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# AN INNOVATIVE AND ENVIRONMENTALLY SAFE METHOD TO MANUFACTURE HIGH-QUALITY IRON CASTINGS FOR POSSIBLE USE AS ELEMENTS OF AGRICULTURAL MACHINES

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**Summary.** The article presents the experience related with the manufacture of utility castings poured in bentonite-bonded sands on a pilot stand. The technological guidelines were presented for the ductile iron castings weighing 40 kg and 10 kg. For individual castings, the mould technology has been developed, cross-sections of the gating and feeding systems were calculated, and pilot pattern equipment was designed. The results of mechanical tests and structure examinations were discussed. The work will continue within the framework of the project No. POIG.01.03.01-12-061/08-00. The technology currently developed relates to high-quality cast iron with spheroidal and vermicular graphite without and with the addition of alloying elements, including also the grade resistant to thermal fatigue. The idea is to simplify the methods used so far for the manufacture of cast iron subjected to spheroidisation or vermicularisation in a ladle and replace them with an in-mould treatment. These steps are expected to improve the ecological conditions, reduce the fume and glare effects related with magnesium treatment, and improve the process economics. The innovative method, discussed in this work and developed further under the above mentioned project, can be successfully used for casting various elements of the agricultural machinery, resulting in increased mechanical properties of the cast elements, longer life on performance and improved magnesium recovery.

**Keywords:** ductile iron, vermicular graphite cast iron, foundry mould, filters, spheroidisers, inoculants, castings for agriculture.

## INTRODUCTION

Various issues related with casting of parts for machinery and equipment as a result of the operations of inoculation, spheroidisation, vermicularisation and filtration in foundry mould are the subject of research carried out by the Foundry Research Institute in Cracow. The basic assumption in the research is that the processes of spheroidisation, vermicularisation and inoculation, also with the use of ceramic filters, are carried out in a foundry mould [1, 2, 3]. The problems of in-mould inoculation and filtration are described in the reference literature [4, 5, 6]. The, introduced in this article, method of cast iron spheroidisation combined with in-mould inoculation and filtration is an original solution among the existing similar technologies as it allows for the simultaneously conducted spheroidisation (vermicularisation), inoculation and filtration of metal, and is substantially different from the methods of cast iron spheroidisation [7] and vermicularisation [8] carried out in a ladle.

## PURPOSE AND SCOPE OF RESEARCH

The aim of the studies was to examine the feasibility of making pilot castings with spheroidisation treatment, inoculation and filtration carried out simultaneously in a foundry mould [9-12], to review the ecological aspects of the process, and to examine the chemical composition, the degree of magnesium recovery, the mechanical properties and structure of thus obtained cast iron [13,14].

In the previously conducted studies, an attempt was made to check the feasibility of spheroidisation, inoculation and filtration of molten cast iron in a foundry mould to pour 6 kg weighing test ingots [15-21]. Here, the main problem was to develop and improve further this technique of spheroidisation and inoculation. The research carried out focussed on the following issues:

- materials were selected to make the spheroidising-filtrating and inoculating-filtrating sets,
- gating systems with reaction chambers for the casting treatment were designed,
- moulds adjusted to the designed sets and to the specific castings were prepared,
- test melts were carried out, followed by spheroidising treatment and inoculation, both conducted in a foundry mould,
- the feasibility of making safely large castings according to the newly developed method was checked,
- the fume and glare effect during spheroidisation was eliminated, and process ecology as well as health and safety conditions were considerably improved,
- the process performance when making utility castings was checked in terms of the metal properties, structure, magnesium recovery in casting, etc.

## MAKING PILOT CASTINGS

Base iron was melted in a RADYNE medium frequency induction furnace in a crucible of 80 kg capacity (basic lining). As mentioned previously, the screen frame weighing 40 kg net and rams weighing 10 kg each were cast. The chemical composition of the base iron and of the cast iron after in-mould spheroidisation is compared in Table 1.

Table 1. Chemical composition of base cast iron and of cast iron after in-mould spheroidisation and inoculation

| **Melt and sample designation** | **Cast iron chemical composition, %** | | | | | |
|---|---|---|---|---|---|---|
| | **C** | **Si** | **Mn** | **P** | **S** | **Mg** |
| 1(w)/R/O | 3,40 | 1,75 | 0,42 | 0,035 | 0,010 | - |
| R/O | 3,15 | 2,50 | 0,42 | 0,035 | 0,010 | 0,055 |
| 2(w)/2s | 3,60 | 1,75 | 0,48 | 0,040 | 0,020 | - |
| 2/s | 3,50 | 2,25 | 0,46 | 0,045 | 0,025 | 0,070 |
| 3w/1v | 3,60 | 1,75 | 0,48 | 0,040 | 0,020 | - |
| 1v | 3,25 | 2,35 | 0,46 | 0,040 | 0,020 | 0,060 |

Note: Symbol (w) denotes base cast iron

A pattern of the screen frame with fragment of the gating system ready for moulding is shown in Figure 1.

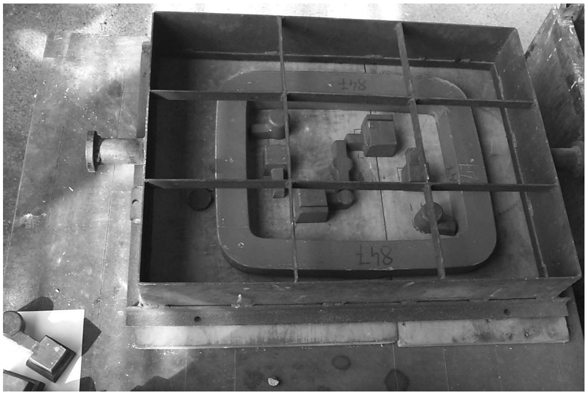

Fig. 1. Pattern of screen frame casting ready for moulding

The ready moulds were poured with molten metal at a temperature of 1440°C. The time of pouring was 23 sec. for the cast frame and 15 sec. for the cast ram. Pouring proceeded calmly and during tests no fume and glare effects related with the spheroidisation process were observed. After cooling, castings were knocked out from the mould and subjected to visual inspection. Figures 2 and 3 show a casting of the frame with gating system and reaction chambers and castings of the rams with cast-on technological samples for testing of the metal properties.

Fig. 2. View of the lower part of casting with a set of chambers for spheroidisation and inoculation


Fig. 3. Castings of rams with gating systems and reaction chambers

Figure 4 shows castings of rams after de-gating.

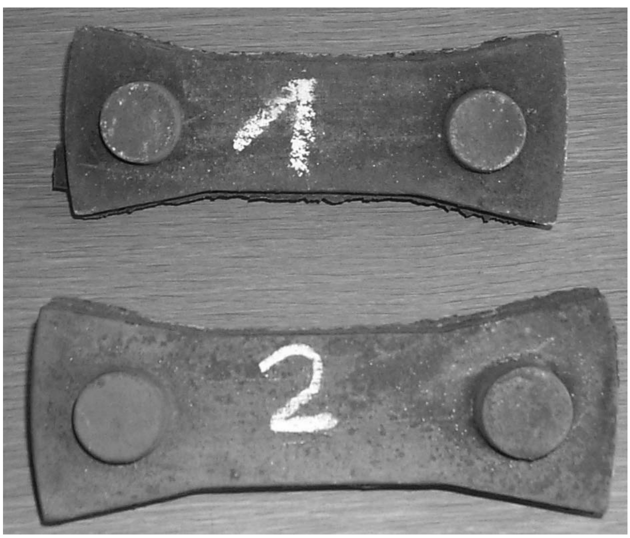


Fig. 4. Photographs of rams after de-gating

## TYPES OF TESTS PERFORMED AND QUALITY OF METAL OBTAINED

Tests performed on the cast material used for the screen frame and rams included:
- analysis of chemical composition,
- observations under the microscope (graphite precipitates, structure of metal matrix),

– mechanical properties ($R_m$, $A_5$, HB),
– visual inspection of the cut pieces of castings.

## RESULTS

The results of this study are provided in Tables 1 – 3.

Table 1 compares the initial chemical composition of the base iron with the chemical composition of the same cast iron after spheroidisation in a foundry mould using spheroidising-filtrating and inoculating-filtrating sets (castings of the frame and ram). Table 2 compares the results of mechanical tests carried out on sample castings.

Table 2. Mechanical properties of the examined cast iron

| **Sample designation** | **Basic mechanical properties of the examined cast iron** | | |
|---|---|---|---|
| | **$R_m$, MPa** | **$A_5$, %** | **HB/5/750** |
| R/0/A | 552 | 12,8 | 145 |
| R/0/B | 555 | 12,0 | 149 |
| 2A | 526 | 16,3 | 163 |
| 2B | 559 | 14,4 | 153 |
| 2/O/A | 572 | 12,3 | 167 |
| 2/O/B | 575 | 11,7 | 166 |
| 1/A | 513 | 15,7 | 150 |
| 1/B | 458 | 6,4 | 136 |

Note: symbol O denotes samples turned out from castings

Table 3. The results of microstructural examinations of cast iron

| **No.** | **Sample designation** | **Graphite microstructure** | **Matrix microstructure** |
|---|---|---|---|
| 1. | R/O | VA5 | Pf1, P6 |
| 2. | 2 | VA6 | Pf1, P6 |
| 3. | 1 | VA6 | P0 |

Table 3 contains the results of examinations of the structure of graphite and metal matrix in iron castings. A photograph of the cast iron structure obtained during the conducted tests is given as an example in Figure 5 (precipitates of graphite and metal matrix).

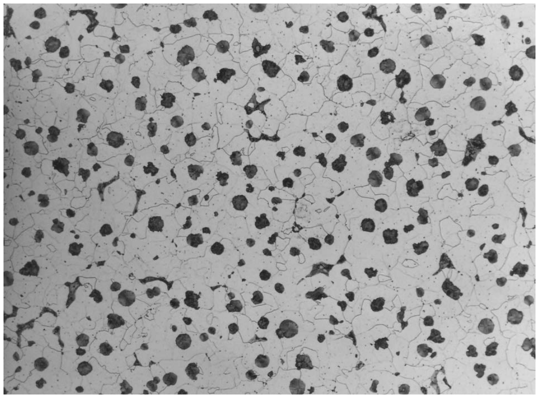

Fig. 5. Microstructure of sample 1; etched section, 100x

All tests and examinations were carried out in accordance with standards valid in this respect:
- determination of cast iron microstructure: PN-75/H-04661,
- characteristics of the graphite precipitates in cast iron: PN-EN ISO 945,
- tensile test for metals: PN-EN ISO 6892-1,
- Brinell hardness measurement: PN-EN ISO 6506-1.

## CONCLUSIONS

1. In cast iron obtained as a result of the conducted studies, the magnesium content was from 0.055% to 0.070%. Compared to ladle spheroidisation, the method presented here enabled reducing the quantity of the added master alloy by about 40%.
2. Graphite microstructure of the type VA5 and VA6 was obtained. In microstructure of the metal matrix, the content of pearlite was up to P6. No cementite was detected.
3. A very good tensile strength of 458–575 MPa, combined with high elongation $A_5$ (from 6.4 to 16.6%) and a hardness of 136–167 units HB was obtained in the samples.
4. No adverse effects, like violent reaction and metal ejection from mould were observed during the process of in-mould spheroidisation. The spheroidisation carried out in a foundry mould proceeded without any visible fume and glare effects. Changes introduced to the design of the gating system and reaction chambers, as well as the application of reducing atmosphere contributed to the good results of the tests.
5. Casting quality was very good; no internal and surface defects were observed.
6. The obtained test results have proved that it is possible to successfully make iron castings as a result of the spheroidisation treatment and inoculation carried out in foundry mould using spheroidising-filtrating and inoculating-filtrating sets.
7. The course of the tests performed and the results obtained have been positive; it seems that the developed technology is very promising and as such should be developed in future.
8. The presented method can serve in the manufacture of cast iron components or spare parts for agricultural machinery, replacing less durable castings of EN-GJL-200, 250 grades with EN-GJS-400 (600) grades.

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**Streszczenie.** W artykule przedstawiono doświadczenia wykonania odlewów użytkowych w formach w masach bentonitowych na stanowisku doświadczalnym. Zaprezentowano założenia technologiczne dla odlewów z żeliwa sferoidalnego o masie 40 kg i 10 kg. Dla poszczególnych odlewów opracowano technologię formy, obliczono przekroje układu wlewowego i zasilającego wykonano omodelowanie próbne. Omówiono rezultaty przeprowadzonych prób, wytrzymałości materiału odlewów i jego struktury. Prace są w dalszym ciągu kontynuowane w ramach prowadzonego projektu: POIG.01.03.01-12-061/08-00. Rozwijana obecnie technologia dotyczy żeliwa wysokojakościowego sferoidalnego i wermikularnego bez dodatków pierwiastków stopowych, jak również z dodatkiem pierwiastków stopowych, także odpornego na zmęczenie cieplne. Ideą zagadnienia jest uproszczenie dotychczasowych metod wytwarzania odlewów z żeliwa poddawanego procesowi sferoidyzacji lub wermikularyzacji w kadzi i zastąpienie procesem sferoidyzacji w formie odlewniczej. Dzięki temu poprawiają się warunki ekologiczne, ograniczone są efekty zadymienia i efekty pirotechniczne związane z reakcją magnezu a także ekonomiką procesu. Omówiona w pracy i rozwijana innowacyjna metoda również w projekcie może być z powodzeniem wykorzystana do odlewania różnych elementów maszyn rolniczych powodując zwiększenie właściwości wytrzymałościowych odlewnych elementów, trwałości a także zwiększenia uzysku magnezu w prowadzonym procesie.

**Słowa kluczowe:** żeliwo sferoidalne, żeliwo z grafitem wermikularnym, forma odlewnicza, filtry, sferoidyzatory, modyfikatory, odlewy dla rolnictwa.