LIGHTWEIGHT DESIGN MADE FAST

A perfect example of innovative lightweight construction: the BMW i8. The high-strength, extremely lightweight passenger compartment, for example, is made from carbon fiber-reinforced plastics.

Photography: BMW

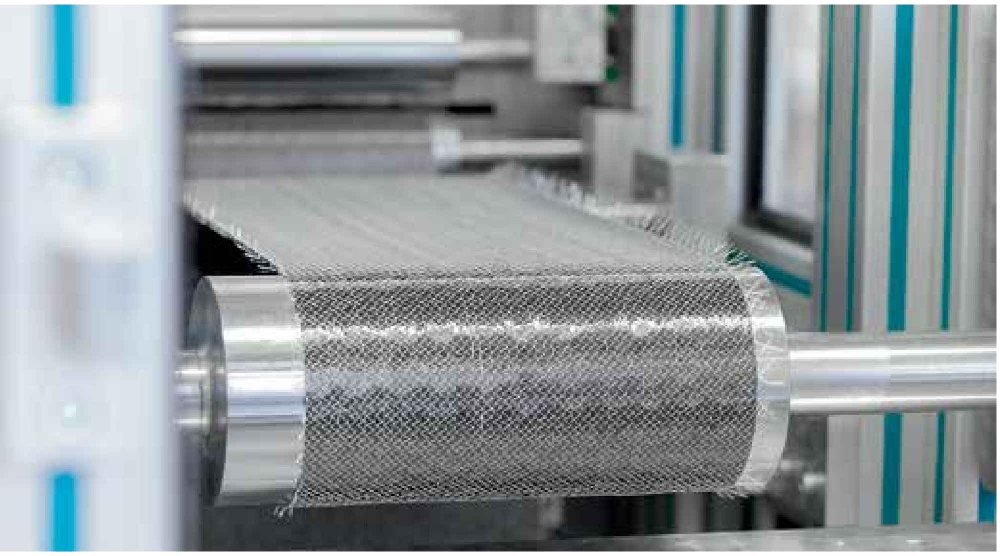
Without fiber-reinforced plastics, energy-saving aircraft, lightweight electric cars, and high-performance wind turbines would not be possible. A team from the Crosslinkers Business Line has developed VESTANAT® PP, an innovative polyurethane-based composite that makes the production of the components faster, easier, and more cost-efficiently. For this system, the developers received the 2015 Evonik Innovation Award.

Eike Langkabel, Dr. Guido Streukens

Wherever decreased weight and high performance are required, plastics and fiber-reinforced polymers in particular are the means of choice. Composites made of lightweight plastic matrix and fine glass or carbon fibers allow the fabrication of thin-walled yet highly durable components. As a construction principle, therefore, lightweight construction makes an important contribution to resource conservation and the reduction of emissions.

Although fiber-reinforced composites have been used for a number of years in a variety of industries, lightweight construction is still associated with intense manual labor. As yet, there is still no fully automated production process. This drives up costs, decreases production figures, and makes production time-consuming and relatively slow. At the same time, the demand for lightweight components, along with the standards for their durability and size, keep rising, which means that conventional fiber-reinforced compounds are reaching their performance limits.

When it comes to wind energy, for example, the dilemma is clear. Rotor blades ➔



Non-impregnated uni-directional fiber in the Marl testing facility.

→ longer than 90 meters made of relatively inexpensive glass fiber-reinforced plastics (GFRP) are simply too heavy. In order to build even larger and more powerful plants for such purposes as offshore wind parks, manufacturers must switch to fiber-reinforced compounds with carbon (CFRP). But the production of extremely thin high-performance carbon fibers is expensive and time-consuming, as they are formed from spun polyacrylonitrile, which is converted into pure carbon at high temperatures in special air-sealed pyrolytic furnaces.

Established methods with drawbacks

Thermosets are the classic plastics of lightweight construction. They consist of two chemical components that react on the fiber to form a stable molecular network. The polymer matrix takes the external forces and feeds them into the fibers.

Two techniques have become established for the production of fiber-reinforced components. With the RTM (resin transfer molding) process, either woven or multilayered fabrics are placed in a hot mold. Resin and curing agents are then injected into the closed mold. The two components of the polymer harden under high temperature to form a thermoset matrix. RTM is standard in car manufacturing. To shorten production time, the fibers are normally preformed to near-net shape. The drawbacks are that handling up to four components—binder, resin, curing agent, and fibers—complicates the process. The process also requires expensive plants and plant components, including a high-performance press, injection plant, and dosing plant.

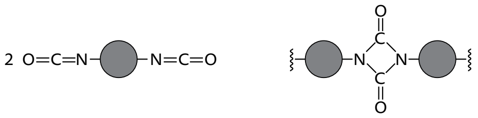
Prepregs (preimpregnated fibers) are an alternative to RTM. In these semi-finished products, endless fibers are coated with the reactants of the thermoset and pre-crosslinked. This technique would seem to simplify production, because the customer (in aircraft construction or the Formula 1 industry) must work with just one single component made of fiber, resin, and a curing agent. But even prepregs have significant disadvantages. The crosslinking continues at room temperature. So within just a few days, the viscosity and specifications change. This is why the transport and storage of conventional prepregs require a costly cold chain. They are also limp and sticky and unsuitable for automated handling with the help of robots.

No need for extensive cooling

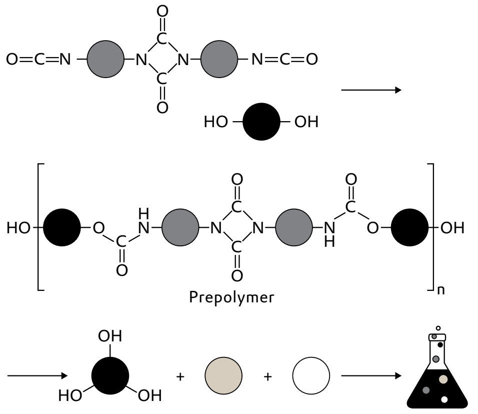
A team of developers from the Crosslinkers Business Line of the Resource Efficiency Segment has tackled these problems. The team has developed an innovative fiber composite that eliminates many of the difficulties of conventional production processes. A prepreg with VESTANAT® PP is solid and dry and easy for robots to handle and lay into molds. It is not reactive at room temperature. That saves cooling costs during transport and storage. Production is accelerated and process costs are reduced.

To achieve all these advantages, the chemistry of the polymer matrix was completely changed. Ordinary thermoset materials for fiber composites are epoxy resin formulations that are cured with amines. In contrast, VESTANAT® PP is based on polyurethane. Its starting material is an aliphatic isocyanate. What makes it special is that about half of its functional groups are reacted to urethane with alcohol, and the other half are chemically blocked in that every two isocyanates form a stable ring-shaped group (uretdione). Additional polyols and an organic catalyst are mixed with this dissolved prepolymer **(Fig. 1)**.

Figure 1:
The chemistry of the polymer matrix



The raw material for VESTANAT® PP is an isocyanate. **Step 1:** Some of the isocyanate groups are chemically blocked as uretdione.



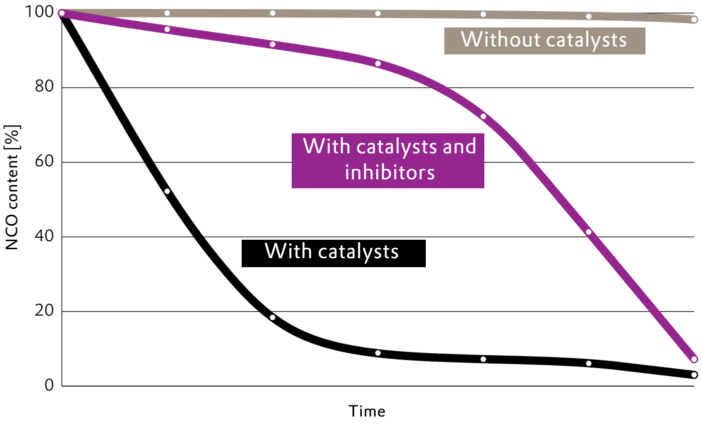
Step 2: The remaining isocyanate groups are polymerized to the prepolymer by adding alcohols. When more polyols and catalysts are added, VESTANAT® PP is produced and is used to impregnate the fibers. Heating the material to over 130 °C causes the uretdione groups to open and the material begins curing to the crosslinked polyurethane.

The fibers are impregnated with this formulation and the wet semi-finished product is dried at about 100 °C. When using carbon fibers, the end product is dry, dark black mats, while glass fibers result in a transparent material. For production, the mats are cut to size on the customer's premises and warmed to about 70 °C. The prepreg becomes supple again at this temperature. After that it is placed in a cold mold; it cools again and solidifies to a preformed component, which can be stored temporarily or finished immediately. To obtain the end product, the component is placed in the final mold, heated to 140 to 180 °C and pressed. The polymer will undergo final crosslinking only at these temperatures, because the uretdione rings open and polymerize by reacting with the polyols **(Fig. 2)**.

Two different reaction mechanisms separating pre-crosslinking and final crosslinking and the associated stabilization of the intermediate product are new for fiber composites but a proven formula at Evon-

Figure 2: Controlled curing

The speed of the final crosslinking of VESTANAT® PP, displayed in terms of the quantity of isocyanate groups (NCO content), can be adapted to the desires of the customer through the use of catalysts and inhibitors.



ik. The method is used in such products as powder coatings. In the development of VESTANAT® PP, this principle was adapted and optimized for the highly promising lightweight construction sector. The speed of the final crosslinking can be adapted to customer needs by adjusting the quantity of the catalyst added, and by varying the temperature: the hotter the curing process, the faster the final crosslinking.

This way, the system can be adapted to the existing fleet of equipment and the desired application. Existing facilities can be used with no problem. For new investments, expensive components such as dosing and injection plants are unnecessary, and the required press needs less power.

A car roof is one third cheaper

Calculations show that the roof of a car, for example, can be produced one third faster. The investment costs for a new plant are only half as high as for conventional production technology, and as much as 35 percent less expensive than RTM. In the laboratory, the team of developers tested all the production steps, as well as a variety of glass and carbon fibers, defined the influence of the catalyst quantity, and experimented with various formulas for the liquid resin.

Prepreg rolls of uni-directional multi-layer (left) and woven fabrics.

VESTANAT® PP is the first storable prepreg that can be reshaped by heating, and it cures by thermosetting. This means that it combines the advantages of both types of polymer—of thermoplastics and thermosets **(Fig. 3)**.

Market launch planned for 2016

The result is a new manufacturing process with advantages over conventional methods, because the RTM process, which is suitable for series production, is simplified by a one-component prepreg. The new lightweight material also displays extreme impact strength with high surface quality. In cooperation with a prepreg manufacturer, the material will be launched on the market in 2016.

Experience over several years of development work clearly shows that, when adapted to the challenges of a new product, expertise from other fields of business can result in excellent alternatives no one had previously thought of and help solve practical problems. Close cooperation with prepreg manufacturers and customers was a particularly important key to success.

The Crosslinkers team took on not only the role of the raw material developer but also that of the formulator, prepreg manufacturer, and direct supplier. Thus knowledge of the entire value chain resulted in a highly promising innovation for one of the most dynamic markets in the world. ■

The Experts

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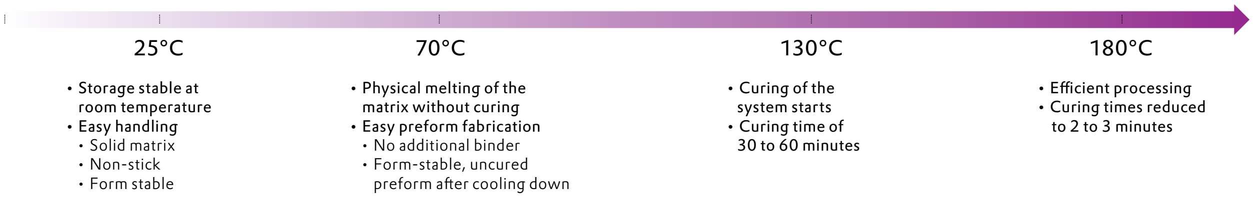
Figure 3: Temperature behavior of the prepregs

Since the prepregs melt at a temperature as low as 70 °C and cure only at 130 °C, they can be processed just as quickly and easily as thermoplastics.



Infographic: C3 Visual Lab Photography: Evonik (4)