HEAT TREATMENT OF LOW CARBON HIGH MANGANESE TWIP STEEL

Pavel PODANÝ, Michal DUCHEK, Tomáš STUDECKÝ

COMTES FHT a.s., Dobrany, Czech Republic, EU

pavel.podany@comtesfht.cz

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Abstract

TWIP steels are steels with a good combination of strength and plasticity. Their application should be relevant in case of critical parts of car bodies. The paper describes the development of a particular type of high carbon manganese steel with low carbon content from the design of the heat to final evaluation of microstructural and mechanical properties of rolled steel sheets. The heat treatment of cold rolled sheets ensured a high elongation in combination with a good yield and tensile strength together with a favorable phase composition of experimental steel.

Keywords: TWIP steels, rolling, mechanical properties

1. INTRODUCTION

Steels alloyed with Mn, Si, and Al in objectively high concentrations show high strength and plasticity when deformed thanks to the mechanical twinning (TWIP steels) or to martensitic transformation induced by deformation (TRansformation Induced Plastisity - TRIP steels. There is no phase transformation in a TWIP steel during cooling or deformation, but the orientation of part of austenite will change due to mechanical twinning. [1-6]

The different performance of the austenite is to its stacking fault energy credited. SFE changes with the alloy composition and deformation temperature [7]. The martensitic transformation from austenite (γ) to ε martensite and/or α´ martensite occurs with SFE being typically lower than 20 mJ/m^2, whereas mechanical twinning occurs if the stacking fault energy lies between 15 and 30 mJ/m^2 [5].

Steels with a manganese content lower than 15 % shows martensite, resulting from deformation - TRIP effect. Both phenomena, TWIP and TRIP effects can be f in the steels with ca 20 % of manganes found. The TWIP effect usually occurs for manganese content above 25 %. However, the exact deformation-transformation performance depends on the particular chemical composition, i.e. the content of the other elements that affect the SFE. These elements in the TWIP steels are carbon, silicon and aluminium. Martensite transformation thus occurs with high manganese content above 25 %, when the carbon content is low (below 0.8). Carbon can suppress a martensitic transformation, but could cause the formation of M3C carbides and the higher carbon content further limits the possibility of welding these TWIP steels together with standard ferritic steels [8].

High manganese steels with TWIP effect usually reach lower tensile strengths (below 1000 MPa) and low yield strengths (YS) of about 250 MPa [9]. This paper shows how proper heat treatment (annealing) after cold rolling could increase the YS together with combination of excellent ductility.

1.1. Experimental material and heat treatment

Chemical composition of studied steel is in **Table 1**. The heat was melted and casted in a vacuum induction furnace into a round ingot mould. After cooling, further, ingot was r up to the forging temperature of 1100 °C reheated. Consequently, in a universal hydraulic press, the ingot into a slab of 280×120 mm cross-section was forged. After grinding, the annealed strip was in four passes rolled to the final thickness of 1.2 mm with interoperation annealing at 950 °C. After cold rolling, the sheets were to the annealing in vacuum furnace at 600, 650, 700 and 800 °C for 2 hours with slow cooling subjected. The main goal of this annealing was to induce recrystallization in the cold rolled microstructure and thus increase the plasticity of experimental steel.

Table 1 Chemical composition of experimental steel

Heat nr.	Element [wt. %]					
	C	Mn	Si	Al	Cr	Fe
V16/90	0.11	28.32	1.36	1.29	0.11	Bal.

1.2. Microstructure analysis

The specimens were prepared by means of following metallographic techniques - grinding and electrolytic polishing in Struers A2 solution. Microstructures revealed by etching with the Klemm's II colour reagent. [11]. For microstructure detection Zeiss Axio Observer light microscope was used. At room temperature, using a Bruker D8 Discover diffractometer, resp. phase analyser (by X-ray diffraction -XRD) was used. For radiation diffraction, one-dimensional detector was used. A cobalt X-ray source had used. The instrument was equipped with a polycapillary lens focusing the primary X-ray beam into a circular spot with a diameter of 0.5 mm.

1.3. Mechanical properties

Tensile tests were according to CSN EN ISO 6892-1: Metallic materials - Tensile testing - part 1: Method of test at room temperature carried out. Samples were from the sheet in longitudinal direction cut. Tensile tests were at electromechanical testing machine Zwick/Roell 250 kN carried out. The deformation was by means of strain gauge extensometer with 25 mm measuring distance measured. Characteristic dimensions were before and after the test measured. These dimensions were used for the investigation of stress-strain characteristics ($R_{p0,2}$, R_m, A_g, A_5 and Z).

2. RESULTS AND DISCUSSION

2.1. Microstructure analysis

In **Figure 1a** microstructure of the sheet after cold rolling without any heat treatment can be seen. Since etching with Klemm's II reagent does not attack ε martensite, it appears white in micrographs. The colour of another phase - γ (austenite) is usually yellow to brown and could be light blue to dark blue according to the etching grade [10]. Steels with high manganese content above 28 % show the prevalence presence of γ (austenite). Nevertheless, this fact is associated with higher carbon content (usually above 0.8 %). Lower carbon content affects the value of SFE and this lead to the increasing of ε martensite volume fraction especially in the deformed conditions of the material after cold rolling. The **Figure 1a** shows the microstructure of deformed austenite with the presence of ε martensite (white phase). **Figures 1b**, **c, d** and **e** shows other states of this steel after different annealing temperatures at 800, 700, 650 and 600 °C for two hours with subsequent slow cooling in the vacuum furnace. It is possible to observe fully recrystallized microstructure in the case of samples annealed at 800 °C and 700 °C (**Figure 1 b** and **c**). Partial recrystallization with remaining deformed grains is visible at samples annealed at 650 °C and 600 °C (**Figures 1 d** and **e**).

The microstructure of the sample annealed at 800 °C is coarse-grained in comparison to cold rolled state and it shows the grain size G = 8.5 (according to ASTM E112). Annealing at lower temperature 700 °C leads to finer grains (see **Figure 1 c**)). After annealing at 650 °C and 600 °C, the recrystallization occurred only partially and not whole microstructure was recrystallized. The influence of the annealing temperature on the grain size of recrystallized grains is summarised in the following **Table 2**.

Table 2 Grain size of recrystallized grains after different heat treatment

Annealing temperature [°C]	800	700	650	600
Average diameter of grain [µm]	14.6	6.1	5.0	2.5
Grain size G [ASTM E112]	8.5	11.0	11.5	14.0
% of recrystallized microstructure	100	100	86	33

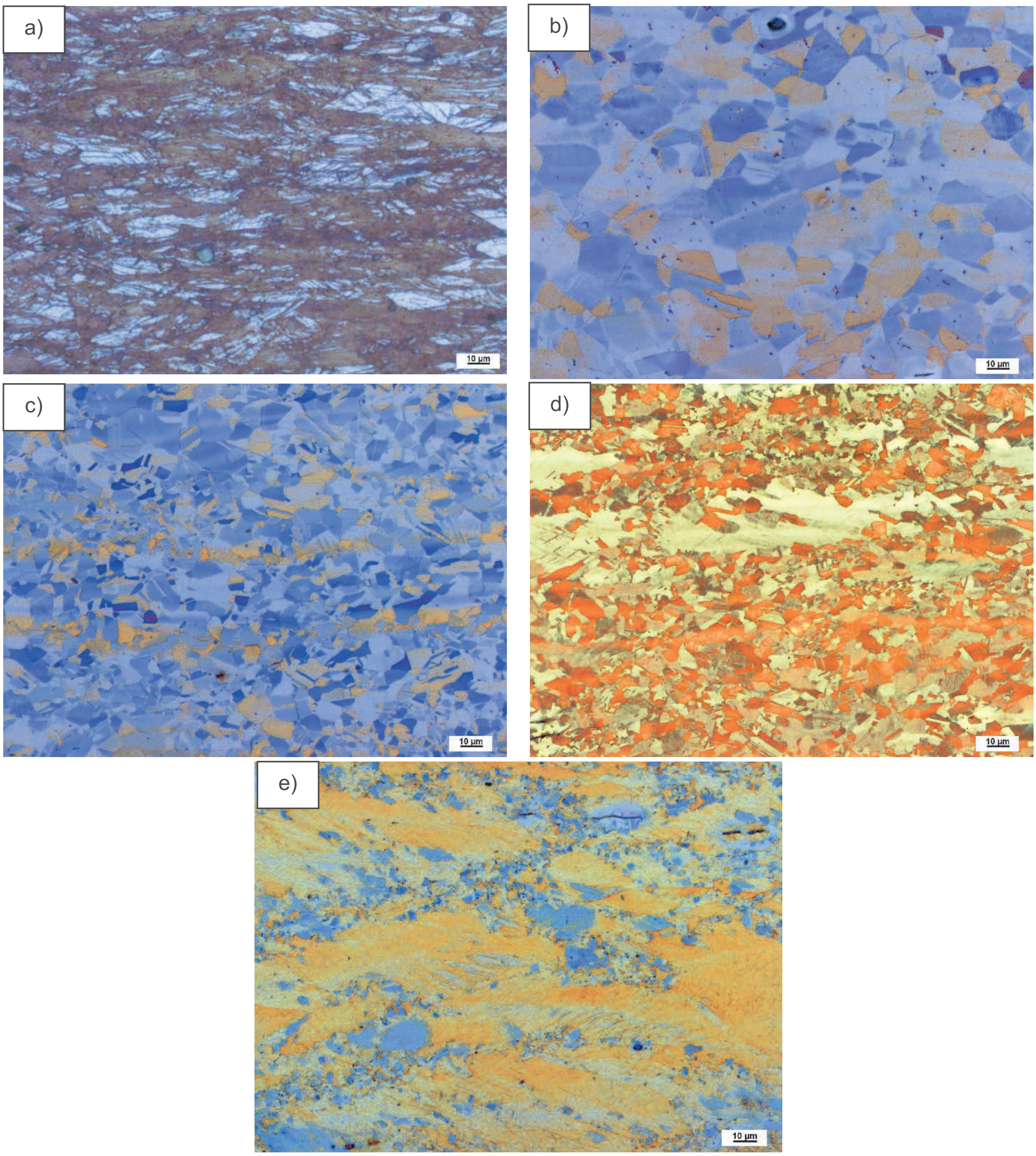


Figure 1 Microstructures of the sheet with thickness 1.2 mm after: a) cold rolling, b) annealing at 800 °C/2h, c) annealing at 700 °C/2h, d) annealing at 650 °C/2h, e) annealing at 600 °C/2h

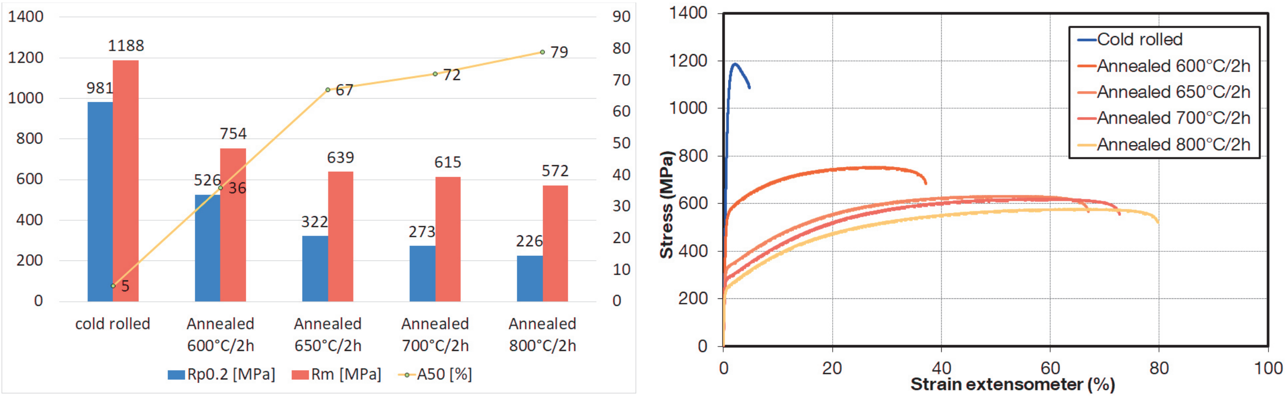
The phase analysis by x-ray diffraction (see **Table 3**) shows that the highest volume fractions of - martensite were obtained on the sheet subjected to the cold rolling without any heat treatment. Annealing leads to the decrease of ε martensite volume fraction. Nevertheless, the increasing of the temperature of annealing (above 600 °C) leads to the increase of ε martensite volume fraction in comparison to the lower annealing temperatures. The explanation of this behaviour consists in the coarsening of the microstructure. Larger grains could promote the austenite decomposition. In previous studies [6] similar behaviour (in the case of medium manganese TWIP steel) was registered. The XRD did not detect any α (cubic) martensite in the microstructure.

Table 3 Volume fraction of structural phases according to the X-ray diffraction

Phase [volume %]	**Annealing temperature [°C]**				
	Cold rolled	**800**	**700**	**650**	**600**
γ - austenite	30.8	93.1	96.5	97.0	100
ε - martensite	69.2	6.9	3.5	3.0	X

2.2. Mechanical properties

The chosen strain rate for standard tensile test was 0.001 s-1. Evaluated mechanical properties $Rp^{0.2}$, Rm and A50 are summarised in **Figure 2 a)**. **Figure 2 b**) shows the engineering stress-strain curves. These results show that the best combination of tensile properties - TS, YS, and elongation - were reached by means of annealing the cold-rolled sheet from the new TWIP steel at 700 °C and 650 °C.



a) b)

Figure 2 Mechanical properties of experimental high manganese TWIP steel: a) Comparison of mechanical properties of cold rolled and heat treated samples, b) Engineering stress-strain curves

3. CONCLUSION

The effect of annealing temperatures on the microstructure, phase composition and mechanical properties of the cold rolled low carbon high-manganese steel was investigated. Experimental steel exhibits the austenitic microstructure with a low austenite content of ε-martensite in annealed state. The best combination of high ductility, good yield strength and tensile strength with a fully recrystallized fine grained austenite microstructure (G = 11.0 according to ASTM E 112) was achieved after annealing at 700 °C for 2 h with YS = 273 MPa and a TS = 615 MPa. Very good combination of yield strength and tensile strength (YS = 322 MPa and TS = 639 MPa) with elongation of 67 % were also achieved for a sample annealed at 650. However, the microstructure of this sample did not completely recrystallize during annealing.

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