Achievements in Mechanical and Materials Engineering

COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology

16th - 19th May 2005 Gliwice-Wisła, Poland

COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND
ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND

13th INTERNATIONAL SCIENTIFIC CONFERENCE ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

Structure and mechanical properties of DP-type and TRIP-type sheets obtained after the thermomechanical processing

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Abstract: The chemical composition of the C-Mn-Si steel with Nb and Ti microadditions was established. The rolling and cooling conditions of the thermomechanical processing of DP-type and TRIP-type sheets were developed. The conditions of the thermomechanical processing were selected on a basis of the determined DTTT$_c$-diagram of plastically deformed undercooled austenite and a dissolution kinetics of TiN and NbC in the austenite. It was found that thermomechanically processed sheets have more fine-grained structure and better mechanical properties than after the classical underhardening or isothermal quenching from the temperature slightly higher than A_{c1} of the investigated steel.

Keywords: Thermomechanical processing, DP-type sheet, TRIP-type sheet, Microalloyed steel, DTTT-diagram

1. INTRODUCTION

Ecological regards decide about searching of automotive industry for new constructional materials with an increasing ratio of strength to density. It enables a production of light-weight cars and it is connected directly with a reduced fuel consumption and a limitation of the emission of harmful exhaust gases. For this purpose, international research projects are realized. An example is the ULSAB–AVC (Ultra Light Steel Auto Body – Advance Vehicle Concept) project concerning a production of a technically advanced car consuming fewer than 3 litres of fuel per 100 km [1]. Lowering of car weight can be achieved using low density metal alloys, i.e. Al, Mg and Ti based alloys and composite materials of polymer matrix but still about 60% of a car weight is represented by constructional elements formed from steel sheets of high strength and required capability to metalforming operations [2].

A variety of produced cars and other vehicles decides about a necessity of manufacturing of weldable thick plates and hot-rolled or cold-rolled sheets, characterized by differentiated yield point, tensile strength and a susceptibility to metalforming operations. Besides generally produced hot-rolled plates of ferritic and ferritic – pearlitic structure, cold-rolled BH-type (bake hardening) and IF-type (interstitial free) sheets with a good drawability [3, 4], the ULSAB-AVC project indicates on a growing significance of multiphase structure sheets [2, 5]. These are sheets of the ferritic - martensitic dual phase structure [6] and TRIP – type structure (Transformation Induced Plasticity) consisted of ferrite, bainite and retained austenite. The TRIP steels are hardened during a technological forming as a result of martensitic transformation of the retained austenite [7]. In order to meet higher strength properties CP (Complex Phase) steels are considered.

A prevalent technology of production of the DP-type and TRIP-type sheets is an intercritical annealing of a cold-rolled product combined with a water quenching to the room temperature (dual phase steels) or a holding period in the bainite field (TRIP steels) [8-10]. An alternative energy-saving technology of the thermomechanical processing [4, 11] is also a subject of a big interest. It is an integration of a hot plastic deformation of steel with direct cooling of sheets after finishing of rolling. The technology is especially privileged for microalloyed steels containing a total concentration of Nb, Ti and V up to 0.1%. Applying of the microalloyed steels enables producing of fine-grained structure sheets with a high strength and a desired capability to metalforming operations [3, 4]. The major importance in obtaining a multiphase structure of the desired grain size and morphology has a suitable selection of plastic deformation conditions and a cooling rate from a finishing rolling temperature, adjusted to the kinetics of plastically deformed undercooled austenite transformations [11-13]. A fundamental problem concerning of the production of TRIP-type sheets is to obtain in their structure a desired fraction of retained austenite. A stabilization of this phase in a steel enable Si and Al, which a total contents should reach up to 1.7 in mass % [14]. However, an increased concentration of Si causes some technological problems connected with a steel decarburation in a high temperature and a corrosion protection of sheets by galvanizing [15]. For this reason, a possibility of the silicon concentration limitation and using of the microalloyed steels, particularly susceptible to formation of fine-grained primary austenite structure during the energy-saving thermomechanical processing are considered.

The aim of this research was to establish a chemical composition of the microalloyed steel and the controlled rolling and cooling conditions of DP-type and TRIP-type sheets. The comparison of the structure and mechanical properties of thermomechanically processed sheets with underhardened or isothermally quenched sheets from the temperature slightly over A_{c1} were also examined.

2. EXPERIMENTAL PROCEDURE

The constructional C-Mn-Si steel with the microadditions of Nb and Ti (Table 1) was investigated. The steel was smelted in a Balzers` VSG-50 vacuous induction furnace using Ce and La for a modification of non-metallic inclusions. Addition of 0.5% Si to the melt, against to 1.5% Si usually used in TRIP steels prevents an ability of the steel to grafitizing and decarburation and also makes possible to avoid difficulties connected with a galvanization of sheets. The liquid metal was cast into the ingot moulds of 25 kg volume in the Ar atmosphere. After solidification, cutting off the ingot top and bottom and also after proper surface preparation, the ingots were forged and roughly rolled in order to obtain the flats of 140x140x8mm. They were homogenized at a temperature of 1200°C in the N_2 atmosphere.

The temperatures of phase transformations of the investigated steel and a diagram of the kinetics of phase transformations of the plastically deformed undercooled austenite $DTTT_c$ were established using the DIL 805 dilatometer. The specimens of 5mm in diameter and 10mm in length after austenitizing at a temperature of 875°C were plastically deformed (ε = 50%) using a compression at a strain rate of $4s^{-1}$ and then cooled to a room temperature at a rate of 114 to 0.17°C/s. Investigations of the sheet structure were performed by means of light microscopy in the polished and etched state. A measurement of a ferrite grain size and its volume fraction were carried out by the use of the automatic image analyser being a part of the Leica MEF 4A light microscope. An analysis of the chemical composition of nonmetallic inclusions was performed with the aid of X-ray spectrometry using the EDAX device, being a part of the XL 30 scanning electron microscopy. The electron beam with a diameter of 1μm, an accelerating voltage of 20 kV and a current of 10^{-8} A were used. Observations of thin foil structure were carried out in the JEM 2000 FX transmission electron microscopy using an accelerating voltage of 160 kV. Chemical composition of interstitial phases observed in the structure were determined by EDS method using the ISIS device and a quantitative analysis of chemical composition of identified particles was carried out using the Cliff – Lorimer method. The qualitative and quantitative X-ray phase analyses were performed by the use of the Siemens D5005 X-ray diffractometer with CoKα radiation and a graphite monochromator. The amount of retained austenite was quantitatively measured by Rietveld method using the SIROQUANT software.

Table 1.
Chemical composition of the investigated steel

Mass contents in %								
C	Mn	Si	P	S	Nb	Ti	Al	N
0.20	1.41	0.50	0.014	0.008	0.027	0.010	0.020	0.0047

Mechanical properties of thermomechanically processed sheets and after underhardening or isothermal quenching from a temperature slightly higher than A_{c1} were determined by means of tensile test using the Zwick Z/100 machine and flat specimens with a thickness of 2 mm and a gauge length of 35 mm.

3. SELECTION OF THE THERMOMECHANICAL PROCESSING CONDITIONS

Selection of the hot working conditions of the steel was based on the dissolution kinetics in the austenite of interstitial phases TiN and NbC. The calculated sequence of precipitation of MX-type interstitial phases in austenite of the investigated steel as a function of temperature is shown in Figure 1. Cooling conditions of sheets from the finishing rolling temperature were established on the basis of the $DTTT_c$-diagram of the plastically deformed austenite. For example, it is shown for TRIP – type sheets in Figure 2. These data were used to create a rolling schedule of flats in order to get the sheets with a thickness of 2 mm by the use of the thermomechanical processing. A detailed analysis of the selection of thermomechanical processing conditions is described in [12].

The classical heat treatment of DP-type and TRIP-type sheets was realized by austenitizing of the samples at 740°C for 200s and the use of the same cooling conditions, which were worked-out in the thermomechanical treatment.

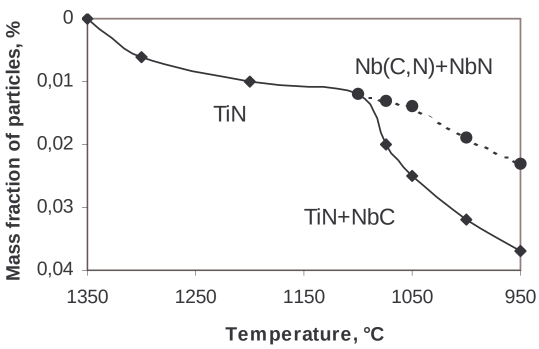

Figure 1. The temperature sequence of precipitation of MX-type phases in the austenite

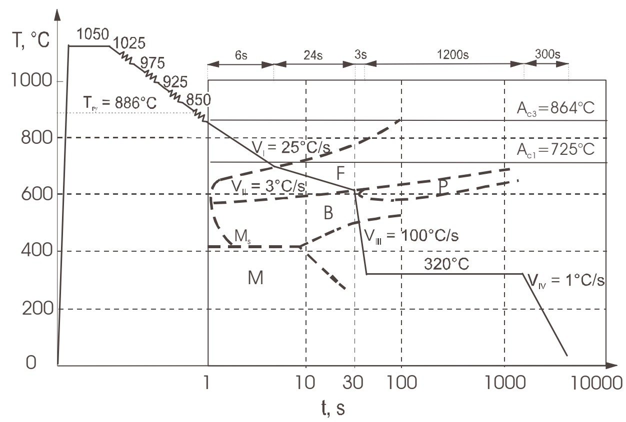

Figure 2. DTTT$_c$-diagram of the investigated steel with marked cooling conditions of TRIP-type thermomechanically processed sheets

4. RESULTS AND DISCUSSION

4.1. Results of metallurgical purity of the steel

The metallographic investigations revealed that a total volume share of oxide and sulphide non-metallic inclusions was about 0.29%. The oxide inclusions usually have a globular shape and the sulphide inclusions are slightly elongated in the rolling direction. It was found that a substantial part of non-metallic inclusions has a non-uniform oxide-sulphide structure. For example, a slightly elongated sulphide inclusion of the (Ce, La)S with fragments of an oxide of the chemical composition nearby (Al, Ce, La)$_2$O$_3$ is shown in Figure 3. The results of these investigations indicated that a modification of non-metallic inclusions using Ce and La additions caused a considerable lowering of a susceptibility of non-metallic inclusions to elongation in the hot rolling direction of the steel.

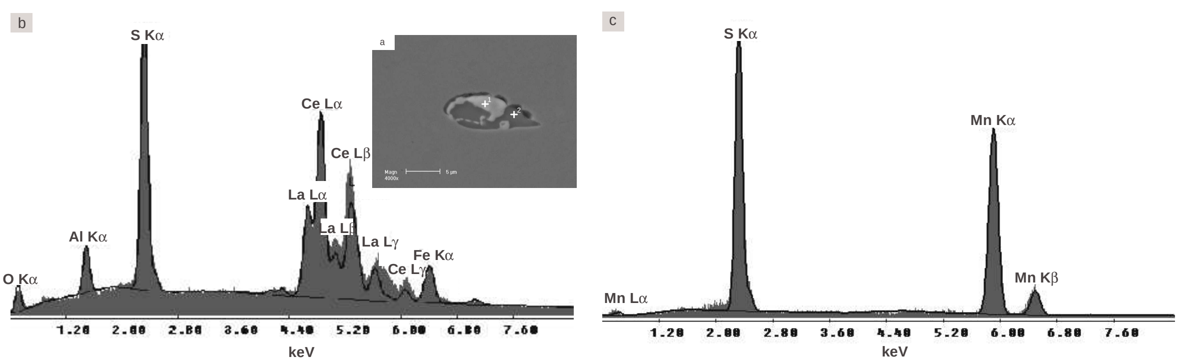

Figure 3. The (Ce, La)S sulphide with an oxide of chemical composition nearby (Al, Ce, La)$_2$O$_3$; a – view of the inclusion, b – spectrum of the non-metallic inclusion from a point no 1, c – spectrum of the non-metallic inclusion from a point no 2

4.2. Results of the structure investigations

Adjusting of the hot working temperature range of the steel to a kinetics of precipitation of MX-type interstitial phases in the austenite and applying a finishing rolling temperature slightly lower than the austenite recrystallization temperature ensured the conditions for creation of a high population of places convenient for a nucleation in the $\gamma \rightarrow \alpha$ transformation. The best solution is a two-stage cooling, first to a start temperature of the $\gamma \rightarrow \alpha$ transformation in air and then to 620°C in a retention shield slowing a cooling rate of sheets to about $3°C \cdot s^{-1}$. In this case a ferrite fraction produced during the $\gamma \rightarrow \alpha$ transformation was 60% and a mean grain size of this phase was 4 to 5μm (Fig. 4). It is twice smaller in comparison with the classical heat treatment (Fig. 5).

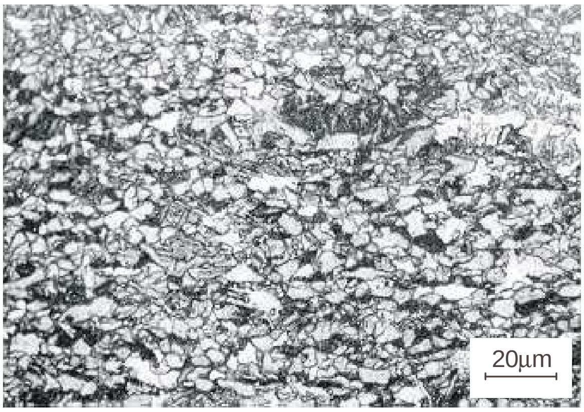

Figure 4. Fine-grained ferritic–martensitic structure of the thermomechanically processed sheet

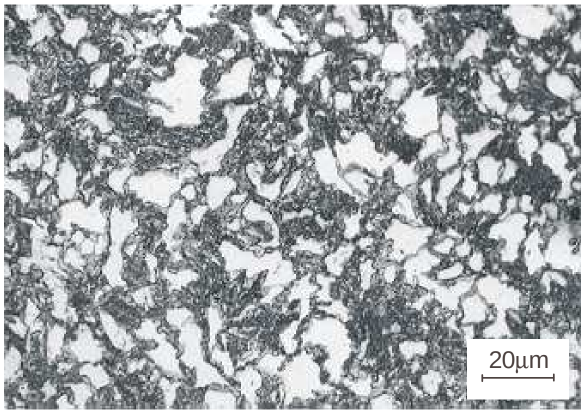

Figure 5. Ferritic – martensitic structure of the underhardened sheet

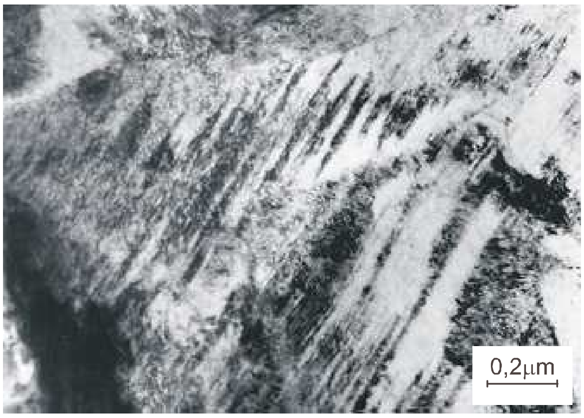

Figure 6. Structure of the lower bainite in TRIP-type sheets

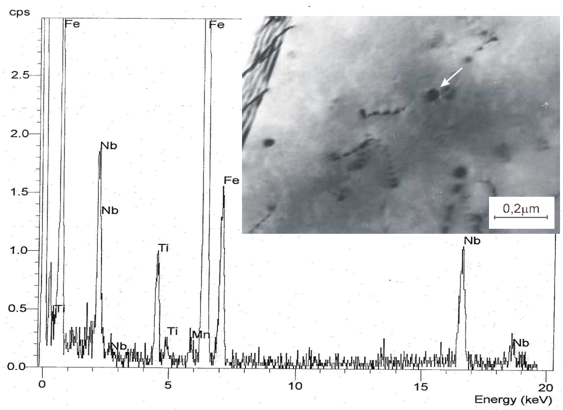

Figure 7. Dispersed particles of MX-type phases; a marked particle of the chemical composition nearby $(Nb_{0.65}Ti_{0.35})(C,N)$

It was observed that most often martensite and bainite occur as islands on grain boundaries of ferrite with a high dislocation density lowering with carrying away from the islands. It is a result of a local strain of the α phase during a martensitic or bainitic transformation of the austenite. A course of an isothermal transformation of the austenite in the case of TRIP-type sheets led to a formation of ferritic bainite with a little fraction of the fine-lamellar Fe_3C carbides (Fig. 6) and simultaneously to an increase of the carbon contents in the untransformed austenite of an increasing stability. It is a result of a pursuit of the system to obtain a thermodynamic equilibrium state between bainite and austenite of increased carbon contents. The retained austenite fraction achieved 5.1% and only 3%, respectively for the thermomechanically processed- and isothermally quenched sheets. It was found that the retained austenite in majority in the form of little islands or narrow fields located between the ferrite and bainite is occured. In the structure of the investigated steel dispersed particles of the Ti and Nb carbonitrides of a size of 10 to 60 nm were identified too. It was observed that the bigger particles are rich in titanium and the smaller ones in niobium (Fig. 7).

4.3. Results of mechanical properties of the sheets

The fine-grained structure of thermomechanically processed sheets has an important influence on their mechanical properties. The sheets after the thermomechanical treatment possess much better mechanical properties [12, 13]. It is caused by more fine-grained structure of the phase transformation products of plastically deformed austenite and due to the presence of the retained austenite fraction of 5% in the case of TRIP–type sheets. The thermomechanically processed DP-type sheets achieve: $YS_{0.2}$ ~ 500 MPa, TS ~ 860 MPa, TEl = 21%, UEl = 17%, $YS_{0.2}$/TS = 0,59 and a coefficient characterizing their drawability TS·UEl about 14000 MPa·%**.** The TRIP-type sheets achieve: $YS_{0.2}$ ~ 500 MPa, TS ~ 780 MPa, TEl = 25%, UEl = 19%, $YS_{0.2}$/TS ~ 0,65 and TS·UEl about 15000 MPa·%.

5. CONCLUSIONS

The developed microalloyed steel is suitable for rolling of DP-type and TRIP-type sheets in the applied conditions of the thermomechanical processing. A proper selection of the thermomechanical processing conditions allows to produce sheets with the ferrite fraction of 60% and a mean grain size of about 4μm. They are also characterized by fine-grained transformation products of the statically recovered austenite. The applied conditions of controlled rolling and cooling can be useful in creation of an integrated technological line of multiphase structure sheets obtaining after the thermomechanical processing a good balance between strength and plastic properties.

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