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Evaluation of Graphite Distribution-Part Thickness Ratio in Gray Cast Irons Microstructure

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Abstract
A wedge-shaped sample of gray cast iron was examined under the microscope where the graphite distribution was graded according to SR EN ISO 945-1 standard. The importance of sample thickness on graphite dimensions and distribution, based on different cooling rates observed during the solidification phenomena, is highlighted. For that reason, six areas from the sample were selected for evaluation in terms of microstructure and hardness. When the sample thickness decreased from 7 mm to a minimum of 1.5 mm, a range of hardness average values from 73HRB to 90HRB was recorded. An average length of graphite separations for each area was calculated. It is observed that in this particular sample, the lamellar aspect of graphite was average measured within 7.8 µm to 118.8 µm. Evidence of sliding planes at the graphite boundaries near the indentation area are presented. Despite of inconvenient as low shock resistance limited tensile strength and reduced elasticity; gray cast iron is widely used across diverse industries.

Keywords
gray cast iron, graphite dimension, hardness

1. Introduction

Cast irons, especially gray ones represent a category of materials well-known for their exceptional versatility and wide-ranging industrial applications [1] with unique microstructures and properties. One of the main disadvantages in using gray cast irons is graphite crystallization in lamellar forms. These graphite shapes can initiate numerous new cracks if the material undergo to a mechanical shock that can lead to component fracture. Is one of the reasons that gray cast iron exhibit low shock resistance, low tensile strength, and poor elasticity. Despite of these aforementioned limitations, gray cast irons is used for heavy engine blocks manufacturing, cylinder heads, gas burners, pressure pipe fittings, furnace parts, gear housings and gears mainly of its ability on wear resistance even when lubrication is limited [2, 3, 4]. Also, chemical composition, liquid treatments, cooling rate from liquid state and heat treatments are the main influence factors that strongly decide the cast iron structure formation and their performance properties.

The various types of unalloyed cast irons can be classified into five categories based on their microstructure, essentially of constituent's shapes and dimensions (see Table 1) [5, 6]. Gray iron is characterized by appearance of graphite flakes, ductile iron by more compacted graphite (vermicular) and malleable iron by spheroidal graphite shapes. Usually these are known as common cast irons and along these, special cast irons (more than 3% alloying elements) can be found as commercials ones. These high alloy cast irons have special properties as a better corrosion resistance, wear resistance also working as material for elevated temperature applications [6].

Table 1. Chemical composition for unalloyed cast irons

Cast iron type	Composition [wt%]				
	C	Si	Mn	P	S
White	1.8 - 3.6	0.5 - 1.9	0.25 - 0.8	0.06 - 0.2	0.06 - 0.2
Malleable	2.2 - 2.9	0.9 - 1.9	0.15 - 1.2	0.02 - 0.2	0.02 - 0.2
Gray	2.5 - 4.0	1.0 - 3.0	0.2 - 1.0	0.002 - 1.0	0.02 - 0.25
Ductile	3.0 - 4.0	1.8 - 2.8	0.1 - 1.0	0.01 - 0.1	0.01 - 0.03
Compacted graphite	2.5 - 4.0	1.0 - 3.0	0.2 - 1.0	0.01 - 0.1	0.01 - 0.03

Actual studies focus on graphite nucleation using different inoculation elements [7, 8] in order to predict and control the gray cast iron solidification with intrinsic material performance. Graphite morphologies in cast irons are diverse and well documented by different forms and dimensions in international ASTM and ISO standards [9, 10]. According to these standards, graphite classification by visual analysis is a well-established method which is well recognized within the industry as it can quickly determine the overall graphite microstructure of a cast iron part. These standards offer guidance on the classification method for graphite but do not specify the suitability of cast iron types and grades for a specific application.

The present study can be used as a guideline for students practice in the university laboratories when the influence of the cooling rate on gray cast iron structure and mechanical properties are studied. Moreover, by correlating the gathered information with the industry standards commonly used in foundries, students acquire a proper methodology for evaluating a material issue.

2. Material and Methods

A near eutectic composition of a gray cast iron sample achieved by sand casting was investigated. To evaluate the graphite size and distribution, the sample was split in six area, five at equal distance of 12 mm and one of 3 mm as it can be seen in Figure 1.

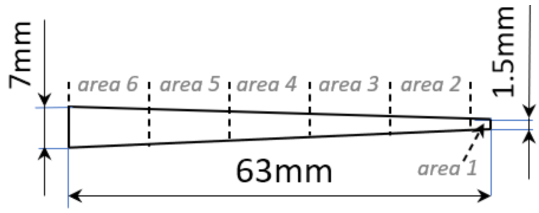


Fig. 1. Wedge-shaped sample and splited areas for evaluation

For microstructures evaluation, the wedge-shape sample was metallographic prepared using water-grinding paper and diamond grinding paste of 0.1 μm particle size at the final step. Microstructures analyses were performed using Nikon metallographic microscope (Nikon Eclipse MA100, Japan).

In order to evaluate the length of graphite separations, an average value of 20 measurements per area were calculated.

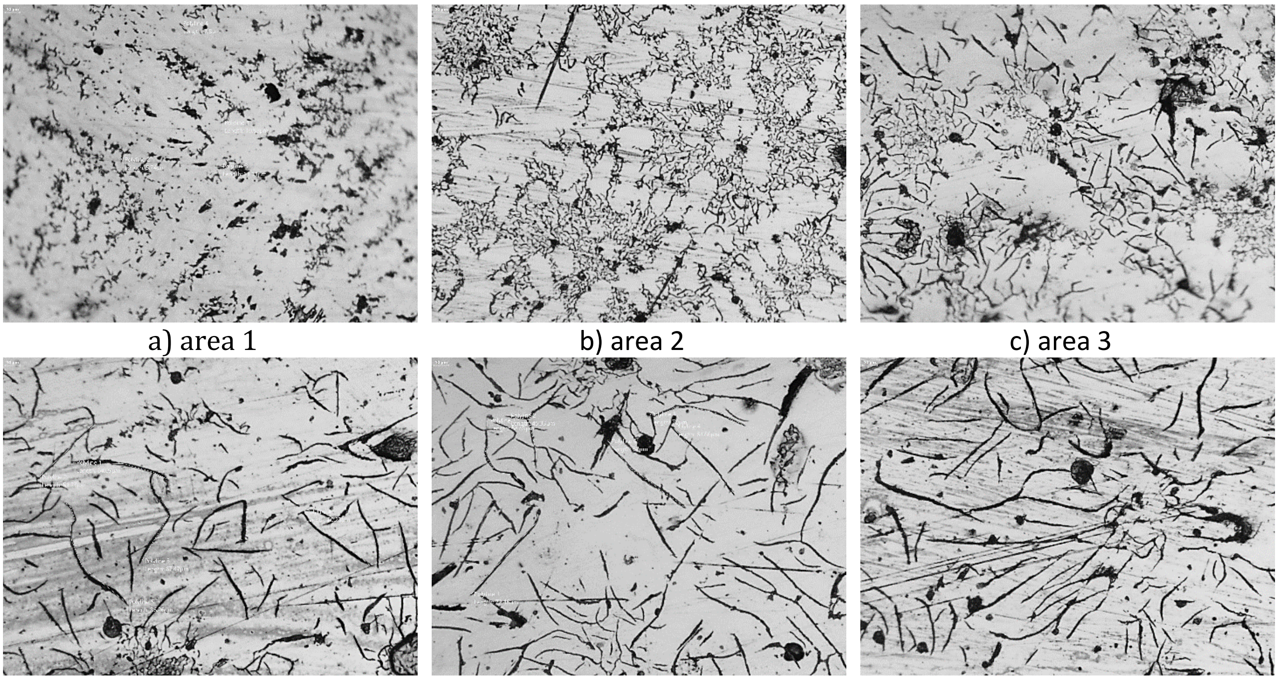
Hardness measurements were carried out using a Rockwell hardness tester with ball indenter (Mitutoyo HR-200, Japan) using a full test force of 980.7N and 5s dwell time as a testing condition. Thus, hardness values were obtained by the average of 3 measurements on each sample area, except area 1 due to its narrowed shape.

By using both ASTM and ISO standards it can bring some benefits in terms of global accessibility, additional detail, and adaptability in the evaluation of graphite form and distribution. For example, in ASTM standard are described seven graphite forms while in ISO standard only six different forms are indicated. Students went through the ISO standard more easily due to the designation system for classifying graphite in cast irons (form, distribution, and size).

3. Results and Discussion

Representative microstructures were inserted in Figure 2 for each of the analysed area. All imagines were done at the same magnification for a good visual evaluation. It can be observed that with the increasing of part-wall thickness is also increasing the length of graphite separation. Due to the fact that the differences of cooling rate during solidification appear along the entire length of the sample, the graphite size can reach from 0.005 mm to 0.15 mm. Average values of measured graphite size are indicated in Table 2. Must be mentioned that the black spots aren't nodular graphite shapes, they are graphite spread marks occurring from the sample polishing process and handling.

In Table 2 were included three different types of characteristics to summary the influence of graphite distribution-part thickness ratio in gray cast iron sample. According to classification standards all areas of the sample have a graphite crystallized in flakes form (Form I, indicated by the standard, also known as lamellar) with different type of distribution indicated in Table 2.



a) area 1 b) area 2 c) area 3

d) area 4 e) area 5 f) area 6

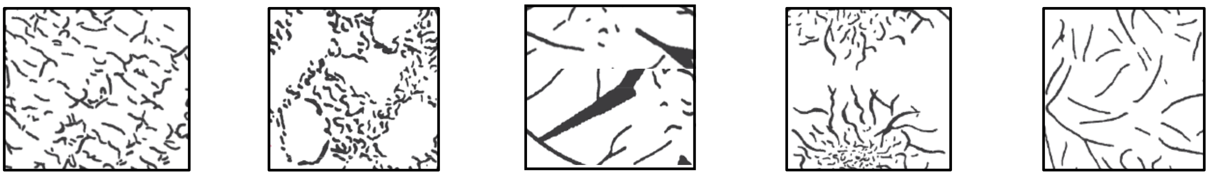
Fig. 2. Microstructures of gray cast iron sample used for graphite size evaluation (X200)

Table 2. Characteristics of analysed areas

Characteristics	Split zone of the as-cast gray cast iron sample					
	area 1	area 2	area 3	area 4	area 5	area 6
Graphite distribution*	E	D	B, C	B, A	B, A	A
Average length of graphite separation [μm]	7.8	11.4	40.5	65	82	118.8
Hardness [HRB]	90	82	75	75	75	73

*Classification according to SR EN ISO 945-1

In Fig. 3 it can be observed images extracted from ISO standard with the distribution of lamellar graphite. By minimize the thickness of the as-cast sample from 7mm to 1.5mm, it was obtained all types of graphite distribution of the lamellar form. Pouring a wedge-shaped sample allows melting to be subjected to a wide range of cooling rates, so it will exhibit different microstructure and properties.



E D C B A

Fig. 3. Distribution forms of graphite flakes (lamellar), from SR EN ISO 945-1

Sliding planes are indicated by white arrows in Figure 4. The presence of these sliding planes at the indentation's edge suggests that the material can fracture precisely at the boundaries of graphite separations. That indicate a poor elasticity and appearance of cracks in the performed material.

4. Conclusions

The present investigation provides aspects of the relationship between graphite distribution, part thickness and material properties for a gray cast iron sample, contributing to a better understanding of microstructural influences on material behaviour.

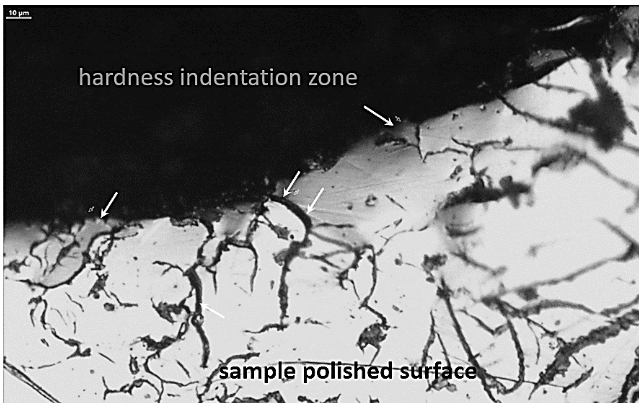


Fig. 4. Edge between indentation and polished surface

The microstructures predominantly exhibit lamellar graphite forms with different distributions. Changes in sample thickness yield to a variety of graphite flakes forms.

Graphite morphology in gray cast iron influence the mechanical properties. By microstructure observation and HRB evaluation it was determined that if a larger form of lamellar graphite appear a decrease of hardness can occur.

In this study can be observed the reduced material elasticity and potential crack formation at graphite separations, with a strong impact on material strength.

References

1. Alp T., Wazzan A.A., Yilmaz F. (2005): *Microstructure-property relationships in cast irons*. The Arabian Journal for Science and Engineering, Section B, ISSN 1319-8025, Vol. 30, is. 2B, pp. 163-175, https://search.emarefa.net/detail/BIM-359751
2. Teng X.Y., Pang J.C., Liu F., Zou C.L., Gao C., Li S.X., Zhang Z.F. (2023): *Fatigue strength optimization of gray cast iron processed by different austempering temperatures*. International Journal of Fatigue, eISSN 1879-3452, Vol. 175, art. 107831, https://doi.org/10.1016/j.ijfatigue.2023.107831
3. Riemschneider E., Bordeasu I., Mitelea I., Utu D.I., Crăciunescu M.C. (2021): *Morphology and mechanism of cavitation degradation of gray cast iron surfaces with lamellar graphite*. Materials Today Proceedings, ISSN 2214-7853, Vol. 45, part 5, pp. 4157-4160, https://doi.org/10.1016/j.matpr.2020.11.929
4. Yakut R. (2023): *Investigation of Mechanical Properties of Gray Cast Irons Reinforced with Carbon Titanium Nitride (TiNC).* Lubricants, eISSN 2075-4442, Vol. 11, is. 10, https://doi.org/10.3390/lubricants11100454
5. Janina M.R. (2004): *Metallography and Microstructures of Cast Iron*. In: *ASM Handbook*, Vol. 9, pp. 565-587, ASM International Publisher, eISBN 978-1-62708-177-1, https://doi.org/10.31399/asm.hb.v09.9781627081771
6. Ştefănescu D.M. (1990): *Classification and Basic Metallurgy of Cast Iron*. In*: ASM Handbook*, Vol. 1, *Properties and Selection: Irons, Steels, and High-Performance Alloys*, pp. 3-11, ASM International Publisher, eISBN 978-1-62708-161-0, https://doi.org/10.31399/asm.hb.v01.a0009206
7. Ştefănescu D.M., Crişan A., Alonso G., Larrañaga P., Suarez R. (2019): *Growth of Spheroidal Graphite on Nitride Nuclei: Disregistry and Crystallinity During Early Growth.* Metallurgical and Materials Transactions A, eISSN 1543-1940, Vol. 50A, pp.1763-1772, https://doi.org/10.1007/s11661-019-05125-z
8. Ştefan E., Chişamera M., Ripoşan I., Stan S. (2021): *Graphite nucleation sites in commercial gray cast irons.* Materials Today Proceedings, ISSN 2214-7853, Vol. 45, part 5, pp. 4091-4095, https://doi.org/10.1016/j.matpr.2020.11.009
9. SR EN ISO 945-1 (2019): *Microstructure of cast irons*. Part 3: *Graphite classification by visual analysis*. ICS 77.080.10
10. ASTM A247-19 (2019): *Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings*. ICS 77.140.80