Composites consist mainly of a combination of polymers that have fibers embedded in them. While the fibers provide high mechanical strength, the polymer or “matrix” transfers the loads evenly over the fibers and protects the fibers against all environmental influences. Such fiber-reinforced plastic materials can be processed into composite parts for lightweight and high performance applications in various markets. While providing the required mechanical properties, composite parts are lighter in comparison to standard metal solutions.

Evonik manufactures a range of products that can be found in almost all components of fiber-reinforced composites. We supply core materials for sandwich construction, thermoplastic polymers, thermoset resins and matrices as well as essential components for crosslinkers, catalysts, impact strength modifiers or processing and process additives.

The overall market for lightweight composite solutions is growing, but costs of composite parts are still too high to compete with conventional metal solutions. Evonik is actively working on new solutions and innovations to reduce costs and enable the integration of composite parts into more lightweight applications.
Content

Innovation for composites .............................................. 4

Composite market challenges .......................................... 6

Innovation topics

Overview of innovation topics ........................................ 8
1. Flame resistant composites ....................................... 10
2. Polyurethane prepregs for FRP metal hybrids .................. 14
3. Thermoplastic prepregs for structural thermoset FRP parts 12
4. Reversibly crosslinking thermoset-thermoplastic hybrid .... 16
5. Thermoplastic unidirectional tapes ............................ 18
6. Short cycle times for large series – PulPress technology ... 20
7. Excellent composite surfaces .................................... 22

Contact us ................................................................. 23
Innovation for composites
Evonik Project House Composites

Project House Composites
To provide innovative solutions for the composite market challenges of today and the future, Project House Composites was founded in 2013. It is a highly specialized development center, where scientists are working close to the market on products and processes for a future where manufacturing of fiber-reinforced composites will play a significant role. Project House Composites belongs to Creavis, the strategic innovation unit of Evonik. The concept of the Project House has proven to supply a unique innovation environment where technical and market experts from different Evonik divisions are pooled for three years in a research center (physical building) to collaborate on solutions within a specialized technical field. Co-funding from the business units ensures a clear focus on market needs and supports commercialization of our activities within the business of Evonik.

Committed to innovation
Our goal in Project House Composites is to develop new materials and processes which enable a more efficient production of semi-finished products and composite parts. To unleash the large market potential, composite solutions need not only cope with existing mechanical performance and lightweight requirements, but also must answer market demands for economically competitive solutions above all.

Increase efficiency to reduce costs
We believe that reducing processing costs is key to enabling the integration of composite parts into lightweight applications. To reduce these costs, we focus on increasing the efficiency in all three aspects: materials, production of semi-finished products and production of final parts. We target high processing speeds at the highest quality standards for semi-finished goods and parts, as well as minimal to no solvent content during production and minimal waste.
Our vision is to reduce costs for composite parts

We have been working towards this goal with multiple topics, which have grown from a collection of inspired ideas into actual production of semi-finished goods, demonstrator parts and even commercially available products.

<table>
<thead>
<tr>
<th>Total costs of painted composite parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material efficiency</td>
</tr>
<tr>
<td>2016</td>
</tr>
</tbody>
</table>

Our target is to increase efficiency to reduce costs

- **Material efficiency**
  - Most effective use of expensive fibers
  - Low production waste for parts and semi-finished products

- **Process efficiency for semi-finished products**
  - Minimized product consumption
  - Minimal to no solvent content

- **Process efficiency for final parts**
  - High processing speeds
  - High process stability/minimal waste
Composite market challenges

Composite markets based on fiber-reinforced plastic materials pose specific challenges. Evonik addresses these challenges by being close to its customers in the different markets and understanding their needs.

Automotive
High mechanical performance of structural lightweight parts has already been demonstrated on a small scale and initial series applications. Still cost reduction and higher manufacturing speeds are challenges to enable the integration of composite parts into large series production. Innovation efforts target new composite materials for enhanced manufacturing processes and a more sustainable mobility.

Aviation
Quality standards are high in the aviation industry, where lightweight solutions are especially relevant. Our innovation activity presented in this brochure focuses on lightweight composite applications, where the materials must fulfill safety requirements (fire, smoke and toxicity).
Oil & Gas
Working in the deep sea to extract oil and gas requires materials that can withstand rough environments: High pressures, salty water and highly corrosive chemicals ($\text{H}_2\text{S}, \text{CO}_2$). Composite materials can meet these challenges, but cost-efficient materials and manufacturing processes are needed.

Wind
The wind energy sector is under pressure to reduce costs as it competes with other forms of power generation. Material innovations focus on high mechanical performance, high resistance to environmental elements and cost efficiency.

Sports
Markets are highly specialized. They challenge material suppliers to develop materials and manufacturing processes for specific needs at reasonable costs.
Overview of innovation topics
Our seven innovation topics address specific composite market challenges based on the needs of our customers. This overview links our topics to the corresponding target markets and possible applications.

1. Flame resistant composites
For many transportation sector applications, excellent mechanical properties and superior protection from fire, smoke and toxicity (FST) are required. Evonik has developed a new thermoset system that combines these properties, as standard epoxy materials have low flammability resistance and phenolic materials do not provide the required mechanical properties. Our new CALIDUR® product range is commercially available and enables the production of thermoset parts with FST protection. An initial demonstrator, an encasement for electrical components for use in airplanes, was successfully produced and tested.

2. Thermoplastic prepregs for structural thermoset FRP parts
A two-step process is used for the production of automotive parts based on storage-stable prepregs. Here, a liquid and reactive system without solvents was developed. It allows easy and cost-efficient manufacturing of prepregs and subsequently thermoplastic processing of automotive parts with thermoset properties. After curing and crosslinking, parts with high mechanical performance and superior quality are obtained.

3. Polyurethane prepregs for FRP metal hybrids
We have developed a polyurethane matrix specifically intended for combination with metals. Prepregs based on this matrix are suited as local reinforcements for automotive metal structures. Due to its capacity for strong adhesion, the material can be bonded to metals without further pre-treatment of the metal surface. Afterwards, the thermoplastic state of the matrix allows joint processing of the multi-material laminate or part. Excellent mechanical properties are achieved after curing.
4. Reversibly crosslinking thermoset-thermoplastic hybrid
Our reversible crosslinked matrix system displays a complete new class of material. Its unique feature is temperature-controlled reversible crosslinking. At an application temperature below 100 °C, the material is in a crosslinked state and exhibits high mechanical properties. When all crosslinks are open, the material enables easy reshaping and fast processing cycles. During cooling, the material crosslinks again. In addition to producing parts with prepregs, the material can also be processed in a combined injection molding and laminate thermoforming process (SpriForm-technology).

5. Thermoplastic unidirectional tapes
To supply thermoplastic unidirectional tapes at high quality and reduced costs, Evonik has developed a new cost-efficient production process suitable for our high performance polymers. An initial application of a tape based on a polyamide 12 and glass fibers was developed for oil and gas applications. With this process, Evonik complements its portfolio as a supplier of composite materials and semi-finished products.

6. Short cycle times for large series – PulPress technology
Today’s processing technologies to manufacture FRP parts with complex geometries, especially for automotive large series production, result in high cycle times and elevated costs. Hence, a novel processing technology “PulPress” has been developed in cooperation with Secar Technologie GmbH in Austria to efficiently manufacture complex FRP structural parts. Complex profiles consist of a fiber-reinforced material and the structural foam ROHACELL® from Evonik. The excellent thermo-mechanical properties of this foam core enable particularly fast and stable processing for mass production and the process offers the ability to produce shaped parts with high geometric complexity. The combined benefits of continuous production, low amounts of waste and a fast curing cycle result in 30–60 percent lower production costs as compared to traditional RTM-processes.

7. Excellent composite surfaces
For lean and more cost-efficient production of optical composite parts, new materials were developed for in-mold coating (IMC) of epoxy composite parts for automotive applications. These parts are manufactured via resin infusion processes such as resin transfer molding (RTM) followed by an IMC process. Using IMC out-of-tool ready paintable parts can shorten the production cycle because post-mold treatment effort is drastically reduced. As a result, costs can be significantly decreased.
1. Flame resistant composites

CALIDUR®, a next generation polyetheramide matrix resin

CALIDUR® was developed as a new class of thermoset matrix resins for prepregs that combines the high flame retardancy of phenolic resins or cyanate ester resins with the mechanical properties of high Tₑₑ epoxy resins. This combination is especially relevant for aircraft interiors and general transportation applications like railway. An alternative to phenolic resins is getting more important from the perspective of a component manufacturer and the OEM. Low surface qualities and poor mechanical properties of the composites require high efforts and costs for postprocessing and result in lower weight advantages of the fiber composites.

CALIDUR® is a one-component resin system that is available as a powder or solution. It is characterized by

- Intrinsic FST performance
- High Tₑₑ
- Excellent surface quality
- No formaldehyde
- Prepregs storage-stable at 8 °C for at least 12 months

Within Project House Composites a new resin formulation was developed with enhanced mechanical and flame resistant properties. Secondly, an encasement for electrical components was produced as tangible demonstration for composites semi-structural applications in the aviation industry.
CALIDUR® is now a commercial product and technical information in more detail is presented in the CALIDUR® brochures.

Fast processing combined with unique material properties
Recent developments focused on establishing curing conditions which can compete with state-of-the-art thermoset resin systems while reducing curing cycles even further. To further improve the customer benefit, Evonik has increased mechanical properties and flame resistance.

Demonstrator application in cooperation with INVENT GmbH
This component is used as an encasement for electrical components of the operating panel in the area of the cargo bay doors of an airplane. The manufacturer INVENT GmbH is a recognized engineering specialist and its contributions to this material development is the production of a representative composite demonstrator and the evaluation of processability in comparison to the qualified cyanate ester resin system.

In the past, the encasement was manufactured with phenolic-based prepregs. Covers manufactured today are produced with cyanate-ester-based prepregs. The manufacturing process with CALIDUR®-based prepregs is comparable to the manufacturing process with cyanate esters and offers high potential for cost reduction.

The encasement is subject to the equivalent fire, smoke and toxicity (FST) requirements as for interior parts in the airplane. Using CALIDUR® instead of cyanate ester resins reduces manufacturing costs by more than 28 percent, because cycle times can be reduced by more than 50 percent. No tack on the prepregs was a significant advantage, because the lay-up was easier and corrections were quickly implemented.

Matrix optimization for significantly improved properties

**Improved mechanical properties**
- Bending strength: +57% (+59%)
- Tensile strength: +59%

**Improved FST properties**
- Total heat release: -15%
- Smoke density: -27%

**Improved curing/cycle times**
- Curing temperature [°C]: 140 -94% to 190 -74%
- Time for 98% conversion [min]: 100 -87% to 10 -74%

**Improving the process and the cost effectiveness**

<table>
<thead>
<tr>
<th>Normalized costs [%]</th>
<th>Phenolic resin prepreg</th>
<th>Cyanate ester resin prepreg</th>
<th>CALIDUR® resin prepreg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>108</td>
<td>63</td>
<td>47</td>
</tr>
<tr>
<td>Autoclave process</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Material costs</td>
<td>7</td>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>

*Manufacturing includes: Cutting, lay-up, vacuum bagging, autoclave set-up, demolding, post-treatment
2. Thermoplastic prepregs for structural thermoset FRP parts

This new thermoset formulation is a liquid, solvent-free, two-step reactive system. It allows lean and cost efficient production of prepregs and subsequently high-quality thermoset parts.

Benefits
The new formulation allows simple and fast processing with fewer steps:

- Excellent fiber impregnation without solvents
- Easy handling of storage-stable and dry prepregs
- Thermoplastic shapeable preheated prepregs
- Fast curing cycles for reduced costs
- Low shrinkage for high surface qualities
- Excellent mechanical properties

1st step: Simplified production of prepregs
In the first step, dry and storage-stable prepregs are produced from the initial formulation without involving solvents. The viscosity of the liquid matrix in the initial state can be adapted to the prepreg manufacturing process within a range of 400 to 5000 mPas. During prepreg production, the matrix polymerizes. Therefore, in the prepreg state, the matrix shows thermoplastic characteristics, because the crosslinks have not yet been established.

2nd step: Fast production of parts
In the second step, the prepregs are processed to the part. In this procedure the prepregs are heated, draped and pre-consolidated into the desired position in the thermoplastic state. Then, the preform is transferred into the mold with the final geometry, where it is pressed and crosslinked. Curing times can be reduced to below 3 min at 185 °C, which makes this process extremely fast. After the crosslinking, the composite part shows high strength comparable to epoxy-based composites. In addition, low shrinkage yields high surface qualities.

Cost-efficient part production
Parts production from semi-finished products like prepregs results in low scrap rates in comparison to state-of-the-art infusion processes. Due to the fast cycle times and high mechanical properties, the formulation is especially suitable for automotive structural and semi-structural parts, where cost-efficient part production on a large scale is important.
Processing of thermoplastic prepregs to thermoset parts

Thermoplastic prepreg → Thermoplastic preform → Thermoset part

<table>
<thead>
<tr>
<th>Temperature</th>
<th>25 °C</th>
<th>80 °C</th>
<th>130 °C</th>
<th>180 °C</th>
</tr>
</thead>
</table>

Storage stability of prepreg

- Catalysed at RT
- Catalysed at 40 °C
- Not catalysed at RT

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of crosslinking [%]</td>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
</tr>
</tbody>
</table>

Curing prepregs

Calculation of production costs for automotive parts

- Epoxy (Wet compressing molding)
- Epoxy RTM (Near net shape)
- New Evonik solution (Prepreg pressing)

Our new solution for structural thermoset FRP parts exhibits calculated cost savings for an exemplary automotive part in comparison to state-of-the-art manufacturing.
3. Polyurethane prepregs for FRP metal hybrids

A new polyurethane matrix formulation has been developed for FRP (fiber-reinforced polymers) metal hybrid structures. Target applications are automotive structural parts in which the multi-material approach enables lightweight construction while maintaining conventional manufacturing and bonding processes. The prepreg can be used either as a sandwich core material or local reinforcement. Cost-efficient production is ensured by the strong adhesion on metal surfaces in the absence of pre-treatment or primers and by thermoplastic processing of the prepreg. Full crosslinking is achieved during the oven process following cathodic dip coating.

Benefits

In short, this new formulation allows

- Flexibility in the manufacturing process due to high storage stability of prepregs at room temperature
- Automated handling of the dry prepregs at room temperature
- High green strength and final adhesion on automotive steel and aluminum grades
- Short cycle times since no primer application or metal pre-treatment is needed
- Very good overall mechanical properties after curing

The reinforcement with composites can be easily integrated into conventional processes

First, dry and storage-stable prepregs are produced. Bonding to steel or aluminum parts requires only a moderate heating of the metal surface. If necessary, the metal FRP laminate can be formed in a subsequent step. Full curing takes place in a final heating step which can be integrated into the cathodic dip coating process. The formulation is targeted to allow a lean and fast manufacturing process, which meets the requirements for automotive large series production.

The formulation was optimized for high metal adhesion, fast processing and high mechanical properties

Efforts during formulation development focused on increasing metal-to-polymer adhesion, the mechanical performance and the processability of the material. Without the need for metal pre-treatment or primers, adhesion to conventional steel and aluminum grades is almost at the level of structural adhesives. Since polyurethanes exhibit high inherent toughness, no toughening agents are required as in the case of epoxies. Other mechanical properties such as strength and stiffness are comparable to typical epoxy resins and clearly outperform thermoplastic matrices.

A B-pillar part was produced as demonstrator

As a demonstrator, B-pillars were reinforced with the polyurethane prepregs. The application demonstrates both high adhesion to the metallic part and lean processing (e.g. good drapability).
Neat PU resin properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage stability at room temperature</td>
<td>Months</td>
<td>&gt; 6</td>
</tr>
<tr>
<td>$T_{g}$ after curing</td>
<td>°C</td>
<td>85</td>
</tr>
<tr>
<td>Water uptake</td>
<td>weight %</td>
<td>1.5</td>
</tr>
<tr>
<td>Flexural strength DIN EN ISO 178</td>
<td>MPa</td>
<td>95</td>
</tr>
<tr>
<td>Flexural modulus DIN EN ISO 178</td>
<td>GPa</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Composite properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength DIN EN ISO 527-4</td>
<td></td>
</tr>
<tr>
<td>Tensile modulus DIN EN ISO 527-4</td>
<td></td>
</tr>
<tr>
<td>Elongation at break DIN EN ISO 527-4</td>
<td></td>
</tr>
<tr>
<td>Shear strength DIN EN ISO 14129</td>
<td></td>
</tr>
</tbody>
</table>

Cycle times in heated press for part manufacturing

Adhesive strengths (prepreg/metal) exceed required 10 MPa for automotive applications

B-pillars as demonstrator parts

Courtesy to Benteler Automobiltechnik & Germa Composite
4. Reversibly crosslinking thermoset-thermoplastic hybrid

A new polymer material was developed, which reversibly crosslinks according to temperature. This is especially relevant for the automotive industry, because the matrix allows high mechanical properties in the crosslinked state below 100 °C and allows fast and thus cost-efficient processing. When all crosslinks are open, the material enables easy reshaping and fast processing cycles are obtained, because no extra curing time is needed. This processing behavior is also interesting for applications in other industries like construction or medical technologies.

Reversible crosslinking

Our new matrix can be heated and cooled many times without loss of properties – from the application temperature to the processing temperature and back to the application temperature to the crosslinked state. The crosslinks open during heating and form again during cooling of the processing tool, resulting in cycle times comparable to standard thermoplastic material. Further more, this allows reshaping, re-use or recycling and results in less production waste in comparison to thermoset materials. In the same way, functionalities of thermoplastic matrix systems such as welding or functional integration by, e.g. combined processes of pressing and injection molding are enabled.

Matrix at application temperatures

Up to the glass transition temperature of 100 °C, our matrix system displays mechanical properties comparable to state-of-the-art thermoset materials like epoxy.

Below 100 °C, all crosslinks have formed. The mechanical properties are much higher than those of state-of-the-art thermoplastic material (e.g. polyamide 6, a typical thermoplastic material in the automotive industry) due to the crosslinking.

In contrast to thermoplastic material, the glass transition temperature is much higher as well and guarantees these properties up to 100 °C.

Matrix at processing temperatures

Above 170 °C, all crosslinks are open and the matrix can be processed like thermoplastics. This allows very short cycle times and a fast production speed. Due to the lower temperature range for processing compared to PA6, the production process is more energy efficient.

Cost efficient part production

Our new matrix allows easy, fast and solvent-free impregnation at room temperature. After drying at 130 °C, the prepregs are storage stable at room temperature for more than two years. To produce parts, the laminates or prepreg stacks are heated at high speed with, e.g. IR radiation up to 200 °C in order to open up all crosslinks. No thermal treatment is needed for curing, because the crosslinks re-establish during the cooling step. As no additional curing step is needed, the cycle time is shorter in comparison to thermoset materials.

Benefits for part production

Laminates produced by compression molding from prepregs display excellent properties:

- High tensile and flexural strength
- Excellent ductility and toughness
- Good weatherability and low water uptake

A B-pillar was produced as demonstrator

These unique material properties allow the reduction of production costs due to fast processing, while obtaining parts with high mechanical properties. As an example, a B-pillar has been produced in a cycle time less than 60 s.

### Neat resin properties (preliminary)

<table>
<thead>
<tr>
<th>Property</th>
<th>ISO</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile modulus</td>
<td>527-1</td>
<td>MPa</td>
<td>&gt; 3300</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>527-1</td>
<td>MPa</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>Elongation</td>
<td>527-1</td>
<td>%</td>
<td>2.5</td>
</tr>
<tr>
<td>$T_g$</td>
<td>11357</td>
<td>°C</td>
<td>100–110</td>
</tr>
<tr>
<td>Water uptake</td>
<td>62</td>
<td>%</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

### Composite properties (GFRP)*

<table>
<thead>
<tr>
<th>Property</th>
<th>ISO</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILSS</td>
<td>14130</td>
<td>MPa</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>14125</td>
<td>GPa</td>
<td>&gt; 44</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>14125</td>
<td>MPa</td>
<td>&gt; 1100</td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>527-4</td>
<td>GPa</td>
<td>&gt; 44</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>527-4</td>
<td>MPa</td>
<td>&gt; 850</td>
</tr>
</tbody>
</table>

* Glass fiber reinforced with ITH 92145
### Composite properties (GFRP)*

<table>
<thead>
<tr>
<th>Property</th>
<th>Thermoset-thermoplastic hybrid</th>
<th>PA6</th>
<th>*Glass fiber reinforced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile modulus</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural modulus at 23 °C</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural modulus at 90 °C</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural strength</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILSS</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_g$</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water uptake</td>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

0% 20% 40% 60% 80% 100%

Related to the maximum value

---

### Schematic view of processing steps

**Prepreg**
- Impregnation at RT
- Drying at 130 °C

**Laminate preparation**
- Multi layer laminates prepared at 180 °C

**IR-Heating**
- Heating to 180 °C

**Thermoforming**
- Thermoforming at 80 °C

---

Crosslinks open upon heating for fast processing and form again during cooling for high mechanical performance.
5. Thermoplastic unidirectional tapes

Unidirectional tapes consist of endless fibers orientated in one direction embedded into a thermoplastic polymer matrix. Reinforcing properties of fibers can fully be exploited. These thin tapes (from 0.15–0.3 mm) are mainly processed in different tape laying or tape winding processes. In the oil and gas market, tapes are used to form continuous pipes and pipe sections.

High performance polyamide 12 for harsh environments
Extracting oil and gas from boreholes deeper than 2000 m in the sea demands high performance materials for pipes. Conventional steel solutions (well-intervention lines, flexible risers and flow-line technology) are reaching their limits in these depths. Pipes from unidirectional composite tapes based on the high-performance polymer polyamide 12 (PA12) offer to go far beyond these depths due to superior mechanical performance. For these, application PA12 offers high chemical resistance (H₂S, CO₂, oil), reduced uptake of water and reduced weight. New one-material solutions for the inliner and reinforcement layer simplify design, and the reduced weight provides easier handling, lowering installation and maintenance costs.

New lean and cost-efficient production process
Using polyamide 12 melt in comparison to fine powders eliminates expensive process steps making the process lean, more cost-efficient and more environmentally friendly. Granules no longer need to be ground to fine powders and suspended to achieve a homogeneous impregnation. As a result, drying is also not required. The new process offers fast and easy manufacturing of PA12 tapes based on glass fibers.

Increased tape quality
The process route starting from melt increases the tape quality. The fibers can be concentrated in the center of the tape, with increased resin content in the outer layers. This allows easier interlayer bonding between the tapes and makes the tape more robust, which facilitates tape handling. In comparison to tapes manufactured from powders, similar mechanical properties are obtained.

Unidirectional tapes for new markets
Lightweight applications in other industries can also benefit from our new lean and cost-efficient manufacturing process. For example, tapes are used for the production of composite structural parts in the automotive industry. These applications benefit from the increased flexibility of the process concerning the matrix system used. With melt impregnation new polymers can be used for making thermoplastic unidirectional tapes in superior quality. Especially compounds with high additive content may be processed by melt impregnation that would otherwise not be available to powder-based processes. Evonik offers a wide range of specialty polyamides, polyphthalamides and compounds thereof whose properties may be custom tailored for specific requirements with respect to temperature and environmental resistance, chemical stability and mechanical properties.

<table>
<thead>
<tr>
<th>Novel melt-impregnation process yields high quality tapes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing process</strong></td>
</tr>
<tr>
<td>[mm]</td>
</tr>
<tr>
<td>Melt-impregnation</td>
</tr>
<tr>
<td>Powder-impregnation</td>
</tr>
</tbody>
</table>

¹ all material properties measured on tape samples acc. to on DIN65469
Production plant located in Marl

Thermoplastic tapes

Cross section of multi layer pipe for oil & gas solutions

Close up on tape layers in cross section

Novel process allows elimination of three process steps in comparison to powder impregnation:
- Granules
- Powder
- Suspension (marked with a cross)
- Impregnation
- Drying (marked with a cross)
- Consolidation
- Tape

Fibers can be concentrated in the center of the tape allowing resin rich outer layers:
- Conventional (less resin rich)
- Resin rich outer layers
6. Short cycle times for large series – PulPress technology

Today’s processing technologies for large series production of fiber reinforced plastic parts with complex geometries and varying surface grades require long cycle times and high costs. Therefore, a novel, highly automated and continuous processing technology has been developed for cost efficient production of such parts in cooperation with Secar Technologie GmbH. This new PulPress technology combines pultrusion and press processes with materials that are used in a new and unique way.

Applications for complex profiles
Complex profiles consist of fiber-reinforced material and the structural foam core ROHACELL® from Evonik. The excellent thermo-mechanical properties of this foam enables particularly fast and stable processing for mass production and the process makes it possible to efficiently shape parts with highly complex surface variation. In the automotive industry, complex profiles can be used as lightweight structural components within the car body design or as add-on parts.

Process innovation & production
At our pilot plant located on the grounds of our partner Secar Technologie GmbH in Austria, the process begins with introduction of a continuous supply of ROHACELL® profiles. Fibers are then pultruded and woven around the rigid foam core and impregnated with a thermoset matrix. This material combination is next pulled into a press system where high temperature and pressure are applied to obtain a 3D profile part with a defined geometry. In the pilot plant, sandwich profile parts up to a length of 1.2 meters can be manufactured. Commercial production of parts in this length is also possible.

Technical & economical advantages
The PulPress process guarantees high production speeds, narrow tolerances and excellent part properties. Currently, 30 parts per hour can be produced using conventional resin systems. With fast curing resin systems, even higher productivity can be realized. A ROHACELL® core provides the necessary shaped form that can include integrated metal or polymer inserts. Finished parts show a weight reduction of approximately 75 percent compared to typical structural steel parts having similar performance. Parts also demonstrate very high energy absorption capacity during impact because of the sandwich design principle. The very low amount of material waste occurring during production combined with fast curing and continuous processing reduces the cost of manufacturing approximately 30–60 percent, compared to today’s FRP processes (e.g. RTM).

Performance validation in crash management
To illustrate the performance of complex sandwich profiles, a car bumper demonstrator was produced and tested to the RCAR vehicle crash standard used in setting German insurance ratings. In comparison to an aluminum bumper, the type commonly found on today’s automobiles, the bumper with a ROHACELL® core showed a reduction of intrusion depth of nearly one-third the part weight.

Foam for structural parts
High performance structural foam ROHACELL®, which is based on polymethacrylimide (PMI), offers boundless possibilities for lightweight construction of parts or products for not only the automotive industry, but also for aerospace, sports equipment, electronics, medical technology and other markets.
### Cost efficiency

<table>
<thead>
<tr>
<th>Weight of parts having similar functions</th>
<th>Part cost for series production</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Steel</td>
<td>100%</td>
</tr>
<tr>
<td>~ 90% Steel (high strength)</td>
<td>~ 140%</td>
</tr>
<tr>
<td>~ 60% Aluminum</td>
<td>~ 250%</td>
</tr>
<tr>
<td>~ 45% CFRP (quasi-isotropic)</td>
<td>~ 900%</td>
</tr>
<tr>
<td>~ 25% CFRP (UD/load case optimized)</td>
<td>~ 1000%</td>
</tr>
<tr>
<td>~ 25% CFRP (UD/load case optimized) in PulPress-process</td>
<td>~ 400%</td>
</tr>
</tbody>
</table>

Source: Illustration based on Roland Berger study and expert talks.
7. Excellent composite surfaces

Painted composite surfaces are important for visible parts, such as automotive Class A parts, when exposed prominently on the exterior and interior of a car. Painting contributes largely to the cost of composite parts. Costs result from multiple manual painting steps and from a series of coating layers, which need to be applied in order to obtain the required surface qualities and avoid waviness.

A heterogeneous distribution of fibers and matrix in combination with varying local shrinkage during consolidation and curing causes surface waviness.

Material and process for out-of-tool ready paintable surfaces
To reduce the preparation complexity and the associated processing costs, new materials were developed for in-mold coating (IMC) of epoxy composite parts manufactured in resin infusion processes such as resin transfer molding (RTM). These new materials allow a surface finish to be applied by coating during the composite part manufacturing process, thus eliminating the need for application of multiple functional layers. As a result, the process yields out-of-tool ready-to-paint surfaces resulting in cost reduction. Formulations can be adapted to the requirements of the automotive industry: short curing times for high productivity and high $T_{C}$ for inline or online painting.

Process for out-of-tool ready paintable parts

*RTM = Resin Transfer Molding  WCM = Wet Compression Molding
Contact us

We welcome you to talk with our experts about what we at Evonik can do for you and what we can do together towards a common goal. For more information, see our brochure "Evonik for composites" or visit www.composites.evonik.com/composites

General contact
Dr. Dr.-Ing. Stephan Sprenger
Evonik Hanse GmbH
Charlottenburger Straße 9
21502 Geesthacht
Germany
PHONE +49 4152 8092-36
stephan.sprenger@evonik.com

Flame resistant composites
Kirsten Alting
Evonik Performance Materials GmbH
Paul-Baumann-Straße 1
45772 Marl
Germany
PHONE +49 2365 49-2259
kirsten.alting@evonik.com

Excellent composite surfaces
Dr.-Ing. Leif Ickert
Evonik Resource Efficiency GmbH
Paul-Baumann-Straße 1
45772 Marl
Germany
PHONE +49 2365 49-5981
leif.ickert@evonik.com

Reversibly crosslinking thermoset-thermoplastic hybrid
Marcel Inhestern
Evonik Resource Efficiency GmbH
Paul-Baumann-Straße 1
45772 Marl
Germany
PHONE +49 2365-2428
marcel.mi.inhestern@evonik.com

Thermoplastic unidirectional tapes
Martin Risthaus
Evonik Resource Efficiency GmbH
Paul-Baumann-Straße 1
45772 Marl
Germany
PHONE +49 2365 49-4356
martin.risthaus@evonik.com

Thermoplastic prepreg for structural thermoset FRP parts
Dr. Guido Streukens
Evonik Resource Efficiency GmbH
Paul-Baumann-Straße 1
45772 Marl
Germany
PHONE +49 2365 49-7241
guido.streukens@evonik.com

Short cycle times for large series – PulPress technology
Dr.-Ing. Sivakumara Krishnamoorthy
Evonik Resource Efficiency GmbH
Kirschenallee
64293 Darmstadt
Germany
PHONE +49 6151 18-4836
sivakumara.krishnamoorthy@evonik.com

Polyurethane prepregs for metals hybrids
Dr. Christina Diehl
Evonik Resource Efficiency GmbH
Paul-Baumann-Straße 1
45772 Marl
Germany
PHONE +49 2365 49-9193
christina.diehl@evonik.com

Short cycle times for large series – PulPress technology
Dr.-Ing. Sivakumara Krishnamoorthy
Evonik Resource Efficiency GmbH
Kirschenallee
64293 Darmstadt
Germany
PHONE +49 6151 18-4836
sivakumara.krishnamoorthy@evonik.com
This information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Evonik assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information and recommendations. EVONIK EXPRESSLY DISCLAIMS ANY REPRESENTATIONS AND WARRANTIES OF ANY KIND, WHETHER EXPRESS OR IMPLIED, AS TO THE ACCURACY, COMPLETENESS, NON-INFRINGEMENT, MERCHANTABILITY AND/OR FITNESS FOR A PARTICULAR PURPOSE (EVEN IF EVONIK IS AWARE OF SUCH PURPOSE) WITH RESPECT TO ANY INFORMATION AND RECOMMENDATIONS PROVIDED. Reference to any trade names used by other companies is neither a recommendation nor an endorsement of the corresponding product, and does not imply that similar products could not be used. Evonik reserves the right to make any changes to the information and/or recommendations at any time, without prior or subsequent notice.