PRODUCTION OF DUCTILE IRON WITH CORE WIRE FOR CENTRIFUGALLY CAST ROLLS WITH HIGH PROGRESSIVES ICDP AND HSS MATERIALS OF WORKING LAYERS.

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Abstract

Production of spheroidal graphite cast iron is today quite mastered technology. There are many methods achieving the globular graphite morphology. Each of these methods have specific characteristics and requirements to technical support, properties and the type of applied modifier. Selection of the modification method is dependent on foundry disposition, production character, economic balance, quality requirements, etc. In case of centrifugally casting the core, which fills body and neck of the roll, is created by ductile iron. Considering the sophisticated production of centrifugally cast rolls for hot rolling mills it is necessary to ensure a high reproducibility and reliability of ductile cast iron production quality in the bulk range of 9-18t per tapping. These conditions are in the Roll foundry in Vítkovicke slevarny, spol. s r.o. provided and verified mastered overpour method and the newly injection of core wire in the melt.

Key words: Ductile iron, method of modification, core wire, ICDP iron, high speed steel HSS

1. INTRODUCTION

Rolls manufactured by centrifugal casting are called two-layer cylinder. The working layer of the roll is from a technological point called shell layer. Second layer which fills the roll body and roll necks is called “core”. The rolls are designed for hot rolling mills. Working layer is made from iron with high chromium content (HiCr), chromium-molybdenum-nickel iron (ICDP), steel with high chromium and molybdenum contents, or high speed steel (HSS) with regards to application rolls and working stand on mills. The core layer is cast from grey iron or spheroidal graphite cast iron. The core iron is alloyed with nickel, chromium, manganese and molybdenum [1]. Figure 1 shows schematic draw of the roll and the distribution of layers. Production of two-ply rolls by centrifugal casting is a highly sophisticated technology, which uses perfect knowledge of material and properties of the melt. This knowledge is important for perfect conditions for production-quality and to assure bonding between layers. Raw weights of cast are in the range 9000 to 25 000 kg.

Core iron is melted in induction furnaces with a capacity of 2 x 9000 kg. The modification is made by overpour method or core wire method. After modification the ladle is moved to the cleaning place, where are removed the slag and other contaminants from surface of melt. After that is done casting in the mold.

Fig. 1. Sketch of two-layer roll, view shell layer (purple) and the core layer (green-white).
The timing and casting speed are precisely defined in a process of centrifugally casting. The final test of chemical composition is always taken from the ladle after slagging. The tests for mechanical properties, metallurgical analysis of graphite’s shape and basic metallic materials are removed from cast. The Melt is controlled by chemical composition analysis, thermal analysis and analysis of the oxygen activity during of all process. Table 1 summarizes informative chemical composition of spheroidal graphite cast [2].

Tab 1. Informative chemical composition of the spheroidal graphite iron.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P_{max}</th>
<th>S_{max}</th>
<th>Cr_{max}</th>
<th>Ni</th>
<th>Mo</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8</td>
<td>0.1</td>
<td>1.5</td>
<td>0.010</td>
<td>0.020</td>
<td>0.5</td>
<td>0.60</td>
<td>0.02</td>
<td>0.030</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>1.0</td>
<td>2.5</td>
<td>0.005</td>
<td>0.010</td>
<td>0.4</td>
<td>1.0</td>
<td>0.20</td>
<td>0.080</td>
</tr>
</tbody>
</table>

2. **PRINCIPLE AND CONDITIONS FOR MODIFICATION**

Fundamental of modification is influence of the graphite morphology during its crystallization from lamellar to a globular shape. This modification of graphite morphology is related to changes of functional characteristics base cast iron. As a modifier is most often used magnesium. The final content of Mg in the cast should be in the range from 0.025 to 0.60% [3].

Modification mechanism is described in many theories, which can be according to [3] summarized in next several points:

1) *Magnesium which enters during the modification at atomic state is absorbed on the surfaces of the existing graphite crystal, thus is changed the rate of growth of crystal surfaces;*

2) *The modification is deoxidation, desulphurization and degassing of the melt, its refining;*

3) *The modification changes the graphitization nucleation conditions, ie., undercooling is increased, there are changed eutectic temperature and length of delay.*

Dissolution of Mg in the melt has its difficulties. We have to mind, that the boiling point of Mg is much lower than the temperature of molten iron. The boiling temperature of Mg is 911 °C. Therefore, the reaction of Mg with the melt leads to spontaneous release of magnesium fume. The reaction is very dependent on the method of modifications and the state of modifier. Magnesium is used in pure form or in the form of master alloys such as Fe, Si, Ni, etc. according to the type of method. The basic overview and comparison of methods with respect to the use of Mg and type of modifier and the evolution of the fume is in Fig. 2. [4].

![Fig. 2. The basic overview and comparison of modification methods.](image-url)
The starting contents of oxygen and sulfur in the melt have the primary role in the process of modifications. Mg has a high affinity to oxygen and sulfur. Therefore it leads to deoxidation of the melt. Part of Mg is consumed by desulfurization. These elements are entered into chemical reactions according to equations (1) and (2) [3].

\[
\begin{align*}
2\text{Mg} + \text{O}_2 & \rightarrow 2\text{MgO} \quad \Delta G = -1000 \text{[KJ.mol}^{-1}] \\
2\text{Mg} + \text{S}_2 & \rightarrow 2\text{MgS} \quad \Delta G = -620 \text{[KJ.mol}^{-1}] \\
\end{align*}
\]

where is \( \Delta G \) free enthalpy.

The range of the final sulfur content is generally from 0.007 to 0.011%. Higher sulfur content makes low Mg yield, increases quantity of modifier, slag formation and costs etc. On the other hand low starting contents O and S can lead to absence of nucleuses [2].

Vitkovicke slevarny, spol. s r.o. performs modification of iron of the rolls by overpour method and injection of core wire into melt. The Selection of modification method is given by technological conditions of production of each casting. Advantages and disadvantages of these methods are described below.

2.1. Overpour method

This is a simple method which is performed in an open ladle at atmospheric pressure. Modifier and inoculation ingredients are put on the bottom of the ladle. Everything is carefully covered with cast iron turnings. The location of these ingredients is oriented to the opposite side of the ladle than the flow of liquid metal. These steps ensure to delay reaction modifier with liquid metal. Rolls foundry uses a modifier based on Ni-Mg. Mg content on this master alloys is in range 10-20% Mg.

2.1.1. Advantage of overpour method

The master alloys NiMg is heavier than the liquid metal. The reaction takes place on the bottom of the ladle. The modification is stable with a high reproducibility of results residual of magnesium Mg\(_{\text{res}}\) in the narrow interval from 0.040 to 0.060 %. The Mg yield is around 40-50%. The temperature decrease is during modification around 50-60 °C. Thermal loss and manipulation with melt during the processes tap-casting is shown in Fig. 3.

2.1.2. Disadvantage of overpour method

The reaction is intense and effervescence. The price of modifier is high, because it contains up to 85% nickel. This nickel from modifier limits the use of returns. If the quantity of melt is higher than the capacity of the one furnace, it is made tapping from second furnace during the modification. Inoculation is made during modification and then in the flow during pouring.

2.2. Core wire method

It is a relatively simple method of modification too. The principle of the method is based on the injection core wire in melt of cast iron. Injection’s speed is set so that core wire was melted on the bottom of the ladle. The ladle is covered with a lid during the modification to increase modification pressure. The literary sources state, that the Mg yield is 35 to 70% depending on the content and design modifications.

2.2.1. Advantage of core wire method

Injection of core wire is made by feeder, which can continuously regulate the injection speed. The feeder is multiple, it can inject two core wires at a same time. It can combine modification and inoculation. The core can be changed according request to modifier from pure Mg to combination of elements such as rare earth
metals, Ca, Si, etc. In case of higher quantities of melt than the capacity of the one furnace the tapings are carried out from both furnaces before the modification. The reaction is not as effervescence as during overpour method. Process of modification is divided until time of injection. Core wired doesn’t contain allow element Ni, it is higher yield of returns.

2.2.2. Disadvantage of core wire method
The time of modification process is longer. The temperature decrease is around 90-100 °C during modification and the temperature of tapping is used higher than that of overpour method. Thermal loss and manipulation with melt during the processes tap-casting is shown in Fig. 3. Next disadvantage is lower Mg yield (from 25 to 40 %) for required interval of Mg<sub>res</sub> (0.040 to 0.060 %).

![Fig. 3. Thermal loss and manipulation with melt during the processes tap-casting for different modification methods inspired by [5].](image)

3. RESULTS, COMPARED
Classification of methods of modification is done with respect to the Mg yield. Mg yield is calculated according to equations (3, 4).

\[
\eta_{Mg} = \frac{0.76\% \Delta S + \%Mg_{res}}{Mg_{sus}} \cdot 100 \quad [\%] \tag{3}
\]

\[
\eta_{Mg} = \frac{Mg_{res}}{Mg_{sus}} \cdot 100 \quad [\%] \tag{4}
\]

Where are:
\[\Delta S\] difference of sulfur before and after modification
\[\eta_{Mg}\] yield of magnesium in %
\[ \text{Mg}_{\text{res}} \text{ residual Mg after modification in } \% \]
\[ \text{Mg}_{\text{us}} \text{ used Mg for modification in } \% \]

Formula (3) is acceptable for processes where the values of S have high variance. Therefore, calculations are made according to formula (4).

Overpouring method is higher magnesium yield than the core wire method. Core wire method is divided by the type of wire that is used for modification. There are wires:
- Ø13 mm with Mg 137 g/m
- Ø 9 mm with 65 g/m
- Ø 9 mm with 56 g/m.

The influence of modifier is well illustrated in Fig. 4. There is showing the graphical dependence \( \text{Mg}_{\text{res}} \) and Mg yield. Next Fig. 5 describes the Mg yield and \( \text{Mg}_{\text{us}} \) required for modification, for the condition of the final content \( \text{Mg}_{\text{res}} \) is in the range 0.040 to 0.060 %. The medians of Mg yield are shown in Tab 2.

**Fig. 4.** Mg yield by the type of modifier, depending on the magnesium residual [\%].

**Fig. 5.** Mg yield and \( \text{Mg}_{\text{us}} \) for necessary the final content \( \text{Mg}_{\text{res}} \) in the range (0.040 to 0.060) [\%].
Tab. 1. The medians of Mg yield.

<table>
<thead>
<tr>
<th>Type of modification</th>
<th>Median of Mg yield [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiMg</td>
<td>42,2</td>
</tr>
<tr>
<td>Core wired 56</td>
<td>37,8</td>
</tr>
<tr>
<td>Core wired 65</td>
<td>28,3</td>
</tr>
<tr>
<td>Core wired 137</td>
<td>23,1</td>
</tr>
</tbody>
</table>

Core wire method is analysed for reasons of injection’s speed. These analyses are shown in Fig. 6. Here you can see the change of Mg yield with depending on the injection’s speed. For core wire method is very important to set the speed, so that core wire was melted on the bottom of the ladle.

Fig. 6. Influence of injection’s speed and Mg yield [%].

Next indicator is the economic analysis of consumption of raw materials and returns. In the advantages and disadvantages were mentioned, that by the core wire method is higher returns yield then overpour method. This is very well evidently on the doughnut charts in Fig. 7.

Fig. 7. Compare returns yield of modifications methods [%].
CONCLUSIONS

By the overpour method is a higher Mg yield than the core wire method. This difference is caused by the thermophysical process. The master alloys NiMg is heavier than the liquid metal. The Reaction place is on the bottom of the ladle. Overpour method is a method at atmospheric pressure. Therefore the modification’s pressure is the same as metallostatic pressure. In the case of core wire method is very important injection’s speed. The speed must be set so that the melting of the modifier is on the bottom of the ladle. In this case, the conditions are approaching to the conditions of overpouring methods. For apply increased pressure between the surface of melt and cover of ladle, it must be ensured tightness of cover.

For the core wires was found the best Mg yield is by core wire with low Mg chart. In Fig. 6 influence of injection’s speed and Mg yield it can be concluded that core wire of higher weight of Mg in the melt should be injected higher speed. But it is not possible for practical reasons.

Increasing the Mg yield for the core wire method can be under the conditions to ensure increased of modification pressure with combination of chosen core wire charge.

By the core wire method is higher returns yield, then overpour method. It can be seen in Fig. 7. Increase is 27%. This fact refund costs decrease Mg yield.

Both methods are reliable methods. The reproducible results of narrow range of Mg values is ensured by well knowledge of the Mg yield, temperature’s loss and properties of iron core in the production of centrifugally cast rolls in Vitkovicke slevarny, spol. s r.o.

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