HEAT TREATMENT WITH BAINITIC HOLD OF CMnSiAl STEEL

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Abstract

TRIP (transformation induced plasticity) steel are modern structural materials which are currently mainly used in an automotive industry. The processing of these steels utilize an effect of transformation induced plasticity resulting in good mechanical properties - high strength (up to 1200 MPa) and formability (around 35 %). TRIP effect is based on stabilisation of sufficient amount of retained austenite and its transformation into strain induced martensite in consequence of applied plastic deformation at low temperature. The properties of this steel are based on a multiphase microstructure, which consists of ferrite, bainite and retained austenite. In this work, CMnSiAl steel was heat treated using various processing parameters. Three different temperature of austenitization (850 - 900 - 950 °C) were applied and the samples were subsequently cooled by cooling rates in the range of 26 - 32 °C / s to different bainitic hold temperatures ranging 410 - 460 °C. The resulting microstructures were evaluated with use of optical and scanning electron microscopy and volume fraction of retained austenite was determined using X-ray diffraction phase analysis. Mechanical properties of this steel were established by HV10 hardness measurement, which reached the values 260 - 301 HV10.

Keywords: TRIP steel; partial substitution; retained austenite

1. INTRODUCTION

TRIP (transformation induced plasticity) steel has been considered as the most promising structural material in the rank of HSS (high strength steel) since it exhibits the best combination of high strength and high ductility. The microstructure of these steels is made of a complex aggregate of phases and structures that consist, in general, of ferrite, bainite, and retained austenite, but in some cases martensite and carbides may be present. Al, Si, and Mn are typically added to the composition of TRIP steel to obtain the characteristic TRIP microstructure. Their characteristic high strength and ductility are obtained in cold-rolled steels by subjecting them to a specific two-stage heat treatment that consists of an intercritical annealing stage followed by isothermal transformation within the bainitic region. The length of the isothermal treatment in the bainitic region is critical, as a minimum amount of untransformed (retained) austenite is required to achieve the TRIP-effect. Tensile strength between 600 and 800 MPa, together with deformation to fracture above 35 % of TRIP-assisted steels are determined by a combination of a ferrite matrix, for ductility, bainite, for strength, and an appropriate volume fraction of metastable retained austenite that will transform into martensite during deformation enhancing ductility [1-3].

In the recent decade, the greatest technological progress in the automotive industry has been made in the development and production of advanced high-strength steels (AHSS). These have alloyed reducing the weight of the car structure with a simultaneous increase in the passive safety of the vehicles users. Reduction of the car weight is directly connected with the complex replacement of mild steels by AHSS and with using modern methods of forming sheets combined with highly efficient processes of joining them. AHSS include multiphase microstructure steels such as Dual Phase (DP), Complex Phase (CP), and Transformation-Induced Plasticity (TRIP). The high strength and plasticity of AHSS can be ascribed to their multiphase microstructure and high capability of work hardening during forming [4].

The increased demand worldwide for high strength steels for automotive applications is driven by the high oil prices, new emissions compliance regimes, and higher safety requirements. The higher strength product could offer equivalent strength at proportionally reduced thickness, and therefore reduced weight. Transformation induced plasticity (TRIP) steel is a possible candidate for automotive applications, as they demonstrate a high ultimate tensile strength (~900 to 1100 MPa) without sacrificing ductility (30 to 40 %). There are two processing routes for TRIP steels: one involves cold rolling and intercritical annealing (IA), whereas the other is controlled by thermomechanical processing (TMP). The substitution of Si by Al is driven by the need for automotive sheet galvanizing, as high Si content degrades the adhesion of Zn by formation of a thin surface oxide layer. Mo increases the hardenability of steel and also assists its galvanizing. Micro-alloying additions of carbide or carbo-nitride forming elements, such as Nb or Ti, are used for refinement of the microstructure and further strength increases. Simultaneous additions of Nb and Mo lead to even further strength increases due to NbMoC precipitation hardening [5].

2. EXPERIMENTAL DETAILS

In this work was chosen low-carbon steel micro-alloyed with niobium: 0.2 % C - 1.8 % Si - 1.5 % Mn - 0.06 % Nb (**Table 1**). The heat treatment was carried out in a laboratory furnace on six experimental bars of about 60 mm in length and 25 mm in diameter (**Figure 1**). Thermocouples were placed in each experimental samples to monitor the temperature flow in the central part. On experimental bars were tested three modes with different austenitization temperatures of 850, 900, 950 ºC. The hold at austenitization temperature was in all experimental cases 20 minutes. The cooling was carried out in all experimental samples in salt bath at a temperature of about 400 ºC. When the temperature of the samples reached 425 ºC, they were placed for 20 minutes in a laboratory furnace heated at 425 ºC. The cooling rates for individual austenitization temperatures (850, 900, 950 ºC) were determined to be about 26-32 ºC / s. These values of cooling rates were determined from temperature curves recorded by attached thermocouples, showing slight increase of cooling rate with increasing heating temperature. Final cooling was done for all experimental samples in the air.

Figure 1 The experimental bars

Thermal parameters of used treatment were design with respect to the results obtained at similar CMnSiNb steel without aluminum [6, 7].

Microstructural analysis was performed with the use of light and scanning electron microscopy. Transverse cross sections were prepared from all experimental bars in a standard way (cutting, mounting, grinding and polishing) and all samples were etched in 3 % Nital. The retained austenite volume was determined for the microstructures with potential for utilization of TRIP effect using X-ray diffraction phase analysis. The mechanical properties were determined by HV10 hardness measurement.

Table 1 Chemical composition of experimental steel (wt. %)

C	Mn	Si	P	S	Cr	Ni	Cu	Al	Nb
0.2	1.5	1.8	0.008	0.005	0.008	0.072	0.058	0.006	0.06

3. RESULTS

Ferritic-bainitic resulting microstructure with 15 % retained austenite was found in all experimental samples cooled in salt bath. Observed bainite was of a special type typical for TRIP steels, consisting mainly of the laths of bainitic ferrite and retained austenite (**Figure 2 - 5**). Pearlite was not observed in any sample however aluminum nitrides were detected in the microstructure of each sample. Their identification was confirmed by EDX microanalysis by scanning electron microscopy (**Figure 6**).

The resulting microstructure with the lowest austenitization temperature 850 ºC was relatively coarse with a small amount of free ferrite placed mainly at prior austenite boundaries. Bainite was above all of a lath type and the islands of the M-A component reached the size about 2 micrometers (**Figure 3**). The austenitization temperatures 900, 950 ºC lead to a more homogeneous bainitic microstructures. The bainite still had lath morphology, however the amount of bainitic ferrite was gradually decreasing with increasing heating temperature and the laths were getting coarser (**Figures 4, 5**). The amount of free polygonal ferrite decreased with growing heating temperature. The coarsest and most homogeneous microstructure was achieved after the heat treatment with the highest heating temperature of 950 °C. The bainitic blocks were distributed equally in the microstructure and the amount of polygonal ferrite in the final microstructure was negligible (**Figure 5**).

Mechanical properties of this steel were established by HV10 hardness measurement. Experimental samples with austenitization temperatures of 850, 900 ºC possessed very similar hardness, 268 and 269 HV10 respectively. The hardness increased in the samples with austenitization temperature of 950 ºC to 292 HV10.

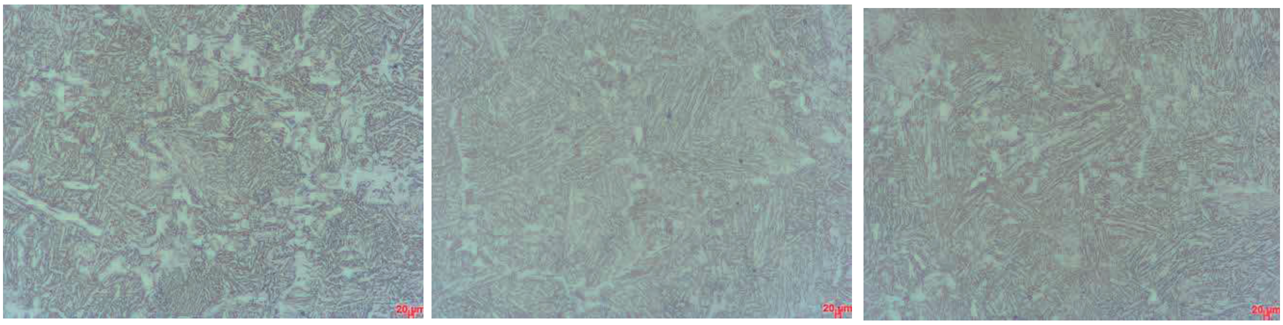

Figure 2 20 min. - salt bath - 425 °C/20 min. Austenitization temperature from the left side: 850 °C, 900 °C, 950 °C

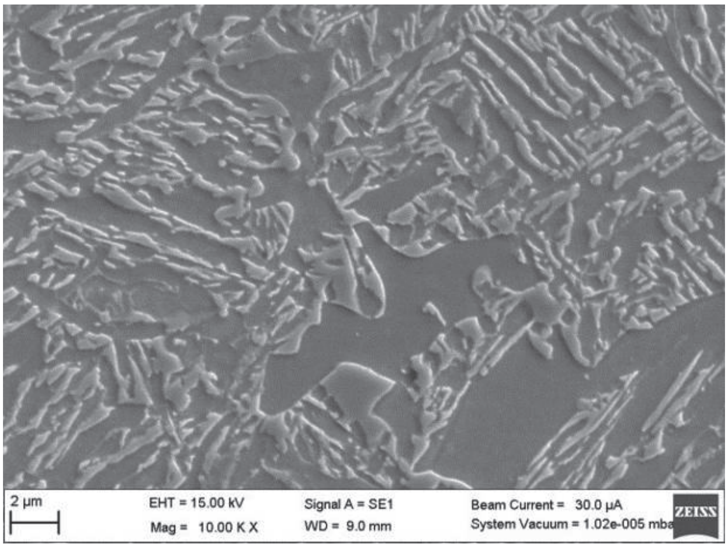

Figure 3 850 °C / 20 min. - salt bath - 425 °C / 20 min. by SEM

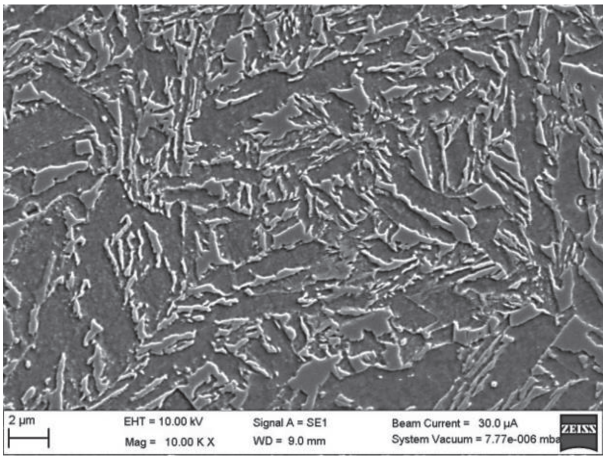

Figure 4 900 °C / 20 min. - salt bath - 425 °C / 20 min. by SEM

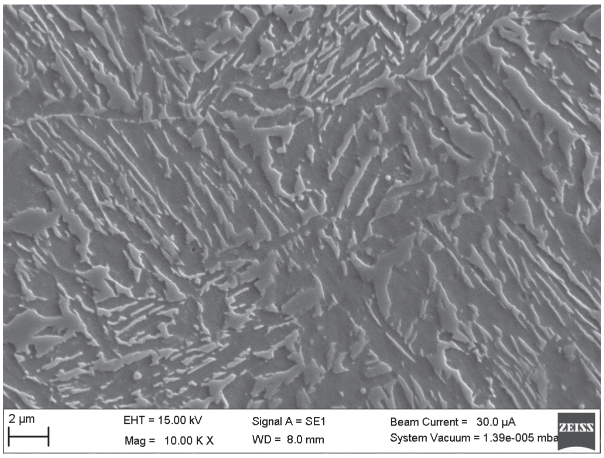

Figure 5 950 °C / 20 min. - salt bath - 425 °C / 20 min. by SEM

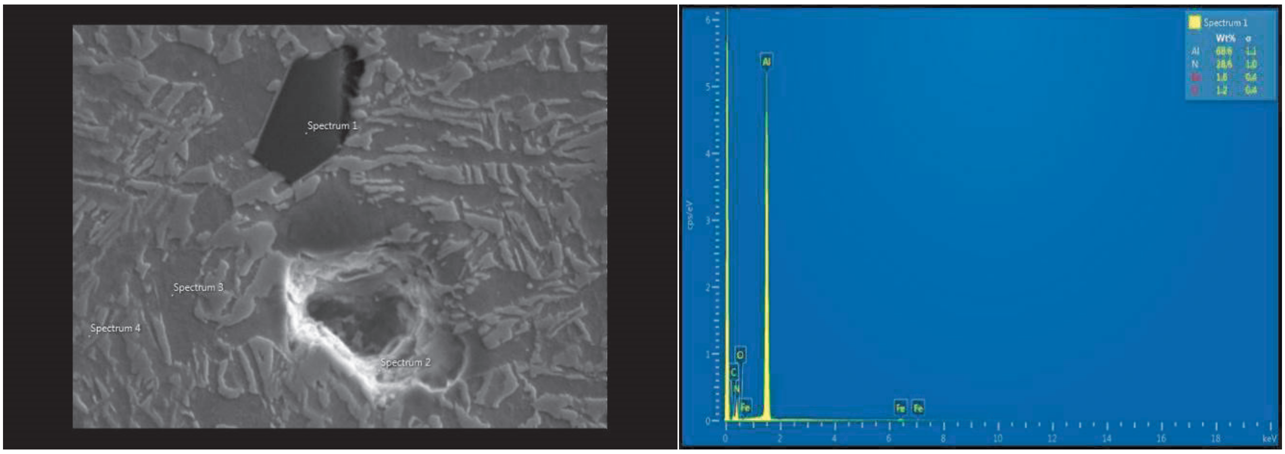

Figure 6 EDX microanalysis by SEM and proof of presence of aluminum nitride

4. CONCLUSIONS

The heat treatment was carried out in laboratory furnace on CMnSiAl low alloy steel. Three different austenitization temperatures of 850, 900, 950 °C were used and each experimental sample was subsequently cooled in a salt bath with a temperature of about 400 °C.

The resulting microstructures of experimental samples heated to austenitization temperature of 850 ºC were bainitic-ferritic, while for the samples with austenitization temperatures of 900, 950 ºC the microstructures turned to predominantly bainitic with decreasing amount of ferrite. All achieved microstructures had potential for utilization of the TRIP effect as they contained all microstructures ferrite, bainite and 15 % of retained austenite, eventually M-A component. Growing heating temperature resulted in more homogeneous microstructures with less polygonal ferrite, smaller amount of bainitic ferrite and longer bainitic laths. The decreasing total amount of ferrite in the sample with the highest heating temperature of 950 °C was accompanied by increase of hardness by 292 HV10 to 300 HV10.

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REFERENCES

[1] LI, L., GAO, Y., ZHU, N Q., et al. Technology for high performance TRIP steel. Science China Technological Sciences, 2012, vol. 55, Is. 7, pp. 1823-1826.

[2] OH, J., CHO, L., KIM, M., KANG, K., DE COOMAN, B.C. The Effect of Bi on the Selective Oxide Formation on CMNSi TRIP Steel. Metallurgical and Materials Transactions A, 2016, vol. 47, Is. 11, pp. 5474-5486.

[3] MONSALVE, A., GUZMÁN, A., DE BARBIERI, F. et al. Mechanical and Microstructural Characterization of an Aluminum Bearing Trip Steel. Metallurgical and Materials Transactions A, 2016, vol. 47, Is. 6, pp. 3088-3094.

[4] GRAJCAR, A., RÓZAŃSKI, M., STANO, S., KOWALSKI, A. Microstructure Characterization of Laser-Welded Nb-Microalloyed Silicon-Aluminium TRIP Steel. Journal of Materials Engineering and Performance, 2014, vol. 23, Is. 9, pp. 3400-3406.

[5] TIMOKHINA, I.B., ENOMOTO, M., MILLER, M.K., PERELOMA, E.V. Microstructure-Property Relationship in the Thermomechanically Processed C-Mn-Si-Nb-Al-(Mo) Transformation-Induced Plasticity Steels Before and After Prestraining and Bake Hardening Treatment. Metallurgical and Materials Transactions A, 2012, vol. 43, Is. 7, pp. 2473-2483.

[6] JIRKOVÁ, H., KUČEROVÁ, L., PRŮCHA, V., MAŠEK, B. Effect of Advanced Thermomechanial Treatment on mechanical properties of low alloyed high strength steels. In METAL 2012: 21st International Conference on metallurgy and materials. Ostrava: TANGER, 2012, pp. 532-538.

[7] JIRKOVÁ, H., KUČEROVÁ, L., MAŠEK, B., MEYER, L.W. Refinement of TRIP steel microstructure by incremental deformation. In Annals of DAAAM for 2011 & Proceedings of the 22nd international DAAAM symposium. Vienna: DAAAM International Vienna, 2011, pp. 25-26.