# A NEW SELF-REINFORCED POLYPROPYLENE COMPOSITE

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## Abstract

A novel 100% polypropylene material has been developed which creates a new class of thermoplastic composites. In a patented process, high-modulus polypropylene tapes are compacted to form a self-reinforced, thermoformable polypropylene sheet. The recently commercialized material exhibits a unique set of properties including: low density, good tensile strength, outstanding impact strength (even at low temperatures), and recyclability. This performance positions the composite between isotropic thermoplastics and highly structured glass reinforced composites.

Work with OEM's and Tier 1 suppliers suggests these composites have significant advantages in a range of interior and exterior applications. The material is under evaluation for a number of upcoming models.

## Background

Polypropylene (PP) has long been highly favored by the automotive industry because of its relative low cost, light-weight and inert nature. However, PP is often reinforced with stiff fibers - normally of glass - to improve its limited mechanical performance. The resulting composites are often difficult to thermoform into component shapes, they can still be relatively heavy, their impact and abrasion resistance are no match for metals (particularly at low temperatures), and glass fibers can be a source of great irritation in the workplace.

Research at the University of Leeds in the 1990s led to development of a process which allows the production of 100% thermoplastic, 'self-reinforced' composites. Initial studies at Leeds used unidirectionally-arranged, high-modulus melt-spun polyethylene fibers.

Subsequent work investigated processability of highly-oriented PP tapes to exploit the outstanding mechanical properties and to utilize a lower-cost raw material. Research turned to woven tapes for ease of handling and to produce a sheet with balanced properties.

BP recently commercialized this novel material as Curv™ composites and commissioned the first manufacturing line at an existing site in Gronau, Germany. Extensive pilot-scale work was completed earlier to develop parts for evaluation.

## Hot Compaction Process

This self-reinforced, or single polymer, composite is formed by compacting high-modulus PP tapes or fibers under carefully controlled temperature and pressure. A small portion of the tape or fiber surface is melted during the process and recrystallized upon cooling to bind the structure together. The rest of the tape or fiber maintains its high molecular orientation (*Figure 1*). The sheet is therefore able to retain a high proportion of the original tape or fibers' physical properties.

The resulting compacted sheet is shown schematically in *Figure 2*. The right-hand picture illustrates a cross-section of the structure, in which the melted 'matrix' corresponds to the light-colored areas in Figure 1.

SEM micrographs confirm this internal structure of the self-reinforced composite (*Figure 3*). This micrograph is of a region similar to that of the boxed area in Figure 2. The original oriented structure within the PP tapes has been retained, while the surface of the tapes has been recrystallized upon cooling.

It is believed that the compaction process of homopolymer PP results in a degree of molecular continuity between the oriented portion and the matrix. This, in turn, leads to higher stiffness than would be found using alternative approaches such as bi-component fibers.

## Mechanical Properties

Mechanical properties of a self-reinforced PP composite were compared to performance of other PP-based materials (*Table I and Figure 4*). Several results are particularly noteworthy:

- Low density of the all-PP composite translates to weight savings at the same part thickness relative to glass/ PP composites.
- Desirable stress-strain properties result in good impact strength. The self-reinforced composite possesses a unique combination of high strain-to-failure and high tensile strength. Due to the unique oriented structure, this impact performance is retained at low temperatures (as shown by test results at -40°C).
- High levels of abrasion resistance also have been demonstrated since, unlike glass and natural fibers, the PP reinforcement is always ductile and cannot fracture.

## Downstream Processes

### Part Formation

To be useful for automotive applications, the hot compacted sheet must be able to be formed into parts. Formability of PP self-reinforced sheets was expected to be between that of isotropic PP, for which vacuum forming can be used, and random glass-reinforced PP (GMT), which requires high-pressure compression molding with matched tools.

Extensive trials were conducted to determine suitable pre-heating and forming techniques and process conditions. The self-reinforced composite can be pre-heated by either infrared heaters or a convection oven. The sheet must be heated somewhat carefully to maintain the orientation of the tapes, typically to 165-170°C. Depending upon the complexity and depth of draw in the parts being formed, the sheet may either be clamped or unclamped during pre-heating.

Vacuum forming, compression molding, and thermoforming have been investigated. A single-sided tool with vacuum alone did not provide sufficient forming pressure for ‘good’ definition in the parts. Several GMT lines with matched metal tools have been used successfully; the self-reinforced PP composite can be pre-heated to lower temperatures and requires lower processing pressures than GMT materials. Cycle times comparable to GMT are achievable.

From a tooling and handling standpoint, the all-PP composite also offers advantages over glass-reinforced materials. Tool life is improved because the all-PP composite is non-abrasive, and the processor does not encounter the handling issues associated with glass fibers. A shear edge is not required since the composite remains as a sheet throughout the forming process. The tool may be either used cold or heated, depending upon the specific part design.

Because of the lower pressures required to process the self-reinforced composite, thermoforming is a very attractive processing alternative. Capital costs and lead times can be reduced through use of aluminum matched tooling and smaller presses.

### Lamination

The self-reinforced composite may be used in conjunction with honeycombs and foams to produce laminated structures offering energy management properties. Components can be selected to achieve the desired mechanical properties. For example, specific applications may benefit from high stiffness without ribbing and/or controlled deformation upon impact.

## Applications

### Exterior Automotive

The self-reinforced PP composite’s high resistance to impact and abrasion – even at low temperatures – makes the material ideal for select exterior automotive components. Long-term evaluations by a major German OEM have shown that self-reinforced PP has significant advantages in an underbody shield application, particularly in terms of improved mechanical properties, reduced weight and enhanced recyclability.

The parts shown in *Figure 5* were both produced on a Tier 1 supplier’s commercial GMT production line for a standard passenger vehicle. The self-reinforced sheet processed very well in a repeatable and reliable manner. The shear edges of the tool presented some initial difficulty, but careful placement of the sheet allowed good quality parts to be produced at cycle times in line with those seen with GMT.

Key results from mechanical testing (*Table II*) demonstrate that the self-reinforced PP undershield is substantially lighter and has much better puncture resistance and impact strength (performing very well even at -40°C) than the GMT part. This development work was completed in Europe, where recyclability of the all-PP part also is a significant advantage.

The self-reinforced PP sheet’s energy management properties are beneficial in other exterior applications such as skid plates and bumper beam components. In conjunction with foam or honeycomb, it can also be considered for uses such as tonneau covers.

### Interior Automotive

Demanding cost restrictions for automotive interiors represent a challenge for material suppliers.

Traditional materials such as plywood and fiberboard are being threatened by thermoplastic alternatives to reduce weight and improve parts integration.

Load floors represent a major opportunity for a self-reinforced PP composite with either foam or honeycomb. A lightweight load floor laminate was placed into a concept car by a leading European Tier 1 supplier (*Figure 6*). Preliminary work indicates that required deflection levels can be achieved with the proper choice of composite construction.

Outstanding energy management properties of self-reinforced PP composites also have application in automotive interiors – for uses such as knee bolsters and pillar covers. As safety requirements continue to evolve, these applications are expected to grow significantly.

**Beyond Automotive**

Other industries are utilizing the self-reinforced PP composite properties for sporting goods, personal protective equipment, luggage, packaging, and several cold-temperature applications.

## Conclusions

Self-reinforced PP composites bridge the gap between isotropic polymers and glass-reinforced materials by providing a unique set of properties. These materials are best suited for applications in which several characteristics of the process and performance are valued.

Processing advantages include:

- Thermoformable, enabling relatively low-cost tooling with low pressure and moderate temperature processing
- Ease of handling and low wear on tools, because of the all-PP construction
- Inertness, since PP is non-toxic and resistant to corrosion
- Recyclability, where available for all-PP structures.

Performance benefits include:

- Weight savings, resulting from PP's low density
- High impact strength, even at low temperatures, due to the unique internal construction
- Resistance to abrasion, since the structure is "tough".

## Acknowledgments

The authors gratefully acknowledge the assistance of BP employees Bernd Elfering, Heinz Homoelle, Josef Uesbeck, and Eckhard Wanscheer for their extensive product and process development and testing work related to Curv™ composites.

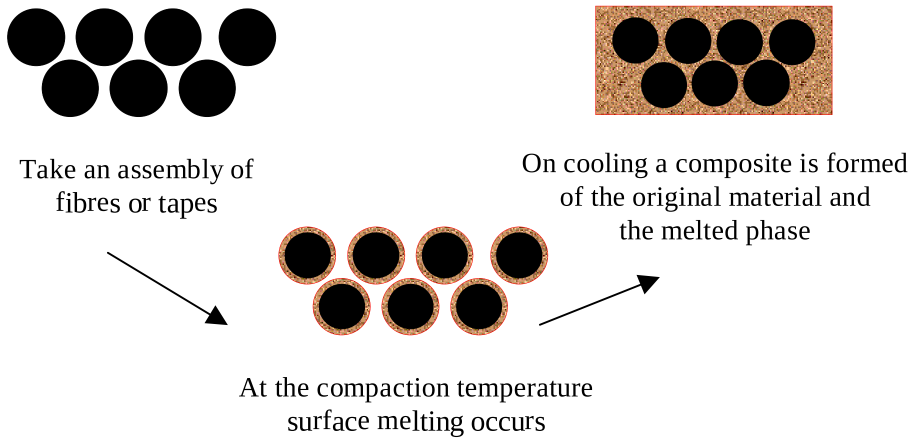


**Figure 1. Schematic of hot compaction process**

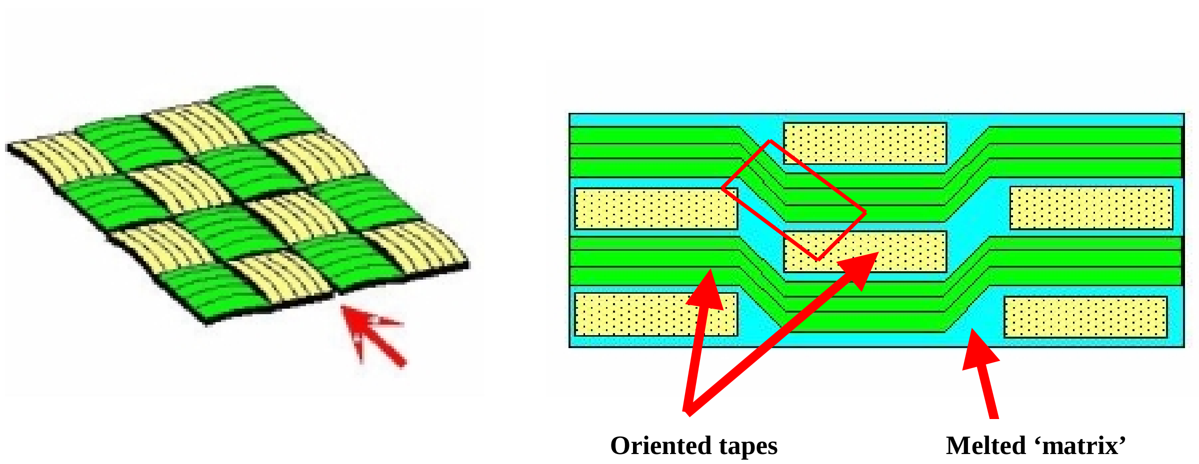


**Figure 2. Schematic of self-reinforced composite structure**

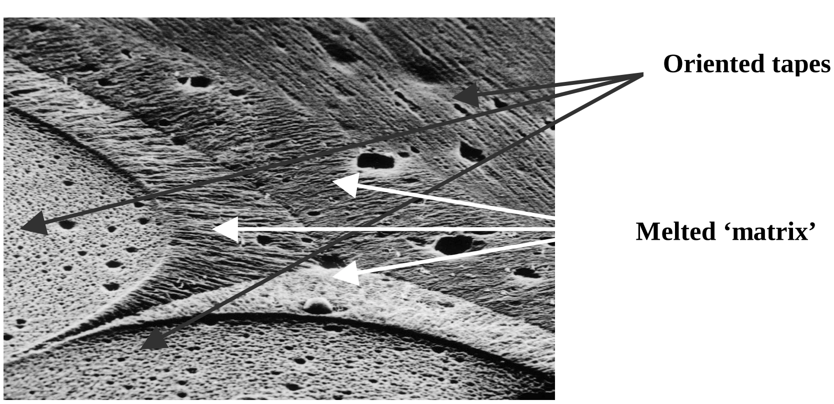


**Figure 3. Micrograph of self-reinforced PP composite**

**Table I: Mechanical Properties, PP-based Materials***

| | | Self-reinforced PP sheet | Isotropic PP | Random mat short glass/PP 40wt% fiber | Unidirectional glass/PP 60 wt% fiber |
|---|---|---|---|---|---|
| Density (Kg/m$^2$) | | 920 | 900 | 1185 | 1500 |
| Tensile Modulus (GPa) | | 5 | 1.12 | 3.5-5.8 | 12 |
| Tensile Strength (MPa) | | 180 | 27 | 99 | 350 |
| Heat deflection temperature (°C) | 455 kPa | 160 | 100 | 157 | |
| | 1820 kPa | 102 | 68 | 152 | 156 |
| Notched Izod impact strength (J/m) | + 20°C | 4750 | 200 | 672 | 1600 |
| | – 40°C | 7500 | brittle | brittle | |
| Thermal expansion (/°C x $10^{-6}$) | | 41 | 96 | 27 | 21 |

** Comparative data: www.matweb.com; averages of all commercially available materials of that type.*

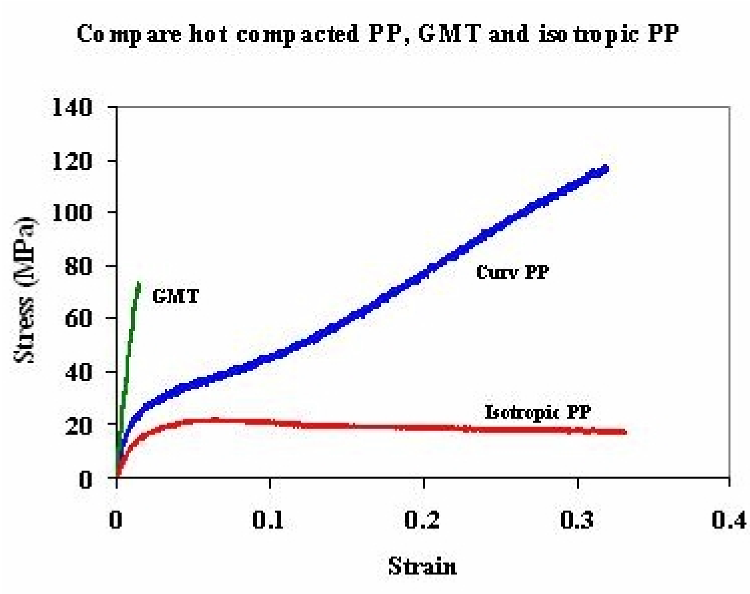


**Figure 4. Stress-strain properties, PP-based materials**

**Figure 5. Self-reinforced PP (left) and GMT (right) undershields**

**Table II: Self-reinforced PP and GMT Undershield Results**

| | | Self-reinforced PP | GMT |
|---|---|---|---|
| Part Weight (g) | | 900 | 1200 |
| Puncture Impact Energy at 20°C (J) | | 14.5 | 9.6 |
| Notched Izod impact strength (J/m) | + 20°C | 4750 | 750 |
| | – 40°C | 7500 | Brittle |
| Abrasion Resistance (time to create 10mm hole on 2mm thick test samples) | | > 3 hours | 1 hr, 40 min |

**Figure 6a.** Self-reinforced PP/ honeycomb laminate load floor with carpets folded back to reveal an easy-clean surface

**Figure 6b.** Self-reinforced PP/ honeycomb laminate load floor – total weight including carpets approximately 2.5 kg