

Volume 68 • Issue 2 • February 2015

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Deformation behavior of bulk TRIP steel

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ABSTRACT

Purpose: Experimental verification of various thermo-mechanical (TM) processing schedules, with aim to modify the structure characteristics using press forging of Si-Mn TRIP (Transformation Induced Plasticity) steel, was described.

Design/methodology/approach: High strength and ductility of TRIP steels is attributed to the TRIP effect resulting from the strain induced martensitic transformation of the retained austenite in the multiphase (ferrite, bainite, martensite) microstructure. In order to rationalize the retained austenite (RA) volume fraction in steel microstructure, several TM schedules were employed at experiment where different austenite conditioning was considered.

Findings: The various multiphase structure characteristics were then resulting after TM processing of steel, where different volume fractions of ferrite, bainite and RA were received in the steel. The modification of structural characteristics of steel then influenced the deformation behavior and mechanical properties TRIP steel.

Research limitations/implications: The present work also focused on monitoring of RA transformation during incremental mechanical straining using in-situ neutron diffraction technique.

Originality/value: This non-convenient experimental method was used to characterize the kinetics of RA transformation and its stability during consecutive straining.

Keywords: TRIP steel; Austenite conditioning; Phase transformations; Structure; Austenite stability

Reference to this paper should be given in the following way:

J. Zrnik, O. Muransky, Z. Novy, P. Slama, Deformation behavior of bulk TRIP steel, Journal of Achievements in Materials and Manufacturing Engineering 68/2 (2015) 59-63.

MATERIALS

1. Introduction

The improvement of steel strength without deteriorating their formability remains one of the most challenging goals for material engineers [1, 2]. 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

The low alloyed Si-Mn steel, the chemical composition of C 0.19, Mn 1.45, Si 1.9, P 0.02, Cr 0.07, Ni 0.02, Cu 0.04, Al 0.02, Nb 0.003, was used for various thermomechanical processing (TM). The three bulk samples of experimental TRIP steel in form of bars. of 25mm in diameter and 70mm in length, were then subjected to various TM treatments applying various thermal and deformation conditions, Fig. 1. The steel samples in form of bars of 25mm in diameter and 70mm in length were subjected to the three different thermomechanical procedures in order to obtain a different TRIP steels structures providing then various and different mechanical properties as regards a relation of strength and ductility. The following design procedures in details have been designed:



Fig. 1. Scheme of special TM treatment of steel

Specimens A,B: 1) heating to T=1000°C/30min. \rightarrow 2) first compression $\varepsilon_1 \rightarrow$ 3) cooling to: A \Rightarrow T₁, B \Rightarrow T₁ \rightarrow 4) second compression $\varepsilon_2 \rightarrow$ 5) first transformation γ - α at T=750°C/300sec. 6) water quenching \rightarrow 7) second transformation at 420°C/300s \rightarrow 8) air cooling (Fig. 1).

Specimens C: 1) heating to T=850°C/35min. \rightarrow 2) cooling to T₁ \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.

The Ac₁ and Ac₃ temperatures, as well as, the required critical cooling rates were estimated from the continuous cooling transformation (CCT) diagram for the initial low alloyed steel [4,5]. The specimens (A,B,C) for tensile test of 6x2mm 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 $\Delta d/dhkl=2x10-3$. However, since such a high instrumental resolution is achieved only in a relatively narrow 20-band (of about $\Delta(2\theta) \approx 7^{\circ}$), 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 in 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 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



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



Fig. 4. Evolution of the austenite volume fraction in dependence on applied strain during the tensile test

Mechanical properties of TRIP steel strongly depend on the composition of microstructure, however in our 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 [5, 6].

The evolution of the austenite transformation during the straining of 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 used as a good approximation for describing kinetics of austenite transformation during the straining [7].

Table 1.

Elastoplastic	properties	of phases	in	TRIP	steel
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	Sample A		Sample B		Sample C	
	E GPa	σ_0MPa	E GPa	$\sigma_0 MPa$	E GPa	σ_0MPa
α-matrix	193	607	206	452	206	350
γ-retained	229	942	220	694	190	690

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 $\epsilon \ge 0.005$ (400MPa) and at strain of $\epsilon \ge 0.12$ (~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 1).



Fig. 5. Measurement of the yield strength of α -matrix (ferrite, bainite) in dependence on applied stress during the tensile test

From the deformation records for sample A it can be seen, that this sample exhibits the highest elongation. The martensitic transformation of retained austenite continued even at the highest strains of $\epsilon \ge 0.18$. In all TRIP specimens at the end of tensile test (failure of samples) in the microstructure still could be found some untransformed stabilized austenite. This austenite does not contribute to the steel deformation, what is then expressed in the total ductility of the specimen, (Fig. 2). It is then supposed that the untransformed retained austenite is present in microstructure in the form the form of the laths inside the bainite islands I [8]. From the results shown in Table 1, it 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 [9].



0.0000 0.00080.0016 0.0024 0.0032 0.00400.0048 Lattice strain

Fig. 6. Austenite volume fraction evolution in dependence on applied stress during tensile test

Some authors as Irvine et all. showed that the effect of the carbon content on the yield strength of austenite is quite large [10].

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 conditions (size, distribution, carbon saturation, morphology) of retained austenite and the state of surrounding (a-matrix) plays important role in affecting deformation mechanisms.

Acknowledgements

This paper was prepared under the project entitled 'Development of West-Bohemian Centre of Materials and Metallurgy' No.: LO1412, which is funded by the Ministry of Education of the Czech Republic.

References

- J. Džugan, Z. Nový, M. Sosnová, Fatigue Life optimization of steel by thermomechanical treatment with the use of physical thermomechanical simulator, Advanced Materials Research 264-265 (2011) 1725-1730.
- [2] D. Hauserová, Z. Nový, P. Motyčka, J. Džugan, Influence of carbides spheroidisation on mechanical properties in medium carbon steel, Journal of Iron and Steel Research International 18 (2011) 417-421.
- [3] V. Zackay, Trans. Of ASM 31/9 (1967) 252.
- [4] T. Ros -Yanez., Y. Houbaert, A. Mertens, Characterisation of TRIP assisted multiphase steel surface topography by atomic force microscopy, Materials Characterization 47 (2001) 93-104.
- [5] E. Wirthl, A. Pichler, R. Angerer, P. Stiaszny, K. Hauzenerger, Y. Titovels, M. Hackl, Fundamental Materials Science of the TRIP Phenomenon, International Conference on TRIP-Aided High Strength Ferrous Alloys, Czech Republic, 2014.
- [6] L. Zhao, J. Moreno, S. Kuruijver, J. Sietsma., S. Van der Zwaag, TRIP-Aided Ferrous Alloys, Processing of

the International Conference on TRIP-Aided High Strength Ferrous Alloys, Ghent, Belgium, 2002.

- [7] P. Lukaš, P. Jenčuš, J. Zrník, Z. Nový, In situ neutron diffraction studies of phase transformations in Si - Mn TRIP steel, Processing of the 9th International Conference on the Mechanical Behavior of Materials, Geneve, 2003.
- [8] O. Muransky, J. Zrník, P. Lukaš, P. Jenčuš, Z. Nový, Acta Metalurgica Slovaca 10 (2004) 228.
- [9] O. Muránsky, P. Lukáš, P. Šittner, J. Zrník, P. Jenčuš, and Z. Nový, The 7th International Conference on Residual Stresses, Xian, China (2004), (CD).
- [10] K.K. Park., S.T.Oh, S.M. Baeck, D.I. Kim, J.H. Han, H.N. Han, S-H. Park, C.G.Lee, S-J. Kim, K.H. Oh. In-situ deformation behavior of Retained Austenite on TRIP steel, Material Science Forum 408-412 (2002) 571-576.
- [11] Q. Furmémont, et al., Fundamental Materials Science of the TRIP Phenomenon, International Conference On TRIP-Aided High Strength Ferrous Alloys, Ghent, Belgium, 2002.
- [12] K.J. Irvine, D.T. Llewellyn, F.B. Pickering, Journal of Iron Steel Inst. 199 (1961) 153-175.