

## Structural Applications of Long Fiber Thermoplastic Composites

by

Pritam Das<sup>1</sup>, Juan Serrano<sup>2</sup>, Selvam Pillay<sup>2</sup> and Uday Vaidya<sup>2</sup>

<sup>1</sup>National Composite Center, Kettering, OH 45420

<sup>2</sup>University of Alabama at Birmingham, AL 35294

### Abstract

The objective of the research effort in this paper is to develop thermoplastic composite materials and product forms and to demonstrate fabrication methods for molding thermoplastic composite materials into components for use in buses and other mass transit applications. Thermoplastic composites technologies possess the potential to provide lower cost, lighter weight, and improved performance structures for mass transit applications. The demonstration components selected for this project was a battery access door for the 60 BRT bus. A battery box access door of a mass transit bus was manufactured from polypropylene/E-glass long fiber thermoplastics (LFT) using the extrusion-compression molding process. The composite door met or exceeded all the design requirements of the steel door, with a 60% reduction in weight and 44% cost saving. Mechanical tests conducted on the door showed excellent correlation with respect to the results of the finite element model during design and analysis. Mold flow and fiber orientation were accurately predicted using a process modeling software when compared to trials during actual production.

KEYWORDS: Long Fiber Thermoplastics (LFTs), Finite Element Analysis (FEA), Plasticator

### Introduction

Long fiber reinforced thermoplastics (LFTs) have received attention largely from the automotive industry due to their superior mechanical properties and relative ease of processing [1]. The global use of LFTs is expected to grow from around 40 million lbs in 2001 to 75 million lbs in 2007 [2]. LFTs (fiber lengths between 12mm and 50mm) possess elastic modulus and tensile

strength almost 90% of that obtained from continuous fibers [3]. The main advantage of LFTs is that unlike continuous fiber reinforced composites, they can be processed using traditional plastics molding equipment, and therefore parts can be manufactured at medium volume rates with excellent consistency and repeatability. The use of a thermoplastic matrix gives the molder the ability to modify and enhance the properties of the resin by blending additives, fillers and fire retardants depending upon the nature of the application [4].

LFTs can be manufactured using extrusion-compression molding and injection molding techniques. Most of the applications in which LFTs have been commercialized include polypropylene (PP) matrix and E-glass fiber reinforcement. In the last few years there have been innovative developments in manufacturing processes of LFTs that improve part quality and increase the output rate. Examples of these developments are D-LFT, SLFT and E-LFT [1]. Variations of these processes have also been used to produce sheets of various thicknesses starting with neat resins and fiber rovings [4]. Advances have also led to the utilization of a wide variety of engineering thermoplastics as matrix materials and other fiber reinforcements [2].

Compression molding is an established composite processing technique which was originally developed for the stamping of thermoset matrix composite pre-impregnated sheets into complex geometries. In this process, the pre-impregnated sheet molding compounds (SMC) were heated to their softening temperature and then transferred to the compression molding press, where a sheet was formed using double sided tooling. The most important feature of this process is that during forming, the material is not subjected to the high level of stresses that are encountered during injection molding, and therefore the reinforcement is not damaged [5]. In the case of LFT-compression molding, the process starts by hot melt impregnating the reinforcing fibers with a thermoplastic matrix and subsequently chopping the continuous tow into pellets of a set length. Hot melt impregnation is performed by wire coating, crosshead extrusion, or thermoplastic pultrusion techniques [3]. The long fiber pellets are fed into the hopper of a single screw low shear extruder for mixing and metering. This machine extrudes a molten charge of a predetermined size and shape (usually cylindrical) which is then transferred by an operator or a robot to the compression molding press for the forming operation. Cycle times for this process can be as short as one part per minute, and this number can be further improved by utilizing multiple cavity tools. This technique is ideal for small-to-medium size semi-structural components for the automotive industry and has already been implemented in applications such as automotive side panels, bumper beams, dash boards, underbody panels, and hoods.

To optimize the processing of LFTs, it is necessary to take into account a number of processing variables and effects not typically encountered when processing unreinforced plastics. Molding pressures, fiber orientations, fiber distribution, and flow fronts of the molten charge within the tool are important parameters which determine the homogeneity of the molded product, and therefore the success of the produced part [6, 7]. Recently developed software tools [8] based on the Finite Element Method (F.E.M) help in the design for manufacturing stage using these materials. By simulating the molding operation in a virtual environment, material properties, resin defects, incomplete mold filling, shrinkage and warpage can be determined before the tool is cut, ensuring a complete control of the process variables along with its limitations. This paper address some aspects of the LFT processing in relation to process modeling for the manufacturing of automotive and mass transit components.

### **Battery Access Door**

The battery door of the 60 BRT bus (Fig. 1) is an external component of the bus. The door protects and houses the several batteries needed for the regular operation of the electrical systems in the vehicle. This door is located at the rear part of the bus, adjacent to the wheel housing. It is currently comprised of an all steel sheet metal fascia which is bent to shape to match the exterior contour of the bus. Four (4) holes in the sheet are cut for further placement of the handles and then welded to a tubular steel frame which provides additional stiffness to the part and accommodates the internal locking mechanism and the sealing gasket. The battery door is approximately 1m long by 0.6 m wide and the current design weights about 12 kg. It is envisioned that by adopting the thermoplastic composite technology, weight savings on the order of 50 to 60 % can be achieved in comparison to the existing design. The material selected for the battery door had to meet various criteria including, but not limited to: (a) equivalent stiffness to that of 3mm thick steel plate; (b) low density; (c) resistance to humid and salt rich environments; (d) excellent resistance to battery acids; (e) low cost; (f) good dimensional stability (low shrinkage and warpage), (g) ease of processing and conformability to the mimic the complex geometry, and (h) material should be paintable to achieve uniformity with respect to the rest of the bus.

### **Concept Design**

The battery door was redesigned using the current metallic battery box door as the baseline. The current battery door design features a two part structure produced by attaching a welded steel frame (made with square steel tubing) to a sheet metal facesheet (Fig 2).

The welded steel door is then painted and fitted with the proper hardware that includes a rubber gasket and the locking mechanism. This candidate door was selected due to the high labor costs related to the fabrication of this part (sheet metal cutting, bending, welding, finishing). In order to reduce labor and therefore cost, the design approach used features a single component LFT based battery box access door structure in which the stiffness of the steel counterpart is achieved by the use of ribs on the internal part of the door as illustrated in Fig. 3. The ribs provide extra dimensional stability to the part by controlling out of plane displacements caused by shrinkage and warpage of the parts as they are withdrawn from the tool and cooled to ambient temperature.

The evaluation of the stiffness of the rear access door was performed by Finite Element Analysis (FEA) [9]. The boundary conditions for the model were selected based on the real assembly of the part to the exterior shell of the bus and are shown in Fig 4. The solid model was meshed using SHELL 63 triangular elements [10]. SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included.

The stiffness of the door as predicted by FEM is shown to be consistent with the experimental stiffness until the maximum deflection reached 15 mm (78% of deflection at failure). At this point the stiffness response of the panel transitions from a linear to a non linear state. The onset of non-linearity can be attributed to the local plasticity effects and/or damage initiation.

The displacement distribution plot on the door when subjected to the proof load is shown in Fig 5a and 5b, exhibiting as expected maximum deflection at the point of loading in the mid-span of the panel. The corresponding von Mises stresses developed on the back of the door are shown in Fig 5b. There is a clear stress concentration in the vertical rib in the surrounding area where failure was mapped during testing (Fig 5). FEM predicted stress levels in excess of 155 MPa in the region which corresponds to the flexural strength reported for the E-glass/PP LFT material [11].

### **Extrusion Compression Molding Strategy For 60 BRT Bus Battery Door**

Compression molding was identified as the processing technology to be implemented for manufacturing the battery box access door. In this process, a pre-measured volume of processed material also known as charge is placed directly in a pre heated tool cavity. Forming is done under pressure generated by the closure of the upper half of the tool. The

manufacturing approach including mold/tooling design, mold placement and an initial assessment of the charge placement, mold filling patterns, etc. required to produce defect free parts was developed.

## Tool Design

An oil heated/cooled two side matched steel tool was selected as the prototype/production tool. This tool would also serve as a production tool for manufacturing of the part in large volumes. The technology can be readily transferred to industry for commercialization. The tool has two main parts; a top tool which is a solid steel block that can be heated to the required molding temperature and has the required machining and surface finish to provide a class-A finish to the fascia (exterior) of the produced battery box access door and a bottom tool, which includes all the machined cavities to generate the ribbed structure on the back of the door and includes the detail to accommodate the lock housing and door handles.

## Compression Molding Simulation

A process modeling software was used to simulate the compression molding process via the FEA method [8]. The analysis and optimization of the different manufacturing variables for molding a thermoplastic composite battery box door were undertaken. Based on the compression molding simulations; processing parameters can be determined before the machining of the tool.

The battery door solid model was imported into the process modeling software after generating a finite element mesh. Several compression molding simulations were performed to optimize the processing parameters. The main variables of the compression molding process are: upper and lower mold temperature, press closing force, resulting fiber orientation, shrinkage and warpage, charge size and proper placement, and proper mold filling. The thickness of the different areas of the part is accounted for in the process modeling software and shown in Fig 6.

Various manufacturing trials were conducted to validate the accuracy of the simulations. The flow of resin from the placement of a single charge (manufacturing trial) as shown in Fig. 6a was compared to the process modeling software simulation. To verify the filling pattern shown in the simulation a short shot (i.e. less material used than required to achieve complete fill) was used. Comparing Fig. 6b, the simulation to Fig. 6c, actual short shot that is compression molded it can be seen that the filling pattern predicted by the model is very accurate.

## Component Fabrication

The production of the prototype battery box access door was conducted using a plasticator in conjunction with a 400 ton compression molding press. The front face (exposed face on bus) of the tool was machined to a highly polished surface, while the back face was rough machined and no finishing done, as seen in Fig. 7.

The heating and cooling was achieved using an oil pump. The following processing parameters from the simulations were used:

- Upper mold temperature: 80° C
- Lower mold temperature: 90° C
- Press closing force: 3.9e3 kN
- Charge diameter: 170 mm
- Charge length: 650 mm
- Charge placement: central and longitudinal
- Knock-off thickness: 1 mm

A specific paint system for polypropylene/E-glass long fiber thermoplastics was identified to give Class A finish to the battery box door as shown in figure 8. The paint system comprised of a special adhesion promoter from Eastman Chemicals for the polypropylene substrate to adhere to the paint without degrading the glass in it.

The battery door and painting procedure was supplied to the bus company for final painting of the component [12]. The recommended procedure resulted in a high quality finished product by NABI. The painted door with all the fittings is shown in Fig. 8.

## Summary

The paper demonstrates a successful life cycle of a metal to long fiber thermoplastics materials conversion in the field of mass transit applications.

It started with the selection of the right LFT material type to fit the application. It was followed by changes in the original metal design of the battery bus door as LFT materials have lower mechanical properties than metals. Process modeling was carried out to determine fiber orientation, required closure pressure of the press, and charge size. Based upon the simulation results, the processing parameters for extrusion compression molding were selected. Various manufacturing trials were conducted that showed good accordance with the simulation results. An effective paint system for polypropylene/E-glass long fiber thermoplastics was also identified to give the door a close to class A finish. After conversion from metal to LFT material, the cost was reduced by 44% and the weight was reduced by 60%.

## References

1. Häuptli & J. Winski. 2003. Direct processing of long fibre reinforced thermoplastics: selecting a feeding system. *Plastics Additives & Compounding* 39.
2. Knights, M. 2004. Long fiber thermoplastics extend their reach. *Plastics Technology*. 1-5
3. Thomason, J, L., and Vlug, M, A. 1996. Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: 1. Tensile and flexural modulus. *Composites: Part A* 27A 477-484.
4. Schut, J. 2004. Compounding: Why Long-Glass Molders Are Compounding In-Line. *Plastics Technology* 1-5.
5. Advani S. and Sozer M. 2002. Process Modeling in Composites Manufacturing. Marcel Dekker Inc. New York 34-35.
6. Vaidya U.K. et al. 2005. Center for Composites Manufacturing. Quarterly Report. Submitted to the Federal Transit Administration. FTA project number FTA-AL-26- 7022-00.
7. Vaidya U.K. et al.. 2005. Design and Flow Simulation of a Thermoplastic Bus Seat. *Journal of Thermoplastic Composites* (In-Press, Publication Date Aug 2005).
8. Cadpress theory manual. 2003. The Madison Group, Wisconsin, Madison.
9. ANSYS theory manual, [www.ansys.com](http://www.ansys.com), Last accessed, May 2006.
10. [www.altair.com](http://www.altair.com), Last accessed, May 2006.
11. Ticona web literature. 2000. Celstran Long Fiber Reinforced Thermoplastics. General Properties and Overview.
12. [www.nabiusa.com](http://www.nabiusa.com), Last accessed, May 2006.

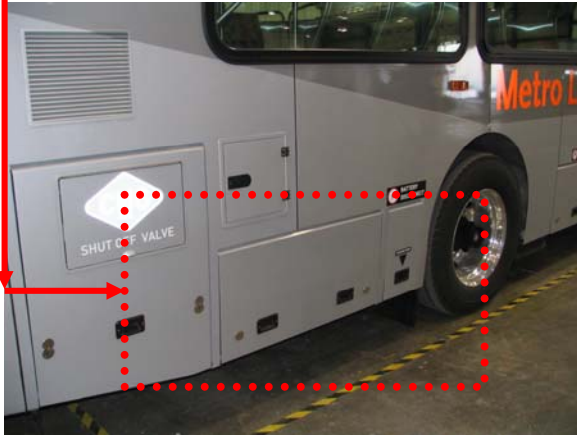
## Authors

Pritam Das is an Application Development Engineer at National Composite Center. He has an MS degree in Polymer Engineering and works in the area of thermoplastic composites.

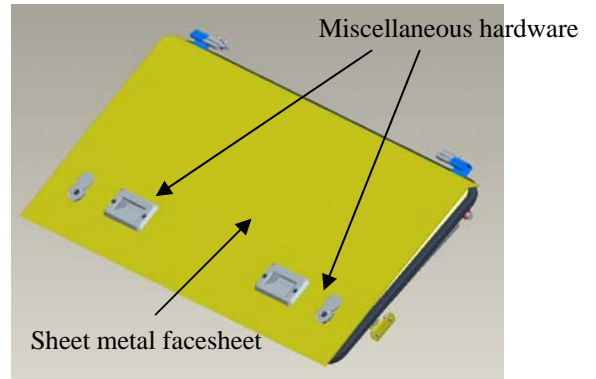
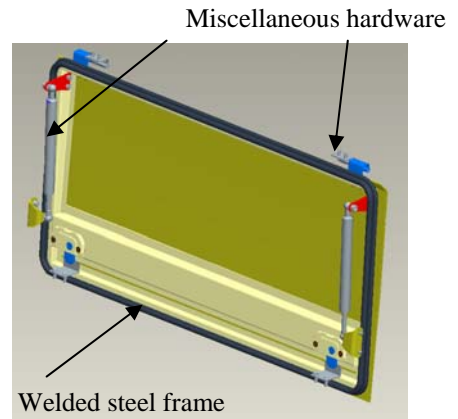
Juan C. Serrano is a Research Engineer at the UAB School of Engineering. He has an MS degree in Materials Science & Engineering and works in the area of polymer matrix composites.

Selvum Pillay, PhD has a in Materials Science & Engineering, He works as a Research Associate in the UAB School of Engineering. His area of work is in thermoplastic composite materials and processes.

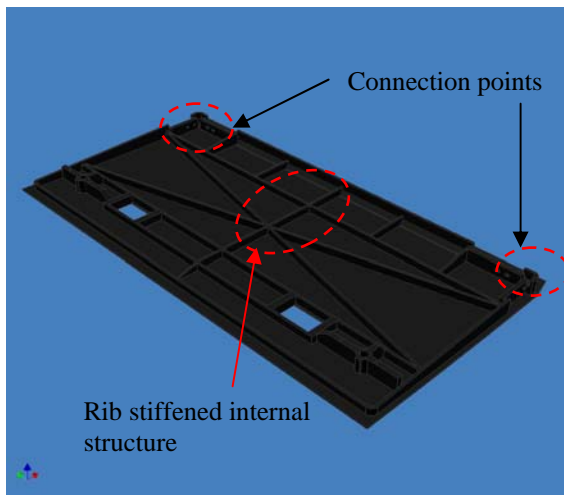
Uday Vaidya, PhD is a Professor of Materials Science & Engineering. He serves as the Principal Investigator on the bus program at UAB School of Engineering sponsored by Department of Transportation.



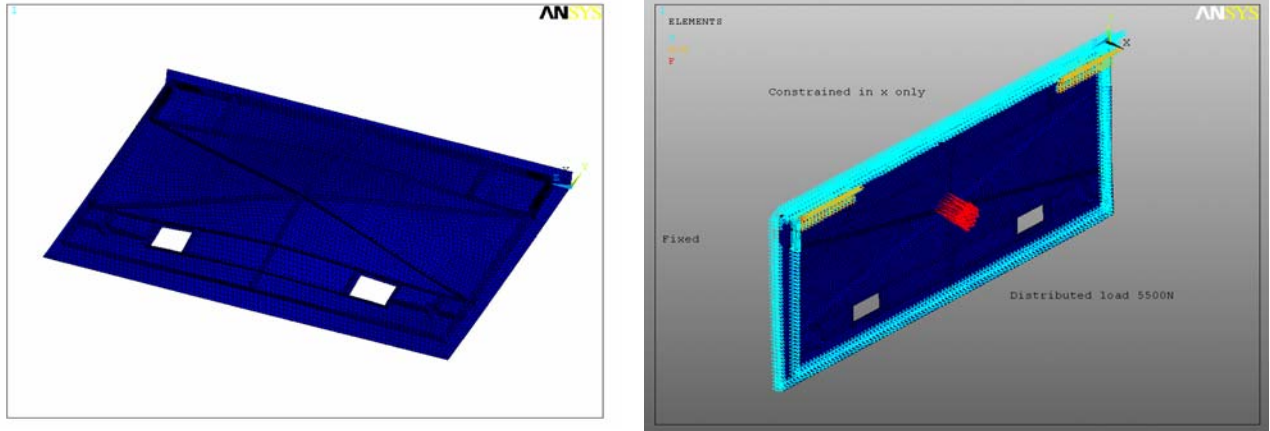
**Fig. 1: Battery Box Access Door**



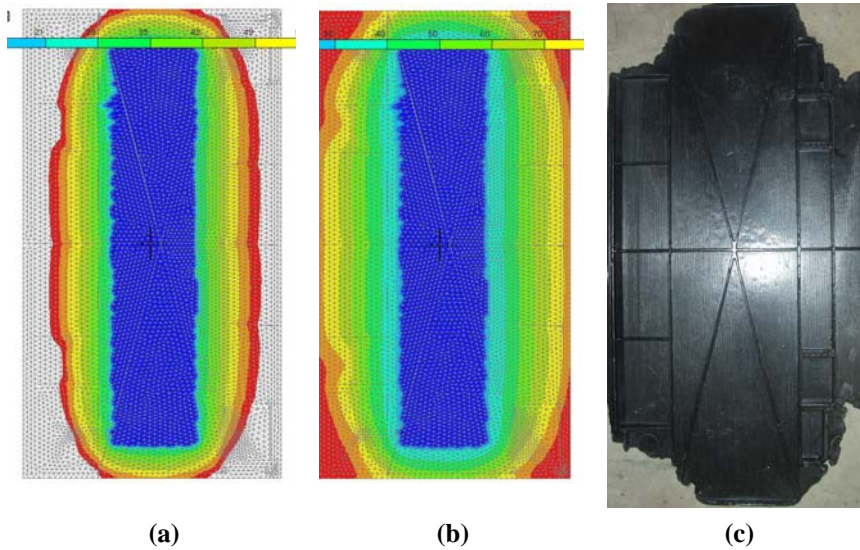
**Fig. 2: Existing design of battery door featuring steel welded frame and sheet metal formed facesheet**



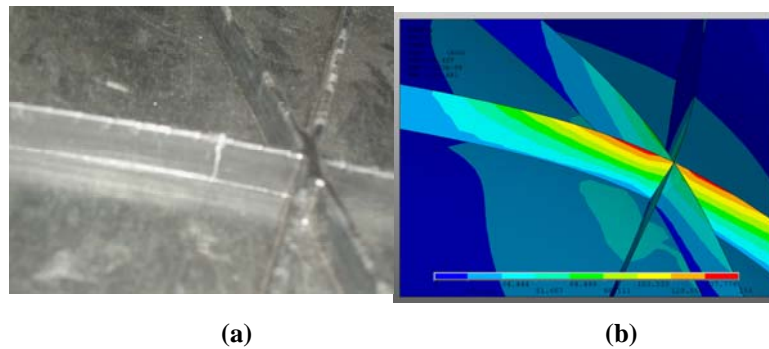
**Fig. 3: Redesign of battery door to achieve a single component structure using thermoplastic composite technology (LFT)**



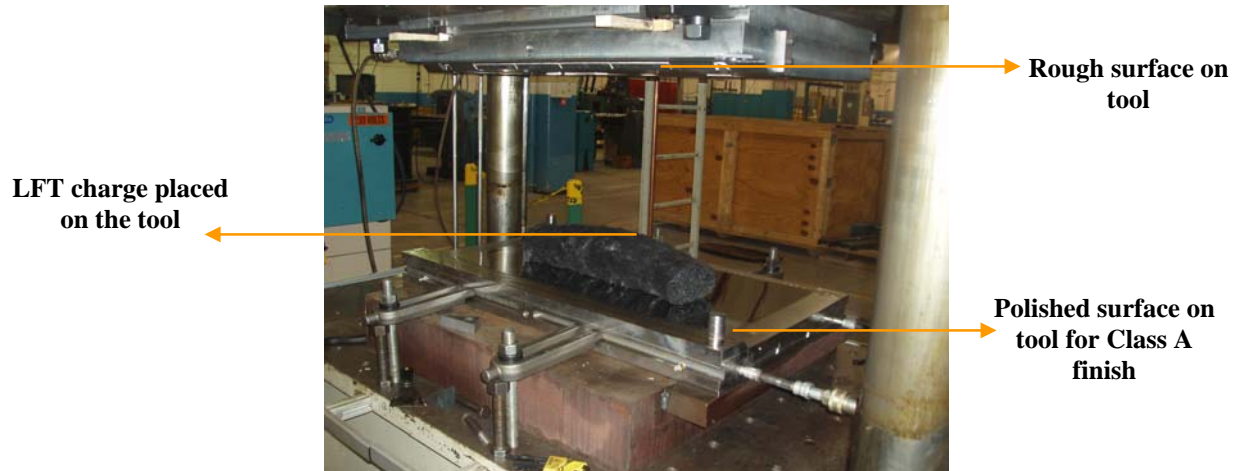
**Fig. 4: Boundary conditions and loading applied to the battery box access door**



**Fig. 6: Simulation of single charge molding of battery box door. (a) charge flow partial filling, (b) charge flow full filling, and (c) short shot experimental verification of flow front**



**Fig. 5: (a) Failure at the rib, and (b) FEA simulation indicating failure at the same location**



**Fig. 7: View of charge placement on the tool, prior to compression.**



**Fig. 8: Finished and painted battery box door**