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Quantitative structural analysis of C-Mn-B steel cooled with different cooling rates

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Abstract: The aim of investigations was to establish a range of the cooling rates for wire rods 5.5 mm in diameter made of C-Mn-B steel after simulation with dilatometry the finishing rolling temperature 1163K and cooling in the air. Dilatometric experiments were done for assumed cooling rates in the range $0.045 \leq V_{8\text{-}5} \leq 12$ K/s. Comparison of the structures was done basing on the qualitative and quantitative metallography. Chords of the flat sections of ferrite and pearlite grains were determined for different microstructures as well as for wire rod structure. Parametric tests of significance; variance ratio test F Snedecora and for consistency of two averages were used. Additionally hardness measurements were done. Homogenous ferrite – pearlite structure of the wire rod and dilatometric samples were achieved for cooling rates $0.833 \leq V_{8\text{-}5} \leq 2.317$ K/s, which corresponded to hardness range $143.3 \leq$ HV10≤ 154.3. Within that range was the average hardness 148.8 HV10 of the wire rod.

Keywords: Cooling rate, Microstructure, Wire rod

1. INTRODUCTION

Steel C-Mn-B is one of the structural grades of common use. It is ferrite-pearlite steel used for cold processing thus type and size of the grain microstructure has an important effect on cold hardening [1]. The mean chord of the flat sections of ferrite and pearlite grains was determined on metallographic samples. Distribution of grain sizes, their average (concentration) and variance (scattering) were established for each dilatometric sample cooled from modeled finish rolling temperature 1163 K.

2. MATERIAL AND EXPERIMENTAL PROCEDURE

Table 1.
Chemical composition of the investigated steel, wt %

STEEL	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Mo	Sn	B
C-Mn-B	0.20	0.89	0.15	0.010	0.024	0.04	0.07	0.15	0.004	0.014	0.012	0.004

Wire rods 5.5 mm in diameter were hot rolling processed from square 105mm continuously cast billets and continuously cooled in the air in the coils. In order to establish range of the cooling rates of the coils, quantitative metallography comparison of microstructures of the wire rods with dilatometric specimens after cooling at chosen cooling rates, which are shown in table 2, were performed. Longitudinal dilatometric specimens of ϕ 3 mm x 30 mm were tested in LSA dilatometer. Metallographic examinations of the specimens were done with NEOPHOT 32 light microscope at magnifications 200x, 500x. Additionally hardness HV10 was measured [2].

3. RESULTS AND DISCUSSION

Continuously Cooling Phase Transformations diagram was established for C-Mn-B steel [3], which is shown, in Figure 1

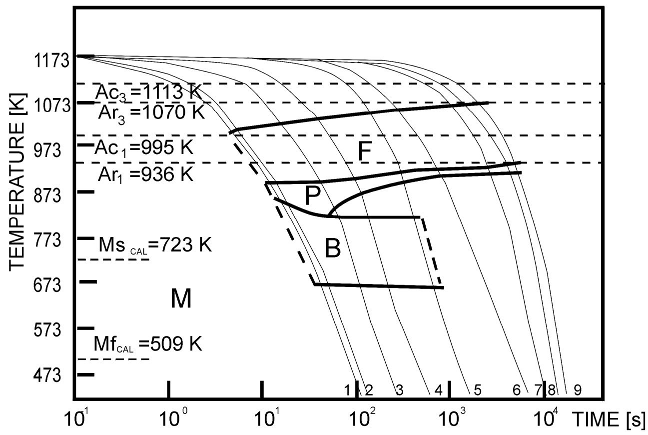

Figure 1. CCT diagram for C-Mn-B steel after austenitizing at 1163 K / 900s

Quantitative metallography of the structures was done at magnification 500x on wire rod ϕ5.5mm and dilatometric specimens with the assumption of necessary measurements [4,5]. The mean chords of the flat sections of the ferrite and pearlite grains were determined and their volume ratio was taken into account. Measurements of hardness HV10 together with classification of the microstructure type for given cooling rate are shown in Table 2.

Table 2.
Effect of cooling rate on the structure, grain refinement and hardness of C-Mn-B steel

Specimen No	**V_{8-5}** [K/s]	**HV10**	**Mean chord** [μm]		**Type of structure**
			ferrite	pearlite	
1	12.018	166.3	5.66	4.93	Ferrite - pearlite Widmanstätten ferrite, bainite
2	11.009	163.0	5.80	5.35	
3	4.444	155.7	6.41	5.70	Ferrite – pearlite, traces of Widmanstätten ferrite and bainite
4	2.317	154.3	7.03	6.32	
5	0.833	143.3	8.13	6.59	
6	0.254	140.3	8.86	7.32	Ferrite - pearlite
7	0.085	137.3	9.30	9.04	
8	0.056	136.3	9.88	9.22	
9	0.045	133.7	9.28	8.90	

From metallographic observations of the wire rod a uniform ferrite-pearlite structure was determined with mean chord for ferrite l_F=7.79μm and pearlite l_p=5.97μm. Widmanstätten ferrite and bainite were observed in the interior of large grains. Mean hardness of the wire rod steel was 148.8 HV10. Using STATISTICA 6.0 PL conditioning of distributions of ferrite and pearlite grain sizes to normal distribution was confirmed. Thus parametric test of significance F Snedecor's was used for checking a hypothesis of analogical spread of measured grain size in both populations. For result data hypothesis H_0: $\sigma_1^2=\sigma_2^2$ against H_1:$\sigma_1^2>\sigma_2^2$ was checked. For values $F<F_\alpha$ there is no basis for rejection of
H_0: $\sigma_1^2=\sigma_2^2$ [6]. Results of calculations are given in Table 3.

Table 3.
Distribution F Snedecor's at significance level α=0.05

V_{8-5} [K/s]	FERRITE			PEARLITE		
	H_0: $\sigma_1^2=\sigma_2^2$ against H_1: $\sigma_1^2>\sigma_2^2$	$F=\frac{\hat{s}_1^2}{\hat{s}_2^2}$	F_α	H_0: $\sigma_1^2=\sigma_2^2$ against H_1: $\sigma_1^2>\sigma_2^2$	$F=\frac{\hat{s}_1^2}{\hat{s}_2^2}$	F_α
4.444	-	-	-	H_0: $\sigma_1^2=\sigma_2^2$	1.22	1.50
2.317*	H_1:$\sigma_1^2>\sigma_2^2$	1.37	1.34	H_0: $\sigma_1^2=\sigma_2^2$	1.28	1.51
0.833	H_0: $\sigma_1^2=\sigma_2^2$	1.04	1.35	H_0: $\sigma_1^2=\sigma_2^2$	1.05	1.51
0.254	H_0: $\sigma_1^2=\sigma_2^2$	1.16	1.35	H_0: $\sigma_1^2=\sigma_2^2$	1.06	1.51

* - given because of $F\approx F_\alpha$

On the basis of two great populations parametric test of the significance of the averages of the mean chord of ferrite and pearlite was applied. The hypothesis H_0: $m_1=m_2$ to alternative H1: $m_1 \neq m_2$ was evaluated using U statistic [6]. Confirmation that $|U|<U_\alpha$ means that there is no reason for rejection hypothesis H_0: $m_1=m_2$. It proves that the mean values of the chords are the same for both populations. Results of calculations, which confirm equality of the average values of grain sizes of ferrite and pearlite for wire rod and dilatometric specimens at given cooling rate, are shown in Table 4.

Table 4.
Parametric test of significance of two mean values at significance level α=0.05

V_{8-5} [K/s]	FERRITE			PEARLITE		
	H_0: $m_1=m_2$ against H_1:$m_1\neq m_2$	$\lvert U\rvert=\frac{\bar{x}_1-\bar{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}}}$	U_α	H_0: $m_1=m_2$ against H_1:$m_1\neq m_2$	$\lvert U\rvert=\frac{\bar{x}_1-\bar{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}}}$	U_α
11.009	-	-	-	H_0: $m_1=m_2$	1.176	1.646
4.444	-	-	-	H_0: $m_1=m_2$	0.479	1.646
2.317	H_0: $m_1=m_2$	1.644	1.646	H_0: $m_1=m_2$	0.651	1.646
0.833	H_0: $m_1=m_2$	0.660	1.646	H_0: $m_1=m_2$	1.082	1.646

The characteristic microstructures of wire rod (Fig. 2a) and dilatometric specimen cooled at 2.317 K/s (Fig. 2b) and 0.833 K/s (Fig. 3c) are shown in Figure 2.

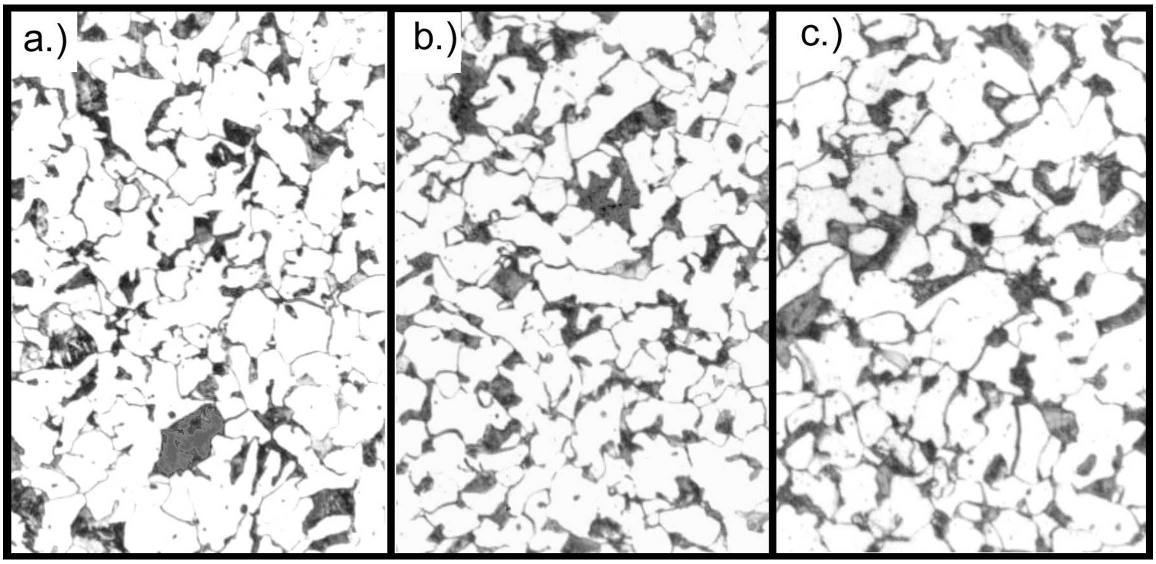

Figure 2. Microstructure of C-Mn-B steel, magn. 500x: a.) wire rod cooled in the air, dilatometric samples: b.) V_{8-5}=2.317 K/s, c.) V_{8-5}=0.833 K/s

4. CONCLUSIONS

1. Ferrite – pearlite microstructure with small amount of Widmanstätten ferrite and bainite was observed at cooling V_{8-5}: 0.833 K/s÷12 K/s in dependence of wire rod place in the coil or along wire length.
2. It was confirmed using F Snedecor parametric tests for mean chord and equality of variances at significance level α=0.05 that the same uniform structure of the wire rod and dilatometric specimens is obtained at cooling rates 0.254 K/s$\leq V_{8-5}$ <2.317 K/s.
3. For cooling rates $0.833 \leq V_{8-5} \leq 2.317$ Ks measured harness HV10 was in the range 143.3 ÷ 154.3 while wire rod hardness was 148.8 HV10.
4. The increase of cooling rate has no influence on furtherer grain refinement of pearlite colonies but causes decrement of ferrite grain size.
5. For faster cooling rates than V_{8-5} >4.44 K/s the amount of Widmanstätten ferrite and bainite increases in the microstructure of C-Mn-B steel, (see CCT diagram).

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