

# Microstructure Control of High-alloyed White Cast Iron

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## Abstract

This paper presents the results of studies of high-alloyed white cast iron modified with lanthanum, titanium, and aluminium-strontium. The samples were taken from four melts of high-vanadium cast iron with constant carbon and vanadium content and near-eutectic microstructure into which the tested inoculants were introduced in an amount of 1 wt% respective of the charge weight. The study included a metallographic examinations, mechanical testing, as well as hardness and impact resistance measurements taken on the obtained alloys. Studies have shown that different additives affect both the microstructure and mechanical properties of high-vanadium cast iron.

**Keywords:** White cast iron, Microstructure, Vanadium carbide, Mechanical Properties, Microstructure modification

## 1. Introduction

The chemical composition of cast iron exerts an important effect on both the graphitisation rate and matrix formation, and thus on properties of the final material. An element that has very interesting properties as an alloying addition is vanadium. Studies [1-3] provide information about the microstructure of Fe-12.9%V-2.94%C alloys, in which the appearance of a regular fibrous  $\gamma + VC_{1-x}$  eutectic with vanadium carbide volume fraction of about 20% was stated, while [4] discusses the properties of vanadium carbides of the VC type.

Fe-C-V alloys with high vanadium content are included in the family of white cast irons, because all carbon present in this material is bound into vanadium carbides. The results of microstructural examinations and of the mechanical and tribological tests carried out on these alloys are given in [5,6].

The analysis of available literature confirms the growing interest in common high-alloyed white cast iron [7, 8], which offers a very good complex of tribological properties, but unfortunately has very low ductility. To correct this obvious drawback, the

authors of [9-12] proposed a modification of the microstructure of high-vanadium white cast iron with a magnesium master alloy, resulting in the formation of vanadium carbides VC characterised by a spherical shape. The applied treatment resulted in an increase of the mechanical properties accompanied by a simultaneous improvement of ductility. In this paper, an attempt was made to examine the impact of elements other than magnesium on the microstructure and hence also on the properties of high-vanadium cast iron.

## 2. Experimental

To perform the required tests, four melts were made, keeping the cast iron chemical composition constant and providing a near-eutectic type of microstructure. Melting was carried out in a Balzers vacuum furnace, in an argon protective atmosphere, using Fe-V master alloy, Armco iron, technically pure graphite and titanium, lanthanum and aluminium-strontium inoculants for the cast iron structure modification. The inoculants in an amount of

1wt% respective of the charge weight were fed immediately before mould pouring. Moulds made from molochite flour with water glass were hardened with CO<sub>2</sub>, heated to a temperature of 550°C, and then poured with liquid cast iron at a temperature of 1700°C. After knocking out of castings, from the lower part of ingots free from the porosity shrinkage defects, samples for metallographic examinations and mechanical testing were cut out. Samples were subjected to a static tensile test (carried out on an INSTRON type testing machine) using an extensometer, and applying a speed of 0.01 cm/min. Tensile curves allowed the determination of the following parameters: yield strength R<sub>p0.2</sub>, tensile strength R<sub>m</sub> and elongation A<sub>5</sub>. Additionally, Vickers hardness (HV30) was measured under a load of 294.2 N and impact resistance was determined using a Charpy impact testing machine with energy reserve of 15 J.

### 3. Experimental results and analysis

Table 1 shows the chemical composition of alloys tested, the content of individual microstructural constituents, the degree of eutectic saturation and carbon-to-vanadium content ratio. The base alloy, i.e. without the addition of inoculant, was designated as W, the alloy modified with lanthanum as La, with titanium as Ti, and with aluminium-strontium master alloy as AlSr.

Polished metallographic sections were first etched with Stead's reagent to reveal the eutectic grains. The observed results are shown in Figure 1. They indicate that, compared to the base alloy, the addition of lanthanum causes sharp reduction in the amount of eutectic grains. These grains crystallise in the form of extensive dendrites. On the other hand, titanium as well as aluminium and strontium give an opposite effect, resulting in the refinement of microstructure, with grains assuming an equiaxed shape.

The prepared microsections were polished once again and etched with Vilella's reagent, followed by examinations under an optical microscope. Figure 2 shows images of the obtained microstructures. It is clear that in the base alloy and in alloys with the additions of inoculants, the matrix is composed of alloyed ferrite, as confirmed by a quantitative analysis of the chemical composition in microregions made by EDX. The same method was also used to determine the chemical composition of the crystallised carbides. In all cases, those were the vanadium carbides; the only exception was an alloy with the addition of titanium. In this particular alloy, the fibrous vanadium eutectic has crystallised on compact vanadium-titanium carbides (Fig. 3a and EDX analysis below). On the other hand, in the alloy with an addition of Al-Sr master alloy, the microstructure, in addition to eutectic vanadium carbides, also contained vanadium carbides of a dendritic structure (Fig. 3b with the EDX analysis below).

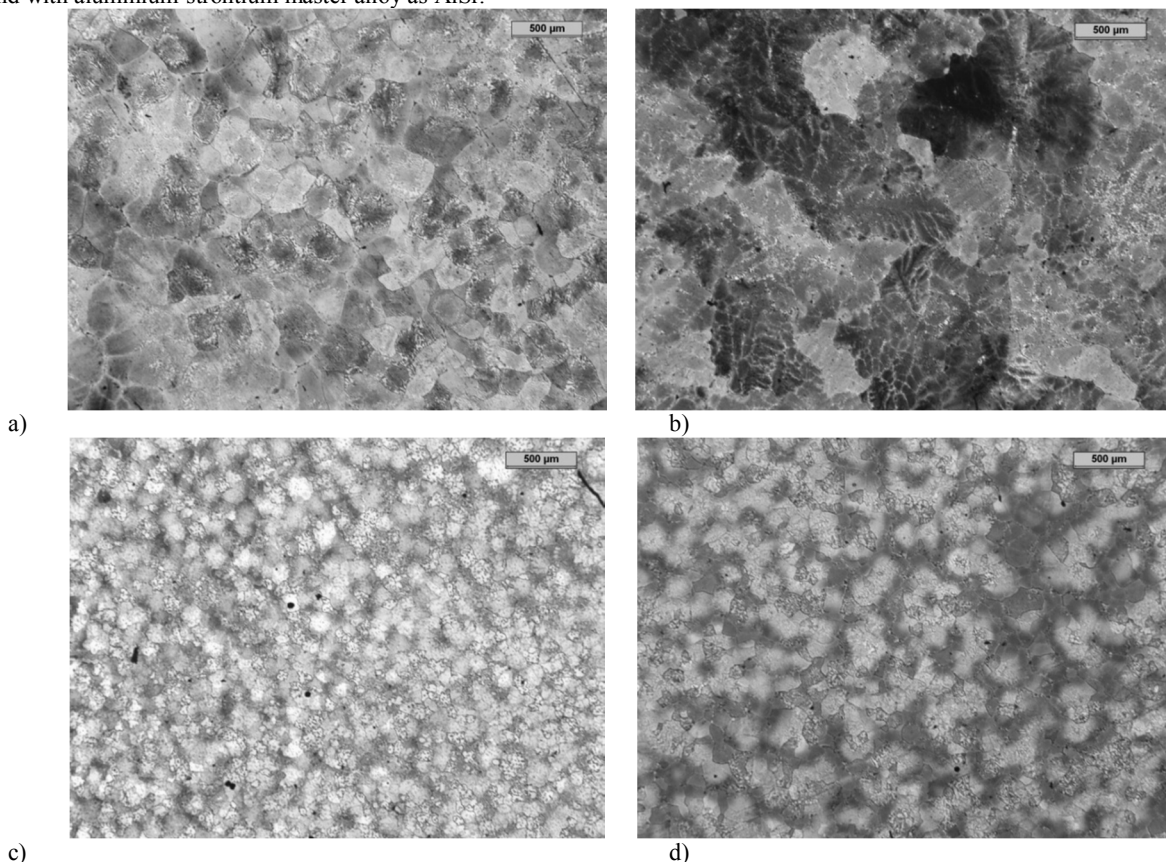
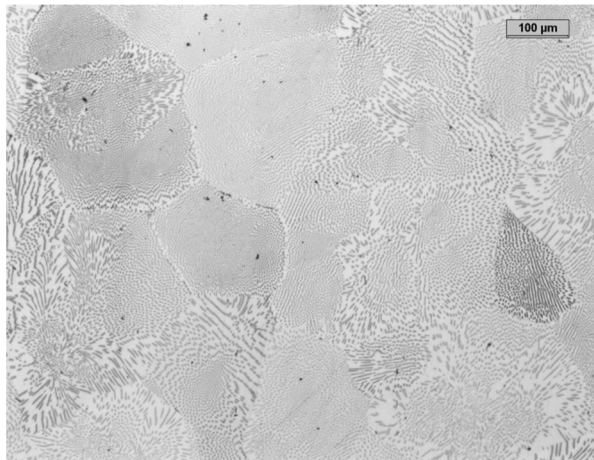


Fig. 1. Microstructure of the examined alloys – base alloy (a), alloy with La (b), Ti (C), Al and Sr (c); etched with Stead's reagent

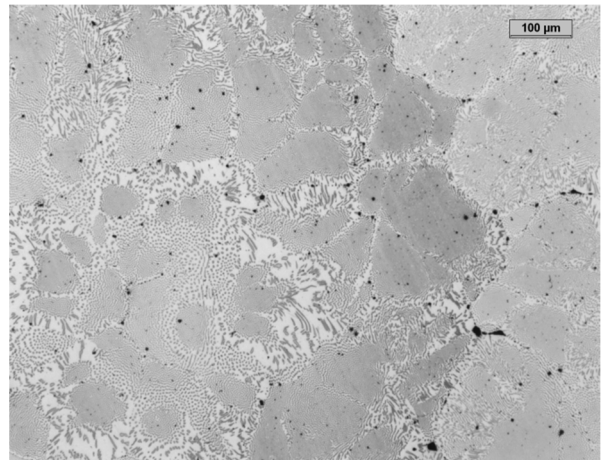
Table 1.

Chemical composition of alloys tested with the corresponding microstructure

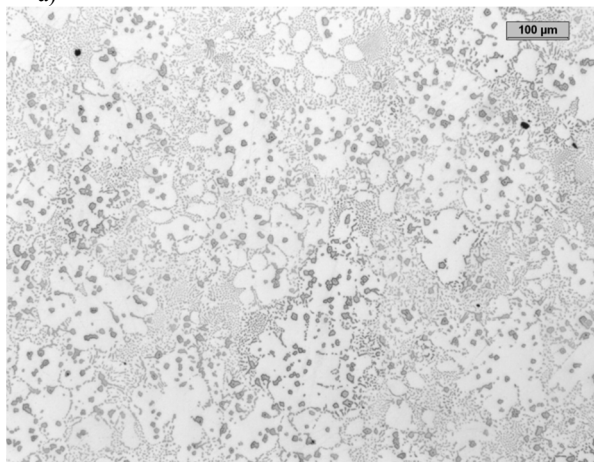
Melt No.	Chemical composition							S <sub>c</sub>	C/V
	V Wt. %	C Wt. %	Si Wt. %	Al. Wt. %	Ti Wt. %	Sr Wt. %	La Wt. %		
W	15.48	1.40	0.16	0.03	0.013	-	0.01	1.00	0.09
La	15.81	1.38	0.20	0.14	0.015	-	0.16	0.99	0.09
Ti	15.77	1.33	0.20	0.15	0.90	-	0.01	0.96	0.08
AlSr	15.56	1.42	0.13	0.88	0.012	0.017	0.01	1.01	0.09



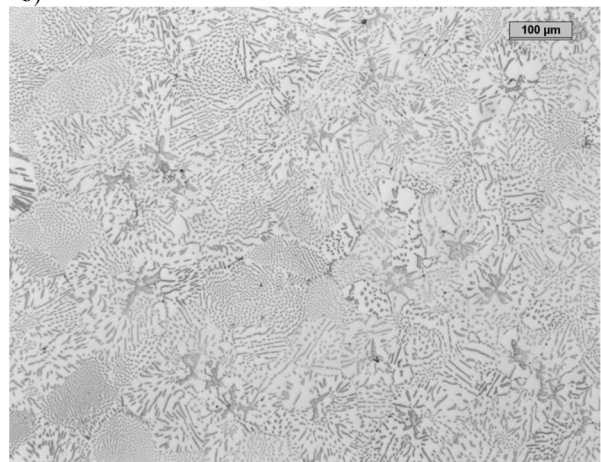
a)



b)

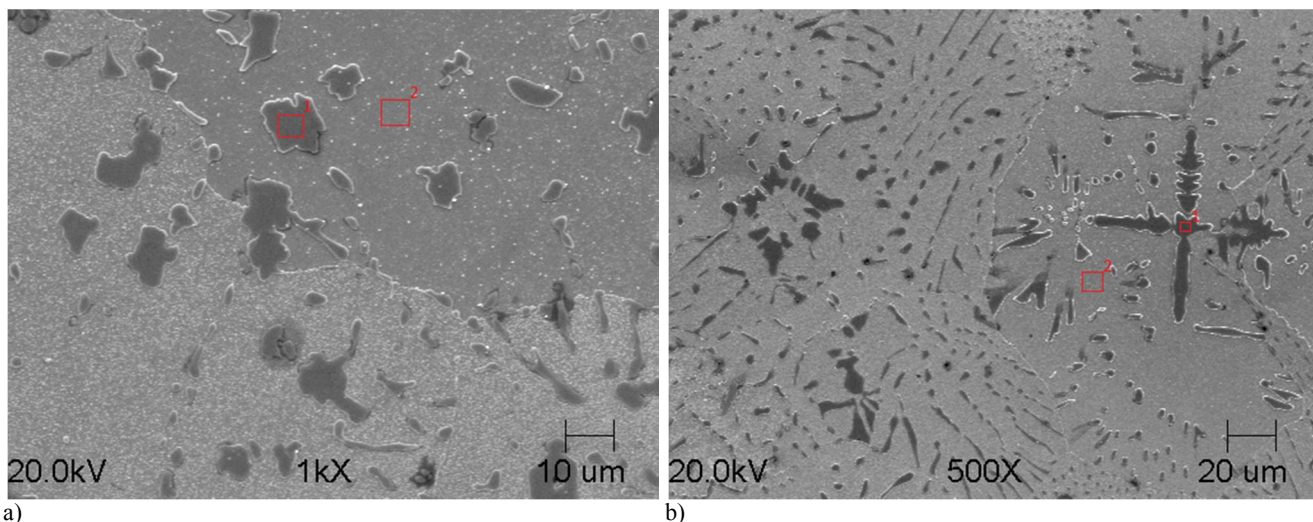


c)



d)

Fig. 2. Microstructure of the examined alloys – base alloy (a), alloy modified with La (b), Ti (C), Al and Sr (c) etched with Vilella's reagent



Area 1

El.	Line	Intensity (c/s)	Error 2-sig	Gauss Fit	Atomic %	Conc	Error 2-sig	Bkg Int (c/s)	Bkg Error 2-sig	MDL 3-sig
C	Ka	10.15	1.163	1.43	56.779	23.736 wt%	2.720	0.27	0.189	0.954
Al	Ka	0.38	0.224	0.32	0.103	0.097 wt%	0.057	2.30	0.554	0.307
Si	Ka	0.48	0.253	0.00	0.111	0.109 wt%	0.057	2.70	0.600	0.293
P	Ka	0.77	0.321	0.24	0.152	0.164 wt%	0.068	3.00	0.632	0.291
S	Ka	0.37	0.222	0.58	0.063	0.070 wt%	0.042	2.67	0.596	0.246
Ti	Ka	23.83	1.783	0.90	3.029	5.047 wt%	0.377	3.30	0.663	0.304
V	Ka	199.17	5.153	2.23	38.137	67.620 wt%	1.750	3.13	0.646	0.475
Mn	Ka	0.28	0.192	0.45	0.075	0.144 wt%	0.099	1.40	0.432	0.483
Fe	Ka	5.29	0.840	0.33	1.550	3.013 wt%	0.478	1.57	0.457	0.563
					100.000	100.000 wt%				

Area 1

El.	Line	Intensity (c/s)	Error 2-sig	Gauss Fit	Atomic %	Conc	Error 2-sig	Bkg Int (c/s)	Bkg Error 2-sig	MDL 3-sig
C	Ka	13.84	1.358	1.48	61.828	27.702 wt%	2.719	0.27	0.189	0.817
Al	Ka	0.15	0.142	0.00	0.033	0.034 wt%	0.032	2.37	0.562	0.271
Si	Ka	2.05	0.523	0.22	0.386	0.405 wt%	0.103	2.53	0.581	0.248
Ti	Ka	0.28	0.192	0.38	0.023	0.041 wt%	0.028	2.47	0.573	0.184
V	Ka	232.61	5.569	2.42	37.067	70.439 wt%	1.686	3.03	0.636	0.417
Fe	Ka	2.72	0.603	0.15	0.662	1.379 wt%	0.305	1.40	0.432	0.473
Sr	La	0.00	0.000	0.70	0.000	0.000 wt%	0.000	2.80	0.611	0.000
La	La	0.00	0.000	0.27	0.000	0.000 wt%	0.000	2.33	0.558	0.000
					100.000	100.000 wt%				

Area 2

El.	Line	Intensity (c/s)	Error 2-sig	Gauss Fit	Atomic %	Conc	Error 2-sig	Bkg Int (c/s)	Bkg Error 2-sig	MDL 3-sig
C	Ka	0.08	0.106	0.33	1.739	0.387 wt%	0.489	0.90	0.346	3.473
Al	Ka	1.06	0.376	0.17	0.830	0.415 wt%	0.147	1.90	0.503	0.426
Si	Ka	1.84	0.495	0.13	1.139	0.593 wt%	0.160	2.33	0.558	0.389
P	Ka	0.84	0.334	0.54	0.422	0.242 wt%	0.097	3.13	0.646	0.404
S	Ka	0.73	0.313	0.25	0.308	0.183 wt%	0.078	3.43	0.676	0.365
Ti	Ka	0.37	0.221	0.23	0.107	0.095 wt%	0.057	2.70	0.600	0.335
V	Ka	26.85	1.892	0.74	7.877	7.438 wt%	0.524	3.60	0.693	0.415
Mn	Ka	0.45	0.246	0.18	0.145	0.148 wt%	0.080	2.33	0.558	0.393
Fe	Ka	163.67	4.671	2.27	87.433	90.500 wt%	2.583	2.80	0.611	0.731
					100.000	100.000 wt%				

Area 2

El.	Line	Intensity (c/s)	Error 2-sig	Gauss Fit	Atomic %	Conc	Error 2-sig	Bkg Int (c/s)	Bkg Error 2-sig	MDL 3-sig
C	Ka	0.79	0.325	0.79	13.667	3.342 wt%	1.372	0.80	0.327	2.988
Al	Ka	2.82	0.613	0.39	1.859	1.021 wt%	0.222	2.40	0.566	0.443
Si	Ka	0.11	0.119	0.44	0.056	0.032 wt%	0.036	2.60	0.589	0.383
Ti	Ka	0.00	0.000	0.25	0.000	0.000 wt%	0.000	3.03	0.636	0.000
V	Ka	28.52	1.950	0.98	7.250	7.519 wt%	0.514	2.97	0.629	0.359
Fe	Ka	167.80	4.730	2.87	76.807	87.323 wt%	2.462	3.00	0.632	0.712
Sr	La	0.73	0.313	0.60	0.248	0.442 wt%	0.188	3.00	0.632	0.824
La	La	1.16	0.393	0.10	0.114	0.322 wt%	0.109	3.03	0.636	0.382
					100.000	100.000 wt%				

Fig. 3. Microstructure of titanium-inoculated alloy (a) and of aluminium-strontium inoculated alloy (b) including the results of quantitative analysis of the chemical composition in selected microregions – EDX.

Table 2. Mechanical properties, hardness, and impact resistance of the examined alloys

Melt No.	R <sub>m</sub> MPa	R <sub>p0.2</sub> MPa	R <sub>0.05</sub> MPa	A <sub>5</sub> %	HV30	KV J
W	499	247	97	7.5	189	1.1
La	418	268	126	1.3	211	1.8
Ti	500	279	156	8.6	183	1.3
AlSr	539	303	152	3.7	207	1.2

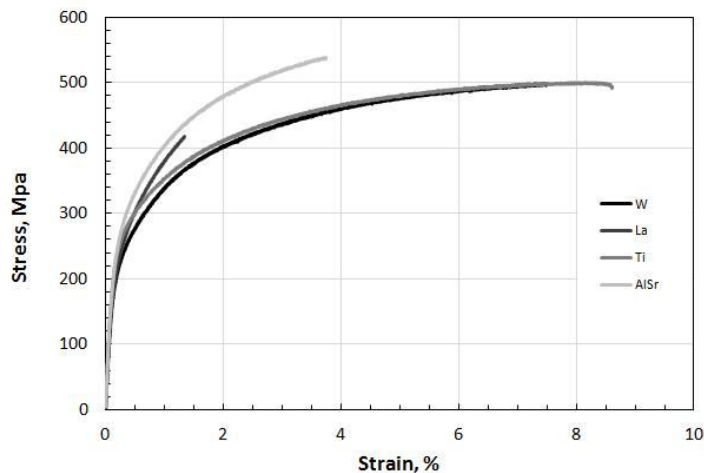


Fig. 4. Stress-strain curves of the alloys tested

Table 2 shows the results of mechanical tests, hardness measurements and impact resistance tests conducted on the examined alloys. Figure 4 compares the tensile curves plotted for the tested alloys. The data analysis shows that, compared with the base alloy, titanium does not change the nature of the stress-strain curve and does not increase the tensile strength. On the other hand, it raises the ductility by 1.1%. The addition of lanthanum reduces both the ductility and tensile strength, while the use of an aluminium-strontium master alloy leads to a strength increase of about 40 MPa and a fifty percent drop of ductility. Hardness of the examined alloys is at a comparable level. All the examined alloys exhibit poor impact resistance, and the addition of lanthanum has slightly improved this property.

## 4. Conclusions

Based on the conducted studies, the following conclusions were drawn:

1. There is no such addition among the proposed inoculating elements that would change the crystallising matrix in high-vanadium cast iron. In all the alloys examined, the matrix is composed of alloyed ferrite.
2. The inoculation of high-vanadium cast iron with titanium and with aluminium-strontium causes slight refinement of the microstructure, while the use of lanthanum - a significant increase in the size of eutectic grains.
3. The use of titanium results in the crystallisation of compact vanadium-titanium carbides, on which the vanadium eutectic crystallises. On the other hand, aluminium and strontium added to the alloy make some vanadium carbides crystallise in the form of non-faceted dendrites.
4. None of the tested inoculants changes the hardness of vanadium cast iron.
5. The plastic properties of high-vanadium cast iron are improved after the introduction of titanium; the addition of other elements deteriorates these properties.

6. Aluminium and strontium increase the tensile strength of high-vanadium cast iron by 40MPa, lanthanum reduces it by almost 80MPa; the presence of titanium brings no changes.
7. Vanadium cast iron is a material of poor impact resistance; the addition of lanthanum slightly improves this property.

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