

# IMPROVEMENTS IN IMPACT AND ABRASION PERFORMANCE OF GLASS FIBER THERMOPLASTICS BY THE LOCALIZED INTRODUCTION OF SELF REINFORCED POLYPROPYLENE

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## Abstract

The past few years have witnessed a rapid growth in the use of glass reinforced thermoplastics for automotive applications. New developments in LFT's and GMT's are beginning to meet the industry's demands for complex modular components – such as front ends, instrument panel carriers and underbody assemblies – with low-cost, lightweight materials which have acceptable mechanical performance. However, in terms of damage tolerance, particularly resistance to heavy impacts and abrasion, LFT's and GMT's are no match for the metals they are designed to replace. This paper will describe the use of a highly impact resistant self-reinforced polypropylene composite to provide localized reinforcement in GMT and LFT components without increasing weight or compromising recyclability.

## Background

The automotive industry's seemingly endless demands for improved material performance, lighter weight and, above all, lower costs have been met to a greater degree by innovative developments in fiber reinforced thermoplastic composites. The success of LFT (long fiber reinforced thermoplastic) and GMT (glass mat reinforced thermoplastic) is demonstrated by the dramatic growth in the use of these materials. The annual rate of worldwide GMT production doubled in the period 1995–2000, reaching close to 200 million pounds. While GMT usage is forecast to remain relatively static the lower cost of LFT is forecast to push demand from just over 40 million pounds in 2000 to a staggering 300 million pounds by 2010 in Western Europe alone. The reasons for this dramatic growth are not difficult to understand: the raw materials (notably glass and polypropylene) are inexpensive and may be processed into complex multi-functional parts with short cycle times.

## Properties

As might be expected, the introduction of glass fiber reinforcement offers a huge improvement in the properties of the polypropylene resin, resulting in high stiffness and good temperature behavior with minimal increase in weight. However, in common with almost all composite materials, glass fibers exhibit a very low strain to failure which can lead to poor damage tolerance at relatively low impact energies. For automotive applications this low resistance to impact, particularly when compared to more traditional materials, can lead to premature failure. This is particularly the case at low temperatures when the matrix itself becomes brittle. In safety critical areas such as front-end modules, it is becoming increasingly common to reinforce the thermoplastic composite with metal inserts and carrier frames. However, this modification increases weight, compromises parts recyclability and adds an extra burden to the cost of manufacture.

## Self-Reinforced Polypropylene

A relative newcomer into the thermoplastic composite field is self-reinforced polypropylene produced by the hot compaction process. This single polymer composite is produced from highly oriented polypropylene tapes which are heated under pressure. By choosing suitable conditions of temperature and pressure, it is possible to melt a thin skin of each tape which, on cooling, recrystallizes, to bind the structure together. The resulting composite is therefore 100% polypropylene and by virtue of molecular continuity between the phases, there is excellent adhesion between the fiber and the matrix. Also, by virtue of melting the skin of each oriented tape, there are none of the wetting problems which can often be an issue for traditional thermoplastic composites. A schematic of the hot compaction process is shown below in Figure 1.

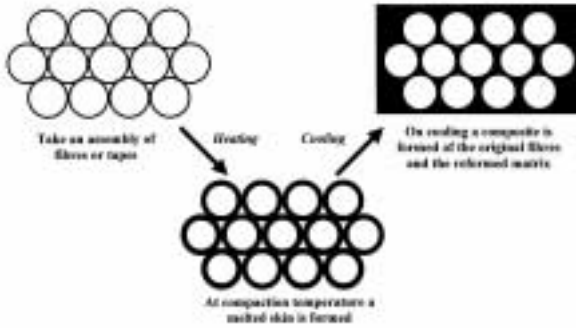


Figure 1: Schematic of the Hot Compaction Process

In practice, the tapes are woven into a fabric before compaction in order to provide a balance of properties. SEM micrographs of compacted woven PP tapes are able to confirm the internal structure as comprising the original tapes surrounded by a layer of melted and reformed matrix. Figure 2 below shows a micrograph taken from a junction between a tape in one orientation (at the top of the photograph) and two tapes of a different orientation (bottom of the photograph). The gap between these tapes is completely filled with melted and recrystallized polypropylene which was formed during the compaction process. Also evident is the original oriented structure within the polypropylene tapes, which has been retained even though substantial melting has occurred. It is believed that the hot compaction process results in a degree of molecular continuity between tapes and matrix which in turn leads to a higher level of stiffness than would be found by using alternative approaches such as bi-component fibers.

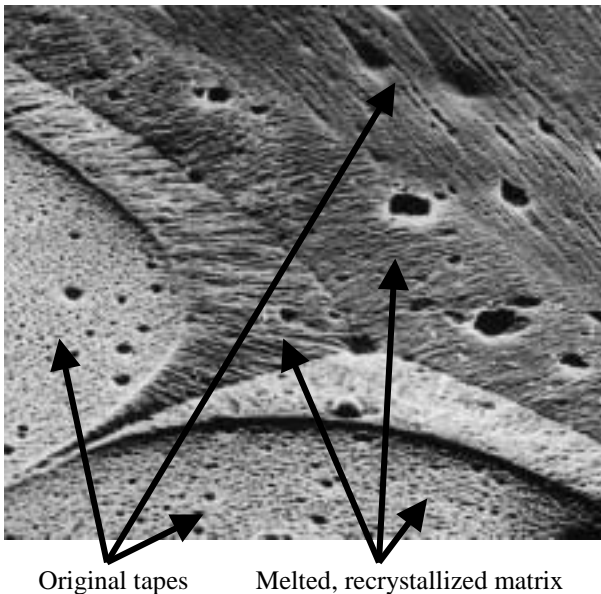


Figure 2: Self-Reinforced PP microstructure

By melting only a small fraction of the original tapes (or fibers), a high proportion of the properties of the tapes are retained in the finished composite. The resulting polypropylene single-polymer-composite possesses stiffness and strength in a similar range to glass reinforced polypropylene but with one major difference – the reinforcing fibers, being polypropylene, exhibit exceptionally high values of strain to failure which, combined with high tensile properties, leads to outstanding damage tolerance. Figure 3 shows a comparison of the stress-strain curves for GMT, self-reinforced polypropylene and regular isotropic polypropylene homopolymer.

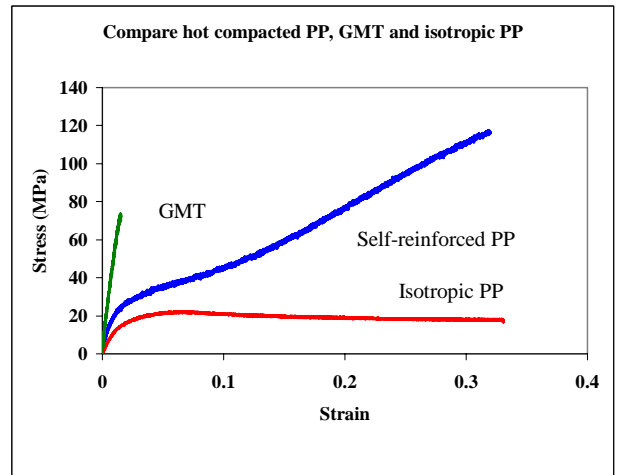


Figure 3: Stress-strain curves of PP materials (20°C)

It can be quite clearly seen that the hot compacted, self-reinforced polypropylene exhibits an initial stiffness equivalent to glass fiber reinforced polypropylene but under increasing stress it yields and continues to strain. More surprisingly, this ability to exhibit very high levels of strain to failure is maintained at very low temperatures. By virtue of the molecular orientation in the tapes, the self-reinforced composite does not show a ductile/brittle transition even at extremes of temperature. Figure 3 shows the same stress-strain behavior measured at minus 40 degrees.

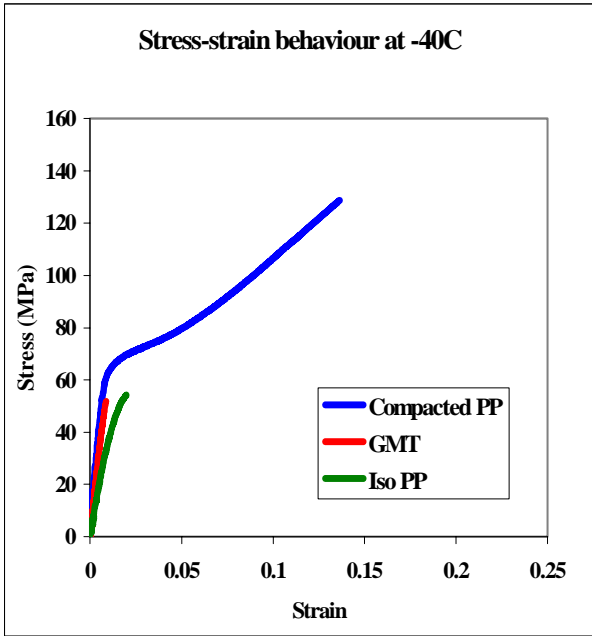


Figure 4: Stress-strain behavior at minus 40°C

Table 1 below shows a comparison of typical mechanical properties of self-reinforced PP sheet, isotropic PP (homopolymer) and 40% w/w glass fibre filled PP (GMT). All the comparative data was taken from the matweb website (www.matweb.com) and are averages of all commercially available materials of that type.

ASTM	Self-R PP	PP homo	GMT 40%
Density (Kg/m <sup>3</sup> )	920	900	1185
Tensile Modulus (GPa)	5.0	1.12	3.5 – 5.8
Tensile strength (MPa)	180	27	99
Izod (J/m)	+20°C	4750	200
	- 40°C	7500	brittle

Table 1: Properties of polypropylene

Perhaps a more important measurement in terms of damage tolerance is the comparison of impact resistance shown in Table 2.

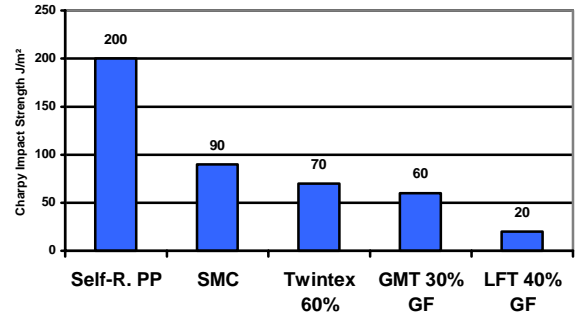


Table 2: Charpy impact resistance of automotive composites

The obvious solution to improving damage tolerance might be to make parts entirely from self-reinforced polypropylene. In fact for certain applications, such as underbody shields, this is the route being taken by a number of OEM's. Figure 4 shows an example of an underbody shield produced by DaimlerChrysler in Europe as part of a long term evaluation of self-reinforced composites. This part is produced from self-reinforced polypropylene sheet molded using matched aluminum tools at a pressure of around 450 psi. A key part of the evaluation in this application has been to assess not only the impact resistance of the material but also its resistance to abrasion caused by small stones and particles of sand. Table 3 shows the results obtained by DaimlerChrysler from laboratory tests using a "gravelometer" – a type of sandblaster designed to simulate extensive road use.



Figure 5: Self-reinforced PP underbody shield (center)

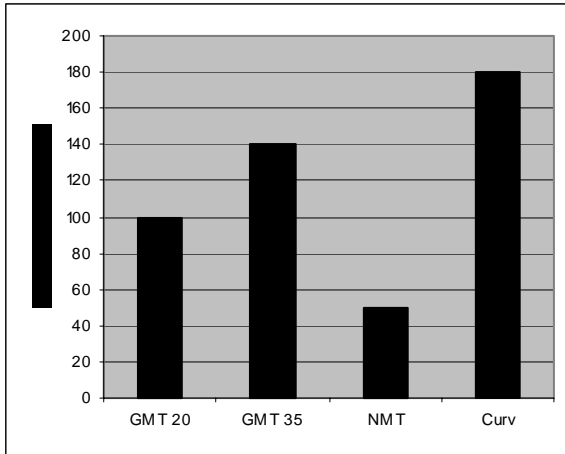


Table 3:

Comparison of resistance to penetration by gravel.

GMT 20 – 20% glass w/w,

GMT 35 – 35% glass w/w plus PET fabric,

NMT – natural fiber reinforced PP,

Curv™ – self-reinforced PP

## LOCALIZED REINFORCEMENT

One limitation of self-reinforced polypropylene is that it must be produced in sheet form and therefore cannot be made to readily flow in molding processes. As a result, parts requiring variable wall thickness and functionality are difficult if not impossible to produce. Furthermore, the outstanding mechanical properties of the hot compacted sheet come at the price of increased manufacturing costs compared to lower performing glass/PP compounds. However, recent developments have shown it is possible to over-mold self-reinforced polypropylene with glass fiber reinforced PP.

Two examples of the resulting hybrid parts with localized reinforcement are discussed here. Figure 6 shows a battery box under development for a European OEM. The box is compression molded from long glass fiber reinforced PP and is designed to be located in the vehicle's trunk floor. The clever use of heavy ribbing provides good mechanical stiffness with minimum weight, and features such as mounting brackets and electrical connections are included during molding. Despite this careful design, the battery box was found to suffer catastrophic damage during crash testing, breaking into several pieces and allowing the battery to fall from its housing. This in turn resulted in an immediate severing of the vehicle's electrical power supply with the loss of all systems. The simple solution was to insert a strip of pre-heated self-reinforced polypropylene into the tool just prior to molding the LFT. Excellent bonding to the LFT is

achieved without causing damage to the highly oriented PP fibers in the self-reinforced material. In this way reinforcement is achieved at the point where it is needed, with no increase in weight, at minimum cost and without compromising recyclability. Crash testing of the reinforced box shows that the reinforced section remains intact despite sustaining severe damage, and the battery is held in place.



Figure 6: LFT battery box with self-reinforced PP reinforcement strip

Figure 7 shows a spare wheel carrier which was compression molded from PP with 10% by weight of short glass fibers. Again, the material choice was dictated by price/performance but in testing it was found that the area highlighted in the photograph suffered undue wear and abrasion from small stones picked up by the left hand rear wheel. The integrity of the part is vital in preventing long term corrosion because the vehicle uses complete underbody shielding with no additional protection to the body in white. The solution, borne out by extensive road testing, was to locally reinforce the part with a 40 mil sheet of self-reinforced polypropylene. The sheet is preheated to around 160°C before being placed in the tool just prior to the injection of the PP/glass. Once again, excellent adhesion is achieved between the two types of polypropylene. In this way, for an additional part cost of around 25 cents, the performance of the part was increased in line with requirements. No alteration to tooling or production method was needed.



*Figure 7: Underbody shield with self-reinforced PP impact and abrasion patch*

## **SUMMARY**

The often conflicting demands for reduced cost, improved safety, weight reduction and parts integration will continue to drive the development of low cost thermoplastic composites in automotive applications. In most cases the performance of the materials is adequate but in safety critical or high demand areas the use of additional reinforcement is often required. Self-reinforced polypropylene, with its unique combination of high strain to failure and high tensile properties, coupled to its compatibility with alternative forms of polypropylene, allows designers the opportunity to meet industry demands in a cost effective manner without weight increase or compromise of recyclability.