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EFFECTIVE INOCULATION OF GREY CAST IRON

Dariusz Kopyciński[1], Józef Dorula[2]

[1]AGH University of Science and Technology; 23 Reymont Str.; Krakow, 30-059, Poland
[2]Vesuvius Poland - Foseco Plant, Leonardo da Vinci Str., Gliwice, 44-109, Poland

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Abstract

The study proves that by introducing the iron powder and disintegrated steel scrap to low-sulphur cast iron still before the inoculation carried out with a conventional graphitising inoculant, the mechanical properties similar to those obtained during the inoculation treatment carried out on cast iron with the recommended high sulphur content are achieved. The said operation increases the number of crystallisation nuclei for dendrites of the primary austenite. In this case, the iron particles act as substrates for the nucleation of primary austenite, due to a similar crystallographic behaviour of the regular face centred cubic lattice The more numerous are the dendrites of primary austenite, the less free space is available in the interdendritic spaces for the formation of graphite eutectic grains, which makes the structure more refined (more eutectic grains) and the mechanical properties higher.

Introduction

In industrial practice, during manufacture of iron castings, the inoculation of cast iron consists in introducing the inoculant into liquid metal, which has a low ability to generate the grain nucleation process. The low-weight inoculant introduced during metallurgical treatment improves the molten metal ability to start the nucleation process of graphite grains. Due to the increased number of active substrates for the graphite nucleation, the structure of cast iron is refined and the consequence of this refinement are higher properties of iron castings. From this definition it follows that with the inoculation treatment are closely related some effects that can be evaluated according to selected criteria. Undoubtedly, the most important indicator of the inoculation process effectiveness used in the technology of cast iron manufacture is the increased number of eutectic grains. Another factor taken into account after the inoculation treatment includes a set of characteristic changes that take place in graphite precipitates and are also subjected to evaluation [1,2]. In the structure of inoculated cast iron, the flake graphite of an even distribution is formed. This effect takes place at the cost of graphite characterized by interdendritic distribution which occurs in the base cast iron before inoculation. The value of the supercooling degree ΔT decreases during the crystallization of graphite eutectic in a way similar as the cast iron chill tendency, while the dominant constituent in cast iron microstructure becomes a pearlitic metal matrix. It has been proved that all changes introduced by the inoculation treatment to cast iron microstructure lead to an increase of the mechanical properties. It is worth noting that there is another important indicator of the successful course of inoculation, and at the same most difficult in practical evaluation, and it is the character of changes in the formation of grains of the dendrites of primary austenite [3,4]. This effect is important since the inoculation of grey cast iron affects not only the grains of graphite eutectic, but also the grains of primary austenite. Technical literature states at least four hypotheses on the cast iron inoculation process, but it appears that the hypothesis that has the highest rationale in the industrial practice of cast iron manufacture with ferrosilicon inoculation and minor additions of elements from group II of the periodic table (Ca, Ba, Sr, etc.) and aluminium, is the hypothesis developed by B. Lux [5]. B. Lux in his work [5] has proved that adding the inoculant to cast iron melt leads to the crystallization of carbides with ionic bonds of the CaC_2, BaC_2, BiC_2, SrC_2, and Al_4C_3 type. These carbides act as substrates for the nucleation of graphite.

Moreover, applying B. Lux hypothesis, it becomes possible to evaluate the positive practical aspect of the use of complex ferrosilicon-based inoculants (Fe-Si) composed of silicon (approx. 75%) with small additions of simple compounds introduced in an amount of up to several percent by weight and iron as a remainder. Iron in the inoculant can form a separate phase of the $FeSi_2$ type.

Therefore, it can not be ruled out that this phase can play the role of a proper substrate for the nucleation of the grains of the primary austenite dendrites. It is also worth noting that complex inoculants used in the technology of the manufacture of inoculated cast iron are sometimes enriched with elements such as Bi, Al, La and other rare earth metals, as well as Ti, and without any doubt, during metallurgical treatment, all these elements can form in the liquid metal proper substrates for the nucleation of the grains of the primary austenite dendrites. Detailed analysis of the literature [1,2,5,6] and industrial practice of the cast iron engineering show us that in the process of inoculation, the problem most often considered is the impact of reagents on the grains of graphite eutectic, while possible effect of this treatment on the primary crystallization, that is, on the primary austenite grains, has been so far largely overlooked. Learning the rules of the crystallization of the primary austenite grains in grey cast iron is critical for conscious application of the optimal inoculation treatment. This paper discusses the possibility to control the primary structure formation in cast iron.

Problem of low sulphur content in cast iron

In recent years, the foundry industry has faced numerous transformations that, among others, include changes in the cast iron melting process (departure from cupolas in favour of electric induction furnaces), significant reduction of pig iron content in the charge used for cast iron melting, and increase in the production of ductile iron castings. It should be noted that in the manufacture of ductile iron the basic requirement is low sulphur content. In contrast, in the inoculated cast iron, the required level of sulphur is 0.05% - 0.08%. Therefore foundries which specialize in the ductile iron technology are not able to satisfy the required sulphur content in the inoculated cast iron. This leads to problems with obtaining the regulatory strength parameters in inoculated iron castings and to the occurrence of casting defects of the microporosity type. Figure 1 shows the tensile strength UTS obtained in the inoculated cast iron grade EN-GJL-250 with standard and low sulphur content.

From the above comparison it follows that in the cast iron with low sulphur content it is not possible to comply with the strength requirements specified by standards for a given cast iron grade, in this case $UTS_{min.}$ = 250 MPa. It should be emphasized that in both cases the microstructure of cast iron is similar and characterized by a pearlitic matrix with evenly distributed interdendritic graphite.

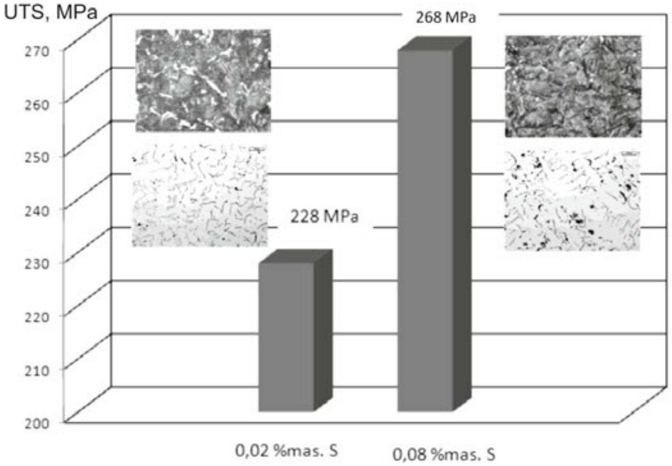

Figure 1. The impact of sulphur in the inoculated grey cast iron on its microstructure and mechanical properties

Moreover, in castings made from the inoculated iron with low sulphur content, the defects of a porosity type may appear. It has been observed that in ductile iron castings, the large number of fine graphite eutectic grains is not favourable in terms of the occurrence of porosity (or shrinkage depressions). On the other hand, increasing the number of primary austenite grains, and thus reducing their dimensions, counteracts this effect. The occurrence of casting defects of this type is best traced during the casting crystallization modelling. Modelling with the PROCAST software is shown on the example of cast electric motor housing. The results of modelling are depicted in Figures 2 and 3.

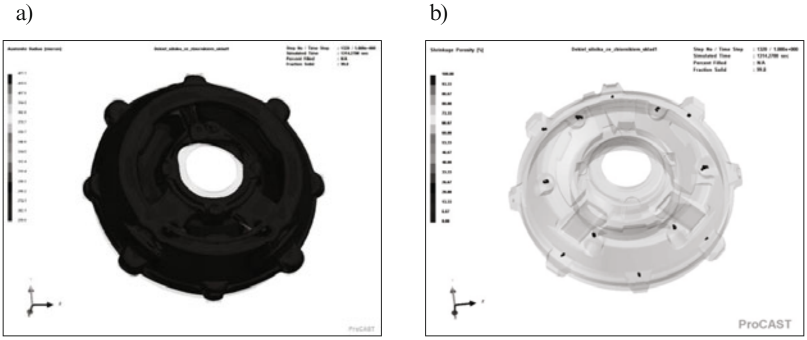

Figure 2. The distribution of primary austenite grains in casting with a small number of substrates for nucleation (a), and microporosity defects visible in this casting (b)

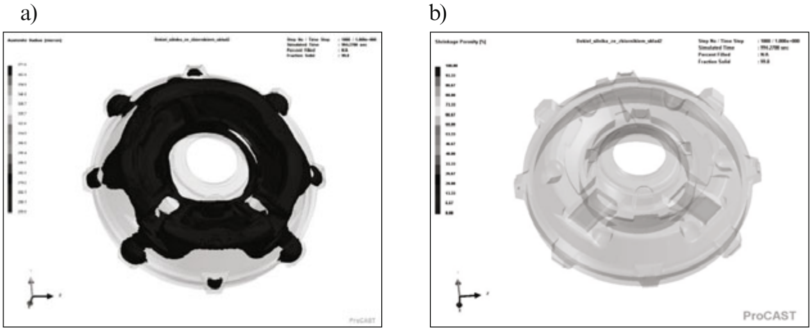

Figure 3. The distribution of primary austenite grains in casting with a large number of substrates for nucleation (a), and absence of microporosity defects in this casting (b)

In simulation, a relationship has been sought between the size of primary austenite grains and possible occurrence of porosity. PROCAST program allows control of a parameter responsible for the average number of substrates for the nucleation of primary austenite grains. This provides a link between the number of substrates for the nucleation of austenite grains and actual number of these grains, allowing also for predicting of their dimensions.

Figure 2a shows the results of computer simulation in which the distribution of primary austenite grains, assumed to have a diameter larger than 250 μm, was determined. The simulation was carried out for the case of a small number of substrates for the nucleation of these grains. Figure 2b presents the distribution of shrinkage porosity, which is consistent with the porosity occurring in real casting of the electric motor housing. Figure 3a shows the results of similar modelling of the distribution of primary austenite grains, also assumed to have a diameter larger than 250 μm, but this time for the case of a large number of substrates for the nucleation of these grains. The resulting casting shown in Figure 3b is free from the defect of shrinkage porosity. The results of both computer simulations confirm the thesis that during the inoculation, very important is also the size of primary austenite grains, but translating this analysis to the conditions of current foundry production is extremely difficult. In this study it has been proved that under laboratory conditions, the number of primary austenite grains can be increased and their morphology can be changed owing to the effect of common FeSi75 inoculant enhanced with the addition of iron powder or shredded steel scrap (chips, scrap metal, shot, etc.).

Methodology

Test melts were carried out in a medium frequency induction furnace with crucible of 15 kg capacity. The chemical composition of produced cast iron and its mechanical properties are compared in Table 1. Thermal analysis was performed with the ITACA software.

Thus prepared cast iron was subjected to an inoculation method using modifier based on Fe-Si and two step inoculation with the iron powder and inoculant based on Fe-Si. The total amount of inoculant in both cases was 0.4%.

Table 1. Type of inoculant, and chemical composition and mechanical properties of grey cast iron

No.	Metallurgical treatment	Chemical analysis, wt%					S_c^*	UTS [MPa]
		C	Si	Mn	P	S		Mean from three measurements
1.	Base cast iron	2.92	1.65	0.38	0.03	0.014	0.78	Hard spots in sample
2.	Cast iron inoculated with 0.4% Fe powder	2.91	1.66	0.37	0.04	0.013	0.78	290
3.	Cast iron inoculated with 0.2% Fe powder and 0.4 % FeSi75	2.94	1.80	0.39	0.05	0.012	0.79	315

$^*S_c$ – degree of eutectic saturation.

Were carried out three melts and made casts of rollers shown in Fig. 4. First melt (no. 1) was without adding inoculant and flooded to form obtain a castings of rollers.

During the second melting (no. 2), the liquid metal has been overheated to a temperature of 1490°C and can hold out for 100 seconds. After lowering the temperature to 1460°C was introduced Fe powder inoculant, waited 180 seconds and in temperature of 1410°C was flooded to form obtain a castings of rollers. In the case of the third melt (no. 3) melting procedure was similar but it was introduced also Fe-Si based before iron powder inoculant. During casting solidification cooling curves were measured. Three melts were carried out and rollers shown in Fig. 4 were cast. Moulds (250mm x 250mm x 170mm) were prepared in No-Bakefuran resin process. When cast in the form of temperature reached 950 °C, a cast was shaken out from mold and placed in a furnace for 30 minutes. After the specified time frame castings were pulled from the furnace and placed in molten salt for isothermal quenching at a temperature of 360°C. (DAAS method [7,8]). Then, it was made test specimens for metallographic.

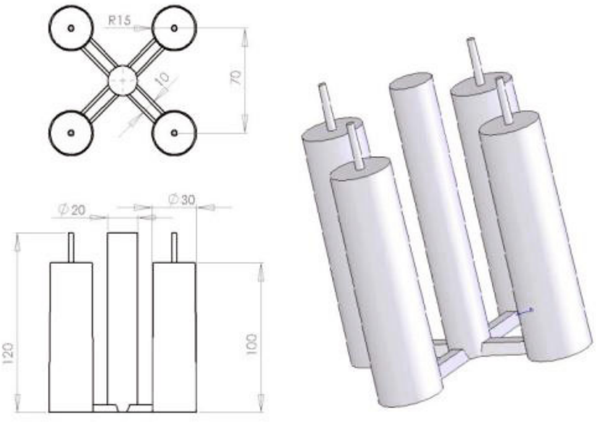

Fig. 4. Scheme of castings of rollers

Evaluation of the inoculation effect

As follows from the tests shown in Figure 5, inoculation treatment changes in the cast iron microstructure not only the number of eutectic grains but also, as has been proved, the number and morphology of primary austenite grains. Therefore, often found differences in the tensile strength UTS have no relevance with the cast iron microstructure revealed by common techniques. In most cases, the cast iron microstructure (without DAAS heat treatment) is as shown in Figure 1.

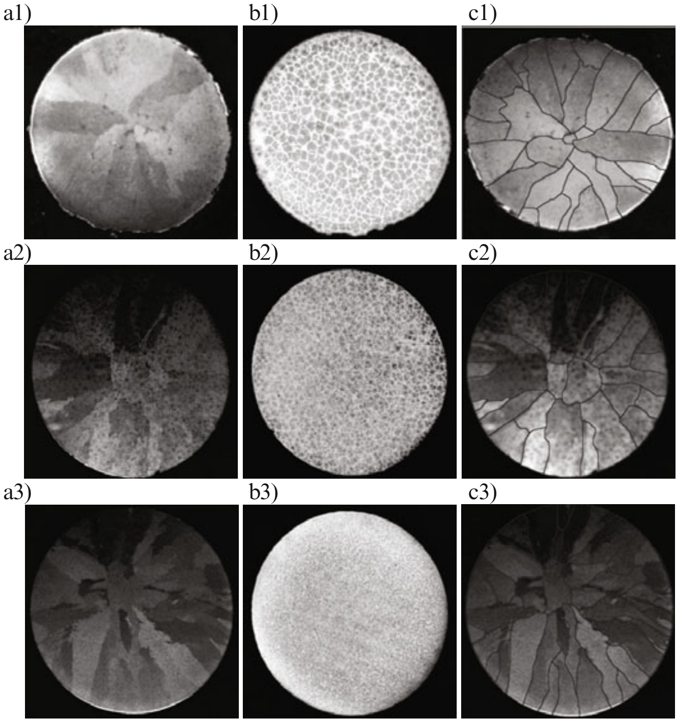

Figure 5. The appearance of primary austenite grains (a) and grains of graphite eutectic (b); visible is also "mapping" of the grain boundaries of primary austenite in sample of grey cast iron after the DAAS heat treatment; designations: 1 – applies to melt no. 1, 2 – applies to melt no. 2, 3 - applies to melt no. 3, as used in Table 1; the actual sample diameter is ϕ 30 mm

Since tensile specimens are taken from the central part of standard 30 mm diameter ingots, only changes in the number of primary austenite grains can explain the tensile strength UTS increase of 25 ÷ 40 MPa. In the middle part of sample No. 3 (Fig. 5-c3), which is the surface of tensile

specimen, the grains of primary austenite are much more numerous and their shape resembles more the shape of equiaxed grains than in the sample shown in Figure 5-c2.
Interesting results of the analysis of primary grains in cast iron are achieved with the ITACA advamced thermal analysis software. ITACA is an abbreviation of the name “Incremental Thermal and Chemical Analysis”. The system was developed in Italy by ProService Technology and distributed in Poland by FOSECO. Figure 6 shows "screenshots” of ITACA system during the thermal analysis conducted for low-sulphur grey cast iron.

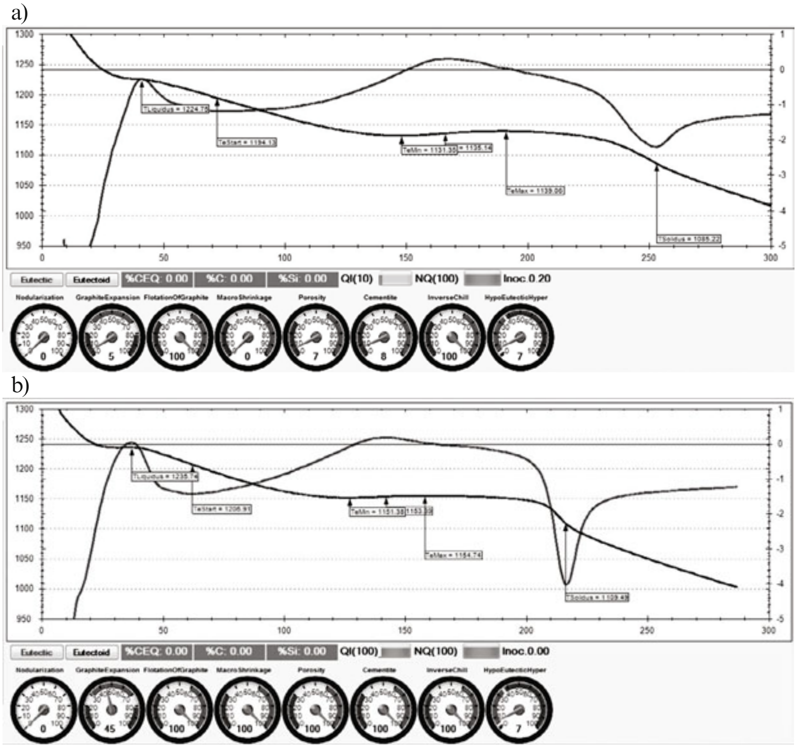

Figure 6. The course of crystallization and cooling of cast iron (Table 1) from melt no. 1 (a) and from melt no. 3 (b), visible is also the graphics of ITACA program displayed in the form of trend indicators, e.g. porosity in casting ("POROSITY" trend indicator, the fourth from the right)

From the course of the crystallization and cooling curves shown in Figure 6, the basic parameters of crystallization were determined by thermal analysis. In this system, worth noting is the graphics of the ITACA program which, among others, allows predicting the porosity in castings ("POROSITY" trend indicator).

Conclusions

Studies prove that it is possible to disclose the primary austenite grains in grey cast iron and link them to the mechanical properties of casting. From the research conducted currectly it follows that the inoculation of grey cast iron characterized by low sulphur content should be assisted with the use of iron particles, which act as substrates for the nucleation of primary austenite grains. Under industrial conditions, the inoculant can be enriched with crushed steel scrap. Then the obtained cast iron will yield products satisfying the normative requirements of mechanical properties. Moreover, as is apparent from Figure 6, the risk of porosity formation in castings drops to zero when the inoculation treatment of grey cast iron with low sulphur content is enhanced by the use of iron particles (Figs. 5c and 6b). These results are certainly valid also for the white cast iron crystallization, where the task of revealing the primary structure is not an easy one at all. However, a comprehensive study of various mechanisms that govern the growth of crystals in white cast iron requires simple methods for the disclosure of primary austenite grains linked to the well visible grains of carbide eutectic, as discussed in [3].

It seems that the condition of iron casting surface (the number of primary austenite grains) will affect the quality of zinc coating applied by the hot-dip galvanization process [9].

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