High alloyed FeMnAlSi-steel - automotive lightweight potential for complex parts

Otto, M.[1)]; Roser, R.[2)]; Brückner, T.[2)]
[1)]Salzgitter Mannesmann Forschung GmbH, Eisenhuettenstrasse 99,
38239 Salzgitter, Germany,
[2)]Volkswagen AG, Stellfelder Strasse 46, 38442 Wolfsburg, Germany

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1 Introduction

In recent years, the interest in steel products with increasing strength has expanded. After the introduction of the so called Advanced High Strength Steels, the present focus is now moving towards the development of Ultra High Strength Steels. A special class of steel in this group is based on the iron-manganese alloying system and commonly referred to as TRIP- or TWIP-steels. The unique properties of these steels outweigh the known properties of carbon steels [1, 2].
Salzgitter AG has made a further step in the area of TWIP-steels and the result is a density-reduced iron-manganese-aluminum-silicon alloy called HSD®-steel [3]. 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 the iron-manganese TWIP-steels.

With the evolution of seat structures under the focus of lightweight and safety performance more and more high strength steel were used as known from the body in white and the car chassis. The seat development of VW used with the modul seat micro alloyed steels with a gauge over 1,0 mm. The 2011 released VW Up was the first VW with seat side members in HCT980X and a thickness of 0,8 mm. This was the first step to significantly reduce weight, by maintaining the seat performance.
As a contribution to the sustainable CO_2-emissions reduction VW is forced to further reduce the weight of seat structures in combination with moderate costs.
Based on the Volkswagen group modul seat structure the lightweight potential of the HSD®-steel is discussed in the following article.
In detail the performance of cross and side members are analyzed in Finite Element Analysis, feasibility study, prototyping and real test to compare the HSD®-steels to conventional serial steels.

2 HSD®-steel

The HSD®-steel is characterized by its high strength and high formability, this combination ranks the material well above the properties achieved by those of carbon steels (**Figure 1**). These mechanical properties are in a similar range to those of austenitic stainless steels [4, 5]. The higher levels of Si and Al ensure optimum mechanical and technological properties and reduce the material's density, where a typical level for HSD®-steel is 7,4 g/cm^3 at room temperature (**Table 1**).

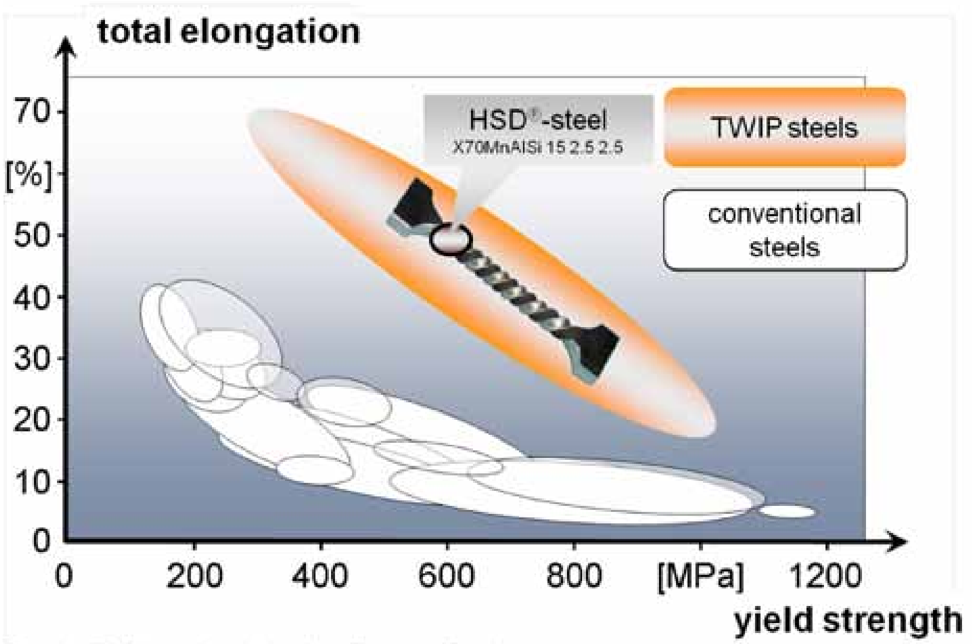

Figure 1: Yield strength – elongation diagram of steels.

High manganese austenitic steels show a unique combination of high strength and high uniform elongation. A very low stacking fault energy of about 20 – 40 mJ/m^2 leads to an additional strengthening mechanism besides dislocation movement. Depending on the chemical composition and consequently the stacking fault energy, the main strengthening mechanism will be either the TRIP (TRansformation Induced Plasticity) or the TWIP (TWinning Induced Plasticity) effect.
In the presented steel type, manganese levels of 15 – 25 % are used [1, 2]. The HSD®-steel developed by Salzgitter AG targets the lower end of the manganese range. The relatively high carbon level approx. 0.7 % guarantees an austenite stability.
Al and Si additions ensure that excellent mechanical properties and low delayed fracture sensitivity can be reached.
The enhanced mechanical properties of the HSD®-steel described are caused by two main strengthening mechanisms: dislocation interactions and micro-twinning.

3 Mechanical Properties

One of the characteristics of HSD®-steels is their combination of high strength and high deformability (**Table 1**).

Table 1: Mechanical properties, overview.

	HSD®-steel	X60MnAl18 1.5 [1]	XIP®-1000 [2]
yield strength [MPa]	620	500	496
total strength [MPa]	1000	995	1102
total elongation [%]	50 (A_{80})	63 (JIS)	52 (A_{80})
Youngs-modulus [GPa]	180	-	-
n-value [-]	0.36	-	0.42
r-value [-]	1.0	-	-
ρ [g/cm^3]	7.4	-	-

A stress-strain curve (**Figure 2**) of the HSD®-steel is compared with a cold-rolled high strength dual phase steel HCT780XD and a micro alloyed HC340LAD. Within an HSD®-steel the high strength level of a dual phase steel can be combined with a high elongation, which is comparable to a soft deep drawing steel.

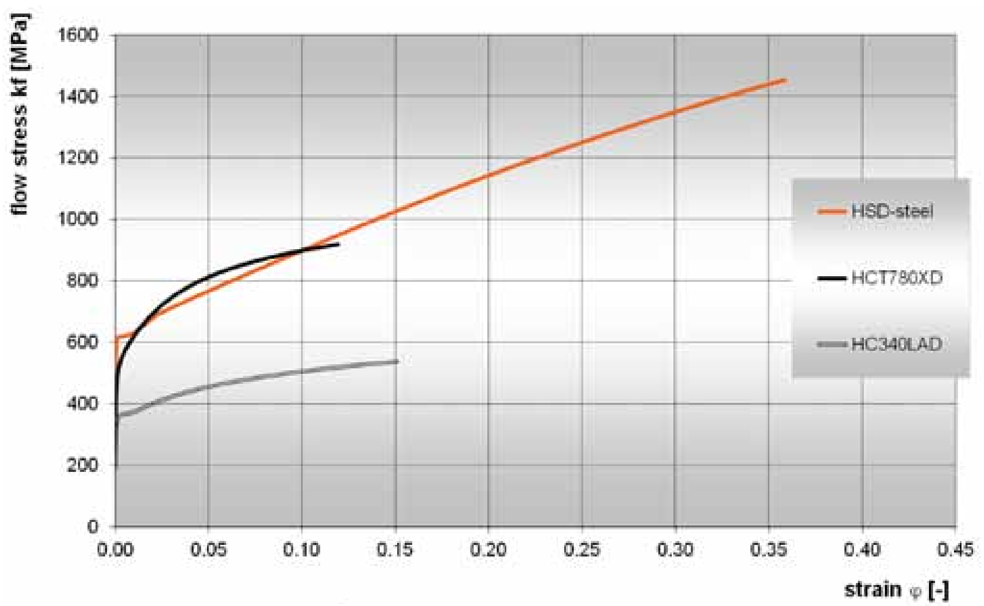

Figure 2: Stress-strain curves, HSD®-steel compared to conventional steel grades.

Due to the TWIP effect, which combines high strain hardening and high elongation, the strength of the material can easily be increased by an additional cold-rolling step. Thus allowing, the possibility to have a material that combines yield strength of 900 MPa with a tensile strength of 1150 MPa and a total elongation of > 30 %.

Customer requirements can therefore be easily accommodated with HSD®-steels through a suitable combination of heat treatment and cold rolling during the steel manufacturing process.

The combination of properties offered by HSD®-steels will be an important tool in the automotive industry for their development of safer and environmentally sustainable cars. Crash performance can be drastically improved whilst maintaining possibilities for downsizing and weight reduction. These are the enablers for the development of the forthcoming hybrid and electrical vehicles.

3 Application

One of the main challenges within car development is the demand for reduced weight combined with an increase in performance of a specific component. Besides the already established lightweight measures in the body-in-white (use of aluminum, press hardening steels, etc), the need for weight reduction in the interior of a car is also present. The biggest trim-weight with nearly 35 % can be found in seat systems (approximately 60 kg).

For a sustainable weight reduction in the seat system, cost attractive measures for the use in high volume serial production is needed. In order, to do so integrative light-metal constructions are desirable, as well as, the use of advanced high strength steels.
In comparison with conventional high strength steels, TWIP-steels, such as the HSD®-steel offer due to their higher strength, strain hardening behavior and because of their high ductility, the potential for use in components which have to absorb high amounts of energy during crash or misuse in order to guarantee passenger safety.

An especially promising use of HSD®-steel is when applied to a front seat structure, with a high weight saving potential due to thickness reduction. For reference, a module front seat structure of a seat from Volkswagen AG was chosen. In a first step, different components were evaluated, concerning their lightweight potential and possible realization. Besides the backrest side-member, lower cross-member, upper cross-member, and seat slides, the HSD®-steel shows a good performance as a seat side-member (**Figure 3**). The chosen reference component is presently manufactured for the serial seat structure out of a micro-alloyed steel (HC420LA) with the thickness of 2,0 mm. Under crash conditions the energy must be taken by these seat side-members.

In order to check the performance of the HSD®-steel, the main loads have been calculated using finite element systems. These simulations point out, that, without an adaption of the component geometry, the sheet metal thickness could be reduced from 2,0 mm to 1,5 mm. This results in a weight reduction of 30 % or 0,6 kg per car.

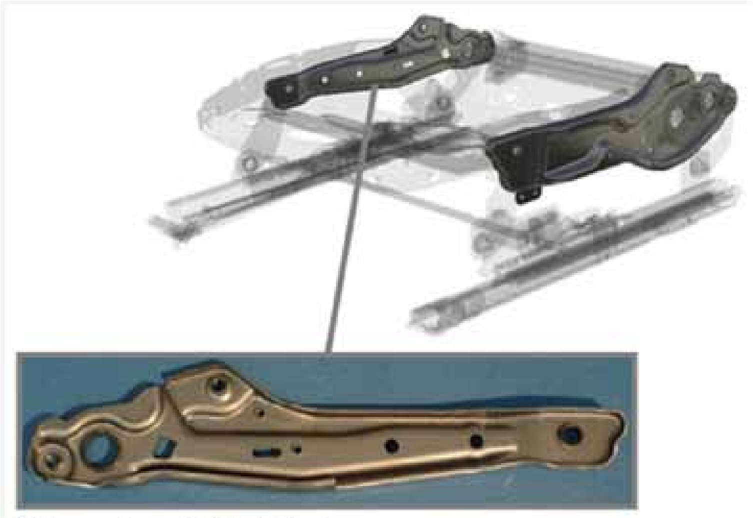

Figure 3: Seat side member out of HSD®-steel.

Due to the high ductility of the HSD®-steel and due to the suitable hole expansion ratio all thread collars could be formed.
Making the most of the forming potential of such a high strength and high ductility steel further weight reduction can be achieved when an adapted geometry is also used (**Figure 4**). With curled edges on the seat side-member, the sheet metal thickness can be decreased to 1,3 mm; meaning that the light weight potential is now at 38 % or 0,9 kg per car. These changes would also not have any effect on the components in the periphery.

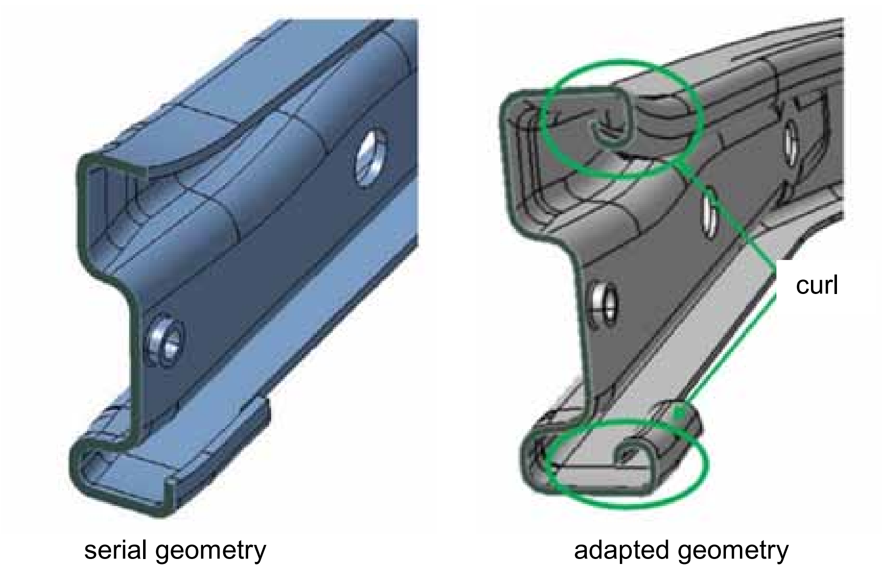

Figure 4: Seat side member with serial and adapted geometry.

The evaluated and calculated component geometry has been formed with prototype tools and was integrated in the modulus serial seat structure. These seats have been tested according to relevant serial loads and demands, namely:

- cargo load,
- heck crash
- front crash.

Additionally a complete continuous load test was carried out.

The established results are similar to the serial seat results and show that with the use of a HSD®-steel, the serial demands can be fulfilled, with a reduced thickness by 25 % or 32 %. Combined with the 5 % density reduction, due to the alloying system Fe-Mn-Al-Si, a weight reduction of approximately 0,6 kg to 0,9 kg per car can be achieved, without any loss in component performance.

5 Conclusions

Besides other solutions, innovative high strength, high ductility and density reduced Fe-Mn-Al-Si-steels like the HSD®-steel can be a sustainable approach for weight reduction.
Due to the use of a HSD®-steel within a seat side member of a module seat structure, a weight reduction of 38 % (0,9 kg per car) could be achieved with an adapted serial geometry. The investigated component properties correspond, although the sheet metal thickness is reduced significantly, to the demands of the serial component.
Other components like a complete front backrest offer an additional weight saving potential of about 20 %. The feasibility of a welding process will be established in further investigations.

6 References

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