management Working Group**
- **Complete User Project for GM/ACC using TMAC to run tension tests on weld-bonded lap shear specimens**

Summary

- Successfully developed a unique test capability that provides user's (government and industry) rate-dependent experimental data for quantifying the energy absorbed in advanced lightweight materials and structures
- Successfully developed the test capability for conducting high strain-rate tension tests for characterizing the strain-rate behavior of materials leading toward the development of rate-dependent constitutive models
- User projects continue to be completed with high interest in future and continuing projects

Advanced Preforming and Related Processes for Manufacturing Low Cost Composites

DOE 2009 Peer Review

R. E. Norris, PI

Oak Ridge National Laboratory

May 21, 2009

Project ID: LM-10-Norris
Agreement Number: 9223

Advanced Preforming Overview

Timeline

- Phase I – FY 2004 to FY 2009
- Phase II * – FY2009 to FY2013
- Percent complete – ~60%

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.)

Budget

- $250K new for FY 2009
- ~$6M Total Funding to Date
- ~$3M in Capital

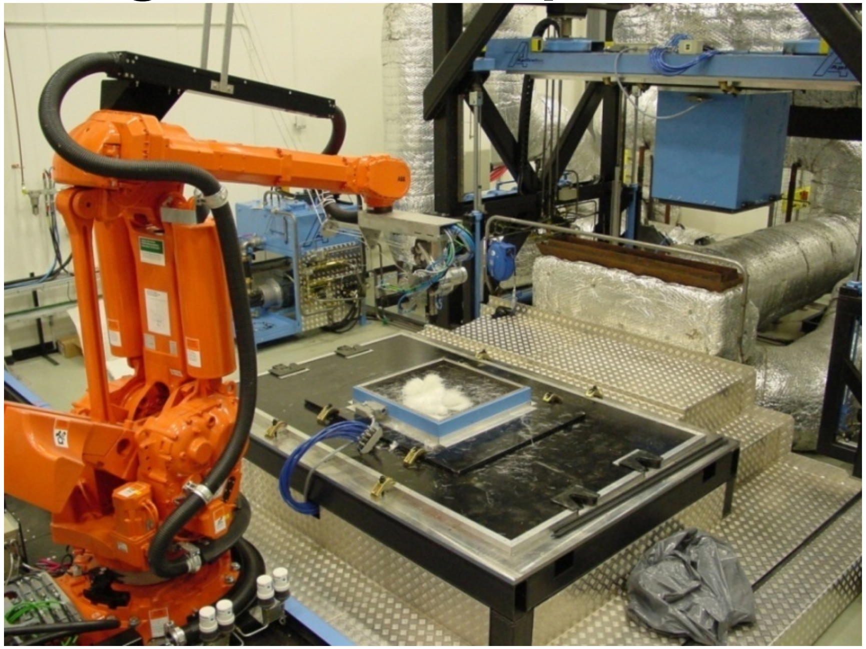
Partners

- ACC Materials and Processing Groups and EPFL
- Materials Suppliers (Polycomp, CF suppliers, Fiber Science)
- Blade Coating Developers (C3 and Swagelok)

* Plans for Phase II Under Development

Objectives and Approach

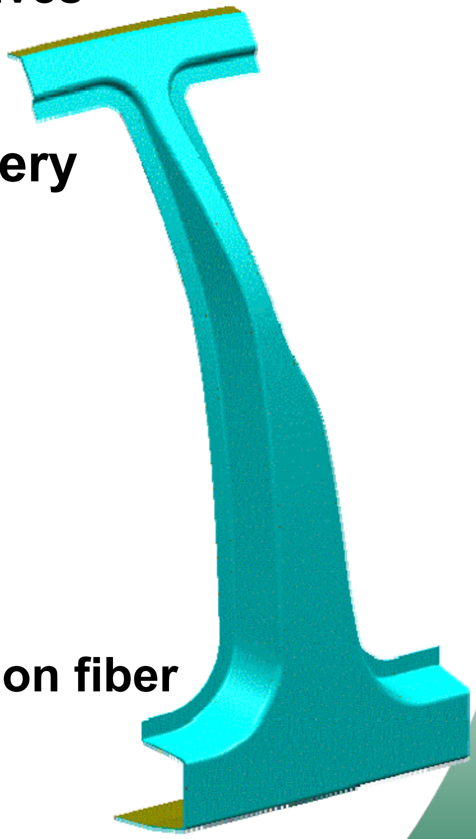
- Achieve significant reduction in vehicle mass with advanced directed fiber preforming and related processes



  - Focus on reinforced thermoplastics, carbon fiber, and hybrid glass-carbon fiber materials providing
    - New materials and material forms demonstration and evaluation
    - Machine improvements
    - Alternative process developments
    - Supporting technologies such as modeling and preform characterization techniques
  - Support, augment, and facilitate the current and future research activities undertaken in related ACC projects

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



Recently Completed Milestones

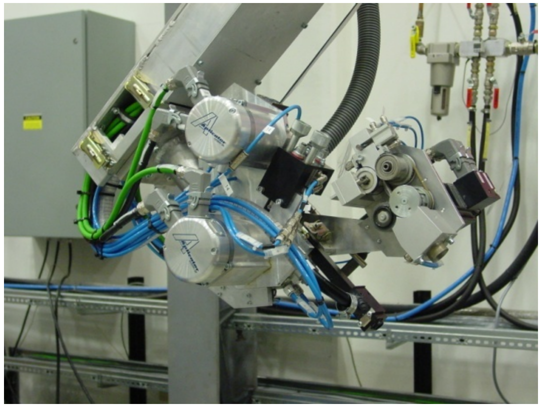
Milestone	Result	Date
Complete initial study of chopping mechanisms including characterization of the WolfAngel chopper with standard and alternative blade coatings.	The prototype Wolfangel chopper was setup to operate within the ORNL preforming system independent of the robot utilizing control signals representing a liftgate preform generated by the preforming system captured and modified by an ORNL-written LabView program. Extensive trials were conducted by ORNL staff assisted by the Automotive Composites Consortium Processing Group in December 2007 to evaluate the Wolfangel chopper capabilities. The chopper performed at ultimate design speed, but the total number of tows was limited by motor torque. Post trial microscopic examination of blades indicated improvement with those coated by C3 process.	December 2007
Upgrade prototype WolfAngel chopper and demonstrate significantly higher output meeting output targets.	ORNL worked with the ACC to select and design capability to replace the existing WolfAngel chopper motor with a somewhat faster and significantly higher power motor and drive electronics. Shafting and other components required upgrades, which have been completed. With these improvements, we have demonstrated reliable chopper output approaching 20 kg/min for the upgraded WolfAngel system versus approximately 2.3 kg/min limitations of the existing P4 chopper when chopping our baseline Twintex product. Targets to meet process economic goals were approximately 12-15 kg/min.	August 2008
Demonstrate in-situ blending of reinforcing fibers (including hybrids) and thermoplastic fibers and characterize process for evaluation of "optimum" blend ratios for performance versus economic tradeoff.	In-Situ blending of polypropolene (thermoplastic) with carbon and glass has been demonstrated. Process for evaluation of "optimum" blends has been developed, though the test matrix not yet completed for the current material.	September 2008

Key Planned Milestones

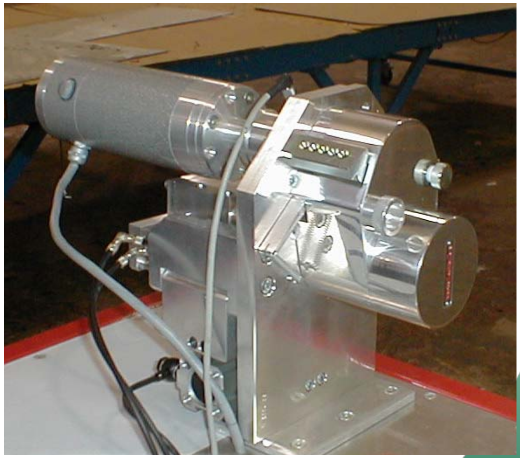
Milestone	Date
Complete mounting of Wolfangel chopper on ORNL preforming machine and demonstrate practical output capacity and quality capabilities for simulated liftgate manufacturing.	May 2009
Procure and install improved charge heating system. Complete installation and checkout of urethane injection machine.	June 2009
Improve in-situ processing and molding techniques and produce composite panel data for comparison of glass/carbon fiber blend ratios.	September 2009

Chopper Gun Development

- Chopping of Twintex® on current P4 baseline equipment is feasible, but inconsistent and not economically attractive
  - Limited to 4 ends of Twintex® material (1870 tex) and low material outputs possible (~1.4 kg/min) due to fiber jamming
  - Higher outputs required (12-15 kg/min)
- 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) with 1870 tex tows
  - Baseline could achieve only ~5 kg/min in testing representing actual preforming (rapid speed changes)
  - Chopper was upgraded with higher capacity motor and other hardware



Baseline Aplicator Chopper



Unmodified Prototype Chopper

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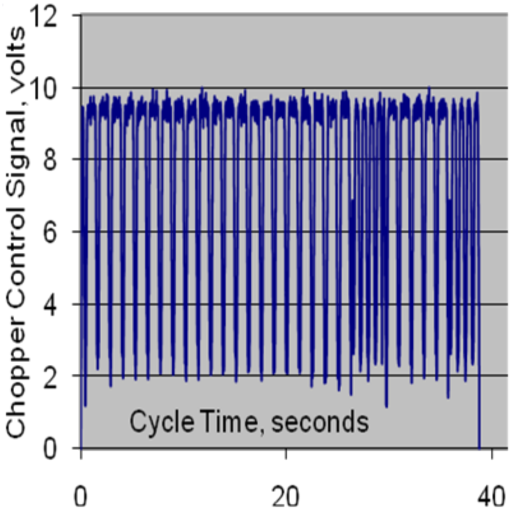
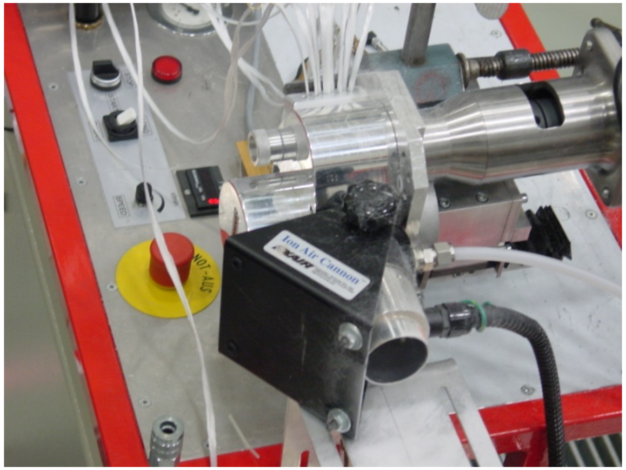
Advanced Chopper Upgrades/Evaluation

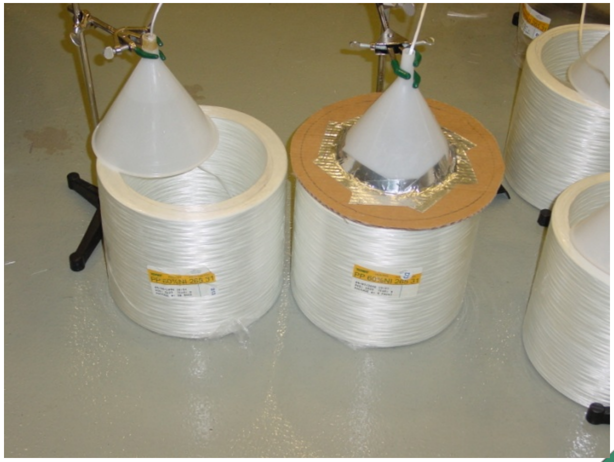


Representative Duty Cycle for Liftgate Preform

- Utilized ORNL –implemented control features to simulate liftgate preforming via numerous hardware and process configuration iterations to achieve higher speeds and more consistent operation
- Characterized Wolfangel chopper at a variety of conditions up to and beyond speed targets



Hardware Modifications to Improve Speed and Consistency

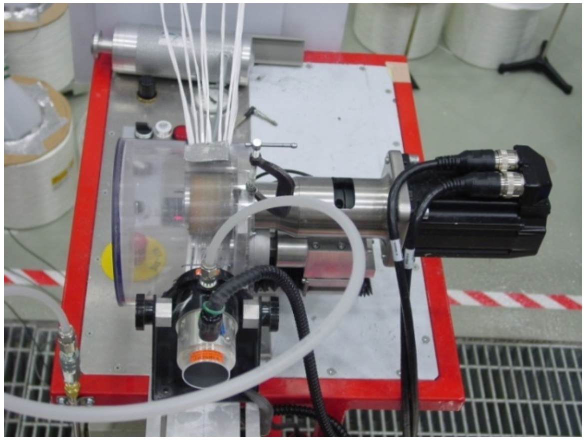


Chopper Speed Goals Exceeded

Output Assuming Tow size is 1870 Tex										
Speed	Velocity *	1 Tow	2 Tows	3 Tows	4 Tows	5 Tows	6 Tows	7 Tows	8 Tows	9 Tows
RPM	m/min	kg/min	kg/min	kg/min	kg/min	kg/min	kg/min	kg/min	kg/min	kg/min
125	28	0.05	0.10	0.16	0.21	0.26	0.31	0.36	0.42	0.47
250	56	0.10	0.21	0.31	0.42	0.52	0.63	0.73	0.83	0.94
375	84	0.16	0.31	0.47	0.63	0.78	0.94	1.09	1.25	1.41
500	111	0.21	0.42	0.63	0.83	1.04	1.25	1.46	1.67	1.88
625	139	0.26	0.52	0.78	1.04	1.30	1.56	1.82	2.08	2.35
750	167	0.31	0.63	0.94	1.25	1.56	1.88	2.19	2.50	2.81
875	195	0.36	0.73	1.09	1.46	1.82	2.19	2.55	2.92	3.28
1,000	223	0.42	0.83	1.25	1.67	2.08	2.50	2.92	3.34	3.75
1,125	251	0.47	0.94	1.41	1.88	2.35	2.81	3.28	3.75	4.22
1,250	279	0.52	1.04	1.56	2.08	2.61	3.13	3.65	4.17	4.69
1,375	307	0.57	1.15	1.72	2.29	2.87	3.44	4.01	4.59	5.16
1,500	334	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63
1,625	362	0.68	1.35	2.03	2.71	3.39	4.06	4.74	5.42	6.10
1,750	390	0.73	1.46	2.19	2.92	3.65	4.38	5.11	5.84	6.57
1,875	418	0.78	1.56	2.35	3.13	3.91	4.69	5.47	6.25	7.04
2,000	446	0.83	1.67	2.50	3.34	4.17	5.00	5.84	6.67	7.50
2,125	474	0.89	1.77	2.66	3.54	4.43	5.32	6.20	7.09	7.97
2,250	502	0.94	1.88	2.81	3.75	4.69	5.63	6.57	7.50	8.44
2,375	529	0.99	1.98	2.97	3.96	4.95	5.94	6.93	7.92	8.91
2,500	557	1.04	2.08	3.13	4.17	5.21	6.25	7.30	8.34	9.38
2,625	585	1.09	2.19	3.28	4.38	5.47	6.57	7.66	8.75	9.85
2,750	613	1.15	2.29	3.44	4.59	5.73	6.88	8.03	9.17	10.32
2,875	641	1.20	2.40	3.60	4.79	5.99	7.19	8.39	9.59	10.79
3,000	669	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.01	11.26
3,125	697	1.30	2.61	3.91	5.21	6.51	7.82	9.12	10.42	11.73
3,250	725	1.35	2.71	4.06	5.42	6.77	8.13	9.48	10.84	12.19
3,375	752	1.41	2.81	4.22	5.63	7.04	8.44	9.85	11.26	12.66
3,500	780	1.46	2.92	4.38	5.84	7.30	8.75	10.21	11.67	13.13
3,625	808	1.51	3.02	4.53	6.05	7.56	9.07	10.58	12.09	13.60
3,750	836	1.56	3.13	4.69	6.25	7.82	9.38	10.94	12.51	14.07
3,875	864	1.62	3.23	4.85	6.46	8.08	9.69	11.31	12.92	14.54
4,000	892	1.67	3.34	5.00	6.67	8.34	10.01	11.67	13.34	15.01
4,125	920	1.72	3.44	5.16	6.88	8.60	10.32	12.04	13.76	15.48
4,250	947	1.77	3.54	5.32	7.09	8.86	10.63	12.40	14.17	15.95
4,375	975	1.82	3.65	5.47	7.30	9.12	10.94	12.77	14.59	16.42
4,500	1,003	1.88	3.75	5.63	7.50	9.38	11.26	13.13	15.01	16.88
4,625	1,031	1.93	3.86	5.78	7.71	9.64	11.57	13.50	15.43	17.35
4,750	1,059	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82
4,875	1,087	2.03	4.06	6.10	8.13	10.16	12.19	14.23	16.26	18.29
5,000	1,115	2.08	4.17	6.25	8.34	10.42	12.51	14.59	16.68	18.76

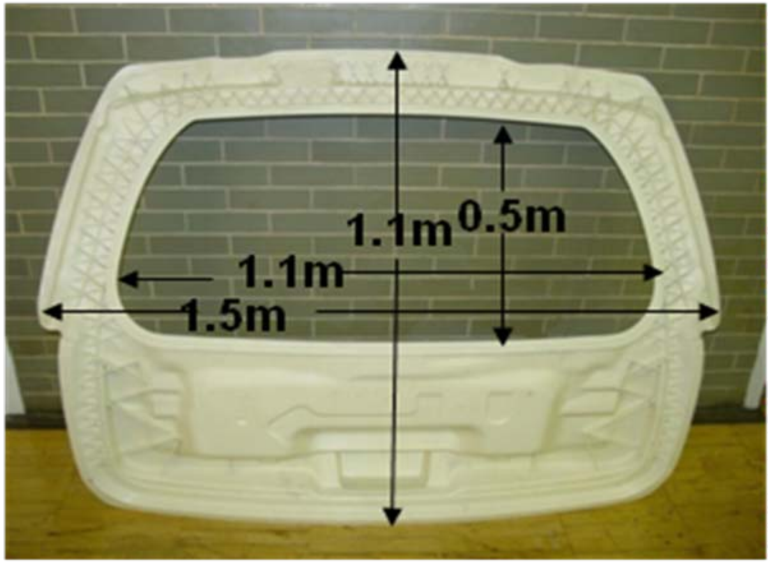
* Roller size assumed to be 71 mm in diameter

- **With 9 strands of 1870 tex Twintex®, we achieved ~18 kg/min top speed and consistent chopping in representative off-robot testing**
- **Testing includes full output and automated switching between 25 mm and 75 mm fiber lengths during cycle**



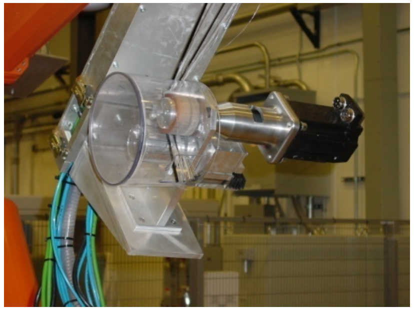
Advanced Chopper Demonstration

- **Additional hardware and controls are being completed to mount modified chopper on robot and use 9 strands**
- **Preform quality vs speed will be evaluated on representative large sections like the liftgate including:**
  - **Fiber deposition mechanics**
  - **Blade wear**
  - **Other chopper alternatives**

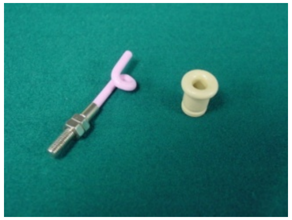


Generic Liftgate Dimensions

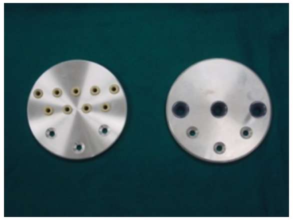
Chopper Mounted on Robot



Large Preforming Screen That Can be Masked Off to Liftgate Dimensions

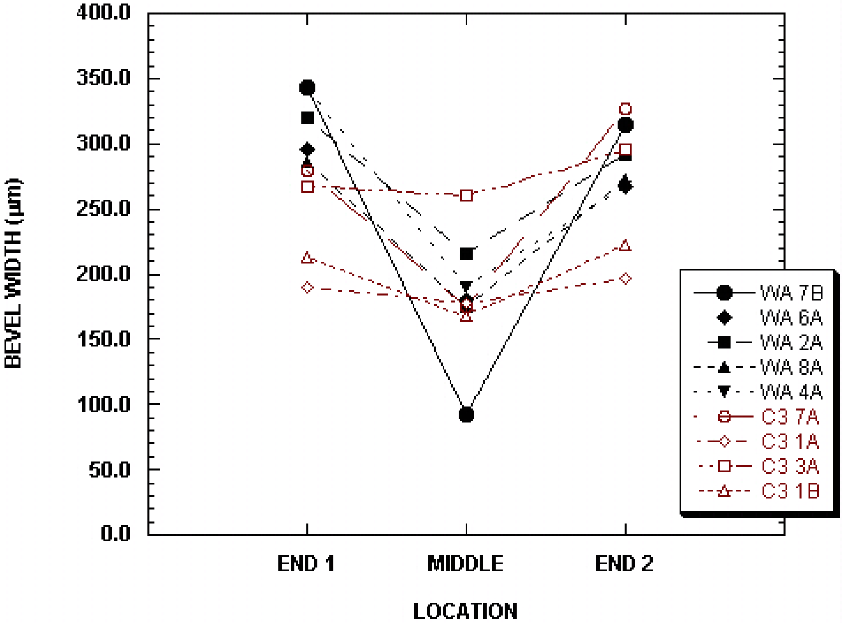


Example Fiber Guides Being Implemented on Preforming System



Fiber Severing Technology

- **Alternative blade materials**
  - **Processed "standard" blades with C3 coatings**
    - **Standard P4 blades became too ductile and immediately bent when chopping materials we have been using**
    - ***Wear improved in initial testing of C3 coated Wolfangel blades***
    - **Plans for more thorough evaluation of C3 coating in Wolfangel durability testing and in other testing**
  - **Looking for blades compatible with Swagelok process**
- **Laser severing**
  - **Demonstrated that fibers can be cut via lasers, but experimental efforts and system modeling have not identified a practical path forward**



Wear is indicated by difference of readings from the ends to the middle.

Hybrid Blends of Carbon and Glass are Key Target

- **Why Hybrids?**
  - Lower cost of materials in part vs all carbon fiber (CF)
  - Smaller CF supplier base/capacity requirements
  - Tailorable and/or synergistic properties
  - *May be the best way to introduce carbon fiber to automotive production*
- **What Are the Options?**
  - No existing blended product forms
  - Can put specific fiber at specific locations
  - Can blend carbon and glass fibers in-situ at desired concentration with thermoplastic (TP) fiber
  - Can blend carbon and glass fibers in-situ at desired concentration and inject with SRIM (thermoset) resin
  - Automated/robotic preforming offers flexibility with the three listed approaches
- **In-Situ Blending with TPs**
  - TP materials have rapid cycle times and are attractive for a number of applications
  - Comingled glass and polypropylene (PP) are available as Twintex® in only limited product forms – no CF or hybrids
  - In-situ blending should be more cost-effective itself and offer potential to evaluate numerous other options

Status of In-situ Blending of Hybrids

Carbon and Glass Hybrid Preform with PP

Molded Hybrid Panel

- Capability to blend, chop, pre-consolidate, and mold in-situ-blends of hybrid glass and CF with PP has been demonstrated - molding limitations have hindered detailed product evaluation
- Plans are underway to procure a combination IR-convection oven to improve heating efficiency (faster heating, less degradation) and mold transfer time.
- A rebuilt SRIM machine (with trade-in) has been procured to evaluate liquid molded hybrid blends and LCCF as well

Plans to Procure Convection Oven With IR Upgrade

Urethane Injection System

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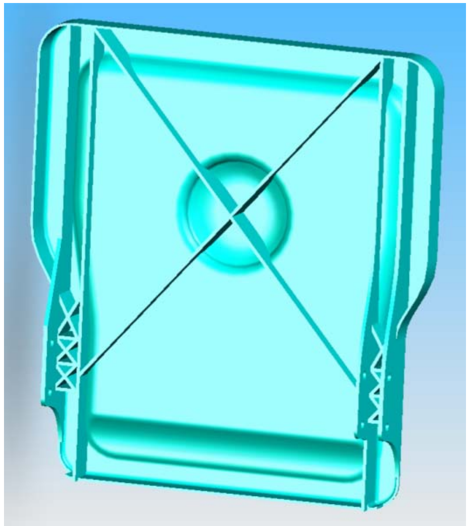
Plans for Preforming to Facilitate Low Cost Carbon Fiber Introduction

- Preforming and molding is a rapid route to demonstrating and determining fiber properties in composites
- Support LCCF program by serving as a key evaluation and developmental tool for new products using chop-ability, areal density uniformity, permeability, moldability, etc.
  - Tow splitting and forms evaluation
  - Surface Treatment
  - Sizing

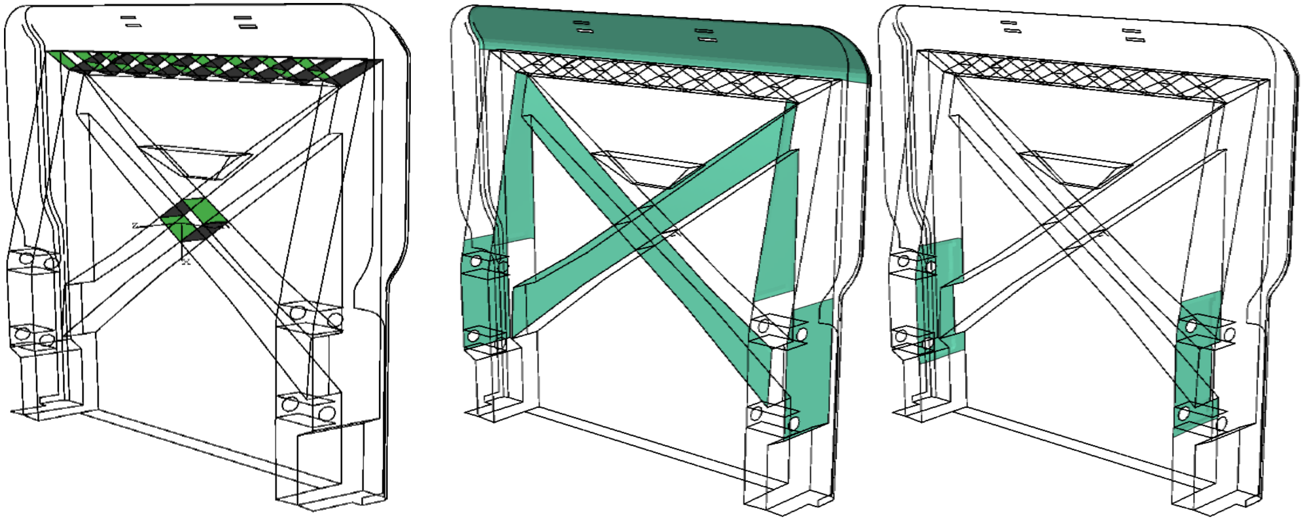
Phase II Will Add More Demonstration Work in Collaboration with the ACC

- **Smaller-scale application demonstrations in collaboration with ACC such as instrument panels, suspension components, underbody components, liftgates, etc.**
- **Conduct preliminary design concepts, M&P tradeoffs, sample fabrication/testing, demo article fab/testing, and economic comparisons**
- **Take advantage of related work such as analysis, trade-off studies, and hardware development by the ACC**
- **Demonstrate materials and processes from other programs such as bio-based products and slurry preforms**



Composite Seat is Initial Candidate

- **EPFL study shows TPP4 process can be cost-competitive and save significant weight versus baseline design**
- **Preforming and molding are within ORNL equipment capabilities - initial work can be done on existing screens at ORNL**
- **A multi-purpose tool would be designed and built for part demonstrations**
- **A variety of materials and processes can be demonstrated, potentially including preforming and molding with multiple TP matrices, SRIM, and SMC – all with carbon, glass, and hybrids.**



Proposed Near-Term Milestones for Phase II

- Evaluate other thermoplastic material forms such as nylon or PPS via in-situ blending and/or DRIFT. *September 30, 2009*.
- Complete requirements for seat molding tool and obtain quotes for design and fabrication. *September 30, 2009.*
- Results from composite seat preforming and initial flat plaque molding trials. *December 31, 2009*.
- Seat tool completed, accepted and delivered. *March 31, 2010.*
- Initial results for initial seat tool molding trials. *September 30, 2010*.

Advanced Preforming Conclusions

- High speed chopper development going very well with preparation ~90% completed to demonstrate on robot in 2009
- In-situ blending is progressing, but molding limitations have hindered product evaluation
- Near-term plans to implement better charge heating and SRIM to enhance thermoplastic processing, hybrid materials development, and LCCF evaluation
- Blade coating changes appear very promising and will be further evaluated
- Identifying longer-term strategy for modeling support in Phase II
- Phase II planning with ACCP for ORNL to assume additional demonstration role – seat is initial candidate