BLAST FURNACE TROUGH AND RUNNERS: TECHNIQUES FOR MINIMIZING THE WORKING LINING OXIDATION PROCESS[1]

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Abstract

One of the major challenges for the refractories industry for iron and steelmaking process is the oxidation control of materials with SiC (silicon carbide) and/or C (carbon) content. The paper shows that besides the antioxidant additives incorporated in the material, some techniques to minimize the oxidation in Blast Furnace trough and runners refractories (Al_2O_3-SiC-C based). Changes in application method, new working lining materials, total relining program, metal shell adaptation and coating protection were applied to minimize the main trough working lining oxidation. An oxidation decreasing was observed and good results of refractory specific consumption were obtained.

Key words: Blast Furnace trough; Oxidation minimization; Specific consumption

CANAIS DE CORRIDA DE ALTOS-FORNOS: TÉCNICAS PARA MINIMIZAR O PROCESSO DE OXIDAÇÃO DO REVESTIMENTO DE TRABALHO

Resumo

Uma dos maiores desafios dos fabricantes de refratários para a siderurgia é o controle de oxidação de materiais contendo SiC (carbeto de silício) e/ou C (carbono). Neste trabalho são mostrados, além de aditivos antioxidantes incorporados ao refratário, algumas técnicas para minimizar a oxidação de materiais a base de Al_2O_3-SiC-C utilizados em canais de corrida de altos-fornos. Alterações no método de aplicação, novos materiais de trabalho, programa de troca do revestimento refratário, adaptações na carcaça metálica e utilização de recobrimento de proteção foram aplicados para minimizar o processo de oxidação de canais principais. Foi constatado um decréscimo da oxidação do material refratário, assim como uma importante diminuição do consumo específico.

Palavras-chave: Canais de altos-fornos; Minimização da oxidação; Consumo específico.

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1 INTRODUCTION

1.1 Silicon Carbide and Carbon as Components of Blast Furnace Trough Materials

The wear in blast furnace trough and runners is mainly caused by the following factors:
- Thermal shock
- Oxidation process
- Chemical attack by molten slag and pig iron
- Erosion of molten pig iron and slag
- High temperatures

The additions of silicon carbide (SiC) as well as C (carbon) in Al_2O_3-SiC-C trough material promote several benefits as thermal shock resistance, increase of thermal conductivity and enhance the slag attack resistance results from the low wetability of carbon by molten oxides [(1)] and the low solubility of silicon carbide.[(2)]

Notwithstanding, the major disadvantage of the SiC and C is the oxidation susceptibility. The immediate consequence for the refractory material is shown as follow:

<u>Immediate consequence of silicon carbide oxidation in trough material</u>

$$SiC \xrightarrow{\text{Oxidation}} SiO_{(g)} \quad \text{or} \quad SiO_2$$

→ $SiO_{(g)}$: Increase of the porosity, decreasing the mechanical resistance and the slag / pig iron infiltration, as well as the resistance of the air penetration.
→ SiO_2: Decrease the refractoriness and the attack of molten slag and iron

<u>Immediate consequence of carbon oxidation in trough material</u>

$$C \xrightarrow{\text{Oxidation}} CO_{(g)} \quad \text{or} \quad CO_{2(g)}$$

→ $CO_{(g)}$ or $CO_{2(g)}$: Increase of the porosity, decreasing the mechanical resistance and the slag / pig iron infiltration, as well as the resistance of the air penetration.

1.2 The Carbon and Silicon Carbide Oxidation

1.2.1 The carbon Oxidation

In despite of the kinetics's oxidation of the carbon is higher over the 600ºC, the direct oxidation of the carbon by the gas oxygen (O_2) begins between 400 and 1200ºC and $P_{O2} \geq 10^{-4}$ atm (equation A). At temperatures over than 1400ºC, the indirect oxidation becomes quickly predominant and the carbon reacts with the solid oxide, liquid or gas suboxides in the system.[(1)]

$C_{(s)} + O_{2(g)} \rightarrow 2CO_{(g)}$ (Equation A)

1.2.2 The silicon carbide oxidation

Silicon carbide is not stable in an oxidizing atmosphere and will be oxidized at high temperature.

There are different oxidation mechanisms, based on the oxygen partial pressure, temperature, impurities and water steam.

- **Passive oxidation**

At relatively high oxygen partial pressure results in the formation of silica according to the following reaction:

$2SiC_{(s)} + 3O_2 \rightarrow 2SiO_{2\,(l\ or\ s)} + 2CO$ (Equation B)

The rate-determining step of the reaction is the oxygen diffusion through the silica film, which is formed by oxidation of the SiC surface. Until the silica film is formed, the oxidation rate is high. However, once the silica film is completely formed, the rate-determining step becomes the diffusion through the silica film, and the rate of oxidation is extremely slow (2).

- **Active oxidation**

In this case, oxidation occurs when the oxygen partial pressure is relatively low and the equation for this reaction is written as follows:

$SiC_{(s)} + O_2 \rightarrow SiO_{(g)} + CO$ (Equation C)

The partial pressure of $SiO_{(g)}$ on SiC increases as the oxygen partial pressure decreases. If the oxygen partial pressure is low enough, the formation of SiO gas is promoted and an oxide film will not be formed. The SiO gas diffuses out of the system and disappears. As no oxide film is formed, there is a relatively high reaction rate, which is higher than the rate of passive oxidation, and the reaction continues. The reaction is usually accompanied by structural damage such as porosity increasing and weakening of the structure.(2)

- **The influence of temperature in the SiC oxidation rate(3)**

There is low probability of SiC oxidation at temperatures between 1100ºC and 1350ºC. That was due to the reaction of silica with other components and refractory impurities forming a protective layer to the SiC grains.

On the other hand, at temperatures lower than 1100ºC the silica layer remains porous and does not avoid the gases contact with the SiC surface. Herewith, the high oxidation rate is particularly occurred around 980ºC. The oxidation rate is drastically reduced to lower than 815ºC, due to SiC stability.

The oxidation rate increases at temperatures above 1350ºC. It occurs because the viscosity of the silica film becomes excessive low and exposes the SiC for oxygen interaction.

- **The water steam**

Even at a relative low temperatures, the SiC oxidation can be accelerated by the water steam. That was due to the silica solubility in water is dependent of temperature and pressure.(4)

The SiC react with water steam as following:

$SiC + H_2O_{(g)} \rightarrow SiO_2 + CO_{(g)} + 3H_2$ for Temp. > 1127ºC (Equation D)
$SiC + H_2O_{(g)} \rightarrow SiO_2 + CH_{4(g)}$ for Temp. < 1127ºC (Equation E)

2.1 The Oxidation Mechanism of Blast Furnace Main Troughs

The most common oxidation mechanisms in main trough working lining are described as follows.

2.1.1 Oxidation from the border

The trough's border does not suffer direct contact with slag or pig iron and becomes the most susceptible region to the oxidation process.

In the long term, the oxidation reaches the regions below called slag line and further the metal line. As the working lining is partially replaced after trough cycle (campaign), the remaining lining can suffer a strong oxidation after a long period of operation (in general, more than 1 year). The mechanism is shown in Figure 1.

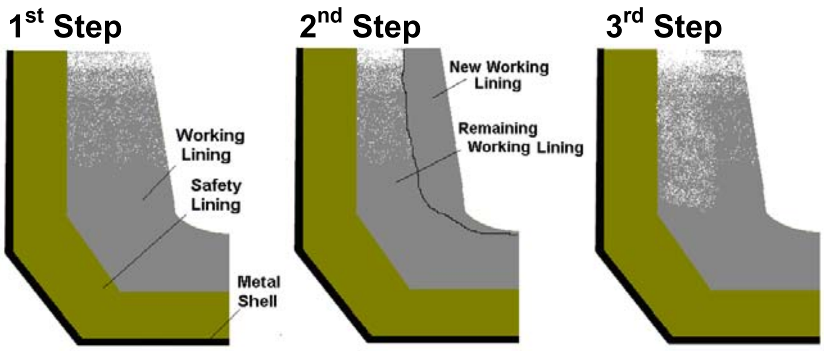

Figure 1. Oxidation process of remaining lining

2.1.2 Oxidation through the working lining and safety lining interface

The safety lining and working lining material have, in general, different thermal expansion coefficients resulting in distinct behavior at high temperatures during the trough's operation.

Many times a gap between the materials occurs as a result of different thermal expansions. In this way, the air penetration though the main trough wall is facilitated. The Figure 2 shows the mechanism.

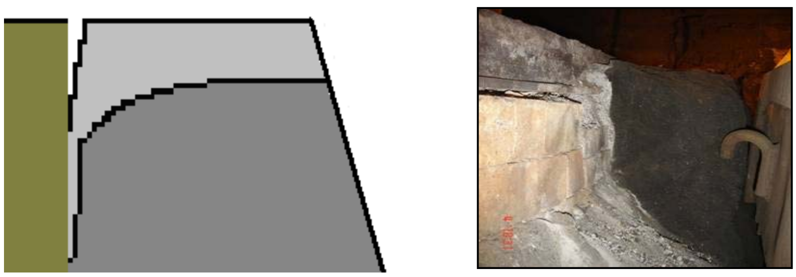

Figure 2. Oxidation process through working lining and safety lining interface

In this case, the oxidation process is faster than the first case and can be detected during the repair process. When the layer with slag and pig iron incrusted is removed with a cutting machine to apply a new material; a big portion of the material falls down due a crack through the oxidized and, consequently, weak interface. Thus, material with good properties is removed from the main trough's walls in the short term, resulting in a high working lining material consumption.

2.1.3 Oxidation through water steam

Practices in the casthouse, where water is widely used during the trough operation, can affect and accelerate the oxidation process. Some of them are listed as follows:
- Cleaning at the casthouse floor
- Mud gun cooling
- Cooling at the main trough close to the tap hole to allow the operator to get closer and prepare the next cast with sand.

When the water reaches the material at high temperature, suddenly become steam. The water steam reacts with the protective layer (SiO_2), resulting in an increasing of SiC oxidation, as already described in the introduction.

Another point is that the water in contact with the trough materials during the operation can cause cracks in the lining due to thermal shock. The cracks formed can facilitate the air penetration through the refractory and accelerate the SiC and the C oxidation.

The Figure 3 shows a trough region with strong oxidation in the slag line after a campaign mainly caused by water used for mud gun cooling.

2.1.4 Others factors

Other factors can be pointed out as causes of premature oxidation of the working lining material:
- Cracks in the metallic shell
- Metallic shell deterioration, allowing the air reach the refractory material
- Metallic shell deformation
- Cutting (repair) with the main trough temperature > 700ºC

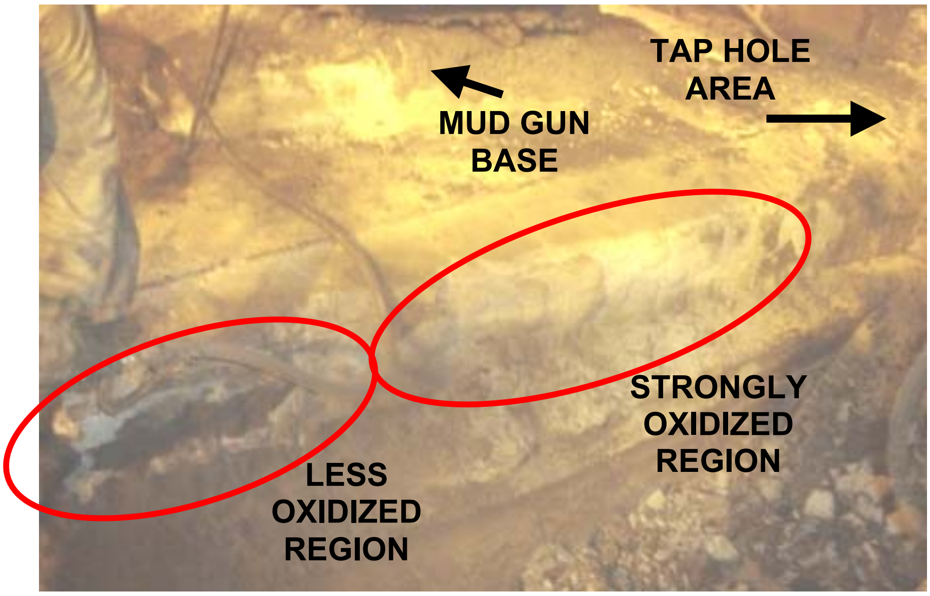

Figure 3. Strong oxidation region caused mainly by water steam

2 METHOD

2.1 Methods to minimize the trough oxidation

2.1.1 New working lining materials

The incorporation of antioxidants components as raw-materials in trough and runners materials is the most known technique to minimize the oxidation process.

Special antioxidant additives (metal powder and its alloys, as well as carbides, borides and nickel oxide) have been used in the slag line to prevent the trough material oxidation.(5) The Table 1 shows the main oxidation inhibitors currently in use.

Table 1. Reaction and characteristics of the main oxidation inhibitors (2)

Aluminium	$1Al_{(l)} + 3CO_{(g)} \rightarrow Al_2O_3 + 3C_{(s)}$
Silicon	$Si_{(s)} + C_{(s)} \rightarrow SiC_{(s)}$, $SiC_{(s)} + 2CO_{(g)} \rightarrow SiO_2 + 3C_{(s)}$
Boron Carbide	$B_4C_{(s)} + 6CO_{(g)} \rightarrow 2B_2O_{3(l)} + 7C_{(S)}$

When the trough material oxidation is controlled, important results can be obtained such wear decreasing, trough campaign prolongation, operational safety increasing and reduction of specific consumption of refractory material.

The zone lining material technique was carried out to prevent the oxidation. This technique consists in casting different materials: one for metal line and another one for slag line. Once the level of castable for metal line is reached, the casting of slag line material is started. The result is showed schematically in Figure 4.

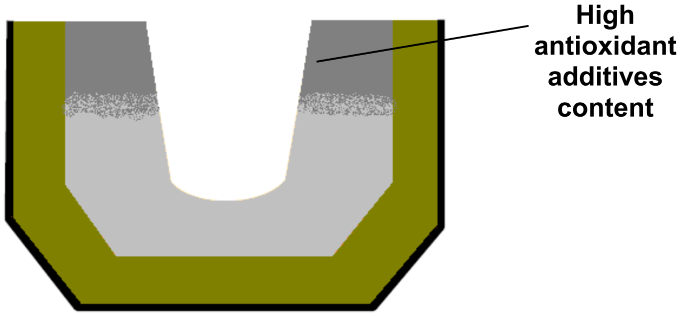

Figure 4. Example of zone lining technique: special materials for specific zones

2.1.2 Total relining program

For the current technology, the main trough oxidation can be minimized but not totally avoided.

Besides the natural oxidation of SiC and C, the process can be intensified by lining's micro-cracks caused by thermo-mechanical stress induced by:

a) Different thermal expansion between the materials: working lining / safety lining / insulation material / metallic shell.

b) Thermal gradient during the operation

c) Thermal cycles:

Cold to hot: when the trough starts its operation after a repair

Hot to cold: when the trough is drained for hot or cold repair

As the remaining lining is not easily inspected, the oxidation can intensify and reach large proportion in a long term. The material's resistance (slag and pig iron attack) decreases with oxidation phenomenon. Hence, a risk of an abrupt increase of the wear speed when a corrosive pig iron or slag reaches the oxidized material is very high, and, in the worst case, a break-out must be considered.

Once oxidized, the remaining material tends to be more porous and more susceptible to the air penetration. Consequently, the partial new working lining material casted during a repair tends to react with oxygen easily when compared with a material casted on a non oxidized remaining material. So, a total relining program was established: each 1.5 million of pig iron throughput.

2.1.3 Metallic shell adaptation

In order to prevent the oxidation process caused by air penetration through working lining and safety lining interface (phenomenon described in *The Oxidation Mechanism of Blast Furnace Main Troughs*), a metallic shell adaptation in the main trough border was introduced (Figure 5).

As it can be seen in the Figure 5, the 80 mm border addition avoids the air exposed interface and the oxidation process, thus the refractory specific consumption tends to be reduced.

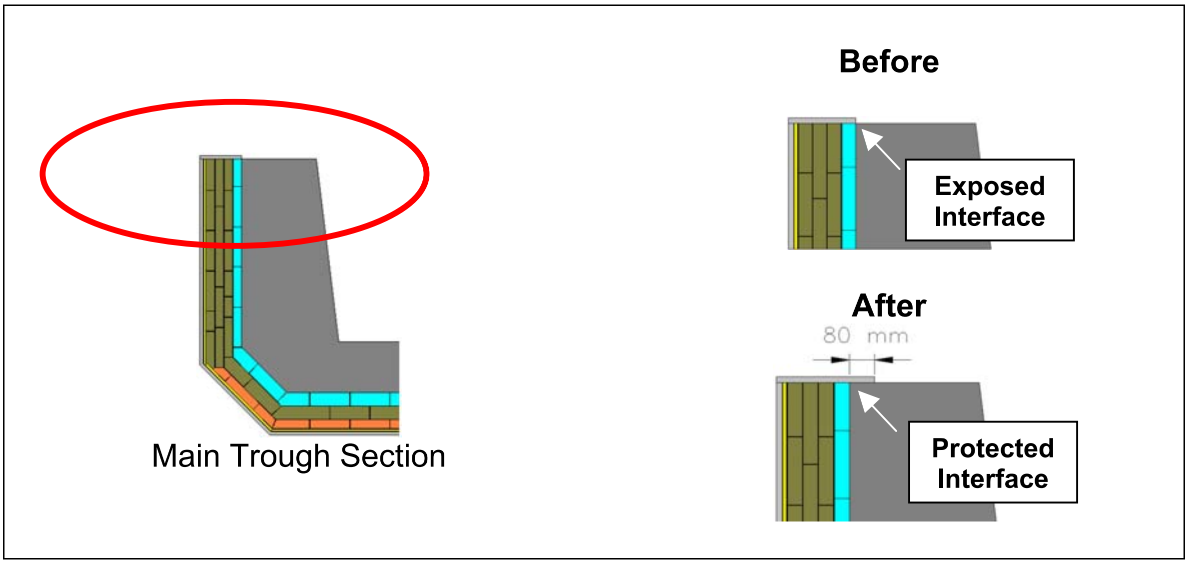

Figure 5. Metallc shell adaptation to minimize the oxidation process caused by air penetration through working lining and safety lining interface.

2.1.4 Coating protection

The use of coating as a protective layer to increase the oxidation resistance of carbon and SiC materials has been investigated [6].

A boron based protective coating was introduced in order to minimize the oxidation mechanism. A 3 mm coating was applied in the main trough border and then a 130 mm of a high density alumina castable was casted on the coating as showed in Figure 6.

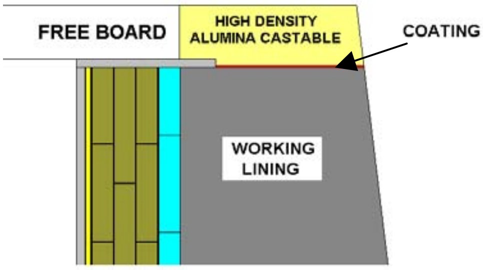

Figure 6. Protective coating to minimize oxidation process

The coating application creates a vitreous layer on the working lining, increasing the oxidation resistance of the though material. An alumina castable was applied on the coating to avoid cracks in the vitreous layer and its damage by iron/slag splash.

3 RESULTS AND DISCUSSION

As it can be seen in the Figures 7, 8 and 9 the specific consumption (kg of refractory material / ton of pig iron throughput) could be reduced after the total relining (working and safety lining) and the other techniques to minimize the oxidation described above.

The Figures 7 and 9 clearly show that the total relining is a good way to reduce the specific consumption.

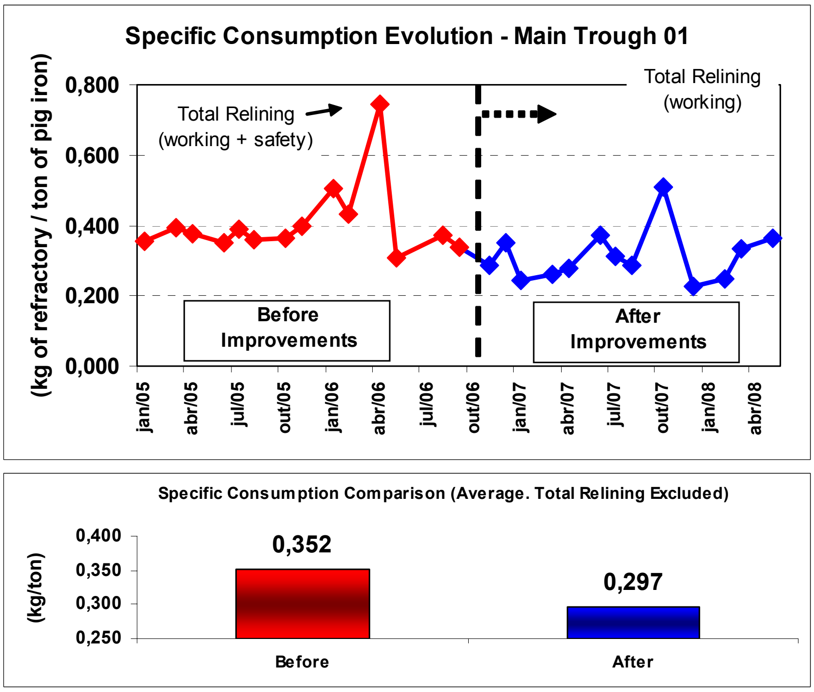

Figure 7. Specific consumption evolution of main trough 01

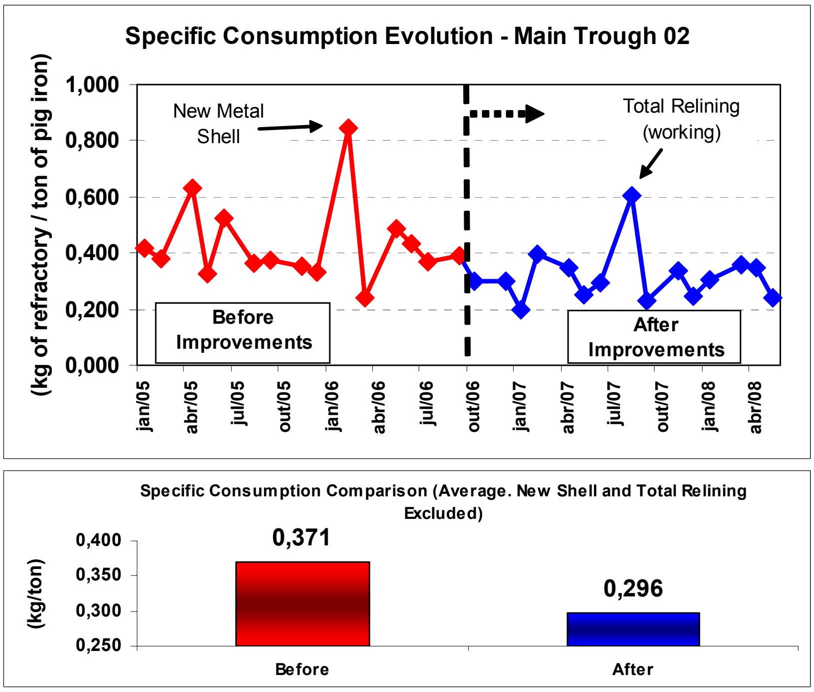

Figure 8. Specific consumption evolution of main trough 02

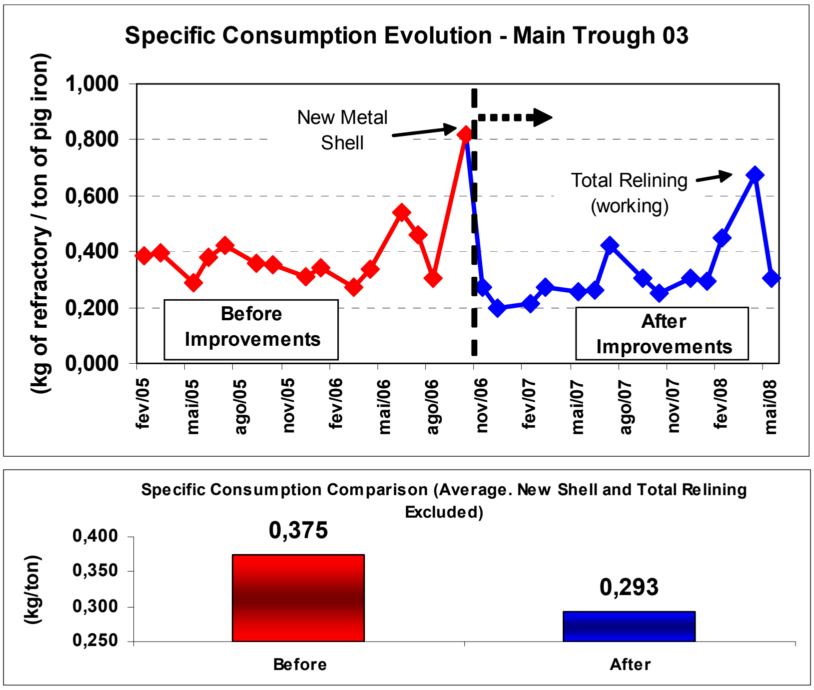

Figure 9. Specific consumption evolution of main trough 03

In case of the main trough 02 (Figure 8), the techniques of zone lining material, metal shell adaptation as well as the coating application, shows that they are important ways to reduce the materials consumption.

The oxidation minimization can be seen in Figure 10. In most of the time is very common the trough border present an oxidation without any problem regarding the operational safety. However, once the border is oxidized the oxidation process easily reaches the remaining lining causing risk of a strong wear or high consumption.

a) Before Coating b) After Coating

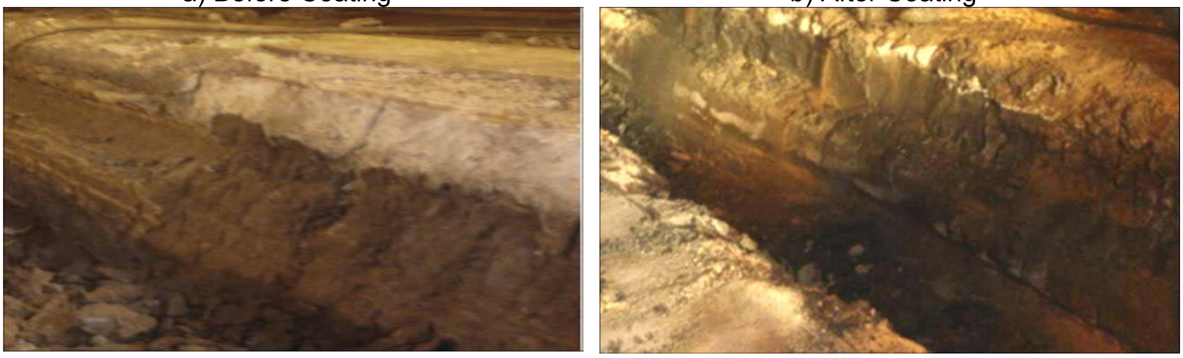

Figure 10. a) Before coating – oxidized border. b) After coating – main trough walls protected

The Figure 11 shows pictures taken during the cutting and shows the benefit of the metal shell adaptation. No more oxidized layer between working lining and safety lining interface was observed. A risk of slag/pig iron infiltration caused by the oxidation process of remaining material was reduced as well as the specific consumption of refractory material.

a) Before metal shell adaptation b) After metal shell adaptation

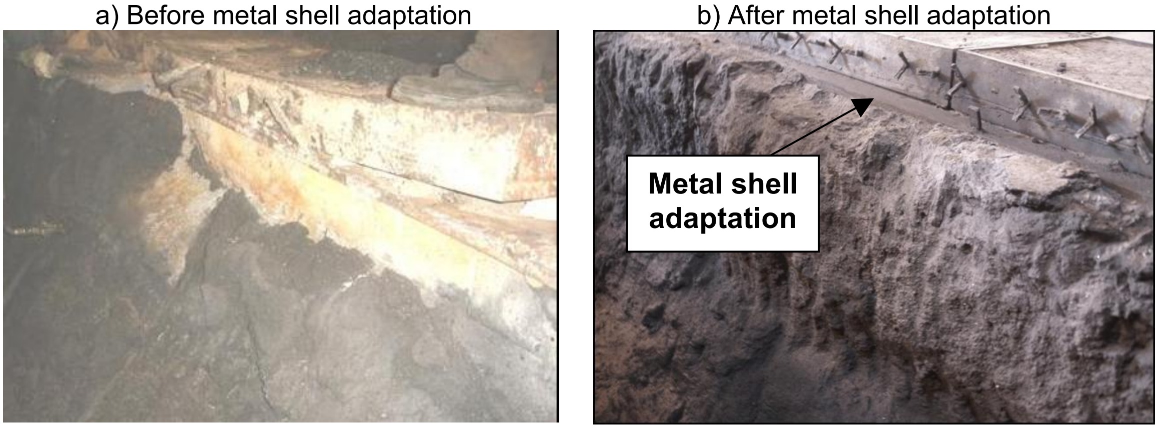

Figure 11. a) Pig iron/slag infiltration risk and loss of good state materials and b) Good conditions

4 CONCLUSION

The Blast Furnace trough and runners refractories (Al_2O_3-SiC-C based) oxidized during the operation causing specific consumption increasing and/or operational risks in long term.

Besides the antioxidant additives incorporated in the material, techniques for minimizing the oxidation like total relining program, zone lining, metal shell adaptation as well as the coating application were effective. As a result, an additional operational safety as well as an important specific consumption reduction of refractory were obtained.

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