Metallurgical and Materials Engineering
Association of Metallurgical Engineers of Serbia AMES

Research paper
https://doi.org/10.30544/811

HISTORICAL OVERVIEW OF REFRACTORY LINING IN THE BLAST FURNACE

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Received 17.03.2022

Accepted 18.06.2022

Abstract

The majority of refractories used today are associated with the iron and steel industries. Typically, the refractory lining of a blast furnace consists of a combination of different refractory materials chosen for different portions of the furnace, as well as distinct process conditions and temperature ranges. Knowledge and requirements for the iron manufacturing system in conjunction with the physical, mechanical, and chemical qualities of the proposed refractories determine the choice of refractory combination. Inadequate understanding of the aforementioned components frequently results in refractory failure, which then becomes a difficult problem to tackle. A blast furnace's refractory liner typically fails owing to any number or combination of these variables. To facilitate comprehension, we will explain the types of refractory lining required in a blast furnace by region, as well as the observed trend in refractory lining patterns over the past few decades.

Keywords: blast furnace; refractory lining; materials selection.

1. Introduction

Refractories are one of the most used construction/engineering materials [1-5]. Application of refractory materials is related to different industries, such are: glass, ceramics, petrochemical, ferrous, nonferrous, incineration, cement and lime industry and steel industry, as it is presented in Figure 1. a) [6].

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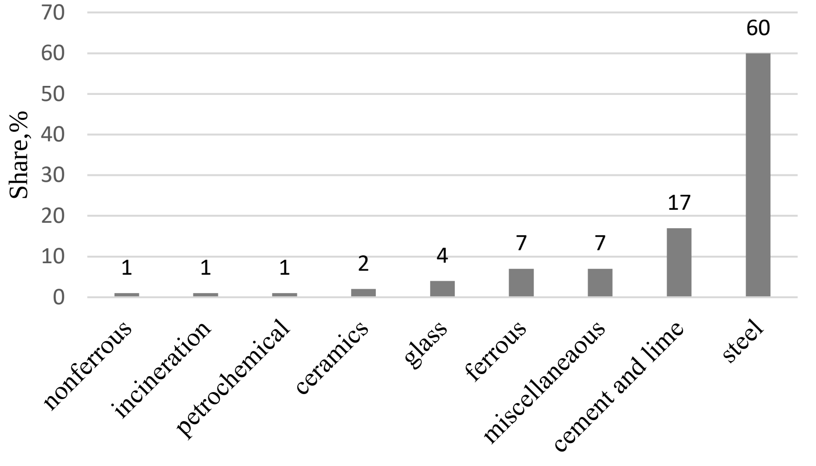

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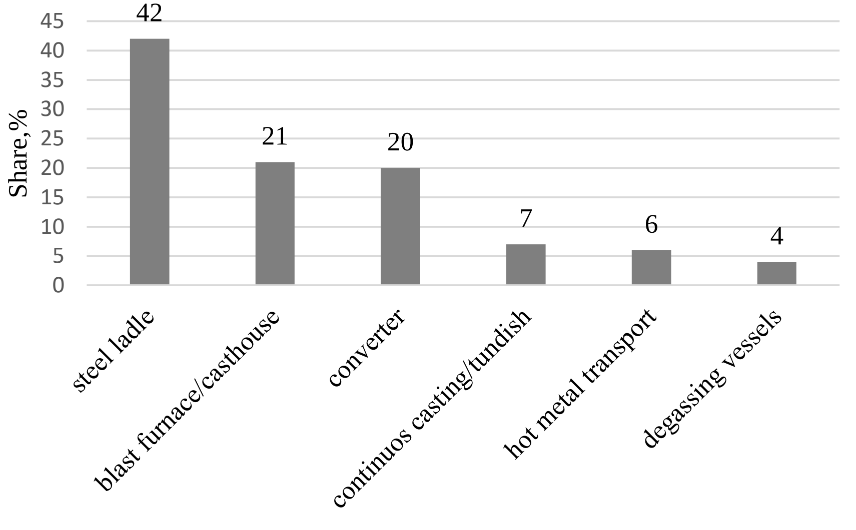


b)

Fig. 1. a) Current distribution of refractories in user industries globally [6], b) Distribution of refractory consumption in different iron & steelmaking equipment [7].

As seen in Figure 1. a), around 60 % of used refractories are expected to be implemented in steel industry. Implementation of the refractories in steel industry is connected to steel ladle, blast furnace, converter, Figure 1. b) [5].

A blast furnace is one of the most complex devices in metallurgy. Adjusting appropriate work conditions with the blast furnace design have grate influence on the refractory lining [1-8]. The most frequently utilized process characteristics for blast furnace operation (load distribution, blast furnace design, gasthouse operations, water cooling system, hot blast quality, gas cleaning system, and warmed air temperature) have a great impact on the selection of the right lining [9-11]. The selection principles for the refractory lining have also been altered by environmental demands. Figure 2 depicts the complexity of the process and equipment associated with blast furnace operation.

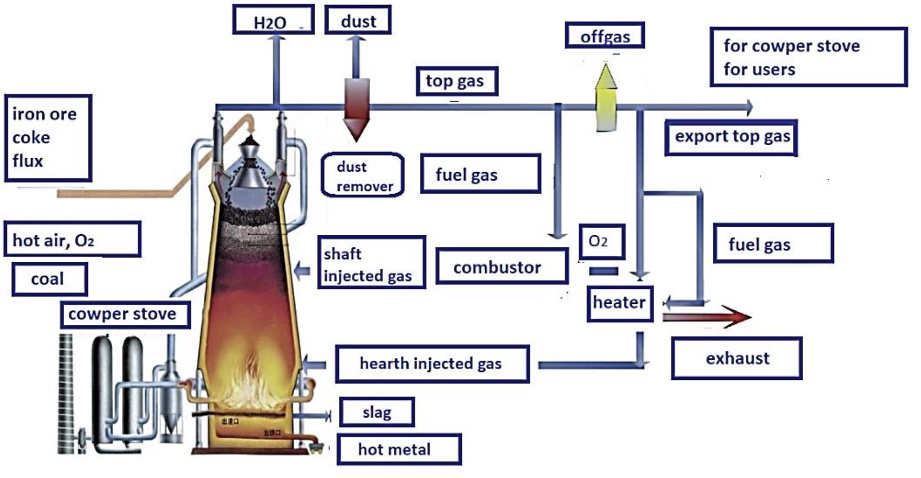


Fig. 2. Blast furnace process flow [12-16].

The typical blast furnace process flow is depicted in Figure 2. This diagram illustrates the complexity of blast furnace processes, material flow, and operational circumstances.

Results: demands for material selection for refractory lining

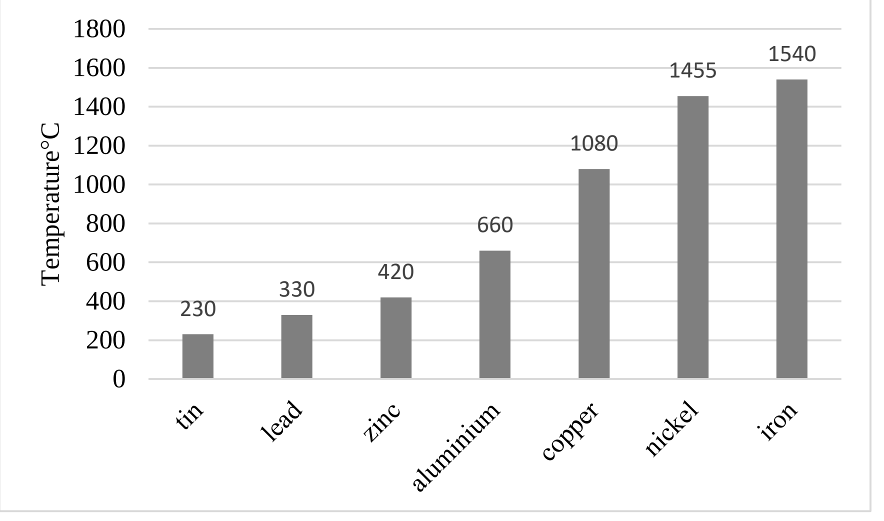
Conditions within the blast furnace vary significantly by region, and the refractories are subjected to a wide range of effects (mechanical and chemical, corrosion, erosion, wear). A summary of attack mechanisms in different regions of the blast furnace is given in Table 1.

In the refractory selection procedure, it is crucial that different sections of a blast furnace correspond to distinct stages and regions of the metallurgical process. The correct selection of refractory lining must take into account the combined influence of these mechanisms. The table is separated into three regions (stack region, Belly and bosh region and raceway and tuyeres, hearth and iron notch region). For each region the attack mechanism which is expected is given, as well the resulting damage.

Table 1. Attack mechanisms in different regions of blast furnace [5, 10, 18-20].

Stack region	Attack mechanism	Resulting damage
Upper stack	Abrasion	Abrasive wear
	Medium temperatures fluctuations	Spalling
	Impact	Spalling, loss of bricks
Middle stack	Medium to heavy temperatures fluctuations	Spalling
	Gas erosion	Wear
	Oxidation and alkali attack	Deterioration
Lower stack	Heavy temperatures fluctuations	Severe spalling
	Erosion by gas jets and abrasion	Wear
	Oxidation and alkali attack	Deterioration
	Thermal fatigue	Shell damage and cracks
Belly and bosh region	Attack mechanism	Resulting damage
Belly	Medium temperatures fluctuations	Spalling
	Oxidation and alkali attack	Deterioration
	Abrasion, gas erosion and high temperature	Wear
Bosh	High temperature	Stress attack
	Slag and alkali attack	Deterioration and wear
	Medium temperatures fluctuations	Spalling
	Abrasion	Wear
Raceway and tuyere, hearth and iron notch region	Attack mechanism	Resulting damage
Raceway and tuyere region	Very high temperature	Stress cracking and wear
	Temperatures fluctuations	Spalling
	Oxidation (water and oxygen)	Deterioration
	Slag attack and erosion	Wear
	Damage from scabs	Spalling, Loss of cooling elements and tuyeres
Hearth	Oxidation (water)	Wear
	Zinc, slag and alkali attack	Deterioration
	High temperature	Stress build up and cracking
	Erosion from hot liquids	Break out risk
Iron notch (tap hole)	Heavy temperatures fluctuations	Spalling
	Erosion (slag and iron)	Wear
	Zinc and alkali attack	Deterioration
	Gas attack and oxidation (water)	Wear and deterioration

In the materials selection process, the temperature ranges and melting temperatures of prospective materials for a given application are among the most important factors. The melting points of some of the most commonly employed metals and refractories are depicted in Figure 2. [17, 18].



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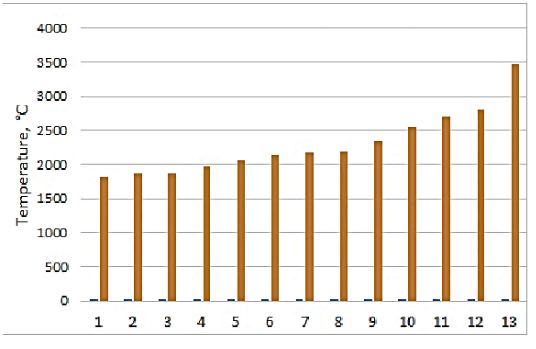

1	1815	kaolin
2	1870	fireclay
3	1870	silicon carbide
4	1970	alumina fused bauxite
5	2050	alumina (pure sintered)
6	2140	chrominum oxide
7	2180	chromite
8	2190	magnesia
9	2350	silicom carbide (pure sintered)
10	2550	beryllia (pure sintered)
11	2700	zirconia (pure sintered)
12	2800	magnesia (pure sintered)
13	3480	graphite (pure sintered)

b)

Fig. 3. Melting points of selected a) metals and alloys, b) refractories.

As shown in Figure 3, if melting point is the only criterion, a range of refractory materials are suitable. Nevertheless, many additional properties (strength, refractoriness under load, thermal stability, resistance to gas, liquid, etc.) and diverse mechanisms are crucial, and a combination of the aforementioned mechanisms may be significant for the selection of the refractory material. Figure 4 depicts the temperature range and chemical reactions within the blast furnace's regions.

The typical chemical processes associated with the various regions of the blast furnace are depicted in Figure 4. This diagram also demonstrates the complexity of the predicted operations in a blast furnace.

The interaction of materials in a blast furnace with dust causes mechanical wear and abrasion. This primarily occurs in the blast furnace stack region (upper, middle, and lower). Other regions are subjected to high thermal loads, and it is a typical impact on the lower stack and belly region of the furnace. The thermal load could be paired with a flow of hot liquid metal, and cavitation is anticipated under these conditions (elephant foot-shaped). In order to reduce or prevent damage caused by these mechanisms, the selection of suitable refractory material is dependent on an awareness of and attention to the various mechanisms that are specific of various regions of the furnace. Using this research of mechanisms associated with different regions of the furnace, it is evident that different regions require refractories of varying types and qualities.

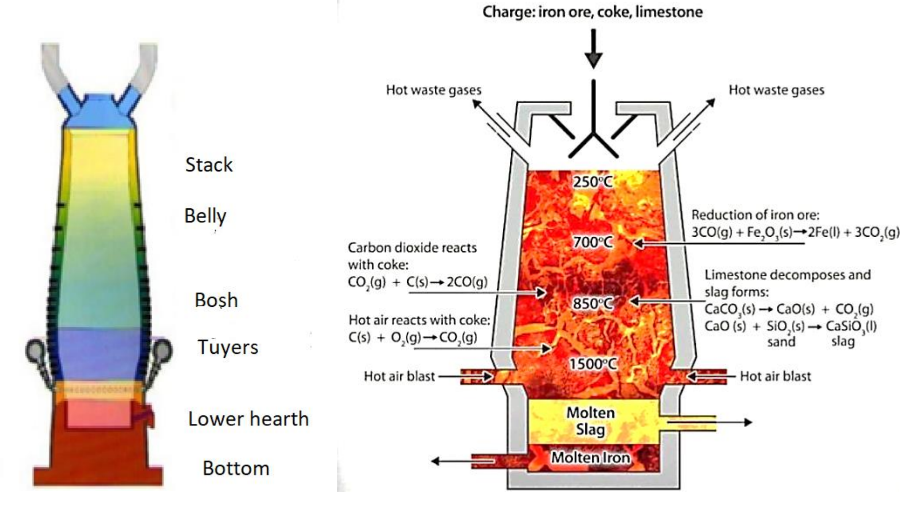

Fig. 4. Regions of the blast furnace with temperature range and chemical reactions [18-21, 31].

Refractory lining materials history

In every region of the blast furnace, refractory material is anticipated to be subject to a variety of complicated forces. As demands for iron and steel production relating to the used materials and products changed, it was anticipated that the selected refractory materials would also undergo modifications. Possible refractory selection in relation to the various regions is shown in Table 2.

The selection of refractory linings has evolved during the past many decades. In the past, blast furnace refractories were selected from alumina-based materials with varying alumina concentrations. Bosh, tuyere, tap hole, and tilting spout contained a higher concentration of alumina, whilst the stack and belly contained a smaller concentration. With the development and rising demand for refractory concrete, certain materials, particularly those with minimal or no cement content, have found a position in blast furnace lining, for the main trough and the tilting spout. Additionally, some SiC-based materials, such as ramming masses and conventional bricks, have become more accessible and their use has increased, with a tendency to replace alumina-based refractories, the most commonly used material for the belly, bosh, tuyere, tap hole, main trough, and tilting spout. As shown in Table 3, SiC-based materials (SiC-Si3N4, self-bonded, tar bonded) are preferred over alumina refractories in the majority of blast furnace regions.

Table 2. The blast furnace refractory lining [10, 18-22].

Region	Past	Present/Conventional	Trend
Stack	Fireclay	39- 42 % Al_2O_3	Super duty fireclay
Belly	Fireclay	39- 42 % Al_2O_3	Corundum, SiC-Si_3N_4
Bosh	High alumina	62 % Al_2O_3, Mullite	SiC-Si_3N_4
Tuyere	High alumina	62 % Al_2O_3, Mullite	SiC self-bonded, Alumina-chrome (Corundum)
Lower hearth	High alumina	42-62 % Al_2O_3, Mullite, Conventional carbon block	Carbon/Graphite block with super micro pores
Tap hole	High alumina	Fireclay tar bonded, High alumina/SiC tar bonded	Fireclay tar bonded, High alumina/SiC tar bonded
Main trough	Silica	Pitch/ water bonded clay/ Grog/Tar bonded ramming Masses, Castables	Ultra low cement castables (ULCC), SiC/Alumina mixes, Gunning repairing technique
Tilting spout	Silica	High alumina/ SiC ramming masses/ Low cement castables	High alumina/SiC/Carbon/ULCC

Demands and solutions for modern and future blast furnace refractories

New techniques can extend life of the other parts of the blast furnace with short stops. Presently, hearth is the single factor for full-scale relines or rebuilt of the blast furnace.

New carbon-based materials were studied in order to analyze the thermal conditions of the heart wall using lining status, carbon hot face temperature, and heat flux. Results indicated that standard block lining at 1375 °C delivers lining status with no skull, but when the temperature is raised to 1395 °C, a crack could be observed 200 mm from the shell. Also, a chemical attack zone may be found in the block at 1440 °C [21, 23].

Specific refractory lining concepts, such as the UCAR® CHILL-KOTETM freeze lining concepts, were created to overcome challenges associated with reducing the effect of refractory "chill" induced by wall cooling. This technique is based on the combination of optimizing wall cooling conditions with optimizing the thermal conductivity of selected refractories (carbon and graphite refractories) in order to "chill" the refractory lining by transporting heat away from it [24].

A cooling system (such as optimized sidewall water cooling) in conjunction with the optimization of heat-dissipating conductive refractories could reduce the refractory lining temperature below the melting temperatures for process materials. This may result in slag and metal solidifying (freezing) and forming a protective coating. This is crucial because the temperature below the melting process causes the production of a protective layer ("skull") for the complete refractory. This created protective coating provides an insulating function to prevent heat loss and a protective function to shield the liner from erosion, chemical attack, and stress-induced damage (thermal or mechanical inducted). This concept extends the lifespan of refractories and enhances their performance [24–26].

One of the attempts of optimal design of blast furnace inner profile is to take into account the blast furnace liner degrading process and the response principle, which could lead to the method of preventing elephant foot. This could be accomplished by properly increasing the well death depth. By increasing the wall depth, direct deadman settlement on the bottom might be prevented. This strategy permits the access of hot metal flow between the deadman and the bottom, so increasing the metal flow. Additionally, the liquid and gas permeability of the fireplace is enhanced. The peripheral flow of molten metal is slowed down. All of the aforementioned enhancements affect the service life of the hearth and base by extending their effectiveness [26-28].

Micro, mezzo, and nanoparticles are utilized in the production of advanced materials, among other methods. This could be related also to the refractories. Typically, nanoparticle-based enhancements target the enhancement of mechanical properties. This need is directly tied to the demand for refractory lining for blast furnaces, particularly for the bottom sections (bottom and hearth). In addition to enhancing the mechanical properties, nanoparticles can influence the reduction of porosity and wetting characteristics, as well as the improvement of erosion and wear resistance conditions [29, 30].

Increased refractory lining wear was a consequence of increased productivity requirements for blast furnaces. Several articles [21, 29-31] addressed the response mechanisms and continued degradation of refractories.

Based on an understanding of these hearth liner wear mechanisms, it has been decided to use various practical operational procedures in order to lengthen the blast furnace campaign [21, 29-31].

The proposed wear mechanisms were based on postmortem analysis [21]:

1. degradation of layer: carbon blocks eroded and dissolved by hot metal
2. protective layer formation: scab of low thermal conductivity, deposited on carbon block hot side
3. Penetration of hot metal forming penetrated layer: carbon block pores penetrated by hot metal
4. formation of the brittle zone: carbon blocks disintegrate
5. slightly changed layer: carbon block physical/chemical properties slightly changed
6. unchanged layer: carbon block physical/chemical properties remain unchanged.

On the basis of experimental and theoretical analysis results, a number of potential solutions and prevention strategies were developed. Utilizing improved carbon refractories was one of the recommended strategies for preventing blast furnace hearth corrosion. The carbon refractory might be impregnated with a titanium-based carrying solution via chemical deposition through its open porosity. This method reduces the contact area with corrosion and seals the pores to prevent hot metal penetration [21,29-31].

Conclusion

The most important criteria for selecting refractories for blast furnace liner are outlined. Different attack mechanisms are anticipated in various regions of a blast furnace, and these were the guiding concepts. On the basis of these principles and various regions, conventional refractory linings have been employed in the past and today, and several trends are given. Trends in blast furnace refractory lining have been associated with the use of refractories that are more resistant to various wear, degradation, and spalling mechanisms.

For most of the regions of the blast furnace (stack, belly, tuyeres, hearth, and tap hope) alumina-based refractories were used. Alumina-based refractories with different content of alumina were replaced with more quality alumina-based refractories (higher content of alumina and LCC and ULCC) and/or other refractories such are carbide refractories (SiC, SiC tar bonded, SiC-Si_3N_4.

Silica-based refractories were replaced with tar bonded ramming masses, and castables, with the trend in using ULCC and SiC and high alumina mixes, for the main trough. Similar high alumina/SiC ramming masses / low cement castables are utilized for tilting spouts, with a trend towards using high alumina/SiC/Carbon/ULCC materials.

Acknowledgments

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract Nos. 451-03-68/2022-14/200135 and 451-03-68/2022-14/200026).

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