ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.2478/v10266-012-0120-z
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (2299-2944)
Volume 12
Issue 4/2012
127 – 134

Microsegregation in Nodular Cast Iron with Carbides

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Received 16.07.2012; accepted in revised form 03.09.2012

Abstract

In this paper results of microsegregation in the newly developed nodular cast iron with carbides are presented. To investigate the pearlitic and bainitic cast iron with carbides obtained by Inmold method were chosen. The distribution of linear elements on the eutectic cell radius was examined. To investigate the microsegregation pearlitic and bainitic cast iron with carbides obtained by Inmold method were chosen. The linear distribution of elements on the eutectic cell radius was examined. Testing of the chemical composition of cast iron metal matrix components, including carbides were carried out. The change of graphitizing and anti-graphitizing element concentrations within eutectic cell was determined. It was found, that in cast iron containing Mo carbides crystallizing after austenite + graphite eutectic are Si enriched.

Keywords: Innovative Foundry Technologies and Materials, Nodular Cast Iron with Carbides, Microsegregation

1. Introduction

Distribution of elements in the components of cast iron microstructure is nonuniform due to non-equilibrium crystallization. Microsegregation phenomenon is manifested the difference in concentration of the constituent elements of cast iron components and their microareas.

References [1 ÷ 3] gives different ways of determining the microsegregation based on differently accepted indicators. The following indicators of microsegregation are known:

- J_d – dendritic, which is the ratio of the element concentration at the edge and the dendrite axis,
- J_e – eutectic, which is the ratio of the element concentration at the edge and the axis of the eutectic grains,
- J_t – total, which is the ratio of the element concentration at the edge of the eutectic grains and dendrite axis,
- K_s – average, which is the ratio the element concentration in a particular structural component to its average content in cast iron.
- K_l – phase, which is the ratio the element concentration in the axis of the structural component to the concentration at its edge.

If the ratio $K_l < 1$, the microsegregation is simple, and for $K_l > 1$ inverse [1].

Schematic structure of ductile iron and microsegregation of its constituent elements is shown in Figure 1 [4]. It shows that graphitizing elements (e.g. Si, Cu, Ni) exhibit an inverse microsegregation ($K_l > 1$) and anti-graphitizing (e.g., Mn, Mo, Cr) are characterized by simple microsegregation ($K_l <1$), both in austenite dendrites and eutectic grains. In the '70s was shown, that the microsegregation of graphitizing elements changes according to a parabolic function: $y = ax^2 + bx + c$, and anti-graphitizing elements by an exponential – parabolic function: $y = c \cdot exp(ax^2 + bx)$

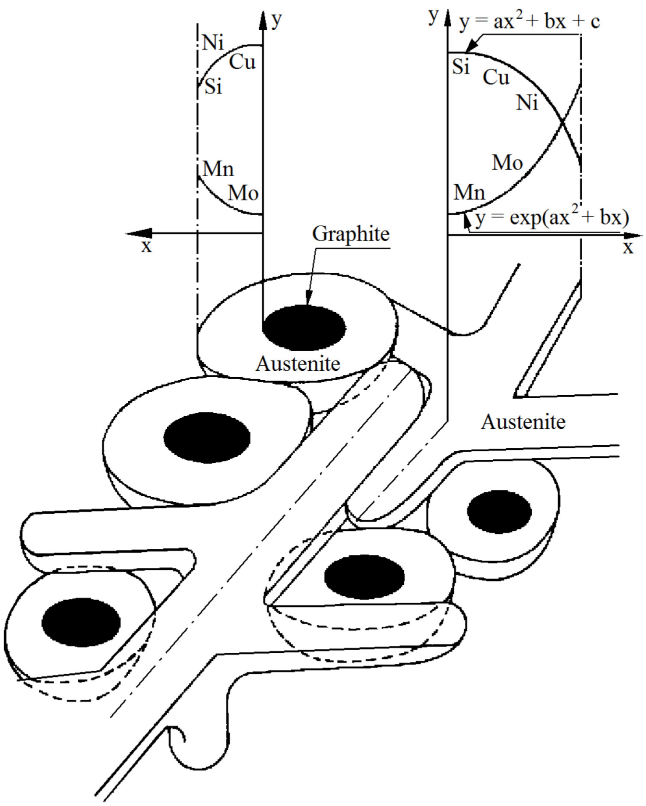


Fig. 1. The scheme of nodular cast iron structure and microsegregation of its elements [4]

In papers [1, 5] was demonstrated, that the larger diameter of the nodule and a smaller distance between them causes the smaller difference in elements concentrations. The smallest microsegregation of constituent elements has a eutectic cast iron [1, 4, 5]. Increasing the cooling rate of cast iron, for example by reducing the wall thickness of castings, increases the difference in elements concentration in the austenite dendrites and eutectic grains.

Eutectic grains often form units, among which the residual liquid is highly enriched in elements of simple microsegregation. Overall, it is clear that in nodular cast iron with a composition similar to the eutectic in areas close to graphite nodules there are maximum concentration of graphitizing elements and minimum concentration of anti-graphitizing elements, while around eutectic cell boundaries exhibit the highest concentration of anti-graphitizing elements and the smallest graphitizing elements [1].

Microsegregation studies have not yet been performed for nodular cast iron with carbides. Therefore, the aim was to investigate the linear distribution of elements within the eutectic cells in nodular cast iron with carbides and to determine the chemical composition of cast iron metal matrix components.

2. Work methodology

To tests the pearlitic and bainitic nodular cast iron with carbides were chosen. Its chemical composition is presented in Table 1.

The chemical composition specified kinds of cast iron has been studied in SPECTROMAXx emission spectrometer with spark excitation made by Spectro Analytical Instruments GmbH.

Table 1.
The chemical composition of tested nodular cast iron

Cast iron group	Chemical composition, %						
	C	Si	Mn	Cr	Cu	Mo	Ni
1	3,45÷ 3,83	2,13÷ 2,57	0,28÷ 0,45	0,52÷ 0,99	0,97÷ 1,55	–	0,98÷ 1,05
2	3,56÷ 3,80	2,49÷ 2,68	0,06÷ 0,09	–	–	1,91÷ 2,11	0,79 1,01

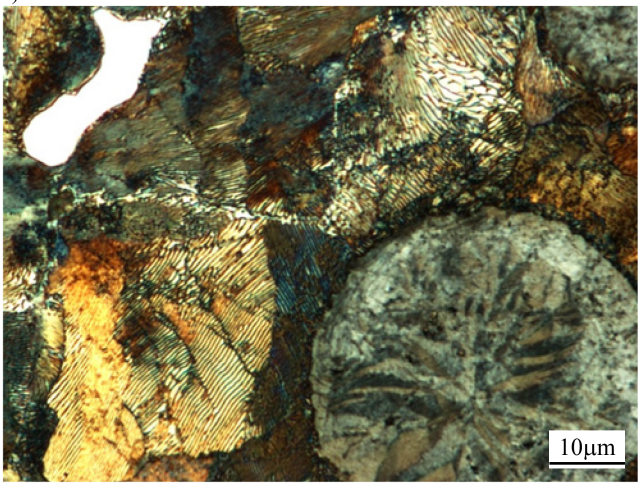
The average concentration of P and S was respectively 0.04% and 0.01%.

Microstructure of pearlite, bainite, and carbides in nodular cast iron was obtained in the raw state by using Inmold method [6 ÷ 11]. Strong modifying effect of master alloy used for this treatment causes significant fragmentation of the cast iron microstructure. Cast iron microstructure was examined on nital etched metallographic specimens at a magnification of × 1000 on the metallographic microscope Nikon Eclipse MA200 and by using a scanning electron microscope Hitachi S-3000N. EDX analysis was performed using Pioneer EDS detector and Ventago software of Noran company to identify the distribution of element concentrations in the eutectic cell and in carbides.

3. Results

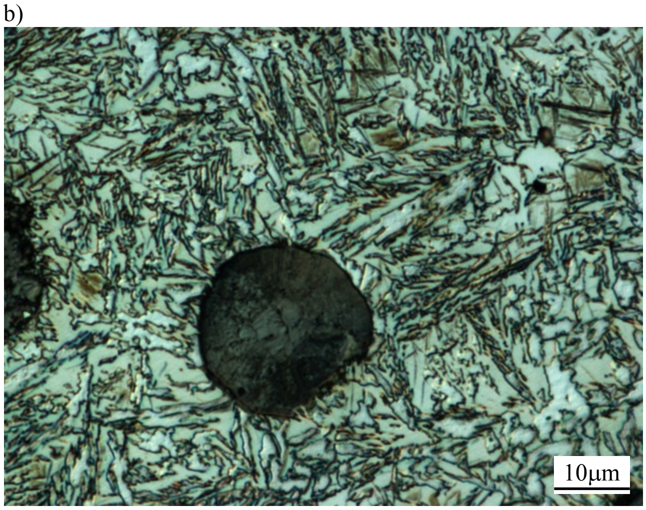
In Figure 2 (a, b) the microstructure of the examined kinds of cast iron is shown

a)



microstructure: nodular graphite, pearlite, carbides

b)



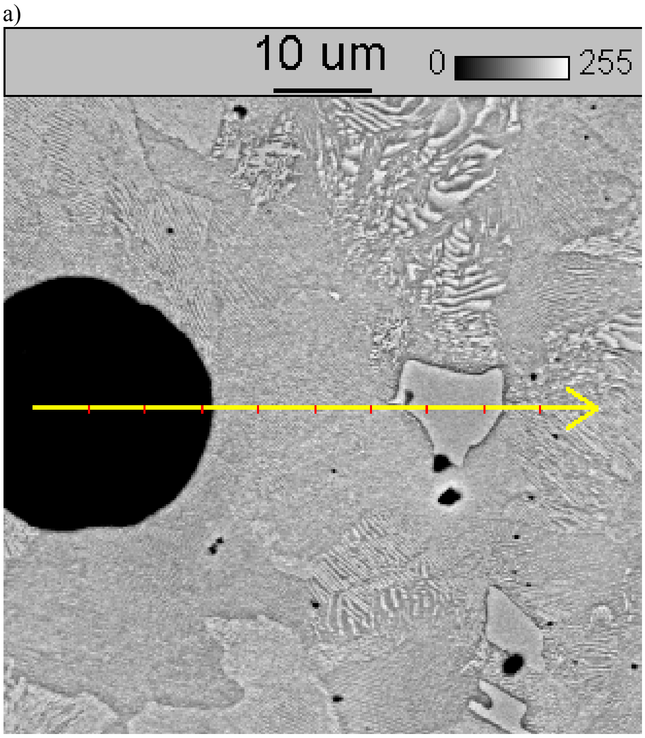
microstructure: nodular graphite, upper bainite, carbides

Fig. 2 (a, b). Representative microstructure of 1 group (a) and 2 group (b) cast iron

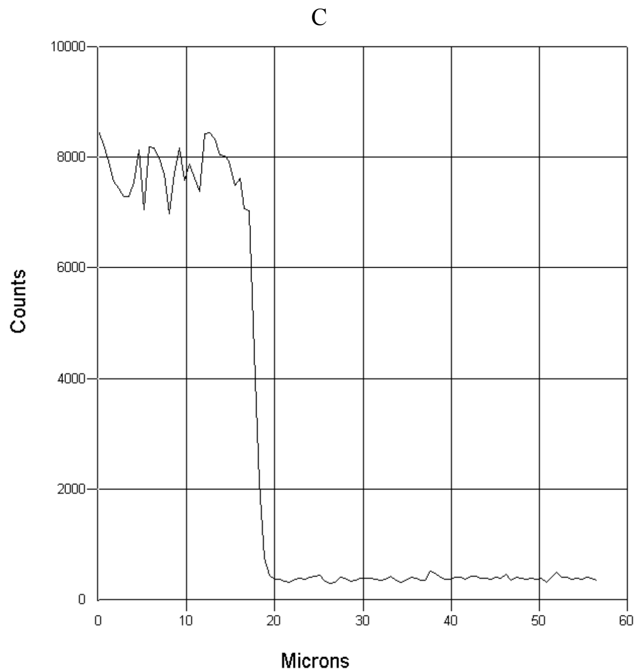
From Fig. 2 (a, b) results, that the metal matrix of cast iron from group 1 consists of pearlite and carbides, while from group 2 – upper bainite and carbides.

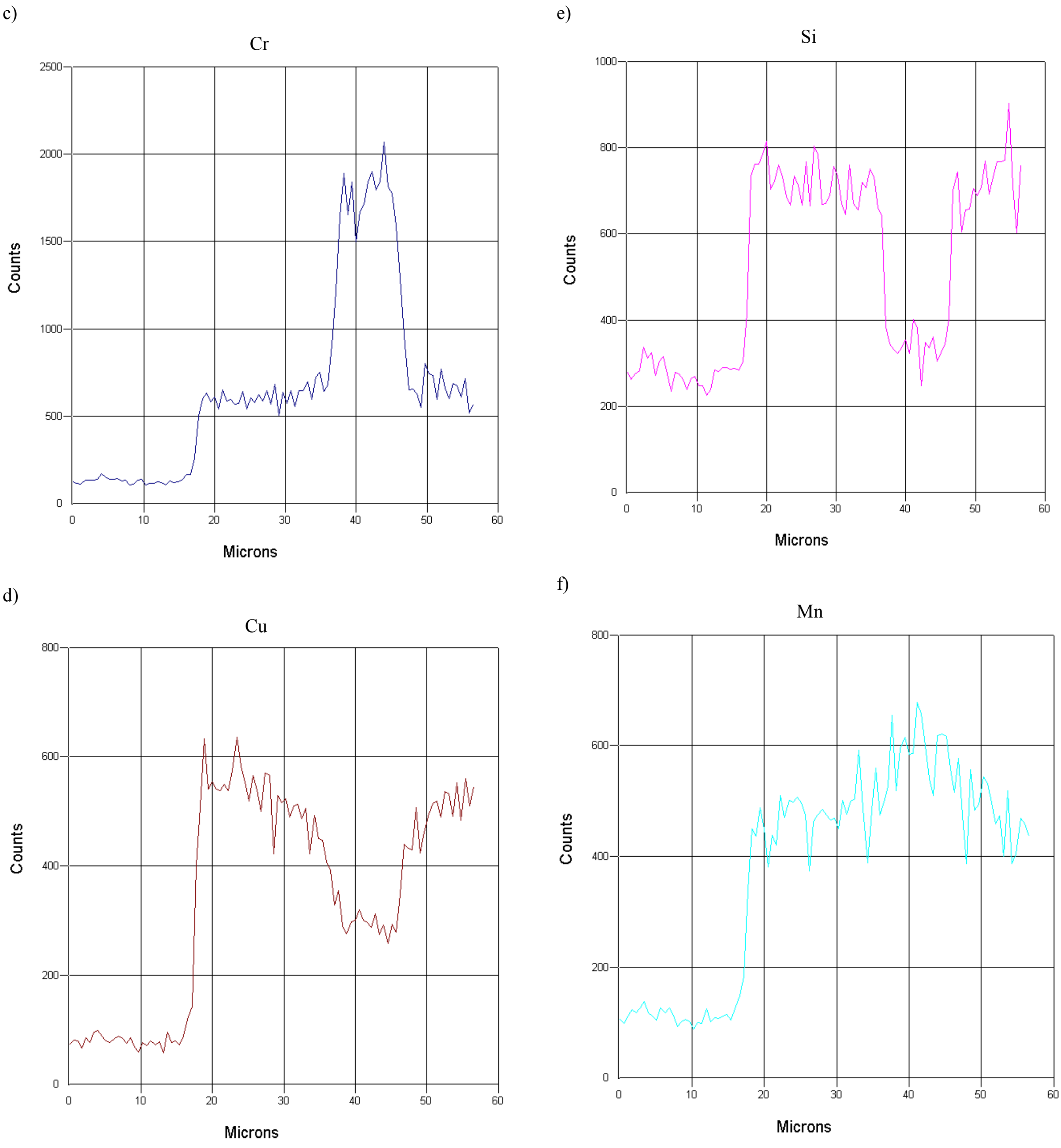
In Figure 3 (a ÷ g) the representative linear distribution of elements within the eutectic cell in pearlitic nodular cast iron with carbides containing about 1.5% Cu, 1.0% Ni and 1.0% Cr is presented (group 1, Tab. 1).

a)



b)




c)
Cr
Counts
Microns
e)
Si
Counts
Microns
d)
Cu
Counts
Microns
f)
Mn
Counts
Microns

g)

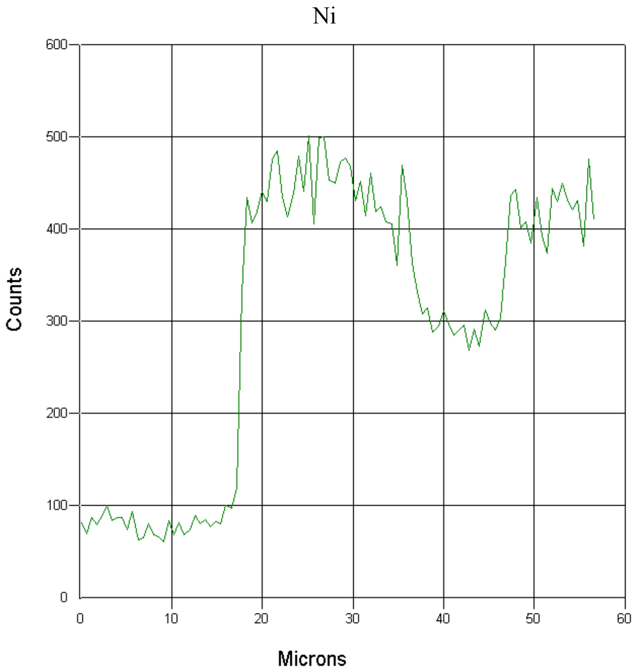


Fig. 3 (a ÷ g). The linear distribution of elements within the eutectic cell in pearlitic nodular cast iron with carbides containing: 3,88% C; 2,23% Si; 0,40% Mn; 1,55% Cu; 0,96% Ni; 0,99% Cr (C_e = 4,66%)

It shows that graphitizing elements indicate higher concentrations close to the graphite than for eutectic cell boundary. This follows from the fact that their atoms are partially "absorbed" by the austenite. The strongest effect was found for copper, while the difference in the silicon concentration is negligible. Carbide forming elements have a slightly higher concentration at the eutectic cell boundary than close to the graphite. From Fig. 3c shows that the concentration of chromium in the carbide is high, while in Fig. 3e shows that manganese is also included in this phase.

Figure 4 shows the microstructure of pearlitic nodular cast iron with carbides and measurement points of the chemical composition, while in Table 2, the content of Si, Cu, Ni, Cr and Mn in the metal matrix components.

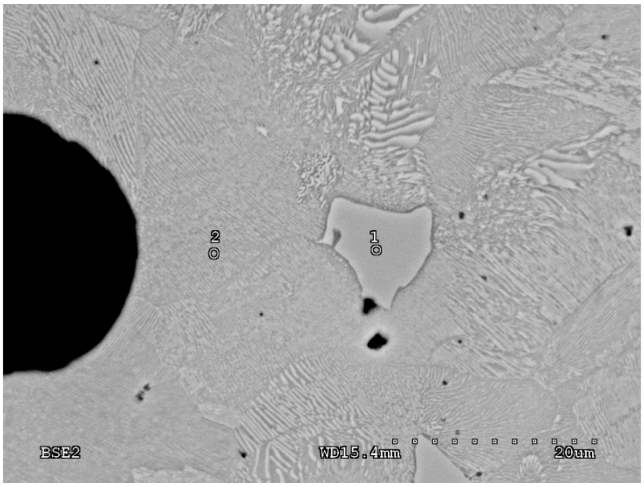


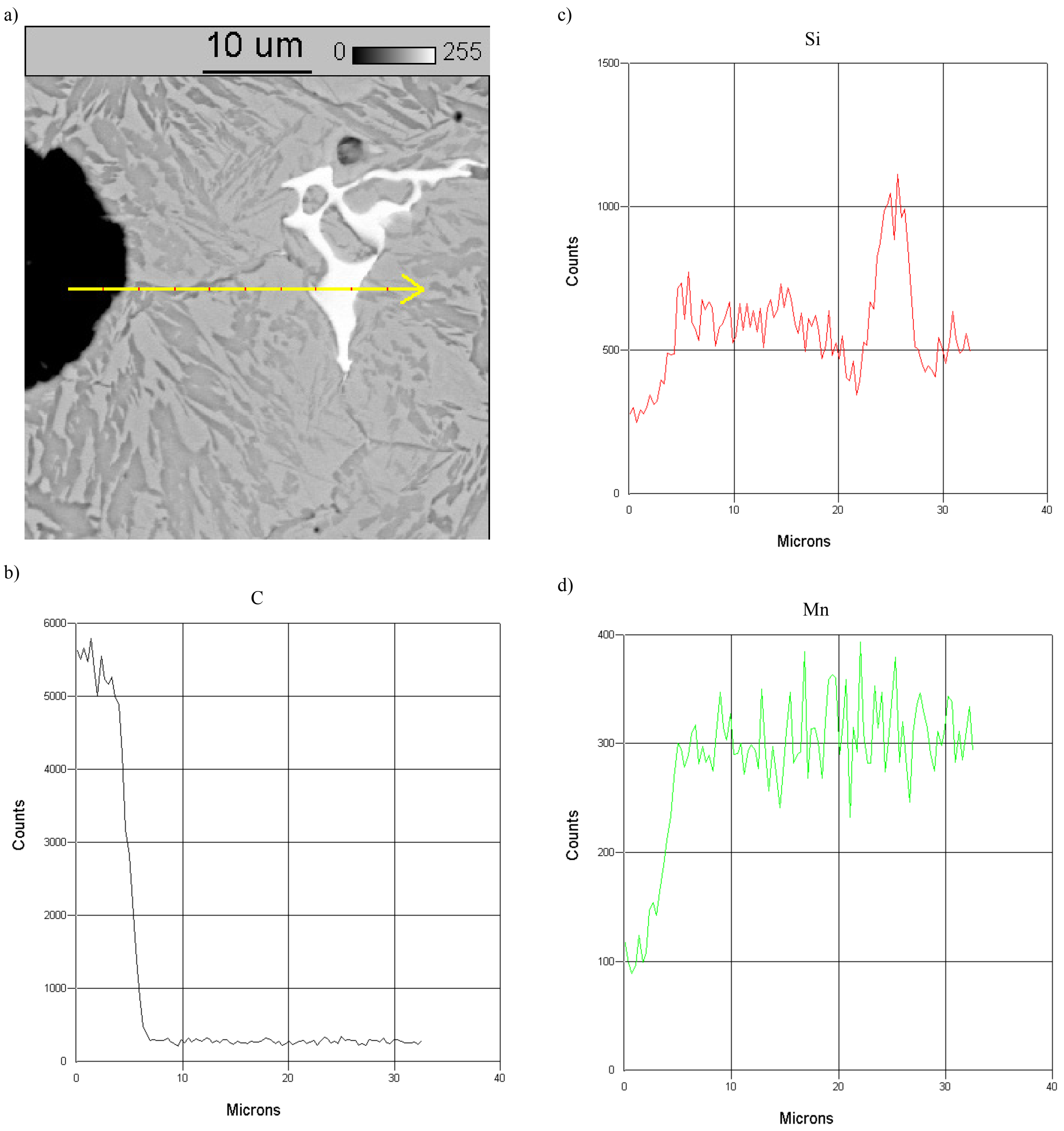
Fig. 4. Microstructure of pearlitic nodular cast iron with carbides with a measurement points of chemical composition

Table 2.
The content of Si, Cu, Ni, Cr and Mn in the metal matrix components

Point	Mass concentration, %				
	Si	Cu	Ni	Cr	Mn
1	–	–	–	5,87	1,10
2	2,09	1,87	1,12	0,76	–

The data presented above shows that the chromium of about 6% occurs in point 1 and its small amount occurs in point 2. This indicates that chromium, like copper and nickel is dissolved in austenite and affects its durability. Tab. 2 shows the increased concentration of manganese in point 1. Graphitizing elements in point 1 do not occur. It follows that the area where point 1 is marked is a $(Fe,Cr,Mn)_3C$ carbide.

Figure 5 shows a representative linear distribution of the elements within the eutectic cells in nodular cast iron with carbides containing about 2.0% Mo and 1.0% Ni (group 2, Tab. 1).


a)
10 um
0
255
b)
C
Counts
Microns
0
1000
2000
3000
4000
5000
6000
10
20
30
40
c)
Si
Counts
Microns
0
500
1000
1500
10
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30
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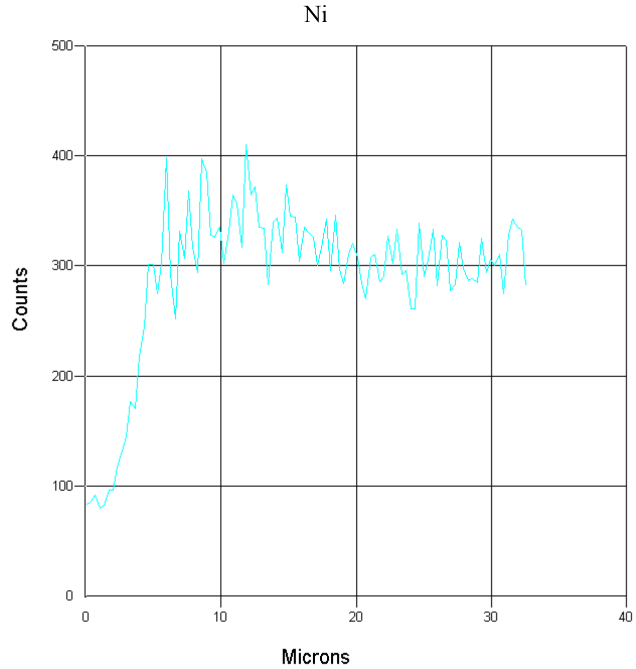
d)
Mn
Counts
Microns
0
100
200
300
400
10
20
30
40

e)



f)

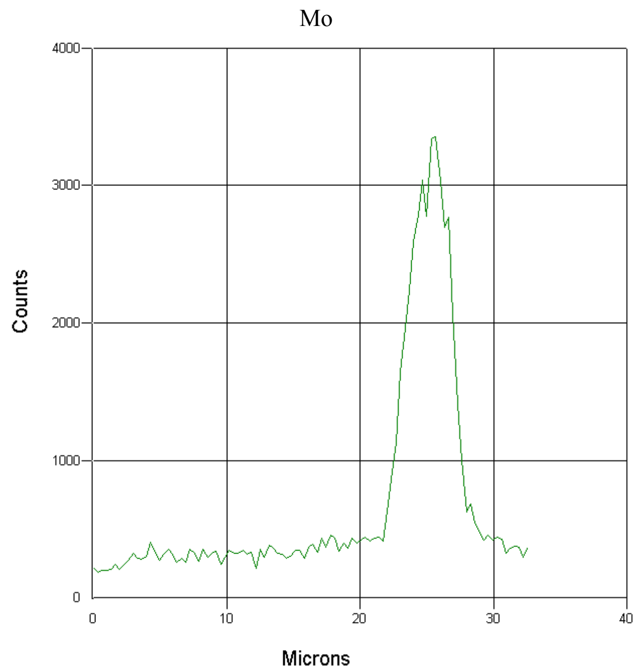


Fig. 5 (a ÷ f). Linear distribution of elements on the eutectic cell radius in nodular cast iron with carbides and upper bainite consisting of: 3.30% C, 2.43% Si, 0.09% Mn, 1.96% Mo, 1.01% Ni (C_e = 4,07%)

It shows that the graphitizing elements, i.e., Si and Ni exhibit a higher concentration close to the graphite rather than eutectic cell boundary. From Fig. 5 (a, c) show increased concentration of silicon in a bright area and lowered in the immediate surroundings. Manganese and molybdenum show a slightly higher concentration at the eutectic cell boundary than close to the graphite. There is a high concentration of molybdenum in the bright area (Fig. 5f), whereas there were no elevated levels of Mn in this field.

Figure 6 shows the microstructure of nodular cast iron with carbides and upper bainite, while in Table 3, the contents of Si, Mo and Ni in the metal matrix components.

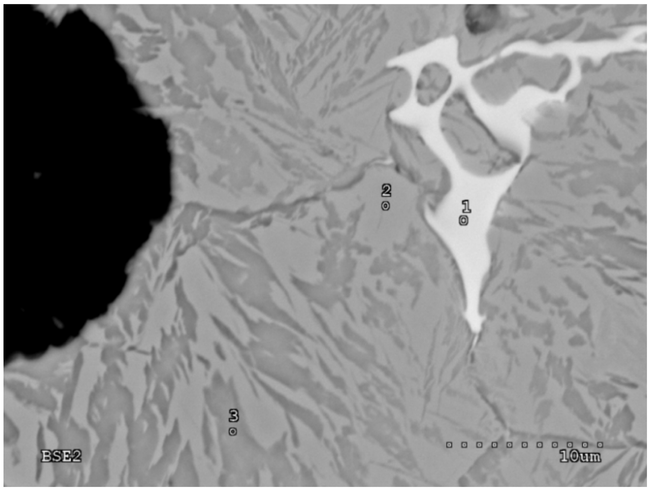


Fig. 6. The microstructure of nodular cast iron with carbides and upper bainite and measurement points of chemical composition

Table 3.
The content of Si, Mo and Ni in the metal matrix components

Point	Mass concentration, %		
	Si	Mo	Ni
1	2,84	36,48	–
2	1,55	1,58	0,80
3	2,35	0,73	1,16

They show, that there is the highest concentration of Si in point 1 compared to the other metal matrix components. Due to the greater solubility of nickel in austenite than in ferrite, the concentration of this element in the metal matrix components are approximately 0.8% (point 2) and 1.2% (point 3). The concentration of molybdenum in point 1 is about 36.5%, while in points 2 and 3 about 1.6% and 0.7%, respectively. It follows that the number of molybdenum atoms is dissolved in austenite after the end of the crystallization process and affect its stability in a way to obtain bainite with continuous cooling. On the other hand, higher concentrations of Mo in the ferrite compared to austenite confirm, that it is ferrite forming element.

4. Conclusion

Conducted research predispose to draw the following conclusions:

- in nodular cast iron with carbides with additions of Cr, Ni and Cu $(Fe,Cr,Mn)_3C$ carbides occurs,
- from among graphitizing elements the strongest inverse microsegregation Cu shows and the least – Si,
- in nodular cast iron with carbides graphitizing elements shows slightly higher concentration at the eutectic cell boundary compared to their concentration close to the graphite,
- in cast iron with of about 2% Mo and 1% Ni phase that occurs at the eutectic cells boundaries are molybdenum carbides Si enriched,
- due to the high fragmentation of the microstructure components, Inmold technology provides low microsegregation of elements on the eutectic cells radius in nodular cast iron with carbides.

Acknowledgements

Scientific project financed from means of budget on science in years 2009 ÷ 2012 as research project N508 411437.

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