Fundamentals and Applications of Mo and Nb Alloying in High Performance Steels – Volume 1
Edited by Hardy Mohrbacher
CBMM, IMOA and TMS, 2014

PROGRESS IN PRESS HARDENING TECHNOLOGY AND INNOVATIVE ALLOYING DESIGNS

Jian Bian

Niobium Tech Asia
068868 Singapore

Keywords: Hardenability, Weight Reduction, Hot Forming, Grain Refinement, Press Hardening, Automotive, Strength, Niobium, Molybdenum, Coating, Precipitation

Abstract

The worldwide automobile industry is currently focusing on developing a new generation of vehicles with more safety, less CO_2 emission and alternative energy. The key to success is the lightweight technology. As a perfect example of lightweight technology, press hardening is presented in 3 major aspects: material, design and manufacturing. The press hardening technology resolves the conflicting issues for application of ultra-high strength steels and makes it possible for carmakers to increase the strength level up to 1500 MPa or more for the safety-critical components and to achieve a weight reduction of about 20% without compromising safety or increasing cost. The good formability at high temperature gives carmakers much more flexibility to design and to form the components in a very precise way. During the cooling process in the die it is possible to control the microstructure transformation locally by changing the local temperature of the die accordingly so that different microstructures and mechanical properties can be realized in a single component. The ongoing developments are focused on the improvement of the toughness and the resistance to delayed fracture of press hardening steels. Finally the author would like to introduce an innovative alloying concept for press hardening steel, which can meet the challenges of automotive application at the present time.

Introduction

There are three major reasons for using press hardening technology:

- Good formability.
- Lightweight.
- Safety.

Over the last decade advanced (AHSS) and ultra-high strength steels (UHSS) have been developed. But with increasing strength, the formability of the steels becomes very limited on the one hand and on the other hand springback during the forming operation becomes larger. Therefore the automobile and the supply industries are facing new challenges to form the high strength steels using the conventional press shop. That is the reason why the application of AHSS and especially UHSS has not reached the level which the automotive industry would like to have. According to the European Car Body exhibition in Germany in 2010, the advanced high strength steels (tensile strength approaching 800 MPa) are currently used up to 15% on average in the European car body structure and the ultra-high strength steels (tensile strength from 800-

1200 MPa) are only used for less than 5% so far. In contrast, the press hardening technology has developed very fast over the last decade. Due to forming at high temperature, even high strength steels have excellent formability and there is no springback after forming. The high strength level makes it possible to reduce the weight of crash relevant components by 20 to 30% without safety compromise and cost increase. The major advantages of press hardening in comparison with the cold forming process are:

- Good formability due to high temperature.
- No springback during forming process.
- Very high strength after forming process.
- Low forming load.
- Less wearing of die.
- Design flexibility and dimensional accuracy.

Figure 1 shows that the number of car components made by the press hardening process increased from 3 million in 1987 to 107 million in 2007 [1]. It is estimated that it will reach 360 million car components by 2016. The typical components made by press hardening are A/B-pillar, bumper, roof rail and tunnel [2]. The rapid increase of car components made by the press hardening process clearly demonstrates that press hardening represents the future for the automobile industry in the years to come.

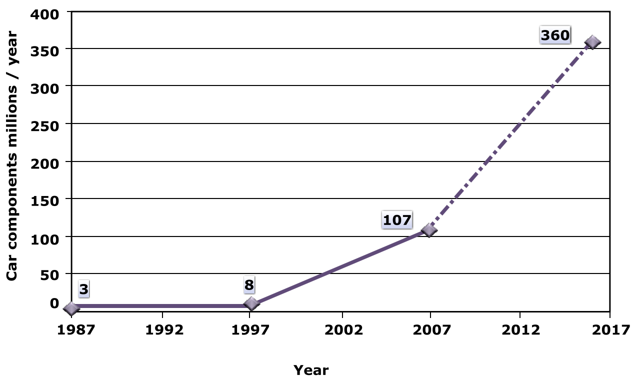

Figure 1. Number of car components produced by press hardening process from 1987 to 2007.

Press Hardening Steels

The standard press hardening steel is 22MnB5 which belongs to the manganese-boron steel group. This steel was developed about 40 years ago mainly as hot rolled or forged for a Q&T process with thick gauge. This steel was found to be suitable for press hardening due to its moderate carbon content and good hardenability. The critical cooling rate for martensite transformation is only about 27 K/s, therefore the first generation press hardening lines usually did not have water-cooled dies. But the disadvantage of uncooled dies is the extended cooling time in the die and consequently lower productivity. For automotive application the press hardening steel will normally be cold rolled down to a thickness below 1.5 mm and subsequently coated with aluminum-silicon alloy or zinc alloy. The mechanical properties of 22MnB5 in the different process stages are listed in Table I.

Table I. Mechanical Properties of 22MnB5 in the Different Process Stages

Condition	YS, MPa	TS, MPa	Elongation, % (A80)
Hot rolled	500-650	650-820	>12
Cold rolled /annealed	310-400	480-560	>18
Cold rolled /AlSi coated	360-500	540-680	>10
Press hardened	950-1100	1450-1650	>5

Apart from the mechanical properties, 22MnB5 possesses a high bake hardening potential up to 100 MPa or more in the press hardened condition, good weldability (spot welding) and coatability, which are also very important criteria to be considered for automotive applications.

Coating System for Press Hardening

The most widely used coating system for the press hardening process is aluminum-silicon (AlSi for short) developed by ArcelorMittal [3]. This coating can protect the steel surface from scaling during the reheating process, but does not provide cathodic protection to the steel in corrosive media like a zinc coating does. The AlSi coating undergoes two major changes during the reheating period in the furnace:

1) Formation of rough surface of coating layer for good paint adherence.
2) Alloying of coating layer with the substrate.

Figure 2 shows that the coating layer becomes thicker and the surface becomes rougher after reheating. According to the investigation made by Arcelor-Mittal, the minimum reheating time for the coating layer should be about 4 minutes in order to get the desired surface condition for the subsequent painting process [3]. Figure 3 shows the alloying process of the coating layer during reheating in the furnace. Through diffusion of Fe to the coating layer, the weldability of the coating will be improved.

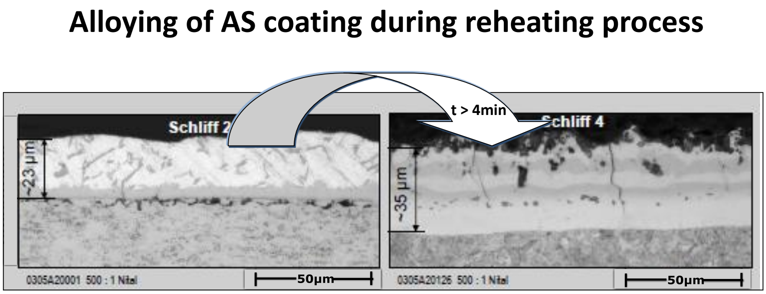

Figure 2. Influence of reheating process on the AlSi coating during press hardening process.

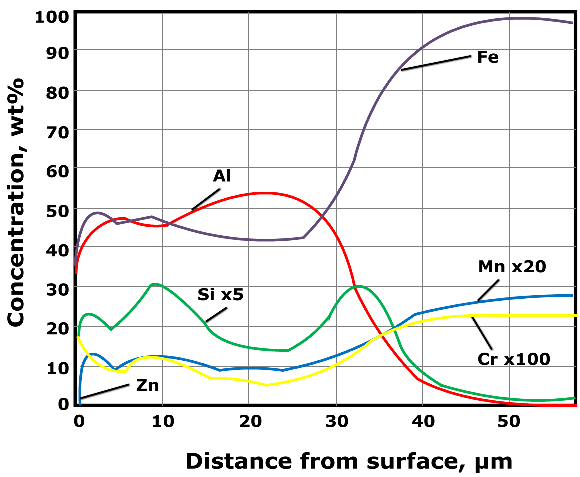

Figure 3. Alloying process of coating layer during reheating.

Process Technology

There are two process approaches for press hardening, namely one-step and two-step processing. For the one-step process, hot forming and quenching take place in the same die and the standard product is Usibor 1500 from ArcelorMittal [3]. For two-step process, which was developed by Voestalpine, the cold forming and quenching take place separately in two different dies and the standard coating is a zinc alloy [4]. The majority of operating press hardening lines are based on one-step processing which is more economical due to shorter process times with only one die. The temperature profile and the microstructure development during press hardening is demonstrated in Figure 4.

The process begins with reheating of coated steel sheet to a temperature between 880 and 950 °C. After that it will be transferred by a robot to the press die for final forming and quenching, which takes normally about 12 s, before the components are released from the die at a temperature between 150 and 200 °C, if the press die is not cooled at all. The martensite-start and finish temperatures of 22MnB5 are about 400 and 200 °C respectively and, due to this reason, the component should be cooled down below 200 °C before release from the die.

The steel microstructure before the press hardening process consists of ferrite and pearlite and at the end of reheating it is fully austenite, which will transform to martensite after quenching in the die.

The bottleneck of the conventional press hardening process is related to reheating time in the furnace and the quenching time in the die. In order to increase the productivity, new developments are being focused on alternative heating technology, for example induction heating to shorten the reheating time, or to alloy the coating outside of the press hardening process. As for the quenching process, a hydraulic press with a water-cooled die and pressure control during quenching represents the state of the art.

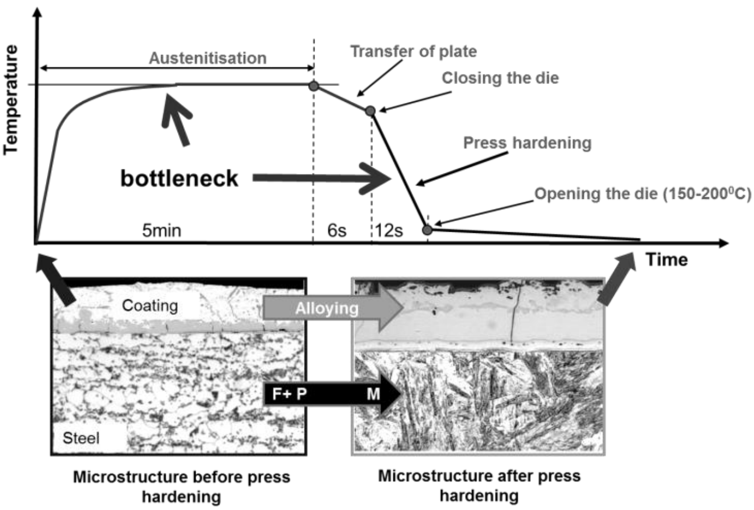

Figure 4. Temperature profile and the microstructure development during press hardening process.

Recent Developments

Press Hardening into Dual Phase Microstructure

The standard microstructure after press hardening is martensite with very high strength but poor toughness. Since press hardening is a high temperature process, it is possible to control the microstructure development by controlling the process temperature and cooling rate during press hardening accordingly. Figure 5 shows just one example of how to make a DP steel by using the press hardening process.

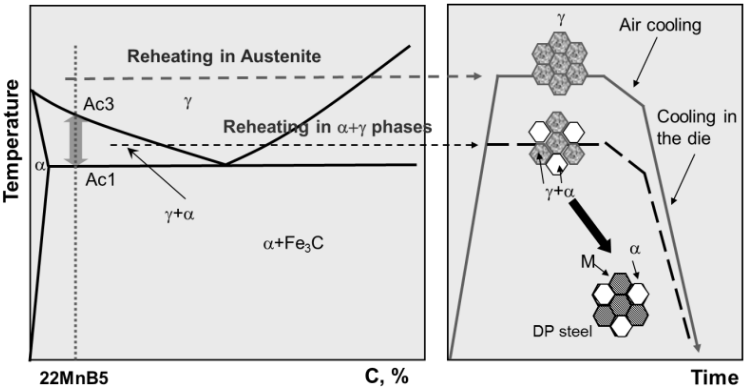

Figure 5. Press hardening into dual phase microstructure.

The only difference between dual phase press hardening and conventional press hardening is the reheating temperature. In order to produce a DP microstructure the steel sheet is reheated in the α+γ region instead of in the γ region as usual, and after quenching the dual phase microstructure can be realized. The influence of reheating temperature on the mechanical properties after press hardening is shown in Figure 6.

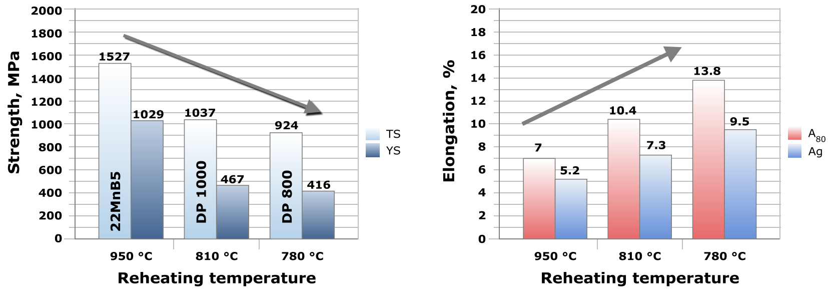

Figure 6. Influence of reheating temperature on the mechanical properties of dual phase steels after press hardening.

The major advantages of the process are:

- Dual phase microstructure with significantly improved elongation.
- Mechanical properties can be adjusted by varying the reheating temperature.
- To produce different products with the same steel composition by adjusting the furnace temperature accordingly.
- Energy-saving due to the lower furnace temperature.

Press Hardening with Higher Strength

The standard press hardening always produces a martensite microstructure. Since the hardness of martensite (strength) is solely related to the carbon content in the steel, it is easy to increase the martensite strength by increasing the carbon content. As mentioned above, the final strength of car components will be realized in the final step of forming and quenching; in this case the increase of strength will not have any evident negative effect on the whole process and especially on the forming process. As we know for the cold forming process, the strength level of the steel always has the dominant influence. Based on this consideration, higher strength can be reached by using a higher grade of manganese-boron steel for the press hardening process. Figure 7 shows some test results from ThyssenKrupp Steel Europe [5].

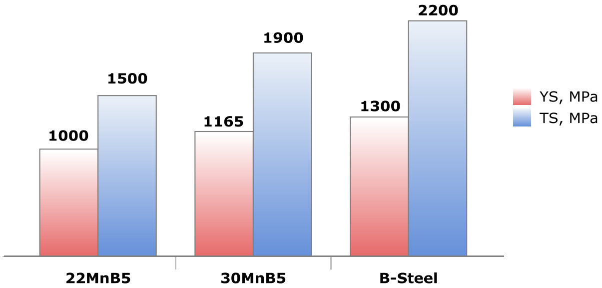

Figure 7. Higher strength up to 2200 MPa can be reached by using press hardening process [5].

By increasing carbon content accordingly, both yield strength and tensile strength can be increased and the total elongation remains at the same level due to the character of martensite. Due to this development, some carmakers in Europe are considering increasing the strength level up to 1900 MPa for some components like bumper and door beams by using the press hardening process. Mazda has already made the very first step to use 1800 MPa press hardening steel in the new CX-5 model [6]. Right now some developments are being focused on new press hardening steels with tensile strength of more than 2000 MPa.

Innovative Alloying Designs for Novel Press Hardening Steels

As mentioned before, the manganese-boron steels are suitable for press hardening due to the moderate carbon content and good hardenability. But manganese-boron steels do not provide the best solution to solve the specific problems with regard to the press hardening process like grain size coarsening during reheating and poor toughness and delayed fracture of the martensite microstructure. Currently these problems remain the major concerns for the automotive application of press hardening steels. Based on these considerations, an innovative alloying concept for the press hardening process, which is shown in Table II, has been developed.

Table II. Innovative Alloying Concept for Press Hardening Process

Mo = 0.15% Nb = 0.05%

Lower P and S

Steel grade	C Max	Si Max	Mn Max	P Max	S Max	Cr+Mo Max	Ti Max	B Max
22MnB5	0.25	0.40	1.40	0.025	0.010	0.50	0.05	0.0050

OUT OUT

Firstly, boron should be removed from the concept because boron can only increase the hardenability. However, hardenability is not an issue for the press hardening process due to the thin gauge of steel sheet for automotive application on the one hand and on the other hand the cooling rate in the die is much faster than the critical cooling rate for martensite transformation. Without B in the steel, Ti should also be taken out in order to avoid large TiN precipitates. The central point of the new concept is to use Nb alloying (about 0.05%) in order to control the grain growth from hot rolling to press hardening. Furthermore, Nb precipitates will help to increase the resistance to delayed fracture. The addition of Mo at 0.15% will compensate the hardenability due to the absence of B and slow down the precipitation process of Nb which will make Nb more effective at refining the microstructure and improving the toughness. Finally S and P should be further limited in order to improve the toughness of the steel. Figure 8 shows the the influence of Nb alloying on the microstructure of manganese-boron steels.

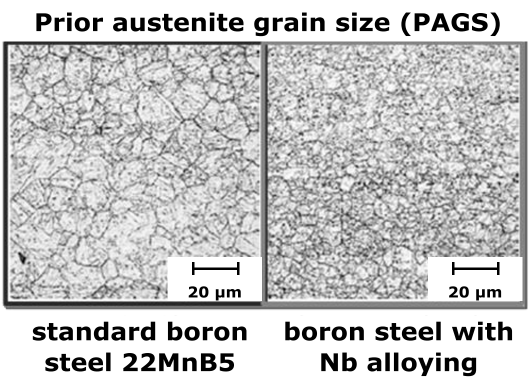

Figure 8. Influence of Nb alloying on the grain refinement of microstructure after press hardening process [7].

Due to the pinning effect of NbC precipitates, the prior austenite grain size at the end of reheating is much smaller than the conventional 22MnB5. Subsequently, the martensite packet size is also much smaller after quenching. The fundamentals of the new concept are to reduce or to avoid the crack initiation by avoiding large particles and inclusions on the one hand and on the other hand to increase the resistance to crack propagation by refining the microstructure and strengthening the grain boundaries (by reducing P, S and B); thus high strength, good toughness and high resistance to HIC can be achieved for press hardening steels. The following advantages of the new concept can be expected:

- Removal of B and Ti will make steelmaking and casting less problematic (clogging).
- Controlling the segregation of tramp elements to the grain boundaries.
- Refining microstructure.
- Avoiding large particles (TiN) and inclusions.
- Improving toughness.
- Trapping hydrogen and making martensitic steel less sensitive to delayed HIC.

Automotive Application

Press hardening steel is now used in almost every car model in Europe, and up to 12 different types of components and 20 parts can be used in the car body structure overall, as shown in Figure 9.

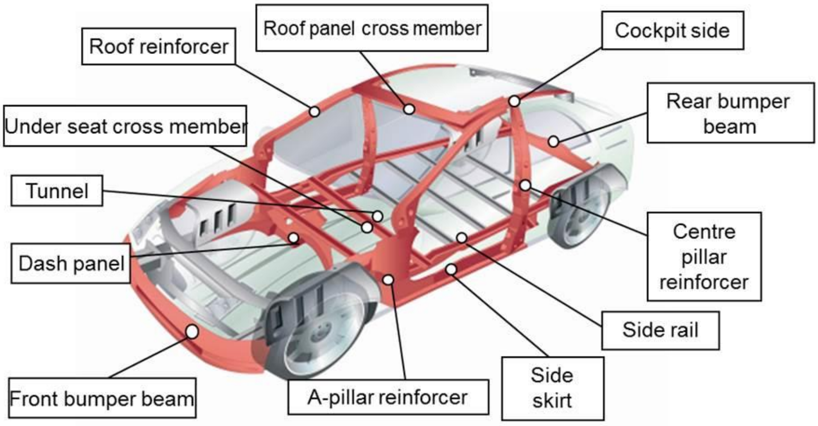

Figure 9. Application of press hardening steels in the car body structure.

The following diagram, Figure 10, shows the application of high strength steels from conventional HSS to PHS in some chosen European car models, which were demonstrated during the European Car Body Exhibition in 2009 and 2010 in Germany.

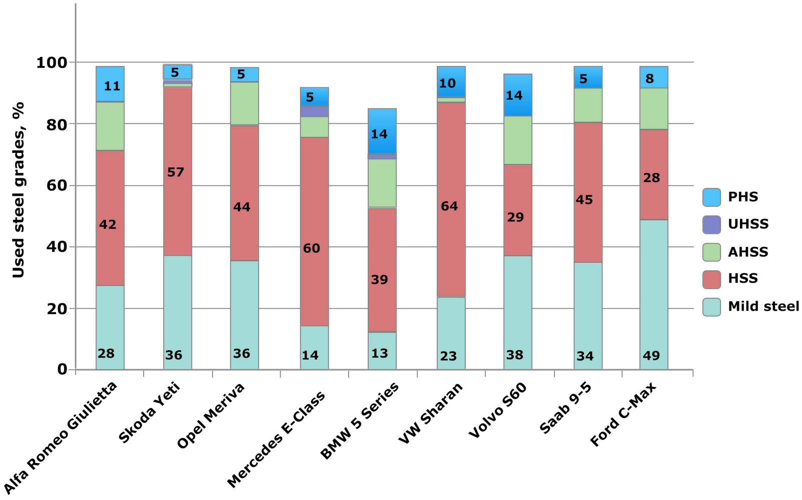

Figure 10. Used steel grades of some European car models from 2009 and 2010.

From Figure 10 the following development trends for car body structure can be concluded:

- Mild steels comprise less and less of the car body.
- Conventional HSS is still the major group used in the car body (up to 64% in the body structure).
- Advanced high strength steels continue to grow (up to 16% in the body structure).
- Ultra-high strength steels are still very limited in automotive application (less than 5%).
- Press hardening steels are present in every car model and used up to 15% in the body structure.

Conclusion

Press hardening technology has been proven to be a good solution to solve the problems of forming ultra-high strength steels like poor formability, springback, high forming load and wearing of the die. Press hardening broke the bottleneck for the application of ultra-high strength steels in the automobile industry and makes it possible to increase the strength level up to 1500 MPa or more for the safety-critical components and to achieve a weight reduction of about 20% without compromising safety or increasing cost. Press hardening is becoming both a technically and economically attractive lightweighting technology for the automotive industry, especially with regard to the reduction of CO_2 emission. Niobium alloying provides an innovative alloying concept to make press hardening steels more suitable for automotive application.

References

1. J. Aspacher, “Forming Hardening Concepts” (Paper presented at the First International Conference on Hot Sheet Metal Forming of High Performance Steel, Kassel, Germany, 2008), 77-81.

2. Stahl im Automobil, Leicht und Sicher: Stahl-Information-Zentrum. 2009, www.stahl-info.de.

3. Arcelor-Mittal , “A New Method to Increase the Productivity of a Press Hardening Line Using Aluminized Boron Steel,” *Proceedings of Conference of Materials in Car Body Engineering*, May 2011, Bad Nauheim, Germany.

4. PHS-Ultraform, Press Release, Voestalpine Stahl, 2011.

5. J. Bian, T. Heller, European Patent 1 865 086, “Verwendung Eines aus Einem Mangan-Bor-Stahl Hergestellten Flachproduktes und Verfahren zu Dessen Herstellung.”

6. *Proceedings of Conference of Materials in Car Body Engineering*, May 2011, Bad Nauheim, Germany.

7. H. Mohrbacher, “Benchmark of Current Body Structures and Future Material Strategies,” *Proceedings of Conference of Materials in Car Body Engineering*, May 2011, Bad Nauheim, Germany.