



The effect of initial microstructure on the final properties of press hardened 22MnB5 steels

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ABSTRACT

This paper addresses the relationship between initial microstructure and final properties of press hardened 22MnB5 steels. Four commercial 22MnB5 steels having different initial microstructures were investigated. An experimental press hardening equipment with a flat-die was used to investigate material behavior in the direct press hardening process. Two austenitizing treatments, 450 s and 180 s at 900 °C, were examined. Microstructural characterization with optical and scanning electron microscopes revealed a mixture of martensite and auto-tempered martensite after press hardening. Electron back-scatter diffraction data of the transformed martensite was used to reconstruct grain boundary maps of parent austenite. Grain sizes of parent austenite (mean linear intercept) were measured for each material. In addition to microstructural evaluation, quasistatic and high strain rate tensile tests at strain rates of $5 \times 10^{-4} \text{ s}^{-1}$ and 400 s^{-1} , respectively, were performed for press hardened samples. The results show that strength and uniform elongation depend on the initial microstructure of the 22MnB5 steel, when parameters typical to the direct press hardening process are used. Parent austenite grain size was shown to influence the morphology of the transformed martensite, which in turn affects the strength and uniform elongation after press hardening. The tensile properties of the press hardened materials are almost strain rate independent in the studied strain rate range. The obtained results can be used to optimize the properties of 22MnB5 steels in the direct press hardening process. In addition, the here revealed connection between the parent austenite grain size and final steel properties should be taken into account in the development of new press hardening steel grades for automotive industry.

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1. Introduction

Press hardening technology has received considerable interest in recent years, especially in the automotive industry, by providing a possibility of reducing weight while maintaining or increasing the passive safety performance of automobiles [1]. Nowadays, press hardening is a useful manufacturing method for producing ultra-high strength safety components of car body from both uncoated and coated boron steel sheets. With the development of coated press hardening steels the corrosion resistance of the components has improved, but, at the same time, the importance of appropriate heat treatment parameters in the press hardening process has increased [2]. In the direct press hardening process a steel blank is first austenitized typically at 900–950 °C for 3–10 min. After that, the blank is transferred to the press in which it is successively formed and quenched in a die. The martensitic

phase transformation leads to a significant increase in strength and facilitates the attainment of excellent dimensional accuracy of the components [2,3].

In recent years numerous studies [4–14] have been conducted in order to understand the physical metallurgy and the characteristics of press hardening process affecting the phase structure and mechanical properties of 22MnB5 steel. The influence of hot plastic deformation of austenite on the phase transformation kinetics during quenching has been highlighted. Both isothermal [4–6,14] and non-isothermal [7–9,14] thermo-mechanical experiments have been carried out in order to characterize ferritic, bainitic and martensitic transformations during hot forming and subsequent die-quenching. Thermomechanical simulators, e.g. Gleeble, enable accurate control of for example deformation temperature and cooling rate of the sample, but do not necessarily meet the industrial conditions. Application oriented studies [11–13], in contrast, have been based on experiments carried out with customized press hardening equipment. This type of approach provides a sufficient interface between theory and practical hot

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forming processes. However, each experimental setup has unique pressing tool geometry and forming conditions, which must be taken into account when the microstructures and mechanical properties of press hardened steels are evaluated.

In terms of the properties of the end-product, the process parameters of the direct press hardening process can be roughly divided into three categories, i.e., austenitizing, hot forming, and quenching. Previous studies [12,15,16] have shown that optimal austenitizing cycle for 22MnB5 steel is 3–10 min soak close to 900 °C. After press hardening, a martensitic microstructure and tensile strength of 1500–1600 MPa are typically obtained. According to Zhou et al. [16], insufficient austenitizing at too low temperature results in a small amount of undissolved pearlite, some fragmentary ferrite, and a limited fraction of martensite. In the case of 22MnB5, too high austenitizing temperature and soaking time need to be avoided since they lead to austenite grain growth decreasing the strength of martensite [12,16].

According to the CCT-diagram determined by Naderi [17], the 22MnB5 grade requires a minimum cooling rate higher than 25 °C/s for a full martensitic transformation to occur. However, deformation of austenite shifts CCT curves to shorter times, which enhances especially the formation of ferrite at higher cooling rates. Thus, the critical cooling rate from the martensite transformation point of view is dominant only when the steel is water quenched or quenched in a flat-die without hot deformation. In the hot forming conditions the required cooling rate is considerably higher depending on the initial forming temperature and local deformation state [18,19]. Despite this sensitivity to the critical cooling rate, 22MnB5 grade has also shown robustness in industrial processes. Bardelcik et al. [10] reported that the hardness and microstructure of 22MnB5 steel (0.22 wt% C) are not dependent on the applied cooling rate above a critical value of 30 °C/s, when hot plastic deformation of austenite does not take place. The authors observed that cooling rates 45 and 250 °C/s result in similar martensite morphologies and hardness of 460–470 HV. Higher hardness values of approximately 500–520 HV have been reported for water quenched 22MnB5 steel (0.21–0.22 wt% C) [10,11]. According to Nishibata et al. [11] the hardness of hot stamped parts is approximately 50 HV lower than the hardness of water quenched 22MnB5 (0.21 wt% C) parts (close to 450 HV). The hardness difference was explained by auto-tempering of martensite occurring at the secondary region of cooling at temperatures near and below 450 °C [11]. Auto-tempering of martensite occurs readily during die-quenching since the cooling rate at temperatures below 450 °C is characteristically 20–300 °C/s. In addition, Fan et al. [2] suggested that the tensile strength of hot press formed parts is higher compared to as-quenched parts due to the grain refinement of martensite originating from the hot deformation of austenite. Hutchinson et al. [20] showed that austenite deformation (10% and 30%) increases hardness and tensile strength of as-quenched 22MnB5 steel.

Even though the phase transformations in 22MnB5 steel in the direct press hardening process are currently well-known, the role of the initial microstructure of 22MnB5 steel has received considerably less attention. Naderi [17] investigated press hardenability of several high strength steels and also analyzed the

initial microstructure, parent austenite grain size and mechanical properties of each grade after press hardening. Maikranz-Valentin et al. [21] suggested that partially recrystallized microstructure results in smaller parent austenite grain size compared to fully recrystallized initial microstructure of 22MnB5 steel, and thus enhances the attaining of improved mechanical properties, especially higher toughness. Despite the aforementioned findings, detailed information concerning the initial microstructure, the parent austenite grain size, and the final mechanical properties of the 22MnB5 grade has remained unclear. Accurate knowledge on the relationships between raw material properties and processing parameters gives possibilities to optimize the properties of the end-product.

In the present study, the effect of the initial microstructure on the final mechanical properties and microstructure of press hardened 22MnB5 steels is investigated. Press hardening experiments with a flat-die were performed on four commercially produced 22MnB5 steels. The present study focuses on the microstructural factors together with tensile properties evaluated at both quasi-static and high strain rates. It is shown that there exists a clear correlation between parent austenite grain size (PAGS) and mechanical properties after press hardening.

2. Materials and methods

2.1. As-received material properties

The test materials of this study, referred as FH, CA₁, CA₂, and BA, consisted of four commercially produced 22MnB5 steels. The samples were supplied as 1.5–1.7 mm thick steel sheets. FH was supplied in a full-hard state, i.e. as cold-rolled. Test materials CA₁ and CA₂ were supplied as cold-rolled and continuously-annealed. CA₁ was supplied as sub-critically annealed below A_{c1}. CA₂ was intercritically annealed, i.e. heat treated in $\alpha + \gamma$ region between A_{c1} and A_{c3}. BA was supplied as uncoated and batch annealed, i.e. the steel coil was sub-critically annealed in a batch furnace. The commercial 22MnB5 grades had minor deviations in chemical composition, e.g. carbon and chromium contents of BA were slightly higher compared to the other materials. Initial properties and chemical compositions of as-received materials are presented in Table 1.

Initial microstructure and mean microhardness (HV 0.5) of each sample material, transverse to the rolling direction, are presented in Fig. 1. The microhardness values were measured from the sectioned samples by using a digital hardness tester Matsuzawa MMT-X7. As can be seen in Fig. 1, the microstructure of as-received 22MnB5 steel typically consists of ferrite and pearlite. FH shows slightly elongated ferrite grains with relatively large and coarse pearlite colonies (Fig. 1a). The microhardness of FH is relatively high (268 HV) due to the high dislocation density created during cold-rolling. In this study, the cold-rolled state is considered as the initial point in microstructural evolution: the microstructure changes step by step in the typical annealing treatments applied in the continuous production line. Annealing temperature regulates the recrystallization behavior of ferrite and the

Table 1
Initial properties of the test materials. Ferrite grain size is expressed as the mean linear intercept (L_M) number transverse to the rolling direction. A₁ and A₃ temperatures were calculated using JMatPro software [22]*.

Material	Production history	Ferrite grain size L_M (μm)	Thickness (mm)	C%	Si%	Mn%	Cr%	B%	Ti%	A ₁ * (°C)	A ₃ * (°C)
FH	Cold-rolled	3.8	1.7	0.24	0.25	1.24	0.20	0.0027	0.034	713	804
CA ₁	Cont. annealed	5.4	1.5	0.23	0.24	1.23	0.21	0.0027	0.029	714	805
CA ₂	Cont. annealed	5.1	1.5	0.23	0.26	1.24	0.21	0.0031	0.040	715	810
BA	Batch annealed	5.0	1.5	0.25	0.26	1.20	0.29	0.0022	0.039	719	806

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