INVESTIGATION OF MICROSTRUCTURE IN INOCULATED AS-CAST HIGH-SPEED STEELS

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Abstract

The structure and phase composition of high-speed steels of different grades after casting, annealing, and subsequent final heat treatment (quenching and tempering) have been studied focusing on carbide structure. In order to investigate kinetics of both the structure and phase transformations in eutectic carbides upon heat treatments, different techniques of optical microscopy, X-ray diffraction, and energy dispersive X-ray analysis have been used.

Key words

high-speed steel, inoculation, heat treatment, structure

Introduction

High-sped steels (HSS) are iron-based alloys with high content of carbide-forming elements such as W, Mo, Cr, and V on the one hand and appropriate amount of carbon on the other hand. Contents of the basic alloying elements and carbon in modern HSS vary very widely being in range as follows - for: W –22.50, Mo –11.0 Cr – 3÷4, V – 0.4÷6.7, and C – 0.6÷2.4 in weight % [1]. It is necessary to emphasise that during the last decades the general trend is in increasing both vanadium and carbon content in order to enhance cutting performance of HSS. As consequent, large amount of carbides are formed during primary solidification of a melt. The origin of the carbides to be formed during primary solidification depends on the chemical composition of the steel [2].

There are different types of carbides which can be found in HSS after solidification: M_6C, M_2C, MC, M_7C_3, and $M_{23}C_6$. Iron, tungsten and molybdenum mainly contribute to the formation of M_6C-type carbides, composition of which is between the extremes $Fe_3(W,Mo)_3C$ and $Fe_4(W, Mo)_2C$ [4].

M_2C-type carbides are Mo_2C-basic or V_2C-basic carbides that depend on the chemical composition of the steel. Mo_2C-basic carbides are dominantly formed in molybdenum HSS and V_2C-basic carbides are formed in tungsten molybdenum HSS [3].

Vanadium strongly promotes the formation of MC-type carbides even when present in HSS in small quantities. These vanadium-reach carbides are considered to be VC or V_4C_3 origin [3]. Titanium and niobium, having like vanadium strong affinity to carbon, contribute to formation of MC carbides too [2]. It is necessary to emphasise that VC, NbC, and TiC-based carbides are isomorphic phases, which can be mutually dissolved at all relative concentrations [5].

As a rule, carbides of both the types, M_7C_3 and $M_{23}C_6$, are the Cr-rich carbides [3]. Despite this the composition of $M_{23}C_6$ carbides in HSS with the high tungsten content has been declared as $Fe_{21}W_2C_6$ [6].

Majority of the primary carbides are formed during eutectic reaction. Some portion of carbides can formed in accordance with the peritectic reaction that is more typical for HSS with the lower carbon content. The type of carbides formed during the primary solidification as well as their volume fraction, size, morphology and distribution have very strong influence on the final properties of as-cast HSS [7-21]. The diffusion redistribution of alloying elements and their mass transfer between the matrix and carbide phases due to their mutual interaction upon high-temperature treatments of the steels has been shown to result in qualitative and quantitative changes in the eutectic carbides [22], [23]. But the effect of heat treatment in this term greatly depends on the chemical composition of the steel treated. For this reason the main goal of the paper is to study the effects of heat treatments on the eutectic carbides in HSS of two quite different, from the chemical composition point of view, grades impacting to the diffusion induced changes.

Experimental

The chemical composition of the experimental HSS on the basis of AISI-M2 type HSS is presented in Table 1. The steels were melted in an electric high-frequency induction furnace. The ferromanganese, ferrosilicon, and metallic aluminium were used as deoxidisers. Inoculating treatment of the M2 type steel melt was carried out using powder additions of the metallic tungsten and titanium diboride. The melts of the steels were poured into ceramic moulds. The mass of the ingots cast was 1.2 kg.

CHEMICAL COMPOSITION OF THE STEELS STUDIED [mass %] Table 1

Steel	Fe	C	Si	Mn	Ni	P	S	Cr	Mo	W	V	Ti	B
(1) M2-type*	Bal.	0.85	0.25	0.27	0.24	0.023	0.028	4.12	5.37	5.67	1.87	—	—
(2) M2-type**	Bal.	0.86	0.24	0.29	0.23	0.024	0.028	4.08	5.30	5.45	1.89	0.028	0.017

Notes: *modified with 0.6 % of tungsten powder; **modified with 0.3 % of titanium diboride powder

Heat treatment of the specimens prepared from the experimental ingots included annealing, austenitising, quenching and tempering. Annealing was carried out at 850 °C for 2 h followed by slow cooling to 720 °C and holding at this temperature for 4 h. When austenitising the specimens were heated to temperatures 1180, 1200, 1220, 1240 and 1260 °C, and held at these temperatures for the same soaking time (10 s per 1 mm of the specimen cross section). Triple tempering at 560 °C for 1 h completed the heat treatments of the specimens from the steels studied.

After heat treatments specimens were prepared for metallographic evaluation. To explain structural changes in the steels took place during heat treatments different techniques of optical microscopy, X-ray diffraction, and energy dispersive X-ray analysis have been used.

Results and discussions

The cast microstructure of the M2 steel inoculated with powder W and TiB_2 was studied in the previous paper [24] according to the XRD analyses of the steels the carbide constituent comprises of M_6C and MC carbides [24]. In both the steels M_6C eutectic form in interdendritic regions in the form of the broken carbide network. In the steel 1 the M_6C eutectic is dominantly of fish-bone morphology, while the volume fraction of the M_6C eutectic of rod-like morphology is very low. In the steel 2 the M_6C eutectic of the specific lamellar morphology dominates. The M_6C rod-like and fish-bone eutectic appears in the steel 2 after casting too, but its volume fraction is relatively small. In both the steels primary MC carbides are also observed, which appear as individual massive crystals being, as a rule, in the connection with the M_6C eutectic colonies [24].

Annealing results first in structural changes induced by diffusion, which deal with the start of the decomposition and coagulation of the eutectic carbides that was shown in the previous paper [24]. Such structural changes are more pronounced after austenitising.

Figure 1 shows the tempering microstructure of the steel 1 austenitised at 1180 °C. The eutectic M_6C carbides of the fishbone (Fig. 1a) and rod-like (Fig. 1b and 1c) types have started to decompose by the precipitation of the small secondary carbides in the bulk of the larger eutectic carbides. It is necessary to stress that the precipitation of the small secondary carbides is more evident in the case of the rod-like M_6C in comparison with the fishbone M_6C carbide. These small secondary carbides have been identified by electron microprobe analysis (EMPA) as V-rich carbides from the result of energy dispersive spectrometer (EDS) profile in Fig. 2a. It is thus probable that at austenitising temperature, vanadium has diffused out of the M_6C eutectic and reacting with surrounding austenite matrix forms own MC carbide.

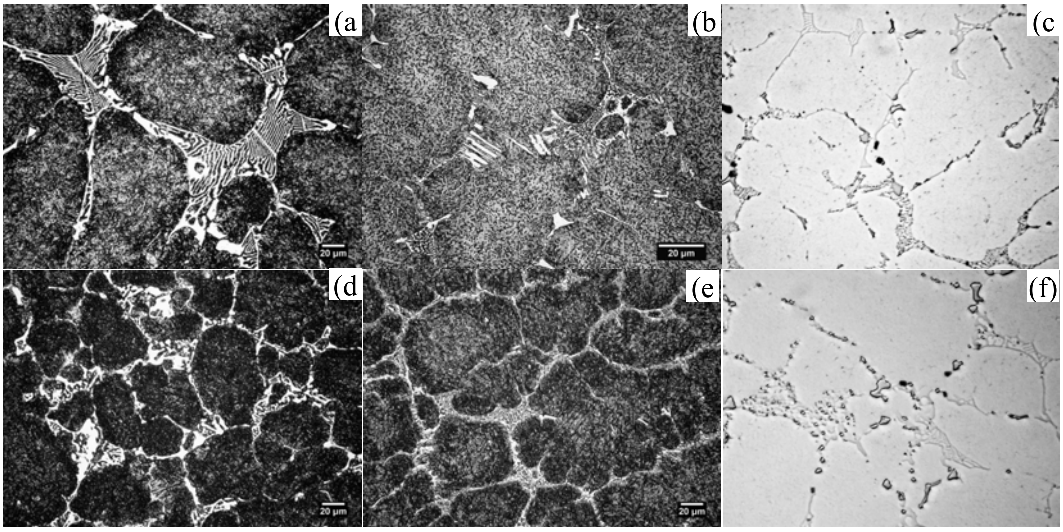

Fig. 1. *Tempering microstructure of the M2 type steel 1 after austenitising at (a, b, c) 1180 °C and (d, e, f) 1260 °C*

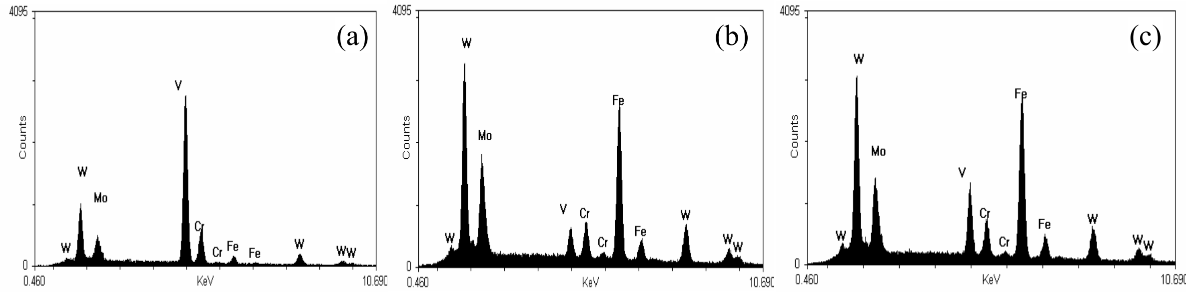

Fig. 2*. EDS profiles of the (a) secondary MC carbide, and the M_6C carbide with (b) fishbone and (c) rode-like morphology in the tempered M2 type steel 1 after austenitising at 1180 °C*

The EDS profiles in Fig. 2b and 2c show that the M_6C eutectic carbides in steel 1 differ in chemical composition, depending on the carbide morphology. [23] The EMPA measurements show that the M_6C fishbone carbide in comparison with the M_6C rod-like carbide has higher content of W (47.69 vs. 42.73) and Mo (14.18 vs. 11.83), and lower content of V (3.99 vs. 9.20), while the Cr content practically does not differ significantly in both cases (3.52 vs. 3.26).

Figure 3 shows the tempering microstructure of the steel 2 austenitised at 1180 °C, from which the higher level of decomposition of the M_6C lamellar eutectic carbide is evident (Fig. 3c). The chemical composition of this M_6C lamellar carbide in the steel 2 is very similar to that of the M_6C rod-like carbide in the steel 1. Both those carbides are enriched, compared to the M_6C fishbone carbide, in vanadium. Taking into account these findings, the more pronounced decomposition of the M_6C lamellar carbide in the structure of the steel 2 in comparison with the M_6C rod-like carbide in the steel 1 may be attributed to the effect of boron, which in iron-based alloys is known to accelerate the rate of diffusion in carbides [10, 13].

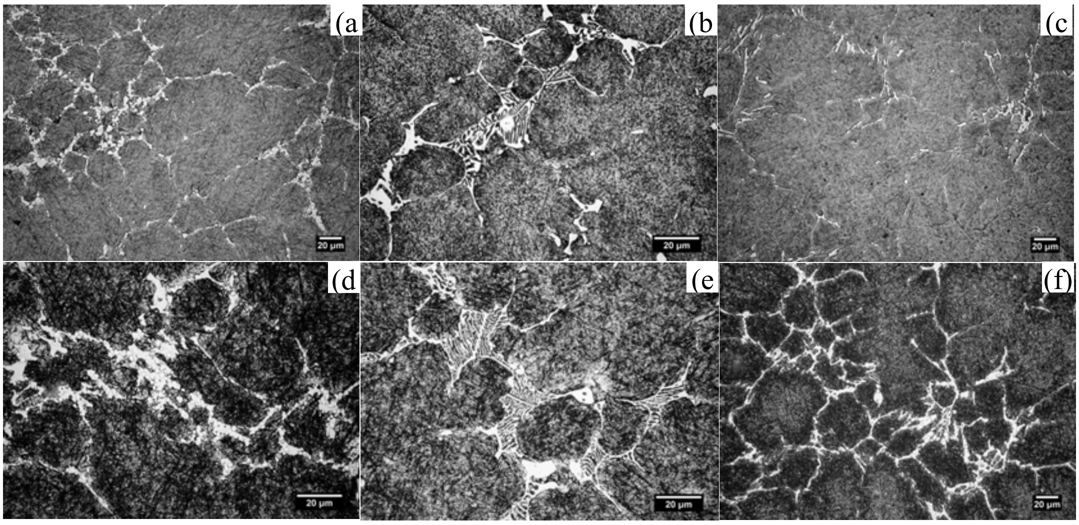

Fig. 3. *Tempering microstructure of the M2 type steel 2 after austenitising at (a, b, c) 1180 °C and (d, e, f) 1260 °C*

According to the EMPA measurements there are no substantial differences in chemical composition of the M_6C fishbone carbide in the steel 1 and steel 2. Like in the steel 1, the M_6C fishbone carbide in the steel 2 seems to be more stable (Fig. 3b).

Figures 1 and 3 show that increase of austenitising temperature from 1180 to 1260 °C leads to acceleration of the carbide decomposition, which is accompanied by coarsening and coagulating of the eutectic carbides. Micrographs show that due to strong diffusion and mass transfer of carbon and alloying elements the initial morphology of eutectic carbide drastically has changed during austenitising. The higher austenitising temperature promotes the most significant structural changes in the M_6C rod-like and lamellar carbide in the steel 2 followed by the M_6C rod-like carbide in the steel 1. Just on the contrary, it seems that the M_6C fishbone carbide is more stable mainly in the case of the steel 2.

Conclusions

It was found that heat treatments affected size distribution, volume fraction and morphology of the eutectic carbides as well as their chemical composition. Initially, changes in the eutectic carbides take place upon annealing. Due to the diffusion redistribution of carbon and alloying elements at high temperature, the carbide morphology changed.

The processes that are common upon austenitising of the HSS of M2 types are the decomposition and coagulation of the M_6C type eutectic carbides that increase with increasing austenitising temperature. It was shown that stability of the M_6C eutectic carbides depends on their morphology that can be attributed to the chemical composition of these carbides. Between M_6C type carbides the more stable one is with fishbone morphology. This is W–Mo-rich carbide with low content of V. According to EMPA measurements the deterioration of the M_6C carbide stability with lamellar and rod-like morphology is attributed to the increased content of V in the carbide. The V-rich carbide MC is the most stable carbide phase in both the steels.

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