ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Issue 3/2008

137 – 140

26/3

Effect of heat treatment parameters on the properties of low-alloy cast steel with microadditions of vanadium

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Received 25.04.2008; accepted in revised form 29.04.2008

Abstract

This article examines the effect of prolonged time of holding at the temperature of 620^0C on the processes of secondary phase precipitation and mechanical properties of low-alloy cast steel with an addition of vanadium subjected to two variants of heat treatment, i.e. U:1150^0C+H:950^0C+O:620^0C and H:950^0C+O:620^0C. To determine an impact of the applied heat treatment operations, testing of mechanical properties and microstructural examinations of the cast steel with 0,21 and 0,27%C were carried out.

Keywords: Low-alloy cast steel; Microstructures; Mechanical properties; Heat treatment

1. Introduction

Modern development of steel grades for responsible engineering castings consists mainly in systematic increase of the imposed requirements. This is the reason why the low-alloy structural steels of high mechanical and plastic properties are gaining importance in both technology and economy. When shaping with microadditions the properties of castings made from low-alloy steel, it is very important to extensively use the impact of heat treatment and various mechanisms of microstructure hardening at a given chemical composition. The greatest possibilities in this field lie in the mechanisms based on microalloying (V, Nb, Ti), grain refining and dispersion hardening [1-3]. The combined effect of microadditives and properly selected heat treatment regime may lead to great changes in the properties of ready casting [4,5]. This is specially true if we remember that dispersion hardening takes place in alloys in which the volume fraction of dispersed phases does not exceed 0.1%, and the size of respective particles is 1-100nm [6]. The data offered by technical literature and the results of own investigations [6-8] indicate that there exist vast possibilities for the use of microadditions in cast steels, having considered the, typical of the solidification process, effects of segregation and changes in solidification rate in casting walls of different cross-sections.

2. Methods of investigation

The examined low-alloy cast steel with microadditions of vanadium (Table 1) was melted in an electric arc furnace of 6 Mg capacity. Melting was carried out under industrial conditions. The obtained test ingots were subjected to heat treatment. Two variants of the heat treatment were applied to castings from each melt, viz. U: 1150^0C, H: 950^0C/water, O: 620^0C/10h/air and H: 950^0C/water, O: 620^0C/10h/air. The changes that took place in the microstructure of the investigated cast steel due to the applied heat treatment were examined by transmission electron microscopy on thin foils and carbon extraction replicas. Carbides were identified by phase analysis using the method of selective diffraction and by quantitative analysis of chemical composition using the EDS technique. The cast steel microstructure in thin foils was examined under the JOEL APR 2010 microscope.

Table 1.
Chemical composition of the examined cast steel, wt.%

Cast steel designation	C	Mn	Si	P	S	Ni	Cr	Mo	V	N	Al
P1	0,26	1,22	0,38	0,02	0,02	0,96	0,15	0,19	0,07	0,016	0,03
P2	0,27	1,23	0,45	0,03	0,02	1,19	0,11	0,22	0,09	0,014	0,055
P4	0,21	1,13	0,39	0,03	0,02	0,91	0,11	0,18	0,09	0,015	0,035

To determine heat treatment effect on the mechanical properties of the examined cast steel, a static tensile test was performed using standard cylindrical specimens. The test was carried out on a ZWICK Z250 machine in accordance with PN-EN 10002-1.

3. Results and discussion

Table 2 gives the results of mechanical tests carried out on the low-alloy cast steel with additions of vanadium and compares them with the results of previous studies made on this cast steel (designated as P1 in Tables 1 and 2) subjected to heat treatment recommended by the respective standard [9].

Table 2.
Mechanical properties of the examined vanadium-containing cast steel after different heat treatments

Cast steel designation	Heat treatment regime	R_m [MPa]	$R_{0,2}$ [MPa]	A_5 [%]	Z [%]
P1	N: 900^{0}C H: 900^{0}C/water O: 600^{0}C	981*	903*	16*	47*
P2	U:1150^{0}C H:950^{0}C/water O:620^{0}C/10h/air	970 1018 990	899 949 909	10 15 12	27,7 47,4 46,5
	H:950^{0}C/water O:620^{0}C/10h/air	976 933 946	895 863 879	13,2 6,0 12,3	42,3 12,1 39,8
P4	U:1150^{0}C H:950^{0}C/water O:620^{0}C/10h/air	918 904 926	811 800 815	14,4 12,8 13,2	47,2 34,9 36,3
	H:950^{0}C/water O:620^{0}C/10h/air	943 963 951	840 849 842	11,1 18,9 11,9	31,9 49,2 37,1

U*- homogenising annealing;* ***H****- quenching;* ***O****- tempering;*
N*- normalising annealing;*
**/mean values obtained on 3 specimens*

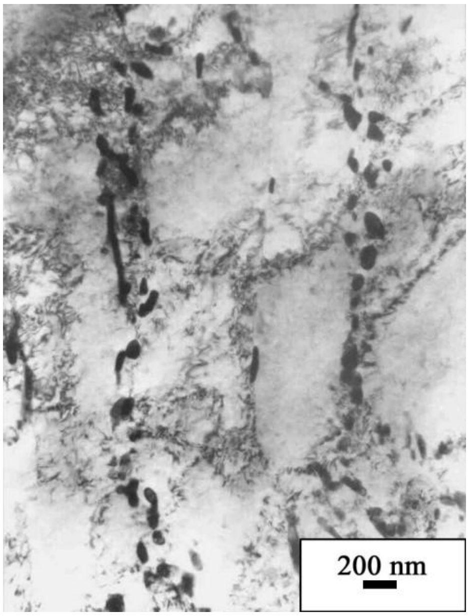
From the obtained results it follows that for the cast steel microalloyed with vanadium, containing 0,27%C and subjected to two variants of the heat treatment, the following values of the mechanical properties were obtained: $R_{0,2}$ above 860 MPa and R_m exceeding 930 MPa. For the cast steel with 0,21%C, $R_{0,2}$ and R_m going in excess of 800 MPa and 900 MPa, respectively, were obtained. Compared with the recommended heat treatment (Table 2 – designation P1), no significant increase of the mechanical properties has been reported.

Evaluation of precipitates morphology after heat treatment

The metallographic examinations performed on low-alloy cast steel with microadditions of vanadium using extraction replicas and thin foils revealed two types of the precipitates:
- large precipitates in the size range of 100-200nm, present as single objects or as clusters, characterised by different shapes (oval and oblong), sizes and chemical compositions,
- fine-dispersed precipitates of carbides in the size range of 20-50nm present in ferrite.

Both groups of the examined precipitates were detected in microstructure of the examined cast steel after both variants of the heat treatment, when carbon content was 0,21% and 0,27%C.
An identification of the large precipitates indicates that these are mainly chromium carbides (Figs. 1 and 2). When only quenching and tempering treatments are applied, they precipitate along the primary grain boundaries (Fig.1), and their shapes and sizes are similar. However, with the homogenising annealing carried out, chromium carbides are distributed much more evenly throughout the examined area.
In numerous large precipitates, besides Fe, Cr and C, also the presence of Mo and/or Si was traced. The precipitates of carbides containing Fe, Cr, Si, Mo, C or Fe, Cr, Si, C were characterised by oblong and trapezoidal shapes.

a)



b)

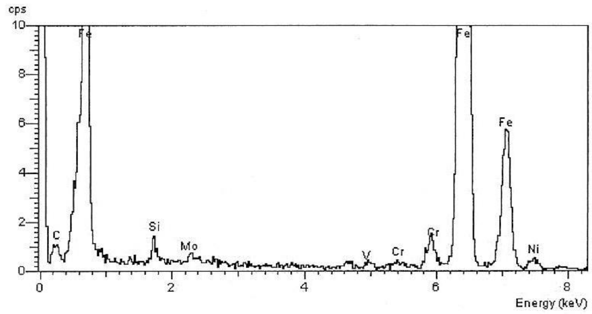


Fig.1. Precipitates in P4 cast steel after H:950^0C/water O:620^0C/10h/ – thin foil a); EDS spectrum from a large precipitate b)

The second group of precipitates form very fine vanadium carbides, distributed in a uniform manner within the ferrite grains (Fig. 2). An analysis of their chemical composition made on respective replicas has revealed the presence of V and C in most of the precipitates (Fig.3). Attention deserves the fact that these precipitates also contain Mo and Ti (Fig.4). Several precipitates contain besides C also W. Both Ti and W originate from the metallic charge and are to be regarded as incidental elements.

a)

b)

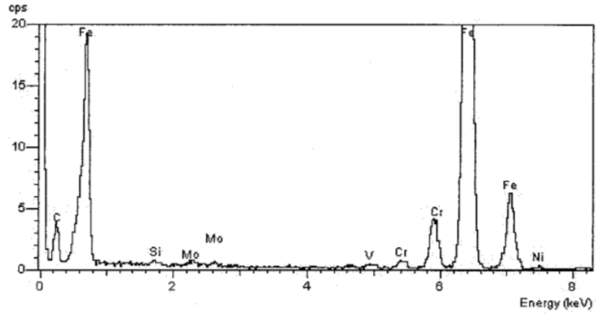
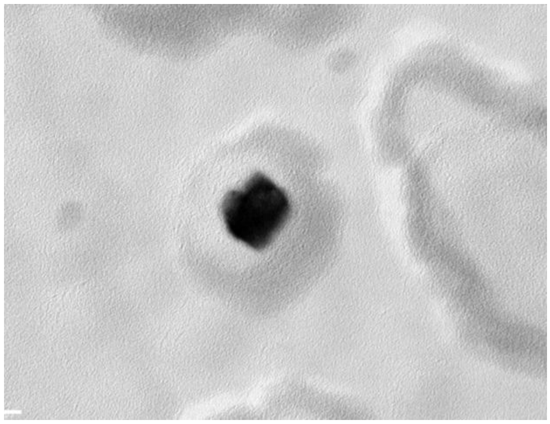


Fig.2. Microstructure of P2 cast steel after H:950^0C+ O:620^0C/10h – carbon replica a) EDS spectrum from large precipitate b)

a)



pow. 100000x

b)

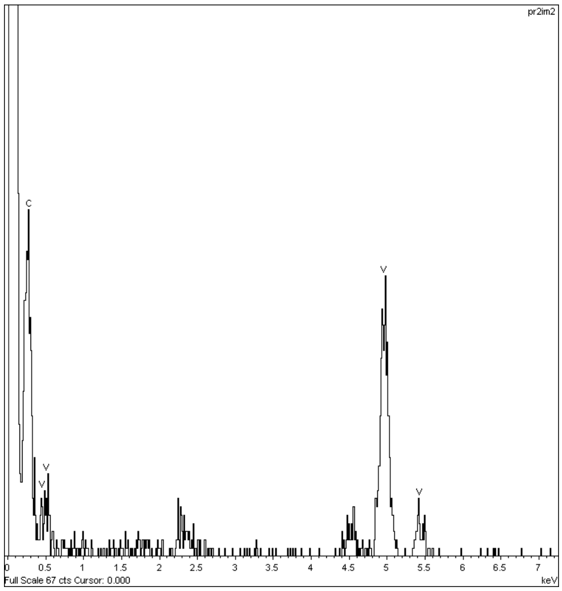
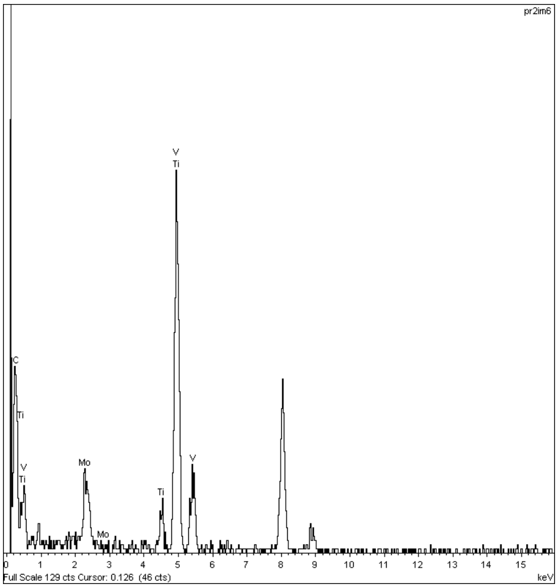


Fig.3. VC precipitate – carbon replica, P2 cast steel after H:950^0C+ O:620^0C/10h a); EDS spectrum b

a)



b)

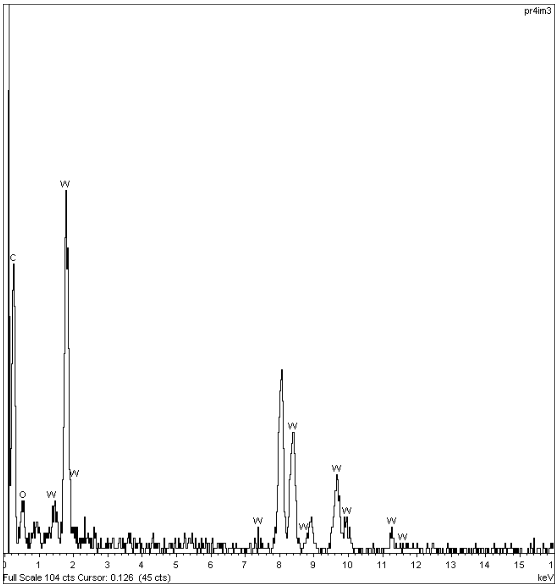


Fig. 4. EDS spectra fom complex fine-dispersed precipitates in P2 cast steel after H:950^{0}C+ O:620^{0}C/10h a); P4 cast steel after H:950^{0}C+ O:620^{0}C/10h b)

4. Conclusions

From the results of the investigations of low-alloy cast steel with microadditions of vanadium the following conclusions are drawn:

- ✓ Application of complex heat treatment with holding at the temperature of 620^{0}C for 10 hours cannot guarantee the required improvement of mechanical properties compared with the common type of heat treatment during which the time of holding at a given temperature is adjusted to the casting wall thickness.
- ✓ Microscopic examinations revealed the presence of two groups of the precipitates of large carbides comprised in the thickness range of 100- 200nm and containing elements like Fe, Cr, C or Fe, Cr, Si, Mo, C, as well as numerous, dispersed, secondary precipitates of vanadium carbides. The precipitates included in the first group were present along the grain and subgrain boundaries. The dispersed secondary carbide precipitates were distributed evenly in ferrite.
- ✓ The effect of fine-dispersed carbide precipitates on the mechanical properties in both heat treatment variants is comparable (similar values of $R_{0,2}$, R_m, A_5, Z).

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