

Control of the oxygen content after the tapping from EAF

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Nowadays the increase of the oxygen content is the most important aspect of the EAF treatment from a metallurgical point of view. Actually, the oxygen content of the steel bath is a fundamental parameter for the change of the melt chemical composition and for the success of the following ladle treatment. The oxygen content at the tapping is determined on the basis of the chemical requirement of the steel (C, P, N) but its decreasing after tapping has to be evaluated as a function of the cleanliness of the steel and for the development of the desired non-metallic inclusions.

Parole chiave: siderurgia

INTRODUCTION

The control of the oxygen content of the metal bath is one the most important aspect for a correct management of the melting and for the following refining process of the metal bath that is devoted to produce a steel with the desired chemical composition which can generate a suitable non-metallic inclusion distribution [1,2].

This final aim has to be balanced with the oxygen content that features the most modern and efficient EAF melting unities. Actually the oxygen is used not only for the decarburization process but also as a source of power to heat the charged scrap and the metal bath. This application can increase the energy efficiency of the process, particularly in the countries where the electricity is generated by thermo-combustion plants [3,4] to lower the cost. So, the injected oxygen has to be considered not only as a decarburizing element but also as a combustion one, so the quantity present in the steel bath can reach very high quantity.

Nowadays, the control of oxygen is a fundamental parameter as well as the techniques used for its injection. The modern melting practice is structured to allow short tap-to-tap period and increase the productivity of the steel plant and the use of the EAF furnace.

The modality of oxidation, its intensity, the first deoxidation operation after tapping imply great consequences on several and fundamental metallurgical aspects:

- the stability of the foaming slag;
- the pick-up of nitrogen;
- the oxygen at the beginning of the re-finishing;
- the design of non-metallic inclusions;
- the cleanliness of the final product.

Although the thermodynamic treatment describing the reaction between the oxygen and carbon are well consolidated in many of its aspects, including the kinetic ones, poor information is present about the application of this relation to the industrial practice and its reliability.

The present study is devoted to the comprehension of the relation between oxygen content and the decarburization during

the melting task in 90tons EAF at high temperature (1750°C-1700°C), the FeO content in the slag and its relation with the foaming slag stability, the relation between the oxidation state and the nitrogen pick up and, finally, the possibility and the advantage to operate the first deoxidation by a recarburization of the metal bath.

Although the amount of information about these items is absolutely interesting, only some few reliable information are published about these operations and the related measurements during the industrial practice.

EXPERIMENTAL PROCEDURE

Several melting tasks are observed during the last two years to create a statistically significant population (for each type of steel more than 20 melting tasks have been performed) and a serious attention has been focused on the production of three steels: 16CrNi4, 42CrMo4, RR ST52.3 (table I) with different composition after the end of the affination period in the ladle furnace (LF).

The mix of the charge has been recorded (table II) and an averaged description of the scrap and the charge has been defined. Moreover, the quantity of injected oxygen and methane has been controlled and recorded during each of the analysed tasks.

The EAF used to perform the experimental task has a capability of 90 tons and was equipped by a single oxygen lance and three co-jet oxygen-methane burners to develop chemical energy and homogenize the temperature and the chemical composition of the melt. This also allows to perform the oxygen activity measures that can be considered significant for the whole steel bath, because the heterogeneity within the bath is greatly diminished if compared with a situation in which the oxidation of the steel bath is performed by a single oxygen injecting lance.

After the complete fusion of the charged materials the samples of steel bath were analysed using an inductively coupled argon plasma spectrometer to obtain the chemical composition.

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	%C	%Mn	%Si	%P	%S	%Ni	%Cr	%Mo	%Al
RRST52.3	0.19	1.2	0.35	<0.01	<0.013	-	-	-	0.026
16CrNi4	0.14	0.9	0.25	<0.01	<0.013	0.9	0.95	-	0.03
42CrMo4	0.43	0.8	0.25	<0.01	<0.013	-	1	0.2	0.025

Table I Chemical composition of the three analyzed steel grades
Tabella I Composizione chimica dei tre tipi di acciaio utilizzati

	kg
Pig iron	12000
Scrap	77000
Metallurgical coke	1000

Table II Average mix of the charged material
Tabella II Media dei componenti caricati

tion. Single used electrochemical oxygen cells (Celox) were used to evaluate oxygen activity in the EAF and at the beginning of the EAF at different steps of the melting period. This measure has been performed varying the position of the sampling point to assure that the measure was not compromised by the heterogeneity due to the mass transport within the bath. Thermocouple allowed measuring of the actual steel temperature at the time of sample collection. The temperature of the steel bath has been recorded during the operation of sampling and at each measure of the oxygen activity. The slags have been analysed by an X-ray diffraction device. A measure of the temperature of the steel has been performed just before each tapping. A sample of the steel bath has been taken at the beginning of the re-finishing period in the LF, after the recarburization to fit the required analysis of the different steel grades.

RESULTS

The metal bath has practically the same average chemical composition for the three types of the studied steel (table III). The average global composition of the charged material implied a content of carbon equal to 5,4%. This content, with the insertion of 30m³ of oxygen and 8 m³ of methane per tons of steel can grant 264,26kWh/ton[5,6]. This result is validated by the measure of the electrical power supplied to the EAF unity that is around 400kWh/ton. The oxidation of the carbon contained in the steel bath contribute for about the 5% of the total energy needed to fulfil the whole melting task. The measures performed to state a relation carbon vs. oxygen permit the development of the two suitable relations for the temperature of interest during the melting task, which stays between 1700°C and 1750°C(fig.1, fig.2). After the tapping the carbon content is between 0,08% and 0,14%. The slag composition varies from the beginning to the end, because of the progressive oxidation of the steel that enriches the surrounding slag by the produced iron oxide (table III). The iron oxide (FeOx) content of the slag varies from a minimum of 8% at the beginning of the oxidizing period and arrives at a maximum of 14% just before the tapping operation, while the value of this parameter at the beginning is of 7-8%. The slag basicity is considered by the ratio

$$B = \frac{\%CaO}{\%SiO_2 + \%Al_2O_3}$$

and it is always maintained between 1.73 and 1.87.

The nitrogen content at the tapping varies between 45ppm and 60ppm. It seems that a relation between the oxygen content of the steel and the nitrogen one shows that the second decreases when the first increases; actually a higher state of oxidation seems to decrease the nitrogen content. However, this general rule cannot be used without a critical evaluation of the features of the charged material that is one of the most important factors of influence for its effect on the nitrogen content.

The definition of a relation between the nitrogen content and the parameters related to the decarburization process needs some further investigations including a precise evaluation of the charged material. Thus, in the following discussion on the obtained results this aspect is not treated and will be considered in successive studies.

The average tapping temperature is of 1665°C and there are not significant differences among the steel grades.

The observations of the oxygen content after the tapping and the recarburization of the steel point out that the oxygen content of for RR ST 52.3 and 16CrNi4 has a maximum content of 45ppm and the minimum one of 30ppm, while for 40Cr-Mo4 this range is between 20-30ppm.

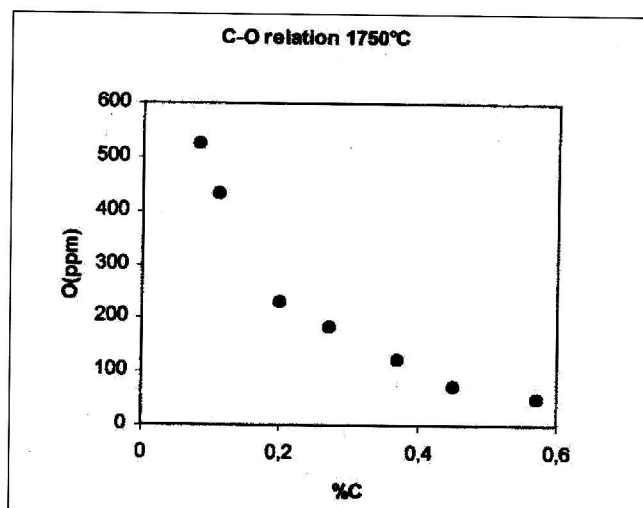


Fig.1 Carbon - Oxygen relation at 1750°C

Fig.1 Relazione Carbonio-Ossigeno a 1750°C

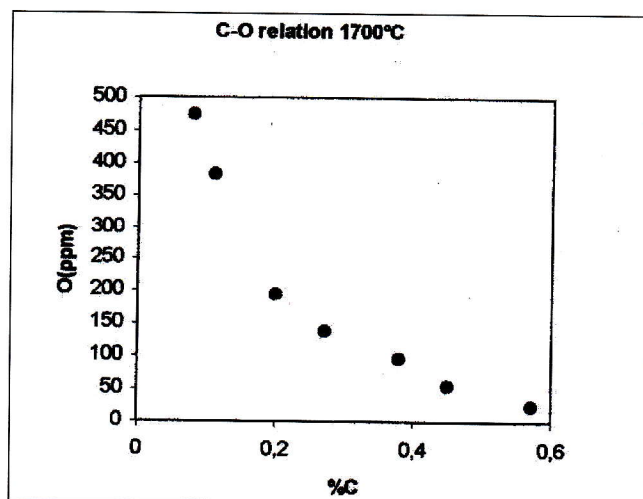


Fig.2 Carbon - Oxygen relation at 1700°C

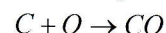
Fig.2 Relazione Carbonio-Ossigeno a 1700°C

DISCUSSION

The mix of the charged material has the features to grant a significant development of chemical energy that can assure a good energy efficiency for the melting process.

On the other hand, a production practice like that described meets a critical aspect in the decarburization period, in which the need to develop heat and to decrease the carbon content of the steel requires a strong oxygen injection, but this has to be balanced with other: maintaining of the foaming characteristics of the slag and to contain the loss of iron through the steel oxidation.

But the fulfilment of this aim can be reached only through the understanding of the carbon versus oxygen relations. The obtained results have been compared with the theoretical value, provided that at the treatment temperature of the bath the product of the reactions is pure CO [7]:



$$K = \frac{h_c h_o}{p_{CO}}$$

$$\log K = -\frac{1160}{T} + 2.00$$

The results of the experimental observations point out that only at high carbon content (0,5-0,6%) the experimental data

and the expected ones tend to feet, while at lower contents the difference between the equilibrium data and the measured ones (fig.3, fig.4) differ significantly. This behaviour is probably due to the influence of the transport phenomena, because at the lowest carbon contents the oxygen finds more difficulties to combine with the injected oxygen (fig.5).

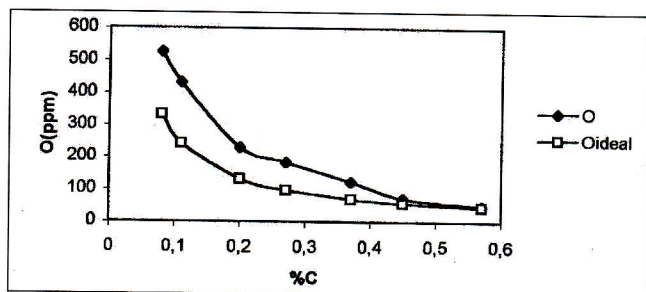


Fig.3 Difference between the measured and expected relation between carbon and oxygen at 1750°C.

Fig.3 Differenza tra i valori misurati e quelli attesi per la relazione carbonio-ossigeno a 1750°C.

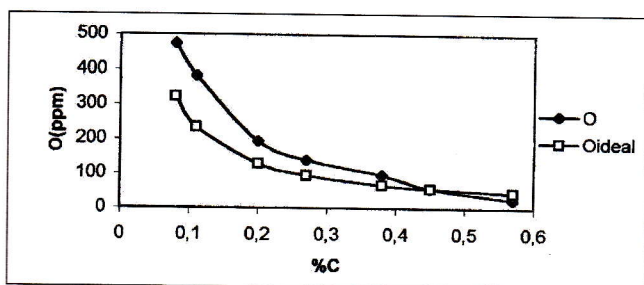


Fig.4 Difference between the measured and expected relation between carbon and oxygen at 1700°C.

Fig.4 Differenza tra i valori misurati e quelli attesi per la relazione tra carbonio ed ossigeno a 1700°C.

This situation points out that under a carbon content of 0,3% the modality of injection has to be changed, to increase the area of the mass exchange between the metal and the injected gas to improve the kinetics of the decarburization reaction and to compensate the slowing effect of the mass transport.

This can also limit the formation of iron oxide that can enrich the slag, lowering the viscosity and causing the loss of the foam stability. The observed values of basicity and iron oxide enrichment allows the evaluation of the slag characteristics during its compositional evolution (fig.6) [8]. The drawn diagram shows that the slag stays in an optimal region of the slag chemical physical characteristics, because in the region of stability with the coexistence of liquid-magnesium wustite-pseudowollastonite there is the best mix of the chemical-physical features: good viscosity induced by precipitation of solid particle to grant a good faominess (fig.7) and fluidity to assure an appreciable mass exchange between the different phases, but not so great to promote the erosion of the refractory materials.

It is worth noting on this representation that a further oxidation of iron oxide can make the slag completely liquid, that is not a favourable metallurgical situation.

The addition of grinded graphitic carbon after the tapping allows to make carbon content according the required prescription but also permits a first deoxidation before the addition of the strongest deoxidizing, i.e. silicon and aluminum. The addition of carbon limits the successive oxygen content to be removed by the deoxidizing elements and does not produce those precipitates that can be detrimental on the mechanical behaviour of the final products.

To understand the correct carbon addition it is necessary to know the real oxygen content, that has been measured in this

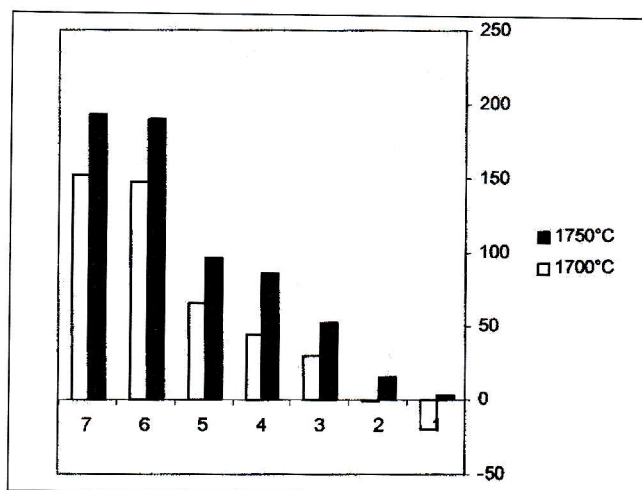


Fig.5 Differences between the expected values and the measured ones at different carbon content (1_%C 0.08, 2_%C 0.11, 3_%C 0.2%, 4_%C 0.27, 5_%C 0.38, 6_%C 0.45, 7_%C 0.57)

Fig.5 Differenze tra i valori attesi e quelli misurati in corrispondenza di diversi contenuti di carbonio (1_%C 0.08, 2_%C 0.11, 3_%C 0.2%, 4_%C 0.27, 5_%C 0.38, 6_%C 0.45, 7_%C 0.57)

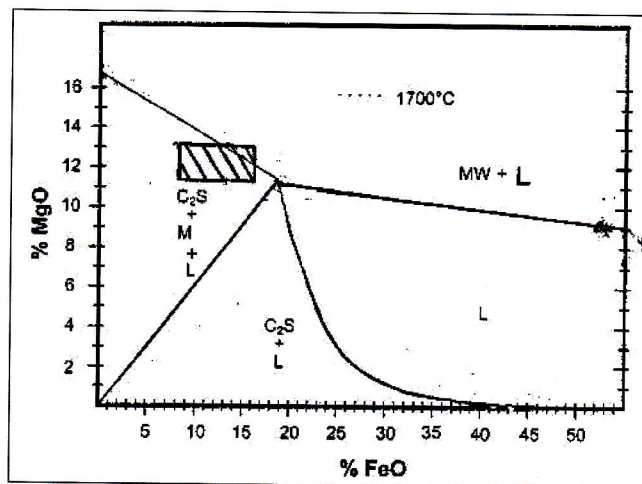


Fig.6 Chemical evolution of the slag during the EAF period (C₂S, 2CaO, SiO₂, MW, MgO, FeO). The basicity (%CaO/[%SiO₂+%Al₂O₃]) is 1.8. The dashed area represents the chemical composition of the observed slags.

Fig.6 Evoluzione della composizione chimica delle scorie osservate durante il trattamento in EAF (C₂S, 2CaO, SiO₂, MW, MgO, FeO). La basicità (%CaO/[%SiO₂+%Al₂O₃]) è pari a 1.8. L'area evidenziata rappresenta la composizione chimica indicativa delle scorie osservate.

study at two characterizing temperatures of the melt contained within the EAF as function of the carbon content at the end of the decarburization. Provided the quantity of carbon that is required and that at end of the tapping, it is possible to determine the correct addition of graphitic carbon. The total quantity of the graphitic carbon to be added and the one necessary to remove the real content of oxygen within the steel bath can be found by the sum of the carbon in order to fit the final required chemical composition and the one necessary to remove the oxygen present in excess (table IV). The computed quantity has to be added to the carbon inserted for the re-carburization of the bath. It has to be taken into account that the quantity of the carbon to be added is also a function of the temperature of addition. At the lowest temperature the carbon can develop a greater deoxidizing effect, but it is not possible to use this effect to produce a deep deoxidation, because the steel bath has to be desulphurised and an excessive cooling

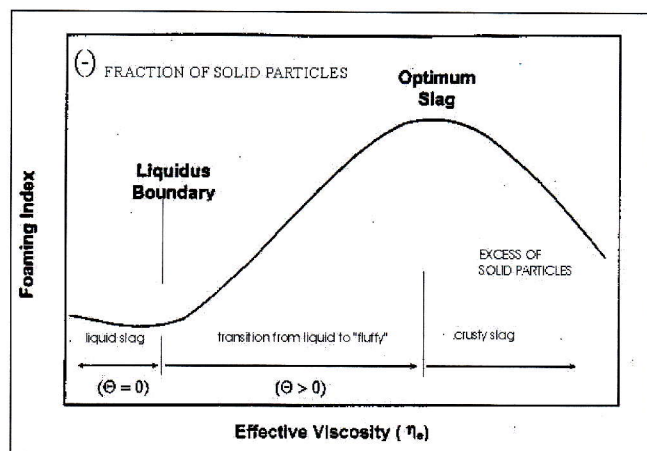


Fig.7 Foaming efficiency as function of the presence of solid particles[9].

Fig.7 Efficienza di schiumeggiamento come funzione della dispersione di particelle solide [9].

can be detrimental for an efficient desulphuration. Actually the steel bath has to be maintained at a high temperature to promote a good desulphuration. Thus, it is a good practice to avoid the temperature of the bath to decrease under 1630-1620°C before the beginning of the refining period in LF. On the other hand, the deoxidizing effect of carbon can decrease the use of other alloying elements with a higher cost. These elements can be substituted by a cheaper graphitic carbon.

	%FeO _x	%MgO
Beginning of EAF	9	11
End of the EAF	15	13

Table III Average value of iron oxide at the beginning and at the end of the EAF treatment

Tabella III Valore medio dell'ossido di ferro all'inizio e alla fine del periodo del trattamento in EAF

%C content after the end of the EAF	0.08	0.11
EAF final temperature 1750°C	14.5kg	13.9kg
EAF final temperature 1700°C	11kg	10.5kg

Table IV Addition of carbon devoted to deoxidation, provided that the carbon addition temperature is 1650°C for a 90 tons bath.

Tabella IV Inserimento di carbonio grafítico destinato alla disossidazione di ossigeno, considerando una temperatura di inserimento pari a 1650°C per un bagno da 90 tonnellate.

CONCLUSIONS

On the basis of the described experimental tasks performed on an industrial plant it is possible to point out:

- the relations between the oxygen and carbon content within the metal bath are determined at two different temperatures;
- this permits to understand the carbon content in which the injecting modality has to be changed to increase the kinetics and decarburation and an excessive oxidation of the bath that can make the slag liquid;
- the addition of the carbon for the first deoxidation can become a very profitable practice in terms of the quality of the steel and of the decreasing of the cost;
- this last practice can be well defined in its parameters by the knowledge of the real curve decarburation defined in this study by the performed experimental measurements.

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— A B S T R A C T —

CONTROLLO DEL CONTENUTO DI OSSIGENO DOPO SPILLAGGIO NEL FORNO ELETTRICO AD ARCO

Il presente lavoro si incentra sulla determinazione della relazione reale all'interno del forno tra carbonio e ossigeno, che risulta di fondamentale importanza per una corretta ed efficiente gestione di un moderno forno elettrico ad arco. Infatti il controllo dei fenomeni di ossidazione all'interno di un moderno forno, eventualmente dotato di sistemi di combustione ausiliaria necessari per migliorare l'efficienza energetica del processo, costituisce la base per una corretta gestione del mezzo fusorio.

Attraverso misure sperimentali svolte su di un forno elettrico ad arco trifase si è potuta determinare la differenza tra i valori della relazione carbonio-ossigeno ed i valori attesi sulla base dei dati termodinamici (fig.1, fig.2, fig.3, fig.4, fig.5). L'eterogeneità propria del bagno metallico è notevolmente ridotta nel tipo di impianto preso in considerazione, in quanto esso è dotato di 3 punti di iniezione del tipo co-jet oltre che della lancia per l'insufflazione di ossigeno. I campioni di acciaio sono stati prelevati da una zona del bagno sufficientemente lontana dai punti d'impatto dei getti di ossigeno così da limitare eterogeneità riconducibili a tale situazione.

Sulla base delle misure effettuate si è potuto valutare il tenore di carbonio in corrispondenza del quale è bene variare la modalità di insufflazione, cercando di aumentare l'area di interscambio onde evitare un'eccessiva ossidazione del bagno senza una concomitante ed efficace decarburazione. Oltre a questo si è considerata l'evoluzione della composizione della scoria in relazione alla sua possibilità di schiumeggiare (fig.6, fig.7) e si è potuta valutare criticamente la possibilità di un'aggiunta di carbonio in eccesso al fine di procedere ad una prima disossidazione (tab.IV).