CONTINUOUS FIBER REINFORCED THERMOPLASTIC COMPOSITES IN THE AUTOMOTIVE INDUSTRY

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Abstract

Composite materials continue to gain popularity in the automotive community primarily due their ability to reduce weight. Other key advantages include function integration, corrosion resistance and low cost tooling.

Although thermoplastic composite products have been commercially available for some time now, new products, specifically continuous fiber reinforced thermoplastics, are spurring engineering activity in this growing segment of the composites industry.

This paper serves to review materials, technologies and applications of continuous fiber reinforced thermoplastics in the automotive industry. Specific application areas include underbody protection, bumper beams and load floors.

Background

Two major technologies have built the foundation of glass reinforced thermoplastics. Injection molding (IM) of "short glass" and "long glass" thermoplastics is well documented as is compression molding glass mat (GMT) thermoplastics. The newest technology relating to these two processes is extrusion compression molding of long fiber thermoplastics (LFT) either through the use of long fiber compound, long fiber masterbatch, or through direct compounding of glass, PP and additives. Although these technologies are interesting and certainly commercially useful, the properties of continuous fiber reinforced thermoplastics are striking in contrast. Table 1 shows data for commercially available glass fiber reinforced polypropylene materials.

It is this range of performance that makes continuous fiber reinforced thermoplastics interesting to the design and engineering community.

Continuous Fiber Reinforced Thermoplastic Materials

There are three basic technologies for making continuous fiber reinforced thermoplastic raw materials[1]. The segment as it existed just years ago was primarily based on prepreg unidirectional "tapes" made by one of several processes – solution coating, electrostatic powder coating, or hot melt impregnation. These tapes could be used as-is for unidirectional applications (primarily thermoplastic pultrusion), or laid up for specific fiber orientation. The laid up prepreg would then be melted and stamped into a form. This technology lends itself to a wide variety of thermoplastic materials including PP, PA, PBT, PET, PPS, PEI, & PEEK, as well as a wide variety of fiber materials including glass, carbon, aramid fibers just to name a few. On the downside, materials made from these prepreg technologies are relatively high in cost, and can be difficult to work with as the tapes tend to be stiff and non flexible.

The second commercial material technology is emerging. This technology is based on the use of thermoplastics with "dynamic viscosity". The base polymer when melted has very low viscosity that enables easy wet out of the fibers during processing. The viscosity builds as the material cools making a tough, durable thermoplastic resin. Although the primary process employed is pultrusion, the transition to processes like RTM to form parts should be realizable in the near future. Commercially available resins include thermoplastic urethane, PBT and PC. Glass fiber is the primary reinforcing fiber.

The third technology uses dry prepregs made by intimately blending thermoplastic fibers with reinforcing fibers. This can be done as an off line secondary process, or in line during the fiber making process. In line "commingling" of thermoplastic fibers and glass fibers offers a lower cost material because the process is a high volume industrial process. The result of this process is a single end roving of intimately mixed or commingled fibers as depicted below in Figure 1.

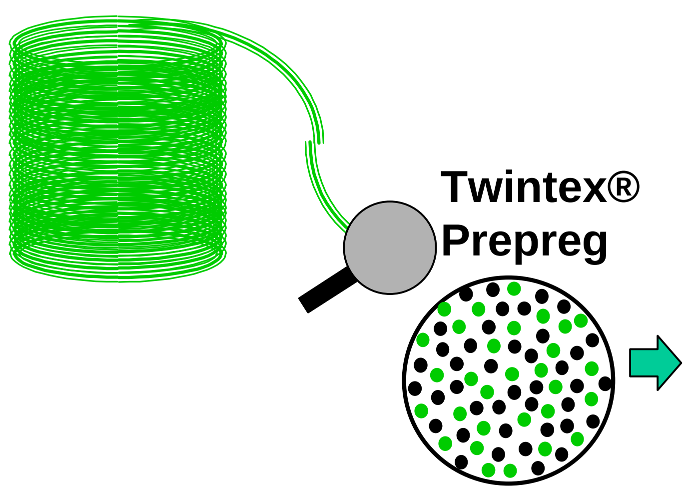

Figure 1

This prepreg can be used as-is for thermoplastic pultrusion and filament winding. It can also be woven into a “fabric” for use in several processes including panel lamination, vacuum bag molding, compression molding and thermoforming using double diaphragms (diaphragm forming). This product form is analogous to the laid up oriented tape noted above; however, it is much more flexible, and has a lower cost. Unlike the prepreg tapes, the fiber in this product form is not impregnated at all. The physical proximity (microns) of thermoplastic fibers to reinforcing fibers allows for quick and easy wet out during processing.

There are limitations to this technology from an in-line manufacturing perspective. Firstly, only thermoplastics that can be fiberized are used. This limits matrix selection. Secondly, the process employed is a high volume industrial process; product customization needs to be volume justified. One key advantage is the ability to achieve glass contents up to 80% by weight.

Although there are many obvious advantages of continuous fiber reinforced thermoplastic materials like no VOC’s, fully recyclable parts, and superior toughness versus traditional thermosets, the true value of thermoplastic composites lies in the design phase. Thermoplastic composites can be post formed to reduce assembly steps and components. Colored films can be molded in to eliminate painting. Thermoplastics can be welded and fastened by a number of traditional methods.

Underbody Protection – Making Use of Superior Impact Resistance

Continuous fiber reinforced thermoplastic composites are a natural fit for automotive underbody protection. Versus metals, they do not corrode or dent, and are lighter in weight. Versus thermosets, they are tougher, and processing is amenable to high volume applications.

Figure 2 illustrates one commercial shield. This particular shield is compression molded from a consolidated plate of 60% continuous glass fiber reinforced PP. The glass fiber is balanced in the 0/90 directions, and is woven. A non-shear edge tool is used; hence the part needs to be trimmed. Designers need to take great care of trim waste during the design phase as it adds cost to the part. The ability to mold in ribs and additional function is easily recognized in the illustration.

Limitations of the “stamping” process include trim waste, uniform wall thickness, and the use of consolidated plate that is more expensive than its “fabric” counterpart. On the positive side, traditional GMT processing is easily modified for this process with a greatly reduced tonnage requirement as the plate input is already fully consolidated – simply melt and form.

Figure 2

Cost reduction of this application may be attained through the diaphragm forming process. This process is a hybrid thermoforming process where thermoplastic composite fabric is laid in between two elastomeric diaphragms. The diaphragms are clamped (not the composite material), and vacuum is pulled in between the diaphragms for consolidation purposes. The clamped diaphragms containing the raw material are heated until the material is melted, then shuttled into a pressure assisted vacuum thermoforming unit that forms the part. Once cool, the part can be demolded. Cost reduction is achieved by several factors. First off, commingled fabrics may be used in place of consolidated plates so there is immediate cost savings by virtue of the raw material form being used. Secondly, pressure assisted thermoforming tooling is generally less expensive than compression molding tooling. Lastly, trim waste can be reduced as the raw material can be more efficiently used. On the negative side, cycle times are higher, and additional labor may be needed to lay up the fabric in between the diaphragms. One positive point to the designer is that this process can be used to create parts with variable wall thickness. A schematic of this process is depicted in Figure 3 below.

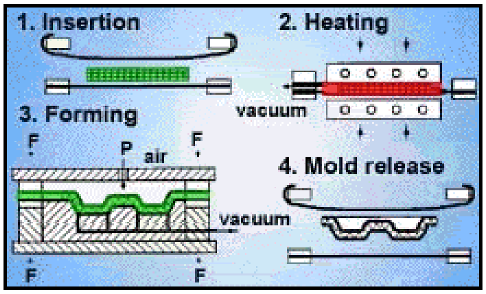

Figure 3

Another commercial underbody shield uses continuous fiber reinforced thermoplastic to locally reinforce GMT in an area of high stress. A comparison of continuous fiber reinforced PP and GMT is found in Table 2.

Bumper Beams: Weight Reduction, Function Integration and Energy Management

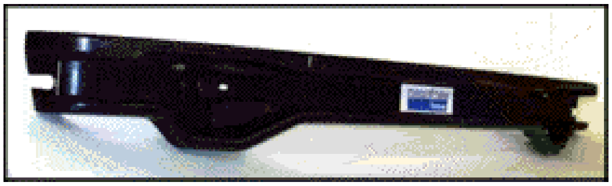

Figure 4

Although thermoplastic composites have lost significant market share to high strength steel over the last several years [2], new opportunities are available and commercial success is being achieved due to new products and technology in the market.

The bumper beam illustrated in Figure 4 is for the Peugeot 806. It is made from a new GMT product that combines continuous fiber reinforced PP skins with a random chopped glass core. The reinforcing fibers in the skins are oriented 80% along the beam / 20% perpendicular, and are woven. This GMT product is molded by a conventional compression molding process.

A new technology [3] is being used to produce the GM U van bumper beam shown in Figure 5.[3]

Figure 5

This beam is made by preforming a 60% continuous glass fiber reinforced PP material, and injection molding glass reinforced PP material over the molten preform. This unique process allows a high level of function integration from the injection molding process, and makes use of the excellent stiffness and toughness of continuous reinforcement.

The advantages over steel are well documented for this beam [4].

- 40% reduction in weight
- No need for light impact absorbing foam – eliminates secondary process and reduces components
- Increased energy absorption reduces damage to vehicle
- Elastic recovery after deformation leads to multi hit capability.

New thermoplastic composite products and processes will have to continue to be developed to regain the market share lost to steel.

Load Floors: Weight Reduction Using PP Honeycomb

Thermoplastic composite sandwich panels made from continuous fiber reinforced skins with a PP honeycomb core are sparking great interest in the automotive community due to incredible potential to reduce weight, and provide energy management solutions to automotive interiors.

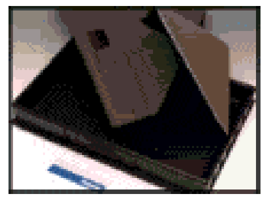

Figure 6

The commercial load floor in Figure 6 is low pressure stamped in a one step process. Carpet, reinforcement, PP honeycomb, reinforcement and film are stamped together and trimmed in mold to produce a semi finished panel. In this case, the reinforcement comes in the form of consolidated plates of 60% glass, and 40% PP. Consolidated plates lend themselves well to low-pressure processes.

One exciting attribute of these sandwich structures is that they can be post formed and molded. Figure 7 demonstrates the ability to form a structure with finished edges from a flat sandwich panel, and Figure 8 shows a compression molded part with good three-dimensional form.

Figures 7 and 8

Summary

Continuous fiber reinforced thermoplastic composites already play key role in the automotive community as demonstrated by the applications and technologies noted above. However, the potential role of these materials far exceeds current usage. Thermoset composites have strong limitations. Components made from them are not readily recyclable, and the ability integrate function through post forming is practically non-existent. VOC of thermosetting materials remains an issue.

Composite products made from continuous fiber reinforced thermoplastics are a solution to these issues while maintaining the key characteristics of thermoset composites that make them valuable to the designer – weight reduction, corrosion resistance, stiffness, and the ability to fabricate complicated shapes cost effectively.

With a host of new continuous fiber reinforced thermoplastic products available, processes need to be further developed to move the thermoplastic composites segment from a niche status to commercial industrial market. One fine example of this is the work done by Fraunhofer ICT on the Daimler Chrysler passenger footrest for the Smart Car [5]. This innovative process uses continuous fiber reinforced skins, and an LFT core of recycled PP and trim waste. This innovative process was awarded by JEC in 2000.

One key development opportunity for continuous glass fiber reinforced materials is to be used in conjunction with conventional injection molding and compression molding processes as demonstrated by some of the previous applications. This combines the excellent physical properties of continuous reinforcement with readily available processes that allow high function integration.

Figure 9: Various Forms of Continuous Fiber Reinforced Thermoplastics Including Direct and Post Formed Pultruded Profiles, Filament Wound Tube, Consolidated Plates and Sandwich Structures

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References

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(2) *PlasticsBRIEF – Reinforced Plastics newsletter*, September 18, 2000
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Table 1
Comparison of Properties for Various Glass Fiber Reinforced PP Materials

Material	Tensile Strength (MPa)	Tensile Modulus (MPa)	Notched Izod (J/m)
40% Long Glass PP (1) Injection Molded	124	9,000	265
60% Continuous Glass PP Balanced Weave	350	15,000	1,600
60% Continuous Glass PP Unbalanced Weave (80/20)	400	26,000	2,200
60% Continuous Glass PP Unidirectional	700	28,000	
75% Continuous Glass PP Unidirectional	800	38,000	

(1) 40% long glass data courtesy of LNP Engineering Plastics, Inc. All other data is from Saint-Gobain Vetrotex America, Inc.

Table 2
Comparison of 60% Continuous Glass Fiber Reinforced PP to Various GMT Grades

Material	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flex Strength (MPa)	Flex Modulus (MPa)	Notched Izod (J/m)
40% GMT A	90	5,600	138	5,200	425
40% GMT B	100	6,200	160	6,100	750
45% GMT	112	5,900	149	5,400	375
60% Continuous	350	15,000	280	13,000	2,200