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# Stereological Analysis of Carbides in Hypoeutectic Chromium Cast Iron

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## Abstract

The results of research on stereological parameters of carbides in modified hypoeutectic chromium cast iron were shown in the paper. The effect of distance the casting heat centre of casting to the carbide phase morphology was examined. The samples for metallographic examination were taken from various locations of the model casting prepared in a special tester. This model casting was designed to simulate the solidification of heavy castings. Using the proposed methodology the relation of the distance from the model mould and the size, perimeter, length, width and the shape factor of carbides was examined. During the analysis, the values of stereological parameters of carbides changed on various sections of the model casting.

**Keywords:** Stereological parameters, Fe-C-Cr alloys, Chromium carbide, Chromium cast iron

## 1. Introduction

Chromium cast iron belongs to a group of materials with high tribological properties, working in abrasive environment and for a long time is applicable for casting the massive elements used in heavy industry [1, 2]. The wear resistance is a result of high-hardness carbides content [3]. However, the wide application of these alloys is limited because of low crack resistance. This problem can be solved by controlling the structure of chromium cast iron. The basic components of chromium cast iron [4], which is iron, chromium and carbon shape the phase structure characteristic for this alloy which give it specific operational properties. The shape and morphology of carbides significantly affect the structure and properties. Achievement of a preferred carbides morphology, decreasing their size and refinement, would allow to improve the mechanical properties of this material. To increase the plastic properties of the material should form a structure consisting of small carbides with rounded shape. Introduction of other elements to chemical composition of plain chromium cast iron is mainly performed to improve its mechanical properties due to the changing the carbides morphology [5].

In this work, stereological parameters of carbides in hypoeutectic chromium cast iron were examined. The alloy was modified by mixture of ferroalloys with misch-metal. Studies were focused on the metallographic examinations of model casting [6] that simulate the heavy – casting conditions of solidification. It was examined, how the distance from the model mould influenced the shape and size of carbides, through their analysis on the sections of perpendiculars and parallel to the heat flux accompanied from the casting.

## 2. Methodology of Studies

Hypoeutectic chromium cast iron modified by mixture of ferroalloys (FeV, FeTi, FeNb) with misch-metal was chosen for investigations of stereological parameters. In the Table 1. chemical composition of examined alloy was shown.

Table 1.
The results of chemical analysis

| No | chemical element | element content [%wt.] |
|---|---|---|
| 1. | C | 2,565 |
| 2. | Mn | 0,207 |
| 3. | Si | 1,03 |
| 4. | Cr | 16,88 |
| 5. | Ni | 1,49 |
| 6. | Mo | 1,62 |
| 7. | Cu | 0,084 |
| 8. | Al. | 0,008 |
| 9. | Ti | 0,071 |
| 10. | Nb | 0,247 |
| 11. | V | 0,315 |
| 12. | P | 0,049 |
| 13. | S | 0,036 |

Model casting was prepared with use of ATD – Is 100 tester. In Fig. 1 the tester construction was shown. Stereological parameters examination of carbide phase was conducted for sections distant from the model mould of: 5; 20; 40; 60; 85 [mm] (indicated in figure 1 as D1 – D5). The aim of the research was to test, how the distance from the heat centre of casting during the crystallization influences the analysed parameters. The specimens for research were cut from the model casting in a way to obtain two samples; one of them prepared on a plane perpendicular and the other on a plane parallel to the direction of heat removal. The samples for metallographic examinations were prepared by sanding, polishing and etching with aqua regia. The stereological parameters were calculated by computer software Nis Elements BR 3.10, based on metallographic sections micrographs. The micrographs were prepared with use of optical microscope Nikon Epiphot equipped with digital CCD-camera. In this paper the following stereological parameters were analysed:

- area,
- perimeter,
- length,
- width,
- shape factor, which specified how much the carbides shape was circle-similar.

The shape factor was calculated using the Eq. 1:

$$Q = \frac{4 * \pi * A}{P^2} \quad (1)$$

where:
$Q$ – shape factor
$A$ – area [$\mu m^2$]
$P$ – perimeter [μm]

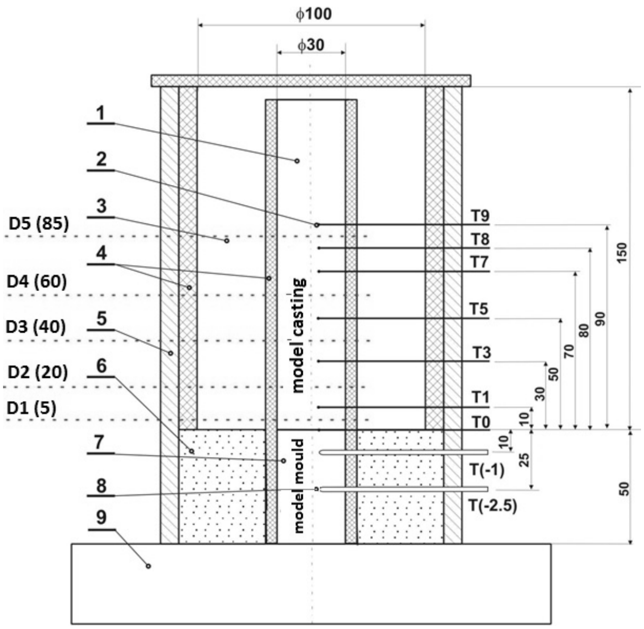


Fig. 1. Construction of the ATD-Is100 tester with indicated position of thermocouples and specimens used in the analysis, 1 – model casting, 2 – S-type thermocouple, 3 – thermal insulator, 4 – insulating material Sibral 300, 5 – steel casing, 6 – moulding material (quartz sand), 7 – model mould, 8 – K-type thermocouple, 9 – base, T0 – S-type thermocouple located on the border of the model casting – model mould, T1 ÷ T9 – S-type thermocouples placed in the model casting [2]

# 3. Results of the Studies

The main aim of the studies was directed towards the comparison of carbides parameters on the sections perpendicular to the direction of heat flow and those observed on parallel sections. To obtain reliable results for analysed regions, the samples were taken from exactly the same place. Even a small distance of two analysed locations significantly affects the result of research and makes it impossible to accurately examine the carbide phase stereology in chromium cast iron. For each sample was taken and analysed 10 micro-regions which enabled the detection and examination of more than 4000 carbides at distances of 5 mm of the model mould. With an increase of distance the quantity of carbides was decreased. At a distance of 85 mm their quantity decreased quadrupled relative to measurements for samples distant by 5 mm.

### 3.1. Stereological Parameters of Carbides on Perpendicular Sections to the Direction of Heat Removal

In Table 2 the stereological parameters of carbide phases on perpendicular sections to the direction of heat removal at various distances from the model mould were presented.

Table 2.
The selected stereological parameters for the various perpendicular sections

| | area [µm$^2$] | perimeter [µm] | length [µm] | width [µm] | shape factor |
|---|---|---|---|---|---|
| D1p | 70,37 | 64,64 | 30,9 | 1,59 | 0,595 |
| D2p | 122,77 | 73,28 | 34,13 | 2,7 | 0,56 |
| D3p | 162,72 | 76,31 | 34,91 | 3,46 | 0,552 |
| D4p | 126,17 | 56,27 | 25,17 | 3,19 | 0,598 |
| D5p | 275,8 | 94,69 | 43,43 | 4,2 | 0,597 |

In Figs. 2 – 5 the average size, perimeter, length and width of carbides on the examined sections were shown. Trend lines showing the observed dependence were also created on the graph. In Fig. 6 the average shape factor of carbides was presented.

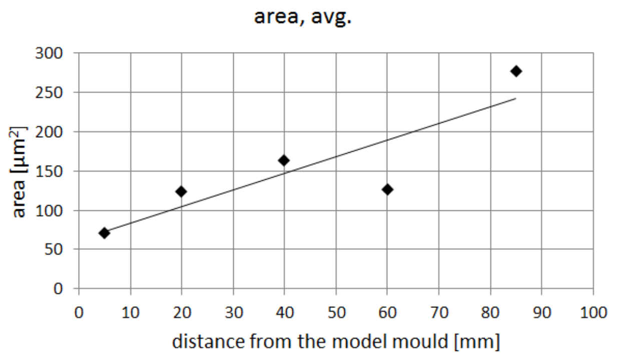


Fig. 2. The average size of carbides on perpendicular sections

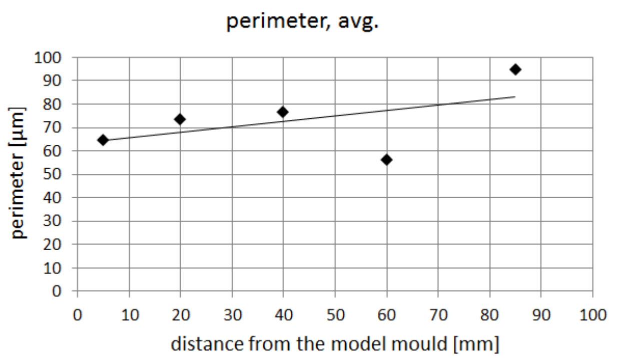


Fig. 3. The average perimeter of carbides on perpendicular sections

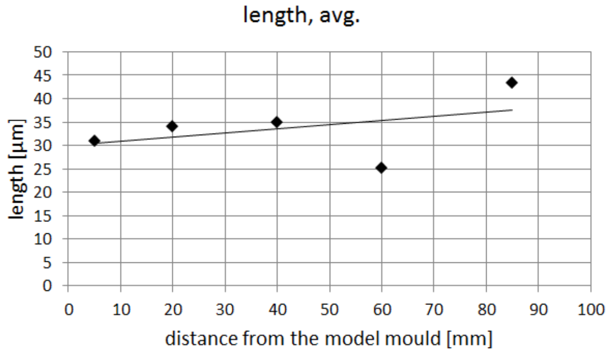


Fig. 4. The average length of carbides on perpendicular sections

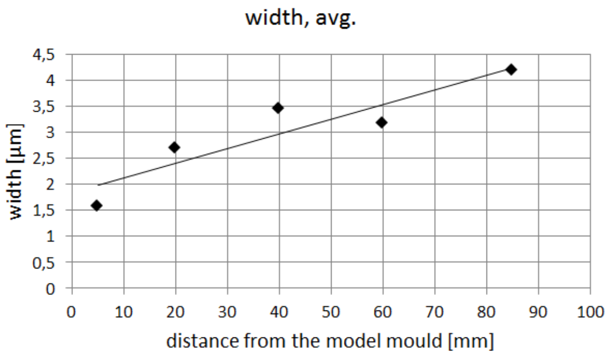


Fig. 5. The average width of carbides on perpendicular sections

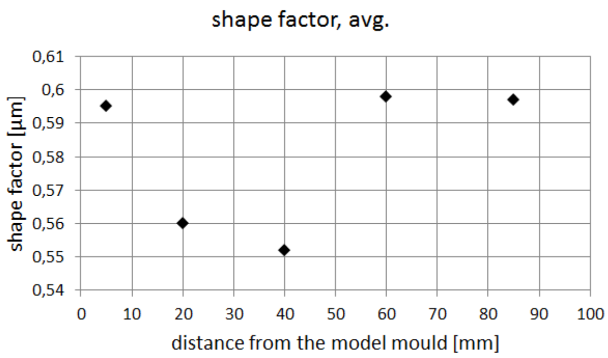


Fig. 6. The average shape factor of carbides on perpendicular sections

## 3.2. Stereological Parameters of Carbides on Parallel Section to the Direction of Heat Removal

In Table 3 the stereological parameters of carbide phases on parallel sections to the direction of heat removal at various distances from the model mould were presented.

Table 3.
The selected stereological parameters for the various parallel sections

| | area [μm$^2$] | perimeter [μm] | length [μm] | width [μm] | shape factor |
|---|---|---|---|---|---|
| D1r | 102,86 | 75,87 | 36,1 | 1,97 | 0,537 |
| D2r | 185,28 | 97,67 | 46,44 | 2,52 | 0,509 |
| D3r | 244,16 | 101,04 | 47,51 | 3,13 | 0,502 |
| D4r | 162,28 | 70,62 | 32,75 | 2,68 | 0,516 |
| D5r | 475,84 | 133,68 | 63,05 | 3,99 | 0,525 |

In Fig. 7 - 10 the average size, perimeter, length and width of carbides on the examined sections were showed. Trend lines showing the observed dependence were also created on the graph. In Fig. 11 was presented the average shape factor of carbides.

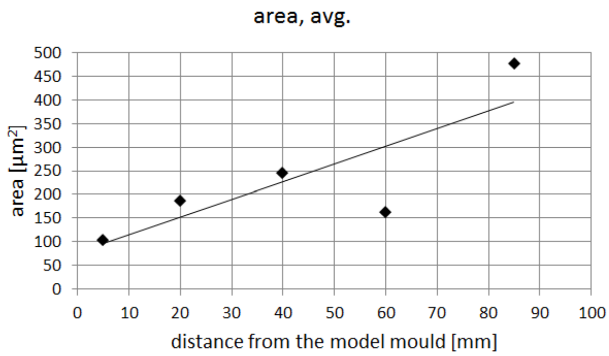


Fig. 7. The average size of carbides on parallel sections

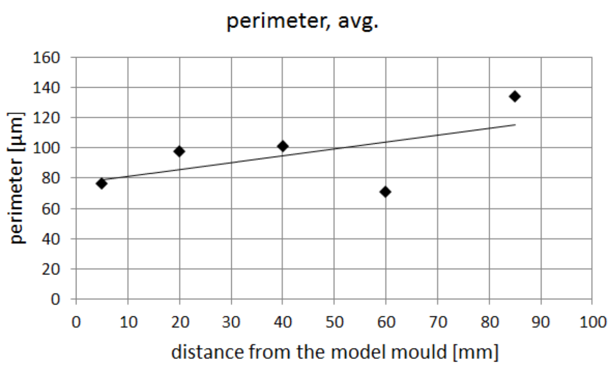


Fig. 8. The average perimeter of carbides on parallel sections

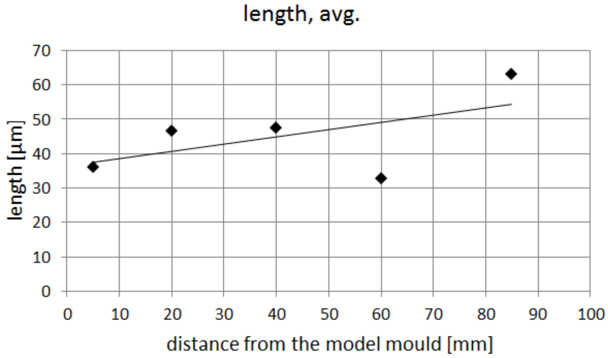


Fig. 9. The average length of carbides on parallel sections

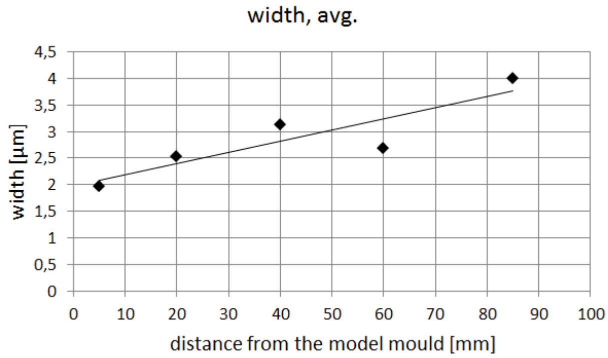


Fig. 10. The average width of carbides on parallel sections

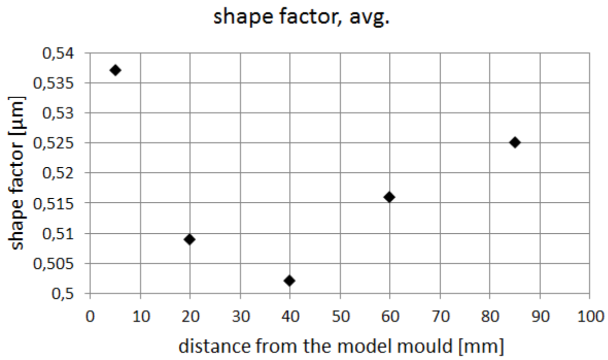


Fig. 11. The average shape factor of carbides on parallel sections

## 3.3. Hypoeutectic Chromium Cast Iron Structure

In Fig. 12 the microstructure of examined hypoeutectic chromium cast iron structure was shown in different regions of the model casting. It can be observed, that the size and morphology of the carbides change, depending on the distance from the model mould.

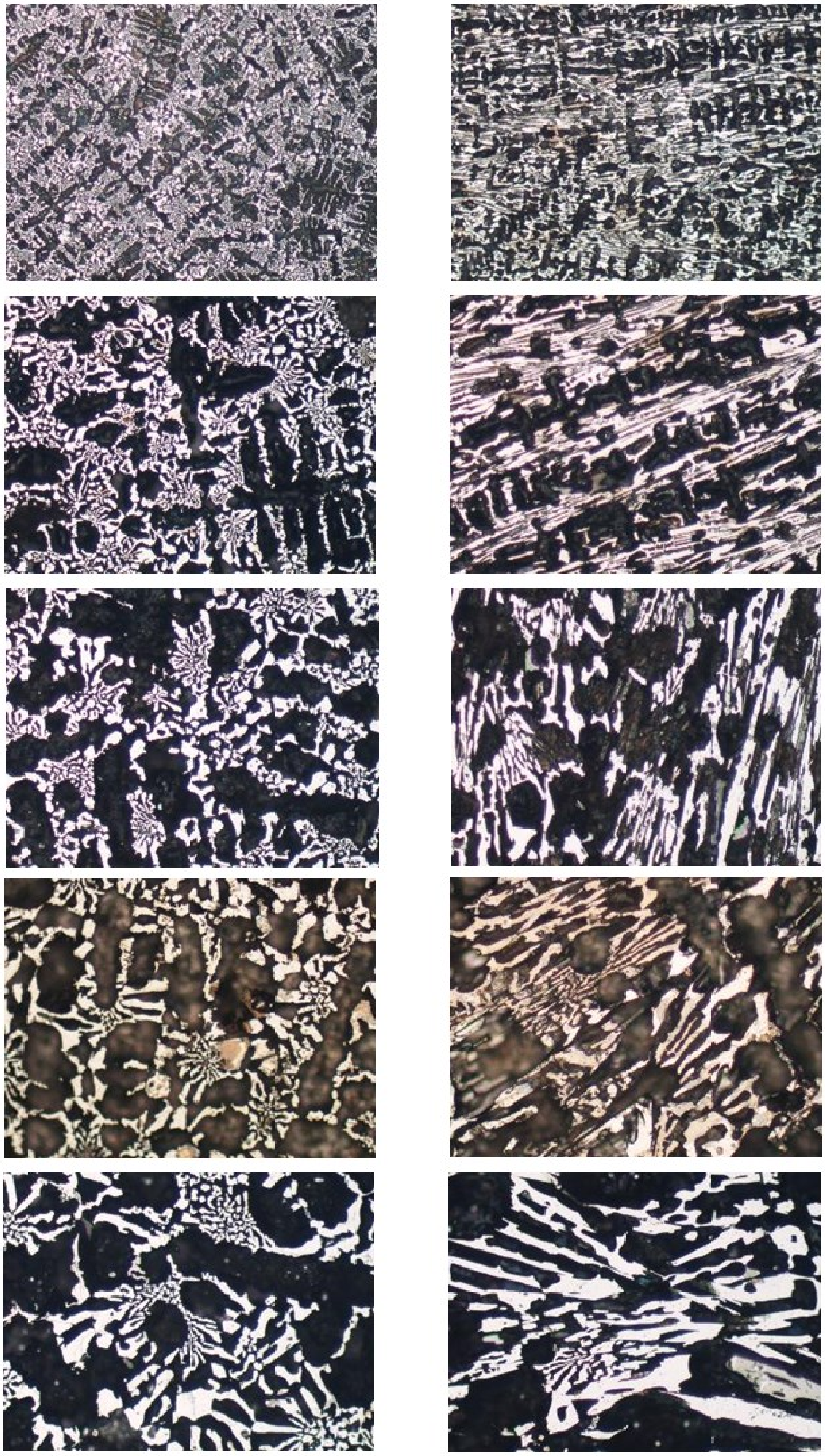

Fig. 12. Microstructure on perpendicular (left) and parallel (right) sections to the direction of heat removal distant from the model mould of 5, 20, 40, 60, 85 [mm], mag. 200x, etched

## 4. Conclusions

Based on the conducted studies, concerning the stereological parameters of the carbides, following conclusions can be formulated:

- The quantity of carbides decreases with the increasing distance from the mould surface.
- Stereological parameters of carbides analysed in the studies (area, length, width, circuit) increased with increasing distance, both at cross section perpendicular and parallel to the direction of heat removal.
- The most disadvantageous shape factor of carbides was observed at a distance of 40 mm from the surface of the mould.
- Such influence shows that carbides nucleation and growth depends on cooling rate.

## References

[1] Sakwa, W., Jura, S., Sakwa, J. (1980). *Wear-resistant iron alloys. Part I. Cast iron.* 2nd ed.). Kraków: ZG STOP. (in Polish)

[2] Gierek, A. (1993). *Abrasive wear of metal working parts.* Silesian University of Technology scrypt., no. 1752. Gliwice, (in Polish)

[3] Szajnar, J., Dulska, A., Wróbel, T. & Suchoń, J. (2014). Diffusion of C and Cr during creation of surface layer on cast steel casting. *Archives of Metallurgy and Materials*. 59(3), 1085-1087. DOI: 10.2478/amm-2014-0186.

[4] Studnicki, A., Jezierski, J. (2012). *Stereological parameters of carbides in modified wear resistant Fe-C-Cr alloys*. In Metal 2012, 23 – 25 May 2012, Brno, Czech Republic, EU.

[5] Studnicki, A. & Suchoń, J. (2011). Stereological parameters of carbides on section of casting made from modified chromium cast iron. *Archives of Foundry Engineering*, Volume 11, Special Issue, 209 – 214, ISSN (1897 - 3310), (in Polish).

[6] Studnicki, A. (2004). Experimental modelling of casting cooling in the mould. *Archives of Foundry Engineerin,* Volume 4, no. 11, 476 – 481.