EFFECT OF THERMOMECHANICAL PROCESSING ON STRUCTURE DEVELOPMENT AND MECHANICAL PROPERTIES OF BULK TRIP STEEL

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Abstract

High strength and ductility of the TRIP (Transformation Induced Plasticity) steels is attributed to the transformation induced plasticity effect resulting from the strain induced martensitic transformation of the retained austenite in the multiphase (ferrite, bainite) microstructure. The precise characterisation of the multiple microstructure of low alloyed TRIP steels is of great importance for interpretation and optimalization of their mechanical properties. The relevant information on the course of transformation can be extracted from neutron diffraction spectra. The integrated intensities of austenite and ferrite neutron diffraction profiles over the time of phase transformation can be then assumed as a measure of the volume fractions of both phases in dependence on transformation temperature. Useful information can be also received on retained austenite stability in TRIP steel during mechanical testing. The in-situ neutron diffraction experiments were conducted to asses the reliability of neutron diffraction technique in monitoring the transformation of retained austenite when subjected to tensile tests. In addition, the results received from neutron diffraction experiments were also used to evaluate the lattice strains in the ferrite and austenite phases during the straining as a function applied load.

Keywords: TRIP steel, thermomechanical treatment, retained austenite transformation, neutron diffraction, stress-strain dependences.

1.   INTRODUCTION

The sustainable requirements of automotive industry are directed to the development of multiphase steels, and particularly to the development of TRIP steels. Employing the TRIP phenomenon is aimed to produce steels with higher strength and improved plasticity.

The improvement of steel strength without deteriorating their formability remains one of the most challenging goals for material engineers. Low alloyed TRIP- assisted steels belong to the group of high strength steels with multiphase structure offering such attractive combination of strength and ductility. The microstructure of TRIP steels consists of ferrite, bainite and retained austenite [1, 2]. An extraordinary combination of high strength and ductility at forming results from the interaction of individual constituent of microstructure. It is known that the high ductility arises mainly from the processes related to the strain induced martensitic transformation of the metastable retained austenite during the straining [2, 3].

The purpose of this study is to contribute to a better understanding of the factors governing plastic straining in multiphase microstructure of TRIP steels. It is believed that not just sufficient volume fraction of the retained austenite is necessary to achieve convenient conditions for TRIP effect in low alloyed steels. But also other structure characteristics, such as morphology, size of the austenite islands and their distribution, solute enrichment and mechanical stability have to be considered in the process of the TRIP steel development as well. For this scope we have been studying TRIP steels contain rather same volume fraction of retained austenite but after different thermomechanical processing.

2.   EXPERIMENTAL PROCEDURE

A vacuum melted medium carbon the low alloyed Si-Mn steel (chemical composition of steel is in **Table 1**), in form of bars of 25 mm in diameter was used for thermomechanical processing. The three bulk samples

Table 1 Chemical composition of used steel (wt.%)

C	Mn	Si	P	Cr	Ni	Cu	Al	Nb
0.19	1.45	1.9	0.02	0.07	0.02	0.04	0.02	0.003

(rods) of TRIP steel by means of the various thermomechanical (TM) treatments, were experienced complex processing, as shown in **Fig. 1**. The prior solutioned samples of Si-Mn TRIP steel in form of bars of 25 mm in diameter and 70 mm in length, were subjected to the different thermomechanical procedures, designated **A, B, C,** in order to obtain the modified microstructure, with respect to modify structure characteristics and volume fraction of individual phases present in the steel. Output of proposed treatment was expected to obtain the TRIP steels with different mechanical properties due to initial structure modification and conditions of designed TM schedules. The applied TM procedure conditions were as follows:

2.1   Thermomechanical procedure implemented for specimens A, B:

1) heating to T=1000°C/30min $\rightarrow$ **2)** first compression $\varepsilon_1 \rightarrow$ **3)** cooling to: A $\Rightarrow$ T_1, B $\Rightarrow$ $T_1 \rightarrow$ **4)** second compression $\varepsilon_2 \rightarrow$ **5)** the first transformation γ-α at T= 750°C/300 sec. **6)** water quenching $\rightarrow$**7)** second transformation at 420°C/300s $\rightarrow$ **8)** air cooling (**Fig. 1**)

2.2   Thermomechanical procedure implemented for specimen C:
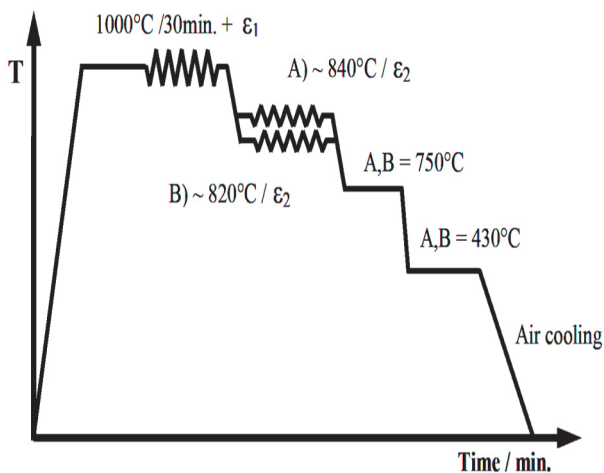
Fig. 1 Scheme of applied thermomechanical treatments of steel

The heating to T=850°C/35min. $\rightarrow$ **2)** cooling to $T_1 \rightarrow$ **3)** compression $\varepsilon_1\rightarrow$ **4)** first transformation γ-α at T= 750°C/300sec. $\rightarrow$ **5)** water quenching $\rightarrow$ **6)** second transformation at 420°C/300s $\rightarrow$ **7)** air cooling, **Fig. 1**.

The Ac1 and Ac3 temperatures as well as the required critical cooling transformation (CCT) diagram of the initial low alloyed steel are important [4, 5]. The specimens (A,B,C) for tensile tests of 6x2 mm in cross-section were manufactured from the bulk rods TRIP steel that had been treated according to above mentioned thermo- mechanical schedule conditions. In-situ neutron diffraction experiments during the tensile tests were carried out at TKSN- 400 difractometer in the NPI Rez., Czech Republic. The difractometer operates at instrumental resolution of $\Delta d/d_{hkl}$ = 2x10^{-3}. However, since such a high instrumental resolution is achieved only in a relatively narrow 2θ-band (of about $\Delta(2\theta) \approx 7°$), one or two diffraction line profiles can be investigated at the same time. In the present experiment, the detector window was set to cover both ferrite (110) and austenitic (111) reflections, simultaneously. The tensile tests were performed at room temperature and neutron diffraction spectra were recorded during temporary stops of the deformation machine. The holding time of 1 hour in each step was necessary to achieve sufficiently good statistics in measured spectra.

3.   RESULTS AND DISCUSSION

Three TRIP steel specimens (A,B,C) with rather different volume fraction of the retained austenite (~15- 20%), were examined in-situ upon tensile loading at room temperature. From stress-strain curves (**Fig. 2**) is clearly seen that each of the TRIP samples have exhibited the different mechanical properties. The visible differences were achieved in yield strengths. The sam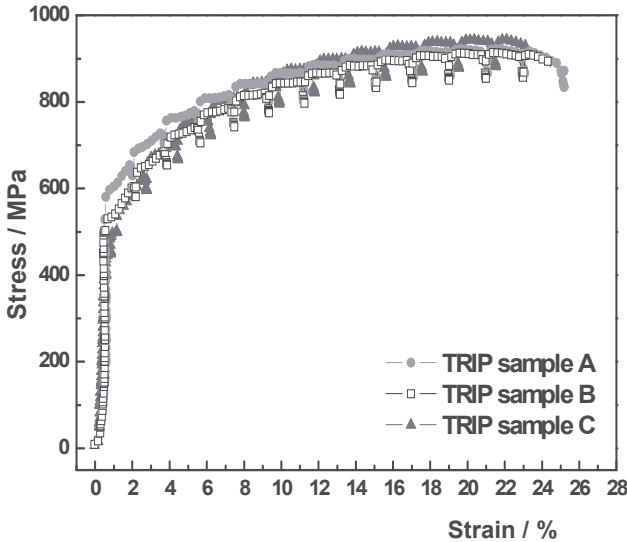ple A has the highest yield strength and elongation, whereas the sample **C** has the smallest yield strength, but on the other hand the highest tensile strength.

Fig. 2 Stress-strain curves of the three TRIP steels

Mechanical properties of TRIP steel strongly depend on the composition of micro- structure, however in our case the volume fraction of preset phases in structure was rather similar. There are a few other influences which can affect the behaviour of TRIP steel during the deformation. Structural characteristics such as a phase morphology distribution, grain size and carbon content in retained austenite are very important for the transformation kinetics of the retained austenite, which as it is known, has the biggest effect on the exhibited mechanical properties of this type of this brand of steel [5, 6].

The evolution of the austenite transformation during the straining in specimens manufactured by different thermomechanical treatments is shown in **Fig. 3** and **Fig. 4**. The changes in the integral intensity of the austenite reflection (111) during the tensile test can be considered as the change in the volume fraction [6]. The volume fraction of the retained austenite at the beginning of tensile test was taken as 100%, just for description of the transformation kinetics. This single peak method analysis can be use as a good aproximation for describing kinetics of austenite transformation during straining [7].

As evidenced by the NPI data (**Fig. 3, Fig. 4**) taken in axial arrangement, the transformation proceeds in slightly different ways for each of tested specimens. From the figures is obvious that the transformation starts the most massively in the sample **C**, at strain of ε≥0.005 (400MPa) and at strain of ε≥0.12 (~ 890MPa) almost all of present retained austenite is transformed to the martensite. Whereas, the transformation in other two samples starts at higher levels of strain (stress), what is related with higher level of yield strengths of the present constituents (**Fig. 2**, **Table 2**).
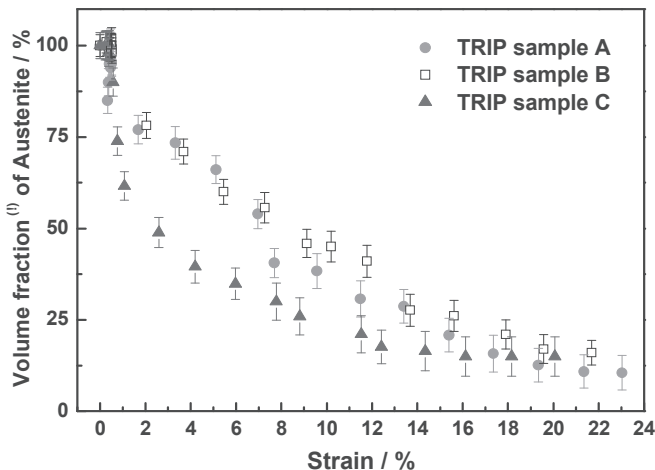

Fig. 3 Evolution of austenite volume fraction in de - pendence on applied stress during the tensile test
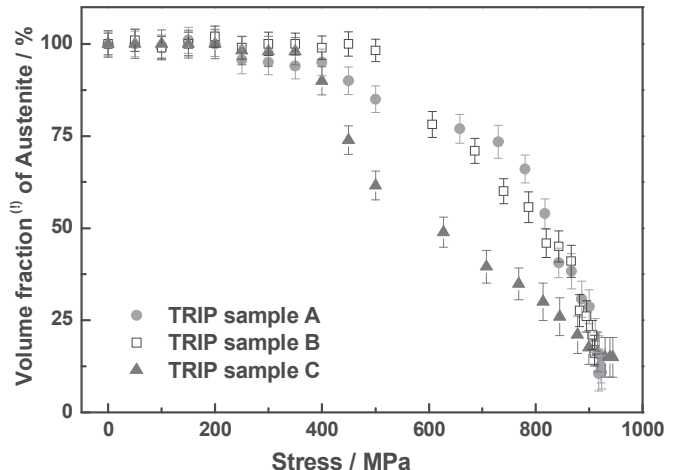

Fig. 4 Evolution of austenite volume fraction in de- pendence on applied stress during the tensile test

As it can be seen from records, in the sample **A**, which exhibits the highest elongation, the martensitic transformation of retained austenite continued even at the highest strains of ε ≥ 0.18. In all TRIP specimens at the end of tensile test (failure of samples) in the microstructure still remains some untransformed stabilized austenite. This austenite does not contribute to the elongation, what is expressed in the total ductility of specimen (**Fig. 2**). It is supposed that the untransformed retained austenite is present in the microstructure in the form of laths inside the bainite islands [8]. In consequence of that is highly saturated by carbon, which has the biggest influence on the stability of the retained austenite present there.

Table 2 Elasto-plastic properties of phases of TRIP steel.

	Sample A		Sample B		Sample C	
	E	σ₀	E	σ₀	E	σ₀
	GPa	MPa	GPa	MPa	GPa	MPa
α-matrix	193	607	206	452	206	350
γ-retained	229	942	220	694	190	690

Additionally, the elastic lattice strain of the phases present in the microstructure has been measured as a function of the macroscopic strain imposed to the specimens during the in-situ tensile test. This measurement allows determining the stress partitioning between the phases during straining. Indeed, the elastic lattice strains are converted into stresses thanks to the knowledge of the elastic constants of the diffracting phases [9]. **Fig. 5** and **Fig. 6** present the macroscopic stress vs. lattice strain curves for the $(110)\alpha$ and $(111)\gamma$ planes measured at all samples, respectively. At first, from the figures can be seen that the stress level is higher in the austenite than in the ferrite phase. All curves at the beginning show a linear evolution of the macroscopic stress with increasing lattice strains. The slopes correspond to the Young's modulus for the specific crystallographic planes. The first change of the linear evolution corresponds to the yield strength of each phase [9].
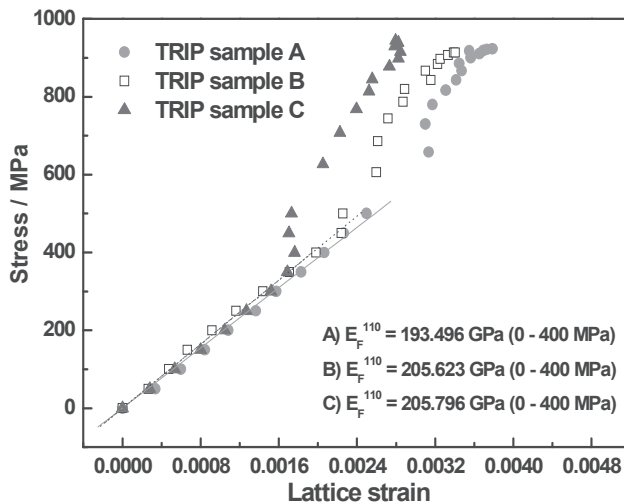
A) E_F^{110} = 193.496 GPa (0 - 400 MPa)
B) E_F^{110} = 205.623 GPa (0 - 400 MPa)
C) E_F^{110} = 205.796 GPa (0 - 400 MPa)

Fig. 5 Measurements of the yield strength of ferrite and bainite (α-matrix)

A) E_A^{111} = 228.682 GPa (0 - 400 MPa)
B) E_A^{111} = 219.529 GPa (0 - 400 MPa)
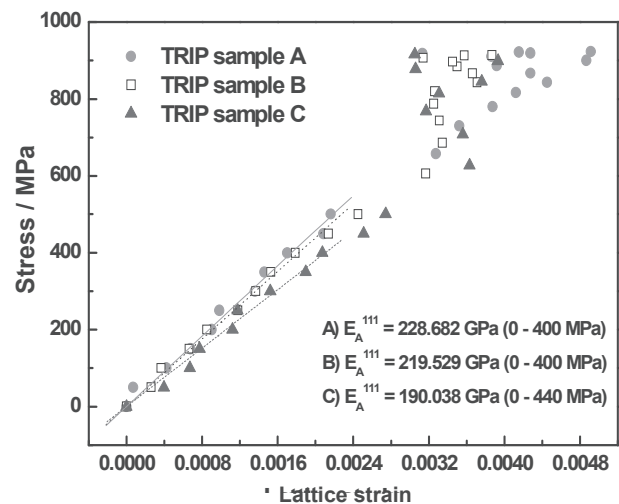C) E_A^{111} = 190.038 GPa (0 - 440 MPa)

Fig. 6 Measurement of the yield strength of ferrite and bainite (α-matrix)

4.   SUMMARY

Results of in-situ neutron diffraction experiments focused on of monitoring phase evolution and on determining the stress partitioning between the phases, present in TRIP steels subjected to tensile loading at room temperature were reported.

Valuable information on the kinetics of the austenite to martensite transformation during mechanical loading can be obtained by monitoring integral intensity of austenite reflection recorded in neutron diffraction experiments. In addition, in-situ neutron diffraction experiments also allowed characterizing the elastoplastic properties of the phases present in TRIP multiphase steels. These properties have strong influence on the

transformation behaviour of the retained austenite during the straining and also critical effect on general mechanical properties of TRIP steel. As is seen from the results, the elastoplastic properties of the present phases can be markedly affected by choice of thermomechanical processing parameters. According to that not only volume fraction of retained austenite has the influence on mechanical properties of TRIP steels, but also the state (size, distribution, carbon saturation, morphology) of retained austenite and the state of surrounding (α-matrix) plays important role in affecting deformation mechanisms.

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