Clean melting for improved productivity and higher quality

Introduction
In recent years foundries have been faced with demands for increased productivity and quality whilst improving working conditions with no negative effects on the environment. At the same time a cost down programme has also had to be maintained. Little emphasis, until recently, has been placed on the influence that clean melting practices can have on the above issues. The use of specially developed fluxes for addition to the metallic charge in mains frequency furnaces, for the production of SG and Flake Graphite irons, as illustrated by the case studies in this paper, show how this can be achieved. The use of fluxes has also been extended to SG iron treatment and pouring ladles to achieve improvements in cleanliness, productivity, consistency and quality.

In order to meet the above requirements of reducing costs without prejudice to quality and conditions, the foundryman has to reconsider electric melting shop practices as follows: -

- ❑ charging with non shot-blasted returns,
- ❑ limiting decantation in the furnace before tapping,
- ❑ reducing super-heating to obtain lower tapping temperatures,
- ❑ optimising furnace lining life,
- ❑ controlling the frequency of lining and repair operations.

These changes have resulted in an increase in slag build up making furnace operation more difficult. Through the use of FERROGEN* 8, a specially developed fluxing agent which is added together with the metal charge, it has become possible to meet these requirements. The use of this fluxing agent has also been extended to SG iron treatment and pouring ladles.

Slag
Slag, which is predominantly a mixture of metal oxides floats on the top of the metal bath and has an important impact on the resulting melted iron. In the cupola, the metal makes it way through the slag, which acts as a filter collecting the impurities, before being collected in the well. Thus the slag contributes to the development of clean metal. The cupola operator therefore take a lot of care over the slag properties to ensure proper working of melting equipment and satisfactory iron quality.

The slag must be:

- ❑ compact and dense
- ❑ normally of dark/bottle green in colour
- ❑ viscous enough to ensure good slag extraction

This is normally controlled by the quantity of limestone added to the metal charge.

The procedure differs with electric melting in a coreless induction furnace. The melting point of the oxide generated is higher than the melting point of the iron. During melting, they are stirred by the power input and either mix homogeneously in the melt or adhere to the lining.

The melting point of the oxides can be lowered through flux addition to the metal charge. The fluidised oxides do not stick to the furnace wall and rise to the surface in the form of slag.

This procedure is the opposite of cupola practice where the iron makes its way through the slag.

Causes of Slag build-up
The stirring effect: (Figure 1)
Stirring is very important in induction melting furnaces because it ensures that the bath is homogenised during correction analysis. However, deposits of slag are generated in calm zones such as the upper part of the furnace and between the induction coils. These zones are “colder” as the lining is not heated through the induced current. Another stirring effect that should be highlighted is wear in the form of an "elephants foot" in the bottom of the furnace.

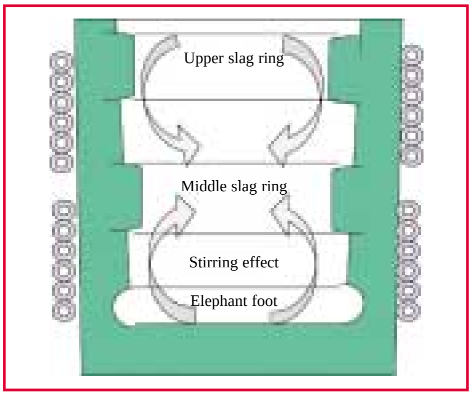

Figure 1: Stirring effect in a low frequency induction furnace

"Tap and charge" melting
The "tap and charge" melting process which is charging a liquid heel with solid material produces small explosions with oxidised metal discharges which adhere to the furnace walls.

Preheating and ladle discharge
Ladle preheating through furnace - ladle – furnace transfer, and excessively frequent discharge of bottom pouring or treatment ladles also produce minor oxidised metal discharges which adhere to the wall of the furnace (Figure 2) .

Figure 2: Typical spark emission of an oxidised melt during decanting from ladle into a furnace

Metal charge - cleanliness and composition
The slag quantity that needs to be removed from the furnace increases considerably through the introduction of non shot blast running systems and feeders (Figure 3) in proportions in excess of 60% of the metal charge weight, as well as through addition of steels with high aluminium contents or other highly oxidisable alloying elements.

Figure 3: Removal of castings through pressing before shot-blasting

Recarburisation
Recarburisation can exceed 2% of the metal charge when the amount of steel added to flake graphite irons exceeds 50%, or when the carbon content of SG based irons amounts to approx. 3.6 / 3.7%. In these cases, use of petroleum coke with an ash content of 2% or more constitutes an additional factor which contributes to slag build-up. In such cases, it is preferable to use a crystalline graphite carbon raiser.

Superheating and decantation
The practice of superheating by 30C° above the tapping temperature and subsequent decantation has all but died out due to pressure to reduce energy consumption and the drive to improve productivity through improved furnace capacity.

De-slagging
De-slagging is an operation to ensure quality metal for castings. It needs to be carried out with care to ensure both operator safety and metal quality.

The interrelated effects of all of these factors have an influence on ironmaking and a well-managed melting shop. This will be shown in the following two case studies.

Société Bretonne de Fonderie et Mécanique
Part of Teksid France Group
S.B.F.M. in Caudan near to Lorient specialises in the production of ductile iron castings for the automotive industry. The annual production is approximately 60,000 tonnes. Like many other foundries, this foundry was facing recurrent slag build-up with their mains frequency induction melting furnaces designed for a capacity of 25 tonnes of molten iron. The build-up phenomena had been steadily rising and increasingly impaired the productivity in the melting shop and, as a result, the moulding lines that were supplied with ductile iron.

Equipment, process

- 4 50 Hz mains frequency induction furnaces with a crucible capacity of 25 tonnes
- power. 5000 up to 7000 kW
- crucible diameter – new 1380 mm – at the end of the campaign 1500 mm
- production/hour, between 6 and 9 tonnes per furnace depending on the power input
- melting time, 40 minutes for 6 tonnes
- tapping temperature: 1510°C
- required amount of metal, on average 24 tonnes per hour for the Spomatic moulding plant
- "tap and charge" of 6 tonnes, i.e. a molten heel of 19 tonnes

❑ metal charge, 3 tonnes consisting of:

- ❑ 60 % returns, non cleaned runners and feeders
- ❑ 25 % steel
- ❑ 15 % pig iron

Consequences of slag build-up

❑ reduced furnace diameter and capacity

❑ lengthened melting time (+10 to 20 minutes) due to build up on the lining

❑ increased waiting time at the moulding plant

❑ analysis difficulties

❑ unstable metallurgical properties

❑ lining wear is more difficult to detect

❑ bath skimming operation becomes more difficult as mechanical devices can not be used

❑ lining repair intervals of 4 weeks or approx. after 2000 tonnes of molten metal:

❑ in the event of excessive furnace build-up, a pre-operation of chipping is inevitable (Figure 4) which can be time consuming.

❑ under standard conditions, that is to say with a clean lining, extraction uses a jack at the base of the furnace operating at a maximum pressure of between 120 and 300 bar. 30 minutes are needed for this operation (Figure 5).

Figure 4: Lining extraction using a pneumatic pick

Figure 5: Lining extraction using a jack actuated with a maximum pressure between 120 and 300bar

Repairs

❑ Standard repairs that need to be carried out on the upper part of the furnace are much more difficult if not impossible on a heavily slagged lining compared to a clean lining.

Weekly servicing is therefore very important as it allows regular checking of the "vulnerable" areas such as the passage or connection between the lip and crucible, which is a real Achilles' heel in the furnace, and where undetected iron infiltration can cause serious problems (Figure 6, 6a).

Figure 6 *Figure 6a*

Weekly servicing, ring adjustments easier on a clean lining. The connection between the lip and crucible is easier to check.

Actions Taken

Chemical slag analysis revealed a silica presence of nearly 80% coming mostly from the sand adhering to returned runners and feeders.

SiO_2 : 77,5 %, Al_2O_3 : 6,5 %, MgO : 5.25 %, CaO : 2 %, BaO : 2.25 %.

Other oxides: Zr, Mn, Ti, Ce, La.

Initial recommendations such as shot-blasting feeders and limiting the ratio of runners using ceramic foam filters added to the metal charge were not possible for economic reasons. Therefore, the most effective and efficient approach was to prevent slag from building up on the wall of the furnace . This could be facilitated through a reduction in the melting point of the slag. In addition. it was necessary to determine the appropriate slag consistency which would allow mechanical means for its extraction

This was the start for a test programme adding the fluxing agent FERROGEN 8 to a furnace during a four week campaign. The FERROGEN 8 additions varied between 0.066 and 0.017% (Table 1).

REFERENCE TEST	CHARGED TONS	ADDITION IN % OF FERROGEN 8	ASPECT OF THE LINING	SLAG CONSISTENCY
1	300	0.066	clean, smooth	liquid
2	480	0.033	clean, smooth	fluid
3	1170	0.017	clean, smooth	viscous

Table 1: Test running on one furnace over four weeks to assess the optimum addition rate of Ferrogen 8 to give a clean lining and make the slag viscous enough to facilitate extraction.

The sequence of photographs shows the various melting operations:

Molten heel of 19 tonnes covered with the first 3 tonnes metal charge, Figures 7,8

Figure 9, the additions : graphite, silicon carbide, FERROGEN 8, (2 bags of 500 g each), calculated for a 6 tonne metal charge, ready for addition, Figure 10

Figure 11, the additions floating on the surface are covered by the second 3 tonne charge like a sandwich, Figure 12

Figure 13, at the end of melting the operator dusts the bath with raw perlite for slag agglomeration; the slag floats to the surface and thickens, Figure 14

Figure 15, the operator uses a poker to force the slag to stand proud of the crucible lining prior to its extraction , and is working without any particular protection. Apart from glasses, he needs no gloves, hood or other heat protection equipment

Figure 16, the slag is removed mechanically

Figure 17, the consistency of the slag facilitates its removal from the furnace in a single operation

Figure 18, the furnace is waiting for a second tapping of 3 tonnes. Note the cleanliness of the lining and the melt

Figure 19, 19a, at the end of a four week campaign and over 2000 t of molten metal, the lining is in perfect condition without any adherence of slag and shows only a slight elephant foot formation at the bottom of the furnace. In this particular case the average diameter is 1485 mm and suggests that increased lining life is achievable once the melting shop runs a furnace campaign longer than 4 weeks.

Figure 7: Bath level 19 tonnes

Figure 8: Metal charge 3 tonnes

Figure 9: Additions : Graphite, SiC, Ferrogen 8 for a metal charge of 6 tonnes

Figure 10: Additions added between two metal charges of 3 tonnes

Figure 11: Sandwich additions between two metal charges

Figure 12: 2nd metal charge

Figure 13: Raw perlite dusting for slag agglomeration

Figure 14: Slag film floating on the top of the bath after a few minutes of decantation

Figure 15: Slag removal from the furnace wall

Figure 16: Mechanical slag extraction

Figure 17: The consistency and compactness of the slag facilitate its removal

Figure 18: Furnace level of 22 tonnes ready for a second tapping. note the cleanliness of the bath and the lining

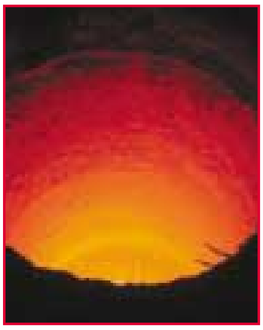

Figure 19 *Figure 19a*

View of an empty crucible after a 4 week campaign and over 2000 tonnes of molten metal. Average diameter 1485 mm, depth 2780 mm. The wall is smooth and only shows a slight elephant foot formation at the bottom of the furnace.

Foundry Leroy Somer

The foundry in Rabion close to Angoulème specialises in the production of mechanical components in flake graphite iron. The average yearly production is 20,000 tonnes. Iron is produced in mains frequency induction furnaces.

Equipment, process

- ❑ 3 induction furnaces, mains frequency 4000 kW with a capacity of 16 tonnes each
- ❑ 5 induction furnaces, mains frequency 1800 kW with a capacity of 8 tonnes each
- ❑ Most melting is done in the 16 tonne furnaces
- ❑ "Tap and charge" of 2 tonnes
- ❑ metal charge of 2 tonnes
    - ❑ 30% of in-house, non shot-blasted returns
    - ❑ 15% of in-house, shot-blast returns
    - ❑ 52% lacquered steel, Al up to 0.5 % and Si 1.5 %
- ❑ Tapping temperature: 1480°C.

Difficulties faced

Since 1994, the foundry has been using pressing scrap from their electric motor manufacturing shop. The steel scrap is lacquered and has a high content of aluminium and silicon. With an addition rate of up to 52% of the metal charge, considerable slag build-up is common, in particular around the middle of the crucible.

Slag analysis revealed a different composition to that met in the preceding example:

80 % Al_2O_3, 8 % Fe_2O_3, 7 % SiO_2, 4 % CaO.

From 1994 onwards, lining life of the 16 tonne furnaces decreased continuously reducing the tap charge from 2200 tonnes to 1000 tonnes. In July 1999, tests started with FERROGEN 8 with notable results. Regular use of this agent started in July 2000 with a 0.075% addition in relation to the metal charge. This is four times higher than the ratio used at S.B.F.M as the slag has a content of 80% alumina and the tapping temperature is 1480°C.

Figure 20 shows clearly that the life curve of the furnace lining is increasing.

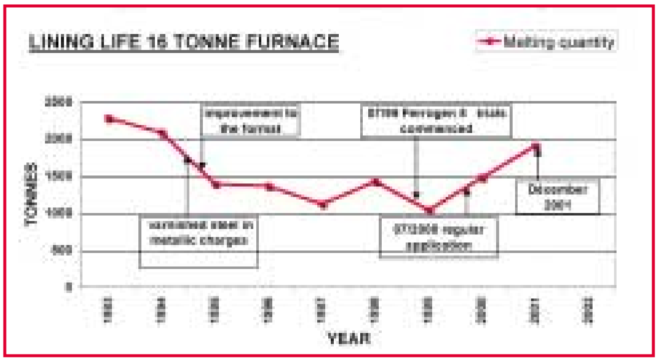

Figure 20: Impact of metal charge and FERROGEN 8 on furnace lining life

Furnace lining life

The 16 tonne furnace graph shows an ascending slope after the introduction of FERROGEN 8. Leroy Somer is now approaching the quantities melted in 1993, that is to say 2200 tonnes per campaign.

Treatment and pouring ladles:

A similar build-up problem was seen in treatment and pouring ladles for which the addition of FERROGEN 8 was also beneficial.

For SG iron treatment using the sandwich, tundish cover or cored wire process, a regular addition of 50 – 100 g of FERROGEN 8 per tonne of treated melt is considered sufficient. The ladle lining remains in good condition and ensures a more uniform magnesium yield.

GF converter

The reaction chamber where the pure magnesium is deposited for melt treatment constitutes the heart of the converter. The mouth between the chamber and the shaft of the converter must maintain its rated diameter. Clogging would otherwise extend the reaction time and consequently impair the magnesium yield. Therefore the reaction chamber is cleaned after each treatment and the mouth is drilled before adding pure magnesium and10 g of FERROGEN 8 per tonne of treated iron for the next treatment, (Figure 21).

Figure 21: The operator adds pure Mg and 10g of FERROGEN 8 per tonne of treated iron.

Conclusions

To achieve the objectives of cost reduction, improved casting quality, improvement in working conditions and environmental compatibility, it was necessary to resolve the slag build-up and slagging problems inherent in electric melting equipment as well as the pouring and treatment ladles.

Addition of a fluxing agent which modified the physical properties of the complex mixture of oxides, in particular their melting point and viscosity compared to the liquid metal, made it possible to meet the above objectives.

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