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Effect of Wall Thickness on the Microstructure of Ductile Iron Castings Manufactured by the Inmold Process Using a Reaction Chamber

J. Kamińska *, M. Angrecki, Z. Stefański, A. Palma
Foundry Research Institute, Department of Technology,
Zakopianska 73, 30-418 Cracow, Poland
* Corresponding author. E-mail address: jadwiga.kaminska@iod.krakow.pl

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Abstract

In the family of iron-based alloys, ductile iron enjoys the highest rate of development, finding application in various industries.
Ductile iron or the cast iron with spheroidal graphite can be manufactured by various methods. One of them is the Inmold spheroidization process characterized by different technological solutions, developed mainly to increase the process efficiency. So far, however, none of the solutions has been based on the use of a reactor made outside the casting mould cavity.
The method of spheroidization inside the casting mould using a reaction chamber developed at the Foundry Research Institute is an innovative way of cast iron treatment. The innovative character of this method consists in the use of properly designed and manufactured reactor placed in the casting mould cavity. Owing to this solution, the Inmold process can be carried out in moulds with both horizontal and vertical parting plane.
The study presents the results of examinations of the microstructure of graphite precipitates and metal matrix of castings after spheroidization carried out by the Inmold process using a reactor and mould with vertical parting plane. Special pattern assembly was made for the tests to reproduce plates with wall thicknesses of 3; 5; 7; 10; 20 and 30 mm. The content of residual magnesium was determined for all tested castings, while for castings of plates with a wall thickness equal to or larger than 10 mm, testing of mechanical properties was additionally performed.

Keywords: Ductile iron, Inmold process, Reaction chamber, Vertical mould parting plane, Cast iron microstructure

1. Introduction

Ductile iron, or cast iron with the precipitates of nodular graphite, is a casting alloy showing the fastest growth rate in developed countries. The share of ductile iron castings in the overall casting production, and in particular in the production of castings from iron alloys, is undoubtedly one of the most recognized indicators of progress in modern foundry and in those sectors of industry where castings made from this material are important components of end products, which means, first of all, machine building industry. From the point of view of machine designers, ductile iron covers a wide range of mechanical properties (according to PN-EN 1563), being available in nine grades which can offer high strength and low ductility typical of bainitic or martensitic matrix, or high ductility and satisfactory strength in the case of pearlitic, pearlitic-ferritic and ferrtic matrix [1-5].

Over the years of using magnesium as a spheroidizer, many methods have been developed for its introduction into liquid cast iron [6, 7]. Currently, spheroidization processes are carried out in the casting ladle, most often using the PE flexible wire method [8].

Another commonly known method is the in-mould spheroidization of cast iron, which consists in placing the spheroidizer and inoculant in the mould cavity [9-11]. The method of spheroidization in casting mould using a reaction chamber developed in the Foundry Research Institute is an innovative, on a global scale, method of cast iron processing [12, 13]. The innovativeness of this method consists in the use of a properly designed and constructed reactor placed in the casting mould cavity.

2. Research methodology

The aim of the present research was to capture changes in the microstructure of ductile iron made by the in-mould process using a reaction chamber. In terms of the characteristics of graphite and metal matrix, the obtained cast iron was expected to have a ferritic matrix with precipitates of nodular graphite in castings of plates with the wall thickness from 3 to 30 mm. Microscopic examinations and photographs were taken with an AXIO OBSERVER Z1M metallographic microscope. The cooling curves (solidification process) were plotted for individual plates using an MrAC 15 recorder with 6 independent measuring channels. In foundry practice, the temperature of pouring, solidification and cooling is one of the most important parameters determining the quality of castings. Both high quality and proper structure depend to a large extent on the run of these parameters.

Melts were made under laboratory conditions in the Foundry Research Institute in Cracow. The melting unit was a medium frequency induction furnace with a power of 100 kW and a crucible of 60 kg capacity. A batch of 50 kgs of base cast iron with the composition given in Table 1 was prepared for the spheroidization process. The spheroidizer was an Al-Si alloy with the trade name FeSiMg 931 added in an amount of 0.9% in relation to the mould capacity; the inoculant was an Alinoc alloy introduced in an amount of 0.2% in relation to the mould capacity.

To investigate the effect of solidification rate on the microstructure of ductile iron casting, a special pattern set was made to reproduce plates with different wall thicknesses, i.e. 3; 5; 7; 10; 20 and 30 mm. The spatial distribution of individual plates in relation to the metal feeding system is shown in Figure 1. The liquid metal was poured into a sand mould reproducing six plates with different wall thicknesses.

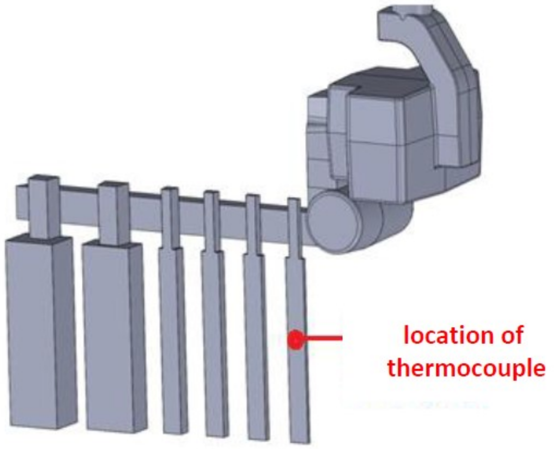


Fig. 1. Spatial distribution of individual plates in relation to the gating system

3. Analysis of the chemical composition of cast iron

Chemical analysis of base cast iron and cast iron after the in-mould spheroidization process was carried out by emission spectrometry on an ARL TYP MA apparatus in accordance with certified test procedures developed and applied by the Foundry Research Institute in Cracow. The obtained results are compared in Table 1. Samples for spectral analysis of chemical composition after the spheroidization process were poured as an integral part of casting into specially prepared chills placed in the casting mould cavity. The chemical composition obtained for different plate thicknesses showed that the solubility of magnesium was increasing with increasing thickness of the plates, which resulted from the adopted longer time of pouring. This was confirmed by detailed studies of magnesium content in individual plates with different wall thicknesses carried out with a Thermo SOLAAR M6 atomic absorption spectrometer. The magnesium content in the plates in order from the thinnest (3 mm) to the thickest (30 mm) plate was: 0.47; 0.52; 0.64; 0.76; 0.87 and 0.107, respectively.

Table 1.
Chemical composition of cast iron before and after spheroidization

	Chemical composition, wt%					
	C	**Si**	**Mn**	**P**	**S**	**Mg**
Base cast iron	3.48	1.98	0.274	0.039	0.010	-
Ductile iron – plate 20 mm thick	3.15	2.80	0.278	0.036	0.010	0.087
Ductile iron – plate 30 mm thick	3.15	2.95	0.278	0.039	0.010	0.107

4. Metallographic examinations of ductile iron

The results of metallographic examinations of graphite particles and metal matrix are compared in Table 2 and Figure 2. Samples for metallographic examinations were cut out from the lower part of castings at a distance of 10 mm from the bottom edge of the casting.

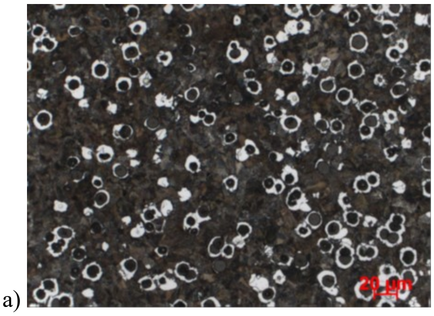
The evaluation of graphite microstructure according to PN-EN ISO 945-1 is a comparative method based on reference images. The standard defines that measurement uncertainty falls within the two adjacent images. The result of measurement is the average of three randomly selected fields of view. The above ISO standard does not include measurement of the number of graphite particles per unit area. Studies of the metal matrix microstructure were carried out by comparing the etched microstructure of samples with the microstructure of standard reference images included in PN-H75-04661. Etching of samples was done in Mi1Fe reagent (4% nital) according to PN-H-04503.

The graphite nodule count was calculated by the Jeffries method.

Studies of data on the number of grains per unit area and ferrite content in the matrix show that these parameters vary and depend on the casting wall thickness. As the thickness of the cast plates increases, the number of grains (graphite nodules) decreases and ferrite content in the metal matrix increases.

Table 2.
Parameters of metallographic examinations of plates cast from ductile iron

Wall thickness, mm	Microstructure of graphite acc. to PN-EN ISO 945-1	Nodule count N, cm^2 (x10^4)	Microstructure of metal matrix acc. to PN 75/H-04661
3	VI8	5.117	Pf1-P70
5	90%VI8 + 10%V7	3.218	Pf1-P70-Pd0.5
7	98%VI7 + 2%V7	2.947	Pf1-P70-Pd0.5
10	VI7	2.874	Pf1-P45-Pd0.5
20	98%VI7 + 2%V7	2.714	Pf1-P20-Pd0.3
30	95%VI6 + 5%V6	2.117	Pf1-P6-Pd0.3



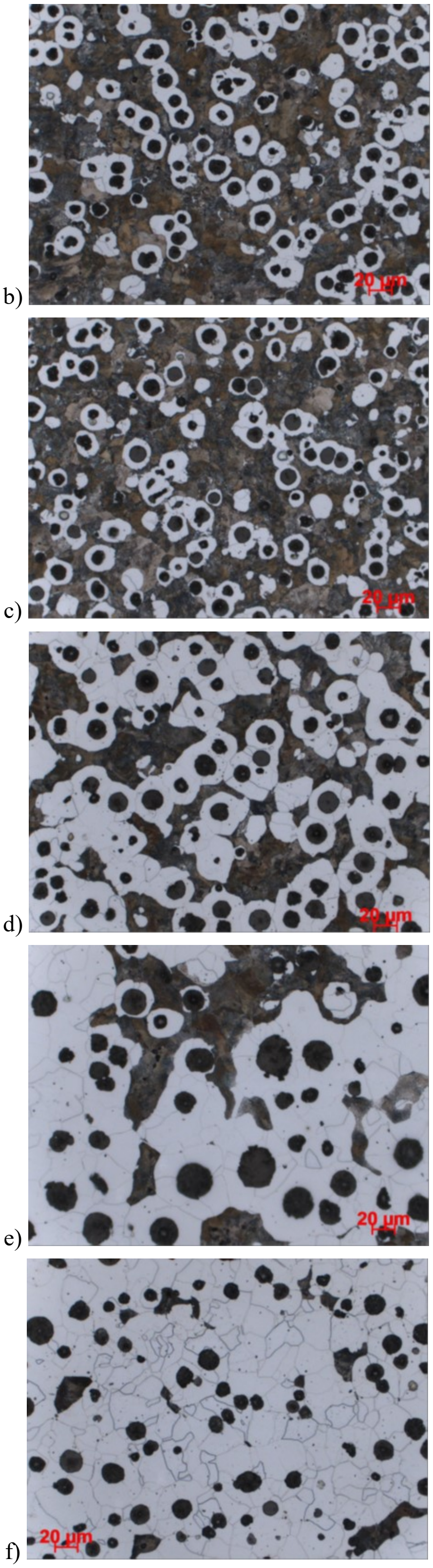


Fig. 2. Microstructures obtained in plates with different wall thicknesses, 500x, mm: a) 3; b) 5; c) 7; d) 10; e) 20; f) 30

5. Thermal analysis

The thermal analysis was carried out on an MrAC-15 multi-channel recorder with accessories supplied by JOTA s.c. (Fig. 3). The recorder is designed to measure electrical signals by means of 15 independent measuring channels.

During this analysis, temperature changes were recorded in the cast iron undergoing the process of solidification and cooling in the casting mould made of bentonite sand. The solidification process

of cast iron was recorded for each plate with different wall thickness. Figure 4 shows curves recorded for the 10, 20 and 30 mm thick plates.

Fig. 3. View of an MrAC-15 multi-channel recorder

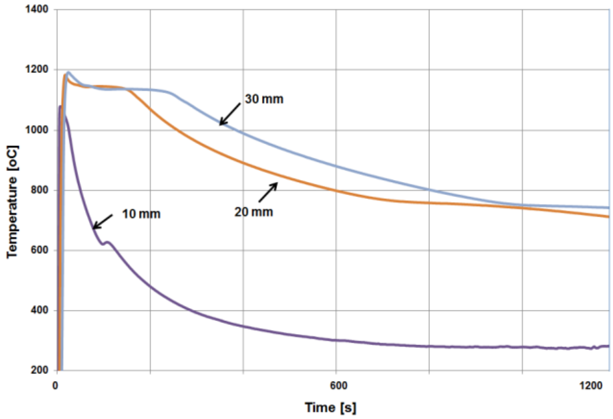


Fig. 4. The course of ductile iron solidification and cooling curves plotted for plates with different wall thicknesses

Cooling curves of plates with a wall thickness of 20 and 30 mm are characterized by a slow run of the solidification process. This results in the formation of a small number of nuclei, as confirmed by the calculations of the number of graphite grains N. The plate with a 10 mm wall thickness is characterized by a much higher cooling rate, which results in the formation of a larger number of nuclei. As the size of graphite nodules increases in the ductile iron, the concentration of carbon in the matrix decreases, resulting in a gradual change of the cast iron matrix from pearlitic to ferritic.

6. Mechanical tests

Testing of strength parameters was carried out on standard samples machined by turning from castings with wall thicknesses of 10, 20 and 30 mm, using a computer-controlled hydropulse test machine.

Mechanical tests carried out on standard 5 mm diameter samples have shown that increasing thickness of the casting wall reduces the tensile strength but increases the unit elongation. This is due to higher ferrite content in the cast iron matrix.

Table 3.
Strength parameters of the test plates

Parameters	**Cast plate wall thickness, mm**		
	10	**20**	**30**
Tensile strength R_m, MPa	648	525	508
Yield strength $Rp_{0,2}$, MPa	508	400	388
Unit elongation A5, %	5.9	8.4	12.1
Reduction of area Z, %	7.8	14.3	15.1

7. Summary

The evaluation of cast iron microstructure showed that, regardless of the casting wall thickness, in the investigated areas, the examined cast iron contains 100% of nodular graphite precipitates. Increasing wall thickness reduces the nodule count per cm2. For the cast plate with 3 mm wall thickness, the nodule count was 5.117 x 10^4 graphite precipitates per cm^2, whereas in a 30 mm plate this value decreased to 2.117 x 10^4.

Differences in the shape of the solidification and cooling curves result from various conditions of the casting solidification process. In the case of walls with 20 and 30 mm thickness, the registered cooling and solidification curves show a characteristic arrest at approx. 1150°C indicating the beginning of ductile iron crystallization. In the case of 10 mm thick castings of the plates, the measurement of temperature in the casting walls so thin failed to record the beginning of the cast iron solidification process. Differences in the solidification rate of plates of different thicknesses affected the number of graphite precipitates and matrix morphology.

The content of ferrite gradually increasing in matrix along with the increasing thickness of cast plate walls reduces the tensile strength of cast iron but increases its unit elongation.

Visual inspection showed absence of any surface defects and satisfactory quality of castings.

Summing up the obtained results, it can be concluded that the use of the reactor in the process of spheroidization allows making high-quality castings, even with heavy walls.

Acknowledgements

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