International Symposium on Niobium Microalloyed Sheet Steel for Automotive Application
Edited by S. Hashimoto, S. Jansto, H. Mohrbacher, and F. Siciliano
TMS (The Minerals, Metals & Materials Society), 2006

POSSIBILITIES AND CHALLENGES USING ADVANCED HIGH STRENGTH STEEL SHEETS FOR AUTOMOTIVE APPLICATIONS

Torsten Hallfeldt

Ford Motor Company
Research and Advanced Engineering
52072 Aachen, Germany

Abstract

Applications of high strength steels in automotive parts and components are already implemented. Nevertheless, new advanced high strength steels continue to be investigated and developed. An understanding about these steels as well as the implementation has become more and more important. In order to fulfill the CO_2 commitment and meet high customer satisfaction, the car manufacturers have to reduce weight and cost while simultaneously improving crash performance and quality. To use these materials, there are many challenges to overcome, e.g., springback compensation and adaptation of simulation tools. Optimized product development and a flawless production process beginning with forming followed by joining and painting are and will be a challenge. Using advanced high strength steels leads to improved products by the improvement of comfort, design, fuel consumption, safety and driving quality. These improvements may be achieved with at no cost increase or just slightly increased costs. The right combination of all material grades and the optimized application will lead to the overall goal of an outstanding and exciting product.

Introduction

The motivation to implement advanced high strength steels in the body-in-white (BIW) is based on different requirements (Figure 1). These requirements are related to the wishes and demands of the customer, technical/legal demands and company requirements. The two major challenges are the optimized product development and a flawless production process.

The implementation of new advanced high strength steel is necessary for weight savings to improve the car performance (Figure 2). There are several advantages, where just weight saving is recognized. The better acceleration for a sporty feeling of the car is improved as well as brake performance. The decreased crash intrusion leads to the potential of more sheet thinning, which also leads to enhanced weight saving. The payload of the saved weight is used for improved quality and additional functions in the interior (e.g. seat position adjustment, cooling system, active safety systems). At least, the customer directly recognizes the fuel economy.

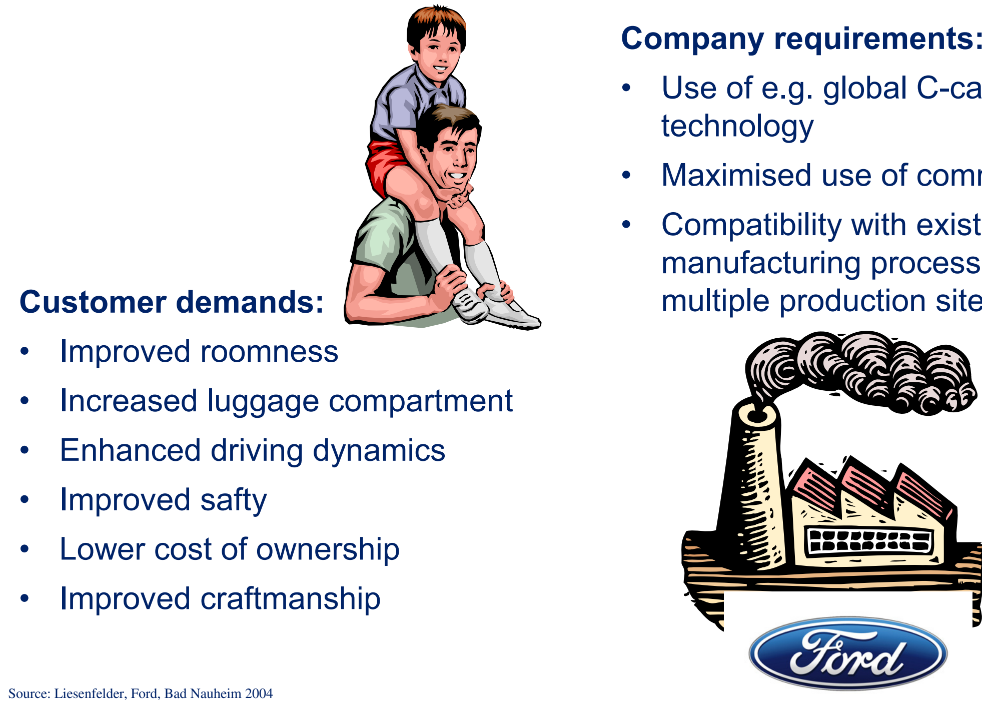


Figure 1. Customer demands and company requirements to new automobile products [1].

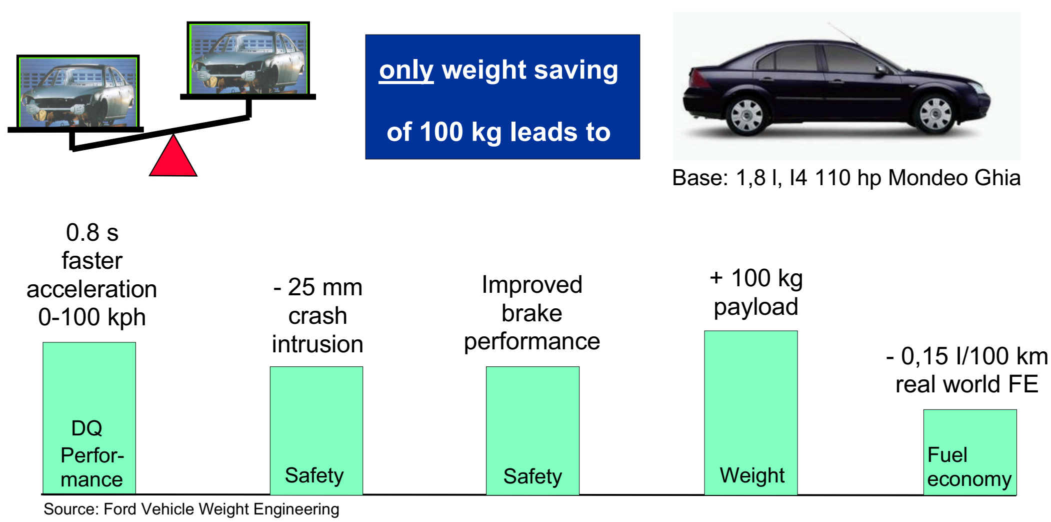


Figure 2. The influence of 100 kg weight reduction on the vehicle performance.

Body Concepts

To achieve the overall goal "best car in class," there are different body concepts on the market. Based on the individual vehicle performance targets due to customer wishes and expectations, the use of modern material mix, aluminum or conventional steel concepts (with high tech steels) are used. The choice of material and material related technology is depending on technical targets and the cost structure. In general, the lower the production volume then the more exotic will be the choice of materials (Figure 3).

The Aston Martin Vanquish uses a material mix of aluminum frames, superplastic aluminum parts, carbon fiber and glass fiber. The new Ford GT is built mainly with aluminum space frame concept whereas the Jaguar XJ uses a unibody aluminum concept. Very high volume products like the Ford Focus are using steel concepts with an increased content of high and ultra high strength steels. One reason for the steel concepts in mass production is material costs and technology costs.

Figure 3. upper left / right: Aston Martin Vanquish with high content of material mix and technologies / Ford GT with aluminum space frame concept lower left / right: Jaguar XJ with aluminum unibody concept / Ford Focus HSS body concept.

To achieve the targets of good crash performance and driving quality, the steel industry developed a number of new grades with different quality in strength and ductility. During the last decades, the implementation of high strength steels in the BIW increases at all automobile manufacturer worldwide. Unfortunately, the overall weight of the cars still increases over the years because of the increased car sizes and number of additional systems, mainly for customer satisfaction, found in the interior of the car.

Advanced High Strength Steels for Application in BIW

The development of so called high strength steels started in the earlier 1970s with the microalloyed steel grades. From this point on, the grades developed by the steel industry exploded over the years [2]. Today, a multitude of steel grades with different mechanical properties is on the market (Figure 4). Whereas the mild steels show good formability and manufacturing properties, the steel development is leading to grades with increasing strength but decreasing ductility. The demands of material properties are different depending on the targets of the engineers. The aim of a product engineer (need of high strength) and a manufacturing engineer (need of high ductility) results in the requirement of steels with both qualities. The material grades combining these qualities are stainless steel and the newly developed FeMn steel grades. However, a very high weight saving of components for acceptable costs is required for implementing these steels in vehicles.

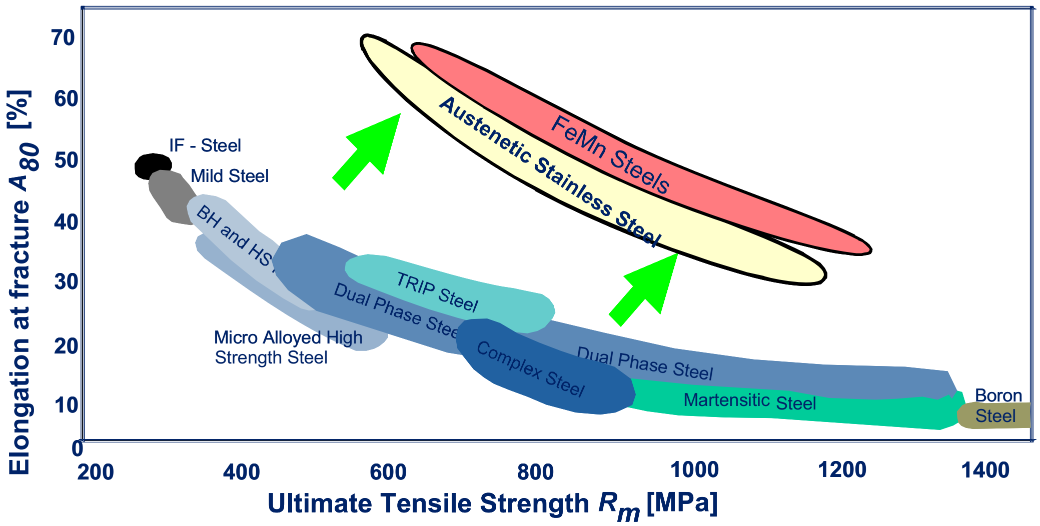


Figure 4. Mechanical properties for sheet steel grades from tensile test.

AHSS Development: Challenges for Customer

It is evident that the weight of cars has increased over the years whereas the weight of the BIW decreased. This could be explained with additional applications and upsizing car dimensions. Furthermore, the demands in crash performance of cars are also increasing. To be competitive on the market, it is not possible to only save weight without simultaneously improving crash performance, driving quality and noise vibration.

Within the last decades the steel industry developed an amount of high strength steel grades to support the demands of the automotive industry. The development process started with microalloyed steel grades, followed by grades with different alloying and production concepts (Figure 5). Today, a high number of grades, cold and hot rolled, with different coatings are available.

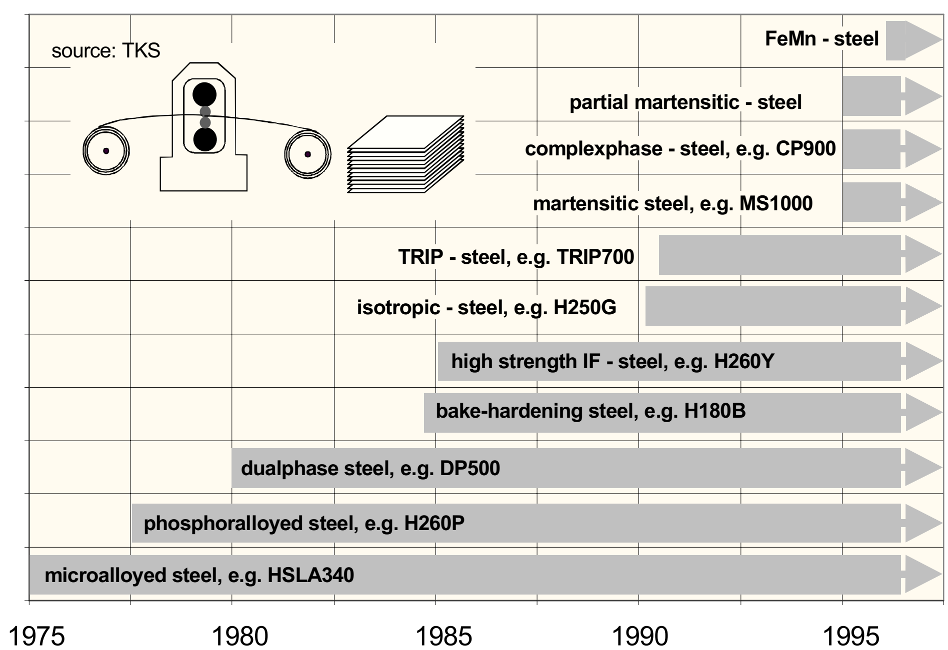


Figure 5. Development time schedule overview for high strength steels.

On the one hand, a wide choice of steel grades is available to address the best steel properties for a component or part. On the other hand, every grade has to be tested and specified.

For example, considering the steel grade DP780 (Figure 6), there are several suppliers with different concepts (alloying and production concept) available on the world market. The differences in alloying concepts could lead to differences in forming and joining behavior. To implement a new material, all mechanical properties have to be known and tested. It is obvious, that these differences lead to considerable testing time and costs although it is the same commercial material,. However, there are more steel grades in the same strength level available. Testing every steel grade and concept is time and cost consuming and virtually impossible. The automotive and steel industry work and testing groups agree that in the interest of reducing testing time and costs, a reduction of steel grades (in use at the automotive industry) will be the aim.

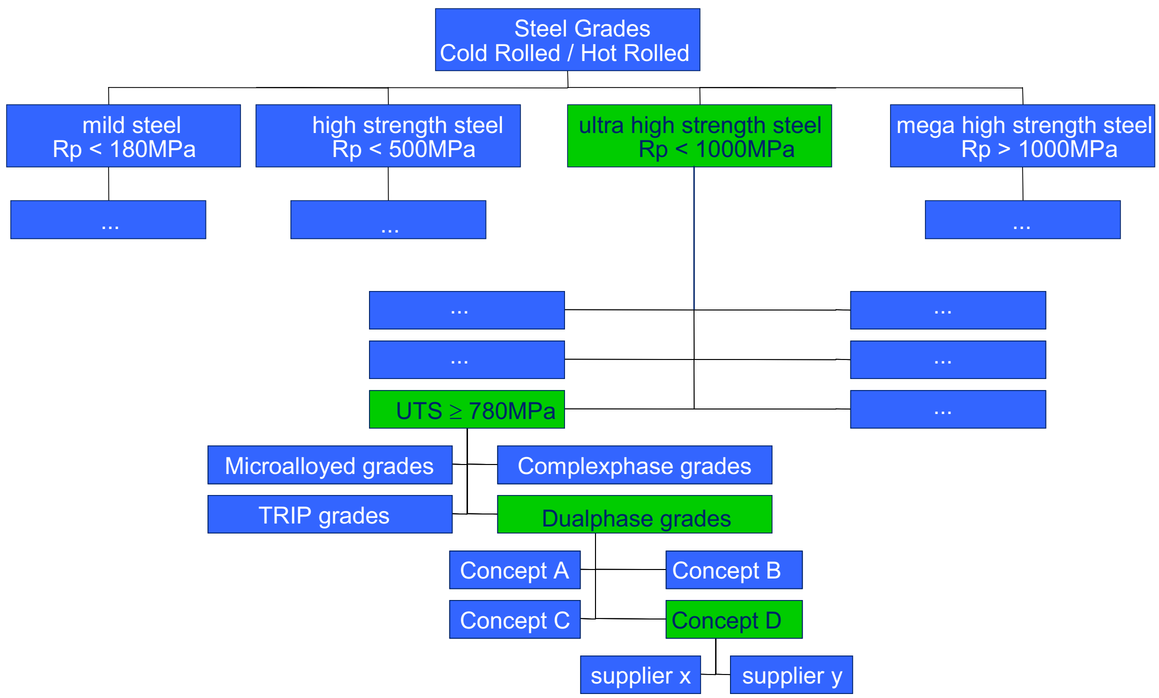


Figure 6. Testing and specifying for one steel grade and strength level out of several steel grades. The demand to test every grade will lead to exploded costs and time.

The right use of advanced steels is characterized by different strategies. Using mild or conventional high strength steels will support manufacturing and body construction. The challenges will be to reduce the increasing weight, which leads to increased fuel consumption. Therefore, the selection of new advanced high strength steels will solve some problems (customer related), but leads to high challenges for manufacturing. The new and implemented hot formed boron steels have addressed many open questions. The very high yield and tensile strength and good part accuracy (tolerances) support this technology. Challenges are part number (cycle time) and higher cost. In the end, the right material grade on the right place to support customer demands and companies requirements is the best solution.

AHSS Challenges for Manufacturing

To implement new advanced high strength steel, it is necessary to have information and test results about mechanical properties, springback behavior, required press forces, microstructure, welding properties and strain rate behavior. For cold stamping processes, tolerance exactness of the stamping parts is in the manufacturing focus. The increased springback of advanced high strength steels compared to mild steels or to high strength steels has to be solved properly (Figure 7).

Figure 7. Springback comparison between mild steel and advanced high strength steel

The springback for different material grades of simple hat sections are shown in Figure 8. It is shown, that the flange angle increases with increasing strength of the steel grades. It is clear, that the flange angle combines the springback in the bottom radius, the wall curvature and the springback in the die radius (side wall to flange). To avoid springback, there are several methods known. Stiffen the geometry of the part or compensation by over bending are just two examples. Nevertheless, the springback problem is not solved yet.

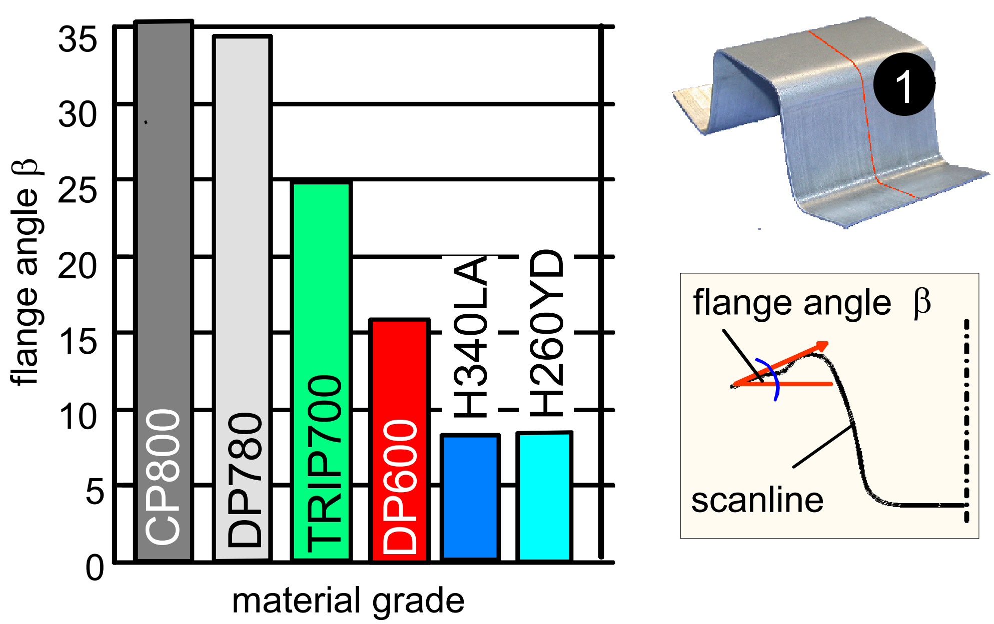


Figure 8. Springback of different material grades as a function of flange angle [3].

Due to the complex part geometries, it is difficult to calculate press forces. Investigations with different steel grades show a very good agreement between stamping force and tensile strength (Figure 9). Therefore, the demand of stamping presses with high press forces and small press tables and the requirements of exact press force calculation is gaining more interest. To choose the right press line, the part dimension, the decision of single or double part and the transfer system in the press line has to taken into account. The production of small and long parts on big press tables can end in a process discussion. The press force is high enough, but the transportation system is not able to transfer the part to the next station.

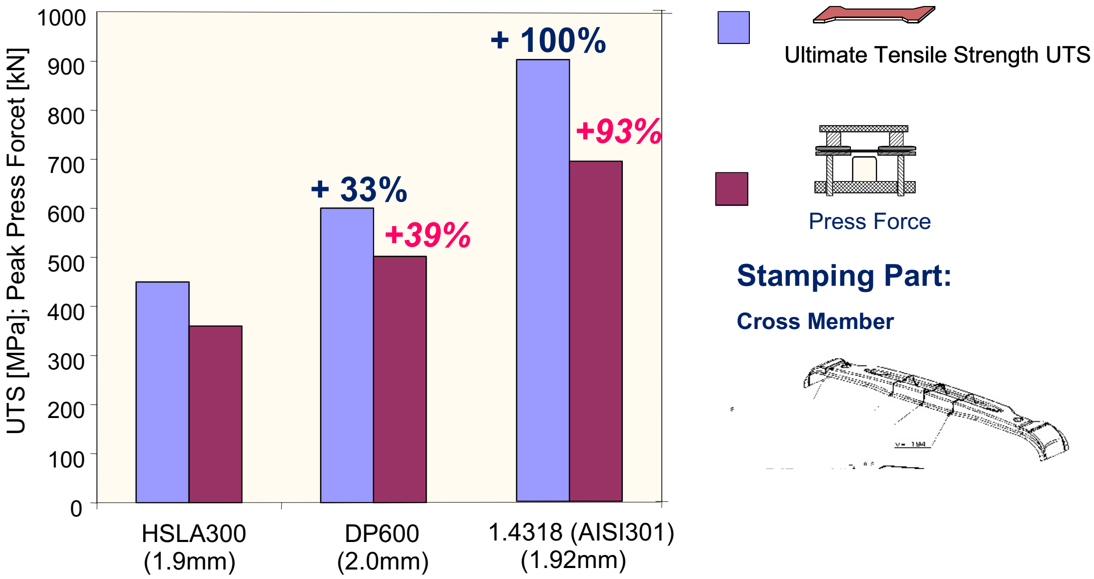


Figure 9. Comparison of measured stamping force and tensile strength of HSLA300, DP600 and the stainless steel AISI301.

A new aspect, which is discussed concerning the implementation of advanced high strength steels is crack sensitivity. In stamping trials, crack sensitivity for different steel grades where observed (Figure 10). The cracks of the blanked sheets started from the edge. Better results were achieved after preparing the edges, e.g., by grinding or polishing. The crack sensitivity can be influenced by the trimming quality (gap optimization, cutter/knife and punch edge quality). For high volume production, this is not acceptable and more details for process optimization are required.

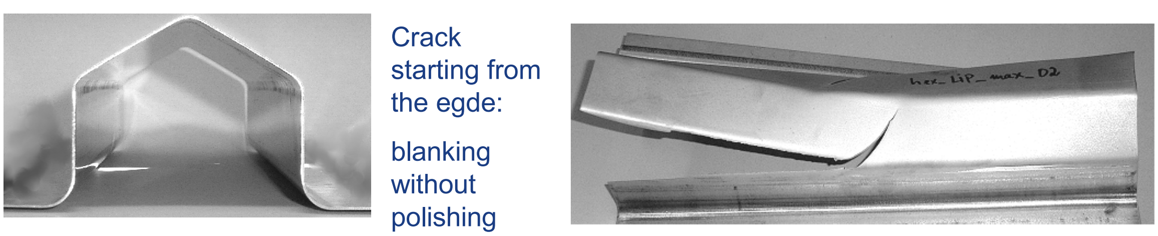


Figure 10. Stamping trials with cracks starting from the blanked edge of the sheets during the forming process.

A more detailed analysis was done with tensile test and hole expansion test. The goal was to investigate the material response after blanking and hole cutting and its sensitivity against cracking. It is obvious that the results directly depend on the cutting edge preparation. Therefore, no grinding and polishing process was used. The results in Figure 11 show clearly, that the crack sensitivity increases with increasing strength.

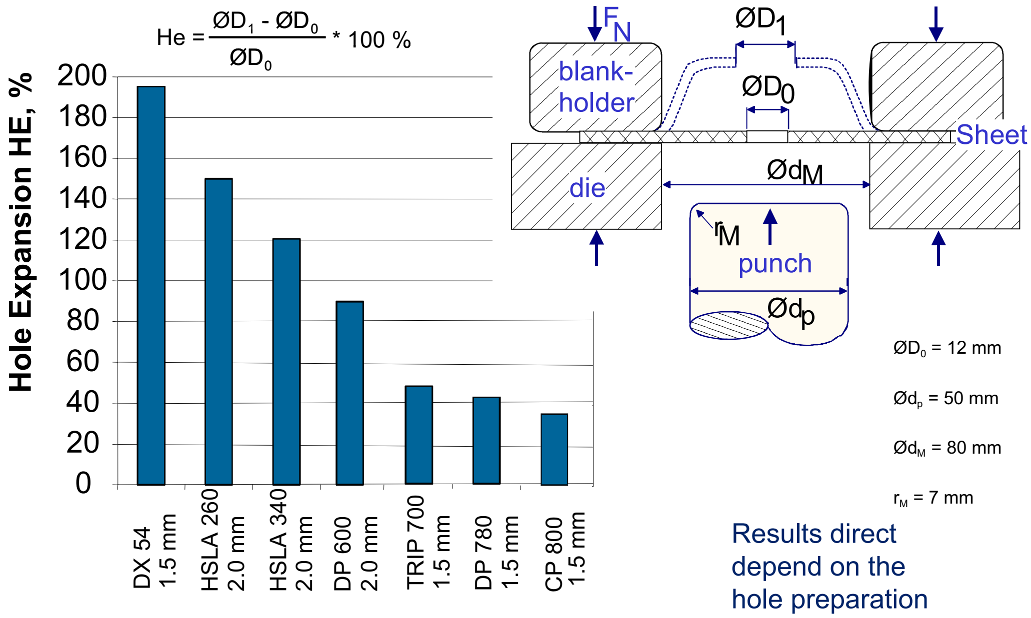


Figure 11. Hole expansion test for several material grades.

Within Ford of Europe, common technologies are implemented. For the C-car segment, the lower structure will be used at Ford of Europe for the Ford Focus and Ford C-Max [1]. Volvo uses the same platform for Volvo S40 and Volvo V50 and Mazda for Mazda 3 (Figure 12). It has to be clear that every brand and manufacturing / assembly area have the ability to produce vehicles with the same high quality. Therefore, all test results have to be available in a very early time at all brands to avoid problems and to solve open issues long before the first vehicle will leave the production line.

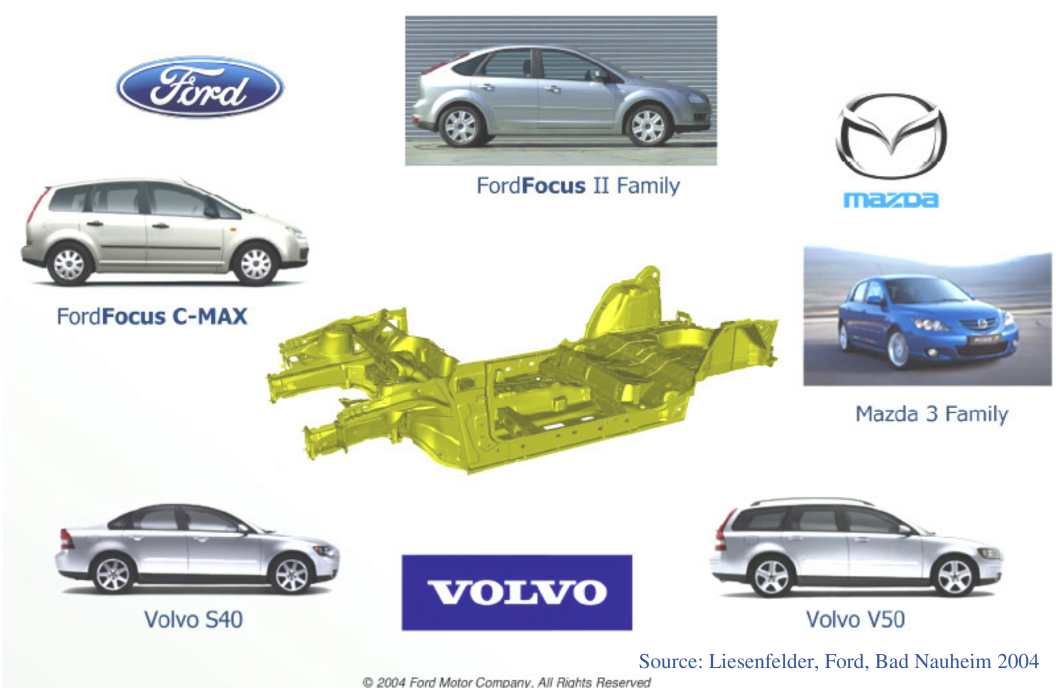


Figure 12. Common body structure strategy with common technologies within Ford of Europe, Mazda and Volvo [1].

Simulation of AHSS

The current input test data for forming simulation are tensile test flow curves. The advantages of the tensile test are standard testing, the uniform stress state and the well-known interpretation and calculation of the test data. The disadvantage, especially for high strength steel, is the limited elongation of the specimens. A proposal for measuring flow curves with high elongation is the use of the bulge test. In cooperation with Aachen University of Technology (RWTH) Department of Ferrous Metallurgy, Germany and Ford Research and Advanced Engineering Europe, the bulge test was used to determine flow curves of several advanced high strength steels. The results were compared to the results of tensile tests [4]. An example of the results for mild steel and DP600 is shown in Figure 13. The true strain of the mild steel was measured and calculated from tensile test to approximately $\varphi = 0.25$ whereas the DP600 curves end at approximately $\varphi = 0.14$. The bulge test results were calculated according to Hill. The calculated flow curves show almost a good agreement to the tensile test curve. The maximum strain was higher. The true strain for the mild steel ends at approximately $\varphi = 1.05$, the true strain for DP600 reaches $\varphi = 0.53$. The new curves lead to better understanding and use of the mathematical models for approximation of the tensile curves.

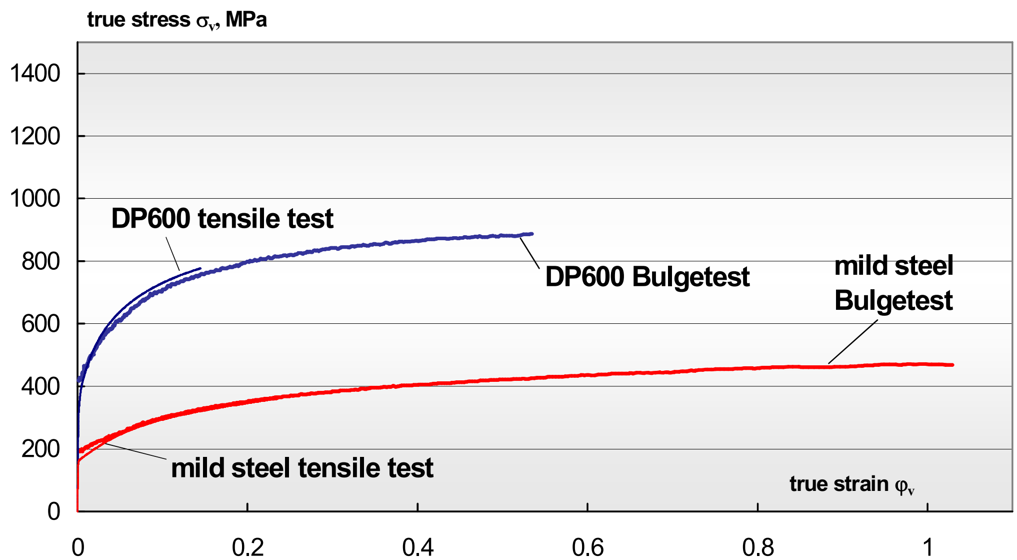


Figure 13. Flow curves from tensile test and bulge test, calculated according to Hill [4].

The work hardening behavior of dual phase steels compared to mild or conventional high strength steels leads to new challenges regarding the simulation of crash performance of components, substructures and full vehicle. In mild steels and conventional high strength steels, the work hardening and sheet thinning effect are compensating. Dual phase and TRIP grades behave differently. Dual phase steels show a higher work hardening effect during forming. Furthermore, the good formability of TRIP and TWIP steels is explained by phase transformation or twinning, respectively. To achieve accurate prediction by using FEM tools and to optimize the material use, the material history, including forming and joining and painting (bake hardening effect) has to be considered (Figure 14).

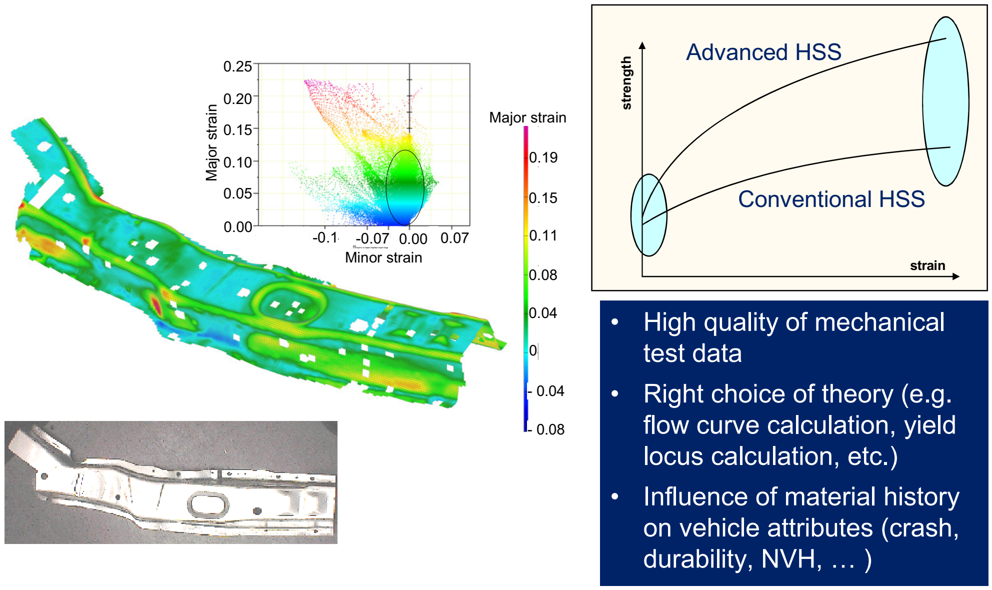


Figure 14. Material data of high quality, the choice of the right material law as well as the influence of the material history have to taken into consideration to predict component properties [3].

A front structure was calculated by CAE to predict the crash performance. Without mapping the forming history from the forming simulation of the components to the crash model, the structure not just buckled, but collapsed in a crash simulation (Figure 15). A second simulation with consideration of the forming history is also shown in Figure 15. The structure buckles in that way as was expected. The collapse mode compared to the first simulation run was not detected. The experimental trial confirms the simulation result in terms of implemented history data. The forming process strengthened the part and the point of collapsing was shifted to a higher strength level, which was not reached in this crash mode.

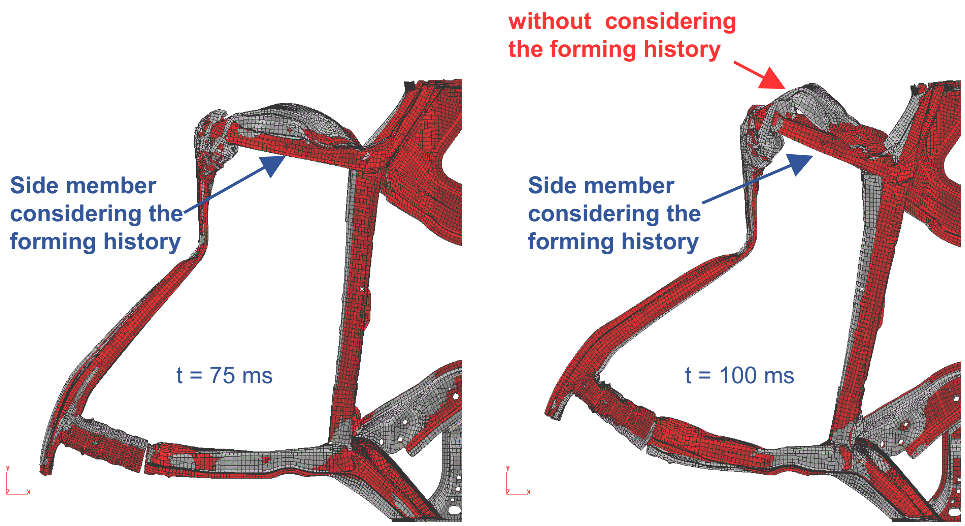
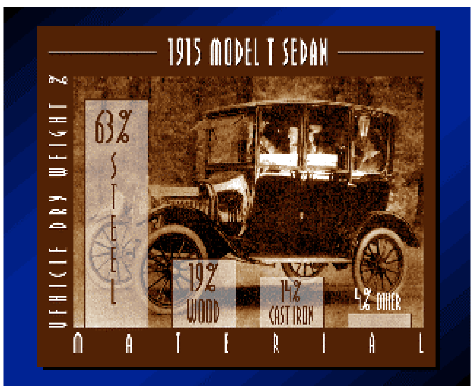


Figure 15. Crash results of a front structure with and without consideration of forming history [5].

Summary

The use of high strength steel for the BIW is increasing from car model to car model. To improve the requirements and customer satisfaction, conventional high strength steels and advanced high strength steels will be implemented more and more over the next years. In order to resolve manufacturing challenges, the investigations of these steels have to be intensified. To solve the challenges in terms of joining and springback, which are related to the material properties, different solutions are possible. The best solution depends on the demands, functions and requirements of the parts. Compared to alternative materials like aluminum, steel is still an attractive material for many applications. To keep steel attractive and use the advantages, there is still a lot of work to be done.

The model T of the year 1915 had 77% Fe-based alloys. Nearly 90 years later the content of Fe-based materials is only moderately decreased to 66% for a mass production model.



Current modell:

Fe-Basis: 66 %

Non-Fe metals: 9%

other: 25%

Everything can always be done better than it is being done

Henry Ford

References

1. Liesenfelder, B.: The Body-in-white of the new Ford FOCUS, International Circle of Experts, Car Body Design, Bad Nauheim 2004, Germany.
2. Drewes, E.-J.; Engl, B.; Kruse, J.: Höherfeste Stähle – heute und morgen. Stahl und Eisen 119 1999 5, 115-122.
3. Hallfeldt, T.; Greisert, C.: Formability and mechanical properties of advanced high strength steel sheets for automotive applications. Recent Advances in manufacture & use of tools & dies and stamping of steel sheets, Oct. 2004, Olofström, Sweden.
4. Dziallach, S.: Untersuchung des Umformverhaltens ausgewählter Karosseriewerkstoffe unter verschiedenen Spannungszuständen. Diploma-Thesis, RWTH Aachen Germany, IEHK and Ford, 2005.
5. Schilling, R.; Lanzerath, H.: Aspekte bei der Crashberechnung von Karosseriestrukturen mit neuen Werkstoffen; VDI-Tagung „Berechnung und Simulation im Fahrzeugbau", 2004, Würzburg, Germany.