15th World Congress on Computational Mechanics (WCCM-XV)
8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII)
Virtual Congress: 31 July – 5 August 2022
S. Koshizuka (Ed.)

DEVELOPMENT OF MOLD FILLING PROCESS SIMULATION CONSIDERING AIR ENTRAINMENT USING SPH METHOD

NOBUKI YAMAGATA[1*] and MASAKAZU ICHIMIYA[2]

[1] Advanced Creative Technology Co., Ltd., 2-10-3 Kojimachi, Chiyoda-ku, Tokyo 102-0083, Japan, yamagata@actact.co.jp
[2] The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 Japan, ichimiya@n.t.u-tokyo.ac.jp

Key Words: *Particle Method, SPH, Die Casting, Air Entrainment, Mold Filling, OpenMP*

Abstract. *Die-casting is a casting method suitable for mass production because it can accurately form complicated shapes. However, when the mold is filled with the molten metal, casting cavities (gas porosity) are generated due to air entrainment, and the strength of the product varies. In this study, the mold filling process considering air entrainment in the die cast are simulated using the two-phase flow SPH method. And then, the behavior of air entrainment due to the filling of molten metal (Aluminum alloy), especially the efect of injection speeds are investigated. In concluson, it is possible to investigate the air entrainment behavior at the time of filling the molten metal and the flow behavior due to different filling speeds. In addition, to speed up the two-phase flow program by SPH method, a parallel algorithm using OpenMP is implemented.*

1 INTRODUCTION

Die-casting is a casting method suitable for mass production because it can accurately form complicated shapes. However, when the mold is filled with the molten metal, there is unsatisfactory performance that gas porosity are generated due to air entrainment, and the strength of the product varies. Recently, with the aim of improving the quality and production efficiency of castings including this air entrainment, there has been many studies of simulating the behavior of molten metal during filling and visualizing the state of gas entrainment using CAE.

In this study, the mold filling process considering air entrainment in the die cast are simulated using the two-phase flow SPH method, that can be applied to the mold flow including gas entrainment [1], [2]. Then, the behavior of air entrainment due to the filling of molten metal (Aluminum alloy), especially the efect of injection speeds are investigated. The particle model (number of particles: 270,000) that simplifies the 3D die-casting shape in the field is used in this simulation.

In addition, to speed up the two-phase flow program by SPH method, a parallel algorithm using OpenMP, which enables parallel calculation on a shared memory type machine, has been implemented.

2 GOVERNING EQUATIONS OF TWO-PHASE FLOW

The two-phase flow is considered in this study, and both phases obey the governing equations of a viscous Newtonian fluid [1], [2].

$$\frac{D\rho}{Dt} = -\rho\nabla \cdot \boldsymbol{u} \quad (1)$$

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

ρ: density
$\boldsymbol{u}$: velocity vector
p: pressure
ν: kinematic viscosity coefficient
$\boldsymbol{g}$: gravity
$\boldsymbol{f}$: surface tension

Water has a slight compressibility and is strictly weakly compressible. The weak compressibility method solves using NS equations and equations of state alternately. The following equation of state is used throughout this paper.

$$p = B\left[\left(\frac{\rho}{\rho_0}\right)^{\gamma} - 1\right] \quad (3)$$

Where, ρ_0: reference density and B is as follows:

$$B = \frac{\rho {c_s}^2}{\gamma} \quad (4)$$

For water or liquid metals we use γ=7, and for gas γ=1 respectively. The SPH used here is weakly compressible and is near the incompressible limit by choosing a sound speed. Consequently c_s, the speed of sound in the analysis, should be set about 10 times the maximum fluid velocity appearing in the analysis, not a physical value.

3 DIE-CASTING SIMULATION CONSIDERING AIR ENTRAINMENT

3.1 Analysis Model

In this application examples, the mold filling process considering air entrainment in the die cast are simulated using the two-phase flow SPH method described in session 1 [1], [2]. And the behavior of air entrainment due to the filling of molten metal (Aluminum alloy) is investigated.

The particle model that simplifies the 3D die-casting shape in the field is used in this simulation is shown in Figure 1. Total number of particles is 226,600, including initial air particles of 135,500. The particle length is 0.1cm.

And particles with a specified injection flow in continuously at the molten metal inflow gate is shown in Figure 2. The initial velocity of liquid Al alloy is 40m/sec and keeps constant during the filling process. In this simulation, 216 particles of liquid Al alloy are generated at each time step (Δt = 2.0 x 10-7sec) and injected in the Y-axis direction shown in Figure 2.

Figure 3 shows the outlet part in the particle model and the air particles flowing out of the mold are erased. The outlet part used in this simulation is larger than that of the actual die-cast in the field, however it is simplified as a region leading to the air vent part.

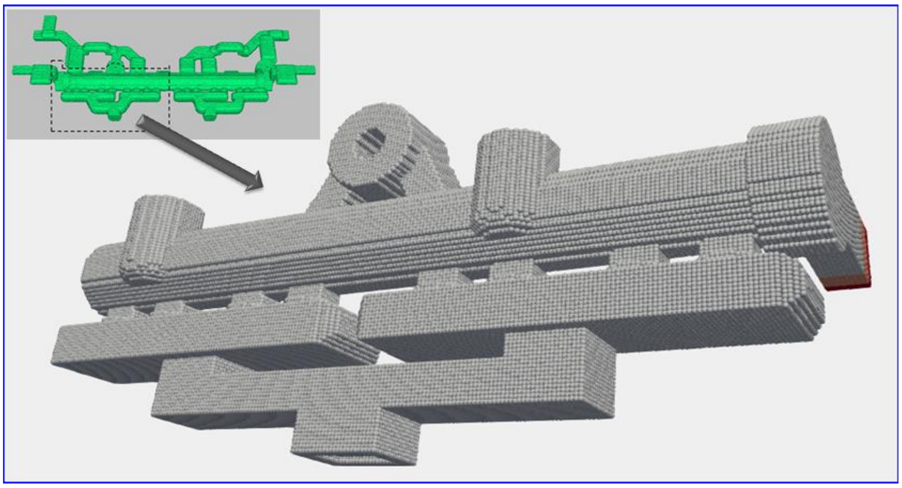

Figure 1: Analysis Model of Die-Casting

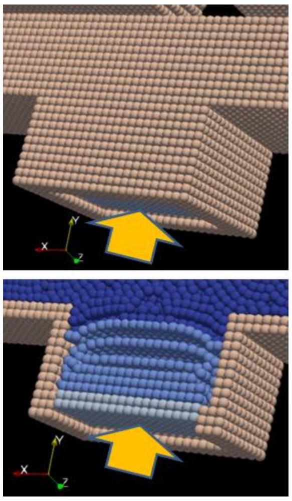

Figure 2: Inflow gate

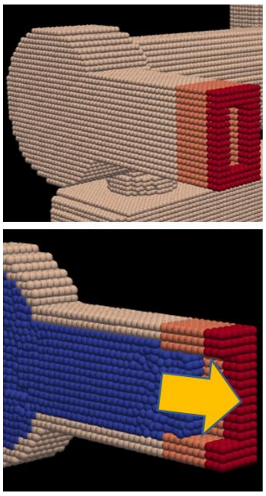

Figure 3: Outlet Part

3.2 Material Properties

The material properties used in this simulation is shown in Table 3. The initial velocity of liquid Al alloy is 40m/sec and keeps constant during filling process.

Table 3 Material Properties

Die-Cast	L=21.8cm, W=9.9cm, H=6.2cm, t=0.2cm	
Gas	Density Kinematic Viscosity Coefficient Initial Pressure	1.293Kg/m3 1.38x105m2/s 1.013Pa
Liquid Al Alloy	Density Kinematic Viscosity Coefficient Surface Tension	2500Kg/m3 1.0x106m2/s 0.9N/m

3.3 Results and Discussions

Figure 4 shows the results of the mold filling process simulation with injection velocity of 40m/sec using the two-phase flow SPH method. According to the filling flow process, it can be confirmed that from the start of injection, the liquid Al alloy splits to the left and right in the die-cast, the eight entrances pass through the narrow gate and then flow toward the outlet part, and airs remain at t=11msec (c).

Figure 5 shows the flow of liquid Al alloy through the gate. The maximum flow velocity occurs at the left gate at time t = 15msec, but occurs at the right gate at t = 90msec when the time has passed. The values were 43.2 m / sec and 37.8 m / sec, respectively.

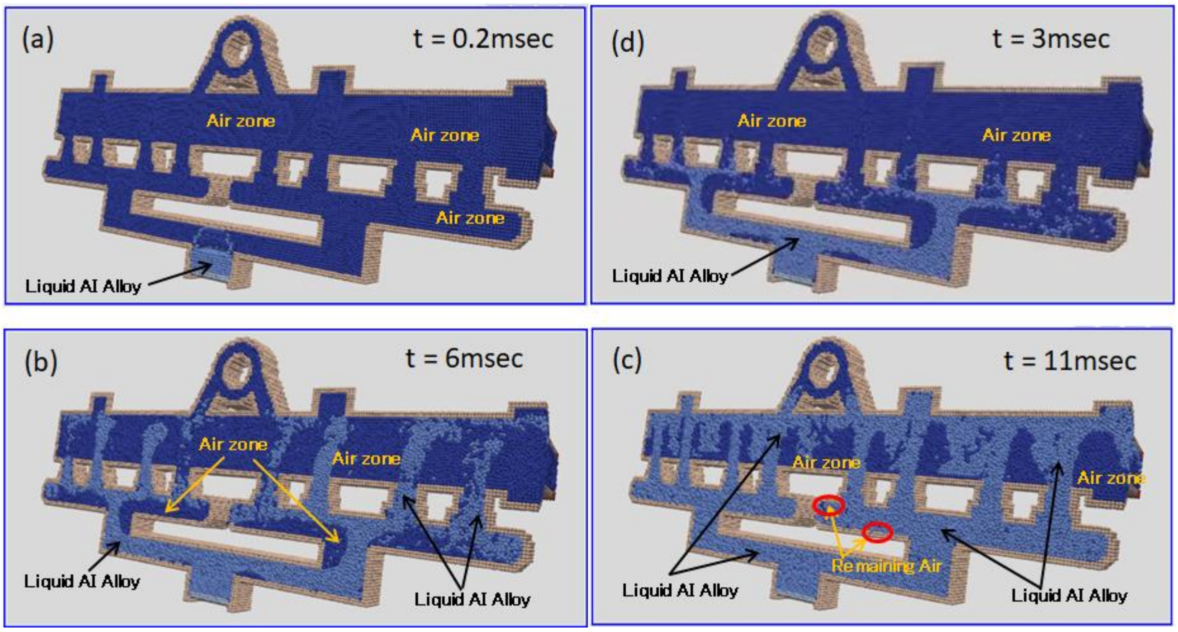

Figure 4: Particle flow during filling the liquid Al alloy in the mold (V=40m/sec)
((a) at t=0.2msec, (b) at t=3msec, (c) at t=6msec, (d) at t=11msec)

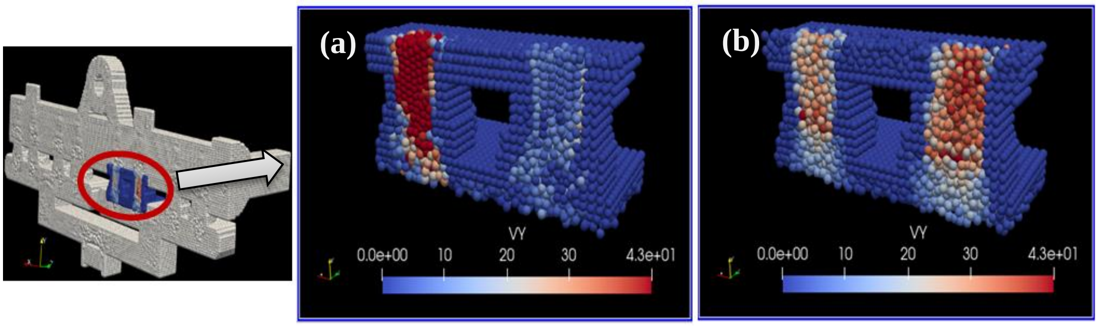

Figure 5: Flow of liquid Al alloy through the gate (a) at t=15msec, (b) at t=90msec

Next, in order to investigate the state of Air Entrainment, we have compared the flow behavior due to 4 different injection velocities, that are, (a) 40m/sec, (b) 25m/sec, (c) 12.5m/sec and (d) 25m/sec in case that air is not contained. The results are shown in Figure 6. Comparing (b) and (d), in the case of (d), the flow of Liquid Al alloy is sequentially filled from the injection gate through eight gates to the upper region, however, in the case of (d), it can be seen that some air regions remain at t = 11.2 msec (Stage C).

Then, we have compared the flow of the liquid Al alloy with the speeds of (a), (b), and (c). In the slow speed (c), the liquid Al alloy is slowly filled up to 8 gates over time. However, in (b) and (a) where the speeds become faster, the existence of air, that is air entrainment, can be confirmed at t = 11.2 msec and t = 7 msec, respectively.

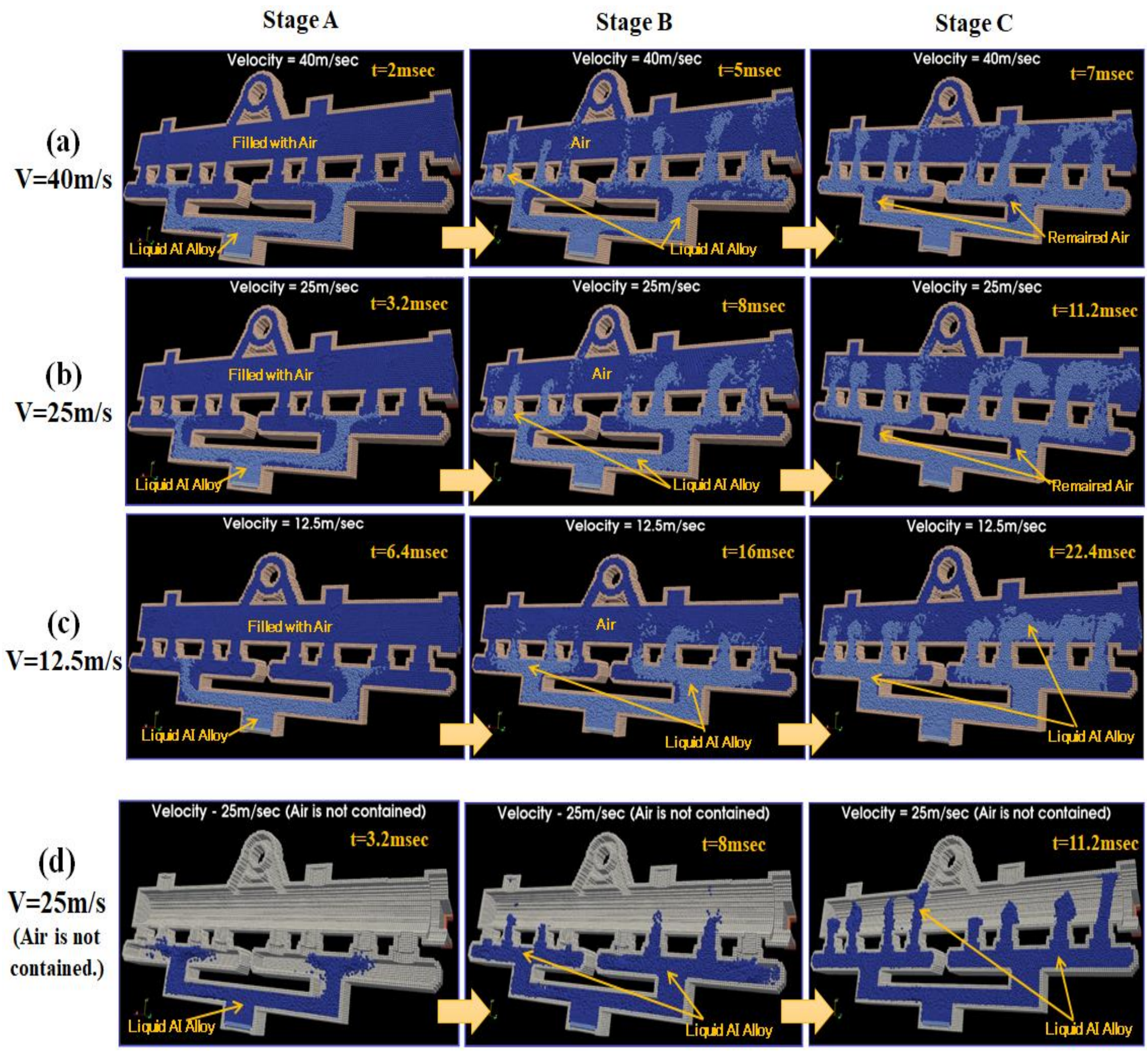

Figure 6: Particle flow during filling the liquid Al alloy in the mold
(a) V=40m/sec, (b) V=25m/s, (c) V=12.5m/s, (d) V=25m/s in case that air is not contained
The stage A B and C are classified groups by the inflow volume of 694.4cm3, 1736.0cm3 and 2430.4cm3 respectively.

4 PARALLEL CALCULATION

OpenMP can be parallelized by inserting directives such as ¡$OMP Use omp_lib and ¡$ call omp_set_num_threads(4). In this study the CPU time of the two-phase flow SPH program, developed using Fortran language, has been improved by OpenMP parallel processing. Table 2 shows the computational perfomance. As a results, we were able to achieve more than 3 times faster parallel performance than single CPU on a PC with 4 cores.

Table 2: Computational Performance

Type	In case of V=40m/s	V=25m/s (Air in not contained)	PC Environment
Single CPU	95.0hours	66.7 hours	OS: 64bit Windows10 CPU: Inteli7-7700 3.6GHz RAM:32GB
Parallel Process (No. of Cores=4)	27.25hours	23.8 hours	

5 CONCLUSIONS

(1) The mold filling process considering air entrainment in the die cast are simulated using the two-phase flow SPH method developed in this study. Then, the behavior of air entrainment due to the filling of liquid Al alloy especially the efect of injection speeds were investigated in this paper.

(2) It can be confirmed that the air entrainment behaviors during filling the liquid Al alloy are visualized and investigated.

(3) By the implementation of parallel calculaton, we were able to achieve more than 3 times faster computational performatnce on a standard PC with 4 cores.

REFERENCES

[1] Ichimiya M., Development of Flow Simulation considering Gas entrainment using Particle Method. Proc., the 169th Casting Engineering Conference, 23, JFES (May,2017).

[2] Ichimiya M., Yamagata N., Development of Two-Phase Flow Simulation using SPH Method, WCCM, Yokohama, July-August (2022) to be published.

[3] Ichimiya M., Yamagata N., Marjierson W.,Development of 3D Flow Simulation considering Gas entrainment using Particle Method. Proc., the 170th Casting Engineering Conference, 16, JFES (September,2017).