Investigation of retained austenite stability in Mn-Si TRIP steel in tensile deformation condition

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ABSTRACT

Purpose: The aim of this study is to contribute to a better understanding of the role of the key factors governing the formation of multiphase TRIP aided steel.

Design/methodology/approach: The present work reports the results of in-situ neutron diffraction experiments focused on monitoring the phase evolution in three TRIP steel samples subjected to different thermomechanical processing and mechanical loading to evaluate the stability of retained austenite.

Findings: In-situ neutron diffraction experiments allowed characterizing the elastoplastic properties of the phases present in TRIP steel. 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.

Research limitations/implications: The precise, fast and cheap measurement of the amount of retained austenite in multiphase structure is a basic limitation for further research work, improvement and development control of TRIP steels.

Practical implications: It is believed that not only the sufficient volume fraction of the retained austenite is the prerequisite to achieve convenient conditions for TRIP effect in low-alloyed steels.

Originality/value: It was found 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.

Keywords: Metallic alloys; Non-destructive testing; TRIP steel; Thermomechanical processing; In situ neutron diffraction method

1. Introduction

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 - 4]. 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, 5].

Various process routes for TRIP steels are either already in use or are subject to discussion depending on products. The processing of low alloy multiphase and TRIP steels is still a matter of current research. A special attention has to be paid to the cooling strategy when producing hot rolled multiphase steels. The temperature – time schedule used for desired structure development, where lower cooling rates are concerned, appears more difficult when great thermals gradients are developing across the specimen in time of cooling. The processing should be carried out in way that the final microstructure comprises of 50 to 60 % ferrite, 25 to 40 % bainite, and 5 to 15 % metastable retained austenite uniformly distributed in bulk specimen. A variation of the cooling rate and cooling temperature support affects the change of the transformation behavior and may to vary the strength level and ductility in a pretty wide range [6].

The precise, fast and cheap measurement of the amount of retained austenite in multiphase structure is an essential item for further research work, improvement and development control of TRIP steels. The difficulty in identifying the different constituents of multiphase high strength steels in final structure is persistent. For determination of retained austenite content in TRIP steels, the X-ray diffraction measurements are preferentially used, sometimes also classical metallography, Mössbauer spectroscopy and magnetic methods. If available, the neutron diffraction (ND) analysis can be helpful as well [7, 8].

The purpose of this study is to contribute to a better understanding of the key factors governing deformation process in multiphase microstructure of TRIP steels. It is believed that not only the sufficient volume fraction of the retained austenite is necessary to achieve convenient conditions for TRIP effect in low-alloyed steels, but also other microstructural characteristics, such as morphology, size of the austenite islands and their distribution, solute enrichment and mechanical stability, which have to be considered in the process of the TRIP steel development as well. Hence, three different specimens subjected to different thermomechanical processing were prepared and investigated by in-situ neutron diffraction techniques capable to follow the evolution of phase fractions and phase stresses in the individual components of the alloy microstructure.

2. Experimental

The low alloyed Si-Mn TRIP steel, which chemical composition is stated in Table 1, was used for processing of three bulk samples by the various thermomechanical treatments (Figure 1). The samples of steel in form of bars of 25 mm in diameter and 70 mm in length were subjected to the following thermo-mechanical processes (A, B, C) in order to obtain the TRIP steels with different mechanical properties.

Specimens A, B:
1) heating to T = 1000°C/30min. → 2) first compression ε_1 → 3) cooling to: A ⟹ T_1, B ⟹ T_1 → 4) second compression ε_2 → 5) first transformation γ-α at T = 750°C/300sec. 6) water quenching → 7) second transformation at 420°C/300s → 8) air cooling (Figure 1).

Specimen C:
1) heating to T = 850°C/35min. → 2) cooling to T_1 → 3) compression ε_1 → 4) first transformation γ-α at T = 750°C/300sec.

→ 5) water quenching → 6) second transformation at 420°C/300s → 7) air cooling

Table 1.
The chemical composition of studied steel (wt. %)

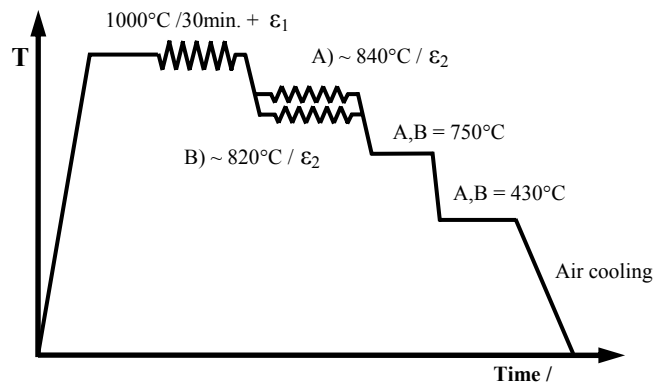| C	Mn	Si	P	Cr	Ni	Cu	Al	Nb
0.19	1.45	1.9	0.02	0.07	0.02	0.04	0.02	0.003

Fig. 1. Scheme of special thermomechanical processing

The Ac_1 and Ac_3 temperatures as well as the required critical cooling rates were estimated from the continuous cooling transformation (CCT) diagram of the initial low-alloyed steel [9, 10]. The specimens (A, B, C) for tensile test of 6x2 mm in the cross-section were manufactured from the bulk TRIP specimens steels that had been treated according to above mentioned (A, B, C) thermomechanical schedule conditions.

In-situ neutron diffraction experiments during the tensile tests were carried out at TKSN-400 diffractometer in NPI Rez, Czech Republic. The diffractometer 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 lineprofiles 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

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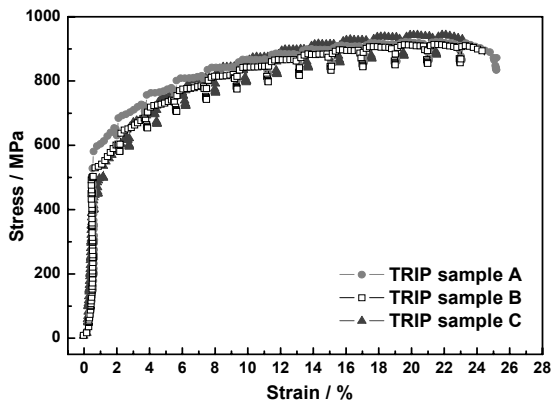
Fig. 2. Stress-strain curves of the three TRIP steels

Mechanical properties of TRIP steel strongly depend on the composition of microstructure, however in studied case the volume fraction of present phases in structure was rather similar. There are a few other influences, which can affect the behaviour of TRIP steel during the deformation. 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 steels [10, 11]. The volume fraction of the retained austenite of about ~15% was achieved in all cases (A, B, C) of thermome-chanical treatment.

The evolution of the austenite transformation during the straining in specimens manufactured by different thermomechanical treatments is shown in Figure 3 and Figure 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 [11]. 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 approximation for describing kinetics of austenite transformation during the straining [12].

As evidenced by the NPI data (Figure 3, Figure 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 $\varepsilon \geq 0.005$ (400 MPa) and at strain of $\varepsilon \geq 0.12$ (~ 890 MPa) 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 (Figure 2, Table 2).

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 $\varepsilon \geq 0.18$. 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 (Figure 2). It is supposed that the untransformed retained austenite

is present in the microstructure in the form of laths inside the bainite islands [13]. In consequence of that is highly saturated by carbon, which has the biggest influence on the stability of the retained austenite present there.
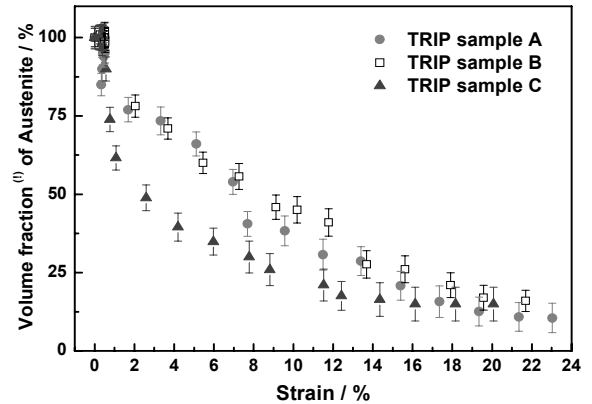

Fig. 3. Evolution of the austenite volume fraction [!] in dependence on applied stress during the tensile.
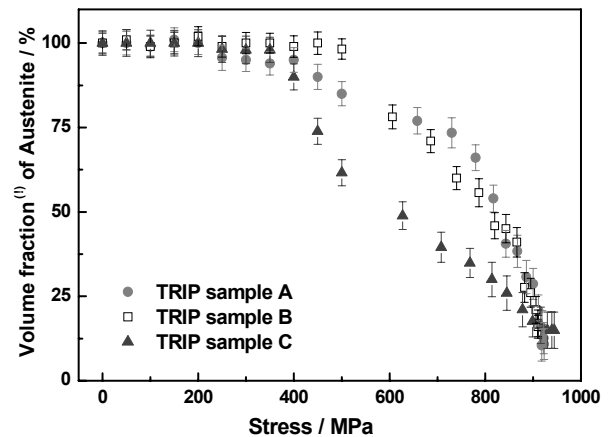

Fig. 4. Evolution of the austenite volume fraction [!] in dependence on applied stress during the tensile.

Table 2.
Elastoplastic properties of phases of TRIP steels

	Sample A		Sample B		Sample C	
	E GPa	σ_0 MPa	E GPa	σ_0 MPa	E GPa	σ_0 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 [14]. Figure 5 and Figure 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 [14].

From the results shown in Table 2, is obvious than in all specimens the austenite is harder than ferrite (α-matrix), however in general the austenite is considered as a softer phase. But the unusual high carbon saturation of the austenite present in TRIP multiphase steels can be invoked as a cause of increase of its hardness [14]. Some authors as Irvine et al. [15] showed that the effect of the carbon content on the yield strength of austenite is quite large [14].
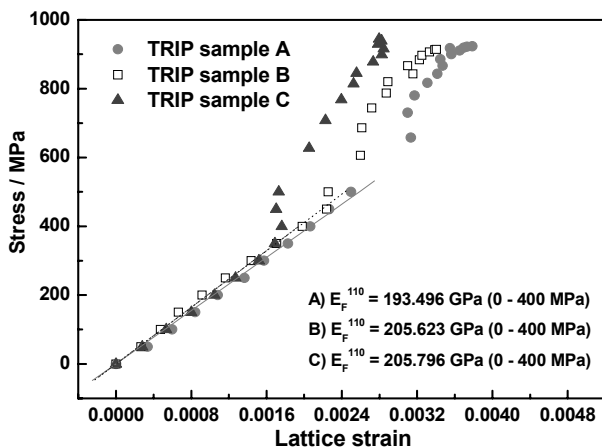

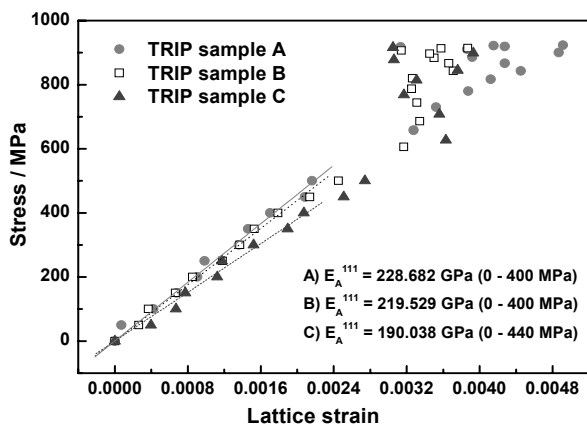Fig. 5. Measurement of the yield strength of α-matrix (ferrite, bainite)

Fig. 6. Measurement of the yield strength of the retained austenite (γ-retained)

4. Conclusions

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.

Acknowledgments

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