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Improved Monitoring of the Water-Cooled Upper Shell of an Electric Arc Furnace Using Fiber-Optic Sensors

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ABSTRACT

Modern Electric Arc Furnaces (EAF) employ ultra-high-power electrical input to minimize the scrap melting time. Increasing the operating voltage increases arc length and enhances the active power, but radiation energy losses also increase if the arc is exposed to the furnace, resulting in a drop in thermal efficiency and causing hot spots in the furnace. The present work introduces a novel approach using fiber optic sensors to create a real-time, spatially distributed thermal map of the EAF's water-cooled upper shell, which can be helpful in detecting operational anomalies and improving EAF energy efficiency. Lab-scale testing using fiber-optic sensors on a spray-cooled steel plate achieved a remarkable spatial resolution of 2.3mm and a 1Hz data acquisition rate, paving the way for industrial-scale implementation. These sensors, providing reliable spatial temperature measurements, offer early detection of sidewall hot spots and precise adjustments to voltage and burner positioning based on granular data from the scrap melting stages. This study strongly advocates the use of fiber optic sensors in EAFs, would enhance efficiency and safety in steelmaking.

Keywords: Electric Arc Furnace (EAF), Fiber Optic Sensors, Thermal Mapping, Water-Cooled Upper Shell, Spatial Resolution

INTRODUCTION

Electric Arc Furnaces (EAFs) play a crucial role in modern steelmaking, offering a cleaner alternative to traditional methods. However, despite their environmental benefits, they still contribute significantly to global energy consumption and carbon emissions. Optimizing EAFs to operate more efficiently is critical for both environmental and economic reasons[1,2]. While the theoretical energy demand for melting and heating scrap in an EAF is around 400 kWh/ton, current furnaces exhibit an average consumption ranging between 680-820 kWh/ton[3–5]. This translates to an overall energy efficiency of 45-60%, indicating ample room for improvement[6].

However, the parameters necessary for optimization extend beyond our current monitoring capabilities. Factors such as feedstock composition, operational practices and concealed threats like water leaks pose challenges that impede optimization and mask potential hazards[2]. The existing state-of-the-art monitoring tools, such as thermocouples and Resistance Temperature Detectors (RTD), have limitations in spatial resolution, hindering insights into the intricate thermal dynamics within an EAF[7,8]. In contrast, fiber optic sensors present a promising solution with their high spatial resolution, real-time data acquisition capabilities, and strain monitoring functionalities. By leveraging technologies like Rayleigh Backscattering, fiber optic sensors can serve as an early warning system for identifying operational anomalies and optimizing process parameters[9–11]. However, the significant challenges of conducting plant trials to evaluate the impact of fiber optic sensors over traditional ones should not be underestimated. Figure 1 illustrates the schematic representation of a conventional single-mode optical fiber. This fiber comprises a dielectric waveguide with a core made of germanium-doped silica, enclosed by a silica cladding. The outer layer

