# DEVELOPMENT OF NOVEL HIGH-GRADE AND HIGH-DENSITY DEAD BURNED MAGNESIA

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## ABSTRACT

Dead burned magnesia (DBM) is one of the most important raw materials for refractory production. RHI Magnesita produces and consumes low, medium and high-grade DBMs, depending on the desired application. This article covers the development of a unique high-grade dead burned magnesia, starting with a magnesium carbonate containing 99% of MgO and aiming to achieve the best sinter properties, and therefore, refractory performance. The study comprised the evaluation of four different calcination methodologies with the magnesium carbonate sample, followed by briquetting and sintering in a laboratory kiln. The best achieved sinter was also tested in bricks to check refractory properties. The different calcining approaches resulted in differences on the produced caustic materials, mainly in lost on ignition, specific surface area, and reactivity. These variations in the calcined material were translated into different sinter properties after firing, especially bulk density and crystal size. The best produced DBM was then tested in magnesia-spinel brick, outperforming the hot properties from a formulation with the reference high grade sinter used for this application. Therefore, the development of this novel sinter expands RHI Magnesita potential alternatives for raw material selection in high end applications, where the high purity and high density are key properties for the performance of the refractory products.

## INTRODUCTION

Sintered magnesia, also known as dead burned magnesia (DBM), is one of the most important refractory raw materials used in high-temperature industrial applications, particularly in the steel, cement, and non-ferrous industries. Its relevance is due to a combination of high chemical purity, excellent thermal stability, resistance to basic slag corrosion, and compatibility with aggressive alkaline environments[1,2].

DBM can be produced at high-temperature sintering of magnesium carbonates such as magnesite, typically between 1500°C and 2000°C. This thermal treatment decomposes the carbonates and promotes the formation of dense periclase (MgO) crystals with high bulk density and minimal porosity[3,4]. Effective sintering eliminates residual porosity and facilitates grain growth, directly improving mechanical strength, dimensional stability, and corrosion resistance under demanding operational conditions[2,5].

The microstructure of DBM is predominantly composed of dense periclase grains. Depending on the level of impurities, secondary phases such as larnite ($Ca_2SiO_4$), hatrurite ($Ca_3SiO_5$), forsterite ($Mg_2SiO_4$), merwinite ($Ca_3Mg(SiO_4)_2$), and monticellite ($CaMgSiO_4$) may form. These secondary phases are undesirable when present in significant amounts, as they reduce the refractory's corrosion resistance and thermal stability, particularly in basic environments[1,5].

Compared to fused magnesia (FM), which is manufactured in electric arc furnaces at temperatures exceeding 2800°C, sintered magnesia has lower density and some residual porosity. However, this porosity imparts DBM with superior thermal shock resistance, which is advantageous for applications that experience rapid temperature fluctuations, such as cement rotary kilns, tundishes, and certain ladle linings[6]. On the other hand, fused magnesia has a significant larger periclase crystal size, leading to better corrosion resistance by steel and slag.[7]

The sintering behavior of magnesia is influenced by several factors, including the purity of the raw material, particle size distribution, calcination parameters, and the presence of liquid-phase formation agents. Impurities such as $SiO_2$ and CaO must be carefully controlled, since they can react to form low-melting secondary phases like merwinite and monticellite, adversely affecting refractory performance[6,8].

In this context, the present work focuses on the development of a novel high-purity dead burned magnesia, starting from magnesium carbonate with an MgO content exceeding 99%. The objective is to optimize the calcination and sintering processes in order to achieve superior densification and microstructural characteristics. By enhancing these sinter properties, the aim is to produce a DBM with excellent refractory performance, capable of meeting the stringent requirements of high-temperature industrial applications.

## CALCINATION AND SINTERING EVALUATION

The production process consisted of several steps. Initially, calcination was performed using four different methodologies The calcination method employed in the production of Caustic Calcined Magnesia (CCM) plays a crucial role in determining the physical characteristics of the final product. The comparative data in the table 1 provide insights into how different technologies — static furnace, flash calciner, rotary kiln, and hearth furnace — affect key parameters, including the DBM produced from this CCM with special emphasis on Grain Bulk Density (GBD), a critical property for refractory applications.

Tab. 1: CCM calcined with different methods

| Properties | CCM Static Furnace | CCM Flash Calciner | CCM Rotary Kiln | CCM Hearth Furnace |
|---|---|---|---|---|
| LOI (%) | 0,9 | 4,9 | 2,4 | 1,0 |
| SSA BET ($m^2/g$) | 20,5 | 59,8 | 51,6 | 18,0 |
| DBM GBD ($g/cm^3$) | 3,25 | 3,31 | 3,47 | 3,50 |
| DBM Crystal size (µm) | 87 | 107 | 174 | 205 |

The GBD reflects the packing density of the calcined material when transformed into Dead Burned Magnesia (DBM). Among the technologies evaluated, the hearth furnace results in the highest sinter GBD value of 3.50 $g/cm^3$, indicating a highly

densified product, illustrated in figure 1, with excellent thermal resistance, ideal for demanding refractory uses. This high density correlates with the largest crystal size (205 µm), which are characteristics of a well-sintered material, illustrated in figure 1.



Fig 1: Produced DBM from Hearth Furnace CCM

In contrast, DBM produced using the static furnace and flash calciner CCM exhibits the lowest bulk density. In the case of the static furnace, the absence of movement during calcination results in non-uniform heat distribution, which contributes to greater material heterogeneity. This heterogeneity adversely affects the material's sinterability, leading to suboptimal densification. For the flash calciner, the high loss on ignition (LOI) and elevated specific surface area (SSA BET) of the resulting CCM negatively affect the subsequent sintering process, ultimately hindering densification.

CCM processed via rotary kiln calcination attains adequate densification, though marginally lower than that achieved through the hearth furnace method. While the rotary kiln remains a technically feasible alternative for the calcination stage, stringent control of the Loss on Ignition (LOI) is imperative. Efforts should be directed toward minimizing LOI values to suppress excessive specific surface area, which may adversely affect could negatively impact downstream sintering performance.

In summary, the bulk density serves as a key indicator of the calcination process's effectiveness in producing dense, sintered magnesia suitable for high-performance refractories. While the hearth furnace leads in producing high density and high crystal size DBM, the flash calciner is optimized for high surface area and applications where this is important. The rotary kiln and static furnace offer compromise solutions with respectable densification and versatility across applications. This outcome demonstrated that the calcination quality has a critical influence on the final product properties.

The CCM Hearth Furnace produces DBM with the highest bulk density among the evaluated calcination methods. The reduced LOI reflects a more complete thermal decomposition of magnesite, indicating that most of the $CO_2$ has already been released during calcination. This enhances the stability and reactivity of the calcined material during the subsequent sintering stage. Additionally, the lower specific surface area signifies reduced porosity and fewer high-energy surface sites, which improves particle packing and facilitates densification by minimizing diffusion barriers. These properties result in a feedstock that is thermodynamically and kinetically favorable for sintering, allowing the production of DBM with superior density and structural integrity. Figure 2 shows the microstructure of the resulting sinter from Hearth Furnace CCM.

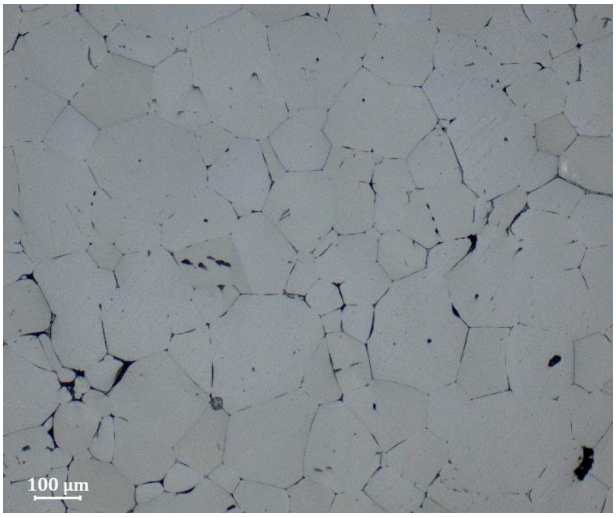



Fig 2: DBM microstructure from Hearth Furnace CCM

The microstructure reveals well-developed, tightly bonded sintered periclase crystals, characterized by low residual porosity and the absence of significant secondary phases or contaminant inclusions. This indicates a high degree of sintering efficiency and material purity, both critical for optimal refractory performance. Based on the favorable quality of the produced DBM, the material was made available for evaluation in refractory application trials.

**REFRACTORY BRICK PERFORMANCE**

The refractory application trials were conducted to evaluate the performance of two distinct categories of refractory products: magnesia-spinel bricks and magnesia-carbon bricks. These trials were designed to assess the suitability of the produced DBM in demanding refractory environments. Figure 3 presents the magnesia-spinel bricks employed during the testing phase, offering a visual reference for the quality of the shaped refractory components evaluated.



Fig 3: magnesia-spinel bricks standard (left) and with novel DBM (right).

Table 2 summarizes the key physical and mechanical properties of the magnesia-spinel bricks incorporating the DBM produced in this study, comparing it to the standard brick that uses high grade DBM. The data indicate that the newly developed DBM contributed to enhanced brick performance.

Tab. 2: magnesia-spinel bricks properties

| Properties | Standard brick | Brick with novel DBM |
|---|---|---|
| Fired density (g/cm³) | 3,02 | 3,13 |
| CCS (MPa) | 95 | 115 |
| HMOR 1485°C-3h (MPa) | 1,2 | 2,7 |
| MOE (GPa) | 34 | 41 |
| Permeability (cD) | 9,2 | 7,6 |

Bricks formulated with this DBM had a higher bulk density after firing of 3.13 g/cm³ compared to the reference value of 3.02 g/cm³. They also demonstrated improved cold crushing strength, reaching 115 MPa compared to 95 MPa for the reference. The hot modulus of rupture at 1485°C was 2.7 MPa, which is significantly higher than the 1.2 MPa observed for the standard product. Furthermore, these bricks showed enhanced resistance to clinker liquid phase infiltration, a benefit attributed to the denser microstructure of the DBM. These improvements underscore the suitability of the material for high-performance refractory applications, with results surpassing those obtained from standard high grade DBM.

In the case of magnesia-carbon bricks, the DBM developed in this study was benchmarked against both a standard high-grade DBM and low-grade fused magnesia (FM), which are commonly used raw materials in this refractory category. This comparative approach was adopted to evaluate the relative performance of the new DBM under conditions that simulate the demanding operational environment of magnesia-carbon applications in steelmaking. Table 3 compiles the main physical properties of the raw materials and the resulting wear on slag line of the tested magnesia-carbon bricks.

Tab. 3: magnesia-carbon raw materials and wear

| Properties | Standard DBM | Novel DBM | Low grade FM |
|---|---|---|---|
| Bulk density (g/cm³) | 3,30 | 3,50 | 3,38 |
| Crystal size (µm) | 120 | 205 | 1495 |
| Wear on Slag Line (%) | 22.7 | 21.4 | 18.4 |

Although the DBM achieved a bulk density surpassing that of low-grade FM, the crystal size, which reached approximately 200 µm, was still considerably smaller than the over 1000 µm typical of FM, even for the lower quality fused material. As a result, the wear resistance of the DBM under aggressive slag conditions was inferior to that of FM, confirming that this material is not suitable as a direct replacement for fused magnesia in applications requiring extreme corrosion resistance. Another observation, for the range of densities compared among the samples, this is not the key factor influencing corrosion resistance, while crystal size is the main contributor.

## CONCLUSION

A novel high-purity dead burned magnesia was successfully developed, achieving bulk densities of 3.5 g/cm³ and periclase crystal sizes over 200 µm. The material demonstrated excellent sintering behavior, achieving high densification.

The comparative analysis of calcination methodologies clearly demonstrates that the choice of calcination technology significantly impacts the physical characteristics of the resulting Caustic Calcined Magnesia (CCM) and its transformation into Dead Burned Magnesia (DBM). The hearth furnace method yields the highest DBM grain bulk density and largest crystal size, indicating superior sintering and thermal resistance suitable for high-performance refractory applications. The rotary kiln CCM also provide a proper sintered material, even though the LOI after calcination was slightly high. Conversely, the static furnace and flash calciner produced lower density sinter and are not suitable for this purpose of high density DBM.

Refractory performance testing confirmed that this DBM offers superior mechanical properties when used in magnesia-spinel bricks, outperforming conventional high-grade sintered magnesia. However, the material does not yet serve as a replacement for fused magnesia in magnesia-carbon applications where extremely large crystal sizes are required to ensure optimal corrosion resistance.

This development expands the available raw material options for high-performance refractory applications. The combination of high purity, excellent sinterability, and dense microstructure makes this DBM a technically robust alternative for applications where purity and bulk density are critical.

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