**Process Stability and Application of 1900 MPa Grade Press Hardening Steel with reduced Hydrogen Susceptibility**

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**Abstract.** While 22MnB5 with aluminium silicon (AS) coating was established as the quasi-standard in press hardening many years ago, the need for steels that offer even higher strength is growing. These needs include corrosion protection of the automotive component and scale prevention during processing in hot forming lines. However, the processing of AS coated ultra-high strength steels involves demands for the furnace atmosphere. Reducing the hydrogen susceptibility and increasing the material strength at the same time was the driving force for the development of MBW 1900 + AS Pro. The paper focuses on the process stability of this steel concerning furnace and stamping parameters as well as the hydrogen induced cracking resistance under different dew points in the furnace atmosphere. In addition, the potential by means of different partial press hardening processes is presented. With tailored tempering, locally heated tools can be used to achieve soft areas in the part. Furthermore, the application potential of MBW 1900 + AS Pro in tailor welded blanks is shown.

1. Introduction
Press hardening (PH) steel is approved since about 20 years in automotive manufacturing. To comply with more demanding crash tests and the increasing vehicle weight of battery electric vehicle (BEV) press hardening steels with strength level above 1500 MPa entered the marked recently. In their first generation, these steels with about 1900 MPa strength level do not have any coating [1, 2]. This reduces the formability in hot forming due to the higher friction coefficient, an additional blast cleaning process of the parts is required and it limits the application to inner automotive parts only. Applying a typical aluminium silicon (AS) coating (e.g. with 11 % Si, 2.5 % Fe and rest Al) to a 1900 MPa grade steel like a 34MnB5 will unfortunately not lead to the desired results. The reason on one hand is a slight decarburization in the furnace of uncoated PH steels, which leads to better folding behaviour during crash. On the other hand, the AS coating is a barrier to the hydrogen effusion, while simultaneously the higher strength grade is more susceptible to hydrogen induced cracking (HIC) [3]. Although there are AS coated concepts that are only based on an adapted chemical composition of the steel [4], an optimization of the coating offers a further increase in the resistance to HIC. Thus, for the development of a coated 1900 MPa press hardening steel grade an adaptation of both the steel and the coating were performed. Although still in development state, the alloying concept of the steel is completed. The applied coating is AS Pro, an improved AS based coating which includes additionally Magnesium. AS Pro is available on the market for 22MnB5 since 2020 and supports a lower hydrogen diffusion into the steel [5].
2. Processing parameters during press hardening of MBW 1900 + AS Pro

2.1. Chemical composition and delivery state

As for most press hardening steels the main alloying elements of MBW 1900 + AS Pro are carbon, manganese and boron. An addition of further micro alloying elements helps to reduce grain growth during furnace heating. A smaller prior austenite grain size improves the tensile strength of press hardening steel [6]. Furthermore, the micro alloying elements decrease the delayed fracture susceptibility and increase the ductility. Concerning niobium this is discussed in [7]. The chemical composition of MBW 1900 + AS Pro is shown in Table 1.

| Grade          | C in % | Si in % | Mn in % | Nb + Ti in % | Cr + Mo in % | B in % |
|----------------|-------|--------|---------|--------------|-------------|-------|
| 34MnB5 uncoated| 0.40  | 0.40   | 1.50    | 0.05         | 0.50        | 0.005 |
| MBW 1900 + AS Pro| 0.35  | 0.40   | 1.50    | 0.05         | 0.50        | 0.005 |

In the as-delivery state the microstructure is ferritic-perlitic and optionally contains traces of harder microconstituents, such as bainite and martensite. The 0.2%-offset yield strength (YS) is between 400 and 650 MPa and the tensile strength (TS) ranges from 600 to 800 MPa. In the as-delivery state the material can be handled easily such as 22MnB5 + AS e.g. for roller levelling, blanking with an elongation at break $A_{80}$ above 12%. The microstructure and coating layer in delivery state are shown in Figure 1. The appearance and handling of the AS Pro coating layer is the same as for typical AS coatings. In the delivery state, the total thickness is approximately 25 µm when a coating mass of 150 g/m² is applied.

With its critical cooling rate of about 30 K/s and $A_c3$ temperature about 820 °C, MBW 1900 + AS Pro is designed for manufacturing automotive parts by the typical direct press hardening process with austenitisation in a furnace at about 900 °C. During this process the AS Pro coating completes its characteristic 5-layered composition (Figure 4f) and the steel microstructure is transformed to mainly martensite with traces of retained austenite (cf. Figure 4a-e). After press hardening the roughness $R_a$ is typically above 2.0 µm.

2.2. Process stability of MBW 1900 + AS Pro in press hardening

MBW 1900 + AS Pro was developed as a process robust hot forming steel to deliver steady properties after press hardening. This is required because of the preferences of different hot forming line designs and for a tolerance regarding the combination of batches with other blanks in the furnace. The process stability was tested under a very wide range of parameters. However, this paper includes only a part of it.

![Microstructure in delivery state](image1.png)

*Figure 1.* Microstructure in delivery state etched with HNO₃ in longitudinal direction, representing a) steel microstructure and b) AS Pro layer formation for 150 g/m² coating weight on both sides.
To evaluate the parameters after press hardening, blanks were press hardened under different conditions. If not stated differently, the standard processing parameters were: sheet thickness: 1.5 mm, holding time in a roller hearth furnace: 300 s at a temperature of 920 °C, transfer time from the furnace to the press in 5 s, closing duration 15 s in a water-cooled tool with 3 MPa surface pressure. The forming start temperature was above 760 °C and the cooling rate was partly >300 K/s. A part of the press hardened parts (condition PH) was further heat treated at 170 °C for 20 min to simulate the paint baking process (condition PB) after electrophoretic coating. All testing samples were EDM wire-cut from flat part areas with homogeneous thickness and tested according to international standards. Results of the tensile testing according to DIN EN ISO 6892-1 (sample size 2) have been performed after press hardening with different temperatures and holding times, see Figure 2. The temperature ‘Rising’ corresponds to a rising furnace temperature inside the furnace over different zones: 800 °C for 60 s, 850 °C / 70 s and 920 °C / 170 s and leads to a lower heating rate in the front area of the furnace as it is performed in a similar way in series roller furnaces.

For all conditions directly after press hardening the tensile strength is between 1850 and 1910 MPa and the yield strength between 1230 and 1300 MPa. The elongation at break $A_{80}$ is above 4.5%. After paint baking the bake hardening effect leads to the typical increase of the YS of about 130 to 150 MPa to about 1400 MPa, see Figure 2b. The resulting decrease of the TS is only about 50 MPa and leads to a TS still above 1800 MPa. $A_{80}$ stays on the same level, but the standard deviation is lower. In general, the higher energy input either by higher temperature or longer holding time leads to a slight decrease both in tensile strength and yield strength. Because of its lower $A_{c3}$ temperature of ca. 820 °C compared to 22MnB5 with ca. 845 °C also a lowered furnace temperature could be possible to austenitize the blanks. However, part complexity and formability have to be considered.

The ductility of MBW 1900 + AS Pro can be evaluated by the plate bending test according to VDA 238-100 (07/2020). The results after press hardening and paint bake simulation are shown in Figure 3a according to the optical measurement. In all conditions a bending angle >45° is achieved. Typically for continuous cast and rolled steel the results transversal to the rolling direction are lower than in longitudinal direction. Still for this steel the anisotropy effect can be limited to only about 2° in plate bending test. The highest bending angles are achieved with low temperatures or low holding times, which are favored by most stampers and enable energy savings.
Figure 3. a) Bending angle according to VDA 238-100 plate bending test longitudinal and transversal to rolling direction for different furnace parameters, n ≥ 6; b) Interdiffusion layer thickness for 1.5 mm MBW 1900 + AS Pro at different furnace temperatures with dwell time of 300 s.

The microstructure after press hardening is influenced by the amount of thermal energy introduced into the steel in the furnace. As an example, the microstructure for 1.5 mm thick MBW 1900 + AS Pro is shown in Figure 4a-e, representing an increase in the furnace temperature from 840 to 960 °C. The growing heat input increases the grain growth of the austenite microstructure and also affects the microstructure of the martensite after quenching in the same way. As a result, the martensite shows a coarser microstructure with rising temperature, especially at 960 °C. The coarser microstructure is mainly responsible for the slight decrease in the mechanical properties, see Figure 2 and Figure 3a.

Figure 4. Substrate microstructure: a) 840 °C / 300 s; b) 880 °C / 300 s; c) 900 °C / 300 s; d) 920 °C / 300 s; e) 960 °C / 300 s; Coating microstructure: f) 880 °C / 300 s

Figure 4f shows the typical 5-layered microstructure (1) of the AS Pro coating after press hardening, with typical total thickness above 30 µm. Cracks, which occur due to different expansion coefficients of substrate and coating during quenching and forming operations (3) stop in the soft ferritic interdiffusion layer (2). The interdiffusion layer grows as a function of energy input due to diffusion of aluminium into the steel substrate. This can be observed in Figure 3b, which represents the interdiffusion layer as a function of the furnace temperature. After heating at 840 °C / 300 s, although the steel is fully martensitic after PH, the coating is not sufficiently alloyed and remains of pure AS Pro coating can be found. These could pollute the forming tools during the stamping operation. Sufficient alloying is achieved even at 880 °C / 300 s, as shown in Figure 4f.

Steels have to have a high resistance against unintentional variation of production parameters or failures, such as problems with the tool cooling system or the transfer unit as this can result in discard of parts. To provide a good process stability against such problems, MBW 1900 + AS Pro has been
tested in different conditions. The results for tensile testing under different circumstances are shown in Figure 5a. A too long transfer time is especially critical for small sheet thicknesses. With increasing transfer time or tool temperature MBW 1900 + AS Pro shows only minor reduction in the ultimate tensile strength. For 15 s transfer time still a $TS$ of above 1730 MPa is achieved even at relatively low 3 MPa of surface pressure. The yield strength shows above 1330 MPa even for 15 s of transfer time or 100 °C tool temperature. The elongation at break $A_{80}$ is not significantly influenced by both tool temperature or transfer time. The surface pressure in the tool also has an influence on the mechanical properties by altering the cooling rate. These results were achieved with relatively low 3 MPa surface pressure. Therefore, by increasing the surface pressure and by this the cooling rate, a further increase of the mechanical properties to compensate longer transfer time or higher tool temperature is possible.

Also the bending angle in Figure 5b is almost not affected by both transfer time or tool temperature changes. In total this makes MBW 1900 + AS Pro a very process robust press hardening steel under different furnace temperatures and dwell times as well as for transfer times and tool temperatures.

**Figure 5.** Influence of tool closing time and tool temperature for 1.5 mm sheet thickness; a) tensile test, longitudinal, after paint baking and b) Plate bending test, paint baking condition

2.3. **Reduced hydrogen susceptibility of MBW 1900 + AS Pro**

During the automotive body assembly of ultra-high strength steel mechanical and thermal stress may occur, which could lead to hydrogen induced cracking if no extra measures are taken into account. A source of hydrogen in press hardening is the surface oxidation and reaction to atmospheric humidity in the furnace during austenitisation [5]. Thus, the dew point of the furnace is generally lowered by injecting dried air. Besides this general processing influence, additional material related measures can be taken. Thus the chemical composition of MBW 1900 + AS Pro with increased micro alloying elements and finer grain make it less susceptible for diffusive hydrogen. Furthermore the recently developed AS Pro coating with the addition of magnesium is one more important step towards a coated press hardening steel with 1900 MPa tensile strength. The driving effect of AS Pro is the lower hydrogen formation and absorption at the surface during heating because of the magnesium-oxide surface layer [5]. The diffusive hydrogen content in steels can be measured by Thermal Desorption Mass-Spectrometric (TDMS) and is compared for different steels and coatings in Figure 6a according to the dew point in the furnace. Already at a dew point of -5 °C MBW 1900 + AS Pro shows a diffusive hydrogen value close to the detection limit of the TDMS. Depending on the situation, about 40% less hydrogen diffuses into the steel as a result of the AS Pro coating [5].
Figure 6. Diffusive hydrogen in dependency of furnace dew point after press hardening in different steels

Besides directly measuring it, the influence of diffused hydrogen can be visualized, by the 4-point bending test under constant load, adapted from DIN EN ISO 7539-2, see Figure 7a. In this test a press hardened part is produced under a controlled dew point in the furnace atmosphere and subsequently set under a specific bending stress for 96 hours or until failure occurs. The bending stress is applied to the sample by turning the screw upwards and measuring the resulting displacement at the center of the sample. According to the mentioned standard the bending stress can be calculated based on the previously measured Young’s modulus and normalized to the respective tensile strength. After reaching yield strength, plastic deformation occurs and the linear correlation of displacement and bending stress is no more valid. As a result, values above the $Y_S$ have to be regarded as surrogate values for the stepwise increase of the bending stress.

Figure 7. Delayed fracture test; a) 4 point bending device; b) passed and failed load levels for 34MnB5 + AS and c) MBW 1900 + AS Pro

Figure 7b and c compare the successfully passed and the failed stress levels for a conventional 34MnB5 and MBW 1900 + AS Pro. Both steels reach the level of yield strength. The final successful level for 34MnB5 + AS is 65 to 67.5% depending on the dew point, while MBW 1900 + AS Pro passes 83 and 90%, depending on the dew point. This shows the positive effect of the deployed measures to increase the resistance against delayed fracture for MBW 1900 + AS Pro.
3. Application of MBW 1900 + AS Pro

Press hardening steels allow the integration of ductile sections to combine both superior part integrity and high energy absorption within one component. Thus, newly developed grades have to be applicable for such technologies as e.g. tail hang out, schwartz thermal printing, tailored tempering and tailor welded blanks. MBW 1900 + AS Pro is well applicable for these technologies, which will be discussed using the examples tailored tempering and tailor welded blanks.

3.1. Tailored tempering

The tailored tempering technology uses partially heated tools of up to 550 °C to prevent full martensite formation during press hardening in certain areas of the part. With a martensite start temperature of $M_s = 340$ °C, MBW 1900 + AS Pro is well applicable for tailored tempering. With increasing tool temperature, the microstructure changes from full martensite for 20 and 100 °C, to first traces of tempering of full martensite (200 and 250 °C), to predominantly bainite (300 and 400 °C), to Bainite and Perlit (500 °C) finally to Ferrite, Perlite and Bainite at 550 °C. The according mechanical properties are shown in Figure 8a and b. Until about 250 °C tool temperature there is only a slight decrease in the mechanical properties, as already discussed in section 2.2. At 300 °C tool temperature when getting close to the $M_s$, there is a significant decrease in tensile strength and hardness. Above 300 °C the yield strength starts to decrease as well. At 500 °C and above the properties stabilise again and tensile strength is below 800 MPa, yield strength below 600 MPa and hardness below 250 HV5. As shown in Figure 8b the ductility starts to increase at 350 °C. At 550 °C a bending angle close to the physical maximum of the test $>120^\circ$ is achieved. The elongation at break $A_{80}$ only starts to increase after martensite is mainly vanished at 450 °C. With tool temperatures at 500 °C and above $A_{80}$ of about 11 % are achieved. The presented results show that press hardened under tailored tempering conditions, MBW 1900 + AS Pro shows the desired low strength and high ductility to provide sufficiently ductile integrated areas in the produced parts.

3.2. Tailor welded blanks

The use of tailor welded blanks is one of the earliest technologies to combine areas with different tensile properties in fully press hardened components. Blanks of different steels are (e.g. laser) welded under laboratory conditions and press hardened with the same parameters as used for monolithic blanks. From a larger test series, some exemplary results are displayed in Figure 9. In the study samples of a very ductile 500 MPa grade and a ductile 1200 MPa grade [8] have been combined with MBW 1900 + AS Pro by laser welding. Parts have been press hardened to hat-shaped profiles with a length of 400 mm, which have been spot welded with counterpart sheets of MHZ 340. After paint baking simulation, the samples have been tested on a drop tower with impact energy of about 2.8 kJ.

Figure 8. Mechanical properties at different tool temperatures, after paint baking; a) Stresses from tensile testing (longitudinal) and hardness results HV10 (500 and 550 °C HV5); b) Bending angle longitudinal and elongation at break $A_{80}$
In all cases the laser welded seam withstood even the direct impact of the impactor and did not show failure. As expected, all deformation is absorbed by the plastic deformation of the softer grade, when the material partition is 37.5% MBW 1900 + AS Pro and 62.5% of MBW 1200 or MBW 500 (Figure 9a). In axial crash testing (Figure 9b) the same hat-shaped profiles with total length of 350 mm have been used, of which MBW 1900 + AS Pro was applied about 36% length at the lower end. After the crash with impact energy of about 8.9 kJ, no deformation occurred in MBW 1900. The weld seam was fully intact, also for the combination with MBW 500, where the folding occurred until the weld seam with the MBW 1900.

![Hat-shaped tailor welded samples after testing with different material combinations](image)

**Figure 9.** Hat-shaped tailor welded samples after testing with different material combinations; a) material partition 37.5% MBW 1900 + AS Pro in longitudinal crash; b) material partition 50% MBW 1900 + AS Pro in longitudinal crash; c) axial crash test

### 4. Conclusions
MBW 1900 + AS Pro is developed as a process robust and widely applicable 1900 MPa strength level press hardening steel grade. For typical processing parameters after paint baking, tensile strength ≥1800 MPa and yield strength ≥ 1400 MPa with bending angle >45° are achieved. These parameters stay largely constant despite varying e.g. tool temperature, transfer time, dwell time or furnace temperature. The special AS Pro coating and the micro alloying make it possible to reduce the absorption of diffusive hydrogen in the furnace and the delayed fracture under constant load condition. Different applications of MBW 1900 + AS Pro for providing local soft areas are possible, of which the application of the tailored tempering process with heated tools and the tailor welding process have been discussed and show excellent applicability. Further possible application options for MBW 1900 + AS Pro are tail hang out, schwartz thermal printing technology and the use in patchwork blanks.

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