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Production of GJS with Cored Wire

Introduction

As is generally known, there are a number of procedures to introduce magnesium for producing cast iron with nodular and compact graphite (DI and CGI). The desire to develop new procedures or to change or improve existing ones resulted in the cored wire treatment technology in the mid to late 1980s [1-8]. This marked the development of a further procedure for producing GJS (Figure 1).

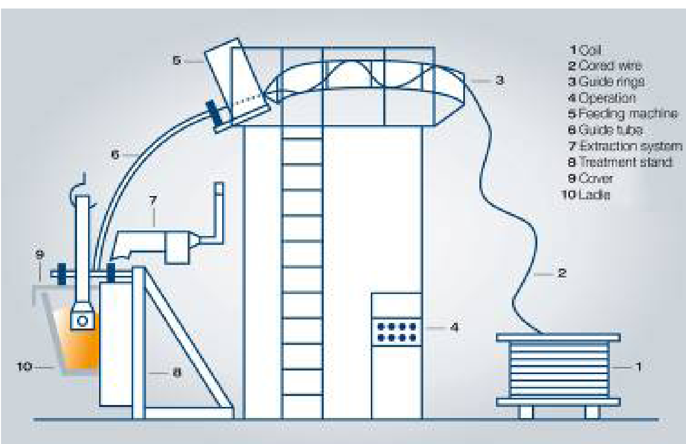

Figure 1: Schematic representation of the wire treatment

After a relatively short start-up phase, the first foundries started switching over to this procedure in 1989. Since then, this treatment technology and the wires have been further developed. Nowadays, one can say that the Mg-treatment procedure with wire has established itself on the market and it is used not only for the Mg-treatment but for inoculation too.

A list dating from late 2012 of 165 German foundries that produce DI/CGI shows that just over 35 % of German foundries now use the cored wire procedure (Figure 2).

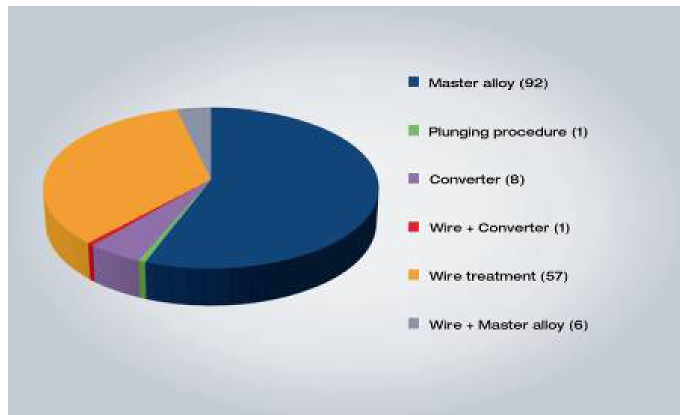

Figure 2: Breakdown of Mg treatment procedures from 165 German foundries (Nov. 2012)

This makes it easy to see how quickly the procedure has gained acceptance.

The wire procedure has supplanted the plunging procedure, the pressure chamber procedure, the osmosis procedure and, in some cases, sandwich/overpouring. With the cored wire process foundries with a cupola furnace were offered the first time an easy-to handling, reliable and economical procedure (besides the GF converter) to produce DI.

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Classification of Mg-treatment Wires

Wires for the magnesium treatment can be produced both with different diameters and wall thicknesses of the wire shell as well as with different fillers. The suitable wire is selected taking the customer's requirement into consideration and in accordance with the production conditions in force in the foundry as well as the product range in question. The classification of the Mg-treatment wires is shown in Table 1.

Classification by diameter and wall thickness	Classification by type of powder (filler)	Classification by base iron	Classification by application
Usual diameter 9, 13 and 16* mm	Pure magnesium wires (Si-free wires)	for cupola furnace iron (Da 0.040-0.120%)	Production of Ductile Iron (DI)
	Mixed wires (CerMM-based or CerMM-free)	for E-furnace iron (Sa 0.010-0.030%)	Production of Compact Graphite Iron (CGI)
Usual wall thickness 0.4* mm	Alloy wires (CerMM-based or CerMM-free)	High initial strength Good Compaction[illegible]keiten Gute Verdichtung	e.g. in the field of valve bodies or when using talcum-powered or coated cores

Table: Breakdown of Mg treatment wires

Sulfur Content of the Base Iron

As in every other Mg-treatment procedure, the S-content of the base iron plays a major role here.

Since S-contents of 0.005 % to 0.012 % are aimed at after the Mg-treatment, every additional percentage point of sulfur before the treatment means more wire, rising costs, and more slag.
With cupola furnaces SA contents of ≤ 0.080 % and with electrical furnaces ≤ 0.015 % are aimed.

If the initial sulfur contents are less than 0.010 %, e.g. 0.008 %, particular attention must be paid to inoculation. This situation may arise following pre-desulfurization, for example. The S-contents following the Mg-treatment may then be in the region of 0.004 %. This iron is heavily deoxidized with very low oxygen and sulfur contents. It is "hard" and must be inoculated more strongly. It could be possible to add a low quantity of iron pyrite (FeS) to raise the sulfur content a little bit.

Main Factors Influencing the Mg Wire Treatment

In order to achieve optimum results in magnesium treatment with cored wire, general influencing factors (e.g. S content of the base iron) are to be borne in mind as is also the case with other Mg-treatment procedures. There are also some particular issues that must be taken into consideration for this procedure.

For this reason, the following are the main factors that influence the treatment result:

- Sulfur content of the base iron
- Type and quality of the cored wire
- Geometry of the treatment ladle
- Treatment temperature
- Treatment quantity
- Feeding speed/treatment time
- Geometry of the wire feeding/setup of the treatment stand

These influencing factors will now be explained in more detail.

Main Factors Influencing the Mg Wire Treatment

a)

- Pure magnesium wires with a diameter of 9 mm (usual for pure magnesium) contain 60 to 65 g/m of Mg,
- with a diameter of 13 mm (rare for pure magnesium wires) contain 140 to 145 g/m of Mg,
- both wires are very reactive,
- an encased treatment station is necessary,
- pure magnesium wires contain no Si and no CerMM.

b)

- Mixed wires (9, 13 and 16 mm diameter)
- These wires are less reactive as they normally contain less Mg as other materials have been added. The Mg-content is between 30 and 120 g/m.

c)

- Alloy wires (almost only with a 13 and 16 mm diameter)
- The alloy wires feature a very low level of reactivity. The Mg-content is between 60 g/m and 120 g/m.

This means that the level of Mg and the form in which it is present have a major influence on the reaction.

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Geometry of the Treatment Ladle

Tall ladles are particularly suitable as treatment ladles (height and diameter in a 2:1 ratio). The tall ladle allows for a high iron column, meaning that the Mg vapor bubbles have to travel long distances through the iron and therefore remain largely in the iron. In addition, the temperature loss is low thanks to the relatively small surface area and the formation of MgO on the surface is low (Figure 3).

Figure 3: Influence of the ladle dimensions during the Mg cored wire procedure

If the iron quantities are larger (e.g. > 2 t), the existing ladle is normally used for cost reasons. In many cases, this means that a very high iron column is also present. The iron column should be at least 500 mm or higher.

Of decisive importance for all ladles is a minimum free space of 300 mm from the iron surface to the edge of the ladle.

Geometry of the Treatment Ladle

There is a general dependency between the treatment temperature and Mg-recovery in the Mg-wire procedure too, i.e. as the treatment temperature rises, the Mg-recovery will fall and vice versa (Figure 4).

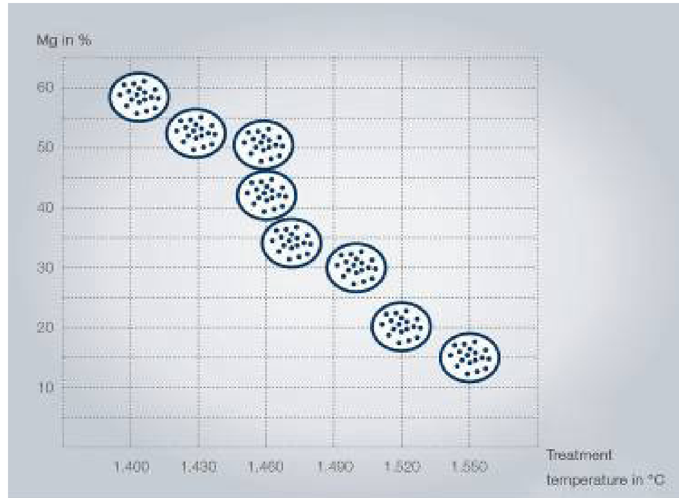

Figure 4: Mg recovery amount depending on the treatment temperature

In machine-molded casting, the treatment temperatures are normally between 1,450°C and 1,520°C; in exceptional cases, this treatment temperature may be higher.

The treatment temperatures for hand-molded casting are normally between 1,390°C and 1,450°C.

The pouring temperature has a major influence on the treatment temperature.

An advantage in the wire procedure compared to other Mg-treatment procedures is the fact that the temperature loss due to the treatment (temperature, measured before the treatment, to temperature measured immediately after the treatment) is normally 30°C to 50°C.

This means that a higher pouring temperature can be obtained thanks to the low temperature loss in the wire procedure, regardless of the furnace.

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Treatment Quantity

A minimum iron column of 500 mm should always be aimed at in the treatment quantity. To date, 200 kg is the smallest unit that has been treated with this iron column with appropriately tall ladles. In practice, the lowest treatment quantities are approx. 500 kg. An upper limit cannot be specified directly.

However, treatment quantities of up to 40 t are already standard today.

Deslagging should be performed before the treatment and must be performed after the treatment.
In general, it can be said that as the iron quantity increases in response to the wire type and the temperature, the recovery amount initially increases and reaches a maximum value, one which cannot be further increased even with larger treatment quantities.

Feeding Speed/Treatment Time

The feeding speed depends mainly on the height of the iron column and the iron temperature. It is normally between 15 m/min and 40 m/min but can also be higher (Figure 5).

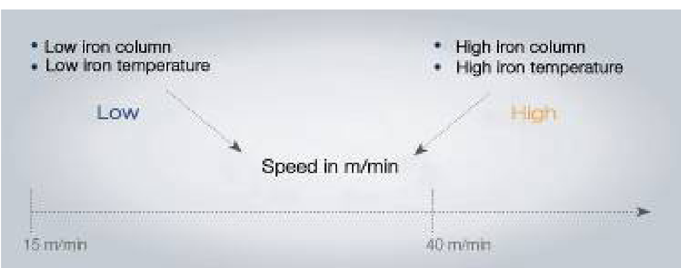

Figure 5: Winding speed

This results in treatment times of 0.5 min to 2 min with quantities of 500 kg to 2,000 kg and several minutes with larger iron quantities. To avoid too long treatment times the use of several feeding machines is also possible.

Because more and more foundries with treatment quantities >10t are using the cored wire technology now the 16 mm diameter wire is offered. This allows, compared to the 13 mm wire, to bring in the same time 50 % more filler into the iron (Figure 6). So the foundries can save treatment time or are able to work with less feeding machines.

Figure 6: Cross-sectional areas of different wire diameters

Setup of the Treatment Stand / Geometry of the Wire Guidance / Cover

The setup of the treatment stand is in most cases determined by the local conditions, the ladle sizes and the resources available.

The treatment stand can be open, semi-encased or completely encased. In all cases, it must be fitted with an adjustable extraction system.

Figure 7 shows the various ways in which the feeding machine and treatment ladle can be arranged. It is always important that the wire enters the iron with little to no bending. The wire should always enter the ladle bottom in the middle so that the reaction can take place just above the bottom.

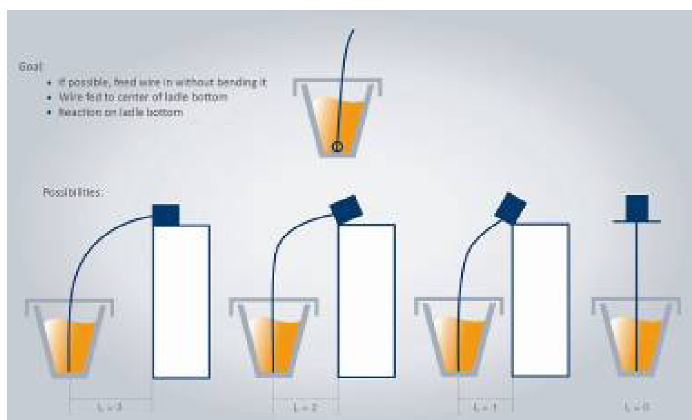

Figure 7: Methods of arranging the winding machine/treatment ladle

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It is beneficial for the wire to be fed in a manner that is as vertical as possible or completely vertical.

Figure 8 shows the wire's behavior when it is fed into the ladle as well as the influence of the temperature, speed, and geometry of the wire guidance.

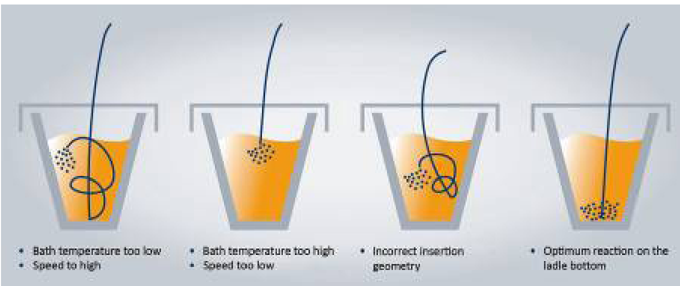

Figure 8: Behavior of the wire while being inserted into the ladle

The cover required for the treatment ladle can have many different forms (Figure 9). It should be cast from cast iron with nodular graphite due to the thermal requirements and equipped with refractory material. The cover should have two holes for the extraction system in addition to the feeding tube for the wire.

If the treatment chamber undergoes indirect extraction, only the hole for the wire feeding is required. The wire feeding tube should not be connected to the cover.

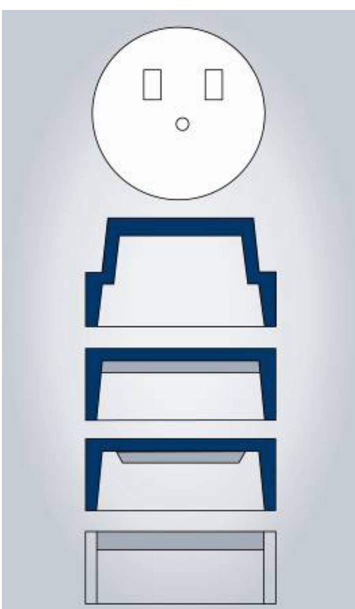

Figure 9: Examples of cover designs

Inoculation of Wire-treated Cast Iron with Nodular Graphite

Cast iron treated with a Mg-wire must be inoculated just like the molten iron in which a different treatment procedure was used. The following can therefore be said for inoculation:

a. Machine-molded casting
The iron quantities treated weight up to 1,500 kg in many cases. Ladle inoculation, pouring stream inoculation, wire inoculation, or mold inoculation can be used here. Frequently, inoculation takes place during transferring into the casting ladle and a second inoculation is performed in addition.

b. Large casting
In the case of larger castings, e.g. hand-molded castings mold inoculation is the best choice of inoculation. There is no need and often no possibility for transferring, i.e. no further temperature losses arise and the fading effect is almost zero. Segregations are counteracted and the number of nodules raised.

Wire inoculation has been increasingly used in recent years; it takes place immediately after the Mg-treatment in the same wire treatment station.

Nowadays pre-conditioning of the iron is increasingly performed during tapping before the Mg-treatment.

Calculating the Wire Quantity and the Recovery Amount

Calculation of the wire quantity required, the recovery amount etc. is frequently an integral part of the wire treatment system now. The wire quantity required can also be calculated with the following easy-to-use equation, although specific assumptions have to be made. The influence of the temperature is discarded in the first instance.

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$$\text{Wire m} = \frac{[(0.76 \times \Delta S) + \%\,MgFe] \times FeLadle}{\%\,Mgrec. \times Mg\ kg/m}$$

$$\%\,Mgrec. = \frac{[(0.76 \times \Delta S) + \%\,MgFe] \times FeLadle}{m\ wire \times Mg\ kg/m}$$

FeLadle	Iron quantity in kg
m	Meter of wire
SA%	Initial sulfur before treatment
SE%	Final sulfur content after treatment
ΔS%	SA% before treatment minus SE% after treatment
% MgFe	Mg-content in the treated iron
% Mgrec.	Mg-recovery
Mg kg/m	kg of Mg per meter of wire

A statistical evaluation is a useful means of determining the exact recovery and the influence of the treatment temperature on the recovery. The result is a recovery at an average temperature and a coefficient that characterizes the influence of the temperature.

Experience has shown that this coefficient "m" calculated from the regression equation $y = b + mx$ lies between 0.05 % and 0.15 % of the recovery / 1°C temperature change.

The influence of the foundry-specific conditions is also reflected in this factor. For example, a pure Mg-wire exhibits higher dependency on the temperature than an alloy wire.

If the parameters are available, preparing a diagram as shown in Figure 10 is appropriate. If the wire length is calculated with a computer, the parameters are to be saved as a calculation basis in the program.

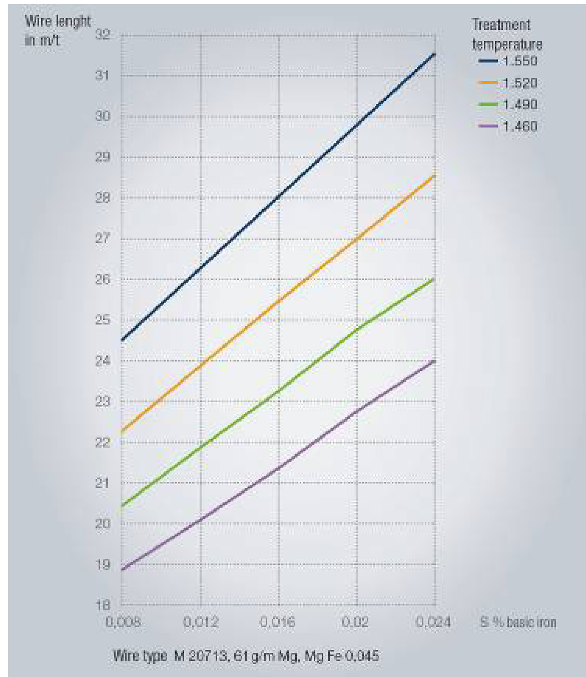

Figure 10: Wire feeding in relation to temperature and sulfur content

Summary

Treating cast iron with a Mg-containing cored wire is a further method for producing DI and CGI. A classification of the wires based on specific criteria and the main influencing factors are shown.
The facts present above are based on over 20 years of application experience under the most varied of foundry-specific conditions and is thus in a position to make statements that have been proven to be true in practice.

Production of GJS with Cored Wire

The following benefits of the cored wire procedure can be highlighted:

- Production of cast iron with nodule graphite from the cupola furnace can be performed in a single treatment step.
- Lower material usage (Figures 11 and 12) and low treatment costs.

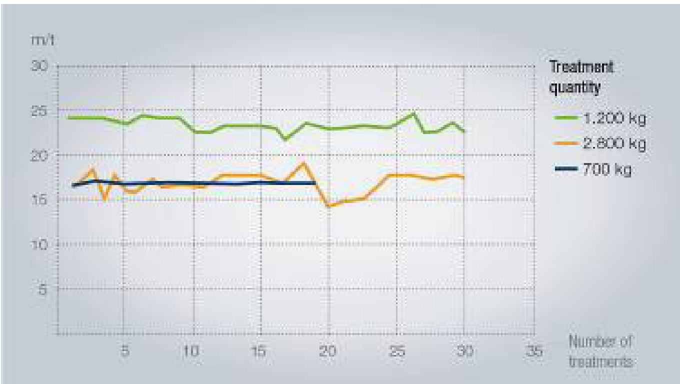

Figure 11: Wire consumption in m per metric ton

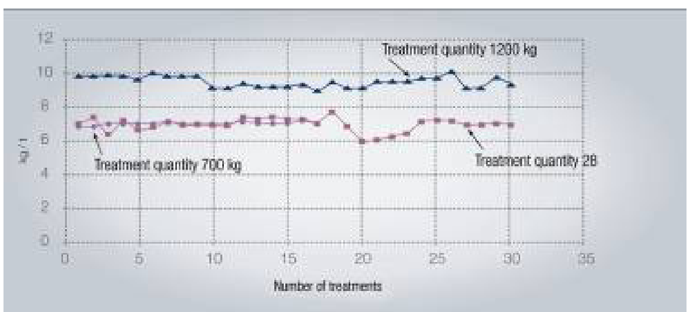

Figure 12: Wire consumption in kg per metric ton

- Temperature losses during treatment are low.
- It offers flexibility with regard to changing initial conditions such as the sulfur content, treatment temperature, and iron quantity. As shown in Figure 13, relatively constant Mg-values can be achieved despite different initial sulfur values and treatment temperatures.
- Suitable hard and software solutions facilitate secured documentation of the magnesium treatment.
- The composition of the wire can be optimally adapted depending on the operating metallurgical conditions.
- The introduction of the cored wire procedure for DI production also offers an opportunity to produce CGI with wire.

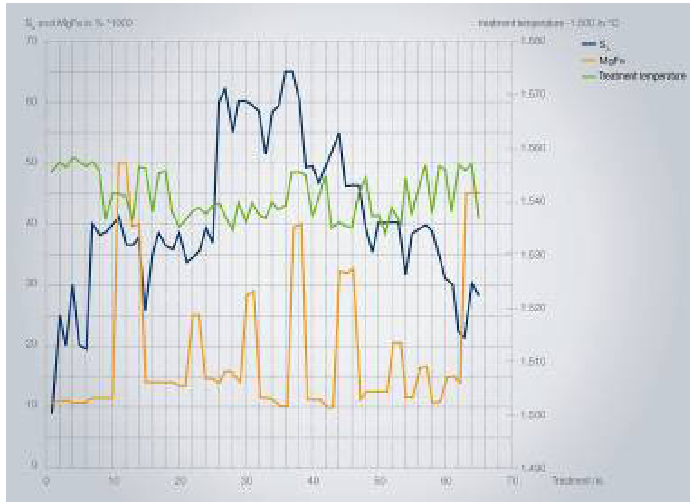

Figure 13: Result of treatment with changing initial conditions of SA and temperature

In addition to a general description, this is designed to give the users of this procedure an opportunity to evaluate their own sites. Furthermore, anyone interested in this procedure can obtain valuable evaluation criteria for choosing a procedure.

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