

THE DEVELOPMENT OF DFT LONG-FIBER THERMOPLASTIC COMPOSITE SOFT-TOP HEADERS

*Dr. John Busch
Mr. Charles Weber
Composite Products, Inc.
Winona, MN*

Abstract

In your father's car, all of the significant body structures were made from metals. Today, composites are increasingly used to produce more and more demanding structures. In concept vehicles such as the Daimler-Chrysler CCV and ESX3, composites are the structure. In production vehicles, pick-up boxes, floor pans, front-end carriers, closure panels, skid plates, and many other structural applications are made from composites.

Direct Feed Thermoplastic (DFT) composites have been used to produce several automotive structures, including front-end carriers, seat bases, and convertible soft-top rails and headers. In this last application, soft-top headers, DFT composites successfully displaced steel and SRIM composites on the basis of relative cost and performance.

Like most technology substitutions, the process of developing the DFT header was lengthy, taking over five years from concept to production. This development process, along with the DFT manufacturing technology and the benefits that it imparts to soft-top headers, are described in this paper. The paper demonstrates that DFT, when used appropriately, offers an unparalleled combination of performance, aesthetic, and economic benefits.

Background

In 1994, CPI worked with Bestop to develop the first composite support rails used in soft-top structures. The support rails in the soft-top combine the functions of the 'B-pillar' and the roof rail for the "convertible" soft top. A soft top support rail is shown in Figure 1. The rail program was an incontrovertible success. It won the SPE's part of the year award and it simultaneously improved the performance and appearance of the soft-top, while reducing costs.

At the 'A-pillar,' the support rail meets up with a "header." The header constitutes the leading edge of the soft top. The soft-top fabric is affixed to the header and,

with two latches, the header and fabric are fastened to the windshield-surround when the soft top is "up." The header structure, as it is currently manufactured, is shown in Figure 2.

In 1995, this header was made from a process that used reaction-injection molding to encapsulate a single steel rod that ran the full length of the header structure. The rod contributed stiffness and the molded RIM structure provided the form and fit, and served as the attachment surface for the fabric top. With the success of the DFT rail structure, it was obvious that the header was next in line. Re-design of the header began even as the production tooling for the rail structure was being cut. That was in 1996.

The Development Story

The first attempt to redesign the header rail was, in retrospect, doomed to fail. This redesign sought to produce an exact DFT molded version of the existing steel and SRIM structure, with little or no change to the part's internal geometry. As with most technology substitutions, to be successful the part must be re-designed to take advantage of the features offered by the new technology. In this case, with the metal rod removed from the design, the DFT technology did not offer enough intrinsic stiffness to produce an acceptable part. In high-speed tests, wind loads would cause the header to lift off of the mating surface of the windshield. The result was an excessive amount of wind noise and, potentially, water ingress. Back to the drawing boards!

The DFT process forces a homogenous mixture of glass and resin to flow into a mold cavity. The glass used in the DFT process is chopped. As a consequence, it is easy to mold complex features such as ribs and bosses with DFT. These design features provide the means for increasing stiffness without resorting to massive cross-sections and without the use of a full-length steel rod. In the second and third generation designs, more and more design complexity was added to the part to improve its operating performance. Still, there are limits to what can

be done with ribs. In particular, ribs must be relatively deep to add significantly to the stiffness. At the ends of the header, where it mates with the ‘A pillar,’ there was not enough space to add meaningful ribs. So, while the second and third design concepts performed better than the first, they were still not acceptable.

A constraint of the header development program was that the new header design could not alter the design of the parts to which it mated. It was clear at the outset that the OEM customer would not undertake a redesign of the windshield surround, the attachment latches, or any other mating parts to accommodate the DFT technology. This constraint is common on what are known as ‘mid-program’ design changes—design changes occurring to a vehicle that is already in production. To be successful, the DFT design team had to make DFT work within the existing system. Back to the drawing board, again.

The ultimate solution came from a fresh piece of paper. Up until this point, the DFT program had been working with two design constraints:

1. The new part must exactly match, in form and function, the existing steel/SRIM design.
2. The new part must be made from DFT, only.

With a “fresh piece of paper,” the second constraint was relaxed and new solutions were sought.

The DFT process, again because it is a flow process involving a homogenous material, is capable of incorporating inserts. For the header program, this meant that it was possible to incorporate a steel rod, as had been done in the SRIM process. Steel is a marvelous material possessing stiffness greater than most other materials, and much greater than that of any molded composite. With steel reinforcement, it would be easy to meet the performance requirements of the application.

Steel also has some severe limitations, and these needed to be factored in to the re-design process. Steel is heavy, with a specific gravity that is five and a half times greater than the DFT material. Steel processing is also relatively inexact, especially for bending small tubing. It is either difficult or expensive—take your pick—to hold precise dimensions on a 4 ½ foot long steel tube.

“Why not use two short lengths of steel at the ends of the header, where stiffness is critical and where there is not enough available space to mold in ribs? Then, we can use a ribbed DFT structure across the face of the header, taking advantage of DFT’s tight manufacturing tolerances and ability to accommodate complex features.” This “clean sheet” approach turned out to be the ultimate

solution. On the fifth design iteration, a successful design was achieved. This “hybrid” design, comprised of steel and DFT composite, used steel for local stiffening and DFT for the form and design complexity. In this manner, each material was asked to do what it was best at.

The DFT Process and Its Intrinsic Advantages

In the DFT process, shown in Figure 3, resin and additives are delivered by gravimetric feeders to an extruder. In this first extruder (“Extruder A” in Figure 3), these ingredients are thoroughly melted and homogenized by the high shear and mixing action of the rotating screw. Molten resin and additives are conveyed from the “A” extruder, through transition tooling, to the rotating screw of a second extruder (“Extruder B” in Figure 3).

The “B” extruder is fed fiberglass reinforcement by a second gravimetric feeder. The initial flights of the “B” extruder screw are used to preheat the fiber prior to mixing with the molten output of the “A” extruder. Preheating the glass opens the fiber bundles and brings the reinforcement to a temperature wherein individual glass fibrils can be thoroughly wet with molten thermoplastic resin. The second screw provides gentle mixing of the fiber/resin melt, minimizing damage to the reinforcing fibers and maintaining a high degree of the initial fiber length in the compounded thermoplastic composite.

The continuously compounded material exits the “B” extruder and is directed to an accumulator. The temperature-controlled accumulator is an open ended hydraulic cylinder containing a piston. It alternately “accumulates” molten composite material, and then discharges it, transferring this material (manually or automatically) into a matched metal mold. The accumulator effectively couples the continuous process of compounding with the discontinuous or cyclic process of molding.

As regards the soft top rail and header, there are a number of unique advantages of the DFT process that make it ideally suited for producing these parts. These advantages can be grouped into two categories: *technical* and *economic*.

Many of the technical advantages—homogenous mixture, ability to accommodate complex designs, ability to accommodate steel inserts—have already been described. Other technical advantages include the ability to mold in color, the ability to adjust compositions “on the fly,” and the ability to accommodate a broad range of input materials. Of this last advantage, the process has been used with polypropylene, nylon, polyethylene, and

polyester resins; glass, flax, hemp, and graphite fibers; with added colorants, UV stabilizers, flame retardants, anti-oxidants, biocides, etc. Some may suspect or argue that this flexibility is a burden—that it imposes inordinate quality control demands on the molder. In truth, in experienced hands, it is a great asset.

The economic advantage of DFT derives, in large part, from the state of the materials used to feed the process. In other composites processes like GMT, LFT injection molding, or SMC, the raw materials are first converted into an intermediate state—whether a sheet or a pellet—and then finally converted into a molded part. Generally, this conversion step is performed by an independent business unit—a “middle man.” The DFT process cuts out the “middle man,” utilizing raw materials in their lowest cost state. By doing so, the technology eliminates the direct cost of converting raw materials into intermediate raw materials—for instance, the need to melt the material twice. More importantly, in cutting out the “middle man,” the DFT process removes SG&A, overhead, and profit costs while shortening the supply chain.

Downstream cost savings can also result from parts consolidation and/or the ability of the DFT process to incorporate additional molded in features. With the header, there were no opportunities to consolidate parts and there was no ability, at the then existing state of re-design, to incorporate additional features. Still, these sources of cost advantages are often as large as the advantage derived from using low cost raw materials and eliminating the “middle man.”

Lessons Learned

In the end, most of the lessons learned from this program are lessons that have been learned over and over again. Once again, these lessons were learned the hard way: by trial and error. And, in the future, we will undoubtedly re-learn them the hard way. No amount of planning, pleading, or “procedure-izing” will prevent it. Nevertheless, here they are:

1. Parts should be designed on a clean sheet of paper to take advantage of the strengths, and to accommodate the weaknesses, of a new manufacturing technology.
2. The lure of cost reduction casts a powerful scent. If the DFT process only offered the promise of improving the form or fit or appearance of the header, it is unlikely that the program would have persevered. Knowing that a significant cost savings

would accompany the performance gains, the program had the driving force necessary to endure 5 re-design cycles.

3. Rome was not built in a day, and neither were the components on an automobile. From initial concept to first commercial production, this program took almost six years. On the surface, this record sounds pretty bad, but in reality it is closer to the norm. A “fast track,” mid-program design change typically takes one to two years (unless there is a dramatic problem with the incumbent technology) even when a new technology is not involved. Throw a new technology into the mix and it is not unusual for substitutions to take a decade just to get started.

The Future

The DFT technology has a bright future. Of the long-fiber reinforced thermoplastic technologies, it offers the best economics, and relative to most of these technologies, it provides superior performance. Over the next decade, it will be increasingly adopted for applications such as:

- Front end modules
- Seat bases
- Instrument panel carriers
- Skid plates
- Intake manifolds
- Oil pans

It will be adopted, first and foremost, because it costs less than the alternatives. Using the lowest cost raw materials and eliminating the “middle man” insure that this cost advantage will be sustained.

The adoption of DFT technology will be slow. It took more than 25 years to convert the majority of the automobile fleet from steel to plastic fuel tanks, and from aluminum to plastic intake manifolds. The proponents of DFT technology have no reason to hope or believe that their adoption schedule will be any different.

The pacing event in the adoption of DFT will be applications development. Like the soft top header, each application must be individually designed to take advantage of DFT’s strengths and to accommodate its limitations.



Figure 1 Soft-top Rail Structure



Figure 2 Soft-top Header

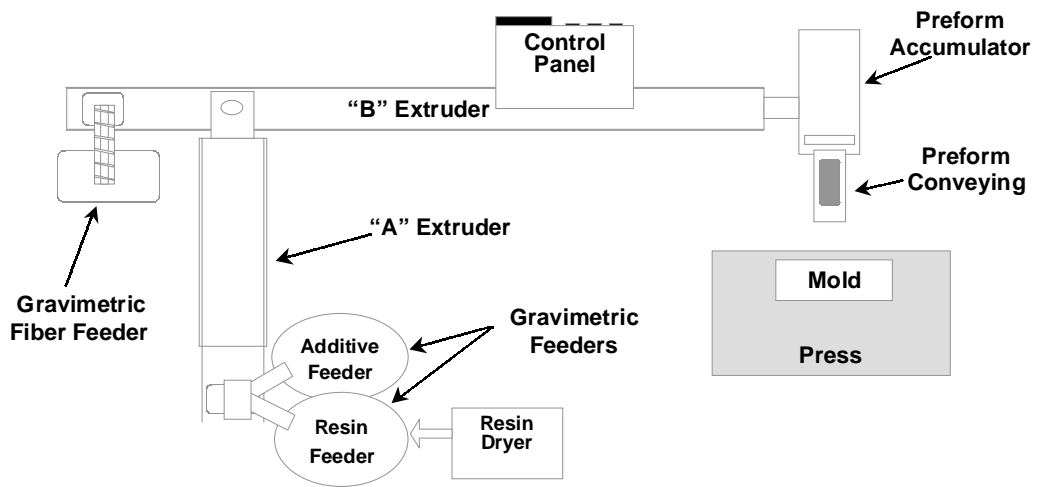


Figure 3 The DFT Process