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White Cast Iron with the Microstructure *in situ* Composite

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Abstract

Alloys based on FeAl intermetallic phases have a heat and corrosion resistance at high temperatures. With the addition of carbon in alloy the carbides appear which makes cast highly resistant to abrasion. However, this material is not widely used because of the presence in the microstructure of the aluminum carbide, which makes the casting disintegrates after a time automatically. The solution to the problem is the decomposition of aluminum carbide and replace it with another carbide forming element. In paper shows that the corresponding elements are titanium, vanadium, bismuth and boron effectively inhibit the process of self-destruction.

Keywords: White cast iron, High-aluminum cast iron, Carbides, Al_4C_3

1. Introduction

The dynamic industry development and the increasing demands of constructors are determined to use the materials which should be characterized by the relative lightness, higher mechanical strength and resistance to high-temperature corrosion. Metal alloys with the matrix of the Fe-Al are seen as materials for high temperature applications. Their main advantages are compact crystallographic and structural stability at high temperatures. These materials are based on the intermetallic phase: FeAl, or Fe_3Al, which is stable up to the melting point of 1240 °C. The use of this material in the presence of high temperatures is beneficial also because of the low cost of production, very good resistance to oxidation and corrosion resistance. Unfortunately, the resistance to abrasion is their weakness.

On the other hand, white cast iron has a high abrasion resistance and hardness. These qualities, are due to the presence in the metal matrix considerable amount of M_3C carbide. Tensile strength of white iron is small, but has a significant (4÷6 times) compressive strength. Pure iron carbide depending on the size of grains, plates or needles and the amount of the dissolved manganese has a hardness in the range of 700÷840 HB. Cast iron with good abrasion resistance are almost all white cast, but their use is limited due to the low strength and large brittleness [1÷7].

Cast irons are not resistant to temperatures up above 250 °C, because of repeated heating may be followed by graphitization of M_3C (cementite) and structural heterogeneity associated different coefficients of thermal expansion of individual phases. Very interesting features would be a material, which is a combination intermetallics and white cast iron - then one could get a high heat resistance combined with high abrasion resistance. The latest technology allows to obtain a new material consisting intermetallic compound - FeAl and carbides of different elements, which can be regarded as a composite *in situ*. The purpose of this paper is to investigate the microstructure of high aluminum cast iron due to changes in the chemical composition by the introduction of carbide-forming elements as alloy addition.

Cast iron containing 30% Al and above has the best properties is heat-resistant and abrasion. It shows very good resistance to oxidation atmosphere at high temperatures, but this type of cast iron have a tendency to disintegrate during exploitation, due to the appearance in the microstructure of the carbide Al_4C_3 as the hydrophilic compound. Carbide Al_4C_3 not only leads to a reduction in mechanical properties, but the most importantly, causes in spontaneous disintegration of the material by reaction with water vapour contained in the atmosphere, according to the reaction [8÷9]:

$$Al_4C_3 + 12H_2O = 4Al(OH)_3 + 3CH_4 \quad (1)$$

$$4Al(OH)_3 = 2Al_2O_3 + 6H_2O \quad (2)$$

The reason for this phenomenon is the formation of a compound of $Al(OH)_3$, which volume is about 2.5 times greater than the specific volume of the water-reactive carbide Al_4C_3. This leads to the formation of high stress and breaking the continuity of the matrix. Another mechanism disintegration high-aluminum alloys Fe-Al-C may include weakening the cohesion matrix by the action of hydrogen dissolved in the iron (hydrogen embrittlement occurrence), which is transferred from the atmosphere during the spontaneous preparation of cast iron metallurgical processes:

$$2Al + 3H_2O = Al_2O_3 + 3H_2 \quad (3)$$

Prevention of disintegrating can rely on the method of setting the exchange of aluminum carbide on the other element forming carbides, which does not self-destruct, according to the reaction:

$$C + Ti = TiC \quad (4)$$

$$4Al + 3C = Al_4C_3 \quad (5)$$

$$Al_4C_3+Ti =3TiC+ 4Al \quad (6)$$

Composites prepared in this way, consists of the metal matrix an intermetallic compound of Fe-Al and carbide. Elements used in place of the existing aluminum carbide: titanium, tungsten, vanadium, zirconium, hafnium, tantalum, or molybdenum. This material does not break apart at ambient temperature, because the microstructure is free from aluminum carbide and has a high resistance to abrasion and the action of an oxidizing atmosphere in a wide temperature range [10÷15].

As follows from the polythermal phase equilibrium developed for a value of 30% Al, the overheating high-aluminum cast iron to a temperature above the liquidus temperature of the aluminum carbide, to give a liquid solution of iron, aluminum and carbon. the result carbide is thermodynamically stable and saturated Introducing the titanium addition to the solution, initiated the reaction by formation of titanium carbide according to Eq. 4. In carbon with a liquid solution. The degree of saturation of the bath depends on the amount of titanium introduced. From reaction (Eq. 4) it follows that 1g of titanium binds 0.25g of carbon, which gives 1.25g of TiC

Hereby, with the appropriate addition of titanium can be bound all carbon in TiC, causing the crystallization of the aluminum carbide is unlikely. Obtained material after crystallization can be treated as a composite *in situ*, comprising a metal matrix strengthened of titanium carbide. The minimum amount needed to bind the titanium atoms in the titanium carbide is:

$$Ti = 3{,}988\ \%\ C_p \quad (7)$$

where: C_p - initial carbon content in the alloy.

Similar effect is possible to obtained applying vanadium addition and other carbide forming elements like tungsten, niobium. In some cases, for example, after the addition of B, Bi, and heat treatment the aluminum carbide Al_4C_3 is converted to another form, such as Al_2C_3, which is not hygroscopic and does not self-destruct. Moreover, the addition of elements, that can create carbides in cast iron, increases the number of eutectic grains, thus promoting the structure refinement in samples cast from the examined high-aluminium iron.

2. Methodology

Seven melts were carried out in the vacuum furnace in a protective atmosphere of argon, the charge capacity 800g. The chemical composition shown in Table 1. The composition of the liquid high aluminum cast iron has overheated to a temperature of 1510 °C then, at a temperature of 1420 °C were poured to a metal mold heated to 300 ºC. Casts with the addition of B and Bi were further annealing in a furnace with an oxidizing atmosphere at a temperature of 950 ºC for 24 hours and cooled with the furnace. Then, from all casts were performed metallographic specimen by grinding and polishing and examined by light (LM) and scanning electron microscopy (SEM).

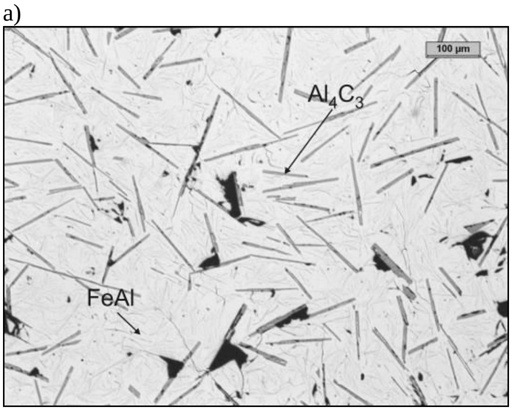
Table 1. The chemical composition of cast iron

Melt No.	**Chemical compositions wt. %**								
	C	**Si**	**Mn**	**Al**	**W**	**V**	**Ti**	**B**	**Bi**
1	1,25	1,1	0,35	34,3	-	-	6,1	-	-
2	1,13	1.0	0.39	35,0	6.08	-	-	-	-
3	1,20	1.0	0.40	33,5	-	6.12	-	-	-
4	1,22	1,1	0,41	34,5	-	-	-	-	-
5	1,18	1,0	0,41	35,2	-	-	-	-	-
6	1,26	1,1	0,43	34,6	-	-	-	0,02	0,004
7	1,24	1,0	0,41	34,7	-	-	-	-	-

3. Results and discussion

Figures below shows microstructures of metallographic specimen from the examined high-aluminum cast iron without addition (Fig. 1a,b) with the additions of titanium (Fig. 2a), vanadium (Fig. 2b), bismuth and boron (Fig. 3a) and tungsten (Fig. 3b).

a)



b)

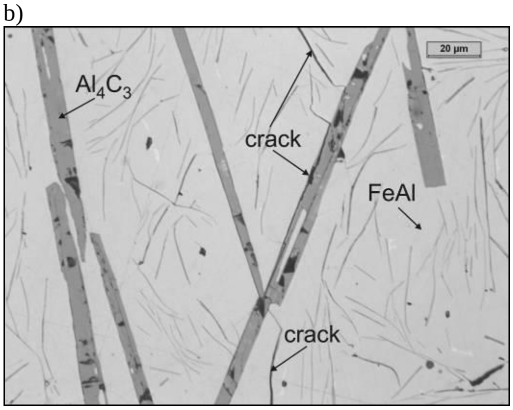
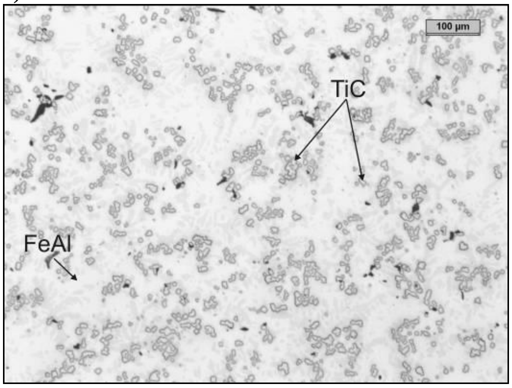


Fig. 1. Microstructure of the high-aluminium cast iron, 4 hours after casting – a), 7 days after casting– b)

Fig. 1a shows microstructure obtained 4 hours after casting. Fig. 1b and Fig. 2 and 3 present microstructure obtained 7 days after casting. It is unable to notice the presence of aluminum carbide in cast with the addition of Ti, V and W.
Interesting results can be observed in the cases of heat treatment carried out for the samples B and Bi. In both samples, despite the continued existence of aluminum carbide Al_4C_3 the process of self-destruction was stopped.

a)



b)

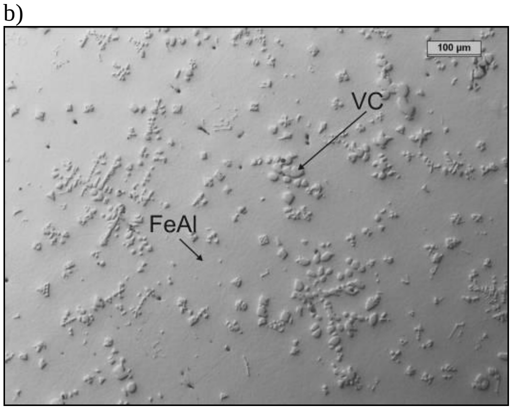
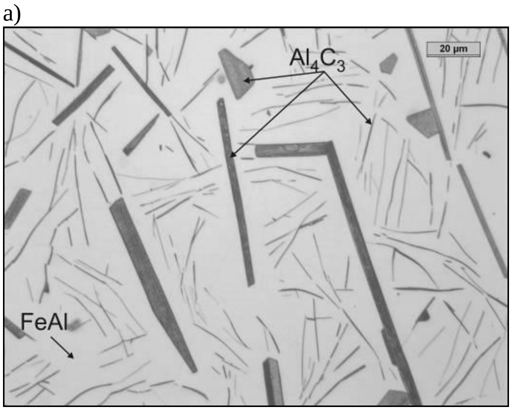


Fig. 2. Microstructure of the high-aluminium cast iron (7 days after casting) with addition: Ti – a), V – b)

a)



b)

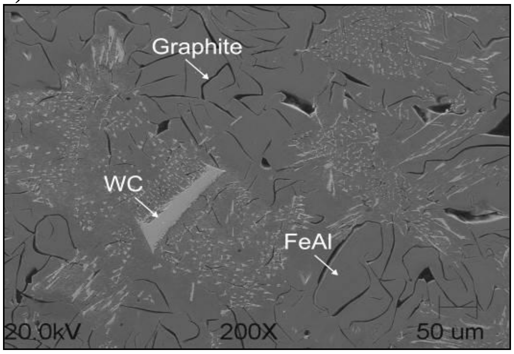


Fig. 3. Microstructure of the high-aluminium cast iron (7 days after casting) with addition: B and Bi – a), W – b)

Figure 4 show fractures test bars cast in cast iron test. It can be seen that addition of titanium to high aluminum cast iron increases in the number of eutectic grains (Fig. 4a) in comparison to the microstructure with aluminum carbide (Fig. 4b). In both cases shrinkage cavity was not observed. Mechanical properties for melt with addition of B and Bi and heat treatment presented in Table 2.

a) b)

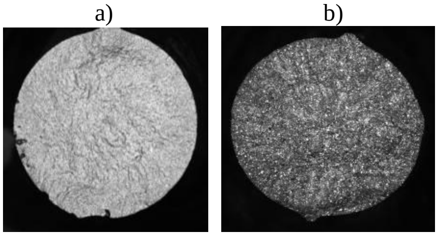


Fig. 4. Fractures of the examined specimens of high-aluminium cast iron with addition of: Ti – a) B and Bi – b)

Table 2.
The mechanical properties for melt No. 6

High-aluminium cast iron with addition B and Bi		
R_c, MPa	HRC	A_5 ,%
400	50	7

4. Conclusions

The addition to high aluminum cast iron, carbide forming elements can transform it into a composite consisting of a matrix strengthened W, V and Ti carbides. In samples with addition of vanadium, tungsten, titanium, there are no evidence of aluminum carbide by those elements. The addition of boron and bismuth to melt alloy and subsequent heat treatment does not cause self-destruction of cast due to the presence of Al_2C_3, not Al_4C_3 in microstructure.

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