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DIRECT OBSERVATION AND SIMULATION OF LADLE POURING AND PLUNGER ADVANCING BEHAVIOURS IN DIE CASTING PROCESS

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Abstract. The ladle pouring and plunger advancing processes are parts of the die casting which has advantages of high speed, good quality and mass production. The molten metal is quickly poured into the sleeve by tilting the ladle, and immediately injected into the die cavity with high speed and high pressure by advancing the plunger. Since the entrapment of air and the generation of solidified layer in the ladle pouring may cause the defects of cast products, it is necessary to simulate the ladle pouring behavior. In the present study, the pouring experiment into the sleeve using die casting aluminum alloy JIS-ADC12 are carried out to observe the flow behavior by tilting the ladle. Further the molten aluminum alloy is injected to the cavity from the sleeve by advancing the injection plunger. Dynamics of the molten aluminum alloy is influenced by the oxide film. The flow behaviors in ladle pouring and plunger advancing of molten aluminum alloy are simulated using "COLMINA CAE", which is the casting analysis software by particle method SPH. The experiments and simulation are executed varying with the shot time lag, which is the interval from finish of ladle pouring to start the plunger advancing, and plunger speeds. Wave behavior obtained by simulation is almost agreed with the actual phenomena. Flow and heat transfer simulation using SPH method with a function of the oxide film is effective method that ladle pouring and plunger advancing of molten aluminum alloy with free surface flow can be simulated accurately.

1 INTRODUCTION

The die casting process has advantages of high speed, good quality and mass production [1][2]. The process consists of the ladle pouring and the plunger advancing processes. The molten metal is quickly poured into the sleeve by tilting the ladle, and immediately injected into the die cavity with high speed and high pressure by advancing the plunger. During the ladle pouring and plunger advancing processes, the entrapment of air and the generation of solidified layer in the shot sleeve are occurred. They inflow to the cavity and causes to the defects [3][4]. In order to determine the operating conditions of the ladle pouring and plunger advancing processes, it is very useful to do the process simulation for die casting. However, it is necessary to execute the particle-based simulation since the ladle pouring and the plunger advancing processes are moving boundary problem [5]-[7].

In the present study, the ladle pouring and plunger advancing experiments using die casting aluminum alloy are carried out to observe the flow behavior. Dynamics of the molten aluminum alloy is influenced by the oxide film. The flow behaviors in ladle pouring and plunger advancing of molten aluminum alloy are simulated using "COLMINA CAE" [6][7], which is the casting analysis software by particle method SPH. The experiments and simulation are executed varying with the shot time lag, which is the interval from finish of ladle pouring to start the plunger advancing, and plunger speeds.

2 EXPERIMENTAL

2.1 Experimental apparatus

Figure 1 shows the experimental apparatus in the present study. The apparatus consists of a tilting device of ladle, a ladle, a glass tube sleeve made of quartz glass, a virtual cavity, an electric actuator, and a video camera. The electric actuator is connected to the PC, and the plunger can be moved forward and backward by using dedicated software. The glass tube sleeve is a cylindrical shape with an inner diameter of 41 mm, a thickness of 2 mm, and a length of 250 mm. The glass tube sleeve has an inlet of 30 x 80 mm to allow pouring of aluminum alloy.

2.2 Experimental conditions and procedures

Table 1 shows the experimental conditions for ladle pouring and plunger advancing experiments. The aluminum alloy of JIS-ADC12 which is a die casting material is used to test material. The amount mass is 300g for the filling ratio of tube sleeve of 33.7%.

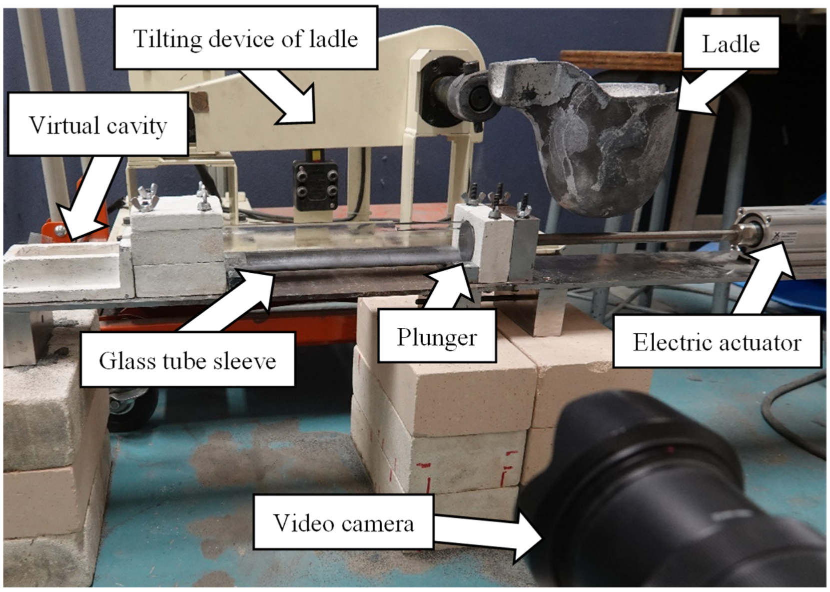

Figure 1: Experimental Apparatus.

In the experiment, the molten metal with temperature of 680°Cis poured by ladle tilting from the ladle to the sleeve. The ladle tilt time is 5.0s with speed of 0.28rad/s. After that the plunger advancing is started. The shot time lag is interval time between the end of ladle tilting and the begin of plunger advancing. A total of four conditions are performed: the shot time lags of 1 and 2s, and the plunger advancing speeds of 120 and 180mm/s. The wave behaviors of molten metal are captured using a video camera of 120fps from forward and top side.

Table 1: Experimental Conditions for Ladle pouring and Plunger advancing.

Test material	Aluminum Alloy, JIS-ADC12
Pouring temperature [K(°C)]	853 (680)
Amount mass of materials [g]	300
Ladle tilt time [s]	5.0
Ladle tilting speed [rad/s]	0.28
Shot time lag [s]	1.0, 2.0
Plunger advancing speed [mm/s]	120, 180

Figure 2 shows the wave behavior of molten aluminum alloy in the shot time lag section, varying the shot time lag. The left side of the glass tube sleeve is the “biscuit side” and the right is the “plunger side”. The time of 0 shown in Fig.2 indicates the end of ladle tilting process. Although the ladle tilting process finished the molten metal pouring continues till about 0.5s. The wave behaviors until 1.0s are the same between shot time lag 1 and 2s. At the time of 1.0s, the liquid level on “biscuit side” and “plunger side” is high, and level of sleeve center is low likes a valley shape. As the shot time lag becomes longer to 2.0s, the liquid surface becomes milder and smoother. The liquid levels of “biscuit side”, center of sleeve, and “plunger side” are almost the same. This is good condition in terms of wave height. However, the lapse of time is not necessarily good because the molten metal temperature drops and the cold flakes generated in the shot sleeve due to heat extraction.

Figure 3 shows the comparison of wave behavior of molten aluminum alloy varying plunger advancing speed in the case of the shot time lag of 2.0s. The wave behaviors are shown in the same position of plunger tip. The liquid level in front of the plunger tip rises when the plunger tip moves to 30 mm. Then, when it moves to 90mm, the wave moves to “biscuit side” faster than the plunger tip movement. Comparing the position of maximum wave height at the plunger tip position of 150mm, the difference is observed varying the plunger advancing speed. In the case of the plunger advancing speed of 120mm/s it is “biscuit side” and the other case is “plunger side”. Further the closed loop of air is generated by the molten metal and the plunger tip. This behavior is no good and it takes to induce defects of castings. On the other hand, the air in the sleeve is ejected first, and then the molten metal is ejected in the case of 180mm/s.

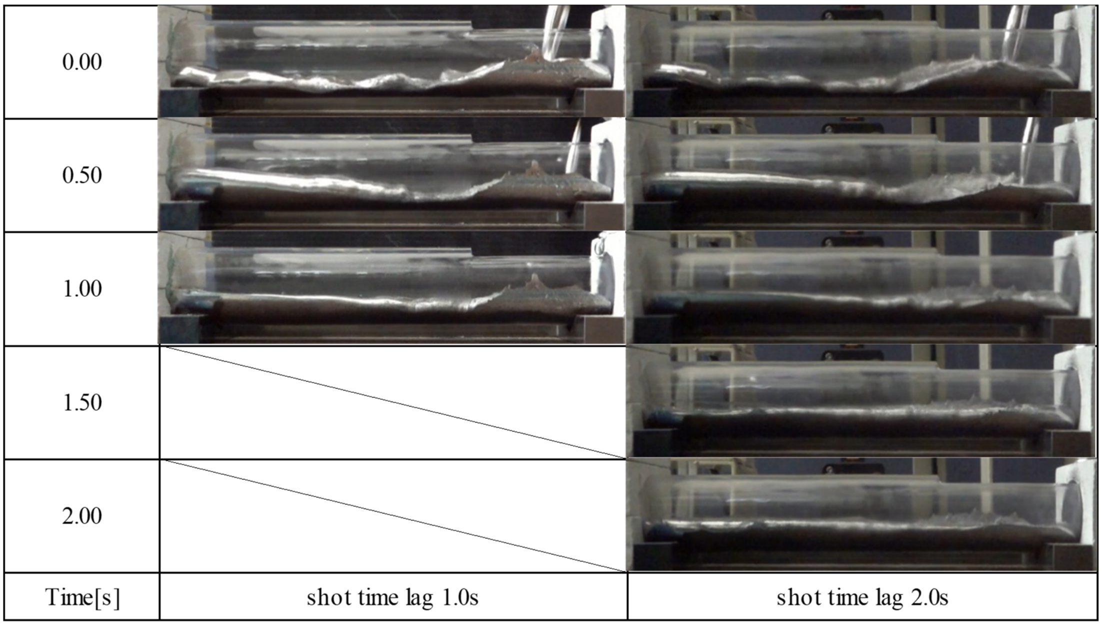

Figure 2: Wave behavior of molten aluminum alloy in the shot time lag section.

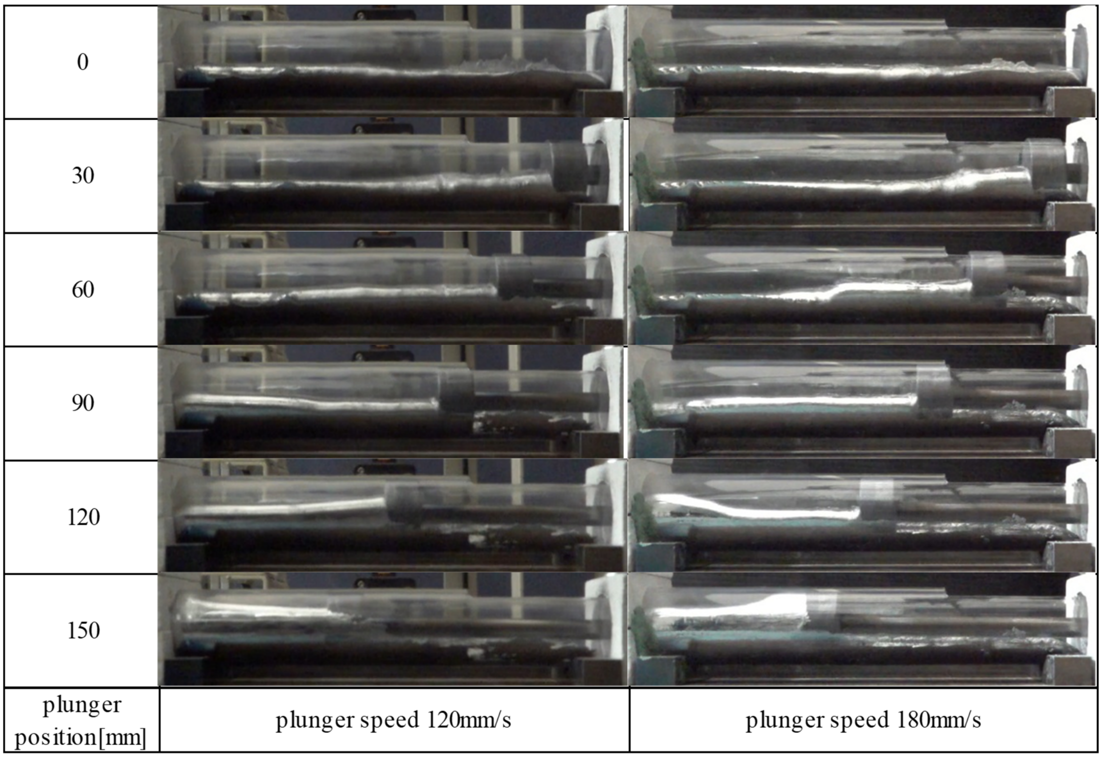

Figure 3: Comparison of wave behavior of molten aluminum alloy varying plunger advancing speed the case of the shot time lag of 2.0s.

3 SPH SIMULATION

3.1 Calculation conditions

The flow behaviors in ladle pouring and plunger advancing of molten aluminum alloy are simulated using "COLMINA CAE" [6][7], which is the casting analysis software by particle method SPH. The calculation conditions are shown in Table 2. Table 3 shows the physical properties of aluminum alloy of JIS-ADC12. Table 4 shows the oxide film parameters of COLMINA [7].

Table 2: Calculation Conditions.

SPH software	COLMINA CAE
Particle size [mm]	1.0
Total number of particles	1,360,000
Influence radius	3.0 times of particle size
Parameter for Sonic Speed [m/s]	20

Table 3: Physical properties of aluminum alloy of JIS-ADC12.

Density [kg/m3]	2480(Liquid phase), 2680(Solid phase)
Specific heat [J/(kg・K)]	1080(Liquid phase), 960(Solid phase)
Thermal conductivity [W/(m・K)]	96(Liquid phase), 237(Solid phase)
Latent heat [J/kg]	396800
Viscosity [Pa・s]	2.728×10^{-3}
Surface tension [N/m]	0.886

Table 4: Oxide film parameters in COLMINA.

Thickness of oxide film [μm]	0.1
Viscosity of oxide film [Pa・s]	27.28
Breakdown pressure of oxide film [Pa]	2000
Regeneration time of oxide film [s]	0.02

3.2 Comparison of experimental and analytical results

Figure 4 shows comparison of wave behavior in the case of shot time lag of 1.0s and plunger advancing speed of 120mm/s. The front views of wave behavior are shown from the begin of ladle tilting (t=0) to the end of plunger advancing (t=8s). It is the state of the glass tube sleeve filled by molten aluminum alloy. Figure 5 shows maximum wave height in sleeve during ladle tilting and plunger advancing in the case of the shot time lag 1.0s and plunger advancing speed of 120mm/s. From these figures, the wave behaviors obtained by simulation are similar to the experiments. This is a result of COLMINA's oxide film model functioning effectively. However the oxide film parameters are not completely tuned for JIS-ADC12 and more moderate tuning will give better results.

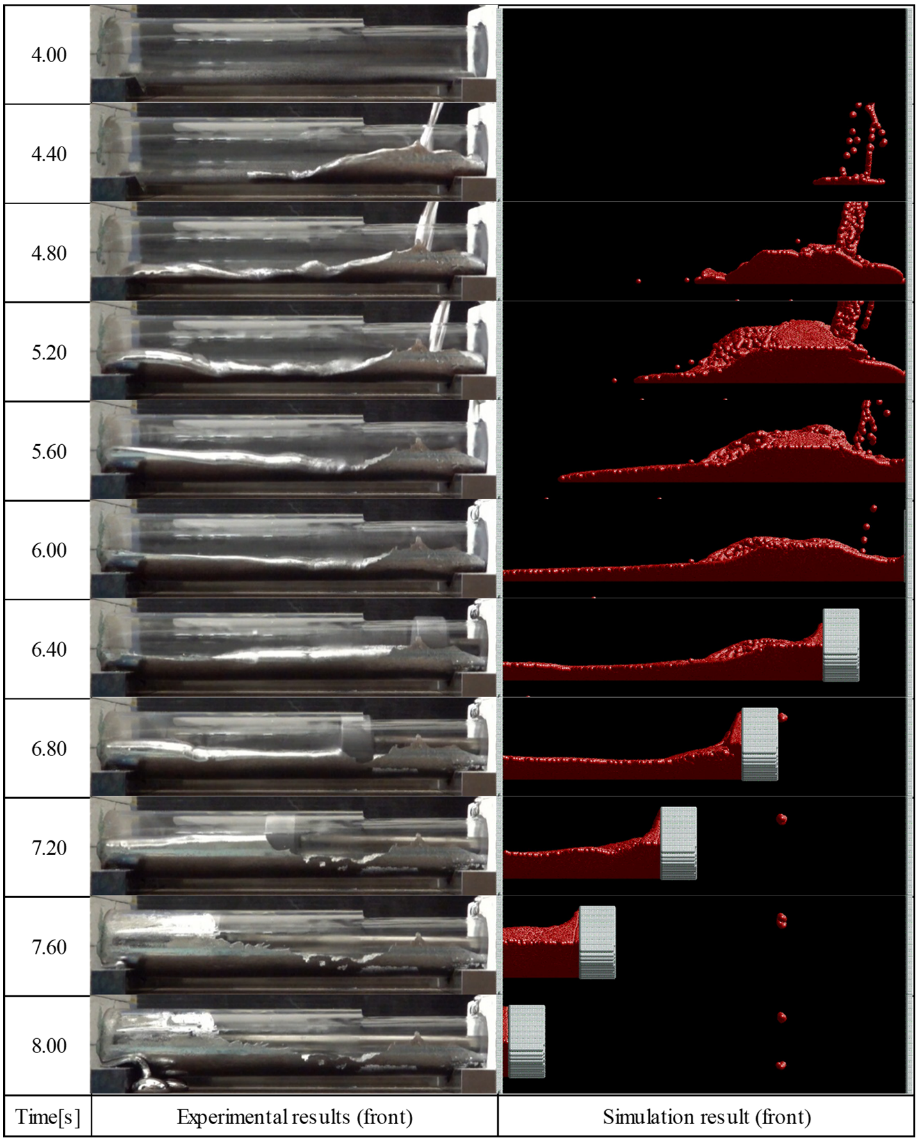

Figure 4: Comparison of wave behavior in the case of shot time lag of 1.0s and plunger advancing speed of 120mm/s.

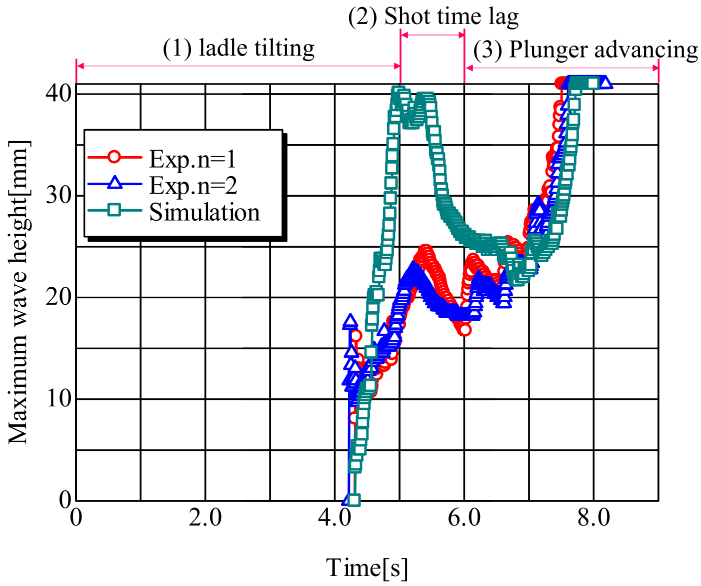

Figure 5: Maximum wave height in sleeve during ladle tilting and plunger advancing in the case of the shot time lag 1.0s and plunger advancing speed of 120mm/s.

4 CONCLUSIONS

The observation of the wave behavior of molten aluminum alloy during the ladle pouring and plunger advancing, and the simulation using particle-based SPH software "COLMINA CAE" are carried out in the present study.

1) The wave behavior became smoother by increasing the shot time lag. Although this is good condition in terms of wave height, the lapse of time is not necessarily good because the molten metal temperature drops and the cold flakes generated in the shot sleeve due to heat extraction.
2) Varying the plunger advancing speed, the behavior of trapping air inside the glass tube sleeve is observed. It is necessary to investigate the appropriate plunger advance speed.
3) The wave behaviors obtained by simulation are similar to the experiments. It indicates the oxide film model functioning effectively. More moderate tuning for oxide film parameters will give better results. It will be possible to determine for injection conditions that can suppress defects.

REFERENCES

[1] Japan Foundry Engineering Society: “Die casting”, Research Report No.91, (2003), p.1

[2] Y. Mochida, A. Hasuno, M. Kazama, T. Suwa and Y. Maeda: “Flow analysis of thin-wall die-cast products by particle method”, Journal of Japan Die casting Congress, (2018), pp.107-110

[3] H. Iwahori, K. Tozawa, T. Asano, Y. Yamamoto, M. Nakamura, M. Hashimoto and S. Uenishi: “Properties of scattered structured included in aluminum die castings”, Journal of Japan Institute of Light Metals, 34(1984), pp.525-530

[4] Y. Maeda and H. Nomura: "Numerical Experiment of Cold flakes Behavior in Shot Sleeve of Aluminum Alloy Die casting", Journal of Japan Foundry Engineering Society, 78(2006), pp.654-660 D.O.I. 10.11279/jfes.78.654

[5] T. Sugihara and Y. Maeda: "Simulation of Thermal and Fluid Flow with Wave in Ladle pouring for Die Casting", J. Japan Foundry Engineering Society, 92(2020), 6, pp.272-277 D.O.I. 10.11279/jfes.92.272

[6] M. Kazama, T. Suwa, and Y. Maeda: "Modeling of Computation of Molten Aluminum Alloy Flow with Oxide Film by Smoothed Particle Hydrodynamics", J. Japan Foundry Engineering Society, 90(2018), 2. pp.68-74 D.O.I. 10.11279/jfes.89.389

[7] T. Suwa, M. Kazama, K. Hatanaka, K. Ogasawara and Y. Maeda: "Development of Numerical Simulation model for Oxide Film and Air Inclusion Defects Using SPH Method and its Applications", J. Japan Foundry Engineering Society, 92(2020), 6, pp.285-289 D.O.I. 10.11279/jfes.92.285

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