

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

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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

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Table 3.



| Element | Mo | Ti | V | Cr | Mn | Р |
|---------|------|-----|------|------|---------|-----|
| 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]

| Ta | ble | e 2. | |
|----|-----|------|--|
| | | | |

Chemical composition of cast iron

| С | Si | Mn | S | Р | 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:

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 of, 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 physicalchemical 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).

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a)



b)

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 μ 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); 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 M₃C.

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

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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 than, 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 procipitations can be eliminated from the cast iron microstructure and the uniforme and stable pearlite fraction in the metallic matrix can be assured.



Fig. 5. SEM microstructure of ductile cast iron



Point No. 1 (oxide)





Fig. 6. SEM microstructure of ductile cast iron



Point No. 1 (oxide)



Cursor=0.305 keV 1 cnt ID=Nb m3n Cain Rh md Caill Ag mz2 Ag mai Ag mz1 Ag mb Zr m2n Nb m2n Vert=200 Window 0.005 - 40.955=7146 cnt





Point No. 3 (matrix - pearlite)







Fig. 7. SEM microstructure of ductile cast iron





b)

a)



Fig. 8. SEM microstructure of ductile cast iron





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Fig. 9. SEM microstructure of ductile cast iron



Table 5.

Hardness HB of tested cone casting

| GSM 001 of chart 2 | Requirement |
|--------------------|-------------|
| | 170-230 HB |
| Zone | HB 10/3000 |
| 1 | 179 |
| 2 | 174 do 176 |
| 3 | 174 |
| | |



Fig. 10. Photograph of the section of the tested cone casting with the values of Brinell hardness marked on it

4. Summary

On the basis of the results of investigations and their analysis following most essential conclusions can be pointed:

- Results of the metallographic investigations indicate that in the cone casting under discussion the microstructure characterized by the type (shape) and dimensions of graphite precipitations as well as by the yield of pearlite in the metallic matrix (30 to 60 % pearlite) have been obtained. In the structure of the zones 1 to 3 there are the precipitations of undesirable cementite (primary or eutectic one) not observed. In the central parts of pearlite grains as component of the metallic matrix small, light fields were found, but they could be identified as ferrite.
- 2. The obtained values of the mechanical properties of casting correspond fully with the requirements of the french client.
- 3. The features of graphite precipitations correspond to the requirements of the french client. Nevertheless, the amount of the graphite precipitations type VI (actually about 85 %) could be increased, through amelioration of the nodularization and inoculations treatments. This could be, for example, achieved by elimination of rare-earth elements (RE) from the filling material contained in the inoculating pipe (in the foundry under discussion the Cored Wire Injection Method is used [3]); as the RE elements favorise crystallization of the vermicular graphite (graphite type III), its amount could be decreased beneath 5 % and at this cost the amount of nodular graphite type VI could be distinctly increased.
- 4. A small correction of the chemical composition could also bring advantage; by increasing the concentration in the cast iron of such elements as Cu which favorise the crystallization of pearlite, the yield of this component of the metallic matrix could be increase up to 50%; as effect of this change the greater values of tensile properties and hardness could be obtained at the cost of elongation which actually achieves values (16%), much higher than it is required (min. 7%). Usually, the greater the yield of pearlite in the matrix is, the greater also the yield of regular nodular graphite precipitations is.

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