C. High Volume Processing of Composites

Principal Investigator: Becky Joitke
DaimlerChrysler NA, Advance Vehicle Engineering
CIMS 489-00-00, 1030 Doris Road, Auburn Hills, MI 48326
(248) 754-9761; fax (248) 754-9720; e-mail: rlj@daimlerchrysler.com

Technology Area Development Manager: Joseph A. Carpenter
(202) 586-1022; fax: (202) 586-1600; e-mail: joseph.carpenter@ee.doe.gov
Field Technical Manager: Philip S. Sklad
(865) 574-5069; fax: (865) 576-4963; e-mail: skladps@ornl.gov

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Objective

- Develop and demonstrate high-volume manufacturing (molding) processes to produce lightweight composite automotive components.
- Provide process development support to Focal Project 3, B-Pillar molding (ACC080).

Approach

- Benchmark current thermoplastic processes.
- Develop new research programs to study high-volume composite manufacturing processes.
  - Determine the technical feasibility of thermoplastic P4 (TP-P4) for chopped-fiber lay-up.
  - Initiate carbon-fiber sheet molding compound (SMC) program with suppliers.
  - Investigate the use of natural fiber as a lightweight and low-cost alternative to glass fiber.
  - Develop a cost model to determine feasibility of new technologies and the viability of existing technologies.
  - Establish gateways to determine program duration.
  - Propose programs to the Automotive Composites Consortium (ACC) Board of Directors for approval.

Accomplishments

- Completed the design of experiments (DoE) to assess the effects of glass type, glass length, thickness, de-mold time and surface veil of plaques created via the long-fiber injection (LFI) method in partnership with Bayer.
  - A LFI plaque tool was constructed based on an existing reinforced reaction injection molding (RRIM) tool at Bayer but incorporating shear edges and a show surface finished to SPI A2.
  - Based on extensive benchmarking of typical class "A" exterior substrates, the ACC Processing (ACCP) Team identified a "Surface Acceptance Standard" linked to specific quantitative techniques for use in future studies.
- New programs initiated:
  - Develop P-4 chopper gun technology to produce tailored hybrid blanks from a combination of glass, carbon and natural-fiber reinforcements for subsequent hot-flow compression molding.
  - Partner with Fiberforge® to validate materials and processes for application to high-volume automotive production.
  - Investigate DRIFT technology with various fiber reinforcements in polymer systems for structural and semi-structural applications.

  - 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.

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.
  - Investigate DRIFT technology with various fiber reinforcements in polymer systems for structural and semi-structural applications, including partnership with the ORNL carbon-fiber line.
- Carbon-fiber SMC body panels for exterior and interior applications:
  - Resolve material and processing issues, including physical property variation, mold flow, low-strength knit lines, and surface appearance
- 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.
- TP-P4 project to be encompassed under ACC040.

Introduction

The purpose of this project is to develop the high-volume composite molding technologies germane to automotive production. Previously, this project mainly supported ACC Focal Project 3 (ACC080); liquid molding processes (see report 4.D). Structural reaction-injected molded (SRIM) technology was utilized to mold carbon-fiber preforms of reduced section thickness. Currently, all molding support of Focal Project 3 is being undertaken through its own efforts. Therefore, a new direction has been defined in this project (ACC115), to collaborate with suppliers to develop low-cost, high-volume molding processes compatible with the material property and processing requirements of the automotive industry.

The first of these new programs was initiated in 2004 with Bayer to investigate the feasibility of their long-fiber injection (LFI) molding process. Personnel from the ACC and Bayer collaborated in a study of LFI of polyurethane to assess its potential for achieving a Class "A" automotive finish, and to characterize its structural capability.

Efforts to reach the Class "A" surface requirements, detailed in prior progress reports, were not fully successful due to air entrapment. Solutions for venting the tool and adding vacuum to the system were explored. Considerable reductions in air entrapment were achieved with the vacuum, and the team also found that sections near the lifter area, where the LFI was particularly compressed, were exceptionally free of defects. This program is now completed and published in the ACC Technical Report TR-P05-04.

Five new programs have been proposed, approved, and initiated: 1.) The P4 process, developed within the ACC, is being studied for producing tailored hybrid blanks with a combination of glass, carbon and natural fiber reinforcements. These blanks are to be used for subsequent hot-flow thermoplastic compression molding. 2.) Collaboration with Fiberforge® has been initiated to determine the feasibility of robotic placement of uni-directional fiber tapes in desired orientations, to produce locally-reinforced blanks at high speed. 3) DRIFT®, a patented pultrusion process, will be studied for its ability to support the project objectives and its compatibility. 4.) A program has been initiated to resolve issues with producing carbon-fiber SMC body panels for exterior and interior applications. Finally, 5) 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 proposed and approved. 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 will be delivered 4Q 2005. The injection tool will be completed 1Q 2006.

Thermoplastic P4

Introduction

Examples of thermoplastic composites are widespread within the automotive industry. This is driven in most part by the design flexibility and weight savings realized through the use of low-density polymers. However, material price is a constant consideration and has often prevented the application of thermoplastics to structural components due to the necessity to attach supplementary reinforcements, which in turn drives up cost. The processing concept which is described in the following sections claims to offer two major benefits. First, components are fabricated using commodity raw materials in an attempt to reduce piece cost. Secondly, the process is designed to take maximum advantage of material properties to allow further design optimization. The latter translates into the elimination of secondary reinforcements which provides opportunities for further weight reduction. As a thermoplastic derivative of the P4 Process (Programmable Powdered Preforming Process), the new process is referred to as the TP-P4 process.

Process Concept

Figure 1 shows the basic process concept. In Station 1, reinforcement fiber and polymer are dispensed, using a pre-programmed deposition cycle, onto a perforated screen. Fibers are held in position using air flow through the screen. A stabilization cycle follows to create a rigid blank which can be easily removed and transferred to the next station. The blank is subjected to a pre-consolidation process (Station 2) to promote fiber-bundle wetting. Depending on the consolidation method, the blank may require a further pre-heating step before being placed as a charge into a shear-edge compression-molding tool. The press closure in Station 3 results in hot-flow compression molding of the charge, and formation of the final part shape.

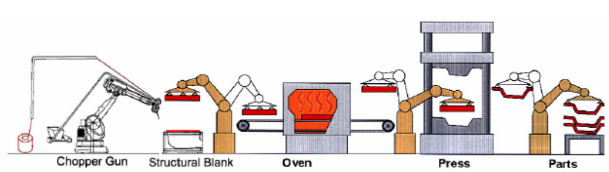

Figure 1. TP-P4 Process Concept.

Notable differences between the original P4 process and the new thermoplastic-based derivative include restricting the fiber deposition to a 2D blank as opposed to a 3D net-shape preform. Furthermore, both the fiber and matrix materials are deposited in the new process, compared to the original P4 process which required a subsequent liquid molding operation. Potential benefits of the process are listed below. The engineering and cost analysis, which form part of the research plan, will address each of these items to validate each of the associated claims.

TP-P4 Process Benefits

- Lower raw material costs and no blank cutting costs.
- Tailored blanks retain fiber length equivalent to glass mat thermoplastic.
- Blank size and shape can be customized for specific applications.
- Local uni-directional fibers can be integrated into the blank for enhanced stiffness and strength. Plus, fibers can be orientated to meet local stiffness requirements.
- Areal density can be adjusted to meet flow condition and press tonnage capabilities.
- Thinner sections are possible where appropriate.
- Option for use of hybrid reinforcement (glass/carbon/natural fiber) within a single blank.
- Applicable to a broad range of thermoplastics applications.

Economic Analysis

An analysis of the TP-P4 process and associated costs has been undertaken in conjunction with Swiss

Federal Institute of Technology (EPFL) Lausanne, Switzerland. This study will also compare the TP-P4 technology to other more conventional thermoplastic technologies. The work is divided into three distinct phases.

Phase 1: Preliminary cost analysis based upon assumptions of TP-P4 capability.

Phase 2: Experimental studies to corroborate process and equipment assumption used in Phase 1.

Phase 3: Refinement of cost model and update of results based upon studies conducted in Phase 2.

During the first phase of the project, baselines cost models have been created for process technologies that are direct competitors to the TP-P4 concept. These models are now established and will provide a realistic assessment of the cost savings forecast using the new technology. In order to execute a comparative analysis, two target components have been selected as the focus of case studies (a SUV liftgate inner panel and a rear seat back structure). To date, materials and process data have been gathered for input into the cost model. Outstanding data, required to enable the first analysis, are being sought with a first series of cost analysis results due by Nov 30th 2005.

The TP-P4 program initiated under the umbrella of ACC115; however, due to the interrelation of this program and the P4 technology, all processing studies have been undertaken under ACC 040. The results of the initial processing studies are therefore presented in the ACC040 Annual Report (see report 4.A).

Fiberforge®

The Fiberforge® process is comparable to the TP-P4, in that it eliminates additional material and process sequences. In the case of the Fiberforge® process, unidirectional tapes are robotically placed to enhance structural performance of specific areas of the components produced. Figure 2 represents an overview of the process. Initial meetings have been held with Fiberforge® to develop a work plan, roles and responsibilities, and a cost analysis. Plaques made via Fiberforge® process, utilizing nylon 6 (PA6) with carbon-fiber reinforcement, are being submitted to the ACC Materials Working Group for analysis and characterization.

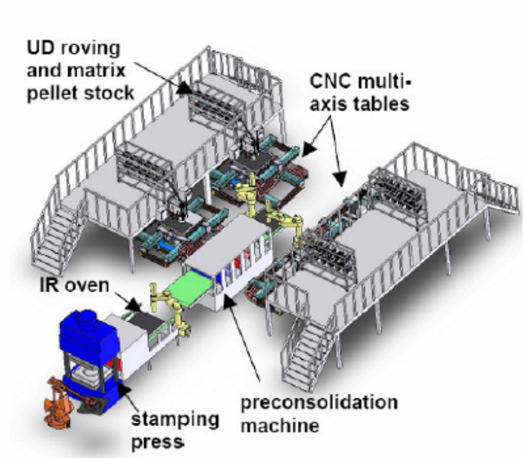

Figure 2. Fiberforge® process diagram.

DRIFT®

In FY 2005, ACC115 began work in conjunction with Oak Ridge National Laboratories (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.

Objectives for the studies 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 program are to develop high-performance, cost-effective, carbon-fiber SMC materials and associated processing techniques for high-volume automotive components. Initial collaborative meetings with Meridian Automotive Systems have been undertaken to determine future program direction. Experience drawn from Meridian's involvement the DOE *21st Century Truck*

Program was reviewed as well as possibilities of utilizing the ACC-funded Toho/Tenax carbon-fiber splitting technology (see report 4.A).

Natural Fibers and Biocomposites

In FY 2005, work began in conjunction with Pacific Northwest National Laboratory (PNNL) to explore opportunities with natural fibers as reinforcements, and soy-based polymers. The objectives were fourfold:

- 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 and conduct characterization and durability evaluations on both test specimens and components.
- Develop the understanding of soy-based polymers with glass and carbon-fiber reinforcements.

Test plaques utilizing a commercially available soy-based vinyl ester resin, reinforced with glass and carbon fiber, were compression-molded at Ashland Chemical. The plaques will be characterized for a direct comparison with petroleum-based resin systems that have been identically reinforced.

In addition, soy-based polyurethane plaques have been provided by Pittsburg State University for characterization; those tests are in progress.

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 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.

In support of numerous ACC projects, a new shear-edge compression tool has been designed and commissioned to enable production of 610 mm x 610 mm flat panels. Test panels, produced using the new tooling, will support process studies and provide a useful source of materials for mechanical testing. A description of the new tooling follows, with key features and capabilities listed below. A 3 D view of the exploded assembly is shown in Figure 3. Tool commissioning trials are complete and the final sign-off is scheduled for November 15th 2005.

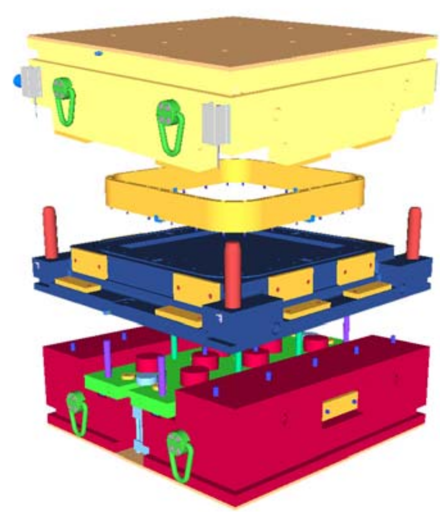

Figure 3. New shear-edge flat panel compression mold.

Basic Tool Description

- Designed for SMC and thermoplastic compression molding.
- Single cavity mold for molding experimental flat plaques, 610 mm x 610 mm (24" x 24") between 1.00 mm and 5.00 mm thick.
- Mold to have external vacuum shroud which should engage with mold open 75 mm and hold 710 mm Hg pressure.
- 6 pressure and 6 temperature transducers each on top and bottom part surfaces.
- LVDTs (displacement transducers) at tool corners to provide position detail for vacuum

system activation and experimental parameter correlation.

- Capability to heat and cool cavity and core to 180°C +/-2°C across part/tool surface using hot oil as the heat transfer median.
- 400 grit finish on core side. 320 draw polish finish on shear edges and other surfaces contacting part.

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 quotation process concluded in the 3rd quarter of 2005 with the selection of Service Mold Inc. Detailed designs are being finalized. Future work includes issuing the purchase orders, proving out the tool once it is completed, and molding plaques from material made with the DRIFT® process for testing. The full requirements list of available on USCAR's VROOM website (www.uscar.org.).

Conclusions

ACC115 explores different approaches to the high-volume processing of composites. Redirection took place early in 2005 as the LFI project with Bayer completed, providing valuable knowledge for future investigations into surface optimization. Since the redirection, five new projects were commissioned, each with the objective of researching ways to save weight in automobiles, at the volumes unique to the industry. Natural fibers and biocomposites also hold future possibilities of less reliance on petrochemicals and greater recyclability.