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Slag Practice Improvement of the Converter Melting Using Iron-Ore Pellets

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Abstract—When steel smelted in a basic oxygen converter at an increased specific hot iron consumption rate of 950 kg/t and over, the slag formation process proceeds with deviations from the specified oxygen-lancing conditions under viscous slag formation during the converter turndown. Solutions are proposed to normalize the slag formation including dissolution of lime. This allows stabilizing of the slagging and lancing conditions, as well as preventing long downtimes of the equipment.

Keywords: converter, hot iron consumption rate, lime, iron-ore pellets, converter slag

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The steel-making in a basic oxygen converter at an increased specific hot iron consumption rate of 950 kg/t and over involves the heat balance upset of the converter-melted heat for the compensation in which extra cooling agents have to be consumed. Fluxes such as lime, limestone, or raw dolomite are used as such coolers [1]. Under increased specific consumption of hot metal, difficulties in converter operation arose primarily in terms of the slag conditions. During the oxygen-lancing of the converter heat, unsatisfactory slag formation and leakage of the slag–metal emulsion out of the converter were observed, which led to sculling of lances, fume-collecting hood components, and off-gas flue. Upon turning the converter down, viscous nonfree-running slags were formed, which resulted in an increase in the rejection of metal tapping samples due to the presence of slag inclusions and the necessity of performing the final blow with oxygen to fluidify the slag. The additional final blow operations and repeated turndown of the converter lengthened the total converter operation cycle, which decreased the output of the converter plant. On the other hand, additional final blows have an adverse effect on the resistance of refractory material of the converter lining.

To analyze the existing situation, it was necessary to preliminarily consider the slag formation process that consists of several basic stages:

(i) the first stage of heating loose lump materials;

(ii) the second stage of the formation of first low-melting FeO- and SiO_2-based slags;

(iii) the third stage of the oxidation and slagging of impurities in the metal charge such as Si, Mn, and P;

(iv) the fourth stage of the dissolution of refractory slag-forming materials in the first slags, such as CaO and MgO;

and

(v) the fifth stage of the slag approaching its saturation with basic oxides.

Upon application of the scull and blast-furnace slag that enters the converter with hot iron and, to a lesser extent, the lining disintegration products and the oxidation products of the impurities in hot iron formed during the charging of the latter, the first slag is formed predominantly from the slag residue of the previous heat solidified on the converter lining surface immediately after hot iron has been poured into the converter. The quantity and composition of this slag is difficult to predict.

During melting, the composition of the slag is changed and its weight is increased as a result of impurity oxidation in hot iron such as Si, Mn, and P, and the dissolution of lime and other materials. The predominant process is the dissolution of lime. As is well known, as the melting proceeds, lime is intensively dissolved. At the very beginning of assimilating lime by the slag, a slag crust freezes on a lump of lime (Fig. 1).

If the silica concentration in the first slag is high, which is characteristic of heats with an increased hot iron consumption rates and/or characteristic of the retreatment of hot iron at an increased silicon content, a dense shell of calcium orthosilicate ($2CaO{\cdot}SiO_2$) with a melting point of 2130°C is formed on the surface of the lime lumps. This retards the lime dissolution process to a considerable extent. In Table 1, the solid-to-liquid-phase transition temperatures of some

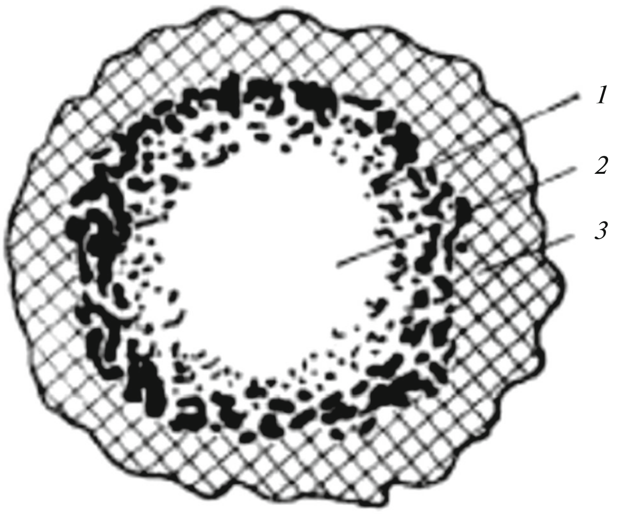

Fig. 1. Structure of a lime lump at the initial dissolution period: (*1*) transition layer, (*2*) core, and (*3*) slag.

compounds of calcium oxide (CaO) with other oxides are presented.

Under steel scrap reduction or its complete exclusion from the charge at the initial stage of the heat, all other conditions being equal, the iron oxide content in the slag is decreased. This circumstance also has an adverse effect on the lime dissolution and slag formation processes, since it is necessary to increase the content of iron oxides in the slag at the initial period of the heat to prevent the refractory film formation on lumps of lime. With increasing contents of FeO and Fe_2O_3 in the converter slag, the wetting of lime with the former is improved and the slag penetrates into the pores and cracks in the lime lumps more easily [2].

In Fig. 2, the Fe content in the converter slag is presented as a function of the specific consumption rate of hot iron. It follows from this dependence that the increase in the consumption of hot iron is accompanied by a decrease in the iron oxide content in the slag. This factor has an adverse effect on the dissolution of lime.

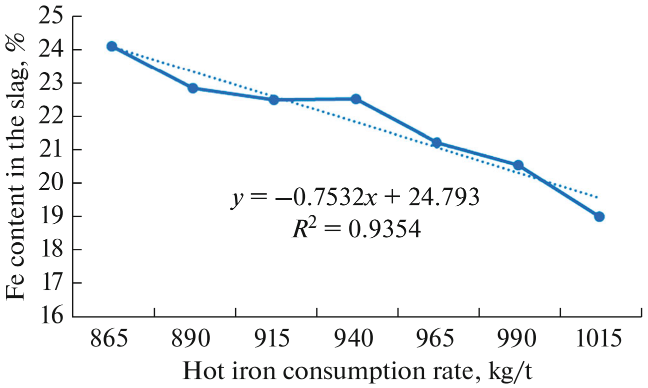

Fig. 2. Change in the Fe content in the converter slag depending on the specific hot iron consumption rate: (y) dependence of the Fe content in the slag on the specific hot iron consumption rate and (R^2) accuracy of approximation.

The deceleration of lime dissolution caused by the formation of refractory calcium orthosilicate and a minimum concentration of iron oxide in the slag impairs the slag formation process. This results in the formation of uncovered spots in the converter bath. The oxygen-lancing of the metal is accompanied by intensive splashing and leakage of the slag–metal emulsion out of the converter, which leads to sculling of the lance, mouth, and fume-collecting hood. These circumstances cause excessive consumption of the metal charge and a reduction in the productivity due to downtimes in the converter operation to remove the scrap. Given that the converter operates in the common ladle-furnace–continuous-casting-machine process chain, unscheduled downtimes of the converter related to scrap removal may bring the batch casting on the continuous caster to an emergency standstill [3]. The melting of steel without using solid metal charge aggravates the situation causing deviations from the specified conditions of the slag practice and the blowing process.

An effective method for increasing the content of iron oxides in the slag is addition into the converter of iron-ore or manganese-containing materials. Considering the logistics of supplying these materials and

Table 1. Melting points of compounds containing calcium oxide

System	Most low-melting compounds	Melting point, °C
$CaO–SiO_2$	$CaSiO_3(CaO \cdot SiO_2)$	1540
	$Ca_5Si_2O_7(3CaO \cdot 2SiO_2)$	1478
$CaO–Al_2O_3$	$Ca_5Al_6O_{14}(5CaO \cdot 3AlO_3)$	1455
$CaO–Fe_2O_3$	$CaFe_2O_4(CaO \cdot Fe_2O_3)$	1200
$CaO–P_2O_5$	$CaP_2O_6(CaO \cdot P_2O_5)$	980
	$Ca_2P_2O_7(2CaO \cdot P_2O_5)$	1300

their prices, the use of iron-ore pellets is more practicable [4].

In 1999 and 2000, pilot heats were conducted, charging the converter with iron-ore pellets as a partial replacement of scrap metal. In the pilot heats at a consumption rate of iron-ore pellets of 15–25 kg/t, the consumption rate of hot metal was about 850–900 kg/t and that of scrap metal was 250–300 kg/heat. The oxygen-lancing of the pilot heats was conducted according to the previous process technologies including the blowing using fluorspar in an amount of 1.5–2 kg/t. Furthermore, the pellets were charged into the converter using scoops for charging scrap metal. Consequently, the previously gained experience in using iron-ore pellets according to the charging practice accepted in the converter plant was not of great practical value.

The mastering of the technology for using iron-ore pellets occurred in several steps. The pellets were loaded into the hoppers and fed mechanically through the loose material conveyor system. The chemical composition of the iron-ore pellets used was (wt %): 7–9 SiO_2, 61–64 Fe, and 0.3–0.5 CaO.

Various techniques of feeding pellets under the conditions of the converter plant were trialed. Summarizing the experience gained, we should point out the following results that ensured satisfactory progress of the heat under the conditions of the converter plant with the heat being cooled by iron-ore pellets:

(i) the feeding of the pellets using mechanical means;

(ii) the entire recommended quantity of pellets is added to the poured hot metal prior to the oxygen-lancing of the heat;

(iii) the addition of pellets during the blowing is possible but not reasonable, since the feeding of this material in the course of blowing is accompanied by the flame intensively erupting out of the movable hood seal, which adversely affects the conditions of the equipment and the off-gas flue components;

(iv) the cooling capacity of 1 t of the pellets reaches about 35–40°C;

(v) the addition of 1 t of pellets ensures a reduction in the oxygen rate of about 200 m^3;

(vi) to maintain the specified slag basicity, one has to consider that the addition of 1 t of pellets requires the input of additional 350–400 kg of lime;

and

(vii) the degree of assimilating iron from the pellets—about 80–85% for heats conducted without intermediate slag removal—is determined by analyzing the data of a representative array of heats and by melting the balance heats.

The addition of iron-ore pellets allows for the formation of free-running slag at the beginning of the heat blowing by increasing the content of iron oxides in the slag. Thus, no faults with the slag practice and leakage of the slag–metal emulsion have been found in the heats with the minimum consumption of scrap metal. At a consumption rate of pellets of up to 120 kg/t and more, the heats with only molten iron in the converter are also blown.

CONCLUSIONS

(1) Under increased consumption of molten pig iron of 980 kg/t and more, the slag formation process is complicated due to the presence in the slag of refractory compounds (calcium orthosilicate) and a low content of iron oxides.

(2) To solve the problem, the technology of iron-ore pellet addition has been developed in the converter plant.

(3) The basic steps of using pellets are as follows:

(i) the addition of the pellets using mechanical means;

(ii) the pellets are added onto the poured hot metal prior to the oxygen-lancing of the heat;

(iii) the addition of pellets during the blowing of the heat is possible but not reasonable due to intensive eruption of the flame out of the converter;

and

(iv) the determination of the cooling capacity of the pellets and the assimilation degree of iron from the pellets. Furthermore, the correcting coefficients of the consumption rates of oxygen and lime under addition of pellets to the converter heat have been found.

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