LONG TERM BAINITE ANNEALING

Dagmar BUBLÍKOVÁ, Ludmila KUČEROVÁ, Hana JIRKOVÁ, Bohuslav MAŠEK

University of West Bohemia, FORTECH - Research Centre of Forming Technology, Pilsen, Czech Republic, EU

Abstract

Several innovative methods of heat and thermo-mechanical treatment have been recently developed to improve mechanical properties of high strength low alloyed steels. On the base of the experience obtained during the development of TRIP (transformation induced plasticity) steels, other methods have been proposed which also use positive effect of multiphase microstructure with controlled amount of retained austenite to achieve excellent strength to ductility ratios. Long term bainite annealing belongs among these methods which stabilize retained austenite in the final microstructure. Low alloyed CMnSi steel with 0.2 % C, 1.8 % Si a 1.5 % Mn was used for experimental program.

Four different processing routes were used in experimental heat treatment of this steel. All of them had the same heating temperature of 1000°C with 25 min hold at this temperature. Three different cooling rates were applied in subsequent cooling to either 150°C or 300°C. The cooling rates corresponded to cooling in water, air and in the furnace. When the desired temperature was reached, long term bainite annealing at this temperature was carried out, lasting either 12 or 24 hours. The choice of these very long annealing times at relatively low temperatures should enable the formation of ultra-fine bainite. Slow grow of bainite units should also influence homogeneity of carbon distribution within bainite laths.

The resulting microstructures were analysed by laser scanning confocal microscopy and scanning electron microscopy. Mechanical properties were established by tensile tests. The above mentioned heat treatments resulted in the final microstructures consisting of various mixtures of free ferrite, pearlite, bainite and small amounts of martensite and retained austenite. The strength of these microstructures was in the region of 630 - 1216 MPa and ductility reached 19-44 %. The highest strength of 1216 MPa with ductility of 14 % was obtained after water cooling and 24 hours annealing at 150 °C. On the other hand, the lowest strength of 630MPa with the highest ductility of 44 % was reached after furnace cooling and subsequent 12 hour annealing at 300 °C.

Keywords: long term bainite annealing, CMnSi steel, heat treatment, AHSS

1. INTRODUCTION

Low temperature long time bainite annealing belongs among advanced methods of heat treatment of high strength steels, which use retained austenite for improvement of mechanical properties. It is possible to reach tensile strength around 2500MPa with hardness of 600-670 HV10 after this processing [1]. Very long hold of the order of several tens of hours is typical for long term bainite annealing and it is carried out at relatively low temperatures. Microstructure after this processing consists of very fine bainitic ferrite units which are surrounded by thin films of retained austenite [2]. The mixture of ferrite, bainite and retained austenite is also achieved by intercritical annealing. Intercritical annealing is typical processing of TRIP (transformation induced plasticity) steels [3]. To further increase tensile strength, another processing was developed, which uses the combination of retained austenite with martensite rather than bainite. This processing is called Q-P (quenching and partitioning) [4-6]. Microstructure of bainitic ferrite with retained austenite after 15 days hold at 125 °C is presented in **Fig. 1** [7].

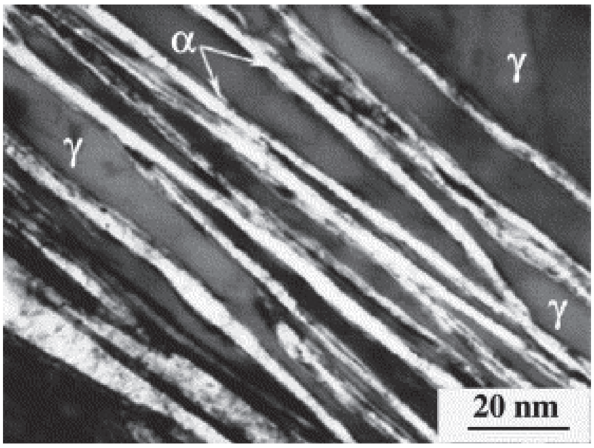

Fig. 1 Microstructure of bainitic ferrite with retained austenite after 15 days hold at 125 °C [7]

2. EXPERIMENTAL PROGRAM

CMnSi steel with 0.2 % C, 1.8 % Si a 1.5 % Mn (**Table 1**) was chosen for experimental program. The chemical composition is typical for TRIP steels, where carbon, manganese and silicon are used to stabilize retained austenite and increase solid solution strengthening. Silicon is a very important alloying element because it does not dissolve in cementite and thus hinders or at least postpones carbides precipitation during baintie formation, which enables diffusion of higher carbon content into retained austenite.

The marteniste start temperature M_s = 370 °C and marteniste finish temperature M_f = 257 ^{0}C were calculated in JMatPro software. The initial microstructure was a ferritic-pearlitic one with hardness 193 HV10. Tensile strength was 623 MPa and ductility 42 %.

Table 1 Chemical composition of experimental steel [weight.%]

	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Nb	Mo	M_s [°C]	M_f [°C]
TRIP CMnSi	0.21	1.449	1.797	0.008	0.005	0.008	0.072	0.058	0.006	0.059	0.02	370	257

2.1 Long term low temperature bainite annealing

Heat treatment was carried out in the furnace. The processing consisted of heating at austenitization temperature of 1000 °C with 25 minute hold. The cooling was performed at the temperature of either 300 °C or 150 °C, where the holds of 12 or 24 hours were applied. The steel was free cooled by the air after the hold. Cooling at 300 °C was carried out in three different mediums with different cooling intensity (air, water, furnace). Cooling at 150 °C was done only in water. Cooling rate was 1.1 °C/s in the case of air cooling, 25°C/s in water and 0.6 °C/s in furnace. The temperature was measured by thermo-couple which was drilled 10mm under the surface of the samples. Obtained microstructures were evaluated with light microscopy, laser scanning confocal microscopy and scanning electron microscopy. Mechanical properties were determined by hardness measurement and tensile strength tests of mini-samples

Table 2 Process parameters for long time bainite annealing of CMnSi steel

Heat+ dwell/		**Cooling**		**Dwell in furnace**	**$YS_{p0,2}$ [MPa]**	**TS_m [MPa]**	**El_{5mm} [%]**	**HV10 [-]**
1000°C	25 min.	300°C	air	12 h.	423	640	41	190
			water		961	1158	19	346
			furnace		395	630	44	186
1000°C	25 min.	300°C	air	24 h.	400	639	42	186
			water		957	1185	19	336
			furnace		415	642	42	185
1000°C	25 min.	150°C	water	12 h.	-	-	-	415
1000°C	25 min.	150°C	water	24 h.	963	1216	14	339

3. DISCUSSION OF RESULTS

3.1 Hold temperature 300 °C

Cooling to the temperature of 300 °C was tested in the first part of experimental program. Lower cooling rates obtained by air cooling or cooling in the furnace resulted in ferritic-pearlitic (**Fig. 3, Fig. 5**). Prolongation of the hold from 12 to 24 hours did not influence the final microstructure. Hardness values were in the interval of 185-190 HV10 (**Table 2**).

Increase in the cooling rate achieved by water cooling from austenization temperature to the hold temperature however resulted in a significant change in the final microstructure. It was composed of tempered martensite, which in some areas corresponds more to bainitic ferrite with low fraction of free ferrite placed at original austenite grain boundaries (**Fig. 2**, **Fig. 4.**). Due to the marteniste in the final microstructure, the hardness of the steel increased to 346 HV 10 after 12 hours hold. Longer hold did not cause more intensive tempering of martensitic microstructure and hardness values was decreased only by 10 points to 336 HV 10 (**Fig. 6**). Microhardness measurement proved that there are areas with very different hardness in the microstructure (**Fig. 7**).

The difference in the microstructures was also reflected in mechanical properties. In the case of free cooling in the air or in the furnace, the strength in the region of 630-642 MPa with ductility of A_{5mm} = 41-44 % (**Table 2**) was obtained. The effect of the length of the hold was not observed. Water quenched steel achieved nearly twice the strength of the slowly cooled steels, reaching 1158 MPa after 12 hours hold and 1185 MPa after 24 hours hold with the identical ductility of 19%.

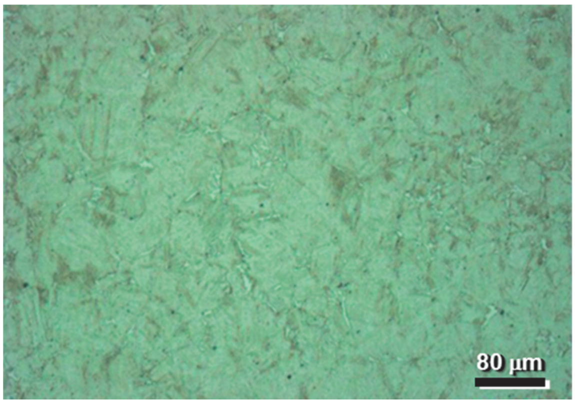

Fig. 2 Temperature dwell 300°C - 12 hours - water, 346 HV10

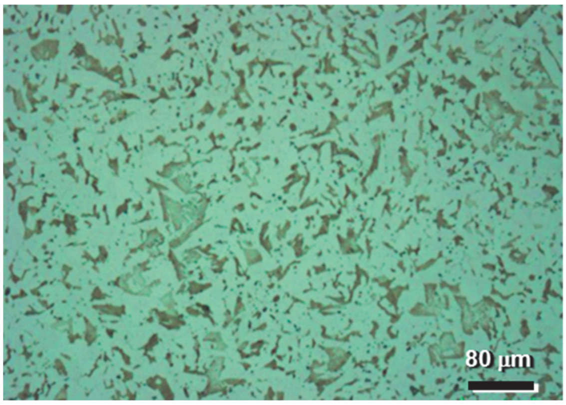

Fig. 3 Temperature dwell 300°C - 12 hours - furnace, 186 HV10

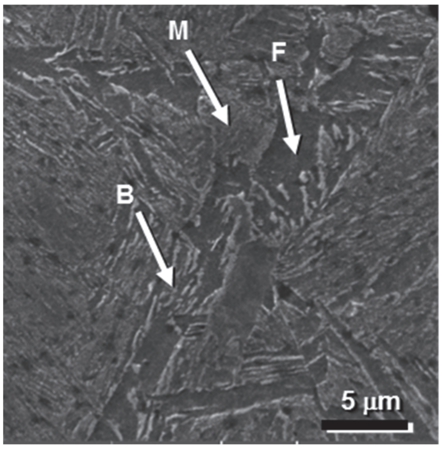

Fig. 4 Dwell temperature 300°C - 12 hours - water, detail SCAN

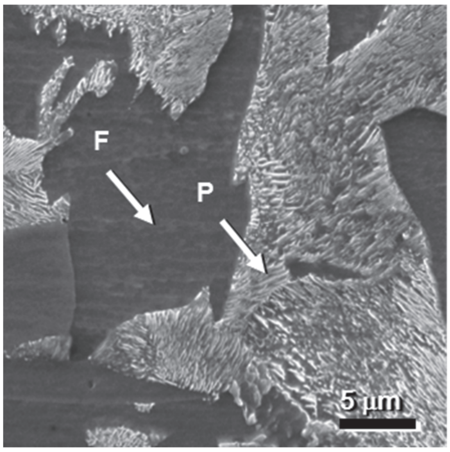

Fig. 5 Dwell temperature 300°C - 12 hours - furnace, detail SCAN

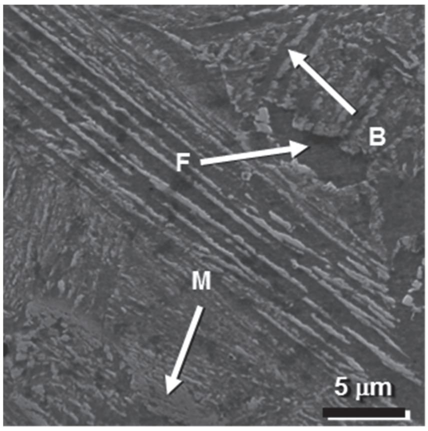

Fig. 6 Dwell temperature 300°C - 24 hours - water, detail SCAN

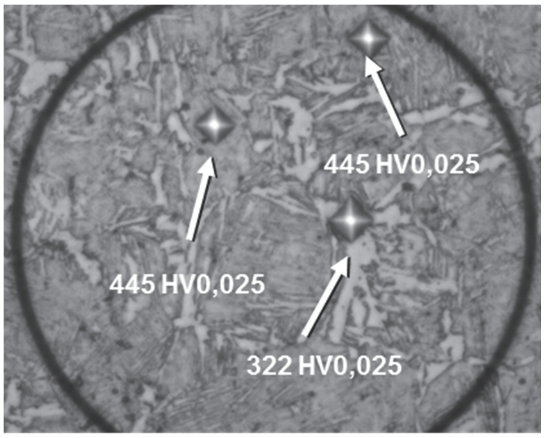

Fig. 7 Dwell temperature 300°C - 24 hours - water, microhardness

3.2 Dwell temperature 150 ^{0}C

With respect to the fact that the best results were obtained after water cooling to 300°C, only this cooling method was used in the second step. Cooling temperature was decreased in this step from the original 300°C to 150°C. The same holds of 12 and 24 hours were also used for this temperature. Complex microstructures of tempered martensite, higher fraction of bainite and low fraction of free ferrite were obtained after both holds (**Fig. 8, Fig. 10**). Prolongation of the hold from 12 to 24 hours resulted in more intensive martensite tempering and decrease in hardness values from 415 to 339 HV10 (**Table 2, Fig. 9, Fig. 11**). The decrease of hold temperature from 300 ^{0}C to 150 °C was reflected also in mechanical properties, where tensile strength increased to 1216 MPa with ductility El_{5mm} 14 % (**Table 2**).

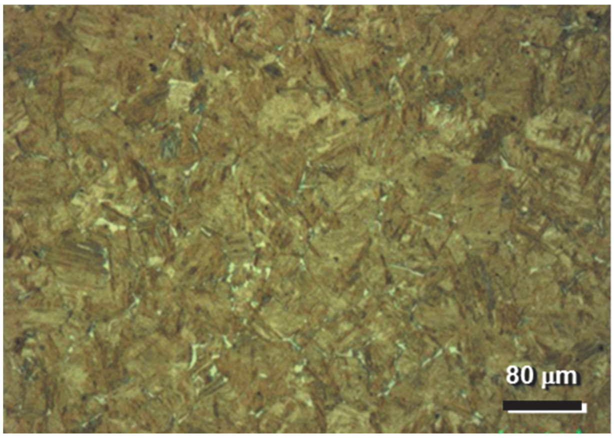

Fig. 8 Dwell temperature 150°C - 12 hours - water,415 HV10

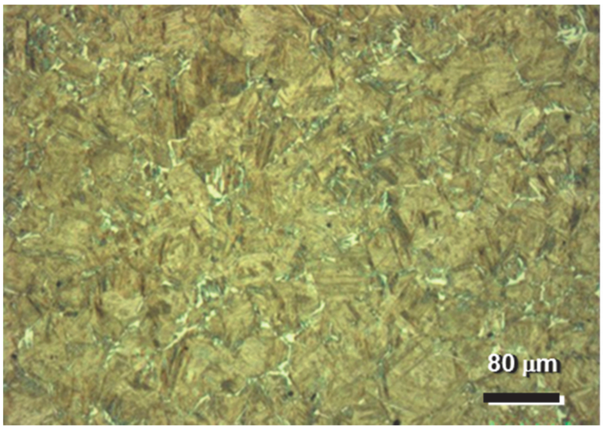

Fig. 9 Dwell temperature 150°C - 24 hours - water,399 HV1

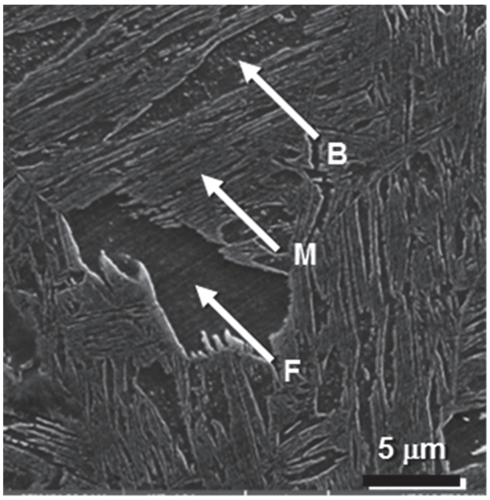

Fig. 10 Dwell temperature 150°C - 12 hours - water,detail SCAN

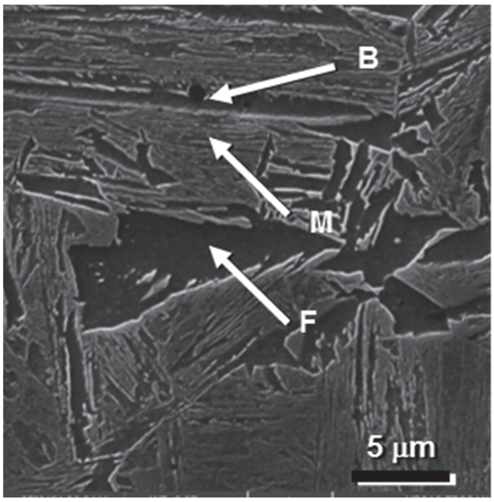

Fig. 11 Dwell temperature 150°C - 24 hours - water, detail SCAN

CONCLUSION

New method of heat treatment for high strength low alloyed steels processing was tested on TRIP type CMnSi steel with typical manganese and silicon alloying. Besides various hold temperatures, various cooling environments were also tested. It was found out that free air cooling and also furnace cooling resulted in purely ferrite-pearlite microstructures. The best results were achieved in the case of water cooling to the hold temperature. The microstructure of tempered martensite was obtained in this way, with bainite and free ferrite fractions. It was also established that lower hold temperature has a positive effect on tensile strength. Lowering of hold temperature from 300 °C to 150 °C caused tensile strength increase from 1158 MPa to 1216 MPa, accompanied by negligible ductility decrease from 19 to 14%.

ACKNOWLEDGEMENTS

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