# Reducing Carbon Footprints and Energy Consumption: Refractory Innovations in Aluminum Processing

Clint Hess, Allied Mineral Products, Inc., Columbus, Ohio, U.S.A.
Tim Hoyt, Allied Mineral Products, Inc., Columbus, Ohio, U.S.A.
Tim Marth, Allied Mineral Products, Inc., Columbus, Ohio, U.S.A.

## ABSTRACT

This paper explores the efficacy of calcium oxide (CaO) based insulating refractory materials in reducing carbon emissions and energy consumption within molten aluminum production equipment. The utilization of these innovative refractories aims to enhance thermal efficiency, thereby lowering energy requirements and mitigating environmental impact. By minimizing heat loss and optimizing furnace operations, significant reductions in both operational costs and greenhouse gas emissions are achievable. This patented technology can reduce energy consumption by up to 30% compared to conventional refractories, leading to substantial cost savings and lower carbon emissions. This paper will also discuss successful case studies whereby actionable insights and practical recommendations for the adoption and implementation of CaO based refractory materials have optimized energy use thus minimizing environmental impact.

## 1. Introduction

The aluminum industry plays a crucial role in global manufacturing, yet it faces significant challenges in reducing its carbon footprint and optimizing energy consumption. Aluminum demand continues to increase on a global scale and is expected to increase 40% by the year 2030[i]. Nearly 2% of the world's greenhouse gas emissions comes from the aluminum sector[ii]. One promising avenue for achieving these goals lies in the adoption of advanced insulating refractory materials in the production process, particularly those based on CaO.

Allied's WAM® AL technology encompasses a range of refractory products specifically designed for the aluminum industry. Known for their superior non-wetting characteristics and enhanced insulation properties, these products contribute to significant energy savings and extended refractory performance. WAM® AL products are made from high purity CaO materials with an ultra-low silica ($SiO_2$) content, helping to minimize corundum formation in aluminum melting and holding furnaces.

## 2. Background

The implementation of WAM® AL refractory materials address the common goal of reducing energy consumption and handling common refractory failure modes within aluminum processing equipment.

This paper explores examples confronting these common failure mechanisms with a CaO based refractory system. The system resists reactions with molten aluminum, dross, and corundum formation while also requiring less energy consumption to maintain consistent furnace temperature. In aluminum furnaces, a significant challenge arises from corundum formation, a byproduct of aluminum's natural tendency to oxidize into alumina, as shown in Figure 1[iii]. Molten aluminum seeks oxygen atoms, which it can acquire from atmospheric sources or from less stable oxides within the refractory material. The reaction tendencies of these oxides are illustrated in Table 1, a partial Ellingham diagram[iv], a tool that delineates their relative stabilities under high-temperature conditions.

**Figure 1 – Aluminum Oxide/Corundum Formation**

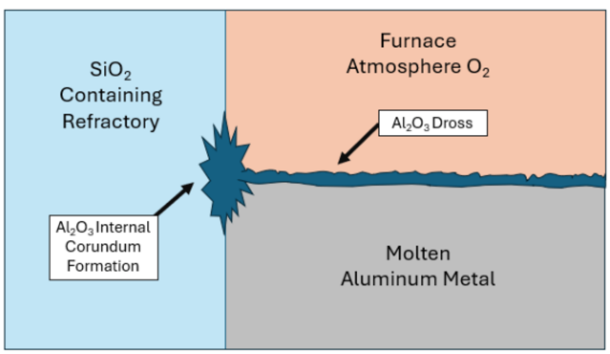
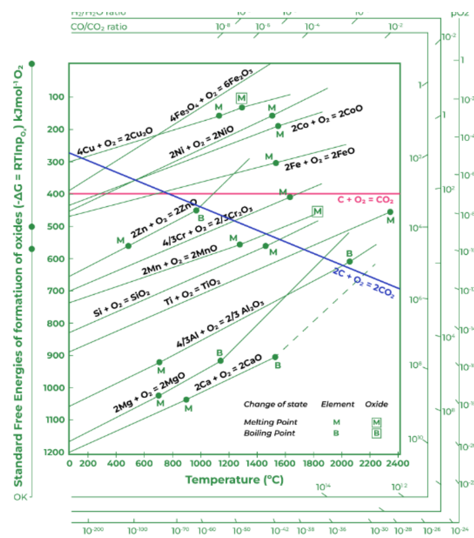



**Table 1 - Partial Ellingham Diagram**




The diagram reveals that silica is more reactive than alumina, indicating silica is less stable in the presence of molten aluminum. This vulnerability makes silica prone to reacting with aluminum, leading to corundum formation and reactions within a refractory matrix. Conversely, oxides like alumina and calcia are positioned below silica on the chart, indicating their greater stability against molten aluminum reactions. Specifically, calcia's lower position relative to alumina confirms that aluminum particles do not readily react with calcia, thereby mitigating reactivity between molten aluminum and the refractory matrix in aluminum processing vessels.

Understanding these dynamics is crucial for refractory selection, minimizing the detrimental effects of corundum formation and subsequent buildup, ultimately enhancing the efficiency and longevity of aluminum contact refractories.

**Table 2**

| Product | $Al_2O_3$ % | $SiO_2$ % | aO % | Density | Thermal Conductivity 815°C (1500°F) |
|---|---|---|---|---|---|
| WAM® AL II | 61.4 | 0.7 | 26.7 | 1.73 $g/cm^3$ (108 $lb/ft^3$) | 0.70 W/mK (4.80 BTU·in / $ft^2$·hr·°F) |
| WAM® AL II HDF | 64.3 | 0.4 | 24.3 | 2.46 $g/cm^3$ (154 $lb/ft^3$) | 1.24 W/mK (8.63 BTU·in / $ft^2$·hr·°F) |
| WAM® AL III | 75.5 | 0.4 | 22.7 | 1.76 $g/cm^3$ (110 $lb/ft^3$) | 0.70 W/mK (4.80 BTU·in / $ft^2$·hr·°F) |
| WAM® AL III HD | 78.1 | 0.4 | 10.2 | 2.66 $g/cm^3$ (166 $lb/ft^3$) | 1.47 W/mK (10.2 BTU·in / $ft^2$·hr·°F) |

WAM® AL's effectiveness in aluminum melting furnaces stems from its unique chemical properties and composition, as shown in Table 2. WAM® AL exhibits minimal silica content, thereby reducing the potential for reactions that lead to corundum formation. Low silica also minimizes opportunities for corundum to bond to the refractory surface, facilitating easy removal using standard cleaning tools. An example of WAM® AL's non-wetting abilities can be seen in Figure 2. In contrast, conventional castables often experience issues with corundum adhesion. This necessitates forceful removal that risks damaging the refractory structure due to corundum's superior tensile strength compared to typical refractory materials. These factors underscore WAM® AL's superior performance and durability in aluminum furnaces. Figure 3 illustrates a clean surface free from the damaging effects of aggressive cleaning and negligible corundum formation taking place after 24 months of service.

**Figure 2**

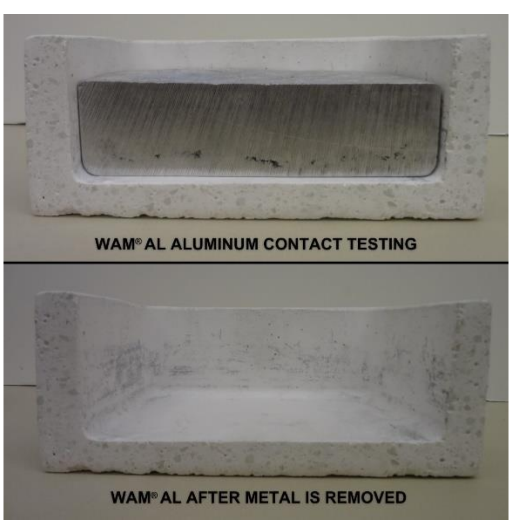



**Figure 3**

WAM® AL's superior insulating characteristics are another major advantage because they reduce energy consumption upwards of 30% in typical furnace configurations.

When considering the total cost implications of refractory materials, it is essential to consider not only the initial procurement expenses, but also the costs associated with installation, operations, and maintenance. The choice of refractory significantly impacts these expenditures throughout its lifecycle.

The WAM® AL product line introduces a patented refractory technology designed to mitigate the formation of corundum. This innovation plays a crucial role in extending the operational life of refractories, thereby reducing the frequency and cleaning intensity of maintenance cycles. By minimizing downtime associated with maintenance tasks, manufacturers can achieve greater operational efficiency and productivity.

WAM® AL materials exhibit a lower density compared to conventional 60-80% alumina-based refractory. This trait not only reduces the amount of WAM® AL refractory required for installations but also enhances thermal insulation characteristics. As a result, less costly insulation board is necessary to achieve equivalent shell temperatures compared to standard alumina-based refractories. This characteristic provides dual benefits: lowering material requirements and contributing to energy savings over the operational lifespan of the furnace.

Adopting WAM® AL's refractory solution is a strategic approach to optimizing refractory value proposition. By minimizing material usage, enhancing thermal efficiency, and reducing maintenance demands, WAM® AL products offer tangible economic advantages while maintaining superior performance in aluminum furnaces.

Steady state heat flow is often used when calculating shell temperatures and freeze planes within a furnace. Table 3 and Table 4 compare the heat loss through a cross section of WAM® AL III and a 65% alumina-based refractory. As is evident from these graphs/charts/tables, the WAM® AL outperforms a common material choice in heat loss under identical temperature conditions and insulation materials.

**Table 3 - WAM® AL III Steady State Heat Flow**

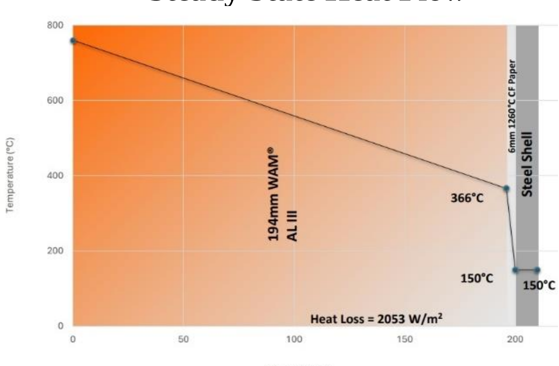
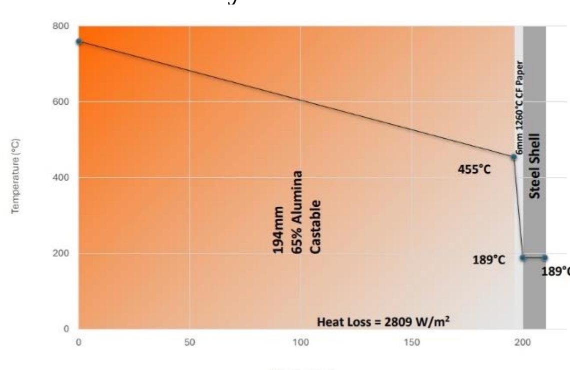



**Table 4 – 65% Alumina Castable Steady State Heat Flow**



The following early adoption commercial case studies illustrate how WAM® AL can lower overall energy consumption. The case studies demonstrate how ease of cleanability enhances operational efficiency and provide total cost savings.

# 3. Industrial Case Studies

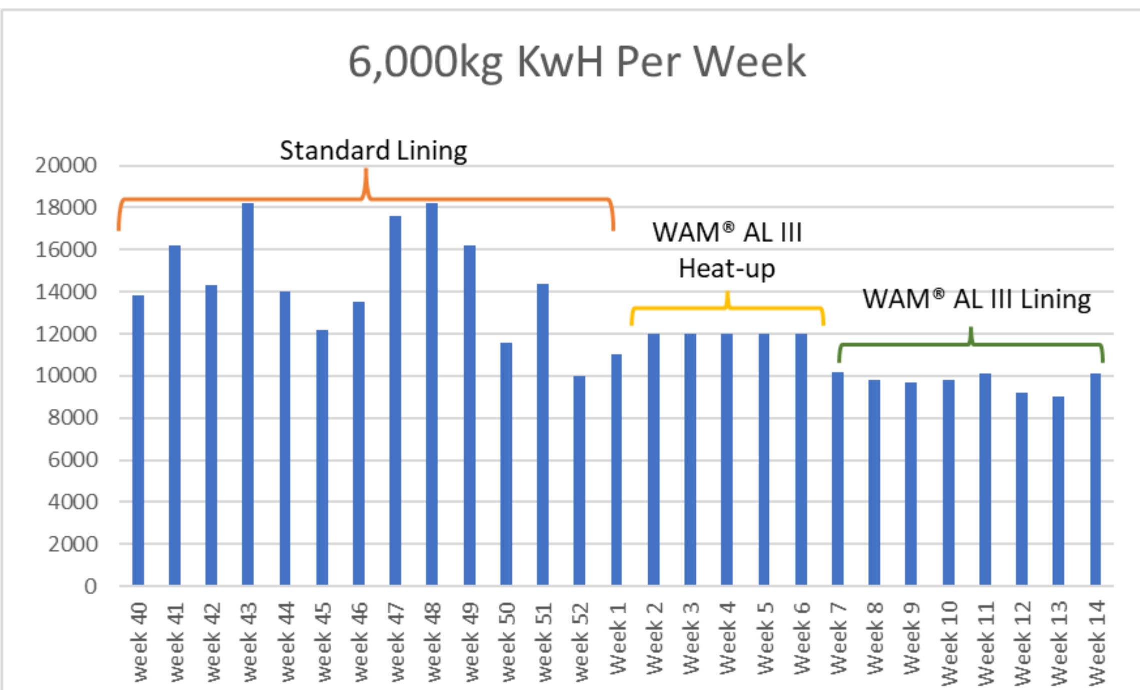
## 3.1 Case Study 1

*Furnace Type:* 6,000 kg holding furnace
*Metal Type:* aluminum
*Previous Refractories:* 60% mullite based, aluminum resistant low cement castable

*Refractory Failure Mode:* The mode of failure within the subject furnace was corundum buildup that needed to be cleaned and repaired bi-weekly. Corundum formation can decrease molten metal capacity when routine cleaning is not being performed. The corundum growth will also increase energy use due to its high thermal conductivity.

*WAM® AL Industrial trial results:* WAM® AL III was installed in a 6,000 kg holding furnace. The furnace lining remains in service after 8 months of operation. The continuously monitored furnace has shown an energy reduction of 38% since the installation of the WAM® AL material. This furnace operator is very pleased with the results and continued energy savings are still realized in this holding furnace. The customer plans to reline two additional furnaces, similar in design, with WAM® AL. Table 5 was shared by the furnace operator showing the instant energy savings upon installation and the start of operation.

**Table 5**



## 3.2 Case Study 2

*Furnace Type:* 1,000 kg low pressure die casting furnace
*Metal Type:* aluminum
*Previous Refractories:* 70% high purity, mullite based, aluminum resistant, low cement castable

*Refractory Failure Mode:* The primary failure mode of this furnace was corundum buildup, which increased energy use due to its high thermal conductivity. The buildup also reduced the overall capacity within the subject furnace. Aggressive cleaning was required on a monthly basis to control buildup.

*WAM® AL Industrial trial results:* The low pressure die casting furnace was lined with WAM® AL II. The furnace operator has been very happy with the lack of corundum buildup and reduced energy consumption. It was reported the aggressive cleaning has been reduced from once per month to once every 6-8 months.

This furnace has been in operation for 30 months and continues to experience 25-30% reduction in energy requirements. Since the original install, 19 additional furnaces have been lined with Allied's WAM® AL material. The customer plans to reline the remaining die casting furnaces within its facility with WAM® AL and to install WAM® AL at other manufacturing facilities.

## 3.3 Case Study 3

*Furnace Type:* Stack melting furnace (installed in holding chamber)
*Metal Type:* aluminum
*Previous Refractories*: 80% bauxite based, aluminum resistant low, cement castable

*Refractory Failure Mode:* The typical stack melter failure mode is mechanical abrasion due to aggressive cleaning of the sidewalls and hearth of the holding chamber. Eventually, the damage results in costly repairs in order to continue operation. The repairs require the furnace to be shut down that, in-turn, puts thermal stress on all refractory materials and affects production due to furnace downtime.

*WAM® AL Industrial trial results:* The stack melting furnace holding chamber was lined with WAM® AL III. The customer mentioned ease of cleaning to be a major benefit. Aggressive cleaning to remove corundum growth was no longer a factor. Due to the ease of cleaning, little damage has taken place within the furnace. It was reported the refractory still looks like new after 10 months of operation.

## 3.4 Case Study 4

*Furnace Type:* 800 kg low pressure die casting furnace
*Metal Type:* aluminum
*Previous Refractories:* 80% bauxite based, aluminum resistant, low cement castable

*Refractory Failure Mode:* The die casting furnace experienced excessive corundum buildup, and therefore, increased energy use and decreased molten aluminum capacity. This furnace experienced similar failure to that described in Case Study 1 and Case Study 2. Aggressive cleaning practices have been performed regularly to control the oxide development. Often, aggressive cleaning damages existing refractory and affects furnace efficiency.

*WAM® AL Industrial trial results:* The 800 kg furnace was lined with WAM® AL III to reduce corundum growth and minimize the need for aggressive cleaning. This operation plans to continuously monitor energy consumption to determine savings with the new lining material. Comparisons were made to old furnace data and the energy usage with the new lining showed a decrease in consumption over 20%. While energy savings is a benefit, the decision makers at this furnace operation are most impressed with the ease of cleaning and lack of oxide sticking to the refractory.

## 3.5 Case Study 5

*Furnace Type:* 800 kg low pressure die casting furnace
*Metal Type:* aluminum
*Previous Refractories:* 80% bauxite based, aluminum resistant, low cement castable

*Refractory Failure Mode:* Similar to the other case studies, the failures within this furnace were related to corundum growth, aggressive cleaning, and costly repairs. The customer's expectations were the thermal properties of WAM® AL would help with a refractory redesign that would increase furnace capacity without the need to make structural modifications.

*WAM® AL Industrial trial results:* WAM® AL III was installed into the subject low pressure die casting furnace. The cross-section thickness was decreased and installed thinner than the previous lining to increase furnace capacity from 800 kg to 1,100 kg. The refractory redesign resulted in a 38% increase in molten aluminum capacity. Even with the reduction in cross-sectional thickness, the energy savings equated to 5MWh less energy consumption per month. After multiple months of monitoring, the energy savings remained constant.

## 4. Summary

This paper discussed several successful case studies within the aluminum industry to reduce energy consumption with the use of Allied Mineral Products WAM® AL refractory technology. This patented technology can greatly reduce the carbon footprint within the aluminum market. Multiple successful outcomes across the applications noted within these case studies underscore the value of utilizing WAM® AL refractory materials. WAM® AL can enhance operational efficiency, reduce maintenance costs, and achieve sustainable energy savings within aluminum melting processes, thus reducing the total life cycle cost to the furnace owners and operators.

---

[i] Aleksić, J., & Vargas, D. B. (2023, November 28). Aluminum demand will rise 40% by 2030. here's how to make it sustainable. World Economic Forum. https://www.weforum.org/agenda/2023/11/aluminium-demand-how-to-make-it-sustainable/

[ii] Reinsch, W. A., & Benson, E. (2022, February 25). Decarbonizing aluminum: Rolling out a more sustainable sector. CSIS. https://www.csis.org/analysis/decarbonizing-aluminum-rolling-out-more-sustainable-sector

[iii] Barandehfard F, Aluha J, Hekmat-Ardakan A, Gitzhofer F. Improving Corrosion Resistance of Aluminosilicate Refractories towards Molten Al-Mg Alloy Using Non-Wetting Additives: A Short Review. Materials. 2020; 13(18):4078. https://doi.org/10.3390/ma13184078

[iv] Ellingham Diagram - Thermodynamics Principle of Metallurgy. (2024, August 5). GeeksforGeeks. https://www.geeksforgeeks.org/ellingham-diagram/