EFFECT OF IMMERSION DEPTH OF A SWIRLING FLOW TUNDISH SEN ON MULTIPHASE FLOW AND HEAT TRANSFER IN MOLD

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Abstract—The effect of the immersion depth of a new swirling flow tundish SEN (Submerged Entry Nozzle) on the multiphase flow and heat transfer in a mold was studied using numerical simulation. The RSM (Reynolds Stress Model) and the VOF (Volume of Fluid) model were used to solve the steel and slag flow phenomena. The results show that the SEN immersion depth can significantly influence the steel flow near the meniscus. Specifically, an increase of the SEN immersion depth decreases the interfacial velocity, and this reduces the risk for the slag entrainment. The calculated Weber Number decreases from 0.8 to 0.2 when the SEN immersion depth increases from 15 cm to 25 cm. The temperature distribution has a similar distribution characteristic for different SEN immersion depths. The high temperature region is located near the solidification front. Temperature near the meniscus was slightly decreased when the SEN immersion depth was increased, due to an increased steel moving distance from the SEN outlet to the meniscus.

Keywords—swirling tundish; heat transfer; submerged entry nozzle; flow pattern; contineous casting mold.

I. INTRODUCTION

Multiphase flow and heat transfer are very important phenomena in the continuous casting mold. These phenomena include steel-slag flow, inclusion motion, solidification, and so on. They can significantly influence the quality of the semifinal steel product. The basis for a good control on multiphase flow and heat transfer is a desirable steel flow in mold. In the past, many studies have been carried out to optimize the multiphase flow and heat transfer in mold. In the past, many studies have been carried out to optimize the multiphase flow and heat transfer in mold. The optimization investigations firstly focused on the structure of the SEN (Submerged Entry Nozzle), such as the SEN type (straight or bifurcated), SEN port design (shape, angle, thickness), and SEN immersion depth. Argon injection in SEN was also a widely investigated method to improve the continuous casting process, with the aim to reduce the nozzle clogging, reduce the steel reoxidation and increase the inclusion floatation in mold. Recently, swirling flow SEN has been considered to be a promising method to further modify the steel flow in mold. The significant improvement with this method is that it can directly change the steel flow characteristics before the steel flows into the mold for example, the prevention of an impingement jet flow from a straight SEN. It was found that the heat and mass transfer near the meniscus can be remarkably activated, and a uniform velocity distribution can be obtained within a short distance from the SEN outlet

.Furthermore, the penetration depth of the SEN outlet flow is remarkably decreased in a billet mold. Industrial trial results show that the swirling flow SEN effectively improved the steel product quality and reduced the clogging problem of the SEN side ports.

II. MODEL DESCRIPTION

A three-dimensional mathematical model has been developed to describe the multiphase flow and heat transfer in a billet mold during the continuous casting of steel. The geometry and the dimension of the billet mold model is shown

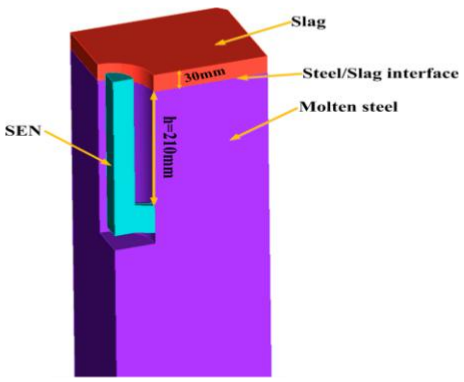
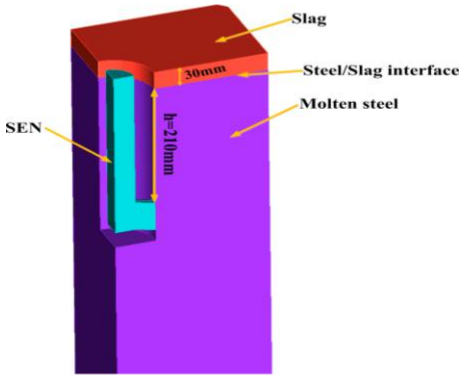


Figure 1.geometry of casting mold(top view and front view) A. Model assumption

The numerical model is based on the following assumptions:

- Steel and slag behave as incompressible Newtonian fluids
- Solidification in the mold is not considered;
- A constant molecular viscosity for steel and slag was assumed. This is due to the fact that the maximum temperature difference in the mold is only 30 K between 1788 K and 1818 K as the superheat of the steel. The viscosity change in this temperature range is not significant, and this can be seen from a previous study.
- A constant steel and slag density was used. The temperature influence on the steel density change was accounted for in the source term of the momentum equation.



Full geometrical models are taken for all cases. For example, the meshed computational model equipped with the two-port SEN is shown in Figure 2, where the technology of local grid refinement is applied to simulate the behavior of the initial solidified shell more accurately. The meshes of FLUENT computational domain include non-uniform grids with approximately 1,700,000 cells.

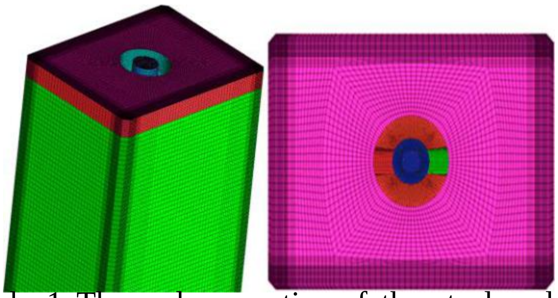


Table 1 Thermal properties of the steel and slag.

Parameters	Symbols	Steel	Slag
Density,kg/m^3	ρ_o	7000	2600
Viscosity,kg(m-s)	µ	.006	.09
Thermal conductivity,w(m-k)	K	35	1.1
Specific heat,j/(kg-k)	C_p	628	1200

B. Boundary Conditions

The velocity profile on the cross section of the cylindrical tundish SEN, which has been solved in a previous study, was used as the inlet boundary condition for the current simulation of the mold flow. This steel flow velocity at the inlet in figure 1, has been presented in a previous study and, thus, it is not repeated here. A nonslip boundary condition was imposed on the SEN wall. A zero-shear slip wall boundary condition was used at the mold surface. For the mold wall, a moving wall boundary condition with the velocity of 0.013 m/s in Z or downwards direction was used to account for the movement of the solidified shell in a real casting process. A fully developed flow condition is adopted at the mold outlet, where the normal gradients of all variables are set to zero. A constant steel temperature of 1818 K was used at the inlet, with a superheat of 30 K. A constant temperature of 1788 K was imposed on the solidified shell. An adiabatic condition was used both at the SEN wall and at the free surface.

C. Solution method

The numerical model was solved using the commercial software ANSYS FLUENT 18.0. The numerical simulations were carried out based on 1.4 million grid cells to guarantee the grid-independent solution. A fine grid was used in the near-wall region, with the y+ value of the first grid layer around 1. The PISO (Pressure-Implicit with Splitting of Operators) scheme was used for the pressure-velocity coupling. Furthermore, the PRESTO method was adopted to discredit the pressure. The governing equations were discredited using a second order upwind scheme. The convergence criteria were as follow: The residuals of all dependent variables were smaller than 1 × 10−3 at each time step.

III. SIMULATION RESULTS AND DISCUSSION

A. Steel flow phenomena

Figure shows the steel flow path in the mold with different SEN immersion depths. It can be observed that the steel flow pattern in mold was similar for different SEN depths. It delivers the steel into the mold along the periphery of the SEN, which is in 360°. The SEN outlet flow moves towards the solidified shell after it flows out from the straight SEN due to the swirling flow effect, inducing a rotational steel flow momentum. After the steel stream reaches the solidified shell, a part of the steel flows downwards along the solidified shell with a horizontally rotational flow momentum, and another part of the steel moves upwards and towards the meniscus.Due to the difference in SEN immersion depth, the top rotational flow region near the meniscus was large when a large immersion depth of SEN was used. This should be beneficial for the decrease of the steel flow velocity, since the steel from SEN outlet needs a long distance to reach the steel-slag interface. Therefore, the current swirling flow tundish SEN can deliver high temperature steel uniformly distributed towards the solidified shell, no matter the change of the SEN depth.

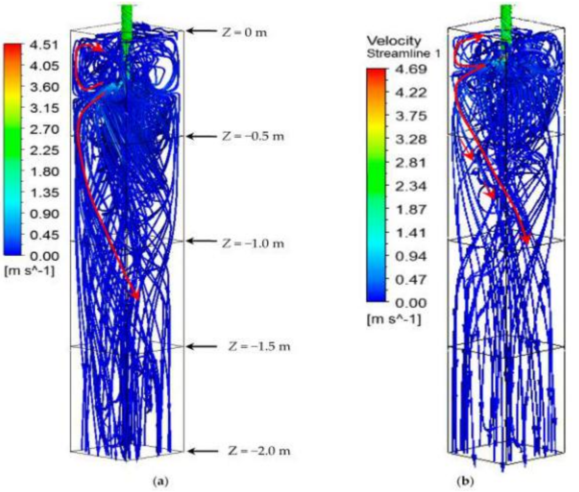


Figure 2.comparison of steel path flow in mold,SEN immersion depth of 25(a) cm and 15(b) cm

The velocity on the vertical plane located at the middle of the mold for different SEN immersion depths. It can be seen that the high velocity region was located at the solidification front in the mold. Steel moves downwards at the region near the solidified shell and it flows upwards in the center of the mold. The effect of the SEN depth is mainly on the steel flow velocity at the top of the mold. It can be seen that the region with a high steel flow velocity was reduced when a large SEN immersion depth was used. This is expected to reduce the risk of the slag entrainment at the steel–slag interface. When a large SEN immersion depth was used, the length of the SEN was increased. The dissipation of the rotational momentum was expected due to the friction of the SEN wall. However, it did not show significant influence on the steel flow in the mold below the height of the SEN outlet.

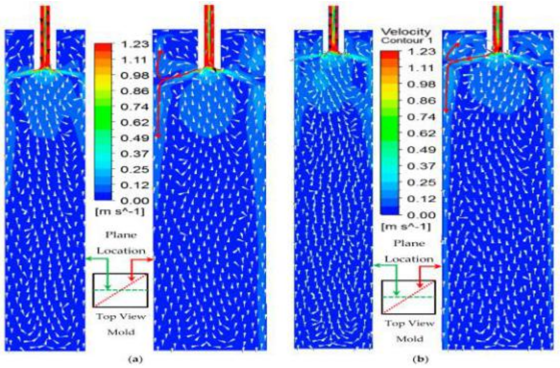
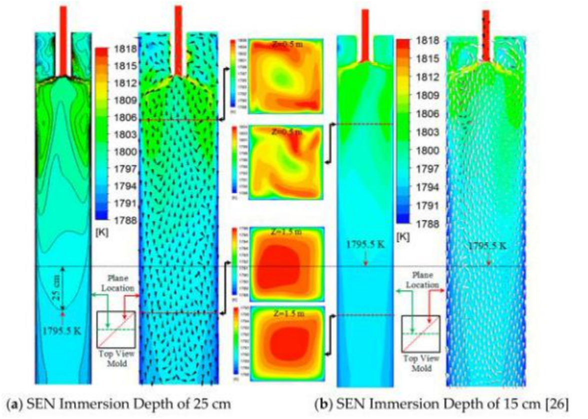


Figure 3.Steel flow velocity in vertical middle plane of the mold both 15 cm and 25 cm of immersion.

Comparison of vertical velocity distributions along the line, with the mold depth of 1.5 m, for different SEN immersion depths. It can be seen that a large velocity with a magnitude of 0.03 m/s exists in the solidification front. This may be helpful to shear off the dendrites from the solidification interface and promotes the nucleate, which results in an enhancement of the transition from a columnar to equiaxed solidification.



(a) SEN Immersion Depth of 25 cm (b) SEN Immersion Depth of 15 cm [26]

Figure 4.Verical steel flow velocity along with horizontal lines in different depths.

B. Steel-slag interface phenomena

One of the most important concerns about the swirling flow SEN is about the steel flow and heat transfer near the meniscus. Due to the existence of the swirling flow, the impingement jet flow in a conventional tundish casting disappeared. The steel flow moves towards the solidification front, the induced steel flow in the meniscus region was increased, and this led to the heat transfer near the meniscus accelerating. However, a large steel flow velocity near the meniscus region also illustrates a high risk of the slag entrainment. Therefore, it is very important to investigate the effect of the SEN immersion depth on the steel-slag interface behavior.

Figure 5.Steel slag interface with steel flow vectors. A. Temperature fields

Steel temperature in the mold is very important, since it significantly influences the solidification structure, which in turn determines the product quality. The swirling flow SEN has proven that it can accelerate steel superheat removal. This is good for the formation of equiaxed crystals. It can be seen that similar temperature distribution characteristics were observed for different SEN immersion depths.Due to the swirling flow effect, steel with a high temperature flows towards the solidified shell. It increased the temperature near the solidified shell as well as the temperature gradient there, while the core temperature of the billet was low. On the cross section at a depth of 0.5 m in the mold, the maximum temperatures for the immersion depths of 25 cm and 15 cm are 1806 and 1804 K, respectively. It can be seen that the high temperature region is not located in the center of the mold. These values decrease to 1796 K and 1795 K at the mold depth of 1.5 m, respectively.

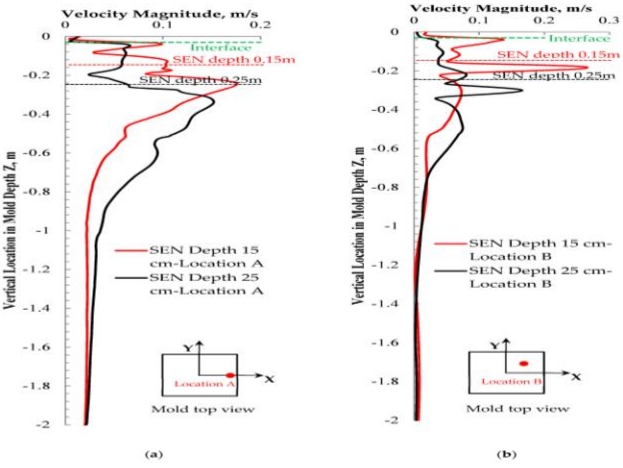


Figure 6.Temperature distribution in mold for

different SEN immersion depths.

Here, the high temperature region was located in the mold center. This is due to the fact that the superheat of the steel near the solidification front can be removed fast, while that in the mold center cannot be easily dissipated. In addition, there are some differences induced by the increase of the immersion depth. The first issue is about the temperature near the meniscus, where a low temperature was observed when a large immersion depth was used.

The velocity magnitude distribution along different lines in mold depth direction. Figure 7a is the velocity distribution at Location A with 1 cm away from the solidification shell. At the top of the mold, it can be seen that the velocity magnitude with a large SEN immersion depth is smaller than that with a small SEN immersion depth. This is helpful to reduce the risk of the slag entrainment. In the low part of the mold, the velocity near the solidification front is larger with a larger SEN immersion depth, and this is helpful for the formation of equiaxed crystals. In Figure7b, the velocity distribution at Location B, which is close to the mold center, was presented. It can be seen that the major difference exists at the top of the mold, with a smaller velocity when a larger SEN depth was used. Furthermore, the velocity was similar at the location in deep mold. In summary, the general trend of the flow change when the SEN immersion depth was increased is that the velocity in the top mold decreased while the velocity at the low part of the mold increased.

Figure 7.Total velocity distribution.

IV. CONCLUSSION

The effects of the SEN immersion depth on the multiphase flow and heat transfer in a mold with a new cylindrical tundish design for continuous casting were investigated using numerical simulations. The main conclusions were the following:

Steel flow patterns are similar for different SEN immersion depths, with the flow direction towards the solidification front.

An increase in the SEN immersion depth decreases the interfacial velocity and this reduces the risk of slag entrainment. The calculated Weber Number is 0.8 and 0.2 for the SEN depth of 15 cm and 25 cm, respectively. The steel flow velocity near the solidification front below the SEN outlet is increased with a large SEN immersion depth.

The temperature distribution has a similar distribution characteristic. The high temperature region is located near the solidification front. Temperature near the meniscus was slightly decreased when the SEN immersion depth was increased.

A large SEN immersion depth was recommended in order to reduce the slag entrainment. This will not reduce the steel flow velocity near the solidification front, nor will it significantly reduce the temperature near the meniscus.

A. SCOPE OF THE PRESENT WORK

Based on the literature review, the baseline geometric model of the tundish will be created by using the ANSYS Design Modeller. The geometry was meshed using the pre-processor tool ANSYS Meshing. Flow behaviour of the baseline model was done in FLUENT and validated against available literature with Volume fraction contours. Finally study the tundish container with swirl chamber with dams to improve the performance of the tundish container.

B. OBJECTIVE

To study the alternative configurations at transient state working conditions to identify the “best available” solution which allows equalization of the liquid metal through-time from the inlet to the different outlets, which is necessary to guarantee homogeneous thermo-chemical characteristics of the metal feeding the different casting lines

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