

Use of the Press Hardening Technology for Treatment of TRIP Steel

Hana Jirková, Kateřina Opatová, Josef Káňa, Martin Bystrianský

Faculty of Mechanical Engineering – Regional Technological Institute, University of West Bohemia, Univerzitní 8, 306 14 Pilsen, Czech Republic. Email: h.jirkova@email.cz

Multiphase TRIP steels are able to absorb impact-deformation energy and therefore they are used as safety components in vehicle construction. One of the ways how to produce these precision sheet metal parts is the press hardening technology. Besides specific alloying which in most cases is done with manganese and silicon, the properties of TRIP steels are also determined by the appropriate heat treatment parameters. The key processing parameter is the holding time at the temperature of the bainitic transformation, at which not only the formation of bainite but also the stabilization of retained austenite take place. This holding time is technologically demanding for use in industry. Therefore, the possibility of processing this type of steel by press hardening technology has been experimentally verified. Material-technology modelling was used to build models corresponding to the press hardening temperature profile. These models were tested on low-alloy CMnSi steels. In the experimental program, the effect of the tool temperature in the range from RT to 550°C, as well as the influence of different cooling rates on the structure development and mechanical properties was investigated. Mixed structures from ferritic-martensitic to ferritic-martensitic-bainitic with different volume fraction of retained austenite were obtained. Tensile strengths ranged from 730 to 1300 MPa with elongations from 24 to 9%.

Keywords: Press hardening, TRIP Steel, retained austenite

1 Introduction

Requirements for a reasonable product price and high productivity are placed on the manufacture of high-strength parts and not only in the automotive industry (Fig. 1) [1,2]. Furthermore, there are efforts to reduce the mass of individual automotive parts, while continuously improving crash safety [1]. One possible approach involves press hardening of high-strength steels, such as multiphase steels [1, 2]. This method of processing of hardenable sheet metal requires only small forming forces and translates good formability into high strengths and reduced springback [1]. Such parts are then used as safety components in the car body. They include, for instance, the B-pillar, side impact beams and bumpers [3, 4].

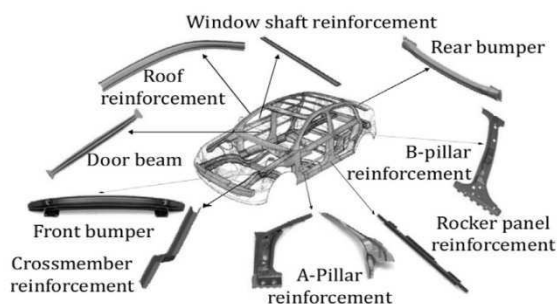


Fig. 1 Car parts manufactured by press hardening at Benteler Automotive [3]

The typical material used in press hardening is the manganese and boron-alloyed 22MnB5 steel [1-5]. After press hardening, it contains martensite and shows strengths of more than 1500 MPa [2, 5]. The use of other steels is expanding as well, such as those with 0.2–0.4 wt. % carbon and 5–8 wt. % manganese, which offer strengths exceeding 1800 MPa and elongation of 16% [6, 7]. Martensitic stainless steels are another viable group here. With them, difficulties arise predominantly from the cool-

ing rate [8]. Steels with 0.4% carbon and manganese, silicon and chromium can be used as well. By means of advanced treatment, i.e. the Q&P process, they can be treated to strengths above 2000 MPa and elongations up to 15% [9, 10].

With regard to their broad usability for press hardening, TRIP steels were explored as well [11]. They belong to the group of multiphase high-strength low-alloy steels. Once used for this purpose, they could be accepted in other industrial sectors.

However, their press hardening had to be tested first. The treatment of TRIP steels has specific aspects which enable them to develop the desired mixture of ferrite, bainite and retained austenite. To achieve this microstructure, the cooling operation includes an isothermal hold above the M_s , during which bainite forms and retained austenite becomes stable [12]. However, since isothermal holding at the bainite transformation temperature is very demanding to arrange in industrial practice, various ways to eliminate it are sought [13, 14].

2 Experimental programme

In this experimental programme, press hardening of a multiphase low-alloy TRIP steel was tested. The capabilities were explored of this heat treatment without isothermal holding as well the classical variant with isothermal holding at the bainite transformation temperature. The purpose was to determine the potential of this steel and characterise its behaviour in several cooling variants.

2.1 Experimental material

The representative of TRIP steels chosen for this study was the low-alloy 0.2CMnSi. Its main alloying elements were manganese and silicon, besides carbon (Table 1). These elements serve the purpose of stabilising retained austenite and strengthening the solid solution. Moreover, silicon and manganese prevent carbide precipitation

in the course of bainite transformation [15]. The as-received microstructure consisted of ferrite and pearlite, and the hardness was 180 HV10 (Fig. 2). The steel was supplied as soft-annealed sheet of 1.5 mm thickness.

The metallurgist needs to know the transformation behaviour of TRIP steels during cooling because formation

of pearlite, an undesirable phase in TRIP steels, must be prevented during heat treatment. For appropriate treatment temperatures to be identified and undesirable phase transformations to be prevented, a CCT diagram was calculated using the JMatPro program [16] (Fig. 3). The M_s was 370°C.

Tab. 1 Chemical composition of the experimental steel [wt. %]

C	Mn	Si	Al	Nb	P	S	Ni	Cu	Mo	W
0.21	1.4	1.8	0.006	0.002	0.007	0.005	0.07	0.06	0.02	0.02

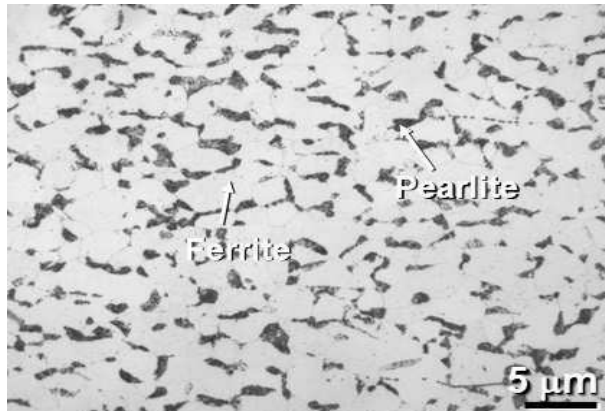


Fig. 2 As-received condition of 0.2CMnSi steel

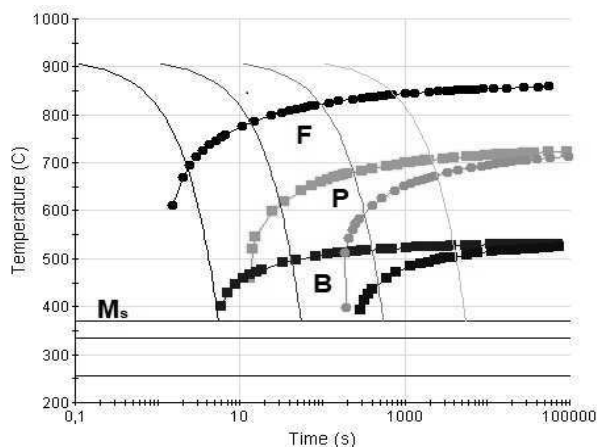


Fig. 3 CCT diagram calculated for 0.2CMnSi steel

2.2 Press hardening

The press hardening process was explored by means of material-technological modelling in a thermomechanical simulator. This machine offers precise heating and cooling control, thanks to which very fast cooling rates, as found in press hardening in a tool at room temperature, can be achieved. The data for constructing the material-technological models was measured in a real-world process.

The first steps in the physical simulation of the heat treatment were heating to 937°C and holding for 100 s. In the next step, the stock was transferred to the tool over 10 seconds, while cooling in air. Once in the tool, the stock cooled more rapidly. The kinetics of this quenching process was governed by the chosen temperature of the tool. After the stock temperature equalized with that of the tool, air cooling began, as the last step in the sequence.

In order to thoroughly characterize the effect of the

cooling rate on microstructural evolution, this experimental programme was divided into three phases. In the first phase, material-technological models were constructed, in which the cooling rate corresponded to press hardening in a tool at room temperature. For detailed description of the effects of the cooling rate, slower cooling rates were tested in this phase as well. These reduced cooling rates were based on 75%, 50% and 25% intensities of cooling in a tool at room temperature. The rate of cooling in a tool at room temperature was 100°C/s and the reduced variants were 75°C/s, 50°C/s and 25°C/s.

Material-technological modelling in the second phase studied press hardening in a tool at 550°C, followed by air cooling whose rate was 2°C/s. An additional experiment in this phase involved press hardening in a tool at 500°C and various rates of cooling to room temperature. These rates were based on 75%, 50% and 25% intensities of cooling in air, and therefore had values in the interval 1.3–0.5°C/s.

In the last phase, classical TRIP steel treatment with isothermal holding for bainite transformation was physically simulated. The value of the tool temperature of 425°C was derived from phase transformation temperatures and based on earlier experiments [17]. The stock was held at this temperature for times ranging from 0 to 600 s and then cooled in air.

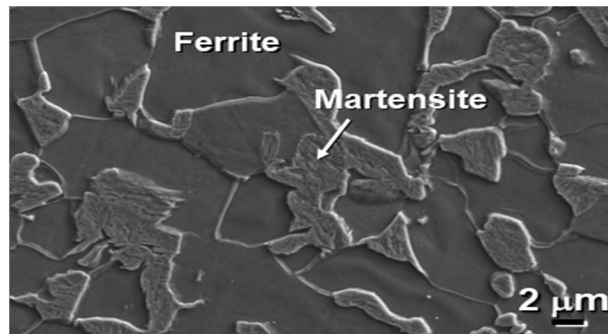
Metallographic observation of the treated specimens was carried out using optical microscopy as well as scanning electron microscopy (SEM) in Tescan VEGA 3 SEM and Zeiss EVO MA 25 microscopes. An EDS analysis was performed with the Zeiss Crossbeam 340-47-44 microscope. The amount of retained austenite was measured by X-ray diffraction. The automatic powder diffractometer AXS Bruker D8 Discover with a HI-STAR position-sensitive area detector and a cobalt X-ray source ($\lambda K\alpha = 0.1790307$ nm) was employed for this phase analysis. Measurements were taken in the centres of metallographic sections at diffraction angles in the interval of $25 \div 110^\circ 2\theta$. Mechanical properties were measured by HV10 hardness testing and tensile testing.

3 Results and discussion

The sequence with the tool at room temperature led to a ferritic-martensitic microstructure and a hardness of 241 HV10 (Fig. 4). EDS analysis confirmed that martensite islands were rich in manganese and the ferrite ones in silicon (Fig. 5). The retained austenite fraction was very low: a mere 3%. The ultimate strength was 876 MPa and elongation $A_{20} = 17\%$ (Table 2).

Tab. 2 Effects of cooling intensity on microstructural evolution with the tool at room temperature

Heating temperature [°C]	Tool temperature [°C]	Cooling intensity [%]	Cooling rate [°C/s]	R _{p0.2} [MPa]	R _m (UTS) [MPa]	A ₂₀ [%]	HV10 [-]	RA [%]
937	RT	100	100	410	876	17	241	3
		75	75	429	874	8	271	-
		50	50	400	851	16	257	-
		25	25	526	821	19	246	-

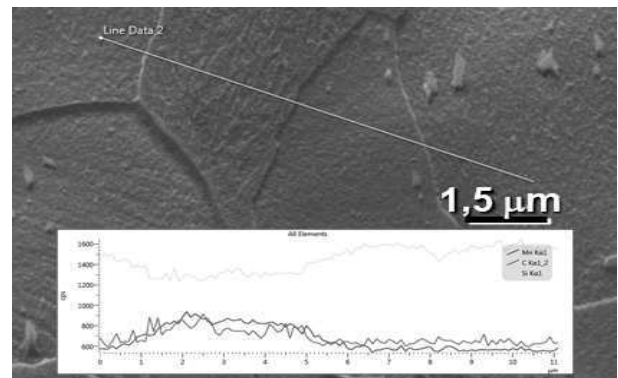
**Fig. 4** Press hardening with the tool at room temperature, ferritic-martensitic microstructure, scanning electron micrograph

The specimens which cooled at reduced rates have not shown any considerable differences in microstructure – which consisted of ferrite and martensite in all cases. Upon the slowest cooling rate, the microstructure showed visible signs of the start of bainite formation along prior austenite grain boundaries. Lower cooling rates led to lower strength levels: 821 MPa at the rate reduced to 25% of the rate of cooling in a tool at room temperature (Table 2). On the other hand, elongation was slightly higher than after cooling in a tool at room temperature. Hardness values remained almost identical to those after cooling in a tool at room temperature, they were in the range 241 – 271 HV10.

Tab. 3 Effects of cooling intensity on microstructural evolution with the tool at 550°C and 500°C

Heating temperature [°C]	Tool temperature [°C]	Cooling intensity [%]	Cooling rate [°C/s]	R _{p0.2} [MPa]	R _m (UTS) [MPa]	A ₂₀ [%]	HV10 [-]
937	550	100	2	311	720	20	229
	500	75	1.3	368	798	24	241
		50	0.9	356	783	21	233
		25	0.5	526	821	19	246

Then, press hardening with a tool at a lower temperature, 500°C, was carried out in combination with various air cooling rates (1.3 to 0.5°C/s) (Table 3). Since the tool temperature, and thus the quenching temperature, were lower than in previous cases, the resulting mixed microstructure of ferrite and martensite was found to contain no pearlite. The sequence with 75% intensity of cooling to ambient temperature (100% intensity of cooling represented air cooling at the rate of 2°C/s) led to a higher ultimate strength, 798 MPa, and an elongation of 24%. Higher strength is the result of elimination of pearlite, which led to a larger fraction of martensite. Cooling at 25% intensity (i.e. at the rate of 0.5°C/s) caused a small fraction of bainite to form, predominantly along prior austenite grain boundaries (Fig. 7). This bainite caused a difference in mechanical properties: the ultimate strength

**Fig. 5** Press hardening with the tool at room temperature, EDS analysis: C, Mn and Si maps

In the second phase of the experiment, the tool temperature was set at 550°C. After press hardening, the product cooled in air (Table 3). The resulting microstructure was ferrite-martensite with a portion of pearlite. Pearlite was found along the boundaries of martensite islands, as well as in the form of separate colonies which formed within and filled completely the prior austenite grains (Fig. 6). By this finding, it was confirmed that during cooling in a tool at 550°C, the cooling curve intersects the pearlite-start curve. The hardness was 229 HV10. The ultimate strength was a mere 720 MPa, with elongation at 20%.

reached 821 MPa and elongation was 19%.

In the last phase, typical TRIP steel treatment with isothermal holding at the bainitic transformation temperature was performed (Table 4). The holding temperature was 425°C and the time at temperature varied from 0 to 600 s. The sequence with quenching in a tool at 425°C and subsequent air cooling led to a ferritic-martensitic microstructure with a small amount of bainite and an ultimate strength of 844 MPa and an elongation of 21%. The volume fraction of retained austenite was a mere 4%. The sequences with longer times at temperature, 100 s and 300 s, have not delivered the expected increase in the bainite or retained austenite fractions. They resulted in lower mechanical properties: 754 MPa and 735 MPa, respectively, and elongations of 25% and 22%, respectively, which was due to the material becoming tempered.

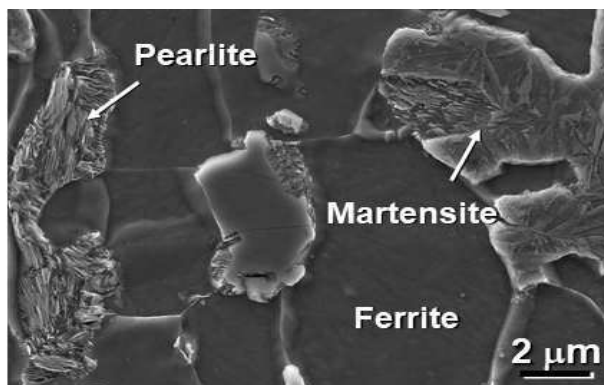


Fig. 6 Press hardening in a tool at 550°C with subsequent air cooling, ferritic-martensitic microstructure with a small fraction of pearlite, scanning electron micrograph

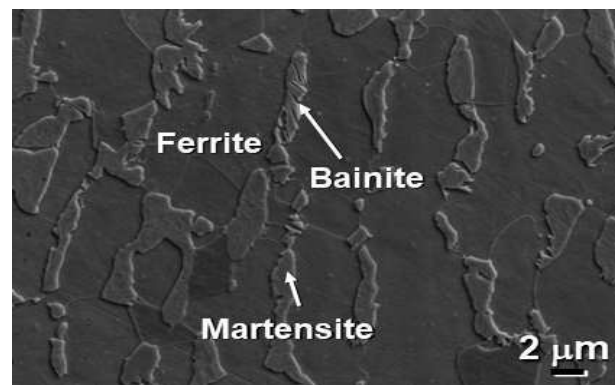


Fig. 7 Press hardening in a tool at 500°C with subsequent cooling at 0.5°C/s to room temperature, ferritic-martensitic microstructure with a small fraction of bainite, scanning electron micrograph

Tab. 4 Effects of holding time during press hardening in a tool at 425°C

Heating temperature [°C]	Tool temperature [°C]	Holding time [s]	R _{p0.2} [MPa]	R _m (UTS) [MPa]	A ₂₀ [%]	HV10 [-]	RA [%]
937	425	0	374	844	21	250	4
		100	352	754	25	228	-
		300	328	735	22	225	6
		600	695	1300	9	408	13

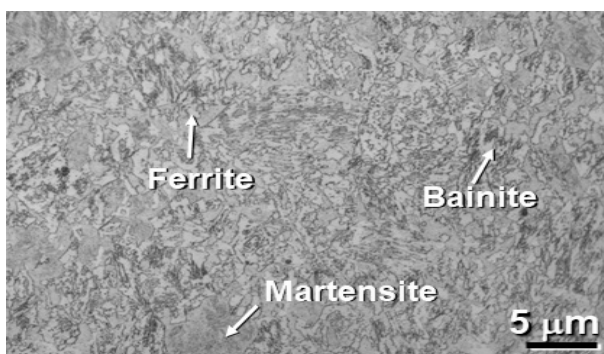


Fig. 8 Press hardening in a tool at 425°C with a holding time of 600 s, ferritic-martensitic-bainitic microstructure with 13% of retained austenite, optical micrograph

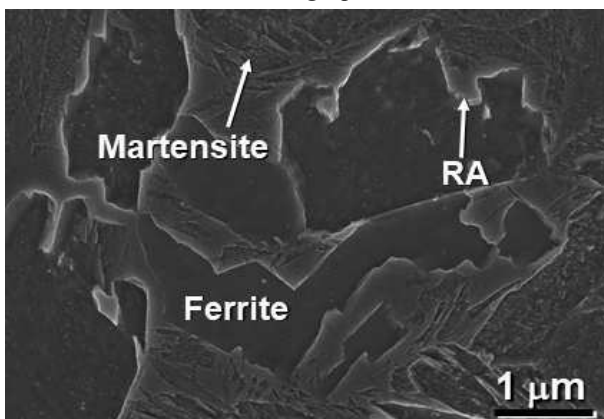


Fig. 9 Press hardening in a tool at 425°C with a holding time of 600 s, detail – visible retained austenite particles along the boundaries of prior austenite grains, scanning electron micrograph

Major differences in microstructure and mechanical

properties were only achieved with the time at temperature of 600 s. Isothermal holding with this duration strongly promoted formation of bainite. As a result, the microstructure consisted of a mixture of ferrite, martensite and bainite, with 13% of retained austenite (Fig. 8). Detailed EBSD analysis confirmed the presence of retained austenite along the boundaries of prior austenite grains, the rest of which have transformed to martensite. The result was the M-A constituent. Retained austenite was also found between bainite sheaves (Fig. 9). This sequence led to the highest ultimate strength: 1300 MPa, along with an elongation of 9% and a high hardness of 408 HV10.

4 Conclusion

Press hardening of multiphase high-strength 0.2CMnSi steel enables such steels to be more widely used, namely in the field of high-strength safety components in the automotive industry. In order to ascertain the feasibility of press hardening of this steel, various cooling parameters were tested. Their effects on microstructural evolution, and thus on mechanical properties, were mapped. The processing was performed in a thermomechanical simulator. The data for material-technological modelling were obtained from a real-world process.

In press hardening in a tool at room temperature, various cooling rates were tested from the interval of 100–25°C/s. In all cases, ferritic-martensitic microstructures were obtained along with ultimate strengths of about 850 MPa and elongation A₂₀ between 16–19%. The other results obtained suggest that the temperature of the tool in press hardening should be under 550°C. Otherwise, pearlite forms in the workpiece, which impairs mechanical properties.

Bainite transformation was only initiated when holding for 600 s was incorporated after press hardening in a

tool at 425°C. This has led to a martensitic-bainitic microstructure with a fraction of ferrite and 13% of retained austenite. The ultimate strength therefore increased to 1300 MPa and elongation was 9%.

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