By substituting metals with carbon composite materials in load-bearing structural components for automobiles, weight savings between 100 and 150 kg are achievable
(photo: BASF)

Latent Accelerators. Epoxy resin systems specifically intended for use with carbon composite materials open up new possibilities for lightweight automotive construction. These newly developed latent accelerators have a considerably longer pot life than conventional systems, but their curing time is far shorter. Moreover, the fibers of e.g. carbon composites are optimally wetted without impairing their mechanical properties. Thus, the epoxy systems meet the demands of automakers.

Fast Systems for Lighter Automobiles

MICHAEL HENNINGSEN

EU legislation aimed at the reduction of carbon dioxide emissions represents an enormous challenge for the automotive industry. Presently, average CO_2 emissions are around 165 g/km. By 2015, this average emission value for every automaker's vehicle fleet must be reduced in steps down to 130 g/km for new vehicles. Starting 2020, the next step down to 95 g/km comes into force (**Fig. 1**). Compared with 2008, this corresponds to a reduction target of more than 40 %. Manufacturers failing to meet this limit value must expect high fines. In order to avoid such penalties, development engineers are introducing a host of measures, of which lightweight construction is one of the most important. Meanwhile, every vehicle builder could cite the following formula in his sleep: Every 100 kg less weight on the road equals about 0,4 liters less fuel consumed per 100 km or about 10 g less carbon dioxide emission. However, it is unlikely that traditional approaches in lightweight construction will suffice: When Volkswagen introduced the Golf I in the mid 1970s, the zippy Beetle successor weighed about 750 kg. Some 30 years later, today's Golf V has gained weight dramatically, and now tips the scales at more than 1,200 kg – no talk of less weight on the road. Higher demands for comfort, and increasing safety requirements have made vehicle weights spiral upwards significantly. New ideas and concepts will be necessary to reverse this development.

The amount of plastics in today's automobiles already lies between 15 and →

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20 % – otherwise the vehicles would be even heavier. Plastics offer two essential properties for automobile construction: Firstly, they are significantly lighter than conventional materials such as steel or aluminum, and secondly their easy and flexible processing permits highly integrated components to be manufactured. Additional advantages are provided by the use of plastics reinforced with short fibers. Compared with metals, they result in weight savings of 50 % per component. Extrapolated to the entire vehicle, this could mean a savings potential of some 50 kg, which corresponds to about 5 g CO_2 per kilometer. Initially, this does not sound like much progress, but it is a large amount considering the fact that automakers are fighting for every gram saved, and even try to reduce the weight of the lacquer.

Engineering plastics are used primarily in vehicle interiors, where they already account for a notable percentage. Exterior applications are significantly less, which is why there is still a high potential for lightweight construction in the field of structural components. Because a vehicle's chassis represents about 20 % of its overall weight, savings of 100 to 150 kg are possible under optimum conditions. In the case of vehicles with IC engines, this corresponds to an additional reduction of CO_2 emissions in the amount of 10 to 15 g. Consequently, fiber-reinforced plastics alone could provide up to 30 % of the CO_2 reductions required by 2020. However, the substitution of load-bearing structural components is only possible with continuous fiber-reinforced carbon composite materials, which explains the great interest expressed for such solutions by the automotive industry. What is more, in various niche areas of automotive construction they are not new – such materials have been dominant in Formula One for years, where they have greatly increased the safety of monocoque chassis. In correspondingly small quantities they are also used in many of today's super sports cars **(Title photo)**.

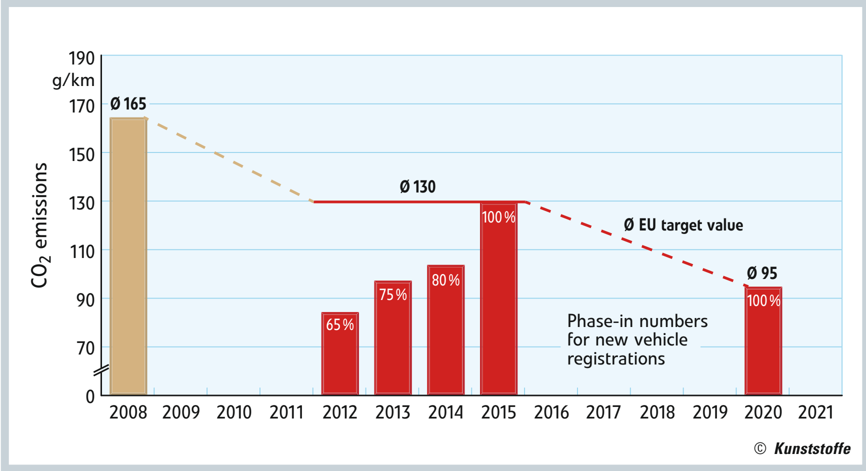

Fig. 1. The timeline for average CO_2 emissions of the EU vehicle fleet is a demanding challenge for the automotive industry (source: ThyssenKrupp Steel)

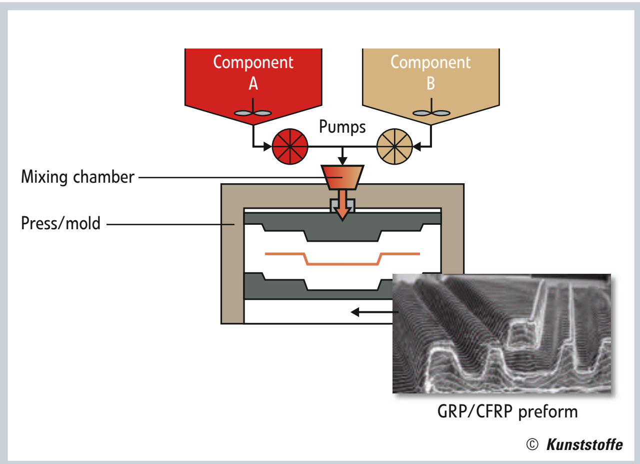

Fig. 2. Sequences of the resin transfer molding (RTM) process (source: Fraunhofer ICT)

The Problem of Conflicting Necessities

In recent years, the so-called RTM process **(Fig. 2)** has become established for the production of these materials, whereby RTM stands for Resin Transfer Molding. For this production process, the first step involves stitching or bonding of two or three-dimensional textile structures made of glass or carbon fiber fabrics. These dry preforms are then placed in a heated mold located in a press. The hydraulic pressure of the press holds the preform in the mold and ensures that the component is given the required shape. In order to obtain a blister-free final product, the air between the fibers must be evacuated. For this, various procedures with or without vacuum are available. Subsequently, a two-component reactive resin is first transferred into a mixing chamber by means of pumps, and then

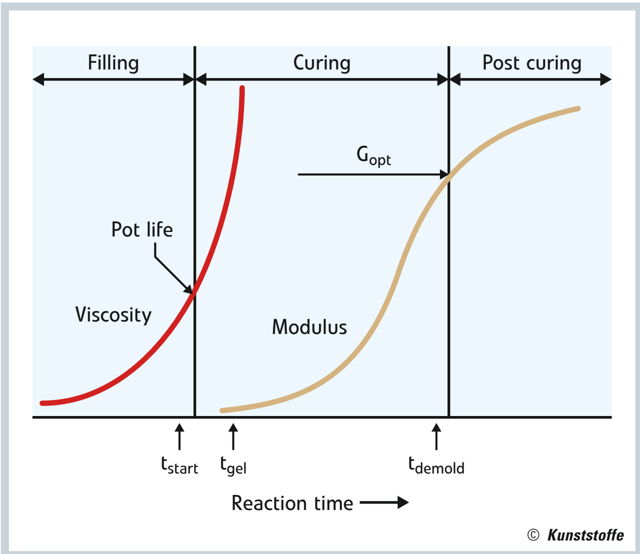

Fig. 3. Processing of reactive resins

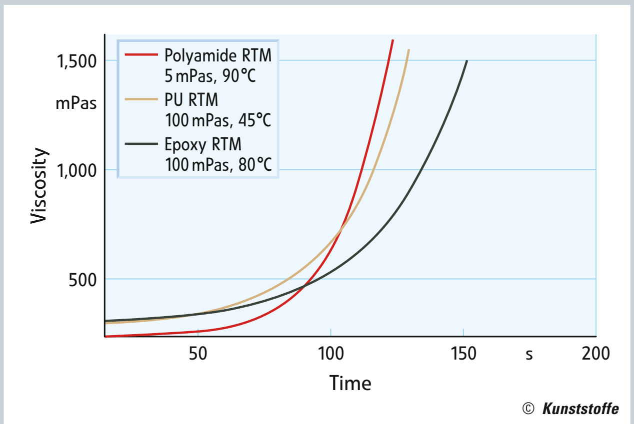

Fig. 4. Viscosity curve of reactive resins based on epoxy, polyurethane (PU), and polyamide, and which are suitable for the RTM process

into the mold as a mixture. To obtain optimum wetting of the fibers, a filling simulation is usually created. Polymerization starts immediately after the two components have been mixed.

And this is precisely where a serious problem of conflicting necessities arises: On the one hand, polymerization must be slow enough to permit the resin/hardener mixture to envelop the fibers completely, and on the other it must be as fast as possible to meet the short cycle times of the automotive industry, and to free the mold quickly for the next component. Due to the onset of polymerization, viscosity already starts to increase during mixing. The so-called pot life is a decisive processing value – it defines how long the fibers can be wetted or how long the polymer's flow path can be. Depending on pump output and the fiber material used, we are talking about a viscosity range of just a few hundred millipascal seconds (mPa). In many cases, this step is followed by a tempering or post curing phase, during which mechanical stresses are removed, and the chemical reaction of the component is completed **(Fig. 3)**. Frequently, this also improves important characteristics such as glass transition temperature or strength, because optimum network and crystal structures are formed.

So far, RTM components have only been used in very small series, e. g. as carbon fiber roof for the BMW M3 or M6, and also in commercial vehicles as roofs, wind deflectors, or parts of the driver's cab. Depending on component size, cycle times between 10 and 20 minutes are obtained. But other values are required for medium series of 30,000 to 100,000 units per year. Cycle times must be reduced significantly. Moreover, the post curing time must be kept as short as possible. For real structural components with corresponding mechanical properties, fiber contents of about 50 % must be implemented. This increases the demands placed on the resin/hardener system: Required are the lowest viscosity and the longest pot life possible, a glass transition temperature of at least 90 °C, and good mechanical properties such as elongation or elastic modulus. However, this wish list cannot be fulfilled with present-day chemical systems; instead, innovations down to the molecular level are needed. Therefore, BASF is investigating three different approaches: novel epoxy, polyurethane, and polyamide systems **(Fig. 4, Table 1)**, whereby development of the epoxy systems has progressed furthest. In order to make efficient use of all options for future lightweight automotive construction, BASF combined the research and development activities of all three material types in an interdisciplinary "lightweight composite team" in the middle of 2011. The team is investigating continuous fiber-reinforced, high-performance composite materials and their processing using the RTM process for automotive applications.

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Latent Accelerator Concept Solves the Conflict

Epoxy systems for automotive applications usually involve two-component epoxy/amine systems. The aminic curing of an epoxy resin takes place in several steps: First, the amino group opens the three-member epoxy ring. The resulting secondary amines are highly reactive →

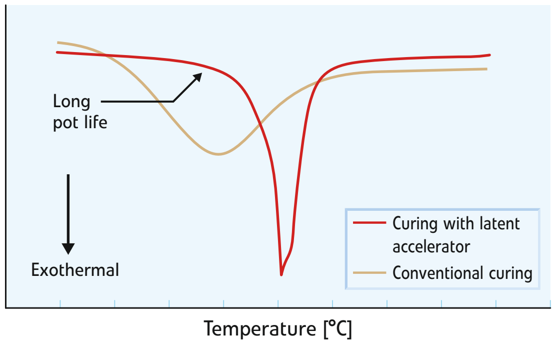

Fig. 5. Comparison of conventional and fast epoxy systems with latent accelerators

and attack further epoxy rings, so that polymer chains are formed. If diamines are used, the results will be three-dimensional bonding and the creation of a thermosetting plastic. With this conventional aminic curing approach, the reaction starts quickly, reaches a maximum, and dies down at a comparatively slow rate. But this means that viscosity also increases quickly, so that pot life is relatively short – a drawback that cannot be overcome with classical systems. Therefore, the BASF Intermediates Division in Ludwigshafen, Germany, has developed the latent accelerator concept **(Fig. 5)** – with success. In a nutshell, this approach leads to a significantly longer pot life, although the system cures considerably faster. In other words – fiber wetting is optimal, without the formation of "dry" areas that could have an adverse effect on the mechanical properties. Conversely, the fast overall reaction permits short cycle times. In this way, the thermally-activated latent accelerators solve the conflict of obtaining fast curing whilst simultaneously providing a longer pot life.

BASF has applied for a patent for this class of new latent accelerators. Experience has already been gathered with numerous different components that were manufactured for test purposes and exhibit the required properties.

BASF's novel epoxy systems open up new possibilities in lightweight automobile construction. Demolding times of less than 5 minutes are achievable, which complies with the automotive industry's requirements. The necessary mixing and batching equipment is available. Moreover, these novel systems can be integrated into existing RTM plants, which is a great advantage. Because the availability of carbon fibers has been improved significantly thanks to new production facilities, the innovative latent epoxy systems have gained clearly in importance. Consequently, the preconditions for building lighter structural parts for automobiles have now been created. And these weight savings will be required in all events – whether for conventional IC engines or for future electric mobility, where every kilogram saved results in extended battery range. ■

	Epoxy RTM	PU RTM	Polyamide RTM
Mold temperature	90–120 °C	80 °C	145–150 °C
Component temperature	80 °C	45 °C	80 °C
Mixing ratio	100:10–25	100:100–150	100:100
Demolding time	3–5 min	4–5 min	2–4 min
Dosing technique	low pressure	high pressure	low pressure
Glass transition temperature	100–135 °C	90–110 °C	0–50 °C
Melting temperature	–	–	220 °C
Viscosity at mold temp.	100 mPas	100 mPas	5 mPas
Processing range	wide	very wide	narrow

Table 1. Properties of reactive resins based on epoxy, polyurethane (PU), and polyamide, which are suitable for the RTM process

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