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# Effect of Microstructure of Fe-C-V Alloys on Selected Functional Properties

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## Abstract

The cast alloys crystallizing in Fe-C-V system are classified as white cast iron, because all the carbon is bound in vanadium carbides. High vanadium cast iron has a very high abrasion resistance due to hard VC vanadium carbides. However, as opposed to ordinary white cast iron, this material can be treated using conventional machining tools. This article contains the results of the group of Fe-C-V alloys of various microstructure which are been tested metallographic, mechanical using an INSTRON machine and machinability with the method of drilling. The study shows that controlling the proper chemical composition can influence on the type and shape of the crystallized matrix and vanadium carbides. This makes it possible to obtain a high-vanadium cast iron with very high wear resistance while maintaining a good workability.

**Keywords:** Microstructure, Fe-C-V alloy, Workability, Mechanical properties, Vanadium carbide

## 1. Introduction

Fe-C-V alloys, due to bound form of carbon are classified as white cast iron [1,2]. In these alloys skeleton is built of hard vanadium carbides $VC_{1-x}$. Matrix, depending on the carbon and vanadium content, may be a plastic alloyed ferrite, or a tensile strength improver pearlite [3-5]. By controlling chemical composition properly, it is possible to obtain high-vanadium cast iron with very high strength properties, high hardness and abrasion resistance, while preserving the relatively high strength [6,7].

Literature data indicate that, in general, with increasing tensile strength and hardness decrease plastic properties and machinability of iron [8]. In the case of Fe-C-V alloys additional difficulty during cutting cast iron can be a hard, branched carbide skeleton. The study attempts to investigate the machinability of Fe-C-V alloys with varying microstructure.

## 2. Experimental

A series of melts was made in a BALZERS (VSG 02) induction furnace under an argon atmosphere. The melting charge was ferro-vanadium with 81.7 wt.% V, Armco iron and spectrally pure graphite. One of the melts was subjected to a spheroidising treatment using magnesium master alloy. The liquid alloys were overheated to 1700°C and then poured in rectangular shaped foundry molds fed from a large feeder. Moulds were made from molochite flour with $CO_2$ hardened sodium silicate, preheated to a temperature of 550°C. The test samples were cut out from the lower part of the test blocks and they were free from any casting defects. Then the cast samples were prepared for metallographic characterization.

The metallographic specimens were examined in a JEOL 5500LV scanning electron microscope (SEM) using secondary electrons. By this means it was possible to distinguish the vanadium carbides from any other phases. The dendrite fraction and the fraction of vanadium carbides (primary + eutectic) were recorded from optical micrographs taken at 100× from non-etched specimens using a LEICA QWin automatic image analyzer. Also in order to examine the shape of the individual phases in a closer detail the specimens were deep-etched with aqua regia and then examined in the SEM. A LEICA QWin automatic image analyzer was used for volume fraction determinations of granular pearlite-like, lamellar pearlite, alloyed ferrite and cementite eutectic using Vilella's reagent etched specimens and with magnifications of 100 and 250×.

The tensile tests were carried out on an INSTRON machine with an extensometer operating at a rate of 0.01 cm/min. Vickers hardness was also measured in the examined alloys according to PN-EN ISO 6507-1, applying a load of 294.2 N.

To machinability studies was used cutting tools (borer 15 mm) with identical contour and angles, which were burdened of force 500 N. Rotational speed of tools was 680 turns on minute. In each investigated samples were bored 3 test-hole and time of boring was measured.

## 3. Experimental Results and Analysis

Table 1 lists the results of the chemical composition of the tested samples, the type of microstructure and the degree of eutectic saturation determined from relationship (1).

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

For $S_c$<1, $S_c$=1 and $S_c$>1 the alloys of, respectively, hypoeutectic, eutectic and hypereutectic composition are obtained.

Figure 1 shows examples of microstructures present in Fe-C-V alloys. To perform the required tests, were chosen six alloys: hypoeutectic, eutectic and hypereutectic type of microstructure with a matrix of alloyed ferrite, granular pearlite-like and lamellar pearlite. It was also examined an alloy, in which the vanadium carbides are spheroidal and the matrix is alloyed ferrite. The microstructure of the alloy was obtained by introducing magnesium master alloy as spheroidiser.

The results of the tensile tests and mean hardness values are compared in Table 2. These data indicate that the highest tensile strength show the alloys with a matrix of lamellar pearlite (677-783 MPa). The plasticity in this group of alloys is very low (about 1%). In the alloy with granular pearlite-like matrix tensile strength is almost 500 MPa, while keeping a relatively high elongation (6%). The best ratio of tensile strength to plasticity was observed in the alloy No. 2, wherein the alloy matrix is a alloyed ferrite and carbides are spheroidal form. The tensile strength in this case is 476 MPa, and elongation 16%.

Recorded data from machinability test are plotted in Fig. 2. They represent actual curves of traverse of the cutting tool with respect to time for all of tested samples. The study results for the alloy No. 6 do not, because in this case the cutting does not occur at a specified load. This alloy, due to the tough pearlitic matrix and the presence of cementitious eutectic in the microstructure showed very poor workability. The indicated data show that the machinability of alloys Fe-C-V influences both hardness and shape of crystallizing carbides. The lowest resistance to the cutting tool put alloy No. 2, which proves its high machinability. Very similar result obtained alloy No. 3, showing a similar hardness. In this alloy in the alloyed ferrite matrix are uniformly distributed fibrous vanadium carbides. The hardest machinable alloy (No. 1) has a pearlitic matrix and fibrous eutectic carbides in addition to the large primary carbides in the shape of dendritic.

Table 1.
Chemical composition of alloys tested with the corresponding microstructure

| No. of alloy | Chemical composition C mas. % | Chemical composition V mas. % | Type of microstructure | C/V | $S_c$ (Eq. 1) |
|---|---|---|---|---|---|
| 1 | 3.07 | 15.25 | ■$f_{p.p.}$ | 0.20 | 2.16 |
| 2 | 1.38 | 15.11 | ▲ $f_{f.}$ | 0.09 | 0.97 |
| 3 | 1.44 | 15.10 | ● $f_{f.}$ | 0.10 | 1.01 |
| 4 | 1.72 | 11.36 | ●$f_{p.z.}$ | 0.15 | 1.01 |
| 5 | 1.79 | 9.19 | ▲$f_{p.p.}$ | 0.19 | 0.92 |
| 6 | 2.16 | 7.66 | ●$f_{p.p.}$ | 0.28 | 1.00 |

$f_{f.}$ – alloyed ferrite; ▲ – hypoeutectic structure;
$f_{p.p.}$ – lamellar pearlite; ● – eutectic structure;
$f_{p.z.}$ – granular pearlite; ■ – hypereutectic structure.

Table 2.
Mechanical properties and hardness of the examined alloys

| No. of alloy | Chemical composition C mas. % | Chemical composition V mas. % | HV30 | $R_m$ MPa | $R_{p0.2}$ MPa | $A_5$ % |
|---|---|---|---|---|---|---|
| 1 | 3.07 | 15.25 | 381 | 738 | 657 | 0.8 |
| 2 | 1.38 | 15.11 | 198 | 476 | 259 | 16.4 |
| 3 | 1.44 | 15.10 | 216 | 388 | 246 | 1.4 |
| 4 | 1.72 | 11.36 | 187 | 493 | 202 | 6.1 |
| 5 | 1.79 | 9.19 | 339 | 677 | 536 | 1.1 |
| 6 | 2.16 | 7.66 | 408 | 783 | 584 | 1.1 |

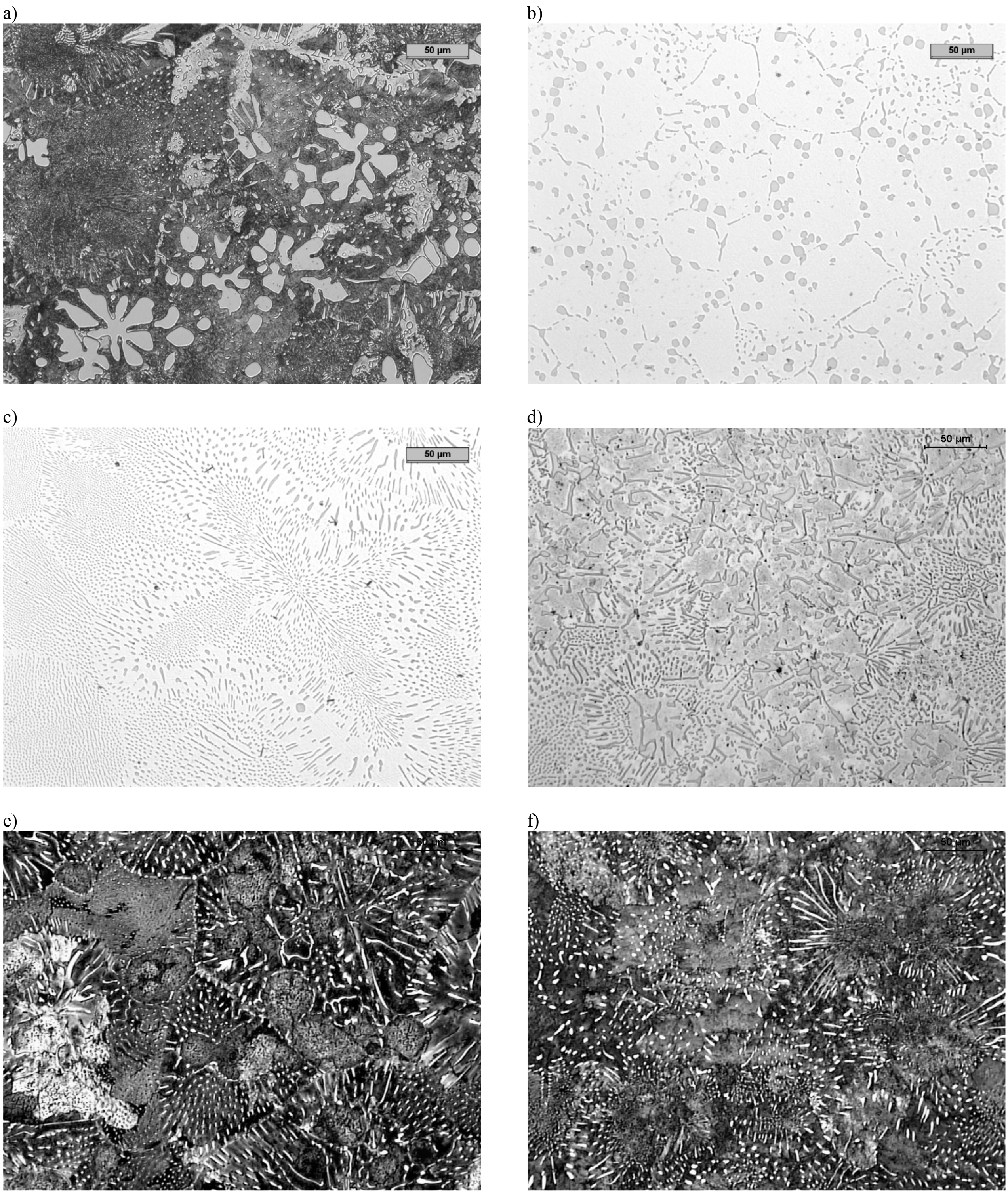


Fig. 1. Microstructures of investigated alloys – a - f respectively alloy No. 1 – 6

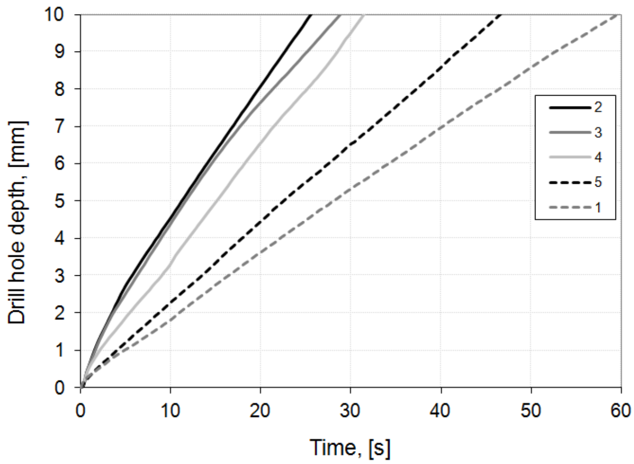

Fig. 2. Cutting curves of the investigated alloys

## 4. Conclusions

The performed studies show that on the machinability of Fe-C-V alloys have influences both the the matrix and the shape of the crystallized carbides. Alloys with the ferritic matrix, although they are classified as white cast iron may be successfully machined using conventional cutting tools. Among the alloys with the matrix alloy exhibits the best properties of spheroidal carbide precipitates VC. While preserving high tensile strength has significant elongation and good machinability.

Alloys with pearlitic matrix, although high-tensile strength show a low elongation and, unfortunately, they are very difficult machinable. In the case of the alloy, wherein except the vanadium eutectic exist also cementitious eutectic, machining with ordinary tools is impossible.

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