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Effect of silicon on the structure and mechanical properties of high-vanadium cast iron

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Abstract

The results of microstructural examinations and mechanical tests carried out on Fe-C-V and Fe-C-V-Si alloys solidifying in volumetric mode, containing 1,38-1,83%C, 6,76-14,72%V and 1,05-3,69 Si, have been reported. The eutectic crystallising in Fe-C-V alloys is composed of ferrite and vanadium carbides of the VC_{1-x} type, and as such is included in the group of fibrous eutectics. Introducing silicon additions to the Fe-C-V system changes the geometry of the solidifying eutectic from fibrous to complex regular, and the shape of primary carbides from non-faceted dendrites to the faceted ones. It has been proved that the tensile strength R_m, proof stress $R_{0,2}$, unit elongation A_5 and hardness HV30 depend mainly on the type of alloy matrix. It has also been proved that adding silicon to Fe-C-V alloys may increase the hardness HV30 by about 24% and the tensile strength R_m by as much as 40%, with simultaneous 80% reduction of the unit elongation A_5.

Keywords: Mechanical properties, Fe-C-V alloy, Eutectic alloy, Eutectic, Cast iron

1. Introduction

The reference literature on high-vanadium cast iron is very scarce. In [1,2] the authors give information on the structure of Fe-12,9%V-2,94%C alloys, which have been reported to include in their composition a fibrous $\gamma + VC_{1-x}$ eutectic with vanadium carbides present in an amount of about 20 vol.%. The results of microstructural examinations carried out on Fe-C-V alloys with carbon contained in the range of 1,38-4,16 and vanadium in the range of 6,7-15,5%, as well as the results of mechanical and tribological tests made on these alloys were described in [3, 4]. The research disclosed in [5] has indicated that, added to the Fe-C-V system, silicon changes the geometry of the crystallising eutectic from fibrous into complex regular, and the shape of carbides. The aim of the research described in this study was to determine the silicon effect on R_m, $R_{0,2}$, A_5 and HV30 of Fe-C-V alloys.

2. Methods of investigations

To perform the anticipated mechanical tests, a series of melts with varying content of carbon, vanadium and silicon were made, using Balzers vacuum type furnace and the atmosphere of argon. The Fe-V master alloy with 81,7% vanadium, armco iron, technically pure graphite and commercial 98,5% Si silicon were used. Moulds prepared from molochite flour with CO_2-hardened sodium silicate were preheated to a temperature of 550^{o}C, and poured next with molten iron at a temperature of 1600^{o}C. After knocking out of castings, the specimens were cut out for metallographic examinations and mechanical tests. The tensile tests were carried out on an INSTRON machine with an extensometer operating at a rate of 0,01cm/min. Vickers hardness was also measured in the examined alloys according to PN-EN ISO 6507-1, applying a load of 294,2N.

3. Results and analysis

The chemical composition and the content of microstructural constituents in the examined alloys are given in Table 1. Figure 2 shows examples of microstructures present in Fe-C-V-Si alloys, while Figure 1 shows the effect of silicon additions on changes in the microstructure of Fe-C-V alloys. From analysis of these results it follows that the addition of silicon changes the morphology of the crystallising eutectic from fibrous (Fig. 1a, c) into complex regular (Fig. 1b, d). The primary carbides are also changing their shape, and after the addition of silicon undergo transformation from non-faceted crystals (Fig. 1e) into faceted ones (Fig. 1f). The results of the tensile tests and mean hardness values are compared in Table 2. Examples of the tensile curves plotted for Fe-C-V alloys with different silicon content, and hence of different microstructures (Table 1), are shown in Figure 3. From the data it follows that silicon causes increase of the tensile strength by 4-40%, depending on the type of the crystallised matrix, with simultaneous rapid decrease of elongation by 30-80%. Basing on the data compared in Table 2, it can also be concluded that introducing silicon addition to Fe-C-V alloys increases the cast iron hardness, the fact that can prove a solution hardening effect exerted by silicon on ferrite.

Table 1.
Alloys chemical composition and fraction component of structure

Melt No.	Chemical composition			Matrix constituent content					Microstructure	C/V
	C [%]	V [%]	Si [%]	f_f [%]	$f_{p.z.}$ [%]	$f_{p.p.}$ [%]	f_w [%]	f_d [%]		
1	1,38	6,76	-	-	88,86	-			■	0,20
Si-1	1,38	7,36	1,05	-	86,11	-	11,14	58,00	■	0,19
2	1,80	9,17	-	-	27,30	57,36	13,89	38,21	■	0,20
Si-2	1,77	9,97	3,69	-	84,81	-	15,35	23,00	●	0,18
3	1,81	11,17	-	-	80,08	-	15,19	-	●	0,16
Si-3	1,83	11,71	1,48	73,10	2,00	-	19,92	-	●	0,16
4	1,55	10,90	-	76,90	5,00	-	24,90	-	■	0,14
Si-4.1	1,44	11,63	1,13	80,50	3,00	-	18,10	23,00	▲	0,12
Si-4.2	1,43	11,86	2,12	63,23	20,00	-	16,50	-	●	0,12
5	1,53	14,70	-	82,11	-	-	16,27	-	●	0,10
Si-5	1,48	14,72	1,22	83,70	-	-	17,89	-	●	0,10

● - hypereutectic microstructure
▲ – nearly eutectic microstructure
■ - hypoeutectic microstructure

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 – vanadium carbide content in cast iron (hypoeutectic and eutectic)
f_d – content of austenite dendrites transformed in ferrite

Table 2.
Mechanical properties and hardness of the examined alloys

Melt No.	Hardness		Mechanical properties			
	HV30	HB	R_m [MPa]	$R_{0,2}$ [MPa]	$R_{0,05}$ [MPa]	A_5 [%]
1	298	283	709	556	267	4,2
Si-1	325	309	774	608	285	1,2
2	338	322	676	525	175	1,1
Si-2	378	359	726	702	415	0,6
3	204	194	585	306	168	5,1
Si-3	253	241	822	714	371	0,9
4	191	182	440	198	99	7,2
Si-4.1	246	234	528	330	188	2,1
Si-4.2	247	236	606	440	212	1,5
5	199	189	580	330	160	7
Si-5	256	244	603	407	225	2,1

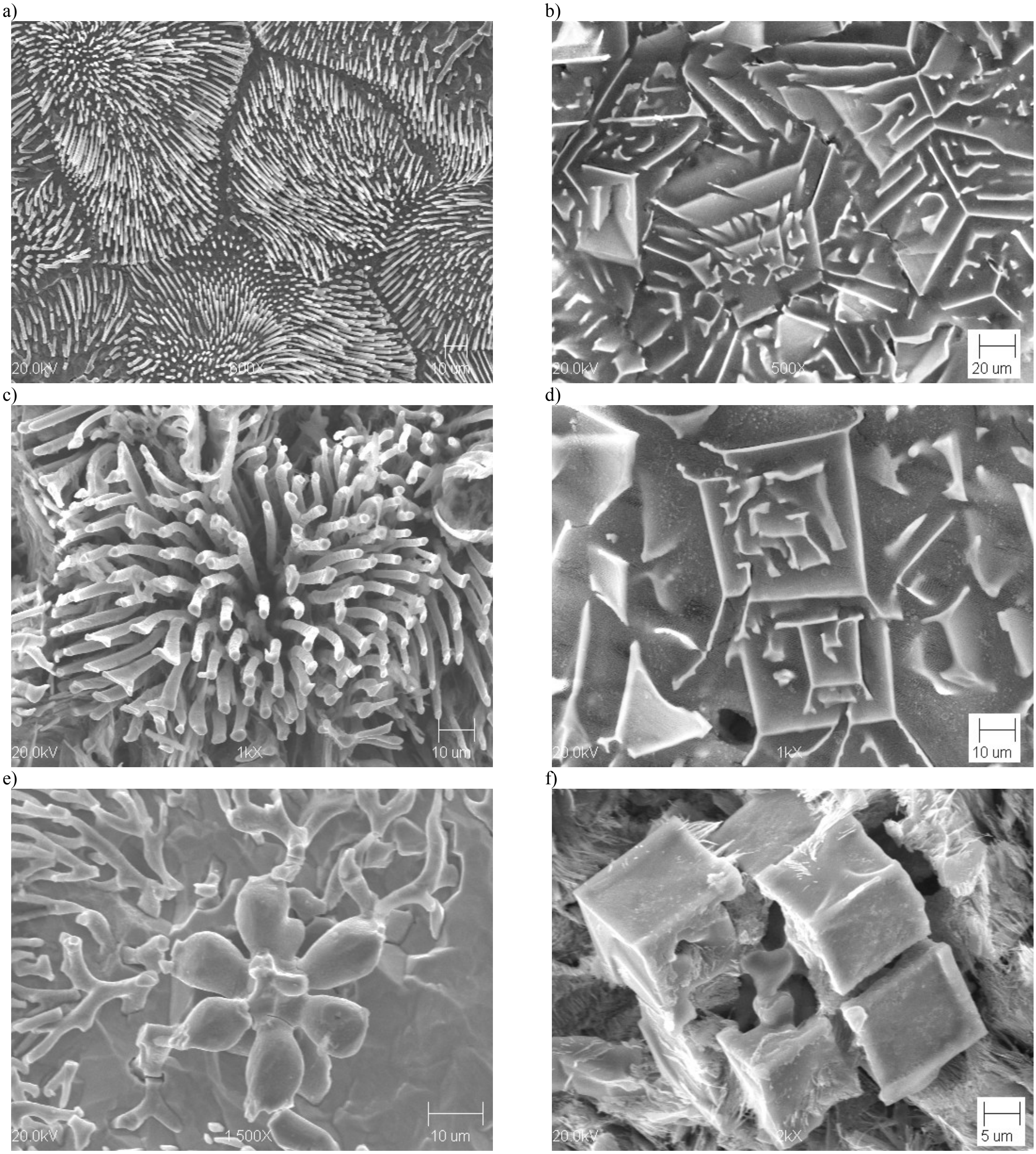

Fig. 1. Microstructure of specimens etched in *aqua regia* (SEI): eutectic grains in Fe-C-V alloy (a, c), grains of complex regular eutectic in Fe-C-V-Si system (b, d), primary vanadium carbides of dendritic form in Fe-C-V alloy (e), primary carbides crystallising in the form of faceted dendrites in Fe-C-V-Si system (f)

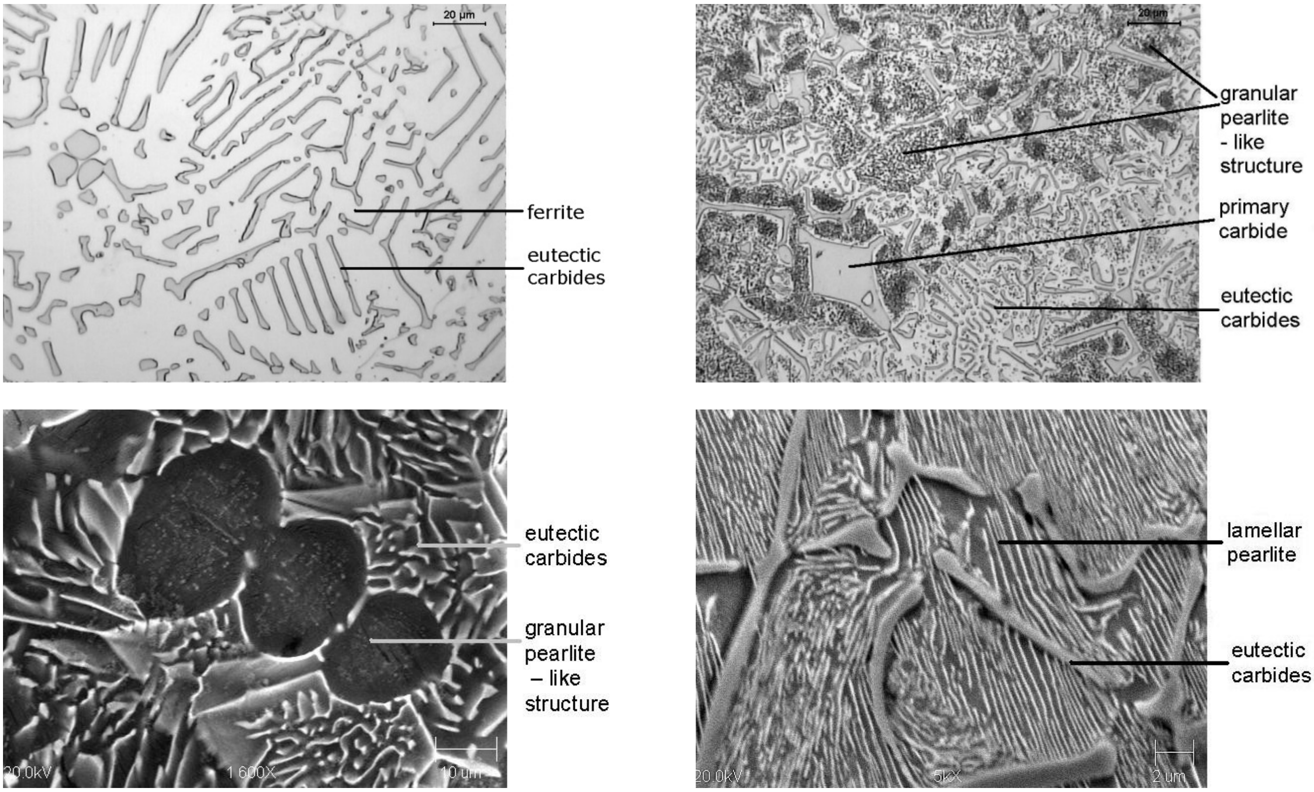

Fig. 2. Microstructure of Fe-C-V-Si alloys

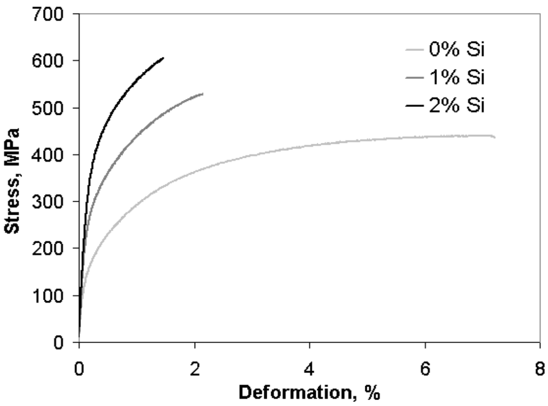

Fig. 3. Example of tensile curves plotted for Fe-C-V alloys with variable content of silicon

4. Conclusions

1. Adding silicon to Fe-C-V alloys in an amount above 1% changes the crystallising eutectic from fibrous regular to complex regular. Silicon addition also changes the shape of primary carbides from non-faceted crystals to the faceted ones.
2. Mechanical properties of high-vanadium cast iron depend on the type of the crystallising matrix, where the ferritic matrix causes relatively low mechanical properties and high ductility, the matrix with lamellar pearlite increases the mechanical properties and hardness on the cost of lower ductility, and the matrix with granular pearlite increases, compared to the matrix with lamellar pearlite, plastic properties and reduces hardness.
3. In the examined range of vanadium and carbon content values, the addition of silicon increases hardness and mechanical properties and reduces the plastic properties of cast iron.

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