Selection of Mould Fluxes for Production of High Quality Steel Ingots

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Introduction

Ingot products account for 8.3% of the total crude steel produced in the world. It is produced either by top pouring or bottom pouring of the liquid in the moulds. The increasing demand for quality steels led to the evolution of bottom pouring technology for casting of steel ingots. This process constitutes of a set up involving pouring sprue and runner system to deliver liquid steel into the bottom of one or more cast iron moulds as shown in Fig.1.

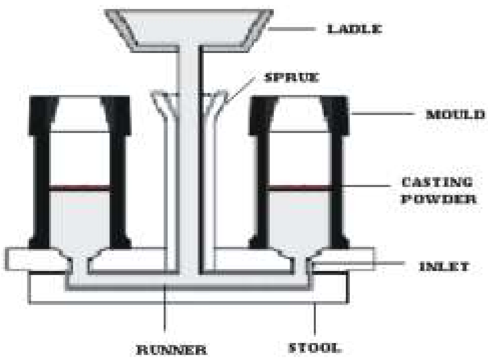

FIG.1. SCHEMATIC OF BOTTOM POURING PROCESS

The application of this bottom pouring technology for production of quality ingots has been mainly due to the reduced turbulence of steel in the mould caused by controlled flow of liquid steel in the mould to result in quiet meniscus leading to superior as cast ingot surface, minimal splashing of liquid metal droplets from ladle stream providing freedom from scab type defects, application of slower teeming rates that reduce turbulence, longitudinal cracks formation & minimize laps and ripple marks and finally, improved mould life.

The application of fluxes for bottom pouring has been a common practice for a long time. These are added to the top of the rising steel meniscus during teeming for completely covering the meniscus and maintaining a powder layer through out the casting process that helped in drastically reducing or even eliminating defects such as laps, ripple marks, entrapment of oxides, surface cracks and pinhole porosity of the ingots. Ever increasing demand for quality steel products accelerated the continuous development of bottom pouring fluxes.

Use & Behaviour of Flux during Teeming

In the bottom pouring practice, pre-weighed flux packets are suspended about 300 mm above the bottom of the mould before the start of the teeming. When the liquid steel enters the mould, the bag burns and the powder gently spread over the surface of meniscus avoiding turbulence as shown in Fig.2 (Ref.1). This procedure is also termed as “central hanging” of the flux and is being practiced regularly at Alloy Steels Plant, Durgapur.

Full bags of flux should not be added once teeming has commenced if not, splashing takes place deteriorating the surface quality of the ingot produced. For maintaining full cover of the

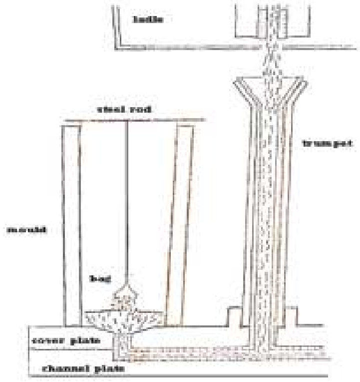

FIG.2. SCHEMATIC OF SUSPENDED FLUX ADDITION IN BOTTOM POURING

meniscus, a bag of flux may be slightly slide down into the mould or sprinkling of the powder from fresh opened bag may be taken up. How ever, the best option would be hang the required quantity of flux before teeming and the amount of application is about 1 to 2 kg/ton of liquid steel accommodated by the mould. When a bag of flux is dropped into the mould before teeming, the incoming steel ruptures the bag and the powder gets distributed over the surface of the steel. However, the steel can engulf the powder entrapping it to produce a defect at the bottom end of the ingot as shown in Fig.3 (Ref.1).

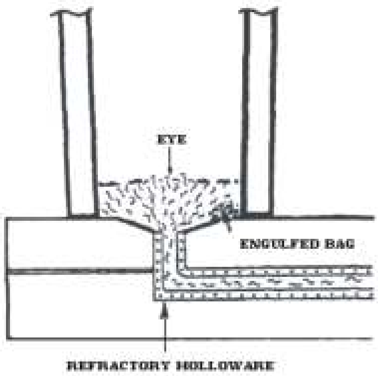

FIG.3. FLUX ENTRAPMENT WHEN ADDED TO MOULD BOTTOM IN THE BAG

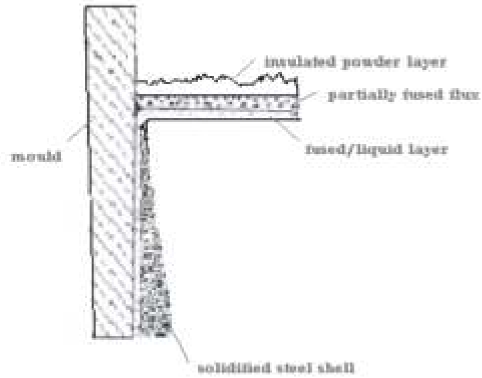

FIG.4 SCHEMATIC OF FLUX BEHAVIOUR DURING BOTTOM POURING

The behavior of the flux during teeming is shown in Fig.4. When the liquid steel enters the mould, the powder in contact receives maximum heat from the meniscus and produces a fused or molten layer. This liquid/fused layer that infiltrates in the gap between the mould and the solidifying steel shell gets coated in the form of thin film on the mould wall smoothening the minor surface imperfections on the inner mould surface improving the cast ingot surface quality, controls & homogenizes the hat transfer rate from the solidifying ingot to the atmosphere through the mould wall and remains as a parting non-metallic film between the ingot & mould wall facilitating easy strip. Above the liquid layer, there is a partially fused layer where the individual particles in the powder have melted & started to coalesce, forming a network of beads of slag as the frame work of porous, fritted structure that involves in absorption & dissolution of non-metallics like oxide scum, de-oxidation product & refractory erosion material. The top layer receives hardly any heat and remains as un-reacted powder till the mould is filled giving protection against re-oxidation and minimizing heat losses from the meniscus to the atmosphere thus providing adequate thermal insulation.

Functions of Bottom Pouring Flux

The functions of the mould flux in bottom pouring are (a) Protection from the atmosphere, (b) Thermal insulation of the meniscus (c) Absorption of the non-metallics and (d) Lubrication & heat transfer.

(a) Protection from the Atmosphere

The prevention of re-oxidation is necessary to avoid the entrapment of scale and other oxides in the solidifying shell. This protection can be taken care by use of any flux that completely covers the meniscus and melts to form a fused slag layer. The liquid slag cover must wet the steel surface and be of a single phase, continuous and capable to withstand strong convection currents. A fusion temperature of the flux 200°C - 300°C or greater below the teeming temperature is desired to ensure the rapid generation of the slag cover (Ref.2). The iron oxide content of the flux should be less as the presence of this oxide promotes oxygen diffusion and hence, iron oxide contents less than 5% is preferred. Also, carbon present in the flux avoids re-oxidation by forming carbon monoxide and thus creates reducing conditions.

As the flux is applied once at the beginning of the teeming, complete coverage of the meniscus needs to be achieved without operator involvement. For ingot sizes of 750 mm & below, complete coverage is generally not a problem. In large moulds, multiple hanging of the flux with improved flowability is necessary to obtain good coverage. The flowability of the flux can be improved by using granular and low bulk density powders.

(b) Thermal Insulation of the Meniscus

Good insulation is necessary to reduce heat loss near the mould wall to prevent formation of laps and ripple marks along the ingot surface. As the teeming proceeds and the powder fuses, the sintered mass break into islands exposing the fused slag. Heavy sintering mass prevents the remaining powder from spreading and covering gaps in the powder layer especially when teeming big end up moulds. Excellent resistance to sintering is ensured through application of mould fluxes with C of about 20% and use of graphite as carbonaceous ingredient facilitates effective insulation (Ref. 2). Along with the above, controlled fusion rate, low bulk density and good flowability of the flux ensure the maintenance of a thick insulating powder layer facilitating good thermal insulation.

(c) Absorption of Non-Metallics

The flux must be capable to assimilate any non-metallic material preventing its entrapment along the ingot surface. Generally, the non-metallics include refractory material, entrained slag and de-oxidation products. The rate at which the non-metallics are dissolved by the flux is dependant on the chemistry and viscosity. Absorption of non-metallics improve with increased basicity, decreased Al_2O_3 in slag and lower viscosity improves the kinetics of inclusion capture & dissolution. High dissolution rates are obtained using low viscosity powders with high basicity (%CaO/%SiO_2), low silica, low alumina and increased contents of fluxing agents such as Na_2O and CaF_2. Low basicity of SiO_2-Al_2O_3 based fluxes produce satisfactory ingots with carbon steel grades where as the higher basicity SiO_2-CaO based synthetic fluxes are more effective with high alloy and stainless steels (Ref. 3). Also, the chances of non-metallic capture can be improved through reduced teeming rate and application of flared in-gate geometry caused by lowered velocity of the liquid steel entering the mould (Ref. 4).

(d) Lubrication & Heat Transfer

Lubrication is necessary for isolation of the ingot from the mould and is achieved using the correct slag viscosity. To assure maintaining a complete slag cover in the meniscus region, the slag must shear at the correct rate for the specific teeming situation with infiltration of fused powder between the mould and the ingot (Ref. 5). It is a known fact that the viscosity is largely determined by the chemical composition that is complimentary to the teeming conditions. As a generalization, lower viscosity fluxes are required for higher alloy & stainless steels and for low temperatures with/without higher teeming speeds. Higher viscosity fluxes are suitable for higher teeming temperatures of carbon & low alloy steels. Also, reduced crystallization temperature of the flux improves lubrication.

For ensuring uniform heat transfer from the ingot to the mould at all points of the ingot surface, an even slag thickness is required around the ingot periphery that could avoid localized hot spots if not these hot spots result in ingot cracking (Ref. 5). Lower solidification temperature of the flux results in increased mould heat transfer. However, the control of heat transfer is usually not a big problem as the chilling effect of the cast iron is not very severe.

Types of Mould Flux

The development of mould fluxes to improve overall ingot surface quality was based on the necessity to eliminate entrapment of ingot scum at the meniscus by forming slag on the top of the liquid steel as the steel rises up the mould. These fluxes are SiO_2-CaO-Al_2O_3 based materials with fluxing agents (alkali oxides and fluorides) to control the fusion rate and viscosity. Elemental carbon in various forms and particle sizzling is added to control the fusion rate and improve the insulation capacity of the flux.

(A) Classification Based

The bottom pouring fluxes are broadly classified into Raw Mixed Fluxes, Prefitted Fluxes, Prefused Fluxes, Granular Fluxes and Preformed Flux Boards (Ref.6).

1. Raw Mixed Fluxes

These fluxes are produced by intimate physical mixing of variety of raw materials selected on the basis of their chemical composition, particle size, melting characteristics, density etc. Although a uniform mix can be obtained, these fluxes being finer in size suffer from higher surface area per unit mass and hence are prone to moisture pick up.

(a) Fly Ash Based Fluxes

These powder mixes rely on coal fired power station by-products with added flux modifying ingredients. These are thermal insulating with good flow ability and are normally lower cost products. These fluxes suffer from inconsistent chemical composition, high viscosity and low basicity.

(b) Synthetic Fluxes

These fluxes are a mixture of chemically consistent oxides containing no byproduct raw materials. Usually, these powders possess low viscosity, high basicity and high inclusion absorption capacity. The powders are costly and suffer from less flowability.

(c) Semi-synthetic Fluxes

These powders are a mixture of fly ash and synthetic raw materials

2. Prefitted Fluxes

These powders are made through conversion of the raw material mixes into green lumps by addition of aqueous solution of binders followed by heating these lumps in the furnace to sintered state and grinding them to desired grain size. After this, carbon is added. These fluxes have homogeneous composition with a defined melting range.

3. Prefused Fluxes

These powders are manufactured by initially converting the raw mixed powders into green lumps followed by melting and quenching in water. Then, the quenched powder is dried and ground after which carbon is mixed. These fluxes also known as premelted variety offer great homogeneity in chemical composition and melting rates with a well defined melting range. However, these are costliest variety of fluxes due to increased amounts of energy required in their manufacture.

4. Granular Fluxes

These fluxes are produced by converting the raw mixed powders into an aqueous slurry followed by addition of requisite water soluble binders and drying the so formed fine droplets in a stream of hot air. The product is in the form of solid or hollow spheres of close granule sieve distribution. The fluxes of this variety are known for better covering power due to reduced density, excellent spreadability & flowability due to the spherical shape, low moisture pick up due to the reduced surface area of the granules and less dust generation.

5. Preformed Board Fluxes

Preformed board products are based on the any flux mixture types with the added benefits of reducing dust and ingot bottom surface defects while ensuring uniform product application. However, non-uniform rate of disintegration of the boards, moisture pick up by the boards, breakage of the boards during transportation & handling, difficulty in correctly positioning o the boards in the mould and the problems in venting the gases generated are the major demerits of the flux boards.

(B) Categorization Based

The bottom pouring fluxes can be broadly categorized into Insulating Fluxes & Absorbing Fluxes (Ref.2).

1. Insulating Fluxes

These fluxes are SiO_2-Al_2O_3 based with low basicity, high carbon contents and low level of alkali oxides conferring high viscosity and low fusion rates. They form a thin layer of fused layer on the meniscus to protect the steel from contact with the atmosphere. This fused/liquid layer provides some capability for non-metallic absorption that reaches the steel/powder interface. The remaining of the unfused layer provides thermal insulation of the meniscus. The combination of small fused layer with thick insulating layer when using these fluxes reduce the heat loss from the meniscus in vertical direction, minimizing solidification on the curved part of the steel meniscus which reduces the severity of ripple marks along the ingot surface.

2. Absorbing Fluxes

These fluxes are SiO_2-CaO based with high basicity, moderate carbon contents, low Al_2O_3 and increased alkali oxide content conferring low viscosity and medium fusion rates. They form a significant fused layer than can absorb large quantities of non-metallic inclusions. The fused layer infiltrates between the mould and the ingot forming a coating on the surface. As the ingot cools and shrinks away from the mould, large voids are formed in the infiltrated slag layer. Hence, high application rates are necessary for providing the fused layer through the entire teeming process.

Along with the above, fluxes are designed with combination of insulating and absorbing properties to meet the specific steel

ITEM	FLUX A	FLUX B	FLUX C
Loss on Ignition	22 – 24	24 – 26	28 – 30
SiO_2 %	37 – 39	35 – 39	36 – 42
Al_2O_3 %	16 – 18	14 – 16	16 – 20
CaO %	10 – 12	12 – 14	12 – 15
Na_2O %	0.8 – 1	2 – 3	-
F %	0.6 – 0.8	4 – 6	-
Fixed C %	10 – 12	12 – 14	16 – 20
MgO %	-	2 - 4	1 - 2
Fe_2O_3 %	1 – 3	2 – 3	2 – 4
Basicity	0.2 – 0.3	0.3 – 0.4	0.3 – 0.4
Softening Point °C	1160 – 1180	1150 – 1170	1180 – 1210
Melting Point °C	1220 – 1240	1200 – 1210	1250 – 1270
Fluidity Point °C	1270 – 1300	Not done	Not done
Viscosity (Pa.S) 1300°C	5.1	3.6	9.6
Flux Performance	Covering good, moderate flame & spreading satisfactory	Eye formation at the center of the mould, high flame & non-uniform spreading	Flame high, covering unsatisfactory & spreading improper
Quality of Ingots	Surface quality satisfactory	Ripple marks, lapping in ingots	Surface rough & flux entrapment in billets observed

Table 1. Performance Of Various Fluxes During Low Carbon & Low Alloy Steel Teeming

ITEM	FLUX D	FLUX E	FLUX F	FLUX G
Loss On Ignition	25 – 30	22 – 24	24 – 26	28 – 30
SiO2 %	20 – 26	35 – 40	37 – 42	25 – 30
Al2O3 %	12 – 15	15 – 18	12 – 14	13 – 15
CaO %	24 – 28	14 – 18	6 – 9	10 – 12
Na2O %	3.5 – 5	4 - 5	8 - 10	8 - 10
F %	5 – 6	-	-	-
Fixed C %	18 – 20	14 – 16	15 – 17	18 – 20
MgO %	2 - 3	2 - 5	1 - 3	1 - 3
Fe2O3 %	1 – 3	1 – 3	2 – 3	2 – 4
Basicity	0.9 – 1.2	0.6 – 0.8	0.3 – 0.4	0.3 – 0.4
Softening Point °C	1150 – 1170	1170 – 1190	1160 – 1180	1180 – 1200
Melting Point °C	1190 – 1200	1230 – 1260	1220 – 1240	1240 – 1260
Fluidity Point °C	1210 – 1220	1300 - 1320	1270 - 1300	1300 - 1330
Viscosity (Pa.S) 1300°C	1.3	2.7	3.5	4.3
Flux Performance	Covering good, moderate flame & spreading satisfactory	Improper covering leading to expose of metal, low flame & non-uniform spreadability	Eye formation at the center of the mould, flame moderate & spreading found non-uniform	Flame high, covering satisfactory & spreading improper
Quality of Ingots	Surface quality satisfactory	Surface rough & flux entrapment in blooms observed	Surface with patches of slag along the bottom, flux entrapment in rolled products observed	Surface rough, flux entrapment in blooms & billets observed

Table 2. Performance Of Various Fluxes During High Carbon Steel Teeming

requirements.

Selection of Flux for Various Steel Grades

The main criterion in flux selection is the steel grade to be teemed as the main teeming parameters such as the temperature and rate of rise are determined largely by the solidification characteristics of the steel grade. In low to medium carbon and low alloy steels, thermal insulation is much important to prevent surface oxidation at low application rates and inclusion absorption is of less importance. Inclusion absorption capability is the primary consideration for the flux used for high alloy and stainless steels.

• Flux for Low Carbon & Low Alloy Steel Grades

For these steel grades, high teeming temperature and low teeming speed are applied because of similar structure of both primary crystals and their melts for improved surface quality. Here, teeming temperature with a superheat of 55°C - 60°C and teeming rate of around 300 mm /min. are rationally adopted.

The flux for this type of steel grade should be insulating with slightly absorbing variety. The composition of the powder need to be designed with high carbon, high viscosity & low basicity for thermal insulation in combination with minor addition of alkali oxides for the melting point reduction & absorption of the inclusions. In line with the above, various fluxes A, B & C were tried at A.S.P., Durgapur for assessing the flux performance and surface quality of the ingots and the details are shown in Table1. Out of these fluxes, Flux A was found to be effective with minimized rippling & lapping of ingots noticed (Ref.6). The amount of the flux addition was optimized to 2 kg/ton of liquid steel poured in the mould.

• Flux for High Carbon Steels

In high carbon steels, metallic crystals having an austenitic or ferritic structure are primarily separated along the liquidus during cooling and solidification. At the same time, in the remaining melt, Fe_3C or $(Fe,M)_3C$ structure i.e. the co-ordinate prism or octahedral of CM_6 with rather covalent bond character is more and more enriched. With such a distinct structure difference between the primary crystals and the remaining melts, low temperature & high speed teeming are necessarily applied to prevent severe segregation and subsequent formation of cracks. In these steels, teeming temperature with a superheat of 40°C - 45°C and teeming rate of around 300 mm /min. are generally applied.

The flux for these steels should be both insulating and absorbing variety. The composition of the powder should be designed with high carbon for improved thermal insulation and high basicity coupled with low viscosity (as attained through use of fluorides & alkali oxides) for increased inclusion absorption capacity. Considering the above, various fluxes D, E, F & G were tried at A.S.P., Durgapur for assessing the flux performance with details mentioned in Table 2. Out of them, Flux D was observed to meet the requirements and this flux was found suitable for steels having carbon exceeding 0.68% coupled with chromium contents below 2.5% (Ref.6). The amount of the flux addition is about 2 kg/ton of liquid steel poured in the mould.

• Flux for Stainless Steels

Because of severer surface concentration of Cr-O bonds in stainless steels, high teeming rates are applied. Also, high temperature teeming is preferred in these grades for inclusion floatation. In these steels, teeming temperature with a superheat of 60°C - 70°C and teeming rate of around 400 mm /min. are generally adopted. The flux used should be of highly absorbing type and should be designed with low carbon for avoiding carbon pick up, medium basicity, low Al_2O_3 along with increased levels of alkali oxides & fluoride for reduced viscosity and improved inclusion absorption capacity. Based on the requirements, various fluxes Y & Z were tried at A.S.P., Durgapur for the flux performance assessment as detailed in Table 3. Out of them, Flux Z was found to meet the requirements for use in stainless steel, steel grades with chromium content of 2.5% or more and 1% aluminium bearing steels (Ref.6). The amount of the flux added is about 2 kg/ton of liquid steel poured in the mould.

ITEM	FLUX Y	FLUX Z
Loss On Ignition	16 – 18	14 – 16
SiO_2 %	20 – 24	44 – 46
Al_2O_3 %	12 – 15	6 – 8
CaO %	24 – 28	18 – 20
Na_2O %	7 - 8	5 – 6
F %	-	2 – 4
Fixed C %	4 - 6	2 – 4
MgO %	2 - 3	-
Fe_2O_3 %	1 – 3	1 – 3
Basicity	0.8 – 1.10	0.45 – 0.5
Softening Point °C	1150 – 1170	1120 – 1140
Melting Point °C	1190 – 1200	1165 – 1185
Fluidity Point °C	1210 – 1220	1200 - 1220
Viscosity (Pa.S) 1300°C	1.3	0.9
Flux Performance satisfactory	Covering improper, moderate flame & spreading	Covering found & spreadability observed
Quality of Ingots	unsatisfactory Inclusions detected in billets & blooms	uniform Surface & internal quality of the blooms & billets satisfactory

Table 3 : Performance of Various Fluxes during Stainless Steel Teeming

Conclusions

The success of bottom pouring technology can be attributed to a large extent for the use of fluxes that are designed to prevent re-oxidation, provide insulation, absorbing non-metallic oxides coupled with lubrication and uniform heat transfer. The right choice of the flux and its application based on the specific steel grade and the teeming conditions can result in production of excellent quality of bottom poured ingots.

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