As part of the safety concept in the front end of the latest S-Class, Mercedes-Benz uses a crash absorber made from polyamide.
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Crash Absorbers made from PA for the Front End Carrier of the Mercedes-Benz S-Class

Accident Protection with Plastics

Most of the energy in a crash is absorbed by metal parts. A new additional polyamide (PA) crash absorber has for the first time been integrated into the front end of the Mercedes-Benz S-Class. The advantage is that an additional loadpath could be added without significantly increasing the mass of the car. Close cooperation between the project partners and the use of suitable simulation tools were key to successful realization of this project.

To design a vehicle that is safe in an accident, it is vital to protect not only the occupants of that vehicle but also those in the other vehicle involved in the accident. The latter requirement has also now been incorporated into the Euro NCAP tests, since the introduction of the new "ADAC crash compatibility test". The latest Mercedes-Benz S-Class is fitted with a crash-optimized front end carrier made from glass fiber-reinforced polyamide (PA) in order to be able to make a partial contribution to this overall function through clever functional integration.

Crash Absorber made from Fiber-Reinforced Polyamide

The introduction of the load compatibility test was prompted by analyses carried out following the crashing of two vehicles of different heights. In such cases, the crash management systems (CMS) of the respective vehicles are unevenly distributed and the vehicle weights also differ. Tests showed that inhomogeneous energy absorption frequently occurred to the disadvantage of the smaller vehicle in the accident.

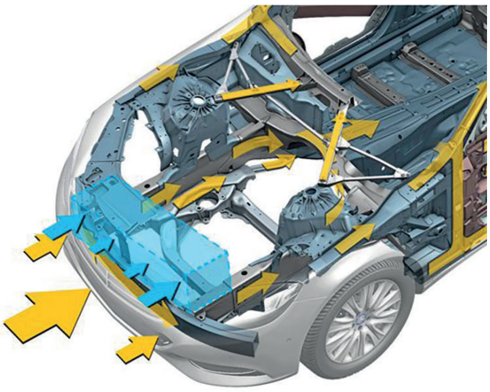

Fig. 1. Example illustrating the relevant load zone: for optimum protection of the other vehicle involved in the accident, the largest possible area should be available for energy absorption. © Mercedes-Benz

Better results in a frontal car-to-car collision can be achieved by front end concepts that offer the largest possible area for homogeneous energy absorption (**Fig. 1**). Here it is important, through intelligent functional integration, to make the best use of the available space, which is constrained, for example, by sensor technology and other peripheral devices. To ensure usability in practice, the project environment must be taken into account. To design components that are functional and safe during the development cycles, computer-aided prediction (CAE) is important.

Plastic crash absorbers are a key element of the whole front end module and fulfill numerous functions in the vehicle front. Besides the general creation of a stable, dimensionally accurate connection to adjacent interface components, such as the radiator bridge and flexible cross member, these functions also include integration of the vehicle hood locks, the provision of headlamp installation points and the possibility of targeted load distribution by the bumper. The main aim of the development was, however, to design the component so that it additionally supports homogeneous energy absorption in the confined space of the vehicle front end.

Use of Plastics Previously Excluded

In the past, the use of plastic components to meet crash requirements in automotive engineering has been largely excluded – for safety reasons among other considerations. But with a glass fiber-reinforced PA (PA6-GF30, grade: Ultramid B3WG6, manufacturer: BASF) and appropriate modeling in BASF Ultrasim software, it has now been possible to use plastic for a crash absorber (**Fig. 2**). The practical feasibility of this solution was worked out in a vehicle project undertaken by Mercedes-Benz in cooperation with BASF and the system supplier HBPO, which culminated in the development of the S-Class front end module.

Motivation and Challenge

In the development of energy-absorbing structures from PA with the aid of the Ultrasim software tool, various requirements have to be met and challenges faced.

Requirements:

- controlled failure,
- robust behavior,
- adjustable force paths, and
- adjustable energy levels.

Challenges:

- numerical prediction of failure with reliable material model,
- integrated climate adaptability (temperature and moisture), and
- design suitability for manufacture (injection molding).

Essentially, the development was based on combining LS-Dyna FE software with Ultrasim. The latter is able to take account of the characteristic properties of thermoplastic materials altogether in a single numerical calculation. Important characteristics are, for example:

- anisotropy: induced by the use of fiber-filled materials;
- strain rate: important in crash-stressed components;
- failure behavior: plastics behave completely differently from metal; »

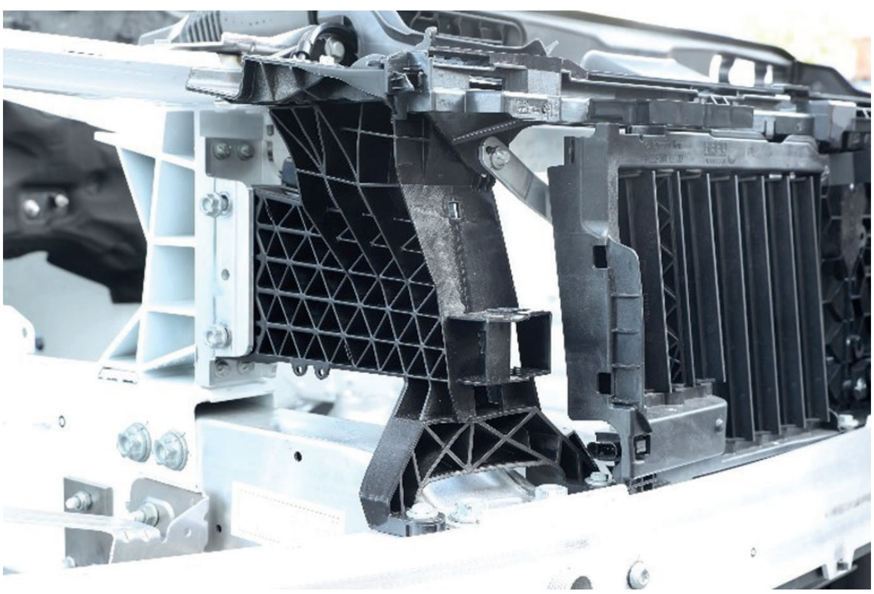

Fig. 2. The crash absorber (component with triangular structures in the center of the picture) is produced from glass fiber-reinforced PA. Besides the integration of several surrounding parts, the component assists in fulfilling safety aspects.

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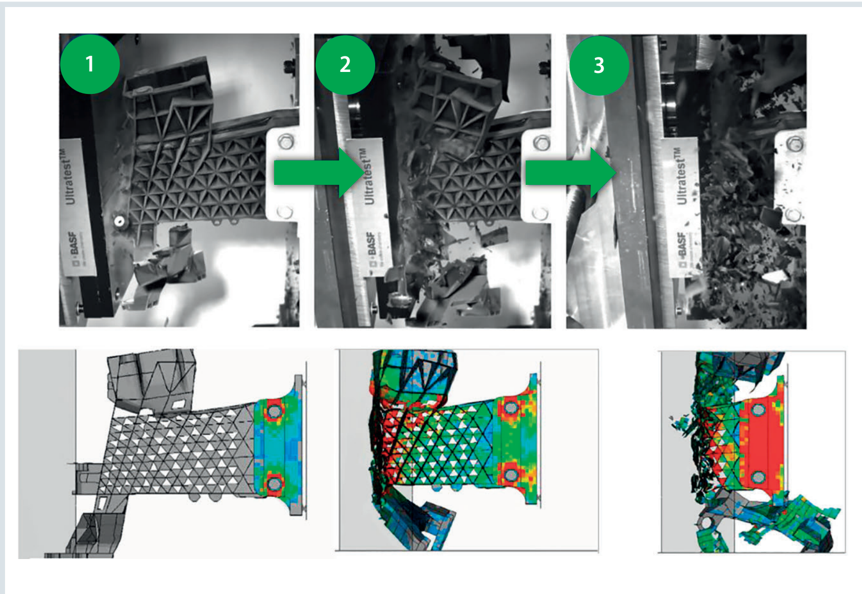

Fig. 3. Comparison between the simulation calculations and the drop tower tests shows the good predictability of the simulation. © BASF

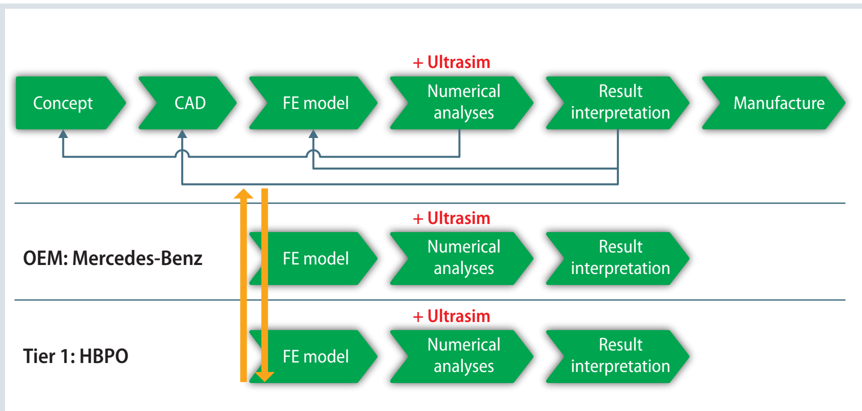

Fig. 4. For successful cooperation between the development partners, simultaneous use of the simulation software is vital. Source: BASF; graphic: © Hanser

- tension-compression asymmetry: in strength and failure;
- temperature: non-linear above the glass transition;
- moisture: particularly relevant with PA-based materials.

The material models created in Ultrasim have proved successful in numerous component developments and in the crash element described here, allowing robustness and controlled failure to be evaluated (**Fig. 3**). In particular, prediction of the forces generated in the crash element, the dissipated energy, and the loads exerted on the rest of the structure provides valuable data enabling simulation of overall vehicle design with plastic elements. It is essential here to ensure simultaneous and targeted use of Ultrasim by all parties involved in the development: OEM, tier 1 and material supplier (**Fig. 4**).

Besides the numerical simulation, correct choice of component geometry is also an important aspect. Hardly any wholly thermoplastic, short fiber-reinforced components have been designed to fulfill the primary function of controlled energy absorption. The design guidelines for this complex type of load were determined in preliminary studies at BASF and validated in component crash tests. They were further refined during development of the first prototypes in order to optimize the crash elements for the confined installation space. Alongside this, the suitability of the components for manufacture by injection molding was continually checked in rheological filling studies. In the first crash tests with real vehicles, Mercedes-Benz were able to confirm the effectiveness of the new component.

Crash Absorber already in Service

The material model and calculation methods developed can also be applied to other load zones in the vehicle. They could be used, for example, in battery protection. All in all, this technology opens up wide-ranging potential for functional integration and the possibility of verifying the safety of plastic structural components at an early design stage.

The crash-optimized front end carrier made from glass fiber-reinforced PA has already been fitted on the new Mercedes-Benz S-Class launched in 2020. Its use in further models is planned. ■

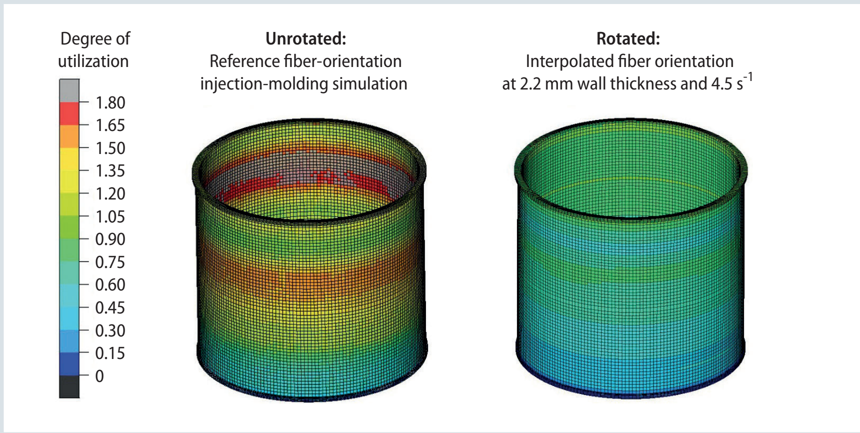

Fig. 5. This application case shows a significant reduction of the utilization ratio due to manufacturing with a rotating core. © University of Osnabrück

entire part length, and the principal orientation direction lies only in the axial or tangential direction, the tensor components of the fiber orientation that are necessary for the micromechanical computation are assigned to each of the n layers.

The same material charts from Converse can subsequently be used, which are also used for designing normal injection molded parts. Finally, the actual structural simulation and the strength analysis with S-Life Plastics are performed using a stress-based Tsai-Hill criterion [8], which takes into account the local orientation state.

The methodology was validated with the aid of burst pressure tests on the PP-GF50 (**Fig. 4**), at the same measuring points as the fiber orientation measurements. The test results demonstrate the significant increase of strength produced by reorientation of the fibers. It increases with increasing rotational speed and can be raised by over 100 % for all wall thicknesses. For a wall thickness of, for example, 2.5 mm, the strength can be increased from 57.5 bar to 120.2 bar.

The use of the simulation methodology for simulating the bursting pressure tests demonstrates that the increases in strength can be readily modeled in this way. In addition, it is possible to calibrate material charts with these simple component tests, which are then used for designing further components subject to internal pressure.

Practical Realization of a Pressure-Loaded Component

The first practical application of this design methodology was a pressure-loaded component from the mobility sector (**Fig. 5**). In the load case presented here, pressures at various levels act along the component, from inside and outside, at a temperature of 80 °C, with a maximum pressure of 23 bar. For this, a reference with the fiber orientation from the injection molding simulation (unrotated) as well as a component with an interpolated fiber orientation at 2.2 mm wall thickness and a rotational speed of 4.5 s^{-1} were simulated. The Tsai-Hill criterion were used to calculate the anisotropic utilization degree, which predicts failure at values greater than 1. Since, according to the requirements profile, the component is required to have a safety factor of 2, the unrotated part would not withstand the stresses with a utilization of 1.8. Due to the rotation of the mold core, the material utilization can be reduced by 50 % to 0.9.

Summary

A mold system with rotating core allows significant influencing of the fiber orientation in the component and a significant increase in the burst strength of components subject to internal pressure loads. In the case of the PP-GF50 investigated here, it was possible to show how, with increasing rotational speed, the axial orientation component decreases and the tangential increases. This change of fiber orientation leads to an increase in the burst strength of over 100 %, almost independent of the wall thickness.

To allow the modified fiber orientation to be taken into account in component design, a simulation methodology was developed and validated on burst strength tests on a demonstrator. When the methodology is transferred to a practical component, it is found that components can be developed that would not meet specifications if produced by conventional injection molding. This illustrates the great potential of this manufacturing process and the practical relevance of the design methodology. ■