ON THE MODELLING OF LIQUID STEEL PROCESSES

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Abstract **–– An iterative (k-L)-predictor / (ε)-corrector algorithm that models turbulent flow was developed in previous publications. In this paper, the 3D finite element turbulent model was used to analyze the liquid steel movement produced by gravity force, inert gas stirring or electromagnetic force stirring.**

Keywords **–– turbulence model, continuous casting process, k-ε turbulent model, industrial fluid dynamic applications.**

I. INTRODUCTION

During the steel manufacturing liquid steel goes through a set of vessels. These vessels are:

- Ladle: where the addition of alloys takes place.
- Tundish: where the liquid steel is distributed among the different lines, and the inclusions are removed by flotation.
- Nozzles: which connect different vessels (ladle-tundish; tundish-mold).
- Mold: where the steel solidifies taking the final shape.

In these vessels it is important to keep the liquid steel in continuous movement to avoid the cooling and solidification in non convenient places.

The liquid steel can be moved by three different mechanisms in the steelmaking process:

- ✓ The gravity force: tundish, submerged entry nozzle, mold.
- ✓ The injection of an inert gas: ladle, mold.
- ✓ The electromagnetic forces: ladle, tundish, mold.

In this paper we show an example of a numerical model of each mechanism used to move the liquid steel

II. TURBULENCE MODEL

Considering viscous incompressible flow, isothermal flow, constant density (ρ), constant laminar viscosity (μ), buoyancy force ($\mathbf{F}_b$) external forces ($\mathbf{F}_e$) and a turbulence k-ε model (k: is the turbulent kinetic energy, ε is the turbulent kinetic energy dissipation rate), the following equations are solved:

$$\nabla \cdot \mathbf{v} = 0 \qquad (1)$$

$$\rho \frac{\partial \mathbf{v}}{\partial t} + \rho \mathbf{v} . \nabla \mathbf{v} - \nabla \cdot \left[(\mu + \mu^t)(\nabla \mathbf{v} + \nabla \mathbf{v}^T) \right] + \nabla P + \rho \mathbf{g} + \mathbf{F}_b + \mathbf{F}_e = \mathbf{0} \qquad (2)$$

$$\rho \frac{\partial k}{\partial t} + \rho \mathbf{v} \cdot \nabla k - \nabla \cdot \left[\left(\mu + \frac{\mu^t}{\sigma_k} \right) \nabla k \right] - \mu^t (\nabla \mathbf{v} + \nabla \mathbf{v}^T) : \nabla \mathbf{v} + \rho \frac{C_\mu k^2}{\mu^t / \rho} - \mathbf{F}^k{}_b = 0 \qquad (3)$$

$$\mu^t = C_\mu \rho \sqrt{k}\, L \qquad (4)$$

$$\rho \frac{\partial \varepsilon}{\partial t} + \rho \mathbf{v} \cdot \nabla \varepsilon - \nabla \cdot \left[\left(\mu + \frac{\mu^t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right] - \rho\, C_\mu C_1\, k (\nabla \mathbf{v} + \nabla \mathbf{v}^T) : \nabla \mathbf{v} + \rho \frac{C_2 \varepsilon^2}{k} - \mathbf{F}^\varepsilon{}_b = 0 \qquad (5)$$

$$L = \frac{k^{3/2}}{\varepsilon} \qquad (6)$$

where $\mathbf{v}$ is the time averaged velocity; P is the time averaged pressure; μ^t is the turbulent viscosity; $\mathbf{g}$ is the gravity force; $\mathbf{F}^k{}_b$ is the correction of k-transport equation by the buoyancy forces; $\mathbf{F}^\varepsilon{}_b$ is the correction of ε-transport equation by the buoyancy forces; L is the mixing length; and the typical constants of k-ε model of Launder and Spalding (1974) are $C_\mu = 0.09$, $C_1 = 1.44$, $C_2 = 1.92$, $\sigma_k = 1.0$ and $\sigma_\varepsilon = 1.0$.

To solve these equations we use:

- A standard isoparametric finite element discretization for $\mathbf{v}$, k and ε.
- Penalization of pressure (Zienkiewicz and Taylor, 2000).
- A Streamline Upwind Petrov Galerkin technique (Brooks and Hughes, 1982).
- Trapezoidal rule for time dependent problems (Zienkiewicz and Taylor, 2000).
- A k-L predictor / (ε) corrector iterative algorithm (Goldschmit and Cavaliere, 1995, 1997).
- Wall functions as boundary conditions (Príncipe and Goldschmit, 1999).

III. MOVEMENT BY GRAVITATORY FORCE

The movement of liquid steel along the continuous caster is driven by gravity. The quality of the steel and the productivity of the caster depend strongly on the