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Circular Economy in Refractory Design: Improving Magnesia-Chromite Bricks with Recycled Raw Material

To meet climate goals, the steelmaking industry increasingly demands innovative products with a low carbon footprint. Among the critical equipment used in steel production, the RH degasser is essential for producing ultra-low carbon steel. It is typically lined with magnesia-chromite refractory bricks, with rebonded grades preferred in the snorkel and throat areas due to their superior abrasion and corrosion resistance. However, as rebonded bricks exhibit lower thermal shock resistance, direct-bonded bricks are applied in the safety lining as well as intermediate and lower vessel working linings, where resistance to thermal cycling is required. To reduce CO_2 emissions and support sustainable practices, circular raw materials derived from spent refractories have emerged as promising alternatives to virgin raw materials. However, while many studies have examined recycling across various refractory types, few have comprehensively investigated the microstructural, physical, thermomechanical, and corrosion resistance properties of magnesia-chromite bricks containing circular raw materials. Therefore, a study was conducted to evaluate the impact of incorporating increasing amounts of recycled magnesia-chromite material into standard direct-bonded compositions. The results showed excellent values across most tested properties, including thermal shock resistance comparable to the standard direct-bonded grade. These findings highlight the potential of magnesia-chromite recycling to reduce the carbon footprint and enhance direct-bonded brick performance while also demonstrating the low CO_2 emissions benefits of incorporating circular raw materials in industrial magnesia-chromite brick applications.

Introduction

According to the World Steel Association, the production of each tonne of steel in 2020 emitted an average of 1.89 tonnes of CO_2 into the atmosphere [1]. That year, global steel production reached 1860 million tonnes, resulting in estimated total direct emissions of approximately 2.6 billion tonnes of CO_2 from the steel sector. These emissions accounted for 7% to 9% of global anthropogenic CO_2 emissions [1]. The blast furnace ironmaking process, while currently essential, is highly polluting and consumes significant quantities of iron ore, coal, coke, and water. For example, producing 1 tonne of molten iron using this route emits approximately 1.4 tonnes of CO_2 [2]. One of the key challenges for the steel industry is transitioning from coal-based blast furnaces to hydrogen-based direct reduced iron processes or other alternative energy routes. In parallel, replacing basic oxygen furnaces with electric arc furnaces is essential to align steelmaking with global climate targets [3].

For industries that produce steel, nonferrous metals, cement, glass, and other materials that require high-temperature processes, refractory products are indispensable. It is estimated that up to 28 million tonnes of spent refractories are generated annually [4]. Despite these large amounts, recycling refractories has historically received limited attention, primarily due to the availability of low-cost virgin raw materials and low disposal costs. However, over the past two decades, growing environmental concerns and rising landfill costs have led to increased interest in recycling refractories [5].

In alignment with the global demand to reduce CO_2 emissions and supporting customers' short- and long-term environmental goals, RHI Magnesita has a sustainability strategy with clearly defined intermediate targets [6]. Since the carbon footprint of recycling is substantially lower than that of using virgin raw materials, depending on logistics and processing steps [7], replacing primary raw materials with circular minerals can potentially reduce the carbon footprint by up to 60% [8]. The typical recycling process involves sorting, cleaning, crushing, sieving, and utilisation [9]. While significant progress has been made in this area, extensive industry adoption of circular economy practices has been hindered by a lack of economic incentives [10]. To achieve substantial use of recycled materials while maintaining performance, refractory companies need a clear strategy and dedicated investment in innovative development technologies. RHI Magnesita is leading the market towards a circular business model with a strong focus on sustainability. Leveraging the expertise of its R&D centres and process experts worldwide, the company achieved a record recycling rate of 14.2% in 2024 [11].

As the largest consumer of refractories globally, the steelmaking industry is increasingly demanding innovative, low CO_2 products from its supply chain, including raw materials and refractory solutions. Among the critical equipment used in secondary refining, the RH degasser plays a fundamental role in producing ultra-low carbon steel and is typically lined with magnesia-chromite bricks due to their superior performance under severe conditions.

Three types of magnesia-chromite bricks are used in RH degassers: Rebonded and semi-rebonded grades, containing fused magnesia-chromite, are applied in high-wear zones like the snorkel and throat, while direct-bonded bricks are preferred for the safety and working linings where there is no direct interaction with molten steel. Despite the effectiveness of these materials, their chromium content poses environmental challenges, making their recycling into new bricks a priority for achieving circular economy goals.

Overcoming the environmental challenges associated with chromium-containing refractories, particularly concerns about their recyclability, is essential. Hexavalent chromium (Cr^{6+}), known for its toxicity and water solubility, can form under certain conditions, primarily at high temperatures in environments rich in oxygen, alkali, and alkaline earth metals, or at pH levels above 7 [12,13]. However, this formation has not been observed in RH degasser applications, and no significant levels of Cr^{6+} have been detected in spent refractories from these operations.

A review of the literature revealed a clear gap in the development and application of recycled materials in magnesia-chromite brick formulations. In response, this study aimed to demonstrate that, through careful sourcing, cleaning, and processing, circular raw materials derived from spent magnesia-chromite bricks can not only meet but potentially enhance product quality. A new internal recycling route was developed to ensure consistency and performance of the circular raw material. The study then evaluated the effect of incorporating three levels of circular raw material (i.e., 25%, 50%, and 75%) into a standard direct-bonded composition. The resulting bricks were assessed and compared to the reference grade in terms of their chemical, physical, and thermomechanical properties.

Figure 1.

Cross-section of a magnesia-chromite brick after application showing severe slag infiltration and metallic phases at the hot face (densified layer) and the inner brick.

Materials and Methods

Laboratory-scale magnesia-chromite bricks were established using Alfred's model, with a customised particle size distribution tailored to the specific requirements of direct-bonded products. The formulations were designed for industrial conditions and were evaluated against key performance indicators, including chemical composition, physical integrity, and thermomechanical behaviour. The aim was to determine the optimal balance between virgin and circular raw materials to achieve the performance required for high-demand steelmaking applications.

The new recycling process route that was developed covers all stages from spent material sourcing to internal quality control. This was essential, not only to ensure the circular raw material meets all requirements for high-performance refractory production, but also to establish a stable long-term supply chain.

Development of this recycling process was driven by the specific wear mechanisms that affect magnesia-chromite bricks in RH degasser applications. These mechanisms occur in three main stages:

- Infiltration of slag and metallic impurities into the brick (mainly Fe_2O_3, CaO and SiO_2).
- Densification of the hot face due to prolonged exposure to high temperatures.
- Structural spalling resulting from thermal and mechanical stress.

An example of this wear pattern is shown in Figure 1 and necessitates mechanical removal of the brick's hot face to eliminate infiltrated slag and metallic impurities prior to crushing and reprocessing. This cleaning process, developed as part of the study, is essential to ensure consistent chemical quality and reliable sintering performance of magnesia-chromite bricks containing this material. The typical chemical composition of the resulting magnesia-chromite circular raw material, determined by quantitative X-ray fluorescence (XRF), is detailed in Table I. Its composition closely matches that of the original electrofused raw materials used in high-performance magnesia-chromite refractories, reinforcing its suitability for demanding industrial applications.

Additionally, samples of this circular raw material were submitted to an external laboratory for Cr^{6+} analysis. The results indicated a concentration of 0.006 mg/kg, confirming that the material is suitable for use in magnesia-chromite

Table I.

Chemical composition of the magnesia-chromite circular raw material, determined by quantitative XRF.

	SiO_2 [wt%]	TiO_2 [wt%]	Al_2O_3 [wt%]	Cr_2O_3 [wt%]	Fe_2O_3 [wt%]	CaO [wt%]	MgO [wt%]	MnO [wt%]
Magnesia-chromite circular raw material	1.42	0.11	7.14	22.90	8.62	1.03	58.68	0.12

brick production and fully compliant with current environmental regulations. This low Cr^{6+} content is primarily attributed to the absence of sodium in the customers' RH degasser processes, which is known to significantly reduce the kinetics of Cr^{6+} formation during high temperature exposure. The measured value was well below both the US Environmental Protection Agency limit (100 mg/kg) and the European regulatory threshold (2 mg/kg) [14].

Following validation of the recycling process to produce high-quality magnesia-chromite circular raw material, a series of brick compositions was evaluated. Three formulations containing increasing levels of circular raw material—25% (A), 50% (B), and 75% (C)—were compared to a reference grade (REF), representing a standard direct-bonded magnesia-chromite brick (Table II). To ensure consistent comparison across all compositions and eliminate variables that could affect firing behaviour, identical binder systems and sintering additives were used throughout.

Laboratory Trial Results

To assess the influence of increasing circular raw material content on the properties of direct-bonded magnesia-chromite bricks, the formulations in Table II were homogenised in a roller mixer, hydraulically pressed into 160 × 85 × 63 mm bricks, and fired above 1700 °C in an industrial kiln. Bulk density and apparent porosity were measured by the water immersion method according to ABNT NBR 6220. Cold modulus of rupture was tested using a KRATOS KE press (3-tonne capacity), while cold crushing strength was measured using a KRATOS ECC press with a 100 kN load cell, following JIS R-2206 standards, on cylindrical 50 × 50 mm specimens. Hot modulus of rupture was determined using 152 × 25 × 25 mm bars tested in an electric furnace equipped with a continuous feeding system and a mechanical press (KRATOS K500/2000, Brazil). Permeability was assessed following ASTM C577, and abrasion resistance according to ASTM C704. Microstructural evaluation was carried out by optical microscopy using a Carl Zeiss AXIO-Imager microscope.

Thermal shock resistance was evaluated on 152 × 25 × 25 mm^3 bars subjected to five thermal cycles (ΔT = 1175 °C) using a water-cooled copper plate after heating to 1200 °C. The decrease in elastic modulus after each cycle was monitored with ultrasound equipment (Emodumeter, James Instruments, USA), and the residual modulus was calculated from the ultrasound velocity and sample density, as specified in ABNT NBR 13202. Corrosion resistance was tested at 1700 °C in an induction furnace, using a steel bath with fayalitic slag addition every 30 minutes over a 5-hour cycle. Results of the physical, thermomechanical, and corrosion resistance properties are summarised in Table III.

The results presented in Table III demonstrate a clear positive correlation between circular raw material content and improvements in key properties, beginning with the observed linear dimensional change. As the proportion of circular raw material increased, the bricks exhibited a progressive contraction after firing, which contributed to greater dimensional stability during sintering and would likely reduce expansion during industrial application. These dimensional effects were closely linked to improvements in bulk density, apparent porosity, and permeability. With each increase in circular raw material content, bulk density rose by approximately 0.03 g/cm³ (A), reaching 3.19 g/cm³ in composition C, while apparent porosity dropped from 17.27% in the reference to 15.73% in C, indicating enhanced grain packing and improved sintering kinetics.

Table II.

Magnesia-chromite brick compositions containing different amounts of circular raw material.

	REF	A	B	C
Circular raw material [%]	0	25.0	50.0	75.0
Sintered magnesia	++++	+++	++	+
Chrome ore	++++	+++	++	+

Table III.

Physical, thermomechanical, and corrosion resistance properties (average of 3 samples) of the direct-bonded magnesia-chromite brick compositions containing different amounts of circular raw material.

	REF	A	B	C
Circular raw material addition [%]	0	25	50	75
Properties				
Linear dimensional change [%]	1.08	0.21	-0.18	-0.28
Bulk density [g/cm³]	3.10	3.13	3.16	3.19
Apparent porosity [%]	17.27	16.20	15.81	15.73
Cold crushing strength [MPa]	52	84	118	106
Modulus of rupture [MPa]	4.2	8.5	12.9	11.9
Hot modulus of rupture (1250 °C/3 hours) [MPa]	13.1	17.5	20.3	19.9
Hot modulus of rupture (1400 °C/3 hours) [MPa]	10.4	14.2	12.6	12.9
Hot modulus of rupture (1485 °C/3 hours) [MPa]	6.7	6.8	8.4	8.6
Abrasion [%]	18.1	12.0	8.1	9.0
Permeability [cD]	80.0	53.0	36.2	42.1
Thermal shock resistance (1200 °C/5 cycles/ΔT = 1175 °C)				
Residual elastic modulus [%]	16.5	16.7	14.0	12.2
Residual modulus of rupture [%]	20.4	28.0	20.7	14.4
Corrosion resistance				
Metal wear [%]	3.43	3.08	2.73	2.43
Slag wear [%]	54.27	51.60	52.87	48.35

These trends were further supported by the permeability values, which showed reductions of nearly 50% in compositions B and C, reflecting a more filled microstructure. This densification not only improved the structural integrity of the bricks but also played a key role in limiting infiltration of molten slag and gases, which is critical for longevity in service.

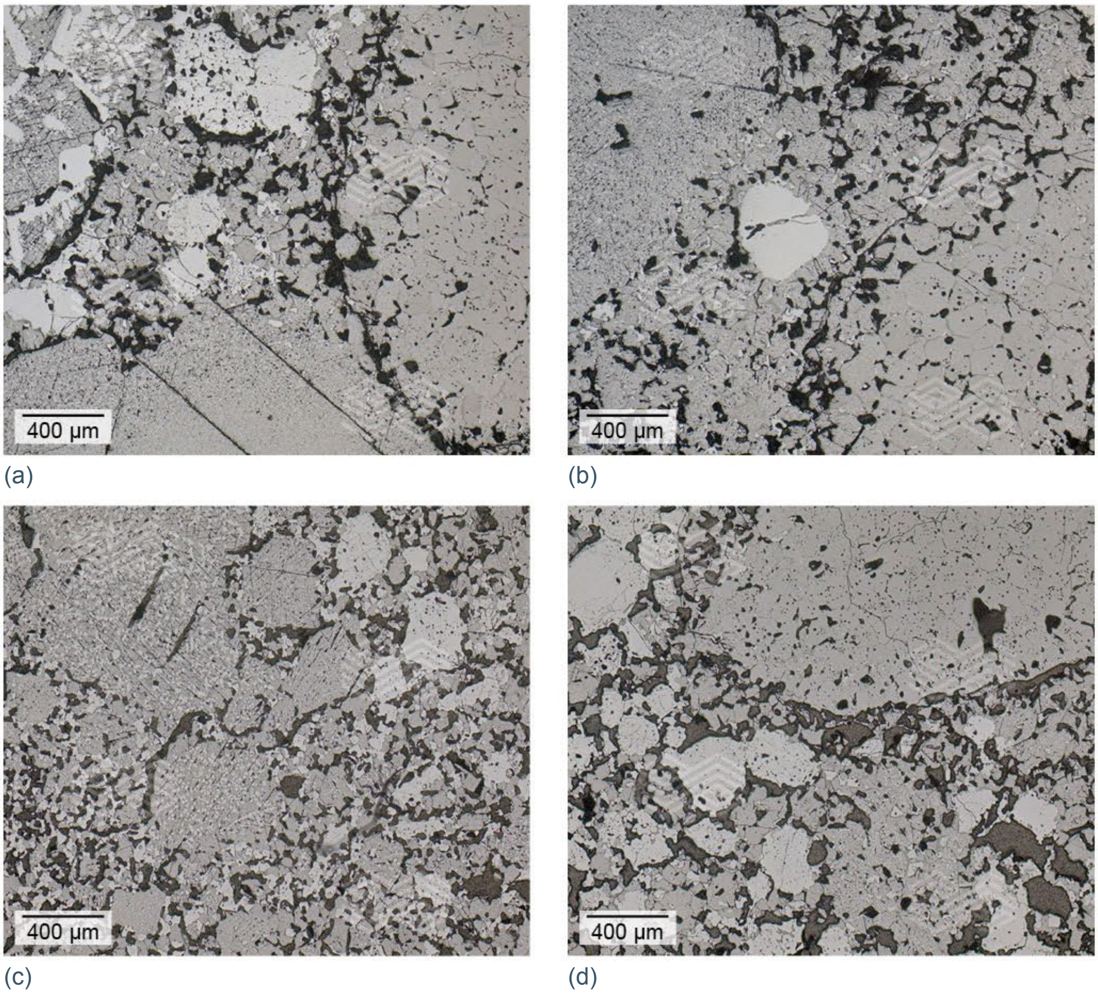
The enhanced microstructure also led to consistent improvements in cold mechanical properties. Both cold modulus of rupture and cold crushing strength increased significantly across compositions A, B, and C, confirming that the densification from circular raw material addition directly enhanced resistance to mechanical stress. In parallel, abrasion resistance improved with increasing circular raw material content, likely due to the formation of stronger ceramic bonds and more homogeneous phase distribution during firing. The combination of reduced porosity, lower permeability, and higher mechanical strength also contributed to improved corrosion resistance. Wear rates from both metal and slag attack were lower in all compositions containing circular raw material compared to the reference, confirming the protective effect of a denser, more chemically stable microstructure under high-temperature conditions.

Finally, thermal shock resistance was evaluated over five thermal cycles at 1200 °C (ΔT = 1175 °C). All compositions containing circular raw material maintained high residual elastic modulus values, indicating good structural integrity after thermal cycling. Compositions A and B performed similarly to the reference, with residual elastic modulus values of 16.7% and 14.0%, respectively, versus 16.5% for the reference. Notably, composition A showed the highest residual modulus of rupture (28.0%), highlighting its capacity to retain mechanical strength under thermal cycling. Although composition C exhibited slightly lower thermal shock resistance (12.2% residual elastic modulus and 14.4% residual modulus of rupture), these values remain within acceptable limits for RH degasser applications. Overall, these results underline the importance of optimising circular raw material content to balance improvements in mechanical strength and corrosion resistance with acceptable thermal shock performance, especially in applications involving cyclic thermal loading.

To further elucidate the origin of the observed improvements, optical microscopy was performed to examine the microstructural features responsible for the enhanced properties of direct-bonded magnesia-chromite bricks containing circular raw material (Figure 2).

Figure 2.

Comparative microstructure analysis of fired direct-bonded magnesia-chromite brick compositions with increasing circular raw material content: (a) 25%, (b) 50%, (c) 75%, and (d) reference composition with 0% circular raw material.



The microstructural evolution illustrated in Figure 2 provides clear evidence of the positive impact of circular raw material on the internal structure of direct-bonded magnesia-chromite bricks. The reference composition (Figure 2d) exhibited a more porous and heterogeneous microstructure, characterised by uneven chromite grain distribution, weaker ceramic bonding, and higher intergranular porosity—features inherent to conventional direct-bonded formulations. In contrast, compositions containing circular raw material, particularly B (50%) and C (75%), exhibited a denser and more uniform microstructure.

These improvements stem not only from the well-defined internal recycling process—which includes hot face removal, selective cleaning, and rigorous quality control— but also from the inherent quality of the recycled source material. The spent bricks used to produce the circular raw material originated from the most demanding zones of RH degassers: The lower vessel, throats, and snorkels. These areas are typically lined with rebonded or semi-rebonded bricks, produced with high-purity, electrofused magnesia-chromite, designed to withstand severe thermal and chemical stress. As a result, the recycled material inherently contains chemically stable, high-performance grains. When reintegrated into new brick formulations, these magnesia-chromite grains act not merely as filler, but as functional reinforcing phases—promoting stronger ceramic bonds, enhanced sintering, and reducing porosity.

The outcome is striking: This combination of premium recycled raw material and rigorous internal processing elevates the final product quality to a level comparable with semi-rebonded bricks—despite being based on a direct-bonded formulation. This reinforces the view that circular raw material is not just a sustainable alternative, but a technically robust solution for enhancing refractory performance in line with circular economy principles. Beyond the technical benefits, the use of circular raw material also contributes to measurable reductions in CO_2 emissions. By replacing carbon-intensive virgin raw materials, each composition containing circular raw material has a lower overall carbon footprint. At RHI Magnesita, an internal methodology is applied to estimate the CO_2 equivalent (CO_2e) savings per tonne of product, based on the degree of substitution and emission factors for each input material and process [15]. The calculated carbon product footprints for the different compositions are detailed in Table IV.

Table IV.

Calculated CO_2e emissions and relative CO_2e reductions achieved from incorporating circular raw material in magnesia-chromite brick formulations.

	REF	A	B	C
Carbon product footprint [t $CO_2e/t_{product}$]	1.77	1.41	1.21	1.01
Relative CO_2e reduction [%]	–	20.34	31.63	42.93

Using recycled materials provides a clear and efficient pathway to reduce CO_2 emissions in the refractory industry. For direct-bonded magnesia-chromite bricks, reliance on primary raw materials such as sintered magnesia and natural chromite is a major contributor to the product's overall carbon footprint. By substituting these virgin inputs with circular raw material derived from high-quality recycled bricks, the environmental impact can be significantly reduced. As shown in Table IV, CO_2e emissions decrease proportionally with increasing circular raw material content. Most notably, composition C (75% circular raw material) achieved a 42.93% reduction in CO_2e emissions compared to the reference formulation, clearly demonstrating the strong sustainability potential of this solution—without compromising technical performance.

Large Scale Production, Commercial Implementation and Emission Savings

Considering the balance between technical performance, industrial feasibility, and environmental impact, composition A (containing 25% circular raw material) was selected for industrial-scale production trials. The objective was to validate the laboratory results under real manufacturing conditions and determine the formulation's suitability for commercial use in steelmaking applications. To ensure consistent performance throughout the firing cycle in a full-scale tunnel kiln, samples were collected from three distinct positions on the kiln car (i.e., bottom, middle, and top) and analysed after firing. The corresponding results of various physical and thermomechanical properties are presented in Table V.

Following successful production trials and consistent results across all evaluated kiln positions, a customer rollout

Table V.

Physical and thermomechanical properties of composition A (25% circular raw material) after firing in an industrial tunnel kiln (average of 3 samples)—results by kiln car position.

Properties	Kiln car position		
	Bottom	Middle	Top
Bulk density [g/cm^3]	3.25	3.27	3.26
Apparent porosity [%]	14.6	13.8	13.9
Cold crushing strength [MPa]	67	81	66
Modulus of rupture [MPa]	8.2	10.2	9.4
Hot modulus of rupture (1250 °C/3 hours) [MPa]	14.6	15.5	15.2
Hot modulus of rupture (1400 °C/3 hours) [MPa]	10.7	10.6	11.0
Hot modulus of rupture (1485 °C/3 hours) [MPa]	5.8	5.7	5.9
Abrasion [%]	10.7	10.2	10.5
Permeability [cD]	51.9	44.8	46.8

phase was initiated to introduce the new product containing circular raw material to the market. Commercial approaches began in early 2025, and until now, the benefits have been strongly positive. To date, combining actual deliveries and confirmed customer forecasts, approximately 350 tonnes of RADEX 6F6 bricks containing 25% circular raw material have been produced and supplied, resulting in the utilisation of over 88 tonnes of high-quality circular raw material.

From a sustainability perspective (see Table V), this implementation has already led to an estimated 20.3% reduction in CO_2 emissions compared to the conventional formulation. Beyond the success of this individual product, the validated recycling concept paves the way for expanding the use of circular raw materials to other magnesia-chromite product lines within RHI Magnesita's portfolio, further strengthening the company's commitment to delivering low-carbon, high-performance refractory solutions for the steel industry.

Conclusion

Among heavy industries, the iron and steel sector remain the largest contributor to global CO_2 emissions [16], and achieving climate targets will require a reduction of at least 50% by 2050. One of the most impactful short-term strategies to support this goal is to improve material efficiency, particularly through recycling refractory materials. This study presented a novel technological route for incorporating high-quality magnesia-chromite circular raw material into direct-bonded bricks for steelmaking applications. The compositions containing circular raw material (A, B, and C) demonstrated superior physical, thermomechanical, and corrosion resistance performance when compared to the standard reference, while maintaining comparable thermal shock resistance. These results confirm that, when supported by a robust and well-controlled recycling strategy, including hot-face removal, sorting, crushing, and strict quality control, circular raw material can not only maintain but in many cases enhance refractory performance.

Composition A (25% circular raw material) has already been successfully implemented in commercial production and is being supplied to customers aiming to reduce their CO_2 footprint. Compositions B and C, capable of delivering CO_2e reductions of up to 42%, are currently under development as part of RHI Magnesita's LC-Series—a portfolio of low-carbon refractory solutions. Importantly, this work also dispels the outdated perception that recycled content is synonymous with lower performance or purely cost-driven products. In reality, delivering high-performance bricks using circular raw material requires substantial investment, rigorous process control, and strategic alignment across the entire recycling chain.

Ultimately, the success of a circular economy model between the refractory and steelmaking industries relies on shared responsibility and close collaboration—from material sourcing and processing to product application. Enabled by local-to-local supply chains, this partnership is key to delivering genuinely low-carbon, high-performance refractories that meet both industrial requirements and environmental goals.

References

[1] https://worldsteel.org/climate-action/climate-change-and-the-production-of-iron-and-steel/

[2] https://steelwatch.org/wp-content/uploads/2025/01/2501_Climate.pdf

[3] Zhang, Y., Yu, L., Cui, K., Wang, H. and Fu, T. Carbon Capture and Storage Technology by Steel-Making Slags: Recent Progress and Future Challenges. *Chem. Eng. J.* 2022, 455, 140552.

[4] https://tufreiberg.de/en/research/grk2802#:~:text=Home,and%20upcycling%20of%20refractory%20materials

[5] Madias, J. A Review on Recycling of Refractories for the Iron and Steel Industry, AISTech 2018 Proceedings, 3271–3276.

[6] RHI Magnesita 2023 Sustainability Report. https://www.rhimagnesita.com/wp-content/uploads/2024/04/rhim-sustainability-report-2023-final-2.pdf

[7] Moraes, M.N., Nogueira, G.G.R. and Silveira, F.T. Desafios Técnicos no Processamento de Reciclados. 42nd Alafar Conference Proceedings. Foz do Iguacu, Brazil, November 7–12, 2022.

[8] Strubel, S. *Developing a Model to Calculate the Carbon Footprint of Refractory Products*, Master's thesis, Leoben University, Austria, 2012.

[9] Moraes, M., Leitner, A., Nogueira, G., Zocratto, B., Heid, S. and Mühlhäußer, J. Technical Challenges for Refractory Recycling and Innovative Processing Solutions. *Bulletin*. 2023, 33–38.

[10] Han, J., Jiao, F., Liu, W., Qin, W., Xu, T., Xue, K. and Zhang, T. Innovative Methodology for Comprehensive Utilization of Spent MgO-Cr_2O_3 Bricks: Copper Flotation. *ACS Sustain. Chem. Eng.* 2016, 4(10), 5503–5510.

[11] RHI Magnesita Annual Report and Accounts 2024. https://ir.rhimagnesita.com/wp-content/uploads/2025/02/rhim-ar2024-final.pdf

[12] Saha, R., Nandi, R. and Saha, B. Sources and Toxicity of Hexavalent Chromium. *J. Coord. Chem.* 2011, 64(10), 1782–1806.

[13] Verbinnen, B., Billen, P., Van Coninckxloo, M. and Vandecasteele, C. Heating Temperature Dependence of Cr(III) Oxidation in the Presence of Alkali and Alkaline Earth Salts and Subsequent Cr(VI) Leaching Behavior. *Environ. Sci. Technol.* 2013, 47, 5858–5863.

[14] Xu, T., Xu, Y., Li, Y., Sang, S., Wang, Q., Zhu, T., Nath, M. and Zhang, B. Corrosion Mechanisms of Magnesia-Chrome Refractories in Copper Slag and Concurrent Formation of Hexavalent Chromium. *Journal of Alloys and Compounds.* 2019, 786, 306–313.

[15] Joos-Bloch, M., Rechberger, L., Haider, C., Moulin-Silva, W., Wucher, J. and Drnek, T. Product Carbon Footprint of Refractory Products. *Bulletin*. 2023, 39–44.

[16] International Energy Agency. Iron and Steel Technology Roadmap. October 2020. https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

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