START-UP PHASE MODELING OF SEMI CONTINUOUS CASTING PROCESS OF BRASS BILLETS

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Abstract

The modeling of semi continuous direct chill casting process has been used to investigate brass billets owing to its ability to produce high quality billets at relatively low operating costs. From the standpoint of defect control, the start-up phase of the direct chill casting process is typically the most problematic. The quality issues of major concern include hot tearing, cold cracking, and dimensional control. In these processes, the formation of some macro defects such as thermal cracking, hot tearing, surface cracking, and dimensional control has been found to initiate during the starting phase of the operation and has been affected by the transient fluid flow, heat transfer and solidification that are dynamically evolving during that period of time. In this paper, a numerical study of transient flow phenomena such as oscillations of the jet and free surface during the start-up phase is presented. The modeling of semi continuous casting process is concerned with the liquid/solid phase change problems in which three dimensional convective heat transfer in liquid metal has an effect on the growth of the solidified shell. The realistic model for start up phase of casting involves solidification drag modeling which has an important effect on solidification patterns within metallurgical zone of solidified brass billet. The software Flow3D has been used to model the start-up process.

Keywords: semi continuous casting, continuous casting, start-up phase, solidification drag, three dimensional turbulent flow, solidification pattern, brass billet.

1. INTRODUCTION

The semi continuous direct chill casting process has been used to produce brass billets owing to its ability to produce high quality billets at relatively low operating costs. At the start of the cast, an entry nozzle is partially inserted into an open cylindrical water cooled mold which is typically 300-400mm in height (Fig.1). The process starts with the introduction of the superheated liquid metal to the mold.

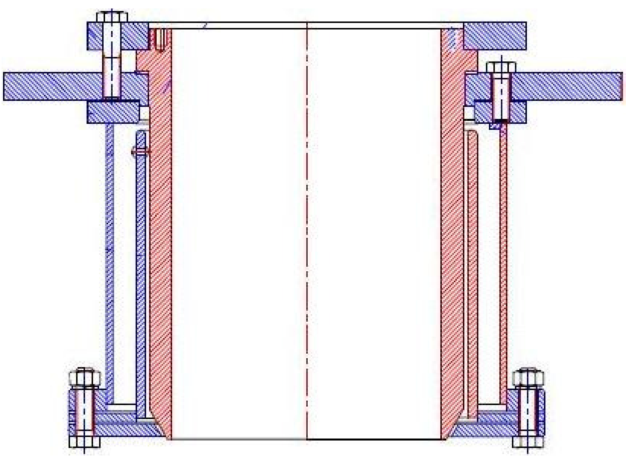

Fig. 1 Cylindrical water cooled mold

Once the molten metal fills the mold to a prescribed height, the entry nozzle is gradually submerged into a liquid metal and the partially solidified billet is withdrawn from the mold. The billet is lowered at a predetermined casting speed. The process is semi continuous, in that, once the ingot has reached the desired length (usually 8 to 10m), the casting is stopped and the flow of liquid metal is suspended. During this process, the ingot is first cooled by the mold (primary cooling) and then cooled through a direct contact with water as it emerges from the mold (secondary cooling). At steady state, which is usually achieved within a cast length of 0.5 to 1m, approximately 80% of the total heat is removed by the secondary cooling and approximately 20% is removed by the primary cooling. In the start-up phase, this breakdown is different as a substantial amount of the heat is initially transferred to the cupper mold and bottom block.

The trend in the industry has been to control the rate of heat transfer during the critical start-up phase by varying the bottom-block filling rate, casting speed and water flow rates. Relatively little fundamental work has been done to rationalize the design of the casting process with regard to controlling the final ingot quality. The development of numerous 3D computer models to describe the heat transfer, fluid flow and evolution of stress and strain in direct chill cast ingots has begun to have an impact on the evolution in the design and operation of the process. However, improvements are needed to capture the various inter-related transient fluid flow and heat-transfer phenomena occurring during the process, particularly during the start-up period.

From the standpoint of defect control, the start-up phase of the direct chill casting process is typically the most problematic. The quality issues of major concern include hot tearing, cold cracking and dimensional control. In these processes the formation of some macro defects such as thermal cracking, hot tearing, surface cracking and dimensional control has been found to initiate during the starting phase of the operation and has been affected by the transient fluid flow, heat transfer, metallurgy [5] and solidification that are dynamically evolving during that period of time.

In this paper, a numerical study of transient flow phenomena such as oscillations of the jet and free surface during the start-up phase is presented. The presented modeling of casting process is concerned with the liquid-solid phase change problems in which three dimensional turbulent convective heat transfer in liquid metal has an important effect on the growth of the solidified shell. The overview of mathematical modeling of the continuous casting process is dedicated work of Konieczny, Dobrzanski, Hufenbach, Czulak, Horňak [1] and Thomas [2].

2. MODEL DEVELOPMENT

The calculation domain for the 3D coupled fluid flow-thermal analysis necessarily includes the fluid region, nozzle, cylindrical mold and bottom block presented in Fig. 2.

Continuous casting process involves moving solid billet that controls the flow of liquid metal. Simulation of this process requires modeling the motion of the solid metal and the interaction between metal and rigid mold. The motion is modeled as rigid mold and nozzle moving up through fixed rectangular grid.

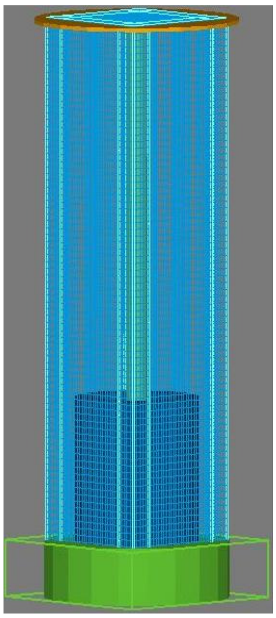

Fig. 2 3D model of fluid region, mold, bottom block and submerged nozzle

The elemental size used for the fluid region of billet and nozzle ranged from a minimum of 6.2mm to maximum of 8.8mm in side length. A higher mesh density along the horizontal *x* and *y* directions was used to ensure proper accounting of the liquid metal splash inside of the mould.
The finite volume software Flow3D was used in the present analysis to simulate coupled turbulent fluid flow, heat transfer and solidification.
This study considers the liquid, mushy and solid zones where the solidification starts to develop at the liquid-solid interface and the effect of the latent heat release is incorporated. The D'Arcy-type drag model for the liquid phase flow in the mushy zone was adopted to model fluid flow in the mushy region to include additional flow effects at low and high solid fractions. The drag should be effectively infinite when material is in the solid phase. At intermediate states consisting of a mush, the drag should assume an intermediate value. In Flow3D [3] the drag coefficient is

$$K=\frac{T_{SDRG}F_S^2}{\left(1-F_S\right)^3}$$

where F_s is the local solid fraction. When $F_s=F_{SCR}$, the drag coefficient K becomes effectively infinite. F_{SCR} is a user defined constant denoting the critical solid fraction value at which all flow in the mushy zone seizes. T_{SDRG} is a user defined constant. Its value depends on the mushy zone microstructure the modeling of which is outside the scope of the solidification model in FLOW-3D. When the value of T_{SDRG} is set to zero, then no drag force is applied to the fluid in the mushy region. The value of T_{SDRG} used to model fluid flow in the mushy zone has been set to one, than drag force is applied. The actual choice for T_{SDRG} is likely to depend on the specific application, and in general, will require some confirmation with experimental data.
The heat transfer associated with the primary cooling to the mold has been applied over a region extending from the top of the ingot (meniscus) to the base of the mold. For the boundary conditions, the heat-transfer coefficient is assumed to be 2000 W m^{-2} K^{-1}.
Sengupta et al. [4] did fundamental work on the mechanisms cooling with the secondary cooling water in casting processes and found that during the start-up phase it is typical to have stable film boiling develop at certain locations on the ingot surface, which can result in water being ejected from the surface. A heat transfer coefficient of 1000 W m^{-2} K^{-1} to simulate reduced heat transfer associated with water ejection was applied to the regions of the calculation domain located below the base of the mold.
At the beginning of the casting process, when the liquid metal enters the bottom block, the rate of heat transfer from the molten metal to the cold bottom block will be high. After a short time, a small gap at the interface forms due to solidification and the rate of heat transfer will drop. For simplicity, the heat transfer coefficient appearing in boundary condition was set constant to 2000 W m^{-2} K^{-1}.
The thermo physical properties, solidus and liquidus temperatures and the latent heat of solidification used in the simulations are presented in Table 1.

Table 1. The used thermo physical properties of CuZn30 alloy

Thermo physical properties	**Units**	**Values**
Solidus temperature	K	1190
Liquidus temperature	K	1230
Thermal conductivity (liquid)	W/m K	77
Thermal conductivity (solid)	W/m K	154
Specific heat	J/kg K	490
Density (liquid)	kg/m^3	7500
Density (solid)	kg/m^3	8420
Latent heat	J/kg	1.78E05

The alloy composition can affect properties of brass and also defects of billets. The effect of alloy composition on properties of brass melt has been analyzed by Bobok, Schützová and Vasková [5], but there exist no quantification of the effect of alloy composition on defects.

3. RESULTS AND DISCUSSION

The figure 3 and 4 show a variation of flow patterns in the cross-section through the axis of the billet for a time 103 and 240 seconds. The molten brass, supplied through the submerged nozzle, impinges on the bottom block and returns along the cylinder wall in the opposite direction. The return flow follows the vertical solidified shell on the surface of the billet and forms recirculation zones. The zone is confined by the meniscus on the top and solidified shells on the bottom and by cylindrical surface of the mold. Such overall pattern appears within the whole process similarly. There is, however, a substantial change in magnitude and pattern of velocity on the bottom zone where the strong impingement causes erosion of the solidified shell and the upward flow can cause turbulence on a free surface.

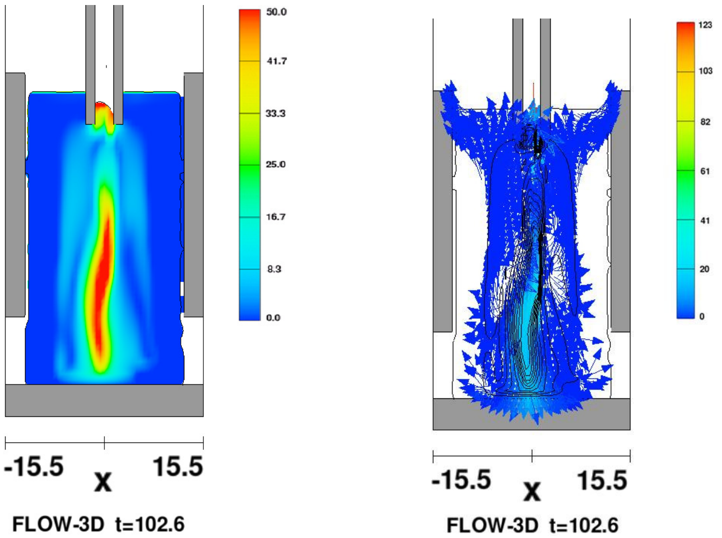

Fig. 3 Calculated velocity contours and vectors inside metallurgical zone t=103 s

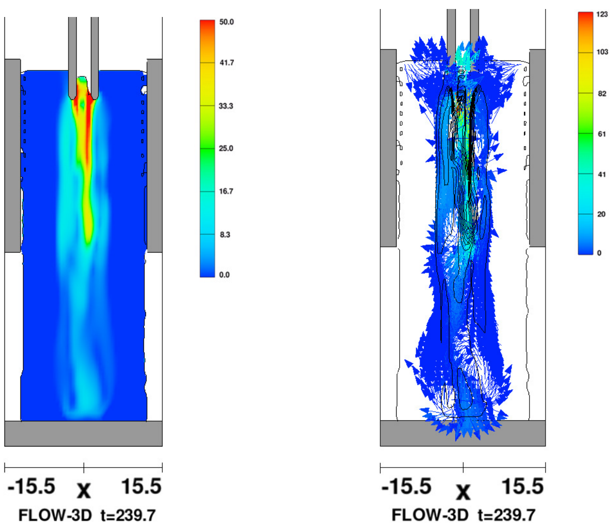

Fig. 4 Calculated velocity contours and vectors inside metallurgical zone t=240 s

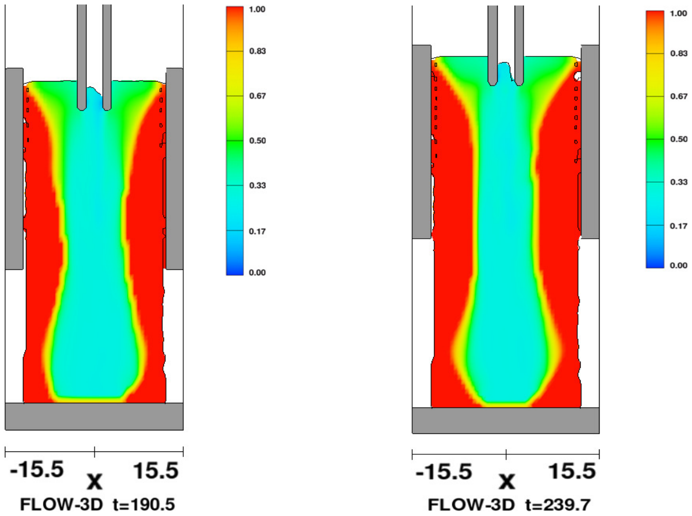

Fig. 5 Calculated fraction of solid ratios at billet geometry t=103 s and t=125 s

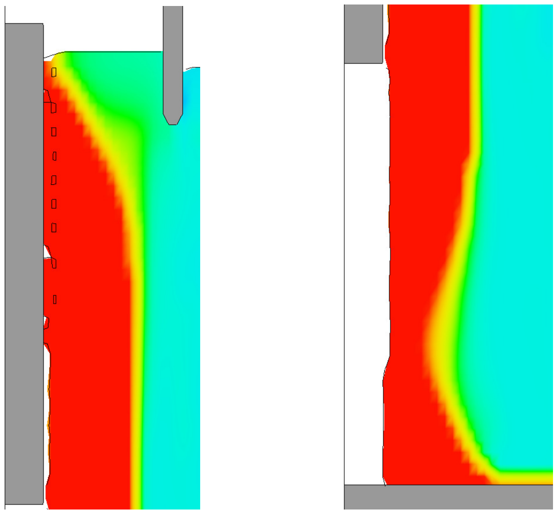

Fig. 6 Details of calculated fraction of solid ratios

Figures 5 and 6 show solid fraction contours near the interfacial boundary between solidified shell and liquid melt. We can see three different zones in the pictures. The first zone is mushy region at the top of metallurgical zone – there is very low gradient of contours due to drag of solid crystals from second zone. At low solid fraction values the crystals of the solid phase are sparse in the second zone and are dragged by the jet of melt from the second zone to the first zone (Fig. 6). The second zone shows very high gradient of fraction solid contours due to high cooling effect and high velocities near the interface solid-liquid. The second zone occurs between the first zone and the third zone. The third zone can be found on the bottom of the metallurgical zone. The third zone shows increasing in the thickness of mushy zone near the solidified shell. This is due to heating effect of hot melt from nozzle and recirculation of the melt within the zone.
Some effects from three dimensional finite volume based on numerical modeling by using Flow3D software are summarized as follows:

- Solidification pattern during the start up phase of continuous casting of brass billet is irregular. This irregularity is due to the effect of the turbulent flow phenomena by strong impinging jet and recirculation within the metallurgical zone of solidified billet.
- Strong impingement causes erosion of the solidified shell and the upward flow can drag crystals to the upper part of mold.
- Three different zones of solidification are visible during the start-up phase of continuous casting of brass billets.

These conclusions can be substantiated by the fact that in a real continuous caster, in the upper part, a narrow mushy region seems to develop. This is due to the highly turbulent state of the molten metal from the inlet nozzle flow. In this narrow mushy region, one can assume an equiaxed solidification process to prevail.

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