Dynamic Heat Flow and Current Distribution Analysis in the Bottom Anode of an Electric Arc Furnace Using Fiber-Optic Sensors






A reliable method for monitoring bottom anode wear during direct current electric arc furnace (DC EAF) operation is of critical importance for safe and efficient steel production. Underestimation of bottom wear poses a serious safety risk that must be avoided, while overestimation of bottom wear also poses challenges, as premature anode replacement is expensive and affects EAF productivity. Previously, it was demonstrated that fiber-optic sensors can be successfully deployed to create a spatially distributed temperature map to monitor the health of the anode. The present work explores the heat flow and current density distribution in bottom anode pins to predict bottom wear and steel penetration events and monitor refractory erosion. Small dynamic variations in pin temperature induced by joule heating during arcing also provide a means to observe local current flows in each pin. When mapped, these measurements provide a real-time view of the nonuniform and dynamic current flow in the bottom anode during EAF operation that can affect bottom wear.

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Introduction

Electric arc furnace (EAF) steelmaking is an increasingly preferred method for steel production due to its high energy efficiency, flexibility in feedstock use and reduced environmental impact.[1–3] EAFs consume 10–15% less electricity, require 20–30% less refractory material and generate significantly lower dust emissions.[4,5] In direct current (DC) EAFs, the bottom anode plays a critical role in completing the electrical circuit, facilitating the flow of high electrical currents through the molten metal bath.[6,7] However, the operational longevity of the bottom anode is compromised by wear, driven by mechanical stress and thermal cycling (scrap charging, bath temperature fluctuations, joule heating and electromagnetically driven flows).[7,8] Additionally, liquid steel penetration into the refractory, particularly during high-power fluctuations or prolonged furnace campaigns, can accelerate wear and pose significant safety risks, including potential furnace bottom breakthroughs.[9–11]

Accurate monitoring of bottom anode wear is crucial for maintaining furnace reliability and optimizing operational efficiency.[12] As underestimating wear poses severe safety risks, including the potential for liquid steel breakout, overestimation leads to unnecessary anode replacements, increasing maintenance costs and downtime.[7] Conventional monitoring methods employ thermocouples embedded at discrete locations within the bottom anode pins or elsewhere in the anode. However, these methods are limited by their spatial resolution and susceptibility to electromagnetic interference (EMI), making them less reliable in capturing localized thermal variations in high-current-density zones.[6,13–16] Recent advancements in fiber-optic sensing technology, particularly Fiber Bragg Grating (FBG) sensors, offer promising alternatives for distributed temperature sensing in harsh industrial environments.[17–19]

This study builds on previous research where fiber-optic sensors were deployed in an industrial-scale DC EAF at Big River Steel – A U. S. Steel Co. to generate a spatially distributed temperature map of the bottom anode.[20] The current research extends this approach by analyzing dynamic heat flow and current