RHI MAGNESITA

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High-Recycling Containing Magnesia-Carbon Bricks for Basic Oxygen Furnace Applications

As part of the so-called green steel transformation, integrated steel plants are looking for solutions to reduce scope 3 CO_2 emissions while lowering costs. RHI Magnesita has developed tempered magnesia-carbon (MgO-C) bricks for use in basic oxygen furnaces (BOFs) with enhanced circular raw material content, demonstrating performance comparable to standard high-performance wear lining refractories. This study presents detailed practical examples of this material in BOF applications.

Introduction

Worldwide crude steel production is dominated by oxygen blowing in integrated steel plants and by electric steelmaking in mini mills. The global share between these two primary steelmaking routes—basic oxygen furnace (BOF) and electric arc furnace (EAF)—was approximately 70% and 30%, respectively, in 2023 [1]. However, these figures only reflect total worldwide steel production; at the country level, the distribution can vary significantly. For example, in Germany the ratio is close to the global average, while in the United States the proportions are essentially reversed.

Since the classic integrated steel plant route is considered highly CO_2 emission intensive, many integrated steel plants are seeking to reduce scope 1 emissions by switching primary steelmaking from the blast furnace–BOF route to EAF steelmaking, often combining the EAF route with hydrogen-based direct reduction. Therefore, it is expected that the share of BOFs in global steel production will continue to shrink in the future [1,2].

The green steel transformation is facing many challenges, such as the accessibility of scrap and hydrogen (for direct reduction), the cost and availability of electrical energy, and the need for financial support for new major investments [3–5]. At the same time, there are initiatives such as Thyssenkrupp Steel's project to combine hydrogen-powered direct reduction with an electric smelter, which then feeds the BOF [6]. However, not all countries are following the global trend and some are even building new integrated steel plants or increasing existing BOF production capacities. For example, in India, additional BOF vessels were deployed by three steel producers from 2022 to 2024 and three additional brownfield projects are already in the pipeline for the coming years. Therefore, the global transition from oxygen blowing to electric steelmaking will take time, and the number of BOFs worldwide will only decline slowly over the coming two decades. That is why the BOF remains a vital part of steel production all over the world, with more than 1000 blast furnaces operating globally, including approximately 650 in China [7].

Nevertheless, the green steel transformation is set to progress, accompanied by taxes and penalties related to CO_2 reduction. As a result, scope 3 emissions are gaining importance, prompting steel producers to assess the carbon footprint of refractory materials, such as tempered MgO-C bricks. Furthermore, scrap from spent refractory materials is creating challenges for steel producers in terms of landfilling, unwanted storage, logistics costs, and potential taxes due to government waste disposal regulations [8,9]. Refractory producers, including RHI Magnesita, are also striving to reduce scope 1 emissions [10,11].

The raw materials in MgO-C bricks account for up to 90% of the final product's total carbon footprint. Therefore, for refractory producers, a key strategy to reduce their own scope 1 emissions and support steel producers in lowering costs and scope 3 emissions is to use circular raw materials in tempered MgO-C bricks at levels of 20% or more. Numerous studies in the literature have demonstrated positive results for this type of material [9,12–14]. In addition to existing products containing circular raw materials for low-wear area applications, RHI Magnesita has developed a new product type that delivers comparable performance to standard high-performance wear lining MgO-C refractories [15]. This study provides detailed practical examples of its use in BOF applications.

High-Performance, Tempered MgO-C Refractories Containing Circular Raw Material

Since 2020, RHI Magnesita has developed over 50 tempered MgO-C products with at least 20% circular raw material for steelmaking applications worldwide. These products are effectively used in both high- and low-wear areas of BOFs, EAFs, and steel refining ladles. Producing these tempered MgO-C products with high levels of circular raw material necessitates stringent quality control of incoming spent refractory materials and specialised knowledge of the required processing steps (Figure 1) [12,14].

There are multiple types of circular raw materials available, rather than a single source. This variety arises from the various originating applications (e.g., EAF, BOF, and steel ladles), multiple refractory suppliers, varying presorting processes in steel plants, and diverse sorting, cleaning, and stabilisation measures applied by different circular raw material suppliers.

Producing MgO-C products with higher circular raw material content (Circular-MgO-C material) requires adjustments to both recipe design and the refractory production process to ensure the final product meets the required physical and chemical properties.

Case Studies

Case 1: 210-tonne BOF

A 210-tonne BOF was equipped with Circular-MgO-C material in the top cone area, tapping pad, and upper part of the cylinder, as outlined in red in Figure 2. Table I compares the chemical and physical properties of the standard MgO-C material used in this particular area of the BOF with the Circular-MgO-C material that replaced it. Although the fused magnesia component in both materials was the same, the Circular-MgO-C material contained 20% circular raw material. The total carbon content of both materials was identical. While the standard material contained antioxidants (AOX) based on aluminium, no AOX was added to the Circular-MgO-C. The physical properties of the Circular-MgO-C material were slightly less optimal than those of the standard material; however, its carbon footprint was reduced by 0.716 tonne CO_2equivalent per tonne of product (t $CO_2e/t_{product}$). This corresponded to a total carbon footprint reduction of 60.6 t CO_2e per lining, and as described below, the wear rate was equivalent to the standard material.

The integrated steel plant where this trial was conducted features three 210-tonne BOFs, one Ruhrstahl-Heraeus (RH) degasser, and supports two continuous casting machines (CCMs) for billet production, along with two Endless Strip Production CCMs. The facility manufactures structural steel and hot-rolled mild steel. On average, each

Figure 2.

210-tonne BOF lined with Circular-MgO-C material in the area outlined in red.

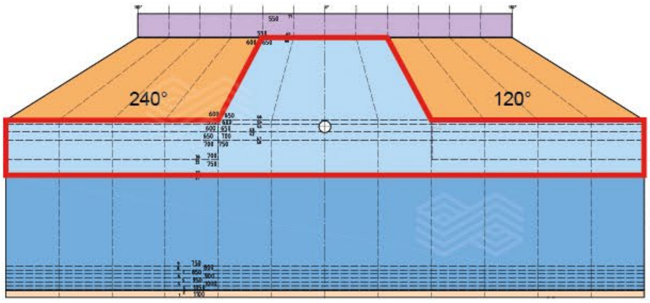


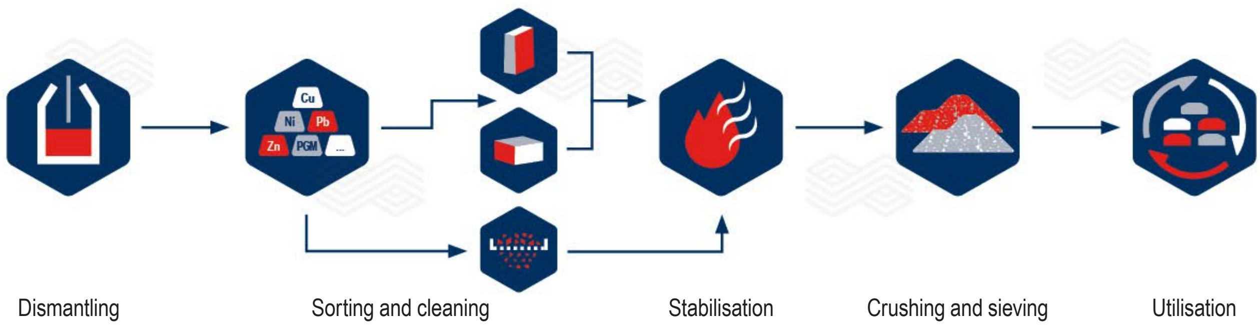
Table I.

Chemical and physical properties of the standard MgO-C and Circular-MgO-C bricks used in the top cone, tapping pad, and upper part of the cylinder. Abbreviations include tonne of CO_2 equivalent per tonne of product (t $CO_2e/t_{product}$).

	Standard MgO-C	Circular-MgO-C
MgO [wt.%]	91.9	94.7
Al_2O_3 [wt.%]	4.6	1.0
Fe_2O_3 [wt.%]	0.9	0.8
CaO [wt.%]	1.4	1.6
SiO_2 [wt.%]	1.2	1.9
C [wt.%]	16.0	16.0
Tempered:		
Bulk density [g/cm³]	3.03	3.00
Apparent porosity [vol.%]	2.0	3.0
Cold crushing strength [N/mm²]	45	35
Coked (1000 °C):		
Bulk density [g/cm³]	2.98	2.90
Apparent porosity [vol.%]	9.0	10.0
Cold crushing strength [N/mm²]	40	25
Product carbon footprint [t $CO_2e/t_{product}$]	3.079	2.363

Figure 1.

Processing steps required to reuse spent refractories in MgO-C products [16].



BOF completes 35 heats per day, with tapping temperatures typically ranging from 1590 °C to 1640 °C. Each BOF is equipped with eight single-hole plugs for bottom gas stirring. The average operational lifespan of a BOF is approximately 11500 heats. For maintenance of the tapping area and the bottom, approximately 800 tonnes of hot patching mix are used per campaign. Additionally, around 120–150 tonnes of gunning mix are applied per campaign, primarily in the trunnion area. Slag splashing is performed after every heat as part of the maintenance routine.

Figure 3 shows the laser scan profile of the BOF equipped with the Circular-MgO-C and, for comparison, the standard MgO-C material. The average wear rate for both the BOF lined with standard material and the BOF with Circular-MgO-C was calculated by dividing the difference between initial lining thickness and remaining lining thickness, as provided in these laser scans, by the number of heats. The area outlined in red indicates where the Circular-MgO-C was installed instead of the standard material. Since areas outside the blue outlined area mainly showed lining thicknesses exceeding the initial thickness, these areas were excluded from the wear rate determination, and only the values inside the blue lines were considered. The reason for these higher values was maintenance performed by gunning and slag splashing. The taphole area, indicated by the small purple square, was also excluded from the wear rate calculation. Based on these measurements, the average wear rate of the Circular-MgO-C lining was 0.008 mm/heat, while the wear rate of the standard lining was 0.009 mm/heat.

Case 2: 150-tonne BOF

In the second case study, a 150-tonne BOF was lined with Circular-MgO-C material in the cylinder area, as marked in red in Figure 4. Table II presents a comparison between the chemical and physical properties of the standard MgO-C material installed in the cylinder area of the BOF and the Circular-MgO-C material that replaced it. While both materials had the same fused magnesia component, the Circular-MgO-C material included 30% circular raw material.

Figure 4.

150-tonne BOF lined with Circular-MgO-C material in the cylinder area highlighted in red.

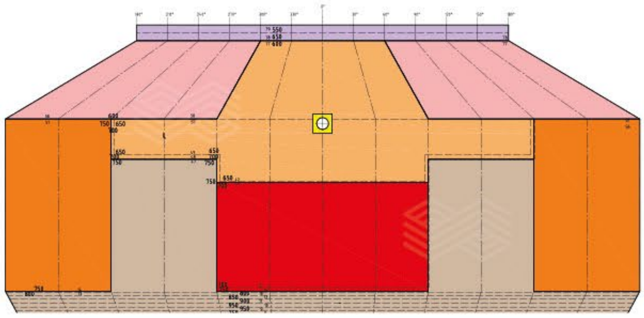


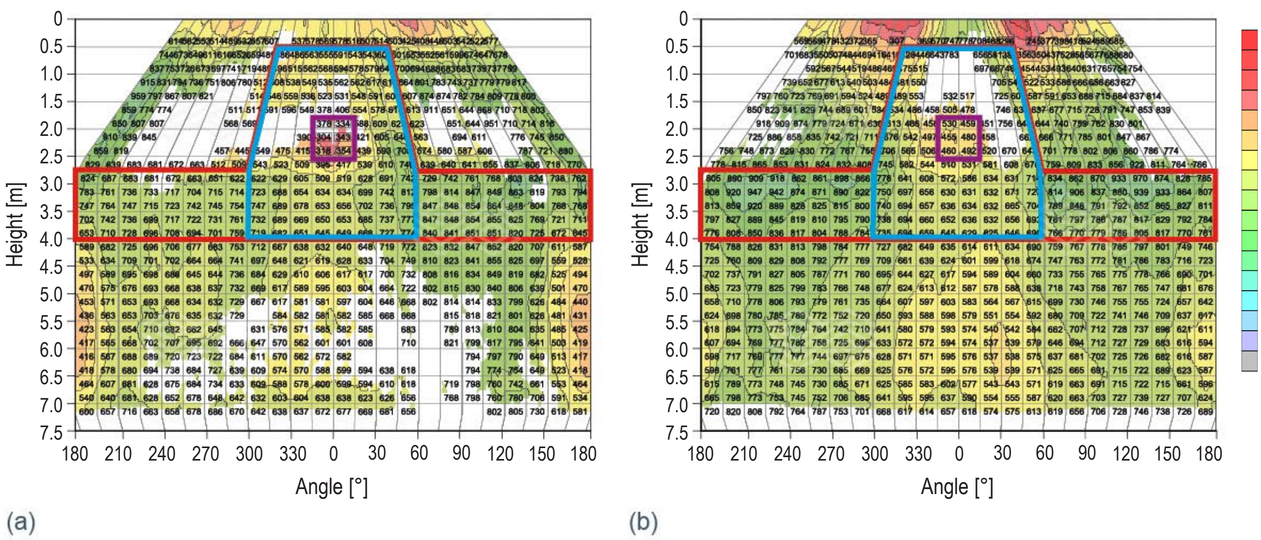
Table II.

Chemical and physical properties of the standard MgO-C and Circular-MgO-C bricks used in the cylinder area. Abbreviations include tonne of CO_2 equivalent per tonne of product (t $CO_2e/t_{product}$).

	Standard MgO-C	Circular-MgO-C
MgO [wt.%]	91.4	91.0
Al_2O_3 [wt.%]	4.7	5.5
Fe_2O_3 [wt.%]	0.9	0.7
CaO [wt.%]	1.5	1.3
SiO_2 [wt.%]	1.5	1.5
C [wt.%]	14.0	14.0
Tempered:		
Bulk density [g/cm^3]	2.99	2.93
Apparent porosity [vol.%]	2.5	2.5
Cold crushing strength [N/mm^2]	35	40
Coked (1000 °C):		
Bulk density [g/cm^3]	2.92	2.85
Apparent porosity [vol.%]	9.0	10.0
Cold crushing strength [N/mm^2]	35	20
Product carbon footprint [t $CO_2e/t_{product}$]	2.836	2.132

Figure 3.

Laser scans of the 210-tonne BOFs lined with (a) Circular-MgO-C material at 11103 heats and (b) standard MgO-C material at 11039 heats.



The total carbon content was identical, and both materials contained aluminium-based AOX. The Circular-MgO-C material exhibited minor differences in physical properties compared with the standard material, while its carbon footprint was reduced by 0.704 t $CO_2e/t_{product}$, resulting in a total carbon footprint reduction of 31 t CO_2e per lining. As discussed later, the wear rate matched that of the standard material.

This integrated steel facility operates two 150-tonne BOFs and two RH degassers, serving two CCMs for slab production and two CCMs dedicated to round billet production. The plant primarily manufactures bearing steel. Each BOF averages 36 heats per day, with tapping temperatures typically ranging between 1600 °C and 1620 °C. Bottom gas stirring is performed using eight multi-hole plugs. The average service life of a BOF is approximately 10000 heats. About 300 tonnes of hot patching mix are consumed for maintenance of the tapping area per campaign. There is no gunning maintenance, but slag splashing is carried out after every heat.

Figure 5 provides the laser scan profiles of the BOF equipped with the Circular-MgO-C and that lined with the standard MgO-C material. The average wear rate for both BOFs calculated by dividing the difference between initial lining thickness and remaining lining thickness, provided in the laser scans, by the number of heats achieved. The area outlined in red shows where the Circular-MgO-C was installed instead of the standard material. Excluding areas within this field where the lining thicknesses exceeded the initial thickness due to maintenance measures, the average wear rate of the Circular-MgO-C lining was determined to be 0.007 mm/heat, compared with 0.008 mm/heat for the standard lining.

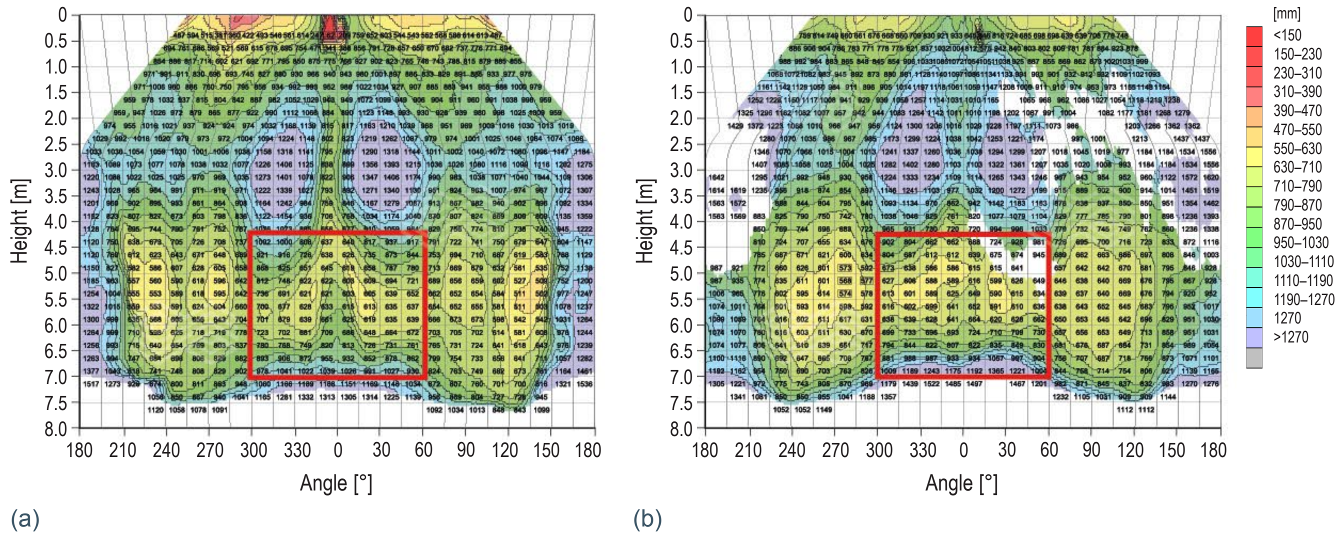
Summary and Conclusion

In this article, two case studies have been presented where standard MgO-C was replaced by Circular-MgO-C bricks in high-wear areas of BOF applications. In both cases, the Circular-MgO-C material significantly reduced the carbon footprint while achieving comparable wear rates to the standard material. Since wear rates are influenced by the steelmaking process, and especially maintenance practices, it can be assumed that the wear rates of Circular-MgO-C and standard MgO-C are comparable. Furthermore, it is important to note that the Circular-MgO-C materials presented in the article have replaced the corresponding standard MgO-C materials in regular operation.

The global success of these new types of high-performance Circular-MgO-C bricks is reflected in the development of

Figure 5.

Laser scans of the 150-tonne BOFs lined with (a) Circular-MgO-C material at 9093 heats and (b) standard MgO-C material at 9007 heats.

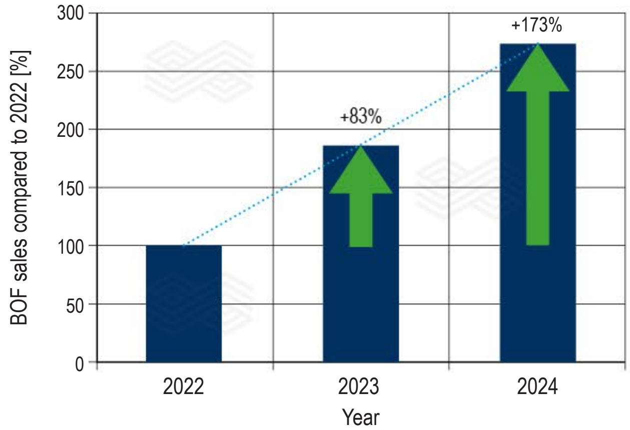


shipments (Figure 6). From 2022 to the end of 2024, sales volumes have steadily increased and almost tripled. This trend is expected to further accelerate worldwide, driven by the growing need to reduce CO_2 emissions, avoid landfilling, and minimise additional costs for storage and logistics of spent refractory materials.

In conclusion, the trials described in this article demonstrate that MgO-C bricks based on circular raw materials are suitable for high-wear areas and aggressive environments. Furthermore, even with a circular raw material content of up to 30%, the latest generation of Circular-MgO-C bricks developed by RHI Magnesita achieves performance comparable to standard MgO-C material, along with significant CO_2 savings.

Figure 6.

Increased global sales of high-performance Circular-MgO-C bricks for BOF applications since 2022.



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