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INFLUENCE OF MICRO-ALLOYING ON THE PHASE TRANSFORMATIONS IN CAST MANGANESE STEELS

VPLIV MIKROLEGIRANJA NA FAZNE PREMENE V LITEM MANGANOVEM JEKLU

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The influence of micro-alloying on the course of phase transformations in cast manganese steel with 0.15 % C and 1.2 % Mn was studied. Vanadium, niobium and titanium were added as micro-alloying additions. Changes in the A_{C1} and A_{C3} temperatures as well as the austenite transformation were recorded using dilatometry. The resulting microstructure and hardness (*HV*30) of samples cooled with various cooling rates and the possibility of a decrease in the critical hardening cooling rate are discussed.

Key words: Cast manganese, steel, microalloying, transformation temperature, cooling rate, microstructure

Raziskan je bil vpliv mikrolegiranja na fazne premene v jeklu z 0,15 % C in 1,2 % Mn ter vanadijem, niobijem in titanom kot mikrolegirnimi elementi. Z dilatometrijo so bile določene temperature A_{C1} in A_{C3} ter premene avstenita. Podana je ocena nastalih mikrostruktur, trdota (*HV* 30) vzorcev, ohlajenih z različno hitrostjo, in možnosti zmanjšanja kritične hitrosti kaljenja.

Ključne besede: lito manganovo jeklo, mikrolegiranje, premenska temperatura, hitrost ohlajanja, mikrostruktura

1 INTRODUCTION

The aim of this investigation was to determine the impact of micro-alloying on the transformation processes in manganese-alloyed steel during the heat treatment after casting. Six aluminium killed heats, a heat of basic material and heats no. 2 to 6 with alloying additions, as listed in **Table 1**, were tested. The specimens were taken from cast plates of size of (250 × 750 × 35) mm.

2 EXPERIMENTAL

The A_{C1} and A_{C3} temperatures were determined by dilatometry during heating at a rate of 2 °C min^{-1} for cylindrical samples of 5 mm diameter and 20 mm length. The austenite transformations were determined with dilatometry as well, for different cooling rates used on prisms with a square section and an 11 mm edge. In the middle of the specimens, the section was machined to a reduced thickness of 2 mm. The effects of the phase transformations were examined in the dilatometric curves. The properties of the material with the resultant microstructures were assessed with hardness measurements and metallographic analyses.

The austenitizing temperatures were determined through the analyses of three random-sampled specimens of the basic heat and one specimen per each micro-alloyed heat. In this way, the impact of the random sampling on the shift of the transformation temperatures as measured by the dilatrometric technique was estimated and the confidence interval was determined for the A_{C1} and A_{C3} temperatures of the basic heat. The transformation temperatures of the micro-alloyed heats may be considered as different if they fall outside the interval that has been set for the basic heat. The procedure for obtaining the A_{C1} and A_{C3} temperatures can be seen in **Figure 1**, while the transformation temperatures in steels of different heats are shown in **Table 2**.

The types of austenite decomposition product depend on the cooling rate and the chemical composition (**Figures 2 and 3**).

Table 1: Chemical composition of the experimental heats in mass fractions (%). Hyphens indicate content of less than 0.01 %.
Tabela 1: Kemična sestava eksperimentalnih talin v masnih deležih. Črtica je označba za vsebnost pod 0,01 %

Heat	C	Mn	Si	P	S	Cu	Ni	V	Ti	Nb	Al	N
1	0.17	1.47	0.39	0.012	0.010	0.15	0.20	-	-	0.01	0.056	0.009
2	0.16	1.54	0.35	0.016	0.015	0.22	0.14	**0.09**	-	-	0.045	0.006
3	0.19	1.40	0.40	0.013	0.010	0.14	0.19	-	-	**0.07**	0.047	0.018
4	0.22	1.39	0.38	0.017	0.017	0.22	0.16	**0.09**	0.01	**0.05**	0.079	0.017
5	0.17	1.43	0.41	0.012	0.010	0.15	0.20	-	**0.03**	0.01	0.064	0.010
6	0.18	1.49	0.36	0.017	0.016	0.24	0.15	**0.09**	**0.03**	-	0.080	0.011

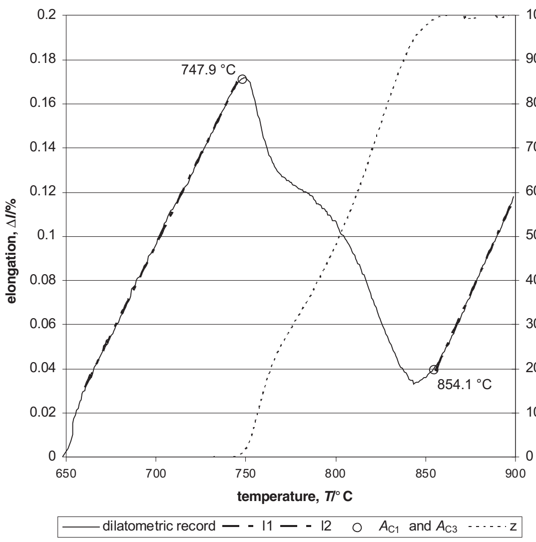

Figure 1: Austenitization of the heat 1 sample at the heating rate of 2 °C min^{-1}. The lines are fitted to the linear sections of the dilatometric curve. The dependence of the specimen elongation on the temperature was assessed as $\Delta l = l_1 \cdot (1-z) + l_2 \cdot z$, (1) where z is the austenitization degree, l_1 is the elongation of the ferrite-pearlite specimen, l_2 denotes the elongation of the austenitized specimen. The A_{C1} and A_{C3} points were selected as the temperatures at which the z parameter reached the values of 1 % and 99 %, respectively.

Slika 1: Avstenitizacija taline 1 s hitrostjo 2 °C min^{-1}. Črti so pripisane linearnim delom dilatometrske krivulje. Privzeta je odvisnost med podaljškom preizkušanca $\Delta l = l_1 \cdot (1-z) + l_2 \cdot z$ (1) in temperaturo: z – stopnja avstenitizacije, l_1 – podaljšek preizkušanca z mikrostrukturo iz ferita in perlita, in l_2 – podaljšek avstenitiziranega preizkušanca. Kot A_{C1} in A_{C3} so privzete temperature, pri katerih je bila vrednost parametra z 1 % in 99 %

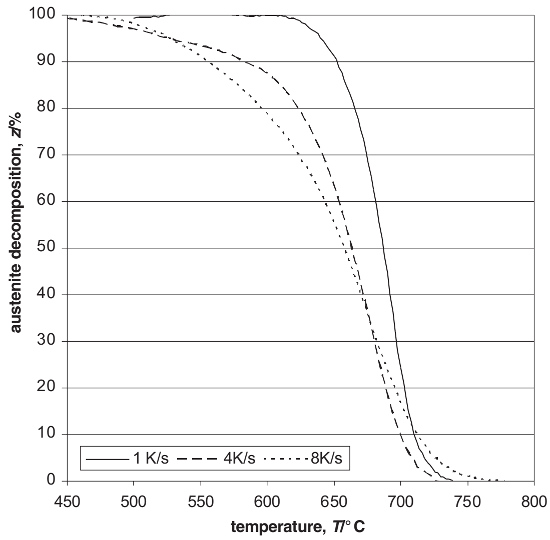

Figure 2: Austenite decomposition during cooling of samples of the basic heat at the rates of 1 K s^{-1}, 4 K s^{-1} and 8 K s^{-1}. According to the break-point positions on curves z, the volume fractions of bainite in the faster-cooled samples seems to be 12 % or 25 % greater than for that cooled by the lowest cooling rate.

Slika 2: Premena avstenita pri ohlajanju osnovne taline s hitrostjo 1 K s^{-1}, 4 K s^{-1} in 8 K s^{-1}. Po položaju prelomnih točk krivulj z je volumenski delež bainita v hitreje ohlajenih vzorcih za 12 % ali 25 % večji kot pri najmanjši hitrosti ohlajanja

3 RESULTS

The dilatometric curves of all the heats are similar at a cooling rate of 1 K s^{-1}. However, the heights of the arcs of the dilatometric curves decrease with increasing cooling rate (see 1 K s^{-1} and 4 K s^{-1} in **Figure 3** left) and with micro-alloying as well (see **Figure 3** right). This corresponds to an increase in the bainite volume fraction at the cost of ferrite volume fraction. The lowest cooling rates sufficient for the formation of the same microstructure as in the sample of heat 1 cooled at 1 K s^{-1} were estimated for all the heats. These cooling rates were supposed to correspond to the critical hardening cooling rates.

The microstructures of the examined specimens showed a pronounced as-cast character with differences in the degree of segregation. In specimens cooled at the slowest cooling rate, the microstructure consisted of ferrite with fine-grained pearlite inside the dendrites and lamellar pearlite in the inter-dendritic spaces. Hardening microstructures were observed in specimens cooled as slowly as 1 °C s^{-1}. In the inter-dendritic spaces of these

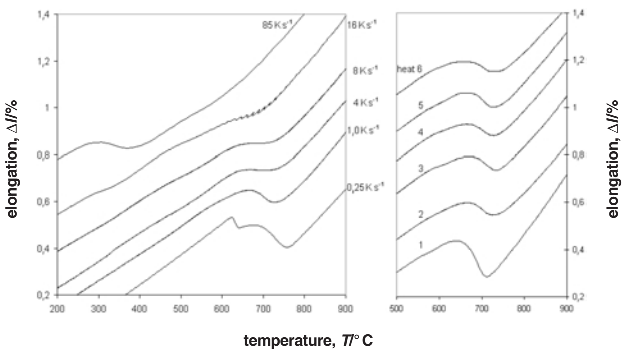

Figure 3: Series of dilatometric curves recorded during cooling – left: heat no. 2 (0.09 % V), various cooling rates; right: heats no. 1 to 6, cooling rate 1 °C s^{-1}

Slika 3: Serija dilatometrskih krivulj pri ohlajanju – levo talina št. 2 (0,09 % V), različne hitrosti ohlajanja; desno taline od 1 do 6, hitrost ohlajanja 1 K/s

Table 2: Comparison between the A_{C1} and A_{C3} temperatures for samples of the basic and micro-alloyed heats. For heat 1 the 95% confidence interval on the mean is given.

Tabela 2: Primerjava med temperaturama A_{C1} in A_{C3} za vzorce primerjalne in mikrolegiranih talin. Za talino 1 je podan tudi razpon 95-odstotne verjetnosti glede na povprečje

Heat	1	2	3	4	5	6
A_{C1}/°C	747.7 ± 1.1	747.2	747.6	751.8	747.8	751.9
A_{C3}/°C	853.3 ± 2.3	855.0	856.0	858.3	856.2	860.7

Table 3: The volume fraction of bainite and the ratios of the critical hardening cooling rates for the micro-alloyed heats and the basic heat estimated according to the heights of the arcs of the dilatometric curves. A cooling rate of 1 K s^{-1} was assessed as critical for the heat 1.

Tabela 3: Volumenski delež bainita in razmerja kritičnih hitrosti ohlajanja za primerjalni in mikrolegirane taline, ocenjene po višini vrhov dilatometrskih zapisov. Hitrost ohlajanja 1 K/s^{-1} je privzeta kot kritična za talino 1

heat number	1			2	3	4	5	6
cooling rate /°C s^{-1}	1	4	8	1	1	1	1	1
bainite φ/%	≈0	12	25	21	18	20	20	22
critical rate ratio	1.00			0.14	0.17	0.15	0.15	0.14

Table 4: Hardness *HV*30 of basic and micro-alloyed samples

Tabela 4: Trdota *HV* 30 za osnovno in mikrolegirane taline

Heat no.	1 K s^{-1}	4 K s^{-1}	8 K s^{-1}	16 K s^{-1}	85 K s^{-1}
1	182	213	247	263	417
2	209	250	247	290	363
3	229	222	234	253	340
4	211	263	299	321	442
5	189	211	240	250	287
6	194	236	264	276	376

specimens fine-grained ferrite and pearlite or bainite and, in some locations, even fine grains of martensite were observed. A further increase in the cooling rate resulted in the formation of bainite and areas of clearly distinguished martensite between the dendrites. At fast cooling rates, bainite formed inside the dendrites and the martensite in the inter-dendritic spaces.

Heat treatment led to a refinement of the microstructure but failed to remove the as-cast microstructure. The volume fractions of the phases in different locations depend not only on the cooling rate but also on the sampling location in taking the specimen or a micrograph.

The hardness of all the micro-alloyed samples cooled at a rate of 1 K s^{-1} was higher than the hardness of the sample of basic heat (**Table 4**). However, the correlation between micro-alloying and an increase of the hardness was not verified for faster cooling rates. Although accelerated cooling results in a larger volume fraction of hardening microstructure, their morphology is very important for the hardness of the steel.

4 CONCLUSION

The shift of A_{C1} and A_{C3} temperatures was examined with dilatometry at low heating rates approaching equilibrium conditions. Austenite decomposition was investigated with dilatometry, metallographic observation and hardness measurements.

The A_{C1} and A_{C3} temperatures showed a slight shift in heats no. 4 and 6. However, the micro-alloying-related shift of less than 5 °C could probably have only a minor technological significance. According to the dilatometric recording, virtually all heats exhibited a marked shift of the critical cooling rate for the formation of the hardening microstructures. To summarize the correlation between the microstructure and the properties of specimen, it is concluded that the dilatometric records provided more averaged information on a larger volume of material than the metallographic observation or the hardness measurement.

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