

Validation of Material Models for Automotive Carbon Fiber Composite Structures (VMM)

**Libby Berger (General Motors), Omar
Faruque (Ford)**

Co-Principal Investigators

US Automotive Materials Partnership

June 17, 2014

LM084

Overview



Timeline

- Project start date: 6/1/2012
- Project end date: 11/30/2016
- Percent complete: 28%

Budget

- Total project funding
 - DOE share: \$3,445,119
 - Contractor share :\$3,445,119
- Funding received in FY13
\$514,968
- Funding for FY14:
 - DOE share: \$1,076,915
 - Contractor share: \$1, 076,915

Barriers

- Predictive Modeling Tools
 - The primary target is the validation of crash models for carbon fiber composites used in an automotive crash structure, which will be demonstrated via design, analysis, fabrication, and crash testing of the structure.
- Manufacturability
 - A secondary target is the ability to manufacture an automotive crash structure suitable for the validation of the crash material models

Partners

- Northwestern University
- University of Michigan
- Wayne State University
- National Center for Manufacturing Studies
- ESI
- Continental Structural Plastics
- Highwood Technologies
- Project Lead: USAMP (a collaboration of GM, Ford, & Chrysler)

Objective - Relevance

Validate crash models for carbon-fiber composites that enable the use of production-feasible composites in primary-structural automotive crash and energy management applications.

Project Goal:

- ☐ Validate existing constitutive models in commercial codes, as well as those models developed by previous Automotive Composites Consortium (ACC) - DOE projects in conjunction with academic partners, by predicting quasi-static and dynamic behavior and structural crash performance of a demonstration part.

Relevance to DOE Vehicle Technologies Mission:

- ☐ Successful validation of predictive carbon-fiber models will enable the future use of these techniques to design structures using lightweight carbon-fiber composites for significant mass savings, enabling more energy efficient and environmentally friendly highway transportation.

❑ ***Experimental and Analytical Characterization of Crash Testing of a Steel FBCC***

As input into the composite FBCC design, a steel FBCC from a current commercial vehicle will be crashed in both high-speed and low-speed modes. The data will be analyzed and used as targets for our composite design.

❑ ***Design of the composite FBCC***

- *Select carbon-fiber material and process system*

At least one material and process system (MPS) suitable for high-volume manufacture (~ 100,000 parts per year) of a carbon-fiber composite will be selected for this project.

Plaques and simple shapes will be made with this MPS, and the appropriate material properties determined.

- *Select and model the joining strategy*
- *Iteratively design a composite FBCC*

The composite FBCC will be designed, in conjunction with the Materials and Process team, via an iterative process using previously-developed ACC models and commercial codes, with the targets from the steel FBCC crash.

Approach, continued

❑ ***Manufacture and assembly of the composite FBCC***

- *Develop the fabrication process for the composite FBCC*

Tooling will be designed and fabricated for the selected design and MPS. While initial fabrication trials may use glass fiber composite, final trials and prototypes will use carbon fiber composite.

- *Fabricate and assemble the FBCC*

Crush cans and bumpers will be fabricated and assembled into the FBCC.

❑ ***Crash testing of the composite FBCC***

- Test the composite FBCC at the determined static and dynamic load cases. Sufficient repetitions will be performed to establish reproducibility comparable to steel.
- Failure modes will be analyzed to determine part-to-part variability.
- Test data will be analyzed to obtain critical crash responses for the composite FBCC which characterize the dynamic forces, deceleration, and transient energy absorption measured during the crash test.

Approach, continued

❑ ***Non-Destructive Evaluation of Composite Structure***

- *Pre- and post test NDE of selected composite FBCC*

NDE methods will be evaluated and developed for the selected MPS. The composite FBCC system will be nondestructively inspected both before and after testing. This will include joints and joint strength, and the properties of the composite materials.

- *Evaluating NDE methods to monitor "health" of composite structure*

Methods will be evaluated for in-service monitoring of the composite structure. Methods may include the use of fluorescent dye in microcapsules, bulk resistivity measurements, resistance of a conductive fiber woven into the structure and capacitive measurements, as well as other methods TBD.

Approach, continued

❑ ***Comparison of the Experimental Results with the Analytical Predictions***

- *Comparison of the Steel and Carbon-fiber Composite FBCC*

The results of the physical testing of the carbon-fiber composite FBCC will be compared with the critical response targets determined from the steel FBCC to determine equivalency of performance.

- *Correlation of Physical and Analytical Results*

The crash response predictions from the commercial models and previously-developed ACC models will be compared to the physical test results to establish the predictive capabilities of these material models.

All analytical model predictions will be compared with each other, to determine the relative utility of these models.

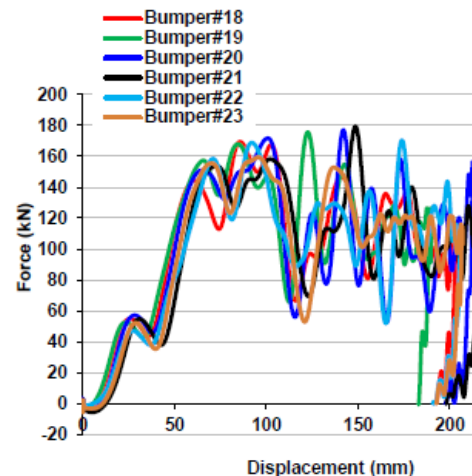
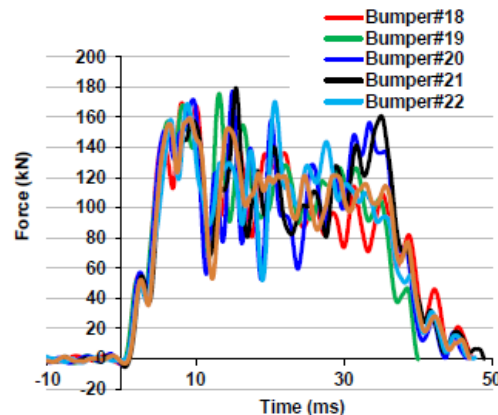
Milestones for 2013 and 2014

M1	<i>Crash Test Fixtures for Steel FBCC Complete</i>	12/20/2013	Complete
M2	<i>Steel FBCC Predictions Complete</i>	4/21/2013	Completion expected by date
M3	<i>Steel FBCC Crash Testing and Targets for Composite FBCC Design Complete</i>	2/28/2014	Complete
M4	<i>Composite Material Property Testing Complete</i>	11/22/2013	Certified lab testing 3/31/2014
M5	<i>Composite Material and Process System Selection Complete</i>	12/20/2013	Complete 3/31/2014
M6	<i>FBCC Design 1 Released for Tooling Kickoff</i>	3/31/2014	To be complete 3 months after M5
M7	<i>Composite FBCC Design Complete</i>	6/27/2014	On track

Technical Accomplishments: Crash Testing of Steel FBCC



- ❑ Built a universal sled system with adaptive front end to vary tests methodology. Used redundant measures for data analysis (i.e., accelerometers & load cells, accelerometers & high speed video analysis).
- ❑ Crash testing complete for 4 high speed crash modes: NCAP Full Frontal, 40% Offset Rigid Barrier, Center Pole, 30° Angular. Low speed pendulum tests underway.



- ❑ Analysis demonstrates excellent repeatability in each test mode, per example – 40% offset mode
- ❑ Simulation of all impact events has been completed for the Steel FBCC system – High speed and Low Speed

Technical Accomplishments: Design of Composite FBCC



❑ A comprehensive material property matrix was developed to meet the needs of academic material model partners and commercial codes.

- University of Michigan Meso-scale Representative Unit Cell (RUC) Model (Waas) and Northwestern University Microplane Model (Bazant)
- PAM-Crash, RADIOSS, LS-Dyna, ABAQUS
- Developed a list of minimum material property data test matrix required to support crash model validation for a high-volume composite FBCC that will meet crash criteria. This includes standard tensile, compression, shear, and flex properties, as well as fracture modes, size effect, and rate effect tests.

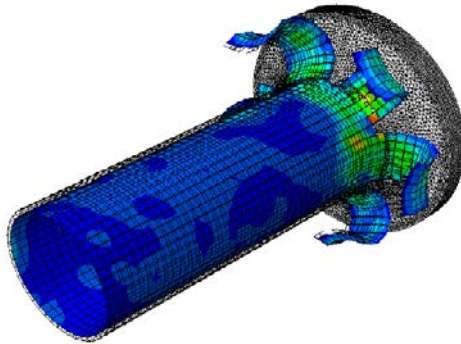
❑ Selection of Material and Process System

- Initial compression molding trial of unidirectional and fabric carbon prepreg and chopped carbon SMC was successful, and in-house plaque testing showed properties in line with literature values.

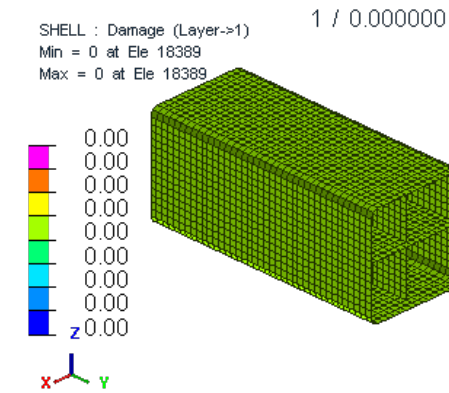
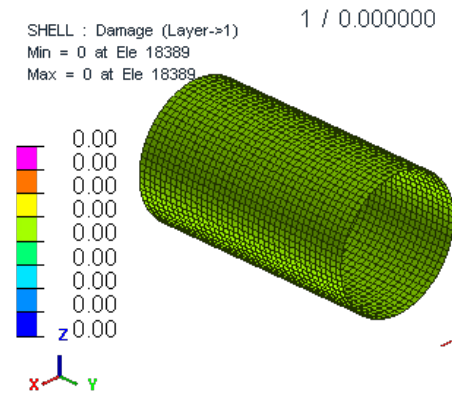
Technical Accomplishments:

Design of Composite FBCC, continued

- Engineering activity has focused on developing section profiles and crush characteristics (peel or axial crush modes) for the crush can



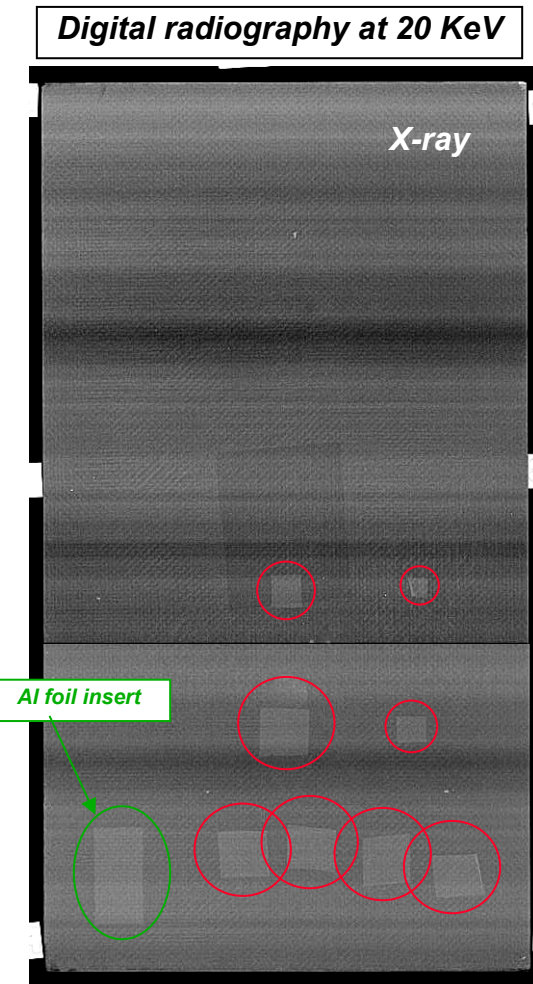
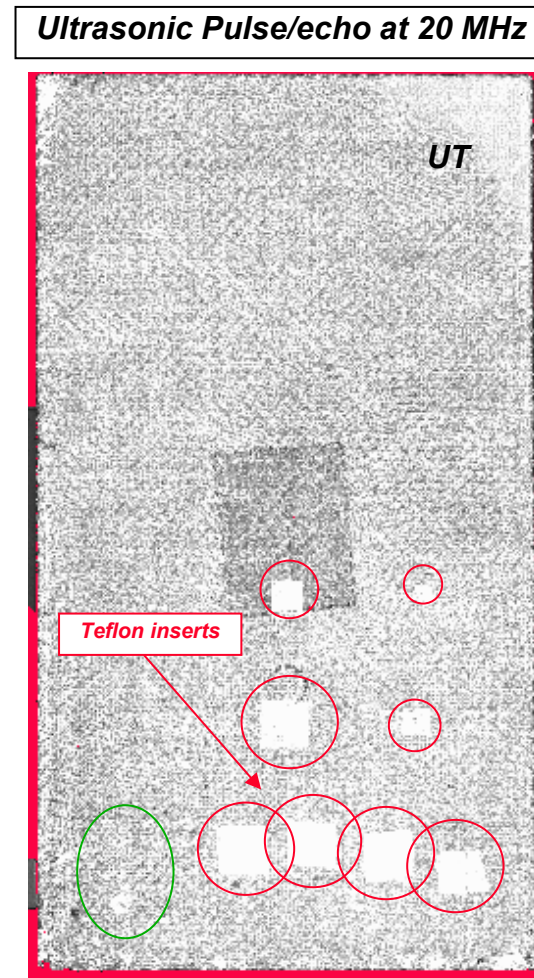
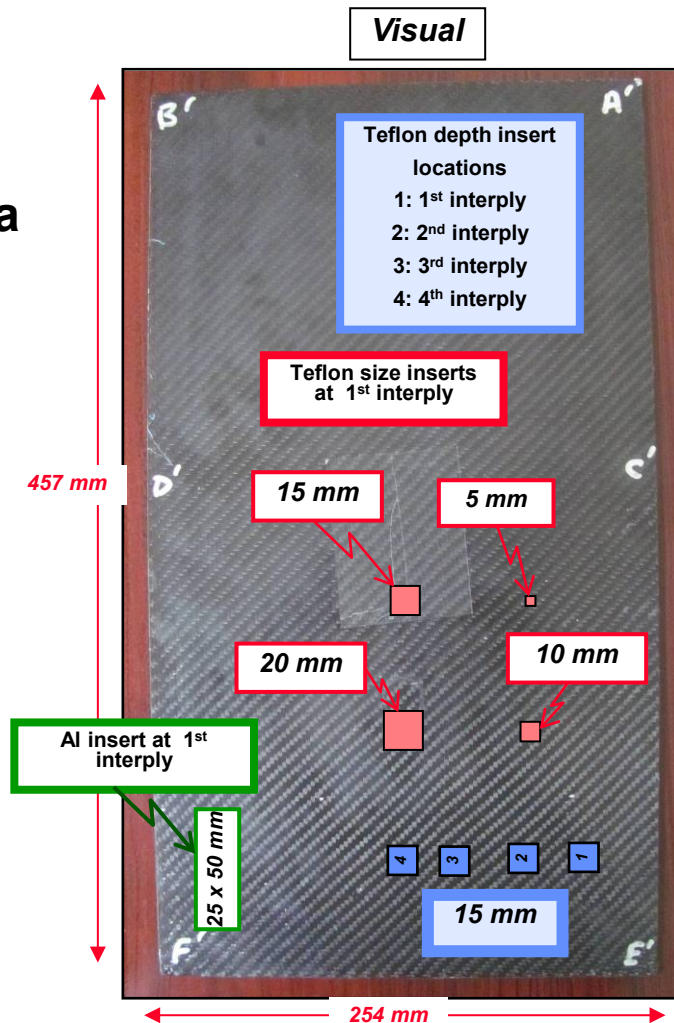
Design using
Microplane model



Two designs using PAM-Crash material model

Technical Accomplishment: Non-Destructive Evaluation Method Comparison

Several “flaws” were molded into a plaque, then imaged by ultrasound and X-ray methods. A variety of flaws at different depths were clearly seen.



Woven plaque 8-ply [(0F,90F)₄]_s, 1.9-mm thick

As this is a fairly new project, beginning towards the end of FY2012, it was not reviewed last year.

Collaboration with other institutions

❑ Northwestern University

- Sub-recipient. Collaboration is within the VT program
- Northwestern is one of the key members of our team. Prof. Bazant has worked with ACC for a number of years on the Microplane model. He and his team will be predictively modeling the crush cans for this project, to determine if their model can be validated in an automotive crash scenario.

❑ University of Michigan

- Sub-recipient. Collaboration is within the VT program
- U of M is one of the key members of our team. Prof. Waas has worked with ACC for a number of years on the Meso-Scale model for an RUC. He and his team will be predictively modeling the crush cans for this project, to determine if their model can be validated in an automotive crash scenario.

❑ Wayne State University

- Sub-recipient. Collaboration is within the VT program
- Wayne State is providing the crash testing for the project, including high speed sled tests and lower speed pendulum tests. Prof. Newaz and his team are participating with equipment development, testing, and analysis.

Collaboration with other institutions, continued

❑ National Center for Manufacturing Studies

- Vendor. Collaboration is within the VT program.
- NCMS is the technical project manager for the VMM project.

❑ ESI

- Vendor. Collaboration is within the VT program.
- ESI is the prime engineering vendor, responsible for the predictive analysis of the steel FBCC and the design and predictive analysis of the composite FBCC, using commercial codes.

❑ Continental Structural Plastics

- Vendor. Collaboration is within the VT program.
- CSP is the major composite fabrication supplier, responsible for fabrication of plaques and simple shapes for materials evaluation, and fabrication of the composite FBCC.

❑ Highwood Technologies

- Vendor. Collaboration is within the VT program.
- Highwood Technologies is responsible for the development of NDE for the carbon fiber composites, as well as the investigation of structural health monitoring methodologies.

Proposed Future Work

□ FY 2014

- Determine the material and process system necessary for the crush can to meet the energy absorption target determined by crash of the steel crush can.
- Optimize the composite FBCC system performance using 40 mph Full Frontal Impact, with acceptable results for other Impact events (Offset, Angular, Center Pole, etc.)
- Develop a technical solution and detailed design for the crush can, the bumper beam, and the joint of the beam to the crush can

□ FY 2015

- Develop methodologies for NDE and SHM of a system with the materials, geometry, and joining of the composite FBCC
- Predict crash test results for the composite FBCC

□ FY 2016

- Fabricate prototype parts for the developed system and run physical crash tests on composite FBCC
- Determine correlation between simulation predictions and physical tests

VMM Project Summary

❑ Relevance

- The *validation of crash models for carbon-fiber composites* enables the use of production-feasible composites in *automotive primary structures* including crash and energy management applications, thus *saving mass* and *increasing transportation energy efficiency*.

❑ Approach

- *Design and build* a composite FBCC that meets the targets of a production steel system, *predict* its performance based on commercial and academic material models, *crash* the composite structure, and *correlate* the design predictions with the crash results.

❑ Technical Accomplishments

- *Crash* testing of *steel FBCC*
- *Design* of several options for *crush cans*
- Initial evaluation and selection of *material and process system*
- Comparison and evaluation of *NDE methods* for carbon-fiber composites

❑ Collaborations

- Northwestern University, U of Michigan, Wayne State University
- Vendors for predictive design, composite structure fabrication, NDE, and project management .

❑ Future work

- Complete the design, predictive analysis using material models to be validated, and build of composite FBCC
- Crash the composite FBCC
- Correlate crash results with the predictive analysis