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Investigation of the Effect of Adding Zirconia (ZrO_2) on the Corrosion Resistance of the Casting Mass of the EBT Duct of the Electric Arc Furnace at Rohina South Steel Company

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Extended Abstract

Introduction

Refractory materials play a critical role in steelmaking processes because they must withstand severe thermal, chemical, and mechanical conditions while maintaining structural integrity. Among different refractory materials, magnesia-based refractories are widely used in the steel industry because of their high-temperature stability and excellent chemical resistance, particularly against basic slags. However, pure magnesia refractories may suffer from low fracture toughness and inadequate resistance to thermal shock, which can limit their service life under severe operating conditions. Electric arc furnaces (EAFs) are extensively used for melting and refining steel scrap. In modern EAFs, the eccentric bottom tapping (EBT) system is employed to facilitate controlled discharge of molten steel while minimizing the transfer of oxidizing slag into the ladle. The EBT duct is exposed to extremely severe conditions, including high temperatures, molten steel, slag penetration, thermal gradients, and chemical reactions between the refractory lining and molten phases. Consequently, corrosion and penetration of slag into the refractory mass can significantly reduce the service life of the EBT system. The porosity and particle-size distribution of the refractory are among the most important parameters controlling slag penetration. Larger pores provide easier pathways for molten slag to penetrate into the refractory body, thereby accelerating chemical corrosion and structural degradation. Therefore, modification of the refractory microstructure through the incorporation of suitable high-temperature additives can be an effective strategy for improving corrosion resistance. Zirconia (ZrO_2) is a promising refractory additive because of its very high melting point, approximately 2715 °C, and its ability to remain stable under severe high-temperature conditions. Its incorporation into a magnesia-based refractory can modify grain size, porosity, slag viscosity, and the interaction between the molten slag and refractory surface. Accordingly, the present study investigated the effect of zirconia addition on the microstructure and corrosion resistance of the magnesia-based refractory mass used in the EBT duct of the Rohina South Steel Company. Particular attention was paid to the relationship between particle-size distribution, porosity, slag penetration, and corrosion behavior.

2. Materials and Methods

The reference refractory material was obtained from the EBT duct used in the electric arc furnace of Rohina South Steel Company. The chemical composition of the reference magnesia-based refractory consisted predominantly of MgO, with approximately 95.7 wt% MgO, together with 1.2 wt% CaO, 1.0 wt% Cr_2O_3, 0.8 wt% SiO_2, 0.8 wt% Fe_2O_3, and 0.5 wt% Al_2O_3. To modify the refractory composition and improve its corrosion resistance, 20 wt% zirconia (ZrO_2) was incorporated into the reference refractory. The zirconia powder had a purity of approximately

99%, with a particle size of about 2–4 μm. The reference refractory and zirconia were homogenized and finely ground using a planetary mill for 1 h. Following zirconia addition, the resulting composition contained approximately 75.7 wt% MgO and 20 wt% ZrO_2 **,** while the other oxide constituents remained essentially unchanged. A crucible-based laboratory test was designed to simulate the conditions experienced by the EBT refractory. A refractory layer with a thickness of approximately 2 cm was prepared inside the crucible. After preparation, the sample was allowed to dry for 24 h**.** Molten material at a temperature of approximately 1650 °C was then poured into the crucible, and the system was maintained for another 24 h to allow complete cooling. After cooling, samples were extracted from the refractory wall for microstructural and corrosion analysis. The microstructural characteristics of the specimens were examined using scanning electron microscopy (SEM) equipped with energy-dispersive X-ray spectroscopy (EDS). For microscopic examination, the crucible specimens were sectioned along the diameter so that the cavity axis was positioned within the cross-section. Samples with dimensions of approximately 1 × 1 cm were then prepared from different regions along the thickness of the crucible wall. The specimens were polished using abrasive papers from 120 to 3000 grit and subsequently etched using an HF-based solution. SEM was used to evaluate particle morphology, porosity, grain-size distribution, and the extent of corrosion, while EDS was employed for microchemical analysis of the observed phases

3. Results and Discussion

The results demonstrated that both the particle-size distribution and the chemical composition of the refractory have a significant influence on its resistance to molten slag penetration and corrosion.

3.1. Effect of Particle Size and Porosity on Refractory Corrosion

The SEM micrographs of the reference and zirconia-containing samples revealed noticeable differences in their microstructures. In the SEM images, the bright regions corresponded primarily to the refractory material, whereas the dark regions represented pores and voids. Comparison of the two samples showed that zirconia addition altered the particle-size distribution and reduced the size and amount of the void spaces within the refractory structure. The quantitative particle-size analysis indicated that the reference refractory exhibited an average particle size of approximately 39 nm. Following the addition of zirconia, the average particle size decreased to approximately 36 nm. Although this reduction appears relatively small numerically, it represents a refinement of the microstructure and contributes to a more homogeneous refractory structure. Porosity is particularly important in the corrosion behavior of refractory materials because pores and interconnected voids provide pathways through which molten slag can penetrate. When the particle size is relatively large, larger voids may form between the particles. Such pores facilitate deeper penetration of molten slag into the refractory and consequently increase the contact area between the aggressive molten phase and the refractory material. The penetration behavior is also influenced by the viscosity of the slag, temperature, pressure, pore diameter, and wetting characteristics. Under the experimental conditions of the present study, these parameters were kept as comparable as possible, allowing the effect of particle size and composition to be emphasized. The relationship between pore size and penetration depth indicates that larger pores facilitate deeper slag penetration. Such penetration can eventually result in structural weakening, spalling, and accelerated corrosion of the magnesia-based refractory. Therefore, refinement of the microstructure and reduction of pore dimensions through zirconia incorporation can be considered an important mechanism for improving the durability of the EBT refractory.

3.2. Effect of Chemical Composition and Zirconia Addition on Corrosion

The SEM observations after exposure to the molten phase demonstrated a clear difference between the reference refractory and the zirconia-containing refractory. The primary constituent of the refractory was MgO. When the MgO-based refractory came into contact with the molten slag, chemical reactions occurred at the refractory–slag interface. These reactions promoted the formation of relatively low-melting phases, including diopside (approximately 1342 °C), monticellite (approximately 1498 °C), and merwinite (approximately 1575 °C)**.** Because the operating temperature of the EAF is approximately 1650 °C, these phases can readily melt and participate in the molten slag. Their formation can alter slag flow behavior and facilitate further penetration of the molten phase into the refractory. Consequently, the chemical interaction between the refractory and slag can become self-promoting: penetration of slag causes the formation of lower-melting phases, which can subsequently facilitate further dissolution and corrosion.

The addition of zirconia modified this interaction. Zirconia has an extremely high melting point of approximately 2715 °C and therefore remains stable under the test temperature of 1650 °C. It can consequently act as a relatively stable protective phase within the refractory structure. In addition, zirconia addition was associated with microstructural refinement and reduced porosity, which further restricted the pathways available for slag penetration. Another important mechanism is the influence of zirconia on the viscosity and fluidity of the molten slag/refractory reaction system. Increasing the viscosity of the molten phase reduces its ability to flow through interconnected pores. Therefore, the reduced fluidity associated with zirconia addition can decrease the depth of slag penetration into the refractory. Wetting behavior also plays an important role in penetration. The interaction among pore radius, surface tension, and wetting angle determines the ease with which molten slag enters the pore network. A reduction in effective pore size and an increase in resistance to wetting and penetration consequently contribute to improved corrosion resistance. The results therefore indicate that zirconia contributes to corrosion protection through several simultaneous mechanisms**:** microstructural refinement, reduction of porosity and pore size, maintenance of a high-melting stable phase, and reduction of molten slag penetration**.** These effects allow the MgO grains to remain relatively intact and reduce the severity of corrosion in the EBT duct.

4. Conclusions

The present study investigated the effect of zirconia addition on the microstructure and corrosion resistance of a magnesia-based refractory used in the EBT duct of an electric arc furnace. A reference refractory obtained from the Rohina South Steel Company was modified by incorporating 20 wt% ZrO_2, and its behavior was evaluated under simulated high-temperature conditions at approximately 1650 °C. The main conclusions can be summarized as follows:

1. Particle-size distribution and porosity strongly influence the corrosion behavior of magnesia-based refractory materials. Larger particles and pores provide more accessible pathways for molten slag penetration and can accelerate refractory degradation.
2. The addition of zirconia refined the microstructure and reduced the average particle size from approximately 39 nm in the reference sample to about 36 nm in the zirconia-containing sample. This refinement was accompanied by a more homogeneous microstructure and a reduction in porosity.
3. Zirconia improves corrosion resistance because of its very high melting point of approximately 2715 °C, allowing it to remain stable at the operating temperature of approximately 1650 °C and act as a protective phase around the MgO grains.
4. The interaction between molten slag and MgO can produce relatively low-melting phases such as diopside, monticellite, and merwinite, which can melt at the operating temperature and facilitate further slag penetration and corrosion. Zirconia addition helps suppress this degradation mechanism.
5. The addition of zirconia increases the resistance of the refractory to molten-phase penetration by modifying the microstructure and increasing the viscosity while reducing the fluidity of the molten slag/refractory reaction system. Consequently, the penetration of slag into the refractory is reduced.
6. Overall, the results demonstrate that incorporating zirconia, particularly at the investigated 20 wt% level, is an effective approach for improving the structural stability and corrosion resistance of the magnesia-based refractory used in EBT ducts. The modification can potentially increase refractory service life and reduce refractory consumption and maintenance costs in electric arc furnace steelmaking.

Keywords: Magnesite refractory mass, zirconia, electric arc furnace equipped with EBT, particle size, corrosion resistance

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