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Editorial

Numerical Modeling of Metallurgical Processes: Continuous Casting and Electroslag Remelting

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1. Introduction and Scope

The multiscale transport phenomena (multiscale turbulence, multiphase flow, multiscale solidification, non-metallic inclusion, etc.) in the metallurgical processes of continuous casting (CC) and electroslag remelting (ESR) have a great influence on the casting quality. Multiscale flow in various metallurgical reactors can couple heat transfer, mass transfer, phase transformation, multiphase flow, and many other processes, forming complex inhomogeneous multiphysical fields. Studies on the hydrodynamic behaviors of the multiscale and multiphysical fields in the mold can provide guidance in optimizing the operational process and designing a novel mold with high performance, which is very important for promoting the quality improvement of steel or superalloy products and the improvement of production. With the development of computer technology, computational fluid dynamics (CFD) methods are becoming more and more widely used in metallurgical processes. A considerable number of new methods have been developed and applied in CC and ESR processes, such as large eddy simulation, population balance model, and volume average solidification model. Moreover, some novel metallurgical technologies have also been mainly investigated by CFD, such as feeding steel strips, vacuum ESR, and rotating electrodes. This Special Issue aims to present the latest research on advanced numerical techniques for CC and ESR processes. Research reports associated with novel metallurgical technology are also welcome.

2. Contributions

Eleven research articles have been published in this Special Issue of *Metals*, including multiple processes in CC, ESR and vacuum arc remelting (VAR).

In the CC process, the ladle refining plays an important role in adjusting steel components, removing harmful and dangerous elements and inclusions. To provide as optimal a performance as possible, Li et al. [1] established a mathematical model coupled large eddy simulation (LES) and discrete particle model (DPM) to study the flow characteristics, mixing behavior, and inclusion movements. This research analyzes the bubble interactions with different slot-porous plugs, providing compatible slot-porous plugs to improve the cleanness of steel. It is important to keep the temperature stable and low superheat of molten steel in the CC process to improve the production efficiency and product quality. Tundish plasma heating is one of the effective methods to achieve steady casting. Zhao et al. [2] presented a three-dimensional transient mathematical model that studies the influence of plasma heating process parameters on the heating effect. This article provides a certain guiding significance for selecting the current plasma heating power on site. The clogging of the submerged entry nozzle (SEN) is a long-term problem in the Al-killed steel CC process, typically resulting in asymmetric mold flow, uneven solidification, meniscus fluctuations, and possible slag entrapment. Hua et al. [3] adopted an LES model coupled with the volume of fraction (VOF) to simulate the steel-slag interface's interaction behavior, and the increase of block rates under nozzle clogging on the flow vortex distribution in the mold was well predicted. Alexander et al. [4] studied the heat transfer in an SEN through an advanced multi-material model based on a newly presented single mesh approach. Results

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show that parasitic solidification occurred inside an SEN bore with partially or completely absent insulation, and the clogging of SEN was found to promote the solidification of the entrapped melt. In order to improve the flow stability, temperature homogenization, and reduce inclusions in the CC mold, the electromagnetic brake (EMBr) and electromagnetic stirring (EMS) technology is widely used. Wang et al. [5] developed an LES model to study the melt flow and solidified shell distribution in a thin slab caster, simultaneously considering a single-ruler EMBr and a strand EMS. Results show that the coupled application of an EMBr and SEMS can produce a high-quality thin slab. Li et al. [6] presented a two-phase LES model to simulate the thermal-magnetic-flow fields in a jumbo bloom caster with a mold electromagnetic stirring (MEMS), and the biased flow was identified and characterized. Liu et al. [7] carried out an LES model to study the inclusion behavior in a planar flow casting process. Results show that the function of EMBr to weaken the flow pattern is most efficient for inclusion removal. The non-metallic inclusions are always a key problem in the CC process. Mo et al. [8] studied the distribution of non-metallic inclusions in the tinplate steel slab using a numerical model combined with ultrasonic detection. Two non-metallic inclusion bands were found, one is the inner and outer arc side of the sample, and the other is the 1/8 to 1/4 slab thickness region of the inner arc side in the sample.

The ESR is an important refining process for producing high-quality steel, and the process always suffers from segregation defects in the ESR ingots, which are caused by a deep V-shaped metal pool profile. Huang et al. [9] developed a comprehensive transient numerical model that considered the magnetohydrodynamic flow, heat transfer, solidification, and electrode melting under the effect of electrode rotation. Results show that the increase of rotating speed accompanied by a reduction of power input is an effective way to simultaneously improve metal pool profiles and reduce the local solidification time and secondary dendrite arm spacing. Non-metallic inclusions in ingots may cause series defects and deteriorate the mechanical properties of final products. Wang et al. [10] established a transient 2D coupled model to analyze the motion behavior of inclusions in a lab-scale ESR process with a vibrating electrode. The motion behavior, distribution pattern, and removal ratio of inclusions in the slag layer and liquid-metal pool are discussed, especially regarding electrode vibration frequency, current, slag-layer thickness, filling ratio, inclusion type, and diameter.

The VAR process can effectively improve the purity of remelting metals and has been widely used to produce superalloys. However, the corresponding research on the prediction of segregation defects is still not comprehensive. Cui et al. [11] established a full-scale model to predict freckles and macrosegregation defects during the VAR process. This model provides a new perspective for understanding the segregation behavior inside the ingot by studying segregation evolution during the VAR process.

3. Conclusions and Outlook

A variety of topics have been compiled in the present Special Issue of *Metals*, providing multiscale transport phenomena in the metallurgical processes of CC, ESR, and VAR. Numerical analysis is a low-cost way to provide insight into multiscale transport phenomena in the metallurgical processes. Therefore, the selected papers touch on a variety of numerical methods. In this research field, there are still many challenges that need to be overcome. Hopefully, the present papers will be useful to researchers working towards the requirement for high-quality steel products.

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