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The spheroidisation of VC carbides in high-vanadium cast iron

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Abstract

High-vanadium cast iron is a type of white cast iron, in which a regular fibrous γ + VC eutectic with about 20 vol.% of vanadium carbides crystallises. The paper presents the results of research during which the high-vanadium cast iron was subjected to spheroidisation treatment with magnesium Elmag 5800 master alloy. The purpose of this operation was to obtain the VC carbides of a spheroidal shape. The study also included metallographic examinations and testing of mechanical properties carried out on high-vanadium cast iron of a eutectic composition in as-cast condition and after the spheroidising treatment. The attempt to spheroidise the vanadium carbides has proved to be quite successful. The introduction of magnesium alloy has made nearly one half of the crystallised vanadium carbides acquire a spheroidal shape. The, obtained in this way, high-vanadium cast iron with vanadium carbides of a spheroidal shape showed very high mechanical and plastic properties. The tensile strength R_m increased by 60% compared to the as-cast alloy, while ductility increased more than twenty times. The presented results are based on the initial trials, but further studies of this new material are planned, mainly to check its resistance to abrasion, to impacts and corrosion. Tests are also planned to increase the fraction of spheroidal carbides and measure the effect of their content on the mechanical and tribological properties.

Keywords: Mechanical properties; High-vanadium cast iron; Eutectic alloy; Spherodisation; Vanadium carbide

1. Introduction

To combine good casting properties of cast iron with high ductility of steel, the spheroidising treatment is carried out, owing to which the cast iron with spheroidal graphite is obtained. The spheroidal shape of graphite is the most compact one, with the smallest surface area - to - volume ratio, owing to which the active casting cross-section is impaired to a lesser extent, and the concentration of stress around the sites where the graphite occurs is reduced compared with the graphite present in the form of lamellae [1]. Using these features of the spheroidisation treatment, the author of the present study has tried to obtain the vanadium carbide VC of a spheroidal shape assuming, at the same time, that by this treatment the material with a favourable combination of high mechanical and plastic properties will be produced.

In [2-14], the author showed that bulk solidification of Fe-C-V alloys leads to the formation of equiaxial eutectic grains, consisting of austenite and branched, continuous, fibrous skeleton of vanadium carbides VC. While the formation of microstructure in these alloys may be regarded as known and described in detail, the question of the mechanical and tribological properties still remains unresolved. There are no data on the toughness and corrosion resistance of these alloys, while the tribological and mechanical tests are still incomplete.

Previous research done by the author has proved that, depending on the content of carbon and vanadium, the Fe-C-V alloys can reach a high tensile strength of 300 to 800MPa, and the maximum elongation of 7%. Moreover, these alloys show very high resistance to abrasion, higher even than the cast Hadfield steel.

A literature review confirms the growing interest in ordinary high-alloyed white cast iron [15-17] and in white cast iron with carbide precipitates in the form of spheroids. In [18-21] information was found on the spheroidising treatment of alloyed white cast iron with a high content of chromium, vanadium and nickel using the rare earth metals; the aim of the treatment was improving the cast iron wear resistance behaviour. However, no information was found on the spheroidising treatment of Fe-C-V alloys or on application of the spheroidising agents other than the rare earth metals.

2. Methodology of research

To perform the planned tests, two melts of around eutectic composition were carried out in a Balzers vacuum furnace in an argon atmosphere. For melting the following materials were used: Fe-V master alloy containing 81.7% vanadium, Armco iron, and technically pure graphite. The first melt was a base melt (W), while the second one was subjected to a spheroidising treatment (S). As a spheroidising agent, the Elmag 5800 master alloy containing 44-48% Si, 5.5-6.2% Mg, 0.8-1.2% RE, 0.8-1.2% Ca, max 1.0% Al was used and added in an amount of 1.5 wt.% respective of the charge weight. Moulds were made of molochite flour with an addition of CO_2 hardened sodium silicate. They were baked up to a temperature of 550°C, then poured with liquid cast iron at a temperature of 1700°C. After knocking out of castings, the specimens were cut out for metallographic examinations and mechanical tests.

Unetched specimens were examined under a MEF4 M optical microscope made by Leica Company and under a JEOL 5500LV scanning electron microscope using secondary electrons. This allowed distinguishing vanadium carbides from other phases, which is not always possible when an optical microscope is the only tool used in the studies. For more detailed examinations of the geometry of individual phases, the specimens were deep etched with aqua regia and examined under the scanning microscope. The percent fractions of structural constituents were determined using a Leica QWin automatic image analyser.

Specimens for mechanical tests were tested at a rate of 0.01 cm/min on an INSTRON type testing machine provided with an extensometer.

3. Discussion of results

Table 1 compares the chemical composition of alloys obtained, their microstructure and the content of microstructural constituents. The degree of eutectic saturation was calculated from the following formula:

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

where:

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

C – carbon content in cast iron, [%].

Both examined alloys had a eutectic composition. Figure 1 shows images of microstructures of the base cast iron (W) and cast iron subjected to spheroidising treatment (S). It is clear that in both alloys the matrix is ferritic, as confirmed by a quantitative EDX analysis of the chemical composition in microregions. An example of the analysed microregions is shown in Figure 2, while below the results of measurements are given.

In base cast iron, vanadium carbides crystallised in the form of eutectic fibres. The addition of a spheroidising master alloy to the second alloy (S) has made more than 5% of the vanadium carbides crystallise in the form of spheroids. The fraction of spheroidal carbides reached nearly 34% of all the vanadium carbides crystallised in alloy S. This confirms that the spheroidisation treatment has been effective.

Deep etching with aqua regia and scanning electron microscopy (Fig. 3) enabled detailed 3D examinations of the crystallised phases.

a) b)

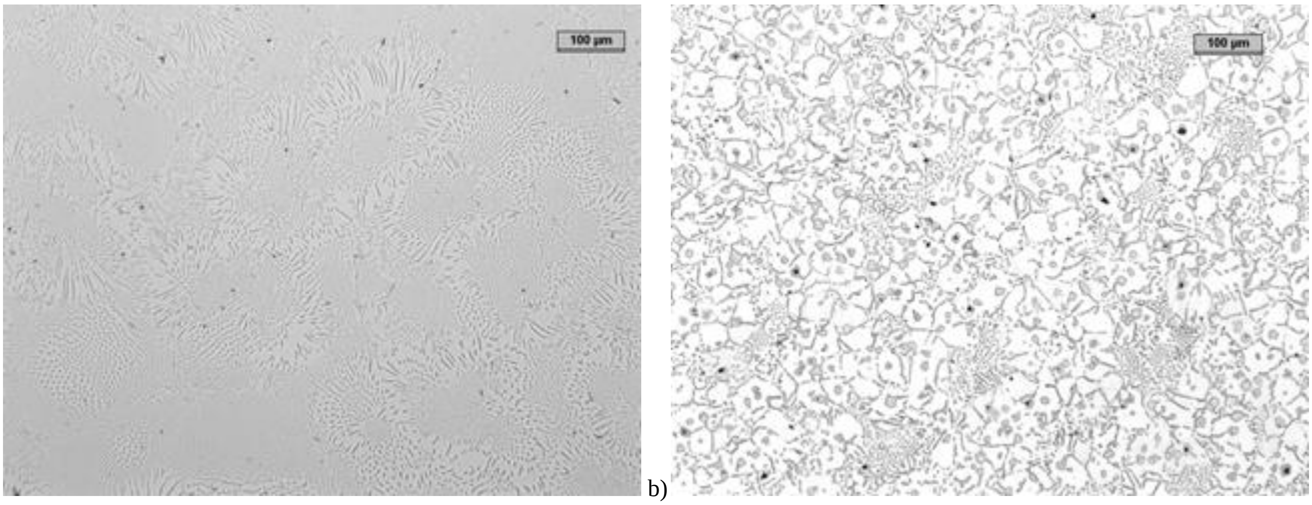


Fig. 1. Microstructure of base alloy (a) and of alloy subjected to spheroidising treatment (b); etched in Vilella's reagent

Table 1.
Chemical composition and content of microstructural constituents in the examined alloys

Melt No.	Chemical composition			Content of microstructural constituent			$f_{w,e}$	$f_{w,s}$	C/V	S_c
	C [%]	V [%]	Si [%]	f_f [%]	$f_{p.z.}$ [%]	$f_{p.p.}$ [%]	[%]	[%]		
W	1.44	15.60	0.32	83.41	-	-	16.59	-	0.09	1.03
S	1.38	16.25	0.54	83.91	-	-	10.64	5.45	0.09	0.99

f_f – ferrite content in cast iron
$f_{p.z.}$ – granular pearlite content in cast iron
$f_{p.p.}$ – lamellar pearlite content in cast iron
$f_{w,e}$ – content of eutectic carbides in cast iron
$f_{w,s}$ – content of spheroidal carbides in cast iron

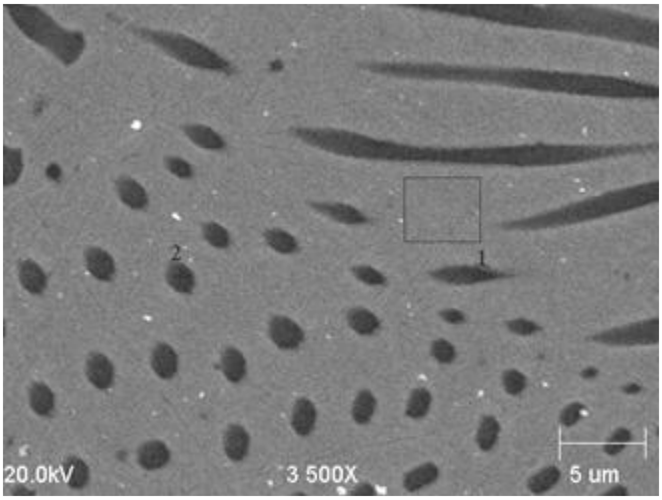


Fig. 2. Chemical analysis of individual phases using local X-ray microanalysis (EDX)

Area 1 – Alloyed ferrite

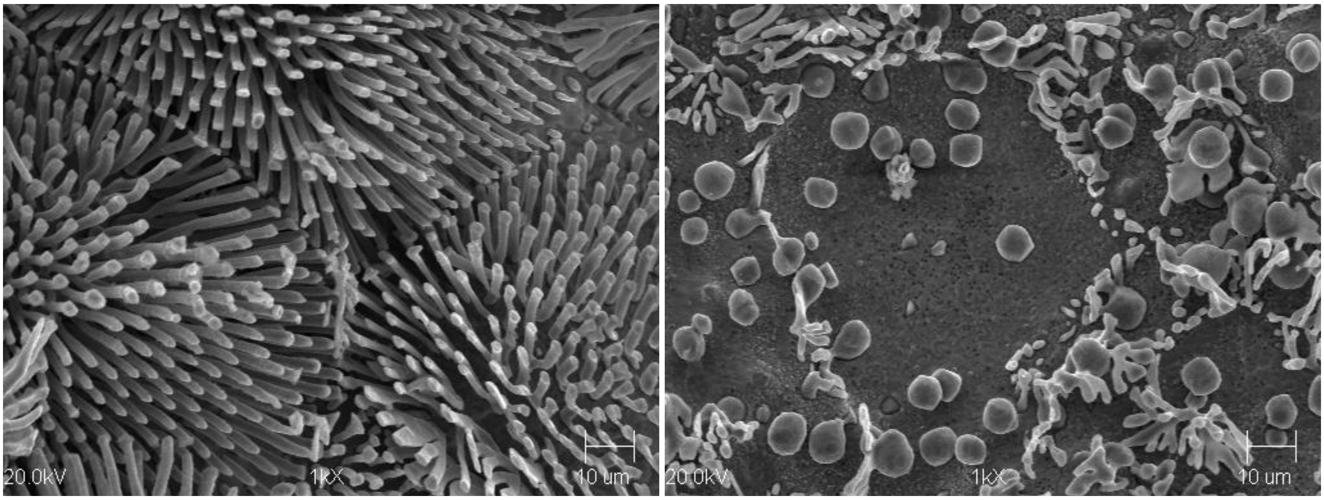
Elt.	Line	Intensity (c/s)	Error 2-sig	Gauss Fit	Atomic %	Conc		Error 2-sig	Bkg Int (c/s)	Bkg Error 2-sig	MDL 3-sig
C	Ka	0.01	0.043	0.00	0.607	0.132	wt.%	0.414	0.23	0.176	3.708
V	Ka	13.34	1.333	0.63	8.574	7.919	wt.%	0.792	1.30	0.416	0.535
Fe	Ka	76.95	3.203	1.60	90.819	91.949	wt.%	3.827	1.60	0.462	1.194
					100.000	100.000	wt.%				

kV 20.0
Takeoff Angle 35.0°
Best Match

Point 2 – Eutectic carbide

Elt.	Line	Intensity (c/s)	Error 2-sig	Gauss Fit	Atomic %	Conc		Error 2-sig	Bkg Int (c/s)	Bkg Error 2-sig	MDL 3-sig
C	Ka	0.01	0.043	0.00	0.607	0.132	wt.%	0.414	0.23	0.176	3.708
V	Ka	13.34	1.333	0.63	8.574	7.919	wt.%	0.792	1.30	0.416	0.535
Fe	Ka	76.95	3.203	1.60	90.819	91.949	wt.%	3.827	1.60	0.462	1.194
					100.000	100.000	wt.%				

kV 20.0
Takeoff Angle 35.0°
Best Match

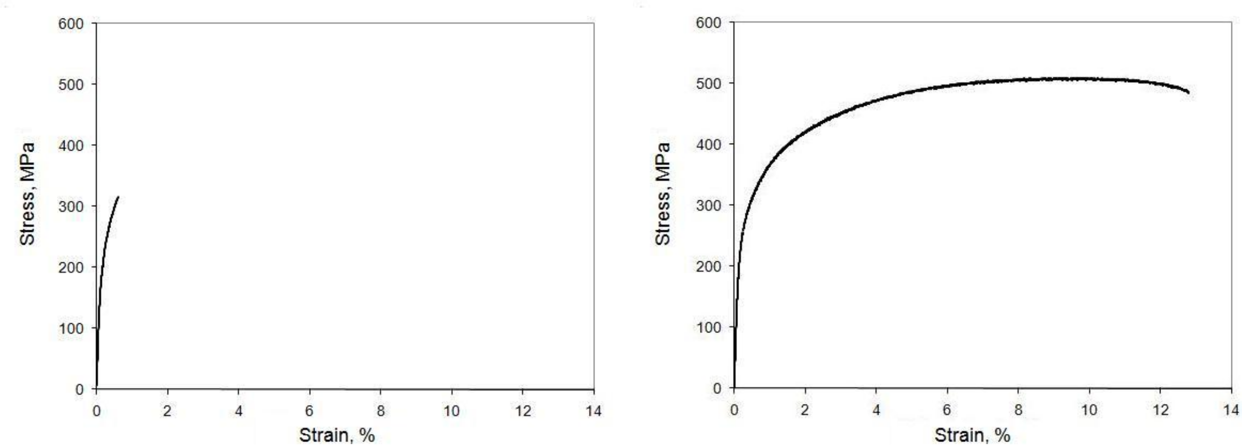


a) b)

Fig. 3. Microstructure of alloy as-cast (a) and after the spheroidising treatment (b); deep etching with aqua regia (SEM)

Table 2.
Mechanical properties and hardness of the examined alloys

Melt No.	Hardness	Mechanical properties			
	HV30	R_m [MPa]	$R_{p0,2}$ [MPa]	$R_{p0,05}$ [MPa]	A_5 [%]
W	205	316	262	85	0.6
S	199	509	292	190	12.8



a) b)

Fig. 4.The stress-strain curve of alloy as-cast (a) and after the spheroidising treatment (b)

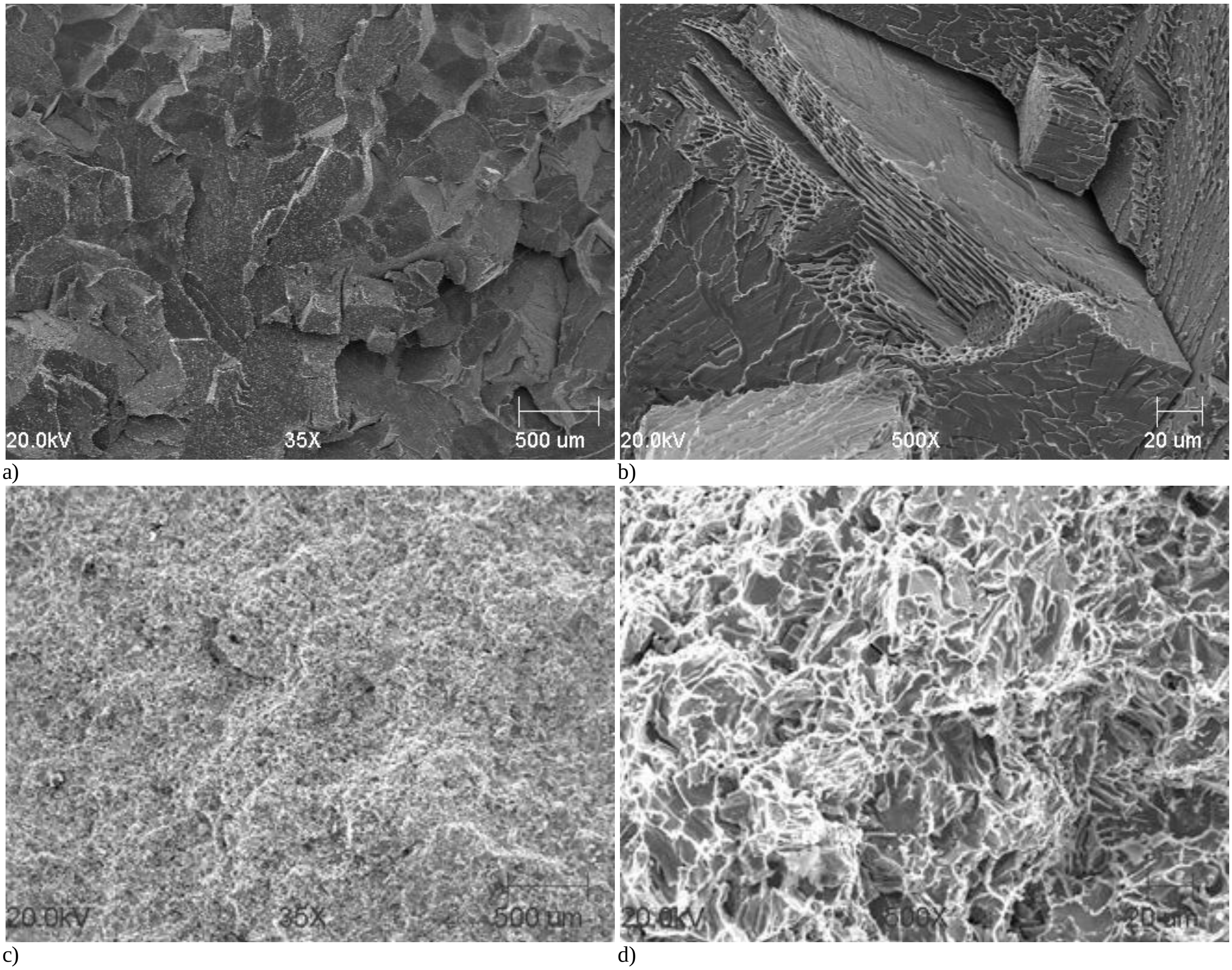


Fig. 5. Microstructure on alloy section as-cast (a, b) and after the spheroidising treatment (c, d); (SEM)

The results of mechanical tests and hardness measurements are summarised in Table 2. Figure 4 shows plotted tensile curves of cast iron in base state and after the spheroidising treatment. A comparison of these two curves clearly shows how strongly the tensile strength and ductility are influenced by the shape of the crystallising vanadium carbides. The alloy in which a fibrous vanadium eutectic crystallised showed a tensile strength of 316 MPa and elongation equal to 0.6%. The second alloy, containing more than 5% of spheroidal carbides and nearly 11% of the eutectic carbide fibres, showed significantly higher levels of mechanical properties. Its tensile strength was 509 MPa, and elongation 12.8%. Hence it follows that the spheroidising treatment of high-vanadium cast iron has increased the tensile strength by 60% and elongation more than twenty times.

Spheroidisation treatment did not affect the alloy hardness, which in both cases amounted to 200 HV30.

To compare the nature of the fracture obtained in specimens from the two melts, microscopic examinations were carried out using scanning electron microscopy. The results of these observations are shown in Figure 5. They also confirm the previously commented results. The fracture obtained during mechanical tests carried out on the high-vanadium cast iron in as-cast state is of a brittle nature (Fig. 4a, b), while in cast iron subjected to the spheroidising treatement, the fracture becomes ductile (Fig. 4c, d).

4. Conclusions

Based on the conducted studies, the following conclusions were put forward:

1. Introducing 1.5% of Elmag 5800 magnesium master alloy to high-vanadium cast iron of eutectic composition makes 34% of vanadium carbides crystallise in the form of spheroids. The remaining vanadium carbides assume the shape of fibres.
2. The spheroidising treatment carried out on high-vanadium cast iron increases the mechanical properties by 60%.
3. The spheroidisation of vanadium carbides in high-vanadium cast iron improves the ductility over twenty times.
4. The addition of spheroidiser does not affect the hardness of high-vanadium cast iron.

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