# POSSIBILITIES FOR THE USE OF METAL-HYBRID-STRUCTURES FOR VEHICLE CRASH LOAD CASES

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**ABSTRACT:** A major challenge of lightweight construction of car bodies, particularly with materials with high density, such as steel, is the need to use a very low wall thickness. This makes the structures susceptible to buckling, especially in crash load cases.

The DLR's institute of vehicle concepts therefore investigates the use of hybrid structures, for example by reinforcing the steel shell of a beam with lightweight cores. This leads to a higher stability of the structure, especially for the side impact or the pole crash, which results in a much higher weight specific energy absorption.

In order to maximize the performance, a specific balance between several parameters such as the wall thickness, the material properties of the core and material properties of the shell, must be achieved. A multi-parameter optimization was therefore conducted, using LS-Dyna and LS-Opt, in order to maximize the weight specific energy absorption. Also, the impact of different materials on the performance of such structures was investigated.

Possible uses for metal-hybrid structures are a rocker rail, or a door reinforcement, for example. They are also extensively used in the car body of a lightweight vehicle which is currently under development at the institute of vehicle concepts.

**KEYWORDS:** lightweight design, car body, crash behavior, metal hybrid structures.

## 1 INTRODUCTION

Conventional car body structures consist of metal shells, which are welded together to form hollow beams. These structures provide good strength and stiffness as well as low manufacturing costs, especially at high lot numbers. However, when they are subjected to a bending load, which is the case during a pole crash, for example, they are susceptible to buckling.

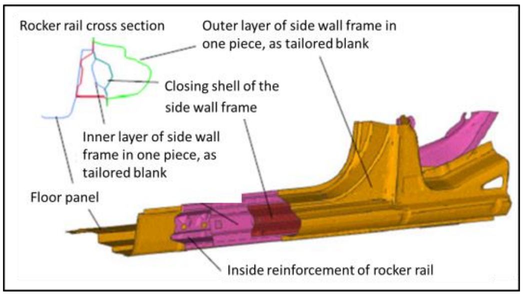

***Fig. 1*** *Audi A4 rocker panel [1]*

At the DLR institute of vehicle concepts, metal-hybrid structures are investigated in order to improve the crash behaviour of such car body parts.

The energy absorption of a rocker panel during the pole crash, for example, is typically only 20 % of the total energy absorption [2].

## 2 BASIC PRINCIPLE

In order to improve the rocker panel area, a metal hybrid design concept was investigated.

This alternative metal-hybrid beam comprises a steel shell surrounding a lightweight core. Fig. 2 illustrates the principle used. The part of the metallic shell of the beam, which is located on the backside in relation to the pole, is elongated. This Elongation of the metal absorbs the major part of the energy of the impact. In order to achieve this, the core of the member does not collapse when bent, but rather maintains the cross section throughout the bending process, thereby ensuring that the section modulus of the member ideally remains

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constant for the full duration of the deformation event. Due to the high degree of elongation on the rear of the section, the best-suited materials for the shell are those with good elongation properties while retaining tensile strength. An example for such a steel this is the HSD®-steel (High strength and Ductility), which was developed by the Salzgitter AG. An HSD®-steel combines, for instance, a yield strength of 620 MPa with a tensile strength of 1000 MPa and a total elongation of 50 % [4].

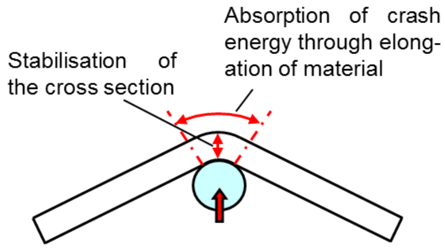


***Fig. 2*** *Energy absorption principle*

In order to investigate this energy absorption principle, initial simulations were carried out for varying core structures using the crash-simulation-tool LS-DYNA. For testing the model, a simplified three-point bending test was used with supports separated by 1368 mm and an impact pole with a diameter of 300 mm. The cross-section of the beam was configured to correspond to the internal reinforcement structure of the rocker panel in a reference vehicle (Fig. 3).

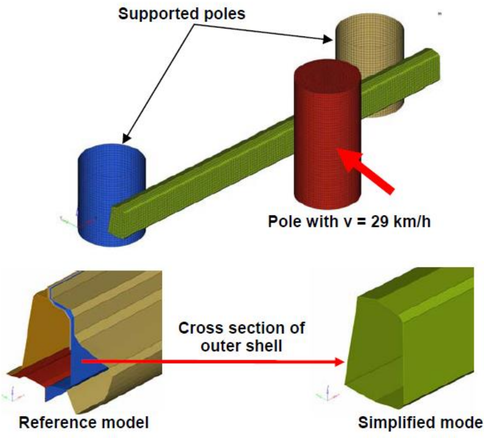


***Fig. 3*** *Geometry of the simulation model and the test setup*

## 3 RESULTS OF TESTING

In order to provide a baseline for the performance of these structures, the rocker panel from a simulation model for a reference vehicle was also subjected to the same 3-point bending test. A comparison with the reinforced-core rocker panel structures shows that, for the load cases considered here, the ratio of energy absorption to component mass can be increased to more than double that of the reference structure through use of appropriate core structures, albeit that, at least in the case of the foam-core variant, the component mass also increases. The result is that the crash load on the surrounding vehicle structure, e.g. the floor pan, is decreased. This opens up the possibility that these structures could be dimensioned with thinner walls, or even made out of different materials.

In order to verify the simulation results, the geometry of the reinforcement section was simplified to allow a more cost-effective manufacturing and a simple test configuration Fig. 4.

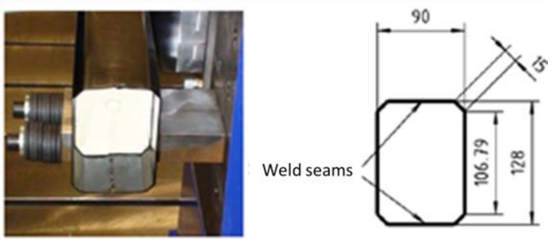


***Fig. 4*** *Cross section through foam-reinforced test component*

These sections were manufactured by welding together two 2 m long half sections of DC04 steel.

In this instance, the core structure was formed from PU foam with a density of 400 kg/m³, manufactured by the DOW Chemical Company. DOW automotive selected a material variant that was suitable for the crash requirements and this was injected into the section via 2 holes.

The sections produced in this fashion were subjected to quasi-static testing on the hydraulic 3-point test rig at the Institute, with the geometry of the test configuration set to correspond to that used in the simulation (Fig. 4).

Testing was conducted with a low penetration speed of 6 cm/s and demonstrated that the proposed principle could be implemented in the real world. Hollow sections with identical geometry were used to provide a benchmark for the anticipated improvements. Using the foam-filling technique, it proved possible to increase the energy absorption by nearly six times of that of the hollow section (Fig. 5), although the absolute component mass itself increased by a factor of 1.7. Consequently, an increase of the mass specific energy absorption by a factor of 3 could be achieved.

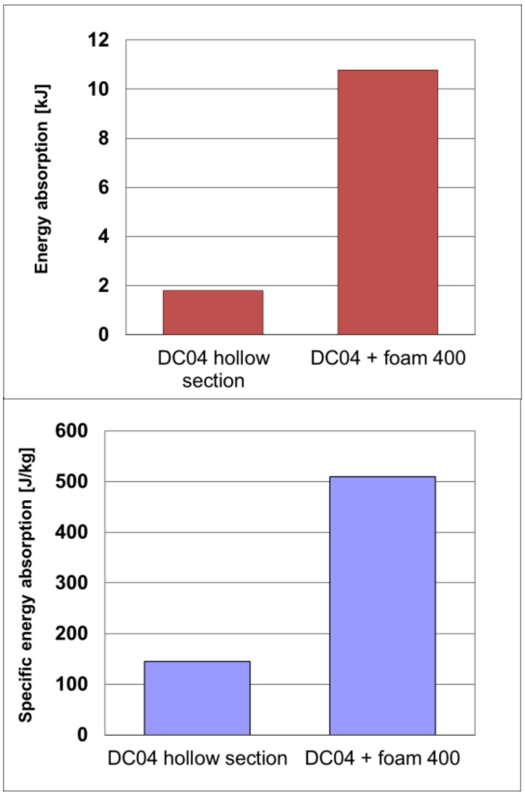


***Fig. 5*** *Energy absorption and mass-specific energy absorption of foam-filled beam compared to a hollow beam with identical geometry*

The foam core prevents the formation of a pronounced fold on the compressed side of the section (see Fig. 6), with the cross section instead remaining relatively constant throughout the deformation process. This property is also mirrored in the force-displacement curve for the section measured during the test (Fig. 7). This stabilisation of the cross section through use of the foam core means that the force required to produce the deformation doubles. The level of force required is increased right from the start and is maintained throughout the whole process. At 420 mm penetration, the point is reached at which the material tears on the side of the section under tension, leading to a large decrease of the force level.

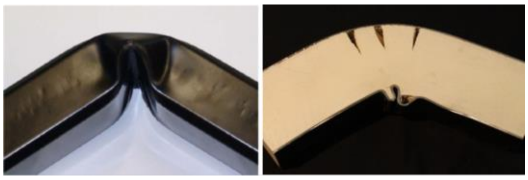


***Fig. 6*** *Formation of fold on compressed side of hollow (left) and PU foam-filled (right) sections*

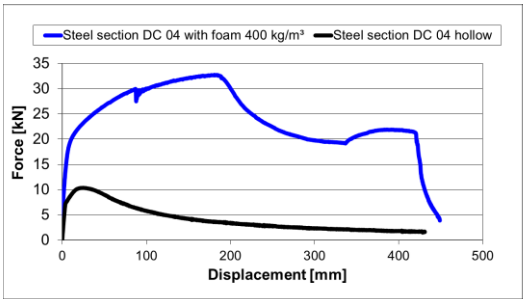


***Fig. 7*** *Force-displacement curves for hollow and foam-filled sections*

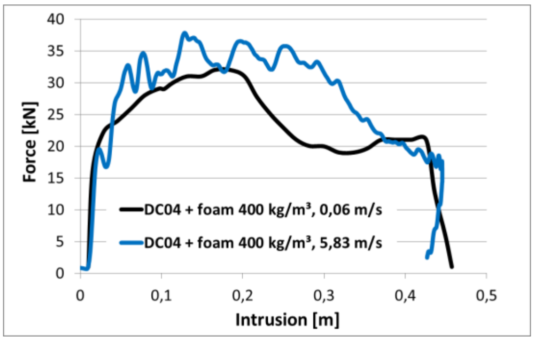


***Fig. 8*** *Dynamic 3 point bending test*

A dynamic 3-point bending test was also performed on the crash facility of the institute of vehicle concepts and results in a slightly higher force level, compared to the static test (Fig. 8).

## 4 OPTIMISATION

Folding of the compressed side of the beam was found to be a major limitation to the energy absorption of the beam, especially, if a material with higher tensile strength is used. Generally, this folding occurs earlier during the bending process, if the strength of the steel shell is increased in relation to the compressive strength of the foam core.

Using LS-Dyna, a foam filled beam made of HSD®600, with a foam core of 200 kg/m³, was simulated, with increasing wall thickness (Fig. 9).

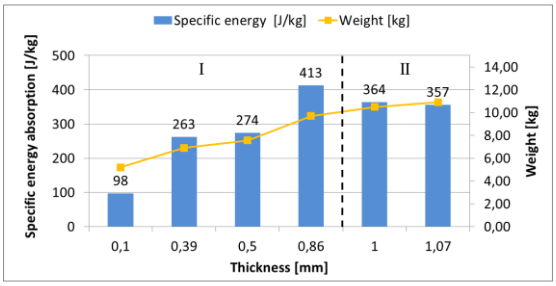


***Fig. 9*** *LS-Dyna results for weight specific energy absorption for varying wall thickness of a foam filled HSD®-beam*

The results can be separated into three phases. During phase I, Starting from 0,1 mm, increasing the wall thickness leads to higher values of specific energy absorption.

A local optimum is achieved, at a thickness of 0.86 mm, which marks the beginning of phase II. Increasing the thickness further, leads to a drop in weight specific energy absorption. At a higher wall thickness, the ability of the foam core to prevent buckling of the compression side, is reduced, which, in combination with a higher weight of the beam, leads to a decrease in specific energy absorption.

A second method that was investigated, is the selective use of different material and/or wall thickness for the compressed side. A very high strength steel, with a tensile strength of about 1300 MPa is used on the compressed side, whereas the rest of the beam is made of HSD®600, which has a yield stress of 620 MPa (Fig. 10). An optimisation was then performed, using LS-Opt, a software for meta-model based optimisation, for a beam with a foam core of 200 kg/m³ density. The wall thickness of both materials was then varied between 0.1 mm and 3 mm. The goal of the optimisation was to achieve a maximum weight specific energy absorption during 3 point bending, which was achieved at a thickness of 3 mm for the high strength steel and 0.82 mm for the HSD®600, with a weight specific energy absorption of 595 J/kg (Fig. 11).

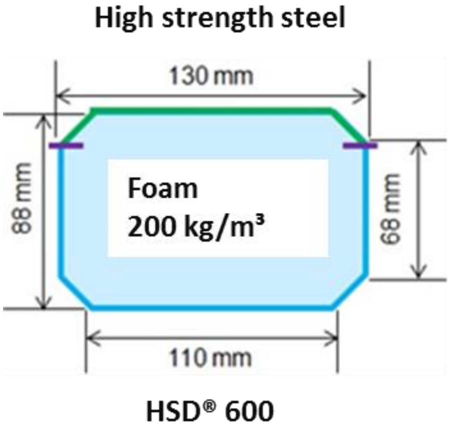


***Fig. 10*** *Hybrid beam with two different materials in the shell*

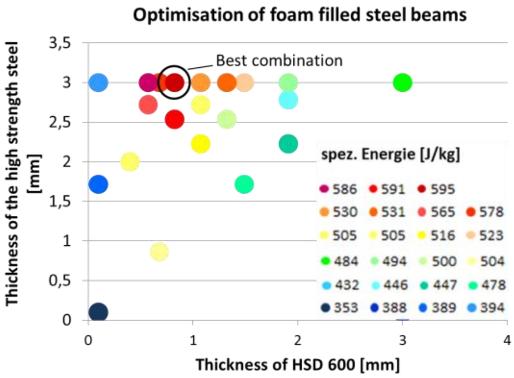


***Fig. 11*** *Optimisation of the weight specific energy absorption*

# 5 APPLICATIONS

## 5.1 Ring-shaped frame

As explained in chapter 2, the core structure of the hybrid beam stabilises the cross section during bending. Therefore a comparatively large area of the outer shell is elongated, leading to a high energy absorption. This basic principle was developed into a ring shaped frame structure (Fig. 12) for use as a central structural member in a lightweight car body. The ring shape leads to a wide distribution of the occurring strain, even in load cases with a highly concentrated load, such as the pole crash. The car body is completed by relatively simple, lightweight sandwich structures, used for the front and rear structure, the seat bench and the tunnel, and weighs only 85 kg. The crash behaviour was investigated by LS-Dyna simulation, resulting in intrusions in different load cases, which are comparable to a conventional car body, that was used as a reference (Fig. 13).

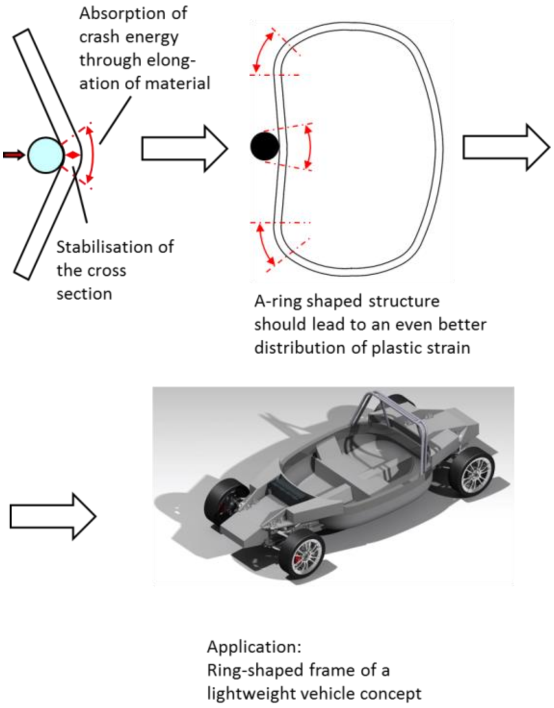
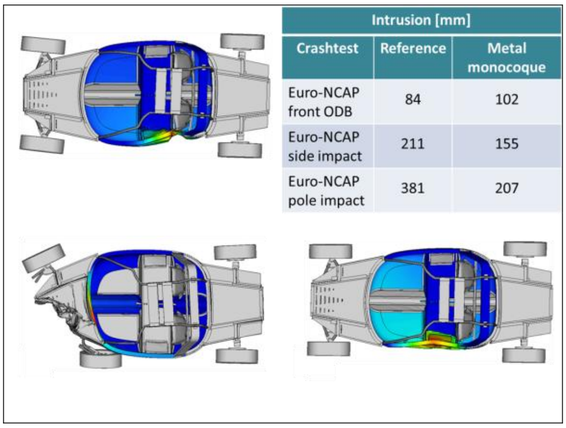


***Fig. 12*** *Development of a ring shaped frame for a lightweight vehicle concept*



| Intrusion [mm] | | |
|---|---|---|
| Crashtest | Reference | Metal monocoque |
| Euro-NCAP front ODB | 84 | 102 |
| Euro-NCAP side impact | 211 | 155 |
| Euro-NCAP pole impact | 381 | 207 |

***Fig. 13*** *Crash behaviour of a lightweight car body*

### 5.2 Door reinforcement

Because of their deformation mode, all load cases, where structures are deformed by bending are generally suited for an application of metal-hybrid-structures. Therefore, a door reinforcement was investigated, by simulation. A conventional door was modified and fitted with a y-shaped reinforcement, consisting of metal-hybrid-beams. The door intrusion was simulated according to FMVSS 214 (Fig. 14 and Fig. 15). Compared to a reference door, the modified structure is 18 % lighter, with a 17 % higher energy absorption. The maximum resistance against deformation was also increased, by 14 %.

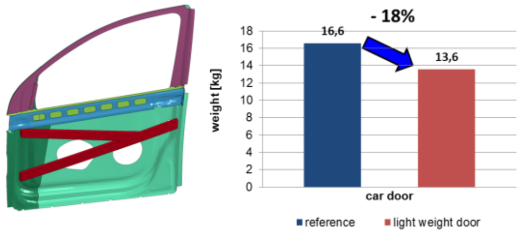


***Fig. 14*** *Y-shaped door reinforcement*

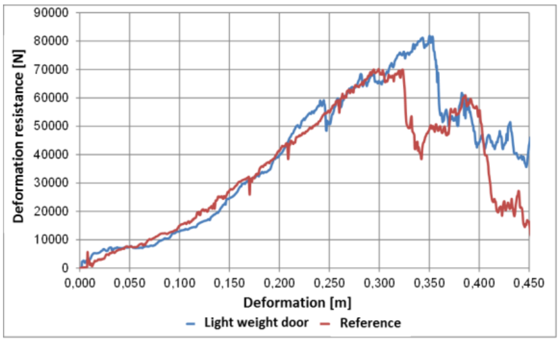


***Fig. 15*** *Deformation and deformation resistance of a lightweight door and a reference*

## 6 CONCLUSIONS AND DISCUSSION

Metal hybrid structures have shown great potential in crash load cases especially during bending. A foam filled steel beam was tested to have a 3 times higher weight specific energy absorption, compared to a hollow beam. The energy absorption of such beams can be increased even more by optimisation of the wall thickness and/or material properties of the hybrid beam’s outer shell.

The specific deformation behaviour was used for the design of the passenger compartment of a lightweight car body, as well as the modification of a door. Significant weight savings were achieved in both cases, with very good crash behaviour.

Even though results of simulation and testing show a similar increase in crash performance, the absolute values of energy absorption may differ by approximately 20 %. One reason for this is the difficulty of accurately modelling the properties of the sandwich core, especially the behaviour during failure, for example the formation of cracks during tensile failure. Research is currently being conducted at the institute of vehicle concepts to provide a more detailed description of the material properties of foam cores, and thus improve the predictions of FE-simulation for this class of materials [3].

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