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Selection of the hot-working conditions for TRIP-type microalloyed steel

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ABSTRACT

Purpose: The aim of the paper is to develop hot-working conditions for a low-carbon Mn-Si-Al TRIP-type steel basing on axial compression tests.

Design/methodology/approach: The influence of the austenitizing temperature on a grain size of austenite was determined on a basis of the dissolution kinetics in the austenite of MX-type interstitial phases. The identification of processes controlling the strain hardening was carried out in hot-compression tests. Specimens were deformed up to a true strain of 1.0 in a temperature range of 850 to 1150°C with strain rates of 0.1, 1.0 and $10s^{-1}$. The σ-ε curves were useful for developing conditions of multi-stage axial compression. The plastic deformation was realized by the use of the DSI Gleeble 3800 equipment.

Findings: It was found that the investigated steel has a fine-grained structure of austenite to a temperature of 1050°C. The obtained σ-ε curves indicate that used plastic deformation conditions influence substantially the ε_{max} strain corresponding to a maximum value of flow stress. It increases with lowering the temperature of plastic deformation. The σ-ε curves obtained during multi-stage compression tests confirmed that under used conditions of temperature and strain a dynamic recovery is a process controlling the strain hardening in a whole strain range.

Research limitations/implications: To design in detail hot-rolling conditions, the analysis of the influence of time between successive strains on a fraction of statically recrystallized austenite should be carried out.

Practical implications: The obtained σ-ε curves are useful in determining force-energetic parameters of rolling and processes controlling the strain hardening during the hot-rolling.

Originality/value: The determined true stress – true strain curves were obtained for the low-carbon TRIP-type steel containing Nb and Ti microadditions.

Keywords: Metallic alloys; TRIP-steel; Hot-compression test; Dynamic recovery; Dynamic recrystallization

MATERIALS

1. Introduction

Increasing demands of automotive industry concerning production of cars utilizing small quantity of fuel and emitting limited amounts of exhaust gas into the environment as well as improvement of passive safety of passengers have led to a development of multiphase steels strengthened through a TRIP effect (Transformation Induced Plasticity) in recent decade [1-4]. These steels are characterized with ferritic-bainitic microstructure with retained austenite, which undergoes martensitic transformation during technological forming of products, additionally contributing the strengthening of a finished part. Steels strengthened through TRIP effect usually consist of around 0.2% C, 1÷2% Mn and around 1.5% Si. Participation of retained austenite, usually being equal from 10 to 15% has a decisive meaning for obtaining high strength and ductility of these steels [5-7]. It generally depends on carbon concentration in austenite increasing in individual stages of production of sheets made of this group of steels. Thermodynamic stability of retained austenite is defined by the temperature of martensitic transformation start M_s [8].

Depending on required sheet thickness and specific application, TRIP-type steels are manufactured through intercritical annealing of cold rolled sheet with successive isothermal holding in range of bainitic transformation temperature or through energy-saving method of thermo-mechanical processing. The majority of research concerning steels with TRIP effect refers to elaboration of optimum heat treatment conditions after cold rolling, allowing achievement of desired participation of retained austenite [9, 10]. Moreover, their behavior during cold plastic deformation with variable strain rate in room temperature, lowered and also increased temperature is also investigated. Application of thermo-mechanical processing apart from its economic assets should lead to further increase of mechanical properties of this steel group, particularly in the aspect of microadditions application for microstructure forming in the conditions of hot-working [11, 12].

Obtaining fine-grained microstructure of the steel before beginning of direct cooling from the temperature of last roll pass requires knowledge of chemical composition influence, and in particular, impact of microadditions introduced into the steel on strengthening processes and recrystallization occurring in hot-working conditions. So far, problems regarding TRIP steels haven't focused much attention, whereas they are essential for correct design of hot rolling. Applied approach should be similar as in case of microalloyed steels as well as IF and DP-type steels, which are the subject of physical simulations and mathematic modeling [13, 14]. Apart from strict monitoring of temperature–time conditions during hot rolling, precise control of the course of cooling after last roll pass, particularly in a range of $\gamma \rightarrow \alpha$ transformation and during isothermal holding in bainitic range is also required [15].

2. Experimental procedure

Investigations were carried out on carbon-manganese steel with 0.24%C, 1.55%Mn, 0.87%Si, 0.40%Al, 0.0028%N, 0.034%Nb and 0.023%Ti. The melt was done in Balzers VSG-50 vacuum induction furnace. Liquid metal was cast into moulds in argon shield. Obtained 25 kg ingots were subjected to open die forging to 220 mm wide and 20 mm thick flats, from which cylindrical ∅10x12 mm samples were made. Temperature conditions of hot-working ensuring fine-grained microstructure of the steel were selected according to the kinetics of interstitial phases' precipitation in the steel. In this case the dependence (1) for TiN and NbC was implemented [15]:

$$\log [Ti] [N] = 0.32 - 8000/T \quad (1)$$

$$\log [Nb] [C] = 3.04 - 7290/T \quad (2)$$

where: [Ti], [Nb], [N], [C] – mass fractions of Ti and Nb as well as N and C dissolved in austenite at the T temperature (in K), the constants: A=8000, B=0.32 for TiN and A=7290, B=3.04 for NbC, given in [15] were used.

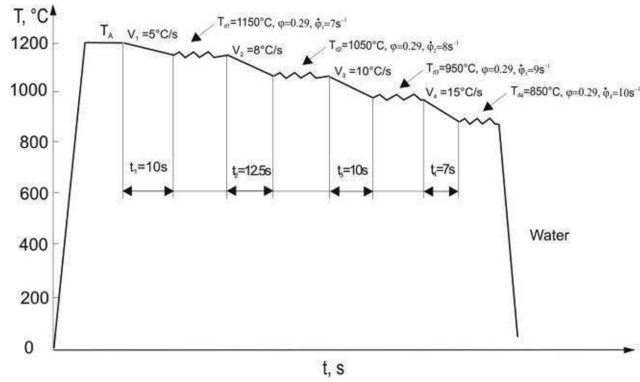

Fig. 1. Conditions of multi-stage hot-compression test

Influence of the impending effectiveness of interstitial MX–type phases on austenite grain growth was performed through analysis of austenitizing temperature influence in a range from 900 to 1200°C on primary austenite grain size. To determine σ-ε curves compression tests in the temperatures of 850, 950 and 1150°C with 0.1, 1 and 10 s^{-1} strain rate were performed. Work-hardening curves were assigned using DSI Gleeble 3800 apparatus. The obtained stress-strain curves and changes of austenite grain size as a function of temperature were a basis for developing conditions of several-stage compression test in the Gleeble thermo-mechanical simulator (Fig. 1.).

Metallographic examinations of samples were performed on LEICA MEF4A optical microscope. In order to reveal primary austenite grain boundaries, samples were etched in saturated aqueous solution of picric acid with addition of $CuCl_2$ at 70°C.

3. Results and discussion

Analysis of the influence of austenitizing temperature on a grain size of austenite indicates that the developed steel possesses a fine-grained structure up to a temperature about 1050°C (Fig. 2.).For instance, the structure of the water-quenched steel from a temperature of 1000°C is shown in Fig. 3. Increasing the austenitizing temperature to 1100°C results in slight increase of the primary austenite grain size (Fig. 4.). Calculations of the precipitation kinetics of interstitial phases in austenite are in agreement with a course of the curve in Fig. 2. Impeding influence on a growth of austenite grains during steel austenitizing at 1200°C have TiN particles. For this temperature, the content of titanium dissolved in austenite equals only 0.0032wt%, whereas a residual part is fixed as TiN (Fig. 5.). NbC precipitates should have a hampering influence on a grain growth of primary austenite in a temperature range of hot-working from 1180°C to 900°C (Fig. 5.).

Flow curves shown in Figs. 6 and 7 allow to state that the developed steel is characterized by comparable values of flow stress as for DP-type steels, commonly used in automotive industry [14]. For applied conditions of plastic deformation the values of flow stress are from 130 to 270 MPa. Determined curves have not a distinct deformation maximum ε_{max} – corresponding to a maximum value of flow stress. It indicates on the intense course of dynamical recovery in an initial state of hot-working.

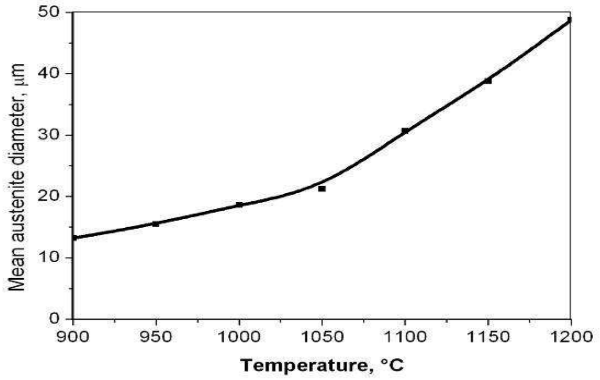

Fig. 2. Influence of austenitizing temperature on a grain size of primary austenite

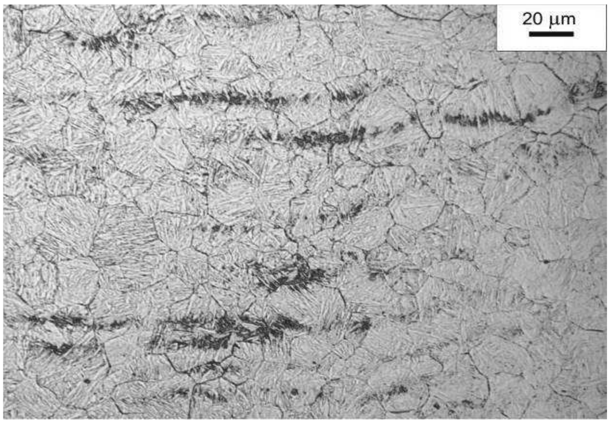

Fig. 3. Structure of primary austenite of the specimen water-quenched from a temperature of 1000°C

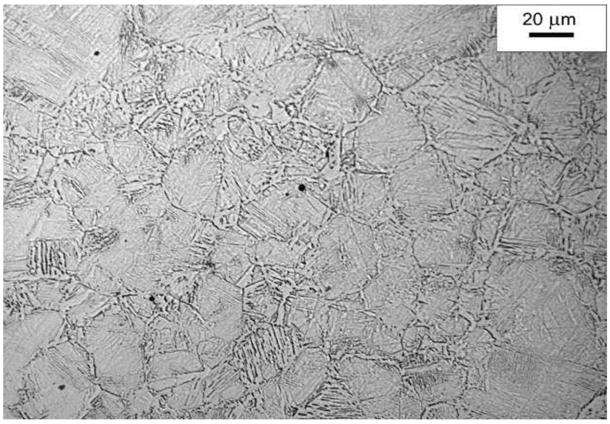

Fig. 4. Structure of primary austenite of the specimen water-quenched from a temperature of 1100°C

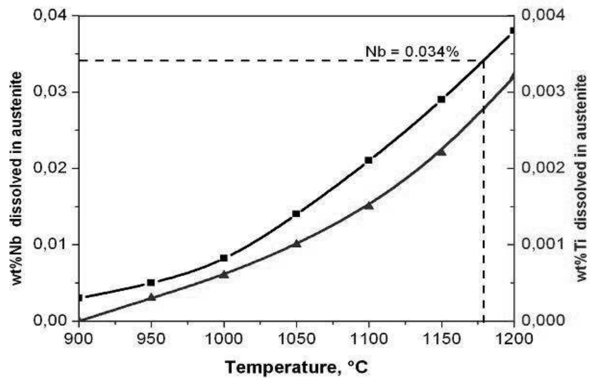

Fig. 5. Temperature dissolution (precipitation) kinetics for TiN (▲) and NbC (■) in austenite

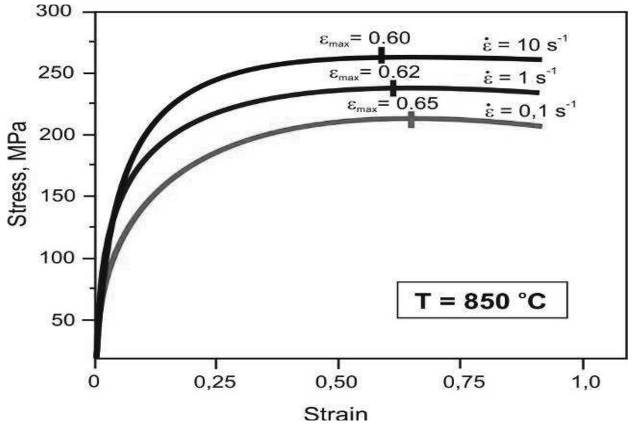

Fig. 6. Influence of strain rate on stress-strain curves of the specimens compressed at a temperature of 850°C

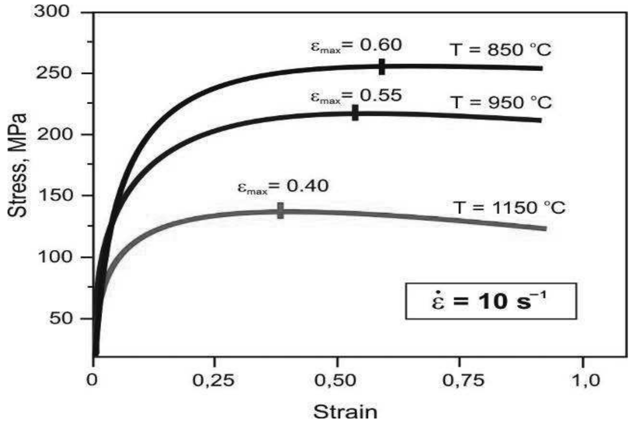

Fig. 7. Influence of temperature on stress-strain curves of the specimens compressed at a strain rate of $10s^{-1}$

The strain rate in a range from 0.1 to $10s^{-1}$ does not affect essentially the deformation value ε_{max} (Fig. 6.). The higher influence has deformation temperature, for which a value of ε_{max} varies from 0.4 at a temperature of 1150°C to 0.6 at a temperature of 850°C (Fig. 7.).

Determination of the influence of austenitizing temperature on a grain size of primary austenite, calculations of the precipitation kinetics of MX-type phases in austenite and σ-ε curves were a basis of developing the multi-stage hot-working simulated finishing rolling passes.

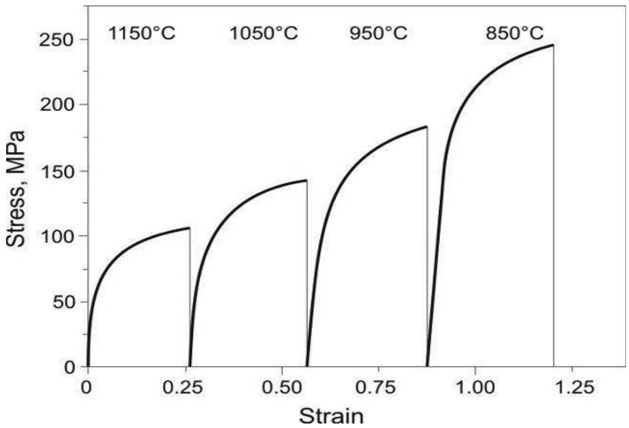

Fig. 8. Stress-strain curves corresponding to hot-working conditions in Fig. 1

The austenitizing temperature was selected taking into account the impeding effect of TiN particles on a grain growth of primary austenite and a hot-working temperature range overlapped a precipitation range of NbC in austenite. Taking into account real conditions of hot-rolling the selected true strain was 0.29. The curves obtained in Fig. 8 indicate that the process controlling work-hardening in the applied range of deformation temperature is dynamical recovery. It is in agreement with the σ-ε curves shown in Figs. 6 and 7, from which result that the beginning of the dynamical recrystallization requires the true strain at least 0.4.

4. Conclusions

Obtaining the fine-grained structure of TRIP-type steel requires using hot-working conditions assuring the fine-grained primary austenite structure before cooling from a finishing hot-working temperature. The carried out calculations of precipitation kinetics for TiN and NbC in austenite indicate on beneficial impact of these particles on limitation of grain growth of primary austenite during steel austenitizing and in a temperature range of hot-working. It is confirmed by the fine-grained structure of the steel quenched from 1000°C. A slight increase in a grain size of austenite proceeds above 1050°C, what is due to partial dissolution of NbC particles.

For applied deformation conditions, the developed steel is characterized by flow stress values from 130 to 270 MPa, showing in a wide range the dynamic equilibrium state between work-hardening due to generating new dislocations and their removing as a result of dynamical recovery. The beginning of dynamical recrystallization requires the true strain at least 0.4. It is difficult to obtain in real conditions of hot-rolling. Due to lowering the true strain to 0.29 the process controlling work-hardening in the whole applied range of hot-working temperature is dynamical recovery.

Acknowledgements

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References

[1] J. Adamczyk, A. Grajcar, Structure and mechanical properties of DP-type and TRIP-type sheets, Journal of Materials Processing Technology 162-163 (2005) 23-27.

[2] A. Basuki, E. Aernoudt, Influence of rolling of TRIP steel in the intercritical region on the stability of retained austenite, Journal of Materials Processing Technology 89-90 (1999) 37-43.

[3] B. Gajda, A.K. Lis, Thermal processing of CMnAlSi steel at (α+γ) temperature range, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 355-358.

[4] A.K. Lis, B. Gajda, Modelling of the DP and TRIP microstructure in the CMnAlSi automotive steel, Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 127-134.

[5] A. Grajcar, Effect of hot-working in the γ+α range on a retained austenite fraction in TRIP-aided steel, Journal of Achievements in Materials and Manufacturing Engineering 22 (2007) 79-82.

[6] B. Gajda, A.K. Lis, Intercritical annealing with isothermal holding of TRIP CMnAlSi steel, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 439-442.

[7] S. Wen, L. Lin, B. De Cooman, P. Wollants, Y. Chun-Xia, Thermal stability of retained austenite in TRIP steel after different treatments, Journal of Iron and Steel Research 15 (2006) 61-64.

[8] K. Eberle, P. Cantinieaux, P. Harlet, M. Vande Populiere, New thermomechanical strategies fort he realization of multiphase steels showing a TRIP effect, Iron and Steelmaker I&SM 26 (1999) 23-27.

[9] N. Apostolos, A. Vasilakos, K. Papamantellos, G. Haidemenopoulos, W. Bleck, Experimental determination of the stability of retained austenite in low alloy TRIP steels, Steel Research 11 (1999) 466-471.

[10] J. Pietrzyk, W. Osuch, G. Michta, The isothermal decomposition of the austenite obtained at a temperature between A_3-A_1 in a steel containing 0.2%C, 1.5%Mn and 1.5%Si, Materials Engineering 19 (1998) 18-23 (in Polish).

[11] A. Grajcar, Hot-working in the γ+α region of TRIP-aided microalloyed steel, Archives of Materials Science and Engineering 28/11 (2007) 743-750.

[12] J. Adamczyk, Development of the microalloyed constructional steels, Journal of Achievements in Materials and Manufacturing Engineering 14 (2006) 9-20.

[13] R. Kawalla, G. Goldhahn, W. Jungnickel, Laboratory rolling condition and its effect on rolling parameters on material properties of hot rolled products, Proceedings of the 2nd International Conference "Thermomechanical Processing of Steel" TMP'2004, Liege, 2004, 17-24.

[14] E. Hadasik, R. Kuziak, R. Kawalla, M. Adamczyk, M. Pietrzyk, Rheological model for simulation of hot rolling of new generation steel strip for automotive applications, Steel Research 77 (2006) 927-933.

[15] J. Adamczyk, Engineering of Metallic Materials, The Silesian University of Technology Publishers, Gliwice, 2004 (in Polish).