USE OF MULTI-PHASE TRIP STEEL FOR PRESS-HARDENING TECHNOLOGY

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Abstract

Development of high strength or even ultra-high strength steels is mainly driven by the automotive industry which strives to reduce the weight of individual parts, fuel consumption, and CO_2 emissions. Another important factor is to improve passenger safety. In order to achieve the required mechanical properties, it is necessary to use suitable heat treatment in addition to an appropriate alloying strategy. The main problem of these types of treatments is the isothermal holding step. For TRIP steels, the holding temperature lies in the field of bainitic transformation. These isothermal holds are economically demanding to perform in industrial conditions. Therefore new treatments without isothermal holds, which are possible to integrate directly into the production process, are searched. One way to produce high-strength sheet is the press-hardening technology. Physical simulation based on data from a real-world press-hardening process was tested on CMnSi TRIP steel. Mixed martensitic-bainitic structures with ferrite and retained austenite (RA) were obtained, having tensile strengths in excess of 1000 MPa.

1 Introduction

Advanced high-strength steels (AHSS) are a promising group of materials for the automotive industry. Since most of them are multiphase materials that benefit from a number of strengthening mechanisms, considerably wide ranges of mechanical properties can be attained [1-3]. They enable the car body weight and fuel consumption to be reduced while improving crash safety [4, 5]. Thanks to their properties they are used for safety components in car bodies [6, 7].

TRIP (TRansformation Induced Plasticity) steels, which possess a good combination of strength and ductility, fall into this group [8, 9]. Their microstructures consist of ferrite, carbide-free bainite and retained austenite (RA) [8-15]. Upon cold deformation, RA transforms into high-carbon martensite which substantially contributes to work hardening [9, 14]. Work hardening is further enhanced by dislocations and internal stresses within the surrounding phases [10].

One of the processes, by which such high-strength components can be manufactured, is press hardening. The process enables sheet stock of hardenable materials to be worked using comparatively low forming forces and leads to a reduced springback [16-18]. The difficulty with TRIP steels is the requirement for isothermal holding which is technologically complicated to meet [16]. If the multiphase microstructure and therefore the desired mechanical properties are to be obtained, various cooling regimes in press hardening need to be tested.

2   Experiments

For this experiment, several press hardening-based variants of heat treatment were proposed. The data for developing the regimes were measured in real-world press hardening processes. The regimes simulated normal press hardening in a tool at different temperatures and broken quenching with different cooling rates.

2.1 Experimental material

The CMnSi TRIP is a low-alloy 0.2% carbon steel alloyed with Mn and Si (**Table 1**). This composition was chosen for the sake of stability of RA, for solid solution strengthening, and to prevent carbide precipitation during bainite formation [9, 10]. Specimens for heat treatment were made from a soft-annealed sheet 1.5 mm in thickness. Its structure consisted of ferrite and pearlite; its hardness was 190 HV10 (**Fig. 1**). The ultimate strength reached 627 MPa and elongation A_{20} was 26%. Phase transformations were identified by calculation performed with the JMatPro software (Release 9.0, 2016).
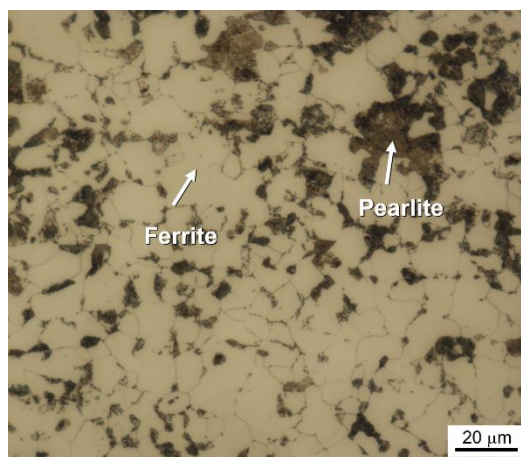

Fig. 1 Initial structure of TRIP steel

Table 1 The chemical composition of the experimental steel [wt. %]

C	Mn	Si	Al	Nb	P	S	Ni	M_s [°C]	M_f [°C]
0.21	1.4	1.8	0.006	0.002	0.007	0.005	0.07	363	249

2.2 Physical simulation of press hardening with different cooling parameters

Instead of conducting trials of new materials or processes in a production plant, which would hamper commercial operation, laboratory physical simulations can be performed using a thermomechanical simulator which offers fast heating and cooling (up to 200°C/s). The data for developing the present simulation regimes were measured in a real-world process, with the tool either at RT or pre-heated to various temperatures.

In the first regime, the tool was at room temperature (RT) (**Fig. 2a**). The first step was soaking at 937°C for 100 seconds. The subsequent step (idle time), which took 7 seconds, was a simulation of the workpiece cooling in the air during transfer from the furnace to the forming tool. The temperature dropped to 760°C. Simulation of press hardening in a tool at RT followed, where the

cooling rate was 100 °C/s (**Table 2**). In the other regimes of this kind, the simulation of press hardening was based on tool temperatures of 300–600°C and was followed by air cooling (**Table 2, Fig. 2a**).

Table 2 Influence of the tool temperature on the mechanical properties

Heating temp. [°C]	Tool temp. [°C]	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{20} [%]	HV10 [-]	RA [%]
937	Room temp. (RT)	900±15	1340±13	7±3	471±3	3
	300	857±4	1130±15	6±3	407±8	7
	425	568±10	977±5	15±3	323±3	10
	600	440±16	903±17	16±3	277±4	-

Table 3 Mechanical properties after broken quenching

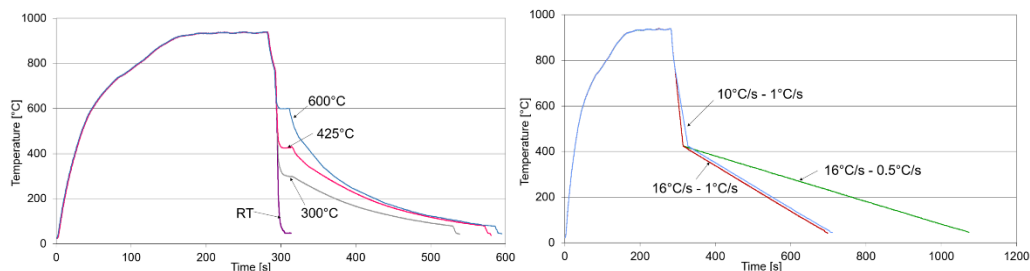| Heating temp. [°C]	Cooling rate above 425°C [°C/s]	Cooling rate below 425°C [°C/s]	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{20} [%]	HV10 [-]
937	16	1	482±16	925±17	15±3	285±2
	16	0.5	471±8	882±5	17±2	280±1
	10	1	436±12	898±11	18±2	279±3

Fig. 2 Examples of regimes for physical simulation of press hardening: a) tool with different temperatures, b) broken quenching

In another group of regimes, the effect of broken quenching was explored, where the slower-cooling stage began at 425°C (**Fig. 2b**). This temperature was chosen on the basis of earlier experiments and findings from intercritical annealing of this steel [19, 20]. The rates of cooling from 760°C, i.e. after the idle time, were either 16°C/s or 10°C/s, being applied down to 425°C. According to the calculation with JMatPro, these cooling rates will guarantee that ferrite forms in the material. The cooling curves, at the same time, do not intersect the pearlite nose in the diagram. Slower cooling from 425°C to RT, at 1°C/s or 0.5°C/s, was expected to support bainite formation – without holding at 425°C (**Table 3**).

Microstructures were examined using optical (OM) and scanning electron microscopy (SEM). The amount of RA was measured using X-ray diffraction on the automatic powder diffractometer AXS Bruker D8 Discover.

3   Results and discussion

The regime, which was a physical simulation of press hardening in a tool at RT, where the cooling rate was 100°C, produced a martensitic microstructure with some ferrite and 3% RA (**Fig. 3a**).

This structure did not represent the typical TRIP structure, because the formation of bainite was not supported by holding time at the temperature above M_s and the cooling rate in the area was too fast for bainite development. The hardness value was 471 HV10. The ultimate strength was 1340 MPa and elongation reached 7% (**Table 2**). The formation of ferrite-martensite structure in the TRIP steel after treatment without holding time was also described by J. Tian et. al. [21]. Besides, K. Sugimoto tried to develop TRIP steels with a martensitic annealed matrix with improved formability for auto-auto body manufactures [15, 22]. The possibility of processing by press-hardening for high strength steels with direct quenching was also presented by Mori et al. [4]. In the next regime, higher tool temperature was simulated, 300°C, which promoted the formation of proeutectoid ferrite. This led to lower ultimate strengths, 1130 MPa, but no significant changes in elongation. The regime with a simulated tool temperature of 425°C produced a microstructure with a majority of bainite blocks, some free ferrite and a small volume fraction of martensite (**Fig. 3b**). The amount of RA was 10%. The formation of bainite was supported by a slower cooling rate after cooling to 425°C and almost typical structure for TRIP steels was obtained. Elongation was higher than in previous regimes, 15%, whereas strength was lower, 977 MPa. The regime, which simulated cooling in a tool at 600°C, led to a mixture of ferrite and martensite and a low volume fraction of bainite (**Fig. 3c**). In addition, a small amount of pearlite was found along grain boundaries. The ultimate strength was lower than in the previous case, 903 MPa, accompanied by elongation 16%.
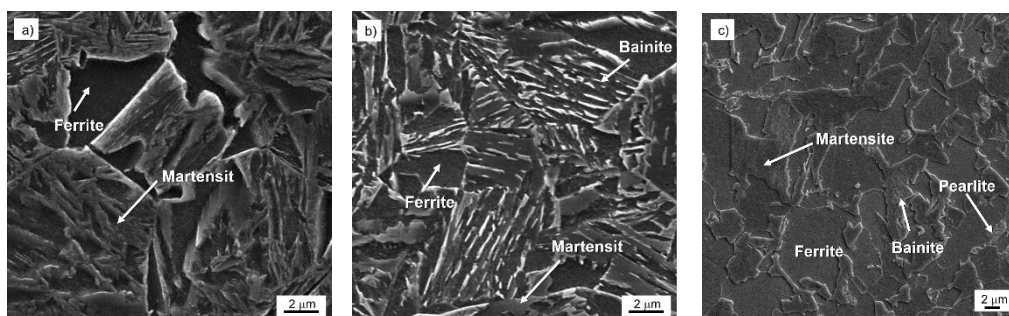

Fig. 3 Microstructural evolution in relation to tool temperature: a) RT, b) 425°C, c) 600°C

The simulated broken quenching regime with cooling rates above and below 425°C of 16°C/s and 1°C/s, respectively, led to a mixture of ferrite, bainite, martensite and RA (**Table 3, Fig. 4a**). Since the rate of cooling above 425°C was slower than in the corresponding press hardening regime, free ferrite was obtained. Very slow cooling rate below 425°C made it possible for bainite to form. The transformation to bainite was incomplete. The remaining unstable austenite then decomposed into martensite once the M_s had been reached. Upon this regime, the ultimate strength was 925 MPa, combined with elongation of 15% (**Table 3**). The regime, in which cooling below 425°C was even slower (0.5°C/s), promoted bainite formation (**Fig. 4b**). In the regime, in which the first stage of cooling was slower than in the previous regimes, i.e. 10°C/s instead of 16°C/s, the transformation to pearlite was slightly more effective along prior austenite grain boundaries. The resulting fraction of bainite was thus lower (**Fig. 4c, Table 3**). The formation of perlite from the cooling rate 10°C/s in the area of perlitic transformation was also confirmed by A. Pichler et al. [23]. They described the influence of cooling rate on the kinetic of bainitic transformation, ferrite growth and the amount of retained austenite.
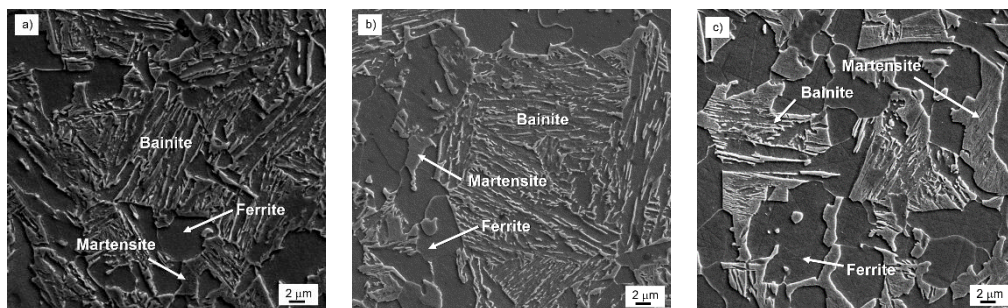
Fig. 4 Microstructures upon different cooling profiles: a) 16°C/s – 1°C/s, b) 16°C/s – 0.5°C/s, c) 10°C/s – 1°C/s

4   Conclusion

Press hardening with different cooling parameters was physically simulated on low-alloy TRIP steel. The simulated press hardening with a tool at RT produced a martensitic structure with a small amount of ferrite. Its ultimate strength and elongation were 1340 MPa and 7%, respectively. The regime in which the simulated tool temperature was higher, 425°C, led to free ferrite and bainite and stabilized RA. It had a favourable impact on elongation: 15%, accompanied by strength of 977 MPa. The broken quenching regimes with much slower cooling below 425°C, led to the intensive formation of bainite and ferrite. Their strengths were 925–882 MPa with elongations of 15–17%.

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