

Quality and Cost Assessment of Treatment with SiMg and NiCuMg Master Alloys vs Cored Wire in Production of Ductile Iron

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Abstract

The results of studies on the use of magnesium alloy in modern cored wire injection method for production of nodular and vermicular graphite cast irons were described. The injection of Mg cored wire length is a treatment method which can be used to process high sulphur cupola iron held in ladles or iron melted in an electric induction furnace. This paper describes the results of using a high-magnesium ferrosilicon alloy in cored wire (Mg recovery 47-70%) for the production of vermicular and nodular graphite cast irons at Ścinawka Foundry, and for the production of nodular graphite iron at the following foundries: GZUT, KRAKODLEW, Centrozap - DEFKA, EE Zawiercie, WSK-Rzeszów, FWM PRZYSUCHA, HSW Stalowa Wola and PIOMA. The results of calculations and experiments have indicated the length of the cored wire to be injected basing on the initial sulfur content and weight of the treated melt. The results of numerous trials have shown that the magnesium cored wire process can produce high quality nodular and vermicular graphite irons under the specific industrial conditions of the above mentioned foundries.

It has also been proved that in the manufacture of nodular graphite iron, the cost of the nodulariser in the form of elastic cored wire is lower than the cost of the FeSiMg or NiCuMg master alloys.

Keywords: Ductile cast iron, PE method, Nodular graphite, Costs, Cored wire

1. Introduction

An important stage in the production of high-quality ductile iron is its treatment with different nodularisers, e.g. with magnesium or with the FeSiMg, NiMg or NiCuMg master alloys. Full success has already been achieved in this respect as regards the implementation into industrial practice of various techniques of introducing the reagents into molten iron, either in bells made from different materials, or by pouring the reagents placed on the bottom of a ladle (Sandwich or Tundish process) or directly in mould (Inmold process). In Poland, in 1995, for the first time a most modern and fully mechanised technique of the nodularising or vermicularising treatment of cast iron by means an elastic cored wire (PE - Fig. 1), known also under the name of "Cored Wire Injection Method", was mastered [1]. As a result of

joint efforts with active participation of the Ferro-Term Lodz, this technique has been implemented in several domestic foundries. From practical experience it follows that both the PE and 2PE techniques (using two elastic wires - one cored with magnesium, and another with inoculant) ensure low manufacturing costs and stabilization of magnesium content at a level of about 0,04%, necessary to obtain nodular graphite, and at a level of 0,017-0,02% Mg, necessary to obtain vermicular graphite. Changing of magnesium level in cast iron is very easy; it is just enough to change the time of feeding the wire on a roller conveyor (at a constant feeding rate). This solution effectively eliminates the time- and labour-consuming operation of repeated weighing of the individual batches of the nodulariser and inoculant, typical of other techniques of the nodularisation and inoculation.

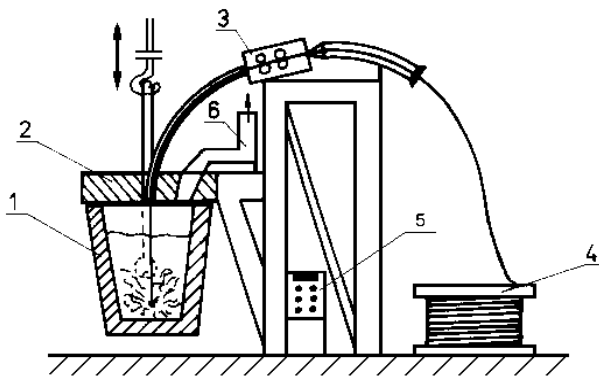


Fig.1. Schematic representation of the cored wire treatment (*PE* method): 1 – ladle with liquid metal, 2 – cover (lid), 3 – wire feed machine, 4 – coil (basket) with cored wire, 5 – set up with electrical control cabinet, 6 – exhaust

The *PE* or *2PE* technique is applicable to both cupola- and electric-furnace- melted iron. Investigations of the cupola process carried out at two domestic foundries in parallel with investigations of the efficiency of equipment for cast iron nodularising treatment have proved full applicability in production of ductile iron of both these installations operating in foundries. Over the past 12 years, the *PE* technique of the cast iron treatment has roused vivid interest of the Polish foundry industry and has been implemented, among others, in several domestic foundries, the Department of Cast Iron Engineering at the AGH University of Science and Technology being responsible for implementation of this process in at least 13 foundries. For production of ductile iron in the above mentioned foundries, the technique of cored wire was used to treat the batches of molten metal in ladles ranging in capacities from 0,15 to 2 Mg. The only exception was a foundry in Cracow where this technique of nodularising was used to treat molten metal in a 10 Mg capacity ladle, and the cast iron was assigned for massive castings [2].

The required weight of the nodulariser and the length of the wire injected to metal are calculated from the following formulae:

- magnesium recovery (Mg_d) depends on several factors and may be calculated as:

$$Mg_d = \frac{Mg_{kr} + 0,75(S_1 - S_2)}{Mg_{uzysk}}, \% \quad (1)$$

where:

S_1-S_2 – is the sulphur content in cast iron before and after treatment, respectively, wt.%;

Mg_{kr} – is the residual magnesium, 0,04 ÷ 0,05 wt%;

0,75 – is the coefficient of sulphur and magnesium count, at %;

Mg_{uzysk} – is magnesium addition, %.

- the following formula is used as a main tool for calculation of the wire length and magnesium recovery:

$$L = \frac{(0,76 \cdot \Delta S + Mg_{kr}) \cdot m_z}{\eta_{Mg} \cdot Mg_p}, m \quad (2)$$

where:

$\Delta S = S_1 - S_2$ is the difference between sulphur content before and after treatment, wt %;

η_{Mg} – is magnesium addition, %;

M_z – is the cast iron volume, kg;

Mg_p – is magnesium content in 1metre of the cored wire, kg/m,

0,76 – is the coefficient of sulphur and magnesium count, at%.

Another important aspect of this nodularising treatment is without any doubt the very encouraging cost of the nodulariser, and therefore the aim of this study has been an assessment of the cost of the FeSiMg and NiCuMg nodularisers as compared with the nodularisers used in the form of cored wire.

2. Cored Wire - production and handling

At the Foundrys of BUCZEK and “WSK–Rzeszów” Metallurgical Plant in Rzeszów, a special technique of the nodularising (or vermicularising) treatment was implemented. It was based on the use of two cored wires, one cored with magnesium, and another with inoculant; this is the, so called, Sinter-Cast technique, which is based on joint effects of the vermicularising treatment (using controlled Mg volume) combined with inoculation, which can be achieved according to the rules of the, so called, Sinter – Cast “chessboard”, described in the paper [3,4].

Compared with other techniques, the method of vermicularising or nodularising treatment by the technique of *PE* or *2PE* offers the following advantages:

- it enables both nodularising as well as vermicularising of cast iron;
- it ensures process stability expressed by target magnesium content in cast iron of 0.04-0.05% Mg for nodular graphite (Fig. 2) and 0.015-0.02% for vermicular graphite;
- it ensures safe work conditions in foundry (no dust and metal “splashes” from the treatment ladle);

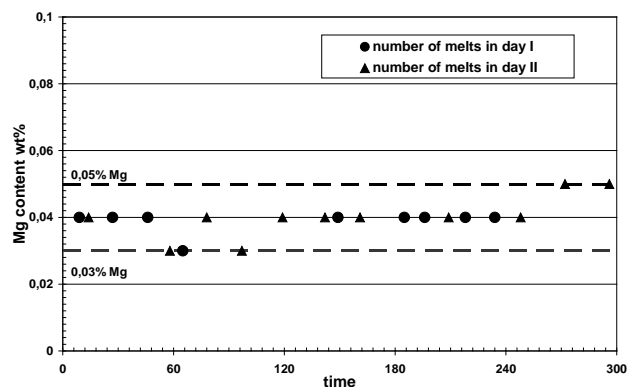


Fig. 2. The change of magnesium content in cast iron in the case of nodularising treatment carried out with cored wire

- it enables production of ductile iron from the cupola-melted metal which, compared with the iron melted in electric furnaces, has high sulphur levels caused by the presence of coke;

- it ensures process flexibility under variable initial parameters, like sulphur content in base iron, and temperature and weight of molten metal;
- it enables collecting and storing the data in the computer of control device [5].

3. Cored Wire- comparison against traditional treatment methods of nodularisation

From analysis of this "chessboard" it follows that the range of parameters of both of the above mentioned operations guarantees the structure of cast iron with either vermicular or nodular graphite. Practical application under industrial conditions of the "WSK- Rzeszów" Metallurgical Plant of two cored wires - one with magnesium and another with inoculant, enabled full realization of the Sinter – Cast "chessboard" idea. Metallographic examinations of specimens taken from ductile iron castings made by the technique of FeSiMg5% master alloy and by the Cored Wire Injection Process have proved that the latter technique produces in the structure of castings higher count of graphite nodules of a regular shape and type "VI" according to ISO 945 (Fig. 3).

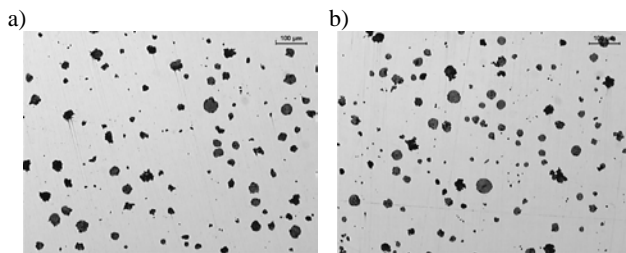


Fig.3. The photomicrographs showing differences in nodule count and characteristics of the tundish ladle treatment with (a) and without (b) cored wire injection

It is worth noting that many domestic foundries have implemented within their own capacity the above mentioned *PE* technique for cast iron treatment, e.g. the well-known foundries of Drawski Młyn (a horizontal design of the *PE* wire spool), Srem and Kuznia Raciborska.

To compare the cost of the cored wire technique with the cost of FeSiMg and NiCuMg master alloys used so far in Poland, relevant calculations were made for a unit weight of the cast iron batch. Under local conditions of the PIOMA Foundry and Buczek Metallurgical Works, an economic analysis was made for the process of cast iron nodularising treatment carried out with *PE* cored wire and with the aforementioned master alloys. The following calculations were made for metal melted in induction furnace.

The cost of ductile iron production with FeSi9Mg master alloy vs *PE* cored wire at PIOMA Foundry in Piotrków Trybunalski

- "light" type master alloy –FeSiMg9 (type VL 53M): price - 5,54 zł/1kg; the weight of molten metal in ladle – 2550 kg; the weight of master alloy type VL 53M – 55 kg, hence 5,54 zł/kg x 55kg = 304,70 zł;

- nodularising cored wire type *INFORM M 42413* (properties: weight = 0,374 kg/m; 63g Mg/mb; 106 g Si/mb); price per 1kg of wire = 7,17 zł; the weight of molten metal in ladle – 2550 kg; the weight of wire – 30kg, hence 30 kg x 7,17 zł/kg = 212,10 zł; extra addition of silicon - FeSi 15 kg x 3,08 zł/kg = 46,20 zł; hence final cost is - 212,70 zł + 46,20 zł = 258,30 zł; The cost of nodulariser to make 2550 kg of ductile iron is:

- nodularising master alloy VL 53M = 304,70 zł (the cost of the steel bell excluded);
- cored wire *M42413* = 258,30 zł (difference in price = 46,40 zł).

The cost of ductile iron in the weight 17000kg production with FeSi9Mg master alloy vs *PE* cored wire:

- "light" master alloy – FeSiMg9 alloy (type VL 53M); price - 5,71 zł/1kg (1430 €/1t); the weight of molten metal in ladle – 17000kg; the weight of master alloy type VL 53M – 233kg, hence 5,71 zł/kg x 264kg = 1507 zł;

$$Mg_d = \frac{0,055 + 0,75 \cdot (0,02 - 0,01)}{0,45} = 0,14\%;$$

$$\text{the weight of master alloy} = \frac{17000kg \cdot 0,14\%}{9\%} = 264kg;$$

- nodularising cored wire made by "JAK" Company - properties: weight = 0,43 kg/ mb; 70gMg/mb; 102 g Si/mb – price); price per 1 kg of wire = 7,07 zł; the weight of molten metal in ladle – 17000 kg; l = 304 m, the weight of wire – 130 kg; hence 7,07 zł/kg x 130kg = 919 zł; extra addition of silicon - FeSi – 3,08 zł/kg x 75 kg = 231 zł; hence final cost is - 919 zł + 231 zł = 1150 zł;

$$L = \frac{(0,76 \cdot (0,02 - 0,01) + 0,055Mg_{kr}) \cdot 17000m_z}{50\eta_{Mg} \cdot 0,07Mg_p} = 304m$$

- for the cored wire of 80 gMg/1mb and 60 % recovery; wire length = 221m, hence the weight of wire is 95kg, hence 7,07 zł/kg x 95kg = 671 zł + cost of FeSi75 (265 zł), hence the total (671 zł + 265zł) = 936 zł;
- the difference in the cost of master alloys and *PE* cored wire: (1507 zł – 936 zł) = 571 zł;

The cost of ductile iron production in the weight 17000kg using master alloy vs *PE* cored wire in the BUCZEK Foundry:

- "heavy" master alloys – BUCZEK Metallurgical Works; a) NiMg17Ce: the weight of master alloy 92kg (↑ Ni by 0,4 %) x the price of master alloy 108 zł/1kg = 9936 zł;

- b) CuMg17; the weight of master alloy 40kg (\uparrow Cu by 0,2 %) x the price of master alloy 36 kg/1kg = 1440 zł;
 c) the weight of nickel in base iron (2,02 %) = 344kg x 107 zł/kg = 36808 zł;
 d) the weight of copper in base iron (0,8 %) = 136 kg x 6,5 zł/kg = 884 zł;
 • (final content in iron: Ni = 2,4 %; Cu = 1,0 %) Total for items: a+b+c+d = 49068 zł.

 • nodularising *PE* cored wire made by *JAK* Company – properties: weight = 0,43 kg/m; 80gMg/mb; 102g Si/mb – price; price per 1kg of wire = 7,07 zł; the weight of molten metal in ladle– 17000kg; length = 204m, the weight of wire – 88kg,

$$L = \frac{(0,76 \cdot (0,02 - 0,01) + 0,05Mg_{kr}) \cdot 17000m_z}{60\eta_{Mg} \cdot 0,08Mg_p} = 204m$$

- hence 7,07 zł/kg x 88 kg = 662 zł; the presence of wire increases Si content by 0,3 %, i.e. (88kg x 50 %Si) Si75 = 70kg x 3,08 zł/kg = -215 zł;
- + the weight of nickel for 2,4 % content in iron, i.e. 408kg x 107 zł/kg = 43656 zł;
- + the weight of copper for 1,0 % content in iron, i.e. 170kg x 6,5 zł/kg = 1105 zł;

Hence the final cost is (662 zł – 215 zł) + 43656 + 1105 = 45208 zł.

Actual difference in the cost of nodularising treatment is 49068 zł – 45208 zł = 3860 zł, and in addition;

- reducing the weight of nodulariser by 56kg enables the temperature of molten metal to be reduced as well;
- it is possible and easy to use process scrap because *PE* cored wire does not introduce any Ni and Cu.

4. Summary

The present study describes the method of nodularising or vermicularising treatment of cast iron using special cored wire. This technique has been used for both cupola- and electric furnace-melted iron in numerous domestic foundries, e.g. Ścinawka Średnia GZUT, KRAKODLEW, Centrozap - DEFKA, EE Zawiercie, WSK –Rzeszów, FWM PRZYSUCHA and HSW Stalowa Wola. The consumption rate of the cored wire was established allowing for the sulphur content in base iron and the weight of the cast iron batch to be treated. The said technique of the cored wire can be successfully used in many other domestic foundries. It ensures the health and safety conditions during spheroidising and vermicularising treatment of cast iron in accordance with the prescribed rules along with the required target content of magnesium. The technical and technological conditions of the treatment which should be satisfied have been highlighted.

From observations of the nodularising treatment of cast iron carried out by the method of *PE* or *2PE* under the conditions of domestic foundries it follows that this technique has gained full approval of the foundry industry.

Therefore it is used more and more often at home and abroad in manufacture of castings from nodular and/or vermicular graphite iron.

Long-lasting experience gained during work in industry clearly indicates that the elegant and efficient techniques of *PE* and/or *2PE* are fully reliable and guarantee making castings from the nodular and vermicular graphite irons characterised by stable properties, consistent with and satisfying the most modern European standards. Both these techniques are equally suitable for the treatment of iron melted in electric furnaces and/or cupolas, an additional advantage in the latter case being the possibility of eliminating the additional process of desulphurising-often indispensable when other methods of the nodularising treatment are used.

It has been proved that the cored wire is very competitively priced, if compared with both types of the master alloys, specially with the imported “heavy” type of NiCuMg master alloy. Compared to the cast iron treatment using master alloys, the operation of cast iron nodularising by *PE* technique is additionally very promising since it provides safe operating conditions, enables stabilisation of magnesium content during nodularising or vermicularising treatment, and ensures a regular shape of graphite nodules in the cast iron structure.

An important technological parameter of the *PE* technique, determining essentially the length of the cored wire injected to molten metal and the cost of the treatment, is the level of magnesium recovery η_{Mg} expressed by equation (2), which depends on the technical conditions of the equipment designed and actually used by the foundry for this purpose. Due to the conducted investigations it has been possible to determine the level of magnesium recovery η_{Mg} in *PE* technique, which is in the range of 35-60% and depends on the weight of molten metal batch to be treated and on the height of its column in foundry ladle.

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