Comparing the Effectiveness of Cast Iron Spheroidization by the Traditional Method and Using a Reaction Chamber (Reactor) Placed in Foundry Mould

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Abstract

The effectiveness of cast iron spheroidization with FeSiMg master alloy by the traditional method and using a reaction chamber placed in the cavity of foundry mould was compared. The method of cast iron treatment in mould cavity using a reaction chamber is an innovative technology developed by the Foundry Research Institute in Krakow.
The effectiveness of the spheroidization process carried out by both methods was checked on a series of test castings. The article also presents the results of metallographic examinations and mechanical testing, including the discussion of magnesium yield and its assimilation rate.

Keywords: Ductile (spheroidal graphite) iron, Magnesium yield, Evaluation of effectiveness, Spheroidization methods, Reaction chamber (reactor)

1. Introduction

It is generally known that cast iron remains the basic casting material used for the manufacture of items serving various purposes, and made in various sizes and weight ranges from several kilograms up to several hundred tones. Ductile iron or cast iron with the spheroidal graphite is a very popular material for numerous and varied applications. This is mainly due to the beneficial mechanical properties of this material depending on the number and size of the precipitated graphite spheroids, and also on the type of matrix. Due to its very good performance, ductile iron is one of the leading casting Fe-C alloys, and is primarily used as a casting material for the automotive industry, agricultural machinery, fixtures and many other items [1-5].

The treatment which has recently become increasingly popular is austempering of ductile iron, resulting in the manufacture of Austempered Ductile Iron (ADI) characterized by exceptionally high mechanical and plastic properties [6-9].

When the required chemical composition of base cast iron prepared for the spheroidizing treatment is provided, a very important element in the manufacture of high quality material is the introduction of a suitable amount of spheroidizer into the molten metal. Magnesium-based ferro-alloys for the subsequent secondary treatment of molten cast iron are among the most expensive ferroalloys used in foundries around the world, while

being at the same time the most commonly used semi-products for the manufacture of spheroidal graphite cast iron [10].

Over the many years of using magnesium as a spheroidizer, several methods have been developed for its introduction into molten cast iron [11-12]. Currently, the spheroidization processes are carried out in the casting ladle, most often using the PE flexible wire method [1].

The Inmold spheroidization technique is also widely known, where the general principle of cast iron treatment consists in placing the spheroidizer and inoculant in foundry mould cavity in a reaction chamber reproduced by the moulding sand [13]. There are different technological solutions to increase the efficiency of this process [14, 15], but none of them uses a reactor made outside the mould cavity.

The in-mould spheroidization process using a reaction chamber developed at the Foundry Research Institute is a world-wide innovative technique of cast iron treatment [16]. The innovativeness of this method consists in the use of a properly designed and constructed reactor placed in the foundry mould cavity.

The properly designed reactor, in which the metallurgical processes take place, is made outside the casting mould and then placed in this mould before its assembly in a way resembling the installation of a typical foundry core. The reactor consists of a casing composed of two divided halves. Inside the reactor is placed the spheroidizing agent, the inoculant and a filter for metal filtration. The reactor has two chambers, the first chamber comprises the master alloy, the other chamber is left empty, and it serves for mixing the cast iron with the master alloy placed in the first chamber and dissolved when the mould is poured with molten metal. When the mould is poured with molten cast iron of the required chemical composition, the spheroidization, inoculation and filtration are all effected simultaneously in the reaction chambers on the cast iron flowing via the gating system to the chamber and subsequently into the mould cavity. The reactor casing is made of appropriately selected binder-coated sands, self-hardening after the casing has been moulded in a special die. The casing is entirely water-free and owing to this, during the cast iron spheroidization or vermiculization treatment and inoculation, the effect of water decomposition and the risk of the penetration of the gaseous products of this decomposition into molten cast iron are practically totally avoided.

During pouring of the reactor with molten cast iron, as a result of pyrolysis of the organic material (reactor casing) taking place under the effect of high temperature, the gasification occurs and a reducing atmosphere is created. The reactor construction and the presence of reducing atmosphere eliminate the risk of magnesium oxidation in the air, the glare effects, and especially the evolution of large amounts of harmful gases emitted into the atmosphere.

The new method of making castings from the spheroidal graphite iron has been developed for use in the two basic technological moulding variants, i.e. with the horizontal or vertical mould parting plane. To this end, a suitable reactor shape and construction have been designed [16].

As it is known, the spheroidization effect tends to fade with time, and therefore in the currently used methods, time control starting with the spheroidizing treatment and ending in the operation of mould pouring with molten metal is of vital importance. This also involves the need to pour out the entire cast iron batch from the ladle into the casting moulds. The use of reaction chamber for the cast iron treatment eliminates these problems.

2. Research methodology

The results of preliminary laboratory tests have shown that the assimilation rate of magnesium is much lower in the conventional method than in the in-mould spheroidization process using a reaction chamber.

The purpose of the conducted research was to compare the effects of the spheroidization process carried out by two methods, i.e. the traditional method in a casting ladle and the innovative method in a foundry mould with reaction chamber. To make the comparison it was necessary to use the same amount of spheroidizer and inoculant (assuming the percent magnesium content in the traditional method at a level of 0.05%), the same base cast iron composition and identical pattern sets. The target was to make castings from the ductile iron in grade GJS-500-7. A number of microstructural examinations and mechanical tests were performed to evaluate the effectiveness of the spheroidizing treatment applied.

Melting was carried out under laboratory conditions at the Foundry Research Institute. As a melting unit, a medium frequency induction furnace of 100 kW power and a crucible capacity of 100 kg was used. A 50 kg batch of the base cast iron was prepared for the spheroidization process. The composition is shown in Table 1. The mould with the reaction chamber placed in the mould cavity was the first one to be poured.

To make a reference casting by the traditional spheroidization method so far prevailing in foundry practice, the remaining batch of cast iron was re-heated to obtain the same starting conditions and then it was spheroidized in a ladle and poured into the second mould. In both cases, a ferrosilicon master alloy known under the trade name of FeSiMg 931 was used as a spheroidizer in an amount of 0.9% relative to the mould capacity (13 kg) and Alinoc inoculant in an amount of 0.2% relative to the mould capacity.

For both spheroidization methods, test castings (Fig. 1) of the same shape and weight were made in the traditional bentonite-bonded sand moulds.
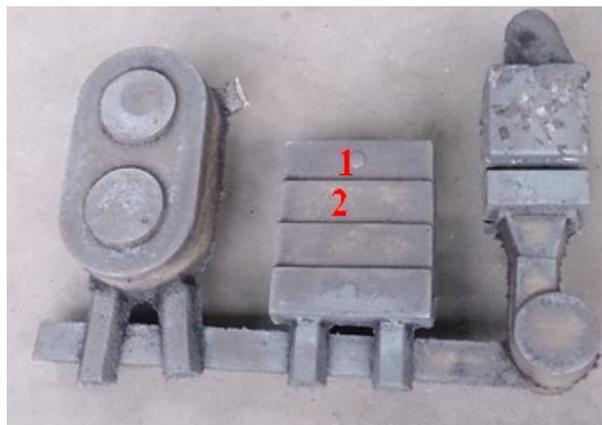

Fig. 1. Test castings with the gating system and reaction chamber

Metallographic studies, which included the evaluation of graphite precipitates and metal matrix, were carried out on samples cut out from the casting with a wall thickness of 11 mm and 15 mm (number 1and 2 in Fig. 1). An Axio Observer Z1m metallographic microscope was used for this purpose. Strength parameters were tested on standard specimens taken from the 16 mm thick casting and prepared for tests by turning (number 2 in Fig. 1). Tests were carried out on a programmable machine operated by hydropulse system.

3. Test results and discussion

For both spheroidization methods, the same amount of spheroidizer and inoculant relative to the mould capacity was used.

Chemical compositions of the base cast iron and cast iron after the spheroidizing treatment are summarized in Table 1. Samples for the spectral analysis of chemical composition after the spheroidization process were poured as an integral part of casting using specially prepared chills placed in the mould cavity.

The chemical composition obtained as a result of the use of different spheroidization methods has shown that, compared to the traditional method, the rate of magnesium assimilation was three times higher in the in-mould spheroidization process using the reactor. The increased carbon content in cast iron after the spheroidization process carried out in the reaction chamber is most likely due to the transfer of the products of the chamber decomposition reaction to molten metal.

The magnesium yield and strength parameters of ductile iron castings are compared in Table 2. The magnesium yield, calculated from the results of measurements of the residual magnesium content in castings, is almost twice as high for the innovative method of cast iron treatment (Table 2). This is due to the fact that in the new process, magnesium oxidization in the air has been effectively avoided.

Tensile tests made on standard 7 mm diameter specimens have proved that only in the case of spheroidization carried out in the reaction chamber, the obtained values were conformant to the EN-ISO Standard, which means that the spheroidal graphite cast iron of EN-GJS-500-7 grade was obtained.

Table 1.
Chemical composition of base cast iron and ductile iron after the spheroidizing treatment

	Chemical composition, wt%					
	C	Si	Mn	P	S	Mg
Base cast iron	3,84	1,82	0,28	0,033	0,003	-
Ductile iron – spheroidization in reaction chamber	3,92	2,31	0,29	0,034	0,004	0,090
Ductile iron – spheroidization by traditional method	3,73	2,28	0,30	0,037	0,002	0,031

Table 2.
Magnesium yield and strength parameters of the tested ductile irons

Parameters	Results obtained	
	In-mould method using reaction chamber	Traditional method
Magnesium yield	about 85÷90%	about 45%
Tensile strength R_m, MPa	505	535
Yield strength $R_{p0,2}$, MPa	376	361
Relative elongation A_5, %	13	5,8
Z-stress, %	15,4	3,2

Information on the microstructure of graphite precipitates and metal matrix is provided in Table 3.

The assessment of graphite microstructure according to PN-EN ISO 945-1 is a benchmark-based method. The standard defines that measurement uncertainty is within the two neighbouring reference patterns. The result of the measurement is an average of the three randomly selected fields of view. The above ISO standard does not take into account the measurement of the nodule count per unit area.

The evaluation has shown that in the ductile iron samples made with the use of reaction chamber 100% of graphite precipitates had the spheroidal shape (VI and V), and only 10% of these spheroids had an irregular spheroidal shape (V). On the other hand, spheroidization by traditional method has yielded the precipitates which in 90% had the vermicular shape (III) and only 10% were the precipitates of a spheroidal shape (VI). This is clearly seen in the unetched metallographic sections. Metallographic sections after etching in both cases showed the prevalence of ferritic matrix (Table 3).

Table 3.
Microstructure of the examined ductile irons

	Results obtained	
	In-mould method using reaction chamber	**Traditional method**
Graphite microstructure according to PN-EN ISO 945-1	90% VI 7 + 10%V 5 VI – spheroidal graphite, V – irregular, spheroidal graphite	90% III 5 + 10% VI 6 VI – spheroidal graphite, III – vermicular graphite
Microstructure of metal matrix according to PN 75/H-04661	P0	Pf1-P6-Pd1,0
Unetched sections		
Sections etched in Mi1Fe		
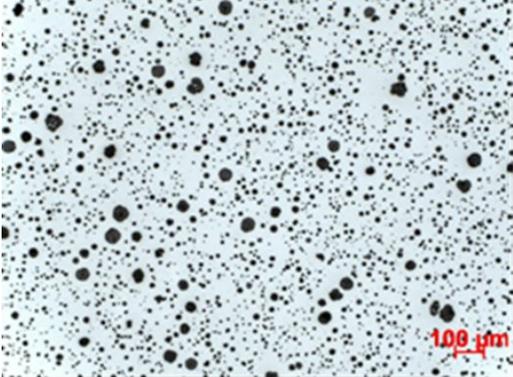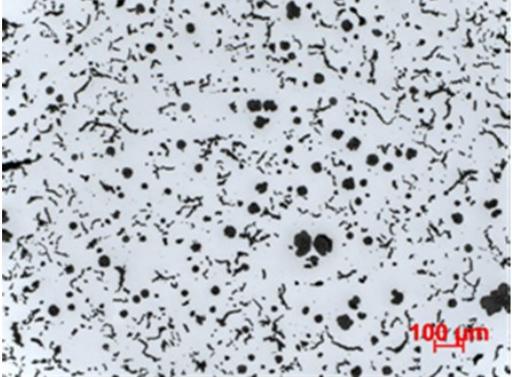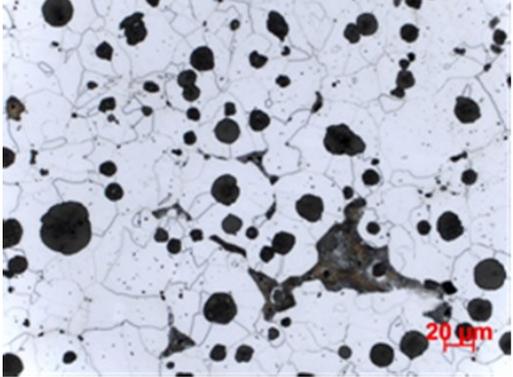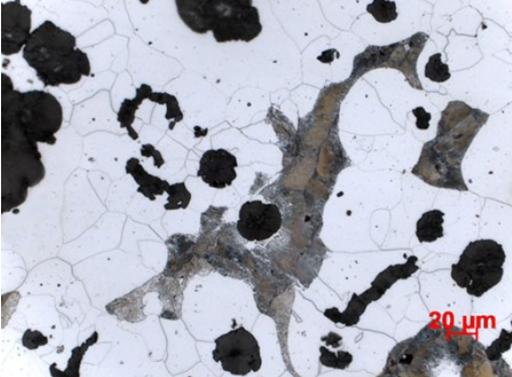
4. Conclusion

The study showed that, compared to the traditional method, the use of the new method of in-mould spheroidization with a reactor has doubled the residual magnesium content in post-spheroidized castings. It is expected that under production conditions this will significantly reduce the cost of ductile iron production owing to the lower consumption of the spheroidizer, as confirmed by the test results using the reactor. The indicated economic effect is one of many positive aspects of the new spheroidization process.

Microstructure examinations have proved that in the ductile iron spheroidized in the reaction chamber, 100% of the graphite precipitates had the spheroidal shape. In contrast, in the ductile iron made by the traditional method, only 10% of the graphite precipitates detected in the examined areas were spheroidal in shape. Moreover, in the latter case, the precipitates were larger than in the case of the in-mould spheroidization using a reactor. The degree of spheroidization directly translates into the obtained values of the tensile strength and elongation. In ductile iron obtained by the traditional method, these parameters failed to meet the requirements established for the GJS-500-7 grade.

Visual inspection of castings made by both methods of spheroidization did not reveal any surface defects and the cast parts were considered to be of high quality.

Another advantage of the spheroidization process using the reaction chamber, compared with other methods commonly used today, is an obvious ecological benefit, manifesting itself in the absence of harmful gases, as well as fumes and flashes emitted during the commonly applied spheroidizing treatment. This is possible owing to the formation of a reducing atmosphere in the

casting mould cavity during spheroidization process that protects the magnesium from oxidation in the air.

Summing up the obtained results, it can be said that the use of reactor in the spheroidization process allows making high quality castings. It should be emphasized that with the proper choice of the best technological conditions of this process, it is possible to produce by the new method on industrial scale castings from high quality iron, as has been confirmed by the subsequent industrial research.

Acknowledgements

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