# Simulation right through to Failure

## Crash Simulation with Plastic/Metal Hybrid Parts

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Structural parts for the automotive sector are being increasingly produced by hybrid technology. Newly-developed computation methods developed specially for crash simulation assist the design engineer with part design.

Crash simulations provide a means of assessing the deformation behaviour, load-bearing behaviour and energy absorption of parts for the automotive sector at the design stage already. So far, Bayer AG has used these calculations primarily in the design of instrument panels, door liners and bumper trim in plastic. The increasing importance of hybrid designs, in the form of plastic/metal composites, in exposed areas of the body calls for systematic computation models for the crash behaviour of these parts too.

By contrast to static and strength calculations of a general nature, the simulation of crash behaviour involves large-scale deformation, right through to destruction of the part. The different parts are subject to varying requirements as a function of their field of application. In the vehicle interior, for instance, it is primarily behaviour in the event of head or knee impact that is of relevance. In this field of application, the component is required to absorb as much energy as possible and must not splinter in the event of fracture. The bumper trim used on the car exterior, by contrast, is expected to ensure that only defined components are destroyed in the event of a low-speed rear-end collision. The damage classification applied by the car insurers is based on these results.

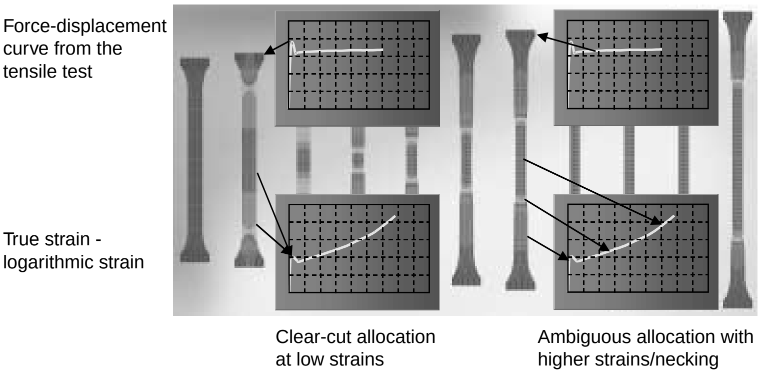

*Fig. 1. Correlation between the force-displacement data from the uniaxial tensile test and the true stress-strain relationship taking the example of PC/ABS (Bayblend T65)*

Typical fields of application for crash simulations in the vehicle interior include instrument panels, door and column trim and, more recently, hybrid parts such as module supports for instrument panels and seat structures. On the vehicle exterior, additional parts are coming to join the bumper trim that has already been referred to, such as front ends, bumper beams and frame structures for doors, flaps and roof structures.

### Simulation of Highly Dynamic Processes

The crash simulation is based on a material model which can be used to establish all the characteristic values that are of relevance for a crash. These include the energy absorption of the structure and the “Head Injury Criterion” (HIC), which record precisely what happens to a part during a crash. For this, it is necessary to have knowledge of the material behaviour as a function of the strain rate. Once this is known, it is then possible to draw conclusions as to how the material behaves when it is subject to rapid or slow stressing.

The description of the temperature dependence also constitutes a key component of the material model, since the physical properties of a polymer change with the temperature of the part. The decisive innovation, however, is the modelling of material failure with the aid of computation programs. As a general rule, crash calculations for body parts work on the basis of metal parts being buckled and do not make allowance for tearing or fracture.

In the case of hybrid parts, failure can at times occur if a high level of deformation prevails, with energy being absorbed by the structure as a whole. What is important here is to realistically model the local stress and strain states, together with the material failure, so as to ensure that reliable statements can be made.

### Basic Data: A Differentiated Assessment of the Tensile Tests

In order to establish appropriate data for the material model, tensile tests are conducted at different temperatures, take-off speeds and hence strain rates. The critical failure strain can then be determined by approximately converting the force-deformation diagrams into curves of true stress versus true (logarithmic) strain. This data is then channelled into a computation program which is used to simulate the tensile test as the first step. The simulated tensile test, however, will generally display deviations from the actual tensile test. These deviations result from the complexity of the true stress-strain behaviour when the tensile specimen suffers necking as it attains the critical load level. At the start of the tensile test, the specimen only stretches to a minimal extent, and a uniform stress state prevails in the tensile specimen. If necking occurs in the course of the tensile test, however, a second, smaller stable cross-section will result. In accordance with the conservation of volume, the necking runs towards the point at which the tensile specimen is clamped.

When the different stages of the test are observed on the force-displacement curve, a clear correlation is seen between the two curves up to the point of necking (Fig. 1). This means that a specific force can be allocated to a defined stress, for example. After necking, the states are no longer distributed evenly in the specimen. A number of stable states can be pinpointed on the stress-strain curve which belong to a point on the force-displacement curve. According to this, there is no longer any clear-cut allocation of the force-displacement curve to the true stress-strain ratio after necking. In these

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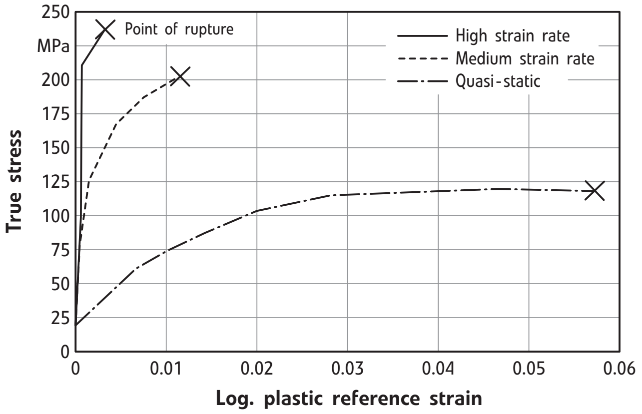

*Fig. 3. Material data for the "Erlangen Beam" crash computation (Durethan B, 30 % GF)*

cases, the stress-strain curve cannot be calculated directly from the simulation but must be established iteratively. The material law parameters are altered until such time as the best possible match is achieved between the force-displacement curves obtained in the simulation and through experiments.

The situation is similar for the strain rates. When the test bar is stretched, the strain rate is no longer distributed uniformly over the bar after necking. At the point where the necking takes place, the strain rate is up to 30 times higher than the technical strain rate at which the test bar as a whole is stretched. For this reason, the relevant strain rates may also have to be corrected iteratively. These alignments call for a great deal of know-how, since it is not possible to achieve reliable simulation results without precise material data.

The material model also makes allowance for the temperature dependence of the material values. Taking a (PC+ABS) blend, for example, it is possible to show that, with a constant stiffness, a simple exponential relationship exists between a temperature shift and the change in the loading rate within certain limits. The material becomes stiffer with more rapid loading and a falling temperature. Within these limits, the influencing parameters can be selectively substituted for each other in accordance with the time-temperature shift principle (WLF principle). This means that the property for a higher strain rate can be established by introducing the property value for a correspondingly low temperature. It makes sense to employ the WLF principle in cases where properties are not easy to measure due to very high loading rates or impact loads. By conducting a test at temperatures in the below-zero range, it is then possible to employ lower speeds.

## The "Erlangen Beam" Hybrid Structure Investigated

The computation model developed to satisfy these requirements by the Plastics Business Group at Bayer AG was applied to the so-called "Erlangen Beam" in the first instance. This is a hybrid structure made of a U-shaped steel-sheet profile that has lateral flanges and injected-in ribs in polyamide 6 with a 30 % glass fibre component (grade: Durethan BKV 30; manufacturer: Bayer) – Fig. 2. The relatively high glass fibre content means that no necking occurs here, and the tensile strain at break is lowered. This material involves the demanding task of converting stress-strain curves for different strain rates into a material law in a realistic manner and generating an appropriate, speed-dependent failure criterion (Fig. 3). The bottom curve represents a slow take-off speed. At higher speeds, the material becomes brittle and fractures at a lower strain but at a considerably higher stress level.

### Hybrid Structures ...

... make it possible to produce complex and ready-to-install structural components in just a few operations. A plastic structure is injected onto a deep-drawn, perforated steel sheet by the injection moulding process so as to produce a positive or non-positive connection that is capable of withstanding high loads. The composite material structure obtained in this way offers physical properties that cannot be achieved with homogeneous materials.

As a result, the load-bearing metal structures of the part can be designed with very thin walls, since the filigree plastic ribbing which is injected onto them reliably counters the tendency of these thin metal structures to buckle or bend under load. This means that, despite having very thin walls, the metal elements can be loaded closer to the material's yield point without suffering failure beforehand on account of geometric instability.

During the design of these innovative hybrid parts the chief focus was on achieving a constant high quality, minimising the weight and reducing the costs. The new front end module for the Audi A6 thus weighs around 1 kg less than the earlier version in a glass-mat reinforced plastic. On the Ford Focus, it proved possible to reduce the overall weight of the front end by 40 % compared with a solution in steel. Major savings can also be achieved on the production and investment costs through the integration of a large number of additional functions in the injection moulding process.

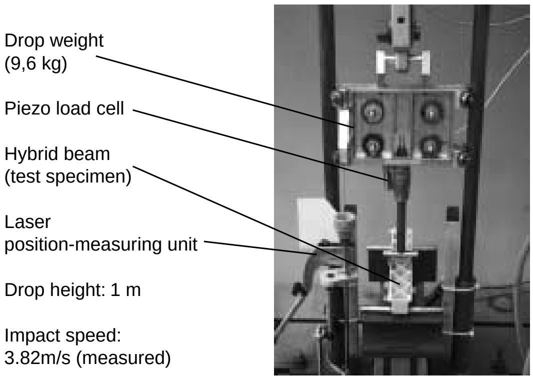

*Fig. 4. "Erlangen Beam" drop test: test setup*

The test setup for verifying the simulation results comprises a drop tower in which a 10 kg weight is allowed to drop onto the beam from a height of 1 m, with the beam resting on two supports (Fig. 4). The contact force is measured by a load cell as a function of the penetration depth. The result can be depicted in the form of a curve on which the force is plotted over the deformation displacement. This data was used as the reference for comparisons with the simulation results.

A total of three load situations were studied both experimentally and mathematically in the context of the development work. The beam was positioned with the open side pointing upwards, sideways and downwards. One of these configurations will be discussed here by way of example.

## Configuration "Open Side Pointing Sideways"

The "open side pointing sideways" configuration led to a lower deformation overall than the "open side pointing upwards" configuration (Fig. 5). When the simulation is compared with the experiment, very good agreement is achieved between the level of force and the deformation displacement. When viewed in detail, however, the fracture situation looks somewhat different in reality than in the simulation – something which is due to the strength of the moulded-on plastic with different loading directions.

The injection points survive the crash in the calculation but not in the experiment. The ribs, by contrast, buckle in the calculation, but this is not confirmed in the experiment. As a result, the ratio of the strength of the rib to the strength of the rib connection is not yet optimally balanced in the calculation – the connection is too strong by comparison with the rib. These are local effects and there is still scope for optimisation, such as in the modelling of the rib connection. All in all, the energy absorption and the deformation behaviour tally well when the experiment and simulation are compared. This agreement is also clear from the force-displacement curve for the “open side pointing sideways” configuration (Fig. 6). Here, the contact force is presented over the deformation for different sets of results. The blue curve shows the results of the experiment, while the simulated curves were calculated with strain-rate-dependence on the one hand (red) and without it (green) on the other. Good agreement is seen in the deformation for the measurement and the simulation with strain-rate-dependence – in other words, in the computed version, the falling body penetrates the specimen just as deeply as in the experiment. The diagram additionally makes it clear that allowance must be made for the strain-rate dependence. Otherwise, the maximum deformation will not be predicted very accurately and the part will be “calculated as being too soft”. In this case, the deformation is not 25 mm as with the other results but 37 mm.

## Prospects

The verification of the material model on the “Erlangen Beam” proved to be successful and highly promising. In future, however, complex parts such as the front end of the Ford Focus (title photo) will need to be designed in purely mathematical terms in respect of their crash behaviour. In order to improve on the level of precision still further, it will be necessary to use, or develop, standardised processes which ensure that high-speed tensile tests can be performed and assessed as accurately as possible. One idea being considered here is video evaluations of the strain zone with the aid of speckled samples. It is also necessary to develop models for the different points where plastic is injected around or through the metal; these must display a high level of accuracy for all types of load and be suitable for transposition to models for the vehicle as a whole.

The decisive factor is that the material model should be designed in such a way that it is easy to use on the one hand, and allows valid statements to be made for all the different loading types, on the other. It is not necessary for the results of the simulation and the practical test to coincide precisely, but the basic statement ought to be reliable. In order to achieve this quality level, however, the underlying computation models for the material model must depict the true situation in a highly accurate manner.

## The Authors of this Article

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*Fig. 2. “Erlangen Beam“ hybrid structure investigated*
*Umspritzung bzw. Steg an der Oberkante der Profilwände = Moulded-on plastic or bar at the top edge of the profile walls; Stahlblech = Sheetsteel; E-Modul = Young’s Modulus; Kunststoffverrippung = Plastic ribbing*

*Fig. 5. Deformed hybrid beam in the “open side pointing sideways” configuration, simulation and test*

*Fig. 6. Result: measured force-displacement curve, simulation result with and without strain-rate dependence*
*Kontaktkraft = Contact force; Verformung = Deformation; Messung = Measurement; Simulation ohne Dehnratenabhängigkeit = Simulation without strain-rate dependence; Simulation mit Dehnratenabhängigkeit = Simulation with strain-rate dependence*