Journal of Materials Processing Technology 233 (2016) 89–99

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Computational and physical simulation of fluid flow inside a beam blank continuous casting mold

Johne Jesus Mol Peixoto[a,*], Weslei Viana Gabriel[a], Leticia Queiroz Ribeiro[a], Carlos Antônio da Silva[a], Itavahn Alves da Silva[a], Varadarajan Seshadri[b]

[a] *Department of Metallurgical Engineering/REDEMAT, Federal University of Ouro Preto, Ouro Preto, Brazil*
[b] *Department of Metallurgical Engineering, Federal University of Minas Gerais, Belo Horizonte, Brazil*

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form 7 January 2016
Accepted 12 February 2016
Available online 17 February 2016

Keywords:
Beam blank
Fluid flow
Continuous casting
Near net shapes
PIV

ABSTRACT

The main features of the flow field inside a beam blank continuous casting mold have been assessed through mathematical and physical modeling techniques. Experimental techniques such as particle dispersion through addition of dye and particle image velocimetry have been used in a physical model of the mold to assess the flow pattern. Different combinations of nozzle geometry and throughput have been employed and the experimental results have been analyzed. In the case of two tubular nozzles, which should ensure good thermal and flow symmetry, six vortices were observed in the mold, two near the web and two in each of the flanges. Increasing the flow rate of the fluid from 100 L/min to 150 L/min leads to a change from 0.74 m to 0.84 m in the jet penetration depth. However even a 67% increase of the nozzle cross section did not affect this parameter significantly. Experiments with one single tubular nozzle (53.2 mm inside diameter) were also carried out and the resulting flow asymmetry has been characterized. The difference in the fluid velocities at the filets could lead to unequal solid shell growth. The depth of jet penetration is larger than mold nominal length (0.8 m). Fluid flow structure as determined by PIV measurements and CFD simulations show a good agreement.

1. Introduction

Actual experimental trials to determine optimum conditions of operation in the continuous casting unit can lead to interruptions in the production schedule and consequently loss of productivity and profitability. Mathematical analysis and physical modeling experiments in the laboratory are an alternative to achieve optimum conditions for achieving increased productivity and improved quality of the product. Hibbeler et al. (2009) developed a mathematical model for simulating the temperature profile and the stress/deformation field inside the solidifying shell in a beam blank continuous casting mold. This model is also capable of throwing light on the mechanism of crack formation at the filet region, due to a combination of a thinner shell, mechanical stress and an extended air gap.

Lee et al. (2000) had observed that the air gap was mainly formed in the flange-tip, which retards the shell development in this region. The irregular advance of the solidifying shell is caused by nonuniform heat transfer and the stress concentration in the thinnest part of the solidified shell, implying a higher probability of occurrence of cracks. Zhao et al. (2014) detected that a large temperature difference between the filet and other regions on the surface can cause longitudinal cracks at the fillet, and an optimization in the cooling system can improve the quality of the beam blank.

The flow field inside the mold is known to impact the steel internal cleanliness and the growth of the shell. In the conventional continuous casting, the flow field is influenced by mold geometry, casting velocity, nozzle geometry as well as immersion depth. Chen et al. (2012a) has highlighted these effects for the beam blank casting process. Yang et al. (2006) considered the effects of a growing shell on the flow and found it to be significant due to the localized small flow section.

Chen et al. (2012a) have performed studies on tubular nozzles and concluded that they cause deep steel penetration depths and small meniscus velocity. This could lead to a decrease in the likelihood of inclusion flotation and also decreasing entrapment of mold powder by the bulk metal. The authors suggest a nozzle immersion depth in the range of 50–100 mm.

The usual arrangement of SEN for beam blank continuous casting employs two tubular nozzles, at the center of each flange. To

---

[*] Corresponding author.
E-mail address: johnepeix@yahoo.com.br (J.J.M. Peixoto).

http://dx.doi.org/10.1016/j.jmatprotec.2016.02.011
0924-0136/

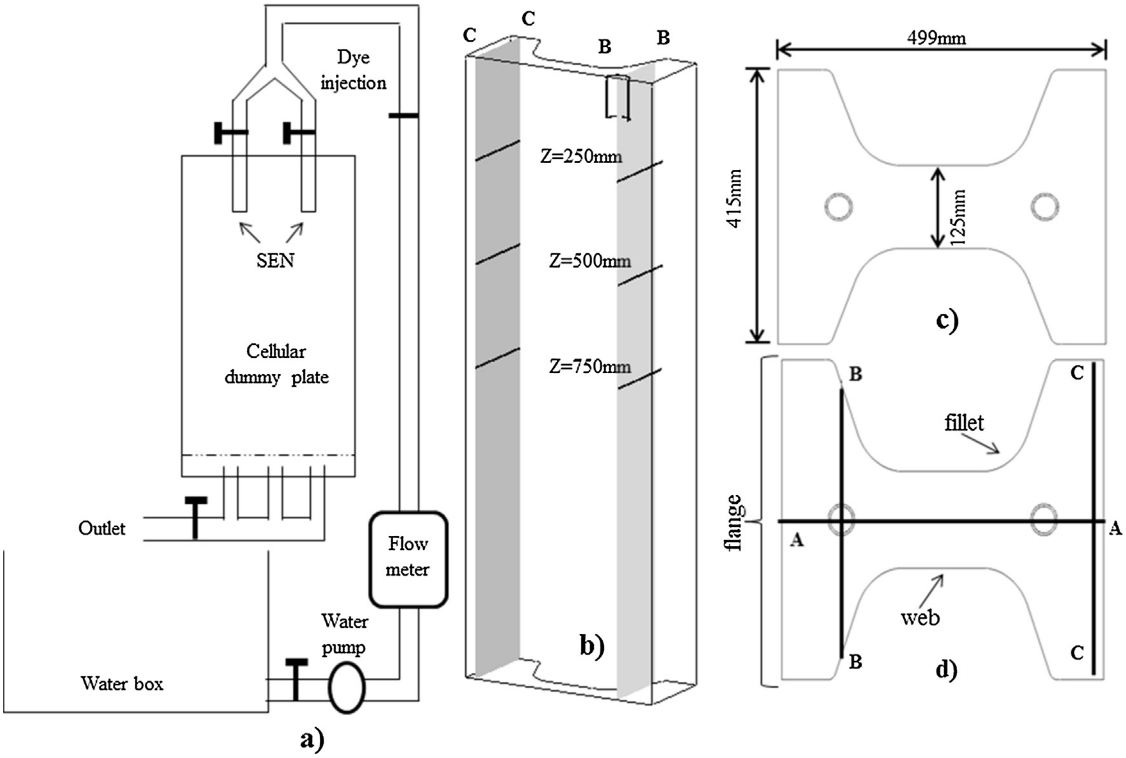

Fig. 1. (a) Schematics of 1:1 beam blank model of a mold; (b) isometric view of the beam blank with one nozzle; (c) beam blank dimensions; (d) cross section of beam blank depicting cutting planes AA, BB, and CC.

improve the product quality and productivity, other configurations have been suggested. Yang et al. (2004) analyzed the fluid flow in beam blank mold fitted with two nozzles, and found that the configuration of a SEN with a frontal and two lateral outlets, with an angle of 120° between the outlets and a port inclination of +15° lead to better inclusion removal from molten steel. According to Chen et al. (2012b), in the case of a three hole SEN, the steel penetration depth would be reduced with a substantial change in the velocity at the free surface accompanied by a more intense fluctuation. This helps in the melting of the mold powder and leads to a better absorption of non-metallic inclusions. The recommended port inclination angle in this case was +9°.

Employment of two nozzles in the mold is complex and requires a good flow control as compared to a single nozzle arrangement. Nozzleís mispositioning can stimulate non-symmetrical flow leading to product defects. On the other hand, a single nozzle feeding can result in a high liquid steel velocity in the mold, which is harmful to the shell integrity and meniscus stability. De Santis et al. (2014) proposed in the case of beam blank continuous casting, feeding the metal with only one nozzle. Multi-holes nozzle geometries have been analyzed through mathematical modeling. A nozzle with a 50 mm diameter throat, a 50mm × 60 mm elliptical lateral port inclined 25° downwards, and a 20 mm-diameter bottom hole, has been proposed as the best SEN design under their operational conditions.

As it can be seen from the above survey the flow field inside the mold is fundamental in controlling the product quality and productivity and hence should be optimized by controlling different variables relevant to the process. In this contribution, mathematical and physical modeling of flow field inside a beam blank mold have been carried out and the effect of nozzle geometry, casting velocity and other parameters have been analyzed.

2. Methodology

Experiments were conducted in a physical model (acrylic) with the following dimensions: 499 mm × 415 mm × 125 mm with the mold length of 1.5 m. Fig. 1 represents the physical model constructed with a scale of 1:1 of the prototype of beam blank mold. The physical model is based on similarity criteria between the industrial steel system and a model employing water as the working fluid. This has been discussed by Szekely and Ilegbusi (1989). According to them, the isothermal flow similarity is achieved if Reynolds and Froude dimensionless groups are taken into consideration. A model with 1:1 scale is preferred considering the physical properties of water (25 °C) and steel (1600 °C) such as dynamic viscosity and density. Hence the model volumetric flow rate is equal to the volumetric flow rate of steel in the industrial unit. However the effect of a growing shell and the convective motion due to variation of temperature in the steel pool in the mold could not be taken in consideration since the fluid used in the physical model is water in isothermal conditions. The techniques involved in the experiments with the physical model were as follows.

A continuous flow of dye was injected in the nozzle. Dye dispersion was followed by taking a movie from which different frames for different times could be detached. In addition to dispersion, the penetration depths of liquid jet were also measured.

General aspects of flow field can be observed by focusing light over the small suspended plastic particles (Goodyear SH6, roughly the same density as water). A laser sheet for visualization can be prepared by directing a laser beam over a cylindrical lens. The displacement of these particles as a function of time gives important information regarding flow structure and location of macroscopic eddies. The schematics of the beam blank physical model can be seen in Fig. 1(a).