BOF STEELMAKING AND ELECTRIC ARC FURNACE SLAG PROPERTY AND IT'S CHARACTERIZATION DIFFERENCES

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Abstract

Slag from Basic Oxygen Furnace steelmaking and Electric Arc Furnace steelmaking develops under very different operating conditions, which leads to clear differences in their chemistry, mineral phases and physical behavior. BOF slag forms in a highly oxidizing environment created by the oxygen blow, where hot metal impurities such as carbon, silicon, phosphorus and manganese are rapidly oxidized. This fast refining cycle produces a basic slag rich in calcium oxide and iron oxide, along with significant amounts of phosphorus and unstable silicate phases. These characteristics make BOF slag reactive, prone to hydration expansion and more variable in physical structure. Its mineralogy often includes dicalcium silicate, tricalcium silicate, wüstite and periclase, with cooling conditions strongly influencing stability.

EAF slag develops in a furnace driven by electrical energy, where scrap or DRI melts under the arc and refining is adjusted through oxygen burners, injectants and slag foaming practice. Because the oxidation potential is lower and more controllable than in a BOF, EAF slag tends to contain lower iron oxide and fewer unstable phases. It often incorporates elements from scrap such as chromium or manganese, forming stable ferrites and spinels. Slow cooling is common in EAF operations, producing a dense, well-crystallized material with low porosity and strong mechanical properties. These traits make EAF slag more consistent and easier to use in aggregate applications.

Characterization methods such as XRF, XRD, microscopy and leaching tests highlight these differences clearly. BOF slag shows higher free lime, stronger oxidation and greater structural variability, while EAF slag displays stable mineral phases, predictable mechanical behavior and lower long-term reactivity. Understanding these contrasts supports better process control in steelmaking and more reliable use of slag in engineering and environmental applications.

Keywords: *BOF slag; EAF slag; Mineralogy; Oxidation Behavior; Steelmaking Processes; Slag Characterization.*

INTRODUCTION:

Basic Oxygen Furnace steelmaking is a process that refines liquid iron from the blast furnace by blowing high-purity oxygen onto the molten bath. The oxygen reacts quickly with carbon and other impurities, creating intense heat and rapid oxidation. The process is fast, usually less than half an hour, and produces steel with controlled chemistry by adjusting the oxygen blow, flux additions and bath temperature. The slag that forms during the blow captures oxidized impurities, especially phosphorus and silica, and becomes a high-basicity mixture of lime, iron oxide and silicates. Because the reactions happen so quickly, the slag's structure and stability depend heavily on how the furnace is operated and how the slag cools after tapping.

An Electric Arc Furnace works differently because it relies on electrical energy rather than hot metal from a blast furnace. Graphite electrodes create an arc that melts scrap steel or direct-reduced iron. Oxygen burners and carbon injectants help speed the melt and promote slag foaming, which improves energy efficiency. EAF steelmaking is flexible because operators can adjust power, oxygen and fluxes at any time, and the process can handle a wide range of scrap grades. The slag that forms in an EAF reflects this flexibility. Its chemistry depends on scrap composition and oxygen practice, often containing stable silicates, ferrites and spinels. Unlike BOF slag, EAF slag is commonly slow-cooled, which produces a dense, durable material suitable for construction and aggregate uses.

OBJECTIVE OF THE STUDY:

This study compares BOF and EAF slags by examining their properties and characterization results to understand how their differences affect steelmaking and potential reuse.

RESEARCH METHODOLOGY:

This study is purely based on secondary data sources such as articles, research papers, books, journals and other sources.

1. Process Foundations of BOF Steelmaking and How They Shape Slag Formation

Basic Oxygen Furnace steelmaking begins with the idea that most of the work is done by oxygen reacting with impurities rather than by complex mechanical steps. A typical heat starts with hot metal from the blast furnace mixed with scrap in the furnace shell. Once the charge is ready, the oxygen lance is lowered and a high-velocity stream of oxygen is blown directly onto the bath. That single action triggers several overlapping reactions, each contributing to how slag develops. Carbon reacts first because it is abundant and reactive at high temperatures. Its oxidation releases carbon monoxide and carbon dioxide, which rise through the bath, stirring it and creating the foamy behavior many BOF operators rely on to improve heat transfer. As the blowing continues, silicon is oxidized to silica, manganese to manganese oxide and phosphorus to phosphorus pentoxide. These oxides dissolve into the slag. The furnace already contains lime, and more is added during the blow to keep the slag basic. The basicity is important. BOF slags need to remain fluid enough to absorb phosphorus but still viscous enough to contain iron losses. Operators adjust the lime addition rate and temperature profile based on the steel grade being produced. Phosphorus removal in particular depends on high oxygen potential and a basic slag, so the amount of added lime and the slag evolution over time become essential process levers.

The temperature in a BOF rises quickly, often reaching steelmaking temperature in less than 20 minutes. That intense thermal environment influences slag chemistry. High temperatures promote dissolution of lime and dolomitic materials, which in turn affects viscosity and the ability to capture impurities. Iron oxide levels in BOF slag tend to stay high because the oxygen blow oxidizes iron along with other elements. That iron oxide affects slag foaming, heat transfer, dephosphorization and refractory wear. Operators monitor this balance continuously because too much iron oxide can erode the lining and trap metallic droplets that represent yield loss.

The underlying steel chemistry also shapes the slag. If the hot metal contains high silicon, the early slag becomes saturated with silica and turns more acidic until enough lime dissolves. When phosphorus in the hot metal is high, the blow pattern and slag basicity must be adjusted to pull it out efficiently. A BOF heat therefore becomes a series of small decisions built around understanding how the slag is forming and how it will behave in the next few minutes.

The physical formation of the slag reflects the speed of BOF steelmaking. Slag forms from a combination of lime dissolution, oxidation reactions and turbulent mixing. The bath movement and gas evolution entrain droplets of steel into the slag, and as these droplets travel through the oxide layer they lose carbon and cool before returning to the metal. This metal-slag interaction is central to refining. The slag layer is not simply a waste phase. It is a reactive medium that determines how clean the steel becomes. Because BOF steelmaking runs so fast, real-time control is critical. Techniques such as sublance measurements and off-gas analysis allow operators to track carbon content, temperature and oxygen utilization. These monitors indirectly describe slag conditions. A sudden change in off-gas chemistry might indicate excessive iron oxidation, poor slag formation or ineffective lime dissolution. These signals help operators correct the blow without shutting down or delaying the cycle.

Even though BOF slags vary with raw materials and operating practice, they share common characteristics. They tend to be basic, rich in calcium and iron oxides, and often contain some magnesium from dolomitic fluxes. Their composition reflects the furnace's purpose: rapid oxidation, high impurity removal and a strong emphasis on phosphorus control. Understanding these fundamentals makes it easier to compare BOF slags with EAF slags, which originate from a process driven by electrical energy rather than oxygen, and whose slag behavior aligns with a different set of refining goals.

2. EAF Melting Dynamics and the Development of Distinct Slag Chemistry

Electric Arc Furnace steelmaking begins with scrap or, in some operations, a mix of scrap and direct reduced iron. The charge sits in the furnace shell while graphite electrodes are lowered. Once the arc is struck, concentrated electrical energy begins melting the top layers of the scrap. The early melt stage creates a small pool of liquid steel that gradually expands as the arc tunnels through the charge. Unlike BOF, where oxygen drives the reactions, the EAF uses electrical energy for melting and relies on oxygen burners and injectants mainly for efficiency, decarburization and slag foaming. The first slag that appears is often oxidizing because the furnace atmosphere carries dust, rust, oil and coatings from the scrap. These materials oxidize and float into the slag. Lime is added early to create a basic environment and protect the refractory. Once enough molten steel accumulates, oxygen lances or burners are activated. They oxidize carbon, silicon and other elements, generating heat and softening the bath. Injecting carbon and oxygen together helps create a foamy slag, which insulates the melt and shields the arc. Foamy slag practice is one of the most recognizable features of modern EAF operations. It boosts electrical efficiency, stabilizes the arc and reduces electrode consumption.

EAF slags change over time in ways that reflect shifting process goals. During melting, the slag is often oxidizing. During refining, operators may push the slag toward a more reducing state, especially when they want to recover chromium or limit iron losses. Alloy steel production in the EAF makes slag chemistry more variable than in the BOF. Some heats contain stainless scrap or high-alloy returns, which introduce chromium, nickel or molybdenum. These metals can oxidize into the slag if the furnace is run too oxidizing. That behavior forces operators to tailor their oxygen practice and carbon injection carefully. The physical behavior of EAF slag differs from BOF slag because the melting process creates a less turbulent environment. While arcs create local turbulence and oxygen lancing produces hot spots, the bulk bath does not experience the same intense circulation as in a BOF. Without the constant gas evolution from decarburization, metal-slag mixing unfolds at a slower pace. This difference affects slag foaming, heat transfer and impurity removal. For example, while BOF slags naturally carry high iron oxide levels, EAF operators must deliberately manage iron oxide through oxygen practice. Too much iron oxide can reduce yield and attack the furnace lining. Too little can limit slag foaming and make the arc unstable.

Temperature control plays a different role in EAF slag formation. Because electrical energy can be adjusted instantly, operators can create thermal profiles that encourage lime dissolution when needed or maintain a foamy slag layer. Unlike BOF temperatures, which rise according to the blow, EAF temperatures rise in a more stepwise pattern, linked to power-on periods and flat-bath conditions. These temperature changes influence slag viscosity and the reaction rates between slag and metal. Scrap quality contributes to slag variability as well. Oily scrap can create carbon boil. Painted or coated scrap contributes zinc, copper or other tramp elements that may report to the slag or the off-gas system. The slag becomes a repository of whatever oxides form from these elements. This variability makes EAF slags more heterogeneous across heats and across different steel plants. It also makes characterization important for evaluating potential uses of the slag outside the furnace.

Once the final refining stage ends, the slag is typically poured ahead of the steel. Some plants practice hot slag foaming before tapping to extract maximum chemical energy. Others keep the slag fluid to simplify tapping and minimize skull formation. In all cases, slag formation in the EAF is tied to energy efficiency, alloy retention and operational flexibility. It behaves differently from BOF slag because the process goals and melting conditions are fundamentally different. These differences become more pronounced when examining physical, chemical and mineralogical properties.

3. Chemical and Mineralogical Characteristics That Distinguish BOF and EAF Slags

The chemistry of BOF slag reflects the oxygen-rich environment of the furnace. It often contains high levels of iron oxide, sometimes exceeding 15 to 20 percent. The abundance of iron oxide results from oxidizing iron together with carbon, silicon and phosphorus. The need for strong dephosphorization leads to a slag rich in lime and silica, with phosphates forming during the blow. Typical BOF slag may contain tricalcium silicate, dicalcium silicate, wüstite, periclase and various mixed phases. The fast-cooling conditions during tapping can create unstable silicate structures that later hydrate and expand. This behavior must be considered when BOF slag is used in cement or construction applications. Phosphorus content is a key feature of BOF slag chemistry. Because phosphorus partitions strongly into the slag at high basicity, BOF slag often carries significant P2O5. In some cases, the phosphorus content can influence the slag's reactivity and its long-term stability. If the slag is slow-cooled, phosphorus may concentrate in certain crystalline phases. If it is rapidly cooled, it may remain dispersed. This diversity in cooling effects contributes to widely varied mineralogy across BOF slag samples even within the same plant.

EAF slag chemistry, by contrast, often shows lower iron oxide content because operators manage oxygen practice to reduce iron losses. Iron oxide may be present in moderate amounts during the oxidizing phase, but it decreases during reducing operations later in the heat. EAF slags contain calcium oxide, silica, magnesium oxide and alumina, similar to BOF slags, but the proportions differ. Scrap composition influences EAF slag chemistry, adding elements like chromium, manganese and sometimes nickel. When stainless or high-alloy scrap is melted, chromium oxide may form, and operators must take steps to return chromium to the metal by adjusting carbon and oxygen practice.

The mineralogical phases in EAF slag include dicalcium silicate, tricalcium silicate, periclase and various ferrites. The presence of spinels such as magnesium aluminate is common, especially in high-alloy operations. These mineral phases give EAF slag mechanical stability that is often greater than BOF slag. Many EAF slags cool into dense, hard aggregates that resist weathering and have suitable properties for road construction. Another major chemical distinction is sulfur behavior. BOF slag usually contains moderate sulfur levels because sulfur partitions less effectively during oxygen blowing. In the BOF route, sulfur is more commonly removed in a separate ladle desulfurization step. EAF slag can display different sulfur levels depending on scrap quality, flux additions and whether the furnace practices hot metal charging. If a plant injects desulfurizing agents or handles sulfur-bearing scrap, sulfur may accumulate in the slag.

The oxidation potential of the furnace atmosphere also shapes slag chemistry. The BOF's strong oxidation pressure forces many elements into oxide form. The EAF allows more flexibility through adjustments in burner oxygen, carbon injection and arc stability. As a result, EAF slags often include more metallic inclusions and partially reduced phases. The cooling process after tapping also plays a significant role. BOF slags may undergo rapid cooling or controlled cooling depending on plant practice. Fast cooling traps metastable phases and increases the potential for expansion due to free lime or unstable silicates. EAF slags are often slow-cooled to promote crystallization because this produces a strong aggregate suitable for construction. Slow cooling allows the formation of defined mineral phases such as gehlenite or merwinite that provide durability. Both slag types contain flux residues, entrained metal droplets and variable levels of oxides. Still, their primary differences stem from furnace operation: the BOF's oxygen-driven refining versus the EAF's energy-driven melting. These conditions result in chemistry and mineralogy that follow different patterns across the two slag types.

4. Physical and Mechanical Properties of BOF and EAF Slags and their Technological Implications

Physical properties of BOF slag are shaped by highly oxidizing conditions, rapid refining and the specific cooling pattern used after tapping. BOF slag often cools unevenly, especially when dumped into pits. This can produce porous structures, microcracks and internal voids. The presence of free lime or periclase can lead to hydration expansion over time, which creates additional cracking. These features influence density and mechanical stability. While BOF slag can be processed into aggregate, it requires conditioning steps such as aging or accelerated cooling to stabilize the expansion. Without these steps, the slag may swell or disintegrate when exposed to moisture. Density values for BOF slags tend to lie in the range expected for calcium-rich oxide systems, but porosity can vary widely. The foamy nature of BOF slag during blowing sometimes leaves behind bubbly textures. These voids lower the effective strength of the slag when used as an aggregate. The combination of iron oxide, silicates and lime makes the slag abrasive, which can be useful in applications like road surfacing but requires careful handling.

Mechanical strength of BOF slag increases once expansion-prone phases have stabilized. When properly aged, the slag can exhibit high compressive strength and resistance to polishing. Its rough texture allows good bonding with asphalt or cement. However, the presence of metallic iron inclusions can cause issues in crushing equipment or create localized weakness if the metal corrodes. EAF slag physical properties often differ because the furnace environment allows more controlled slag formation and cooling. Many EAF operations slow-cool their slag in slag pots or designated cooling areas. Slow cooling encourages crystallization, producing a dense, hard material with low porosity. The mineral phases formed under controlled cooling conditions give EAF slag good abrasion resistance and high mechanical stability. These qualities make EAF slag desirable for road base layers, concrete aggregate and railroad ballast.

Particle shape also differs between BOF and EAF slag. BOF slag particles can be irregular and angular because of the fragmented structure resulting from rapid cooling and internal expansion. EAF slag particles tend to have more uniform, blocky shapes because slow cooling promotes defined crystal growth. These shapes affect workability and compaction characteristics in civil engineering applications. Thermal properties also vary. BOF slag may retain residual free lime, which reacts with water and produces heat. This behavior can be problematic in concrete, where expansion and heat release must be controlled. EAF slag, having more stable mineral phases, typically shows lower reactivity. Its thermal expansion is more predictable, making it suitable for structural applications that require dimensional stability.

Magnetic properties differ as well. BOF slag often contains higher levels of metallic iron and wüstite, which give it stronger magnetic response. This can assist in metal recovery but may be undesirable in some construction uses. EAF slag contains metallic inclusions too, but their quantity depends heavily on oxygen and carbon practice. Slow cooling sometimes locks small metallic droplets inside mineral matrices where they cause minimal functional impact. The surface chemistry of the slag influences how it interacts with binders in construction applications. BOF slag surfaces may include free lime that reacts with moisture, which can improve bonding in some cases but create instability in others. EAF slag surfaces contain stable silicates and ferrites that bond well with cement but do not cause significant expansion. Processing differences also shape physical properties. BOF slag often requires weathering or stabilization before use, while EAF slag can often be crushed and screened with minimal aging. These differences influence cost, storage needs and environmental handling.

5. Characterization Techniques and What They Reveal About Differences Between BOF and EAF Slags

Characterizing slag involves applying chemical, mineralogical and physical tests to understand how it formed and how it will behave in practical use. The methods used for BOF and EAF slag are similar, but the insights they produce differ because each slag type has distinct properties. Chemical analysis typically begins with X-ray fluorescence. For BOF slag, this method highlights high calcium oxide, high iron oxide and significant phosphorus content. These results reflect the oxygen-rich refining reactions. In EAF slag, X-ray fluorescence reveals more balanced oxide levels and potential traces of alloying elements from scrap. When chromium or manganese appears at notable levels, it suggests alloy oxidation or the melting of high-alloy scrap. Chemical characterization also includes determining free lime content. BOF slag often shows higher free lime because of heavy flux addition and incomplete dissolution. High free lime requires aging to avoid expansion. EAF slag usually contains lower free lime, especially when cooling is controlled.

X-ray diffraction provides mineralogical identification. When applied to BOF slag, the technique reveals silicates such as dicalcium silicate and tricalcium silicate, along with high-iron phases like wüstite. If the slag contains unstable phases, X-ray diffraction can show changes as the slag ages. In EAF slag, X-ray diffraction identifies well-defined crystalline phases, spinels and stable ferrites. These results confirm the dense structure typical of slow-cooled slag.

Microscopy offers another layer of understanding. Optical or electron microscopy can visualize slag textures, pore structures and entrained metal droplets. BOF slag microscopy often shows porous structures, fractured grains and complex oxide layering. These features support the idea that BOF slag forms quickly under turbulent conditions. EAF slag microscopy shows larger, well-formed crystals and lower porosity. Entrapped metal droplets may be present but in smaller quantities than BOF slag. Thermogravimetric analysis helps detect free lime and magnesia hydration behavior. BOF slag often shows weight changes associated with hydration and carbonation. This behavior signals potential expansion. EAF slag usually shows minimal weight change, confirming its greater stability.

Leaching tests are used when slags are evaluated for construction or environmental use. BOF slag may release higher levels of phosphorus or iron during leaching, depending on slag conditioning. EAF slag may release small amounts of chromium or vanadium when high-alloy scrap is used. These tests help determine whether slag requires stabilization or whether it meets regulatory standards for reuse. Mechanical testing includes hardness, abrasion resistance and aggregate suitability tests. BOF slag may show more variable results, reflecting its internal voids and unstable phases. EAF slag often performs strongly because its dense structure resists crushing and abrasion. Spectroscopic methods can provide additional insight into oxidation states. Mössbauer spectroscopy or similar techniques can distinguish between Fe^{2+} and Fe^{3+} in slag. BOF slags often show a greater presence of oxidized iron species. EAF slags, depending on furnace conditions, may show a mixture of oxidation states.

CONCLUSION

Slag from BOF and EAF steelmaking reflects the fundamental differences in how each furnace operates and the refining goals they serve. BOF slag forms under strong oxidation during the oxygen blow, which drives out carbon, silicon and phosphorus while producing a basic, iron-rich slag with reactive phases that change as the slag cools. These conditions create a material that can be effective for impurity capture but requires careful aging and stabilization before use in construction. EAF slag, shaped by electrical melting and controlled oxygen practice, develops more slowly and usually cools under conditions that encourage crystallization and structural stability. The influence of scrap chemistry, slag-foaming practice and reducing conditions makes EAF slag more uniform and mechanically robust, especially when used as aggregate. Characterization tools such as XRF, XRD, microscopy and leaching tests highlight these contrasts and help determine how slag will behave in industrial and environmental applications. Understanding these differences supports better furnace control, more reliable slag utilization and improved resource efficiency across the steelmaking route. Both slag types hold value when properly understood, but their distinct origins mean they must be managed and applied with attention to their specific chemical, mineralogical and physical behaviors.

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