THE INFLUENCE OF CONSTEEL® EAF PRACTICE ON THE REDUCTION OF N_2 PICK-UP AND THE INCREASE OF METALLIC YIELD[1]

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Abstract
Besides the expected reduction of production costs and increase of productivity, the Consteel® EAF has demonstrated along its 20 years of development to bring to EAF steelmaking lots of other benefits and improvements. In this paper it is analysed the reduction of Nitrogen pick up and the increase of metallic yield that can be achieved trough the standard melting practice typical of the Consteel® EAF: the continuous scrap feeding and foamy slag during the whole power on time. As a matter of fact, being the electric arc covered for the entire melting process there is an important reduction of the Nitrogen content in the liquid steel. Of course there are other main factors that may influence the N2 pick-up, and all of them are analysed in this paper. An additional benefit that characterize the Consteel® EAF process is the possibility to achieve, with the same scrap mix, a higher metallic yield. This is thanks to the peculiarity of the melting process and the correct management of the oxygen injection that can be optimized for the flat bath process of the Consteel®. During the heat the lances and injectors typically use always the nominal flow rate and then the efficiency in carbon removal is maximized and the iron oxidation can be minimized. Results of Consteel® plants in operation in different Countries are given in this paper and data are compared in order to confirm the mentioned benefits.
Key words*:* Steelmaking; Nitrogen removal; Consteel system; Nitrogen control.

A INFLUÊNCIA DA PRÁTICA FEA CONSTEEL® NA REDUÇÃO DE ABSORÇÃO DE N_2 E AUMENTO DE RENDIMENTO METÁLICO

Resumo
Além da redução esperada de custos de produção e de aumento de produtividade, o FEA Consteel® demonstrou, ao longo de seus 20 anos de desenvolvimento, trazer à fabricação de aço por FEA vários outros benefícios e melhorias. Este trabalho analisa a redução de absorção de nitrogênio e o aumento de rendimento metálico que podem ser alcançados através da prática normal de fusão típica do FEA Consteel®: a alimentação contínua de sucata e a escória espumosa durante todo o tempo de Power on. De fato, estando o arco elétrico coberto por todo o processo de fusão, há uma importante redução do teor de nitrogênio no aço líquido. Obviamente há outros fatores importantes que podem influenciar a absorção de N2, e todos eles são analisados neste trabalho. Um benefício adicional que caracteriza o processo FEA Consteel® é a possibilidade de se atingir, com o mesmo mix de sucata, um rendimento metálico maior. Isto graças à peculiaridade do processo de fusão e ao gerenciamento correto da injeção de oxigênio que pode ser otimizada para o processo de banho plano do Consteel®. Durante o aquecimento as lanças e injetores tipicamente utilizam sempre a taxa de injeção nominal, maximizando a eficiência de remoção de carbono e minimizando a oxidação do banho.
Resultados de plantas Consteel® em operação em diferentes países são apresentados neste trabalho e os dados são comparados de forma a comparar os benefícios indicados.
Palavras-chave: Fabricação de aço; Remoção de nitrogênio; Sistema Consteel®; Controle de nitrogênio.

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1 INTRODUCTION

This paper describes the study conducted on the Nitrogen pick-up using a EAF-Consteel® system.
The study has examined and compared two different processes: a Conteel process and a top charge process. In both cases the amount of nitrogen entering and exiting the furnace has been analysed
As a matter of fact, in order to evaluate the effect of the melting process on the nitrogen pick up it's necessary to remove the effect of metallic materials charged and to compare the nitrogen content at the same initial condition.
Literature has been considered in order to understand the phenomena of absorption and removal of nitrogen during the process.
Comparing with converter process the nitrogen content in EAF steel is higher because scrap contains high [N] content and because the liquid in the electric arc area is easy to absorb nitrogen.
The final nitrogen content in steel is influenced by different contribution: Nitrogen content in raw materials, denitrogenation during EAF process, absorption of Nitrogen during EAF process, absorption of Nitrogen during tapping and refining, denitrogenation during degassing process and Nitrogen increment during casting process.
A degassing process of molten steel is often applied to reduce nitrogen in the metal. However, it is difficult to achieve the desired level of nitrogen concentration using only the degassing process. Moreover the typical process is often constituted by EAF-LF-CC process, without the degassing treatment. It's important reduce the bringing of nitrogen during the whole process.
In order to reduce nitrogen content in the steel, it's necessary to reduce first of all the nitrogen content in the raw materials. This is possible using hot metal, DRI, HBI or pig iron in charge. These materials reduce nitrogen primarily trough dilution. The CO that evolves from these products does not remove nitrogen. However it has been demonstrated that the CO developed from reaction of C and FeO in the DRI/HBI is evolved at lower temperatures (1.000°C) and is released during heating or in the slag phase. Since it does not pass trough the metal it doesn't remove nitrogen.
The nitrogen removal using 25% and 50% DRI/HBI is shown in Figure 1.

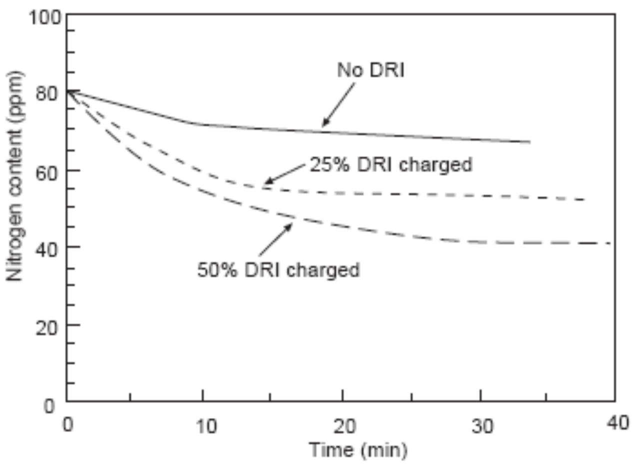

Figure 1: Effect of DRI on Nitrogen content in EAF steelmaking

As shown in the Figure 2 the nitrogen content reduction is the result of the dilution of the nitrogen in the metal.

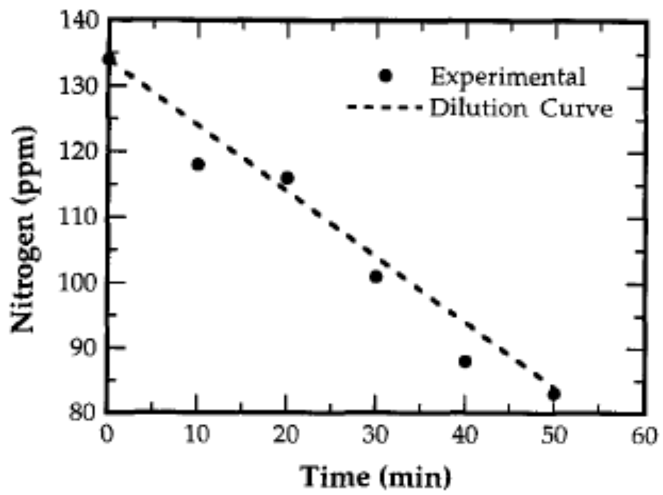

Figure 2: The rate of reduction in nitrogen content by adding DRI to 400g of iron compared to simple dilution.

The denitrogenation in EAF is achieved blowing oxygen. It is proved in practice production that blowing oxygen in liquid steel can remove nitrogen effectively, as the same as in converter process.
In Figure 3 the nitrogen removal is shown for a 100 ton EAF as a function of oxygen usage. Nitrogen removal decreases once the carbon content falls below approximately 0.3%, as most of oxygen is then reacting with Fe and is therefore not producing CO. Starting at a higher initial carbon allows for more CO evolution and reduces the activity of oxygen, which retards the rate of the nitrogen reaction.

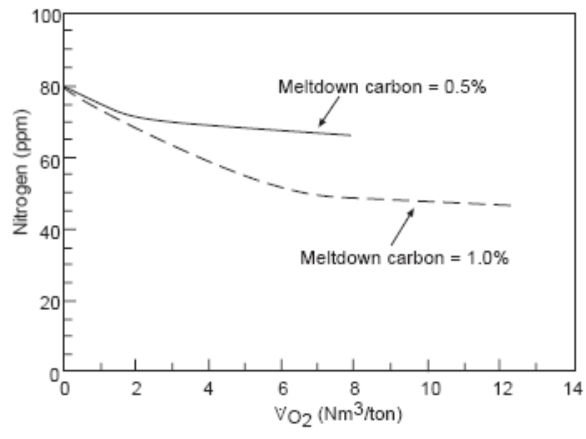

Figure 3: Removal of Nitrogen as a function of oxygen usage and carbon content

Oxygen and sulphur play an important role in the nitrogen removal. Oxygen and sulphur in molten steel are surface elements, which gather in the molten steel surface, resists the reaction of [N] = ½ N_2 at the interface, finally resist the nitrogen removal from liquid steel. Some experimental results pointed out that the effects of oxygen and sulphur on the rate of nitrogen transfer, decrease as the liquid steel temperature increases.

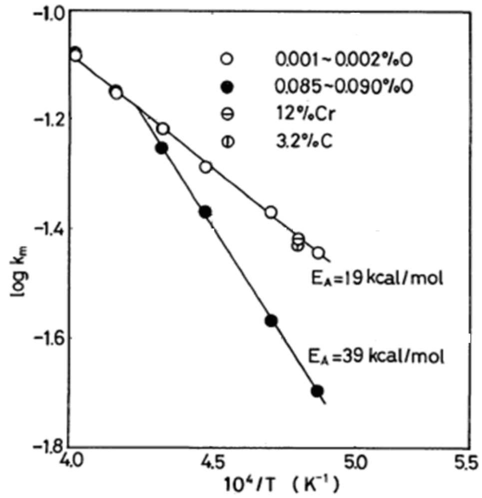

Figure 4: Effect of temperature and oxygen on removal of nitrogen

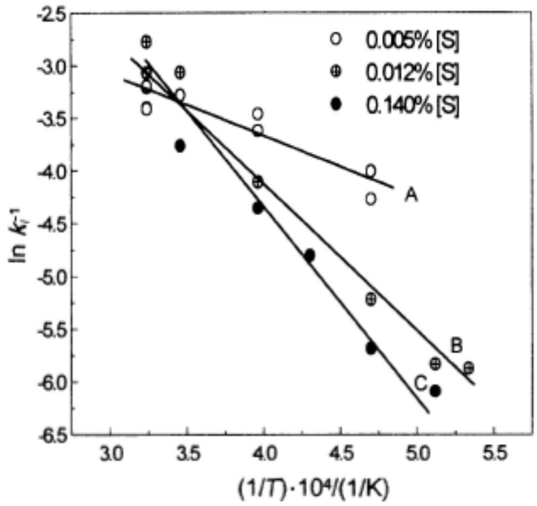

Figure 5: Effect of temperature and sulphur on removal of nitrogen

Although the [O] and [S] are high, the nitrogen can be efficiently removed during the decarbonation process by blowing oxygen. Under these conditions the temperature determines the rate of denitrogenation. The higher is the temperature the higher is the rate. The resistance of sulphur to the rate of nitrogen removal from liquid steel disappear above 2.600 °C. Above the 2.130 °C the disadvantage of oxygen disappears.

2 PREVIOUS STUDIES

The Consteel® process is well known and will only be briefly described here. Scrap is loaded by charging cranes directly inside the charging conveyor and moves toward the furnace through a slip-stick movement. In the last conveyor section, the scrap enters the preheating tunnel, where gases leaving the furnace flow over the metallic charge. Chemical and sensible heat of the off-gases is transferred to the charge likely counter flow heat exchanger.

Solid scrap falls down in the liquid. The melting of the scrap happens per immersion in the hot heel which is kept in temperature with the electric arc that works always on a flat bath , covered by foamy slag.

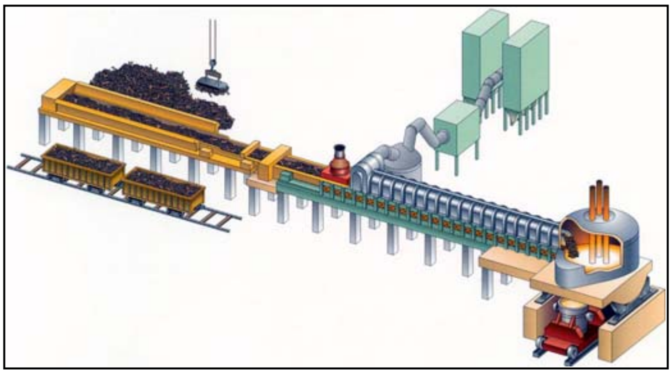

Figure 6: The Consteel® System

The foamy slag covering the arc shields the furnace wall and roof from heat radiation. The arc is stabilised, thus dramatically increasing the efficiency of heat transfer from arc to steel bath. This minimises ‘flicker’ effects on the power supply network. With the arc covered by slag, the melting process is a much less noisy operation than in the case of an arc that is not covered.

The operation of the oxygen and carbon lances is easier and more efficient with a flat bath than when there is solid scrap in the furnace. Also, the slag formers can be added and distributed to ensure that not only is the slag always liquid and homogeneous in composition, but is efficiently reactive with an optimum ferrous oxide content. When the furnace crew become proficient in performing these tasks, the process can be used effectively to achieve substantial advantages compared to the operation of a top-charged EAF.

Several metallurgical studies have shown that flat bath operation and foamy slag practice result in a better chemical equilibrium between the slag and steel. The gas content in the steel is lower and there is less oxidation of steel. In the case of a batch-charged furnace, these conditions occur only at the end of the heat whereas in the new process they persist during the entire melting phase.

Figure 7 are shows, from previous studies, the result of monitoring 80 heats of aluminium-killed steels of different grades before and after implementation of the new melting technology. The heats were melted without changing the procedure for treatment after tapping or the additives used for deoxidation and decarburisation, or any of the other treatments. The figure shows the narrower range of nitrogen contents achieved in billets before and after Consteel®.The difference in average content is 15 ppm.

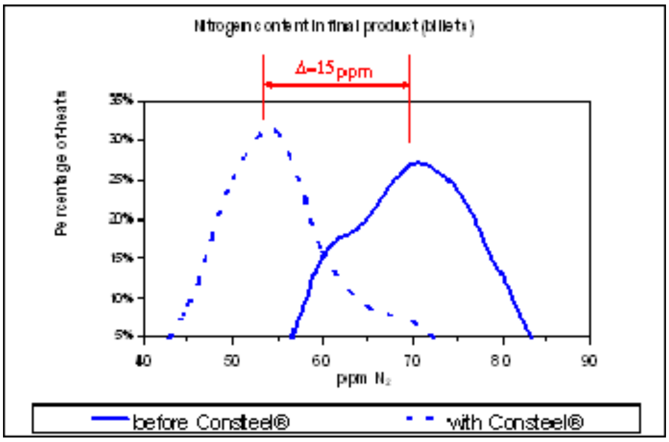

Figure 7: Nitrogen content in cast billets

The level of iron oxide in the slag is considerably lower, in the range 15 to 25 per cent at the beginning of superheating. This observation is based on a series of tests made under the following conditions: bath carbon, 0.07-0.08 per cent; slag basicity, 2.7-2.9; slag MgO, 7-8 per cent; slag FeO, 15-25 per cent; and bath temperature, 1590-1600oC. Steelmaking in batch-charged furnaces typically results in slag FeO contents of 30-35 per cent at that time in the melt.
As a consequence of this much lower FeO content, the oxidation level of the finished steel is lower, the corrosion/erosion of refractories is reduced, and slag viscosity is optimised for foaming purposes. A lower FeO content in the slag also means an increase in the scrap yield so that for the same tapped steel, less charging scrap is requiredl resulting in lower production costs.

3 ANALYSIS OF NITROGEN LEVEL

In order to understand the influence of Consteel® process on the nitrogen pick up and to validate the mentioned study, the data from two steelmaking route are compared: a steel plant with the EAF- Consteel® (Ori Martin, Brescia) and a steel plant with an top charge EAF (TenarisDalmine, Bergamo).

3.1 Ori Martin

ORI Martin Steel Plant, located in Brescia, Italy, produces about 600,000 tons per year of special steel for several applications. The Meltshop is equipped with a 80ton Consteel® EAF, two LMF, one VD and one CCM 5-strands.
The Ori Martin furnace is equipped with a door lance, 1 oxygen burner and the TDRH, the digital electrodes regulation.
In order to confirm the previous results about the lower nitrogen pick up using the Consteel® system, over 6000 data have been collected in the steel plant of Ori Martin. Different mix of metallic materials (Table1) in charge have been considered and for every mix the data average and the distribution have been calculated.

Table1: metallic materials charged in Ori Martin and Nitrogen content

	Mix 1	Mix 2	Mix 3	%N2
Deep Forming Bushellings Scrap	88%	47%		0,004
Bushellings Scrap		47%	32%	0,005
Demolitions Scrap			32%	0,006
Turnings Scrap			32%	0,005
Pig Iron	12%	6%	6%	0,0025

In the following different graphs are shown the nitrogen content in the steel after the tapping for the 3 charging mix.

As shown below the steel produced with Mix 1 has an average Nitrogen content of 0,0049%, with Mix 2 of 0,0053% and with Mix 3 of 0,0055%.

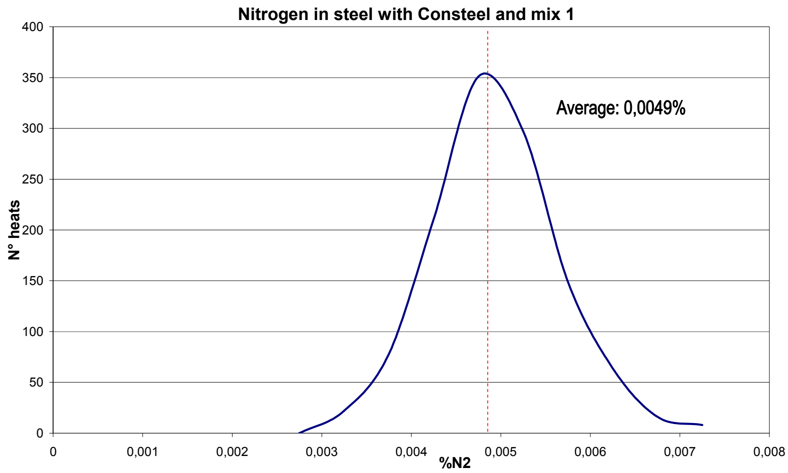

Figure 8: Distribution and average of nitrogen data using the Consteel® and Mix 1

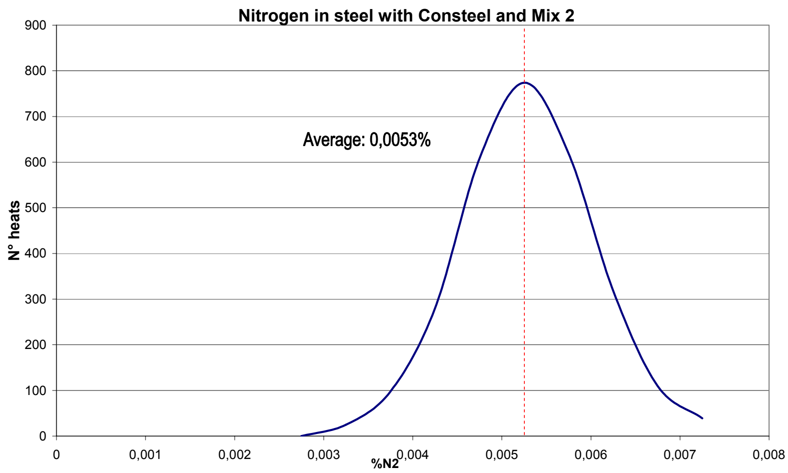

Figure 9: Distribution and average of nitrogen data using the Consteel® and Mix 2

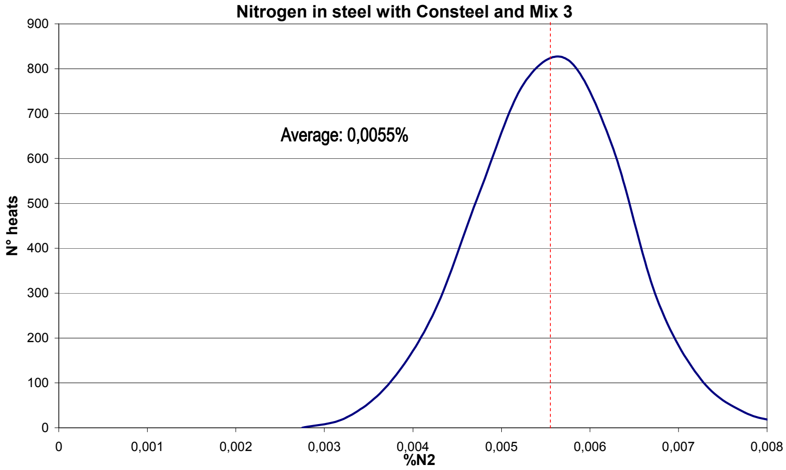

Figure 10: Distribution and average of nitrogen data using the Consteel® and Mix 3

With the aim to understand the influences of the process on the nitrogen pick up, it is evaluated the content of nitrogen in the metallic charge.
The influence of the process has been calculated considering an average content of nitrogen for any mix of charge. Any Mix has a different nitrogen content according to the different metallic materials in charge.
Considering the nitrogen content of any kind of metallic materials, as describe in table 1 the difference between the nitrogen in steel tapped and the nitrogen in raw materials has been calculated. This difference can represent the influence of the process on the Nitrogen pick up.
In Consteel® case, the process influence the nitrogen pick-up for a range of 0,0005% - 0,0008%
Figure 11 shows the percentage of nitrogen in the steel and in the raw materials. The effect of the process in the three cases is shown in Figure 12.

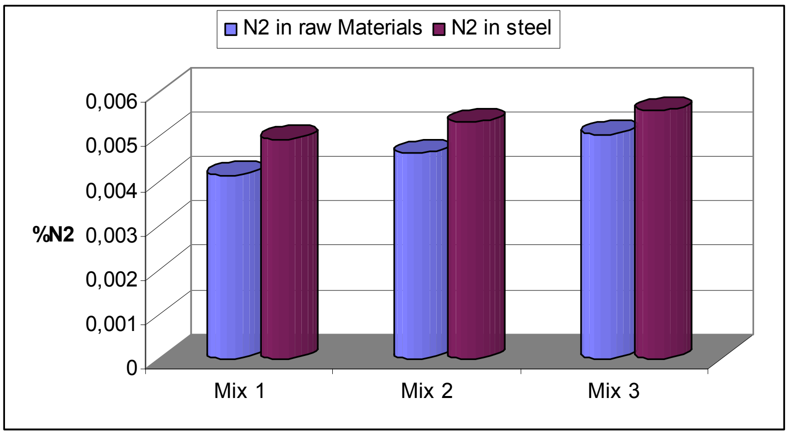

Figure 11: Nitrogen percentage in raw materials and in the steel

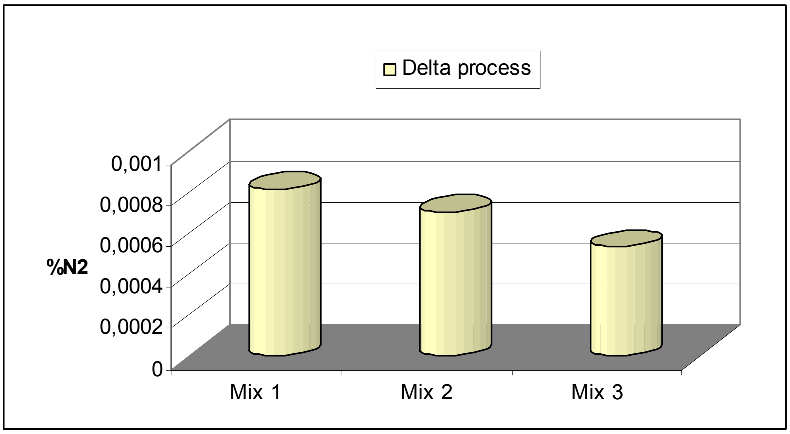

Figure 12: Effect of the Consteel® process on the Nitrogen content in the steel

3.2 TenarisDalmine

The EAF of Tenaris Dalmine, located in the area of Bergamo in the North of Italy, is a 6 m furnace with a tapping capacity of 96 tons of liquid steel. Downstream of the EAF, the Meltshop is equipped with two ladle furnaces, one vacuum degasser and two continuous casting machines for round-bars for the production of seamless pipes, the main product of the Tenaris Group. The EAF is equipped with five burners, three fixed-wall oxygen lances and three fixed-wall carbon injectors as well as a door lance. Over 8000 heats from TenarisDalmine have been analyzed to compare nitrogen level between the top charge and the Consteel® process. In this case for any heat analysed is known which kind of scrap and in which quantity it is charged into the furnace. For this reason it is not necessary to split the data in different categories. It is possible for every heat calculate exactly the amount of nitrogen charged with the raw materials and the nitrogen content in the tapped steel.
The tipical charged materials and the nitrogen content are shown in the Table 2.

Table 2: Average Quantity of charged scrap and nitrogen content

	Average	%N2
Bushellings Scrap	31%	0,005
Demolitions Scrap	12%	0,006
Pig Iron	15%	0,0025
Internal Recovery Scrap	15%	0,0067
Shredded Scrap	10%	0,0045
NPF scrap	9%	0,006
Turnings Scrap	8%	0,005

The following graph shows the distribution and the average of Nitrogen content in the tapped steel. The process analysed shows an average of Nitrogen in steel of 0,0067%.

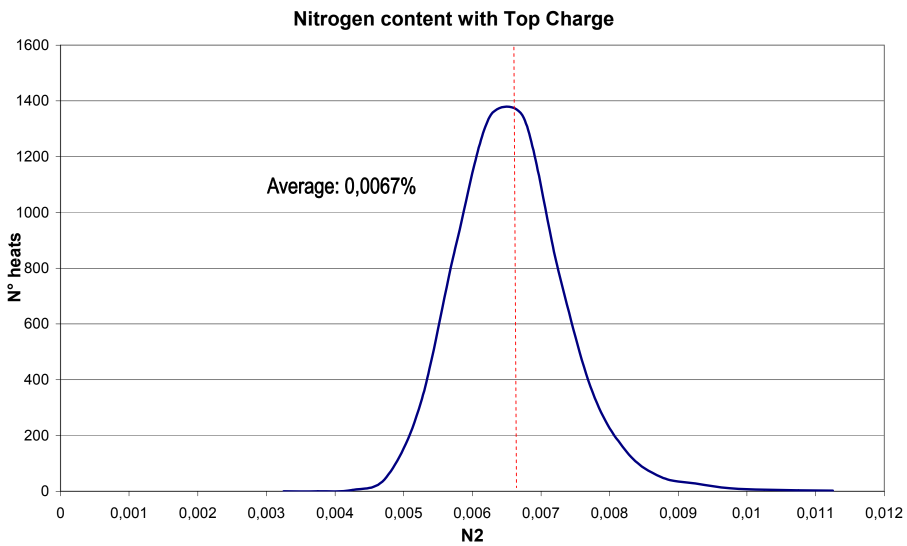

Figure 12: Distribution and average of nitrogen data using a top charge furnace

As said above, the quantity and kind of scrap are known for every heat. For every heat, the amount of Nitrogen charged with the raw materials, and the difference between the nitrogen in steel and the nitrogen charged have been calculated. The average of nitrogen charged with scrap, the average content off nitrogen in tapped steel and the difference are plotted in the graph 13.
As in the previous process, the difference represents the contribution of process on the nitrogen pick up.For the top charge case the process contribute is about 0,0020%.

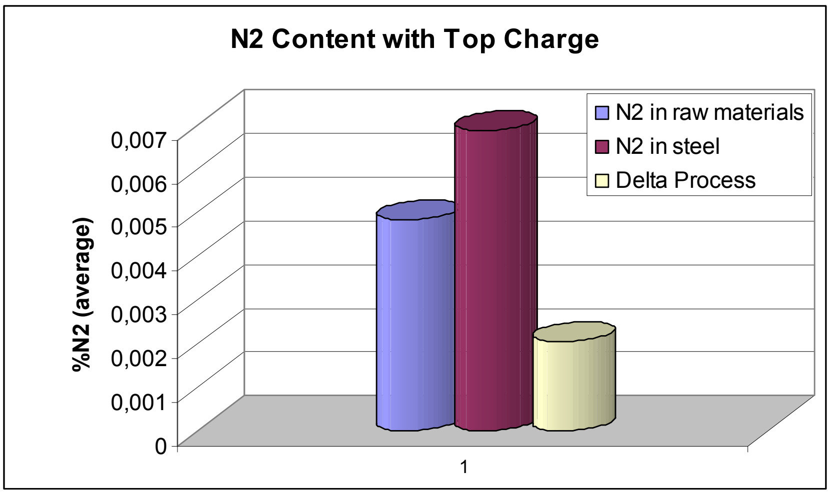

Figure 13: Percentage of nitrogen in raw materials and in the steel, and effect of the top charge process.

4 DISCUSSION

The effect of the Consteel® and the top charge process on the Nitrogen pick up has been compared.
The comparison have to be done between the data referred to the process. In fact, is necessary to avoid the influence of the metallic charge that can affect heavily the Nitrogen content in the tapped steel.
In the following graph the Consteel® and the top-charge effect on nitrogen pick-up are shown. The difference between the 2 processes is about 15 ppm.

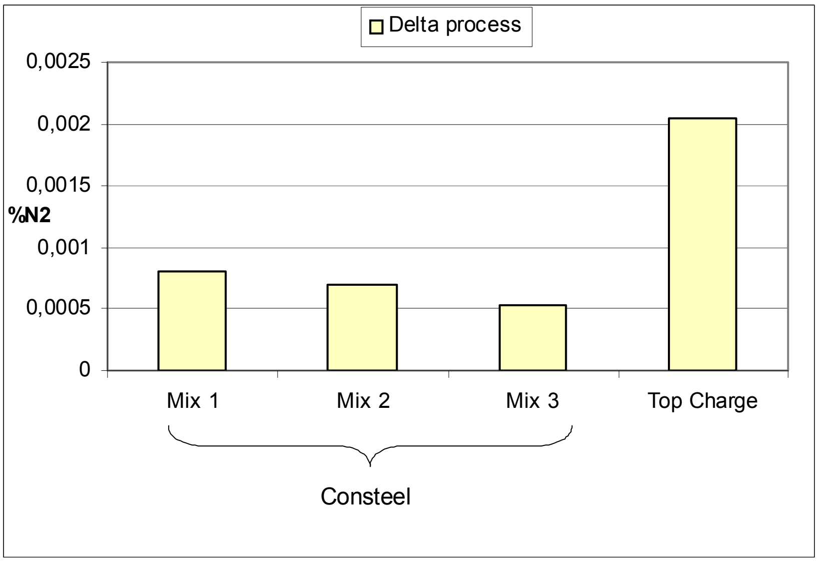

Figure 15: Comparison between the effect of Consteel® and top charge process on the nitrogen content in the steel.

This result agrees with the practical operation of the Consteel® system. The constant flat bath operation permits to the electric arc to be always buried by foamy slag during the whole heat. The presence of foamy slag around the electric arc avoids the contact between the steel and the air. This is the primary reason for lower nitrogen absorption during the melting process.

5 CONCLUSIONS

With the Consteel® process it's possible to reduce the Nitrogen pick-up. Two different process have been analysed: a Consteel® process and a top charge process. In both cases over 6000 heats have been analysed and the nitrogen data have been collected. The effect of metallic charge have been removed and only the effect of the process, calculated through the difference between the amount of nitrogen in the tapped steel and the amount of nitrogen in the raw materials, has been taken in account. The results according to previous studies, show a strongly reduction on Nitrogen pick up in the case of Consteel® process.

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