CARBON FIBER COMPOSITE BODY STRUCTURES
FOR THE 2003 DODGE VIPER

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Abstract

The first automotive application of carbon fiber sheet molded composite (CFSMC) is made in nine components of the 2003 Dodge Viper Convertible to provide structural performance and to achieve significant weight savings. Right and left fender support systems employ a total of six carbon fiber composite moldings. In addition, carbon fibers are used to provide selective stiffening to the windshield frame and door inner structures, which consist primarily of conventional glass fiber SMC (GFSMC). The design and analysis, CFSMC materials and process, and performance of these innovative composite structures are discussed.

Introduction

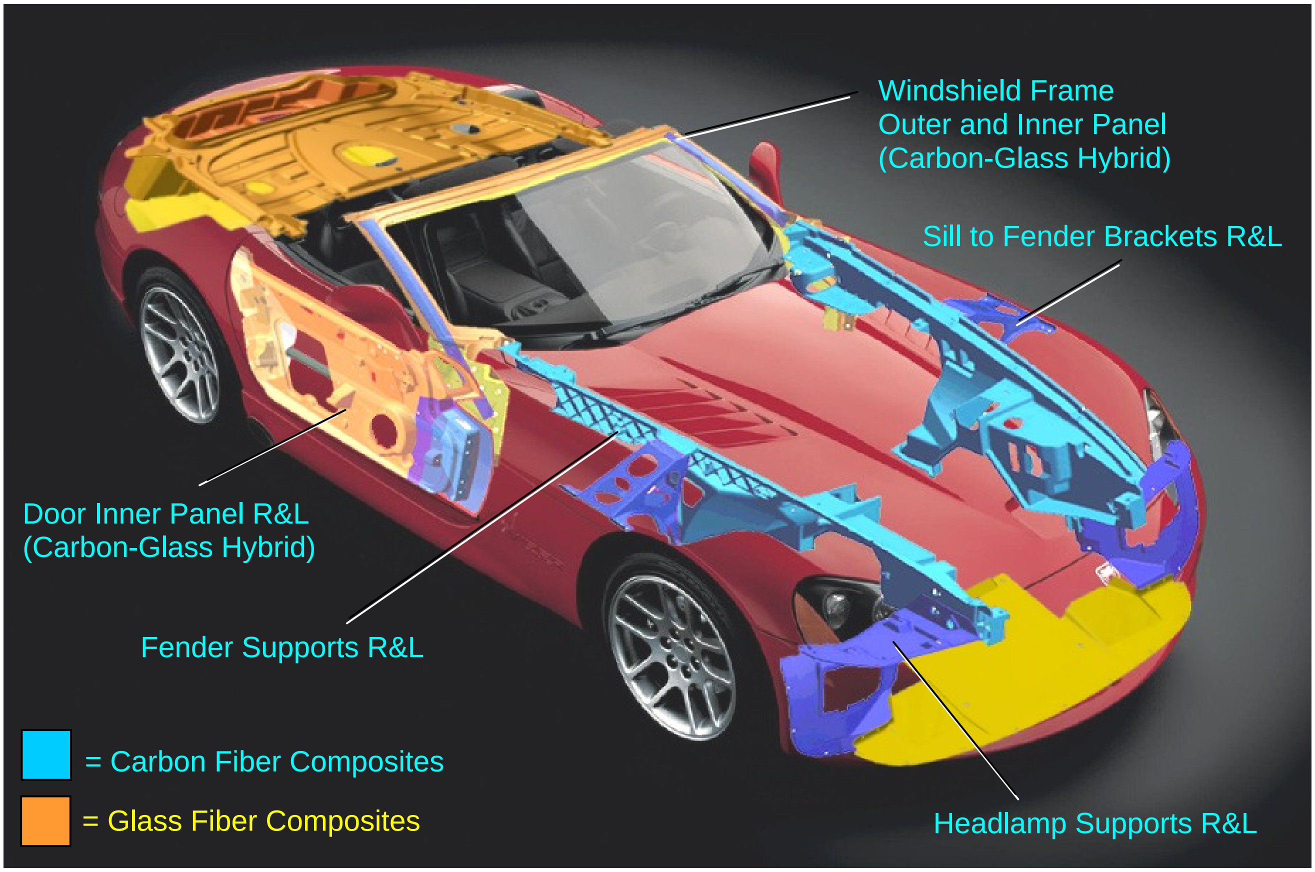
The primary objective of DaimlerChrysler Performance Vehicle Operations for the development of the all new 2003 Dodge Viper Convertible was maximizing vehicle performance while maintaining low vehicle mass. An important consideration in the vehicle development was the judicious application of new technologies that potentially can be extended to higher volume car and truck lines. Consequently, the new Viper makes innovative use of compression molded carbon fiber SMC in several break-through body structure applications. A total of eight kilograms of carbon fiber composite is used in nine body components.

Glass fiber reinforced composites have been used for decades in the automotive industry to provide light-weight structures with reduced capital investment. Composites provide additional advantages such as parts consolidation, design flexibility, and corrosion resistance. Carbon fiber composites offer the possibility of even greater weight savings than glass fiber composites, but the cost of the material is significantly higher. As a result, they have typically been applied in very limited applications using processes capable of very small volumes (under 1000/year). The 2003 Viper is the first use of a materials system and process capable of higher volume production (100,000+/year).

While carbon fiber SMCs have been commercially available for 16 years, the application of these materials in the automotive industry have been slow to develop due to the high cost of carbon fibers, and the lack of understanding of carbon fiber composites. Recent developments at carbon fiber supplier companies have reduced costs and hold promise for further price reductions (1). In addition, programs under the sponsorship of the U.S. Department of Energy are exploring methods to fundamentally change the production of carbon fibers to reduce their cost (2). Work within the Automotive Composites Consortium and studies at the Oak Ridge National Laboratory are providing a better understanding of the performance and durability characteristics of commercial grade composites containing carbon fibers (3,4). All of these efforts are increasing the feasibility of using carbon fiber composites in the automotive industry.

Three Viper structural systems that employ the high modulus of carbon fiber SMC to achieve exceptional stiffness in lightweight structures are presented in this paper. Thin-wall sections in the six-piece fender support system provide numerous functions at a minimum weight. The hybridization of random CFSMC with low-density glass SMC improves the stiffness of structural inner panels to minimize door sag. And the blending of SMC containing continuous oriented carbon fibers with high glass content structural SMC in the windshield frame provides stiffness to resist deflections.

Figure 1. Carbon and Glass Fiber Composites on the 2003 Viper



Carbon Fiber-Vinyl Ester SMC

Carbon fiber SMC is compounded and molded in a manner similar to conventional structural-grade glass fiber SMC. The Viper parts use two CFSMC materials produced by Quantum Composites, Bay City, MI. AMC™ 8590 is a toughened vinyl ester resin with 25 mm random chopped 12K PAN (polyacrylonitrile) based carbon fiber tows. AMC-8595 contains a continuous, unidirectional cross-stitched mat with the same 12K carbon fibers and the same toughened vinyl ester matrix as AMC-8590.

All of the Viper components containing AMC-8590 and AMC-8595 are compression molded by Meridian Automotive Systems in Shelbyville, IN. CFSMC cures at conventional temperatures (145-155°C) and cure times (1-3 minutes). AMC-8590 requires 70%-90% of the mold be covered with the charge to minimize flow lines. AMC-8595 does not flow in the fiber direction. Consistent charge preparation and placement are critical to the structural performance of the molded part.

The primary advantages of carbon fibers in SMC are higher modulus and lower specific gravity relative to glass fibers. The modulus of commercial-grade carbon fibers is approximately 230 GPa, which is more than three times higher than E-glass fibers. In addition, the 1.8 specific gravity of carbon fibers is about 70% of the specific gravity of glass fibers. These fiber properties translate into thinner and lighter composite structures. With the exception of the windshield surround, nominal part thicknesses ranged from 2.0 to 2.5 mm. Properties of the Quantum Composites CFSMCs are presented in Tables 1 and 2.

Table 1. Properties of Quantum Composites AMC-8590 (Random chopped carbon fibers)

Property	Method	Net Shape Molded Specimens[a]	Specimens Cut From Panel, Machine Direction	Specimens Cut From Panel, Cross-Machine Direction
Fiber Content (% by weight)	Solvent Wash	55%		
Specific Gravity	ISO 1183	1.48		
Tensile Strength (MPa)	ISO 527		212	134
	ASTM D 638	287		
Tensile Modulus (GPa)	ISO 527		42.2	32.5
	ASTM D 638	55.0		
CTLE (mm/mm/°C)	ASTM D 696		6.17 x 10^{-6}	5.54 x 10^{-6}
Heat Deflection Temp. @ 1.80 MPa Stress (°C)	ISO 75	>260		

a – Molding induces fiber orientation in the specimen direction and cuts fewer fibers.

Table 2. Properties of Quantum Composites AMC-8595 (Continuous oriented carbon fibers)

Property	Method	Specimens Cut From Panel, Machine/ Fiber Direction
Fiber Content (% by weight)	Solvent Wash	55
Specific Gravity	ISO 1183	1.49
Tensile Strength (MPa)	ASTM D 3039	1200
Tensile Modulus (GPa)	ASTM D 3039	120
CTLE (mm/mm/°C)	ASTM D 696	9.47 x 10^{-7}
Heat Deflection Temp. @ 1.80 MPa Stress (°C)	ISO 75	>260

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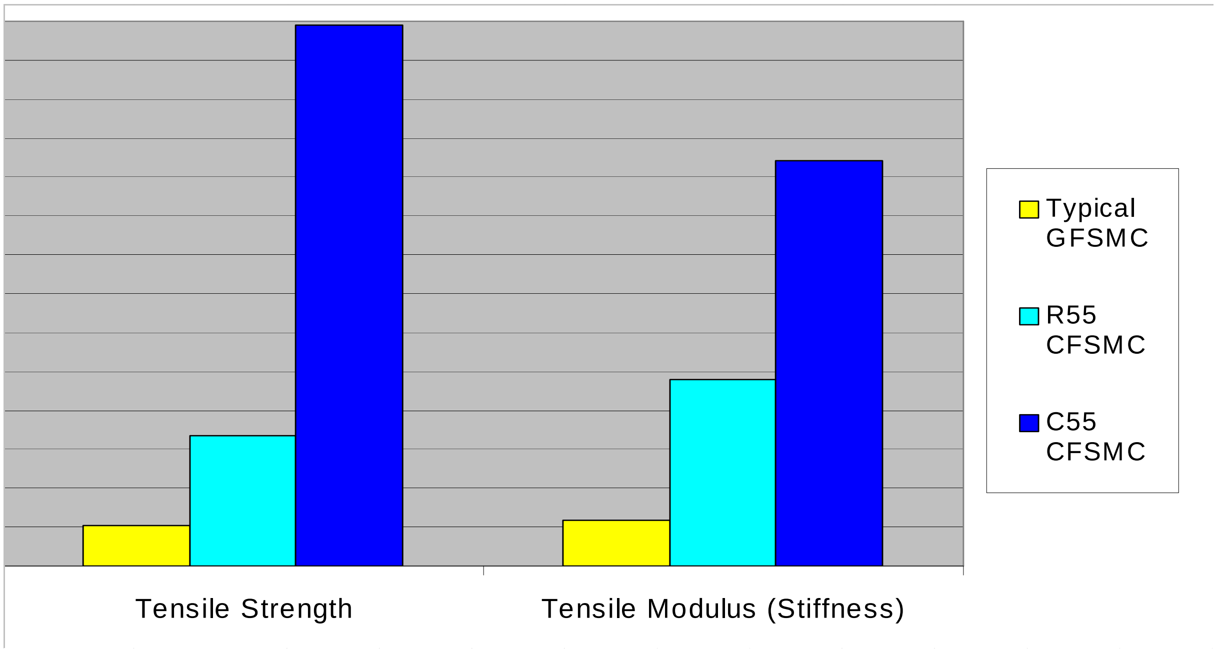
Figure 2. Materials Comparison - Typical Property Averages



Windshield Frame

Evolution of the Composite Windshield Frame - From Viper to Prowler to Viper

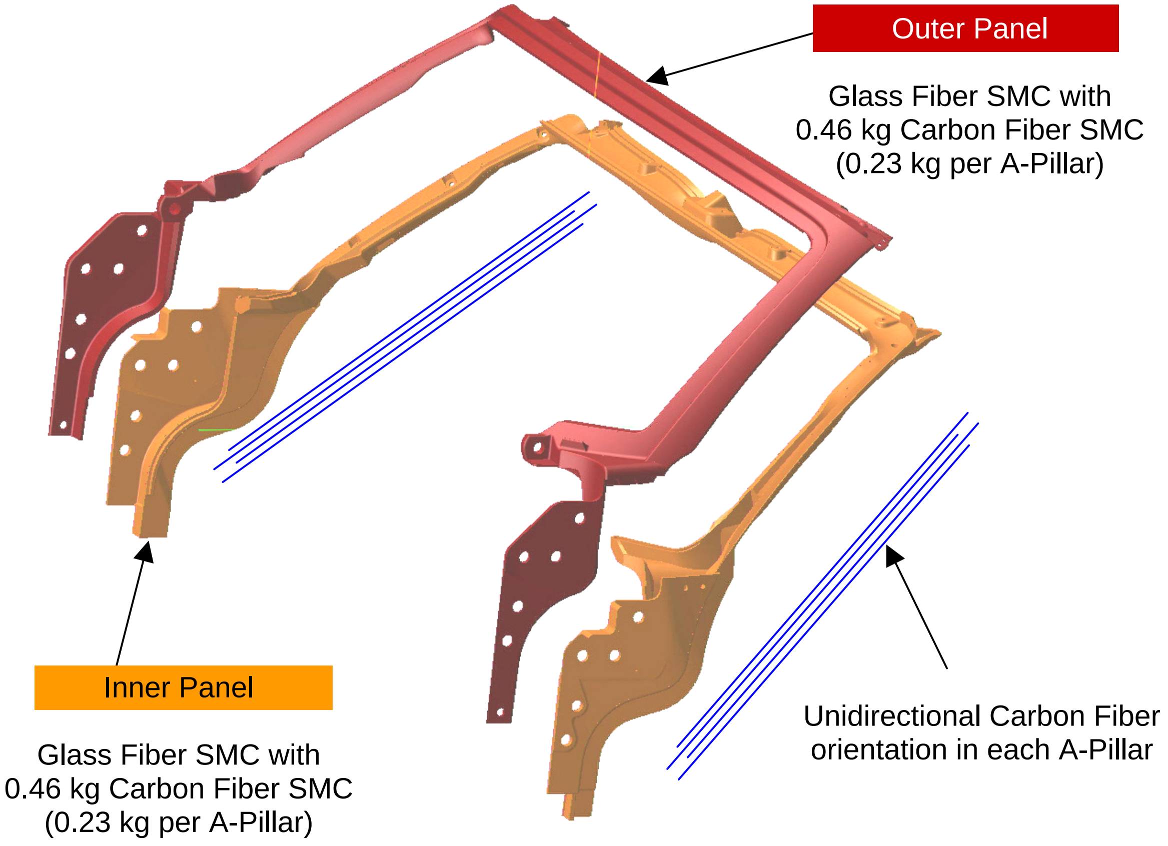
The new 2003 Viper uses a composite windshield frame as was introduced on the original Viper and the Plymouth Prowler. The design incorporated by the new Viper represents a further step forward in the evolution of the composite windshield frame. Composites were chosen for this application because of the lower tooling cost and part consolidation benefits.

The 1992 Viper used RTM composite technology on the windshield surround. The design included random glass pre-forms wrapped around a foam inner core with steel reinforcements and molded in a single cavity. This process required extensive hand finishing particularly around the eight parting line edges of the part.

The 1997 Prowler used a new patented application for the windshield frame. The Prowler design consisted of a two-piece glass SMC surround bonded together with structural adhesive. The bond seam required hand finishing on four edges of the part. SMC offered greater design flexibility and part consistency than RTM. The Prowler surround used unidirectional glass SMC in the A-Pillars to maximize stiffness and was able to achieve a 9% improvement in bench stiffness compared to the outgoing Viper.

The 2003 Viper adopts a Prowler-type windshield frame because of its design advantages. The new car also further refines the two-piece SMC design by limiting the hand finishing to only one edge (rear header) of the part and increasing part stiffness.

Figure 3. Windshield Frame Components and Materials



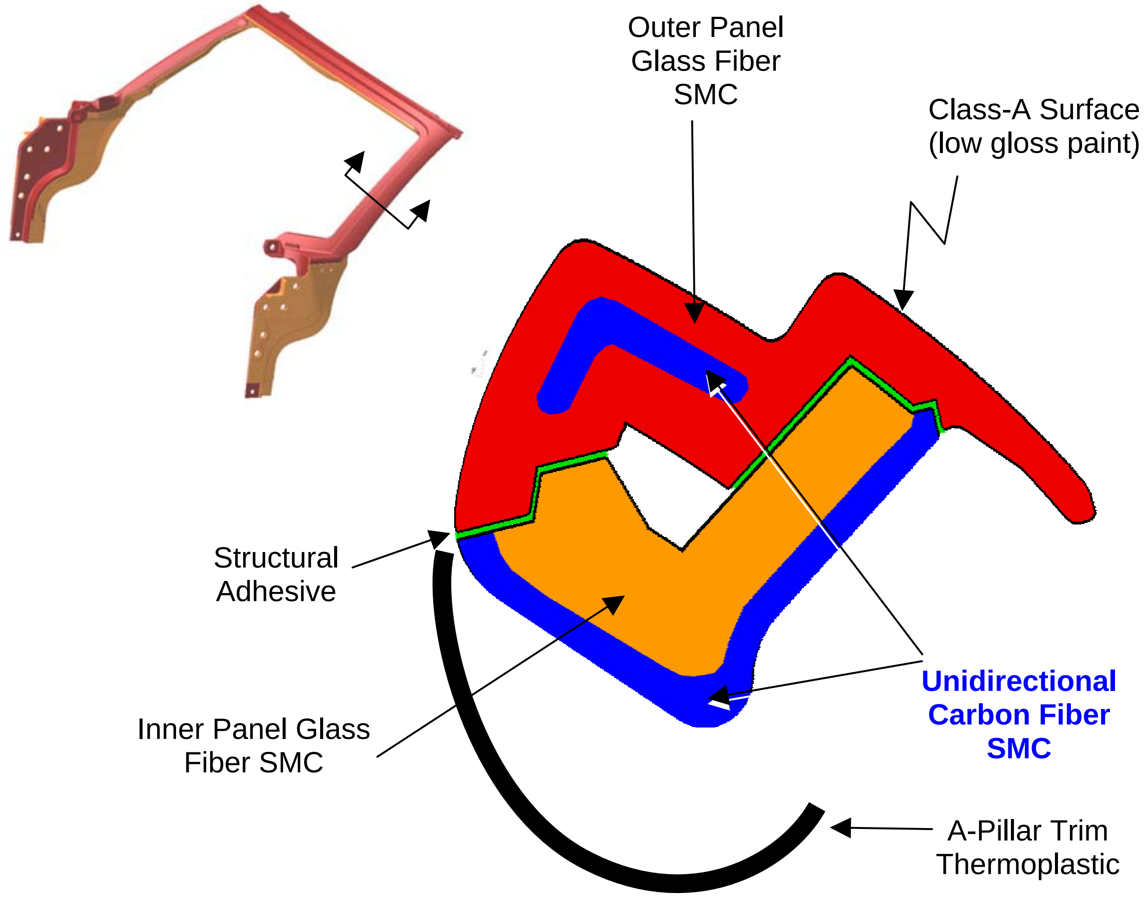
Windshield Frame CFSMC content: 0.92 kg

Styling Challenges and Federal Requirements

The styling on the 2003 Viper angles the windshield further back and increases the A-Pillar length to 610mm; nearly 25% longer than the Prowler and original Viper (495mm and 490mm respectively). The new federally mandated head impact requirement drove the addition of energy absorbing A-Pillar trim covers on the interior. This decreased the cross-section area for added stiffness. In order to achieve the performance objectives the engineering team turned to carbon fiber SMC.

Each windshield frame contains 0.92 kg of unidirectional carbon fiber SMC. The unidirectional fibers are oriented along the length of the A-Pillars in both the inner and outer panels. The fibers are layered in the section to maximize stiffness and minimize appearance effects. The total weight of the surround is 8.9 kg.

Figure 4. Windshield Frame A-Pillar Cross Section



Performance Results

The 2003 Viper windshield surround has 45% less bench test deflection than the original model. Factoring in the longer A-Pillar, this is a 122% increase in normalized stiffness.

Glass-Carbon Hybrid Door Inner Panel

Challenges of a Viper Door

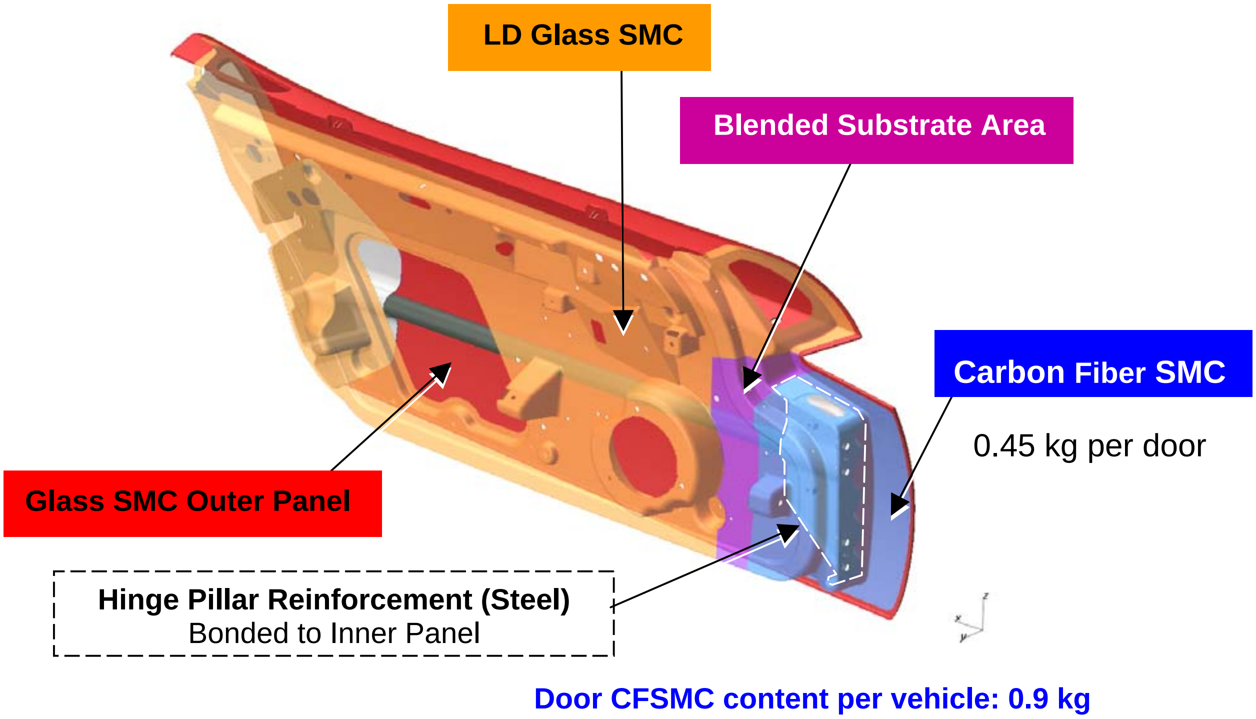
A styling trademark on Viper is the large “gill” opening on the body side just behind the front wheels. This gill opening creates an unconventional door cut-line that limits the hinge pillar surface to nearly half the height of the door. This in turn increases the moment load on the hinges and the front section of the door inner. The original Viper and the 2003 model both use only a single hinge per door.

The original Viper doors were constructed of RTM outer and inner. The original doors used large steel panels on the hinge pillar and latch pillar for strength and stiffness. The intention for the new car was to decrease the cost, complexity and weight of the doors by using Class A SMC, low density SMC and smaller steel reinforcements. However, further enhancements were needed to meet all of the performance objectives.

Performance Requirements

During the development of the door the critical performance criteria were door sag deflection and permanent set. Door sag is the maximum deflection measured on a door in the open position with a specified load applied. Permanent set is the deflection measured after the door sag load is removed. A new technique of blending random carbon fiber SMC and glass fiber SMC was developed to improve the performance of the door in these two areas without increasing the size of the steel reinforcements.

Figure 5: Door Component Materials



Hybrid Blending of CFSMC and GFSMC

The door inner design called for blending carbon and glass materials to maximize on stiffness in the high strain energy areas at a minimum cost. The front portion of the door (20%) would be made up entirely of carbon fiber SMC and the rear portion of the door (80%) would be made up of low density SMC containing glass fibers. This hybrid blending in the door presented a more difficult challenge than the windshield surround. The windshield surround glass fiber materials complete enveloped the reinforcing carbon fibers. In the case of the door panel, a transition from the CFSMC to the GFSMC is required in the plane of the part. A study of different blending techniques was performed to determine the optimum joint for molding these two materials together. The strength, dimensional accuracy and processability of the joint were the main considerations.

This study focused primarily on two methods of blending equal volumes of carbon fiber SMC with low-density glass fiber SMC to form a molded "joint." In the first, the GFSMC and the CFSMC are overlapped in the mold charge by either 25 mm or by 50 mm. In the second, GFSMC is inserted by either 25 mm or 50 mm into the two ply stack of the CFSMC. Plaques containing only carbon fiber SMC or glass fiber SMC were molded as controls. The charge patterns, covering 55% to 70% of the 305 mm x 305 mm mold, were molded into uniform 2.5 mm thick panels. Flow of the SMCs generally caused the transition zones to double in length. In cross-section the molded overlap joint appeared to approximate a single scarf joint, where as the insert joint approximated a double scarf joint. Straight edged tensile bars measuring 25 mm x 305 mm were cut with a diamond tipped blade and tested in general accordance to SAE J2253 / ASTM D5083.

Figure 6: Material Charge Pattern Configurations for the CFSMC to GFSMC Transition

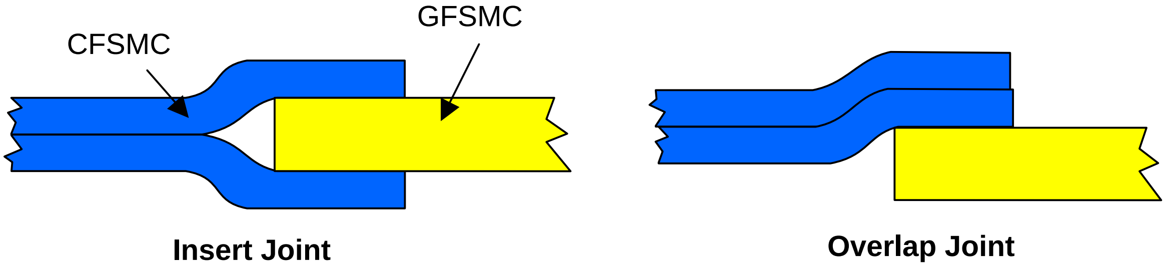
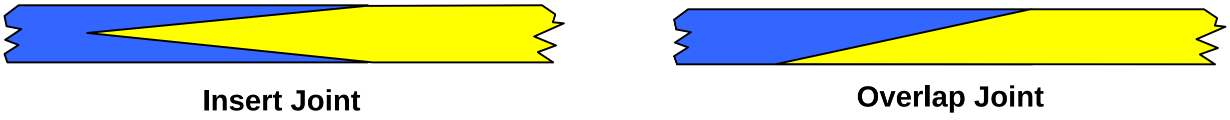


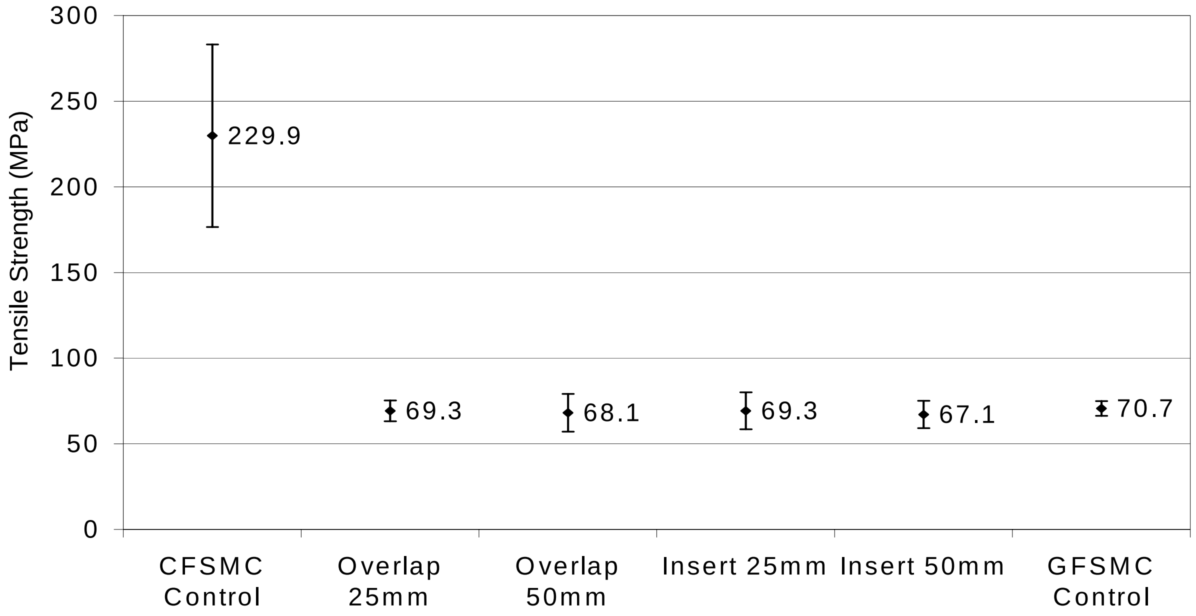
Figure 6. Transition of carbon fiber composite to glass fiber composite in molded parts.



A summary of tensile strength data is presented in Figure 7. Six specimens were tested at each condition. It is evident that the strength and the variation are much greater for the carbon fiber SMC than for the glass fiber SMC. The coefficients of variation are 23.2% and 6.1%, respectively. The strengths of the four different configurations are all statistically equivalent to the strength of the glass fiber SMC. Thus, it appears that stress concentration caused by the interface between the two dissimilar materials is not reducing the tensile strength below that of the glass fiber SMC. However, it was noted that most fractures occurred at the interface between the two different SMCs.

While strength did not differentiate the two types of joints, it became evident from visual examination of the panels that out-of-plane distortions were different. Individual panels were fixed along one edge and the deviation of the opposite two corners was measured. This revealed that the asymmetric joint, the overlap, resulted in nearly a four-fold greater deviation from plaque planarity than the symmetric "insert" joint. Results of this study were used in the design of the charge pattern for the door inner panels.

Figure 7: CFSMC / GFSMC Transition Study Results (brackets indicate +/- one standard deviation)



Performance Results

The final construction of the door yielded a 206% improvement in door sag stiffness and a 350% improvement in resistance to permanent sag deflection. Reducing the size of the steel reinforcements gave a weight savings of approximately 3 kg.

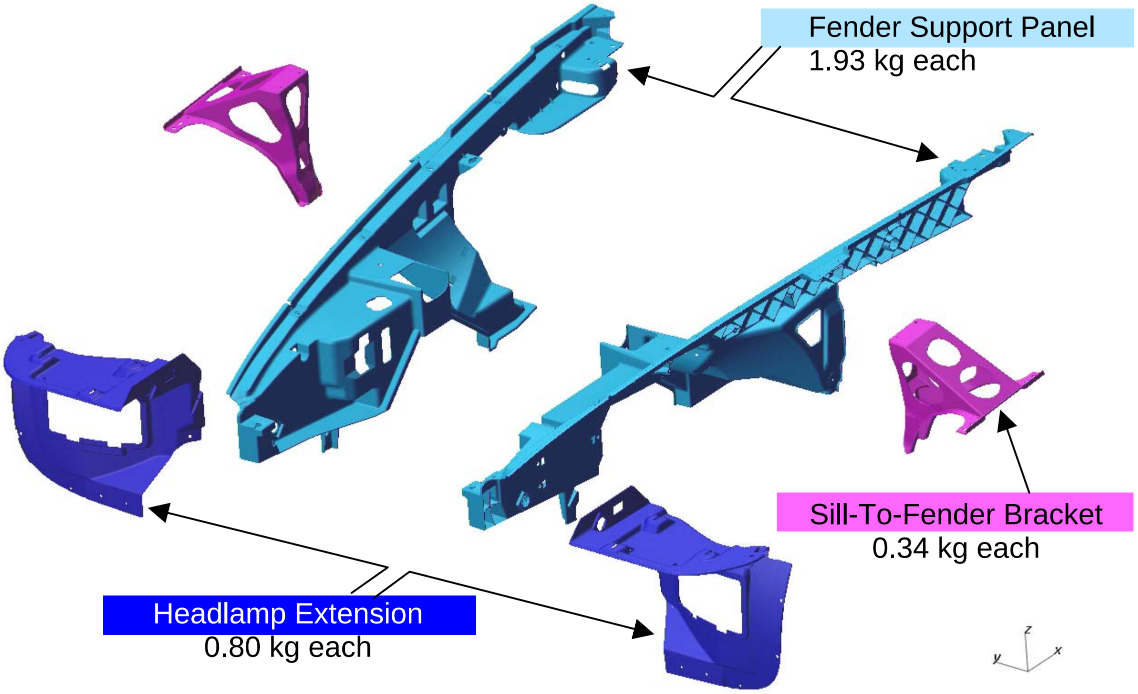
Fender Support System

Design Concept

The front-end of the original Viper was made up of a one-piece clamshell hood. With a multiple piece inner panel, excessive hand finishing, and its massive size, the hood was a very difficult part to manufacture. The styling of the 2003 Viper would offer the advantage of a traditional hood and fenders, keeping however the same space-frame chassis architecture. Many different options were considered to attach the new hood and fenders to the Viper space-frame including local stamped brackets, tubular metal reinforcements and fender inner panels. The engineering team decided to investigate new materials and a new concept for supporting the front end of the vehicle.

Carbon fiber SMC was ultimately chosen as the material for the new front-end fender support system. This process and material gave the design team great flexibility in consolidating brackets and increasing the function of the system. The initial design intent was to create one left and one right molded panels that would support the fender, the headlamps, and provide the dimensional reference for the entire front end of the Viper body. The design evolved into three molded panels per side: a fender support; a headlamp support; and a sill to fender bracket. Each of these panels would be molded out of carbon fiber SMC. The panel break up was driven by two main factors: 1. Minimize complexity of the molding tools; 2. Provide serviceability of the headlamp supports and the sill to fender brackets (areas of the system most likely to be damaged in a minor collision).

Figure 8. Fender Support System Components



Total carbon fiber content = 6.14 kg per vehicle

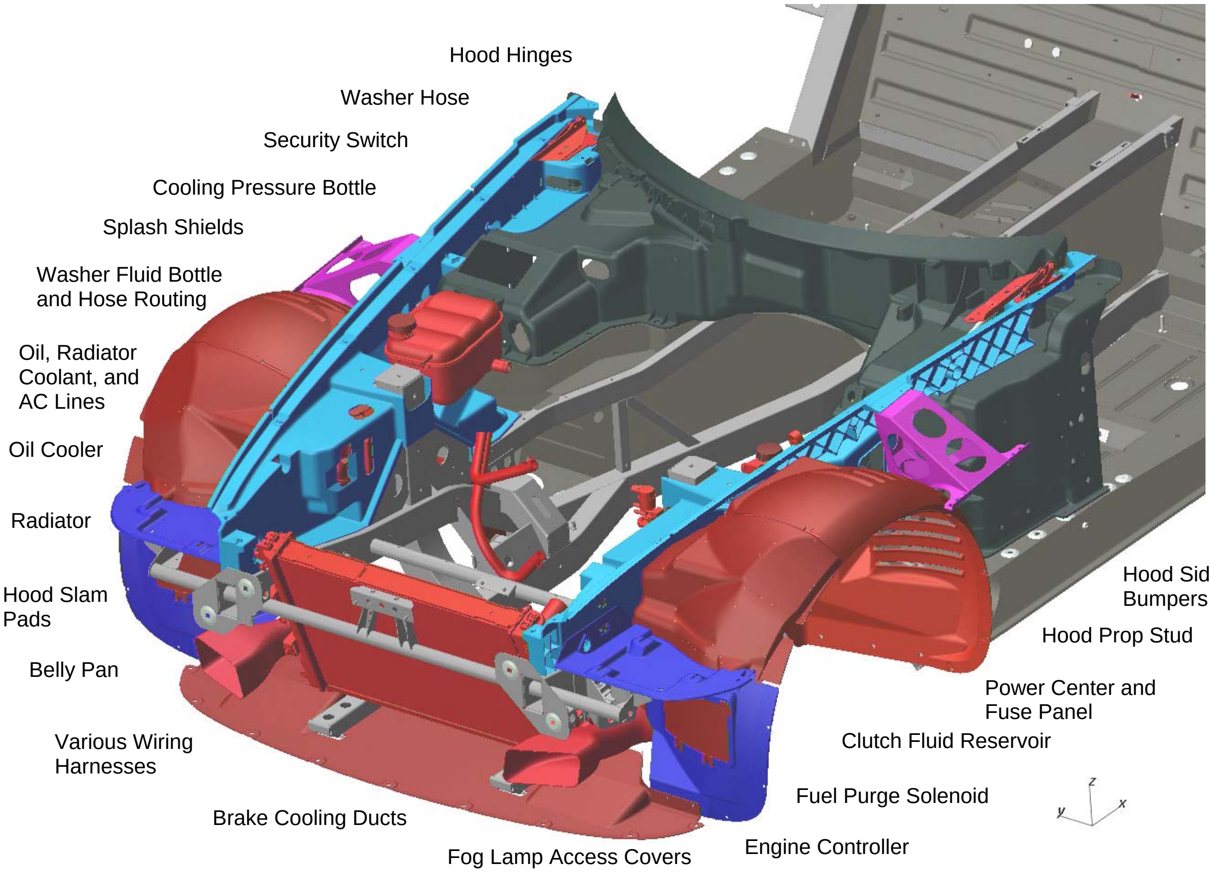
The fender support system is constructed by first bonding the headlamp support to the fender support with structural adhesive. This sub-assembly is next water jet cut and final assembled with fasteners. The fender support assembly is located to the vehicle by four net-form-and-pierce locations on the frame and two small locating fixtures. The fender supports are bonded to the frame by structural urethane adhesive and mechanically fastened with four screws and two nuts. Finally, each sill-to-fender bracket is fastened to the fender support assembly with three rivets.

Evolution

The fender support system increased in functionality as it evolved. The design flexibility of SMC allowed additional attachments at a minimum cost without adding panels and brackets. The fender supports use molded embossments, U-Nuts, Rivet-Nuts, Rivet-Studs and snap-in features to provide attachments for the following components: Fenders, Side Sills, Hood, Fascia, Headlamps and Cowl Screens.

Attachments for several under-hood components were added to the fender supports. On conventional body-in-white, most of these attachments would have required separate brackets in order to gain the same functionality.

Figure 9. Fender Support Under-Hood Component Attachments



Performance

The bonding of the fender support assemblies creates an upper torsional load transfer path to the frame. The fender supports also provide structural stability to the magnesium front-of-dash near the center of the car. FEA studies show that the fender supports increase the front-of-dash and A-Pillar stiffness by 22%, and increase the first bending mode by 3.1 Hz.

The fender support system, which has an average section thickness of 2 mm, reduces the weight of the vehicle by approximately 18 kg. The system, which is made up of 6.14 kg of carbon fiber SMC, dramatically reduces the number of brackets and metal reinforcements on the front end. An estimated 15-20 metal parts would have been required to achieve the same functionality of the six molded carbon fiber panels in the fender support system.

Conclusion

The 2003 Viper makes first automotive application of carbon fiber SMC to a vehicle body structure. Both thin section structures of all-carbon fiber SMC and the tailored hybridization of carbon fiber SMC to reinforce glass fiber SMC moldings are demonstrated. Mass reductions and stiffness improvements are achieved in the fender support system, windshield surround structure and door inner panels. The commercial manufacture of these parts represents a milestone for automotive composite technology as the industry begins to explore higher volume applications for carbon fiber reinforcements. The introduction of carbon fiber in a familiar material form and process, SMC, provides a relatively easy transition from glass fibers to this high performance fiber.

Acknowledgements

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References

(1) A. Dry, “The Development of the Carbon Fiber Industry,” 42nd International SAMPE Symposium & Exhibition, May 5 -8, 1997.

(2) C. David Warren, “Carbon Fiber in Future Vehicles,” SAMPE Journal, Vol. 37, No. 2, March/April 2001.

(3) R. G. Boeman, N. L. Johnson, "Development of a Cost Competitive, Composite Intensive, Body-in-White," Proceedings of 2002 Future Car Congress, Arlington, Virginia, June 3-5, 2002

(4) J. M. Corum, et al., "Durability-Based Design Properties of Reference Cross-ply Carbon-Fiber Composite," ORNL/TM-2000/322, Oak Ridge National Laboratory, April 2001