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Influence of the heat treatment on the mechanical properties and structure of TWIP steel in wires

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ABSTRACT

Purpose: The aim of this paper is to determine influence of the drawing process of TWIP steel wires on their mechanical properties and the structure changes.

Design/methodology/approach: The heat treatment of steel containing 29.4 % manganese and little amount of carbon (0.0049%C) allows to obtain TWIP effect, and the austenitic structure for this type of steel was realized. In order to investigate the structure changes, the optical microscopy was used. Mechanical properties were determined by the compression test and drawing process.

Findings: The analyses of changes of mechanical properties and the structure after particular drawings stages was carried out. At the total draft of 93.4 % the value of drawing stress was 1060MPa, however further deformations of the wire brought relation $R_m/R_{0.2}$ to be above 1.6.

Research limitations/implications: Continuation of the investigations with the use of transmission electron microscopy makes it possible to identify all phases that appear in this steel.

Practical implications: Drawn products characterized by high strength properties together with good plasticity might be used for production of connecting elements because they can absorb large quantity of energy.

Originality/value: For the first time there were obtained so high hardening level as well as so high plasticity in the drawing process.

Keywords: Metallic alloys; Drawing process; Austenitic steel; TWIP effect

MATERIALS

1. Introduction

The development of automobile industry in the last years favours arising new materials that characterize notably good strength properties and high plasticity. The group of such materials includes TRIP, DP and TWIP steels [1-3]. The main reasons of the industry interest in face-centered cubic steels (austenitic steels) with low stacking fault energy are their ability to achieve high strength and good plasticity during mechanical deformation. These effects are caused by twinning as a main deformation mechanism, which the TWIP effect is named for Twinning Induced Plasticity. This kind of deformation of the materials structure causes high hardening together with large plasticity, what is among other a desirable effect in the joint elements used in the automobile industry. The TWIP effect is the most useful hardening effect among all possible kinds of structure deformation of the austenitic steels. It might be observed that the twinning deformation causes an increase of the hardening rate through a movement of obstacles of slip dislocation.

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Besides slip and martensitic transformation, mechanical twinning is one of the basic deformation mechanisms of metals and alloys. A large tendency to deform by twinning have the materials with low stacking fault energy, for example Cu, Au and Ag alloys [4]. The mechanical twinning was also observed in Hadfield steel. This deformation process takes place when the slip becomes insufficient deformation mechanism. The manganese content in these steels is conducive to report twinning as it reduces the stacking fault energy at the ambient temperature in the considerable way [13]. Its presence in the alloy in the large quantity increases hardness of the steel and prevents oxides from formation, that means it deoxidises steel in the heat treatment process. In connection with the small carbon quantity, which is the case of the TWIP steel, the steel can reach not only the higher hardening level but also good plasticity.

Twinning process affects the manganese steel in such a way that they can compensate rapidly the high deformation without occurrence of cracks. Therefore, they are interesting from the viewpoint of absorbing destruction energy in the elements undergoing deep drawing as well as in the highly deformed elements. That material may be used/applied for the connecting elements and others in the automotive industry. Austenitic steels are the subject of intensive empirical and theoretical studies [5-14].

The mechanical twinning process during which the transformation of dislocations substructure takes place, influences in the fundamental manner the increase of strength properties in these materials [15-16]. To this moment, the properties of the TWIP steel during tension, compression and rolling processes were studied. Development of structure in the micro and macro scale was also analysed. However, another methods of plastic deformation *e.g.* drawing process [17-18], in which much higher intensity and strain rate occur, were studied marginally.

2. Experimental procedure

2.1. Material and heat treatment

The chemical composition of the TWIP steel used in the investigation is presented in table 1. Two types of samples were studied: (1) samples ϕ = 5 mm and 10 mm long designed to the compression test, and (2) ϕ = 4 and 250 mm long earmarked to the cold drawing process.

All the samples were made from the material after hot rolling, and then they were heat-treated: held in temperature 1100°C for 20 minutes and then water-cooled [10].

Table 1.
Chemical composition of the investigated steel

Mass contents in %					
C	Mn	Si	Al	S	Fe
0.0049	29.4	3.0	3.3	0.0033	64.2918

2.2. Methodology

The investigations of the mechanical properties consisted of a few stages.

In the purpose of determination of the strength curve the compression tests on the universal simulator of metallurgical processes GLEEBLE 3800 with the strain rate $1s^{-1}$ were carried out.

In order to determine the structure changes during the deformation, there was made a drawing process of a wire with diameter ϕ 4,0 mm to the finish diameter ϕ 1,0 mm in the laboratory conditions. The sample was deformed in the 11 trusts on the strength machine ZWICK Z100 with the strain rate 10^{-2} m/s, by the means of drawing die with the sintered carbides about the angle $2\alpha = 12°$.

The mechanical properties of the finished wire having the diameter of 1.0 mm was also carried out according the norm PN-EN 10002-1.

Observations of the structure after the following thrusts were carried out on the metallographic microsection prepared on the longitudinal section of the wire on the optical microscopy AXIOVERT 25. The wire samples after heat treatment and after selected deformation stages were analysed.

3. Results and discussion

After the analysis of the plastometric tests it may be reported that the mechanical properties of the properly heat treated TWIP steel are quite high, figure 1. The stress level of approximately 1100 MPa and the true strain $\varepsilon_{rz} = 1.4$ were obtained.

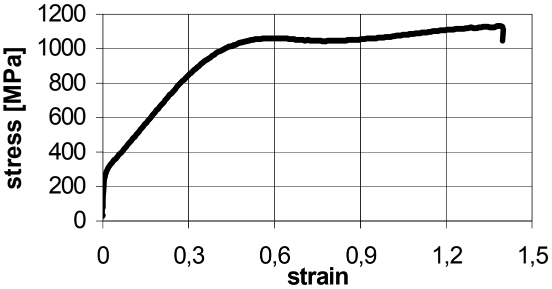

Fig. 1. The compression characteristic of the TWIP steel

The parameters of the drawing process in the 11 drafts are given in table 2.

After the last 11-th draft, the drawing stress obtains the value 1059 MPa and the total draft is 93.42%, what correspond to a true strain 2.77.

Finished wire with diameter ϕ 1.0mm was submitted to a static tension test. It was found that the material was characterised by high strength during the tension (R_m=1930 MPa) and uniform elongation ≈ 1.32 %. To special attention deserves fact, that the ratio $R_m/R_{0,2}$ equals 1.63. It is a proof that material still posses the reserve of hardening that was not exhausted, and further material deformation by drawing is possible.

The carried out analysis of the changes in the structure shows that formation of the twins strongly contribute to development of the texture and refinement of the structure.

After applied heat treatment the homogeneity of the austenitic structure with regular annealing twins is observed, figure 3. The grains shown on figure 3 are equiaxial and uniform.

Table 2.
Distribution of drafts, forces and stress of drawing

Number of drafts	Diameter of die [mm]	G_p [%]	G_c [%]	F_c [N]	σ_c [MPa]
0	4.0	-	-	-	-
1	3.4	23.9	23.99	3142.3	346.1
2	2.95	24.7	42.75	3759.7	550.1
3	2.53	26.4	57.92	3912.8	778.3
4	2.18	25.7	68.75	3015.5	807.9
5	1.9	24.0	76.26	2538.8	895.4
6	1.7	19.9	80.99	1704.8	751.1
7	1.52	20.0	84.81	2035.2	1121.6
8	1.36	19.9	87.84	1511.24	1040.3
9	1.22	19.5	90.21	1315.3	1125.2
10	1.1	18.7	92.04	924.9	973.31
11	1.0	17.4	93.42	831.8	1059

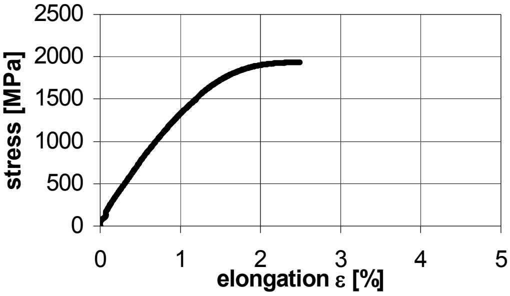

Fig. 2. Tensile characteristic of the TWIP steel wire after the 11-th draft

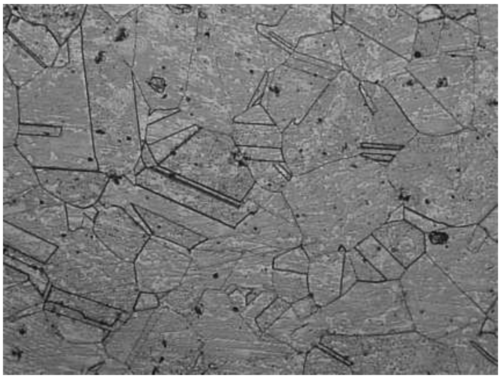

Fig. 3. Austenitic structure of the TWIP steel, magn. 200x

The microstructure of wire after the first draft (Fig. 4) shows intersected slip bands (black arrows on the figure 4) and thin twin bands about the micrometer width. On the figures 5, 6, 7 development of the microstructures during the drawing process are shown. It can be observed that with the increase of the total draft the development of standard structure for the drawing process is visible, and also increase of structure banding is observe.

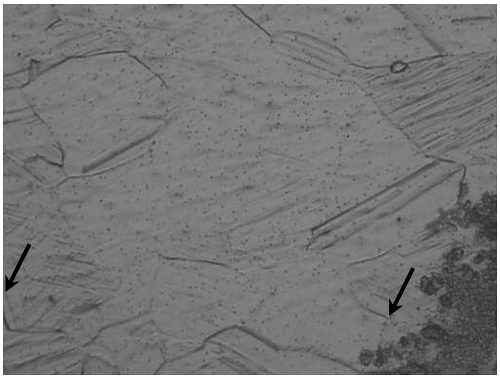

Fig. 4. The wire structure with the TWIP steel deformed $G_c = 23.9\%$, magn. 500x

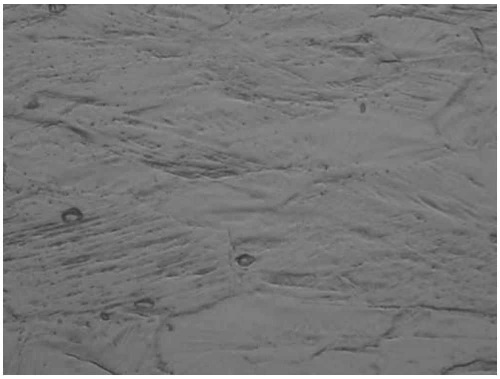

Fig. 5. The wire structure with the TWIP steel deformed $G_c = 42.7\%$, magn. 500x

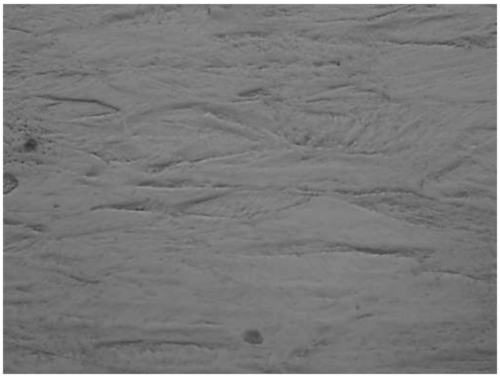

Fig. 6. The wire structure with the TWIP steel deformed $G_c = 57.9\%$, magn. 500x

Already for minor deformations the slip bands and twinning deformation bands have been formed. Formed structure is typical for materials about low stacking fault energy. It has significantly fibrous character. If there is eventual presence of other phases, among others the ε hexagonal phase, it is necessary to make more detailed investigation with use the methods of transmission electron microscopy.

Fig. 7. The wire structure with the TWIP steel deformed G_c = 84.8 %, magn. 500x

4. Conclusions

The proposed in this work heat treatment allows to obtain material, that can be drawn with high true strain values to ensure high strength properties 1930 MPa and concurrently high plasticity, as the ratio $R_m/R_{0,2}$ = 1.63 proves.

The TWIP steel is very suitable for cold drawing process, so its application to the production of high strength connecting elements for automotive industry is possible. This steel can be also applied as the wires for special products.

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