

# The Comparison of Selected Methods of Cast Iron Spheroidization in Industrial Conditions

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## Abstract

Production of spheroidal graphite cast iron is today quite mastered technology. There are many methods achieving the nodular graphite morphology. Each of these methods have specific characteristics and requirements to technical support, properties and the type of applied modifier. Selection of the spheroidization 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 9-18 t per tapping. These conditions are in the Roll Foundry in Vitkovické Slévárny, spol. s r.o. provided and verified mastered overpour method and the newly injection of cored wire in the melt.

**Keywords:** Product Development, Ductile Iron, Method of Modification, Core Wire, Spun Cast Rolls, ICDP Iron

## 1. Introduction

Rolls manufactured by centrifugal casting are called two-layer cylinder. From a technological point is called layer forming the working layer of the roll shell layer. Second layer which fills the roll body and roll necks called "core". The rolls are designed for hot rolling mills. Working layer is made of iron with high chromium HiCr, chromium-molybdenum-nickel iron ICDP, steel with high chromium and molybdenum, or high speed steel HSS by application rolls and working stand on mills. The core layer is casting from cast iron or spheroidal graphite cast iron. The core iron is alloyed with nickel, chromium, manganese and molybdenum [1]. Schematic drawing of the roll and the distribution of layers is in Fig. 1. Production of two-ply rolls centrifugal casting is a highly sophisticated technology using by perfect knowledge of material and properties of the melt. These knowledge are important for perfect conditions for production-quality and ensure bonding between layers. Raw weights of cast are in the range 9 000 to 25 000 kg. Core iron is melted in

induction furnaces with a capacity of 2 x 9 000 kg. The modification is made by overpour method or cored wire method. The ladle is moved to the cleaning place after spheroidization. There is removed the slag and other contaminants from surface of melting. After that is done casting in the mold.

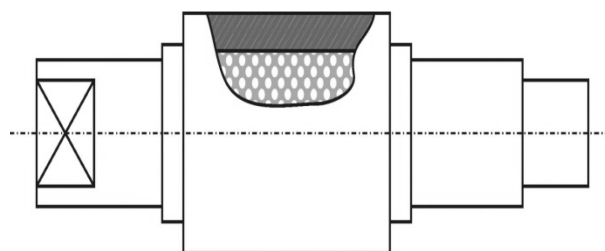


Fig. 1. Sketch of two-layer roll, view shell layer (purple) and the core layer (green-white)

The timing and casting speed are precisely defined in a process of manufacture centrifugally cast rolls. The final test of chemical composition is always removed from the ladle during slagging. The tests for mechanical properties and 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. Informative chemical composition of spheroidal graphite is shown in Table 1 [2].

Table 1. Informative chemical composition of the spheroidal graphite iron

C	Mn	Si	P <sub>max</sub>	S <sub>max</sub>	Cr <sub>max</sub>	Ni	Mo	Mg
2.8	0.1	1.5	0.100	0.020	0.5	0.60	0.02	0.030
3.5	1.0	2.5				1.0	0.20	0.080

## 2. Principle and conditions for modification

The principle of modification is influenced the shape of graphite during its crystallization. Lamellar graphite shape is changed due to spheroider to a nodular shape. This are fundamentally change the functional characteristics of basic cast iron. As a spheroider is most often used magnesium. The final content should be in the range 0.025 to 0.60% [3].

Modification mechanism is described in many theories. They can be summarized in these nowadays basic theories, citation from the literature [3]:

- 1) By the spheroidization is evaporating magnesium, which enters the atomic state and absorbed on the surfaces of the existing graphite crystal, thus is changed the rate of growth of crystal surfaces;
- 2) The spheroidization is deoxidation, desulphurization and degassing of the melt, its refining;
- 3) The spheroidization changes the graphitization nucleation conditions, i.e., 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 vapor. The reaction is very dependent on the method of spheroidizations 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 spheroider and the evolution of the vapor is in Fig. 2 [4].

The starting contents of oxygen and sulfur in the melt have the primary role in the process of spheroidizations. Mg has a high affinity for oxygen and sulfur. Therefore it leads to deoxidation of the melt. Part of Mg is consumed in desulphurization. These elements are entered into chemical reactions according to equations (1) and (2) [3].

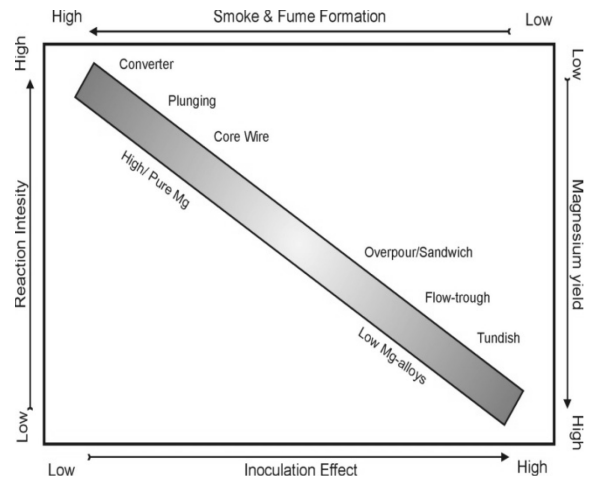
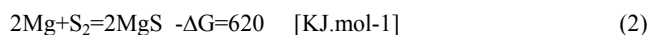


Fig. 2. The basic overview and comparison of spheroidization methods



The range of the final sulfur content is generally from 0.007 to 0.011%. Higher sulfur content makes low Mg yield, increased quantity of spheroider, more slag formation, increased costs and etc. On the contrary, low starting contents O and S can lead to absence of nucleuses [2]. The modification of iron is made on this foundry of the rolls by two methods as mentioned above. Overpour method and injection of cored wire into melt. The selection of spheroidization method is made 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. It 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 is the flow of liquid metal. These steps ensure to delay reaction spheroider with liquid metal. In rolls foundry uses a spheroider on based 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 place is on the bottom of the ladle. The spheroidization is stable with a high reproducibility of results residual of magnesium Mg<sub>res</sub> in the narrow interval 0.040 to 0.060. The Mg yield is around 40-50%. The temperature decrease is around 50-60°C for spheroidization. The temperature's process is shown in Fig. 3.

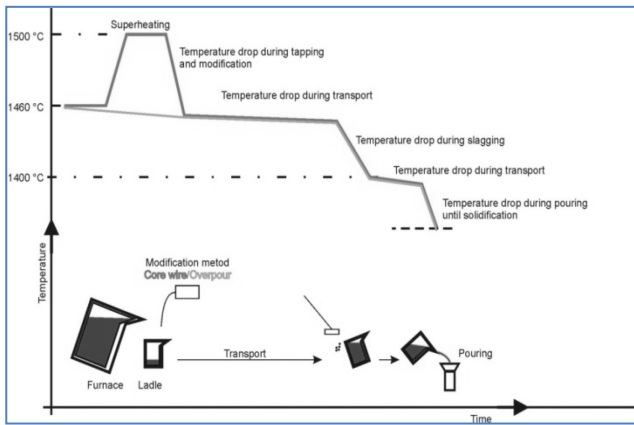


Fig. 3. The temperature's process core iron by centrifugally cast rolls [5]

### 2.1.2. Disadvantage overpour method

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

## 2.2. Cored wire method

It is a relatively simple method of modification too. The principle of the method is based on the injection cored 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 for increasing spheroidization pressure. The literary sources state, that the Mg yield is 35 to 70% depending on the content and design spheroidizations.

### 2.2.1. Advantage of cored wire method

Injection of cored wire is made by feeder, which can continuously regulate the injection speed. The feeder is multiple, it can injection two cored wires at a time. It can combine modification and inoculation. The core can be changed according to the pure Mg, combination of elements such as rare earth metals, Ca, Si, etc. When it is higher quantities of melt than the capacity of the one furnace, they are made tapings from both furnaces before the spheroidization. The reaction is not effervescence. Process of modification is divided until time of injection. Cored wired doesn't contain allow element Ni, it is higher yield of returns.

### 2.2.2. Disadvantage of cored wire method

The manipulation's time is longer. The temperature decrease is around 90-100°C for spheroidization. The temperature's process is shown in Fig. 3. The tapping's temperature must be higher. There are increased titles for the spheroidization process

safety by castings centrifugally cast rolls. The Mg yield is from 25 to 40 % for an interval of  $Mg_{res}$  (0.040 to 0.060 %).

## 3. Results, compared

Classification of methods of spheroidization is done with respect to the Mg yield. Mg yield is calculated according to equations (3 and 4).

$$\eta_{Mg} = \frac{0,76\% \Delta S + \% Mg_{res}}{Mg_{us}} \cdot 100 \quad [\%] \quad (3)$$

$$\eta_{Mg} = \frac{Mg_{res}}{Mg_{us}} \cdot 100 \quad [\%] \quad (4)$$

where is:

$\Delta S$  - difference of sulfur before and after spheroidization,

$\eta_{Mg}$  - yield of magnesium in %,

$Mg_{res}$  - residual Mg after spheroidization in %,

$Mg_{us}$  - used Mg for spheroidization 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 cored wire method. Cored wire method is divided by the type of wire that is used for modification. There are wires:

- 1) Ø13 mm with Mg 137 g/m
- 2) Ø 9 mm with 65 g/m
- 3) Ø 9 mm with 56 g/m.

The influence of modifier is well illustrated in Fig. 4. There is showing the graphical dependence  $Mg_{res}$  and Mg yield. Next Fig. 5 describes the Mg yield and  $Mg_{us}$  required for spheroidization, for the condition of the final content  $Mg_{res}$  is in the range 0.040 to 0.060%. The medians of Mg yield are shown in Table 2.

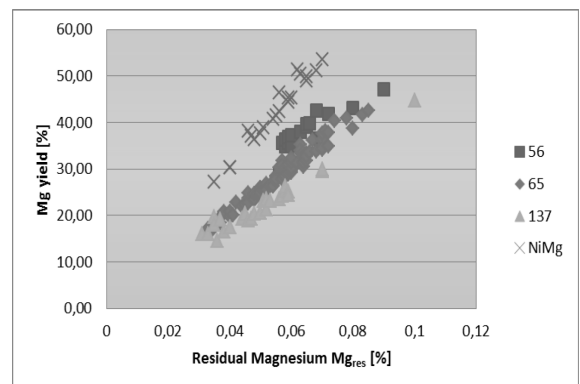


Fig. 4. Mg yield by the type of spheroidizer, depending on the magnesium residual [%]

Cored wire method is analyzed 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 cored wire method is very important to set the speed, so that cored wire was melted on the bottom of the ladle.

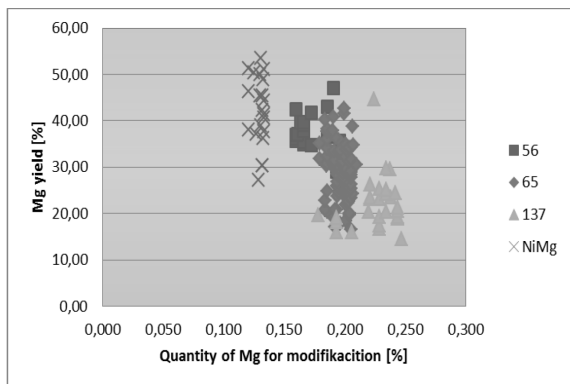


Fig. 5. Mg yield and  $Mg_{us}$  for necessary the final content  $Mg_{res}$  in the range (0.040 to 0.060) [%]

Table 2.  
The medians of Mg yield

Type of spheroidization	Median of Mg yield [%]
NiMg	42.2
Cored wire 56	37.8
Cored wire 65	28.3
Cored wire 137	23.1

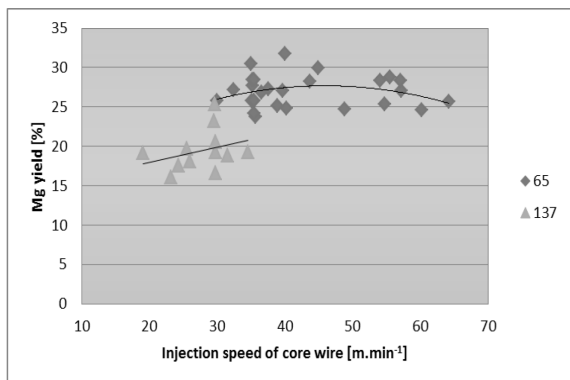


Fig. 6. Influence of injection's speed and Mg yield [%]

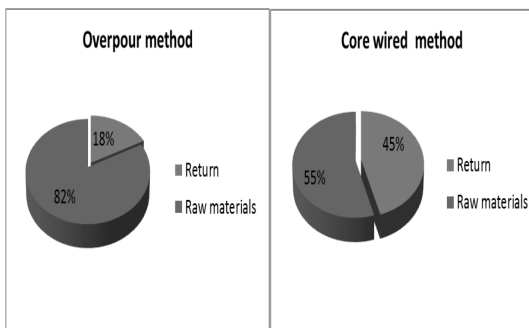


Fig. 7. Compare returns yield of modifications methods [%]

Next indicator is the economic analysis of consumption of raw materials and returns. In the advantages and disadvantages

were mentioned, that by the cored wire method is higher returns yield than overpour method. This is very well evidently on the doughnut charts in Fig. 7.

## 4. 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 spheroidizations pressure is the same as metallostatic pressure. In the case of cored wire method is very important injection's speed. The speed must be set so that the melting of the spheroider 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 cored wire was found the best Mg yield is by cored 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 cored wire method can be under the conditions to ensure increased of modification pressure with combination of chosen core wire charge.

By the cored 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  $Mg_{res}$  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 Vítkovicke Slavany, spol. s r.o.

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## References

- [1] Valek T. & Hampl J. (2011). Prediction of Metallurgic Quality of ICDP Material before Tapping. *Physics Procedia* 22, 191-196.
- [2] Data sheets of Vítkovicke Slavany spol. s r.o. (2008).
- [3] Vondrák V. (1992). *Secondary metallurgy of iron*. Ostrava: VŠB.
- [4] Vomacka P. (2010). *High and Low Volume Production of CGI, Case Studies*, Düsseldorf: Novacast.
- [5] Dötsch E. (2009). *Inductive melting & holding*. Berlin: Vulkan-Verlag.