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EFFECTS EXERTED BY SLAG CARRIED OVER FROM CONVERTER IN THE LADLE ON THE ALUMINUM ASSIMILATION

Petre Stelian NIȚĂ
"Dunarea de Jos" University of Galati, Romania
e-mail: pnita@ugal.ro

ABSTRACT

In the present paper are shown aspects of the influence exerted by the some less controlled parameters of BOF steelmaking, mainly of slag characteristics at tapping. Following the necessities to control the steel deoxidization by aluminum assimilation evaluated by soluble aluminum and its behavior, the presented data are evaluated based upon direct measurements of dissolved oxygen in steel before tapping, steel temperature before tapping, argon bubbling in tapping ladle under slag at various contents of (FeO), including its final content. The presented data are obtained in full scale plant conditions on standard weight of heats and applying an established steel making technology. It is concluded that steel temperature in final stage of steel making and (FeO) content of slag carried over from BOF to the ladle exert a strong influence on the aluminum assimilation in steel and further on the other quality characteristics of steel. A strong variability of the parameters taken into account is present and this is due to the insufficient control of the amount of slag carried over to the ladle at tapping.

KEYWORDS: steel, slag, tapping temperature, FeO in slag, aluminum assimilation

1. Introduction

In a previous paper [1] it was shown, based mainly on theoretical considerations and simulation, the influence on the chemical composition of the slag in the ladle due to some chemical compounds in the converter slag, at some fixed ratios. The present paper deals with the evaluation in industrial conditions of the effect exerted by the slag carried over from converter in the ladle on the final composition of the steel before ladle refining or continuous casting. It is known that, despite the use of slag stoppers, important variations of the amount of slag carried out from converter are transferred in the ladle in a random manner. In consequence, the whole process of the liquid steel treatment is perturbed, this causing important decreases of quality products and of the economic efficiency of steel production. Due to the necessity to achieve low carbon contents in the liquid steel before taping, heats are processed in a specific manner by oxygen blowing in the converter and usually, after that, the iron oxides content in slag is higher then desired, despite a final argon/nitrogen bubbling through bottom nozzle. This situation is important for the steel quality in the general case of many classes of steel grades [2, 3], but it is extremely critical mainly in the case of the low carbon aluminum killed steels (LCAK). In many papers it was shown by simulation that an important lose of aluminum content occurs in the presence of important amounts of slag carried out from converter in the ladle during argon bubbling. Then, the thermodynamic equilibrium conditions between aluminum and oxygen in the steel ([Al]-[O]) has been considered. Due to multiple advantages, the most convenient oxygen blowing technology of steelmaking in LD converter consists in technological operations and blowing parameters leading to the obtaining of a low carbon content $[C]_o$ at the end point (index o), corresponding to an equilibrium value (index e), $[C]_{o,e} \approx 0.05\%$ mass. In the case of thin rolled products for deep drawing and having high quality of surface, an average chemical composition of the steels in the ladle is in the following range: $C \leq 0.05\%$, $Si \leq 0.03\%$, $Mn \leq 0.2-0.4\%$, $Al_{sol}=0.015-0.40\%$. Index "sol" refers to soluble aluminum content in the steel. Many other chemical elements in the liquid steel could be specified, among them sulphur and phosphorus, many times also in restricted limits of contents, usually as limited maximal values. The selection of heats in the present paper excludes those out from the common practice, from the point of view of variability of influencing parameters taken into account. This means that those heats, where the analyzed parameters are too far out of the general trend, are not taken into account in this work.

2. The main features of the steel making technology

The schedule of steps and operations in the oxygen converter steelmaking technology is a common one and consists in the use of the process computer of each converter on the level two, taking into consideration the following final parameters of the heats:

1. - mass of heats (usually 175-180 t liquid steel);

2. - carbon content at end point ($[C]_o \leq 0.05\%$);

3. - phosphorus content at the end point ($[P]_o \leq 0.015\%$);

4. - final temperature of the liquid steel at tapping T_{tap}, according to necessities of continuous casting and/or required by necessities of a secondary treatment by different ladle metallurgy process;

5. - specific imposed value of the final slag basicity in the ladle, according to a computational relation; for the considered case it was used the value of the basicity index of slag B_{slag}=(%mass CaO)/(%SiO_2) ≈ 4.5. If it is applied a final argon bubbling period in converter, before taping the slag composition could be at best within the following range CaO=52-58%, SiO_2=12-14%, MnO=max.5%, MgO=max.5%, P_2O_5=1.5-2.2%, Fe_t=18-22%. A small variability of components around these Figures cannot be considered as nonconformities. From them, the process computer program establishes the necessary amounts of liquid pig iron, initially treated for advanced desulphurization and of scrap, the necessary amount of lime and the recommended oxygen blowing diagram. This last one contains also an argon post-bubbling period of a standardized duration and rate, according to the requirements imposed by the steel grade quality. At tapping, among usual addition operations of the required materials, a special addition of petroleum coke is introduced in the first moments after the beginning of steel tapping in order to reduce the activity of oxygen in the liquid steel. The aim is to decrease the content of the dissolved oxygen at levels below 400 ppm, i.e. at levels closed to those corresponding to the theoretical equilibrium [C]-[O] at the considered temperature. In order to remove the excess of the dissolved oxygen, amounts of about 60-70 Kg of petroleum coke per heat are usual additions and only in extreme cases they could increase the carbon content in the liquid steel, perhaps with no more than about 0.01%. In order to evaluate correctly the amount of petroleum coke to be added and the necessary amounts of ferromanganese and aluminum as deoxidizers, a measurement of oxygen activity using an adequate device must be performed before tapping. Usually, the amount of Al considered as necessary to deoxidize such crude liquid steel is considered to be 1 kg/t. The total amount of aluminum representing 175 Kg is introduced in several stages; in the form of blocks-100 Kg after addition of ferromanganese, when half of steel was tapped, 25 Kg granule or gross flakes in mixture with lime (800-1000 Kg/heat) and 80-100 kg of fluorine; the rest of aluminum, representing 50 kg Al is spread on the surface of the slag in the ladle, after finishing the tapping, as granules or gross flakes with the definite purpose to urge a strongly advanced deoxidization of the slag. The results of steel deoxidization operations depend on how much effective are the technological operations before mentioned, mainly on the effectiveness of aluminum assimilation in the steel and its effectiveness in the slag deoxidization, both being the key control of the steel quality for the initially mentioned purposes. The effectiveness of all final treatments in the ladle and further the quality of steels are strongly dependent on the characteristics of the carried–on slag from converter to the ladle and on its amount. These factors at the origin of a strong variability in the final steel quality and the following paragraphs are dedicated to these aspects.

3. Experimental data

Higher values of assimilation of aluminum in steel (over 25-30%) at tapping are obtained when steel before tapping contains low values of dissolved oxygen. The activities of oxygen in steel converted in mass contents must be below 600 ppm and the temperature must not exceed too much the necessities to cover losses in normal practice; a limit of about 1650 ^oC seems to be acceptable in the case under focus.

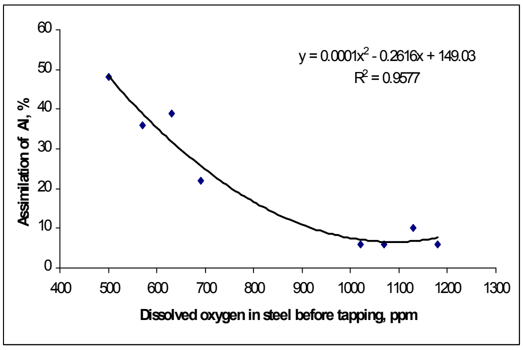

Fig. 1. *Dependence of aluminum assimilation in the ladle as function of the dissolved oxygen in steel before tapping, based on Celox measurement*

In industrial conditions of steel making in LD converters only a limited number of edificatory factors regarding the quality are available for direct measurements. The dissolved oxygen content and the temperature of the steel before tapping are among the most important. Assimilation of aluminum as function of these parameters is shown respectively in Fig. 1 and in Fig. 2. The graphical representations are linear because the highest values of correlation coefficients of dependence have been obtained for this type of dependence.

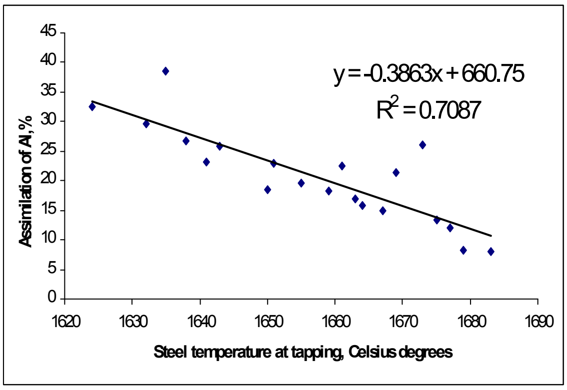

Fig. 2. *Assimilation of aluminum in steel at tapping in the ladle, as function of steel temperature in converter before tapping*

In extreme cases, when the dissolved oxygen contents exceed 1000 ppm and steel temperature at tapping is over 1670 °C assimilation of aluminum in steel is less than 10-15%, in this research. The effects of such values of these parameters are deleterious for the quality of steel products and in order to avoid them costly supplementary addition of aluminum, feed by wire, must be done. Both factors of influence present high enough values of the coefficient of determination R^2. This means that in the case of the selection of heats, making the object of the present research, the oxygen activity in steel before tapping and the steel temperature are among the most important technological factors of influence of the aluminum assimilation in the liquid steel. An important variability of aluminum assimilation, taken as objective function, is due to many other concurrent parameters, less controlled for various reasons. Among them there could be included variations of the amounts of slag carried–over at tapping, the rate of steel tapping, respectively time duration of tapping, the fastness of aluminum additions in the most adequate period of tapping. The moments of sampling of steel or Celox measurements could induce other variations of assimilation values. The amounts of carried-over slag and their content of ion oxides are two other important parameters involved in controlling the steel quality in the tapping ladle and further, in the following steps of liquid steel processing. The slag amount of carried-on slag from converter to the ladle can be supposed only as amount, despite many efforts and devices used in the purpose to limit it. It was shown [1] by numericalsimulation that amounts over 500 Kg converter slag/heat are deleterious for aluminium assimilation due to the effects of its oxidation, according to the reaction (1) taking place at interface steel-slag. This reaction occurs in both regimes of contact, permanent and transient. The first is specific to periods after argon bubbling, as state in the tapping ladle or in secondary steel metallurgy facilities, up to the moment of continuous casting that means 20-40 minutes as time duration. The second is referring to the intended technological processing, consisting in argon bubbling and several minutes after that, also in distributors at continuous casting of steel.

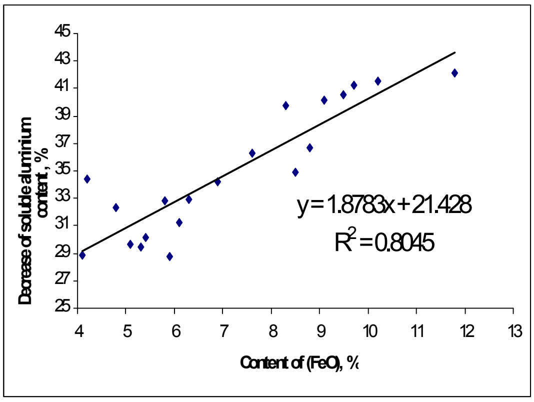

Fig. 3. *Decrease of the soluble aluminum content in steel during argon bubbling in the ladle, as function of (FeO) in slag*

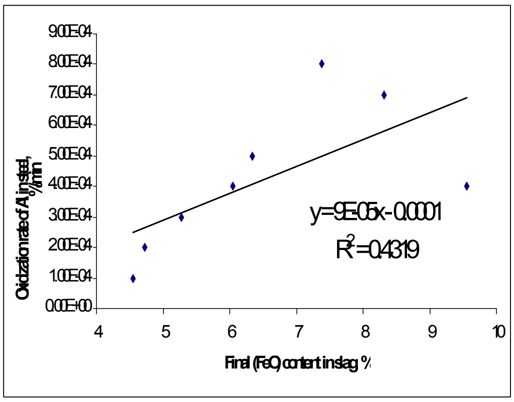

Fig. 4. *Oxidization rate of aluminum in steel after argon bubbling period as function of final content of (FeO) in slag*

The content of iron oxides in slag (FeO) influences in great measure the behavior of aluminum in the ladle. Fig. 3 and Fig. 4 show this influence by two important parameters which could be established by direct measurements. It is obvious that, at higher contents of (FeO) in the top slag in the ladle, at the same intensity of argon bubbling by porous plug in the bottom of the ladle, the values of both dependent parameters grow. There are differences of the dependence coefficient R^2. This shows that the permanent and the transient regime of contact between the top slag and the steel in the treatment ladle, influences in different measure the oxidation of aluminum in the steel. In the permanent regime, in absence of bubbling, an important part of the top slag becomes totally inactive because of the increasing of its viscosity and even because of partial solidification at surface. Mass transfer of (FeO) by diffusion from upper layers of slag to the steel-slag interface is lower in the permanent regime when argon bubbling is missing. However, as it is shown in Fig. 3, if the (FeO) content after bubbling argon is lower, the decrease rate of soluble aluminum in steel is significantly lower than in the case of higher contents of (FeO). It seems that at less than 5% (FeO) due to the combination of favorable actions of the mutually reinforcing kinetic and thermodynamic factors, shown before, the rate of oxidization of soluble aluminum decreases drastically.

The last two data in Fig. 3, at contents (FeO) <5 mass% sustain this behavior which is in fully agreement with other published data. These observations are sustained also by the data presented in Fig. 5 where the same general and particular tendencies are maintained for aluminum oxidization behavior after argon bubbling period. In Fig. 6 the evolution of assimilation of aluminum in steel as function of its content in steel is presented, in conditions of a narrow range of aluminum additions in steel, around 1 Kg/t. Factors affecting drastically the assimilation in steel. i.e. the temperature at tapping, the activity of oxygen in steel, before tapping, the content of (FeO), the tapping duration and moments of addition, contribute to the trend and data shown in Fig. 6 and are responsible for lowering of steel quality in conditions when only low contents of soluble aluminum are present.

Conclusions

Despite the application of unitary technology of steel making (BOF) in in the industrial conditions of the experimental data of the present paper, factors depending on heat charge influence the final parameters at tapping such as temperature, activity of oxygen in steel and (FeO) content.

Influences of these factors are transferred to the ladle at tapping and decrease the values of assimilation of aluminum in variable measures. Further, because of the lack of control of oxygen activity in steel, the quality of steel products become variable and this is the weak point of the technology applied in the present case. Limitation of influence of these factors is the only way to ensure the necessary levels of liquid steel quality and further of steel products.

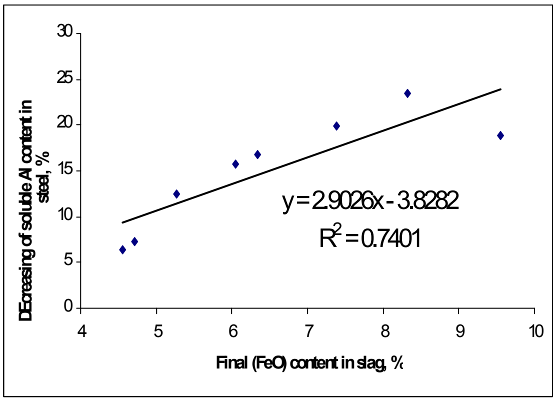

Fig. 5. *Decreasing of the content of soluble period as function of the final content of FeO in slag*

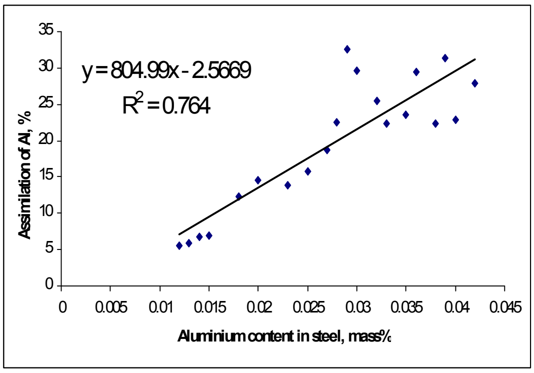

Fig. 6. *Assimilation of aluminum as function of its content in steel in conditions of a narrow range of amounts of aluminum additions*

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