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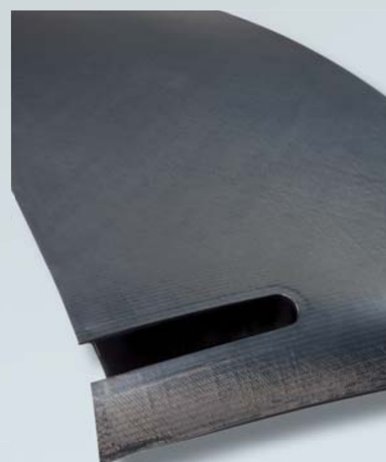

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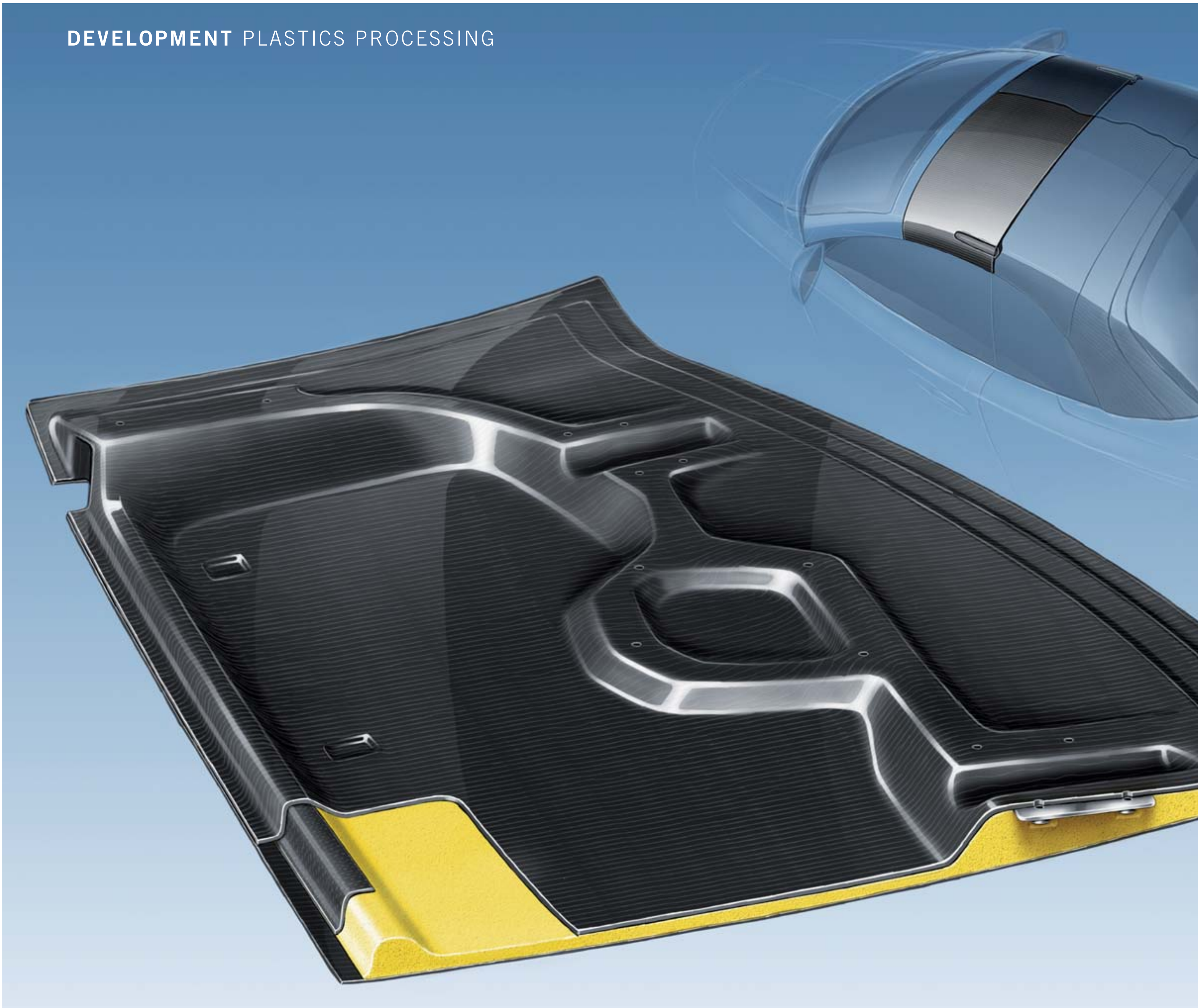
# FIBRE-REINFORCED COMPOSITE CONCEPT FOR A CONVERTIBLE ROOF MODULE



# FIBRE-REINFORCED COMPOSITE CONCEPT FOR A CONVERTIBLE ROOF MODULE

Edag and BASF have jointly developed a convertible roof module with a fibre-reinforced composite sandwich design that offers high weight-saving potential compared to metal concepts. The demonstrator relies on custom-formulated, carefully matched material systems as well as production methods suitable for high-volume production thanks to short cycle times and justifiable costs.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## TASK

For future urban mobility, vehicle mass will be a major factor, since it affects the energy requirement of both conventional and electrically powered vehicles. While rolling resistance and aerodynamics are also significant, their effects are of only secondary importance due to the numerous acceleration and braking phases that occur during normal operation in cities.

The pressure to implement new lightweighting concepts that go beyond what is currently being put into practice is increasing as car makers can expect fines if they do not achieve the ambitious $CO_2$ limits coming in the future.

To bring the opportunities for weight reduction and improved functionality within reach through the use of fibre-reinforced plastic composites (FRPC), the plastics experts at BASF, working together with the engineering company Edag, have developed a fibre-reinforced composite sandwich demonstrator for a convertible roof module.

The demonstrator has all the typical features and illustrates the lightweighting potential of a custom-engineered FRPC component. It demonstrates how to dimension such very lightweight components to withstand the anticipated loads in automotive applications as well as how to manufacture them cost-effectively with short cycle times.

The fibre-reinforced sandwich construction principle can be employed for normal roof systems based on a hybrid design as well as for other automotive and non-automotive applications.

## IDEA AND TECHNOLOGIES

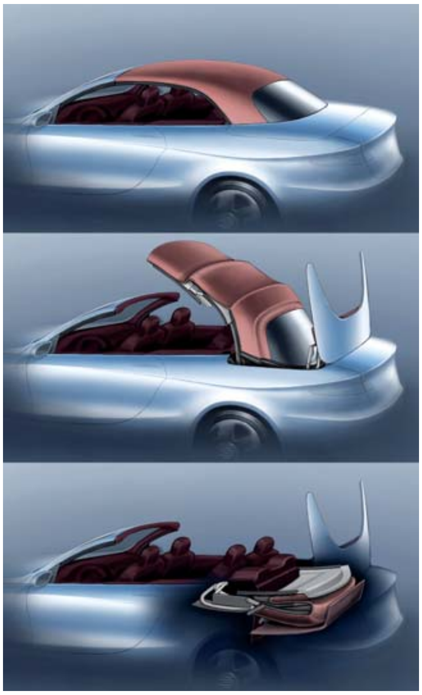
In the course of planning for the FRPC demonstrator, the decision was made in favour of a convertible roof module, since it promised relatively fast introduction to the market because of the relatively moderate volume of about 20,000 units per year. On the one hand, these quantities are still medium scale, while on the other the volume is already high enough that no FRPC technology would be economical without industrial and automated manufacturing processes.

A convertible roof module was also considered a suitable demonstrator because weight reduction above the vehicle's centre of gravity has a positive effect on driving dynamics. Thus, the somewhat more costly lightweight FRPC construction compared to that of steel or aluminium is more likely to be implemented.

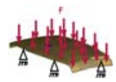
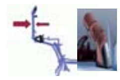
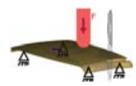
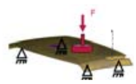
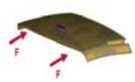
Moreover, the measures taken to increase the strength and stiffness of the convertible's body above those for a conventional car adversely affect its weight. This is an additional argument for lightweight design. At the same time, the customers in this already high-price segment are in a position to accept the additional costs that come along with the elaborate lightweight FRPC design, which partly compensates for the higher basic weight of the convertible, ❶.

Nevertheless, there are still roadblocks hindering the adoption of novel FRPC designs for high-volume production in the automotive industry today. From today's perspective, these include:

- the still relatively high costs in relation to the weight saved
- the lack of experience at OEMs and their suppliers in successfully combining the individual manufacturing competences in the supplier environment into a continuous value-added chain.



❶ The “EDroof” convertible roof module concept offers convertible manufacturers new and unique selling points through its combination of functionality as a retractable hardtop (RHT) with the design features of a fabric soft top

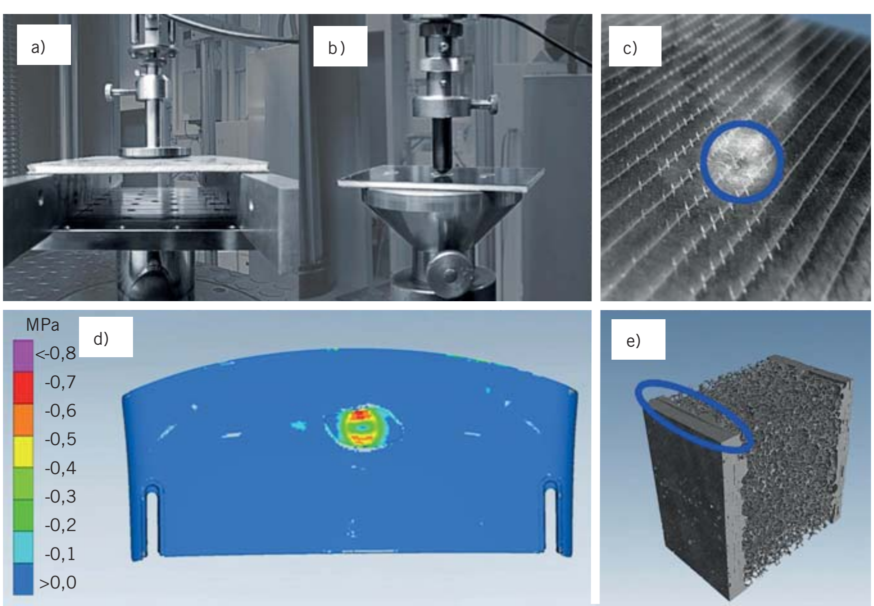
| Load case | | Requirement |
|---|---|---|
| Modal analysis |  | Determination of the eigenfrequencies for neutral behaviour in vehicle |
| Snow load |  | No damage to component and surroundings under high snow load on roof |
| Wind load |  | No damage if roof raised while driving ($V_{max}$ = 50 km/h) |
| Dent resistance hail impact |  | No permanent deformation from hail |
| Dent resistance polishing |  | No permanent deformation from pressure applied over a large area |
| Centre blockage |  | No damage from malfunction in locking system |
| Crash load |  | No component failure due to windshield frame movement during frontal impact |

❷ Load cases for the two reference designs and the generic fibre-reinforced composite concept for the roof module

While Edag contributed its development expertise in the automotive sector to the cooperative effort, BASF provided its now extensive portfolio of products and processing know-how in the three material classes of epoxy resin, polyurethane and polyamide.

The efforts of the car industry to further extend the use of plastics to body and chassis applications, which is expected to be the next big step in terms of weight reduction, will raise the performance requirements for materials to a new, as yet unattained level.

For this reason, BASF established a multi-disciplinary and multi-material lightweight composite team in 2011 and expanded its competences in the above-mentioned three plastic matrix systems to include continuous fibre reinforcement for high-volume production. This is dem-




❸ For the load cases of stiffness under polishing pressure (a) and hail impact (b), the stability of the sandwich as well as the quality of the surface after application of the load (c) were investigated as orientation; the design of the fibre-reinforced composite sandwich with regard to dent resistance required interaction between the development engineers, the CAE department (d) and the accredited testing laboratory at Edag; CT imaging of the test specimen (e) shows the effects of delamination when overloaded by a factor of about 7.5 times nominal

| Concept comparison | Reference A: Steel construction | Reference B: Aluminium construction | Generic concept: FRPC sandwich construction |
|---|---|---|---|
| |  |  |  |
| Construction | Two-piece: ribbed inside + exterior skin | Two-piece: ribbed inside + exterior skin | Sandwich of CFRP outer cover layers and PU foam core with inserts |
| Characteristic features | Metal parts, steel: Outer skin 0.7 mm Inside ribs 0.8 mm Local reinforcements 1.2 mm – 2.0 mm 7637 g | Metal parts, aluminium: Outer skin 1.15 mm Inside ribs 1.0 mm Local reinforcements 2.0 mm 3674 g | CFRP structure Cover layers, upper + lower 1.4 mm: two layers of unidirectional mats (UD), orientation 0°, 90°, +45°, -45°, add'l. UD strips at rear edge Matrix system: Epoxy 1661 g |
| | Fasteners, sealing system, adhesive 661 g | Fasteners, sealing system, adhesive, stiffening for dent resistance 879 g | Foam core: 80 g/l PUR 526 g |
| | | | Inserts at attachments points for kinematics, closing and sealing system: PA6 GF30, aluminium 609 g |
| **Weight comparison** | **8298 g** | **4553 g** | **2915 g** |

❹ Concept comparison with characteristic features of the reference designs and the fibre-reinforced composite sandwich concept; the fibre-reinforced composite sandwich offers a significant weight advantage

onstrated in the sandwich roof module through the use of the resin transfer moulding process (RTM).

Using this process, it is possible to produce large and complex composite components in a multilayer fibre- or fabric-reinforced structure through the use of very low-viscosity, fast-curing resins.

## COMPONENT CONCEPT AND DESIGN

A generic reference roof module was first created from an analysis of benchmark information. Two versions in steel and aluminium were then derived from this basic design. Using the design load cases, the reference was dimensioned and calibrated in a CAE-controlled development to achieve manufacturability and minimum weight. This reference had to be comparable to today's design in terms of technical functionality, weight and manufacturing costs, ❷.

From numerous different manufacturing principles and constructions that were basically suitable for the RTM process and ensured the functionality of the component, a one-shot method with a foam core was ultimately selected for the roof module: impregnation of the carbon fibre cover layers with an embedded form core in a single process step.

This permitted development of the first design concept on the basis of the geometry-determining and functional features, such as attachment points for the kinematics and closing system as well as the seals. In several development loops, it was possible to improve the function and weight of the layer structure. In addition, aluminium inserts were incorporated, locally applied unidirectional reinforcements added and the drapability of the mats assured.

CAE material models developed in-house and based on data measured on test specimens of various fibre-matrix combinations provided the basis for the further simulation-driven development process.

## OPTIMISATION OF THE FIBRE-REINFORCED COMPOSITE SANDWICH

Working in close cooperation with the design engineers, the CAE department and the accredited testing laboratory at Edag, the load and misuse load cases were investigated in detail and addressed in the course of the optimisation loops. This included satisfying local requirements in the sandwich composite, such as withstanding the impact of hail. In this way, the fibre-reinforced composite sandwich achieves high overall rigidity and maximum possible function integration.

When translated into a process suitable for high-volume production, a previously moulded foam core with the selected textile structures on both sides is placed in an RTM mould and completely impregnated in a single shot.

With a weight of only 2.9 kg, the resulting fibre-reinforced composite sandwich roof module is over 35 % lighter than the aluminium reference and up to 65 % lighter than its steel counterpart. In addition, the envisioned manufacturing process is expected to have considerably lower costs per kg saved than do current fibre-reinforced composite structures, ❸, ❹ and ❺.

Once development, dimensioning and optimisation had been completed, prototypes of the mould, foam core and individual components of the roof module were produced. For future manufacturers, a briefing document containing all the necessary preliminary investigations, technical and economic estimates was prepared in conclusion, ❻ and ❼.

## MATERIALS AND INTEGRATED FUNCTIONS

In addition to the mechanical performance of the fibre-reinforced composite component, the good flow properties of the resin matrix system (even with long flow distances), the impregnation characteristics and the short cure time of the

| Functional requirements | Reference A: Steel construction | Reference B: Aluminium construction | Generic concept: FRPC sandwich construction |
|---|---|---|---|
| Modal analysis<br>1st bending /1st torsion eigenfrequency > 35 Hz<br>Spreading torsion – bending > 5 Hz | 59.7 Hz/45.9 Hz<br>13.8 Hz ✓ | 59.4 Hz/48.4 Hz<br>11.0 Hz ✓ | 70.9 Hz/64.5 Hz<br>6.4 Hz ✓ |
| Snow load<br>No plastic deformation<br>Elastic deformation < 1.5 mm | Satisfied<br>0.9 mm ✓ | Satisfied<br>0.8 mm ✓ | Satisfied<br>1.5 mm ✓ |
| Wind load<br>No plastic deformation | Satisfied ✓ | Satisfied ✓ | Satisfied ✓ |
| Resistance to dents/hail impact<br>Max. failure criterion CFRP < 1.0<br>Max. compression/shear stress, foam < perm.<br>No plastic deformation (metal)<br>Max. deformation < 7.5 mm | – *<br>– *<br>Satisfied<br>4.0 mm ✓ | – *<br>– *<br>Satisfied<br>5.2 mm ✓ | 0.10<br>Satisfied<br>– *<br>0.8 mm ✓ |
| Resistance to dents/polishing<br>Max. failure criterion CFRP < 1.0<br>Max. compression/shear stress, foam < perm.<br>No plastic deformation (metal)<br>Max. deformation < 7.5 mm | – *<br>– *<br>Satisfied ✓<br>7.6 mm ● | – *<br>– *<br>Satisfied<br>7.0 mm ✓ | 0.20<br>Satisfied<br>– *<br>2.5 mm ✓ |
| Centre blockage<br>No plastic deformation | Satisfied ✓ | Satisfied ✓ | Satisfied ✓ |
| Crash load<br>No failure | Satisfied ✓ | Satisfied ✓ | Satisfied ✓ |

Legend
* Not a relevant criterion

Symbols
✓ = Result achieves target
● = Result slightly above target, but still acceptable

❺ Comparison of the results for all relevant load cases for the reference designs and the fibre-reinforced composite sandwich concept; the fibre-reinforced composite sandwich offers component properties comparable performance to the aluminium and steel versions but with a significant weight advantage

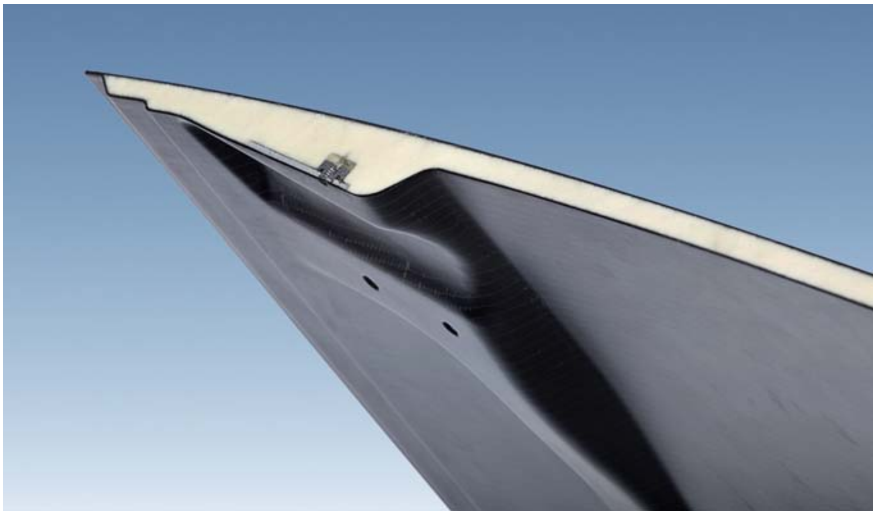
resin components for all three material classes under consideration for the RTM process are of central importance. All materials, epoxy resins, polyurethanes and polyamides can be processed on commonly available high-pressure and low-pressure equipment.

In the demonstrator roof module, the materials used are carefully matched system components from BASF: The centre layer of the sandwich structure is a closed-cell PU structural foam from the Elastolit D product line. It has a low density, serves as a spacer between the carbon fibre-reinforced laminate (CFRP) cover layers and is responsible for the component's high rigidity. In addition, it gives the roof module good insulating characteristics – an aspect that will arouse interest, as future electric vehicles will not be able to rely on the heat generated by an internal combustion engine. The PU foam, which is encapsulated in a single operation in the RTM mould exhibits high compressive strength and heat resistance at a low density. This helps to prevent compression of the foam core during the resin injection phase. To protect the sandwich against UV radiation and other environmental factors, the component receives a final coating that contains the BASF additive Tinuvin CarboProtect.

Overall, the convertible roof module

❻ Low-density polyurethane foam core with high compressive strength; the manufacturing concept in the form of a one-shot RTM process is based on a moulded foam core with integrated aluminium and short fibre-reinforced plastic inserts

❼ Weighing only 2.9 kg, the roof module is significantly lighter than a comparable aluminium design that weighs 4.5 kg; the generic component incorporates all typical features of a fibre-reinforced composite sandwich suitable for high-volume production via the RTM process



❽ Cross-section of the demonstrator: of the characteristic features of the novel fibre-reinforced composite concept, the polyurethane foam core, the impregnated CFRP skin layers and a metal insert can be seen

exhibits the following six characteristic features of the fibre-reinforced composite sandwich structure that was developed:

- dry CF mat with fibre orientation based on the load applied
- low-density polyurethane foam core with high compressive strength
- fast-curing RTM resin systems with good flow properties
- unidirectional reinforcements
- metal inserts at points where forces are applied and
- short glass fibre-reinforced plastic inserts.

The cross-section illustrating the principle of construction employed in the convertible roof module shows some of these typical features, ❽.

## SUMMARY

The example of a fibre-reinforced composite sandwich convertible roof module described here illustrates the high weight-savings potential of the concept compared to metal counterparts. The demonstrator relies on custom-formulated, carefully matched material systems from BASF as well as production methods suitable for high-volume production thanks to short cycle times and justifiable costs.

In addition, the fibre-reinforced composite sandwich design contributes to a considerable reduction in the vehicle's overall energy requirement as a result of improved insulation of the passenger compartment from its surroundings. This is important for electrically powered vehicles in particular, as the energy required to heat and cool the interior reduces the vehicle's range considerably.

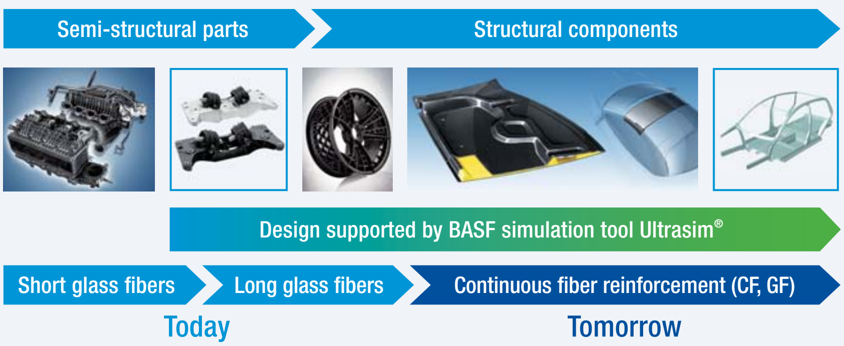
BASF

The Chemical Company

# LIGHTWEIGHT CONSTRUCTION WITH HIGH-PERFORMANCE COMPOSITES

**Automotive Solutions** Performance Passion Success

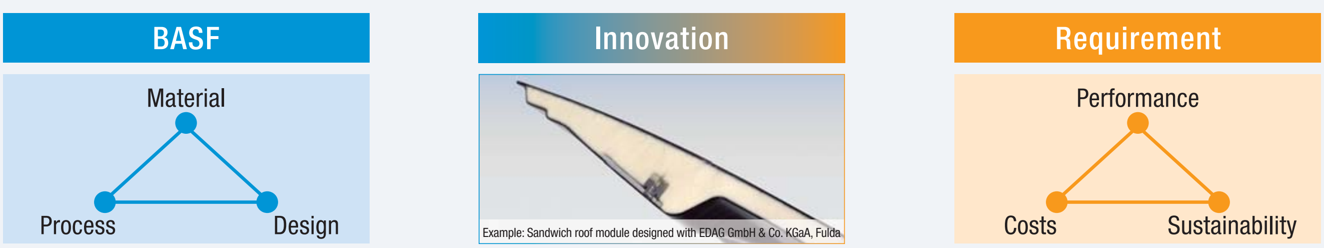
## STRUCTURAL COMPONENTS WITH CONTINUOUS FIBER REINFORCEMENT




**Future lightweight construction concepts**

- more than 50 % weight reduction in structural components
- new processing technologies, matrix materials and fibers
- continuous fiber reinforcement with more than 50 % fibers
- carbon and glass fibers are used
- optimum lightweight construction with multi-material systems

## HOLISTIC APPROACH



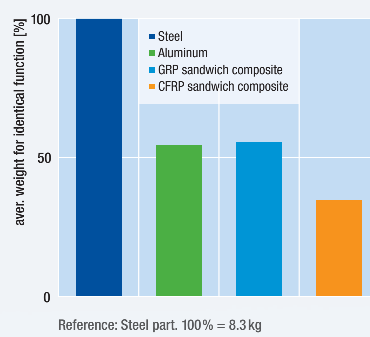

**Cost- and eco-efficient lightweight construction via holistic innovations in material, process and design/simulation**

- selected BASF lightweight construction materials: epoxy, polyurethane, polyamide
- design adapted for processing through simulation with Ultrasim®
- processing to form multi-material systems

## INTEGRATED LIGHTWEIGHT CONSTRUCTIONS WITH BASF SYSTEM SOLUTIONS

### Concept study – lightweight sandwich roof module


- generic fiber composite sandwich concept with tailor-made system components from BASF
- Structure:
  - lightweight polyurethane foam core, Elastolit® D
  - rigid CFRP surface layer with BASF matrix
  - UV-protected with Tinuvin® CarboProtect coating




- Weight reduction of 60 % with CFRP sandwich in comparison to steel