Lighter, stronger, more ductile: Modern steels offer a range of benefits for automotive manufacturers

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This article was published in STAHL + TECHNIK, issue 8/2020

Summary

Lightweight steel construction plays an important role in automotive engineering. In the chassis area, for example, micro-alloyed HSLA steel is being replaced by stronger multiphase steel. The growing trend toward higher strength is also seen in structural components, for instance in the use of third-generation multiphase steel for cold-formed parts. For hot-formed structural components there is increased interest in steels in the 2000 MPa strength range, such as BENTELER BTR2000.

Introduction

Stricter regulatory requirements, improved sustainability, reduced climate impact, lower costs: The demands facing today's automotive industry are all driving research into new materials. Nevertheless, steel remains the material of choice for chassis and structural components. Compared to aluminum, magnesium and fiber-reinforced plastics, steel is very cost-efficient and is available globally. Cold-formed products made from micro-alloyed steel are state of the art for chassis components. Alloyed manganese-boron and multiphase steels are generally used for structural components. The manganese-boron alloyed steels are processed by an austenitizing treatment in a furnace followed by press hardening in a forming tool, which is usually water cooled. This results in a completely martensitic microstructure. In addition, cold-formed multiphase steels are increasingly used in the structural area, which often enable the components to be produced more cost-effectively.

In both areas described above, a trend towards the use of higher strength steels is discernible. With chassis components, multiphase steels are gaining importance and for cold-formed structural components it's third generation multiphase steels. For hot-formed structural components, the focus is on manganese-boron alloyed steels with tensile strength values above 1900 MPa.

This article provides an overview of the trends in the use of new high-strength steels at BENTELER Automotive, a leading global partner for the automotive industry. To do this, we will examine the potential areas where new steels can be used for chassis and structural components.

Steels for chassis components

In contrast to structural components used in body-in-white, chassis components (Figure 1) are generally made from hot-rolled steels. This is mainly due to the specific requirements regarding stiffness, noise, vibration, harshness and corrosion resistance. Plus, hot-rolled materials are more cost-effective than cold-rolled steels. The corrosion resistance of chassis components is ensured by cathodic dip coating downstream of the forming process, sometimes with additional measures such as pickling or subsequent waxing. In some cases, coil-coated steels are also used. However, the formation of pores during welding is a challenge.

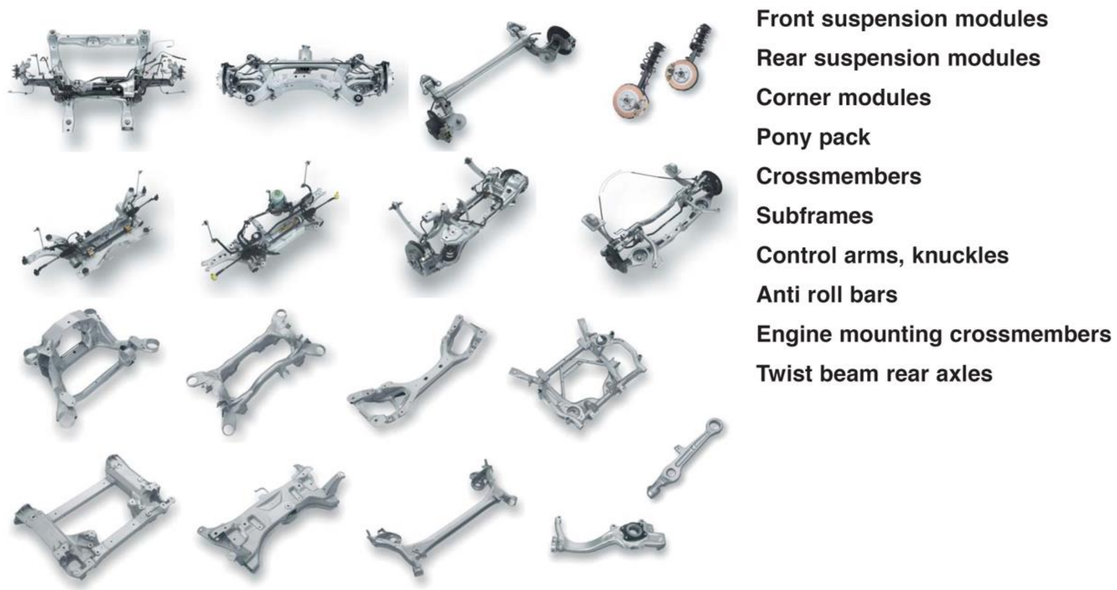

Figure 1: Chassis components and modules produced by BENTELER.

The various steels available are described in the so-called "banana diagram" (Figure 2), It shows the relationship between tensile strength and elongation determined in quasi-static tensile tests.

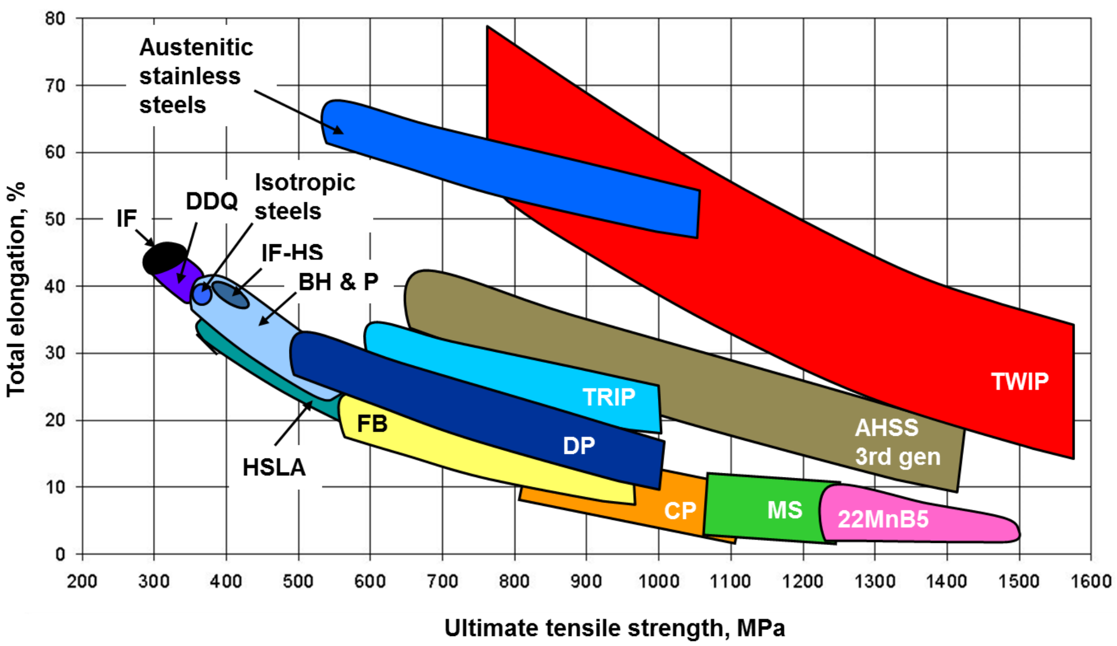

Figure 2: Steel classification according to ultimate tensile strength and total elongation.

Until now, chassis components have been primarily made from micro-alloyed steels or C-Mn steels with tensile strength values below 400 MPa. This results in heavy components with high wall thicknesses. In recent years, however, steels with tensile strength values above 600 MPa have been gaining in importance. These allow the production of lighter components with reduced wall thicknesses. The following steel grades are currently used in the chassis area:

* *Microalloyed, high-strength low-alloyed (HSLA) steels*

Most commonly used for chassis components, HSLA steels are available in a wide strength range. They are produced by a thermomechanical treatment during hot rolling in combination with a special alloying concept using micro-alloying elements (Nb, Ti. V). VDA standard VDA239 defines steels ranging from 300 MPa to 700 MPa in yield strength, while DIN EN 10149-2 extends this to 960 MPa. In chassis components, these steels are mainly used in a yield strength range between 300 and 500 MPa; values of up to 700 MPa are common for components with higher strength requirements. A major advantage of these steels, apart from the advantageous ratio between strength and formability, which is enough for many components, is their worldwide availability. They are available in almost all regions of the world either conformant to European or comparable regional standards and differ only slightly in quality. If tighter wall thickness tolerances are required (e.g. for torsion profiles in rear axles), these grades can also be obtained from thin slab casting or medium strip mills.

These steels are currently developed in two directions. On the one hand, they are optimized for cutting, e.g. by reducing the P and S contents and minimizing hardness deviations in the microstructure. This results in a smoother cutting edge in conventional (single-stage) shear cutting. The reduced number of cracks at the edges during subsequent forming also leads to longer life in component testing. On the other hand, material concepts based on an even finer, purely ferritic, grain structure are being developed to improve the cuttability and hole-expansion behavior. The latter is often a weak point of conventional steels. Unfortunately, these developments are not yet covered by existing standards and therefore only represent local solutions of individual steel manufacturers.

* *Multiphase steels*

Multiphase steels have been used in chassis components for several years. In the chassis area, ferritic-bainitic (FB) steels, dual-phase (DP) steels and complex-phase (CP) steels play the most important role. Transformation-induced-plasticity (TRIP) steels, on the other hand, are very difficult to produce and rarely found in the market.

FB steels are currently the most relevant multiphase steels for chassis components. Their alloying concept is similar to that of micro-alloyed steels and their two-phase structure is created by controlled cooling during the hot rolling process. The relevant standards list such materials with tensile strength levels of 450, 600 and 780 MPa, as well as some individual developments in the 980 MPa range. The great advantage of these steels is their improved cuttability and the increased hole expansion ratio compared to the micro-alloyed grades. The use of these steels is particularly successful for control arms where punched holes often have to be widened, and defined collar heights need to be achieved. Also, they are increasingly used in torsion profiles for rear axles or in front axle beams.

Compared to FB steels, DP steel, with its ferrite and martensite phases, plays only a minor role in the chassis area. This is due in part to the low yield strength of the standard DP600 grade, which can also be achieved with a lower-priced micro-alloyed steel. In addition, the strong hardening that characterizes these steels is often not taken into account in the design, so that the use of these steels is usually ruled out early in the development process. Furthermore, the hole expansion ratio is significantly reduced compared to FB steels. However, these steels are interesting for special applications where the semi-finished product is not a sheet but a welded tube, e.g. for torsion profiles. The tube forming process increases the yield strength, which is relatively low for DP steels, and the good formability is maintained.

In contrast to FB and DP steels, complex-phase steels, originally developed for structural applications, consist of three phases (ferrite, bainite, martensite). These combine high yield strength with almost equally high tensile strength. They are currently mainly used for components where high buckling strength is needed or that have a function in crash load situations. Examples include control arms and cross struts. These steels are available in the 780 to 980 MPa strength range and are already used in series production. However, CP steels in the strength range of 980 MPa require high pressing forces especially at higher wall thicknesses. They are also sensitive to cracking at the cut edges during forming. Which is why some steel manufacturers modify the typical multi-phase concept to an almost single-phase bainitic concept. While this significantly improves the hole-expansion behavior while retaining the other relevant mechanical properties, it also results in different alloying and microstructure concepts. Direct replacement of these steels in global projects therefore requires renewed approval and component tests.

Cold-formed steel grades for structural components

Lightweight structural components can be cold formed using modern third generation high-strength steels (AHSS). These are available in a wide range of strength levels up to the typical hot forming grades. Galvanized grades are also available, offering improved corrosion resistance over hot-formed steels. Compared to conventional first generation AHSS, third generation AHSS offer weight reduction due to their improved elongation values at the same strength levels. This is mainly achieved by optimized alloying and manufacturing concepts. These are aimed at stabilizing the retained austenite in the microstructure so that the microstructures consist of bainite, tempered martensite, retained austenite and ferrite. The mechanical properties are adjusted by the respective phase proportions. For example, an increased portion of retained austenite in the microstructure leads to increased ductility.

In general, third generation AHSS have the potential to replace first generation AHSS for structural components, as the new steels have a higher residual ductility after cold forming. This higher ductility also allows a higher number of stiffening elements to be integrated in the geometry of body-in-white parts, resulting in thinner and therefore lighter components.

Table 1:Mechanical properties of tested cold forming materials for structural applications according to the steel suppliers

Material	Type	min. $Rp_{0,2}$ [MPa]	max. $Rp_{0,2}$ [MPa]	min. Rm [MPa]	max. Rm [MPa]	min. A80 [%]	min. A50 ASTM [%]	min. A50 JIS [%]
1	1050-DH	700	820	1050	1180	14	14	15
2	1180-DH	850	1060	1180	1330	13	13	14
3	980-CH	605	845	980	1085	-	19	-

4	950-TWIP	450	600	950	-	45	-	-
5	980-TRIP	600	750	980	-	-	-	25
6	1180-TRIP	850	-	1180	-	-	-	14
7	980-TRIP	600	750	980	1100	-	-	21
8	1180-TRIP	850	1100	1180	1300	-	-	14
9	1470-DP	-	1400	1470	-	-	-	5
10	1180-DH	850	1050	1180	1350	13	-	-
11	980-DH	700	850	980	1180	13	14	14
12	980-CH	780	950	980	1140	10	-	-
13	1180-CH	900	1150	1180	1350	7	-	-
14	980-DP	590	740	980	1130	10	11	11

These cold forming grades offer high potential but there is a lack of documented comparison. We therefore investigated 13 uncoated cold-formable third generation AHSS with a view to their suitability for structural components. A list of the steels tested is shown in table 1. All had a thickness of t=1.4 mm. The results obtained were compared to reference material CR590Y980T-DP (No.14).

In the first step, the microstructure, mechanical properties and flow behavior were investigated. With the latter results and the material cards supplied by the steel manufacturer, cold forming simulations using Autoform were carried out. Forming tests were also carried out on a B-pillar geometry. For these tests a transfer tool die with four forming stages at a set total forming force of 1600 tons was used. Approximately ten B-pillars were produced from each material.

In addition, FEM crash simulations of a drop tower test were carried out. For these, a closing plate made of 1.00 mm CR330Y590T-DP-UC-U was fixed to the B-pillar.

In the forming tests, only one material, 1470-DP, showed failure during forming, which had been predicted by simulations. Compared to the reference material, the crash simulations showed a noticeable weight reduction for some materials while retaining the same crash performance. For example, the 1180-DH achieved a weight reduction of 8% compared to the reference material.

In addition, after the forming process, the springback scatter on the components was measured at 27 points for all investigated steels using GOM ATOS III Triple Scan in a non-tensioned state. Furthermore, the scan results were compared with the springback simulation results at the same points. The permissible tolerance deviation was +/- 0.50 mm. Considerable deviations of the measuring points from the permissible tolerances were shown for most of the materials examined. In addition, the deviations increased with increasing strength of the materials, see Figure 3.

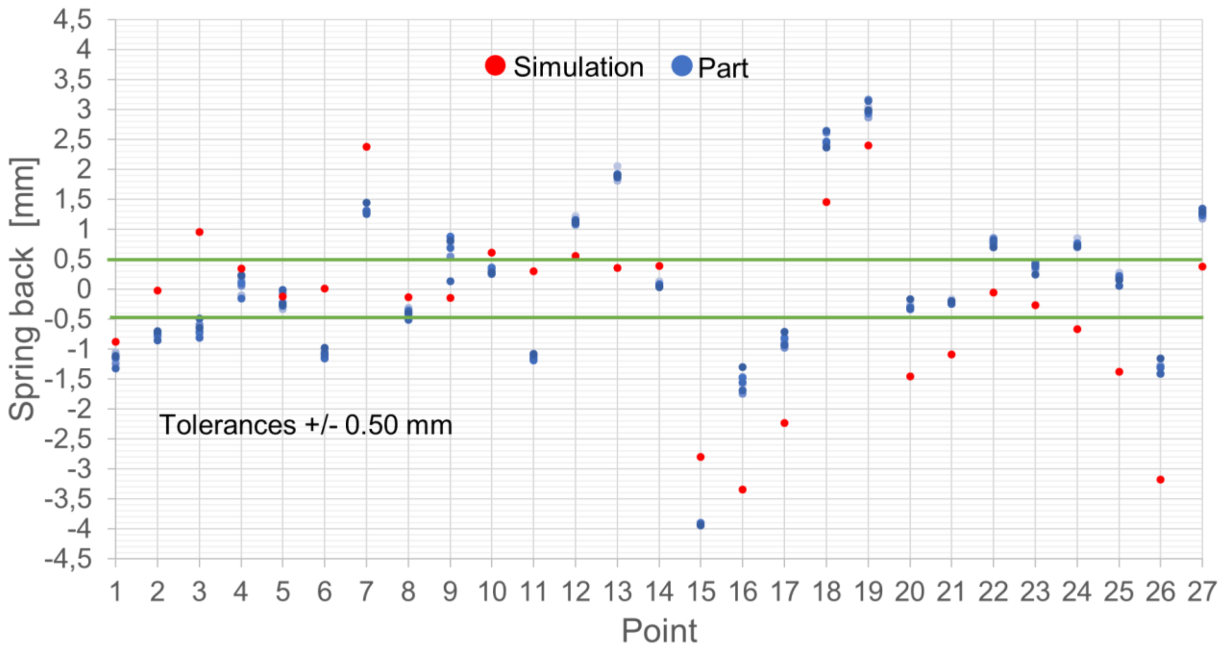

Figure 3: Comparison of the spring back of 1180-DH determined at BENTELER.

The known prediction difficulties of springback are often attributed to kinematic hardening effects. These are not considered in the isotropic hardening models usually used in the material cards provided by steel suppliers. Better results can be obtained by using kinematic strain hardening models such as the Yoshida-Uemori model.

Today, the coexistence of cheaper first generation AHSS and more expensive third generation AHSS is evident. Many steel suppliers also indicate that this will remain so. Although some OEMs are already using the new steels for some applications, it remains to be seen whether the new third generation steels will prevail on the market.

Hot-formed steel grades for structural components

The demand for higher strength hot-forming steels is increasing. The goal is to lower structural component weight by reducing wall thickness. To meet this requirement, BENTELER's metal processing specialists developed BTR2000, a hot forming steel with tensile strengths in the range of 2000MPa . The tensile strength is increased by approx. 25% compared to conventional hot forming steels and thus offers high potential for lightweight construction.

In the following, BTR2000 is compared to the standard hot forming grade, 22MnB5. The mechanical properties of 22MnB5 and BTR2000 were determined in tensile and bending tests, both in the press-hardened as well as in the press-hardened and e-coated condition. These are summarized in Table 2. BTR2000 has higher values of yield strength and tensile strength than 22MnB5 in both conditions. Furthermore, the coating process heat treatment results in an increase of the yield strength and a simultaneous decrease in tensile strength. Although BTR2000's strength values are significantly higher than 22MnB5 (approx. 25%), the ductility given by the total elongation (A30) and the bending angle (α / α1mm) is similar. BTR's similar ductility and high increase in strength can be attributed to its finer microstructures that come from alloying with niobium. Finer microstructures lead to higher strength and ductility values. Niobium, which combines with carbon to form niobium carbides, restricts austenite grain growth during the austenitizing process. This provides a higher nucleus density, which eventually leads to finer martensitic structures after press hardening. A significant consequence of these finer structures is increased yield strength as well as tensile strength, hardness and bending forces according to the Hall-Petch relationship. At the same time, the fine microstructures exhibit good ductility, which is represented by the total elongation and the bending angles.

Table 2: Mechanical properties of 22MnB5 and BTR2000 after austenitization and subsequent press-hardening and partially e-coating determined at BENTELER

	22MnB5 t =1.8 mm press-hardened	**22MnB5 t = 1.8 mm press-hardened + e-coating**	**BTR2000 t = 1.8 mm press-hardened**	**BTR2000 t = 1.8 mm press-hardened + e-coating**
$R_{p0,2}$ [MPa]	1020	1140	≈ + 25 %	≈ + 30 %
R_m [MPa]	1600	1520	≈ + 25 %	≈ + 20 %
A_{30} [%]	8.7	9.0	≈ ± 0 %	≈ ± 0 %
α [°]	51	52	≈ ± 0 %	≈ ± 0 %
α_{1mm} [°]	68	70	≈ ± 0 %	≈ ± 0 %

BTR2000's high strength and ductility level make it suitable for use in energy absorbing components, which is why cross members for bumper systems were made from it. As a reference, cross members were also made from 22MnB5. Both bumper systems did not have a closing plate to achieve high deformation during the crash test. Furthermore, the Pole Crash Test was used, as high deformation occurs and high tensile and bending loads are superimposed, which is particularly critical.

Given the critical test conditions, early failure of the components was expected. Nevertheless, both materials withstood the test and showed no cracks during the pole crash test. Therefore, it can be concluded that both materials offer sufficient ductility for high energy absorption of the bumper system.

The force-displacement and energy-displacement curves determined in the pole crash tests are shown in Fig. 4. The force-displacement curves show a higher force absorption of the BTR2000 compared to 22MnB5. In detail, a 15% higher force is measured for the BTR2000. The maximum force absorption is measured for both materials at the same displacement just before the bending of the cross beam starts. The higher force absorption can be attributed to BTR2000's higher yield and tensile strength, which results in a delayed deformation of the cross member. However, the increased force level of only 15% compared to the 25% increase in strength is due to the mixed tensile and bending loads that occur and geometric factors that are incorporated in the pole crash test.

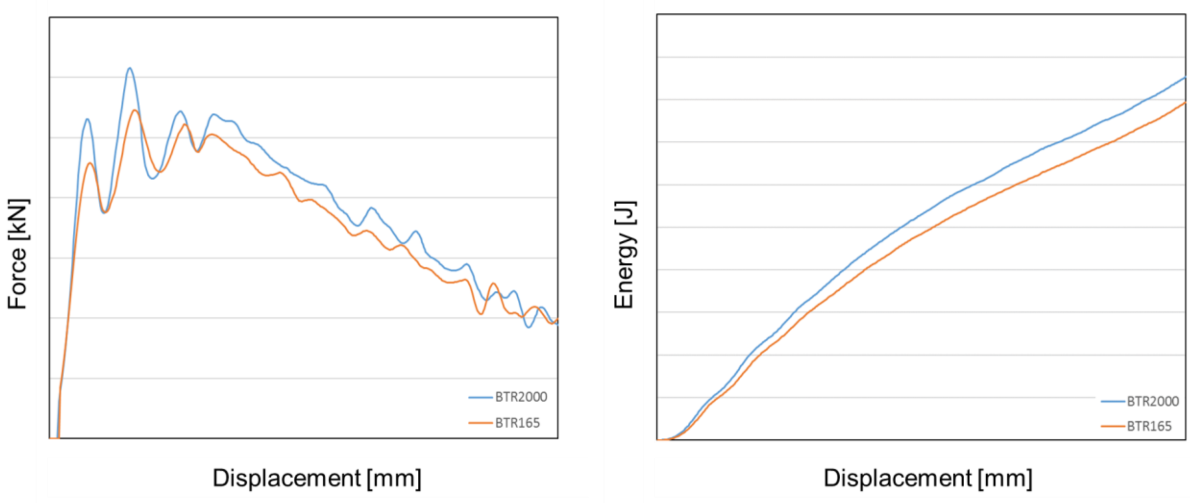

Figure 4: Force-Displacement and Energy-Displacement curves resulting from a pole crash test of bumper systems for 22MnB5 and BTR2000, respectively determined at BENTELER.

The energy-displacement behavior of BTR2000 is about 8% higher than that of 22MnB5. The higher energy absorption of BTR2000 is due to the constantly higher force level, viz. Fig. 4. In addition to the higher forces, BTR2000 showed no failure in the pole crash test, indicating good ductility of the material.

BTR2000's higher force and energy absorption compared to 22MnB5 in the pole crash mean that the component thickness of hot formed parts can be reduced while maintaining crash performance. In the case of the hot-formed cross member described above, simulations of pole crash tests and bumper-to-bumper crash tests revealed a potential reduction in sheet thickness from t=1.8 mm (22MnB5) to t=1.6 mm (BTR2000) with the same intrusion levels.

Conclusions

New advances in steel technology are playing an important role in modern automobile construction. In the chassis and structural area, higher strength steels allow component wall thickness to be reduced and thereby save weight. Multiphase steels often replace microalloyed steels in the field of chassis components. Recently, however, the use of third generation multiphase steels that offer higher strength and better formability has increased. For hot-formed structural components, manganese-boron steels are being used. BTR2000 from BENTELER uses innovative processing and alloying concepts to extend these benefits even further. Its significantly improved ductility and high tensile strength mean that manufacturers can continue to fulfil stringent crash requirements while meeting the environmental standards of today and tomorrow.