Thermoformable Composite Panels

From automotive to aerospace, thermoformed composites are growing exponentially, offering short cycle times, tailored properties, recyclability and lower cost.

Thermoformable composite panels are thermoplastic materials—e.g. polypropylene (PP), nylon 6, polyetherimide (PEI), polyphenylenesulphide (PPS)—reinforced with some type of fiber, and then supplied to customers as solid sheets, which are then thermoformed into shaped structures. Although many of these products are also sold as prepregs, the materials covered in this article are preconsolidated panels. There are also stand-alone core materials which can be thermoformed; however, this article will only explore panels, one of which is a unique thermoformable, in-situ foamed sandwich material.

Reinforced Thermoplastic Composites

The use of thermoplastics in composites offers a range of attractive features:

- Short manufacturing cycles (typically 2 minutes or less).
- Increased toughness and impact resistance.
- Post forming possibilities such as corrections and forming in multiple steps (e.g. edge close-outs and then folding).
- Unlimited shelf life, no VOCs and reduced issues with waste and material handling.
- Recyclability, both during manufacturing (recycling scrap) and after service life.

These features are driving huge growth. According to the market research report ***"Opportunities in Continuous Fiber Reinforced Thermoplastic Composites 2003-2008"***, published by E-Composites (Grandville, MI), "the market for continuous fiber reinforced thermoplastic composites has experienced … a global growth rate of 105 percent in the last 5 years. The growth rate in 2002 was 93 percent." The report continues, "Historically, continuous fiber reinforced thermoplastic composites were used in niche applications in the aerospace and defense markets. But in recent years, the market has exploded in automotive, sporting goods, transportation, industrial and other applications. … even finding their way into furniture, fastener, medical, marine and other applications."

Reinforced thermoplastic composites continue to develop from two different ends of the property and cost spectrum. The low-property, low-cost end started with engineering plastics being modified with various fillers for automotive applications. As automotive manufacturers have sought to reduce vehicle weight, improve safety, reduce noise, add electronics, and streamline manufacturing via modular assemblies, they have fueled the development of increasingly stronger, stiffer and lightweight thermoplastics that offer tailoring of properties, better impact and acoustic performance, complex shaping capability and flexibility in manufacturing. This development has seen a trend toward reinforcement with increasingly longer glass fibers, as well as new products with natural fibers and self-reinforced polypropylene (PP). It has also pushed automotive thermoformers away from the traditional low-price, low-performance polymers such as Acrylonitrile-Butadiene-Styrene (ABS), polyvinyl chloride (PVC) and high density polyethylene (HDPE), and moved them toward higher performance materials including nylon 6, polyethersulfone (PES), polyetherimide (PEI) and polyphenylene sulfide (PPS). Now these materials are moving into other applications,

[INSERT LOW-TO-HIGH SCALE OF REINFORCED THERMOPLASTICS DIAGRAM]

such as rail, bus and marine interiors, sporting goods, consumer products and ballistic armor. The high-property, high-cost end of reinforced thermoplastic composites started with transferring from thermoset prepregs to thermoplastic prepregs in niche aerospace applications. The resulting uni-tape and semi-preg materials use traditional aerospace-type glass, aramid and carbon fiber fabric reinforcements combined with polyethersulphone (PES) and polyetherimide (PEI) at first, and have now moved toward higher performing thermoplastics such as polyphenylene sulphide (PPS) and polyetherketoneketone (PEKK). The development trend here is to improve manufacturability while reducing both the cost of materials and the overall finished part.

Thermoforming

Thermoforming is one of the oldest plastics forming processes. Baby rattles and teething rings were thermoformed in the 1890s. The process saw major growth in the 1930s with the development of the first roll-fed machines in Europe.

Thermoforming uses heat and pressure to transform a sheet into any shape. The sheet is preheated using one of three methods:

- Conduction via contact heating panels or rods
- Convection using ovens
- Radiant heating achieved with infrared heaters.

The preheated sheet is then transferred to a temperature-controlled mold and held against the surface until cooled. The final part is trimmed from the sheet, and the trim is typically reground, remixed with virgin material and reprocessed into moldable sheet.

There are numerous variations of thermoforming, which arise from how the thermoplastic sheet is pressed against the mold surface or shaped. These range from simple sheet bending using a folding machine or simple jig, to more complex processes such as vacuum forming and pressure forming, which use negative pressure (vacuum) and/or positive pressure (compressed air) in conjunction with compression molding machines or presses. When higher pressures and more traditional compression molding machines are used, the process may be termed as matched metal die stamping or rubber block stamping, depending on what type of upper mold surface is employed. Diaphragm forming / diaphragm molding is good for simple geometries, is typically a lower pressure process and employs air pressure to form the sheet through a flexible diaphragm. Twin-sheet forming uses two preheated sheets, positioned between two female molds with matching perimeters or contact surfaces. The twin sheets are drawn into the molds and formed using a combination of vacuum and air pressure to produce hollow, shaped parts.

Thermoforming pressures can range from low-pressure materials requiring only 10 to 50 psi (0.7 to 3.5 bar)(.07 to .35 MPa) to products approaching more traditional glass mat thermoplastic (GMT) pressures of 2000 to 3000 psi (138 to 207 bar) (1.38 to 2.07 MPa). For low-pressure materials, tooling does not have to be steel, but can be aluminum or epoxy for production, and even wood or plaster for prototyping. This offers significant benefits in costs and lead-times. Forming temperatures depend on the specific thermoplastic being used, but typically range from 300°F to 400°F (149° C to 205°C).

Fiberglass Reinforced Thermoplastic Panels for Headliners

One of the main applications for fiberglass reinforced thermoplastics is automotive headliners. Three different fiberglass-reinforced polypropylene (PP) materials have been recently developed to meet new demands in this application, all having a glass content of 55 percent by weight for their standard product:

Product	Manufacturer	Description	Process
AcoustiMax®	Owens-Corning, OC™ Automotive (Toledo, OH)	PP combined with a multidirectional glass fiber (length greater than 1 inch) mat, augmented by additional fiber reinforcement	Proprietary OC product has three layers including bottom scrim and top adhesive; fabric bonded to adhesive by customers
SuperLite®	Azdel, Inc. (Shelby, NC)	Composite of long, chopped glass fibers and PP powder combined with outer layers as needed	Wet process adapted from paper making with nip roll for consolidating and laminating top scrim and bottom adhesive film
SymaLITE	Quandrant Plastic Composites (Lenzburg, Switzerland)	Commingled long (78 mm) glass fiber and PP fleece	Dry, textile process to create fleece, which is then needlepunched to tailor properties

All three products offer an improvement over traditional polyurethane (PU) GMT products for headliners, including:

- Reduction from eight layers to four, eliminating multiple production steps and reducing overall part cost.
- Enables varying thickness across the part molded in a single cycle.
- Higher strength and stiffness with lower weight and/or increased noise reduction.

<u>AcoustiMax®</u>

AcoustiMax® was developed by Owens Corning Automotive (Toledo, OH), a glass fiber and process technology-based addition to their acoustics-driven product line. AcoustiMax® is a competitive product to Azdel SuperLite® and Quadrant Plastics Composites SymaLITE. According to Tom Ketcham, product line manager for AcoustiMax®, the superior noise reduction of AcoustiMax® comes from its greater lofting ability. A 1000 g/m^2 (GSM) sheet of AcoustiMax® starts out at a thickness of 4 to 5 mm, increases to 12 to 14 mm due to lofting during preheating, and then is molded to a final thickness of 6 to 7 mm, depending upon the geometry and compaction of the mold.

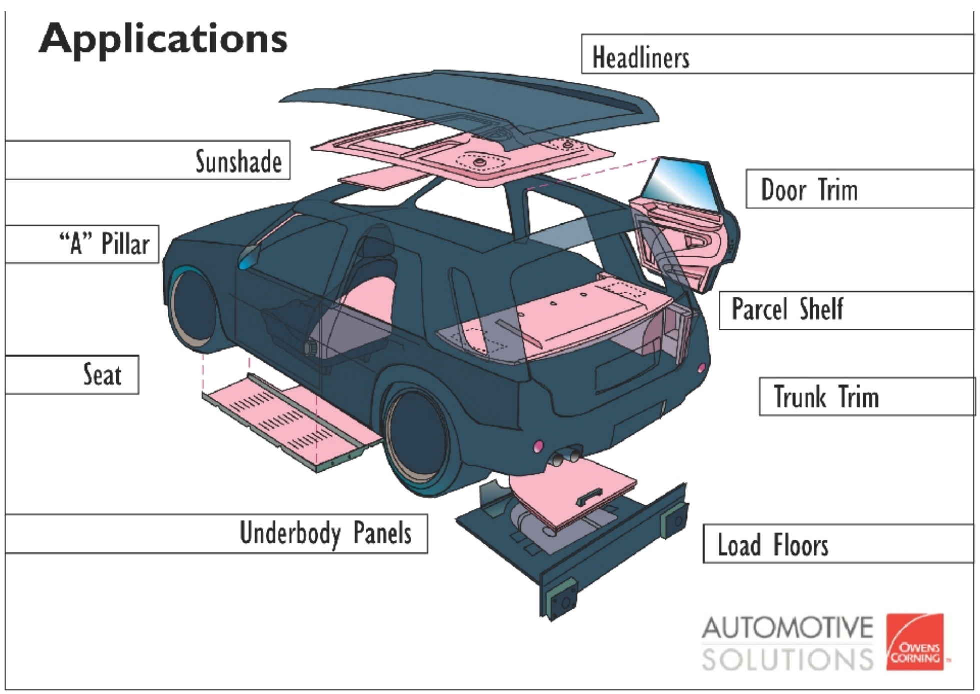
Product	GSM	Sheet Thickness (mm)	Lofted Thickness (mm)	Molded Thickness (mm)
AcoustiMax®	800	4	10 - 12	5 - 6
	1000	5	12 - 14	6 - 7
SuperLite®	800	2.7 - 3.0	4.7 - 5.2	1.5 - 4.0
	1000	3.5 - 4.0	6.0 - 6.5	2.0 - 5.0

Headliners are becoming increasingly complex, with variations in part geometry and thickness across width and length. At the edges, headliners are quite thin, with a thickness as low as 1 mm for better attachment and load transfer ability. At the center, they are designed to be thicker, offering increased head impact protection and maximum noise reduction for the auto interior.

Automotive headliner made using AcoustiMax® with cut-outs to accommodate equipment such as DVD monitors and sun roof.

Side view of a molded headliner using AcoustiMax® fiber-reinforced thermoplastic, showing typical thickness.

AcoustiMax® is supplied in a range of GSM weights, with a scrim on one side and an adhesive film on the other for bonding fabrics as specified by the customer. It is slit to widths and cut to lengths also according to customer specifications, and the sheets are then shipped on pallets. Although there are no commercial applications of this product in-service today, there are several Tier 1 automotive suppliers that have completed prototyping and are in the final stages of selecting the material for use in specific vehicles. In addition to headliners, AcoustiMax® is being developed for automotive interior uses such as trunk liners, door modules, seat backs and package trays.



SuperLite®

SuperLite® is manufactured by Azdel Inc. (Shelby, NC), a 50/50 joint venture between GE Advanced Materials and PPG Industries. SuperLite® product data sheets list forming temperatures of 375°F to 400°F—slightly lower than those for AcoustiMax®—and forming pressures of 30 to 45 psi (2 to 3 bar), which are almost half of the 70 psi (4.8 bar) required by AcoustiMax®. In fact, the SuperLite® Processing Sheet states that the typical forming pressure for the material is around 10 psi (0.3 bar). Gordon King, commercial director for Azdel Europe, has claimed that this low pressure formability as well as the material's light weight enables it to reduce system costs by up to 20 percent. As can be seen in the table below, when comparing published property data, SuperLite® offers higher strength and modulus than AcoustiMax® for sheets of the same areal weight and thickness.

Property	AcoustiMax®	SuperLite®	SuperLite®	SymaLITE	SymaLITE
Areal Weight (g/m2)	1000	1000	800	1000	800*
Thickness (mm)	2	2	1	1*	1
Tensile Strength (MPa)	15	34	52	48	62
Tensile Modulus (MPa)	2026	3800	5600	3750	4600
Flexural Strength (MPa)	20	25	7	not available	not available
Flexural Modulus (MPa)	1595	1900	2750	not available	not available

* Note that it is not possible to compare SymaLITE directly because its 1000 GSM product has a thickness of only 1 mm versus 2 mm for AcoustiMax® and SuperLite®. Also, its 800 GSM product has a glass content of 40 percent by weight vs. 55 percent by weight for AcoustiMax® and SuperLite®.

SuperLite® is currently being used in numerous applications, including in headliners for sixteen different production vehicles, in sunshades for five different vehicles, in the rear parcel shelf for the Honda Accord and Toyota Camry and in the back-panel for the Dodge Ram. It is also used in eleven different interior applications on the Ford GT limited production sports car.

Current SuperLite® Production Applications as of January 1, 2004	
Headliners • Acura MDX • Acura TL • Dodge Dakota • Dodge Viper • Ford Falcon (Australia) • Ford High Series PU (Australia) • Holden Commodore (Australia) • Honda Accord • Honda Accord (China) • Honda Civic • Isuzu Axiom • Mazda 6 • Nissan Frontier • Nissan Pathfinder • Toyota Camry (Australia)	**Sunshades** • Lincoln LS • Nissan Maxima • Mitsubishi Galant • Toyota Camry • Toyota Sienna **Other Parts** • Dodge Ram Back-panel • Honda Accord Rear Parcel Shelf • Toyota Camry Rear Parcel Shelf (Australia)

SymaLITE

SymaLITE is produced by Quadrant Plastics Composites (Lenzburg, Switzerland). Although its standard headliner product does have a glass content of 55 percent by weight, its normal products for underbody shields, door inner panels and sandwich top layers use a glass content of 40 percent by weight. SymaLITE can be made with a glass content from 20 to 60 percent, with higher glass content producing increased lofting and lower density, which translates into higher stiffness-to-weight ratio parts. Like AcoustiMax®, SymaLITE boasts reinforcement in the z-direction. SymaLITE is boasting that the laminate lofts from 5 to 6 times its original thickness, where AcoustiMax® claims lofting to more than twice its original thickness, and SuperLite® data shows lofting of less than 200 percent. Although a direct property comparison is not possible, due to differences in sheet thickness and glass content for the same GSM, SymaLITE's properties seem roughly in-line with those of AcoustiMax® and SuperLite® (see table on previous page).

Quadrant Plastic Composites (QPC) claims that SymaLITE can be processed at 50 psi (3.5 bar). Its first commercial application was the underbody shield for the BMW 5/6 series, where it replaced traditional GMT and resulted in a 30 percent or 8.8 pound weight savings. The shield is made from four different components, all molded in less than 60 seconds using a family mold with cavities for all four parts. The center areas of the parts are 4 mm thick, optimizing stiffness and noise reduction, while the perimeters are 1 mm think for attachment and seal strength. Harri Dittmar, market manager for development composites at QPC, describes how this is achieved, "To get a thicker section, you construct the tool in such a way that it doesn't compact the material as much in the chosen areas." Thus, areas requiring high tensile strength are pressed thinner, and areas requiring high stiffness are not pressed as much.

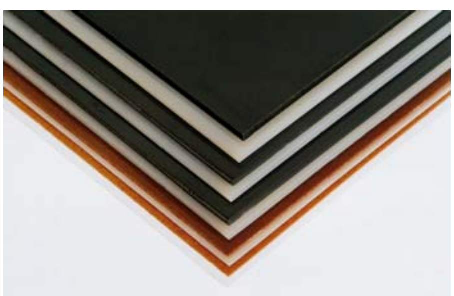
Standard Product Specifications				
Product	**Areal Weight (g/m2)**	**Thickness (mm)**	**Width (mm)**	**Fiber Content wt-%**
AcoustiMax®	800 – 2000	**4 – 7**	**custom less than 82"**	**55**
SuperLite®	**600, 700, 800, 900, 1000, 1200, 1400, 1600, 1800, 2000**	**2 – 9**	**1260 mm (50") 1400 mm (55") 1450 mm (57") 1600 mm (63") 1800 mm (71") 2000 mm (79") Uncut sheet size is 55" by 72"**	**55**
SymaLITE	800, 1000, 1200, 1400, 1800, 2000	**n/a**	**22" 30" 45" 90" custom**	**40, 55 20-60 custom**

SymaLITE is also being used in a load floor/trunk separator for the 2005 Crossfire by DaimlerChrysler. This one-piece structure is made using a 2000 GSM sheet for the trunk separator and an 1800 GSM sheet for the load floor. Density is varied across the part to provide more stiffness in the center. This large, complex part is produced using two tools with a cycle time of 90 seconds and includes in-mold decoration via pressure-sensitive carpet on one side and polyester scrim on the other. QPC says that SymaLITE is under evaluation for other automotive load floors as well as interior trim components, like door panels. It is also under development in roof modules, hoods and trunk lids, where the composite would be used behind a Class A surface material such as coil-coated aluminum or polypropylene film. Dittmar believes that within five years, SymaLite panels weighing 3 kg/m^2 will replace steel roofs in production today weighing 7 to 9 kg/m^2. SymaLITE is also being targeted for recreational, agricultural and construction vehicles as well as sporting goods and building panels.

Other Fiberglass Reinforced Thermoplastics

PennFibre (Bensalem, PA) produces a variety of thermoformable composite sheet materials including Pennite® 4512, Celcon®, Fortron® PPS, Ryton PPS and Celanex®. All of these materials are reinforced with short glass fibers and are new, having been introduced over the last 12 to 18 months. Although standard sizes do exist, most of these products are delivered to customer specifications in terms of thickness, width and length in order to provide optimum-sized blanks for thermoforming.

Property	Pennite® 4512	Pennite® 4515	Fortron® 1130LO	Fortron® 1140L0	Celcon® CKX-5522	Zytel® FS
Density (g/cm3)	1.22	1.16	1.58	1.65	1.51	1.18
Polymer	Nylon 6	Nylon 6	PPS	PPS	Acetal Copolymer	Nylon
Glass Content (wt-%)	12	12	30	40	15	15
Tensile Strength (MPa)	110	85	160	185	102	107
Tensile Modulus (MPa)	n/a	n/a	11,000	n/a	5900	5100
Flexural Strength (MPa)	165	105	255	280	140	n/a
Flexural Modulus (MPa)	4650	3125	10,400	14,000	5700	n/a
Melting Point (°F)	428	428	590-640	590-640	340	428
Drying	24 hrs @ 212°F	24 hrs @ 212°F	3-4 hrs @ 275°F	3-4 hrs @ 275°F	3 hrs @ 180°F	n/a



PennFibre produces a variety of thermoformable composite sheet materials reinforced with short glass fibers including Pennite® 4512, Celcon®, Fortron® PPS, Ryton PPS and Celanex®.

Pennite®, Fortron® PPS and Cecon® Sheets

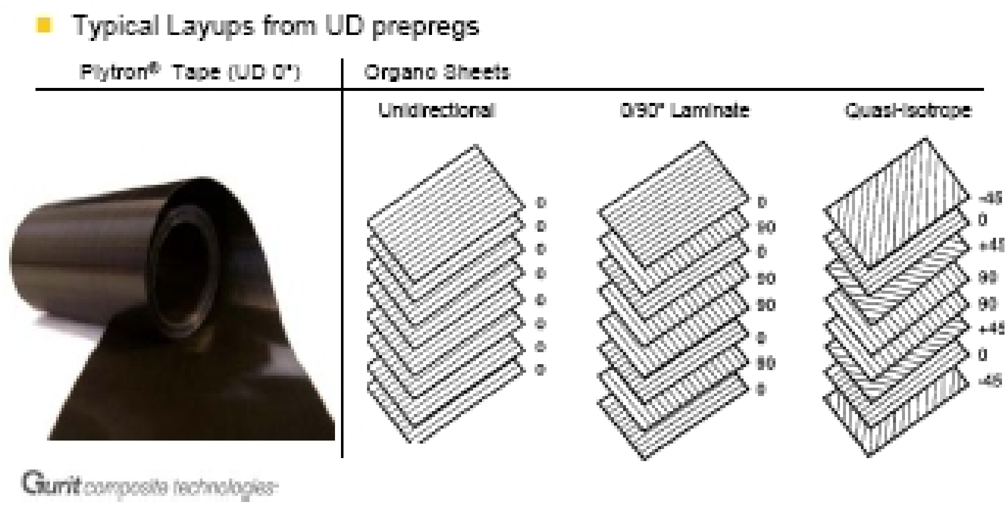
Pennite® 4512 was developed for under the hood automotive applications such as air dams, ducts and radiator shrouds. Parts made from Pennite® 4512 can withstand 280°F (138°C) continuous in-service temperature. Fortron® PPS products were developed for aircraft and automotive applications, as well as baking trays due to the characteristics of PPS, including high temperature resistance, non-flammability, excellent resistance to chemicals and high strength. Celcon® was developed for gasoline tanks and under the hood applications where the structural integrity and chemical resistance of acetal copolymer meets end-use requirements.

Pennite® 4512 was developed for under the hood automotive parts like this radiator shroud; it can withstand 280°F (138°C) continuous in-service temperature.

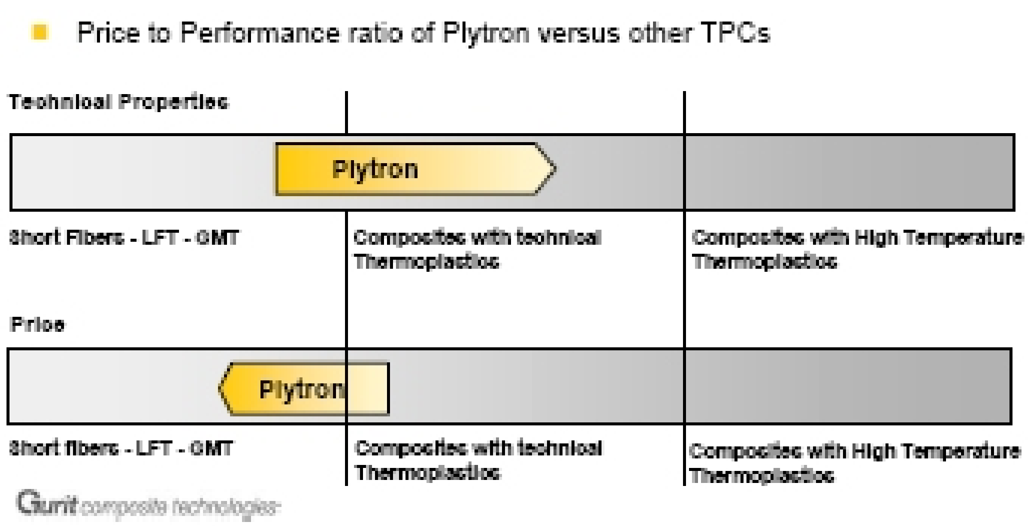
Polyamide thermoplastics like nylon are hygroscopic, making them susceptible to moisture absorption. Pre-drying is required for successful thermoforming of these materials, using a desiccant or recirculating type of oven. Failure to do so results in moisture being released during forming, which produces surface blisters on the finished part. Fortron® PPS sheets are preheated to between 610°F and 625°F (321°C and 329°C), typically using infrared ovens. PPS sheets can be formed using aluminum tools without a cooling system. The molds are preheated to 390°F (199°C)and total cycle time from preheating sheet to forming and final cooling is between 60 and 90 seconds. Pennite® 4512 and Celcon® are both used in current production vehicles, however Tier 1 suppliers are protective of details, and thus, PennFibre is not able to discuss specifics.

Plytron®

Plytron® is a polypropylene (PP) composite manufactured by Gurit Suprem (Flurlingen, Switzerland), which is reinforced with continuous unidirectional fiberglass. Plytron® is predominantly supplied as a unidirectional prepreg, but is also sold as sheets with custom tailored layup and fiber orientation. Typical layups are 0°/90° and quasi-isotropic, but numerous stacking sequences are possible. Plytron® sheets are consolidated and have a fiber content of 60 percent by weight. When comparing its properties to the other fiberglass reinforced thermoplastics reviewed in this article, Plytron® shows the highest specific properties—i.e. mechanical properties normalized for density. This is not surprising when considering that the sheet in the table above is made from 8 plies of 0° and 90° unidirectional fiberglass composite. However, Gurit Suprem describes the product as offering higher, more technical properties at lower cost.



Plytron® is supplied as a unidirectional prepreg, but also as solid sheets with tailored layup and fiber orientation.



Gurit Suprem describes Plytron® as offering higher properties at lower cost.

Gurit Suprem markets Plytron® as competitive to commingled yarn products such as TWINTEX®. Christophe Bourban, key account manager for Gurit Suprem, explains that Plytron® offers shorter cycle times, customized solutions via fiber orientation and layup, superior surface quality to GMT and LFT, as well as higher thermal and mechanical properties. He states that the one limitation may be with regard to part geometry, "if the part contains two-dimensional or sharp curvatures, then slits in the material may be needed locally to ensure proper drapability. However, parts have been produced with surprisingly good drapability at the cost of slightly longer cycle times." Typical thermoforming equipment can be used to produce parts at 185°C (365°F) and a pressure of 4Mpa (40 bar). Cycle times range from 45 seconds for forming only to 2 minutes for heat up, forming, cool down and demolding in a double forming machine.

Plytron® unidirectional plates are thermoformed and stamped to make springs for Bico beds.

Springs for Bico beds are made using Plytron® unidirectional plates which are thermoformed and stamped. More than five million parts have been produced to-date, with benefits including lightweight, a virtually endless service life, and a competitive price. Plytron® has also demonstrated its ability to offer Class A surface finish without additional and expensive surface treatment. BI Composites (Bridgtown, Cannock, UK) and MG Rover (UK) developed an automotive car bonnet (hood) using a sandwich construction with a core of PP nonwoven mat and Plytron® skins. Christophe Bourban describes this application: "Advantages are the modest tooling costs which allows for a competitive pricing for small series of sport version cars. The use of PP near the heat radiated by the engine proved to be no problem, even for long-term service. This is possible due to the continuous glass fiber reinforcement. Unfortunately, MG Rover went bankrupt in 2005 so the bonnet did not become a commercial product." Bourban states there are several customers developing commercial applications with Plytron®, but details are not available due to non-disclosure agreements. However, the production of Plytron® increased by a factor of 5 from 2004 to 2005 and further increases are planned for 2006. Plytron® is targeted for automotive components such as floor panels, bumper beams and hoods. It is also aimed at housing appliances, pipe reinforcement and as local reinforcement in combination with GMT/LFT for high volume applications. The product is currently available at a maximum width of 600 mm with an individual ply thickness of 0.27 mm. The sheet product can be supplied from 1000 mm lengths to 440-meter rolls packaged on palettes. Future developments include carbon fiber reinforcement and wider range of thermoplastics including polyamide nylon 6 (PA6), thermoplastic polyurethane (TPU), polyphenylene sulfide (PPS) and blends.

TWINTEX®

TWINTEX® P PP is a consolidated plate made from TWINTEX® commingled polypropylene and continuous fiberglass fiber. TWINTEX® commingled fiber was introduced in 1997 and is made by Saint-Gobain Vetrotex (Chambéry, France). The glass content is 60% by weight, and fiber reinforcement is either a balanced twill or plain weave (4/1) fabric. Products include areal weights of 745, 935, 1485, 1870 and 2970 g/m^2. Advantages of TWINTEX® are said to include:

- Excellent mechanical properties due to high glass content and continuous fibers.
- Excellent energy absorption due to continuous glass fibers and ductile PP matrix.
- Better dimensional stability and behavior in a wet environment than standard thermosets and other thermoplastics due to the hydrophobic nature of PP matrix.
  (**Note** that data sheets state "TWINTEX® P PP must be stored in its original packaging, away from humidity and at a moderate temperature.")
- Fast consolidation.
- Good drapability.
- Recyclable.

After preheating above the melting point of PP (180°C to 230°C/360°F to 450°F), TWINTEX® is thermoformed at various pressures, depending upon the exact forming process used:

- Diaphragm—1 to 8 bars (15 to 116 psi).
- Thermo compression—25 to 200 bars (363 to 2900 psi).
- Sandwich thermo compression—1 to 5 bars (15 to 73 psi).
- Co-molding with GMT or LFT as local reinforcement—25 to 200 bars.

Like Plytron®, TWINTEX® is marketed as an excellent local reinforcement for GMT and LFT compounds. As an example, consider ribs. Placing TWINTEX®, a non-flowing material, in specific local areas in combination with GMT or LFT, which are flowable materials, enables the two systems to work together. The end-result is a part with integrated ribs which have the necessary high section modulus, all in one-step molding. Another promising technology is forming sandwich structures using TWINTEX® skins and foam or PP honeycomb core. These cored panels can be formed into shaped parts by low-pressure stamping. Textile coverings or carpets can be easily over-molded during stamping for automotive interiors.

Applications include the trunk floor for the Nissan (UK) Primera Estate. The part was developed by Peguform (Saint Marcel, France) and weighs 4.2 kg. TWINTEX® 935 GSM skins and polypropylene honeycomb core offer the desired stiffness to weight ratio, and carpet is incorporated during the fast cycle time molding process. Peguform produces 100 parts per day using their patented Sandwiform® process. These same materials and process are used by Peguform to produce the floor for the Microcar MC1 at 40 parts per day. Jacob Composites (Wilhemsdorf, Germany) developed and manufactured a back seat structure for the BMW M3 CSL using a sandwich of TWINTEX® skins and polyether sulfone (PES) foam, with polyester carpet over-molded on one side. 1500 parts were produced using a one-step thermoforming process. The 5.0 kg composite part offered more than a 50% weight reduction versus steel, as well as good acoustic insulation, excellent crash performance and low capital investment, due to the low-pressure molding process. General Motors produces a series of under vehicle skid plates for one of their most popular SUVs using TWINTEX® 3000 GSM skins on a PP foam core.

TWINTEX® P PP is sold in standard widths of 104 or 152 cm and as cut-to-size plates or rolls packaged on pallets. TWINTEX® is also now available with a thermoplastic polyester (PET) matrix.

Materials with Glass, Aramid and Carbon Fiber Reinforcement

Cetex® and TEPEX® materials are the "high-property, high-cost" thermoplastic composites referred to at the beginning of this article. They were developed initially for aerospace applications, in an attempt to move away from the labor-intense hand layup of thermoset prepregs to the short cycle time, automated production possible with thermoplastics. Cetex® still seems mainly focused on aerospace applications, while TEPEX® appears to be gaining success in sporting goods and consumer applications.

Cetex®

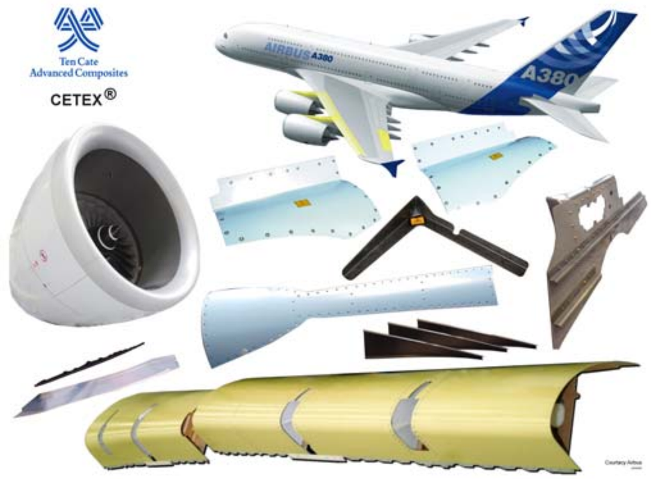
The basic technology for Cetex® fabric reinforced thermoplastic laminates was developed at Delft University in cooperation with Ten Cate (Nijverdal, The Netherlands) in the 1980s. Cetex® continuous fiber reinforced laminates are offered in standard products featuring glass, carbon or aramid unidirectional tapes and fabrics combined with polyetherimide (PEI) or polyphenylene sulphide (PPS) thermoplastic matrix materials. The fiberglass is supplied by PPG in the U.S., while the carbon fiber is sourced from Toray-Soficar in France. PEI is supplied in granulate form by GE Plastics (Pittsfield, MA) and PPS is supplied as film by Amcor (Gent, Belgium) and as granulate by Ticona (Kelsterbach, Germany). Sheets are typically 3.8 m by 1.3 m and range in thickness from 0.2 to 50.0 mm.

Property	PEI	PPS	PEI	PPS
Fiber	glass	glass	carbon	carbon
Fabric	7781-8HS*	7781-8HS*	T300J-3K	T300J-3K
Density (g/cm^3)	1.91	1.93	n/a	n/a
Fiber volume %	n/a	n/a	50	50
Tensile Strength (MPa)	484	324	656	592
Tensile Modulus (MPa)	26,000	23,000	56,000	54,000
Flexural Strength (MPa)	669	489	870	854
Flexural Modulus (MPa)	28,000	24,000	50,000	52,000

* 8-harness satin

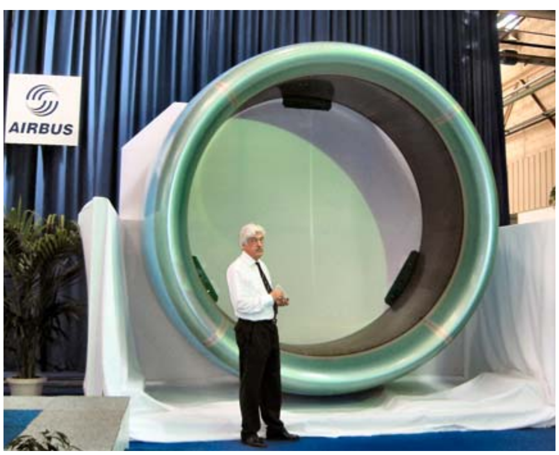
Thermoforming guidelines for carbon fiber/PPS Cetex® sheets recommend preheating at temperatures between 300°C and 330°C (572°F and 626°F)and maintaining tools at approximately 180°C (356°F). Pressures of 4 MPa (580 psi) are recommended for forming.

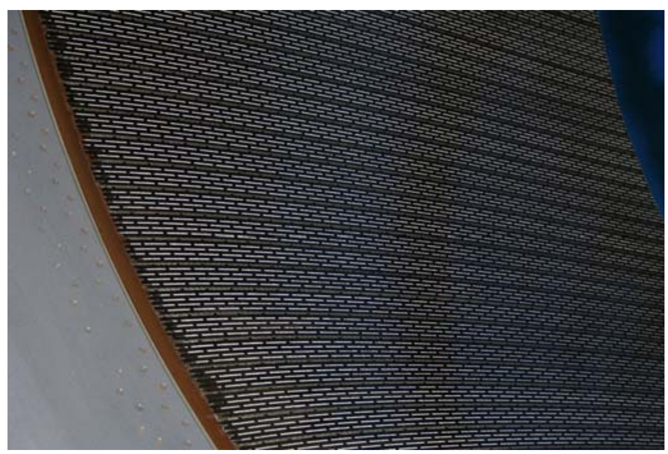
Willem van Dreumel, director of research and development at Ten Cate, explains why thermoformed composites are attractive for aerospace applications, "A limiting factor of thermoset composites is the costly and complex autoclave process. Many smaller components like ribs, brackets and curved panels are very suitable for thermoforming technologies, which offer a typical four minute cycle time at a very low cost compared to autoclaved products." According to van Dreumel, there are roughly 1500 different part numbers in thermoplastic composite on Airbus aircraft. This number will be growing significantly with many thermoplastic composite parts on the new Boeing 787 and the development of the Airbus A350.



Cetex® reinforced thermoplastic composites are used to make numerous structures on the Airbus A380 aircraft.

Ten Cate also supplies the material for the A380 engine air intakes made by Airbus France. Mr. van Dreumel describes this application in more detail, "The air intake is an innovative no-splice design, made possible by the use of thermoplastics, which gives the A380 a very low noise profile". A list of applications for Cetex® PPS and PEI products are shown in the table on the next page.





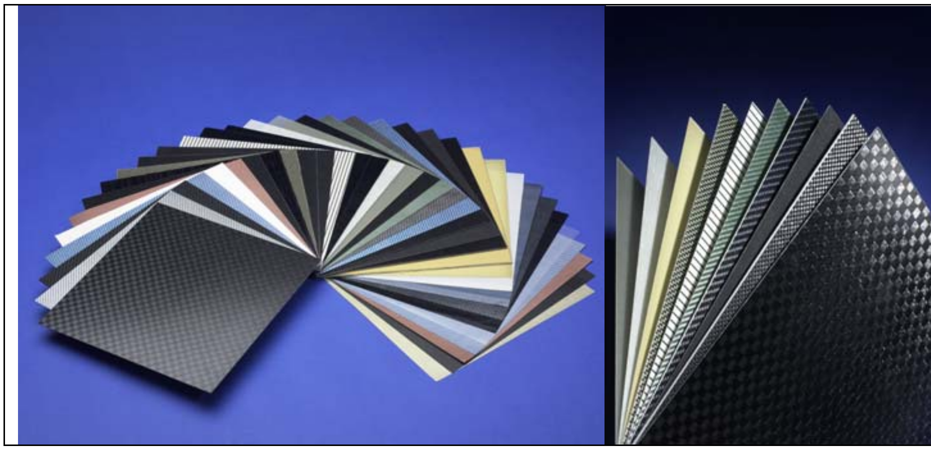
Cetex® is used in the A380 engine air intakes made by Airbus France. The air intake is an innovative no-splice design, made possible by the use of thermoplastics, and gives the A380 a very low noise profile.

PPS	PEI
• Airbus A330-200 rudder nose ribs • Airbus A330, A340-500/600 and A380 aileron ribs and rudder leading edge parts • Airbus A340-500/600 and A380 fixed wing leading edge • Airbus A340-500/600 inboard wing access panels • Airbus A340-500/600 and A380 keel beam connecting angles • Airbus A340-500/600 and A380 keel beam ribs • Airbus A340-500/600 and A380 pylon panels • Boeing 787 passenger doors	• Boeing 737 smoke detector pans • Boeing 737/757 galleys • Boeing 747 environmental climate system components • Boeing 787 environmental climate system ducts • Boeing 737 flax slat tabs • Boeing 767 aircraft acoustical tile • Boeing 767 and other Boeing aircraft brackets • Airbus A320 bulk cargo floor sandwich panels • Airbus A330-340 lower wing fairings • Beluga heavy-duty entrance floor panels • Dornier 328 landing flap ribs • Dornier 328 ice protection plates • Fokker 50 ice protection plates • Fokker 50 trailing-edge wing shroud skins • Fokker 70/100 structural floor panels • Galleys on most commercial aircraft models • Gulfstream G-V structural floor panels • Gulfstream G-IV and G-V rudder ribs • Gulfstream G-IV and G-V rudder trailing edges • LearJet air steps

TEPEX®

TEPEX® is a line of thermoplastic composite products made by Bond-Laminates (Brilon, Germany), which combines aerospace-type fabric reinforcements with a variety of thermoplastic matrix materials using a double-belt press. The resulting products have less than a 2 percent void content. TEPEX® products include semipreg as well as dynalite consolidated sheets. A wide variety of combinations are available including glass, carbon and/or aramid fibers, and polypropylene (PP), thermoplastic polyurethane (TPU), polyphenylene sulfide (PPS), and polyamide (PA 6/Nylon 6), PA 12, PA46 and PA66 matrices. According to Peter Boer at Bond-Laminates, "Dynalite materials have a customized lay-up, varying reinforcement type, thickness and fiber volume to satisfy the cost and performance requirements of a specific application. It is our philosophy to solve many application development issues by optimizing the material rather than leaving the developers to maneuver around engineering compromises with the standard materials." TEPEX® sheets can be produced with fiber volumes between 35 and 55 percent, in thicknesses as thin as 50 µm up to 6.0 mm , and may include up to twenty layers.

Bond-Laminates also produces a TEPEX® flowcore product, which consists of long fibers (30-50 mm), similar to traditional GMT materials, with the difference that they are based on engineering resins. For example, TEPEX® flowcore 102-RGR/PA6 is a commercial grade product with random glass reinforcement (RGR) and PA6 matrix. Mr. Boer gives more detail, "These materials are often combined with TEPEX® dynalite to enable the molding of stiffeners and ribs along a continuous fiber reinforced structure. It is very cost effective, as it eliminates the cutting procedure after molding a part, which also reduces the cutting waste to virtually zero." TEPEX® flowcore materials can be molded using standard compression molding tools and are intended for automotive and industrial structures where glass/PP GMT and injection molded thermoplastics cannot meet new and higher technical requirements.



Tepex® materials are available in a variety of colors and patterns.

Tepex® has been developed for both aerospace and industrial applications. It offers excellent mechanical properties via continuous fabric reinforcements, but with the lower-cost, fast cycle manufacturing of thermoplastics. Mr. Boer explains, "Most Tepex® materials have cycle times of 30 to 60 seconds, depending on the level of automation the customer has installed. The main factor is the cooling time of the thermoplastic matrix in the tooling.." Data sheets for Tepex® dynalite fiberglass-reinforced and carbon fiber-reinforced polyamide 66 composite laminates indicate forming temperatures between 280°C and 300°C (536°F and 572°F), and consolidation pressures of 5 to 100 bar (73 to 1450 psi). Mr. Boer indicates that the molding temperature for PP and TPU based products is from 190°C to 300°C (374°F to 572°F).

Property	Tepex® dynalite 101-FG290	Tepex® dynalite 201-C200
Fiber	glass	carbon
Fabric	2/2 twill	2/2 twill
Polymer	polyamide 66	polyamide 66
Area weight (g/m^2)	290	200
Density (g/cm^3)	1.8	1.5
Glass Content (wt-%)	47	48
Tensile Strength (MPa)	400	785
Tensile Modulus (MPa)	21,800	53,000
Flexural Strength (MPa)	590	760
Flexural Modulus (MPa)	22,800	45,500

TEPEX® dynalite glass/PP and glass/PA6 are mainly used in automotive applications replacing aluminum for cost and weight savings. Glass/TPU and carbon fiber/TPU are mianly used in orthopedic and sporting goods applications, offering superior performance to unreinforced thermoplastics. Carbon fiber/PA 66 dynalite was developed for structural sporting goods and helmet shell applications, and PPS materials are being used in aircraft interiors at lower cost than traditional thermoset composites. Tepex® carbon fiber/PPS has recently been selected by a major aircraft seat manufacturer to replace aluminum in lumbar and thigh supports, armrest table covers and shields for video screens. The Tepex® lumbar support weighs around 150 g (5.3 oz), saving 130 g (5 oz) versus the aluminum part at 280 g (9.9 oz). This results in cutting roughly 72 kg (158 lb) per aircraft when multiplied by the 555 seats in a typical Airbus A380 plane. Other applications include:

- Carbon or fiberglass composite frame for Granite Gear backpacks using dynalite 101 and 201 Tepex® products.
- Racing bike brake lever for Campagnolo using dynalite 201.
- Racing brake pedal for Look Cycle that is at least 40% than all its competitors, made with dynalite 201.
- Puma Soccer Power Insole gives a springback effect and reduces fatigue using dynalite 101.
- Fujiwara attaché case and Otto Bock orthopedic soles are made from dynalite 401.
- Electronics sensor housing offers excellent impact resistance using dynalite 102.
- Prijon white water helmet uses dynalite 701.

Standard width for Tepex® sheet is 620 mm, but it can be supplied up to a maximum width of 1350 mm. Length is only limited by transportation requirements. The sheet sizes are typically specified according to customer needs.

Materials Reinforced with Natural Fibers

Natural and wood fiber composites are made by combining wood or natural fibers such as flax, hemp, kenaf, sisal or jute with polymers including polyethylene, polypropylene or PVC, with polypropylene (PP) being the most common. Natural fibers and wood flour are perhaps the oldest additives used in plastics, dating back to the original plastic, BAKALITE, where they were used to reduce cost, control shrinkage and improve impact resistance. They were eventually replaced with mineral fillers and fiberglass in the 1950s and 60s. However, they are making a comeback, offering properties comparable to fiberglass but at 70 percent of its weight, resulting in lower finished product cost. This trend started in Europe, where end of life recycling requirements have forced manufacturers to look at new materials. Principia Partners (Exton, PA) estimated that the 2002 market for natural fiber composites in North America and Western Europe was almost 1.3 billion pounds valued at $900 million. At that time, natural fiber composites were mostly used for decking and building products in the U.S., while over half of the 300 million pounds used in Western Europe went into automotive applications. The U.S. is catching up, with most major suppliers and OEMs either now using natural fiber reinforced thermoplastics in certain applications or participating in development programs.

FlexForm®

FlexForm® is a composite made from natural fibers, such as kenaf, hemp, flax, jute and sisal blended with thermoplastic matrix materials such as polypropylene and polyester. According to Harry Hickey, sales manager for FlexForm® Technologies (Elkhart, IN), the product was developed in response to a customer: “One of our automotive customers in the U.S. had seen this type of product in Europe and wanted to develop it here. They wanted the environmental advantages, but also improved weight and strength while maintaining one-step processing and competitive part cost.” FlexForm® offers a lighter weight and more environmentally friendly alternative to wood flour reinforced plastics. FlexForm® also offers good mechanical properties, claiming a 25 percent improvement in strength over wood fiber reinforced thermoplastics. Natural fibers are heralded as a renewable resource and eliminate the handling and irritant issues of glass fiber. FlexForm® is sold in four different product forms. It is thermoformed at 392°F (200°C) and 55 psi (0.379 MPa) using matched metal tooling, but FRP, aluminized wood and hardwood tooling can be used as well.

FlexForm® thermoformable products include a non-woven mat, low-density and high-density hard boards, and materials approved for Toyota interiors.

Product	Weight (g/m^2)	Tensile Strength (MPa)	Flexural Modulus (MPa)
50% PP / 50% natural fiber	1200	20	1793
50% PP / 50% natural fiber	1400	21	1862
50% PP / 50% natural fiber	1800	27	2551
50% PP / 50% natural fiber with PA*	1600	36	3103
50% PP / 50% natural fiber with PA*	1800	43	3792
AcoustiMax®	1000	15	1595
SuperLite®	1000	34	1900
SuperLite®	800	52	2750
SymaLITE	800	62	n/a

* PA = Performance Additive

FlexForm® MT	Flexible non-woven mat used in a contact oven for 3D applications with optional forced hot air preheat.	Weights: 170 to 2400 g/m^2 Widths: up to 3.2 m (10.5 feet)
FlexForm® LD	Low-density board preprocessed to allow use in forced hot air systems for 2D and 3D applications. Enables variable geometry within a common forming tool.	
FlexForm® HD	High-density, full compressed sheet used in infrared or hot-air heating systems for 2D and 3D applications.	Weights: 300 to 5000 g/m^2 Widths: up to 1.5 m (5 feet)
FlexForm® T10	Approved by Toyota for interior trim applications.	Available in MT, LD and HD.

FlexForm® is being used in numerous production automotive vehicles. It is also being marketed to RV and trailer manufacturers for sidewalls and into a variety of consumer goods including furniture, office partitions, and ceiling tiles.

Automotive door liner made with FlexForm® composite sheet shows how fasteners can be bonded and integrated during a one-shot thermoforming process.

FlexForm® natural fiber reinforced thermoplastic is used in automotive interior applications such as this seat back.

FlexForm® in Production Automobiles	FlexForm® in Production Trucks
DCX Sebring Convertible Door Panels	Freightliner M2 Business Class Ext. Cab Headliner
DCX Sebring Convertible Door Panels	Freightliner M2 Business Class Pillars
DCX Stratus Door Inserts	Freightliner M2 Business Class Cab Sidewall
DCX Viper Door Panels	International HD2 Door panel
DCX Viper Center Console	International HD2 Front Header
Ford Expedition Door Inserts	International HD2 Rear Cab Wall
GM Cadillac Sedan DeVille A, B, C Pillars	International HD2 Side Cove
Saturn LS Rear Package Tray	International HD2 Sky Rise
2004 DCX Grand Cherokee Door Uppers & Lowers	Mack Class 8 Headliner
2004 Mercedes 164/251 Door Panels	Volvo Sidewall
2004 Ford D219 Seat Backs	

VolcaLite®

VolcaLite® is Azdel's natural fiber reinforced GMT Lite product, made with polypropylene reinforced by long chopped basalt fiber. Basalt is an inert rock found worldwide, and is also the generic term for solidified volcanic lava. Its main advantages are higher service temperatures, higher modulus and better chemical resistance compared to fiberglass. It is being targeted as a replacement for both glass and carbon fiber reinforcements in composites. VolcaLite has been targeted for headliners, offering ultra-thin profiles down to 3 mm, a 50 percent reduction over traditional GMT products. Currently, VolcaLite is being evaluated by multiple Tier 1 automotive suppliers.

Wood-Stock®, Gornaf® and Tecnogor®

Wood-Stock® is a family of wood flour-reinforced polypropylene (PP) composites, produced by G.O.R. (Buriasco, Italy), a subsidiary of Solvay Industrial Foils (Brussels, Belgium). **Gornaf®** is a new material, comprised of polypropylene reinforced from 5 to 35 percent by weight with long sisal fibers (20 to 30 mm). **Tecnogor®** is the second generation of Gornaf®, reinforced from 10 to 40 percent by weight with even longer fibers (40 to 250 mm) that may be natural fiber or glass fiber. Note that in the table of properties below, Tecnogor® is not showing higher properties than Gornaf®. Adriano Odino, technical marketing for G.O.R., explains this discrepancy, "it is because the parts tested are very small sizes, where the long fibers are cut; however, the higher properties are realized in actual large-sized parts." All of these natural fiber reinforced products are extruded as thermoformable and recyclable flat sheets.

Wood-Stock® wood flour reinforced polypropylene composite sheets are used in automotive applications.

Gornaf® natural fiber reinforced thermoplastic sheet.

Tecnogor® thermoplastic sheet uses longer (40 to 250 mm) natural or glass fiber reinforcement.

Wood-stock® is the base product, reinforced with wood flour from 5 to 55 percent by weight. It was developed to meet customer needs for a cheap material with good quality and recyclability in automotive interior applications such as door panels, rear shelves and pillars. Gornaf® offers higher tensile and flexural strength for components with specific technical requirements, and significant weight savings. G.O.R. has performed recycling tests on door panels and confirmed that over 90% of the original weight can be re-used in the same design products when combined with the proper percentages of virgin material. G.O.R. buys manufacturing scrap from its customers, which it then grinds and mixes with virgin materials for use in production of new sheet products.

Material	Density (g/cm^3)	Tens. Str. (MPa)	Tens. Mod. (MPa)	Flex. Str. (MPa)	Flex. Mod. (MPa)
AcoustiMax® 1000 gsm	0.5	30	4052	40	3190
Celcon®	1.5	68	3933	93	3800
Zytel®	1.2	89	4250	n/a	n/a
Pennite® 4512	1.2	92	n/a	138	3875
Fortron® 1130	1.6	100	6875	159	6500
Fortron® 1140	1.7	n/a	n/a	165	8235
SuperLite® 800 gsm	0.8	65	7000	9	3438
SuperLite® 1000 gsm	0.5	68	7600	50	3800
SymaLITE 800 gsm	0.8	78	5750	n/a	n/a
TWINTEX®	1.5	200	9333	187	8667
Plytron® $(0/90)_2$)S	1.5	240	10,667	233	11,000
FlexForm® 1200 gsm	0.9	20	n/a	21	1793
FlexForm® 1400 gsm	0.9	21	n/a	34	1862
FlexForm® 1800 gsm	0.9	27	n/a	48	2551
FlexForm®+ 1600 gsm	0.9	36	n/a	59	3103
FlexForm®+ 1800 gsm	0.9	43	n/a	67	3792
Wood-Stock®	1.1	n/a	3000	40	18
Tecnogor® natural fiber	1.0	n/a	2341	43	23
Tecnogor® mineral fiber	1.1	n/a	2060	51	26
Gornaf®	0.96	n/a	2785	55	33

FlexForm®+ = with performance additive

Thermoforming these materials is a very easy and clean process, explains Mr. Odino, "In the standard process we use, sheets are heated at 180°C to 190°C (356°F to 374°F) for 50 seconds. The sheets are then transferred automatically to the mold and pressure of 8 to 10 kg/cm2 (114 to 142 psi) is applied for 40 seconds." He states that typical equipment requirements include an oven with infrared lamps, a 200-ton hydraulic press, a steel mold with water cooling system, and just 20 square meters of floor space. Odino adds, "You can obtain a finished part with coverstock on both sides (fabric or vinyl) and integrated plastic brackets, all molded in one step, in a very fast cycle time."

Applications for these materials include automotive interior components such as pillars, door panels, and the rear parcel shelf. Gornaf® has been used in the front and rear door panels for the Peugeot 406 Coupe. Tecnogor® is in the process of being evaluated by customers.

A door panel for the Alfa Romeo 159 sportwagon made by Johnson Control using Wood-Stock® thermoformable sheet material.

All Polypropylene (PP) Composites

These products are comprised of a polypropylene matrix reinforced with high-performance polypropylene fibers, and are often referred to as self-reinforced polypropylene or self-reinforced plastics (SRPs). The resulting composite offers excellent recyclability, being basically a mono-material, as well as specific strength and stiffness properties comparable to fiberglass-reinforced composites. This is due to polypropylene's very low density, which also enables all three products described below to claim 40 to 60 percent weight savings versus GMT and other traditional GRP materials. Another benefit is the soft crash behavior imparted by the ductile failure mode of polypropylene, and the material does not splinter. The excellent impact resistance of these materials holds up even in very low temperatures. These materials were developed initially for automotive end-uses, but are also being proven out in sporting goods, industrial and consumer goods applications.

Material	Density (g/cm^3)	Tens. Str. (MPa)	Tens. Mod. (MPa)	Flex. Str. (MPa)	Flex. Mod. (MPa)
Curv®	0.92	120	4200	-	3500
MFT	0.78	200	5500	-	5500
PURE®	0.78	200	5500	50	4800

Curv®

Curv® is manufactured using a patented hot compaction process by Propex Fabrics (Gronau, Germany). Extruded polypropylene film is stretched into tapes with exceptionally high stiffness and strength. These tapes are then woven into fabrics, which are then fed into a specially designed double belt process. The surface of every tape is partially melted, creating a matrix which bonds the tapes into a self-reinforced composite.

Thermoforming is achieved using pressures of 5 bars (73 psi) and up, depending on the complexity of the part, and temperatures of 150°C to 160°C (302°F to 320°F). Typical cycle times are less than 60 seconds. The consolidated sheet is available is thicknesses from 0.3 to 3 mm. It is slit to specified width, and then cut to length or rolled according to customer specifications. Standard dimensions are lengths up to 3 meters and widths up to 1360 mm.

Curv® is being marketed into myriad end-use applications including:

- Automotive bumpers, body panels, and under-body shields
- Automotive interior headliners, door liners, load floors, pillar trim and rear parcel shelves
- Building cladding
- Personal protective equipment
- Sporting goods
- Briefcases and luggage
- Audio speakers
- Shoe inserts.

Daimler-Chrysler has evaluated Curv® for under-body shields, and several processors are testing it for use as a local reinforcement for injection-compression and compression molded parts.

MFT

Milliken & Company (Spartanburg, SC) produces Moldable Fabric Technology (MFT) using the PURE® technology through a license agreement with Lankhorst Indutech. MFT claims to provide the same basic weight and property benefits of all SRPs, but details the impact resistance offered as 2 to 15 times improvement over typical thermoplastics and thermoplastic composites, even at temperatures as low as -40°C (-40°). Milliken is receiving high interest in MFT from manufacturers using unreinforced polyethylene, ABS and polypropylene, as well as suppliers using glass-reinforced polypropylene, including GMT and newer, oriented reinforcement materials. Milliken recommends in-mold painting as a method to color MFT; however, painting after molding is possible, technology currently used with polypropylene bumpers.

Milliken & Co. has licensed the PURE® technology to produce Moldable Fabric Technology (MFT) self-reinforced polypropylene in the U.S.

A molded seat for playground equipment demonstrates the formability of MFT products.

Although there are currently no commercial applications in service, Milliken is actively pursuing development of structures for the watersports and ballistics markets, with commercialization targeted for Summer and Fall 2006, respectively. Additional markets described by Milliken include: truck liners, kayaks, canoes, body panels for personal watercraft and snowmobiles, car-top carriers, recreational vehicles, piping and construction.

PURE®

PURE® is manufactured by Lankhorst-Indutech (The Netherlands). Their patented process uses three flat tape layers: a highly-oriented polypropylene core and two thin polypropylene skins specially formulated with a lower melting point for welding the tapes together and forming the matrix. A hot compaction process using a hot press or continuous belt process consolidates the two skins and core into a composite sheet.

Thermoforming is used to produce parts using relatively low pressures starting at 3 bars (44 psi) and temperatures from 150°C to 160°C (302°F to 320°F). Typical cycle times are less than 1 minute and can be as low as 25 seconds, depending on the complexity of the part.

PURE® all-PP sheets are made by compacting multiple layers of highly oriented polypropylene tapes into a single consolidated composite.

Thermoforming of suitcase shell from PURE® self-reinforced polypropylene sheet.

According to Astrid Wijninga, customer service for Lankhorst-Indutech, PURE® was originally developed as an alternative to GMT in automotive applications. "PURE® offers up to 50% weight savings over comparable GMT sheets, it does not become brittle at very low temperatures like GMT does, and PURE® is fully recyclable whereas GMT is not." She continues, "PURE®'s specific impact performance is so good that it is now considered for use in anti-ballistic applications in the defense industry and for protective applications in sporting goods." PURE® is being tested in several applications by manufacturers in multiple countries, the details of which cannot be disclosed.

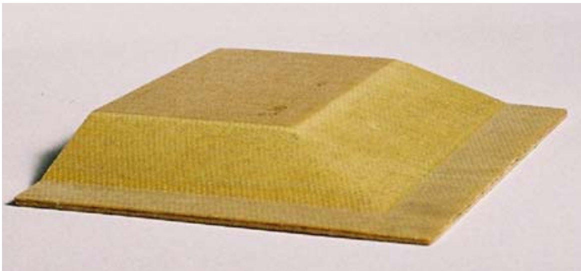
PURE® is generating interest in automotive, sporting goods and ballistics protection applications.

The finished sheet is typically 0.3 to 3 mm in thickness, although higher thicknesses are available on request. The sheet is cut to width and length as specified by the customer and shipped on spools.

Cored Panels and Other Panel Products

FITS

FITS stands for Foamed In-situ Thermoformable Sandwich. Using unique manufacturing technology, FITS Technology (Driebergen, The Netherlands) produces an isotropic polyetherimide (PEI) foam core bonded to fiber reinforced PEI faceskins all in one step. The resulting panels are high-strength, high-stiffness, lightweight and thermoformable. This means end-use products are quicker, and thus cheaper, to manufacture. According to Martin de Groot, managing director of FITS Technology, FITS was initially developed from a research program at Delft University in The Netherlands. "The goal was to make a product having an airy core with solid surfaces, similar to the excellent structural design of bones. If this product could be thermoplastic, then it would be thermoformable, offering low cost and versatile processing/ fabrication." Thermoforming revolutionizes edge close-outs, fastener inserts and joining, eliminating the need for potting compounds, which reduces time, cost and weight. FITS panels also meet all flammability and smoke toxicity requirements for aircraft interiors.



FITS panels are provided with edge close-outs during thermoforming, which eliminates labor, time and cost of potting compound.

FITS panels can be easily folded and shaped to form complex structures.

FITS panels can be designed for easy joining so that labor, potting compound and fasteners are greatly reduced or eliminated entirely.

Material	Density (lb/ft^3)	Shear Str. (MPa)	Shear Mod. (Mpa)	Comp. Str. (Mpa)	Comp. Mod. (Mpa)
PEI in-situ foam	5	0.8	12	1.8	80
PEI in-situ foam	5.6	1.2	19	2.5	100
PEI in-situ foam	6.85	1.5	26	3.5	110
PVC foam	5	1.0	31	1.2	85
Nomex® honeycomb	5	2.2	70	4.8	255

NOTE: core density expressed in lb per cubic foot is commonly abbreviated pcf.

Sandwich Configuration	Weight (g/m^2)	Panel Thickness (mm)	Max. Load/ Displacement*	Max. Load/Displacement at 80 °C, 144 °F
FITS panel with 85 kg/m^3 (5.3 pcf) Insitu foam*** **	2570 0.526 lb/ft^2	10 0.395 inch	858 N / 20.7 mm 193 lb / 0.815 inch	730 N / 20.5 mm 164 lb / 0.81 inch 85% retention
FITS panel with 90 kg/m^3 (5.6 pcf) Insitu foam*** **	2440 0.5 lb/ft^2	8 0.315 inch	810 N /24 mm 182 lb / 0.955 inch	85% retention
Nomex panel with 48 kg/m^3 (3 pcf) and Epoxy Adhesive**	2435 0.499 lb/ft^2	11 0.43 inch	730 N / 15 mm 164 lb / 0.59 inch	65-75% retention

* 4 point bending test (ASTM C393)
** Top and bottom faceskins using Cetex thermoformable sheet material: 2 plies of 7781 style glass fabric with PEI thermoplastic resin 32 wt-% after consolidation.
*** Tg of in-situ foam: 210°C (378°F).

One of the initial targets for FITS is replacement of traditional Nomex® honeycomb cored sandwich panels in overhead storage bins and other aircraft interior components. Roughly 25 percent of the panel weight for the Nomex® honeycomb panels comes from potting compound, paint, inserts, and decorative surface film. For FITS panels, this drops to only 5% of the total panel weight. Thus, FITS can offer a 15% weight savings, which then enables it to use a higher density core, say 5.6 pcf, versus a Nomex® cored panel at 5.0 pcf. The FITS panel thus meets all end-use part requirements while still offering a 5 to 50 percent weight reduction but a very significant reduction in final part cost. This same traditional Nomex® cored sandwich system is used in numerous other interior components including: trolley carts, galleys, cargo ceiling and floor panels and cabin floor panels. If the weight and cost reduction demonstrated for overhead storage compartments were extended to all of these parts, the total savings per aircraft would be very attractive. According to Martin de Groot, "FITS cannot compete with Nomex® on its own because the honeycomb core is so lightweight. However, FITS can compete if you take advantage of its thermoforming to eliminate potting compound and other traditional costly and time-consuming processes such as edge finishing, installing inserts, etc. Traditional potting of fastener holes, waiting for potting compound to dry and then installing fasteners is replaced by thermoplastic inserts installed via ultrasonic welding, offering a dramatic time and cost savings. So with FITS, you start with a higher weight panel, but end up with a lower weight finished part at a much lower cost for high volume applications."

Cost Comparison of FITS vs. Nomex® Cored Sandwich Panels in Aircraft Overhead Storage Compartments (OSC)		
Production of 200 OSC/week	**FITS**	**Nomex® Cored Sandwich**
Panel cost	**3 m^2/OSC**	**3 m^2/OSC**
Painting labor	**No**	**3 employees/week**
Paint, potting compound, tape	**No**	**35 Euro/OSC**
Deprication machines	**10 Euro/OSC**	**?**
Required area	**30%**	**100%**
Employees per week	**10**	**35-40**
Milling	**Minimal**	**Extensive**
Cutting	**Yes**	**Not possible**
Sawing	**Yes**	**Yes**
Lead time	**3 to 24 hours**	**2 to 4 days**

Typical thermoforming temperatures for FITS are 330°C to 350°C (626°F to 662°F), which is a little lower than the melt temperature of the PEI facings. Forming pressure is around 0.321 Mpa (47 psi) depending on the density of the in-situ PEI foam. A heated die or tool is used for shaping and then a consolidation die or tool is kept at a temperature below the melt temperature of the thermoplastic faceskins. The process can also perform in-mold decoration. Faceskins can be in-mold painted white or receive a transferred decoration—using a printed paper technique—which takes advantage of the thermoforming heat and pressure to imprint the faceskins within 2 to 3 minutes.

FITS panels can receive in-mold decoration during thermoforming using a printed paper technique.

An almost endless array of designs and patterns are possible.

A wide variety of faceskins are available in addition to PEI, including polyphenylene sulfide (PPS) and polyphenylene sulfone (PPSU). Facings are reinforced with style 7781 fiberglass fabric impregnated to a fiber content of 32 percent by volume, but may also use aramid and carbon fibers. Top and bottom faceskins are typically 0.7 mm thick and faceskin layups per panel can be 1 ply top/1 ply bottom, 1 ply top/2 plies bottom and 2/2. FITS panels are manufactured with a thickness of 5 to 25 mm (0.2 to 1 inch) and a density of 85 to 150 kg/m^3 (5.3 to 9.4 pcf).

In addition to aircraft interiors, applications for FITS may include interiors for marine and rail, and panel structures used in the offshore oil and gas industry. Ability to form large-scale panels of 4 feet by 4.5 feet and then 4 feet by 8 feet is being demonstrated now. Due to the high interest in PEI in-situ foam as a stand alone product, FITS Technology will pursue marketing that product as well.

Rail-Lite®

Rail-Lite® is a foam-like product reinforced with long glass fibers developed by Azdel for large semi-structural panels in train interiors. Approximately half the volume of the composite structure is air, making the material very lightweight and enabling it to char when exposed to flame, emitting very low levels of smoke. This foam-like character also provides good sound absorption and heat-insulation properties.

Azdel is marketing Rail-Lite® into rail interior components such as window masks, ceiling panels, seat backs, arm rests, tray tables, stowage bins, valances, and partitions. GE Advanced Materials has formed a joint development agreement with the largest OEM supplier of train interiors in China, in which plans have been announced to use multiple grades of Rail-Lite composite for various applications in passenger train interiors.

— *Ginger Gardiner, Contributing Writer*