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USING CORED WIRE INJECTION METHOD IN THE PRODUCTION OF AUSTENITIC HIGH Ni-ALLOYED DUCTILE IRON CASTINGS

WYKORZYSTANIE METODY PRZEWODÓW ELASTYCZNYCH DO PRODUKCJI ODLEWÓW Z WYSOKONIKLOWEGO ŻELIWA PLASTYCZNEGO O OSNOWIE AUSTENITYCZNEJ

Below are described results of the analysis concerning the use of two cored wire injection method (2PE- 9) and the unique application of a drum ladle as a treatment, transport and casting one, instead of a vertical treatment ladle. Parameter optimization, like: length of nodulariser wire, residual magnesium content, treatment and pouring temperature have been shown. Influence of various treatment temperatures, magnesium-cored wire velocities (Mg-treatment times) and weights of molten alloy on magnesium recovery are demonstrated. Moreover, graphite nodule content in relation to different raw materials in the charge mix are presented. Typical microstructure, mechanical properties and treatment costs are given as well. Using specific industrial conditions for tests and optimal, low scrap production of austenitic nodular cast iron (EN-GJSA-XNiSiCr35-5-2 Grade, according with EN 13835), makes this innovative method very credible. Injection of two Ø 9 mm wires; cored in FeSi + Mg nodulariser mixture and inoculant master alloy into a drum ladle is a treatment method that can be used for the production of ductile iron melted in a coreless induction furnace.
Keywords: treatment ladle, magnesium-cored wire, nodular cast iron, austenitic matrix, magnesium recovery

W artykule przedstawiono analizę wyników badań otrzymanych podczas produkcji żeliwa sferoidalnego, z zastosowaniem nowej metody sferoidyzacji metalu w kadzi bębnowej (w miejsce powszechnie stosowanej kadzi smukłej), przy użyciu dwóch przewodów elastycznych (technika nazwana umownie jako 2PE - 9). Kadź bębnowa z ciekłym sferoidyzowanym metalem, jest wykorzystywana do transportu ciekłego stopu i zalewania form odlewniczych. Zaprezentowano wyniki badań w zakresie optymalizacji parametrów procesu, takich jak: długości przewodu sferoidyzującego, krytycznej zawartość magnezu, temperatury zabiegu i temperatury zalewania. Pokazano wpływ temperatury zabiegu, prędkości przemieszczania przewodu sferoidyzującego (czasu zabiegu sferoidyzowania) i masy ciekłego stopu na uzysk magnezu ze sferoidyzatora. Określono liczbę wydzieleń globularnej eutektyki grafitowej w zależności od stosowanych materiałów wsadowych. Przedstawiono mikrostrukturę wysokoniklowego, austenitycznego żeliwa sferoidalnego (zgodnie z normą PN-EN 13835, gatunku EN-GJSA-XNiSiCr35-5-2), jego właściwości mechaniczne oraz koszt obróbki pozapiecowej przy zastosowaniu metody 2PE - 9. Przeprowadzone badania zabiegu sferoidyzowania metalu bezpośrednio w warunkach przemysłowych, pozwoliły zminimalizować wielkość braków odlewów i potwierdziły innowacyjność tej techniki obróbki pozapiecowej. Wprowadzenie dwóch przewodów elastycznych o średnicy Ø 9 mm; jeden wypełniony mieszaniną FeSi + Mg, a drugi modyfikatorem grafityzującym, do zabiegowej kadzi bębnowej, jest nową metodą obróbki pozapiecowej, która może być wykorzystana do produkcji żeliwa sferoidalnego.

1. Introduction

High Ni-alloyed nodular cast irons have six regular grades according to EN 13835 standard; with the range of (wt. %): 18.0-36.0 Ni, 1.5-6.0 Si, 0.2-3.5 Cr, 0.5-4.5 Mn and max. 3.0 C. Mechanical properties of them are specified too: Tensile strength = 370-500 MPa, Yield strength = 170-270 MPa, Brinell hardness = 130-255 and Elongation = 7-40 %. These grades are principally used for high-temperature service. Typical applications for three of them (EN-GJSA-XNiCr20-2, EN-GJSA-XNi22, EN-GJSA-XNiSiCr35-5-2) are parts like exhaust manifolds and turbochargers housings for the automotive sector.

An important stage in the production of high-quality ductile iron was its implementation into industrial practice, a new, fully mechanised technique of introducing Mg- and inoculant reagents into molten alloy, called cored wire injection method. This 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 both the one (Mg- treatment) and two (with additional inoculant wire) cored wire method ensure low manufacturing cost and residual magnesium content at a level of $\geqslant$ 0.045 wt. %, necessary to obtain nodular graphite, e.g. production of roll castings [1]. Setting of residual magnesium content in an alloy is very easy; it is enough to change the length of magnesium-cored wire feed-

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ing [2, 3]. This technique eliminates time and labour, like the repeated preparation of nodulariser and inoculant individual batches, typical in other methods [4].

The required length (weight of a nodulariser) of magnesium-cored wire injection into molten alloy and magnesium recovery depends on several factors and can be calculated from the following equation, Eq. (1) [3]:

$$\eta_{Mg} = [(0.76 \cdot \Delta S + Mg_r) \cdot m]/(L \cdot Mg_c), \% \qquad (1)$$

Magnesium recovery is constant and characteristic for Mg-treatment method.

2. Experimental procedure

Although it has been said for years in the on-topic literature that ductile iron castings should be produced with the use of a vertical treatment ladle, this experiment tried to prove that a drum ladle can be taken for the same process of two cored wire injection method with good results as well. Common use of vertical treatment ladles comes from the assumption that the height of a molten alloy column in the ladle against its diameter must be at least (2:1) [5].

In one of the West European foundry, a special technique of Mg- and inoculation treatment was implemented. It comprised changing of the ladle type and treatment method. Instead of molten alloy treatment with use of the FeSiMg master alloy placed at the bottom of the vertical treatment ladle, followed by the two-stage emptying from the treatment ladle to pouring ladles, two Ø 9 mm cored wire injection method in the drum ladle was applied. The same drum ladle was not used only for treatment, but also for transport and pouring process. The angle at which of the wires were inserted into molten alloy in a drum ladle was chosen empirically.

Typical chemical composition of EN GJSA-XNiSiCr35-5-2 used during tests was (% wt.): 1.78 C, 4.76 Si, 1.74 Cr and 0.48 Mn.

Two sorts of raw materials in the charge mix were tested. It means that during the process optimization and in the first half of the optimized process, the mix of special pig iron and returns of austenitic nodular cast iron was used. In the second part of the optimized process, mild steel scrap was applied instead of special pig iron. In the first case, the mean value of sulphur content was equal to 0.016 wt. % and in another one to 0.013 wt. % (decrease of sulphur content was not observed after Mg-treatment in both cases). After melting and superheating of the charge mix, the coreless induction furnace was set at the tapping temperature. The drum ladle with a standard capacity of about 950 kg was next filled with molten alloy and transported to the treatment chamber. Weight of molten alloy in ladle was controlled and had the range of 935 to 955 kg. Exception was the treatment of a lower volume of molten alloy. Four ladles with 700 kg (each of them feed with 19 m of magnesium-cored wire length) were investigated to check magnesium recovery change, in relation to standard full capacity ladles. As the treatment process was finished, the drum ladle was directly transported to the pouring line and used as casting ladle of green sand moulds.

The Mg- and inoculation treatment was carried out by means of two Ø 9 mm wire injection method after adjustment of parameters. The optimized length of the nodulariser wire was 24 m and had been reduced from 32 m, which is 25% less. The mean value of magnesium content inside the wire was 0.0313 kg/m for 24 m and 0,0326 for 32 m. The cored wire length used for inoculation process was 51 m. For all tests, exhaust manifolds castings were taken with a number of 455 molten alloy treatments. The treatment temperature had the range 1518 to 1537°C, and was slightly reduced from about 1550°C, which yielded an optimization of about 20 grades. The mean value of residual magnesium content was optimized in parallel with the nodulariser length decreasing. A decline from 0.072 wt. % for 32 m to 0.055 wt. % was achieved in the optimized process. After that, the process was frozen and the value kept in the range 0.043 to 0.064 wt. %. A lower residual magnesium level was not able to ensure ductile iron in each section of casting, which was ordered by automotive customers. Fading effect of spheroidization process (difference of magnesium content before and after pouring) was measured with some tests. The mean value of from 0.08 wt. % to 0.05 wt.% correspond with results presented by W. Orlowicz [6] and E. Guzik [7].

The loss of carbon in process was checked as well, and was equal to 0.12 wt. %.

Additionally, the magnesium-cored wire velocity was optimized. The magnesium recovery mean values were calculated and presented on a graph in relation to various magnesium-cored wire velocities (5, 10, 15, 17, 20, 25, 27, 30, 35, 40, 45 and 50 m/min). The test number of all twelve magnesium-cored wire velocities was 51.

A specimen for the microstructure analysis was cast with the last mould for all tests. It had been correlated with a standard sample before. Together with each specimen, one casting was analyzed in its thin and thick section. Controls of metallic matrix and graphite were made under the Nikon, Epiphot optical microscope.

In parallel with three experiments, a standard sample was poured (Type "YII" – 25 mm block standard, according with EN 1563). They were turned to the geometry of a tensile test sample (shape C 14×70 mm), according with DIN 50125. Mechanical properties were tested on a machine of UHP type, manufactured by LOS, and hardness with Dia Testor 3b-E, manufactured by Wolpert, Hahn & Kolb.

3. Results and analysis

From the analysis it can be concluded that parameters and their ranges used in this method guarantee the microstructure and mechanical properties of tested austenitic high Ni-alloyed nodular cast iron. Metallographic examinations of all specimens and castings proved that this technique produces ductile iron (EN-GJSA-XNiSiCr35-5-2 Grade) with graphite type V, VI >85% with a regular shape of nodules and their size of 7 and 8, according with EN-ISO 945. The metallic matrix was austenitic with 6 up to 11% carbides in the thick and 8 up to 15% in the thin section. One specimen and casting showed a microstructure out of specification, which is equal to 2200 ppm of metallographic scrap rate. The reason for that were probably some technical problems during the molten alloy treatment. During the magnesium-cored wire velocity optimization, an extra analysis of nodule content vs. raw material type in the charge mix was investigated. The results showed that charges based on mild steel scrap had 30% more nodules on an average in comparison with those created with special pig iron.

Mechanical properties: tensile strength UTS, elongation El, hardness HB and yield strength YS of austenitic ductile iron are shown in Table 1.

TABLE 1

Results of mechanical properties of austenitic nodular cast iron (EN-GJSA-XNiSiCr35-5-2 Grade) in "YII" block standard cast during experiments

Properties	Tensile strength, UTS, MPa	Elongation, %	Brinell, HB	Yield strength, YS, MPa
min. limit	380	10	130	210
max. limit	500	20	170	270
Results	414	20	154	225

An analysis of scrap rate of castings showed a reduction in comparison with the old technique of nodular cast iron manufacturing. Especially, the reduction of residual magnesium content improved the castings quality.

An increase of magnesium recovery mean values was observed during the process optimization. It means that 66%, which was in our case their minimum, was calculated for the highest length of a nodulariser wire equal to 32 m and for a range of higher treatment temperatures, roughly 1550°C. A decrease of the nodulariser wire length along with a decline of the treatment temperature enabled a reduction of residual magnesium content to the optimal limit range (Fig. 1), and the magnesium recovery increased up to 70%.

The magnesium recovery decreased when a lower weight of molten alloy was treated. In relation to the optimal (full) ladle capacity it was 6% less. The magnesium recovery mean values in opposition to the optimal range of treatment temperatures and vs. velocity of magnesium-cored wire are presented on Fig. 2. Values of the magnesium recovery tend to reach their maximum when the magnesium-cored wire velocity rises, and then start decreasing. Castings from one ladle, that was served with 5 m/min were scrapped, because of nodule content, which were only 60% in the thick section. Nodules shape and size were the same for all magnesium-cored wire velocities apart from 5 m/min. They were slightly different but sill within standard. Magnesium-cored wire velocities, 5 and 10 m/min (288 and 144 s) were critical and in case of any deviation from the frozen process, could produce scrap.

Lower values of residual magnesium content (0,043 wt. %) and magnesium recovery (55%) were due to a higher magnesium oxidation caused by the magnesium-cored wire reaction in the subsurface of molten alloy and a longer treatment time. Both these phenomena are not good for an optimal Mg-treatment process. Finding optimum magnesium-cored wire velocities means that the intensity of magnesium reaction and limited properties of the refractory must be taken into account as well. Because of that, too high magnesium-cored wire velocities could not be used. The optimum must be chosen empirically. In our case, it was 27 m/min (53 s).

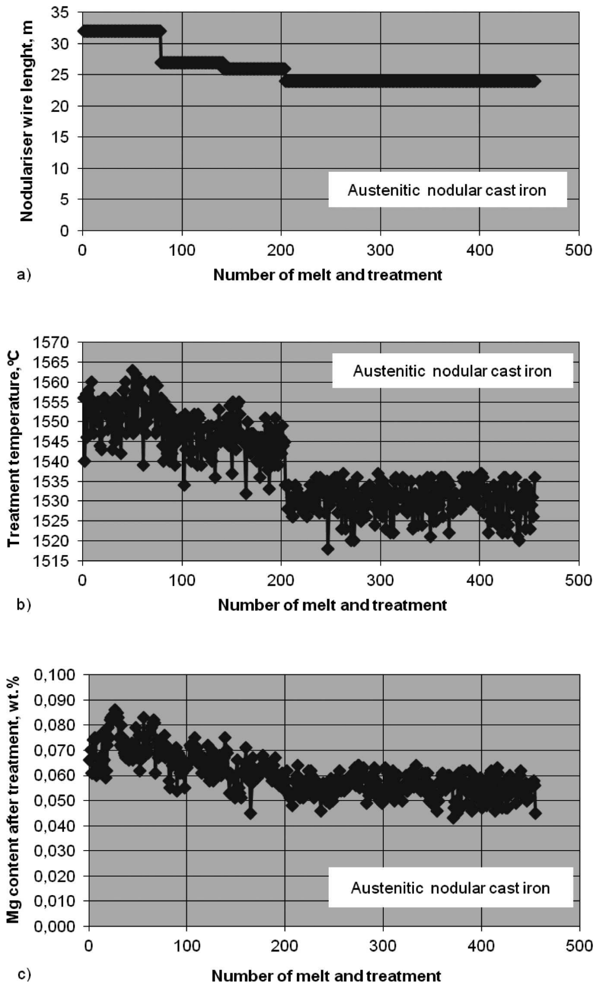

Fig. 1. Optimization of the length of nodulariser wire a), treatment temperature b) and residual magnesium content c) carried out during experiments of austenitic nodular cast iron (EN-GJSA-XNiSiCr35-5-2 Grade)

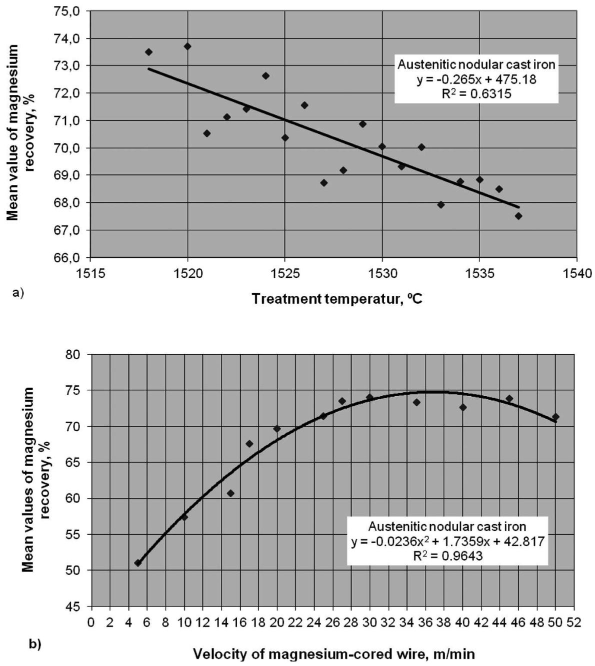

Fig. 2. Magnesium recovery mean values as a relation to the range of optimized temperature of molten alloy treatment a) and their trend as a relation to the velocity of a magnesium-cored wire b)

The cost analysis were made for the Mg- and inoculation treatment of molten alloy, carried out with two cored wire injection method:

- Mg-treatment. Cored wire cost per 1000 kg of molten alloy = 13.43 €.
- Inoculation treatment. Cored wire cost per 1000 kg of molten alloy = 29.41 €.

The final cost of 1000 kg alloy treated with Mg- and inoculant wire = 42.84 € and is about 4.48 € less than the treatment cost of not optimized process.

Treatment of 700 kg cost 31.84 € and recalculated per 1000 kg gave 45.49 €.

Using a full ladle capacity ensures not only a better magnesium recovery but also gives economic advantages, resulting from an increase in process efficiency.

Results of experiments have indicated that a residual magnesium content, based on a total weight of pure magnesium (in treatment length), time (velocity) of magnesium-cored wire treatment and weight (height of molten alloy), as well as the treatment temperature of molten alloy in the ladle.

4. Conclusion

Comparing with the old technique that had been used in the foundry before, the innovative way of Mg- and inoculation treatment with two cored wires being fed into a drum ladle offers the following advantages:

a. safe work conditions in a foundry, because of Mg-treatment combining with a treatment chamber, ladle cover and fume exhaust (flare screening, few alloy "splashes" and no fume);

b. automation of the process, which guaranties flexibility under variable initial parameters, like sulphur content in molten alloy, treatment temperature, weight of molten alloy and magnesium weight in a wire;

c. data storing in a computerized control device, which enabled the process to be controlled and analyzed;

d. no preparation of nodulariser and inoculant individual batches;

e. saving up to 40 grades of temperature loss thanks to the use of only one ladle in the whole production process of austenitic nodular cast iron;

f. one, common ladle type in process means saving high investment cost for a "well-designed" vertical treatment ladle;

g. lower number of ladles results in manpower reduction, as well as better logistics for ladles and molten alloy in the foundry;

h. reduction of the refractory consumption and labour needed for the refractory maintenance;

i. energy savings;

j. less carbon oxidation;

k. very good pouring conditions of thin-wall castings due to a reserve of pouring temperature;

l. better homogeneity of melt because of turbulent mixing during the whole Mg- treatment;

m. increase of Mg-treatment weight as well as an increase of pouring weight, due to a better geometry of the drum ladle, which is not blocked by narrowness of the pouring line of the moulding machine;

All those advantages guaranties better stability, quality, economy and efficiency of this production process.

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