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Intercritical annealing with isothermal holding of TRIP CMnAlSi steel

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ABSTRACT

Purpose: The purpose was to obtain the TRIP microstructure in the modern CMnAlSi steel, after cooling from the temperature 850°C. Samples were continuously cooled with the rate 20°C/s to the R.T or isothermally annealed in the bainitic transformation range during 600s at 500, 450 and 400°C. The influence of cooling type on microstructure and amount of retained austenite were investigated.

Design/methodology/approach: Dilatometric experiments of the CMnAlSi steel were done. Microstructures were investigated by light optical microscopy OM and scanning electron microscopy SEM. The amounts of retained austenite were investigated with X-ray diffraction technique and LePera color etching method. Quantitative analyses of phases were done using Image pro Plus program. Vickers hardness HV10 measurements were done.

Findings: The TRIP type microstructure can be obtained for the investigated steel through continuous cooling from 850°C/60s or after cooling with the isothermal holding at the bainitic transformation temperatures range. The highest amount of austenite (~12%) was observed in samples isothermally annealed at the temperatures 450/600s and 400°C/600s.

Practical implications: Steel CMnAlSi is well suited for production of TRIP grade in a large range of isothermal holding temperatures from 500°C to 400°C and also after continuous cooling with the rate 20°C/s to the R.T. The amount of 39 % austenite at temperature 850°C allows for production of TRIP microstructure with stable retained austenite.

Originality/value: The additions of Al and/or Si to the CMn steels have the influence on Ac_1 and Ac_3 temperatures, morphology of bainite and on stability of retained austenite in the TRIP steels. Therefore it is important to determine the heat treatment parameters for each grade of TRIP steels to obtain optimal microstructure with good mechanical properties for such applications as car bodies and car parts.

Keywords: Heat treatment; Isothermal holding; TRIP steel; Retained austenite

1. Introduction

In recent years, there has been a growing interest in the automotive industry in the application of high-strength TRIP steels consisting of ferrite, bainite and retained austenite for use in car structural parts [1-4]. In high strength TRIP steels precipitation of cementite during bainitic transformation can be suppressed by alloying the steel with about 1% of Al or/and 1% of Si, which have very low solubility in cementite and greatly retards its growth from austenite. The carbon, that is rejected from the bainitic ferrite, enriches the residual austenite, thereby stabilizing it down to ambient temperature. The resulting microstructure consists of ferrite matrix with fine plates of bainitic ferrite and carbon-rich retained austenite [5,6]. This steel has a high resistance to cleavage fracture due to absence of fine carbides and the high strength and toughness, good ductility because of the transformation induced plasticity effect (TRIP) [7,8].

The heat treatment at the ($\alpha+\gamma$) temperature range near the Ac_1 temperature, and also the addition of Al and/or Si cause the refinement of the ferrite and bainite grains [9-12] which also have the strong influence on mechanical properties. It is very important to determine the optimal parameters of the heat treatment of the

TRIP type steel, because overheating during annealing may cause the grain coarsening. Too low temperature and time of austenitization at the (α+γ) temperature range may left the carbides in the structure [12]. Also the cooling rate has the strong effect on TRIP microstructure. From the previous works [12,13] it is known, that the investigated steel should be cooled faster than 10^{o}C/s in the pearlite temperature range (700-650^{o}C) to avoid the pearlite transformation. Isothermal holding at the bainitic region allows for stabilization of carbon-rich retained austenite in the microstructure [14]. In the present work the influence of various types of cooling from the 850^{o}C/60s partial annealing temperature were investigated in order to determine the optimal parameters of heat treatment to obtain TRIP microstructure.

2. Material and Experimental Procedure

The chemical composition of the investigated CMnAlSi steel used for the work is shown in table 1.

Table 1.
Chemical composition of the investigated CMnAlSi steel

Steel	C	Mn	Al	Si	P	N
CMnAlSi	0.150	1.550	1.090	1.010	0.013	0,003

The steel for the investigations was cold rolled with 75% reduction of section. The microstructure consisted of strongly deformed pearlite colonies and elongated ferrite grains. The amount of ferrite was 78% [12]. The microstructure of the cold-rolled sample is shown in figure 1.

The steel sheets were machined to dilatometric samples i.e. rectangular specimens of 10mm length, 5 mm width and 1 mm of thickness. The 805DIL dilatometer with inductive heating was used to measure the thermal expansion. Samples were heated with the rate 20^{o}C/s to the austenitization temperature 850^{o}C/60s and then cooled with the rate 20^{o}C/s to the bainite transformation temperature range (500 ^{o}C, 450 ^{o}C and 400^{o}C, samples no. 1 - 3), isothermally annealed during 600s and then cooled to the R.T. One sample after austenitization at the 850^{o}C/60s was continuously cooled with the rate 20^{o}C/s to the R.T (sample no. 4) in order to determine ranges of ferrite, bainite and martensite transformations during cooling with the rate 20^{o}C/s. The scheme of heat treatments is shown in figure 2.

The volume fractions of retained austenite were quantified using X-ray diffraction method on SEIFERT type XRD 3003 T-T diffractomether from intensity of (011)α, (002)α, (112)α, (111)γ peaks of Cu-Kα radiation ($\lambda Co_{K\alpha}$ – 1,7902 Å).

Microstructures after various heat treatments were observed using light optical microscopy Neophot 32 for the initial examination and identification of the different types of microstructures. Specimens were sectioned parallel and transverse to the rolling direction. Nital etching technique and color etching LePera [15] was used to give satisfactory results for the characterization of the microconstituents. A Philips scanning electron microscopy SEM JEOL JSM-5400 was used for more comprehensive and detailed identification of phases.

The quantitative analyses of the microstructures of the steel were done with the software Image Po Pus 3.0 applied for microstructures observed using light optical (OM) and SEM microscopy. Vickers hardness measurements HV10 were also done.

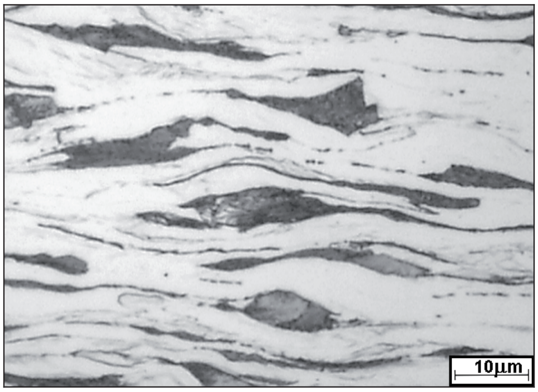

Fig. 1. Band ferrite-pearlite microstructure of the cold-rolled sample in the initial conditions, magn.1000x

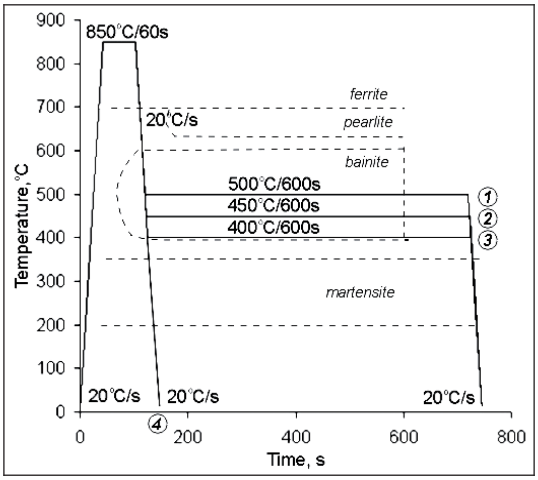

Fig. 2. Heat treatments scheme of investigated CMnAlSi steel

3. Discussion of results

Thermo-calc calculations together with the experimental investigations from the previous works showed, that the Ac_1 and Ac_3 of investigated CMnAlSi steel equaled respectively 724 ^{o}C and 1148^{o}C [12,13] During partial austenitization at the 850^{o}C/60s the polygonal ferritic-austenitic microstructure was obtained with 39% of ferrite and 61% austenite, which transformed into various phases (bainite, martensite) during cooling to the R.T. Some austenite remained in the microstructure as a residual austenite. Cooling with the rate 20^{o}C/s caused no occurrence of pearlite transformation [14].

The investigated heat treatments according to scheme from the figure 2, have led to the obtaining of typical multiphase TRIP type microstructure, with the bainitic ferrite and retained austenite grains in the ferrite matrix. During cooling with the rate 20^{o}C/s no pearlite transformation was observed. After ferritic transformation about 8-

12 % of austenite transformed into carbides-free bainitic ferrite during continuous cooling or isothermal holding at the bainitic transformation region (600°C-400°C). The rest carbon-rich austenite remained in the microstructure as a retained austenite γ_R. The isothermal holding avoided the martensite transformation during cooling and also stabilized the γ_R. Analysis of the dilatometric curves of the investigated samples showed, that the time of isothermal holding may be shorter, because the bainite transformation, which started at about 600°C during continuous cooling, ended after about 450s during isothermal holding at the temperatures from the range 400-500°C. It is shown in Figure 3.

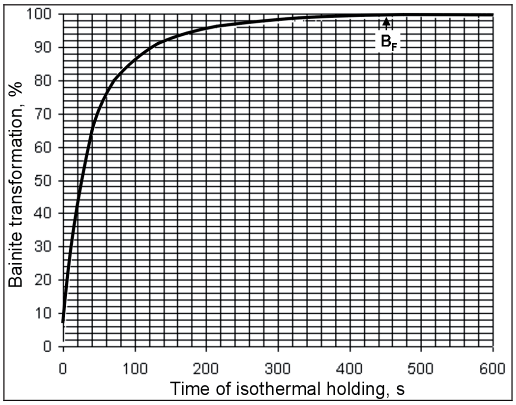

Fig. 3. Kinetics of bainite transformation during isothermal holding 450°C/600s of the sample no 2

The exemplary OM microstructure of the sample isothermally annealed at the temperature 450°C/600s (sample 2) at the magnification 1000x is shown in Figure 4.

The detailed investigations of microstructure were done using SEM. In Figures 5a, 5b the exemplary microstructures after various heat treatments (samples 1,3) are shown.

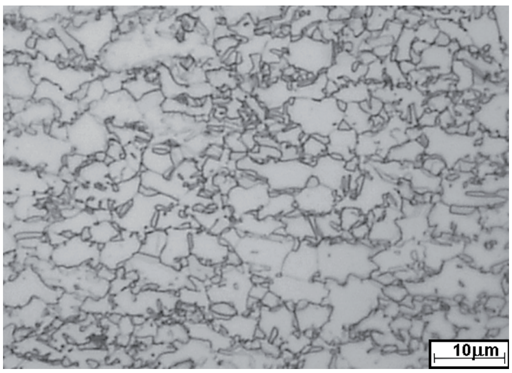

Fig. 4. TRIP type microstructure of the sample 2 austenitized at 850°C/60s, isothermally annealed at the temperature 450°C/600s

The LePera color etching technique was used in order to differentiate the phases in the obtained TRIP microstructures. The exemplary microstructure for the sample no. 1 annealed at 500°C/600s is shown in Figure 6. The bright, non-etched areas show the retained austenite. Bainite is the darkest. Medium grey areas represent the ferrite matrix.

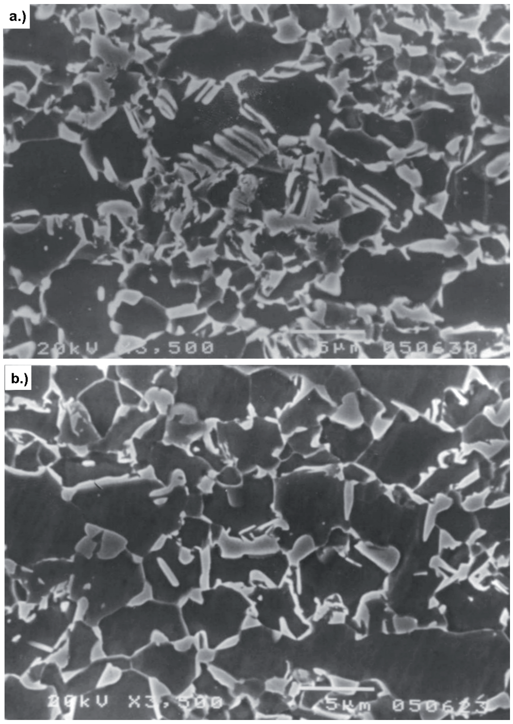

Fig. 5. SEM microstructures of samples after annealing at 850°C/60s and isothermal holding at: a) 500°C/600s – sample 1; b) 400°C/600s – sample 3

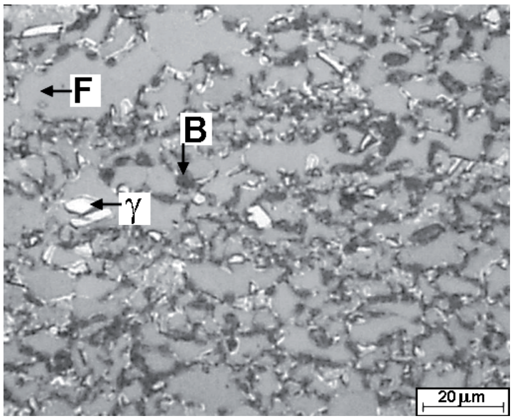

Fig. 6. Color etching of TRIP type microstructure of the sample 1 isothermally annealed at 500°C/600s

The x-ray diffraction analyses of the samples after heat treatments showed the occurrence of the three reflexes of ferrite (0,202nm; 0,143nm; 0,117nm) and one of the austenite (0,207nm). The quantitative analysis of austenite amount in the microstructures using Toray equation [12] showed the occurrence of retained austenite in the amount of 12% in the samples after heat treatments with isothermal holding at 450°C and 400°C during 600s. For this samples the amount of carbon in the retained austenite was 1,088%C. In the sample continuously cooled to the R.T. and in the sample cooled with isothermal holding at 500^{o}C/600s no reflexes of austenite were found due to testing limitation of diffractomether (<10% of austenite).

Using the OM and SEM microphotographs the quantitative analyses of phases were done. The amount of ferrite was about 80% for samples after various heat treatments. The mean chord of ferrite grains of the sample continuously cooled to the R.T. equaled 2,5μm. The mean chord of the samples isothermally annealed at the temperature 400-500^{o}C were in the range 3-3,5μm. The mean size of bainite-retained austenite islands equaled about 1-1,5 μm.

Vickers hardness measurements HV10 of the samples from CMnAlSi steel were examined. Hardness of the cold rolled sample in the initial state (cold rolled F+P) equaled 301 HV10. After the heat treatments (TRIP) it equaled ≈207 HV 10.

4. Summary

During annealing of the investigated cold-rolled CMnAlSi steel at the temperature 850^{o}C, the amount of 61% of ferrite and 39% of austenite is present. Austenite during cooling with the rate 20^{o}C/s partially transforms into ferrite (19% of γ), the rest transforms partially into carbide-free bainitic ferrite, and also some austenite remains in structure as retained austenite. In consequence, the multiphase TRIP type microstructure consisted of 80% of ferrite, ~10% of austenite and ~10% of bainitic ferrite can be obtained. The highest amount of stable residual austenite can be obtained after cooling with the rate 20^{o}C/s to the temperatures 450-400^{o}C (samples 2,3), isothermal annealing at this temperature during 600s and then cooling to the R.T. Continuous cooling without isothermal holding (i.h.) or cooling with i.h. at temperature 500^{o}C causes the origination of retained austenite in the amount below 10%.

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