BENEFITS FOR BOF/EAF STEEL PLANT RESULTING FROM THE PARTIAL SUBSTITUTION OF MANGANESE BY SMALL ADDITIONS OF NIOBIUM

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Abstract

Recent developments proved that it is possible to reduce manganese content by adding small amounts of niobium, keeping the same mechanical properties of structural steels. For low yield strength around 350 MPa, small additions of niobium like 0.010% are enough to maintain the same mechanical properties of the original material, even reducing 0.50% of manganese content. This results in reduction of the costs of alloying design, which must be analyzed based on updated ferroalloy prices. This paper points the benefits that reductions of manganese content can bring to the steelmaker and to the quality of product. The reduction of manganese content results in less additions of FeMn alloys to the liquid steel, allowing to decrease the tapping temperature. This brings many benefits, e.g., regarding the consumption of refractories of BOF/EAF furnace and ladle, the increase of metallic yield, the reduction of amount of aluminum as deoxidizer, phosphorus and sulphur contents, of absorbed hydrogen, nitrogen, of macro-segregation in the semi-products. This paper presents a simulation that considered the reduction of Mn contents from 1.40% to 0.90% associated with the addition of 0.010% Nb, resulting in the reduction of 15ºC in tapping temperature, which brings savings of 8.651 kg/t of FeSiMn; 0.116 Kg of BOF lining/liquid steel; 0.050 kg of ladle lining/t of liquid steel; increase of 0.49% in metallic yield; savings of 0.135 kg/t of aluminum as deoxidizer; reduction of 34 ppm of phosphorous; 1.7 ppm of hydrogen; 8.7 ppm of nitrogen contents; 2.0 ppm of sulphur; 64 % of Mn macro-segregation in the semi-products.

1 INTRODUCTION

Since the start of its activities in Araxá, CBMM strives to provide technology to develop applications where niobium can increase the performance, the life cycle or reduce the costs of the components where it is applied. For this purpose, CBMM provides the technology that can help to overcome the main challenges worldwide: growing wisely and in a sustainable way. CBMM has a technical group acting together with steelmakers, research universities, institutes, and end users. The company started a program for partial substitution of manganese by small additions of niobium in structural steels aiming to reduce the natural resources consumption by using the proper alloy design. The idea was based on the equivalence ratio of Mn and Nb contents for steel plates, proposed by Morozov and presented at Figures 1 and 2 [1]. He and coauthors, studying low alloy steels, realized that there was a clear relation between manganese and niobium contents for the same mechanical properties (Figure 1). For low values of yield strength, 350 MPa, very small additions of niobium (0.010%) are enough to allow considerable reductions of manganese content (0.50%) (Figure 2). Or, alternatively, to get an extra strength increase keeping the same Mn amount.

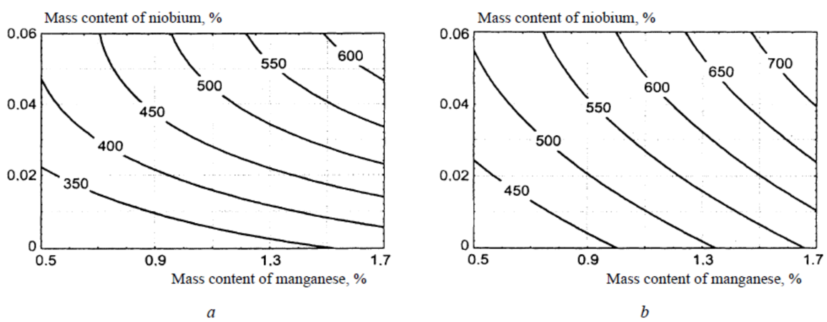

Figure 1. Relationship between manganese and niobium contents for the same values of yield strength (a) and tensile strength (b) for 8 to 12 mm plates [1].

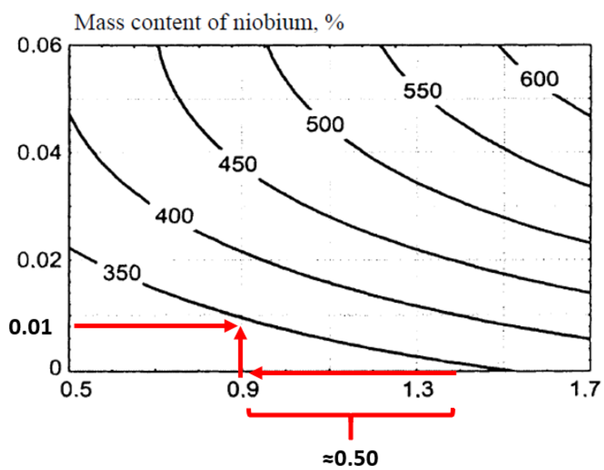

Figure 2. Example showing that a reduction of Mn content from 1.4 % to 0.9% can be compensated by adding 0.010% Nb, keeping 350 MPa of yield strength [1].

A significant cost reduction due to the decrease of manganese consumption has been enabled through the adoption of this concept [2,3]. The objective of this paper is to show the benefits the reduction of manganese contents can bring to the melting shop processes.

2 EFFECT OF FERROALLOY ADDITIONS ON THE TEMPERATURE OF LIQUID STEEL IN THE LADLE

During and after the tapping of liquid steel from the BOF/EAF furnace into the ladle, the temperature of the liquid steel is influenced by some factors, such as heat conduction through the refractory lining, radiation, convection losses to the environment (by the slag and metallic structure of the ladle) and alloy dissolution. Each alloy added causes different thermal effects when dissolved in steel, as they have different chill factors. The chill factors represent the thermal effect of each alloy on the temperature of the metal bath, when dissolution and oxidation reactions occur in the steel. The dissolution of silicon and aluminum in steel, for example, are exothermic, resulting in the heating of the metallic bath, unlike the dissolution of manganese alloys, which are endothermic, causing a decrease in temperature [4].

Steel grades with high Mn contents require high tapping temperatures from the BOF/EAF furnace to the ladle to compensate for the thermal loss caused by the addition of Mn alloys (e.g., FeMnHC or FeSiMn). High tapping temperatures result in high material consumption and accelerate the damage of furnace lining; lengthen operation time and increase the cost of steelmaking. In addition, non-metallic inclusions in molten steel are more difficult to control, and finally affect the quality of the steel products. For structural flat products up to 355 MPa yield strength, large amounts of Mn ferroalloys need to be added to the liquid steel to reach the required Mn content. The reduction of the necessary additions of FeMn alloys will lead to a reduction in the BOF/EAF furnace tapping temperatures. This temperature reduction will open the door to other opportunities to reduce the cost of steel production in the melt shop. Figure 3 shows the savings of FeSiMn addition due to the reduction of manganese content of the steel. Figure 4 shows the resulting reduction of tapping temperature of BOF/EAF furnace. This will result in cost reductions of various Key Performance Indicators (KPI) of BOF/EAF furnace process and equipment, as will be presented.

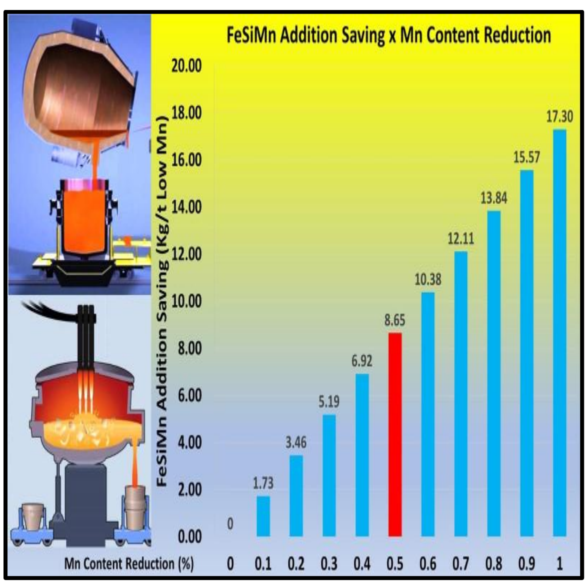

Figure 3. FeSiMn savings as function of lower Mn.

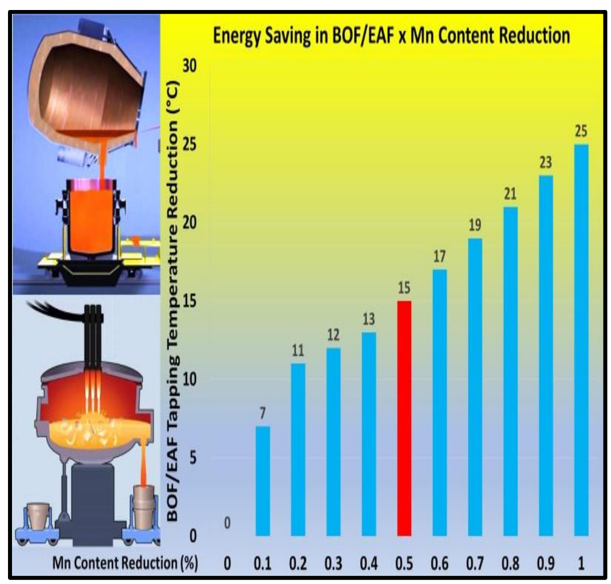

Figure 4. Energy saving as function of lower Mn.

3 DEVELOPMENTS

3.1 Effect of Mn content on BOF furnace lining refractory useful life

3.1.1 BOF furnace with "Slag Splashing" technology

Lining life is a technical and economic concern of oxygen steelmaking. An increase in lining life can not only decrease refractory consumption and reduce smelting cost, but it can also promote efficient production and increase steel yield. A technology known as "slag splashing" is a simple and effective method to increase the life span of BOF furnace lining. The slag splashing was introduced in USA in 1993 and in China in 1995; it is now used for more than 95% of steel produced by the BOF process in China. Slag splashing is the result of the interaction between a top blown gas jet (nitrogen generally) and liquid slag. The top blown gas jet impinges on the bath surface, producing a jet impact zone and making slag splash by a reflex force. Slag is splashed along the edge of the jet impact zone mostly (Figure 5) [5]. A slag coating on the furnace stays on the lining refractory. With enough know-how, up to 60,000 heats with one vessel lining have been realized. Slag splashing is directly associated with factors such as slag properties and amount, lance height and tapping temperature. Tapping temperatures tend to be higher in steels with high Mn content and in cases where there is a lack of secondary refining facilities to heat liquid steel (e.g., ladle furnace). During splashing, if the temperature of the liquid steel is too high, slag is not distributed uniformly and tends to build up in the bottom of the vessel. Figure 6 shows the effect of steel tapping temperature on refractory life [6]. Figure 7 shows the Mn content reduction on the potential reduction in BOF refractory consumption by reducing the tapping temperature.

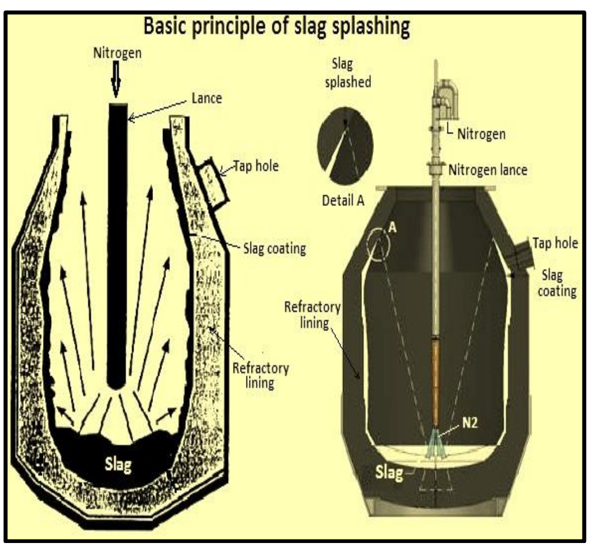

Figure 5. Basic principle of slag splashing [5].

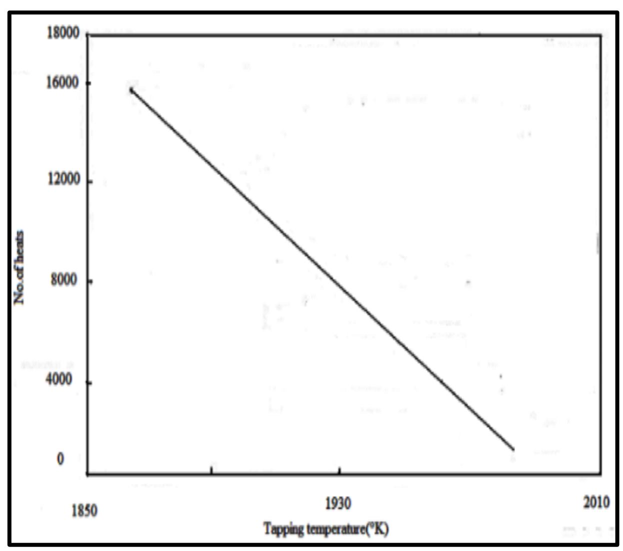

Figure 6. Effect of steel tapping temperature on refractory life [6].

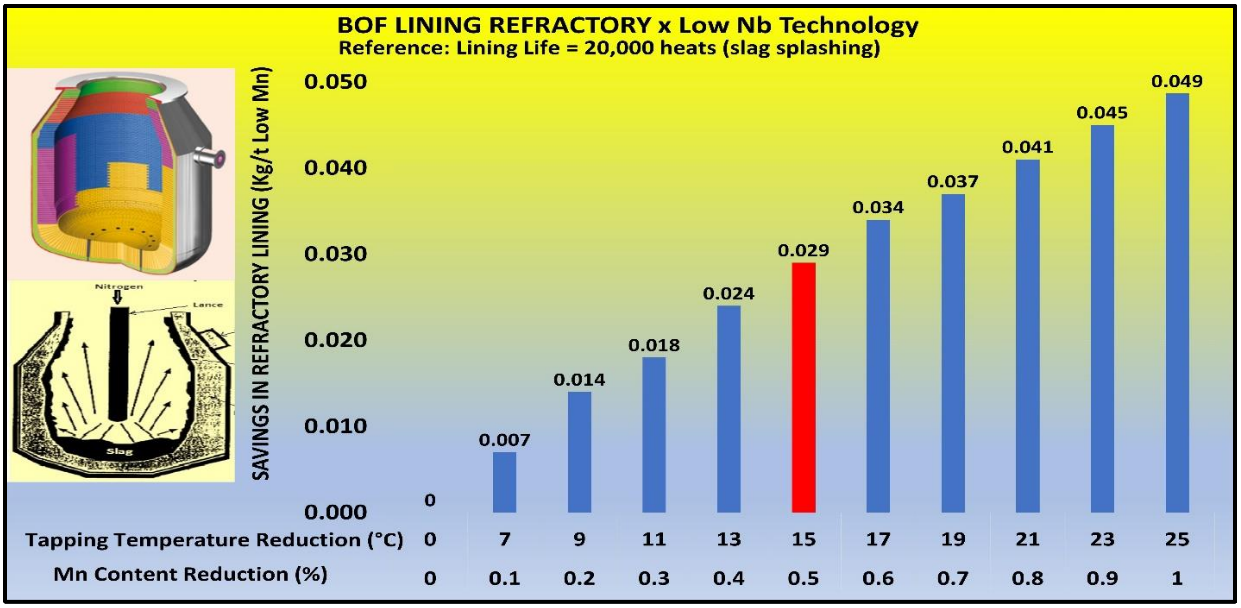

Figure 7. Refractory lining saving in BOF furnace as function of Mn content reduction.

3.1.2 BOF furnace with "Gunning Repair" technology

A technique to extend the vessel lining service life is the gunning of pre-worn areas with special gunning mixes. Accurate gunning leads to a uniform lining wear rate and maximizes utilization of all refractory materials of the vessel. Accelerated wear is also experienced in the trunnion areas of any oxygen furnace, mainly because this area is the most difficult to coat with protective slag. Figure 8 illustrates one furnace campaign in which rapid trunnion wear was experienced in the first 500 heats [7]. Prolonged lining life, no doubt, increases the availability of the BOF furnace, but extending its useful life using the gunning technique increases the cost of the refractory from 5000-6000 heats (Figure 9) [8]. The reduction of manganese content of the steel allows to reduce the tapping temperature. Consequently, the protection repair will have less damage due to the action of the liquid steel, increasing service life for the lining refractory (Figure 10).

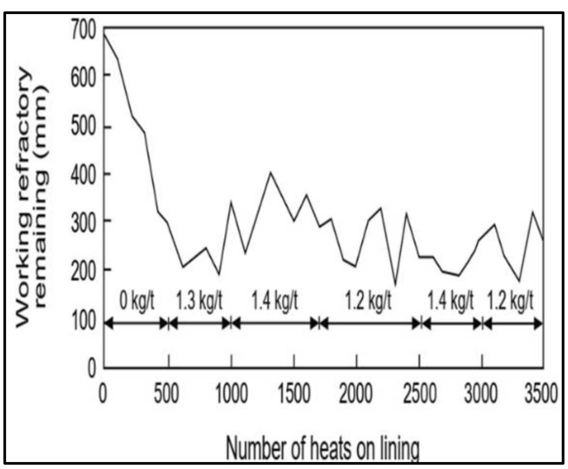

Figure 8. Wear and gunning rate in the trunnion area [7].

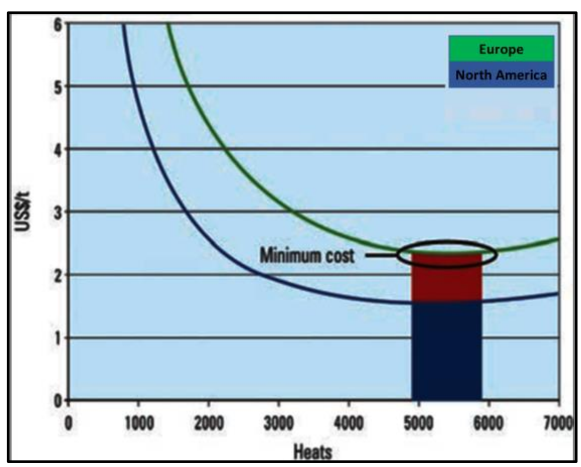

Figure 9. Optimum BOF furnace cost as a function of the number of heats [8].

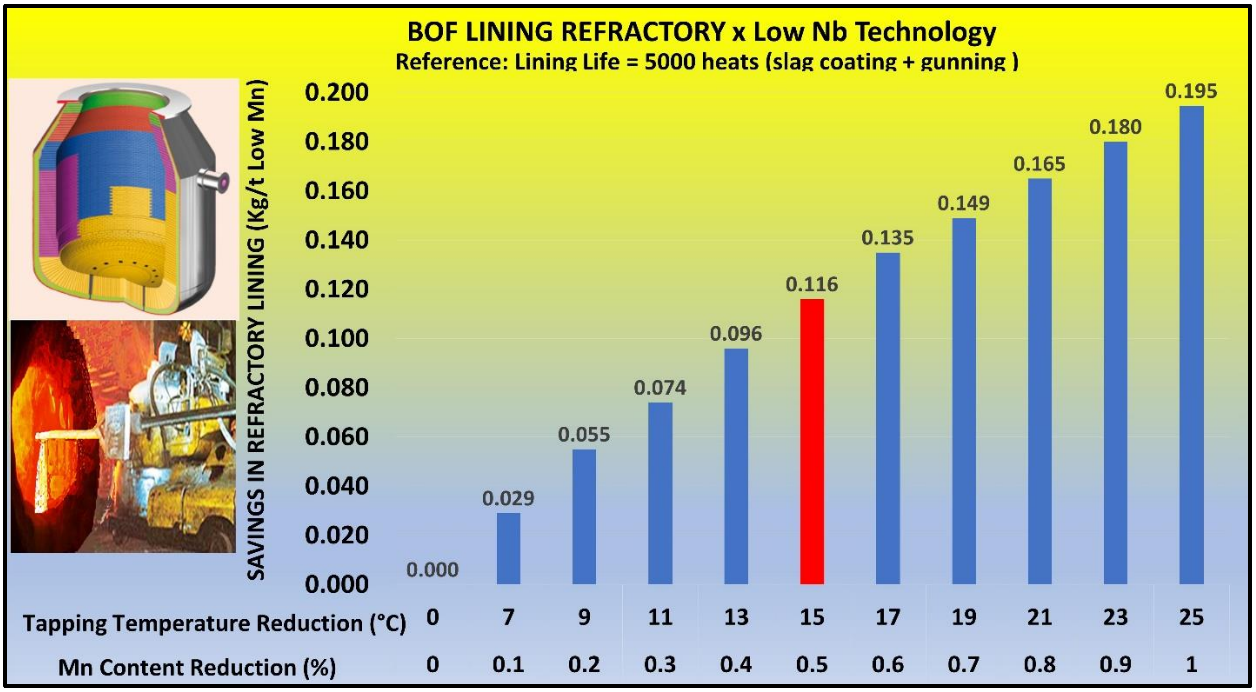

Figure 10. Refractory lining saving in BOF furnace as function of Mn content reduction.

3.2 Steel ladle lining refractory life Low Nb Technology.

There are many variables that influence the life of the steel ladle lining refractory life just like occurs in the BOF/EAF furnace. The tapping temperature is one of these variables, as shown in Figure 11 [9]. In this case, too, the adoption of Low Nb technology will lead to a reduction of refractory costs (Figure 12).

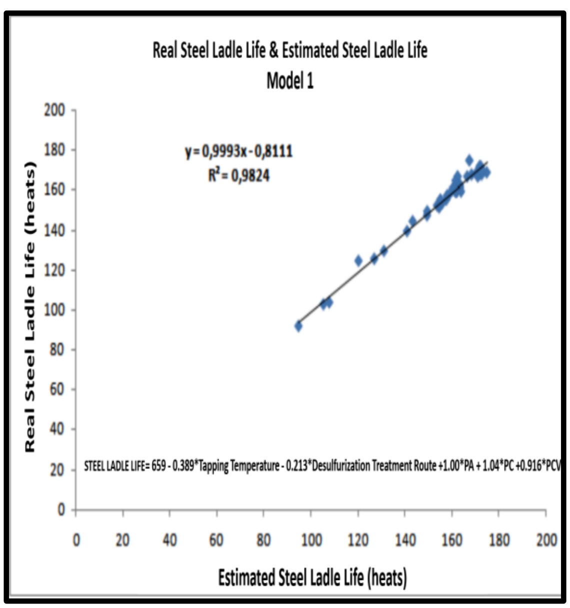

Figure 11. Tapping temperature influence on steel lining refractory life [9].

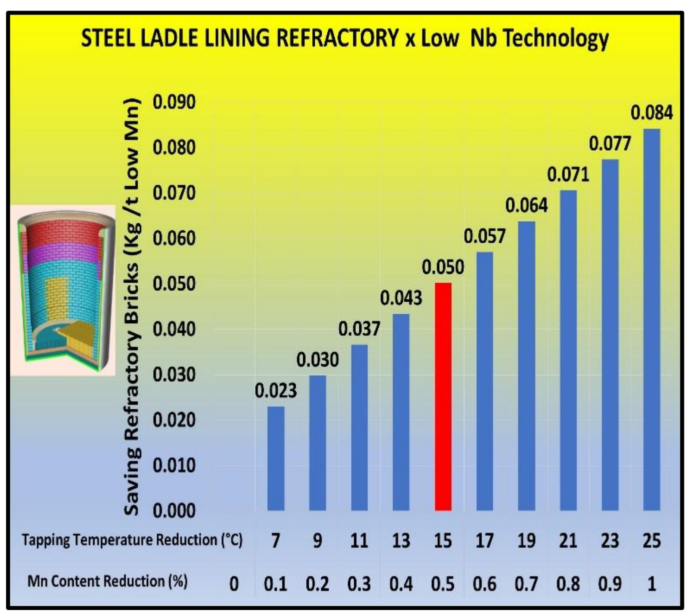

Figure 12. Refractory lining saving in steel ladle as function of Mn content reduction.

3.3 Metallic yield and Low Nb Technology.

The index FeT (that is, *FeT= 0.8*% FeO*) in the slag represents the amount of iron that was oxidized during the blowing of oxygen in the BOF furnace and that became part of slag [10]. Tapping temperature influences the FeT content, as shown in figure 13. The higher the FeT content in the slag, the lower will be the metallic yield, since a greater portion of iron was oxidized and migrated to the slag, rather than remaining in the liquid steel. The use of *lower tapping temperatures* should be aimed for increasing the metallic yield as well. The reduction of Mn on alloy design leads to the increase of metallic yield (Figure 14).

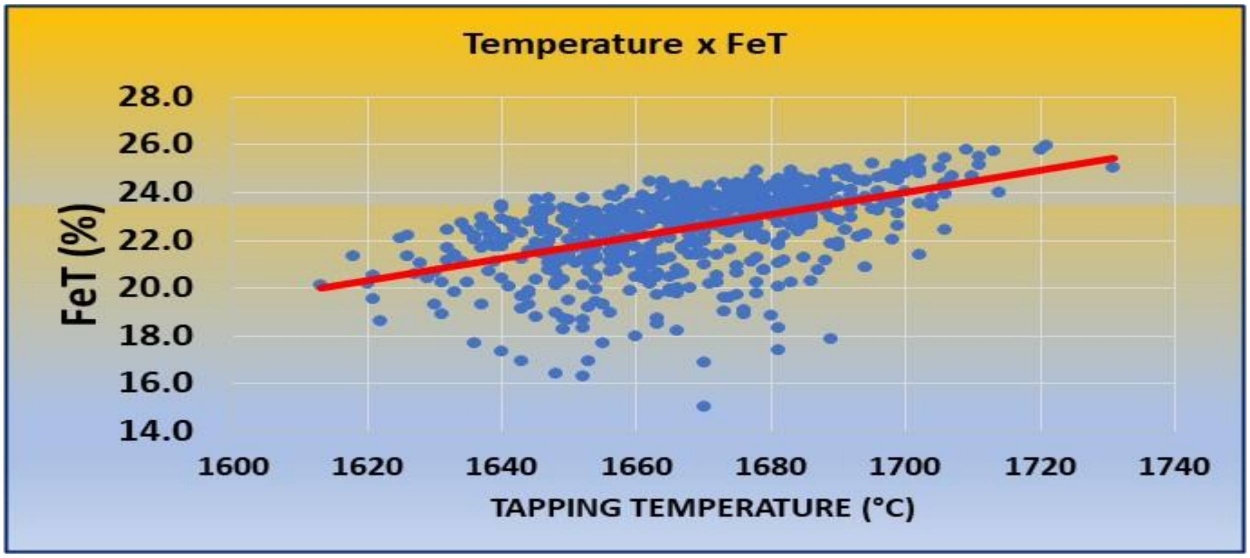

Figure 13. Tapping temperature influence on FeT in the slag.

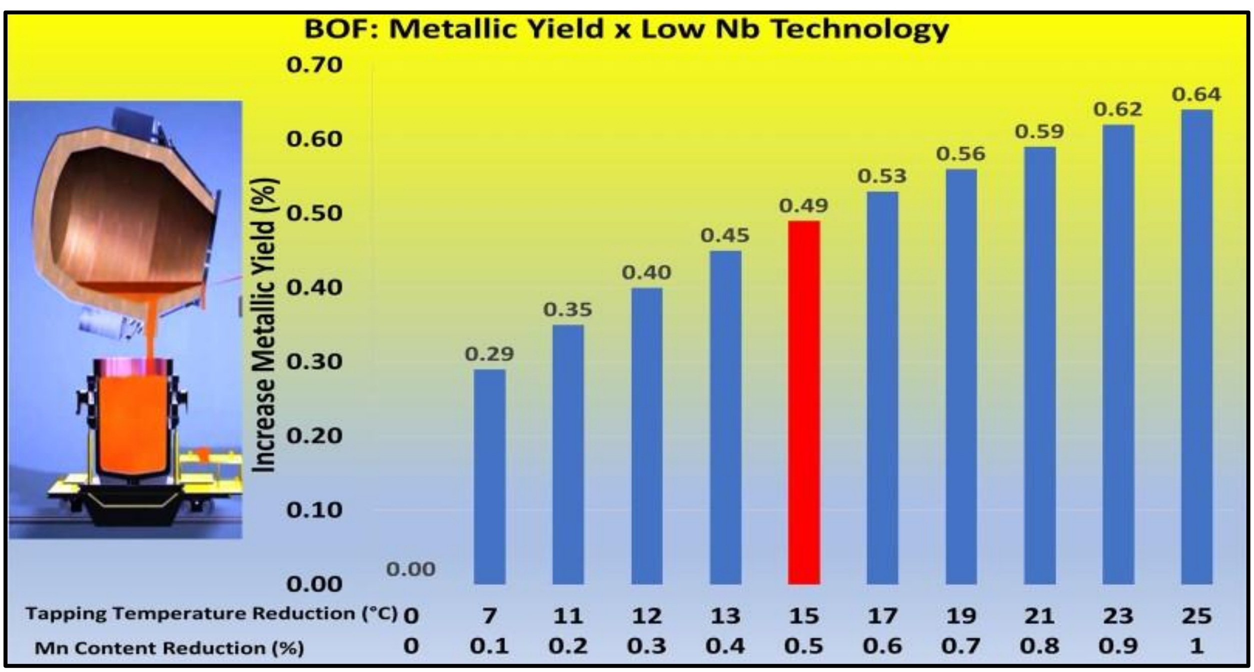

Figure 14. Increase in the BOF furnace metallic yield as function of Mn content reduction.

3.4 Aluminum addition and Low Nb Technology.

Temperature also influences the dissolved oxygen content of the steel, as shown in Figure 15 [11]. Higher tapping temperatures lead to higher dissolved oxygen contents in the metallic bath, increasing the need of aluminum to reduce its oxygen content. The decrease of Mn content allows to adopt lower tapping temperatures and so less aluminum is necessary (Figure 16).

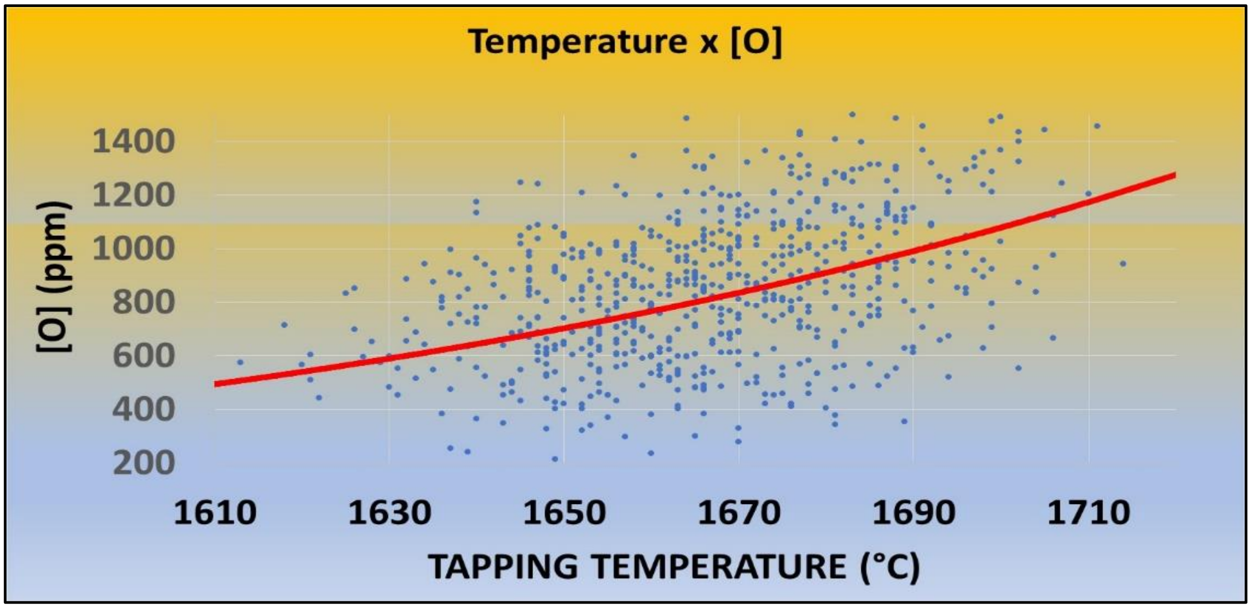

Figure 15. Tapping temperature influence on [O] content.

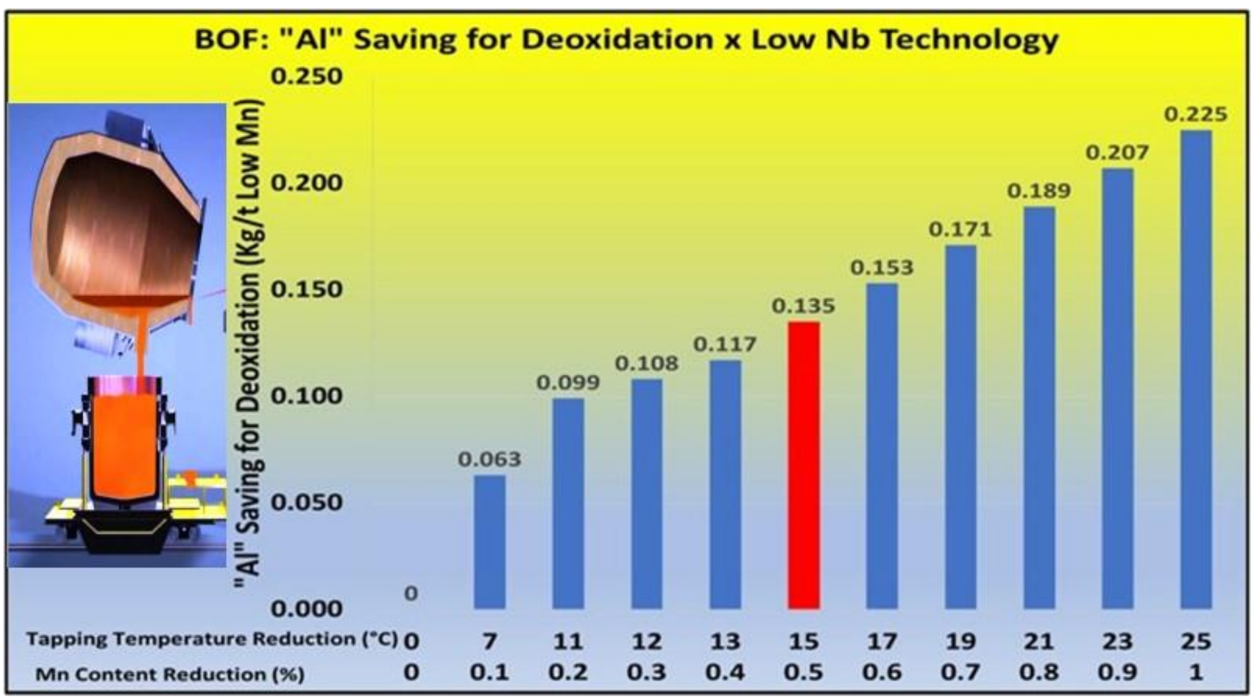

Figure 16. Addition decreases of the deoxidizer Al due to the reduction of tapping temperature at BOF furnace.

3.5 Phosphorus content and Low Nb Technology.

Dephosphorization of steels has become a very important metallurgical technique in steelmaking process to produce high quality steels. P content is controlled by the reactions in the BOF furnace, mainly due to the composition of the slag and the temperature, as shown in Figure 17 [12]. Lower tapping temperatures means lower phosphorus contents in steel (Figure 18).

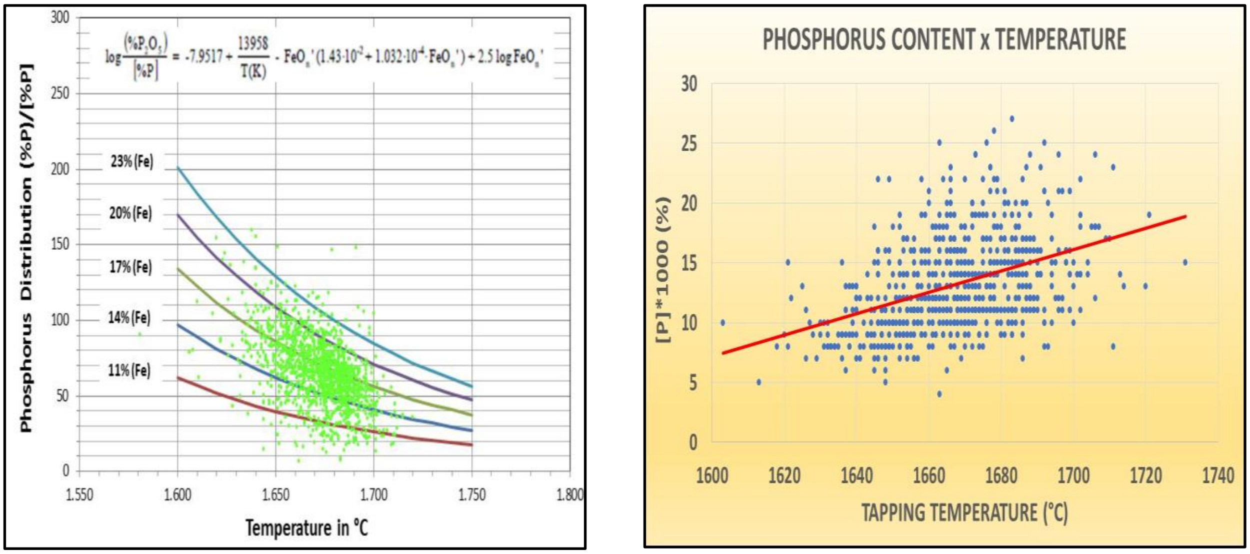

Figure 17. Tapping temperature influence on P contents [12].

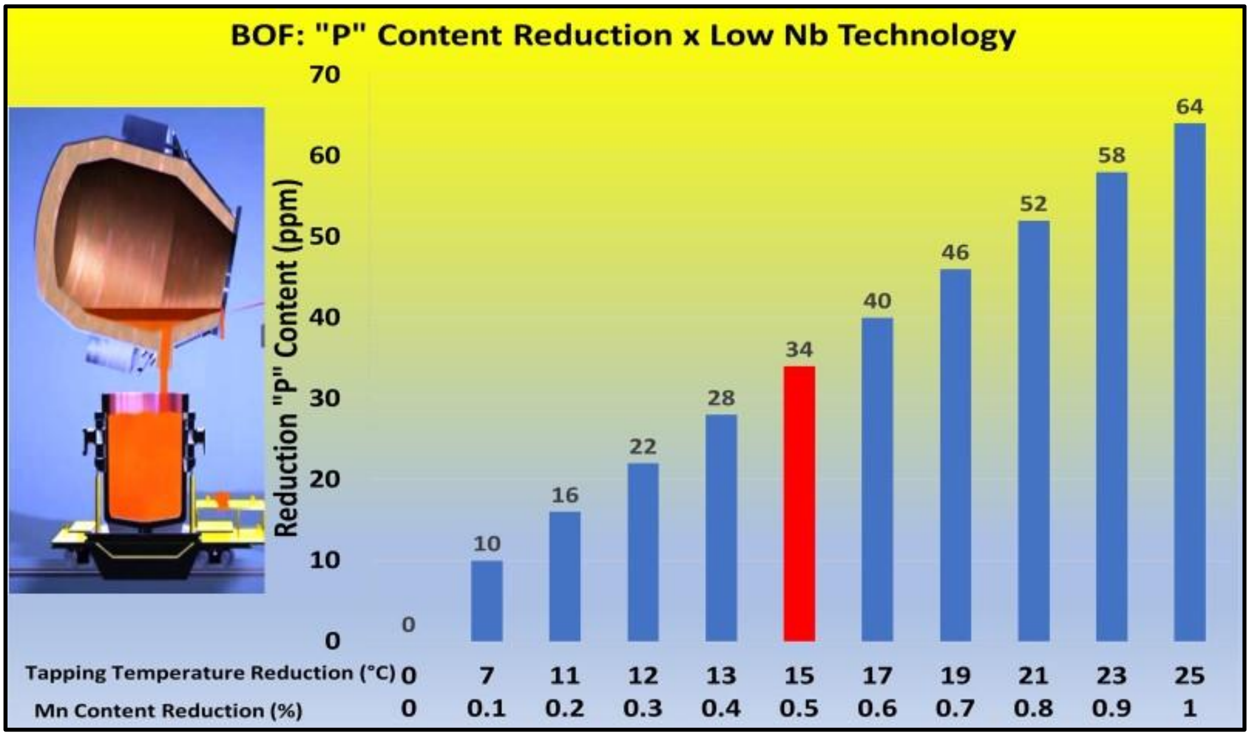

Figure 18. P content reduction as function of Mn content decrease.

3.6 Hydrogen content and Low Nb Technology.

The deleterious effect of hydrogen on steels is well known, especially in high grade steels where hydrogen induced cracks (HIC) can occur. Therefore, every effort should be made to avoid H pick up in steel. There are numerous sources of hydrogen in liquid steel, being ferroalloys an important source to be considered. The addition of some types of ferroalloys, in special, FeMn, causes incorporation of hydrogen in the liquid steel due to their hydrogen and moisture contents, as shown in Figure 19 [13]. Therefore, by reducing the addition of Mn ferroalloys, hydrogen content in steel can be decreased (Figure 20).

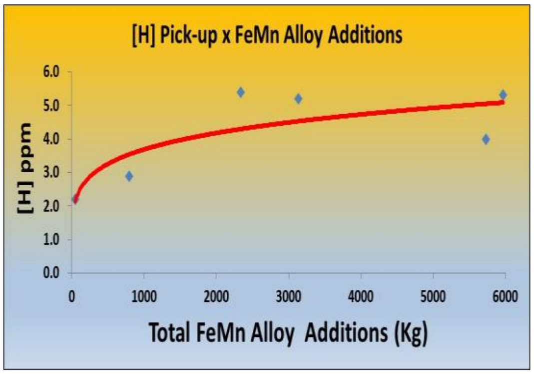

Figure 19. FeMn influence on H content [13].

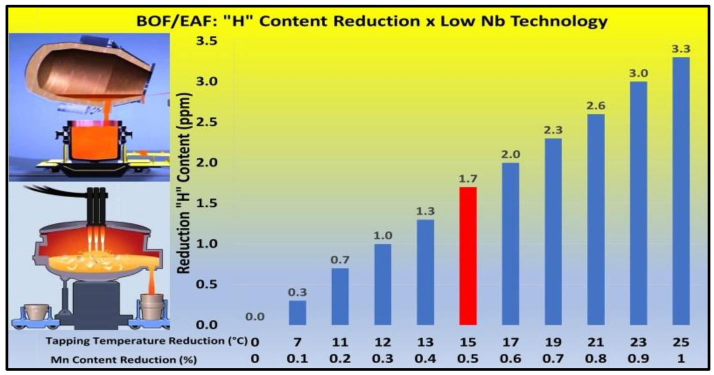

Figure 20. H content reduction (ppm) as function of Mn content

3.7 Nitrogen content and Low Nb Technology.

Ferroalloys, particularly ferrovanadium, ferrochrome, and ferromanganese, are major sources of nitrogen that must be considered in any nitrogen control program. In the melting of low and medium carbon steels, these ferroalloys are added in the ladle and directly increase the nitrogen content of the steel. This pickup can be in the range of 10-20 ppm N, depending on the type and amount of ferroalloy added. Typical nitrogen analysis for ferroalloys, by manufacturing process, are shown in Table I [14]. Therefore, by reducing the addition of Mn alloys, N in steel will decrease (Figure 21).

Various Ferroalloys (Process)	N, ppm
75 percent FeSi	70
80 percent FeV (Aluminothermic)	200 max.
55 percent FeV (Silicothermic)	60 max.
Ferromanganese (Blast Furnace)	200-500
Ferromanganese (Silicothermic)	300-500
Ferromanganese (Aluminothermic)	600-800
FeMo	110
FeTi	220
FeW	10

Table I. Nitrogen content of various ferroalloys and processes [14].

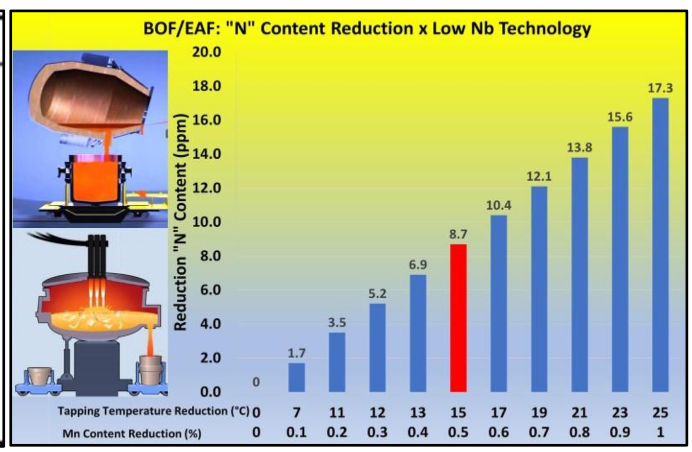

Figure 21. N content reduction (ppm) as function of Mn content decrease.

3.8 Manganese segregation in continuous casting and Low Nb Technology.

High strength steels with high manganese content offer an exceptional balance of strength and ductility. However, the occurrence of segregation in these steels, particularly at the strand centerline, leads to quality control issues in the continuously cast slabs. Moreover, segregation of manganese during the continuous casting process can lead to the formation of detrimental microstructural banding in subsequent manufacturing operations. The Figure 22 shows that Mn centerline segregation in the continuous casting slab grows exponentially with the increase in its content (red curve) [15]. Reducing Mn content results on the reduction of centerline segregation, improving slab quality (Figure 23).

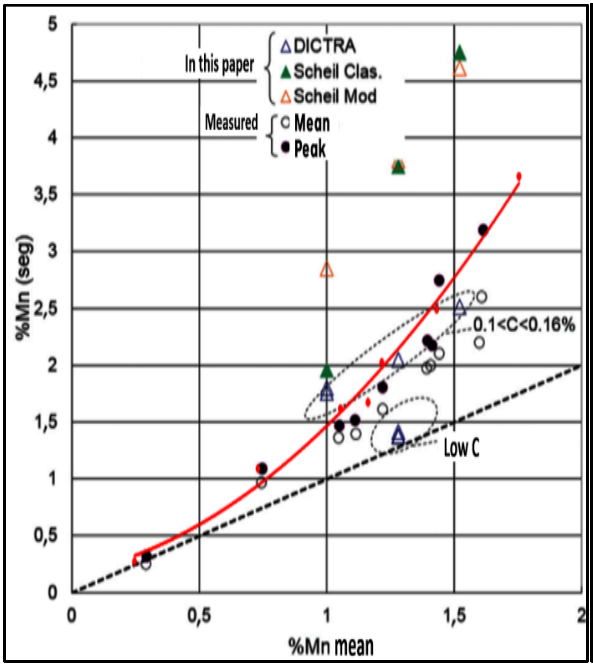

Figure 22. Segregated Mn content during continuous function of its nominal content [15].

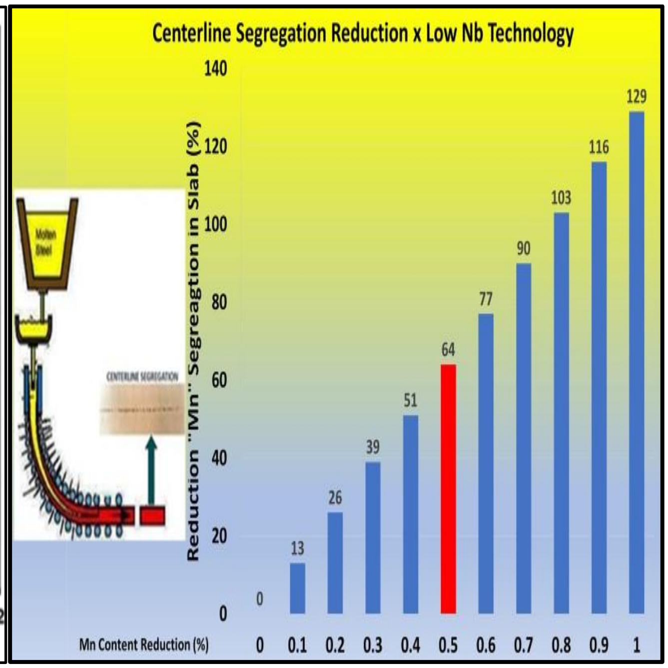

Figure 23. Centerline segregation percentage casting as a reduction as function of Mn content decrease.

4 EXAMPLES OF POTENTIAL GAINS WITH LOW NIOBIUM TECHNOLOGY

Considering all these KPIs in a computer program, one can get a summary of improvements that the reduction of Mn content from 1.40% to 0.90% compensated with the addition of 0.010% Nb can bring for structural steel production. This reduction of Mn amount allows the decrease the FeSiMn addition which implies in tapping temperature reduction, resulting on savings of BOF furnace lining/t of produced steel (when applying the gunning technique), savings on ladle lining/t of produced steel, increase metallic yield and saving aluminum, as presented at Table II. The Low Nb technology also improves steel quality with reductions in P, H, N, S amounts, and macro-segregation in continuous casting.

Table II. Simulation of the benefits that reduction of manganese content from 1.40% to 0.90% by adding 0.010%Nb can bring to the production of structural steel.

EXAMPLE OF POTENTIAL GAINS WITH LOW Nb TECHNOLOGY

"TRADITIONAL" Q 345	ELEMENT	C	Mn	Si	P	S	Cu	Ni	Nb	V	Ti	Al	B	Cr	Mo	N
	%	0.16	1.40	0.25	0.020	0.005	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.00	0.00	0.005
"NEW"Q 345	ELEMENT	C	Mn	Si	P	S	Cu	Ni	Nb	V	Ti	Al	B	Cr	Mo	N
	%	0.16	0.90	0.25	0.020	0.005	0.000	0.000	0.010	0.000	0.000	0.025	0.000	0.00	0.00	0.005

Addition Savings: FeSiMn		Kg / t LOW Nb	8.651
Tapping Temperature Reduction		° C	15
Saving LD Lining Refractory Consumption	SLAG SPLASHING	Kg / t LOW Nb	0.029
	GUNNING	Kg / t LOW Nb	0.116
Saving Steel Ladle Lining Refractory Consumption		Kg / t LOW Nb	0.050
Increase LD Metallic Yield		%	0.49
Addition Savings: Al for deoxidation		Kg / t LOW Nb	0.135
"P" Content Reduction in the Ladle		ppm	34.0
"H" Content Reduction in the Ladle		ppm	1.7
"N" Content Reduction in the Ladle		ppm	8.7
"S" Content Reduction in the Ladle		ppm	2.0
Manganese Centerline Segregation Reduction		%	64

5 CONCLUSIONS

Recent developments proved that it is possible to reduce manganese content in structural steels by adding a small amount of niobium and keeping the same mechanical properties (Low Nb Technology). For low values of yield strength, like 350 MPa, small additions of niobium like 0.010% are enough to keep the same mechanical properties of material, even reducing 0.50% of manganese. Normally there are reductions of alloy design costs that must be analysed based on updated ferroalloy prices. Once the reduction of Mn content results in less additions of FeSiMn, the tapping temperature can be decreased, bringing the following advantages for the steel production:

- Saving of refractory lining in the BOF/EAF furnace and in the ladle,
- Increase of metallic yield,
- Reduction of amount of Aluminum as deoxidizer, Phosphorus and Sulphur contents,
- Reduction of absorbed hydrogen and nitrogen,
- Reduction of macro segregation in continuous casting,

Acknowledgments

The authors are grateful to CBMM for its kind support during the elaboration of this paper.

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