

# Using Cored Wires Injection 2PE-9 Method in the Production of Ferritic Si-Mo Ductile Iron Castings

E. Guzik\*, D. Wierzchowski

AGH University of Science and Technology, Reymonta 23, 30-059 Kraków, Poland,

\* Corresponding author. E-mail address: guz@agh.edu.pl

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## Abstract

The results of studies on the use of modern two cored wires injection method for production of ferritic nodular cast iron (ductile iron) with use of unique implementation of drum ladle as a treatment / transport and casting ladle instead vertical treatment ladle was described. The injection of length of  $\emptyset$  9mm wires, cored: in FeSi + Mg nodulariser mixture and inoculant master alloy is a treatment method which can be used to produce iron melted in coreless induction furnace. This paper describes the results and analysis of using this method for optimal production of ductile iron under specific industrial conditions. It means, that length of nodulariser wire plus treatment and pouring temperatures were optimized. In this case, was taken ductile iron with material designation: EN-GJS-SiMo40-6 Grade according EN 16124:2010 E. Microstructure of great number of trials was controlled on internally used sample which has been correlated with standard sample before. The paper presents typical ferritic metallic matrix and nodular graphite. Additionally, mechanical properties were checked in some experiments. Mean values of magnesium recovery and cost of this new method from optimized process parameters were calculated as well.

**Keywords:** Drum ladle, Cored wires injection 2PE-9 method, Si-Mo ductile iron, FeSi + Mg nodulariser mixture, Inoculant master alloy, Ferritic matrix, Mechanical properties, Magnesium recovery, Vertical ladle

## 1. Introduction

The high-silicon gray irons were developed in the 1930s by BCIRA and are commonly called Silal. The advent of ductile cast iron led to the development of high-silicon ductile irons, which currently constitute the greatest tonnage of these types of iron being produced. Converting the eutectic flake graphite network into isolated graphite nodules further improves oxidation resistance and growth. The higher strength and ductility of the ductile iron version of these alloys qualify it for more rigorous application. The high-silicon ductile iron (DI) alloys are designed to extend the upper end of elevated temperatures for ferritic

ductile irons; are used to temperatures of 900°C. Silicon decreases the eutectic carbon content, which must be controlled to avoid graphite flotation. For most applications, alloying with 0.5 up to 1.1 wt.% Mo provides adequate elevated-temperature strength and creep resistance. High molybdenum additions (>1wt.%) tend to generate interdendritic carbides of the Mo<sub>2</sub>C type, which persist even through annealing, and tend to reduce toughness and ductility at room temperature [1]. Ferritic nodular graphite cast iron (DI) alloyed with silicon and molybdenum is also known as Si-Mo cast iron. The silicon and molybdenum content of low alloyed ferritic nodular graphite cast iron has nine grades according prEN 16124:2010 standard; with range 2.3-5.2 wt.% Si and 0.4-1.1 wt.% Mo. Mechanical properties of the nine Si-Mo

ductile iron grades have been specified too: Tensile strength = 480-600 MPa, Yield strength = 380-500 MPa, Brinell hardness = 190-260 and Elongation ( $A_5$ ) equal from 8 to 3%. Typical applications for the first three grades are castings like turbine housings and compressor parts. The other six grades are mainly applied for exhaust manifolds and turbocharger parts in automotive applications.

An important stage in the production of high-quality ductile cast iron was implementation into industrial practice new fully mechanised technique of introducing Mg- and inoculant reagents into molten alloy called cored wire injection method. Cored wire injection method is applicable to both cupola- and electric melted iron furnace. Investigations of the cupola process carried out in two domestic foundries have fully proved that based on practical experience can be said that both the one- (Mg treatment) and two (with additional inoculant wire) cored wires method ensure low manufacturing costs and constant residual magnesium content at level of more 0,045 wt.%, necessary to get nodular graphite. Setting of residual magnesium level in alloy is very easy; it is enough to change the length of feeding Mg- cored wire. This solution effectively eliminates time and labour of repeated preparation of individual batches of nodulariser and inoculant, typical in other methods [2,3,4].

Magnesium recovery and required length (weight of nodulariser) of wire injection to molten alloy are calculated from the following formula [2]:

- magnesium recovery ( $\eta_{Mg}$ ) is constant and characteristic for Mg-treatment method. It depends on several factors and may be calculated as:

$$\eta_{Mg} = [(0,76 \cdot \Delta S + Mg_{kr}) \cdot m_z] / (L \cdot Mg_p), \% \quad (1)$$

where:

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

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

$Mg_{kr}$  – is the residual magnesium content, wt.%;

$m_z$  – is the molten alloy weight in ladle, kg;

$L$  – is the wire length, lm;

$Mg_p$  – is the Mg content in 1 metre of the cored wire, kg/lm;

- the following formula is used as a main tool for calculation of the wire length (weight of nodulariser):

$$L = [(0,76 \cdot \Delta S + Mg_{kr}) \cdot m_z] / (\eta_{Mg} \cdot Mg_p), \text{ lm} \quad (2)$$

Another important aspect of magnesium- and inoculant treatment with cored wires injection modern 2PE-9 method is its cost in comparison to other ones.

## 2. Experimental procedure

Although, since years is said in literature of the subject that ductile iron castings must be produced with use of vertical treatment ladle this experiment tried to prove that drum ladle can be taken for the same process of two cored wires injection method with same result as well. Common use of vertical treatment ladles comes from assumption which says that high of molten alloy column in ladle must be minimum 1.0 : (1.5-2.0).

At the foundry of Eisengiesserei Monforts (actually EGM Automotive GmbH) in Mönchengladbach-Germany, a special technique of Mg- and inoculation treatment was implemented. It was based on change of the ladle type and method of treatment. In case of the FeSiMg master alloy treatment at the bottom of the vertical treatment ladle was taken two  $\varnothing$  9 mm cored wires injection method in drum ladle that is use not only for treatment but also transport and pouring process. Additionally, the best angle of introducing the wires into molten alloy in drum ladle was chosen empirically (Fig. 1).

The charge mix (special pig iron + mild steel scrap + returns of ferritic nodular cast iron = mean value of sulphur content equal 0,01 wt.%) after melting and superheating in coreless induction furnace is set for tapping temperature. The drum ladle with capacity of about 0,95 Mg is next filled with molten alloy and transported to the treatment chamber (Fig. 2). Weight of molten alloy in ladle is controlled and has range between 0,93 and 0,96 Mg. After process the drum ladle is directly transported to the pouring line and used as casting ladle of green sand moulds.

The Mg- and inoculation treatment is carried out by means of two  $\varnothing$  9 mm wires injection method after parameter adjustment. Optimized length of nodulariser wire is 32 lm and was reduced from 41m which is 22% less. Magnesium content inside the wire is 0,0306 Mg/lm. Cored wire length used for inoculation process is 28 lm. For trials were taken turbocharger housing castings with number of 395 molten alloy treatments. Optimized treatment temperatures have range between 1390 and 1412°C and were decreased from about 1460°C which makes about 60 grades. Mean value of residual magnesium is equal 0,054 wt.% and during all experiments was in the limit between 0,043 and 0,064 wt.%. Lower residual Mg level is not able to ensure ductile iron in each section of casting that is ordered by automotive customers.

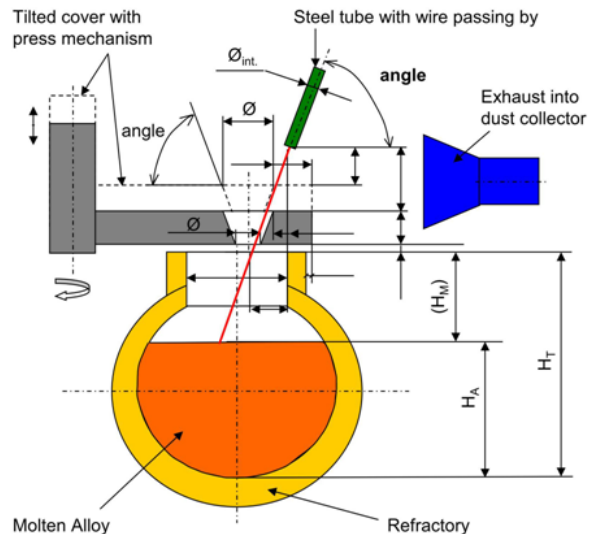


Fig. 1. Schematic view of placing the steel tube against molten alloy in drum ladle under treatment

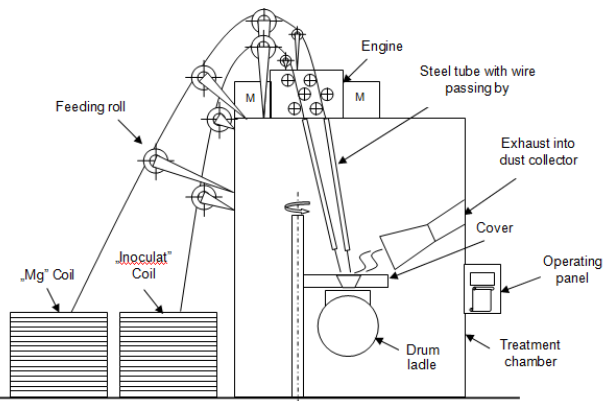


Fig. 2. Schematic view of the two cored wires injection 2PE-9 method used during experiments

Specimen for further microstructure analysis is casted with the last mould of all trials and has been correlated with standard sample before. Controls of metallic matrix and graphite are made under the Nikon, Epiphot optical microscope.

Parallel with four experiments the standard sample was poured (Type YII - 25mm block standard). They were turned to the geometry of tensile test sample (shape C 14x70) according PN-EN 1563. Mechanical properties were tested on the machine type UHP and hardness with Dia Testor 3b-E, Hahn & Kolb.

### 3. Results and analysis

From analysis it follows that the range of parameters used in this method guarantees the microstructure and mechanical properties of tested ferritic Si-Mo ductile iron. Metallographic examinations of all specimens have proved that this technique produces ductile iron (EN-GJS-SiMo40-6 Grade) with graphite type V, VI >80% in regular shape of nodules and their size of 5 up to 7 according to EN-ISO 945. Metallic matrix is about 97% ferrite with up to 3% carbides (Fig. 3). One specimen has shown microstructure out of specification which is equal 2500ppm of metallographic scrap rate. Reason for that are probably some technical problems during molten alloy treatment. The mechanical properties: tensile strength UTS, yield strength YS, and elongation of Si-Mo ductile iron are shown in Table 1.

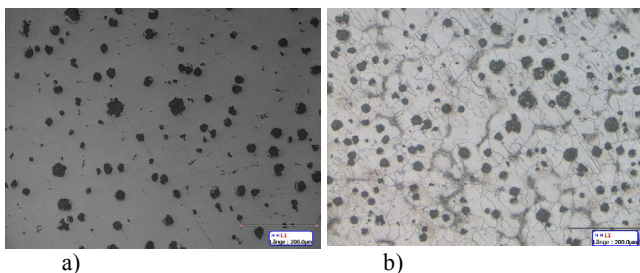


Fig. 3. The photomicrographs showing graphite after polishing a) and metallic matrix after etching b) of ductile iron manufactured during experiments

Table 1.

Results of mechanical properties of EN-GJS-SiMo40-6 Grade in "YII" block standard

Properties	UTS, MPa	A <sub>5</sub> , %	YS, MPa
Standard, min.	480	8	380
Results of trials	603	14	464

Hardness HB2,5/ 187,5 measured with these trials has mean value equal 226.

Analysis of scrap rate of castings made during experiments shows decreasing in compare to old technique of nodular cast iron manufacturing. Mean value of magnesium recovery ( $\eta_{Mg}$ ) was calculated with use of formula (1). On the schematic diagram all parameters values are shown (Table 2).

Table 2.

Parameters of cored wires injection 2PE-9 method for production of Si-Mo ductile iron (EN-GJS-SiMo40-6 Grade)

Parameter mean values for optimized process:	
$\Delta S$	0,004
$Mg_{kr}$	0,054
$m_z$	943
L	32
$Mg_p$	0,0306
$\eta_{Mg}$	55

Change of Mg recovery mean values was observed during process optimization. It means that 42% which is in our case its minimum was calculated for length of nodulariser wire equal 41 lm and for range of high treatment temperatures. Magnesium mean value recovery increases during process optimization because of permanent reduction of treatment temperature of molten alloy. Parallel with temperature decreasing, the length of nodulariser wire is also reduced. This let the residual Mg limit be in its range (Fig. 4). The cost analysis was made for the optimized process of molten alloy magnesium- and inoculation treatment carried out with two cored wires injections method as well. The following calculations were made:

- Mg-treatment with cored wire (properties: wire weight = 0,225 kg/lm; price per 1kg of wire = 2,35€; weight of molten alloy in ladle = 943kg; length of wire = 32 lm), hence 32 lm • 0,225 kg/lm = 7,20kg • 2,35 €/kg = 16,92€, Cored wire cost per 1 Mg of molten alloy = 17,94€
  - Inocuation treatment with cored wire (properties: wire weight = 0,240 kg/lm; price per 1kg of wire = 2,27€; length of wire = 28 lm), hence 28 lm • 0,240 kg/lm = 6,72kg • 2,27 €/kg = 15,25€, Cored wire cost per 1 Mg of molten alloy = 16,17€
- The final cost of 1 Mg alloy treated with Mg- and inoculant wires is 34,11€.

Results of experiments have indicated that residual magnesium content basing on the initial sulfur content and weight- as well temperature of treated molten alloy in the ladle.

Comparing with old technique has been used in the foundry before, the new way of Mg- and inoculation treatment with two cored wires being conveyed into drum ladle offers the following advantages:

- it ensures process stability and quality;

- b) it ensures safe work conditions in a foundry (no dust and no alloy “splashes” from the treatment ladle);
- c) it ensures process flexibility under variable initial parameters, like sulphur content in molten alloy, as well as temperature and weight of molten alloy;
- d) it enables collecting and storing the data in computer of control device;
- e) it reduces about 50 grades temperature loss because of using only one ladle in whole production process of Si-Mo ductile iron (Fig. 5);
- f) it ensures pouring of thin wall sections in turbocharger housing castings and reduce production cost (because of less number of ladles in process, energy saving);
- g) it reduces of refractory consumption and labour demand;
- h) it increases process efficiency.

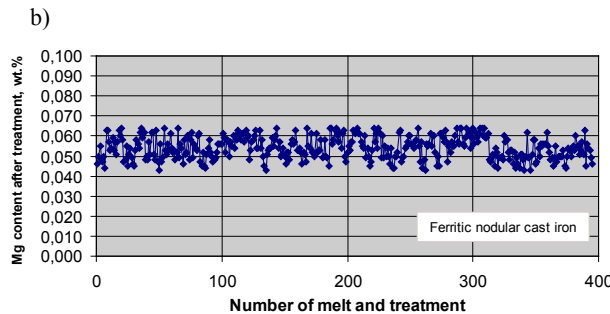
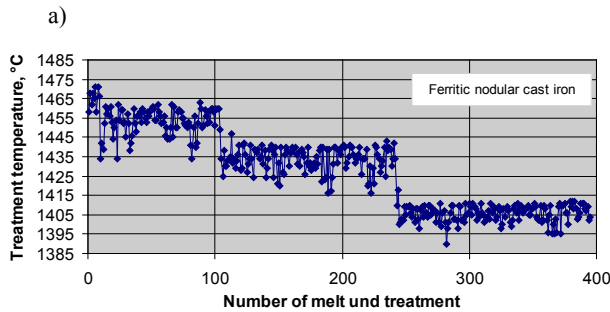
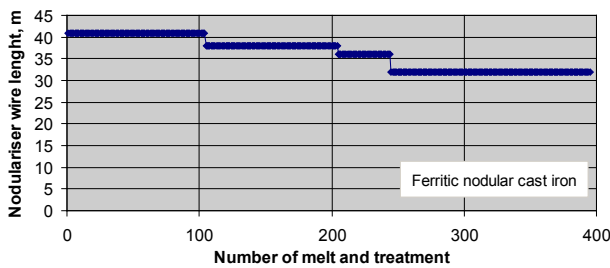


Fig. 4. Optimization of length of nodulariser wire a) and treatment temperature b) under residual magnesium content control c) in ferritic Si-Mo ductile iron carried out with two Ø 9mm cored wires injection method in drum ladle (2PE-9 method)

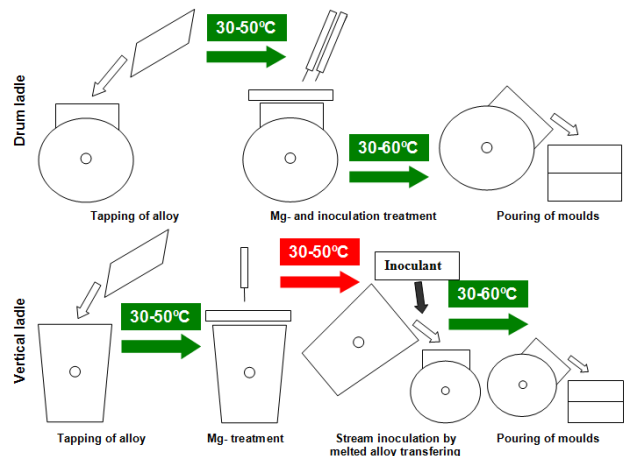


Fig. 5. Comparing classic technique being used in foundries with new way of Mg- and inoculation treatment in the drum ladle

## 4. Conclusions

Based on conducted studies of Si-Mo ductile iron production with new technique of Mg- and inoculation treatment of molten alloy in the drum ladle following conclusion have been generated:

- 1) Experiment of profitable use of the drum ladle as a treatment ladle was finished successfully.
- 2) Results of ferritic nodular cast iron production proved that this method has gained full approval of the foundry industry.
- 3) This is important stage opening without any doubts possibility of high-quality castings manufacturing with use of Mg- and inoculation treatment of molten alloy in the drum treatment ladle.
- 4) One ladle in process (as treatment/ transport and pouring ladle) saving 50 grades of temperature loss, that gives foundries big advantage due to of elimination of molten alloy transferring form the vertical treatment ladle to the pouring one (Fig. 5).
- 5) The whole Si-Mo ductile iron production process is effective.
- 6) High of the molten alloy column in ladle has not so big influence on Mg recovery in compare mainly to weight of batch, treatment temperature and base S content in molten alloy.

## References

- [1] Gundlach, R. (1988). High-Alloy Graphitic Irons, Metals Handbook Ninth Edition. *Casting*, 15, 698-701.
- [2] Guzik, E. (2001). Some selected problems concerning the processes of cast iron improvement, *Archives of Foundry Engineering*. Monograph. No. 1M, 1-128.
- [3] Guzik, E., Aślanowicz, M., Kluk, R. (1995). Using cored wire in the production of nodular cast iron, *Solidification of Metals and Alloys*, 22, 76-81.
- [4] Guzik, E., Wierzchowski, D. (2012). Modern cored wire injection 2PE-9 method in the production of ductile iron. *Archives of Foundry Engineering*, 12(2), 25-28.