NEW 2-LAYER AUTOMOTIVE BODY-PANEL SYSTEM USING LIGHTWEIGHT THERMOPLASTIC COMPOSITE BACKSIDE & AESTHETIC SURFACES

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Abstract

The automotive industry has long sought new materials for exterior body panels. Metals are heavy, easily dented, many corrode, and all require complex tooling to meet today's styling requirements. Thermoplastics offer good impact strength, design freedom, Class-A finish, and cost effectiveness, but lack stiffness and strength for truly structural applications. Thermoset composites are lighter, stiffer, and have simpler tooling than metals or injection-molded thermoplastics, but require extensive secondary-finishing operations to achieve Class A. Thermoplastic composites offer significantly higher stiffness and strength than unreinforced thermoplastics, but cannot provide a glossy, Class-A surface, although they have long been used in applications where a grained first surface is acceptable.

This paper reviews innovative work on a 2-layer body-panel system incorporating a new, lighter weight, structural thermoplastic composite backside and an aesthetic surface layer – either precoated aluminum or inherently colored thermoplastic or paint films – to meet aesthetic requirements. Topics to be covered include materials, molding, and target applications.

The Ideal Body-Panel Material

The ideal material for use in an exterior automotive body panel would have a wish list of properties that included:

- Corrosion, chemical, and dent resistance,
- Light weight but with sufficient stiffness & strength,
- Class-A surface finish,
- Design freedom with capabilities for parts consolidation,
- Easy manufacturing and inexpensive tooling,
- Good repeatability and reproducibility (R&R),
- Readily available and with a long history of use,
- Inexpensive and reliable with good customer acceptance.

Unfortunately, no single material now in use meets all these criteria.

Classes of Candidate Materials

While long used in the industry, steel is relatively heavy, prone to denting and corrosion, and is more limited in terms of design flexibility and parts consolidation without costly tooling and secondary operations. Aluminum and more-exotic metals still suffer from denting, can be quite costly, and share many of steel's design challenges with high tooling costs.

Injection-molded thermoplastics are attractive as potential body panel materials due to their corrosion and dent resistance, impact performance, fast cycle times, design freedom with parts consolidation, and potential for significant cost and weight savings. However, unreinforced thermoplastics creep in horizontal body-panel applications and have high coefficients of linear thermal expansion (CLTE), requiring larger gaps between panels, which can interrupt certain styling lines. Thermoplastic alloys are often used to improve CLTE and meet the required levels of chemical resistance to common automotive fluids. While they offer Class-A surfaces, their lower thermal performance requires thermoplastic parts to be painted off-line from the body-in-white. Although far lighter than metallic counterparts are, thermoplastics lack sufficient stiffness and strength for required mechanical properties unless glass or carbon fiber reinforcements are added, which affect surface finish, weight, and cost.

Industrial thermoset composites provide the design freedom and parts consolidation of thermoplastics, plus the added benefit of greater stiffness and strength, with better chemical resistance. The tradeoff is that they require longer cycle times to cure, numerous secondary-finishing operations, and some types can require a high level of rework, making total systems costs rise. Thermoset composite parts also must be painted off-line from the main vehicle structure. Comparably speaking, they are also heavier than equivalent thermoplastic parts, although they are still significantly lighter than metals. Furthermore, many of these composites are brittle and prone to catastrophic failure in high-speed impact events.

Thermoplastic composites such as glass-mat thermoplastics (GMT) provide corrosion, chemical, and dent resistance, light weight, and design freedom with parts consolidation approaching that of injection-molded thermoplastics. They also are cost competitive, have good R&R, a long history of use, and are easily manufactured on inexpensive tooling. Selective addition of various glass, natural fiber, and carbon fiber reinforcement technologies allow designers to tune required stiffness, strength, and impact properties of the composite relatively easily without changing tooling. However, achieving a Class-A finish with these materials – a critical property for body panels – has proven to be quite challenging. With so many other attributes that would make them good candidates for body-panel materials, the challenge becomes how to achieve a Class-A surface from GMT composites.

Previous Attempts to Achieve Class A with GMT

Over the years, numerous attempts have been made to produce exterior automotive body panels with acceptable aesthetic and mechanical properties using compression-molded, GMT-type composites.

In the case of classic GMT, the parts failed to meet Class-A surface requirements because of "waviness" of the part surface. This is caused by the coarseness of the typical fiber reinforcements used in traditional GMT composites – bundles of hundreds of filaments of continuous strand, randomly oriented fibers. These heavy strands stay together during flow forming and are always visible on the surface of the part. This is further exacerbated by shrinkage of the resin matrix around these large bundles, leading to the undulating or bumpy surface appearance.

To overcome the problems with fiber bundles on the surface of the composite, a newer type of GMT materials with a different mat were tried as a second approach. Produced via a modified-papermaking technique, these GMT composites are reinforced with individual short-glass filaments rather than the continuous-strand mat used in traditional GMT. Although the modified composites achieved a better surface due to the significantly finer fiber reinforcements used, they were still unable to meet Class-A requirements. In this case, the flow-forming process used to mold parts was to blame. Because the top blank on each side of the tool freezes off first as it contacts the relatively cool mold surface, it leaves a "witness" mark with a glass-rich surface.

While failure to achieve engineering goals is always frustrating, researchers made a number of important discoveries based on lessons they had learned from these earlier attempts. This included the necessity of separating the "*structural*" functions from the "*aesthetic*" functions of the panel. Once it was understood that these were two quite different sets of properties, it became clear that both could be achieved by taking a multilayer-sandwich approach. Since it was not possible to achieve Class A with the composite alone, it was reasoned that adding an aesthetic first-surface layer might solve the problem.

As inherently colored thermoplastic or paint films became generally available, attempts were made to back-mold them with GMT by pre-shaping them and molding the GMT behind using a flow-molding process. While the fiber bundles were less visible behind the films, than with no covering at all, they still were visible enough not to produce a Class-A surface. It was determined that to completely hide the fiber bundles would require a film that would be too thick to be practical.

A New Multilayer Approach

While approaches based on flow molding were not entirely successful, they did give researchers the idea that – by taking a slightly different processing approach – the multilayer concept could work. Whereas in previous molding attempts the GMT and paint films were shaped simultaneously, this time researchers decided to use a form-pressing or stamping process. It was believed that this should lead to a more homogeneous appearance across the entire surface of the part, since a no stacking area exists with the stamping technique. To accomplish this, the researchers envisioned a 2-step process using a compression press fitted with a single female tool and 2 male tools – the latter on an indexing table. The first male tool would preshape the aesthetic first-surface layer, and the second would shape the structural backside. In addition to changing the processing technique, researchers also decided to explore other material options for the first-surface layer.

Since the structural backside would be stamped as a second step from that of the first-surface, it would be necessary to find a way to attach the two layers while achieving good adhesion. With GMT composites, this is generally achieved with multilayer adhesion films, which are already in use during processing on GMT structural composites. To ensure that adequate adhesion was achieved, a minimum temperature is needed, but the temperature should not be so high as to affect the surface layer.

Depending on the material used as the decorative surface layer, the processing window could be too small, and a 3-step-process would have to be used instead. In this latter case, the surface film and structural back would need to be formed in different steps and subsequently vacuum-bonded afterwards.

Additional Technical & Commercial Requirements

Besides the processing requirements outlined above, additional technical and commercial requirements would need to be met in order for this approach to yield commercially viable parts. Reviewing likely criteria, researchers determined that the parts must experience no post-mold warpage due to differentials in CLTE values between the first-surface and the structural-backside layers. In other words, either there must be little difference in CLTE values between the 2 layers, or the backside layer must be sufficiently stiff not to warp if the first-surface layer's CLTE was different.

Furthermore, whatever multilayer/multi-material combination was chosen, the resulting composite structure would have to be lightweight. Hence, either a backside material with high specific stiffness (in relation to weight) had to be selected, or a sandwich structure had to be created.

Additionally, in an industry as cost-competitive as the global automotive market, the technology had to be low cost relative to other options and offer a rapid cycle time to keep up with vehicle build. Only a thermoplastic composite would offer the low systems cost at high production rates necessary.

Finally, the system needed to be recyclable to meet legislation requirements in multiple geographies, which meant that a single-material-concept or a solution to separate non-similar materials.

Although in production, the first-surface layer would be the initial component processed, in development, it was the structural backside layer that was created first.

Development of a Structural Backside Material

In reviewing the required attributes of the structural backside layer and what such requirements would mean about the material itself, Quadrant researchers created a list of desired properties (and their ramifications) as follows. The ideal material for the structural backside layer would:

- Provide long-fiber reinforcement to avoid fiber bundles (the initial manufacturing process would need to create a composite with individual filaments),
- Have a high stiffness / weight ratio (hence use a structural reinforcement),
- Mold at very low pressure (to avoid damage to the surface material),
- Offer excellent impact strength at all service temperatures,
- Impart 3D formability (would need long reinforcement fibers to avoid thinning in areas of deep draw),
- Give good sound damping and thermal insulation (plastics are softer, so they offer inherently better sound absorption, plus they are thermally insulating),
- Provide rapid cycle times, compatible with automotive production scenarios and offer a cost-effective process,
- Offer excellent mechanical performance and chemical resistance (hence, a glass-filled polypropylene composite would be a good choice).

Such a material would be targeted for use in both interior as well as exterior passenger-vehicle applications, for uses ranging from:

- *Interior*: roof liners, parcel shelves, door/pillar cladding, trunk liners, instrument panel covers, and load floors, to
- *Exterior*: underbody shield and roof modules.

Formation of a Lightweight Composite

Researchers identified a new composite that was being developed at the time for underbody shields at Quadrant R&D as a perfect candidate to fulfill these requirements. This particular material – commercially available from the company under the tradename *SymaLITE*™[1] – offered an even higher stiffness-to-weight ratio per cm^3 than conventional GMT composites. This was achieved by design, since the material was not fully consolidated, as is the case with traditional GMT materials. By means of a technique called "*tailored consolidation*," the density could be reduced to one third that of the original, thereby creating a kind of a long-fiber reinforced composite foam.

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[1] *SymaLITE*™ is a trademark of Quadrant AG.

The new, lighter weight composite makes use of a technology comprised of mixed-fiber fleeces of glass and polypropylene fibers, which creates a composite with individual reinforcement fibers but no fiber bundles. Varying the "recipe" for this fleece in terms of ratio of the various fibers and the way the fleece is subsequently needled allows numerous mechanical properties to be "tuned" for a given application. The ratio of glass to polypropylene can range from 20-60% glass. Underbody-shield applications, requiring greater impact and ductility, typically contain lower loadings of glass, while interior parts, requiring greater stiffness, are typically formulated with more glass. The core of these composites contains a fleece that has a density of 600-2,000 g/m^2.

Different functional and/or decorative surface layers can be applied during manufacture, as will be discussed shortly. To facilitate blank placement in customers' tools, the width of the blank can be varied and 4 standard blank widths are available: 2,300 mm, 1,150 mm, 766 mm, and 575 mm. Blank length can also be varied, but is typically a minimum of 300 mm.

Blank Production Process Makes the Difference

The new, lighter weight composite is manufactured in a dry production process. First, mixed-fiber fleeces are produced using a modified-textile process, where glass and thermoplastic fibers are mixed and a homogeneous, high-loft fleece is formed and needled. In a second and newly developed step, the fleeces are heated above the melt temperature of the matrix and are then consolidated online to a solid laminate. In this step, the glass fibers are impregnated completely to make the most effective use of the reinforcement and to avoid loose glass fibers in the product. During this lamination step, it is also possible to attach functional layers to both sides of the laminate, which could be thermoplastic films, scrims, or adhesion films. While still online, the continuous laminate is cut to blanks in customer-specified sizes.

Use of this dry process allows blank thickness to be varied for a given level of glass content and density or area weight, which in turn affects properties of the final molded part. The higher the glass loading of a blank is going into the tool, the higher its loft and the lower its density, as is shown in Figure 1. Blanks with higher glass content will also yield parts with higher stiffness and lower deflection. Said another way, the greater the area weight, the higher the loft will be after heating.

Another commercially available technology, which also yields lighter weight GMT-like composites, uses a wet manufacturing process similar to papermaking. In this older system, powdered polypropylene is fed into a slurry solution containing glass and water, plus a foam solvent. This slurry is then fed into a laminator and rolled out into sheets. The main disadvantage of the wet production system vs. Quadrant's new dry process is that the older, wet system does not allow use of fibers longer than 13 mm compared to 78 mm in the composites produced via the dry manufacturing process. This leads to a high 3D-forming capability for the new dry-process composites without the thinning and tearing that can occur with short fibers. The other disadvantage of the wet manufacturing process is that it offers little control over the loft behavior of the material, as is achieved in the case of the dry-process composites by both fleece forming and needling. The needling creates a 3D reinforcement, providing higher interlaminar strength for the new composite. Furthermore, with the dry-process, the use of fully consolidated laminates leads to very short heating times due to good heat flow into the material.

Table I lists select properties for 5 grades of 3 types of glass-mat thermoplastic composite. The first 3 grades represent the new lightweight composite, distinguished by application usage and material properties. The 4th grade, the Benchmark material, is a lightweight GMT composite produced using the wet manufacturing process. The final grade is a traditional GMT composite with normal density and a continuous-strand, randomly oriented glass mat. It is especially interesting to note the structural stiffness values for these materials. Structural stiffness is based on the bending elastic modulus and is dependent on wall thickness, which goes into the calculation with the power of 3. Hence, the thicker a material is, the lower its bending elastic modulus values, but the higher its structural stiffness, E x I.

Processing Information

Since it is constructed and manufactured differently than conventional GMT, the new lighter weight composite is processed in a different manner. Blanks of the multilayer composites are heated to a processing temperature of 180-200C via infrared, hot air, or contact ovens. This causes the fleece to loft up 5 - 6x its original thickness, based on fleece formation and needling. Glass fibers have memory (or back force) and try to return to their initial orientation upon heating. Hence, the more glass in the composite, the higher the loft.

The heated blanks are then moved robotically from the oven to an aluminum tool, where they are subjected to low-pressure forming (< 0.21 MPa vs. 14 – 17 MPa) for conventional GMT). In fact, because stamping pressures are lower with this process than with the compression flow-forming process used with traditional GMT, prototype tooling can be made quickly and inexpensively from wood.

Tooling for the new composites does not have a shutoff (shear edge) as it does for traditional GMT. This is because material is stamped, not flow-formed into a net part shape. Owing to the low pressures of the process, large single blanks can be used to form multiple parts at the same time in a family tool, improving throughput. After opening the tool, the blank with the formed parts is moved by robot into a unit, where the individual parts are cut out of the blank and holes are also cut into the part. This can be done via mechanical cutting tools, water jet, or laser. Unlike conventional GMT, with the new composites it is much easier to stamp holes out of the finished part while still in the tool because the wall thickness around the hole can be thinned out (fully consolidated) in the mold prior to punching the hole. In addition, because there is no material flow, knitlines are not a problem and holes can be located relatively close to the edge of the part.

Typical cycle times for underbody shields, with density of 1,500 g/m^2 (gsm), 40% glass, and 4-mm wall thickness, is 50 - 60 sec. Due to the low pressure needed to mold the new composite material, a multi-cavity tool can be used, as noted above. To avoid sagging across the width of these big blanks, they are processed vertically in a molding unit that is acting horizontally. The first commercial-scale line running in industry was installed in Germany and is currently molding, molding the loadfloor for a sportscar.

Another unique property that the new multilayer composite offers vs. conventional GMT is the ability to vary thickness across the finished part while maintaining the same part weight. With conventional GMT, density is the same across the whole part. Therefore, to make a part thicker, additional or larger blanks must be stacked up inside the tool, but that has the effect of increasing part thickness in that particular location and overall part weight. With the new composite, however, due to the flexibility of the tailored consolidation achieved by the high lofting of the fleece, to have a thicker section, the tool is simply constructed so as not to press down as deeply into the composite. This is in stark contrast to metal stamping, where the entire part must be of the same thickness. In effect, this allows a part to be made thicker (maintaining a higher degree of loft) without sacrificing stiffness/area weight and increasing mass. Said another way, if a particular section of a part needs higher area stiffness, the part should be designed to keep the composite as thick (and with as high a degree of loft) as possible there. However, in sections where it is more important to have higher tensile strength, the blank should be more fully consolidated (pressed thinner).

First-Surface Systems under Evaluation & Development

To date, 3 surface technologies have been explored for the new composites.

- Thin layers of coil-coated aluminum (CCA),
- Thermoplastic film using engineering resins, and
- Thermoplastic polypropylene-films.

In the case of the thin layer of coil-coated aluminum, advantages are that the CLTE values for the metal and composite are quite similar (20 x 10^{-6} 1/K), so properly designed and processed parts should experience no warpage over the full service-temperature range of the composite (-40 to 120C). Further, since a thin sheet of aluminum is used, there is a significant opportunity to reduce weight vs. a solid aluminum stamping. However, disadvantages of this system are that it is difficult at this time for the coil-coating industry to deliver the high volumes of material in the wide variety of colors required for the automotive industry on a just-in-time, just-in-sequence basis and still meet the auto industry's quality requirements for exterior body panels (color-match).

In the case of the inherently colored engineering-thermoplastic films, advantages are that the higher temperature resins used do not melt at the composite processing temperatures, so they are less likely to melt through during molding. However, the difference in CLTE values (20 - 80 x 10^{6} 1/K) increases the chance of warpage and/or delamination between the paint film and the composite during high and low temperature excursions. An optimized adhesion layer and a stiff structural backside, like a sandwich, are needed to make the system work.

Finally, in the case of the inherently colored film system using a polypropylene substrate, the advantages are that the combined system would represent a single polymer family, facilitating recycling and materials-recovery efforts at end of part life. Disadvantages are that the paint film has a different CLTE value from the substrate, so warpage and delamination could be a problem during high and low temperature cycling. In addition, molding temperatures would need to be watched extremely carefully, as it would be easy to remelt the surface film.

While to date, researchers have focused most of their efforts on the aluminum-surfaced composites, there seems to be unique advantages to each type of construction. Which system to use will most likely depend on the type of application and the needs of a given OEM. In the case of the aluminum-faced composite, there should be no delamination or warpage problems during temperature excursions. In addition, since the paint used on CCA is the same as that used for steel and aluminum body panels, it should match exactly. However, like solid-metal body panels, the coil-coated aluminum face on the composite can be dented and scratched.

In the case of the composites faced with inherently colored films, they will be lower in weight than their aluminum-faced counterparts will be. If an olefin-based film is used, recycling will be much simpler. It is also possible that with these films, the numerous special-effects packages available for polymers could be brought into play.

Regardless of the type of facing used on the multilayer, lightweight-composite structure, when competing against steel systems, the new system will be much lighter in weight (30 - 60% lower for a comparable part), and while somewhat thicker, will also offer higher stiffness. Furthermore, they will offer far greater impact strength and intrusion resistance, as well as better acoustical (sound damping) performance. Additionally, they will require far less tooling to produce, and can be delivered as a module to the OEM.

Progress at Targeting Key Applications

While the multilayer lightweight composite system is new, much progress has already been made in targeting key applications. Exterior body panels using the new composite and a CCA skin have now been validated as a fully developed material system. A roof module is the first commercial application where prove-out of the system is planned.

In the area of hoods, trunk lids, and doors, concept studies using the same CCA/composite technology are underway. For these parts, hybrid systems using functional aluminum components (not just an aesthetic skin) – for attaching hinges, which could be molded in or fixed after molding – are also under evaluation at this time. However, automakers will likely wait for the roof-module project to prove the system in a commercial application before moving forward.

Inherently colored, film-faced composite systems will be somewhat longer in development since adhesion and warpage problems still need to be solved.

Summary and Next Steps

A multiyear research project has shown that exterior body panels can be produced using a 2-layer system consisting of a lightweight thermoplastic composite backside for structure and a decorative skin layer that may or may not also add function. Several different surface-layer systems have been tested, including precoated metal sheets and inherently colored thermoplastic films.

A new lighter weight thermoplastic composite has been developed that is ideal for the structural backside. It can be molded using a low-pressure stamping process. Due to the material's thermoplastic matrix, short cycle times, high throughput, and cost-competitive parts can be achieved. The ability to tailor the level of consolidation of this composite during initial manufacturing allows a high specific stiffness to be achieved during subsequent molding, while also saving weight vs. conventional composites like GMT and LFT. For higher performance applications, future research will focus on similar composite structures using engineering thermoplastic rather than polypropylene matrices and fleece technologies encompassing carbon fiber. In the meantime, the first commercial applications in roof modules should be on the market this year, which will help speed other opportunities to market.

Data

Table I: Select Properties for 5 Thermoplastic Composites

Material	SL[§]	SL[§]	SL[§]	Benchmark[§§]	GMT[§§§]
Typical application	*Headliner*	*Underbody shield*	*Sunroof & load floor*	*Underbody shield*	*Underbody shield*
Glass content %	55	40	40	42	30
Area weight in g/m²	1,000	1,500	2,000	1,500	2,260
Wall thick-ness of test part in mm	4	4	4	4	2
Density in g/cm³	0.25	0.37	0.5	0.38	1.12
Structural stiffness E x I	**3.7**	**4.5**	**8.5**	**4.0**	**2.3**

[§] SL = New SymaLITE lightweight composite from Quadrant made using dry manufacturing process.
[§§] Benchmark = Older technology lightweight composite made with wet manufacturing process.
[§§§] GMT = Conventional GMT composite with continuous-strand, randomly oriented glass mat.

Figure 1: Loft vs. Area Weight for New Lightweight Composite Backside Material – Comparison of 40% and 55% Glass Content