C. High Volume Processing of Composites (ACC 115[i])

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Objective

- Develop and demonstrate high-volume manufacturing (molding) processes to produce lightweight composite automotive components.
- Expand the scope of the Automotive Composites Consortium (ACC) composite efforts into the thermoplastic area.

Approach

- Benchmark current thermoplastic processes.
- Develop and study high-volume composite manufacturing processes within approved research efforts.
  - Develop manufacturing processes for carbon-fiber SMC body panels amenable to cost-effective high-volume applications.
  - Investigate compatibility of natural-fiber reinforcements with polymer systems for structural and semi-structural applications.
  - Develop understanding of soy-based polymers in conjunction with glass and carbon-fiber reinforcements.
  - Investigate DRIFT technology with various fiber reinforcements in polymer systems for structural and semi-structural applications, including partnership with the ORNL carbon-fiber line.
  - Acquire tooling necessary for the support of ACC115 research programs.

Accomplishments

- Provided process support for the duration of Focal Project 3, B-Pillar molding (ACC080, see 4.D).
- Preliminary experiments with carbon-fiber SMC completed with Meridian Automotive Systems and sample benchmarking plaques submitted for testing.
- Injection-molding plaque tool completed and undergoing final preparation for starting work on thermoplastic characterization database.
- Compression molding plaque tool complete and supporting ACC040 (see 4.A) investigations.
- Completed investigation into acquiring 3000T press to be used in development work.
- Technology benchmarking in Germany and Switzerland, January 2006.

Future Direction

- High-volume processing of lightweight structural thermoplastic composites.
  - Characterize panels fabricated with Fiberforge® technology and proceed with optimizing the polymer systems to enhance performance and appearance.
  - Participate in DRIFT® investigations at ORNL relative to testing and processing optimization.
- Carbon-fiber SMC body panels for exterior and interior applications:
  - Continue working with fiber and resin suppliers to develop properties, improve repeatability, and optimize manufacturability within cost and supply constraints.
- Natural-fiber reinforcements and soy-based polymers:
  - Characterization results will be used to refine testing methods for determining durability properties of natural-fiber composite systems.
  - Optimize fiber-surface treatments and polymer systems to minimize the moisture absorption of natural-fiber composite systems.
- Provide process support to Focal Project 4, Composite Underbody/Seat (ACC007).
  - Utilize the injection-molding and compression-molding plaque tools to manufacture composite plaques for material characterization and development of a thermoplastic reference database.

Introduction

The purpose of this project is to develop the high-volume composite molding technologies germane to automotive production. The direction of ACC115 is to collaborate with suppliers to develop low-cost, high-volume molding processes compatible with the material property and processing requirements of the automotive industry.

Four processing investigations are under way. 1) Collaboration with Fiberforge® was initiated to determine the feasibility of robotic placement of uni-directional fiber tapes in desired orientations, to produce locally-reinforced blanks at high speed. 2) DRIFT®, a patented pultrusion process, is being studied for its ability to support the project objectives and its compatibility. This work is being conducted at ORNL. 3) A program has been initiated to resolve issues with producing carbon-fiber SMC body panels for exterior and interior applications. Finally, 4) natural fibers and soy-based polymers are being studied for their compatibility with current systems, and their physical characteristics, with the intent of adding the desired feature of sustainability to the other objectives.

To support these initiatives, purchase of two plaque tools, one for compression molding and one for injection molding, was completed in FY 2006. These molds can be used at various suppliers and national laboratories to create plaques for mechanical testing using various thermoplastics and reinforcements. The compression molding tool was delivered 4Q 2005. The injection tool was completed at the end of FY 2006. In addition, purchase of a new compression-molding press was proposed to support the research needs of existing and future projects being pursued by the ACC working groups.

An investigation was completed on securing a new compression-molding press for the purposes of supporting the research objectives.

Fiberforge®

In the Fiberforge® process, unidirectional tapes are robotically placed to enhance structural performance of specific areas of the components produced. Initial meetings have been held with Fiberforge® to develop a work plan, roles and responsibilities, and a cost analysis. Plaques made via the Fiberforge® process, utilizing nylon 6 (PA6) with carbon-fiber reinforcement, have been submitted to the ACC Materials Working Group for analysis and characterization.

DRIFT®

In FY 2005, ACC115 began work in conjunction with ORNL to address the compatibility of Directly Reinforced Fiber Technology (DRIFT®) with low-cost carbon-fiber program objectives. DRIFT® is a patented pultrusion process by which tapes, chips, pellets, sheets, or woven fabrics are produced, which then are capable of feeding a variety of molding processes.

As part of its Advanced Preforming Initiative, ORNL has been working at a low level with Polycomp (inventor of DRIFT®) and Fiberform (a key licensee) to evaluate possibility of chopping the DRIFT® product form in the ORNL preforming machine. Polycomp made sample quantities of glass-impregnated polypropylene using a 2400 tex glass tow which had been processed into a ribbon about 0.2 inch wide and .035-in thick. As expected, the ribbon handles more like a solid strip of plastic than a pliable fibrous tow and does not cut as easily as the glass tow, even with scissors.

In initial trials, ORNL was able to get some of the material through the preformer's chopper, but with only very small amounts were cut before blades began to break in the chopper. Plans are to make more samples in FY 2007 using a smaller tow size (most likely 1150 tex, which is about the size of the current TwinTex® product) in order to get a thinner ribbon. Once it has been established that the material can be rapidly chopped using the existing rotating blade configuration or one similar to that currently in the preforming machine, work will proceed on optimizing material forms and chopper configurations that might be economically feasible for implementation. ORNL plans to continue initial evaluations of laser severing and to initiate a more basic study of mechanical chopping in FY 2007 for various materials forms.

Fiberform has also put ORNL in touch with a supplier of cutting equipment with whom Fiberform has worked in the past. With a better understanding of this background and related equipment experience provided by the supplier, ORNL will be able to better address alternative means for processing the DRIFT® material form.

Longer-term and perhaps more importantly, ORNL continues working with Polycomp and Fiberform towards putting a prototype DRIFT® line at the end of a low cost carbon-fiber pilot line to evaluate and demonstrate technical and economic potential for various automotive applications of the DRIFT® process.

More definitive work plans are being developed for collaboration in both broad application of DRIFT® with carbon fiber as well more specifically with utilization in preforming equipment. Objectives would include optimizing the fiber types, percentages, and types of polymer systems to achieve needed levels of mechanical performance and appearance. Important process characteristics such as low warpage and reduced material system cost will be explored. Test specimens and components will both be tested for characterization and durability for use in structural and semi-structural applications.

Carbon-Fiber SMC

The objectives of this work are to develop high-performance, cost-effective, carbon-fiber SMC materials and associated processing techniques for high-volume automotive components. The technical emphasis is to optimize properties, improve consistency of the properties, and to optimize the manufacturability of the compound. The project assumptions are that the material could be used for all current structural and Class-A SMC applications; that the current SMC compounding, molding processes, and equipment can be utilized; and that the thickness of the new materials will be in the range of 1.0 to 3.0 mm. In addition to the technical issues and constraints, there are the business challenges of the carbon-fiber cost, the limited supply of carbon fiber, and the disinclination of the carbon-fiber suppliers to cooperate on research, perhaps due to the low-cost requirement of the automotive industry.

A few preliminary experiments have been done using Hexcel A54C1925 and split-tow Toho XO502 carbon fibers with Meridian Automotive Systems' vinyl ester resin. The results suggested that fiber format and sizing could have a strong influence on short-beam shear properties and styrene solubility. Additional effort has subsequently been made to

arrange the cooperation of carbon-fiber suppliers (Toho Tenex, Toray, and Zoltek) and resin suppliers (AOC, Ashland, and Reichhold). For benchmarking, sample plaques of Meridian's in-house structural carbon-fiber SMC using Toray T700 fibers have also been prepared for physical and mechanical testing through the Automotive Composites Consortium.

Natural Fibers and Biocomposites

A DOE project titled "A Fundamental and Applied Investigation of Kenaf-Based Fiber/Polymer Composites as Potential Lightweight Materials for Automotive Composites," at ORNL and Mississippi State University was started in FY 2006. The ACC was assigned to the project as an industry partner. The project kick-off was accomplished and project objectives were established.

Project objectives are listed below:

- Investigate the compatibility of natural-fiber reinforcements with polymer systems, for usage in exterior and interior applications of both structural and semi-structural purpose.
- Optimize fiber-surface treatments and polymer systems to enhance compatibility and performance, as well as minimize moisture absorption.
- Develop an economical, automated, high-throughput fiber retting process.
- Improve natural-fiber composite properties by the addition of inexpensive, nanoscale additives and/or excellent interfacial bonding.

Ashland Chemical Soy Resin Project

Test plaques utilizing a commercially-available, soy-based resin, reinforced with glass and carbon fiber, were compression-molded at Ashland Chemical. The test plaques were fabricated for a direct comparison with petroleum-based resin systems that have identical reinforcement percentages. The characterization was conducted by the ACC. Tensile and compression results are shown in the following charts. Tensile stress results shown in Chart #1 for glass-reinforced composite indicated the petroleum-based and soy-based plaques performed similar with little anisotropy. Carbon-fiber results indicated the petroleum-based plaques performed better with a noticeable difference in anisotropy. Tensile-modulus results shown in Chart #2 for glass-reinforced composite indicated the petroleum-based and soy-based plaques performed similar with some anisotropy. Carbon-fiber results indicated the petroleum-based plaques performed much better in the 0^{o} direction and better in the 90° direction. Tensile strain-to-failure results shown in Chart #3 indicated higher strain-to-failure values for glass reinforced composite when compared to carbon fiber, which was expected. Compression-stress results shown in Chart #4 for glass-reinforced composite indicated the petroleum-based and soy-based plaques performed similar. Carbon-fiber results indicated the petroleum-based composite performed better with lower variability.

Additional testing for shear, density, fiber and void content, dynamic mechanical analysis (DMA), coefficient of linear thermal expansion (CLTE) and moisture absorption for the soy and petroleum-based plaques still remains to be completed.

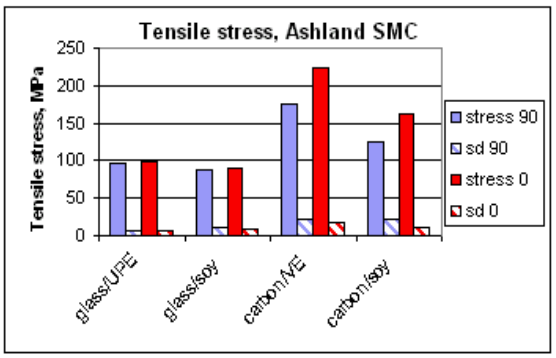

Chart 1. Tensile Stress, Petroleum vs. Soy Resins.

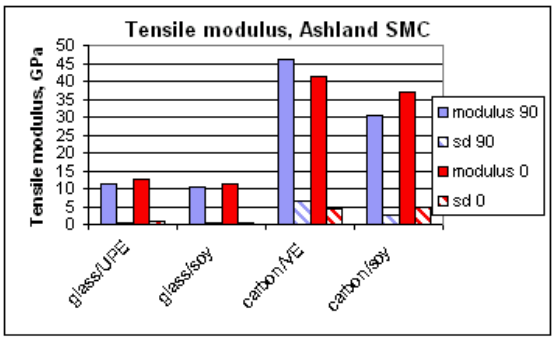

Chart 2. Tensile Modulus, Petroleum vs. Soy Resins.

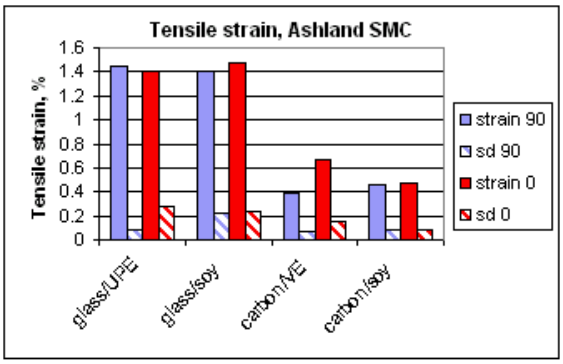

Chart 3. Tensile Strain, Petroleum vs. Soy Resins.

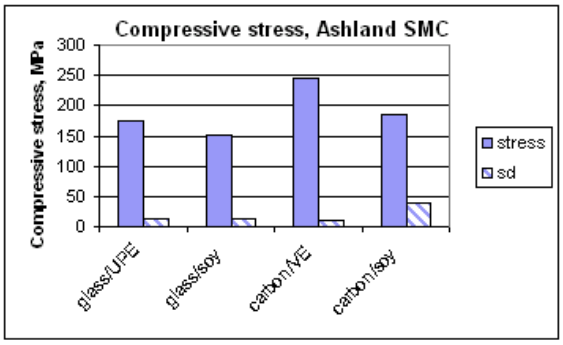

Chart 4. Compressive Stress, Petroleum vs. Soy Resins.

Tool Acquisitions

One of the obstacles identified with studying the consistencies of processing various materials has been the inability to make test plaques. To address this concern, the ACC Board of Directors approved the proposals to build an injection-mold plaque tool, and a compression molding plaque tool.

Each tool was designed to produce a 610 mm X 610 mm (24" x 24") plaque using a wide variety of materials and be capable of multiple thicknesses. The individual tools can be shipped to various molders to compare samples made from the same tool but with optimum process conditions. In addition, pressure sensors and thermocouples were specified for several positions in each tool so that process data can be collected and compared between trials in a consistent fashion. Tool-commissioning trials are complete and the final sign-off occurred November 15th 2005.

The injection-molding tool was designed by a team of ACC members and incorporated many "lessons learned" on prior projects. The stringent requirements included options of producing test panels from 2.0 mm to 5.0 mm in thickness in increments of 0.5 mm, easy access to multiple sensors at prescribed positions, and capability of withstanding high clamp forces without flashing. The full requirement list is available on VROOM*.

The injection plaque tool completed runoff in late September. The tool will be a significant part of the Material Working Group's thermoplastic database development.

ACC Compression-Molding Facility

Purchase of a new compression-molding press has been proposed to support the research needs of existing and future projects being pursued by the ACC working groups. With this objective, a new press facility was proposed for installation at the North Central Campus of Emerging Technologies (NCC-ET). This satellite of the National Composite Center was considered a suitable location for both logistical and infrastructure reasons. Hence, during 2006 extensive discussions were held with the proprietors of the NCC-ET facility and Dieffenbacher, the proposed press manufacturer. The scope of the overall facility capabilities was also extended to include a proposed collaboration with the German institute, Fraunhofer, ICT.

*Available only by authorization

The total project cost for USAMP and NCC equipment purchases and building modifications was estimated at $4M.

Although approvals were secured through USAMP for the project to go forward, several key events in 2006 ultimately prompted a cancellation. The first main issue emerged following an attempt to secure the purchase of the main press unit. The press manufacturer stated several objections to the USAMP purchase order terms and conditions. After many months of protracted discussions, an impasse was reached and the USAMP order for the press was cancelled. Instead, the NCC offered to purchase the press and rent time to the Automobile Composites Consortium on an as-needed basis. However, the NCC failed to secure financing for such a project and by the end of September, the ACC members made a decision to cease further activity related to the new press facility. Therefore, for the time being, the ACC has decided to continue supporting process investigations by attempting to rent access to equipment within the tier supply base.

European Benchmarking Trip

In line with the objective of benchmarking current plastics processes, a group of seven members from the ACC Board of Directors and the ACC115 working group spent a week in January 2006 touring companies and educational sites in Europe to gather information about the state of the plastics industry. Europe is widely considered to be the seat of automotive plastics innovation, particularly within the thermoplastics area, as the economic forces for lightweight vehicles are stronger in Europe than in the United States.

An aggressive five-day agenda took the team to 7 different suppliers and 2 academic research sites. Valuable contacts were made and opportunities for further processing research were discussed; a summary of the visits and technologies was presented in the semi-annual report.*

Conclusions

ACC115 explores different approaches to the high-volume processing of composites. Four processing programs are in progress, each with the objective of researching ways to save weight in automobiles, at the volumes unique to the industry. Carbon-fiber SMC research is progressing slowly against constraints of cost and supply. Natural fibers and biocomposites C. ACC115[2]-- also hold future possibilities of less reliance on petrochemicals and greater recyclability. DRIFT® and Fiberforge® work continues; basic characterization is in progress and applications will be considered. Acquisition of new equipment specifically owned by ACC will speed research by eliminating time needed to move tools between suppliers, and will also provide the benefit of reducing variation in the test results.

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[i] Denotes project 115 of the Automotive Composites Consortium (ACC), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development.