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Thermal processing of CMnAlSi steel at $(\alpha+\gamma)$ temperature range

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ABSTRACT

Purpose: Investigations of microstructure changes in the modern high-strength CMnAlSi steel after austenitization at $(\alpha+\gamma)$ temperature 900°C/60s were presented in order to determine the influence of the cooling rate on the phase transformations and obtaining multiphase TRIP-aided microstructure. Also the effect of alloying elements on the A_{c1} and A_{c3} temperatures and the volume fractions of austenite in various $(\alpha+\gamma)$ austenitization temperatures for the investigated steel were presented.

Design/methodology/approach: Thermo-calc program was used in order to determine influence of alloying elements such as Al, Si on A_{c1} and A_{c3} temperatures. Dilatometric experiments of the CMnAlSi steel were done for the temperature 900°C from $(\alpha+\gamma)$ temperature range. Microstructures were investigated by light optical microscopy and scanning electron microscopy. The amount of retained austenite in the obtained microstructures was investigated with X-ray diffraction technique. The quantitative analysis of phases in microstructure were done using Image pro Plus computer program. Mechanical properties of investigated steel were examined.

Findings: The multiphase microstructure containing about 10% retained austenite can be obtained in steel of 0.15 % C, 1.55 % Mn, 1% Si and 1% Al through continuous cooling from 900°C/60s to the room temperature without isothermal holding at bainitic transformation temperature range.

Practical implications: Steel CMnAlSi is well suited for production of TRIP grade in a large range of temperatures from 800°C to 900°C at the cooling rates of about 10°C /s to 40°C/s. The amount of 50 % austenite at temperature 900°C allows for production of TRIP microstructure with stable retained austenite.

Originality/value: The TRIP steels can be processed only if annealing parameters are perfectly adjusted to the chemical composition of the steel. The A_{c1}¬ and A_{c3} temperatures differ for the various chemical compositions and they strongly depend on the C, Si and Al contents. It is hard to match the same annealing temperature for every TRIP steel grade. Also the cooing rate has an important role in obtaining the proper multiphase TRIP microstructure with stable retained austenite.

Keywords: Heat treatment; Automotive steel; Quantitative analysis

1. Introduction

Formable high- or ultra high-strength TRIP-aided sheet steels with bainitic ferrite matrix were developed for automotive applications such as center pillar reinforcements, seat frames and so on in order to attain a weight reduction and crash worthiness performance. Transformation-induced plasticity (TRIP) of retained austenite is very useful for improving the formability of these steels. In TRIP metastable austenite is transformed into martensite during deformation processes such as forming and stretching, thus yielding an outstanding uniform elongation and formability at a very high strength level. Bainitic ferrite lath structure is favorable for improving the strech-flangeability of ultra high-strength steels because it has uniform fine microstructure without stress concentration sites [1,2].

In the work a new type of TRIP-aided steel grade with 0.15 wt. % C , 1.55 wt. % Mn, 1.01 wt. % Si, 1.09 wt. % Al was investigated. The steel can be processed to have a triple phase microstructure and pronounced TRIP-aided mechanical properties. As a consequence laboratory testing and industrial trials have focused on optimizing their microstructure and mechanical properties by changing intercritical annealing parameters such as time, temperature and cooling rate. Concerning production of these low alloyed TRIP steels, the most important step is annealing of the as-cold-rolled material. During annealing in the ($\alpha+\gamma$) temperature range, recrystallization, dissolution of cementite and formation of austenite occurs. The dissolution of cementite and the formation of austenite is quite rapid, and the amount of austenite is mainly determined by the annealing temperature. Depending on the annealing temperature, different amounts of ferrite and austenite are adjusted, and carbon concentrates in the austenite. During cooling of the steel the transformation to pearlite should be avoided. Depending on the cooling rate growth of ferrite and enrichment of carbon in remaining austenite occurs. At bainite transformation temperature, in TRIP steels, because of the high Si, Al content, the precipitation of iron carbides is prevented and carbon from the austenite, which transforms into bainitic ferrite, builds up in the remaining austenite. Increasing amount of bainite results in better stabilization of the retained austenite due to mechanical effect from the surroundings of the austenite. [1,3,4].

The chemical composition is also very important in planning of the heat treatment of TRIP steels. In the work the effect of alloying elements such as Si and Al on phase transformations characteristics TRIP steels was shown.

2. Material and experimental procedure

The chemical composition of the TRIP steel used for the present work is listed in table 1.

Table 1.
Chemical composition of the investigated steel

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

The Thermocalc software was used to calculate the Ac_1 and Ac_3 temperature of the investigated steel [5]. This theoretical calculations were verified by experimental investigations using dilatometer sample heated and cooled with the rate 180°C/h. The results for the investigated CMnAlSi TRIP steel are shown in figure 1. In the investigated CMnAlSi steel the Ac_1 and Ac_3 temperatures equals respectively 724°C and 1148°C [5].

The steel in the initial state was hot and cold rolled to thickness 1mm. The steel sheets were then machined to dilatometric samples i.e. rectangular specimens of 10mm length, 5 mm width and 1mm of thickness. The 805DIL dilatometer with inductive heating was used to measure the thermal expansion. Samples were heated with the rate 20°C/s to the austenitization temperature 900°C/60s and cooled with the various cooling rates from 40°C/s to 0.5°C/s to the room temperature. Dilatometric data were used to examine the influence of the cooling rate on the phase transformations after intercritical annealing. The CCT diagram for the austenitization at 900°C/60s has been presented.

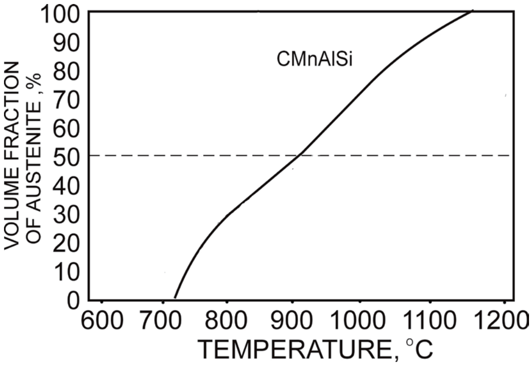

Fig. 1. Volume fraction of austenite as a function of temperature of CMnAlSi steel, equilibrium calculations

The volume fraction of retained austenite was quantified using X-ray diffraction method on Philips diffractomether from integrated intensity of (011)α, (002)α, (112)α, (111)γ peaks of Cu-Kα radiation ($\lambda Co_{K\alpha} - 1,7902$ Å). Recording of data was done with the "step-scanning" method with the step 0.02° with the 4 seconds counting time. The amount of retained austenite in the microstructure were calculated using Toray equation [5].

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 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 microconstituents.

The quantitative analysis of the microstructures of the steel were done with the software Image Po Pus 3.0 applied for microstructures observed using light optical and SEM microscopy.

Tensile tests were carried out on ZWICK Z100 type of testing machine with digital controller using flat specimens of gauge length of 50 mm, gauge width of 15 mm and thickness 1,143 mm. Two types of microstructures were examined: the sample in the initial state after hot and cold rolling, with ferrite- pearlite microstructure and typical TRIP microstructure obtained after austenitization at 900°C and cooling in air.
Vickers hardness measurements HV10 were also done.

3. Discussion of results

Thermo-cal calculations of the Al and Si influence on the Ac_1 and Ac_3 temperatures were done. Results of investigations for CMn steel (0.15 wt.% C and 1.55 wt% Mn) with various contents of Si and/or Al were shown in figures 2 and 3.

It is shown in fig. 2 and 3 that the additions of Al and/or Si haven't got the strong influence on Ac_1 temperature, it varies from 688 °C to 733°C, but with the increasing of Al and/or Si content in the steel the Ac_3 temperature grows strongly. It is not possible to obtain the fully austenitic region for the steel with the addition of Al or Si higher than about 1.5%. Al and Si are the elements strongly stabilizing ferrite.

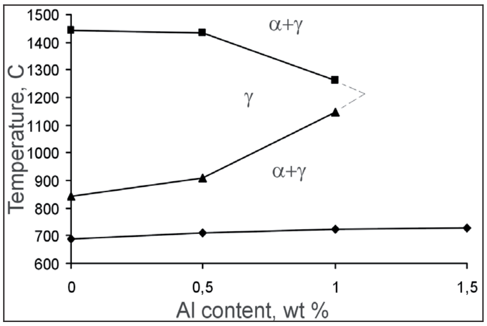

Fig. 2. The influence of the Al content on Ac_1 and Ac_3 temperatures for CMnSi steel (0.15%C, 1.55%Mn, 1.01%Si)

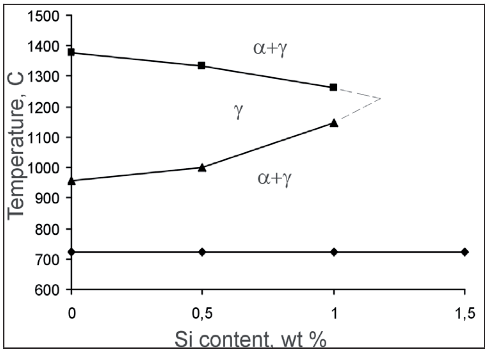

Fig. 3. The influence of the Si content on Ac_1 and Ac_3 temperatures for CMnAl steel (0.15%C,1.55%Mn, 1.09%Al)

In the investigated steel after austenitization at 900°C/60s the amount of about 50% of austenite is obtained. Cementite is completely dissolved. The new austenite saturated with carbon and manganese transforms during cooling to various phases. Dilatometric curves of the samples heat treated at 900°C / 60s were used for creation of CCT diagram of investigated CMnAlSi steel. The diagram is shown in figure 4. On the base of CCT diagrams from 900°C and 800°C [5] can be stated that in order to obtain typical multiphase TRIP microstructure with retained austenite in amount about 10% and bainitic ferrite the cooling rate of about 10-20 °C/s should be applied. For the higher cooling rate the martensite transformation occurred, which lowered the volume fraction of retained austenite in the microstructure. Also the pearlite occurrence is unadvisable. It's transformation is observed after cooling below 10 °C/s.

Typical TRIP microstructure of sample cooled with rate 20°c/s is shown in figure 5.

After cooling with the slowest cooling rate the large clusters of pearlite are observed in the ferrite matrix. At higher cooling rate 3°C/s the smaller amount of pearlite was observed and it coexist with the bainitic ferrite and retained austenite in the microstructure. Typical TRIP microstructure has been obtained after cooling with the rate 20°C/s. In the microstructure, bainitic ferrite and retained austenite coexist with ferrite matrix. Similar microstructure has been obtained after cooling with the rate 40°C/s but the higher amount of bainitic ferrite has been observed together with the small amount of martensite. For the cooling rates of about 80°C/s the ferrite – martensite microstructure were observed.

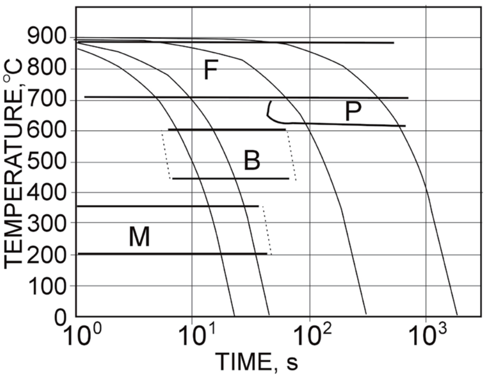

Fig. 4. CCT diagram of investigated CMnAlSi steel after austenitization at 900°C/60s

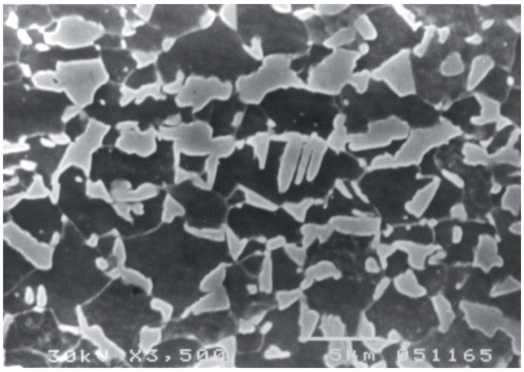

Fig. 5. Typical TRIP microstructure of CMnAlSi austenitized at 900°C/60s cooled with the rate 20°c/s, SEM

The volume fraction of retained austenite was quantified using X-ray diffraction method.The x-ray diffraction analysis of the samples 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 showed the occurrence of retained austenite in the amount of about 10% for the sample cooled with the rate 20°C/s. Samples cooled with higher or lower cooling rates had lower amount of retained austenite (about 2-7%).

The quantitative analyses of the phases received after various thermal experiments were done using Image Pro Plus computer program. Cold rolled initial sample had ferrite-pearlite microstructure. The amount of pearlite was calculated using optical micrographs and it equaled 22%. The refinement of the grain size of ferrite after intercritical annealing hindered the calculation of grain size and volume fraction of phases after experimental heat treatments using light optical microscopy. SEM micrographs were used.

On the base of Thermo-Calc can be stated that in the equilibrium conditions at 900°C there is about 50% of austenite, which transforms into various phases in the dependence of cooling rates. For the cooling rate 0.5°C/s almost whole austenite transforms into new ferrite and pearlite in amount of about 40%. After cooling with the rate 20°C/s austenite transforms into ferrite and bainitic-ferrite and the rest of austenite remain as retained austenite (10%). For the higher cooling rates (80°C/s) austenite transforms mainly to martensite.

After heat treatment at 900°C/60s the high refinement of microstructure was observed. Mean chord of ferrite in the cold-rolled initial sample equaled 15μm. For the heat treated samples can be seen that with the increase of cooling rate from 0.5 °C/s to 40 °C/s the mean chord of ferrite grains decreases from 3,4 μm to 2.3 μm. The mean chords of new phases (P, BF, M) varied from of about 1.5 to 1.8 μm.

Mechanical properties of cold rolled sample and TRIP sample austenitized at 900°C were examined and they are listed in table 2.

Table 2.
Mechanical properties of the cold rolled initial sample and heat treated at 900°C TRIP sample

Sample	$YS_{0,2}$ [MPa]	TS [MPa]	A_g [%]	A [%]
Cold rolled	1002.77	1066.55	1.09	3.71
TRIP	304	806.53	15.93	21.05

Vickers hardness measurements HV10 of the samples from CMnAlSi steel were examined. Hardness of the cold rolled sample in the initial state equaled 301 HV10. Increasing of cooling rate from 0.5 to 40 °C/s causes increasing of Vickers hardness from 176 to 228 HV 10, what is caused by ferrite grain size refinement from 3,4 μm to 2.3μm and hard bainite-martensite phases occurrence in the microstructure.

4. Conclusions

During continuous annealing of the CMnAlSi steel at the 900°C temperature two metallurgical mechanisms took place: recrystallization of the work hardened ferrite and partial austenitization during the holding at intercritical temperature. After austenitization whole cementite dissolves and about 50% of new austenite is obtained.

Continuous cooling with the rate 20°C/s to R.T. allows for obtaining TRIP-aided microstructure consisting ferrite matrix with fine dispersed bainitic-ferrite and retained austenite. For lower cooling rate 0.5 and 3°C/s austenite transform to pearlite. Cooling with the 40°C/s and faster induces martensite transformation.

Increasing of cooling rate from 0.5 to 40 °C/s causes increasing of Vickers hardness from 176 to 228 HV 10, what is caused by ferrite grain size refinement from 3,4 μm to 2.3μm and hard bainite - martensite phases occurrence in the microstructure.

YS and TS of CMnAlSi steel in the cold rolled initial state equaled respectively 1003 and 1067 MPa, for TRIP type sample annealed at 900°C and cooled on air, YS and TS respectively equaled 304 MPa and 807 MPa. The total elongation of the sample after heat treatment increased from 3.7 % to 21 % in comparison with the cold rolled sample.

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References

[1] K.Sugimoto, T. Muramatsu, T. Hojo, S. Hashimoto, Y. Mukai, Ultra High-Strength C-Si-Mn-Nb-Mo TRIP-Aided Sheet Steels,materials Science & Technology (2005) 15-24.

[2] J.E. Garcia-Gonzalez, C.I. Garcia, M. Hua, A.J. DeArdo, Fundamental study of the austenite formation and decomposition in high strength low-Si, Al aided Nb-Mo TRIP steels, Materials Science & Technology , 2005,p.3-14.

[3] J. Mahieu, D van Dooren, L. Barbe, B.C. De Cooman, Influence of Al, Si and P on the kinetics of intercritical annealing of TRIP-aided steels: thermodynamical prediction and experimental verification, Steel Research 73 (2002) No.6+7, p.267-273.

[4] A. Pichler, S. Traint, G. Arnolder, P. Stiaszny, M. Blamschein, High strength hot-dip galvanized steel grades: A critical comparison of alloy design, line configuration and properties, I&SM, 2003, p.21-31.

[5] A.K. Lis, B. Gajda, A.J. De Ardo, New Steel Chemistry Design for TRIP and Dual-Phase Structures, Developments in Sheet Products for Automotive Applications, Materials Science & Technology, 2005, p.47-52.