ARCHIVES
of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (1897-3310)
Volume 14
Special Issue
1/2014
143-146
29/1

Crystallization of Eutectics in Fe-C-V-Si Alloys

M. Kawalec[a*]
[a]Faculty of Foundry Engineering, Department of Engineering of Cast Alloys and Composites,
AGH University of Science and Technology, ul. Reymonta 23, 30-059 Kraków, Poland
* Corresponding author. E-mail address: kawalec@agh.edu.pl

Received 12.03.2014; accepted in revised form 31.03.2014

Abstract

This article addresses the results of microstructural examinations of the volume solidifying Fe–C–V–Si alloys containing carbon in the range of 1.39÷1.76%, vanadium in the range of 6.77÷7.77% and silicon in the range of 0.02÷3.10. The melting charge was Armco iron, ferro-vanadium with 81.7 wt.%V, spectrally pure graphite and technically pure silica. It was shown that with increasing the silicon content, the microstructure of the resulting alloy changing. These changes include both a matrix the shape of the primary carbides and type of crystallizing eutectic. In the studied alloys was observed following eutectic: fibrous (crystallize as non-faceted/ non-faceted eutectic), complex regular (crystallize as faceted/ non-faceted eutectic), spiral (crystallize as faceted/ faceted eutectic). The results illustrated by the images of the microstructures made with an optical microscope and a scanning electron microscope.

Keywords: Theory of Crystallization, Fe-C-V-Si alloys, High vanadium cast iron, Microstructure, Eutectic grain.

1. Introduction

Properties of many alloys with a high technical importance depend inter alia on the eutectics structure present in the alloys. Therefore very important to know the type of eutectic phases, their shape and the volume fraction and the thermodynamic stability [1].

The Fe–C–V–Si alloys as well as Fe–C–V alloys, belong to the group of white cast iron because all of the carbon is bonded at vanadium carbides [2,3]. These alloys have a very interesting mechanical and tribological properties [4-7], which may be shaped by the microstructure. In papers [8,9] provides information about the microstructure of alloys Fe-12.9% V-2.94% C. They found the presence of fibrous eutectic γ + VC_{1-x}. Vanadium carbide volume fraction in the eutectic is about 20%.

The degree of saturation of the eutectic in Fe–C–V–Si alloys can be determined in the following way:

$$S_c = \frac{C}{7.618 \cdot V^{-0.617} - 0.2 \cdot Si} \qquad (1)$$

where: C, V and Si are carbon, vanadium and silicon content in cast iron [4, 6].

2. Experimental

A series of melts was made in a BALZERS (VSG 02) induction furnace under an argon atmosphere. The furnace charge consisted of Armco iron, ferro-vanadium with 81.7 wt.% V, spectrally pure graphite and technically pure silica. Moulds made from molochite flour with water glass were hardened with CO_2, heated to a temperature of 550°C.The liquid cast iron was poured at a temperature of 1700^{o}C. After removing casting from the mold, from the lower part of ingots free from the porosity shrinkage defects, samples for metallographic examinations were cut out.

3. Experimental Results and Analysis

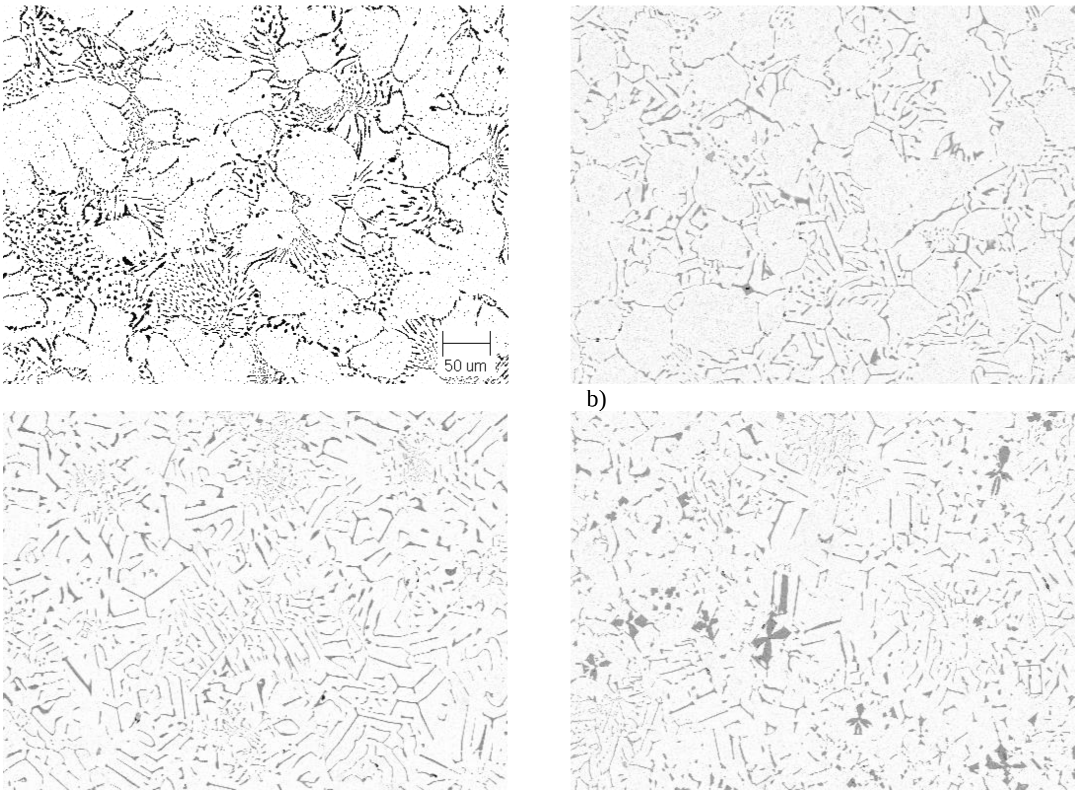
Table 1 lists the results of the chemical composition of the tested samples, the content of microstructural constituents and the degree of eutectic saturation determined from relationship (1). Metallographic analysis was performed using a JEOL 5500LV scanning electron microscope (SEM), using the secondary electrons (BEIS). In this way, it was possible to distinguish the carbides from other phases.

Crystallizing Fe-C-V-Si cast iron can be categorized into three groups: hyper- (fig. 1d), hypo- (fig. 1a, 1b), and near-eutectic alloys (fig. 1c).

Detailed analysis of samples using SEM confirmed that in hypereutectic Fe–C–V–Si alloys the primary vanadium carbides crystallize as faceted/faceted dendrites (see fig. 1d).

Deep etching with *aqua regia* followed by observations under the scanning microscope have proved that the pre-eutectic vanadium carbides are crystallizing in the form of faceted dendrites (fig. 2d). Figures 2b-2f shows the effect of silica addition on changes in the microstructure of Fe–C–V alloys. Analysis of these results shows that silica addition changes the morphology of the crystallising eutectic from fibrous (fig. 2a) to complex regular (fig. 2b, 2e).

Generally, the eutectic grains in the studied alloys Fe–C–V–Si can be described as faceted/nonfaceted. This type of eutectic is among the group of complex regular eutectics. In work [10] Kesri and Durand-Charre called such morphology as "Chinese script". In addition, growth of eutectic grains is strongly dependent on the restrictions of crystallographic whenever spiral growth is observed. This kind of eutectic showing on Fig. 2f. This rare microstructure of spiral segments was observed in one of the eutectic Fe–C–V–Si alloys. This rare eutectic observed so far only in the following systems: α–Al–Th, α–Al–Mg_2Si, $BaNb_2O_6$–$SrNb_2O_6$ and Zn–Zn_2Mg systems [1].



a) b) c) d)

Fig. 1. Microstructures of investigated alloys – a - d respectively alloy No. 1 - 4; unetched specimens, BEI.

Table 1 Chemical composition of alloys tested with the corresponding microstructure

No. of alloy	Chemical composition			Type of microstructure	C/V	S_c (Eq. 1)
	C%	V%	Si%			
1	1.39	6.77	0.02	R. $f_{p.z}$	0.21	0.59▲
2	1.39	7.35	1.05	R+C; $f_{p.z}$+$f_{p.p}$	0.19	0.69▲
3	1.72	7.48	2.65	C+S; $f_{p.p}$	0.23	1.03●
4	1.76	7.77	3.10	C+S; VC_F; $f_{p.p}$	0.23	1.15■

$f_{p.p}$ – lamellar pearlite; $f_{p.z}$ – granular pearlite;
VC_F – primary faceted VC carbides;
▲ – hypoeutectic structure; ● – eutectic structure; ■ – hypereutectic structure;
R – regular fiber-like eutectic cells;. C – complex regular morphology of eutectic cells; S – spiral eutectic cells.

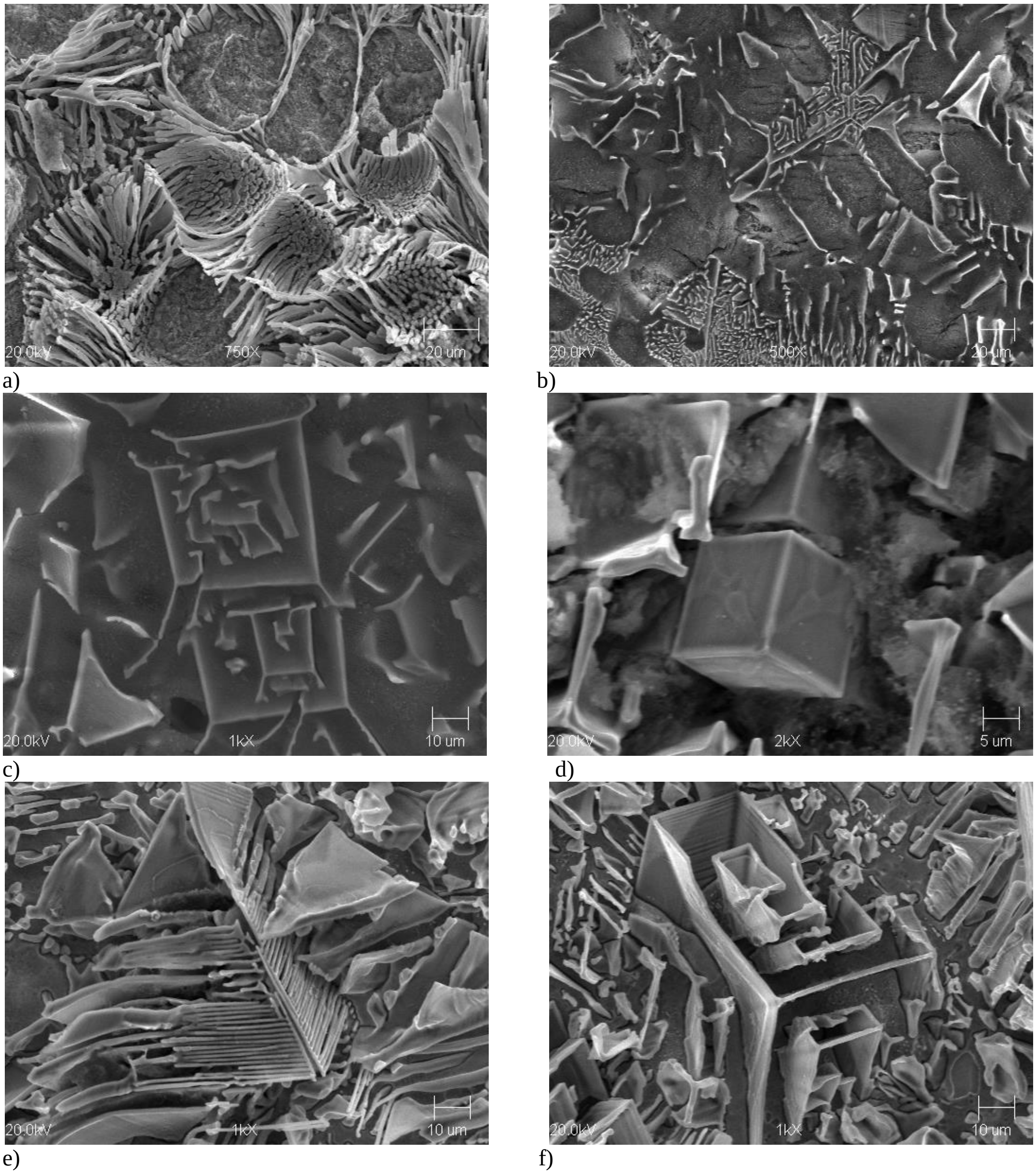


Fig. 2. Microstructures found in Fe–C–V–Si alloys; SEM micrographs of samples deep-etched with aqua regia.

4. Conclusions

1. Solidification processing was used in Fe–C–V–Si cast alloys with variable content of C, V and Si. Obtained alloys can be divided into -, hyper- and near-eutectic depending on the ratio C/V, and the amount of added silica.
2. In Fe–C–V alloys the content ratio of carbon to vanadium is an important parameter and it has a large influence on the type of crystallized matrix, fraction of vanadium carbides and the amount of eutectic grains.
3. In tested alloys the crystallized eutectics may be counted towards following groups:
   - non-faceted – non-faceted eutectic with regular fiber like structures,
   - non-faceted – faceted eutectic with complex regular structures,
   - faceted –faceted eutectic with spiral structure,
   - non-faceted – non-faceted + faceted – non-faceted (dual morphologies). The first with regular fiber-like structures and the second with complex regular eutectic structures.

Acknowledgments

The project was funded by the National Centre for Science from funds awarded by the decision No. DEC- 2011/01/D/ST8/06456

References

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

[2] Kopyciński, D., Kawalec, M., Szczęsny, A., Gilewski, R. & Piasny, S. (2013). Analysis of the structure and abrasive wear resistance of white cast iron with precipitates of carbides. *Archives of Metallurgy and Materials*. 58(3), 973-976.

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

[4] Fraś, E., Kawalec, M. & Lopez H.F. (2009). Solidification microstructures and mechanical properties of high-vanadium Fe-C-V and Fe-C-V-Si alloys. *Materials Science and Engineering A*. 524, 193-203.

[5] Fraś, E. & Kawalec, M. (2009). Effect of silicon on the structure and mechanical properties of high-vanadium cast iron. *Archives of Foundry Engineering*. 9(3), 231-234.

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

[7] Kawalec, M. & Fraś, E. (2009). Abrasive wear resistance of high-vanadium cast iron. *Archives of Foundry Engineering*. 9(4), 103-108.

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

[9] Fraś, E., Guzik, E., Kapturkiewicz, W. & Lopez H. F. (1997). Carbide morphology in bulk and undirectionally solidified Fe-C-V eutectics. *Materials Science and Technology*. 13, 989-996.

[10] Kesri, R. & Durand-Charre, M. (1988). Metallurgical structure and phase diagram of Fe-C -V system: comparison with other forming MC carbides. *Materials Science and Technology*. 4, 692-699.