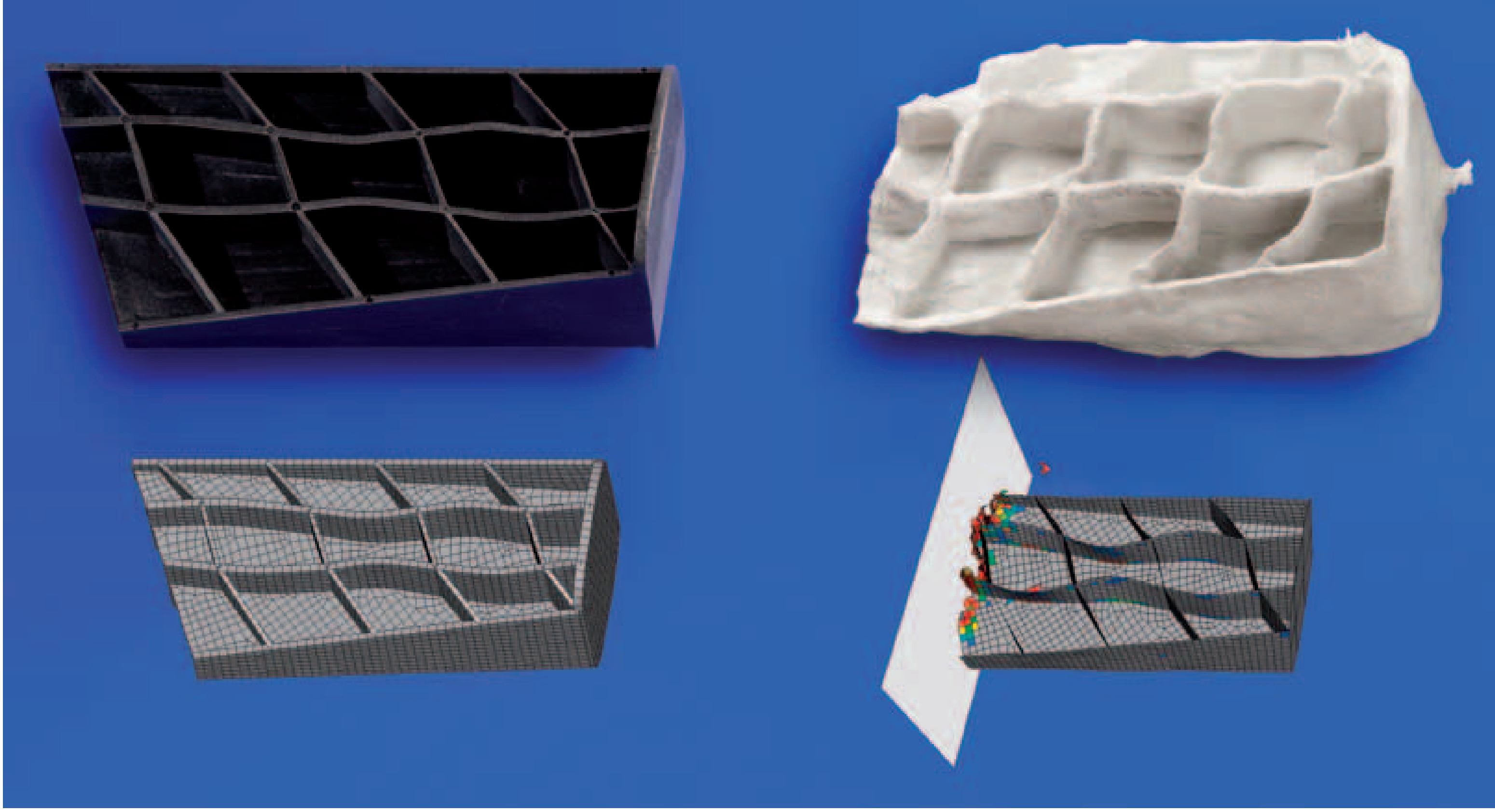

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METAL SUBSTITUTION IN THE FIELD OF CRASH SAFETY

In safety-oriented applications such as pedestrian and vehicle occupant protection, but also in terms of vehicle protection from the standpoint of the insurance industry, the requirements are especially challenging. In these areas in particular, BASF has, in recent years, made significant contributions to innovative applications of plastics with its Ultrasim universal simulation tool [1-6]. In particular glass fiber-reinforced plastics require special treatment when it comes to predicting their anisotropic stiffness characteristics. Considering plastic components as isotropic, soft steel without taking the production method into account does not result in components with an optimal design in terms of strength and stiffness. Instead, what is really needed are modern numerical methods for describing the material in conjunction with mathematical techniques for optimizing design in the CAE environment of today [7]. On the material side, BASF is launching its first long glass fiber-reinforced polyamides under the name Ultramid Structure. Together with suitable prediction methods, these are expected to trigger the next wave of metal substitution in the field of crash safety.

CHALLENGE: MODELING FAILURE

In addition to a durable component design under static or dynamic load conditions and a variety of service temperatures and ambient conditions, designing for controlled failure in crash situations is an additional challenge for the development engineer. This requires first of all being able to describe the relationship between stress and strain numerically in a satisfactory manner even when exceeding an acceptable state, ❶. The pronounced asymmetry under tension and compression can be seen clearly: On the one hand, the maximum sustainable stress under compression is

MORE CRASH SAFETY FROM HIGH-PERFORMANCE POLYAMIDES AND OPTIMIZED SIMULATION METHODS

It is hard to imagine the modern automobile industry without plastics. The percentage of components made of engineering plastics in practically all vehicle component categories is increasing continually: Plastics will be developed further as long as the trend toward lightweighting and metal substitution continues. At the same time, appropriate simulation methods for designing virtual components must keep pace. The authors from BASF show that only such a combination will make it possible both today and in the future to use thermoplastics in high-load applications that until a few years ago were reserved for steel and aluminum.

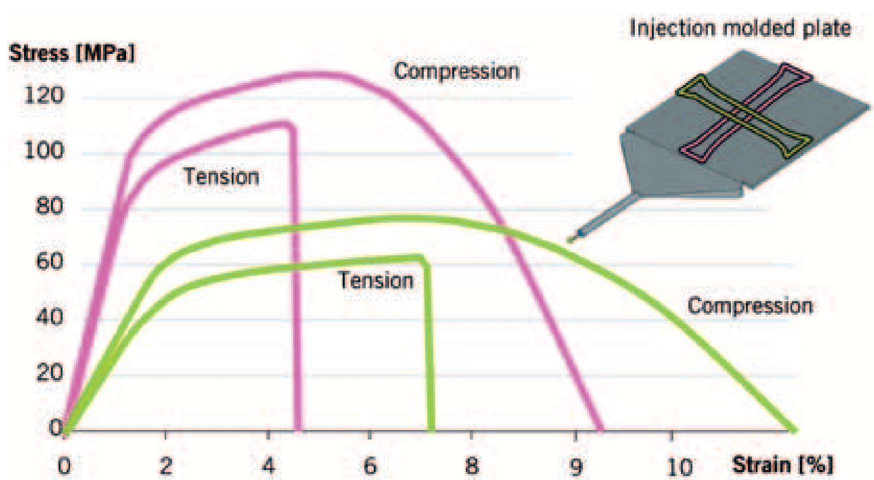
higher than under tension, on the other hand the failure mode under compression differs completely from that under tension. The energy that the material can absorb (indicated by the area under the curve) can be several times higher under compression than under tension.

The figure shows the simple case of a constant strain rate. There are, however, further relationships in the failure mechanism that cannot be shown even approximately using conventional material formulations. When employing failure models normally used for metals that are based on plastic strain, for instance, and calibrated for the most part only with the aid of simple tensile tests, a plastic component will exhibit different behavior than that predicted numerically. The reason for this is the complete and abrupt disappearance of elements in the finite-element analysis upon reaching a specified failure value. This approach is physically unrealistic and in a finite element analysis leads to physically unrealistic responses, and thus wrong predictions.

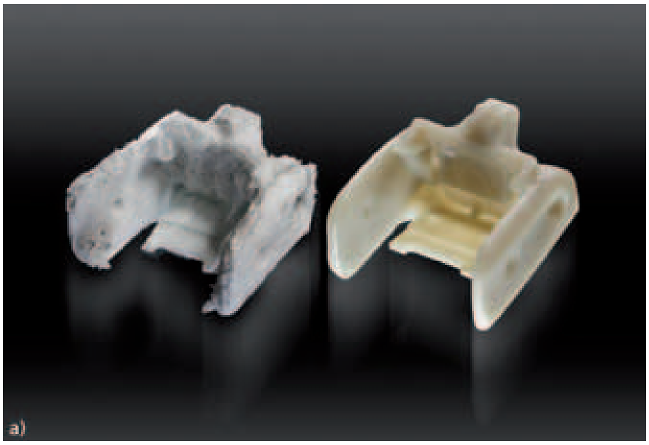
A complete description of the failure behavior after taking all of these factors into account is possible with the numerical methods employed in Ultrasim. A prerequisite for use of this highly sophisticated methodology is correct calibration of the material laws. In addition to high-speed tensile tests of anisotropic specimens, more material and component investigations are needed to obtain the required data: this knowledge is available for the BASF plastics used to date in crash-related applications [3].

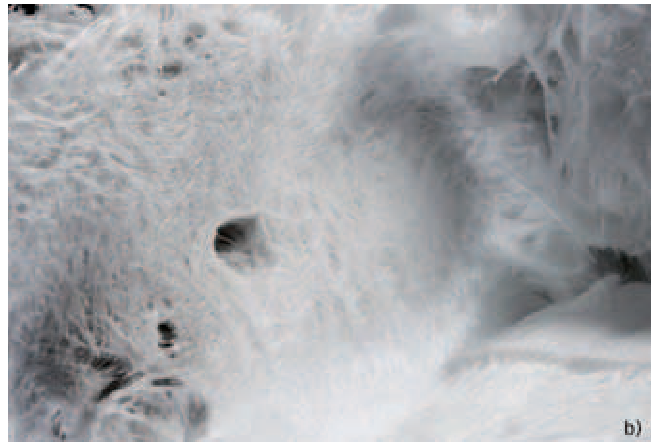
IMPROVED PERFORMANCE WITH LONG GLASS FIBER-REINFORCED POLYAMIDES

Only recently, however, BASF has developed a class of high-performance polyamides that better satisfy crash requirements than traditional plastics. At the K 2010 trade fair for the plastics and rubber industry,



❶ Example of stress-strain curves for short glass fiber-reinforced polyamide test specimens (lengthwise and crosswise); influencing factors include fiber orientation and the hydrostatic stress component





❷ a) The exceptional feature of components made from long glass-fiber-reinforced plastic is the three-dimensional glass-fiber network that forms during conventional injection molding (left, white), which imparts the end product – here, a ski binding component – with its outstanding physical properties; b) three-dimensional fiber network after ashing (enlarged photo)

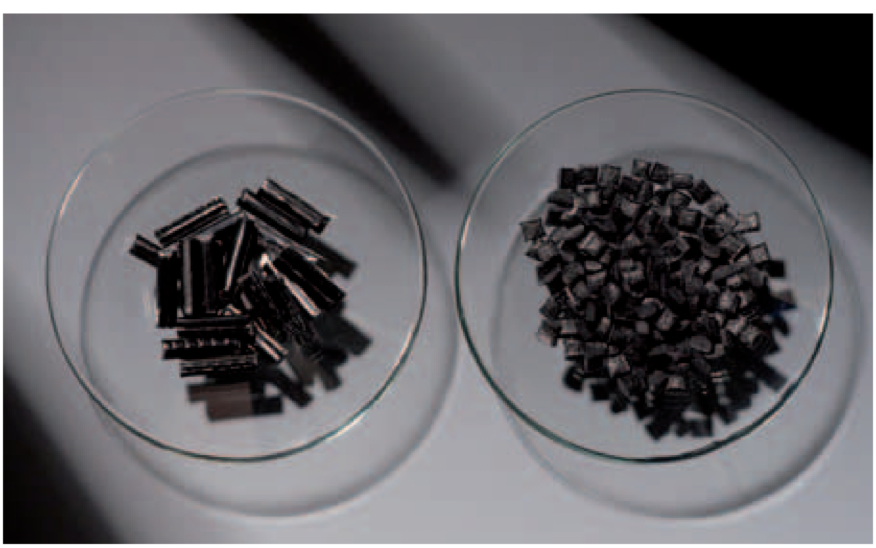
the company has introduced its new Ultramid Structure line of polyamides with long glass fiber (LF) reinforcement. This product group, which is new in BASF's portfolio, represents a considerable advance in terms of performance with metal substitution as the objective, since where even highly optimized short glass fiber-reinforced products reach their limitations, LF polyamides offer new opportunities.

The exceptional feature of components made from long glass-fiber-reinforced plastic is the three-dimensional glass-fiber network that forms during conventional injection molding, imparting the end product with its outstanding physical properties at both low and elevated temperatures. The fiber network forms the skeleton of the component and is retained even after ashing, ❷ a and b. This structure is the reason why the warpage, creep behavior and energy absorption of this material class already approaches the behavior of metals without losing the classical benefits of plastic.

With a favorable distribution of fibers in the molded plastic part, a three-dimensional fiber network of primarily three to six millimeter long fibers is formed directly without any significant additional effort. Processors can avoid major investment costs, and still gain access to a new sophisticated material: compared to classical reinforced polyamides with their only 0.3 millimeters long fibers, entirely new component characteristics are achieved, ❸.

These exceptional component properties come from the enhanced mechanical capabilities brought about by the long glass-fibers: the LF polyamide grades Ultramid Structure are very stiff and strong at elevated temperatures, while at low temperatures they exhibit outstanding impact strength. Favorable creep behavior, the minimal warpage and the far higher energy absorption – and thus crash performance – compared to conventional materials are further benefits, ❹.

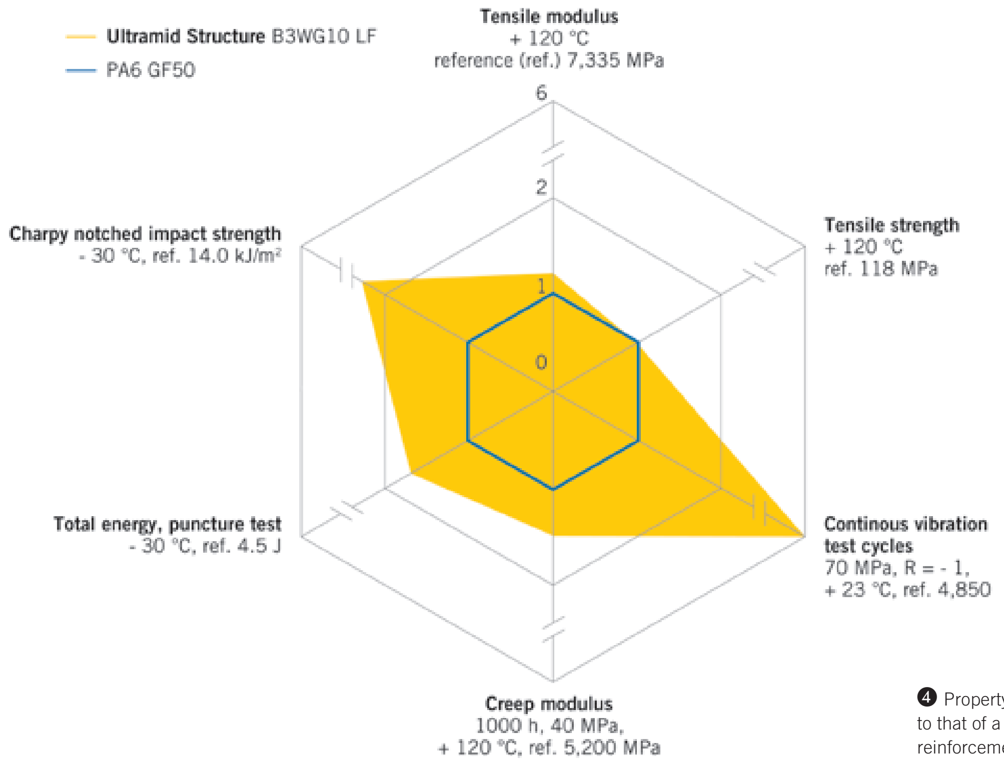
With the aid of these plastics, it is now possible to develop even more efficient and safer automobile components that must withstand high loads: these include engine mounts and inserts in seat structures, but above all crash absorbers which are intended to undergo controlled destruction upon impact in order to absorb as much energy as possible and thus protect the rest of the vehicle.



❸ Comparison of pellet lengths: Ultramid Structure (left) and standard polyamide with short glass fibers

SIMULATION OF LF POLYAMIDES

However, the benefits of LF materials for energy-absorbing structural components such as crash absorbers can be incorporated into simulations only through use of modified methods. First of all, it is necessary to describe accurately the fiber orientation that results during the filling process and which differs considerably from that found in short glass fiber-reinforced materials. In addition, the failure behavior must be described along with all important variables.



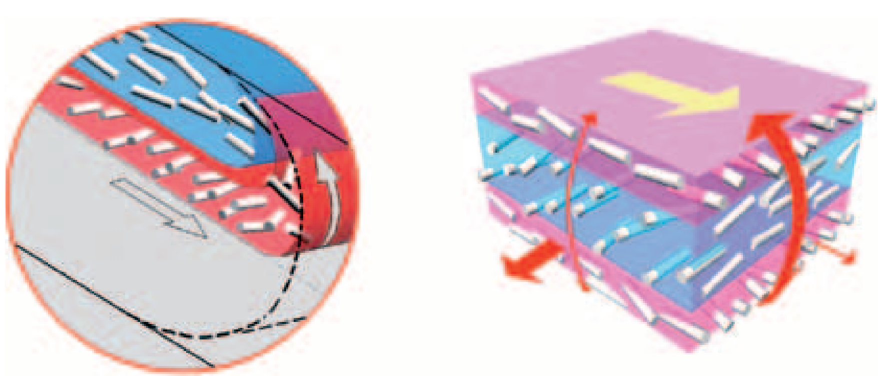
❹ Property profile of Ultramid Structure compared to that of a standard polyamide with short glass fiber reinforcement (50 %)

In the melt state, fiber-filled plastics are non-Newtonian in behavior (i.e. they demonstrate shear thinning). As a result of the rheology induced during injection molding, they exhibit a multilayer fiber orientation in the component that varies with wall thickness, ❺ [8]. Compared to the relatively thin middle layer found frequently in the case of short glass fibers, use of longer fiber results in a different distribution of layers over the wall thickness and varying degrees of orientation. This is related to the more pronounced interactions between the longer fibers [9].

DESIGNING A CRASH ABSORBER GEOMETRY – MATHEMATICAL OPTIMIZATION

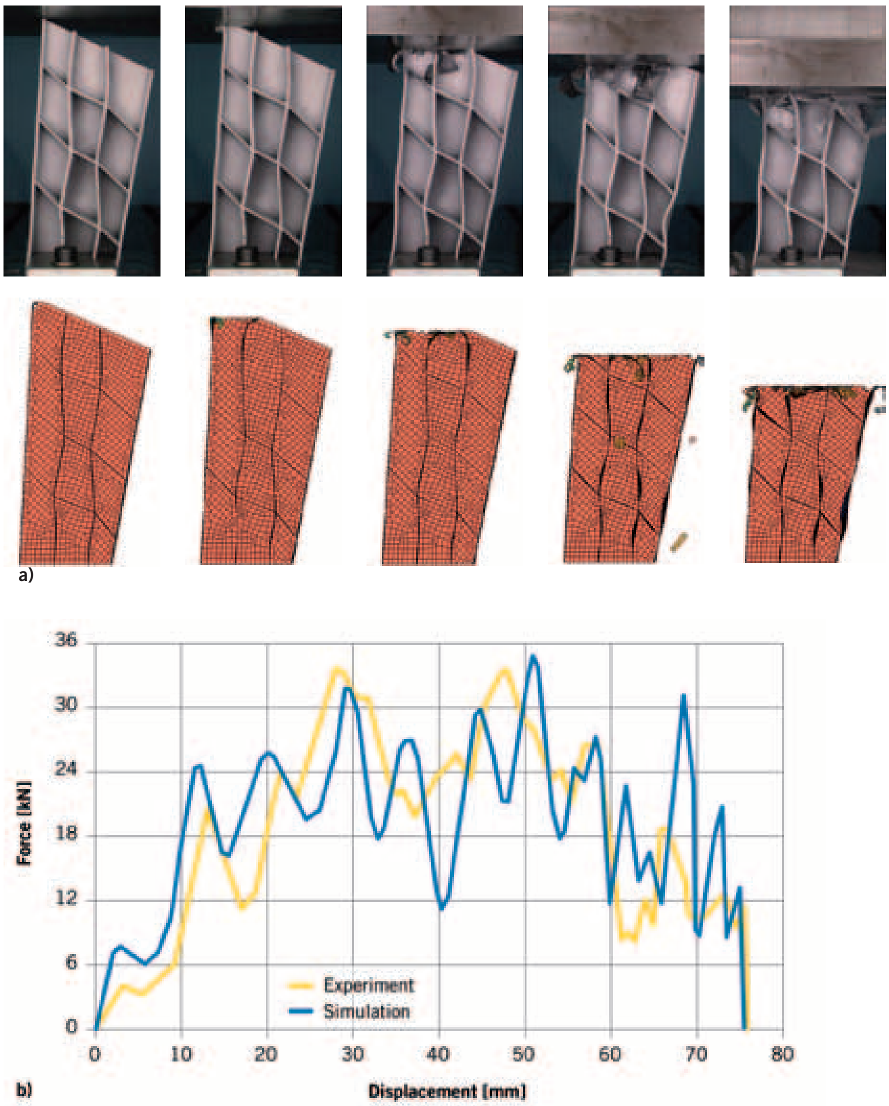
Components such as the Ultramid Structure crash absorber developed by BASF, ❻, are intended to absorb energy through controlled failure in the case of a crash. ❼ a and b show the real and calculated behavior of the component upon impact with a 60 kg mass moving at a speed of 25 km/h.

It can be seen that the structure fails from top to bottom ideally and in a con-



❺ The orientation of the fibers between the middle and skin layers of the component vary with the rheological properties of the resin – left: fiber transport during injection; right: fiber-containing layer arrangement in the compound

❻ The Ultramid Structure crash absorber (very similar to production parts), developed and manufactured in the BASF laboratory, provides the data for future projects with automobile manufacturers from both simulation and experiment; the dimensions of the part are 150 x 60 x 60 mm



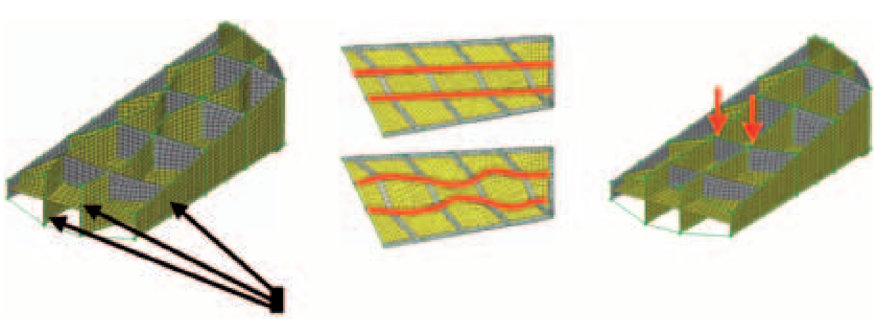
❼ a) The accuracy of prediction from the simulation is exceptionally high – above: real high-speed crash; below: simulation of the same event in Ultrasim; b) the figure shows the considerable agreement between experiment and simulation: The desired failure of the Ultramid Structure crash absorber upon impact is predicted and shown accurately using Ultrasim

trolled manner practically only at the contact point with the impactor. By using Ultramid Structure A3WG10 LF, an LF polyamide with 50 % fiber content by weight, 1500 J of energy can be absorbed over the impactor travel of about 75 mm. The approximately 150 gram component is only half-destroyed.

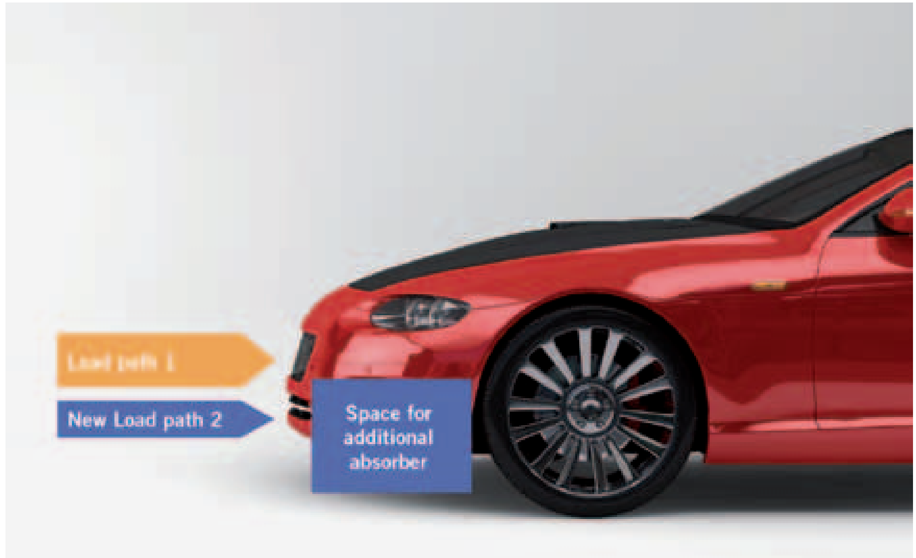
Failure modeling methods are necessary, but in no way sufficient to predict such component behavior. Instead of just a locally correct description of the material's behavior – meaning a correct calculation of the component – what is indispensible is the selection of the appropriate shape, that is calculation of the correct component.

This distinction is important, as otherwise the existing methods and plastic properties cannot be employed to obtain optimal results. To design the current absorber, an FE shell model was first created after selecting a basic shape, and then parameters for numerical optimization were assigned. In addition to three wall thicknesses, more geometry parameters are incorporated through use of morphing methods [10]. This makes it possible to affect the waviness of the axial ribs, while at the same time varying the initial linear axial height of the basic component shape, ❽.

The different wall thicknesses and geometry parameters serve as design variables during mathematical optimization. Maximum energy absorption is the objective of the optimization. The primary constraint is a maximum force that must not be exceeded. This forces the most uniform possible force distribution. Optimization is accomplished by means of a successive response surface technique with an approach based on radial basis functions for the metamodel [11]. The significance of the design variables with respect to system response can be established using correlations or variance analyses from a preceding screening. Even simple observation of the component's behavior with selected variable combinations permits a deeper understanding of the system: The intended, controlled and axially progressing failure is achieved only when the individual wall thicknesses are combined together properly.



❽ During morphing, a special type of shape optimization, each parameter – here, the three wall thicknesses (left), the rib deformation (center; above: zero; below: maximum) and the axial height (right) – is incorporated directly into the optimization problem as a continuous variable and contributes to improved part design on the basis of the selected optimization objective



❾ The crash absorber may be of interest in the future for the secondary load path at the front of the vehicle

STATE OF THE ART AND OUTLOOK

The long glass fiber-reinforced material Ultramid Structure was able to demonstrate its capabilities in numerous component impact tests using a variety of materials (varying matrix material, glass fiber content and length), ambient conditions (temperature/humidity) and impactor speeds. Compared to a short glass fiber-reinforced material, cracks propagate considerably less, so that the desired controlled, axially progressing failure is more readily achieved with the selected component shape. This observation agrees exactly with the impact strength values for LF materials determined from impact bending tests [12].

The amount of energy that can be absorbed with this component concept (in relation to component mass and size) makes this absorber especially interesting for use in the pedestrian protection zone (lower/upper leg impact) and in the secondary load path at the front of the vehicle, e.g. for energy absorption in a repair crash, ❾.

Using the procedures described here for failure modeling, component design on the basis of mathematical optimization methods and high-performance polyamides such as Ultramid Structure, the field of application for plastics in the automobile industry has been expanded significantly. With this combination of techniques and materials, additional – sometimes completely different – absorber concepts are possible that do not necessarily rely on the principle of controlled destruction, but rather on directed, calculable and adjustable force characteristics. Applications involving head impact on the vehicle's hood or occupant protection, for instance, are the object of current developments. In combination with lightweight metal shells or intelligent metal reinforcements, hybrid solutions are also possible in modern vehicle concepts: innovative components that were totally inconceivable in plastics a few years ago.

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