RFCS SMARTLADLE Deliverable summary

Work Package

Preparative modelling			**Start date:** 01/07/2021
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Deliverable 3.2: Set-up and specifications of CFD model for stirring based on ladle status

Work Undertaken	3D model of ladle is developed and applied to Uddeholm ladle geometries. The model incorporates modules such as fluid flow, and electromagnetic stirring concepts. The model is able to predict the ladle flow behaviour and wall stresses.
Main Results	The ladle model is being developed with different modules based on the need. Results from modelling activity will be discussed at deliverable 4.1.
Future work to be undertaken	Final model setup to be undertaken during Q2 of 2022 while the comprehensive modelling activity will be done in Q3 2022.
On schedule (Yes /No)	No
Main problems encountered	Industrial trial at Uddeholm with Laser Contouring System (LCS) is planned in Q3 2022. The modelling task requires the ladle geometry from the industrial trial to complete, hence there is a delay in modelling activity.
Corrective actions	Ladle model with ideal settings will be setup during summer 2022. When the industrial trial is completed, the modelling can be carried out without any delay.
Publications, patents	Not available

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1 Introduction

The modelling of ladle furnace is performed in PHOENICS® CFD software. The basis of CFD software is the governing equation namely conservation of mass, momentum and turbulence. The model for electromagnetic stirring will be developed and incorporated to the ladle model.

2.1 Governing Equation

Computational fluid dynamics uses the governing equation for conservation of mass and momentum when calculating the fluid flow. Additional equations for turbulence and electromagnetic stirring are included to improve the accuracy of the model.

2.1.1 Conservation of Mass

The conservation of mass also known as continuity equation is expressed as follows.

$$\frac{\partial \rho}{\partial t} + \mathrm{div}(\rho \mathbf{u}) = 0$$

For an unsteady three-dimensional conservation equation at a point incompressible fluid where density is constant then the above equation becomes the following as expressed below.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

2.1.2 Conservation of Momentum

The conservation of momentum is based on the Newton second equation that states that the rate of change of momentum of a fluid particle equals the sum of the forces on the particle. The rate of change of x, y and z component of the momentum equation equals to the total force in the respective direction due to the surface stresses in addition to the rate of increase of momentum due to the source term. The rate of change of the momentum equation for x component is given by

$$\rho \frac{Du}{Dt} = \frac{\partial(-p+\tau_{xx})}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{Mx}$$

$$\rho \frac{Dv}{Dt} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial(-p+\tau_{yy})}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + S_{My}$$

$$\rho \frac{Dw}{Dt} = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial(-p+\tau_{zz})}{\partial z} + S_{Mz}$$

2.2 Fluid flow

The fluid flow is governed by solving the Navier Stokes equation. The turbulence model plan to be used is standard k-e model due to its robustness. The standard k-e modal is based on the transport

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equation for turbulence kinetic energy (k) and dissipation rate (e). The transport equation for k-e model are as follows,

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial k}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon$$

2.2.1 Electromagnetic Stirring Forces

The electromagnetic stirring forces will be calculated by ABB metallurgy AB using the commercial software OPERA. The force density in the x, y and z-direction due to the electromagnetic stirrer will be provided by ABB in a CSV format. The forces will be interpolated into the mesh by User Defined Function code, UDF. The electromagnetic stirring force data provided is usually for a stationary melt in a ladle furnace and since in practice the electromagnetic stirrer is designed to provide a pulsating force field, a compensation factor is incorporated in the source term. A fully coupled electromagnetic stirrer meant that the stirrer would be operational when the flow velocity is developing and once the desired velocity as defined by the user is reached, then the force should pulsate in relation with the velocity to maintain the velocity at the desired range. The compensation factor is meant to provide the coupling is added to the source term UDF and the forces are regulation in real time with the simulation. The compensation factor is expressed as

$$\langle \vec{f} \rangle = \langle \vec{f}_0 \rangle \left(1 - \frac{\langle \vec{f}_0 \rangle \cdot \vec{v}}{|\langle \vec{f}_0 \rangle| v_{travelling\ wave}}\right),$$

where $v_{travelling\ wave}$ is the traveling wave speed of the stirrer, $v_{travelling\ wave} = 2\tau f$, τ is the pole pitch of stirrer, f is the frequency of stirrer, $\vec{v}$ is the speed vector of melt.

$$1 - \frac{v}{2\tau f}$$

Where,

v = speed of melt

τ = pole pitch of stirrer

f = frequency of stirrer

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3 Ladle model

The modelling activity is planned for Uddeholm 70 tons ladle. The ladle geometry is shown in figure 1. The geometry shows details from the ladle exterior which is negligible for modelling activity since the focus is mainly in the molten melt and the refractory zone .

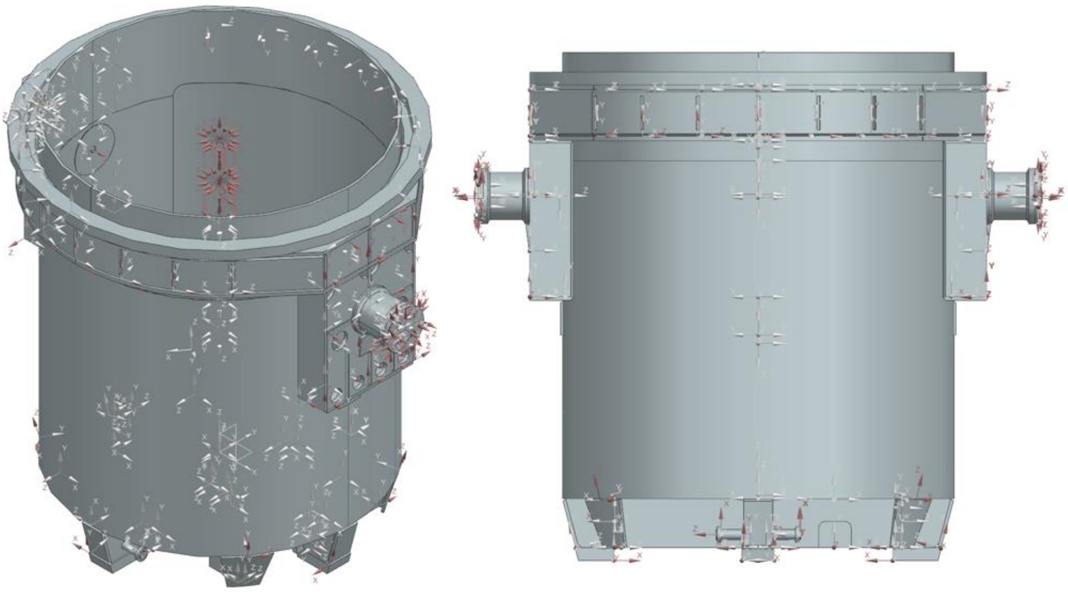

Figure 1. Uddeholm ladle

For the initial stage of modelling activity, an ideal ladle geometry of 70 tons is virtually constructed. The ladle geometry shows solid and liquid domain, where molten steel is liquid zone (red). The solid domain namely ladle refractory (yellow) and shell (brown) is included in the geometry. The concept to include ladle refractory zone is to calculate the wall stresses thereby evaluate the refractory wall wear.

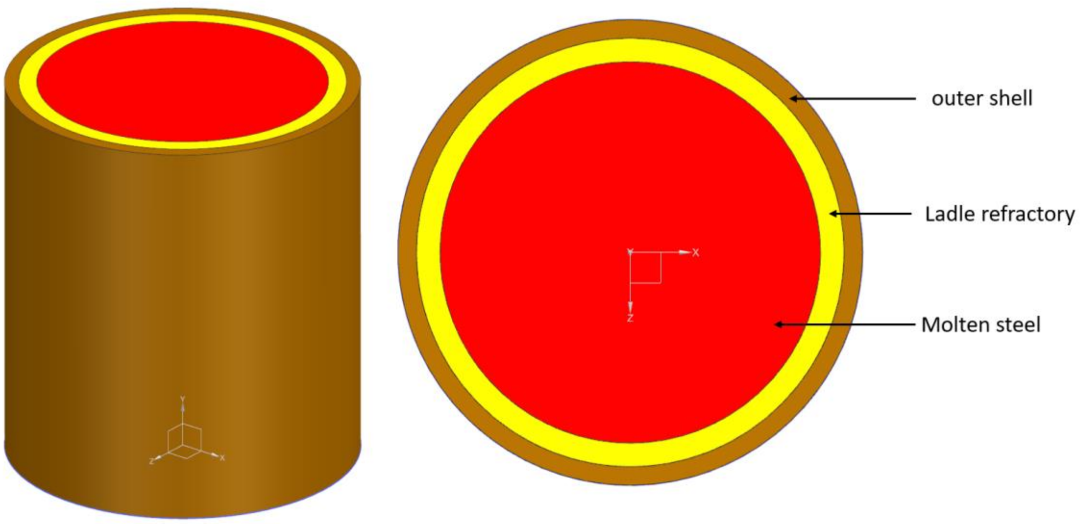

Figure 2. ladle model with ideal geometry

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