The storing of Mg treated liquid iron as a new process for the production of spheroidal and vermicular graphite castings

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Summary

The design and development of a new type of holding furnace for the storing of liquid iron for SG castings has produced a large number of advantages. An existing channel holding furnace was converted and, in so doing, it was necessary that it should be particularly well sealed in order to prevent the ingress of atmospheric oxygen. The article describes the individual conversion and sealing measures, the argon feed, the arrangement of the inductor and syphon as well as the refractory lining. Furthermore, there are detailed descriptions of the magnesium treatment, the holding practice and the production process. The article concludes by presenting a number of practical results and their corresponding advantages.

Both of the important groups of materials
- SG cast iron and
- vermicular graphite iron
are produced by the magnesium treatment of suitable base iron. In addition to magnesium there is a series of other elements, in particular the rare earth metals (cerium misch-metals) which can also be used for the treatment of the base iron. These materials change the form of the graphite in the microstructure, i.e. from lamellar via a worm-shape up to a spheroidal shape. This results in materials which on the one hand in their liquid state have favourable casting properties similar to those of grey iron but, on the other hand, on account of the compacted graphite, in their solidified state exhibit strength properties that are similar to those of steel.

A series of methods has been developed for the magnesium treatment of liquid iron. These range from the use of pure magnesium through Fe-Si-Mg alloys up to Ni-Mg alloy. Treatment with pure magnesium is undoubtedly the most economical method.

However, working with magnesium is unfortunately accompanied by problems which are brought about by the following properties:
- The melting point of pure magnesium is 657°C;
- It has a vaporization point of 1102°C;
- It has a high affinity to other elements.

The problem of the production of SG or vermicular graphite iron castings is associated with these basic physical and chemical characteristics, particularly when it is considered that for technical reasons the normal treatment temperatures are between 1400 and 1550°C. At these temperatures the magnesium is in its vaporized state and the treatment of iron at around 1500°C produces a vapour pressure of 10 bar.

One of the most unwelcome effects of the treatment of iron with pure magnesium or Mg alloys is the so-called fading effect which normally occurs within a period of 20 to 30 min after treatment. The magnesium has then either vaporized or oxidized, or has otherwise chemically combined.

In practice, this always leads to the magnesium treatment of the suitable base iron in charges only a short time before pouring, which is then quickly followed by pouring without sufficient opportunity of being able to check the success of the preceding treatment.

For these reasons there has for some time existed the desire to hold hot magnesium treated iron instead of hot base iron and thereby produce the following advantages:
- assured quality,
- defined pouring temperature,
- improved productivity and
- better flexibility.

Basic idea and constructional features of the holding furnace

The basic idea was to develop constructional features which would enable the economical conversion of conventional holding furnaces so that they could be used for the holding of magnesium treated iron. These features also to serve as a basis for the manufacture of new furnaces. In so doing, the capacity of the holding furnaces should correspond with that of the normal sizes for cast iron or base iron (around 20 to 110 t capacity).

Working with pouring furnaces for magnesium treated iron is already known from recent publications. However, apart from their low capacity, these furnaces are only limited suitable for holding purposes. Furthermore, a special storing furnace with a relatively small content of 17 t is also known. From the experience with these furnaces it was not possible to derive whether the principle of holding magnesium iron could be applied to other types of furnaces and, in particular, to large holding furnaces.
Before laying down the design for the conversion of an existing 30 t channel holding furnace (hearth type induction furnace built in 1969, useful content 22 t) tests were carried out on another furnace of this type. These tests showed that the sealing of the furnace is an essential prerequisite for the holding operation. Figure 1 shows the main features of the newly converted furnace for the holding of magnesium treated iron. It holds in the same position as the old furnace. Its capacity has been increased from 30 t to 45 t, with a useful capacity of 35 t.

Sealing of the furnace vessel. The measures carried out for sealing are as follows:
- Reinforcement of the vessel, primarily in the top rim region;
- Building up of the top rim into a U-shape for the housing of the seal;
- Caulk welding of the roof around the outer rim to a shape to fit into the seal;
- Construction of the roof and vessel in such a way that these can be bolted together as a press fit;
- Integration of the deslagging opening cover in the roof; the U-channel running around the deslagging cover houses the seal, into which a male projection running around the opening in the roof fits. This arrangement ensures that the seal is not damaged during deslagging;
- Integration of argon feed and discharge connections in the deslagging cover.

Introduction of inert gas. In order to exclude oxygen from the melt argon is introduced above the bath at a pressure of 5 to 30 mbar. Argon gas is supplied via a normal commercial pressure chamber evacuator. Figure 2 shows the circuit diagram for the argon feed and discharge. The argon flows from the tank into the furnace via a gate valve, pressure regulator and indicator, safety exhaust valve, gas meter and filter. In case of excess pressure the furnace can be relieved via a damper and emergency exhaust valve. Because slight excess pressure occurs during the filling of the furnace the operator can actuate the excess pressure valve via a foot switch located at the filling point.

Inductor. The inductor had to be newly arranged. It was possible to design it so that use could be made of the electrical equipment from the existing 30 t furnace. The essential alterations were as follows:
- Enlargement of the channel diameter to 200 mm;
- Maximum power input 300 kW;
- Increase in the inclination of the inductor in the holding position from 50° to 35° to the vertical;
- U-shape inductor channel;
- Water cooling of inductor furnace flange;
- Inductor side of furnace neck; particular attention was given to the arrangement of the inductor-furnace neck, i.e. the region where the inductor enters the furnace is provided with the widest possible angles in order to avoid slag accretions.

Syphon. For reasons of sealing and the prevention of the ingress of oxygen the common inlet and discharge syphon incorporates the following main features:
- Syphon channel at the lowest point in the furnace;
- 350 mm diameter syphon channel;
- Wide angle on the furnace inlet side of the syphon;
- Syphon equipped with flanges so that the furnace entry is easily accessible for repairs;
- Enlargement of the furnace from 30 to 45 t. This increase in capacity was incorporated in order to be able to store the complete requirement for liquid iron in one furnace instead of the previous two 30 t furnaces. Nevertheless, in increasing the capacity it was necessary to replace the existing tilting cylinder with a new telescopic cylinder in order to enable emptying.

Conversion costs. The conversion costs, without refractory lining, amounted to 150,000 DM. The new value of this furnace would be 1.5 million DM.

Refractory lining. After lining with dry corundum the converted holding furnace was first commissioned in May 1984. Dry corundum lining was firstly selected because this material has long proved to be advantageous in all holding and pouring furnaces. However, after only a few months it became apparent that the dry lining used was not suitable for the storing of magnesium treated liquid
iron. There was a considerable amount of flaking, which made the furnace unusable for this purpose and this finally led to taking it out of service in February 1985.

After cooling down it was seen that the dry corundum lining had become detached in the form of leaves. Refractory specialists were able to explain this phenomenon. Magnesium treated iron leads to the formation of spinels (MgO-A12O3) which grow within the hollow spaces in the lining and then produce a bursting force. Because the dry lining contains the impurity SiO2, with a certain composition, at around 1300°C it can form a low melting eutectic from the MgO-A12O3 and SiO2 phases. The combined effect of both these phenomena then leads to flaking.

After thorough consultation it was decided to reline with a sintered corundum base cast concrete. Sintered corundum or tabular alumina has a higher degree of purity than the previously used fused corundum. In May 1985 the furnace was relined with cast concrete and, after completion of the sintering process, was firstly put into service with untreated iron in June 1985. After a few days it was filled with treated iron and, after a period of stabilization, was used for the complete production of SG iron castings from the beginning of July. As with the initial lining of the furnace in 1984, the inductor was lined with a dry magnesite. A number of inspections during 1985, the last being on 4. 2. 1986, showed that the selected new cast concrete lining is successful. After approx. eight months of operation and the first deslagging no part of the furnace has shown any signs of either accretions or flaking.

Holding practice and metallurgy

The old practice was to melt the base iron during the night and to hold it in the holding furnace at a temperature of 1500 to 1550°C. The base iron was then magnesium treated in charges directly before casting. The new practice since July 1985 is to still melt during the night but then to use the immersion bulb process for the treatment of 3 to 4 ton charges with pure magnesium. These treated charges are then filled into the holding furnace and cast during the day. If required, treated melts can also be filled into the furnace during the day. In addition to the change in the magnesium treatment practice (only with pure Mg), the holding temperature has been predominantly reduced to 1400 to 1450°C.

Apart from the silicon content, the chemical composition of the treated iron corresponds with the desired nominal values of the final analysis. The silicon content is set at around 0.2 to 0.4% lower in order to enable inoculation with ferro-silicon before pouring. The following features of the holding practice are based on the experience gained up to now.

Magnesium treatment. Treatment with pure magnesium is the most suitable process, the reasons being:

a) As against a master alloy the use of pure magnesium results in greater flexibility and it is the most reliable way of achieving the nominal chemical contents of all elements in both the liquid iron and the casting.

b) It is the most economical process.

c) Because a reliable holding practice requires the use of partially magnesium treated melts the pure magnesium process is most suitable for this purpose; additional treatment can be necessary during the starting up of the furnace, after shutdowns, after weekends and holidays as well as after deslagging.

Start-up of a new or refined furnace. It is best to use untreated iron for the sintering process. This should be immediately followed by filling the furnace with magnesium treated iron. The stored iron should then be immediately used for production, namely, by adhering to the previously usual practice of magnesium treatment but with a continuous reduction of the amount of magnesium to match its content in the holding furnace. This practice can be maintained until the furnace has stabilized over a period of a few days or up to 14 days.

Method of working when the Mg content of the iron in the furnace is too low. If for any reason the magnesium content in the furnace should be too low, the following procedures can be adopted:

a) Intermediate treatment of the iron from the furnace with pure magnesium until such a time as its desired content is achieved.

b) Addition of around 0.1 to 0.3% of FeSiMg5 alloy into the pouring ladle. The silicon content in the furnace is then set lower in order to take account of the pickup from the master alloy.

Start-up of the holding furnace after shutdowns. If the furnace has to be shut down for repairs or deslagging at weekends or during holidays it is firstly necessary to ensure that it is sealed and that the inert gas supply is maintained. As with other holding furnaces, at the end of production the furnace goes out of operation with a liquid heel. Before the beginning of production it is started up again with additionally treated liquid iron (as already explained). This presents no problems even with longer breaks in production of around 14 days.

Possible methods of working. There are two possible methods of working:

a) Less favourable case: melting of iron overnight, treatment, storage and then casting during the day. The only problem here is the progressive drop in the magnesium content of the iron in the storing furnace. However, if for example the iron is correctly adjusted to 0.060% Mg at 06.00 hours, it can be poured for a period of 10 hours, in this case up to 16.00 hours.

b) More favourable case: melting of iron, treatment and storage in a continuous production process. In this case the magnesium content in the holding furnace can be constantly maintained.

Deslagging. The furnace slag consists of a dry, clod-like crumbly material which can be easily removed by a slag dredger. The selected deslagging opening in the furnace roof has proved to be advantageous for this purpose.

Production

The described furnace design and mode of operation have achieved the objective of being able to store magnesium treated iron for the production of SG castings and to pour it within the close tolerances on the chemical analysis, temperature and weight. In accordance with the experience gained up to now, castings are considerably easier to produce in about half the time previously required for the old treatment process and pouring practice.
Figure 3. Statistical distribution of the mechanical properties of SG cast iron before and after installation of the holding furnace: a) tensile strength; b) 0.2% yield strength; c) elongation

3. Because of the cleaning effect of the melt that takes place in the furnace there are no oxide or dross defects as are typical in SG iron castings. The cleaning effect stems from the fact that the melts can "quieten down" in the holding furnace. The different specific gravities of the impurities (MgO, MgS etc.) means that they have time to rise to the surface in the slag. The effect of the self-cleaning is best evident in the very low sulphur content of the iron in the holding furnace.

4. All SG iron castings are produced with iron out of one instead of the original two holding furnaces. This results in:
- Savings in energy, personnel and maintenance costs 507,000 DM/year
- Reduction of melting costs by dispensing with smaller furnaces 175,000 DM/year
- Dispensing with one caster 65,000 DM/year

5. Comparison of the mechanical properties achieved without and with the holding furnace shows that, in addition to higher ductility, castings produced from the stored iron predominantly have a smaller scatter range of the individual properties (Figure 3). However, in this case, ultimate optimization has not yet been achieved.

6. In the comparison between the magnesium contents in the casting (with and without stored iron), in the case of stored iron these are considerably lower, the average values being:
- without storing furnace; $X = 0.052\%$
- with storing furnace; $X = 0.042\%$
Iron with a lower magnesium content is less prone to defects. Perfect quality castings have already been produced with only 0.025% Mg (microstructure in Figure 4).

7. The combination of magnesium treatment with subsequent storage leads to a material cost saving of around 50 DM/t of liquid iron. With an annual production of 5000 t this amounts to a saving of 250,000 DM.

8. Figure 5 Shows the fading of magnesium in the holding furnace. At an argon pressure of 260 mmHg (0.026 bar) the fading rates for 45 t at a holding temperature of 1400°C are 0.0097 and 0.00088%/h and 0.0019%/h for 26 t at 1450°C.
9. The argon consumption in the furnace is around 300 l/h and is consequently very low. It should be mentioned that nitrogen can be used as the inert gas. However, nitrogen contains more impurities than argon. On account of the small difference in cost between argon and nitrogen for the amounts consumed in the foundry described, as well as the higher degree of impurity, the foundry has not up to now used nitrogen.

10. The magnesium content in the casting is an average of 0.006% lower than that in the liquid iron because, on leaving the holding furnace, the iron immediately reacts with the ambient oxygen. Consequently, the oxidizing loss commences immediately.

11. The first tests for the production of vermicular graphite cast iron proved to be successful. They showed that this material can also be readily produced from stored liquid iron.

12. The following potential savings have not yet been evaluated:
- Saving of energy costs on account of lower holding temperatures in the furnace;
- Reduction of scrap;
- Lower inspection costs;
- Use of more favourably priced charge materials;
- Accurate dosing of liquid iron per casting;
- Less residual iron;
- Savings in personnel because the process is simplified;
- Potential cost saving through longer life of the refractory lining because of lower holding temperatures.

Moreover, there are improvements with respect to emissions (fumes and dust) during the magnesium treatment process through the extraction of these pollutants. Only one size of ladle is required for the treatment of the iron and this naturally represents a considerable simplification of the treatment process.

The introduction of the combination of immersion treatment and storing furnace can dispense with the reinforcement of the craneway in the bay containing the holding furnaces.

13. One remaining disadvantage is the currently still necessary weekly repair to the lower bend point of the syphon. Moreover, it is necessary to achieve an additional reduction in the fading of the magnesium in the furnace. Recent experience seems to show that it is not sufficient that the furnace is only pressure sealed; it must also as far as possible be impervious to diffusion.

On the basis of these results the advantages of the use of this holding furnace can be summarized as follows:
- Assured uniformity of quality because the magnesium content of the iron is known prior to pouring;
- Assured supply of iron to the caster, both the amount and the quality; this reduces the interruption and waiting times and, with an interruption on the moulding plant, it is possible to return the iron to the holding furnace;
- Better utilization of the melting facility because of dispensation with waiting times before the discharge of iron;
- De-coupling of the melting operation, magnesium treatment and production operation;
- Reduction in the number of magnesium treatments (1 to 2 treatments/h);
- Only one vessel required for magnesium treatment.

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**Figure 5. Fading of magnesium content of stored tested liquid iron in relationship to the holding period:**
- a) 45 t held at 1400°C, Mg fading rate 0.0007%/h;
- b) 26 t held at 1450°C, Mg fading rate 0.0019%/h

- Non-problematic use of pure magnesium (most economical treatment method);
- Guaranteed casting temperature;
- Use of the most economical charge materials in the melting operation;
- Uniform and very low sulphur content;
- Lower initial temperature of the base iron; temperature adjustment in the holding furnace (energy saving);
- Lower holding temperature during shutdown (100 to 150 K) and consequently further energy saving;
- Potential improvement in lining life because of the lower holding temperatures;
- Lower scrap rates;
- Easier deslagging of pouring ladles (less slag formation) and lower ladle repair costs;
- Working with lower magnesium contents;
- Savings in personnel for the magnesium treatment, casting and holding operations;
- More accurate dosing of the liquid iron during puring;
- Low residual iron losses;
- Potential saving in capital investment costs because of better utilization of the melting-holding capacity;
- Reduction of inspection costs per charge;
- Cleaner working area through low emissions of dust and fumes because these are extracted during the immersion treatment process; only low dust emissions during tapping from the holding furnace.

**Outlook**

In accordance with the existing results the possibility of storing magnesium treatment liquid iron in a 45 t holding furnace does not appear to be dependent on the shape of...
the furnace. This means that holding is possible in all known and established shapes of furnace (hearth, spherical or cylindrical types). Further investigations should show whether furnaces with a smaller bath area (spherical or cylindrical shape) are indeed more favourable from the point of view of magnesium fading. It is not only possible to economically convert old holding furnaces in accordance with the described features but also to produce new furnaces incorporating these features. The storing of magnesium treated liquid iron also seems not to be dependent on the size of the furnace. The decisive factor is that the furnaces are pressure sealed and probably should also be impervious to diffusion.

If necessary, such furnaces can also be equipped with separate filling and discharge syphons but this requires the use of special closing mechanisms.

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