

Advanced glass-mat thermoplastic composite applications for the automotive industry

ABSTRACT

Glass-mat thermoplastic (GMT) composites have a long history of use in the automotive industry. New developments have led to the creation of advanced GMT composites capable of higher mechanical performance or able to meet entirely new stiffness / weight and aesthetic criteria. Within the advanced GMT category, two distinct classes of composites have evolved. One type is reinforced with various types of engineered textiles to provide higher stiffness and strength in more demanding end-use environments. The other type is reinforced with a high-lofting fleece that provides improved stiffness to weight ratio and that, for the first time, provides the enhanced aesthetics required for first-surface applications right out of the tool. This paper will discuss both new classes of advanced GMT.

KEY WORDS: Glass-Mat Thermoplastic (GMT) Composites; Structural; Automotive

OVERVIEW

Traditional glass-mat thermoplastic composites have been used in the automotive industry for more than 40 years for structural and semi-structural applications to replace steel and aluminum, as well as thermoset and thermoplastic composites, and some injection-molded thermoplastics. Early uses included floor pans, seat backs, battery boxes, bumper beams, and load floors. More recently, new developments in mat technology have enabled a new category of GMT composites to be created. These advanced GMT composites are being used in applications with more demanding performance, cost, and weight requirements – applications where traditional GMT cannot compete. Now, it is common to find advanced GMT composites used in: spare-wheel wells with integrated features, liftgates (liftdoors) for hatchback cars, rear-axle support brackets, highly loaded underbody shields for off-road use, pedestrian-protection beams, and new-generation seat structures and bumper beams.

Indeed, applications for GMT composites continue to grow because this class of material provides excellent stiffness, strength, and impact performance at relatively low cost and mass vs. other structural materials like metals and thermoset composites. Traditional and advanced GMT composites, with their polypropylene resin matrix, are lighter than all of these, can be processed into complex 3-D components on a single, low-cost tool, and are easily recyclable at end of vehicle life. With the pressing need to reduce mass and cost on all automotive components, GMT composites can offer automakers and tier suppliers numerous benefits.

GMT also offers advantages vs. long-fiber (reinforced) thermoplastic (LFT or LFRT – and when produced with a direct in-line compounding process, DLFT) composites as well. The later also feature a polypropylene matrix and chopped glass reinforcement – although the LFT reinforcement is shorter and “looser” form of glass with individual fibers, not the entangled mat structures used in GMT. If an application is primarily concerned with stiffness,

then LFT may be as viable a material choice as GMT. However, if the application also requires strength, toughness (impact), and creep or fatigue properties, then a composite with a needled (entangled) mat structure, such as GMT, has a clear advantage over one with short, loose (individual) fibers.

TRADITIONAL GMT COMPOSITES

Benefits Offered by Traditional GMT

Experience has shown that when the true cost to produce final assembled modules is compared between various materials technologies, those applications where GMT composites have a viable fit – structural or semi-structural components that are not first-surface parts – offer customers some compelling benefits vs. thermoset composites or metals, including:

- Lower mass (leading to better fuel economy),
- High degree of functional integration (fewer parts, reduction in assembly),
- A resin matrix that with a high strain-to-failure (higher durability under creep, impact, or fatigue),
- Elimination of rust and galvanic corrosion due to exposure to salt, water, and automotive fluids,
- Higher energy absorption / kg than steel and equivalent to aluminium (lighter, thinner parts at comparable energy absorption),
- Better sound damping due to lower modulus (quieter underbody shields during rain or stone chipping),
- Reduced assembly-line effort (shorter “belt length” on assembly line),
- Reduced costs (owing to lower mass, greater integration, and faster & easier assembly),
- Fully recyclable in-plant scrap and parts at end of vehicle life,
- High productivity (deriving from fast and largely automated parts production), and
- Low tooling costs vs. cost to stamp steel (especially attractive for production volumes of <100,000 units / year).

Anatomy of Traditional GMT Composites

In production for decades, traditional GMT composites have a polypropylene resin matrix and a reinforcing mat structure that is comprised of either:

- Original, continuous-strand, randomly oriented glass (which offers high stiffness, strength, impact, and ductility in all 3 axes), or
- Chopped long-(50-100 mm)-glass fibers (which offers superior fill in thin-sections such as ribs and bosses), or
- Unidirectional, very-long glass fibers running the length of the blank cut from this sheet-form material (which offers extremely high stiffness and strength along 1 axis).

All traditional GMT composite mats are needled to create an interlocking, 3-dimensional network of fibers. This entanglement of glass is the key material feature for the GMT composite to handle energy more efficiently than composites with loose, individual-fiber reinforcement (e.g. LFT).

Just prior to molding, the blanks are passed through an indexing infrared (IR) or convection oven and heated above the melting point of the polypropylene matrix. The preheated blanks are then moved (manually or robotically) to the nearby press and position inside the open

tool. Once blanks are positioned, the press quickly closes, stamping (compression molding) and flow forming the part. The tool opens, the part is removed (manually or robotically), and the molding cycle begins again.

ADVANCED GMT COMPOSITES

Starting from the technology base of traditional GMT, advanced GMT composites were developed to enhance two areas of performance: to provide higher stiffness and strength in more demanding applications (*textile-reinforced advanced GMT composites*), or to offer good stiffness at significantly lower weight and the opportunity for enhanced aesthetics (*lightweight reinforced thermoplastic (LWRT) composites*).

Benefits of Textile-Reinforced Advanced GMT Composites

With textile-reinforced types of advanced GMT composites, all the traditional plastics and GMT composite benefits apply (such as those named above). However, since these composites feature highly engineered fabrics with woven or non-crimped stitched mat structures, they can be used in applications where traditional GMT composites, LFT composites, and even many thermoset composites cannot compete. Advanced GMT offers improved performance:

- Where higher stiffness is needed,
- Under higher creep loads,
- Under higher fatigue loads,
- Under more extreme impact conditions,
- With higher strain rates,
- With higher maximum strength at any strain rate, and
- In applications subject to elevated and low temperatures.

The textile-reinforced advanced GMT composites outperform so many other materials because of their highly engineered mat structures, which provide a very effective path for transferring loads under all loading conditions, especially for managing greater loads at higher strain rates.

Anatomy of Textile-Reinforced Advanced GMT Composites

This category of advanced GMT composites makes use of a combination of traditional glass mats plus one or more layers of textile reinforcements to create sheet-form composites with very high stiffness, strength, and impact resistance. The textile reinforcement layers are all formed from continuous fibers in the form of woven fabrics or non-crimped stitched products using glass or other types of fibers, such as aramid, thermoplastic polyester, or carbon fiber. The most common fabrics include:

- Commingled glass / thermoplastic polypropylene-based fabrics are typically used for spare-wheel wells, bumper beams, and hatchback doors (Figure 1a).
- Woven glass fabrics, which offer cost / performance benefits in applications like spare wheel wells (Figure 2b)
- Special-weave polyethylene terephthalate (PET) fabrics, which offer high strain-to-failure and are used to make underbody shields to protect the vehicle's underside (Figure 1c).
- Non-crimped, stitched fabrics, which features several layers of straight glass fibers stitched together with various fibers (Figure 1d); similar fabrics are used for rear-axle support brackets.

GMT products that feature one or more layers of these special reinforcing textiles in combination with traditional glass mats are called GMTex¹ composites. With this technology,

¹ GMTex is a registered trademark of Quadrant AG.

there is great versatility to tailor the properties for a given application. For instance, the ratio of fibers in the warp and weft position can be varied. A balanced 1:1 fabric has the same number of threads in both directions and offers balanced orthotropic properties for applications like rear-axle support brackets (as shown in Figure 2). A fabric with a 4:1 weave has 4x as many threads in one direction as the other (Figure 3). This type of reinforcement is useful for applications where higher properties are needed in one direction, such as a bumper beam.

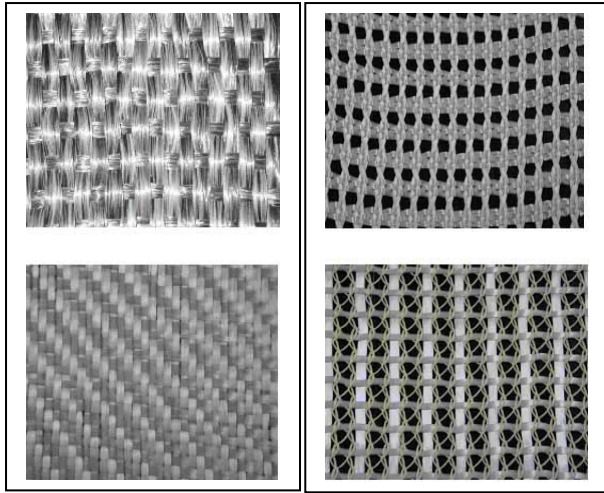
Additionally, order of placement of the fabric layers in the sandwich also affects properties. Figures 4a-b show, respectively, engineering fabrics in the middle (surrounded by a traditional chopped glass mat) and on both surface (surrounding a core of traditional chopped glass fiber). If a better surface is required on a part, chopped mat is used as the top layers and fabrics are used in the middle. When the fabrics are used on the surface, the resulting composite has higher flexural modulus (such as is needed for a bumper beam) but with less desirable aesthetics.

Advanced fabric-reinforced GMT composites are molded in the same way as traditional GMT.

Benefits of Lightweight Reinforced Thermoplastic (LWRT) Advanced GMT Composites

Just as there are applications where the higher strength of fabric-based advanced GMT composites is required, there are also applications where lightweight stiffness and the ability to create a first-surface in a one-step process are a benefit. For those types of applications, there is another new class of GMT materials called lightweight reinforced thermoplastic (LWRT) composites with the following key features vs. traditional GMT:

- Higher stiffness / weight ratio,
- Part stamping at very low pressures (allowing a one-step decoration with fabrics, films, etc),
- Ability to mold very large parts in a single piece or multiple parts in a family tool,
- Higher sound absorption and damping, plus higher thermal insulation, and
- Ability to vary thickness over the part to tailor stiffness and strength according to local needs.



Left Top to Bottom Right: Figure 1a (top left): Commingled glass/polypropylene fabric; Figure 1b (bottom left): woven glass fabric; Figure 1c (top right): special-weave PET fabric; Figure 1d (bottom right): non-crimped stitched glass / aramid product

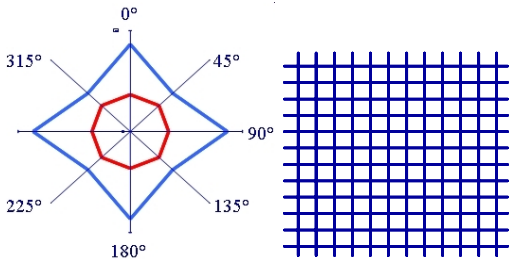


Figure 2: Elastic modulus for advanced GMT composite with a balanced 1:1 weave pattern that provides same stiffness in warp and weft direction for applications subject to loading in more than one axis.

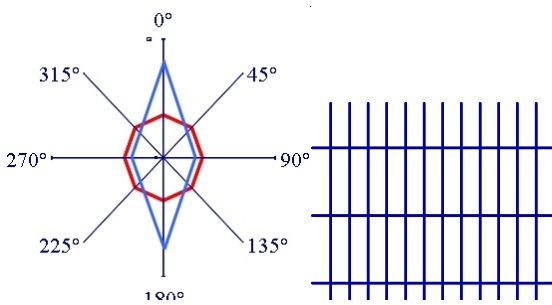


Figure 3: Elastic modulus for advanced GMT composite with a 4:1 weave pattern that provides higher stiffness in the direction with more fibers for applications subject to loading in a single axis.

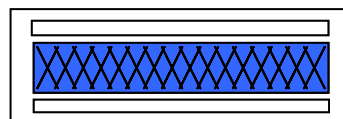
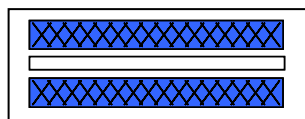


Figure 4a (left): Use of engineered textile as the middle layer surrounded by the chopped glass mat / PP matrix in the advanced GMT sandwich; Figure 4b (right): Use of engineered textiles as top and bottom surface layers, surrounding chopped glass mat / PP matrix in a different type of advanced GMT composite

Anatomy of LWRT Advanced GMT Composites

LWRT composites feature fleeces with an area weight of 300-2,000 g/m² that are formed by glass and polypropylene fibers. Varying the “recipe” for this fleece in terms of ratio of the various fibers (20-60% glass) and the way the fleece is subsequently needled allows numerous mechanical properties to be “tuned” for a given application. As the fleece is heated, the PP fibers melt and form the matrix material, creating a composite with individual reinforcing fibers but no fiber bundles. LWRT composites offer good stiffness and toughness at significantly lower weight. Figure 5 shows the relationship between loft and area weight for

2 grades with 40 and 55% glass. The higher the ratio of glass to PP fibers, the higher the composite lofts during heating and the stiffer the resulting part is. Higher glass loadings are ideal for applications such as interior-trim panels (e.g. headliners) where lightweight stiffness is key. For applications requiring higher impact and ductility (e.g. underbody shields), formulations with a lower level of glass are used.

Another unique property of this material vs. conventional GMT or stamped metal is the ability to vary thickness across the finished part while maintaining the same area weight. The tool is simply constructed so as not to press down as deeply into the composite. In effect, this allows a part to be made thicker (maintaining a higher degree of loft) and improving stiffness locally where needed without adding mass by reducing the density. However, in sections where it is more important to have higher tensile strength, the blank can be more fully consolidated (pressed thinner, e.g. around fixation points).

Since LWRT composites are stamped at very low pressure, this process allows very large parts and the option of creating first-surface parts out of the tool. The low-pressure stamping process does not damage various functional and/or decorative surface layers (adhesive films, vinyl or olefin skins, carpet or fabric, polyester scrim) that can be applied during blank manufacture or in the tool (put on heated blank and molded to final part in a single step).

A number of automotive applications are already making use of the benefits of LWRT materials, including load floors, parcel shelves, sun shades, and trim panels for instrument panels, pillars, and doors.

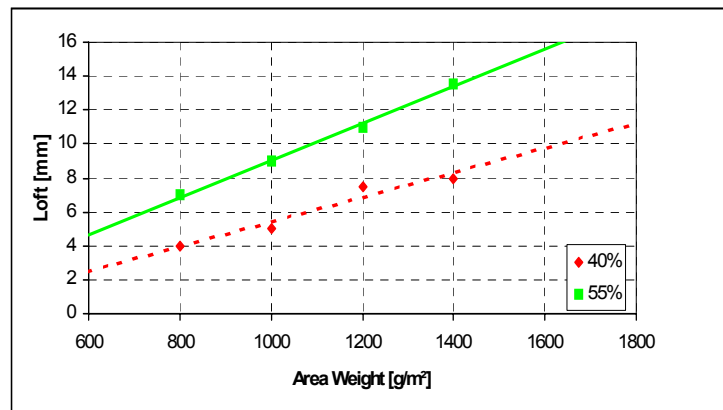


Figure 5: Loft vs. area weight for 2 grades of LWRT with different glass loadings (40 and 55%)

SUMMARY

Advanced GMT composites – both fabric-reinforced and LWRT types – are already expanding the range of automotive applications in which GMT composites can compete thanks to the cost and mass savings they offer vs. thermoset composites and metals. They also offer improvements in stiffness, impact, creep, and fatigue vs. thermoplastic composites made with (D)LFT using compression or injection molding. An exceptionally versatile technology allows great flexibility in tailoring composite properties. Future programs currently under development with these materials will expand the applications portfolio even further, with usage in structural front-end modules, rear wall modules, airbag containers and covers, integrated firewall – IP concepts, floor modules, and components for 3rd-level crash.

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