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Modification of the High-alloyed White Cast Iron Microstructure with Magnesium Master Alloy

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Abstract

High-vanadium cast iron is the white cast iron in which the regular fibrous γ + VC eutectic with the volume fraction of vanadium carbide amounting to about 20% crystallises. This paper presents the results of studies on high-vanadium cast iron subjected to the inoculation treatment with magnesium master alloy. The aim of this operation is to change the morphology of the crystallising VC carbides from the fibrous shape into a spheroidal one. The study also examines the effect of the amount of the introduced inoculant on changes in the morphology of the crystallising VC carbides. To achieve the goals once set, metallographic studies were performed on high-vanadium cast iron of eutectic composition in base state and after the introduction of a variable content of the inoculant.

The introduction of magnesium-based master alloy resulted in the expected changes of microstructure. The most beneficial effect was obtained with the introduction of 1.5% of magnesium master alloy, since nearly half of the crystallised vanadium carbides have acquired a spheroidal shape.

Keywords: High-vanadium cast iron, Eutectic alloy, Microstructure modification, Vanadium carbide, Spheroidal carbides

1. Introduction

The chemical composition of cast iron has a significant impact on both the graphitisation and matrix formation, and thus on the properties of final material. The conventional division of cast iron is into the unalloyed and alloyed grades. The latter group includes those cast iron grades in which the introduction of alloying elements either changes the type of matrix and the morphological features of graphite, or results in carbides crystallisation. The element that has very interesting properties as an alloying addition is vanadium. In [1,2], some information has been provided about the microstructure of Fe-12.9%V-2.94%C alloys, where the appearance of a regular fibrous γ + VC_{1-x} eutectic with vanadium carbides volume fraction of about 20% was stated, while in [3] the properties of vanadium carbides of the VC type were described.

Alloys from the Fe-C-V system with high vanadium content are in the family of white cast irons, because all carbon present there is bound in vanadium carbides. The results of microstructural examinations, and mechanical and tribological tests carried out on these alloys are given in [4,5].

A review of literature confirms the growing interest in the ordinary alloyed white cast iron [6, 7] as well as white cast iron with carbide precipitates in the form of spheroids. In [8-11], information has been found on the spheroidising treatment of alloyed white cast iron with high content of chromium, vanadium and nickel, using rare earth metals to improve the abrasive wear resistance.

To combine the good flowability of cast iron with the high ductility of cast steel, the spheroidising treatment is carried out, whereby the cast iron with spheroidal graphite is obtained. The spheroidal form of graphite is the most compact one, with the lowest surface-to-volume ratio, owing to which the active section of the casting is weakened to a lesser extent, and stress concentration around the sites where graphite occurs is reduced compared with the graphite that occurs in the form of lamellae [12].

These precisely features of the spheroidising treatment were used in an attempt to produce vanadium carbides VC of a spheroidal shape in the research described in [13-15]. The applied treatment increased the mechanical properties, improving also the alloy ductility.

In this paper, an attempt was made to modify the microstructure of high-vanadium cast iron using magnesium-based master alloy. The effect of the addition of inoculant was investigated and the resulting microstructure was examined.

2. Experimental

To perform the anticipated tests, four melts of the same nearly eutectic composition were made in a Balzers vacuum furnace in a protective argon atmosphere. The melt was prepared using an Fe-V master alloy containing 81.7% vanadium, Armco iron, and commercially pure graphite. The first melt was base melt (W0), while to the successive melts, 0.8%, 1% and 1.5% of inoculant (identification sequence W1-W3) were added. The inoculant was magnesium master alloy with magnesium content of about 6%. Moulds made from the molochite flour with water glass hardened with CO_2 were heated up to a temperature of 550°C, and then poured with liquid cast iron at 1700°C. After knocking out of castings, samples for metallographic examinations were cut out from these castings.

Unetched samples were examined under a LEICA MEF4 M optical microscope and JEOL 5500LV scanning microscope using secondary electrons. This enabled distinguishing vanadium carbides from other phases, which is not always possible in studies using only an optical microscope. For more detailed examinations of the geometry of various phases, samples were deep etched with aqua regia and examined by scanning electron microscopy. The percent fractions of structural components were determined using a LEICA QWin automatic image analyser.

3. Experimental Results and Analysis

Table 1 shows chemical composition of the obtained alloys and the content of microstructural constituents. The degree of eutectic saturation was calculated using formula (1).

$$S_c = \frac{C}{C_e} = \frac{C}{7.618\ V_e^{-0.617}} \tag{1}$$

where:

C_e and V_e – carbon and vanadium content in the eutectic, respectively, [%],

C – carbon content in cast iron, [%].

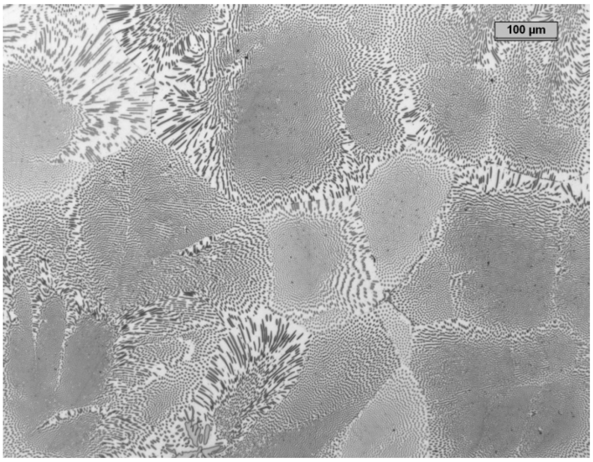
All the examined alloys had a nearly eutectic composition. Polished metallographic sections were etched with Vilella's reagent, followed by microscopic observations under an optical microscope. Figure 1 shows microstructures of the base cast iron (W0) and of the cast iron after the introduction of different amounts of the inoculant (W1-W3). Clearly, all alloys have the matrix composed of alloyed ferrite, as confirmed by a quantitative analysis of the chemical composition in microregions - EDX.

In the base cast iron, i.e. without the addition of inoculant, vanadium carbides crystallised in the form of fibrous eutectic. In Figures 1a and 2a, the grains of vanadium eutectic in the form of a branched carbide skeleton are clearly seen. The addition of 0.8% of the inoculating master alloy has made nearly 20% of all the carbides crystallise as fine non-faceted dendrites. Increasing the amount of inoculant to 1% increased the content of "compact" VC carbides to about 30%; carbides of a nearly spheroidal shape have also appeared. The most favourable results were obtained after the addition of 1.5% of the inoculating master alloy. In thus modified alloy microstructure, the majority of crystallised carbides had the form of spheroids (over 50%).

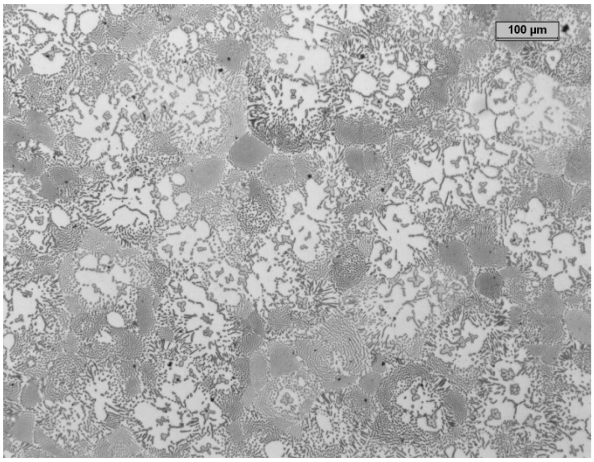
Deep etching with aqua regia and observations by scanning electron microscopy (Fig. 2) enabled detailed spatial observations of the crystallised phases. Figure 2b clearly shows that on the "spheroidal" vanadium carbides, a fibrous eutectic has started to grow in a way similar to the hypereutectic vanadium cast iron.

Table 1.
Chemical analysis of the examined alloys and the corresponding microstructure

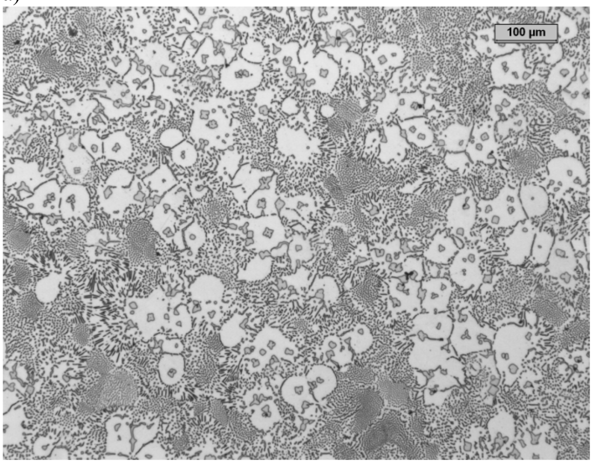
Melt No.	C wt. %	V wt. %	C/V	S_c	f_{we}	f_{ws}	f_w
W0	1,43	15,59	0,09	1,02	18,6	-	18,6
W1	1,40	15,34	0,09	0,99	13,4	3,7	17,1
W2	1,41	15,41	0,09	1,00	11,9	4,9	16,8
W3	1,39	15,29	0,09	0,98	7,9	8,5	16,4



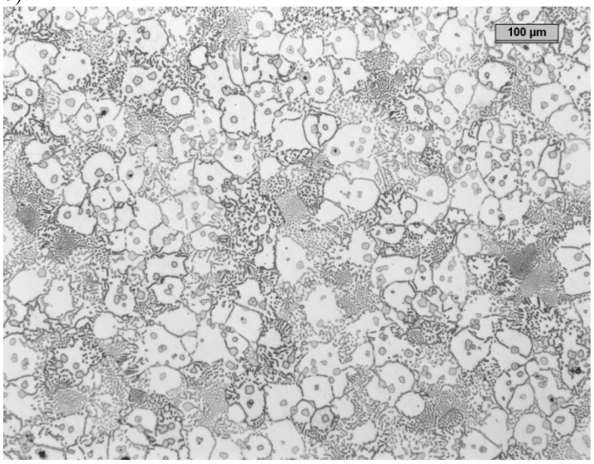
a)



b)

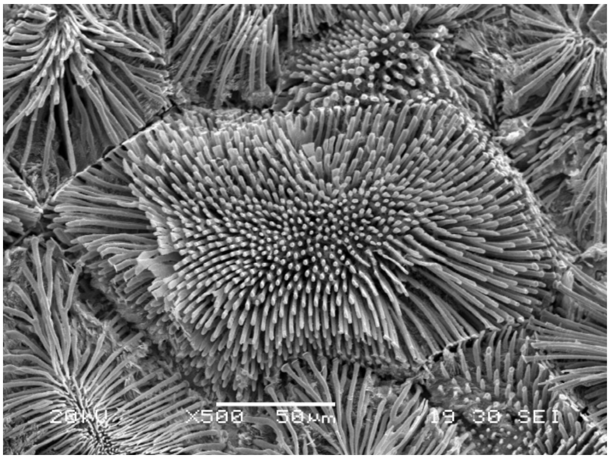


c)

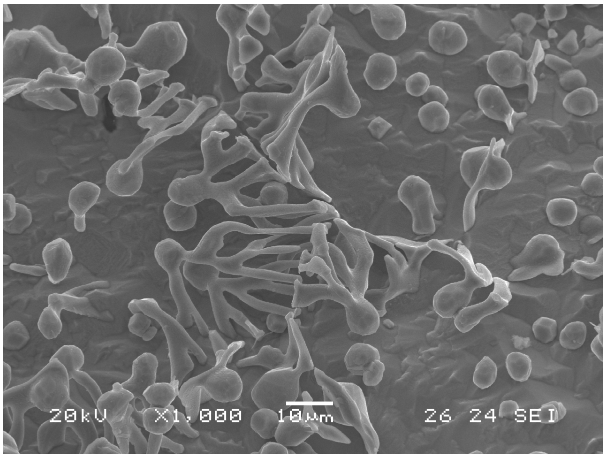


d)

Fig. 1. Microstructure of alloy in base condition – W0 (a) and after adding the inoculant in an amount of 0,8% - W1 (b), 1% - W2 (c), 1,5% - W3 (d); etched with Vilella's reagent.



a)



b)

Fig. 2. Microstructure of alloy in base condition - W0 (a) after adding the inoculant in an amount of 1,5% - W3 (b); deep etching with aqua regia (SEM).

4. Conclusions

Based on the results obtained in the studies, the following conclusions were drawn:

1. The use of magnesium master alloy as a modifier of the microstructure in Fe-C-V alloys causes changes in morphology of the crystallising VC carbides.
2. Increasing the amount of the introduced magnesium master alloy makes numerous vanadium carbides crystallise as fine non-faceted dendrites (W1); spheroidal forms follow as the next ones (W2, W3).
3. Introduction of 1.5% magnesium to high-vanadium cast iron of eutectic composition makes over 50% of all carbides crystallise in the form of spheroids. The remaining vanadium carbides assume the fibrous shape.
1. On vanadium carbides in a spheroidal form, the fibrous eutectic starts growing in a way similar as it happens in the hypereutectic vanadium cast iron

Acknowledgements

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References

[1] Fraś, E. & Guzik, E. (1980). Primary microstructure of the Fe-C-V alloys. *Archivess of Metallurgy*. *25*(4), 757-772.

[2] Fraś, E. (2003). *Crystallization of metals*. Warsaw: WNT.

[3] Kopyciński, D. & Piasny, S. (2012). Influence of tungsten and titanium on the structure of chromium cast iron. *Archives of Foundry Engineering*. 12(1), 57-60.

[4] Kawalec, M. & Fraś, E. (2008). Structure, Mechanical Properties and Wear Resistance of Highvanadium Cast Iron. *ISIJ International*. 48(4), 518-524.

[5] Fraś, E. & Kawalec, M. (2008). Structure, mechanical properties and abrasive wear resistance of Fe-C-V alloys. *Materials Engineering*. 29(2), 78-85. (in Polish).

[6] Kopyciński, D. (2009). Inoculation of chromium white cast iron. *Archives of Foundry Engineering*. 9(1), 191-194.

[7] Kopyciński, D., Guzik, E. & Piasny, S. (2011). The structure of abrasion-resisting castings made of chromium cast iron. *Archives of Foundry Engineering*. 11(1), 61-66.

[8] Uematsu, Y., Tokaji, K., Horie, T. & Nishigaki, K. (2007). Fracture toughness and fatigue crack propagation in cast irons with spheroidal vanadium carbides dispersed within martensitic matrix microstructure. *Materials Science and Technology*. 471(A), 15-21.

[9] Tokaji, K., Horie, T. & Enomoto, Y. (2006). Effect of microstructure and carbide spheroidization on fatigue behaviour in high V-Cr-Ni cast irons. *International Journal of Fatigue*. 28, 281-288.

[10] Tanaka, M., Shimizu, K., Ito D. & Noguchi, T. (2011). Fatigue Characteristic of Spheroidal Vanadium Carbides Cast Iron. *Key Engineering Materials*. 457, 279-284.

[11] Nishiuchi, S., Yamamoto, S., Tanabe, T., Kitsudo, T., Matsumoto, H. & Kawano, Y. (2003). Development of Stainless Spheroidal Carbide (VC) Cast Iron. *Transaction of the American Foundry Society*. 831-844.

[12] Guzik, E. (2001). The process of transforming cast iron – chosen questions. *Archives of Foundry Engineering*.

[13] Kawalec, M. (2011). The spheroidisation of VC carbides in high-vanadium cast iron. *Archives of Foundry Engineering. 11*, 111-116.

[14] Kawalec, M. & Olejnik, E. (2012). Abrasive wear resistance of cast iron with precipitates of spheroidal VC carbides. *Archives of Foundry Engineering*. 12(2), 221-226. DOI: 10.2478/v10266-012-0065-2.

[15] Kawalec, M., Górny, M. (2012). Alloyed white cast iron with precipitates of spheroidal vanadium carbides VC. *Archives of Foundry Engineering*. 12(4), 95-100. DOI: 10.2478/v10266-012-0113-y.