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Fe-Mn-Al-Si-steels, lightweight potential for cars, trucks and trains

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1 Introduction

In recent years, the interest of the automotive industry in construction materials with enhanced strength increased. However, steel is still an important material that can satisfy such demands, both, technically and economically.

Advanced High Strength Steels have been established in the recent years. At present a special class in this steel group is based on the iron-manganese alloying system and commonly referred to as either TRIP- or TWIP-steels. The unique properties of these steels exceed the properties of conventional carbon steels.

Salzgitter AG has furthered the development of TWIP-steels and the result is a density-reduced iron-manganese-aluminum-silicon alloy called HSD®-steel (**H**igh **S**trength and **D**uctility). One of the main characteristics of HSD®-steels is their relatively low manganese level, whilst still maintaining the good mechanical and technological properties typically exhibited by iron-manganese TWIP-steels [1].

Within this paper the mechanical and technological properties of such iron-manganese TWIP-steels will be discussed, as well as the potential of weight reduction in the automotive industry and for future railway concepts.

2 HSD®-steel, mechanical and technological properties

The HSD®-steel is characterized by its combination of high strength and however high formability. This unique combination ranks the material well above the properties achieved by those of conventional carbon steels. The mechanical properties are even better than those of austenitic stainless steels. The higher levels of Si and Al ensure optimum mechanical and technological properties and furthermore reduce the material's density, where a typical level for HSD®-steel is 7,4 g/cm^3 at room temperature (-5 % less than conventional carbon steels).

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The enhanced mechanical properties of the HSD®-steel are caused by two main deformation mechanisms: dislocation generation/motion and micro-twinning. Typical mechanical properties of the group of HSD®-steels are shown in **table 1**.

table 1: Mechanical properties of HSD®-steels.

		HSD®600	**HSD®900**	**HSD®1100**
$R_{p0.2}$	[MPa]	620	920	1120
R_m	[MPa]	1000	1150	1250
A_{80}	[%]	50	30	17
Young's modulus	[GPa]	180	180	180
Density	[g/cm³]	7.4	7.4	7.4

A comparison of mechanical properties between the HSD®-steels with conventional steels already utilized in the automotive industry is shown in the strength-elongation diagram in **figure 1**. The potential of weight reduction (high strength in combination with high total elongation) is also illustrated by the stress-strain curves established by tensile tests for the derivates HSD®600, HSD®900 and HSD®1100 (see **figure 2**) and by the forming limit curves (see **figure 3**) for sheet thicknesses (t) 0.7 mm up to 0.9 mm.

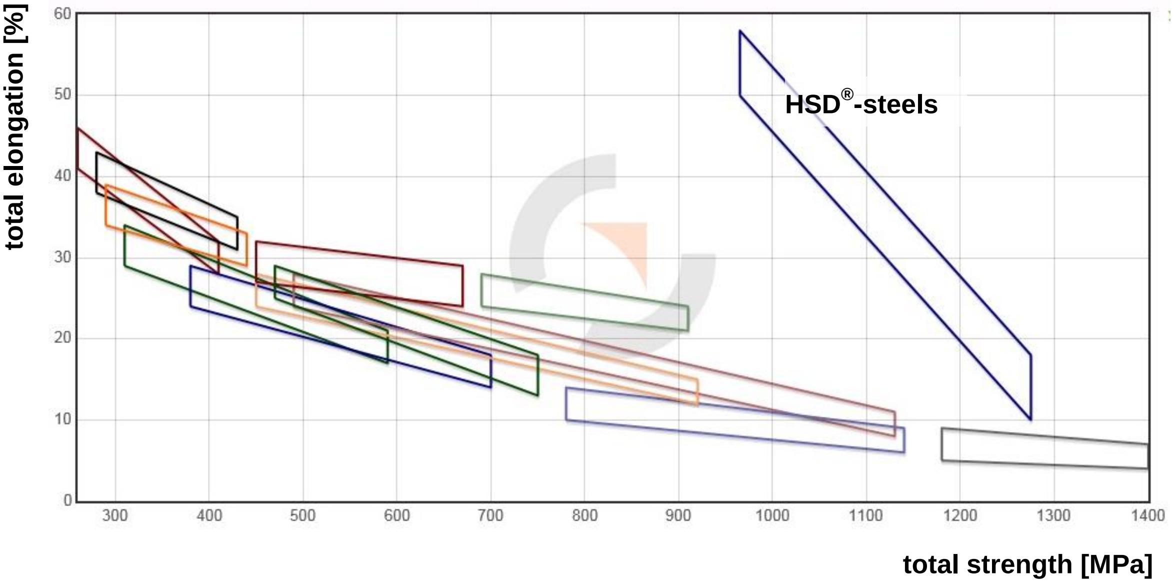


figure 1: Strength-elongation-diagram.

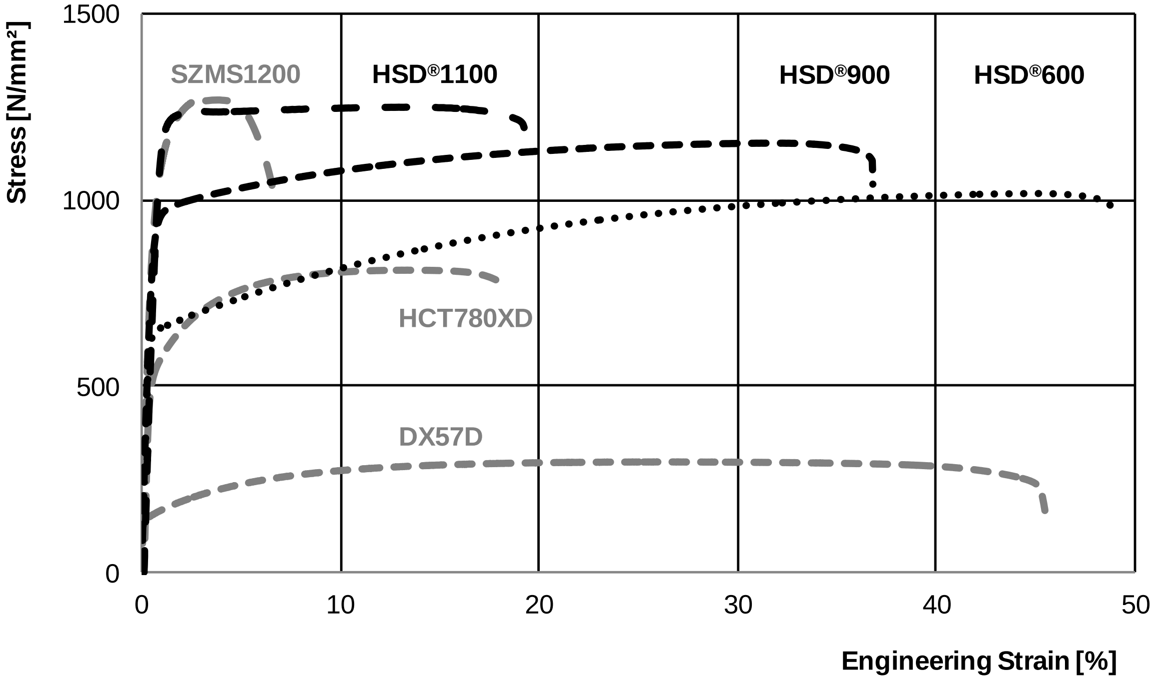


figure 2: Stress-strain-curves HSD®-steels and conventional steels.

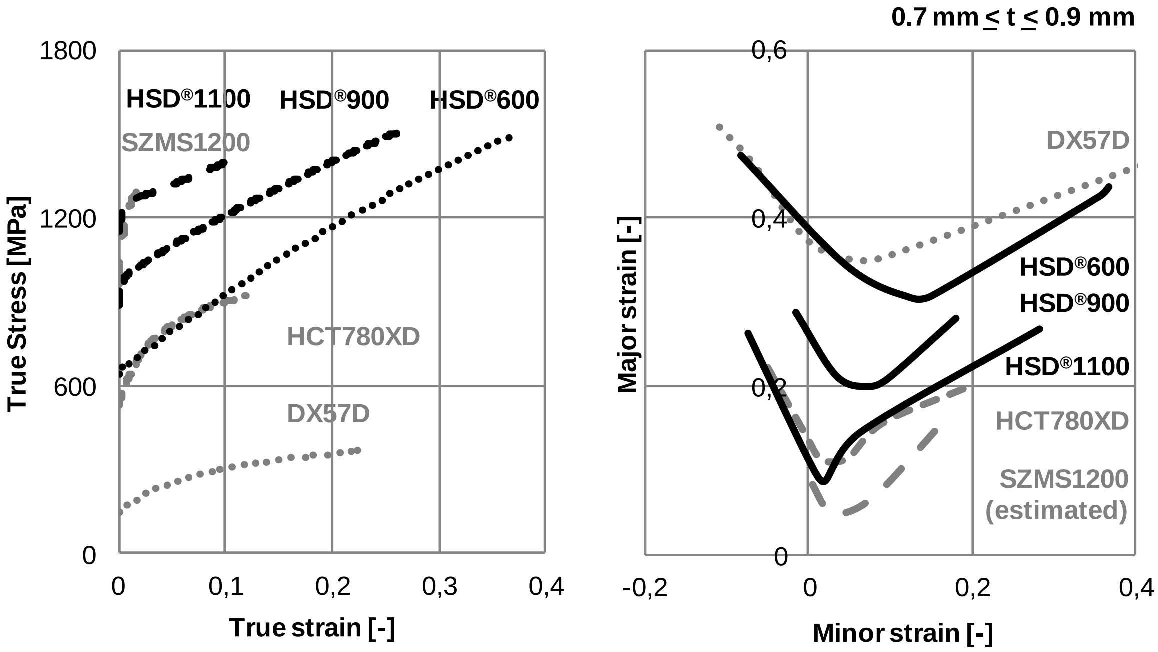


figure 3: True stress true strain curves (left) and forming limit curves (right).

These examples for the mechanical and technological properties are initially established results. Before a new part is considered, usually an extensive test program is conducted with designs, forming and testing in cooperation with potential partners. For example, the following aspects were taken into account for a discussion within a pre-serial development project:

- surface technology:
    - galvanizability
    - liquid metal embrittlement (LME)
- forming technology:
    - comparison with other AHSS
    - springback
    - resistance against hydrogen induced stress cracking / delayed fracture (DF)
- joining technology:
    - resistance spot welding (hot cracking, failure criteria, …)
      new state of technology [2]
    - laser welding
    - arc welding (specific filler wire developed, …)
    - mechanical joining

3 Potential for weight reduction

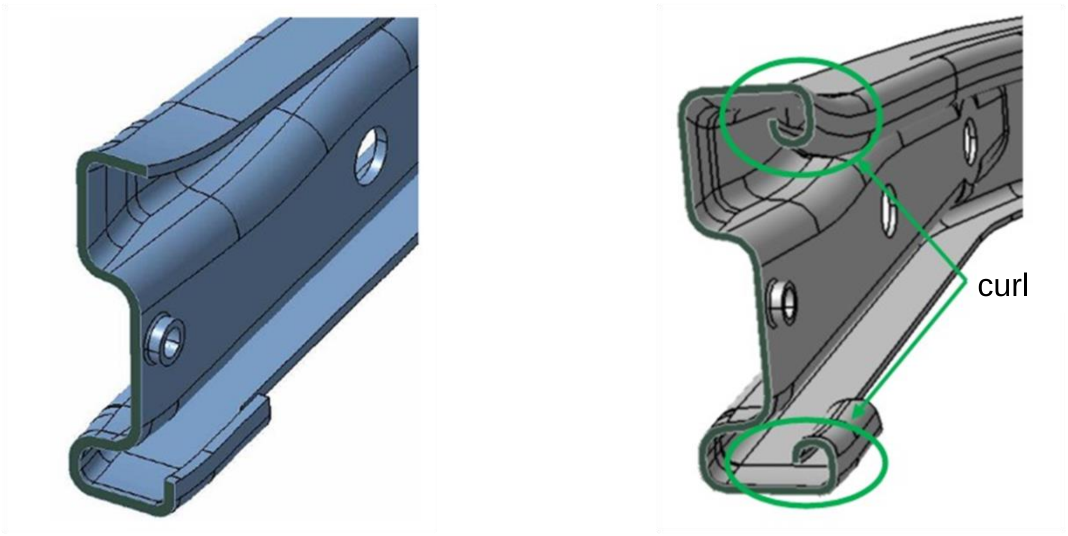
In the following section, the light weight potential of the HSD®600 and the HSD®1100 will be shown with selected pre-serial development projects; a seat side member, in cooperation with Volkswagen AG, Wolfsburg, further a door beam / side impact beam, in cooperation with Audi AG, Ingolstadt, and a one-piece rear bumper concept, in cooperation with Kirchhoff Automotive, will be discussed. Finally, a non-automotive pre-serial development project, with a crash system made of HSD®600 for the Next Generation Train (Railway), in cooperation with DLR Institute of Vehicle Concepts, Stuttgart will also be presented.

3.1 Seat side member

A seat side member, as shown in **figure 4**, is a component carrying a high crash load. With the advantages, that a seat side member is only painted (not galvanized) and in some case don’t need a welding process to be integrated into the lower seat structure; this component was suitable to evaluate the possible energy absorption under crash conditions. Typical crash loads for a seat side member are cargo load, rear crash, and front crash. In order to estimate a possible gauge reduction, finite element forming-simulation and finite element crash simulation have been carried out. These simulations show that a weight reduction by 30 % can be achieved even if the links and overall dimension of side members would remain the same. After completing the feasibility study, prototypes made of HSD®600 at 1.5 mm thickness were realized and tested with above mentioned crash cases.

figure 4: Seat side member made of HSD®600.

Since the seat side member is not only a strength relevant component but also a stiffness related one; in a second step the overall stiffness was improved in such manners, that the outer regions of the C-shaped part were curled inwards, as shown in **figure 5**. With that improvement the weight reduction could increased to 38 %, compared to the serial part, made out of an HC420LA with the thickness of 2.0 mm [3].



serial geometry adapted geometry

figure 5: Seat side member with serial and HSD®-adapted geometry.

3.2 Door -beam / side impact beam

Within the scenario of a side impact the side impact beam plays an important role, together with the sill or the lower car structure. The potential either of an improved crash performance or a reduced weight was shown on prototypes made of HSD®-steel, compared to the serial part made of a dual phase HCT780XD.

Similar to the seat side member project (see **paragraph 3.1**), a finite element simulation (forming / crash → 3-point-bending, **figure 6**) was carried out first, to establish the feasibility of the project. After proving the potential, prototypes made of HSD®1100 (similar FLC as HCT780XD, higher strength level + 500 MPa) were produced (**figure 7**).

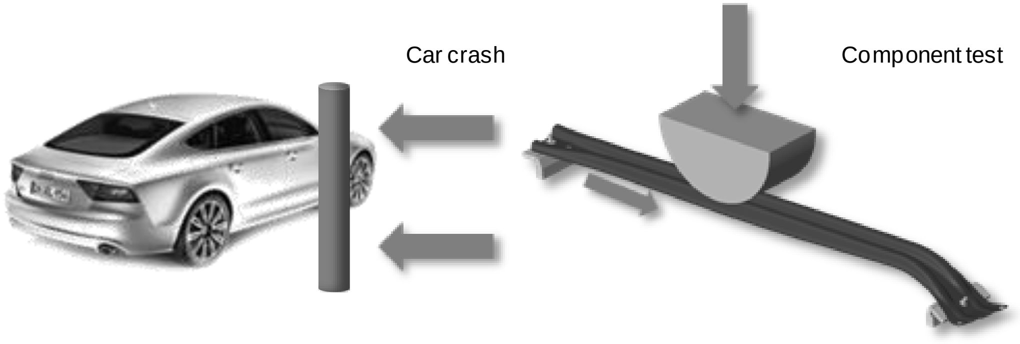


figure 6: Vehicle crash (left) and quasi-static component crash (right).

figure 7: HSD®1100 prototype, side impact beam.

These prototype components were tested. Due to the fact, that the geometry was kept the same and the thickness was reduced from 1.25 mm (serial part) to 1,0 mm (HSD®1100 prototype) a geometry with a deeper profile of the bead is needed to fulfill the demands (reference curve, 3-point-bending), **figure 8**.

With the formability of a HSD®1100, a 4.0 mm deeper bead was possible, such that the reference curve could be surpassed, showing that a weight reduction of 17 % can be achieved, if the part design meets the material possibilities [4].

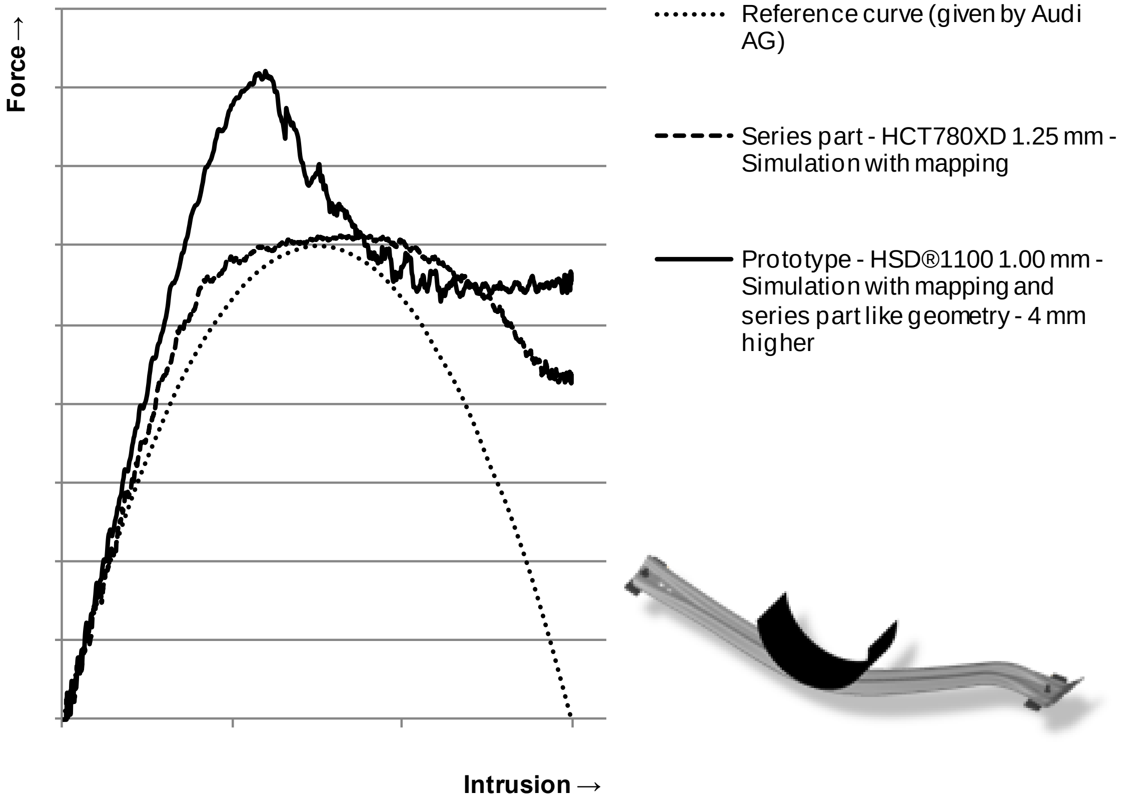


figure 8: Performance of adapted geometry.

3.3 Single-piece rear bumper demonstrator

Material based design for the demonstrator of a single-piece rear bumper is a good example to illustrate the possibilities of part integration with a high strength and ductile steel.

An automotive bumper design in many cases consists of a welded assembly containing two base plates, two crash-boxes (made out of 2 half-liner) and a bumper (sometimes even with a closing sheet underneath). All these parts are made of high strength steels. The position of such a bumper system is shown in **figure 9** (left side) and the design of the one-piece rear bumper demonstrator is enlarged in **figure 9** (right side).

position of a rear bumper system [5]

single-piece rear bumper demonstrator [5]

figure 9: Position of rear bumper demonstrator.

Utilizing the good formability of the HSD®600 and its high work hardening potential (**figure 3**, left side) the complex geometry of the single-piece rear bumper demonstrator (**figure 9**, right side) was produced within one forming step and intensively tested under quasi-static loads (**figure 10**).

The demonstrator shows a good energy absorption without cracks in the folding areas and therefore indicates the possibilities for a simplified single step production process as well as a component reduction due to functional integration.

figure 10: Test setup for one-piece demonstrator.

3.4 Train (Railway) crash system

For new railway wagons, care is taken to prevent a pile-up of the wagons during a crash. In order to achieve these goals, crash zones are equipped at the front and the rear end of the wagons. A crash-concept was established with very high energy absorption after intensive analyses regarding different concepts. The outcome of these research activities shows that tubes formed in a conical die (**figure 11**) demonstrate a constant force level along the length of the tube. The combination of the crash-concept layout and the advanced crash performance of a HSD®-steel showed the highest specific energy absorption of all investigated concepts. Another positive effect is the possibility to integrate the crash elements in the load bearing structure.

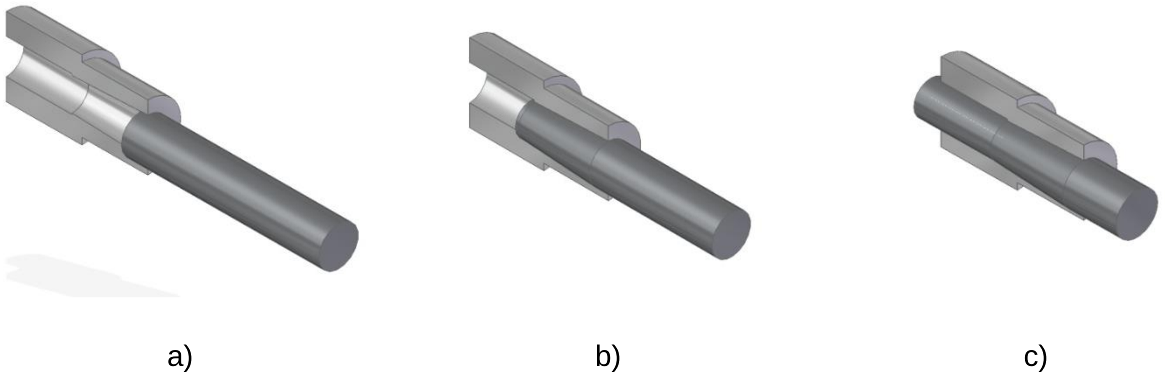
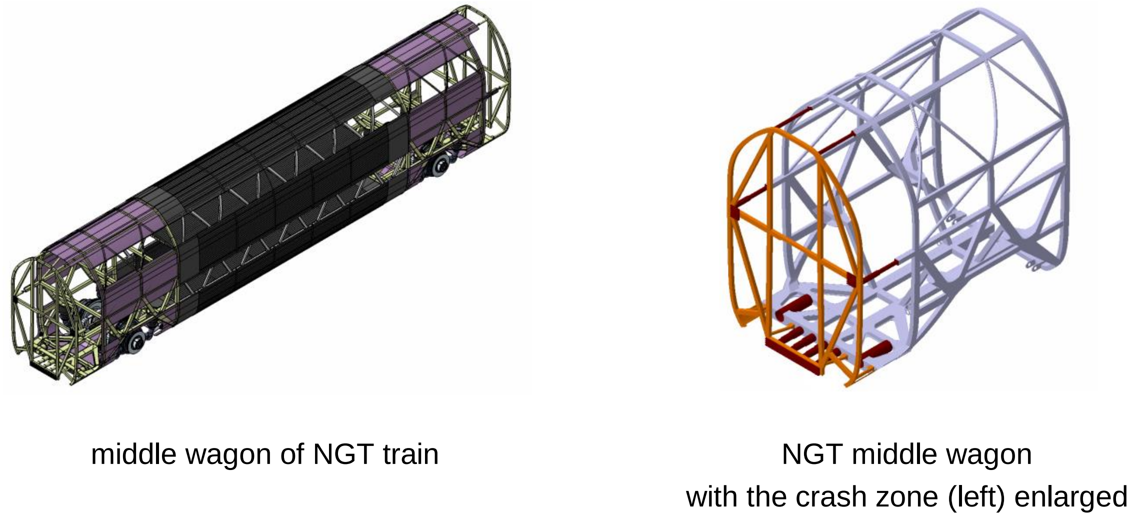


figure 11: Crash-absorber of the Next Generation Train (NGT) middle wagon (Railway).

This concept was first tested as a single component, as shown in **figure 11** and then integrated into a Next Generation Train (NGT)-crash-structure [6], as shown in **figure 12** [6, 7].



middle wagon of NGT train

NGT middle wagon
with the crash zone (left) enlarged

figure 12: NGT-crash-concept.

In order to prove the calculated data in a real-life scenario, a complete NGT-crash-zone was build and tested as a demonstrator, **figure 13**. The established test data shows that the assumptions and finite element simulations predict the crash behavior of the tested system.

crash set up of NGT
middle wagon crash zone [7]

crash test [7]

figure 13: Crash-test NGT-crash-concept.

4 Summary

In this paper, an overview of the mechanical and technological properties of the High Strength and Ductility (HSD®)-steels, characterized by their high strength and concurrent high formability with an even reduced density, is given, as well as the light weight potential of the HSD®600 and the HSD®1100 with four selected pre-serial development projects is explained.

At first, in cooperation with Volkswagen AG, Wolfsburg, a seat side member, showed a potential of 30 % (serial geometry) / 38 % (adapted geometry) weight reduction, when realized with a HSD®600, instead of high strength micro-alloyed steel.

Secondly, in cooperation with Audi AG, Ingolstadt, a door beam / side impact beam, is discussed utilizing a HSD®600 subsequently reducing the weight of the door beam by 17 %.

Thirdly, in cooperation with Kirchhoff Automotive, a single component design of a rear bumper concept, shows both, the economical and technical potential of part integration (seven parts to one).

Finally, in cooperation with DLR Institute of Vehicle Concepts, Stuttgart, a non-automotive pre-serial development project of a crash system using a HSD®600 for the Next Generation Train, was presented, showing the highest specific crash absorption level.

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