

Concept of Semi-Continuous Casting (SCC) for Large Steel Strand: A Numerical Study

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Semi-continuous casting (SCC) technique, combining some merits of continuous and ingot castings, has been proposed for production of steel strand of large formats^[1-2]. The strand of SCC is withdrawn vertically to a specified length, and then undergoes a hot topping stage till it is fully solidified. The withdrawn stage is similar to that of the continuous casting process. The strand is pulled out of the mold and subject to the secondary cooling by the water spray. The high cooling rates during the withdrawing stage causes pronounced radial orientation of the crystallization (columnar). During the hot topping process, the inner strand is solidified very slowly similar to ingot casting. Thus the strand center, where the crystallization front meets from all sides, gets sensitive to porosity. The main concern of developing SCC technology is its sensitivity to centerline shrinkage porosity, and structural and compositional heterogeneities, i.e. mixed columnar-equiaxed structure and macrosegregation. This study is to use a numerical method to investigate the formation of as-cast structure, centerline shrinkage and macrosegregation, and hence to prove the concept of the SCC.

In order to improve the metallurgical quality of the steel strand, counter measures, e.g. controlled cooling/hot topping or electromagnetic stirring (EMS), are necessarily implemented and optimized (Fig.1a). Meanwhile, dynamic cooling or heat shielding, which can adjust the heat transfer condition, is placed around the strand during hot-topping period. Those combined measures can enhance the hot topping efficiency and reduce the metallurgical length in the strand center, hence to prevent the risk of centerline porosity and minimize the macrosegregation^[1,2].

A three-phase mixed columnar-equiaxed solidification model^[3] is applied. The liquid, equiaxed and columnar phases are considered (Fig.1b). The key phenomena during solidification are considered: evolution of columnar phase, dendrite fragmentation, floatation/sedimentation of equiaxed crystals, thermal solutal convection of the melt and the flow as caused by crystal sedimentation and EMS, development of as-cast structure and macrosegregation. Fragmentation is an important origin of equiaxed crystals^[4]. The formulation of crystal fragments is taken into account and the equiaxed crystals originate from the remelting-induced fragmentation. The centerline shrinkage porosity is estimated by a modified NIYAMA criterion. A SCC strand of industry scale is numerically studied. Based on the numerical calculations, the merits of SCC technique vs. conventional ingot casting and continuous casting techniques are discussed.

Typical solidification process of SCC during the hot topping period is shown in Fig.2. The core region of the casting is still liquid, which is confined by the solid shell (columnar structure). The equiaxed crystals mainly located in the lower part of the strand due to crystal sedimentation. Obviously, equiaxed crystals move in the melt pool coupled with the flow of melt. A small amount of equiaxed crystals are captured in-between of the columnar dendrites, while the solid shell of the strand consists of a mainly columnar structure (Fig.2a). The strand electromagnetic stirring (EMS) is applied to create new equiaxed crystals by the mechanism of fragmentation. Crystals with large equiaxed velocity are located in the region of the EMS. Crystals in the strand near the middle of the EMS have the largest velocity, which is with a magnitude of 10^{-1} m/s (Fig.2b). From the cross section, we can observe an obvious equiaxed crystal circulation (Fig. 2c). This kind of circulation is coupled with the melt flow through the drag force. In the lower part of the melt pool, an equiaxed sedimentation is witnessed. Specifically, near the bottom of the melt pool, the crystals tend to settle down, attaching to the equiaxed network below (Fig.2d).

The major advantage to apply the numerical model is to show the inside details of the formation of as-cast structure, centerline shrinkage and macrosegregation during solidification of SCC. On this base some counter measures can be suggested to control the as-cast structure and minimize the undesired casting imperfections like the centerline shrinkage and macrosegregation. It should also be stated that, although the current model has been

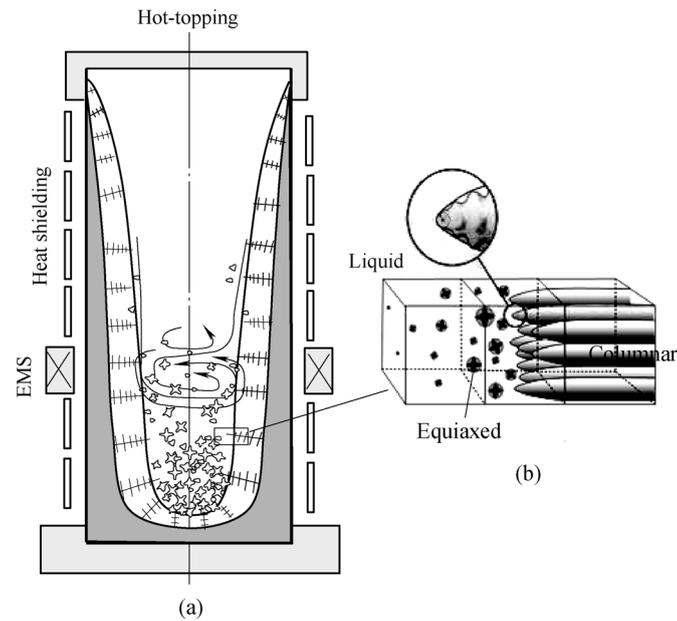


Figure 1 Schematic of semi-continuous casting process during hot-topping period (a) and a zoom-in view near the columnar tip front (b)

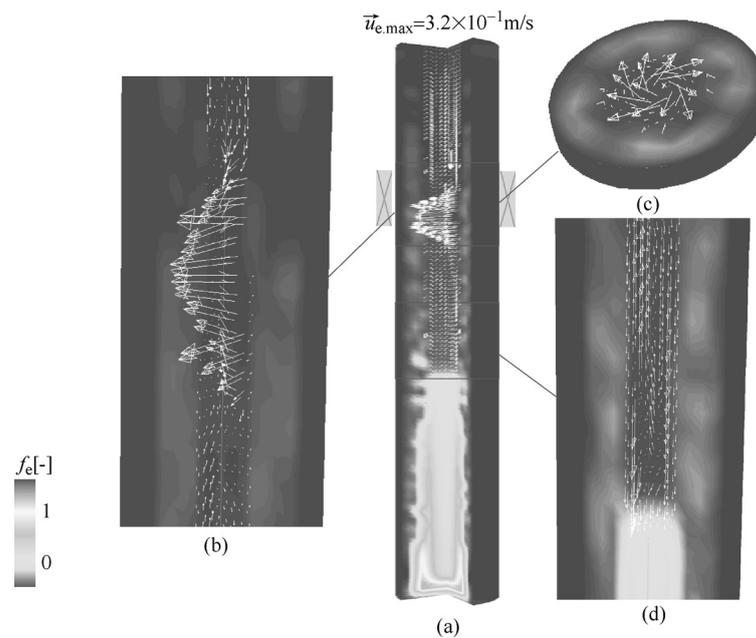


Figure 2 Typical solidification process of SCC during the hot topping period. The contour of volume fraction of equiaxed phase overlaid with equiaxed velocity (white arrow) is shown: (a) global view; (b) zoom-in view in the region of the electromagnetic stirrer; (c) the cross-section view in the region of the electromagnetic stirrer; (d) zoom-in view near the bottom of the melt pool

verified against laboratory experiments and limited industry trials, further validations are desirable.

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