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WEAR MECHANISMS IN DIFFERENT ZONES OF LD-CONVERTERS[1]

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Abstract
Different wear zones in BOF refractory linings are presented and discussed. Whereas chemical wear in terms of corrosion and oxidation is the main wear mechanism in the tapping- and slag-zone, a combination of chemical and thermomechanical wear can be attributed to the lower cone and bottom. In the trunnion and barrel the MgO-C bricks are affected by oxidation, in the upper cone additionally by abrasion. Heavy mechanical shocks act on the scrap impact pad. The wear can be balanced by the use of MgO-C bricks based on various MgO grades (96, 97, 98 % MgO, Fused Magnesia, Dead Burnt Magnesia), stainless steel-fibres and Ceramically Bonded MgO-C Bricks. Cardboards allow destruction-free expansion of the bricks and minimization of thermomechanical wear.
Key words: BOF; Refractories, Fused magnesia; Dead burnt magnesia.

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1 INTRODUCTION

MgO-C-brick linings are standard in Basic Oxygen Furnaces (BOF) all over the world. Different zones in the vessel with specific loads require a well-balanced lining to achieve high efficiency of the whole lining and thus optimal cost effectiveness. Wear mechanisms and suitable countermeasures in different zones in a BOF are discussed in the following.

Refractory wear can be attributed to three main phenomena:[1]

- Corrosion and Oxidation

Reactions between refractories and slags or other compounds and formation of liquid or gaseous substances on the hot face of the lining.

- Spalling and Thermomechanical wear

Mechanical destruction by stresses, generated by thermal expansion or mechanical shocks; filling of open pores of the refractories with liquids or sublimating gases, deterioration of inner structure because of different thermal expansion properties and / or reactions accompanied by a change in volume.

- Abrasion and Erosion

Mechanical removal of the original or weakened surface of the refractories, often in combination or as a result of corrosion.

In the practical use of refractories in BOFs one will find that wear is mostly attributed to a mixture of these three main wear mechanisms, as illustrated in Figure 1.

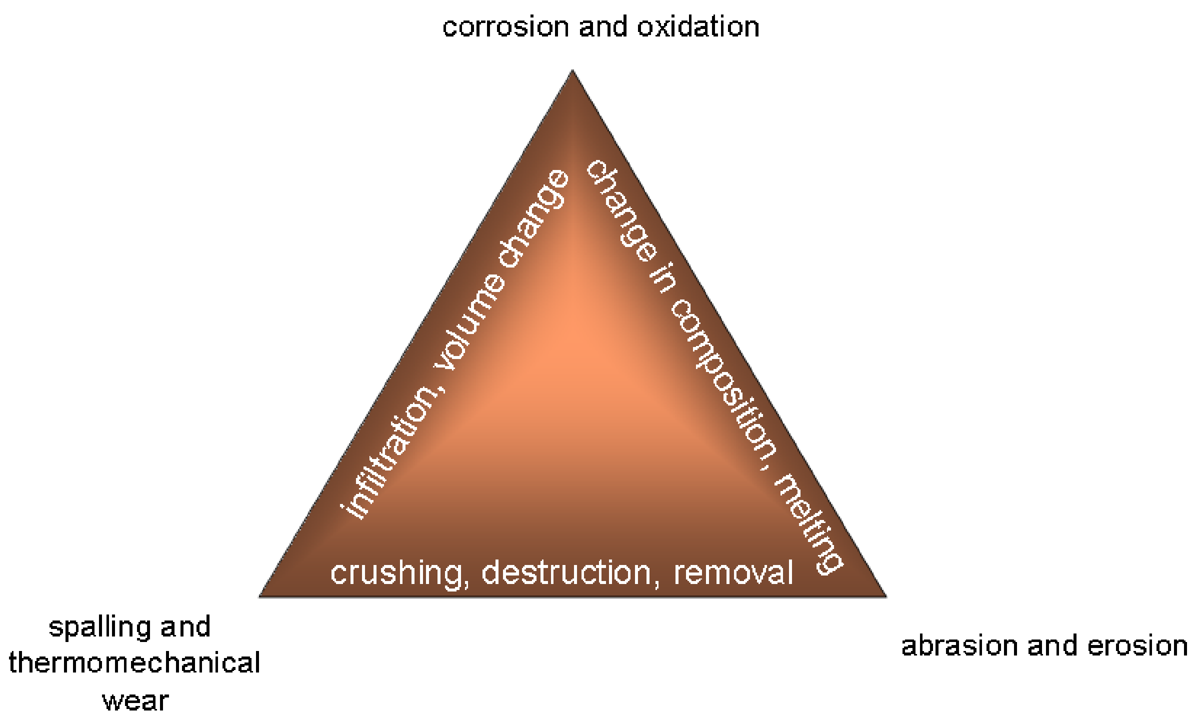

Figure 1: Triangle of refractory wear in a BOF.

2 REFRACTORY ZONES IN A BOF

The refractory lining of a BOF comprises different areas in which different wear mechanisms occur. In the following these different areas will be presented.

2.1 Upper Cone and Barrel

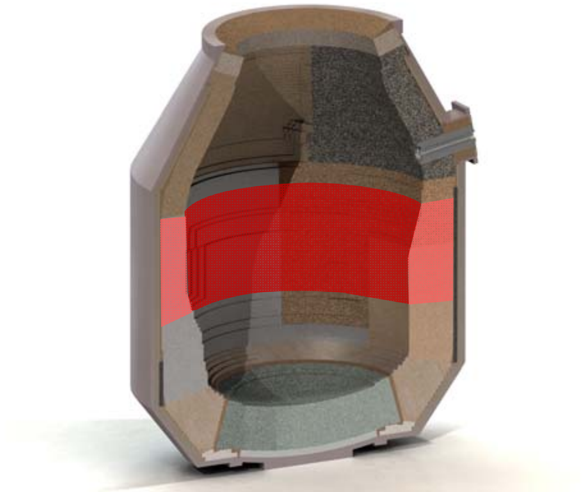

Figure 2: Barrel in a BOF-lining.

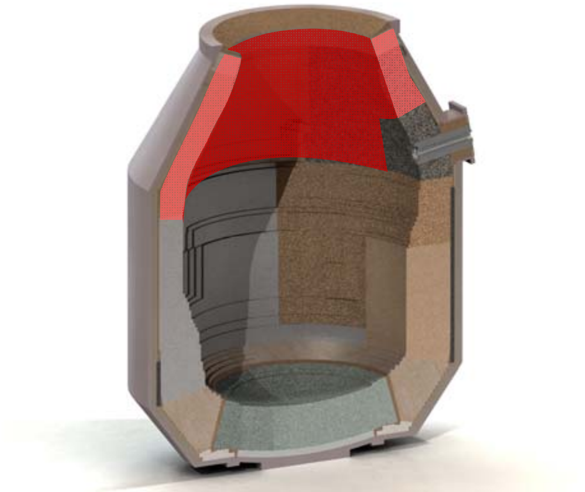

Figure 3: Upper Cone in a BOF-lining.

The upper cone, i.e. the topmost, conical part of the BOF and the barrel are rather slightly stressed zone. The bricks are eroded there by gas-particle jets as well as by carbon burnout. Brick grades based on dead-burned magnesia (DBM) containing 96 to 97 % MgO + 5 to 10 % carbon have proved efficient in these parts. Even use of MgO-C bricks based on recycled MgO-C grog can be useful in upper cone linings. Reinforcement in the part close to the tap hole might be necessary in some cases. Sometimes, the upper layers can loosen and fall into the BOF, especially in vessels without a lip ring fixation. During cleaning of the mouth from solidified slag and steel these bricks are sometimes torn off the lining. To stop further loss of bricks this part is closed by gunning. Sometimes burnt MgO bricks are used instead of MgO-C due to there stability against oxidation, but also Ceramically Bonded MgO-C Bricks (“CBMC”)[(2)] show better performances in this application due to there higher residual strength after complete oxidation.[(3)]

However, recent investigations have shown that MgO-C bricks tend to decompose and wear out just by high temperatures even in those areas where slag, thermal and mechanical shocks, abrasion etc. do not affect the bricks.[(4)] Figure 4 shows that MgO and graphite are stable only in a limited temperature range between 1546 K (1273°C) to 1916 K (~1642°C), depending on the $p(O_2)$.

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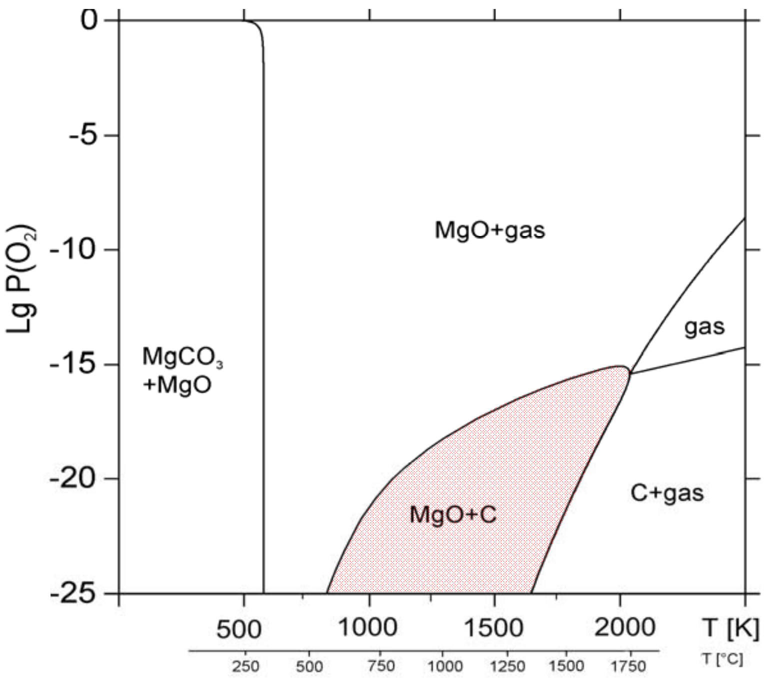

Figure 4: Temperature - $p(O_2)$ - Diagram of MgO-C.

- MgO-C is unstable at any $p(O_2) > 10^{-15}$ bar
- MgO-C is unstable between 577 K (~304°C) and 873 K (~600°C) at any $p(O_2)$.
- MgO-C is stable only in a limited temperature range of 1546 K (~1273°C) to 1916 K (~1642°C), depending on the $p(O_2)$.
- MgO-C is unstable at any $p(O_2)$ and temperatures > 1916 K (~1642°C)

As a conclusion an "Endogenous Wear" of MgO-C bricks was defined, that leads to loss of brick substance without any other influence of process parameters like stress, corrosion, abrasion, etc. than temperature and $p(O_2)$.[5]

2.2 Tapping Zone

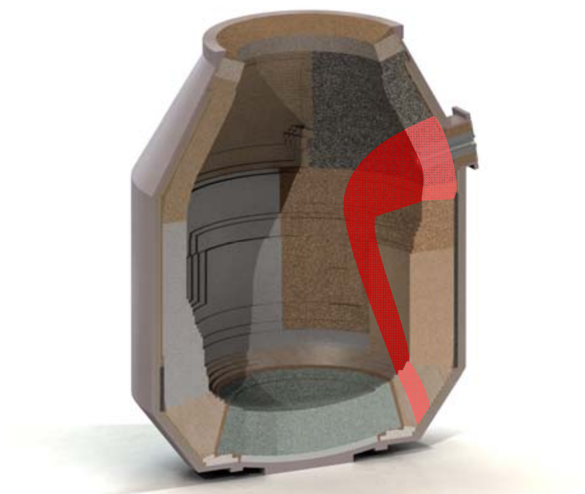

Figure 5: Tapping Zone in a BOF-lining.

The tapping zone is an area where the refractory lining gets in contact with super hot and oxygen-rich slags while the vessel is tilted and the steel is tapped into the ladle. The high oxygen contents leads to an enrichment of iron in the slags (wus-tite FeO and sometimes even magnetite Fe_3O_4 or haematite Fe_2O_3). These iron-oxides affect the MgO-C bricks in two ways: by formation of magnesiowustite solid-solutions with the periclase grains and by oxidizing carbon and formation of carbon monoxide. Traces of the oxidized carbon can be found as voids ("gas-bubbles") as shown in Figure 6.

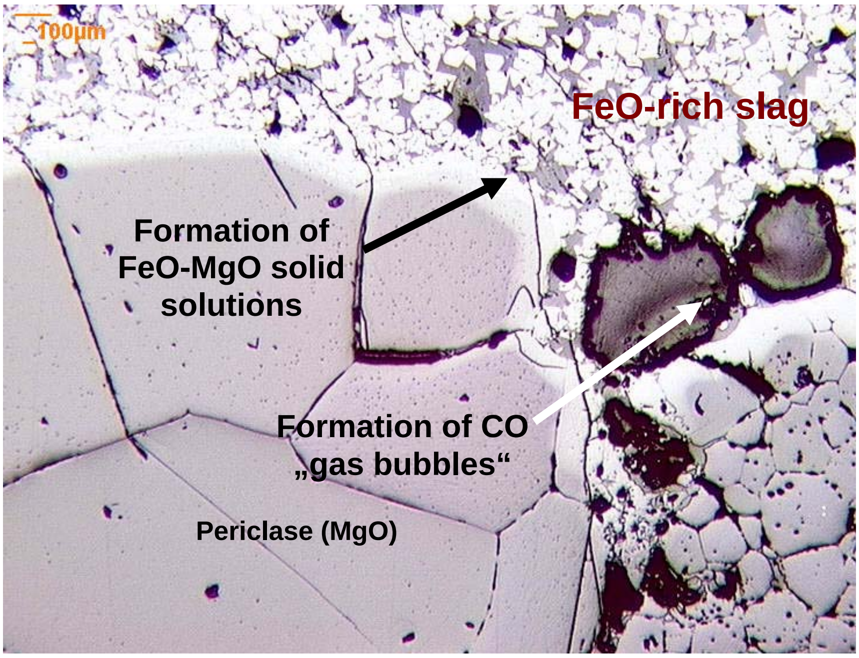

Figure 6: Microphoto of an MgO-C brick with severe corrosion attack by FeO.

Loads acting upon the tapping zone depend very much on the produced steel grade and the set-up of the melt shop.[6] Melt shops without ladle furnace but demanding steel grades in terms of required time for secondary treatment such as alloying, vacuum treatment, purging and stirring and the like have to put as much energy as possible into the melted steel to ensure sufficient melt temperatures until the end of the secondary metallurgy treatments. This leads to tapping temperatures of up to 1800°C and premature wear because of promoted oxidation and corrosion. Therefore MgO-C brick grades with 10 % C and 98 % MgO Large Crystal Fused Magnesia (LCFM) are used in these areas.

2.3 Trunnion

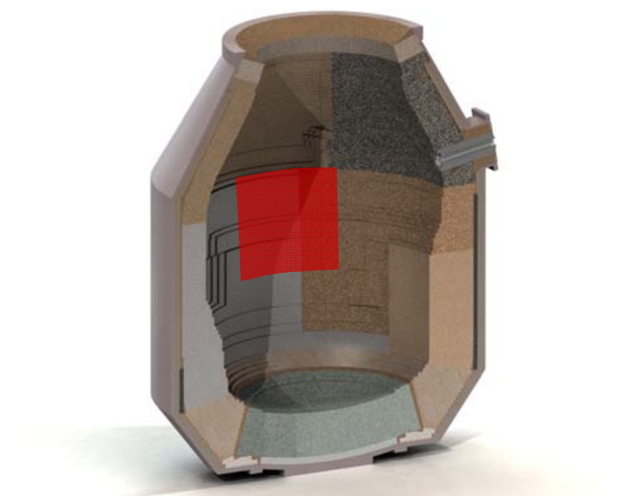

Figure 7: Trunnion in a BOF-lining.

The trunnions cannot get in contact with melt because of the low filling level of the vessel. In consequence it is impossible to obtain a protective slag layer on the lining surface by turning the BOF. Although metallurgical slags very often have a high reaction- and thus corrosion-potential with refractories it can also work as a protecting cover, when it solidifies, sealing the brick from further attack of slag and oxygen. By rising up the carbon proportion to 15 % the brick becomes particularly dense but yet flexible. Carbon works as a pressing-lubricant during manufacturing of the bricks. But in opposition to normal, burnt dense bricks the flexibility and elasticity is not lowered by densification but improved. The high resistance to oxidation of the flake graphite added ensures a delayed loss due to burning.

A common way to protect bricks in areas with enhanced oxidation from wear has been the addition of anti-oxidizing agents. However, investigations have shown, that the influence of the antioxidants Al and Si on the oxidation of graphite is negligibly small [7]. The benefit of using metal-powders is rather the reinforcement of the bricks in service by the formation of Al-carbide and MgO-Al_2O_3-spinel, causing an additional densification and sinter-bond in the MgO-C-bricks. Experiences in practical applications collected in the last years in steel plants verify these investigations.

2.4 Slag Zone

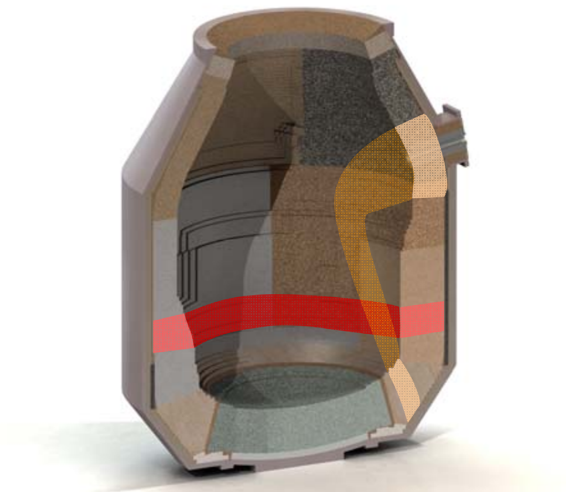

Figure 8: Slag Zone (red) and intersection ("slag-cross") withTapping Zone (yellow, see Fig. 5) in a BOF-lining.

The slag zone is subject to increased wear due to continuous rinsing with hot slag, especially at the beginning and end of the blowing process when the slag contains high amounts of FeO. In this case the addition of high purity Fused Magnesia reduces the wear. Due to varying positions of the BOF-vessel during blowing and tapping, two different slag zones emerge. Extreme stress affects the "slag cross", as it is called, i.e. both intersections of the slag zones resulting from reclining and standing position of the converter. Like in the tapping area the loads and stresses become more severe if tapping-temperatures are extremely high, because the higher energy promotes corrosion reactions and mobility of slag and corrosion-reaction products.

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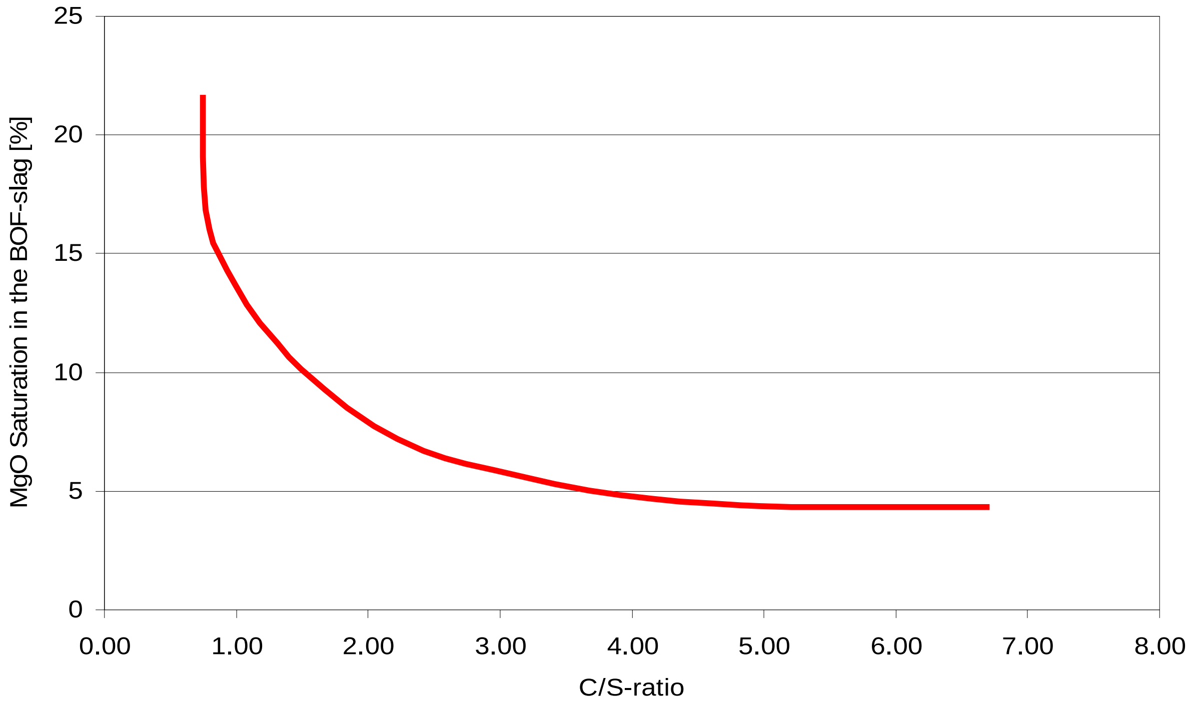

Figure 9: MgO-saturation in LD-slags as a function of the CaO / SiO_2 – ratio.[8]

The wear-potential of a slag is strongly related to the CaO / SiO_2 – ratio in the slag, as illustrated in Figure 9. The diagram shoes that the MgO-solubility into LD-slags increases significantly if the CaO / SiO_2 – ratio drops under the value of 2, resulting in a quick dissolution of MgO from the MgO-C bricks into the slag. Figure 10 shows a microphoto of SiO_2–rich slags infiltrating an MgO-C brick and progressive dissolution of MgO-grains.

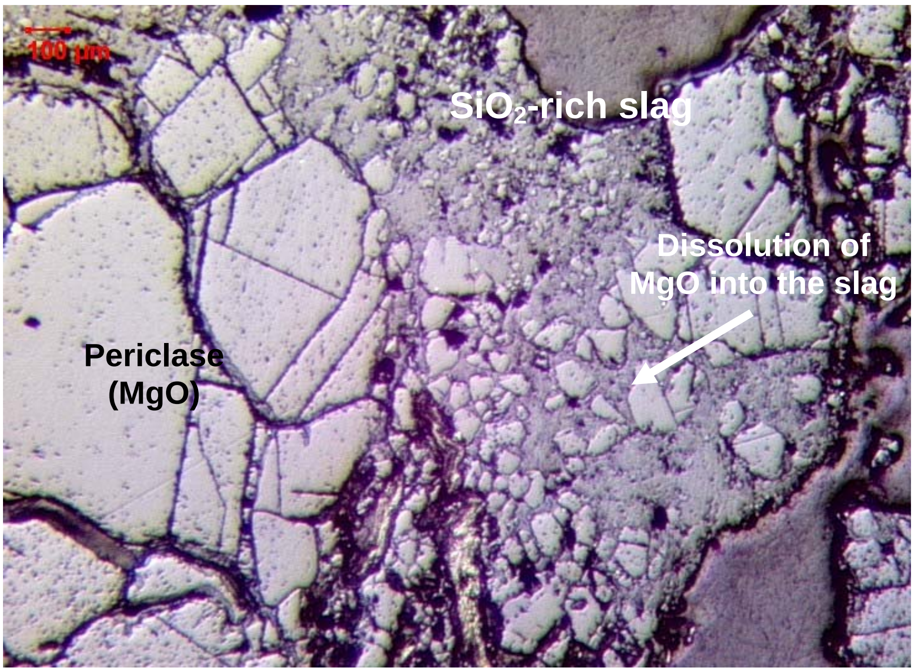

Figure 10: Microphoto of an MgO-C brick with corrosion attack by SiO_2–rich slags.

2.5 Lower Cone and Bottom

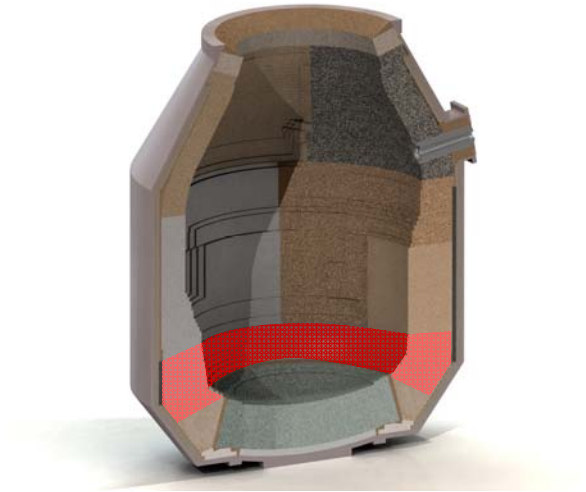

Figure 11: Lower Cone in a BOF-lining.

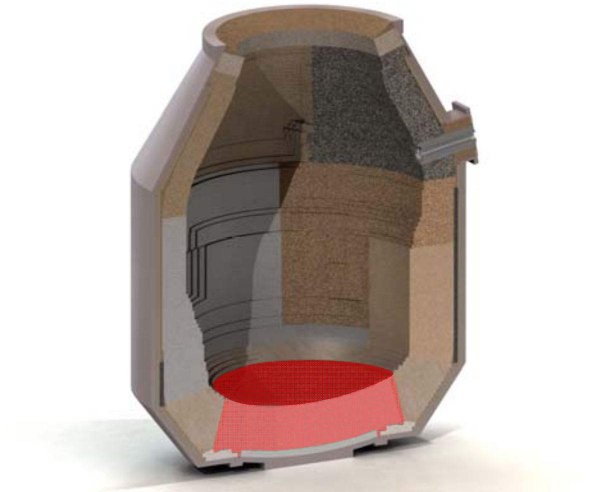

Figure 12: Bottom in a BOF-lining.

Loads in the lower cone and the bottom are different to those in the slag zone or tapping area, since the steel bath is less aggressive than slags are. The main loads are thermal expansions of the massive block of tightly set bricks in the bottom and thermal shocks while filling the BOF. Particularly thermal cycling (rapid cooling and reheating) can lead to crack formation, as shown in Figure 13:

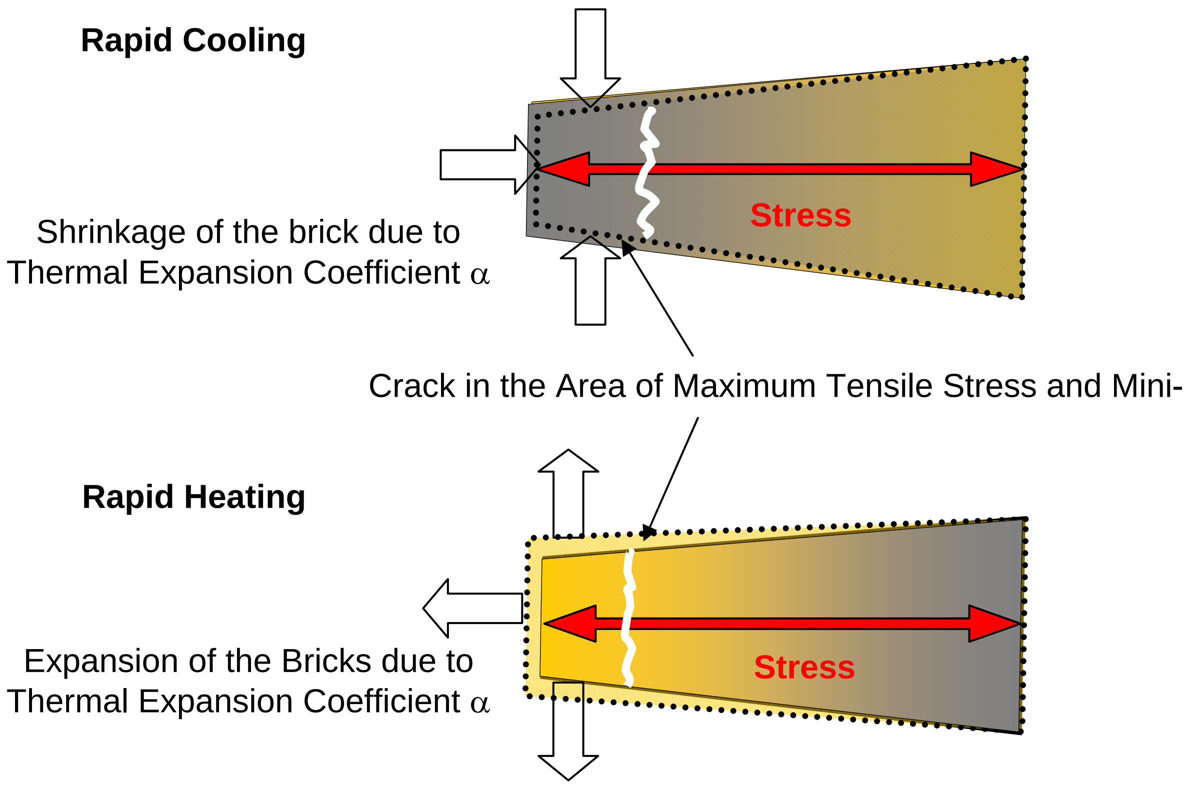

Figure 13: Crack formation in MgO-C bricks through thermal cycling.

Shrinkage and expansion of the brick tips induce stresses that lead to cracks and spalling once the stresses exceed the strength of the bricks. To avoid damage due to thermal expansion of MgO-C bricks (the Thermal Expansion Coefficient α of

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~1.3 - 1.5 % at 1000°C of MgO is the highest of all refractory oxides!) during the first heat-up of the MgO-C lining in a BOF some general rules have proven to be effective. The thermal expansion can be balanced by use of cardboards in the masonry. Cardboards must be used in the barrel in vertical joints, after each 3rd or 4th brick. Depending on the state of the permanent lining, backfill and deformation of the vessel the number of cardboards may be reduced. Cardboards should not be used in the scrap impact in BOFs with rammed joints between bottom and lower cone (“ordinary bricklaying”). Larger converters (> 180 tons capacity) require additional installation of cardboards for horizontal expansion joints in the cylinder area, every 5th layer, 1 mm, in the case of an ordinary lined bottom. Additional installation of horizontal expansion joints in the cylinder area, every 3rd layer, 1 mm, should be used in BOFs with spherical bottoms. Here also cardboards are required in the scrap impact. The bottom is not provided with expansion joints, both in the classical design, as well as in spherical linings. Double-wedged layers to tilt the lining in the upper and lower cone are also laid without expansion joints.

While only some years ago normal brick grades based on Dead Burnt Magnesia were used in this part of a converter nowadays bricks containing Fused Magnesia or blends of FM and DBM are standard. In some converters the blends of FM and DBM are the perfect solution due to their higher thermal shock resistance in comparison to pure FM MgO-C bricks. Reinforcements with aluminium powder additions can be necessary in the vicinity of the tuyeres because of the locally increased erosion and abrasion.

Scrap impact

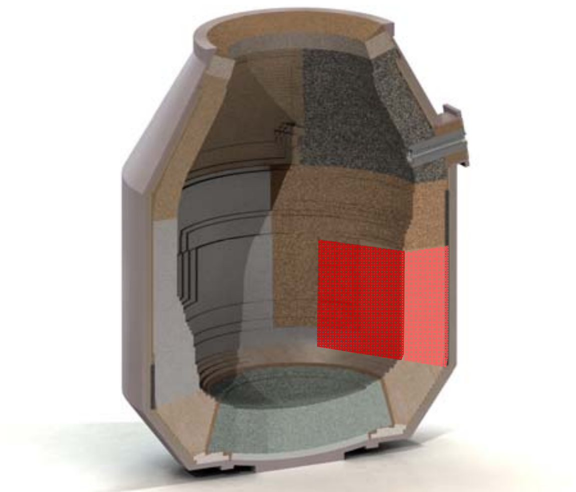

Figure 14. Scrap Impact in a BOF-lining

Generally the scrap impact zone is often the most heavily stressed area in a BOF. Scrap pieces, weighing up to several tons like rails and beams, fall from a distance of 5 - 10 m and hit the hot bricks. Only due to the firm brick bond of the masonry the bricks are able to withstand these loads at all. Additional load occurs if the scrap impact is on the same side as the tapping area. In this case, apart from mechanical loads, it is stressed additionally by corrosion and oxidation. The stresses in a scrap impact area of a BOF require the use of bricks with high fracture toughness or damage tolerance as well as an optimal thermo-shock resistance. Due to shattering of the brick by impact or massive temperature shocks, erosion is promoted and finally results in loss of brick substance. Current state-of-the-art brick for the scrap impact are bricks based on 98 % LCFM with 5 or 10 % C and stainless-steel fibre reinforcement. The fibres lead to a strong increase of strength, toughness and Work Of Fracture. Despite the fact that the fibres might be liquid under process temperatures of a steel plant, the fibres protect themselves by the formation of a dense ceramic layer on top of their surface during service that keeps the shape of the material and stops oxidation and corrosion.[9]

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