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.
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 \( M_{d} \) depends on several factors and may be calculated as:
  \[
  M_{d} = \frac{M_{kr} + 0.75(S_{1} - S_{2})}{M_{szysk}},\%
  \]
  where:
  \( S_{1} - S_{2} \) – is the sulphur content in cast iron before and after treatment, wt.%;
  \( M_{kr} \) - is the residual magnesium, 0.04 ÷ 0.05 wt%;
  0.75 - is the coefficient of sulphur and magnesium count, at %;
  \( M_{szysk} \) - is magnesium addition, %.

- the following formula is used as a main tool for calculation of the wire length and magnesium recovery:
  \[
  L = \frac{(0.76 \cdot \Delta S + M_{kr}) \cdot m_{w}}{\eta_{Mg} \cdot M_{p}},m
  \]
  where:
  \( \Delta S = S_{1} - S_{2} \) is the difference between sulphur content before and after treatment, wt %;
  \( \eta_{Mg} \) – is magnesium addition, %;
  \( M_{p} \) – is the cast iron volume, kg;
  \( M_{kr} \) – is magnesium content in 1 metre 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);
- 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).

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 Mlyn (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;

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• nodularising cored wire type INFORM M 42413 (properties: weight = 0,374 kg/m; 63 g 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).

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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;

\[
Mg_d = \frac{0.055 + 0.75 \cdot (0.02 - 0.01)}{0.45} = 0.14%;
\]

the weight of master alloy = \(\frac{17000kg \cdot 0.14%}{9%} = 264kg\);

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• 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;
1 = 304 m, the weight of wire – 130 kg;
hence 7,07 zł/kg x 264kg = 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;

\[
L = \frac{(0.76 \cdot (0.02 - 0.01) + 0.055Mg_d) \cdot 17000m}{50\eta_{Mg} - 0.07Mg} = 304m
\]

• 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 + 265 zł) = 936 zł;
• the difference in the cost of master alloys and PE cored wire: (1507 zł – 936 zł) = 571 zł;

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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;

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Fig.3. The photomicrographs showing differences in nodule count and characteristics of the tundish ladle treatment with (a) and without (b) cored wire injection
b) CuMg17; the weight of master alloy 40kg (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%) = 344 kg 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/m; 102g Si/m; – price;
price per 1kg of wire = 7.07 zł, the weight of molten metal in
ladle– 17000kg; length = 204m, the weight of wire = 88kg,
\[ L = \frac{(0.76 \cdot (0.02 - 0.01) + 0.05 \cdot Mg_{\text{w}}) \cdot 17000m}{60 \eta_{\text{mg}} \cdot 0.08 \cdot Mg_{\text{w}}} = 204m \]
• 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.
Siwinka Średnia GZUT, KRAKODLEW, Centrozap - DEFKA,
EE Zawiercie, WSK – Rzeszów, FWM PRZYSUCHA and HSW
Ścinawka Średnia GZUT, KRAKODLEW, Centrozap.

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