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# Examination and Elimination of Defects in Cone Casting Made of Ductile Cast Iron

E. Guzik<sup>a</sup>, M. Łagowski<sup>b</sup>, A. Nowak-Dudek<sup>b</sup>, B. Niedzielski<sup>b</sup>

<sup>a</sup> AGH - University of Science and Technology, Kraków, Poland

<sup>b</sup> ZM “WSK Rzeszów” Ltd. – Cast Iron Foundry, Rzeszów, Poland

\* Corresponding author. E-mail address: guz@agh.edu.pl

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## Abstract

In the scope of existing cooperation with the Foundry of Cast Iron ZM “WSK Rzeszów” Ltd. there was carried out research work of microstructure and mechanical properties in the walls of a cone casting made of ductile cast iron. The particular attention was being put to the search of the potential brittle phases which have deleterious effect on ductility and dynamic properties of highly strained use of the casting prone to the potential risk of cracks during the highly strained use.

**Keywords:** Ductile iron, Cone casting, Casting defects, Ferrite, Pearlite, Graphite

## 1. Introduction

Ductile Iron exhibits range of mechanical properties, that make it suitable for light as well as heavy weight section castings replacing other known cast alloys as steel or even aluminum in some cases. However, these properties are sensitive to microstructural defects which characteristics and occurrence are, in some cases, related to the casting size. One of defects that have a major impact on the quality of a cast iron is formation of carbides which have deleterious effect on ductility and dynamic properties by segregation of the embrittling phases [1,2]. Segregation during solidification is the result of the partitioning of elements (see Fig.1) at the solid/liquid interface.

The ranking, segregation factor, is as follows, stating that a Figure  $<1,00$  indicates an element that goes to the “first freezing” and a figure  $>1,00$  indicates an element that segregates to the “last freezing” liquid. The elements with a factor  $<1,00$  (see Tab.1) will segregate inside the eutectic cell, the other (factor  $>1,0$ ) outside the eutectic cell, intercellular area.

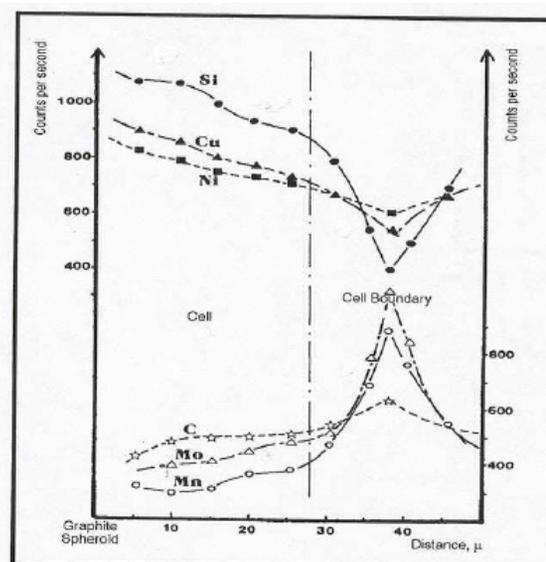


Fig. 1. Segregation pattern of Various Elements in Ductile Iron

Table 1.

Segregation factor of the elements

Element	Mo	Ti	V	Cr	Mn	P
Factor	25,3	25	13,2	11,6	1,7-3,5	2,0
Element	Si	Co	Ni	Cu		
Factor	0,7	0,4	0,3	0,1		

Topic of the investigation was a cone casting which samples due to the highly stressed work had to be thoroughly inspected on account of carbides presence.

Since segregation is not only influenced by the concentrations of prone to partitioning elements, but also combined with the solidification rate and the nucleation potential of the iron, some preventive actions were proposed to eliminate the mentioned above defects.

## 2. Methodology

- Chemical composition of cast iron for cone casting was as follows [wt.% - Table 2]

Table 2.

Chemical composition of cast iron

C	Si	Mn	S	P	Cr	Mg
3,61	2,53	0,5	0,009	0,04	0,01	0,05
Ni	Ti	Cu				
0,01	0,02	0,19				

The composition of ductile cast iron was measured using Spektro LECO type GDS 500A and apparatus HARIBA type EMIA – 8200 B(W) for carbon and sulfur,

where:  $S_c = C / (4,26 - 0,3*Si - 0,36*P) = 1.04$

- From casting samples were taken for metallographic examinations in order to determine microstructure of ductile cast iron; graphite and matrix using quantitative image analyzer Leica QWin. The Scanning Electron Microscope metallographic tests were performed using Joel with EDS.
- Microhardness of phases measures were performed with the use of Vickers method using Norgpol model HV – 1000B, with the application 25 g load and with 15 s as the time of loading.
- Mechanical properties characteristics (on products) YTS, UTS, Elongation  $A_5$  measures were performed with the use apparatus Zwick GMBH & Coe (type BZ 200 SN 6S).
- A cone cast produced by ZM “WSK Rzeszów” Ltd. given back from France for testing purposes – its properties required by the client are as follows:

Table 3.

Requirement of microstructure of Ductile Cast Iron – to GSM 001

Grade	EN-GJS-500-7 (EN – JS 1050)
Graphite	VI shape, for 85% of Nodules, I and II Shapes, Excluded, 6 to 8 Dimension
Microstructure	30 % < Pearlite < 60 %
Free carbides	acceptable < 2 %

Location of cutting off samples for testing structure and mechanical properties are presented in Fig. 2.

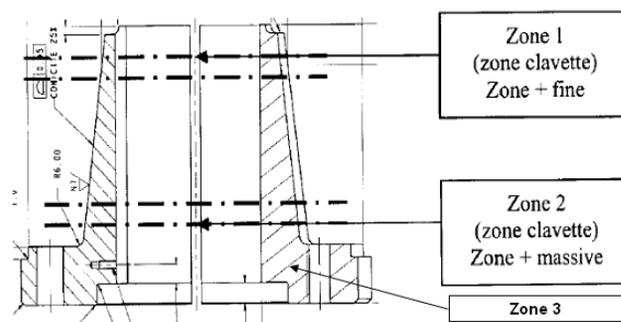


Fig. 2. The sample diagram cutting for mechanical property tests and microstructure evaluation

## 3. Results of investigations

From a half of the cast cone received from ZM “WSK” – Rzeszów” Ltd. (the ductile iron casting has been delivered back by the client from France) (Fig. 3) there were cut off, for investigations at AGH-University, the matrix microstructure, features of the graphite precipitations and, eventually, of other precipitations, samples from the zones No. 1, 2 and 3 (see Fig. 2.)

On the basis of the metallographic investigations of the particular casting parts such cast iron features as: shape and dimensions of graphite precipitations, as well as the kind of the metallic matrix depending on the wall thickness and shape can be determined; these features are directly connected with the effects of nodularization and inoculation and thus with the physical-chemical and chemical state of the liquid metal as well as of casting’s cooling rate influenced by the wall thickness; and all these features influence directly on the mechanical properties of the casting’s material, i.e. the nodular cast iron.

In result of the investigations of the nodular cast iron with the chemical composition (given in the table No. 2) and the value of  $S_c = 1.04$ , the shape of graphite precipitations as well as the kind of the metallic matrix in three samples being investigated (samples No. 1, 2 and 3) have been determined (Fig. 4).

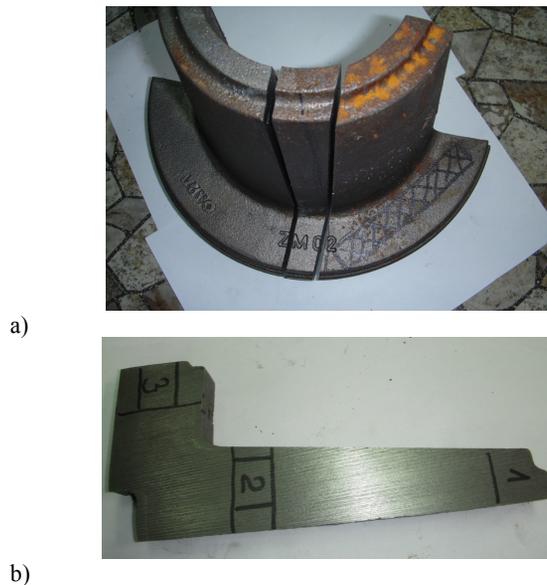


Fig. 3. Photographs (a, b) of the cone casting elements with the fields 1, 2 and 3 being marked (see Fig. 2) from which samples were taken for the inspection of microstructure and mechanical properties

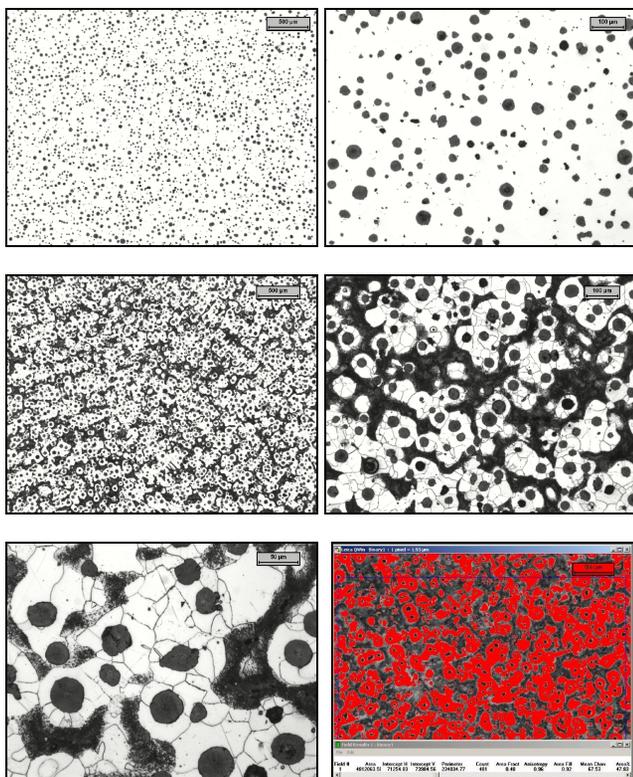


Fig. 4. Appraisal of the graphite precipitations and metallic matrix in the sample No. 1 ( taken from the casting – see Fig. 2 and 3b)

In the structure of the sample No. 1 (see Fig.4) the precipitations of the nodular graphite type (shape) VI (after EN-

ISO 945) can be observed; only 15 % are the graphite precipitations type V together with the kind III – vermicular graphite {about 5%}. The dimensions of the precipitations correspond to the numbers 6 to 8 (the smallest ones nodules). The matrix make 35 % pearlite + 65 % ferrite.

In the sample No. 2 taken from the zone No. 2 (see Fig. 1) also the nodular graphite type VI in amount about min. 85 % has been stated; the rest is composed of the types V and III. The dimensions of these precipitations correspond with the numbers from 6 to 8.

In this samples greater yield of pearlite in the matrix (about 45 %) can be observed – the rest makes ferrite.

The structural features of the sample No. 3 taken from the zone No. 3 (see Fig. 2) of the casting under investigation are similar to these of the sample No. 1. But, on the surface of this sample only, by magnification 500x, at the boundary of the pearlite colonies small, light precipitations have been observed. The microhardness of these sites has been measured.

The value of 420 HV has been obtained; for comparison: the microhardness of pearlite amounts 410 HV and this of ferrite – 228 HV; it means that our observations concern the hardened ferrite and not the cementite  $M_3C$  (where: M- metal; Fe, Mn, Cr).

Also investigations carried out on the Scanning Electron Microscope (Fig. 5 to 9) distinctly confirm the above observations concerning the graphite precipitations and kind of the metallic matrix. Moreover, in the structure come to light precipitations of oxy-carbides (Fig. 5) and composed oxides (Fig. 6), what could be confirmed by phase analysis of these precipitations (Figs. 5 and 6).

In the structure there can also be observed very small precipitations showed in Fig. 7 of dimension about 8  $\mu m$  (see magnification marker in Fig. 7). In the structure of the sample No. 3 are they visible, in small amount, at the boundary of the pearlite grains and in the neighbourhood of graphite precipitations (Fig. 8); and the difference results from different cutting angle of the sample surface.

Also in other sites in the central part of the matrix small amounts (under 0,2 %) of the light precipitations can be observed; it results from the phase analysis, that they are ferrite (Fig. 8c and Fig. 9) and not precipitations of the undesirable, hard cementite  $M_3C$ .

The results of the investigations of mechanical properties carried out on the samples taken from a part of the tested casting (see Fig. 3), are placed in Table 4.

It follows of them that all the requirements concerning the tensile (YTS and UTS) and plasticity (elongation  $A_5$ ) properties presented by the french client have been exceeded.

Table 4.  
Mechanical properties of tested samples

	YTS, MPa	UTS, MPa	$A_5$ , %
GSM 001 of chart 2	min. 300	min. 450	min. 7
Sample 1 – Zone 3	319	489	16,0

The results of hardness tests carried out along the section height are given in Table 5 and presented in Fig. 10. The HB

values are relatively uniform at the whole height and they are located in the scope required by the client, i.e. from 170 to 230 HB.

Summarizing, it can be stated that, by ensuring the control of the metallurgical process, taking into account the mentioned above components of the metallic charge and chemical composition of melt as well as in the inoculation treatment, the undesired carbide precipitations can be eliminated from the cast iron microstructure and the uniform and stable pearlite fraction in the metallic matrix can be assured.

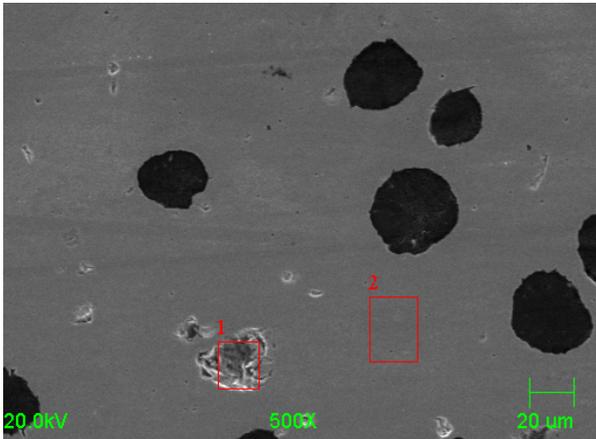


Fig. 5. SEM microstructure of ductile cast iron

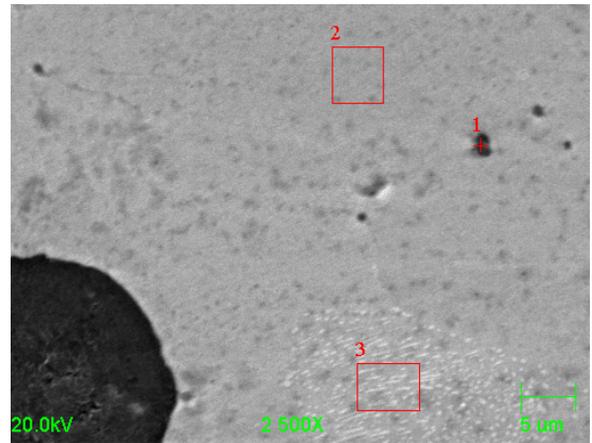
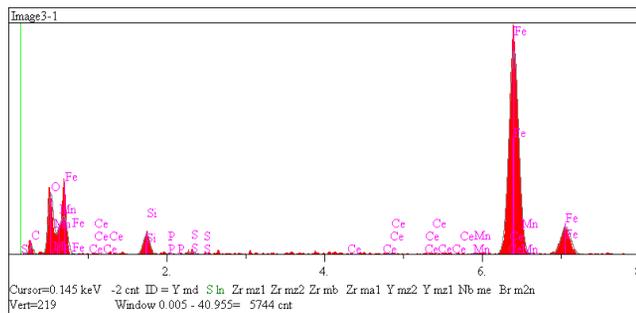
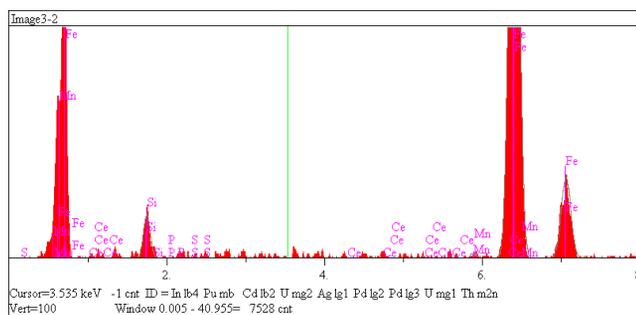


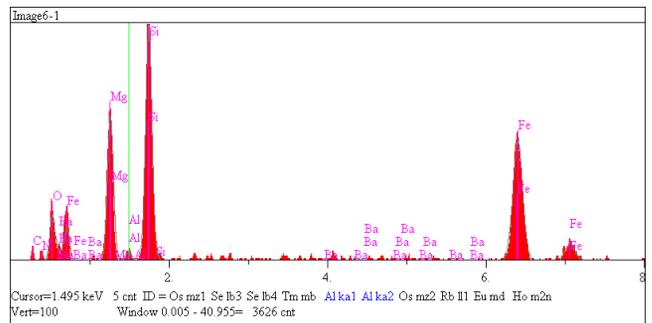
Fig. 6. SEM microstructure of ductile cast iron



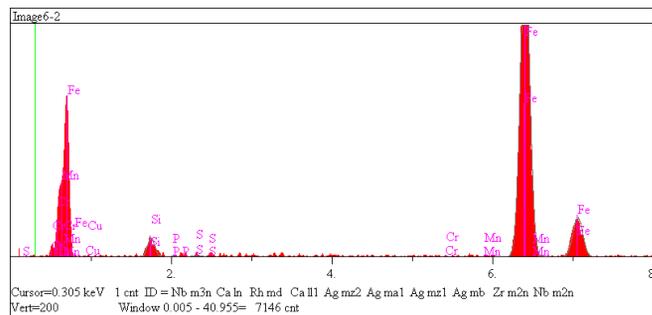
Point No. 1 (oxide)



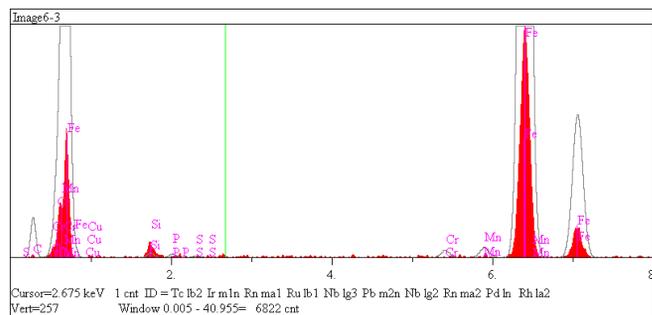
Point No. 2 (ferrite)



Point No. 1 (oxide)



Point No. 2 (matrix –ferrite)



Point No. 3 (matrix – pearlite)

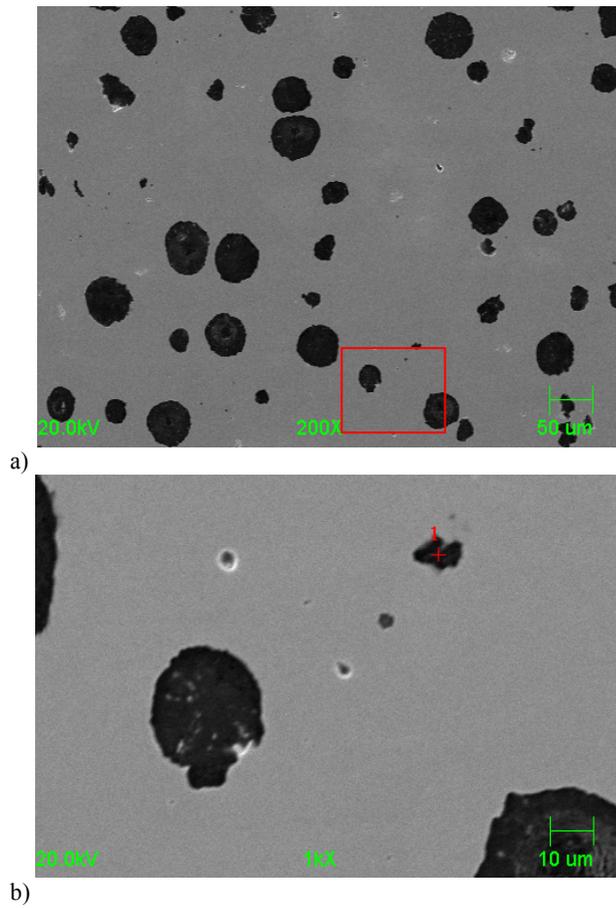


Fig. 7. SEM microstructure of ductile cast iron

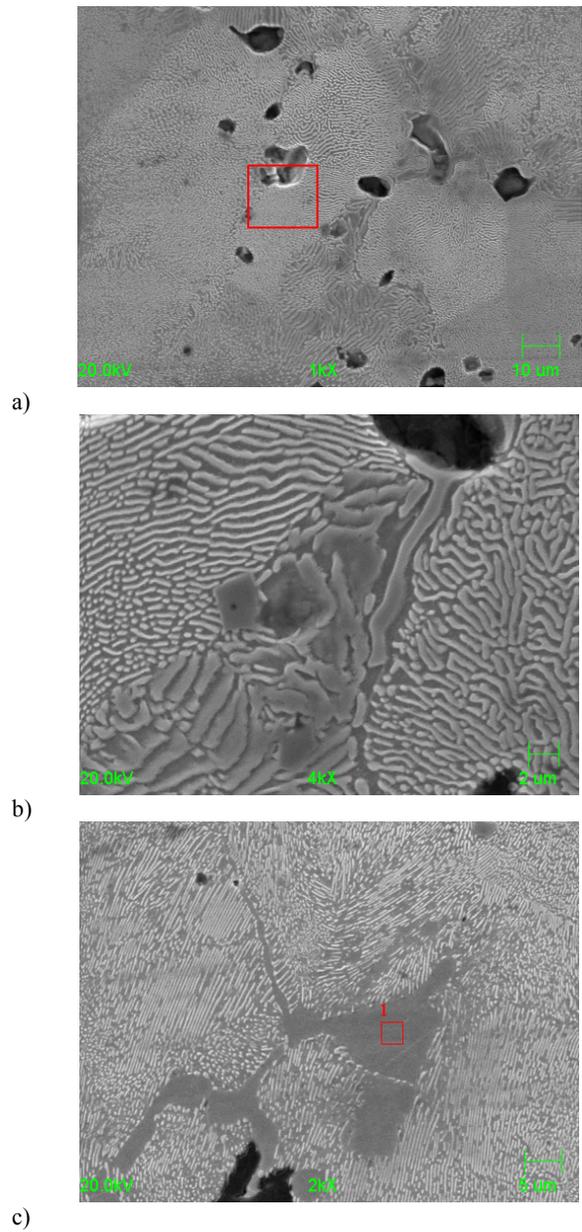
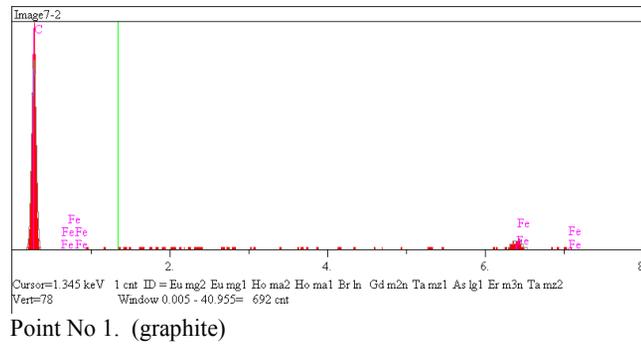


Fig. 8. SEM microstructure of ductile cast iron

