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A FREE SURFACE FINITE ELEMENT MODEL FOR MOULD FILLING PROBLEMS

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Abstract. The simulation of low Froude number mould filling problems on fixed meshes presents significant difficulties. As the Froude number decreases the coupling between the position of the interface and the resulting flow field increases. The usual two phase flow model provides poor results for such flow. In order to overcome the difficulties a free surface model [1] that applies boundary conditions at the interface accurately is used. By free surface model we understand that the influence of air on the molten metal is neglected. The particularity of the approach we use is that despite the domain is moving (since only the liquid is simulated) a fixed mesh is used. Mould filling problems borrowed directly from the foundry are presented. The position of the free surface is captured using the Level Set method.

A stabilized finite element method with standard trapezoidal rule time discretization is used to solve both the Level Set equation and the Navier Stokes equations. SUPG stabilization is applied to the Level Set equation. The Navier Stokes equations are stabilized using the Algebraic Sub-Grid Scales (ASGS) method that deals with convection-dominated flows and allows equal velocity-pressure interpolations (thus avoiding the need to satisfy the classical inf-sup condition). Equal order linear tetrahedral finite elements are used to discretize the complex tridimensional geometries found in mould filling problems.

Contrary to what one might intuitively think, we have observed that in mould filling problems, lower filling velocities typically lead to more complex simulations. The lower the Froude number, the higher the relative importance of the gravitational forces. Since the spatial distribution of the gravitational forces is determined by the position of the interface, the coupling between the position of the interface and the resulting flow increases as the Froude number decreases.

The method provides very good results for low Froude number flows thanks to a careful treatment of the elements cut by the front that allows to accurately impose the boundary conditions at the interface. In molten metal mould filling applications surface tension is usually negligible and therefore a zero traction boundary condition must be applied at the free surface. By enhancing the integration rules at the elements cut by the front and integrating only in the filled part, this natural boundary condition can be correctly applied at the interface, even if the interface does not coincide with element faces. This is the key ingredient of the formulation we propose.

In order to deal with a moving domain on a fixed mesh we use a FM-ALE approach [2]. It combines an ALE approach with a fixed background mesh onto which the results are projected at each time step. A simplified Eulerian free surface model that provides very similar results is also presented.

Straight out of the foundry examples where either the flow rate or the pressure is applied at the inlet of the mould are presented. The results can be used to improve the casting process. Regions with high velocities that can lead to premature wear of the mold can be predicted. The quality of the resulting piece can also be improved, for example, by determining regions of possible air entrapment.

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