

CHALLENGES FACING THE REFRACTORY INDUSTRY IN RELATION TO METALLURGICAL PROCESSES

Sizwe Lloyd MSIBI, Michel Kalenga WA KALENGA, Willie NHETA

University of Johannesburg, Johannesburg, South Africa, sizwelloyd@gmail.com, michelk@uj.ac.za; wnheta@uj.ac.za

<https://doi.org/10.37904/metal.2025.5101>

Abstract

Refractory materials have been around since the inception of human civilization. They have played a significant role in the development of pyrometallurgical processes. Therefore, it is important to be acquainted with the challenges and opportunities presented by the industry. The industry faces several challenges; mainly supply chain issues, which include freight costs and raw material availability, rising costs of virgin raw materials and changes in quality, changing process conditions, and environmental and sustainability issues. All these contribute to a circular economy or lack thereof. One of the preferred remedies in the industry is circular economy. This is because of its multi-faceted benefits namely, reduce, reuse and recycle, called 3Rs philosophy. Huge strides have been achieved in the recycling of refractories, also referred to as grog-based products in monolithics or unshaped refractories. However, limited research is available on the use of grog in shaped or brick-type refractories. The use of grog has been well entrenched and integral in reducing the cost of monolithics with controlled quantities for non-critical applications. However, the interaction between virgin-grog bricks and different types of slags is yet to be understood as these bricks may appear to have unchanged elemental chemical composition, and they may have mineralogical changes with non-uniform phases. This is a challenge because of weak links that may be created for corrosion propagation. This paper discusses the challenges faced by the industry in relation to possible deviations resulting from the use of grog in shaped refractories.

Keywords: Metallurgy, Refractories, Circular Economy, Recycling Applications

1. INTRODUCTION

Refractories play a significant role in pyrometallurgical processes serving as protective linings in high-temperature and corrosive environments [1]. Despite technological advances, the industry continues to face various challenges ranging from economic, technical and environmental issues [2]. The study aims to examine these challenges within the framework of the circular economy, which has been increasingly endorsed by the industry as a sustainable approach to addressing these shortcomings. On a macroeconomic level, issues such as supply chain disruptions, the escalating cost of virgin raw materials, environmental regulations, reduction of carbon emissions and circular economy will be discussed. On a micro or industrial level, the impact of issues such as fluctuating chemistry of process input material, operating conditions, refractory performance and disposal costs shall be discussed. This paper covers a literature review of refractory materials, key challenges and opportunities, and their contribution to the circular economy. Furthermore, the magnesia-chrome study will illustrate the operational challenges and quality concerns regarding the reintegration of recycled materials.

What are refractory materials? Refractory materials belong to a group of ceramics that have high-temperature properties [3]. [3] stated refractories can be classified according to various parameters such as their application, service temperature etc. [4] further classified them in three main categories namely, acidic, basic and neutral. Silica, alumina silicate and zircon are classified as acidic, whilst magnesia, dolomite and spinel combination

can be classified as basic refractories. Neutral refractories refer to alumina or chrome-based refractories due to their resistance to slag corrosion [5]. [6] categorised refractories into six primary oxides namely, chromic oxide, magnesia, zirconia, silica, carbon and alumina.

In terms of manufacturing, refractory material can be supplied either as shaped or unshaped products, based on application [1]. Shaped refractories, covers products such as dense bricks, precast blocks, or special shapes, whilst unshaped refractories, also referred to as monolithics, cover joint free installed linings either by ramming, gunning, or casting the material into place [3,5]. Insulation materials can also be supplied as either shaped or unshaped. Figure 1 illustrates the combination of different types of refractory-shaped and unshaped products used for the installation of a new taphole.

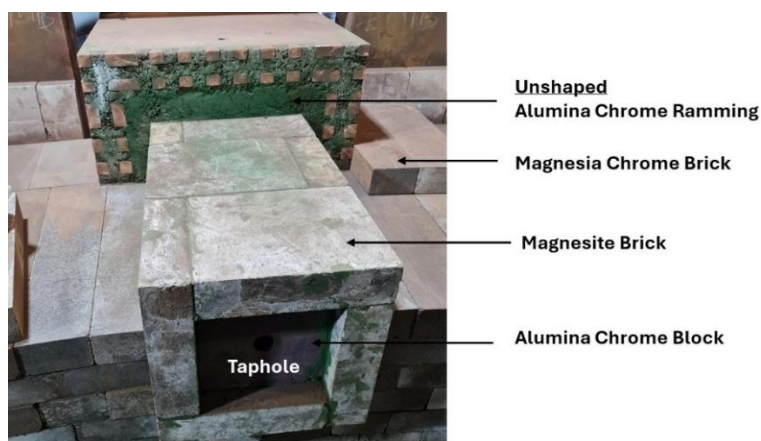


Figure 1 Different forms of refractories, shaped and unshaped in service

In terms of pyrometallurgical footprint, refractories are used in both ferrous and non-ferrous operations such as iron and steel, based metals (e.g. zinc, copper and nickel), platinum group metals (PGMs), and various ferroalloys [5,6].

2. CHALLENGES IN REFRACTORIES

2.1 Macroeconomic Level

- Supply Chain Disruption - Raw material sources of refractories are limited worldwide, as such overreliance on specific countries creates logistical challenges and longer lead time for refractory products [7].
- Escalating cost of primary raw material – Refractory materials are finite and geographically constrained making their supply vulnerable to geopolitical constraints and market fluctuations. Therefore, the sustained demand for virgin raw materials leads to export restrictions and escalating costs [7].
- Environmental regulations - This is mainly driven by stringent carbon footprint restrictions, rising disposal costs and landfill space [7].

2.2 Microeconomic Level

- Fluctuating chemistry of feedstock – The sustained demand for natural raw materials has led to a gradual decline in their quality, thus affecting the refractory lining performance or campaign life due to physicochemical incompatibility [2,8].
- Operating Conditions – Consequently to the change in feedstock, process condition changes to accommodate the variance in feedstock hence leading to the degradation of refractory linings [2,8].

- Refractory product performance - This is increasingly influenced by the decline in virgin raw material quality to make products and further exacerbated by unquantified and uncontrolled integration of recycled material into virgin formulations [2,8].
- Landfill and disposal costs – these are rising due to stringent environmental regulations and the effect of resource nationalism which limits export and raw materials availability [2,8].

2.3 Opportunities in refractories

Although there are several opportunities in refractories such as advanced formulations for high-temperature applications, artificial intelligence equipment, and alternative raw materials. The circular economy concept offers a multifaceted solution for both macro and micro economic challenges facing the industry [2]. The circular economy aims to minimize the environmental footprint by promoting the reduction, reuse and recycling of waste generation across industrial processes [2]. By promoting this concept, issues such as over-dependence on virgin refractory raw materials, freight cost, landfill space and dumping cost are mitigated [1,2]. [2] stated that using recycled materials can lower the carbon footprint of refractory linings by over 60%. However, technical challenges remain, such as the need for close collaboration with end-users to properly sort dismantled linings and reduce contamination. Operationally, integrating recycled material reduces the overall cost of refractories [2].

3. REFRACTORY RECYCLING AS AN INTEGRAL COMPONENT OF THE CIRCULAR ECONOMY

In refractories, alumina and magnesia-based materials are the most recyclable, often reused as grog [4]. While grog use is common in monolithic (unshaped) refractories, its application in brick production remains limited.

3.1 Refractory recycling in monolithic (unshaped products)

Recycled or grog-based products have proven effective in reducing production and disposal costs for monolithics, with studies supporting their substitution for virgin raw materials without major quality compromises [3,8]. However, [8] identified upper limits to grog usage, highlighting increased water demand and porosity that could compromise performance. While monolithics have been extensively studied, the application of grog in shaped refractories, such as bricks, remains understudied [1]. This gap restricts broader recycling efforts, given that refractories are supplied in both shaped and unshaped forms [1,3].

3.2 Refractory recycling in shaped products (bricks and Precast shapes)

In shaped refractory products or bricks, there is limited research on the suitability of replacing virgin raw materials with grog and this does limit the scope of recycling refractory material. Moreover, the application of grog in monolithics targets non-critical applications [8], whereas the scope of bricks has to be extended to critical applications. Recycling of grog is further limited by the fact that refractories are manufactured and used as shaped or unshaped. An analysis was conducted to investigate the challenges faced by end-users in verifying the grog content in refractory bricks, a factor contributing to the refractory lining degradation.

4. METHODOLOGY

4.1 Materials and analysis techniques used

Magnesia-chrome (MgCr) bricks were analysed using XRF, XRD and SEM-EDS techniques to assess the chemical, mineralogical and microstructural variations associated with the presence recycled material. According to [9] MgCr bricks can be manufactured using three common methods, namely, fused grain, co-sinter and co-clinker, and in situ reaction of chromite and magnesia. [5] classified magnesia-chrome according to the most common products as either fused grain (FG) or direct bonded (DB) for industrial applications. In this case, a comparative study was conducted to determine whether a MgCr (DB) brick had any traces of recycled material by comparing it to a reference MgCr (DB) brick with over 30% grog content.

Initially, the XRF analysis showed similar chemical compositions but could not confirm the presence of grog in the brick, which is usually detected by high levels of impurities. XRD analysis was then used to identify mineralogical phases, although the results were inconclusive, they highlighted the presence of ferrite phases. Consequently, SEM-EDS analysis was used to assess the microstructural and compositional differences. As shown in Figures 2 and 3, with the same magnification of 5µm, both bricks had non-uniform microstructures and higher Fe elemental values of over 20%, which is indicative of potential slag contamination associated with recycled material.

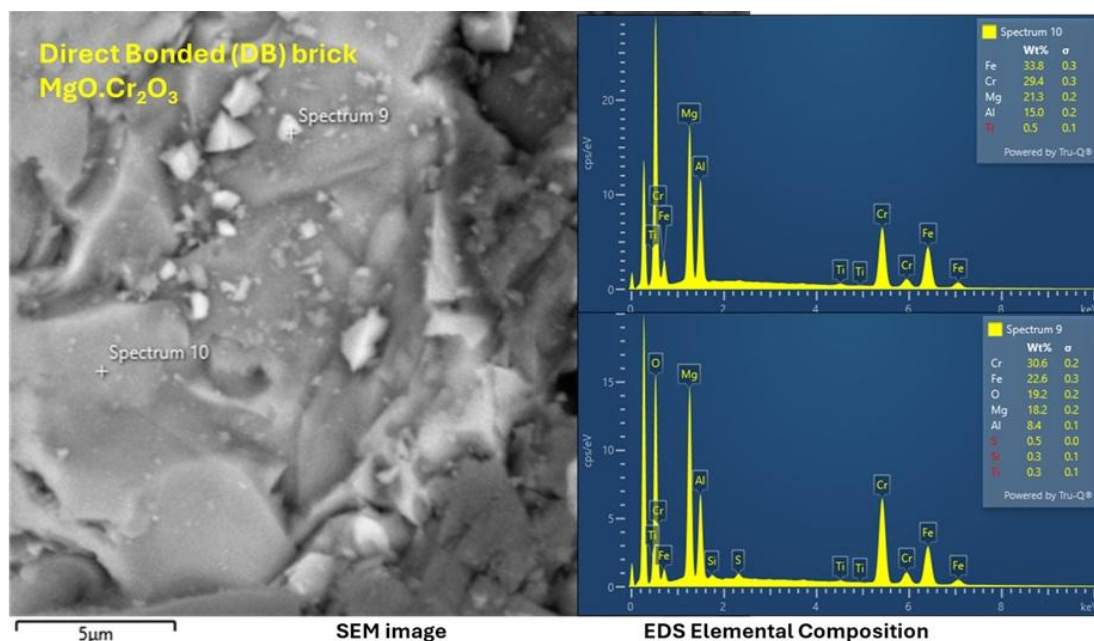


Figure 2 Direct bonded MgCr reference brick presumed grog-free

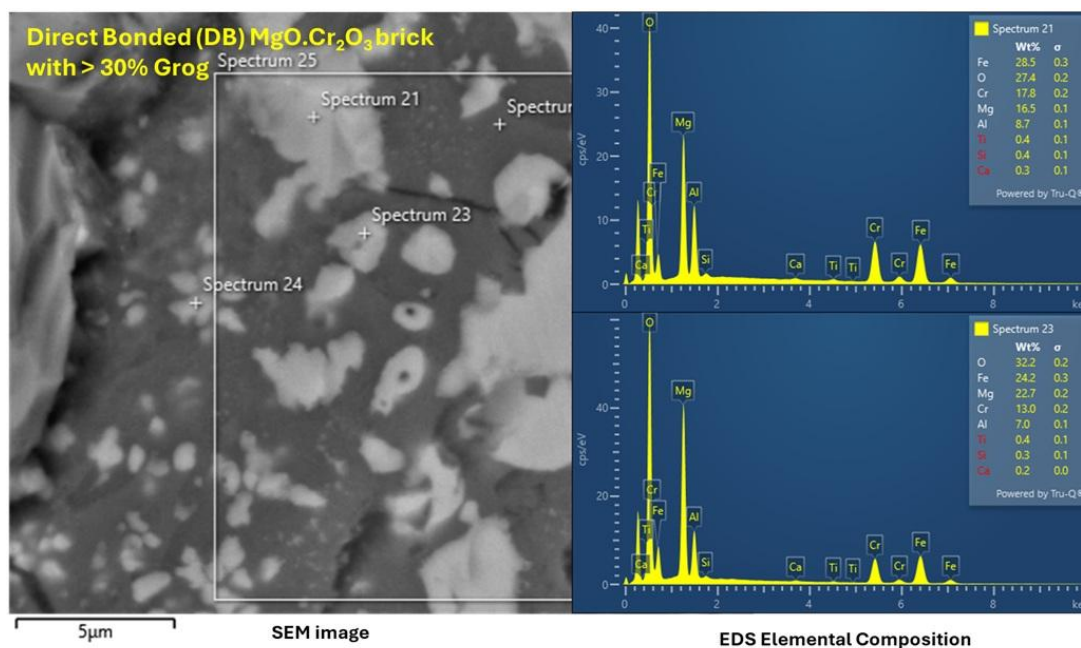
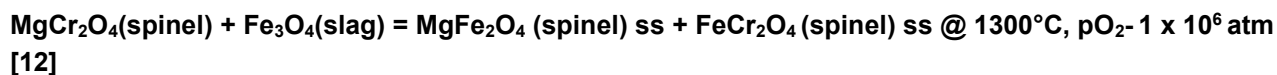


Figure 3 Direct bonded MgCr brick with over 30% grog

Studies by [10] and [11] demonstrated that the corrosion of MgCr bricks is significantly influenced by the presence of iron in the slag, which promotes the formation of magnesio-wüstite. [12] examined the interaction of ferrous calcium silicate slag with MgCr bricks and found that the absorption of Fe₂O₃ by the bricks results in volume expansion which may create stresses in the bricks as shown in the reaction below:



Therefore, the analysis of the two bricks indicates that the reference DB sample may contain recycled grog, as suggested by the high presence of Fe₂O₃ associated with process slag. Such discrepancies may undermine trust between refractory manufacturers and the end-users. Therefore, encouraging collaboration between the two stakeholders is critical to improve transparency and support the controlled integration of grog-based products whilst minimising operational risks.

5. CONCLUSION

The implementation of a circular economy in refractories offers a remedial response to key challenges faced by the industry, including the overreliance on primary materials, escalating raw material and freight costs, environmental concerns, and rising landfill costs. Reintegrating grog-based products in pyrometallurgical operations mitigates these issues. However successful adoption of grog-based products is dependent on the strong collaboration and alignment between refractory producers and end-users. Furthermore, ongoing technical evaluations of grog-based formulations are important to ensure suitability for specific applications, particularly with respect to slag chemistry and operational conditions.

REFERENCES

- [1] GARBERS-CRAIG, A.M. Presidential address: How cool are refractory materials? The Journal of the Southern African Institute of Mining and Metallurgy. 2008.
- [2] MORAES, M., LEITNER, A., NOGUEIRA, G., ZOCCRATTO, B., HEID, S. AND MÜHLHÄUSER, J. Technical challenges for refractory recycling and innovative processing solutions. Journal of Sustainable Metallurgy. 2023, pp. 33 - 38.
- [3] HANCOCK, J.D.. Practical refractories: Refractories for industrial users. 2018.
- [4] HORCKMANS, L., NIELSEN, P., DIERCKX, P. AND DUCASTEL, A.,. Recycling of refractory bricks used in basic steelmaking: A review. Resource, Conservation & Recycling. 2019, vol.140, pp 297-304
- [5] HARBISON AND WALKER. Handbook of refractory practice. Harbison-Walker Refractories Company, 2005.
- [6] HLOBEN, P. Refractory materials: Major industrial applications. 2000.
- [7] O'DRISCOLL. Squaring the Circle: Challenges and Opportunities in Recycling Refractory Minerals.[online]. 2024. [viewed:2025-03-23]. Available from: <https://imformed.com/wp-content/uploads/2024/02/Squaring-the-Circle-Refractory-Recycling-Trends-RWF-1-24.pdf>.
- [8] MORITZ, K., DUDCZIG, S., ENDRES, H.G., HERZOG, D., SCHWARZ, M., SCHÖTTLER, L., VERES, D. AND ANEZIRIS, C.G.. Magnesite-carbon refractories from recycled materials. International Journal of Ceramic Engineering & Science. 2021, pp 53 -58. DOI: 10.1002/ces2.10115.
- [9] MCEWAN, N., COURTNEY, T., PARRY, R.A. AND KNUPFER, P., BRAZIER, D. The product development and continuous improvement process for refractories in the base metals industry a text book and practical perspective. South African institute of mining and metallurgy. 2011, p443-462.
- [10] TAKEBE, H., SHIMADA, G., ARMAN, A., AND. FUKUI, T. Interfacial reaction between magnesite-chrome refractory and iron silicate slag melt. UNITECR2015 – 14th Biennial Worldwide Congress. 2015.Proceeding 262.
- [11] BETSIS, K., KOURTIS, A., KARALIS, K., AND. XENIDIS, A. Assessment of Magnesite Refractories Corrosion by Iron-Rich Slags. Materials Proceedings. 2021, 5, 135. doi.org/10.3390/materials2021005135.
- [12] KAUR, R.R., SWINBOURNE, D.R., WADSLEY, M.W., AND. NEXHIP, C. Comparison of Ferrous Calcium Silicate Slag and Calcium Ferrite Slag Interactions with Magnesite-Chrome Refractories. The Minerals, Metals & Materials Society and ASM International. 2011, vol. 42B, pp 451 – 457.