Modeling Macrosegregation in Continuously Cast Round Bloom with Combined Electromagnetic Stirring

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Abstract: The electromagnetic stirring (EMS) can effectively improve the macrosegregation, central porosity, shrinkage, cracking, and other defects of continuous casting round blooms. Thus, based on the volume-averaged method, a three-phase solidification model is established, which considers the nucleation, growth of the columnar and equiaxed crystals, deposition of equiaxed crystals, and transmission of solutes. The effect of the individual EMS and combined EMS on the temperature, velocity, phase distribution, and macrosegregation distribution in a large vertical CC round bloom was studied. The results show that the CC bloom shell is built by columnar crystals, and equiaxed crystals fabricate the central zone. Individual M-EMS has a notable impact on expediting the dissipation of superheat, enhancing the initiation of grain formation, and enlarging the equiaxed region. The percentage of equiaxed grains increased from 58.56% to 62.17% with the increment in current intensities of M-EMS from 150 to 250 A. Furthermore, the implementation of individual F-EMS demonstrated its effectiveness in reducing center positive segregation. The ratio of center positive segregation decreased from 1.14 to 1.10, when the current intensity increases from 150 to 250 A. The combine EMS has multiple advantages of M-EMS and F-EMS. The notable enhancement in the equiaxed grain ratio up to 60.13% was observed combined EMS models were simultaneously employed during continuous casting of round blooms. And, there was a reduction in center segregation ratio for round blooms to as low as 1.09.

Keywords: continuous casting; EMS; three-phase solidification model; macrosegregation

1 Introduction

Recently, various industries based on large-scale equipment have been developed, including wind power generation, petrochemical industry and machinery manufacturing. In order to meet the production demands, the products of special steel continuous casting round blooms are increasing gradually. However, macrosegregation is a key problem in continuously cast round blooms [1,2]. Numerous scholars [3] have made long-term commitments to the mitigation of macrosegregation. Such investigations will contribute to the development of enhanced production techniques for continuously cast round blooms, facilitating the manufacturing of defect-free rolled products caused by macrosegregation. Presently, electromagnetic stirring (EMS) [4] stands out as one of the most efficient measures to diminish macrosegregation in continuously cast round blooms.

Although there are numerous experimental and theoretical investigation on the effect of EMS on the macrosegregation in as cast steel, the synergistic effect of combined M-EMS and F-EMS are still needed to be further studied in order to achieve the optimum metallurgical function of EMS on elimination of macrosegregation in continuously cast steel. This study is based on a three-phase solidification model. By studying the effects of the EMS, combined EMS electromagnetic parameters, and stirring models on the microscopic structure evolution and solute segregation behavior, the influence of only EMS and combined EMS on the internal quality of slab is further revealed.

2 Experimental procedure

In this paper, a control volume based on the finite difference method was applied to solve the governing equations and define the source terms and exchange terms through the UDF functions in ANSYS FLUENT software. All phases shared the same pressure field and obtained the pressure correction equation by the phase coupled SIMPLE algorithm. The 3D/2D structured grid used in the simulation initially consists of 952000 computational cells. The growth of calculation region was considered by the dynamic layering method under unsteady conditions. For each time step, 60 iterations were adopted to decrease the convergence criterion of the normalized residual of the continuity equations, momentum equations, species transport equations, and user-defined scalar equations below 10^{-5} and the energy equation below 10^{-6}.

3 Result and discussion

Figure 1 shows the area fraction of the equiaxed phase zones at the end of solidification with different EMS processes. The area fraction of the equiaxed phase zones of individual EMS, and combined EMS were 59.26%, 51.59%, and 60.13%, respectively. The results demonstrate that M-EMS significantly improves the extension of the equiaxed grain zone, whereas the F-EMS effect on increasing the equiaxed grain zone is not as pronounced. The main reasons are that the CET transition and solidified equiaxed grain zones are established before the installation position of the F-EMS.

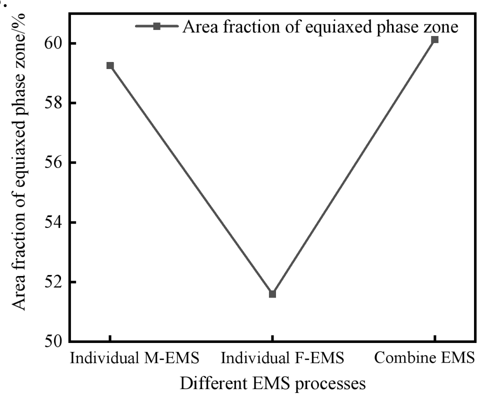

Figure 1 Area fraction of the equiaxed phase zones at the end of solidification with different EMS processes

Figure 2 shows the distribution of macrosegregation ratio with different EMS processes. The ratio of center positive segregation at the center of round bloom was 1.17 with only M-EMS. The ratio of center positive segregation at center position was 1.10 with only F-EMS. In the case of the combined EMS models, the ratio of center positive segregation reached at 1.09. The results indicate that M-EMS has limited improvement on center positive segregation, while F-EMS can effectively reduce center positive segregation. The combined EMS models further decrease the center positive segregation based on the metallurgical efficacy of F-EMS.

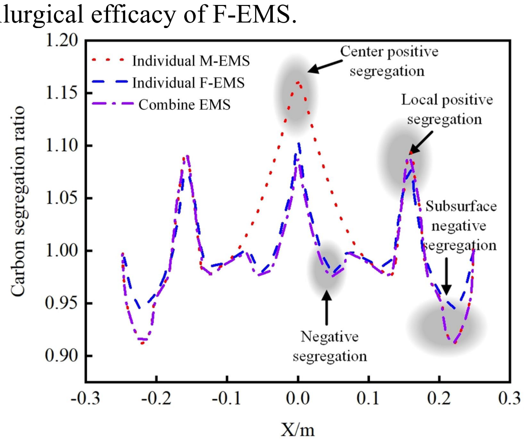

Figure 2 Distribution of macrosegregation ratio with different EMS processes

4 Conclusion

Based on the volume-averaged method, a three-phase solidification model is established. The effect of the individual EMS and combined EMS on the macrosegregation distribution in a large vertical CC round bloom was studied. The main conclusions can be drawn:

(1) Individual M-EMS has a notable impact on expediting the dissipation of superheat, enhancing the initiation of grain formation, and enlarging the equiaxed region. The percentage of equiaxed grains increased from 58.56% to 62.17% with the increment in current intensities of M-EMS from 150 to 250 A.

(2) The implementation of the individual F-EMS demonstrated its effectiveness in reducing center positive marcosegregation.

(3) The combine EMS has multiple advantages of M-EMS and F-EMS.

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