VALIDATION OF MATERIAL MODELS: FABRICATION AND CRUSH TESTING OF CARBON FIBER REINFORCED THERMOPLASTIC COMPOSITES FOR AUTOMOTIVE ENERGY ABSORPTION APPLICATIONS

Jeff McHenry, Shape Corporation

Jian Tao, FCA US LLC

Anthony Coppola, General Motors

Glen Smith, Ford Motor Company

Manish Mehta, M-Tech International LLC

Abstract

Thermoplastic composites are increasingly competing with thermosets for structural applications in the automotive industry because of advantages such as shorter cycle time, excellent toughness, and better recyclability. However, thermoplastic composites, especially those that are reinforced with continuous carbon fibers, still have significant barriers to overcome before they are widely used in large and complex automotive structural components. These include cost, development of mass production methods, and predictive tools and techniques for performance and processing.

Research was conducted as part of the Validation of Crash Material Models (VMM) for Automotive Carbon-Fiber Composite Structures via Physical and Crash Testing project [1]. This is a $7 million U.S. DOE and USAMP Cooperative Agreement project to validate and assess the ability of physics-based material models to predict crash performance of primary load-carrying carbon fiber composite automotive structures. In this portion of the project, we explored the use of continuous carbon fiber reinforced nylon for crush cans in a vehicle front-end energy absorption structure. We also investigated methods to use low cost carbon fiber developed by Oak Ridge National Lab's Carbon Fiber Technology Facility (CFTC) in these structures. This paper will review the design, fabrication, and testing of these materials.

Background of Project

Purpose

Recently, the need for lightweight materials in automobiles has surged to meet the demand for increased fuel economy. In response, composite materials are moving from a material for high-end applications to viability in large-scale production vehicles. Part of this change is the increased monetary value placed on lightweighting when making material decisions. However, new materials and manufacturing processes are being developed in tandem to bring down the cost of composites and make them more competitive.

The goal of the VMM project was to assess the ability of material models to predict the crash behavior of a structural composite system during crash. To accomplish this, a front bumper and crush can (FBCC) assembly was chosen for simulation and testing of carbon fiber composites. While simulation was the main focus, one critical task was to manufacture the FBCCs and supply them to the crash team for evaluation. Materials and processes were selected to be relevant to both current and anticipated future technologies that are available to the industry.

Design of Crush Structures

The composite FBCC design was based on the existing packaging space and performance of a production from steel system [2]. The FBCC is comprised of five parts, including the beam and the right- and left- hand side crush cans, which are each composed of one “A” and one “B” half (Figure 1). The crush cans are designed as two halves of a tapered cylinder that are joined using flanges. The components of the FBCC are joined using adhesive bonding. In addition, rivets are strategically placed on the crush can flanges to enhance bonding and mainly act as peels stoppers. Features were designed into the beam and crush cans to facilitate the bonding process. A system of bumps and dimples along the crush can flanges that were molded in is to align the halves and control the bond gap (Figure 2). The FBCC is mounted to the vehicle using four bolt holes in the large flanges on the vehicle side of the crush cans. In the event of a frontal crash, the crush cans are the main energy absorbers and do so by progressive crush of the composite. By design, crush starts at the impacted-end of the crush can and progresses towards the vehicle-end. While traditional metal bumper systems absorb energy through many deformation, composites absorb through delamination, micro-cracks, fiber fractures, and other damages that are generated during a dynamic loading event.

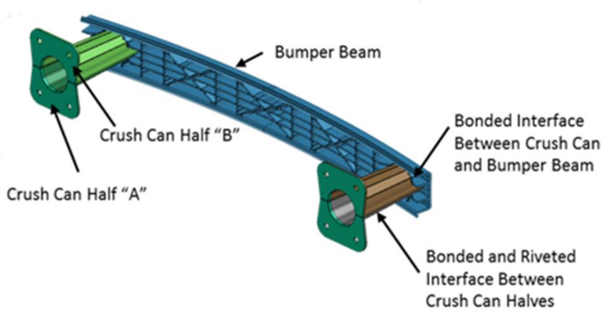
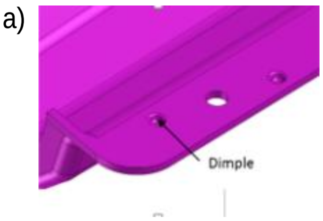
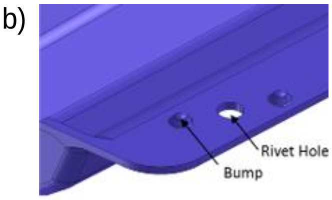


Figure 1: CAD image of the composite FBCC system.





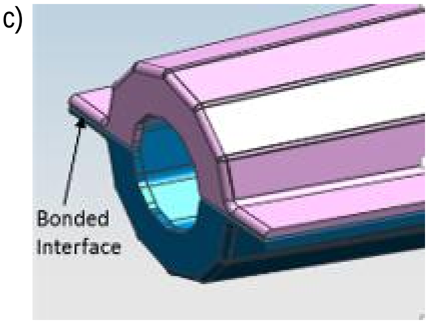


Figure 2: Details of the bonded interface for the crush can halves. a) Zoom-in of half “A” showing the bumps and rivet holes. b) Zoom-in of half “B” showing the receiving dimples and matching rivet holes. c) Schematic of the assembled crush can showing the location of the interface. Rivets are not shown.

Thermoplastic Background

Currently, there is much discussion regarding the use of thermoset vs. thermoplastic materials for a variety of applications in the automobile. Thermosets are generally thought to be easier to process and result in higher strength materials, while thermoplastic materials have much higher fracture toughness and better recyclability, among many other differences. Improvements in thermoplastic material technology and their potential energy absorption in crush, makes them attractive in an FBCC system. In this project, we investigated both thermoset and thermoplastic materials in the crush cans and compared them head-to-head.

Material cost is a key driver in making composite materials competitive. Recently, new low cost carbon fibers (LCCF) developed by ORNL’s CFTF have become available for evaluation, and soon on the commercial market. These fibers are advertised as having mechanical performance comparable with commercially available standard modulus carbon fibers, at a potential cost of just $5.5/lb. This cost is significantly below the current market cost of over $8/lb. for similar fibers. Towards our goal of validating the models using the most up-to-date materials, we incorporated these carbon fibers in the crush can for our evaluation.

Material Selection

Materials and Process Selection and Development

The main objective of this portion of the project was to demonstrate predictability during a crash event when using a thermoplastic composite version of the crush can. Tooling was developed along with a layup and flat pattern for the thermoset epoxy prepreg and polyester based SMC materials. By using a similar strategy for the thermoplastic material, the team sought to directly compare energy absorption of carbon-fiber/ thermoplastic composites to carbon-fiber/thermoset composites. This required parts to be molded using 2x2 twill woven carbon fabric in the can body layered in a quasi-isotropic configuration. Additionally a chopped carbon fiber thermoplastic was needed to fill in the flange areas of the part.

Material Offerings and Availability

Material requirements and part design limited the supply base immediately. After pursuing the remaining material suppliers, commercial availability and engineering support determined the materials offered by Tencate Performance Composites and BASF would meet the need of the project. Additionally, Nylon 6 was the chosen thermoplastic resin system based on compatibility with carbon fiber, low processing temperature, and availability among the other options.

The material supplied by Tencate was 200 gsm 2x2 twill woven carbon fabric laminated with layers of PA6 film. This material was based on a standard product, however, due to the performance and molding requirement, the laminate panels were further tailored for this project. This material was used in the crush can body to serve as an equivalent to the epoxy prepreg system used previously.

Carbon fiber tape pre-impregnated with PA6 supplied by BASF was used to make the flanges of the crush can. This was a standard product that allows significant flexibility in processing. It was selected to mimic the characteristic of the SMC used previously in the thermoset system. Additionally, it would serve to provide some process friendly characteristics needed for handling the charge during molding.

Layup Selection and Panel Production

The crush can design and simulation suggested a quasi-isotropic layup would produce a crush mode that was more stable and efficient than a cross-ply 0/90 layup [2,3]. Target laminate thickness was 2.81 mm in the can body and 5.81 mm in the back flange. Panel production was completed using a vertical stack press for lamination (Tencate Performance Composites division). Carbon fabric was alternated with PA6 film to achieve desired thickness and fiber wetting. Heat was cycled to 535° F and cooled to 200° F under 100 psi of pressure to produce 95 cm X 125 cm panels. Although the thermoset manufacturing used a 12 layer laminate, the thermoplastic film thickness and viscosity limited consolidation to 7 layers of carbon reinforcement. Any additional layers would exceed the design thickness, preventing direct comparison of crash performance to models and thermoset parts construction. The final panel construction was 0/±45/90/±45/90/±45/0. This achieved a panel thickness of 2.85 mm.

Processing Development

Crush Can Half Production Procedure

The manufacturing of the PA6/carbon crush can required a different set of processing conditions to allow use of the compression tooling. These composite charges required a design for fast transfer into the mold to keep the PA6 resin at a molten state until mold close. These composite charges also required an oven that would allow for steady rise to melt temperature without reaching a temperature gradient that would cause the resin oxidation and further degrade the performance. To produce can halves from the laminated composite panels the following procedure was followed:

1. Fibersim pattern/charge laser cut from laminated panel for the crush can body;

2. UD carbon tape molded to proper charge dimensions for the crush can flanges;

3. Charges heated in oven;

4. Charges rapidly transferred from oven to mold;

5. Mold closes to form and cool part;

This process, described in detail below, was used to produce the charges that were trimmed and joined to produce crush can halves.

Draping Analysis for Preform Design

Fibersim was used initially to evaluate the preforming process for a single ply of material. Initial simulation of the preforming process for the crush can half used a simple rectangular ply design. This rectangular design was unable to conform to the complex geometry of the crush can half without significant wrinkling, particularly around the edges of the ply. Figure 3 shows a modified ply shape that was developed. Simulation results confirmed that this improved design was better able to conform to the geometry during preforming without wrinkles. Draping analysis was found to be a valuable tool to workout potential preforming issues before finalizing the tool and ply-shape designs.

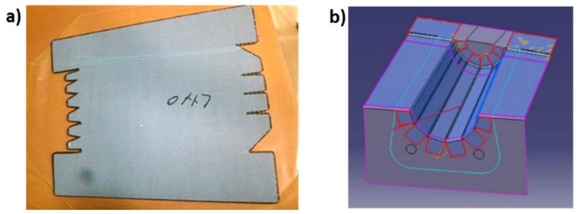


Figure 3: Based on the Fibersim predictions showing wrinkling when the kit was rectangular, a modified ply design was developed. a) The flat pattern generated by Fibersim used for thermoset kit and thermoplastic pattern. b) The forming simulation for Fibersim flat pattern.

Charge Pattern Cutting

The pattern used for the laminated twill woven carbon panel was the same as used to produce the thermoset preforms. Since, the reinforcement material and layup were similar, the draping behavior was also very similar. The flat pattern shown is Figure 3a was nested within the laminated panel to produce 9 pieces per sheet. Although waterjet trimming is preferred, a laser was used to cut these patterns due to availability. The resulting cut showed a heat affected zone of approximately 3 mm; however, much of this material is trimmed off during molding.

Flange Preform Production

The process flow for producing the chopped carbon fiber charges for the flanges is shown in Figure 4. The material chosen to fill the flanges of the crush can was UD carbon tape. This material, when chopped into platelets, is capable of flowing, yet has some challenges when handling and transferring during molding. The heated charge would need a carrier to prevent the chopped material from separating during transfer. This carrier was created by laminating the UD tape into 1.2 mm thick 0/90 panels which were cut to the net shape of each flange. These laminated UD layers serve as a base to the chopped material for easier transport. Each flange needed a measured amount of material to fill the entire thickness and pressurize the cavity without preventing the can body material from reconsolidating. Combining a calculated mass into a near net shape charge ensured critical areas of the part were filled during compression. This net shape was produced using a steel or die that was filled first with the UD laminate, and second with the measured mass of chopped material. This arrangement was heated to melt temperature in a radiant oven to tack all the material together. Once the material was cooled, it was removed from the die and set aside for molding. During the compression molding, these charges were reheated to melt state to fill in the flanges of the crush can.

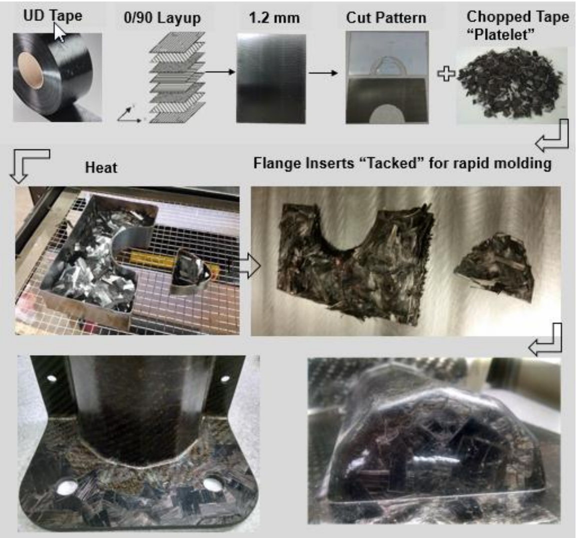


Figure 4: Flange preform productions steps

Compression Molding

The success of the molding of the crush can halves relied heavily on the composite charge design, placement accuracy, and rate of transporting the charges from oven to closed mold. Initial trials identified the proper tool orientation shown in Figure 5. Placement sequence required chopped material to be inserted prior to the can body charge. Manual transfer and manipulation of the molten charges, while not without error, allowed enough of the preform to clear the shear edges before shutoff to completely consolidate the parts. Transfer time ranged from 18-22 seconds from the point of removal of the charges to start of mold close. The aluminum tooling was heated to 150°C by steam to prevent rapid heat removal from the composite prior to compression. Once the targeted closed mold pressure was reached, the tool was held closed for 60 seconds to cool the completed part to a state of dimensional stability. This part and tool design did not require high ejection force to remove, so a demold temperature of 150°C was not a concern. Once outside the compression mold the part was cooled in open air at a nearby work station. Total cycle time from removal of charges from oven to removal of completed part from the tool was approximately 2 minutes. Once cooled, the parts were measured and shipped for trimming and joining. In total, 18 complete crush can sets were molded. Final part thickness averaged approximately 2.81 mm in the can body and 5.27 mm in the base flange.

Figure 5: Compression tool orientation during molding allows for more accurate charge placement.

Processing Issues and Potential Solutions

The process used to produce these crush cans yielded acceptable prototype parts for evaluating crash behavior of carbon fiber/ PA6 composite. There were some challenges to achieving defect free parts that may affect performance as well as predictability. Many of these challenges could be overcome with a production level equipment and automation to ensure proper heating and placement of charge.

Temperature Control and Oxidation

The oven used in this prototype process was a radiant panel oven which was capable of surface temperatures of 850° C. Since the processing temperature of the nylon 6 was only 265° C, controls had to be added to prevent resin from significant oxidation or degradation. The oven was built with an adjustable distance between the heating element and the tray containing the composites as well as controls to cycle power to each heater. The power was cycled with timers to adjust on and off time for each heater to limit surface temperatures. Once the material reached melt temperature, a wire rack holding the composite allowed for easy removal. While this setup was functional for these samples it was dependent on careful observation to properly setup and heat the composites. Through multiple setup trials, the power-on time for the heaters was set to 5 seconds and the power-off cycle to 10 seconds. For this setup at steady state, the radiant panel surface temperatures measured from 280° C to 300° C. This translated to a heat time of 3 min. 30 sec. to reach melt state. Exceeding this time by more than 15 seconds caused a high level of oxidation of the PA6 resin that was observed as a brown discoloration.

Further exploration into sampling with Nylon6/carbon-fiber composites would benefit from a more advanced heating environment. An enclosed system with a nitrogen blanket would minimize resin oxidation. Continuous monitoring of composite surface temperature with feedback would prevent overheating or under heating. Rapid automated removal of charges from the oven for transferring to the mold would provide better part quality and consistency in manufacturing.

Charge Orientation

The transfer of the molten composite charge was completed manually and was the source of many of the defects observed in molded parts. While the charge pattern generated by Fibersim was optimized for draping, the part geometry and construction still created some challenges. The first issue was the thickness of the laminate made the charge fairly stiff even at molten state. This required extra manipulation of the charge after initial placement to drape the material into the tool geometry. Since the compression mold incorporated shear edge shut-offs, the material had to be clear of the edges before mold close. The second issue was the 90° transitions to each flange created areas where the charges migrated or bunched. To improve these conditions, the mold should be designed with charge handling and forming blades to hold the material in place and aide in preforming prior to mold close. Such features are typical in production molding of thermoplastic composites, but should also be used in prototyping to develop the optimized charge handling processes.

Summary of Non-Destructive Evaluation Findings

The non-destructive evaluation highlighted some issues shown in charge placement and forming. This work was reported in more details by Dasch et al [4]. Fabric bunching was evident in the transition area from the can body to the flange (Fig 6a). The area of transition from twill woven fabric laminate to chopped material also showed some evidence of porosity as seen in

Figure 6c. An additional unique characteristic of the thermoplastic laminate was the variations in fiber density. Distinct bands of resin rich areas were visible along the surface and toward the center of the laminate (Figure 6b, d). Much of this could be attributed to the thickness of the laminate and the heating method used for molding. With this heat source coming from radiant transfer, it was difficult to ensure a complete and equal temperature distribution of the laminate prior to transfer and compression.

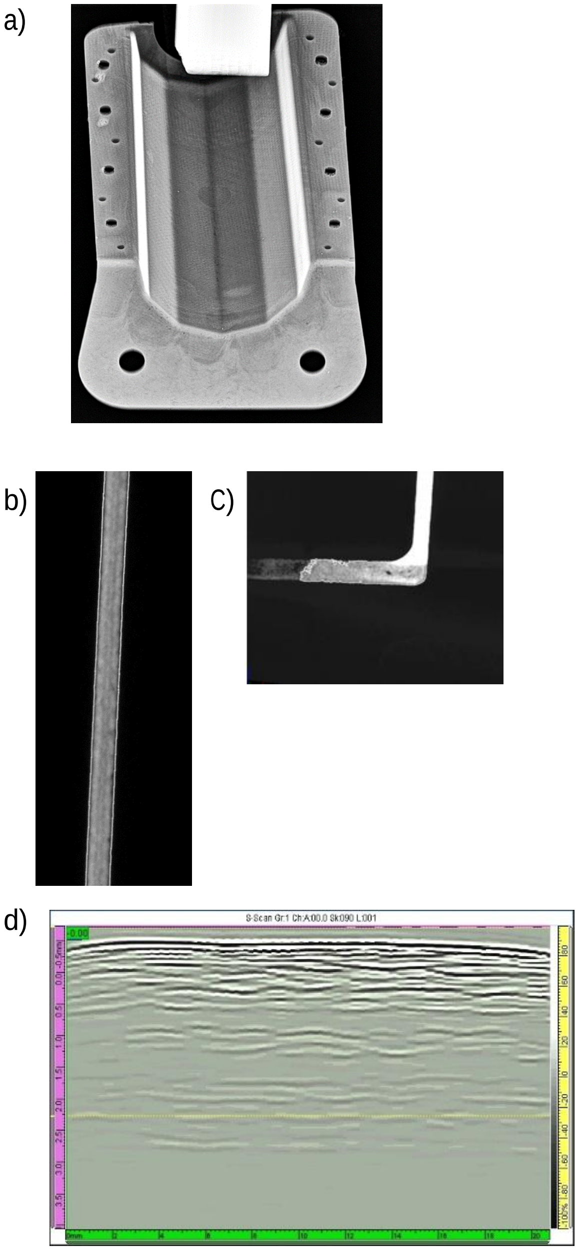


Figure 6 a) Radiograph of completed PA6/Carbon crush can showing fiber bunching at base of can body. b) CT scan of crush can body showing resin rich bands within laminate. c) CT scan showing some porosity at transition to flange. d) Ultrasonic inspection showing unequal fiber density though thickness of twill laminate.

Material Testing

Coupon Testing and Simulation

Two materials as indicated in the section of Material Selection were used to generate MAT_058 for LS_DYNA simulation. This testing consisted of tension, compression, and shear at 0°, 45°, 90° at strain rates of 0.01/s, 1.0/s, 100/s. This material card was generated to replace the thermoset material card for crash simulation but was not initially tuned using an intermediate crush structure due to time constraints of this portion of the project. This data was collected after project extension for use in future optimization of simulation and part design. This initial simulations done without this data is shown in Figure 7 with an overlay of an axial impact of a single crush can at 5.14 m/s.

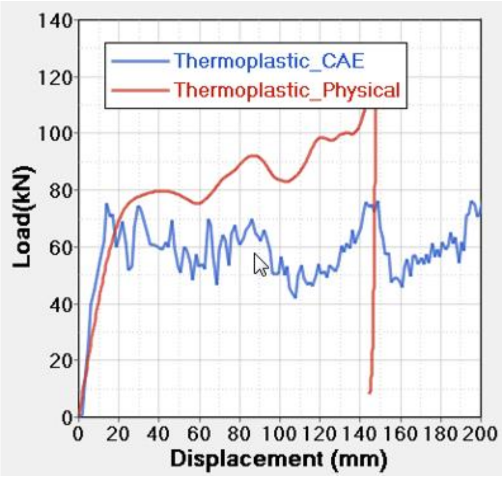


Figure 7: Overlay of axial crush can impact with a MAT_058 card generated without tuning.

Assembly

Crush Can Trimming

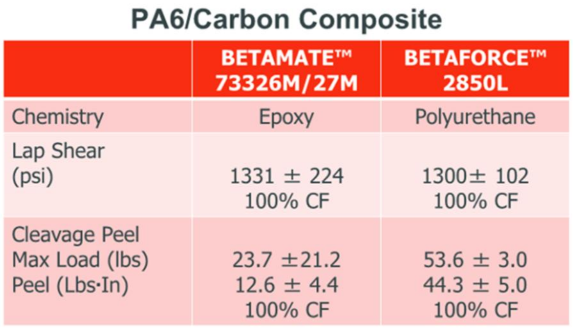
Following molding, the crush can halves were trimmed to final dimensions using CNC milling. Custom fixtures were designed to accurately hold the complex parts in place during trimming. After that, the holes were drilled through the side flanges for rivets used as part of the joining process.

Adhesive Selection

Coupon level testing on the adhesive was conducted to compare several options. Three adhesives were evaluated for use in joining the thermoset FBCC system, each with distinct mechanical properties. Only two of those adhesives were compatible and tested for bonding the PA6/Carbon components:

- DOW BETAMATE® 73326/73327, a 2-component epoxy adhesive, with lap shear of approximately 10 MPa and elongation of approximately 13%
- DOW BETAFORCE® 2850L, a 2-component polyurethane (PU) adhesive, with lap shear for metal substrates of less than 11 MPa and elongation of approximately 115%

Table 1: Result Comparison of bond strengths on the PA6/Carbon System



PA6/Carbon Composite

	BETAMATE™ 73326M/27M	BETAFORCE™ 2850L
Chemistry	Epoxy	Polyurethane
Lap Shear (psi)	1331 ± 224 100% CF	1300± 102 100% CF
Cleavage Peel Max Load (lbs) Peel (Lbs·In)	23.7 ±21.2 12.6 ± 4.4 100% CF	53.6 ± 3.0 44.3 ± 5.0 100% CF

Component Joining

The parts were joined using adhesive bonding and riveting. The mating surfaces were primed with Dow BETAPRIME 5406 and BETASEAL 43532 then bonded with BETAFORCE 2850L. Rivets and mechanical clamping fixture held the parts in place during cure.

While this procedure did successfully achieve geometrically-accurate and repeatable joining of the components, it is carried from the thermoset joining operations due to time constraints as mentioned above. There are multiple technologies for joining the thermoplastic components through the welding process such as hot plate, ultrasonic, IR, laser etc. that fully leverages the resin benefits.

Physical Testing

Sled Testing Results

Sled tests were performed on both the thermoset- and thermoplastic-based (standard CF only, not LCCF) crush cans to compare their behavior. While the materials used for the thermoset and thermoplastic crush cans were not perfect analogs, they were designed to be as similar as available materials allowed. A comparison of the materials is shown in Table 2. Figure 11 shows an image of a crush can ready for testing.

Crash results showed very similar behavior between the thermoset and thermoplastic crush cans (Figure 12). Thermoplastic crush cans had slightly less total crush length and slightly higher peak load than the thermoset crush cans. However, it is notable that the thermoplastic crush cans contained 38% carbon fiber by volume, whereas the thermoset crush cans contained 58% carbon fiber by volume While a detailed cost analysis has not been conducted on the two materials, this has the potential to reduce the cost of thermoplastic-based material compared to the thermoset-based material. Another notable difference between the behaviors of the two materials is that the thermoplastic material fractures into larger pieces and creates less dust. Post-test images of the crush cans show this difference very clearly (Figure 13).

Table 2: Comparison of the epoxy-based (thermoset) and PA6-based (thermoplastic) crush can materials.

Attribute	Epoxy/CF	PA6/Woven CF
Ply Count	12	7
Average Side Wall Thickness (mm)	2.95	2.82
Average Mass (kg)	0.74	0.64
Average Fiber Volume Fraction	58±1%	38±1%

Figure 11: Image of a crush can ready to be impacted. Four load cells are used to track the force during the impact. The crush can is mounted stationary on the wall while the sled travels along rails to impact it. The impactor weighed 1145 kg and traveled at 4.85 m/s at the time of initial impact.

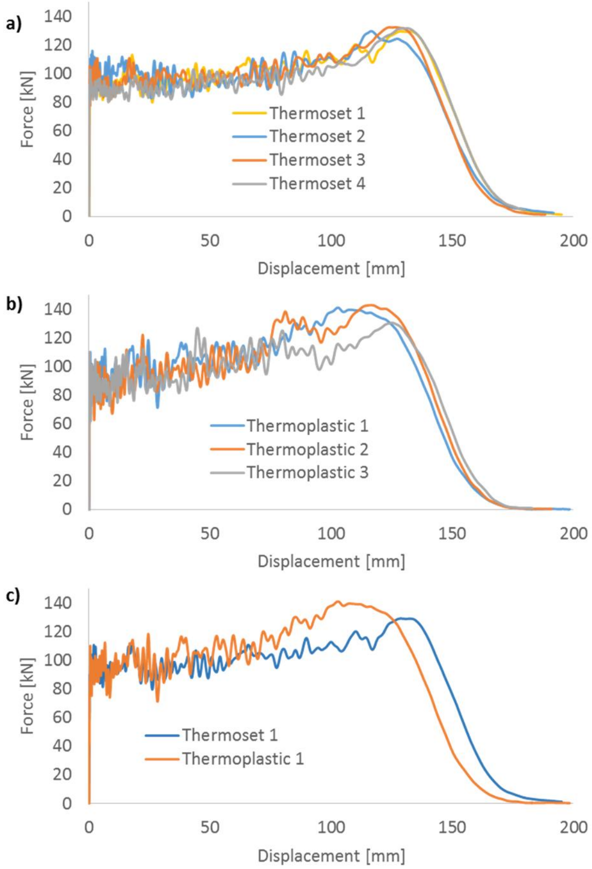


Figure 12: Force vs displacement from the crash tests of thermoset and thermoplastic crush can. a) Results from 4 separate thermoset crush cans. b) Results from 3 separate thermoplastic crush cans. c) Overlay of thermoset and thermoplastic crush cans.

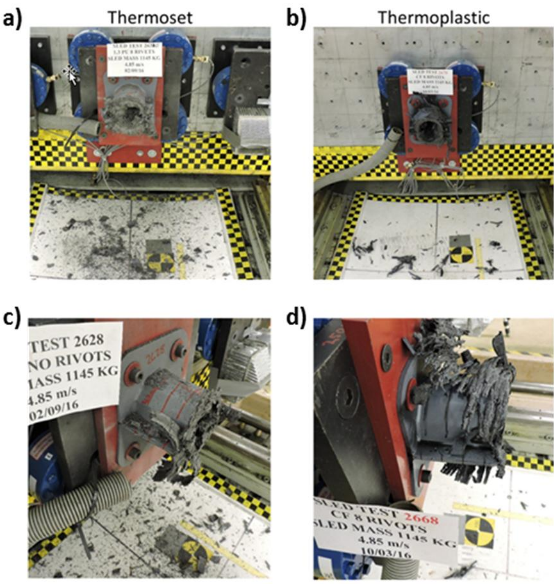


Figure 13: Photographs of the crush can following the test. (a) and (c) are thermoset crush cans while (b) and (d) are thermoplastic crush cans.

Low Cost Carbon Fiber Exploration

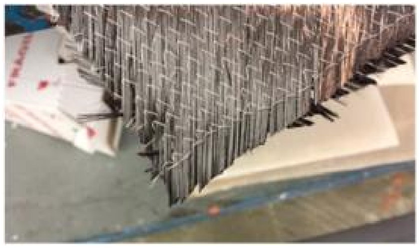
The remaining tasks associated with the thermoplastic work involved evaluating LCCF produced from ORNL's CFTF. This large tow format (457K tow) required significant time developing methods to spread and place into a 120 gsm knit for use in the automotive market. This task is complicated by the nature and viscosity of the thermoplastic Nylon6 resin system used in the previous laminates. Special steps have to be taken ensure proper fiber wetting and panels consolidation.

First Round of Trials

There was significant effort invested in the production of fabric for a thermoplastic system using the LCCF. The large tow format made it unlikely to be successfully woven, so a non-crimp fabric (NCF) was the production method of choice. Initial trials focused on evenly spreading the tow into a ±45° NCF that could be useful in many different processes and applications (Figure 14a). These initial runs provided 20 linear meters of 120 gsm double bias fabric that were trialed with 340 gsm PA6 thermoplastic film to determine what level of fiber wetting could be achieved. In this trial, 10 layers of the double bias NCF was stacked with nylon film between each layer (Figure 14b) then consolidated using the same process used to produce the previously discussed thermoplastic panels. The layup was quasi-isotropic (0/45/90/45/0/0/45/90/45/0) with film on the outside layer and between each ply of fabric (Figure 14b). As with the previous material, a vertical stack press was used for lamination.

Woven reinforcement is often the textile of choice for thermoplastic composites because the interlocking and crimp of the tows allows resin to flow and properly wet out the fiber while locking the tows in a fixed orientation. In contrast, the NCF acts like a barrier to the thermoplastic resin, limiting fiber wetting and forcing resin flow along the face of the ply instead of through. This first round of consolidation trials confirmed this hypothesis and resulted in significant resin-less regions through the thickness of the composite (Figure 14c). These layers were easily separated by hand, confirming poor fiber wetting and the need for the film to be stitched between each sub-ply. Also observed, was the absence of the polyester stitching due to the relatively lower melt temperature when compared to nylon, yet fiber remained orientated. This was likely due to the frictional interaction of the dry layers of carbon fiber within each fabric ply.

a)



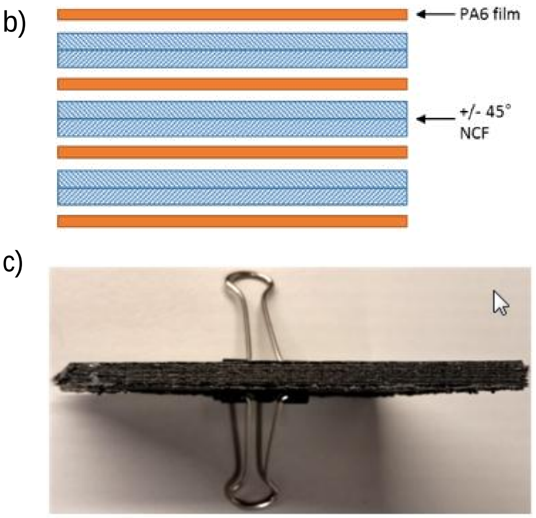


Figure 14: a) Double bias produced from initial trials with large tow low cost carbon fiber. b) Schematic showing the stacking arrangement of the nylon and NCF in the first trial. c) Section of first low cost carbon panels showing visible bands of resin and dry fiber.

Second Round of Trials

The primary concern with the original trials was that the high viscosity thermoplastic film would not penetrate past the carbon fibers to reach the area between the +45° and -45° plies. To address this, the team modified the fabric production process to stitch a layer of nylon film between the +45° and -45° sub-plies. To prove the concept was possible with the fabric production equipment, PA6 film was initially stitched to the outside of the fabric (Figure 15a). After these promising results, the final step of stitching film in between each sub-ply was successfully completed producing 20 linear meters of material (Figure 15b). The resulting material was 120 gsm carbon combined with 340 gsm film to produce a 460 gsm thermoplastic fabric kit. This fabric was then sent to be laminated with multiple layers of alternating film and fabric containing film to achieve the target thickness and quasi-isotropic layup (Figure 15c).

The material produced with PA6 film stitched between each sub-ply was laminated into 8 layer panels (0/45/90/45/45/90/45/0) with film added between each layer of fabric. This resulted in a laminate with PA6 film between each sub-ply (Figure 15c). Fiber wetting was improved, but fiber and resin migration was a significant problem (Figure 15d). The defect occurred due to the melt temperature of the polyester stitching being well below the melt temperature of the Nylon 6 resin. This is evident visually in Figure 16d, as no evidence of the stitching can be seen. The result is a laminate with a high variation in fiber orientation and density. This is an area that would require further development to provide stitching material that would survive the thermoplastic processing temperatures. Additionally, the fiber volume fraction should be optimized with film thickness to provide better laminating characteristics.

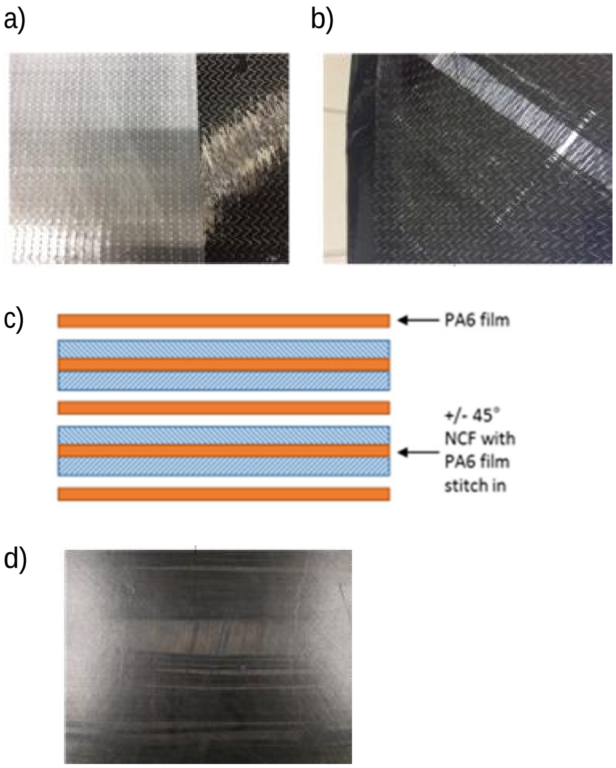


Figure 15: a) Early development of stitching PA6 film to outside of carbon knit to validate process. b) Sample of final double bias with film stitched between each sub-ply. Some carbon tow has been removed to show film presence in knit. c) Schematic showing the stacking arrangement of the nylon and NCF in the second trial. d) Panel produced with film stitched between each sub-ply showing fiber wash.

Comparison of Thermoplastic and Thermoset Component Performance

Drop Tower Testing Results

Drop tower tests were performed on hat-sections (see Figure 16 for sample details) molded from carbon fiber/epoxy prepreg, woven standard carbon fiber and nylon, and NCF LCCF and nylon material for comparison of the materials. Note that the LCCF-based material described above had major defects to fiber alignment and spacing and results are only provided for general comparison purposes. Significant improvements to the crush performance would be expected if these defects were eliminated. The drop tower tests were performed by GM R&D at the Warren Technical center. During the test, a 276 kg weight was dropped from 84 cm. The hat section samples were supported by placing them approximately 1 inch into the cavity of an aluminum fixture providing approximately 1-3 mm of spacing around the edges and using hot-melt adhesive to hold the sample in place (Figure16). Two bolts were added on each flange, as shown in Figure17, to provide additional support between the two parts of the sample.

Drop tower results are shown in Figure 18 for each of the three sample types. Overall, the epoxy-based samples had the highest peak load, while the woven-CF/nylon-based material performs similarly. In contrast, the LCCF/nylon material showed significantly lower loads throughout the test, likely as a result of the defects in the fiber architecture. Additionally, the use of an NCF for this material, rather than weaving the carbon fiber, may have also contributed to these differences. However, the experiment was not designed with the proper controls to indicate whether the difference in NCF vs. woven, the defects in the NCF samples, or the effect of reduced fiber performance in the LCCF were a larger contributor to the poor performance of these samples.

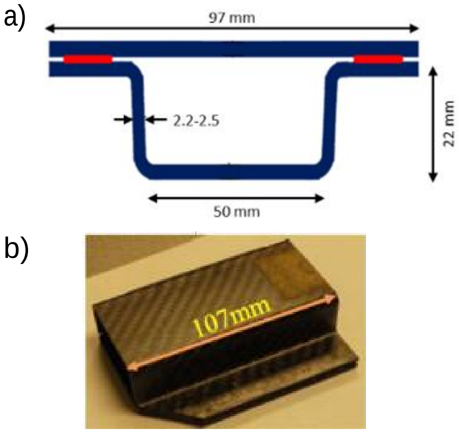


Figure 16: a) Schematic of the geometry of the tube sample. b) Photograph of the sample.

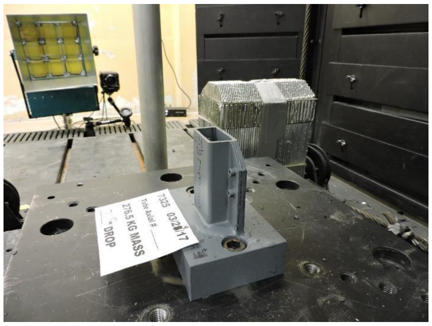


Figure 17: Image of hat section ready for drop tower testing.

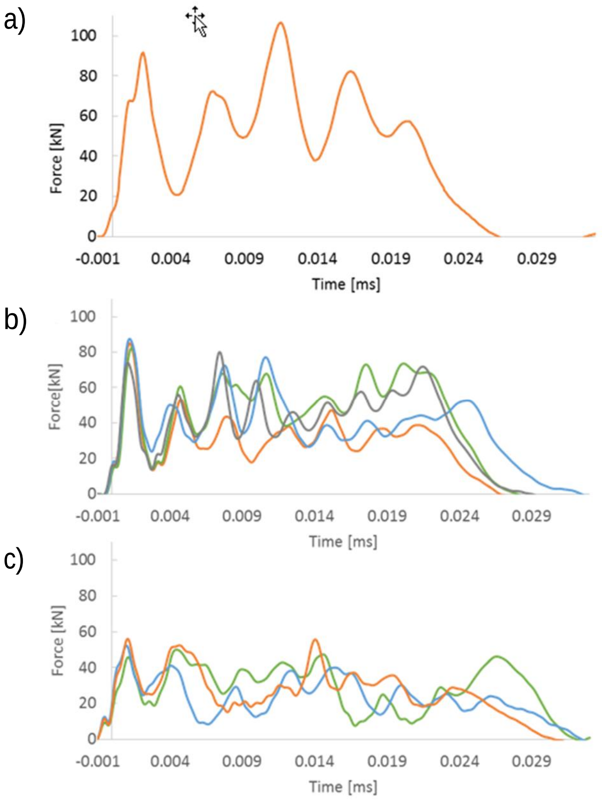


Figure 18: Drop tower test results for a) carbon fiber/epoxy prepreg, b) woven standard carbon fiber and nylon, and c) NCF LCCF material. Each curve represents the results from 1 test. Only one test was run for the epoxy-based material under these particular conditions.

Summary and Conclusions

In this portion of the VMM project, we developed a manufacturing process and then produced thermoplastic composite parts for crash testing of the crush can for an automotive front energy absorption system. This included selection of materials and measurement of material properties that were then passed onto the design/CAE team for designing and predicting performance of the FBCC. Significant effort was placed in manufacturing a thermoplastic carbon composite crush can for direct comparison to an epoxy carbon system. Manufacturing is a key consideration in the development of models for predicting composite behavior in crash events. The realities and challenges of the molding operation result in imperfect parts containing defects. However, comparison of these two resin systems showed significant energy absorption potential for thermoplastics in crush can applications. If low cost carbon fiber reaches large scale production, the automotive industry has an opportunity to benefit with more integration of carbon fiber composites at lower cost. Furthermore, thermoplastic composites, given the appropriate environment, could make a positive impact to lightweighting in higher volume applications.

Acknowledgements

This program is supported by the U.S. Department of Energy under Cooperative Agreement Number DE-EE0005661 awarded to the United States Automotive Materials Partnership. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This is a collaboration involving many researchers and organization. The authors would like to extend special thanks to, Art Cawley (Dow), Chris Mikesell (Chomarat), Bob Reynolds (Tencate), and Chris Korson (BASF).

References

1. Coppola, A.M., L. Berger, D. Board, M. Jones, J. Truskin, and M. Mehta. “Validation of Material Models for Crash Testing of Carbon Fiber Composites: Overview,” SPE ACCE, Sept 2016, Novi, MI.
2. Trameçon, A., M. Doroudian, R. Dwarampudi, P. Pasupuleti, L. Berger, O. Faruque, Y. Chen, and J. Truskin, “Validation of Material Models: Design of a Composite Bumper-Beam and Assessment of Current Composite Crash Simulation Capabilities,“ SPE ACCE, Sept 2016, Novi, MI.
3. Coppola, A.M., L. Berger, G. Smith, D. Armstrong, and C.J. Dasch, “Validation of Material Models: Thermoset Composite Materials and Processing For a Composite Bumper-Beam System,” SPE ACCE, Sept. 2016, Novi MI.
4. Dasch, C.J., G.J. Harmon, and M.H. Jones, “Validation of Material Models: Non-destructive Testing Throughout the Development of a Carbon-Fiber Composite Automotive Front-Bumper/Crash-Can Structure,” SPE ACCE, Sept 2016, Novi, MI.