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Engineering, simulation and part-design for new TWIP-steels in automotive car body crash systems

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1 Summary

With a combination of normally opposite mechanical properties the TWIP steels (TWinning Induced Plasticity steels) open a wide design area for the automotive engineer. On the one hand TWIP steel with yield strength of 1100 MPa enables the forming of present part-designs with an enormous increase of the yield point. On the other hand TWIP steel with yield strength of around 600 MPa provides an extreme forming potential ($A_{80} \geq 50$ %). If this potential is used for a specially designed deep-drawing part, the very strong work hardening leads to even higher yield points. In this case there is an additional potential for function integration.

In this paper one example component will be presented to show the challenges in lightweight design and the potential of these new TWIP steels. Engineering steps and finite element simulations for a side-impact beam are shown. After adapting for the TWIP steel, the beam was 17 % lighter, compared to the series part.

2 Keywords

TWIP, steel, automotive, numerical simulation, crash system, energy absorption, side-impact beam

3 Introduction and motivation

The increasing demands for lightweight design in the automobile and truck sector have significantly pushed the innovations of new steel grades. The body in white, and also the chassis are today and will be in the future, a wide application area for modern steel grades. Thus, the steel producers have accepted the challenge to combine formability and strength. Especially the development of steels based on a Fe-Mn-Al-Si alloy system – so-called TWIP steels (TWinning Induced Plasticity steels) – constitutes a huge technological leap. These steels offer an extreme forming potential combined with high strength. As a result, this combination is in this intensity very exceptional, one has to reconsider today's construction actions and rules to realize the complete lightweight potential.

4 TWIP-Steel

TWIP stands for TWinning Induced Plasticity. As an external force loads the steel, it normally reduces the stresses by dislocations. The lattice of atoms gets a little misalignment. A twin of dislocation means that two neighbor dislocations compensate each other's misalignment. Both dislocations are cobbled together like twins. This microscopic twinning effect enables very high elongation of the macroscopic scale. The crossing of twins is held in the macroscopic scale responsible for the high work hardening of these TWIP-steels.

The Salzgitter AG developed a type of TWIP-steel named HSD®-steel (High Strength and Ductility). Its manganese content of 15 % stabilizes austenite and supports the TWIP-effect. Aluminum and silicon reduce its density and increase the resistance against hydrogen-induced stress cracking. This extreme high alloyed steel demands a new type of production process. The Belt Casting Technology (BCT®) enables the production without bending casted strip and also with low energy inputs and low CO_2 emission.

The remarkable mechanical properties of the HSD®-steel are shown in Table 1.

		HSD®600	**HSD®900**	**HSD®1100**
$R_{p0.2}$	[MPa]	620	920	1100
R_m	[MPa]	1000	1150	1250
A_{80}	[%]	50	30	17
Young's modulus	[GPa]	180	180	180
Density	[g/cm³]	7.40	7.40	7.40

Table 1: Mechanical properties of HSD®-steels

The potential of these steel grades is more recognizable when they are compared with common grades. Figure 1 presents the tensile test results. HSD®-steel has an ultimate tensile strain comparable to a deep drawing steel and exceeds the strength of a dual-phase steel HCT780XD by far. The energy absorption is much higher as the stress strain curve illustrates.

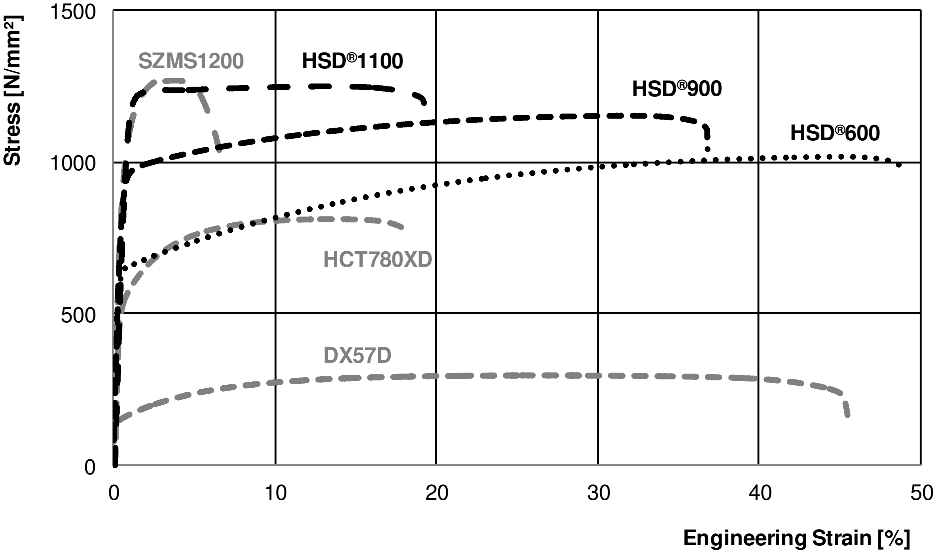

Figure 1: Results from tensile tests of different steel grades

Besides the stress-strain curves, the true plastic strain – true stress curves in Figure 2 (left) give an impression of the work-hardening behavior. This is also a reason for the very good forming potential of the HSD®-steel. Figure 2 (right) compares the forming limit curve of different steels grades. All curves were determined with an optical strain measurement system ARAMIS [1] in accordance with ISO 12004 [2].

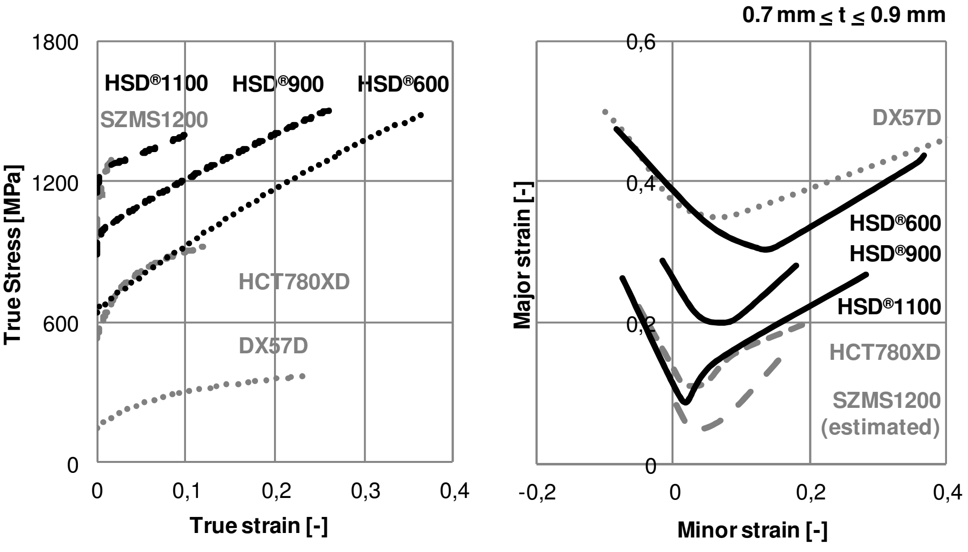

Figure 2: True plastic stress true plastic strain curves (left) and forming limit curves (right)

Knowing the characteristics of the HSD®-steel one can consider possible fields of application. Some examples are illustrated in Figure 3.

HSD®600	**HSD®900**	**HSD®1100**
• High geometrical complexity • Extreme formability • Energy absorption over long deformation distance	• High geometrical complexity • High formability • High work hardening	• Very high yield stress • Extreme stress hardening

Table 2: Fields of application

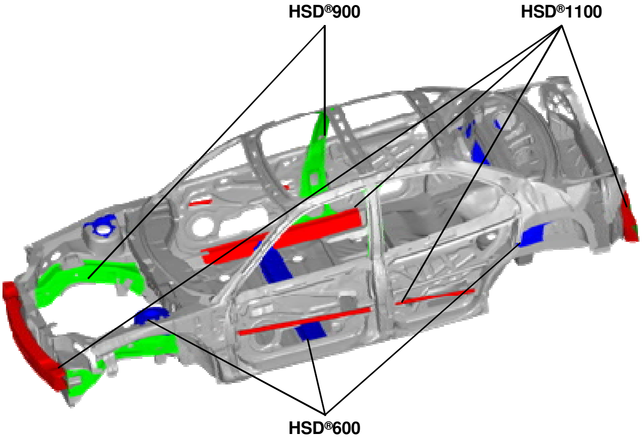

Figure 3: Fields of application (Source: CAD-model from www.topcrunch.org)

5 Side-impact beam

5.1 Series part

The enormous energy absorption potential shown in the tensile test data motivated to benchmark the lightweight opportunities for a side-impact beam.

The Audi A7 doors are made of aluminum. The side-impact beams are fastened with a rivet-nut and screw. The beam itself is made of the dual-phase steel HCT780XD; with a thickness of 1.25 mm and weighs 1.35 kg.

Energy absorption in side crash is the main function of the side-impact beam. It has to ensure the safety-space for the passengers during a side crash (Figure 4 (left)). For the development of a new beam design, a component test shown in (Figure 4 (right)) is used. The ends of the beam are fixed into rotatable mountings. When the impact pillar deforms the beam, the distance between the mounting can decrease without a counterforce.

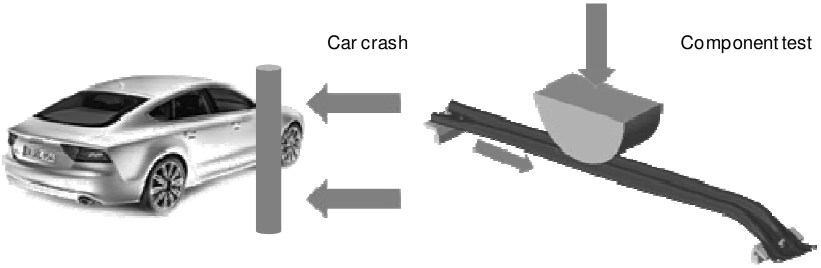

Figure 4: Vehicle crash (left) and component crash (right)

5.2 Target definition and approach

Target for a lightweight benchmark is the series part. The crash performance of the series part in the 3-point-bending test has to be reached or improved. This implies that the load-deformation behavior of the prototype has to be better than the reference. The stiffness at the beginning of the test has to be high enough, a maximum force has to be reached, and an abrupt collapse has to be avoided. In addition, the energy absorption during the whole test has to be higher than certain value.

To reach this target the following steps have to be taken:

1. Producibility check with HyperForm
2. LS-Dyna finite element model of 3-point-bending test
3. Mapping of forming information from HyperForm
4. Adjustment of 3-point-bending simulation
5. Forming trials in a series tool
6. Optical strain measurement of prototype with ARGUS
7. Adjustment of work hardening information from HyperForm
8. Emulation of the prototype geometry with its deviation in geometry
9. Optimization of part geometry based on calibrated model

Pre-studies showed that HSD®1100 has the highest potential for the side-impact beam. The drawing depth of the part is too small for the other two HSD®-steels to exhaust the forming and work hardening potential. At that time the simulation experience with this grade was minimal. As a short-term solution the behavior of prototypes with series part geometry will be compared with the simulation. As a long-term solution for a precise forecast of properties, a research project was started. It is funded by the Research Fund for Coal and Steel (RFCS) and named TWIP4EU (RFSR-CT-2012-00019). Here, a physically based model will be trained on a detailed analysis of microstructure and forming behavior of a TWIP-steel. The target is a precise material model for industrial use with LS-Dyna and Pam-Stamp.

5.3 Mapping

The one-step-solver of HyperForm is used to estimate the producibility of the series part. Due to the higher ultimate tensile elongation of the alternative material compared with the series material, a positive result was predicted. Despite this, the influence of the forming operation on the crash behavior is very high due to the strong work hardening. To achieve an adjusted work hardening, the strain distribution from a forming test in series tool with HSD®1100 in 1.05 mm was compared with the HyperForm results. This validation was performed as shown in Figure 5, with the optical strain measurement system ARGUS [3].

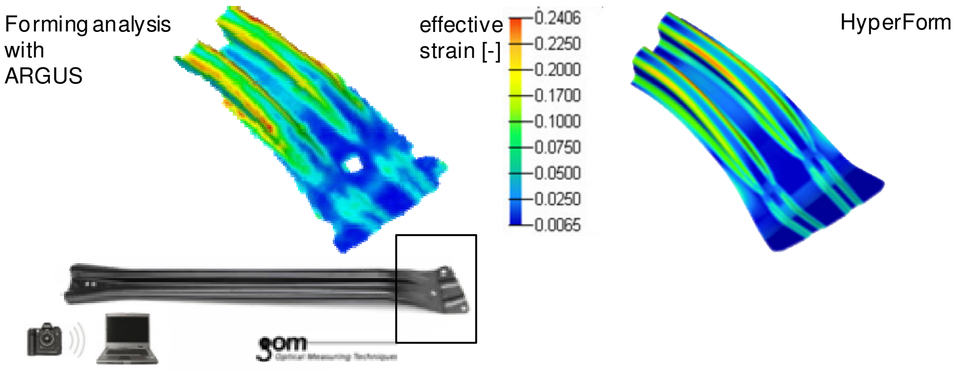

Figure 5: Strain distribution from ARGUS (left) and HyperForm (right)

The influence of the work hardening on the performance in the 3-point-bending test can be seen in Figure 6. The tested series part had a thickness of 1.35 mm. Therefore the series parts outperform the specifications.

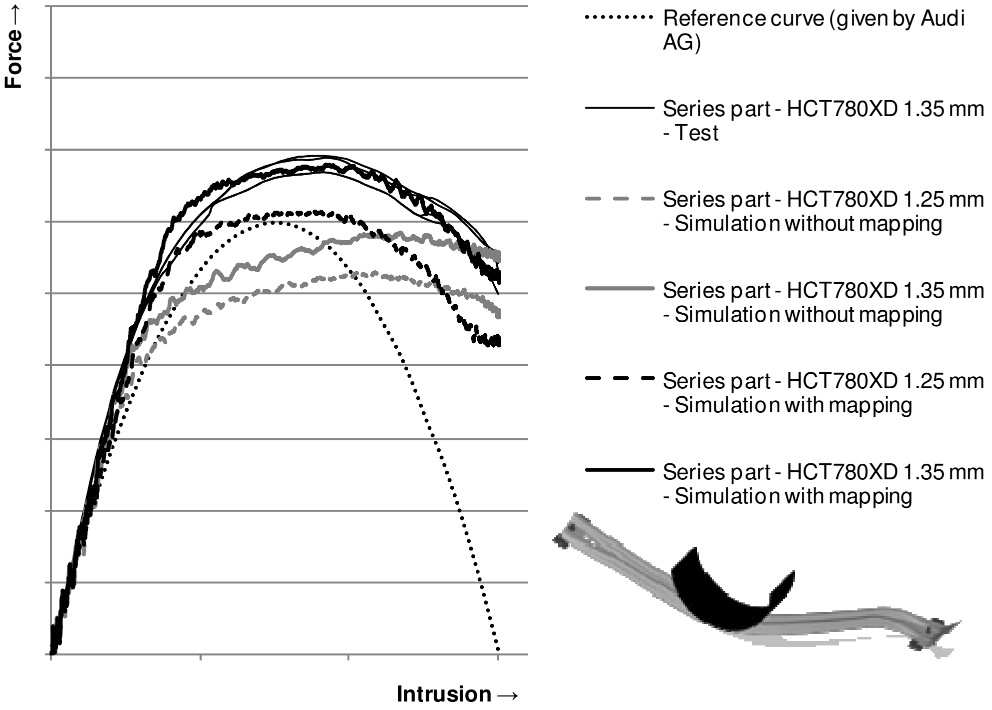

Figure 6: Load-deformation behavior of series part

Without the work hardening resulting from the forming operation it is not possible to reach the reference curve. Adding this strain information to the model and adjusting the thickness, the curves from test and simulation are in good accordance. All these simulations were carried out with the common *mat24 material model, which assumes isotropic material with a Hill48 yield locus [4].

Regarding the high influence of pre-strain in the crash test, the forming operation should be arranged by tool geometry, binder force or optimized draw beads [5].

5.4 Simple substitution

To provide the data for an adjustment of the simulation model, some first prototypes (HSD®1100 in 1.05 mm) were formed and tested. These prototypes are pressed in the series tool (used for thickness range from 1.25 mm up to 1.35 mm). The results of the 3-point-bending test are shown in Figure 7.

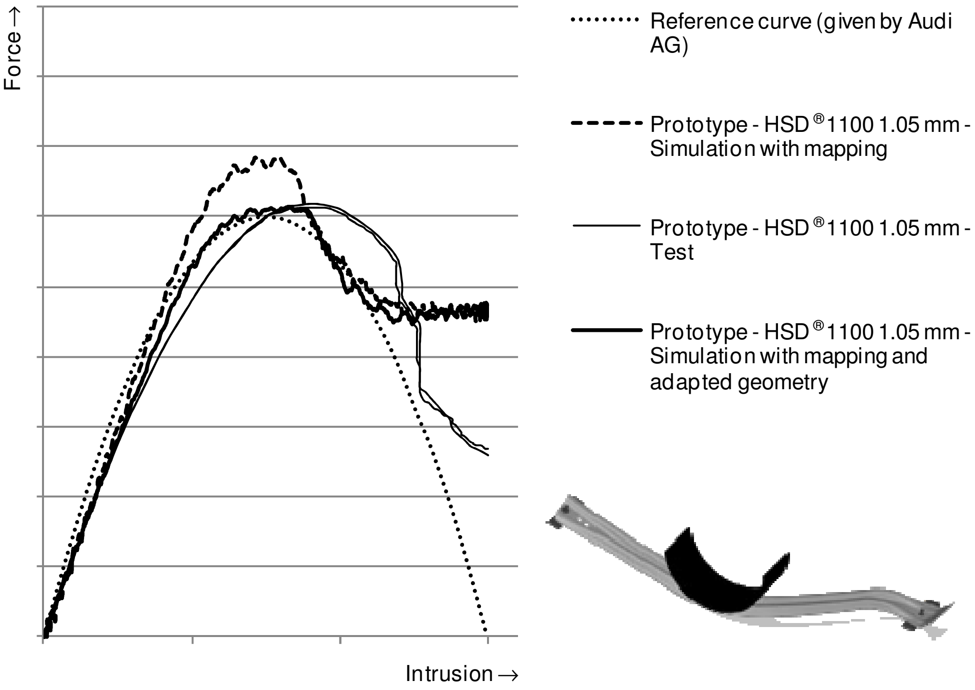

Figure 7: Load-deformation behavior of first prototype with series geometry

Thus the tool is normally used for material with larger thickness, the shape cannot be perfect. Additionally the HSD®-steel has a lowered Young's modulus of 180 GPa and a higher yield stress but the tools are designed for HCT780XD. These boundary conditions caused a high deviation in the geometry. A 3D scan of the prototype with surface digitizing system ATOS [3] makes clear the quantity of deviation as shown in Figure 8. This results in a more spread w-cross-section, which is much weaker than the series geometry. This can be verified when using the real cross-section for simulation as presented in Figure 7.

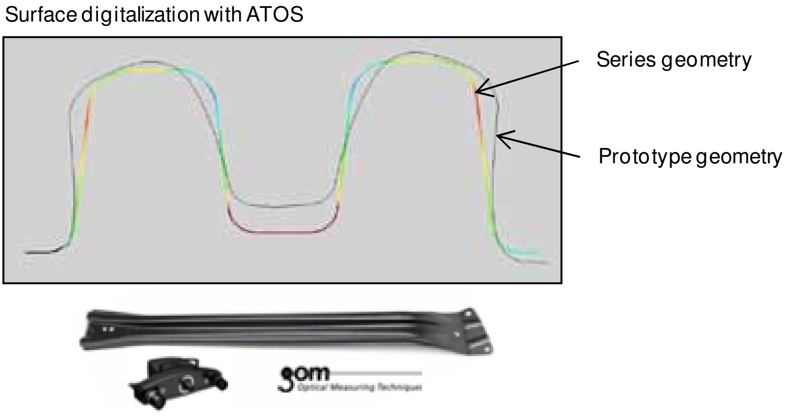

Figure 8: Optical measurement of geometry deviation

Regarding the different spring-back behavior of the HSD®-steel, the tool has to be adjusted. Otherwise a more open cross-section will be the result. Also, a higher binding force at the end of the forming operation can lead to a better contour.

5.5 Adapted geometry

Assuming that the series tool is trained for the HSD®1100 in 1.05 mm, the stiffness of the part is however lower than that of the series part, due to the lower Young's modulus and thickness. An increase in thickness or beam height would result in higher stiffness but also weight as shown in Figure 9. Therefore there should be a perfect combination of beam height and thickness.

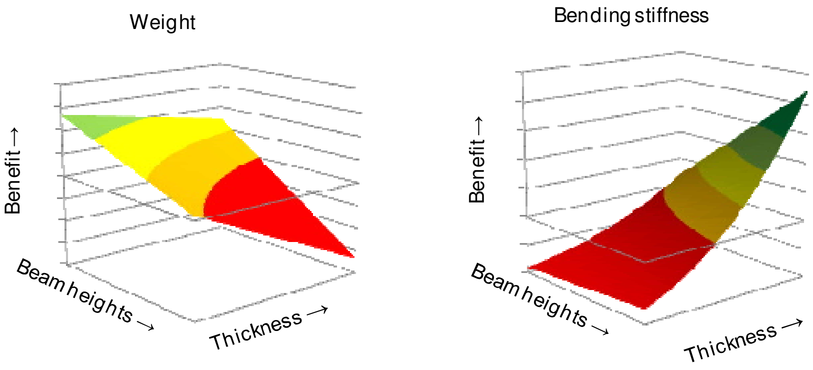

Figure 9: Influence of beam heights and thickness on weight (left) and bending stiffness (right)

This relationship can be determined by combining the two relationships from Figure 9. A good combination of height and thickness can be found along the orange line in Figure 10. There might be a global optimum in the left corner of the diagram but going here increases the risk of buckling of the beam slopes. Keeping this and the design-space in mind the beam height was increased up to 4.00 mm higher in the middle of the beam and the thickness was determined by the objective function to 1.00 mm.

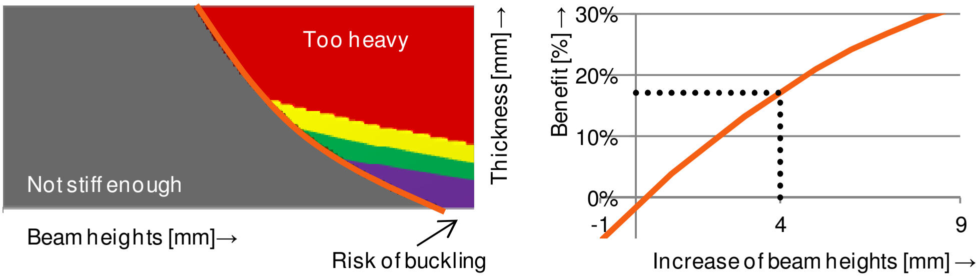

Figure 10: Objective function for adapted geometry

The performance in the 3-point-bending test of this new virtual prototype with adapted geometry is shown in Figure 11.

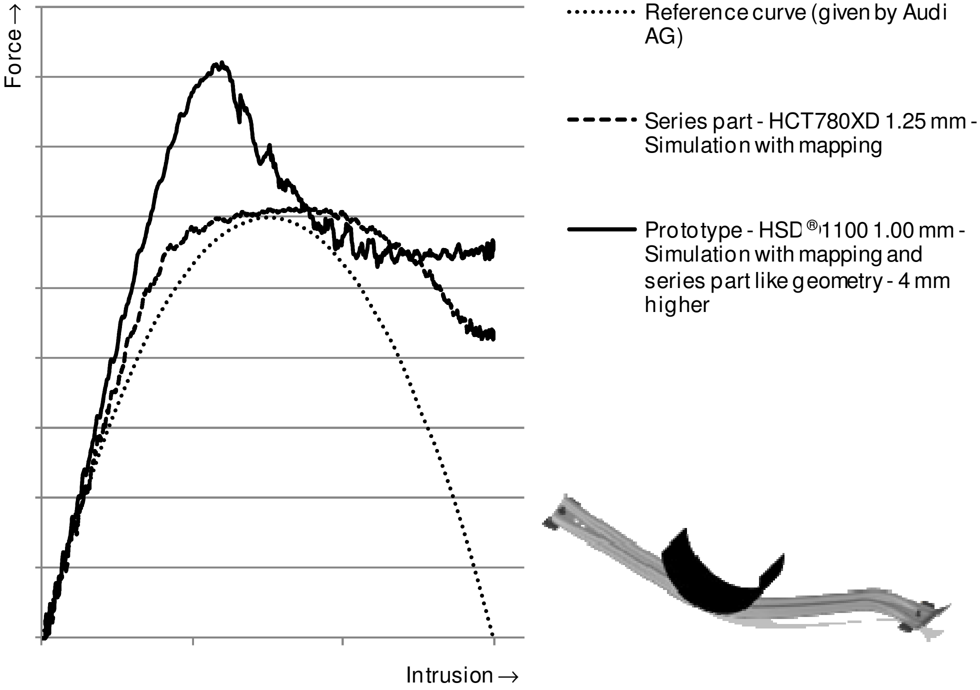

Figure 11: Load-deformation behavior of prototype with adapted geometry

6 Results and Discussion

The side-impact beam Audi A7 is in series made of HCT780XD with a thickness of 1.25 mm. By using HSD®1100 with a thickness of 1.00 mm and an adapted geometry a weight reduction of 17 % can be achieved.

7 Conclusion

Due to a lower Young's modulus compared with "standard" steel, a direct substitution of a TWIP steel might lead to an unsatisfying stiffness performance. Therefore, the geometry needs to be adapted. Only with mapping of the forming data to crash simulation, a realistic estimation of the lightweight potential can be realized. The high work hardening potential has a significant positive influence of the performance of the part under crash load.

8 Acknowledgements

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