Hot stamping steel grades with increased tensile strength and ductility - MBW-K 1900, tribond 1200 and tribond 1400

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Abstract. The use of hot formed 22MnB5 steel with an aluminium-silicon (AS) coating is well established for high strength automotive parts to combine weight reduction and passenger safety. Recent developments aim to increase the material strength for further weight saving and to improve the ductility. Especially an improved ductility makes hot formed parts suitable for additional applications, such as parts with higher energy absorption or even axially loaded parts. thyssenkrupp Steel Europe AG has developed new hot stamping grades. With an increased strength of about 1900 MPa, the MBW-K 1900 allows the application of even lighter parts compared to 22MnB5. Due to the increased strength level, delayed fracture has to be evaluated. Furthermore, the recommended parameters for processing MBW-K 1900 are regarded.

A high crash performance of a material implies a high strength, while the material still shows no cracking during folding or heavy bending of the automotive part. This is the basis for the development of tribond 1200 and tribond 1400. As a new concept for hot stamping, tribond 1200/1400 are composite materials, which bond two outer layers of a ductile 500 MPa steel grade with a high strength 1500 MPa steel core layer. Both grades are already well known as monolithic steels MBW 500 and MBW 1500 for hot stamping. An aluminium-silicon coating allows tribond 1200/1400 to be processed in the same way as AS coated 22MnB5. Nevertheless tribond 1200/1400 show a reduced susceptibility to hydrogen embrittlement in the 4-point bending test compared to 22MnB5. By their improved crash behaviour, tribond 1200/1400 enable the manufacturing of more kinds of hot formed parts such as longitudinal beams. An advanced simulation method takes the composite structure of tribond 1200/1400 into account to evaluate the crash behaviour.

1. Introduction to hot stamping and 22MnB5 with aluminium-silicon coating

Hot stamping is a technology to produce complex shaped steel parts with an extremely high strength for the automotive body in white. The main advantage is the possibility to reduce the sheet thickness, while maintaining the same strength of the part, which favours lightweight products. In the basic concept, sheets of manganese boron steel are heated to austenite temperature and quickly cooled in the tool, directly after forming. An overview of hot stamping in the recent years can be found in [1].

Since more than 20 years, thyssenkrupp Steel Europe AG is a supplier of manganese boron steel for hot stamping. The basic grade is 22MnB5 and has an efficient chemical composition of about 0.22 wt% carbon, 1.25 wt% manganese and maximum of 0.005 wt% boron (thyssenkrupp trade name MBW® 1500). After hot stamping it has a tensile strength of about 1500 MPa, a yield strength of
1000 MPa and a minimum elongation at break of $A_{80} > 5 \%$. For the protection against decarburization and scale formation during austenitization for hot stamping, MBW 1500 is usually supplied with 150 g/m² aluminum-silicon coating (AS). The coating does not influence the part production as the coating can be hot formed, welded, painted etc. Additionally, it enhances the corrosion protection of the part [2]. AS coated MBW 1500 is available in the automotive market since 2004.

2. Motivation
Some parts only require an extraordinary high strength, while the ductility is not of such importance. In this case, a steel grade with an even increased strength compared to MBW 1500 would be of great advantage to further support lightweight in the body in white. As a result, thyssenkrupp developed a steel grade with an increased carbon content of max. 0.38 wt%. The new MBW-K® 1900 steel and its properties after hot stamping as well as further processing are discussed in this paper.

However, conventionally processed and thus fully hardened MBW 1500 is currently not effectively used for all types of parts in the automotive body in white. Some parts have to absorb a large amount of the impact energy during a crash. Thus, these parts bend or fold, preferably without cracking. The requirement for the steel in this case is to have a high strength and also high ductility, such that the material folds instead of fracturing at a certain deformation. As a solution to this problem, the paper also describes the newly developed steel compounds tribond® 1200 and tribond® 1400, which have a highly increased ductility, compared to common 22MnB5.

3. MBW-K 1900 hot stamping grade
Compared to the common 22MnB5, MBW-K 1900 provides a further increased hardness of the martensite after hot stamping, due to the increased carbon content of up to 0.38 wt%. The manganese content remains at a maximum of 1.4 wt%, while up to 0.005 wt% of boron are applied to increase the time for the microstructure transformation. The main advantage is the increase of the tensile strength after hot stamping to $> 1900$ MPa and the yield strength to $> 1200$ MPa. The main use of MBW-K 1900 is for parts, which need an extremely high strength in a crash load case, which have to supply a very high integrity to the overall structure of the automotive and which do not have to absorb much crash energy, such as bumpers, cross members, and in part, pillars.

3.1. Processing and mechanical properties
MBW-K 1900 is currently produced uncoated, and thus the austenitization furnace has to be supplied with a protective atmosphere to avoid scaling, such as nitrogen. As uncoated material has a higher emissivity, the dwell time can be reduced by about 30 to 40 % compared to AS coated steel. As the carbon content is increased, the $A_{c1}$-temperature is with 720 °C about the same as for MBW 1500 and the $A_{c3}$-temperature with 815°C is 30 K lower compared to usual MBW 1500. This leads to a more efficient austenitization process, as the furnace temperature can be lowered to e.g. 880 °C, while still receiving excellent mechanical properties. After hot stamping, shot blasting is strongly recommended to remove the thin oxide layer, which forms during transportation from the furnace to the press. Due to the extreme hardness of MBW-K 1900, which is about 540 to 620 HV, a slight stress relief of martensite by tempering is required, to further enhance the mechanical properties. In the usual car production, the tempering is included during cataphoretic painting and the followed paint baking process (KTL). The average temperature during KTL is 170 °C for about 20 min and leads to an increase in yield strength of about 100 to 160 MPa, while the tensile strength is reduced by about 50 to 100 MPa, see Figure 1. The reason for the shift in the mechanical properties is the highly increased diffusion of carbon to dislocations, which hinders sliding in the sliding planes of the crystal lattice.

For testing parts during prototyping or material validation, the KTL has to be simulated separately. The required stress relief of the martensite can be achieved by tempering between 150 °C and 250 °C for about 20 to 40 min. Higher temperatures than about 220 °C lead to a loss of strength, but the overall ductility and energy absorption of the part might be increased. Figure 1 shows the reduction of
the tensile testing properties, while Figure 2 shows the effect of an additional tempering between hot stamping and KTL simulation.

![Figure 1. Results of A80 tensile testing of MBW-K 1900 after hot stamping (HS: 920 °C, 4 min), additional KTL simulation (KTLS: 170 °C, 20 min) and additional tempering (T1: 200 °C, 30 min, T2: 250 °C, 30 min) for a sheet thickness of 1.5 mm.](image1)

![Figure 2. Quasistatic three point bending test of hat-shaped profiles with counter sheet of MHZ340 + Z, bending speed 20 mm/s, distance between supporting points 300 mm, sheet thickness 1.5 mm.](image2)

### 3.2. Stress corrosion cracking (DIN EN ISO 7539-2)

Steel with a tensile strength above 1000 MPa could be susceptible to hydrogen embrittlement [3]. Especially when the further processing brings in additional stresses in local areas such as the cutting edges, parts could easily fail without any further loading. To test the susceptibility of steel and processing methods for this kind of combined load, the four-point bending test according to DIN EN ISO 7539-2 is used. In this test, hot stamped samples of 120 x 20 mm were prepared by shot blasting and laser cutting. The samples were put under bending load in special devices and these are immersed in 5% sodium chloride (NaCl). Further tests were performed using additionally hydrochloric acid to reduce the pH value to 3 and zinc coated samples to enhance a cathodic polarisation. All three methods generate different amounts of hydrogen, which diffuses into the steel. Diffusible hydrogen easily moves through the lattice and segregates to grain boundaries or other imperfections and reduces the ductility of the material. The time until failure of the bending sample is measured and compared for different bending stress values and cutting technologies. The four-point bending test results of MBW-K 1900 are shown in Figure 3. The bending stress is equivalent to the $R_{p0.2}$ value, which was previously measured to 1300 MPa for the hot stamped steel and 1450 MPa for the hot stamped and KTL simulated steel. All samples survived the total testing time of 336 hours without failure.
3.3. Tailored Tempering properties

The tailored tempering process, also called partial press hardening, is a patented process for the production of parts with customized mechanical properties in different regions of the part. To achieve different mechanical properties, the surface temperature of the tools is adjusted between 550 °C and ambient temperature (AT) by using heating cartridges and/or water cooling. The underlying effect is to keep the temperature in a certain range to allow a specific part of the microstructure to transform to bainite or ferrite. An exemplary part is a B-pillar, with a high ductility and medium strength in the lower area to absorb the energy of a side impact, while the upper part has the maximum strength of the material to protect the passenger [4].

MBW-K 1900 has a similar transformation behaviour as MBW 1500, so that tailored tempering is the preferred option to choose from a variety of different mechanical properties. For the evaluation of material properties, different, flat sheet samples of 1.5 x 100 x 300 mm have been austenitized in a roller hearth furnace (925 °C, dwell time 300 s) and transferred to a tool within 4 to 6 seconds. The samples were stamped for 20 s in a flat tool, which was at ambient temperature or heated. After hot stamping, KTL simulation (170 °C, 20 min) was performed and specimen for metallography and tensile testing were extracted.

With increasing tool temperature, the microstructure shifts from about > 95 % fully hardened martensite to martensite with tempering effects (at about 250 °C), followed by an about equally distributed martensitic and bainitic microstructure (at about 400 °C), to a bainitic microstructure with parts of ferrite (< 10 %) at above 500 °C. Exemplary microsections are shown in Figure 4 (right).

To indicate the wide range of possible mechanical values, which can be achieved, Figure 4 (left) shows the average results of four tensile testing samples. At ambient tool temperature, the usual values of MBW-K 1900 are achieved, such as yield strength with 0.2 % offset $R_{0.2} = 1540 \pm 10$ MPa, tensile strength $R_m = 1910 \pm 10$ MPa and elongation at break $A_{50} = 5.5 \%$. With an increasing tool temperature, the strength is reduced to a first plateau at about 300 to 350 °C, with $R_{0.2} \approx 1250$ MPa and $R_m \approx 1600$ MPa. As a drawback, the elongation at break is reduced to about 4.2 %. When the surface temperature of the tool reaches approximately 400 °C, the temperature over time during hot stamping is reduced in such a way, that the bainitic transformation of the microstructure gets dominant. This leads to a shift of the mechanical properties. Thus the strength values drop with an increasing temperature and the elongation increases. At about 500 °C to 550 °C the steel is quite ductile with an average elongation at break of about 15 %, $R_{0.2} \approx 480$ MPa and $R_m \approx 750$ MPa. The mechanical properties can further be influenced by varying the duration of closing of the tools. So using tailored tempering, local areas of a part or even the whole part can be adjusted.
Figure 4. A80 tensile testing after hot stamping with heated flat tools (AT ambient temperature).

3.4. Forming simulation
The main purpose of a bumper beam is to resist a crash impact and transfer the energy further into the automotive body, e.g. crash boxes. A special lightweight solution for a bumper was presented in [5]. The design is an open bumper bracket with a wave-shaped cross-section. A feasibility study was performed, using 1.7 mm MBW-K 1900 in a numerical simulation using the software LS-DYNA. The complex bumper shape is shown in Figure 5. To manufacture this part shape, a complex forming die was necessary. The weight reduction potential of 19 % can be achieved by using this geometry [5].

Figure 5. Numerical simulation of hot stamping of a bumper of MBW-K 1900. Thinning and temperature distribution directly after reaching bottom dead centre are presented.

4. tribond 1200 and tribond 1400
4.1. Concept of tribond 1200 and tribond 1400
To supply cost efficient and low alloyed steels with very high strength and at the same time high ductility, the two steel compounds tribond 1200 and tribond 1400 have been developed. The final failure of a part mainly occurs by failure of the material under bending load situations: bending, followed by local folding of the steel in the case of a lateral load and only folding in the case of an
axially loaded part. So, the main goal is to increase the local folding capacity of the steel sheet. During bending of the sheet, most stress occurs in the outer layer of the sheet. So, the basic idea is to clad a highly ductile steel material (outer layer) onto a core layer with a high strength. This concept increases the local and overall ductility while maintaining the high strength of the core layer for the whole part.

4.2. Mechanical properties and application scenarios

With regard to the material properties, even if they are contrary (e.g. strength and ductility), the new steel grade family tribond enables regular steel grades for hot or cold forming applications to be combined in a composite structure to improve more than one property simultaneously and thus to achieve an enhanced property profile. The first two products in hot stamping are tribond 1200 and tribond 1400, which consist of an outer layer of MBW® 500 and a core layer of MBW 1500. The mechanical properties can be adjusted by varying the proportional thickness of the layers. tribond 1200 focuses on the ductility performance and each outer layer represents 20 % of the total sheet thickness, while tribond 1400, with an outer layer thickness of 10 %, is mainly designed for high strength situations, see Figure 6.

According to the combined materials, the tensile strength is in-between both material: for tribond 1200 $R_m > 1100$ MPa and for tribond 1400 $R_m > 1300$ MPa. However, the level of ductility of cladded material should not be measured by a tensile test. Concerning the crash ductility, the plate bending test according to VDA 238-100 has shown a good correlation. While MBW 1500 reaches a bending angle of > 50°, tribond 1400 achieves > 75° and tribond 1200 is above 130° for 1.5 mm sheet thickness after austenitization at 920 °C for 6 min and hot stamping. With its high ductility and energy absorption, tribond 1200 enables hot stamping steel for parts, which currently are often cold formed, e.g. longitudinal beams or roof cross beams. Figure 7 shows a hat-shaped profile which has been crashed in axial direction.

**Figure 6.** Microsections of hot stamped samples, showing the distribution of MBW 500 and MBW 1500 in tribond 1200 and tribond 1400 as well as the corresponding diffusion zone.

**Figure 7.** Axially crashed hat-shaped profiles of AS coated tribond 1200 and 22MnB5.

**Figure 8.** Laterally crashed hat-shaped profiles of AS coated tribond 1400 and 22MnB5.
Although the steel was hot formed and possesses a high strength of > 1100 MPa, folding of the member and no cracking could be observed. With the high strength almost at the level of MBW 1500 and the highly increased ductility, tribond 1400 is the ideal material for laterally loaded parts, such as automotive pillars or sills. As Figure 8 shows, even when severe deformation / bending of the whole part occurs, no cracking results and thus the maximum energy absorption potential of the steel is used.

4.3. Stress corrosion cracking (DIN EN ISO 7539-2)
As the outer layer of tribond 1200/1400 consists of the low strength MBW 500, this might be an advantage concerning the susceptibility to hydrogen embrittlement. Hence the four-point bending test, has been compared for different cutting situations for AS coated 1.5 mm thick tribond 1200, tribond 1400 and MBW 1500. As a difference to section 3.2, the more demanding 0.1N hydrochloric acid (pH 1) has been applied and for all samples the $R_{p0.2}$ of MBW 1500 of 1032 MPa was used. All laser and water jet cut samples did endure 96 hours until the test was stopped. Samples of MBW 1500, which were mechanically cut with a clearance of 7.5% of the sheet thickness did break between 3.5 and 5 h, while corresponding tribond 1200/1400 samples withstood the test for > 96 h. Thus tribond 1200 as well as tribond 1400 showed notably less sensitive to hydrogen embrittlement and thus mechanical cutting should be taken into account for the production in comparison to laser cutting.

4.4. Numerical simulation of tribond 1200/1400
As tribond 1200/1400 consist of three layers with different mechanical properties, for numerical simulation an advanced method had to be applied: the multi-layered shell method. This method is integrated in usual FEA software, such as Pam-Crash or LS-DYNA. So it is possible to apply different material properties to different shell elements in thickness direction. For the softer outer layer (MBW 500) and the core layer (MBW 1500), flow curves have been evaluated in experiments. The properties for the diffusion zone have been interpolated linearly. This concept has been validated in crash and Nakajima experiments [6] and is shown in Figure 9. For the numerical simulation of hot stamping of tribond 1200/1400, it is recommended to use the temperature depended flow curves of MBW 1500, as both materials have a very similar behaviour in hot forming.

![Figure 9. Numerical simulation of tribond 1200/1400 using the multi-layered shell method.](image)

To evaluate the multi-layered shell method for the numerical simulation of tribond, crash tests with B-pillars have been performed [5, 6]. In the same test, hot stamped 22MnB5 and tailor tempered 22MnB5 were included. The numerical crash simulation of tribond 1400 showed a good correlation with the experiment, see Figure 10. Although the sheet thickness was reduced, compared to 22MnB5, sufficient energy absorption in the rocker area could be established. Furthermore, no cracks were visible in the deformation zone. The weight saving potential in this case for tribond 1400 compared to a reference of 22MnB5 with tailored tempering is about 8%.
5. Conclusion

Current demands for hot stamping steels with extremely high strength and increased ductility can be satisfied by the steel grades MBW-K 1900 and the two AS coated composite steel grades tribond 1200 and tribond 1400. Especially tribond 1200 allows the application of hot stamping steel with > 1000 MPa strength in axially loaded cases, which are currently supplied only by cold forming grades, see Figure 11. All new hot stamping steels allow further lightweight solutions and applications, as material models for numerical crash / hot forming simulation are well established and an easy integration in the process chain due to comparable processing parameters is assured.

![Figure 11. Exemplary parts for optimal application for the new hot stamping grades.](image-url)

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