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# The Structure of High-Quality Aluminium Cast Iron

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## Abstract

This study presents an analysis of aluminium cast iron structure (as-cast condition) which are used in high temperatures. While producing casts of aluminium iron, the major influence has been to preserve the structure of the technological process parameters. The addition of V, Ti, Cr to an Fe-C-Al alloy leads to the improvement of functional and mechanical cast qualities. In this study, a method was investigated to eliminate the presence of undesirable $Al_4C_3$ phases in an aluminium cast iron structure and thereby improve the production process. V and Ti additions to aluminium cast iron allow the development of FeAl - VC or TiC alloys. In particular, V or Ti contents above 5 wt.% were found to totally eliminate the presence of $Al_4C_3$. In addition, preliminary work indicates that the alloy with the FeAl - VC or TiC structure reveals high oxidation resistance. The introduction of 5 wt.% chromium to aluminium cast iron strengthened the $Al_4C_3$ precipitate. Thus, the resultant alloy can be considered an intermetallic FeAl matrix strengthened by VC and TiC or modified $Al_4C_3$ reinforcements.

**Keywords:** Aluminium cast iron, $Al_4C_3$; TiC, VC; Intermetallic FeAl, Iron aluminides

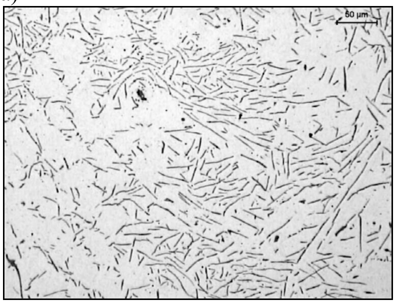
## 1. Introduction

Aluminium is one of the alloying elements used in the manufacture of cast iron, intermetallic compounds (iron aluminides), and various composites.

In the phase equilibrium Fe-Al, there are three important places. These places can be used in foundry technology. Thus, you can predict the iron aluminides FeAl and $Fe_3Al$ and materials with the right side of the equilibrium phase systems and the Fe-Al alloys - the area where there is an eutectic reaction [1-4].

Iron aluminides have a stable structure at elevated temperatures in combination with a unique collection of useful properties[5,6]. These materials are suitable for operation at high temperatures and in chemically active environments. Their main advantages are low density in comparison with the structural alloys such as steels and super alloys of nickel; good tensile strength both at room temperature, as well as elevated temperatures; and excellent resistance to oxidation, even at high concentrations of gases containing sulfur or hydrogen sulfide, as well as resistance to some environmental chemicals corrosive liquid. Also, interesting properties are found in the Al-1.8 wt.%Fe alloys. In these, are isolated eutectic alloys Al-$Al_3$Fe and several metastable phases including: $Al_6$Fe $Al_m$Fe, $Al_x$Fe, $Al_p$Fe, $Al_9Fe_2$. These phases in the reaction of (α)Al can create five eutectic morphologies. The introduction of alloying elements is to move the stability of the eutectic reaction. An example [2] is the addition of vanadium to change the microstructure and properties of an eutectic alloy (Fig. 1).

a)



b)

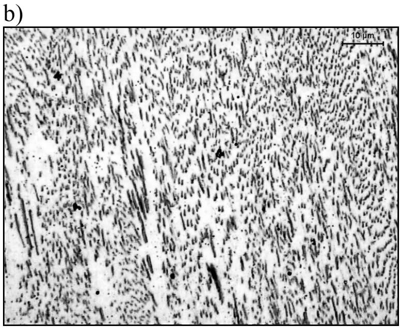
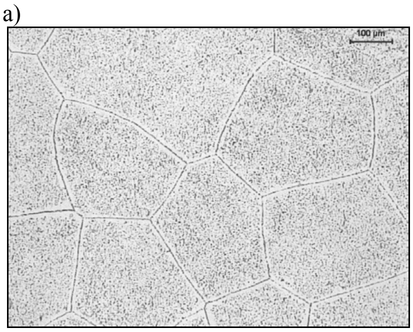


Fig. 1. Microstructure of Al-Fe alloy [2] – (a) and Al-Fe alloy with addition vanadium – (b)

Similarly, additions of titanium, vanadium and chromium have a positive effect on the structure and functional properties of alloys FeAl (iron aluminides). An example of the structure of Fe-(24 wt.%)Al alloy is shown in Figure 2.

a)



b)

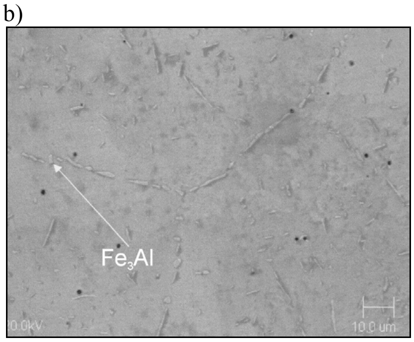



Fig. 2. Microstructure of an Fe-Al alloy [own studies] – optical microscope (a) and scanning electron microscope – (b)

Furthermore, the addition of carbon to these alloys leads to cast aluminium. In cast iron, $Al_4C_3$ is the expected equilibrium phase where the aluminium content is relatively high according to the Fe-C-30wt.%Al phase diagram (see Fig. 3).

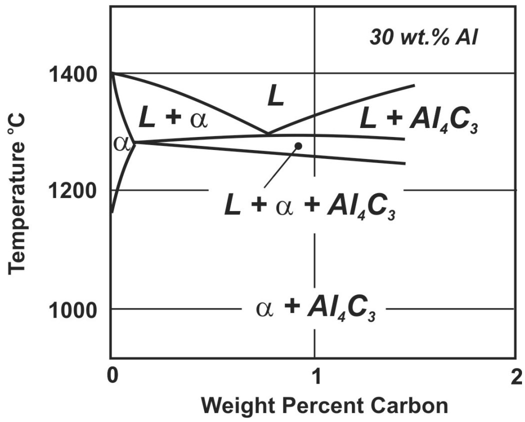



Fig. 3. Polithermal cross-section of the Fe-C-30wt.%Al alloy phase equilibrium system [1]

An example of the structure of aluminium cast iron is shown in Figure 4. In this structure there is a primary and eutectic $Al_4C_3$ precipitate. These carbides are hydrophilic compounds, which lead to drastic reductions in the mechanical properties and to material self-destruction as a result of appreciable swelling. The extent of swelling is related to a net volume increase, which accompanies the carbide reaction with water as [7-12] the following:

$$Al_4C_3 + 12H_2O \rightarrow 4Al(OH)_3 + 3CH_4\uparrow \qquad (1)$$

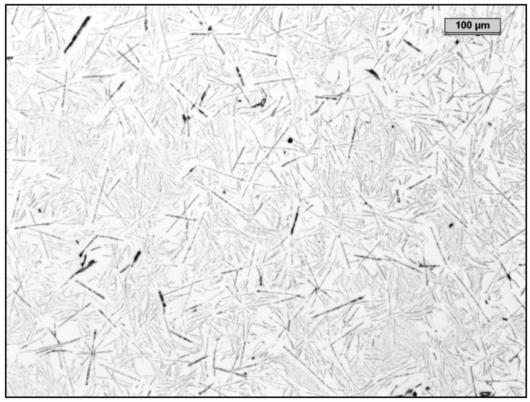



Fig. 4. Microstructure of the aluminium cast iron [own research]

## 2. Method of investigation

A basic cast iron was produced by melting pig iron and steel scrap, aluminium (99,9%), titanium sheets (99.5%), Fe-V, chromium (99,9%) in a 15 kg, capacity induction furnace. The chemical composition of the melts are given in Table 1. Bars ϕ30x260 mm were cast.

Table 1.
The chemical composition cast iron, wt. %

| Melt No. | C | Si | Mn | Al | Ti | V | Cr |
|---|---|---|---|---|---|---|---|
| | wt. % | | | | | | |
| 1 | | | | | - | - | - |
| 2 | 1.25 | 0.29 | 0.25 | 32.7 | 5.5 | - | - |
| 3 | | | | | - | 6.1 | - |
| 4 | | | | | - | - | 5,4 |

Metallographic characterization and quantitative measurements were carried out on transverse sample micro-sections using a Leica optical microscope and a computer driven image analyzer. Finally, oxidation kinetics studies were made by exposing the specimens to air as a function of temperature and time.

The melting conditions employed in this work enabled the formation of a Fe-Al-C liquid solution. Moreover, titanium or vanadium additions into the liquid allowed the precipitation of TiC or VC through the following reactions:

$$C + Ti = TiC \tag{2a}$$

or

$$C + V = VC \tag{2b}$$

The above reactions are thermodynamically stable at the over-heating temperatures employed in this work.
According to this reactions (2), the degree of carbon removal from the melt is strongly influenced by the amount of Ti or V additions. Hence, proper titanium or vanadium concentration can result in total removal of carbon from the liquid. Any remaining carbon can lead to the formation of undesirable $Al_4C_3$ through the following reaction:

$$4Al + 3C = Al_4C_3 \tag{3}$$

The consequence is that by proper Ti or V additions to the melt, the formation of $Al_4C_3$ during crystallization, the alloy under discussion, will be excluded. The introduction of 5.4 wt.% chromium to aluminium cast iron strengthened the $Al_4C_3$ precipitate.

# 3. Results and discussion

Figure 5 shows the resultant microstructures as a function of the Ti and V and Cr content in the Fe-Al-C solidified alloy. From this Figure, it is apparent that in the Ti-free alloy, primary and eutectic $Al_4C_3$ phases are present (Fig 5). Ti additions of 5,5wt.% lead to total replacement of the eutectic $Al_4C_3$ by TiC. The addition of 6.1 wt.% vanadium same effect on the structure of aluminium cast iron (Fig. 5c). However, after the introduction of 5.4 wt.% chromium to the alloy Fe-Al-C in the structure we see another character $Al_4C_3$. A detailed study in this regard will be published.

The macrostructure in Figure 6 a,b shows a coarse-grained fracture, while the photographs in Figure 6c indicate the predominant role of volume solidification in the process of casting formation.

Owing to the process of modifications (vanadium addition), this macrostructure is now of a fine-grained character.

The large number of grains is due to the modification effect, increasing the number of substrates for the nucleation of structural constituents present in this cast iron.

a)

b)

c)

d)

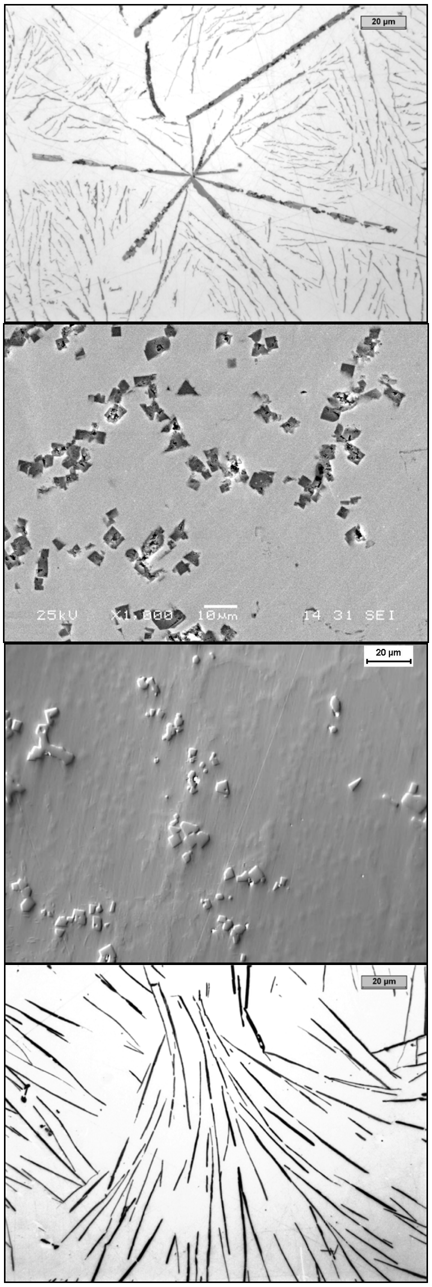



Fig. 5. Microstructures of castings made from aluminium cast iron: melt No. 1 - (a), melt No. 2 - (b), melt No. 3 - (c), melt No. 4 - (d)

Additionally, by breaking the test casting, it has been proved that the modification treatment with vanadium not only refined the microstructure, but also changed the molten alloy parameters which enabled the manufacture of castings free from defects. Fig. 5a shows the shrinkage cavities present in the fracture of the casting poured; these defects were not formed in castings (Fig. 5c,d) made from the FeAl-TiC and FeAl-VC. In the future, vanadium carbide spheroidization will be performed, according to [13].

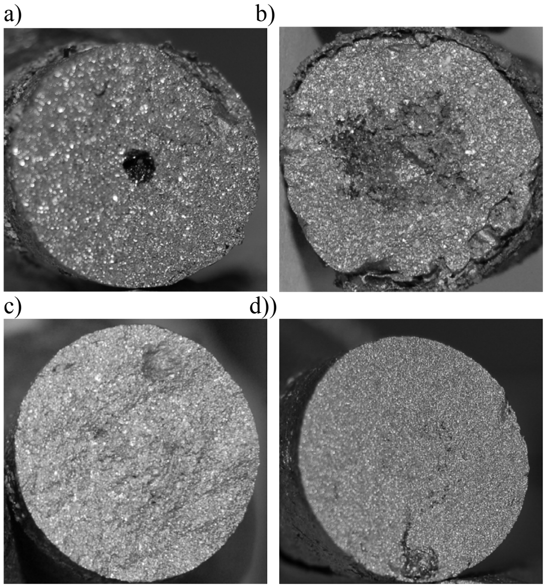



Fig. 6. Macrostructures in fractured experimental castings: FeAl - $Al_4C_3$ – (a), FeAl - TiC – (b), FeAl - TiC with addition Mg - (c), FeAl - VC – (d)

It was found that the aluminium Fe-C alloy exceeded the oxidation resistance of conventional cast irons and high-chromium cast steels used in practice. In particular, notice that the experimental Fe-Al-C (with addition V, Ti, Cr) alloy is as resistant to oxidation as the aluminium cast iron from which it was formed. Yet, it is not prone to self-destruction due to the lack of aluminium carbide in the structure. The oxidation kinetics of the FeAl-TiC alloy exhibited the typical parabolic behaviour associated with diffusion controlled scale growth as seen in Figure 7.

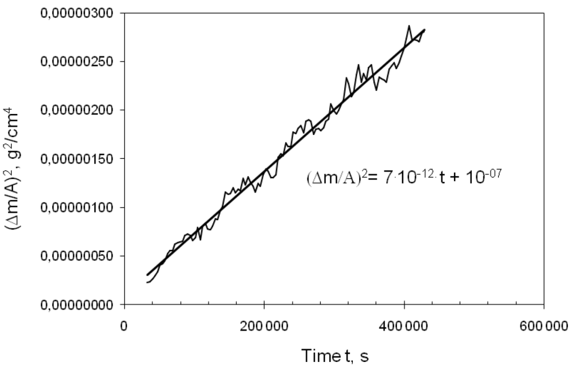



Fig. 7. The designed modified aluminium cast iron oxidation diagram

The magnitude of the parabolic constant for the oxidation rate is relatively high ($7 \cdot 10^{-12}$ $g^2/cm^4 \cdot s^1$). The parabolic constant for the Fe-Al-C alloy was found to be close to that reported in Fe-20%Cr, Ni-20%Cr and Fe-25%Cr-5%Al alloys [9].

# 4. Conclusions

In this work, a method was investigated to eliminate the presence of undesirable $Al_4C_3$ phases in an aluminium cast iron composite, and thus improve the production process. V or Ti additions in aluminium cast iron allows the development of Fe-Al-V(Ti)-C alloys which resemble in-situ composites. In particular, V(Ti) contents above 5.0-6.0 wt% were found to totally eliminate the presence of $Al_4C_3$. In addition, preliminary work indicates that the FeAl-TiC alloy posseses high oxidation resistance (just as in aluminium cast iron), exceeding that of high-chromium cast iron and chromium cast steels. Thus, the resultant alloy can be considered an intermetallic FeAl matrix strengthened by VC and TiC and modified $Al_4C_3$ reinforcements.

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