Modelling of Solidification with Shrinkage in Vertical Shell Using Particle Method with Spring-Damp Interaction

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***Abstract*—Modeling of the solidification process of a shrinking material injected into a vertical shell is the main focus of this work. It is motivated by the problems in the filling processes of the explosive material in bullet or artillery shells where formation of void occurs. In this study, a particle method was employed to simulate the solidification process. A spring-damp interaction was introduced in order to flexibly create solid links for solidification of freely-moving fluid particles. The material properties in this paper mostly followed those of commercially-available paraffin wax. The phase of particle (i.e. liquid, mushy, and elastic solid) was categorized using the enthalpy method. The change of wax properties in the mushy zone (particle consists of liquid and solid parts) was assumed to be linear to the temperature. The transient numerical simulation was used to simulate the process of solidification with the contraction of material volume in the specified controlled boundary temperature. The numerical results showed the result of the developed model in capturing the shrinkage and formation of void in the example case. (*Abstract*)**

Keywords—Multiple particle simulation; Solidification; Heat transfer.

I. INTRODUCTION

Solidification in enclosures has received a lot of attention from researchers in the past decades. A considerable amount of numerical and experiment studies on this topic had been conducted [1–5]. For the studies of solidification in complex domain or with temperature dependent material properties, numerical methods are commonly used. However, for traditional mesh-based methods, it is typically difficult to implement in problems where material density or the computation domain significantly change during the simulation (large deformation).

Due to the limitation of traditional mesh-based methods which are based on Eulerian, particle methods based on Lagragian have attracted a lot of attention for free surface and moving boundary problems. The Smoothed Particle Hydrodynamics (SPH) and the Moving Particle Simulation (MPS) are popular particle methods that are widely used in various applications. The SPH is a complex method formulated for compressible flow. On the other hand, the MPS is a simple method similar to Finite Different Method (FDM) and developed for incompressible flow. Both SPH and MPS methods were also successfully implemented in the solid dynamics and solid-fluid interaction applications [6, 7].

In the present study, the Moving Particle Simulation (MPS) method is employed and modified to simulate the solidification process of an example material in a two-dimensional geometry to mimic filling processes of the explosive material in bullet or artillery shells. Since the properties of explosive materials cannot be disclosed, the properties of example material which mostly followed those of paraffin wax were used. Note that the properties of paraffin wax were followed because the material volume significantly changed during the phase-change and the shrinkage of material was the main interest of this work.

With an attempt to predict the filling results in the controlled room or shell temperature, the focus of this work was to develop a simulation method that results acceptable predictions within a short amount of time. This paper is organized as follows. First, related concepts and simulation process are described. Then, the implementation is shown. Finally, the numerical results are presented and discussed.

II. MPS METHOD

A. Governing Equation

For the solidification process, there are three main equations in order to represent fluid flow, solid motion, and heat transfer. For fluid, the flow is described by

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{u} + \vec{f} \quad (1)$$

where $u, \rho, P,$ and ν are the velocity (m/s), density (kg/m^3), pressure (kg/ms^2), and dynamic viscosity (m^2/s) of the particle, respectively. $\vec{f}$ is the acceleration due to external forces acting of the particle (including the gravitational acceleration, g)

For solid, the motion is described by

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla\sigma + \vec{f} \quad (2)$$