MBW 1200 – Hot Stamping Steel with Increased Ductility

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Abstract. Hot stamping steels are trending towards increased ductility without sacrificing too much stiffness. Thus a new aluminum silicon coated grade, MBW 1200 + AS has been developed, with typical yield strength after hot stamping and paint baking of $YS \approx 1000$ MPa, tensile strength $TS \approx 1200$ MPa and $A_{80}>5.0$ %. The highly increased ductility compared to 22MnB5 expresses through the particularly increased bending angle of $>75^\circ$ and the logarithmic true thickness strain of $\approx 0.90$. Hence MBW 1200 shows the desired significantly higher ductility compared to 22MnB5 in lateral crash testing without crack appearance. The process stability has been approved by different tests, e.g. increased furnace dwell time, tool temperature and transfer time. Verifying MBW 1200 in patchwork blank applications with total thicknesses of 3.0 and 3.5 mm showed only a minor decrease of $YS$ and $TS$ between 30 and 50 MPa and leaves the Vickers hardness at $\approx 400$ HV10 with fully martensitic microstructure. In partial press hardening tests, using tools heated of up to 550 °C, bending angles reach the test’s maximum and $YS$ falls below 500 MPa with a hardness of $\approx 210$ HV1. Finally in a comparison between experiment and numerical hot stamping simulation it can be shown, that the determined material modelling parameters can well be used in the feasibility analysis of new automotive components.

1. Introduction
Hot stamped (press hardened) manganese boron steels such as 22MnB5 are well known for their excellent strength, which makes them perfect for applications in the automotive body in white. Although cold forming grades have reached similar strength levels in the meantime, hot formed steels offer the advantage of homogeneous mechanical properties and excellent shape accuracy. Thus, there is a recent demand for hot stamping steel with increased local ductility. The paper focuses on the development of MBW 1200 + AS, an aluminum silicon (AS) coated monolithic manganese boron steel with a tensile strength level of $\approx 1200$ MPa and increased ductility compared to 22MnB5.

2. Concept of steel grade MBW 1200
The concept of manganese boron steels for hot stamping is mainly based on the elements carbon, manganese and boron. Carbon delays the formation of bainite and ferrite and increases the tensile strength. To stay within the desired range of 950 to 1250 MPa, the carbon content is limited to 0.14 %. On the one hand this increases the weldability by lowering the carbon equivalent and on the other hand it increases the ductility and especially the local ductility. Manganese highly reduces the formation of bainite and ferrite and its maximum content is 1.80 %. Boron’s effective range on the suppression of ferrite formation without forming boron carbide and/or -nitride is 0.001 to 0.007 % [1]
and thus the content in MBW 1200 is maximum 0.005 %. Additionally, up to 0.05 % niobium reduces the grain growth. Table 1 compares commonly known 22MnB5 and MBW 1200.

Table 1. Maximum content of selected chemical elements in manganese boron steels.

| Grade     | C in % | Si in % | Mn in % | Nb in % | Ti in % | Cr + Mo in % | B in % |
|-----------|--------|---------|---------|---------|---------|--------------|-------|
| 22MnB5 [2]| 0.25   | 0.40    | 1.40    | -       | 0.05    | 0.35         | 0.005 |
| MBW 1200  | 0.14   | 0.40    | 1.80    | 0.05    | 0.05    | 0.50         | 0.005 |

MBW 1200 provides similar microstructure characteristics both in the as-delivered as well as in the press-hardened condition compared to 22MnB5. In the as-delivered condition the microstructure mainly consists of a finely dispersed ferrite-perlite microstructure, see Figure 1 (a) and (b). Some traces of harder microconstituents, such as bainite and martensite, may also occur. In the as-delivered condition, the 0.2%-offset yield strength (YS) ranges from 320 to 580 MPa, the tensile strength (TS) from 500 to 750 MPa and the elongation at break $A_{80}$ is >12 %. These properties mainly correspond to AS-coated 22MnB5.

![Figure 1](image.png)

Figure 1. Microstructure in delivery state (a)-(b) and after hot stamping (c)-(d), etched with HNO$_3$ in longitudinal direction, representing (a)/(c) base material microstructure in the 1/3-position over thickness and (b)/(d) AS-layer formation.

Hot stamping MBW 1200 can be conducted following the commonly used conditions of 22MnB5, i.e. using furnace temperatures of ≥ 900 °C which produce a complete austenitic microstructure in the heated condition. After press-hardening with accelerated cooling rate below martensite finish temperature the microstructure converts to a homogeneous, fully martensitic structure, see Figure 1 (c). The critical cooling rate of MBW 1200 is estimated with 45 K/s, which can easily be accomplished in all common hot stamping tools. In comparison the critical cooling rate of 22MnB5 is only about 33 % (30 K/s) lower [3]. The prior austenite grain size under usual furnace conditions is homogeneously at ≤ 10 μm and accounts for a finely grained martensitic microstructure after quenching. The aluminum silicon coating develops a sequence of multiple sublayers in the furnace, see Figure 1 (d). This layer formation is comparable with 22MnB5 after hot stamping. In delivery state, the total thickness is approximately 25 μm when a coating mass of 150 g/m² is applied. After hot stamping it ranges from 30 to 50 μm, which is commonly expected by OEM. The thickness of the purely ferritic interdiffusion layer is 8 μm at usual press hardening conditions. After press hardening the roughness $R_s$ typically is above 2.0 μm. This indicates sufficient roughness to allow paint adherence in cataphoretic painting treatment and was approved by cross-cut adhesion tests.

3. Increased ductility and crash testing
The mechanical properties after hot stamping of MBW 1200 with a thickness of 1.5 mm have been evaluated after heat treatment in a roller hearth furnace at 920 °C for 6 min, transportation from furnace to press within 10 s and stamping in water cooled tools. After hot stamping (HS) and partly paint baking simulation (PB) at 170 °C/20 min, testing samples were wire-cut by electrical discharge machining from flat part areas. Tensile testing was performed according to DIN EN ISO 6892-1 and the plate bending test according to VDA 238-100. Exemplary results of MBW 1200 + AS and
22MnB5 + AS are compared in Table 2. Please note, that the presented results are only exemplary and will vary for different production lines and production parameters within the common specifications.

For manganese boron steel, paint baking will commonly result in an increase of YS. Thus for MBW 1200, YS increases from about 900 to 980 MPa. TS is not influenced by paint baking and achieves as expected 1200 MPa. The elongation at break is above 5.5 %, which is common for a fully martensitic hot stamping steel. The increased ductility can be displayed by the bending angle, which is above 75° and thus about 20 to 25° higher than for 22MnB5.

| condition           | YS* in MPa | TS* in MPa | A80 in % | bending angle in ° | hardness in HV |
|---------------------|------------|------------|----------|-------------------|---------------|
| MBW 1200, HS        | 900        | 1200       | 5.9 ± 0.5| 81 ± 1            | 416 ± 2       |
| MBW 1200 HS+ PB     | 980        | 1200       | 5.6 ± 0.4| 84 ± 2            | 416 ± 3       |
| 22MnB5, HS          | 1040       | 1500       | 5.7 ± 0.2| 55 ± 1            | 489 ± 6       |
| 22MnB5, HS+PB       | 1140       | 1480       | 5.8 ± 0.1| 60 ± 1            | 484 ± 6       |

The determination of the local ductility, e.g. for material failure simulation, is of increasing importance [4]. Fracture surfaces of A80 tensile testing samples of 1.5 mm MBW 1200 have been measured in 4 locations on each of the two sample pieces. As arithmetic mean from 8 samples transversal and 8 samples longitudinal from different positions of the strip a logarithmic local thickness strain at fracture of 0.90 ± 0.03 was found. This represents a large increase of more than 33 % in comparison to 22MnB5 with 0.67 ± 0.03 on A80 samples. The effect of the larger local ductility can well be shown in crash testing. For this test hat-shaped profiles with a length of 400 mm have been hot stamped and a counterpart sheet of HSLA 340 has been attached by spot welding. After paint baking simulation, the samples have been tested in longitudinal direction on a drop tower with 71 kg of weight and 4 m height. MBW 1200 + AS still absorbs about 75% of the energy compared to 22MnB5 + AS at the same displacement. After inspection of the samples, minor cracking is visible on the 22MnB5, while MBW 1200 only shows little thinning, see Figure 2.

![Figure 2](image-url)
22MnB5. Hence MBW 1200 can be processed above 900 °C to about 950 °C. For 1.5 mm thick material the dwell time can be adjusted between 4 and more than 16 min at 920 °C, as YS and TS after hot stamping do stay within a range of 50 MPa around the mean value. However, the mutual increase of the interdiffusion layer between coating and substrate has to be considered, which limits the dwell time generally to less than 12 min.

If tools are not sufficiently cooled or malfunctions occur at the cooling system, the tool temperature might quickly increase. To test the stability of MBW 1200, parts have been hot stamped in heated tools and tensile tests and plate bending tests have been performed. As a result sufficient mechanical values are achieved at 200 °C tool temperature, since YS decreases only by about 50 MPa and TS by 130 MPa, see Figure 3. The elongation at break A80 stays on the same level, while the bending angle grows by about 15 %. Increasing the transfer time from the furnace to the tool to 10 or even 15 seconds results in a decrease of YS and TS of at most 75 MPa. Additionally, no significant influence on A80 could be found. At a transfer time of 15 s the bending angle decreases by about 5° and thus, no longer transfer time is recommended. With a high or low contact pressure, within the scope of different conditions in hot stamping tools, the mechanical properties are well consistent.

![Figure 3](image-url)  
**Figure 3.** Influence of processing parameters on tensile testing results for MBW 1200 + AS in 1.5 mm after hot stamping at 920 °C/6 min, without paint baking according to [5].

5. **Patchwork blank application and tailored tempering**

To achieve a local reinforcement of e.g. a b-pillar a smaller reinforcement part could be hot stamped separately and joined to the pillar. An alternative could be a patchwork blank consisting of two blanks welded on top of each other and hot stamping afterwards. Benefits are the reduction of tools and a highly increased strength of the weld spot, because of the homogeneous microstructure/hardness. However, mechanical properties and sufficient alloying of the AS coating have to be regarded. To evaluate this, MBW 1200 (thickness 1.5 mm) and 22MnB5 (1.5 and 2.0 mm) blanks of 200 x 300 mm have been joined by resistance spot welding using 12 weld points to represent patchwork blanks. These blanks have been heated for 480 s at 920 °C, transferred within 10 s to a water-cooled tool and hot stamped with a contact pressure of 10 MPa for 20 s. Some of the stamped parts underwent paint bake simulation (170 °C/20 min). Subsequently the more critical samples transversal to the rolling direction were wire-cut by EDM from the MBW 1200 and tested, see Table 3.

It is found that all results show only minor differences between the two total patch thickness combinations and so the results will be discussed together. After hot stamping in the patch combinations YS is on the same level as YS for the monolithic blank. The increase of YS after paint baking is about 40 MPa and thus about 30 MPa lower than for the monolithic blank. TS is in both conditions still above 1170 MPa and thus only about 3 % lower than for the monolithic blank. As only A50 samples could be tested, the results are not directly comparable to the monolithic blank, but
represent the expected results for a fully martensitic grade. The bending angle according to VDA 238-100, which is more expressive for the ductility, slightly increases. The minor reduced hardness of 400 to 406 HV10 corresponds to the reduction in TS. All samples show a fully martensitic microstructure. Both sides of the AS coating, pointing to the 22MnB5 and to the atmosphere, show the same thickness of interdiffusion layer and characteristic layer composition of AS, according to Figure 1 (d). In summary MBW 1200 + AS is very well suited as partner in patchwork applications as the mechanical parameters maintain on the same high level as for the monolithic blanks. As almost constant parameters have been evaluated for total thicknesses of 3.0 and 3.5 mm it is highly expected that higher total patchwork thicknesses are quite possible.

| total patchwork blank thickness, condition | YS in MPa | TS in MPa | $A_{80}$ in % | bending angle $\gamma$ | hardness in HV10 |
|------------------------------------------|-----------|-----------|--------------|----------------------|----------------|
| 3.0 mm, HS                              | 900 ± 10  | 1180 ± 10 | 7.4 ± 0.3    | 79 ± 2               | 406 ± 2        |
| 3.5 mm, HS                              | 900 ± 10  | 1180 ± 10 | 7.5 ± 0.5    | 79 ± 4               | 400 ± 2        |
| 3.0 mm, HS+PB                          | 930 ± 20  | 1180 ± 10 | 7.3 ± 0.2    | 81 ± 2               | 406 ± 2        |
| 3.5 mm, HS+PB                          | 940 ± 10  | 1170 ± 10 | 7.2 ± 0.4    | 80 ± 2               | 404 ± 4        |

Tailored tempering is a hot stamping technology with one area of the tool heated to 550 °C to prevent martensite formation during hot stamping and to achieve local softened areas in the part for energy absorption during a crash situation. With its martensite start temperature of about 375 °C, MBW 1200 is well designed for use in tailored tempering conditions. Blanks of MBW 1200 in 1.5 mm have been hot stamped for 20 s in heated tools after typical austenitisation. The tool temperature was set to different temperatures from 250 to 550 °C, corresponding results are shown in Figure 4.

![Figure 4](image-url) Mechanical properties after hot stamping MBW 1200 with heated tools, according to [5].

At a tool temperature of 250 °C the mechanical results are quite close to results with water cooled tools. With rising tool temperature up to about 450 °C there is not a large improvement of the ductility, this means of $A_{80}$ and the bending angle, nevertheless YS, TS and Vickers hardness are constantly decreasing. At the usual tailored tempering temperature of 550 °C, MBW 1200 achieves values similar to non-boron high ductility hot stamping steel for tailor welded blanks such as MBW 500. Especially the plate bending test according to VDA 238-100 achieves the maximum possible bending angle (> 135°) and the elongation at break $A_{80}$ reaches about 15 %, YS is below 500 MPa, TS is lower than 700 MPa, while the Vickers hardness is about 210 HV1. The corresponding microstructure consists of ferrite and bainite.
6. Numerical hot stamping simulation of MBW 1200
In order to perform suitable reference tests for the validation of a simulation models for MBW 1200 a flexible hot stamping tool has been used. This tool is compact, see Figure 5 (a), and can be mounted with three different punches, so that different sheet thicknesses can be processed with it. The manufactured reference components were gridded in advance in order to enable a later forming analysis and thus to determine the strain distribution in the component. As an example, Figure 5 (b) shows the thinning distribution for an area of the component in which strain localization has started.

![Figure 5.](image)

Figure 5. (a) The flexible multi-function tool (punch side) used in this work and (b) a gridded component with thinning distribution in an area resulting from the forming analysis.

The strain information obtained in this way is very suitable for comparison with simulation results and for validation of simulation models. Indeed, the strain distribution represented in the space of the main strains (pairings of minor and major strains) for MBW 1200 + AS in 1.5 mm and for 30 mm drawing depth, see Figure 6, has been plotted together with the corresponding simulation results, as shown in Figure 7. This method delivers an overview for the correlation between experimental and simulated strains in a single diagram, and for the whole part at once.

![Figure 6.](image)

Figure 6. Strain distribution on the inner side of a component out of MBW 1200 + AS in 1.5 mm and for 30 mm drawing depth with highlighted strain states.
Although forming analysis is well established in cold forming, it is somewhat difficult to implement in hot sheet metal forming, since there is a need to use a grid that can withstand the hot forming process with high furnace temperatures and high friction. The grid is applied using a special heat resistant color, which is applied on the blank using the silkscreen printing method.

The strain distribution in Figure 6 shows in detail, that the hot stamping process for this geometry delivers information about a number of strain states. Five of them, going from almost equibiaxial tension to pure shear over plane strain, can be well distinguished from each other and have been highlighted with circles. An adequate simulation model should thus be able to map all these strain states simultaneously and with sufficient accuracy. The simulation results on Figure 7 show very good agreement with the experimental observations for almost all five strain states emphasized on Figure 6, which gives a certain confidence in applying the simulation models used in this work for feasibility analysis of further components out of MBW 1200 + AS.

Concerning the only strain state which is not caught very precisely, on the upper left region of the diagram, the simulated strains are higher than the measured ones. As shown in a more complete simulation study [6], which has been realized with the same tool and part geometry, but for 22MnB5 + AS, the prediction accuracy of this specific strain state may be further improved, for example in adapting the \( r \)-values, the friction coefficient or the heat transfers. Changing their description would nevertheless affect other strain states as well, especially the one near to the plain strain state. This study finally helps in understanding why the simulation results shown here for MBW 1200 are very satisfactory. In comparable circumstances in process design, it is nothing bad to overestimate somewhat the strains since it may have the positive effect of making the designed process slightly safer.

7. Conclusions

The newly developed steel grade MBW 1200 + AS and 22MnB5 + AS show close similarities in delivery state and after hot stamping both in microstructure of the substrate and the aluminum silicon coating. Thus it comes with the same excellent processability in hot stamping. However, main differences are the lower carbon content of \( \leq 0.14 \% \) and further minor adaptions of the chemical composition, leading to an increased ductility and better performance after spot welding.

After hot stamping and paint baking with usual processing conditions, MBW 1200 shows its more ductile properties, such as a bending angle of \( >75^\circ \) both longitudinal and transversal to the rolling
direction, a logarithmic true fracture strain of $0.91 \pm 0.05$ on $A_{50}$ samples and more ductile and less crack sensitive behavior in the lateral drop tower test. The high 0.2%-offset yield strength ($\approx 980$ MPa) and ultimate tensile strength ($\approx 1200$ MPa) offer enough potential for highly loaded parts in the automotive body. An excellent process robustness in hot stamping, regarding furnace temperature, dwell time, insufficient cooled tools, transfer time and tool contact pressure support the efficient use of MBW 1200 for OEMs and car manufacturers.

MBW 1200 approves well for patchwork applications, as the mechanical properties remain on a constant high level. In a patchwork blank combination with a total thickness of 3.5 mm, only a minor decrease of $< 50$ MPa in both $YS$ and $TS$ and a Vickers hardness still $\approx 400$ HV10 were evaluated. These results indicate usage in patchwork applications with even thicker sheet combinations. Additionally, MBW 1200 is well suitable for partial press hardening methods, as its critical cooling speed of $45$ K/s for a fully martensitic microstructure and its martensite start temperature of $\approx 375$ °C are close to these of 22MnB5. In usual tailored tempering conditions, the maximum bending angle of $>135^\circ$ and a low hardness of 210 HV1 can be achieved and anticipates excellent energy absorption in both longitudinal and axial crash testing.

Finally, to design hot stamping processes for new components of MBW 1200 + AS based on FEM analysis, material modelling parameters have been implemented and studied. By comparing experimental data from strain analysis on the actual part with results from the numerical simulation, a good correlation was found. All this makes MBW 1200 an excellent, reliable and flexible alternative in the more ductile strength level directly next to the common 22MnB5.

References
[1] Koley S, Karani A, Chatterjee S and Shome M 2018 J. of Materi Eng and Perform 27 3449–59
[2] 2016 Nachschlagewerk Stahlschlüssel: Key to Steel, La Clé des aciers, Version 8.0 (Marbach, Germany: Verl. Stahlschlüssel Wegst)
[3] Turetta A, Ghiotti A and Bruschi S 2006 Testing Material Formability in Hot Stamping Operations Drawing the things to come: Trends and advances in sheet metal forming : IDDRG International Deep Drawing Research Group 2006 conference ; June 19 - 21, 2006, Porto, Portugal ; proceedings ed A D Santos (Leça do Balio, Portugal: Instituto de Engenharia Mecânica e Gestô Industrial)
[4] Frömeta D, Lara A, Casas B and Casellas D 2019 IOP Conf. Ser.: Mater. Sci. Eng. 651 12071
[5] Banik J, Gerber T, Parma G and Rosenstock D 2020 Warmumformung von duktilen Stählen unter Berücksichtigung von Prozessstabilität und Performance 15. Erlanger Workshop Warmblechumformung: Tagungsband zum 15. Erlanger Workshop Warmblechumformung (17.11.2020) ed M Merklein (Erlangen: Lehrstuhl für Fertigungstechnologie, Friedrich-Alexander-Universität Erlangen-Nürnberg)
[6] Graff S, Werner-Bielefeld S and Brenner T 2018 Erweiterung und Validierung des Simulationsmodells für die Warmblechumformung Tagungsband zum 13. Erlanger Workshop Warmblechumformung (Erlangen, 22.11.2018) ed M Merklein (Erlangen: Lehrstuhl für Fertigungstechnologie, Friedrich-Alexander-Universität Erlangen-Nürnberg)