Structural RIM Choices for Today's Automotive Design

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ABSTRACT

Bayer Polymers has been engaged in extensive development of Structural RIM (SRIM) polyurethane materials for over two decades. Out of these developments two traditional plus one new composite technologies have evolved. These afford the automotive designers as well as the engineers to capitalize on the composite advantages that are increasing with the demand for lighter weight cars and trucks. This paper discusses these three composite technologies.

Historically SRIM composite have enjoyed interior applications, such as door panels, roof modules, instrument panel retainers, sunshades, spare tire covers, etc. Additionally, SRIM materials have enjoyed exterior applications such as seat frames, bumper beams, truck boxes, midgates and tailgates. Recent Bayer SRIM developments have brought about another composite technology choice. This technology combines traditional reinforcing materials with honeycomb cores. The result is a lighter weight composite than ever before, with exceptional load bearing properties.

Since a variety of manufacturing processes and/or equipment are involved to produce SRIM composites, some process descriptions are discussed. Finally, real production applications in use today are provided as typical examples.

INTRODUCTION

With the advent of the Chevrolet Corvette in 1953 the public was introduced to structural composite materials. While development work on composite materials had taken place prior to this in other industries, this was the first application where the technology was available to the general public. The formability of polyester resins in combination with the strength of fiberglass provided a composite material that could be used to mold shaped body components at a relatively lower cost than steel. The sleek design of the car provided a showcase for "fiberglass parts" that were tough and dent resistant.

Since that time, almost 50 years ago, structural composites have expanded into a wide variety of uses including automotive, agricultural, industrial, aerospace, and recreational applications.

For many years, polyester resin based structural composites formed the staple of the technology. However, during the early 1980's a new line of fiberglass composite products came into existence for use in the automotive industry. The new products combined conventional urethane reaction injection molding (RIM) with fiberglass reinforcement to form structural materials known as Structural RIM, or more commonly known today as SRIM. These SRIM composite products are being used in a wide range of applications from light structural interior automotive door panels to highly structural bumper beam supports. This breadth of applicability was due, in part, to the relative ease by which the percentage and type of glass could be varied, and to the variety of polyurethane systems developed for the automotive application. Therefore the overall composite density and structural property of the molded SRIM composite part could be tailored to meet the need of the specific application.

MARKET APPLICATION

Interiors-
Currently there are a number of SRIM composite applications being produced today. Several General Motors, DaimlerChrysler, BMW, Audi, etc., carmakers use SRIM composites in their vehicles. Currently, interiors utilize the SRIM composites for door trim substrates, instrument panel retainers, spare tire and load floor covers, to name a few. In almost every instance it has been the composites' lighter weight and excellent

strength properties that has led to its selection over competitive alternatives. Moreover, the higher heat stability and lower coefficient of linear thermal expansion (CLTE) properties are better than thermoplastic materials.

The following two tables illustrate the specific advantages of SRIM composites. Considering a door panel substrate example, the SRIM composites are, in every case, lighter weight and dimensionally more stable than thermoplastic materials.

First let's look at the weight comparison of an average door panel of 0.54 m^2 area. For the Baydur® LD-SRIM and the Baypreg® F substrates, Table 1. shows a weight savings of about one-half that of the thermoplastic materials. For a four-door vehicle, the weight saved per vehicle is significant for the SRIM technologies; the total weight saved could be as much as 3000 g per vehicle. This amount of weight reduction for the automotive market is noteworthy.

	Baypreg® F +NM*	**Baydur® LD-SRIM**	**PP**	**ABS**
Part Thickness, mm	1.75	2.5	2.5	2.5
Part Volume, cc	945	1350	1350	1350
Part Density, g/cc	0.7	0.5	0.97	1.06
Part Weight, g	662	675	1310	1431

***Notes**: NM with Baypreg® F indicates natural mat reinforcement.

Table 1.
Door Panel Substrate Weight Comparison

Next, comparing the mechanical properties of the substrates, Table 2. lists the density, flexural modulus, and CLTE. The SRIM composites show good stiffness and better thermal stability.

	Baypreg® F, NM	**Baydur® LD-SRIM**	**PP**	**ABS**
Density, g/cc	0.7	0.5	0.97	1.06
Flexural Modulus, MPa	3000	1800	1500	2500
CLTE, x10-6 /°K	15	20	22	25

Table 2.
Mechanical Properties
for Interior Substrates

The following table, Table 3., shows a partial listing of current production series and their respective composite technology.

Part	**PU system**	**Reinforcement**
Avalanche Midgates	Baydur® HD-SRIM	50% glass mat
Corvette seatback frames	Baydur® HD-SRIM	35% glass mat
Honda Sunshades	Baydur® LD-SRIM	20% glass mat
Mercedes Sunshades	Baypreg® F	Glass mat and honeycomb core
Audi spare tire cover	Baypreg® F	Glass mat and honeycomb core
BMW load floors	Baypreg® F	Glass mat and honeycomb core
Mercedes door panels	Baypreg® F	Natural fiber mat
Buick seat pans	Baydur® LD-SRIM	20% glass mat
Mercedes roof modules	Baydur® LD-SRIM	25% chopped glass process

Table 3.
SRIM Composite Applications

Exteriors-
For exterior applications, there typically two general uses for SRIM composites; both are HD-SRIM. One use is for structural reinforcements that replace steel structures: for example bumper beams and underbody structures. Several General Motors and DaimlerChrysler vehicles have used this type of technology at one time or another. A second exterior use is for light truck boxes, and tailgates. The Chevrolet Silverado truck offered a SRIM composite truck box and tailgate option to their traditional steel box and tailgate. It provided a significant durability and ruggedness improvements, while also reducing the vehicle's weight. Photo 1. shows the truck box and tailgate.

Photo 1.
SRIM Composite Box and Tailgate

Also, the Chevrolet Avalanche and Cadillac Escalade EXT SUVs use HD-SRIM composites for their midgate panels. As in the case for interiors, the HD-SRIM technology is lighter weight than steel as well as another composite technology, SMC. The HD-SRIM has demonstrated excellent impact resistance, abrasion resistance, and corrosion resistance for these applications.

Although not usually considered a candidate for a Class A finish part, the HD-SRIM composite can produce a painted appearance acceptable for textured finish applications. In the meantime, development work is underway to make this desire a reality.

Future Composites-

While there are many applications in use today, there is a growing market for more. In search of ways to reduce overall automotive vehicle weights in order to improve the fuel efficiency, SRIM composites are increasingly more desirable. The SRIM composite choices for interiors are well established; and the need for better and lighter weight vehicles is driving the car designer towards composites to accomplish their required performance targets. In the case of exteriors, obviously the next feature to achieve is to develop external SRIM composites that truly have an automotive Class-A finish. Bayer, in cooperation with other suppliers to the SRIM composite market, is developing technology to meet this challenge.

Whether it is interior or exterior, overall part costs are an important consideration. Today's world competitiveness further intensifies the manufacturing market to seek out the best performing product at the lowest possible cost. SRIM composites compete for a wide variety of applications in a vehicle; and they compete against an equal number of alternative technologies for these applications. Therefore comparing costs of one technology versus all of the others is difficult to do in the amount of space available here. However a general summary and a couple of specific examples are possible.

Table 4. shows the relative cost comparison of SRIM composite to various other technologies for general uses in a vehicle. Note, that a specific technology's cost and ways to improve its cost situation is always possible. And as often is the case, a specific cost versus performance benefits study makes sense in order to determine the best technology fit for a given application at a given cost. The key here is to develop and design parts that utilize the composites' strengths and features instead of simply swapping one technology for another within a fixed design.

	Interior Trim and Substrate Parts	**Exterior Structural and Functional Parts**
SRIM Composite	+	+
Injection Molded Plastic	+	-
SMC	0	0
Steel	-	+

Table 4.
Relative Part Cost Advantage Comparison

A cost comparison of a load floor part is a specific example worth mentioning. Assuming a total new manufacturing plant start up scenario in this comparison, Table 5. shows estimated costs to produce such a part. What is also included in the comparison is a relative part performance rating. This rating is based on the part's ability to consistently support a load and not deform permanently, throughout the entire temperature spectrum experienced inside a vehicle.

	Baydur® LD-SRIM	**Baypreg® F +HC***	**PP**
Part cost estimate	$7.25	$6.52	$9.63
Performance	Excellent	Excellent	Fair
Part weight, g	960	820	2606

***Notes**: HC with Baypreg® F indicates paper honeycomb sandwich construction reinforcement.

Table 5.
Load Floor Part Comparison

Another comparison example is a sunshade part, again using the part's design performance requirements for low mass-inertia and sag-deformation properties. In this example shown in Table 6., the comparison is SRIM composites to traditional SMC.

	Baydur® LD-SRIM	**Baypreg® F +HC***	**SMC**
Part cost estimate	$6.99	$5.35	$11.22
Performance	Good	Excellent	Fair
Part weight, g	935	615	3991

***Notes**: HC with Baypreg® F indicates paper honeycomb sandwich construction reinforcement.

Table 6.
Sunshade Part Comparison

The key point in both of these part examples is that the SRIM composite technologies can offer better part performance, weigh significantly less, and be a cost competitive product. These features and benefits should compel car designers and engineers to use SRIM composites.

TECHNOLOGY

LD-SRIM Composites-

Basically there are two traditional polyurethane (PU) systems' technologies. These two have been used to produce nearly all of the SRIM composite parts in existence today. One system uses a PU foam polymer in combination with glass reinforcements. This composite is commonly referred to as Low Density SRIM (LD-SRIM). The amount and type of glass can vary. It usually comprises less than 30% or the SRIM composite by weight. The glass loading amount required depends on the design or purpose of the part, its inherent functional property requirements, and naturally the molder's production capabilities. The glass loading levels and its processing form to accommodate the production molding process is affected by these factors as well. Glass reinforcements will be discussed in further detail later on, but first another commonly used PU composite technology needs to be mentioned here.

HD-SRIM Composites-

Another PU system uses a solid elastomer in combination with glass reinforcements. This is referred to as High Density SRIM (HD-SRIM). Just like with LD-SRIM described before, the amount and type of glass can vary; but usually it is at a higher percentage in the molded part, typically 30 to 50% by weight. The factors for determining the glass weight amount are again based on the same criteria as before.

Glass Reinforcements-

Glass reinforcements of varying types and manufacturing processes have been used throughout the industry. For general two-dimensional shapes, or three-dimensional shapes with a shallow depth of draw, a glass mat is used. The glass mat can be comprised of chopped glass filaments, continuous random filaments, woven rovings, or sometimes a combination. Glass mats are easy to use, and are readily available from several sources.

If the geometric shape has a deep three-dimensional shape, then a glass mat may not work in the corner areas of the part. In the corner areas, glass folding onto itself presents a manufacturing problem. Therefore, it is necessary to make a preformed shape of glass reinforcement (or directed chopped preform glass) that nearly matches the shape of the molded part. The directed chopped preform is fabricated in a separate production operation as a prerequisite to the SRIM composite molding step. Fabricating a preform requires special equipment that can add costs. It is best suited for large volume production situations to reduce the investment cost impact (i.e., greater than 125,00 units per year), or is best suited for large parts (i.e., light truck composite boxes). The glass reinforcement starts out as glass rovings. These are robotically chopped and directed onto a three dimensional screen-form undergoing a vacuum.

Then the resultant glass preform is baked to cure the specially designed, integral, binder resins. These binder resins hold the preform shape all together during handling and subsequent PU composite molding operations.

An alternative way to consider molding a deep three-dimensional shape is to use more recently developed SRIM process equipment. This equipment combines chopping glass rovings and pouring the PU system concurrently. This manufacturing method requires that the PU system have extraordinarily long mold-open time (i.e., cream times for LD-SRIM, or gel times for HD-SRIM). This is in order for the process equipment to distribute the glass+PU materials across the entire mold surface before closing. From an overall equipment investment standpoint, this manufacturing approach is less costly than making glass preforms for SRIM production.

Table 7. shows a comparison of mold-open times and cure times to make the noted part examples. Naturally the part producer strongly desires that the overall cure time of the

PU system is not compromised for this alternative SRIM technology.

Composite Part Examples	Open Time, sec	Cure Time, sec.
Baydur® LD-SRIM: Door panels, with glass mats	15- 20	60 - 70
Baydur® LD-SRIM: Door panels, with glass chopping process	20 - 25	60 - 70
Baydur® HD-SRIM: Tailgates, with glass mats	6 - 10	80 - 100
Baydur® HD-SRIM: Tailgates with glass chopping process	25 - 30	80 - 100

Table 7.
SRIM Process vs. Reactivity Requirements

PU Natural Mat and Honeycomb Composites-
In recent days, Bayer has developed an additional PU system, Baypreg® F, for still another SRIM composite technology. This PU system is being used with a combination of a few different reinforcement choices. It can be used with natural fiber mat reinforcements to produce a very thin composite substrate. Also, it can be used with a core spacing material to make a "sandwich" composite. The core is overlaid with glass mats or overlaid with natural fiber mats to make the reinforcement structure. The typical core material used for interior part production today is paper honeycomb. Alternative core materials include, but are not limited to, aluminum honeycomb, plastic honeycomb, and balsa wood. Photo 2. shows some examples of these core materials.

Photo 2.
Core Material Examples
for Baypreg® F Composites

The glass mat choices are similar to those used in the LD-SRIM and HD-SRIM production: chopped glass or continuous filament strand mats. The natural mat choices have been studied; these include jute, hemp, flax, and sisal. But the preferred choice to date has been a 50/50 mixture of flax and sisal.

The manufacturing process for these composites is very different from the LD-SRIM and HD-SRIM process.

This process applies the PU system to the reinforcement external to the mold itself. Then the PU impregnated reinforcement is inserted into the mold for subsequent molding and curing. The entire operation can be accomplished automatically. Referring to Figure 1. for an equipment layout illustration, a related manufacturing description follows here as an example of natural fiber mat door panel substrate production.

Processing Natural Fiber Mats-
The cut-to-size natural fiber mat is picked up by a robot-controlled gripper system (item 5) and conveyed into a booth (item 2). There the Baypreg® F system is applied as quickly as possible (<15 sec) using several mixing heads. The system must be applied to both sides of the thick, impermeable natural fiber mat (cf. Photo 3.) to guarantee complete impregnation in the subsequent pressing process.

Photo 3.
Natural Fiber Mat Roll

For reliable, top-quality production, the mixture should be applied using a high-pressure metering device (item 3) and self-cleaning mixing heads. These mixing heads are designed to allow several thousand consecutive shots without adjustment or cleaning.

Special catalysts adjust the reactivity of Baypreg® F systems so a discernible reaction only takes place at a high temperature in the mold. The reaction takes place very slowly at room temperature. If routine production of parts is interrupted (i.e., a plant malfunction) several minutes may elapse before a sprayed mat becomes unusable and has to be discarded.

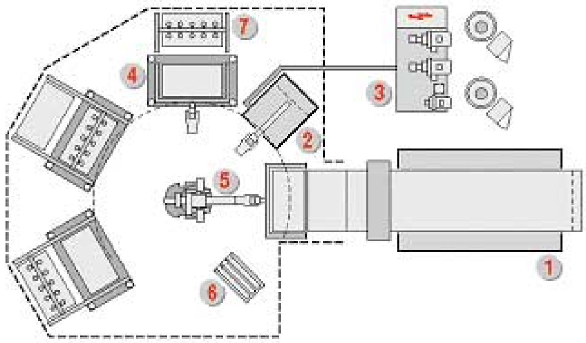

Figure 1.
NafpurTec® Equipment Technology

The gripper then deposits the flat natural fiber mat wetted with Baypreg® F in a heated mold (item 4), and the mold is immediately closed. The pressing process shapes the part itself while it cures. The reaction of the polyurethane system is triggered by heat supplied by the hot mold.

In contrast to the other two PU processes previously discussed, the reinforcing material is combined with the Baypreg® F system outside the mold. The combined materials are inserted into the mold, where a simple compression process carries out the shaping and curing of the part.

Molds are generally made of metal (preferably aluminium, or alternatively steel), for three reasons:

1. relatively high pressing force (about 200 t to 250 t for a door trim with an average area of 0.6 m^2),

2. mold temperatures of about 130 °C, and

3. the systems contain internal mold release additives which only act in metal molds.

Figure 2. shows the pressing force required to press a flat piece of natural fiber mat having an initial thickness of about 8 - 10 mm and weighing about 900 g/m^2. When producing components, this piece of mat would be compressed to a wall thickness of about 1.7 - 1.8 mm. According to Figure 2., a pressing force of about 12 bar, which converts to about 75 t, is required for a door trim of average size (~0.6 m^2). This pressing force is determined on flat material and is not sufficient for producing actual door trims, which usually have considerable vertical regions requiring more than the pressing force calculated for the projected area. In practice, door trims require a pressing force of at least 150 t, and preferably 200 t to allow a safety margin.

Aluminium molds are quite adequate for normal production. Steel is required if cutting operations are incorporated in the actual pressing mold (for example sheer edge trimming). A further 50 - 75 t pressing force may have to be added, depending on when these cutting operations actually take place, i.e. by how much the mat is already compressed.

The processing of Baypreg® F involves mold temperatures of about 130 °C for two particular reasons:

1. The internal mold release additives contained in the systems only act at mold temperatures above about 120 °C.

2. Molding times can be markedly reduced owing to the high temperature of the mold in combination with carefully selected catalysis. Today, molding times of 45 seconds are feasible, and the next step is to reduce them to 30 seconds.

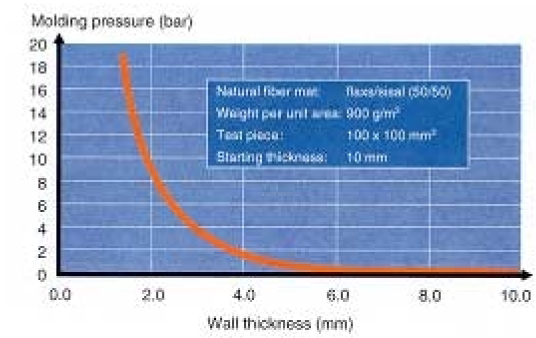

Figure 2.
Molding Pressure for Natural Fiber Mat

Once the mold has been opened, the components can be released automatically (cf. Figure 1, item 7) and placed on a cooling rack. After cooling, they are conveyed to subsequent fabrication stages such as cutting and lamination.

With a PU content of < 40 % by weight, based on the end product, the molded components can still be laminated under vacuum. Vacuum holes do not generally have to be drilled into the components under these conditions. Fasteners (such as glass fiber-reinforced polyamide) can be inserted and pressed directly in the mold.

Another use of the Baypreg® F composite technology incorporates the use of paper honeycomb. The paper honeycomb is used as a core, or spacer, to create a sandwich panel composite. The paper honeycomb provides the physical property feature of exceptionally high stiffness at a very low composite part weight. In this Baypreg® F construct with paper honeycomb, either natural fiber mat or glass mat reinforcements are possible for the surface layers of the composite.

The manufacturing process is essentially identical to the natural fiber mat process described earlier. In this case, a paper honeycomb core separates two outer surface layers of either the natural fiber mats, or the glass mats. This entire composite is handled by the gripper system for the subsequent spraying process. Since the honeycomb core acts as a thermal insulator during the curing step in the mold, the cure times are somewhat longer than that of natural fiber mat alone, as described previously. The pressing force for this particular process is much lower, since the paper honeycomb crushes easily. 30 t to 75 t is typically adequate for interior trim parts.

The Baypreg® F sandwich composite construction is becoming quite popular for sunshade, spare tire covers, and load floor applications. In Europe, this particular composite technology is being used for BMW, DCX, and Audi, to mention a few.

Photo 4.
Audi A4 Spare Tire Cover

Photo 4. shows the Audi 4 spare tire cover, which uses Baypreg® F sandwich composite construction. This composite uses glass mats and paper honeycomb to produce the structurally strong part.

Photo 5. shows a cut away view of the honeycomb sandwich composite. Notice that this also shows an incorporation of metal brackets integrated into the design.

Photo 5.
Sandwich Composite with Metal Piece

The paper honeycomb can be used in various thicknesses for a specified application. Although the Baypreg® F composite manufacturing process is not generally changed, the molded part's mechanical properties do. Table 8. shows some comparison of properties with and without paper honeycomb, and at different paper honeycomb thicknesses. Note that the different values reported in the Composite Thickness category are a result of using the mat alone, or in combination with a paper honeycomb core. Note also that the paper honeycomb core sandwich properties are exceptionally good at composite densities well below 0.5 g/cc.

Composite Construction*	**1.**	**2.**	**3.**
Fiber Mat, g/m^2	800	525	450
Composite Thickness, mm	1.6	12.0	10.0
Composite Density, g/cc	0.7	0.40	0.25
Weight/Unit Area, g/m^2	1200	4800	3820
Flexural Modulus, MPa	3000	2950	2900

***Notes:**
No. 1=Natural mat only
No. 2= Natural mat with 12 mm paper honeycomb core
No. 3= Glass mat with 10 mm paper honeycomb core

Table 8.
Mechanical properties of Baypreg® F Composites

CONCLUSION

Many exciting applications are utilizing SRIM composites and more are on the way. The combination of SRIM composites' lightweight, and inherently stiff properties can not be overlooked for future designs. Improving fuel economies and overall better car performance are demanding that composite materials be chosen. The SRIM composite choices available today are quite varied. They can enable the automotive carmaker to achieve the challenges they face.

European OEMs have used SRIM composites for a number of years. Their interior applications are normally the same as NAFTA. Regarding the latest SRIM composite technologies (using Baypreg® F), however they are already ahead. Their engineering groups are reaching forward to incorporate better, lighter weight composite performance into their automobiles. Today several applications are using Baypreg® F technology. Several new models are soon to launch with this technology.

NAFTA's OEMs have similar needs as Europe's. SRIM composites are being used in NAFTA for interior and exterior applications. These composites range from LD-SRIM for many different interior parts, to HD-SRIM for bumper beams, seat frames, truck boxes and tailgates. In every instance these applications have demonstrated lighter weight parts with specific performance benefits. SRIM composites offer the technology that supports the performance and design demands for today and the future.

BIOGRAPHY

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Terry D. Seagrave is the Market Channel Manager for the NAFTA Automotive Composite Business at Bayer Corporation. He has held several positions with increasing responsibility during his 14 years at Bayer. These positions include Business Team Leader for Automotive Composites, Sr. Technical Marketing Representative for Automotive SRIM, and Development Chemist and Technical Service Representative for Automotive RIM. He holds a BS Degree in Chemistry from Taylor University.