Optimization of Alloy Addition Timing During BOF Tapping: A Model for Establishing the Minimum Required Steel Level

Steel tapping from the basic oxygen furnace into the ladle is a pivotal stage in steelmaking, during which alloying materials are added to ensure rapid homogenization. This study addresses the challenges of alloy addition, particularly the timing and its impact on ladle operations. Improper handling can damage the refractory lining and obstruct visual monitoring, while delayed additions reduce mixing efficiency and compromise process control. A mathematical model was developed to establish the required minimum steel level for a safe and efficient alloy addition process, accounting for the movement of alloying material through the feeding pipe, freefall and immersion into the liquid steel in the ladle.

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Introduction

Steel tapping from the basic oxygen furnace (BOF) into the ladle represents a critical phase in steelmaking, serving as the initial step in ladle treatment. As illustrated schematically in Fig. 1a, alloying materials are added from a silo and conveyor belt through a movable feeding pipe, making use of the stirring energy of the steel inside the ladle, which is agitated by the tapping free stream to promote rapid homogenization. Commonly added materials include synthetic slag, limestone, aluminum (Al), ferrosilicon (FeSi), ferromanganese (FeMn) and coke.

Recent advancements in understanding the tapping process have employed thermodynamic modeling[1] and computational fluid dynamics (CFD) simulations. Berg et al.[2] analyzed BOF and electric arc furnace (EAF) tapping using CFD, conducting a comprehensive parameter study on alloy type, particle size and addition timing. Their findings emphasized that smaller alloys (5–20 mm) yield better results than larger particles (up to 80 mm). Laux et al.[3] expanded this work by enhancing CFD methodology to include three-dimensional flow dynamics and entrained gas effects. These studies primarily addressed steel flow and chemical reactions inside the ladle during tapping.

This study focuses instead on the alloy addition process, specifically the freefall and immersion of solid alloying materials into a ladle partially filled with liquid steel. The timing of this process is critical: improper handling can damage the refractory lining at the ladle bottom or disturb the filler sand deposit above the slidegate, potentially leading to a non-free-opening ladle. To avoid these issues, a minimum steel level must be established before alloying begins. However, late additions reduce stirring efficiency and mixing performance. Alloying also generates fumes that obstruct visual monitoring of the tapping process, as illustrated in Fig. 1b.

To address these challenges, this study developed a physical model to simulate the movement and immersion of alloying materials in liquid steel. The model provides valuable insights for optimizing the timing of alloy additions, ensuring a more controlled and efficient process.

Modeling

The model presented in this study is designed to simulate the movement of alloying additions through the inclined feeding pipe, followed