SOLIDIFICATION OF HIPEREUTECTOID HIGH SPEED STEEL FOR ROLLS

This work presents results of microstructural development through solidification, heat treated processes and characterization of two low-alloyed hypereutectoid alloys, emphasizing the effects of the alloy chemical composition. Samples of different compositions were prepared by melting in the induction furnace. The microstructural difference of the different HSS steels will affect the performance of the end products. The main features of the as cast microstructure are the distribution and morphology of eutectic carbides which have been obtained through progress in alloy design concerning the type, morphology, and the volume fraction of the eutectic carbides. Samples were characterized by optical and Scanning electron microscopy.

Key words: High Speed Steel, Solidification, Heat treatment, Eutectic carbides, STA

Kristalizacija nadeutektoidnog brzoreznog čelika za valjke. U radu su prikazani rezultati razvoja mikrostrukture kroz faze kristalizacije, postupke toplinske obrade, te karakterizaciju dvije niskolegirane nadeutektoidne legure, s naglaskom na utjecaj kemijskog sastava. Uzorci različitog kemijskog sastava su dobiveni taljenjem u indukcijskoj peći. Razlika u mikrostrukturi brzoreznih čelika utjecat će na svojstva gotovih proizvoda, valjaka za vruće valjanje. Glavne karakteristike lijevane strukture, raspodjela i morfologija eutektičkih karbida, ovisit će o napretku dizajniranja legure, koji utječe na vrstu, morfologiju i volumni udio eutektičkih karbida. Uzorci su istraživani svjetlosnim optičkim i skenirajućim elektronskim mikroskopom.

Ključne riječi: brzorezni čelik, kristalizacija, toplinska obrada, eutektički karbidi, simultana toplinska analiza

INTRODUCTION

High-speed steels are based on iron in the Fe-C-X multi-component system. The carbon content of HSS is generally 1,5 to 2,0 %, most of which are combined with the carbide formers such as V, Mo, W, Cr etc., to form MC, M_2C, M_6C, M_7C_3, and fine carbides inside the matrix [1, 2]. The low-alloyed hypereutectoid alloys materials can be considered as composite materials of two phases: the matrix and of the carbides. As a consequence the hardness and the wear resistance of these materials may be markedly affected by the amount and the hardness of carbides [3-5]. The main characteristics of the cast microstructure are the distribution and the morphology of the eutectic carbides [6] because of their decisive influence on the mechanical properties and on the operation effects of the hot HSS. Due to the high temperatures of some processes, many phenomena such as precipitation of carbides and their coarsening take place during the service, resulting in changes of the material microstructure that may modify the mechanical properties of the steel. The as cast microstructure of the HSS is usually composed by the dendrites of the modified austenite (mostly martensite with some retained austenite) and the lattice of the eutectic colonies of carbides.

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These colonies are thicker in the ingot centre where the formation of the eutectic "pools" is enabled and they are heterogeneously distributed through the interdendritic regions.

By the subsequent heat treatment that lattice was broken, the size was reduced and the carbide distribution was improved. The engineering control of the cast microstructure operates on two basic microstructural characteristics:

– Dendritic structure (including the secondary or lateral branches of dendrites, columnar or equiaxial morphology and the size of the macroscopic grains).
– Morphology of the eutectic carbides.
– The theoretical carbide nucleation sequence was also established. These theoretical calculations were compared to some experimental results on carbide precipitation in low-alloyed hypereutectoid steel.

The final volume fraction of the eutectic, the volume fraction of the single eutectic and the order of precedence, by which they are precipitated, depends on the chemical composition, cooling rate and the presence of other elements [7-9]. Commonly the entire volume fraction of the eutectic is growing by increasing of the carbon fraction in the alloy.

Table 1 **Chemical composition of steels A and B /wt. %**

Alloy	C	Si	Mn	P	S	Cr	Ni	Mo	W	Co	V
A	1,97	0,40	0,40	0,023	0,027	3,90	1,60	3,10	2,00	0	6,00
B	2,00	1,00	0,90	0,022	0,024	7,00	1,30	6,10	1,90	0,87	6,00

Table 2 **Hardness of A and B after particular heat treatment /HRc**

Alloy	As cast	Aust 1040/1	Aust 1040/2	Y1 650	Y1 350	Y2 500	Y2 350
A	62,8	64,4	59,4	55,2	48,3	52,8	39,2
B	60,0	60,5	60,7	55,7	59,4	54	61,4

EXPERIMENTAL

Two charges of the low-alloyed hypereutectoid materials with a different Si, Mn, Cr, Mo and Co content were melted by using a high-frequency electric induction furnace. The chemical composition of each charge is shown in Table 1.

Two specimens were prepared and analyzed according to the following steps:

(1) The HSS was melted at approximately 1550 °C and poured into two sand moulds and then cooled down to a room temperature.

(2) After solidification, two samples with a dimension of 20 mm×15 mm×20 mm and labelled A and B were cut by the watter jet from the same position of the mould for each alloy to retain the basic structure of as cast material.

(3) The upper surface (20 mm×20 mm) of each sample was ground and polished. All samples were etched using Villela's reagent.

(4) Microstructural studies were first carried out using an optical microscope (OM).

(5) After OM, the specimens were ground and polished to remove etched layer and prepared for SEM. The carbides were observed by SEM, and identified by EDS.

(6) The hardness tests were made for each step of heat treated sample.

(7) Reactions were determined using the STA analysis.

The formation of the eutectic carbides and the procedures, which were applied for the control of the morphology and distribution at the classical and very rapid cooling have been investigated.

Due to the heat treating procedure, the following steps of the samples heat treating were performed: holding at the austenitising temperature at 1040 °C for 2 hours, air cooling and then heating at 650 °C for 4 hours, air cooling, heating at 350 °C for 6 hours and then quenching in oil.

RESULTS AND DISCUSSION

The microstructural analysis of A and B alloys in as cast state are shown in Figure 1A and 1B. Microstructure of A and B comprises the martensitic matrix and the noticeable volume fraction of carbides. The V-rich carbides can distribute evenly in the matrix (Figure 1, 2), the Mo-rich carbides often segregate along the cell boundaries as shown in Figure 2. Comparing alloys A with B in as cast state, there is no significant difference in size of transformed austenite grains, however at alloy A more eutectic carbides segregated by the grain boundary can be slighty noticed. Alloy A has also finer distributed carbides according to the B microstructure. Alloy A has also less content of Cr which is the weakest carbide former among V, Mo, W. Generally speaking when the Cr content is less than 5 %, the Cr-rich M_7C_3 can not be formed.
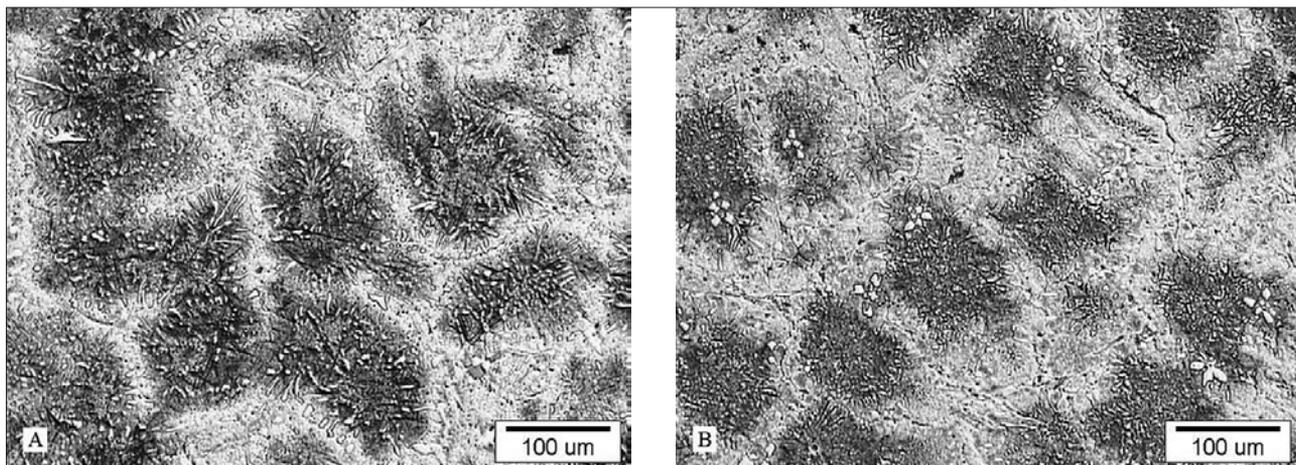

Figure 1 As cast microstructure of samples A and B, etched using Villela's reagent. Darker areas are austenite grains (martensite) with MC carbides. Bright interdendritic area are segregated eutectic carbides
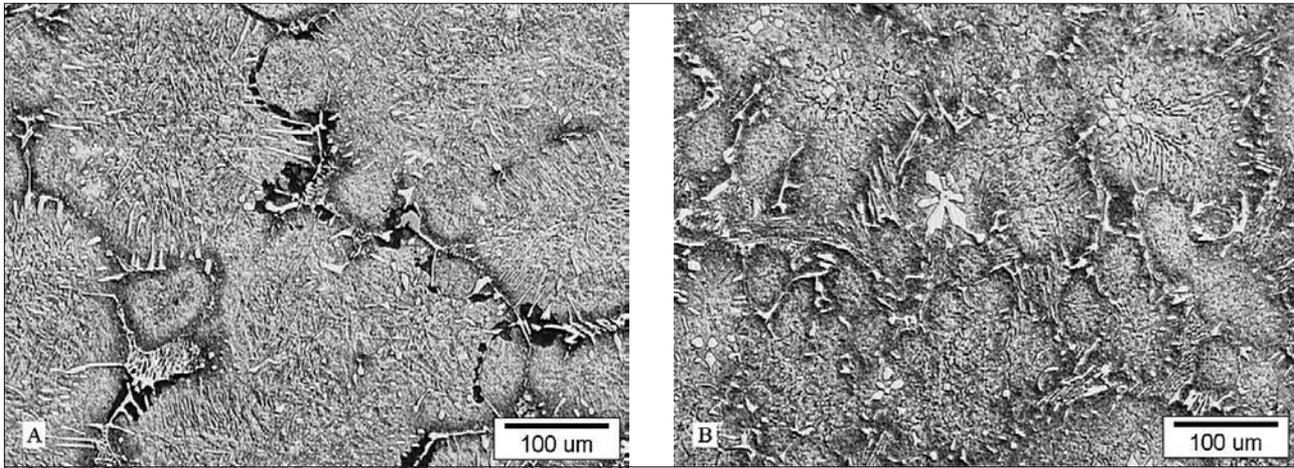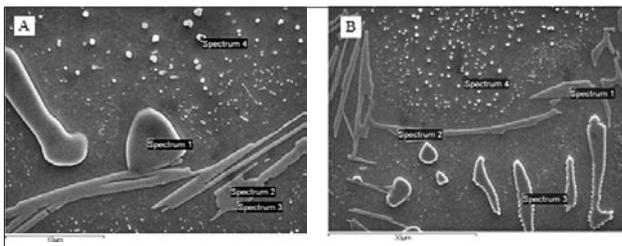
Figure 2 Heat treated samples held at 1040 °C for 2 hours, 650 °C for 4 hours and 350 °C for 6 hours. The samples were quenched in oil

	Spec-trum	C	V	Cr	Fe	Mo	W	Car-bide Type
A	Spec-trum 1	19,15	41,88	4,52	5,44	15,50	13,49	MC
B		15,85	14,02	14,76	6,68	38,11	10,58	M₂C
A	Spec-trum 2	15,51	11,67	12,33	7,63	36,33	16,53	M₂C
B		15,19	13,94	21,04	8,10	34,47	7,25	M₂C
A	Spec-trum 3	15,96	8,72	20,98	13,99	32,04	8,31	M₂C
B		20,02	40,32	3,75	4,50	14,24	7,23	MC
A	Spec-trum 4	21,18	31,38	4,25	24,21	10,44	8,54	MC
B		19,43	30,62	5,83	23,51	13,71	6,89	MC

Figure 3 EDS analyses of MC and M_2C carbides /wt.%/

It is found that two types of carbides, MC and M2C, exist in each sample. MC carbides are rich in V, while M2C carbides are rich in Mo (Figure 3). The EDS results for MC and M2C are shown in Figure 3c. The chemical compositions of MC and M2C carbides are similar to each other in both of samples.

Significant drop of the hardness in alloy A after heat treatment at the Y1 350 (Table 2), is the result of the formation of the fine perlite among the eutectic carbides over the grains boundary (Figure 2A), which is caused by the higher Ni fraction in the original alloy, while Ni is known as the pearlite-former.

The simultaneous thermal analysis technique STA (Figures 4, 5) was used to investigate the solidification sequence and especially the carbide precipitation in al-loys. During the cooling only the solidification peak of the austenite and the peaks corresponding to eutectics reactions have been observed.

The first eutectic reaction (Table 3, peak 1) $L_o > \gamma_p + L_1$ is well defined and shows the primary austenite dendrite forms and follows by precipitation of ($\gamma + MC$). The two peaks 3 and 4 corresponding to $(\gamma + M_2C)_E$ and $(\gamma + M_6C)_E$ reactions are difficult to be separated. But due to the fact that the volume fraction of M_2C is higher than that of M_6C, we can assume that the peak at 1178,2 °C on the cooling curve correspond to the transformation of eutectic $\gamma + M_2C$; the peak 4 at 1023,1 °C correspond to the transformation of eutectic $\gamma + M_6C$ (Figure 4). The peak number 5 on cooling curve correspond to the martensite start transformation.

CONCLUSIONS

In this paper, the influence of alloy composition and heat treatment on microstructure was investigated. Hard MC eutectic carbides improve strongly the wear resis-tance, but too big amount of them can lead to the in-crease of the friction coefficient. Other M_2C eutectic carbides are also very good wear resistant and precipi-tates mainly in the flake morphology (needles-like) that makes the material very brittle, which is not desirable, particularly in mechanical processes such as rolling. The
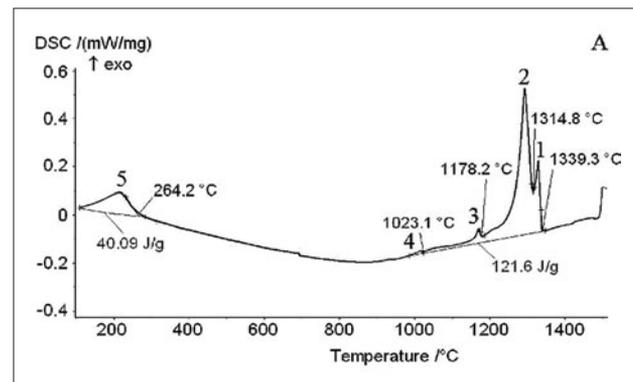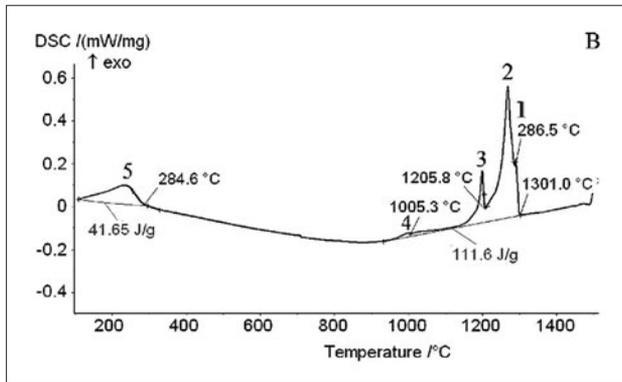

Figure 4 DSC curve during cooling, A

Figure 5 DSC curve during cooling, B

Table 3 **Temperatures of transformations in A and B during cooling**

	A			B	
Nr.	T_{trans}, $^{\circ}$C	Transformation	Nr.	T_{trans}, $^{\circ}$C	Transformation
1	1339,3	$L_o > \gamma_p + L_1$	1	1301,0	$L_o > \gamma_p + L_1$
2	1314,8	$L_1 > (MC + \gamma) + L_2$	2	1286,5	$L_1 > (MC + \gamma) + L_2$
3	1178,2	$L_2 \rightarrow (M_2C + \gamma)_E$	3	1205,8	$L_2 \rightarrow (M_2C + \gamma)_E$
4	1023,1	$L_3 \rightarrow (M_6C + \gamma)_E$	4	1005,3	$L_3 \rightarrow (M_6C + \gamma)_E$
5	264,2	Ms	5	284,6	Ms

solidification sequence of the major high speed steels for rolls is composed by primary crystallization of austenite and eutectic decomposition of residual interdendritic liquid, which leads to the formation of up to three eutectics: γ +MC, γ +M$_2$C and γ +M$_6$C.

Higher content of Mo in B is also a cause for a higher portion of M$_2$C eutectic. The eutectic carbides presented in the structure are harder due to the fact that the amount of soft carbides such as M$_7$C$_3$ is actually equal to zero and that the amount of hard carbides such as MC or M$_2$C is high.

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