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Effect of hot-working in the γ+α range on a retained austenite fraction in TRIP-aided steel

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ABSTRACT

Purpose: The aim of the paper is to determine the influence of thermomechanical processing conditions on an austenite stability in a TRIP-aided microalloyed steel.

Design/methodology/approach: The heat treatment and thermomechanical processing in a two-phase region to obtain ferritic – bainitic structures with the retained austenite in a low-carbon microalloyed steel were conducted. The heat treatment consisted of austenitizing of specimens at 750°C, oil cooling, isothermal holding in a temperature range from 300°C to 500°C and slow cooling to room temperature. A part of the specimens was forged with a degree of deformation of 28% before cooling. Optical and transmission electron microscopy were employed for structure observations. The retained austenite amount was determined by X-ray diffraction method.

Findings: It was found that hot-working in the γ+α range contributes to a considerable refinement of a ferritic matrix. The grain size of the α phase is about 4 μm and its volume fraction equals from 60 to 68%. The optimum structure containing 10% fraction of retained austenite was obtained for the specimen forged in the two-phase region and isothermally held at a temperature of 300°C.

Research limitations/implications: To determine with more detail the relationship between hot-working conditions and the stability of retained austenite investigations in a wider deformation temperature range should be carried out.

Practical implications: The proposed thermomechanical treatment route can be useful in a development of the technology for TRIP-aided low-carbon microalloyed steels with a reduced silicon content.

Originality/value: The design thermomechanical treatment conditions made for obtaining the 10% fraction of retained austenite in a steel containing 0.5% Si only in comparison to 1.5% Si concentration used in TRIP-aided steels usually.

Keywords: Metallic alloys; TRIP-aided steel; Thermomechanical processing; Retained austenite

1. Introduction

One of the priorities of the automotive industry is to decrease the weight of vehicles. It is connected with the reduced fuel consumption and exhaust emission reduction. In recent years, the growing significance in relation to aluminium and magnesium alloys as well as composite materials can be observed [1,2]. However, steels have still the highest potential in a scope of operate properties and in relation to manufacturing economics. For many years diversified requirements concerning strength and ductile properties of steel sheets used for different elements of cars are satisfied by microalloyed steels [3,4], IF-type (Interstitial Free) steels, BH-type (Bake Hardenable) steels [5,6] and steels with a ferritic – martensitic structure [7,8]. However, the increasing importance have TRIP-aided (Transformation Induced Plasticity) steels of multiphase ferritic – bainitic structure with the retained austenite [9,10]. It was found [9-16] that strain-induced martensitic transformation of retained austenite prevents a localization of plastic deformation delaying necking during a tensile test and thinning during sheet-metal forming.

The most often investigated TRIP-aided steels contain about 0.2%C, 1.5%Mn and 1.5%Si. These steel sheets after a multi-stage heat treatment have ferritic – bainitic structures with a volume fraction of retained austenite from 5 to 15%. The essential effect for a thermal stabilization of retained austenite has silicon, suppressing carbide precipitation during an isothermal bainitic transformation [12,13]. However, silicon causes technological difficulties connected with casting, a surface quality due to appearance of red scale defects and hot dip galvanizing, caused by a lack of wetting. For this reason investigations aiming at decreasing its concentration [14,15] or a partial substitution by Al and P [10,16] are carried out. It was also found [17,18] that a positive influence on a thermal stabilization of retained austenite can have a refinement of the structure. The highest opportunities for the grain refinement of multiphase structure are present for using the thermomechanical processing during manufacturing process of sheets. It consists of hot-working in a range of the γ phase and cooling from a finishing rolling temperature [17,19]. Basuki and Aernoudt [20] observed that further increasing the thermal stability of retained austenite can be obtained by hot-working of steels in a two-phase region. However, there is a lack of enough data concerning this process, particularly in relation to steels containing a decreased content of silicon and microadditions of Nb and Ti.

2. Experimental procedure

The structural microalloyed steel containing 0.26%C, 1.44%Mn, 0.5%Si, 0.04%Al, 0.027%Nb, 0.012%Ti and 0.0042%N was investigated. The steel contains small concentrations of impurities, i.e. S = 0.008% and P = 0.016%. It was smelted in a Balzers` VSG-50 vacuous induction furnace using mischmetal for modification of non-metallic inclusions. Addition of 0.5% Si to the melt, against to 1.5% Si usually used in TRIP steels aimed at determining its reduced content on a thermal stability of austenite. The liquid metal was cast into ingot moulds of 25 kg volume in the Ar atmosphere. After solidification the ingots were forged to obtain the rods of 24x24 mm. They were homogenized at a temperature of 1200°C in the N_2 atmosphere. The specimens with a diameter and a height of 14 mm for the heat treatment and thermomechanical processing were prepared by machining.

The heat treatment and thermomechanical processing of the specimens were realized according to the routes, schematically illustrated in Fig. 1. In order to design properly thermomechanical treatment conditions, the knowledge of critical temperatures A_{c3}, A_{c1} and M_s as well as B_s for the γ phase is needed. The temperatures calculated on the basis of the chemical composition using Andrews' equations [21] are the following: A_{c3} = 828°C, A_{c1} = 722°C, M_s = 385°C and B_s = 630°C. In case of martensite and bainite start temperatures, it has to be taken into consideration the carbon enrichment of the γ phase during annealing in the diphase region. The $M_{s\gamma}$ and $B_{s\gamma}$ temperatures of austenite are decreased then. The heat treatment to obtain ferritic – bainitic structures with the retained austenite consisted of austenitizing of specimens at a temperature of 750°C, oil cooling with a rate of about $90°Cs^{-1}$ and isothermal holding in a temperature range from 300°C to 500°C for 600 s. The specimens subjected to the thermomechanical processing were upset forged with a degree of deformation of 28% and a strain rate of about $30s^{-1}$. Forging tests were performed on an eccentric press PMS50 by the use of flat dice. The cooling rate applied between the annealing and the holding stage is sufficiently high to prevent the formation of any pearlite.

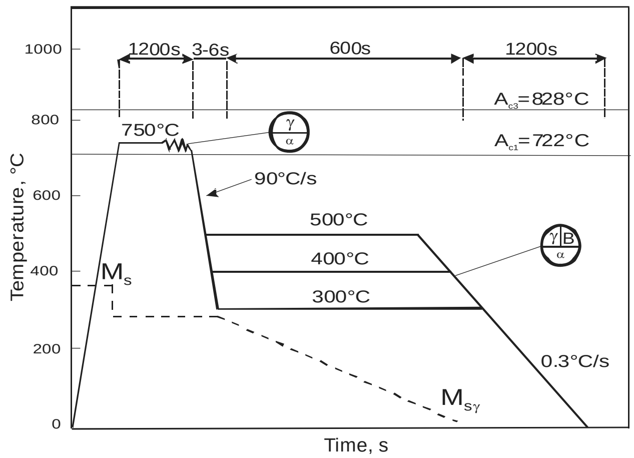

Fig. 1. Schematic representation of the thermomechanical processing of the investigated steel, M_s – martensite start temperature of the steel, $M_{s\gamma}$ – martensite start temperature of the austenite with increased carbon concentration

Structure investigations of thermo-mechanically processed specimens were performed by means of optical microscopy using LePera etching [22]. The structure observations were carried out by the use of the Leica MEF4a light microscope and observations of thin foil structure were carried out in the JEM-200CX transmission electron microscope using an accelerating voltage of 120 kV. The type and phase fractions in the structure of the steel were determined by means of qualitative and quantitative X-ray phase analyses using the DRON2.0 X-ray diffractometer with CoK_α radiation. The volume fraction of retained austenite was quantitatively measured applying Averbach-Cohen's method.

3. Results and discussion

The structure of heat-treated specimens is composed of ferrite, bainite and retained austenite of the phase fraction dependent on an used isothermal holding temperature in a bainitic range. The largest fraction of the stable γ phase after isothermal holding at a temperature of 300°C was obtained (Fig. 2). It is 8.2% and decreases to 4.6% and 3.5% with increasing an isothermal bainitic transformation temperature to 400 and 500°C – respectively. The retained austenite is visible as white grains with a grain size of about 2 μm against the background of ferritic – bainitic matrix. When hot-working in a two-phase region applied a clear refinement of the ferritic – bainitic structure with a directional grain arrangement in a direction of plastic flow can be observed (Fig. 3).

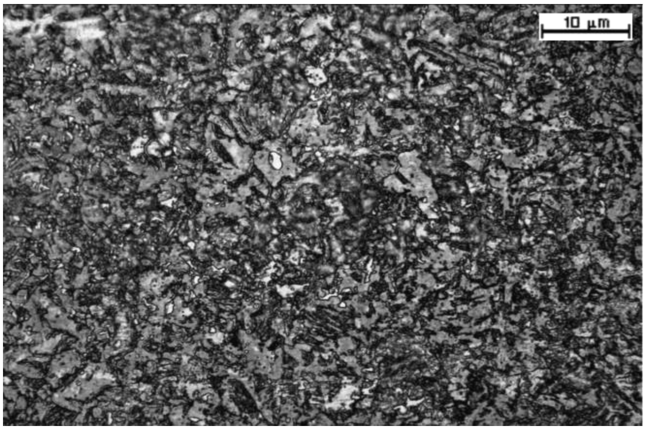

Fig. 2. Ferritic – bainitic structure with the retained austenite of the heat-treated steel isothermally held for 600 s at a temperature of 300°C

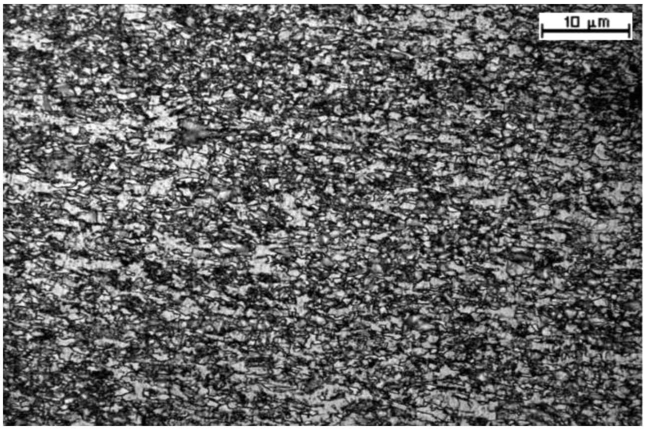

Fig. 3. Ferritic – bainitic structure with the retained austenite of the thermo-mechanically processed steel isothermally held for 600 s at a temperature of 300°C

A fraction of ferrite grains elongated in a direction of plastic deformation for heat-treated specimens (Fig. 2) and thermo-mechanically processed specimens (Fig. 3-5) is comparable. However, a grain size of the α phase for plastically-deformed specimens is about 4 μm, when for heat-treated specimens is twice larger. It was found that like in case of heat-treated steels the largest fraction of retained austenite occurs for a lowest isothermal holding temperature of 300°C. It averages 10.1% and is higher in comparison with the specimens heat-treated under comparable conditions. Due to an increased diffusion rate of carbon and carbide precipitation a fraction of stable retained austenite decreases to 6.2 (Fig. 4) and 5.9% (Fig. 5) – respectively for a bainitic transformation temperature of 400 and 500°C.

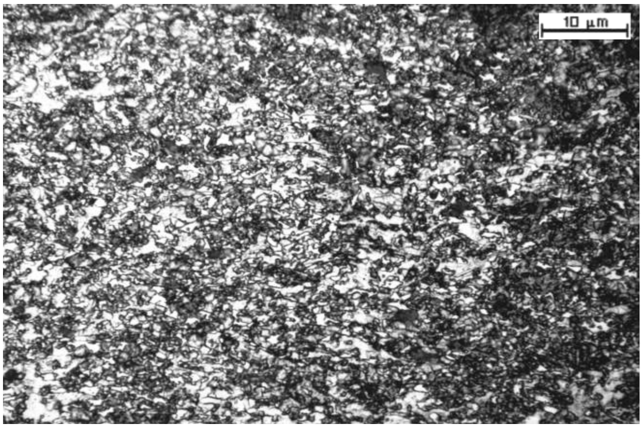

Fig. 4. Ferritic – bainitic structure with the retained austenite of the thermo-mechanically processed steel isothermally held for 600 s at a temperature of 400°C

Fig. 5. Ferritic – bainitic structure with the retained austenite of the thermo-mechanically processed steel isothermally held for 600 s at a temperature of 500°C

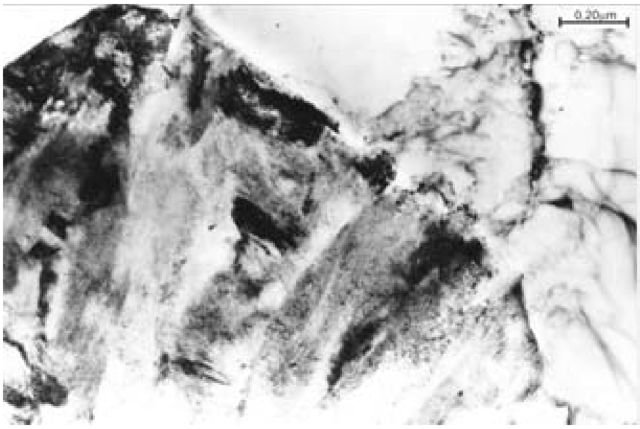

Fig. 6. Structure of bainitic ferrite with the retained austenite located between its laths and on a boundary of bainite and ferrite with an increased dislocation density

Figure 6 is a transmission electron microscopy micrograph of the thermo-mechanically processed steel isothermally held at a temperature of 300°C. It can be seen that the slightly elongated retained austenite grains are located between laths of bainitic ferrite and at a phase boundary of bainite and ferrite.

4. Conclusions

The investigated microalloyed steel can be used for manufacturing the products characterized by ferritic – bainitic structures with the retained auustenite using isothermal quenching from a temperature slightly higher than A_{c1} of steel. The optimum isothermal holding temperature in respect of maximum retained austenite fraction stable to room temperature is 300°C. After the heat treatment under these conditions the structure of steel consists of ferrite, bainitic ferrite and retained austenite with a volume fraction of 8.2%. It is favourably for retained austenite stabilization to use hot-working in the $\gamma+\alpha$ range. The plastic deformation in this region results in distinct multiphase structure refinement of steel. Additionally, the increase of retained austenite fraction to 10% for an optimum bainitic transformation temperature of 300°C was obtained. The reason for the thermal stabilization of higher retained austenite fraction is decreasing its grain size and probably a higher enrichement of the γ phase in carbon during hot-working in the two-phase range. The retained austenite is located between laths of bainitic ferrite with a small carbide fraction or on ferrite – bainite boundaries.

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