VIII International Conference on Particle-Based Methods
PARTICLES 2023
U. Perego, M. Cremonesi, A. Franci (Eds)

EXAMINATION OF VARIABLE TILTINNG SPEED ON FLOW BEHAVIOUR DURING LADLE POURING IN DIE CASTING USING SPH SIMULATION

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Abstract: Disturbance of the molten metal flow during ladle pouring before the plunger advancing in the aluminium alloy die casting process can cause entrapment defects of air and oxide film. Slow pouring to control the turbulence of the flow front reduces productivity due to increased cycle time. Further, the risk of cold flake formation increases caused by large temperature drops in accordance with the long cycle time. On the other hand, rapid pouring is desired to improve productivity, but the risk of air entrapment increases. Therefore, quick and quiet pouring is desired in the ladle pouring process.

In the present study, we focus on variable tilting speed as a method to achieve good ladle pouring. The effects of variable ladle tilting speed and switching time on the wave behavior of molten metal are investigated in visualization experiments and simulations. The flow behaviours in ladle pouring are simulated using "COLMINA CAE", which is the casting analysis software by particle-based SPH method. Furthermore, the plunger advancing process is also examined. From the simulation results, the variable tilting speed from fast to low can suppress the rise of the maximum wave height of molten aluminium alloy. However, the pouring completion time is longer. Further, the falling position of molten metal poured from the ladle varied with changing tilting speed. And then, the wave height is influenced not only by ladle pouring but also by the plunger advancing process. These trends of wave behaviour obtained in the simulation are similar to that of the actual phenomenon. Therefore, the present simulation method can accurately estimate the ladle pouring process and plunger advancing process. So, casting CAE is an effective tool for exploring die casting conditions.

Keywords. Aluminium Alloy, Ladle Pouring, Tilting Speed, Wave Behaviour, Oxide Films

1 INTRODUCTION

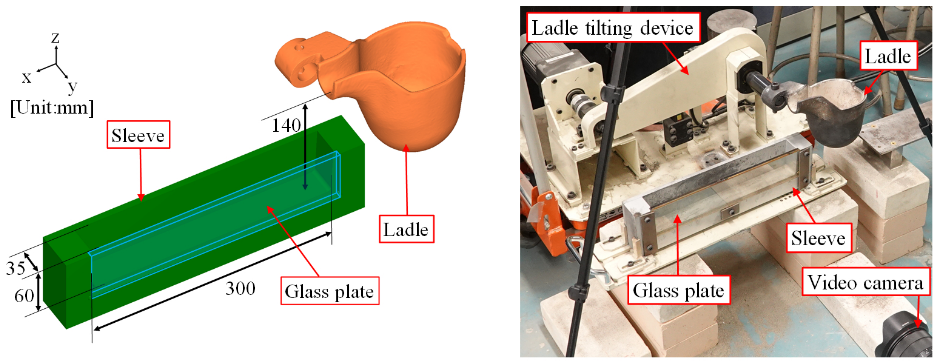
The die casting process is a casting method in which molten metal is filled into a mold at high speed and high pressure. Molten metal is poured into the sleeve by tilting the ladle and into the cavity by advancing the plunger. In ladle pouring, air entrainment due to turbulence in the flow front [1],[2] and the formation of cold flakes due to a drop in molten metal temperature [3],[4] are causes of defects. They inflow into the cavity and cause defects [5]-[8]. Therefore, quick and quiet pouring is desired in the ladle pouring process. Simulation is an important tool in the search for ideal ladle pouring conditions. However, to reproduce the flow behavior of aluminum alloys in simulations, it is necessary to take oxide films into account [8],[9]. Thus, we have developed an oxide film model in “COLMINA CAE”, which is the casting analysis software by particle-based SPH (Smoothed Particle Hydrodynamics) method [10]-[13].

In this study, the effect of changing the ladle tilting speed from high to low during pouring is investigated to control the liquid level rise during ladle pouring. Varying the switching time and the tilting speed of the low-speed section are examined. Further, how waves generated by ladle pouring behave during plunger advancing is also investigated by simulation and experiment.

2 LADLE POURING SIMULATION

2.1 Analysis model and calculation conditions

Figure 1 shows an overview of the analysis model made by the visualization experimental apparatus [9],[10]. The analysis model consists of a ladle, sleeve ($L300 \times W35 \times H60mm$), and glass plate. The ladle height is 140mm from the sleeve.



(a) Analysis Model. (b)Experimental apparatus.

Figure 1: Analysis model and experimental apparatus.

The calculation conditions are shown in Table 1. Aluminum alloy JIS-ADC12 is used as the test material. The simulation uses particle-based SPH software ”COLMINA CAE”. The particle size is set to 1.0mm and the radius of influence is set to three times the particle size. COLMINA CAE uses the explicit weakly compressible SPH method. Table 2 shows the physical properties of JIS-ADC12 aluminum alloy.

When the mass of molten metal inside the sleeve is 675g, the sleeve filling rate is 39.3%. The ladle and sleeve are set at 300℃ to prevent a rapid temperature drop of the molten metal.

Table 1: Calculation conditions.

Test material	Aluminum Alloy, JIS-ADC12
Amount mass of materials	675g
Pouring temperature	700℃
SPH software	COLMINA CAE
Particle size	1.0mm
Total number of particles	1,405,441
Influence radius	3.0mm
Parameter for Sonic Speed	20m/s

Table 2: Physical properties of aluminum alloy of JIS-ADC12.

Phase	Liquid phase	Solid phase
Density	2480 kg/m^3	2700 kg/m^3
Specific heat	1080 J/(K·kg)	960 J/(K·kg)
Thermal conductivity	96 W/(K·m)	237 W/(K·m)
Latent heat	396800 J/kg	-
Viscosity	2.728×10^{-3} Pa·s	-
Surface tension	0.886 N/m	-

Table 3: Ladle tilting condition of speed change of the low-speed section.

Ladle tilting speed of high-speed section	0.66rad/s
Ladle tilting speed of low-speed section	0.16, 0.21, 0.26, 0.31, 0.36, 0.41rad/s
Switching time	1.3s

2.2 Ladle tilting conditions

Two kinds of ladle tilting conditions are investigated. One is the speed change of low-speed section and the other is the switching time change from high-speed to low-speed. Firstly, Table 3 shows the ladle tilting condition of speed change of the low-speed section. At the switching time of 1.3s when molten metal begins to outflow the ladle, the ladle tilting speed, the tilting speed is switched from the high speed of 0.66rad/s to a low speed. The ladle tilting speed of the low-speed section is varied to 0.16, 0.21, 0.26, 0.31, 0.36, and 0.41rad/s. Table 4 shows the ladle tilting condition of switching time change from high-speed to low-speed. The ladle tilting speed of the high-speed section is 0.66rad/s and the low-speed section is 0.26rad/s. The switching time from high-speed to low speed is varied to 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, and 1.7s.

Table 4: Ladle tilting condition of switching time change from high-speed to low-speed.

Ladle tilting speed of high-speed section	0.66rad/s
Ladle tilting speed of low-speed section	0.26 rad/s
Switching time	0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7s

2.3 Evaluation of wave height

Figure 2 shows the illustration of the evaluation of wave height generated by pouring. The maximum wave height is measured to the maximum height of the free surface of the molten metal from the bottom of the sleeve using the frontal image at 0.01s time step.

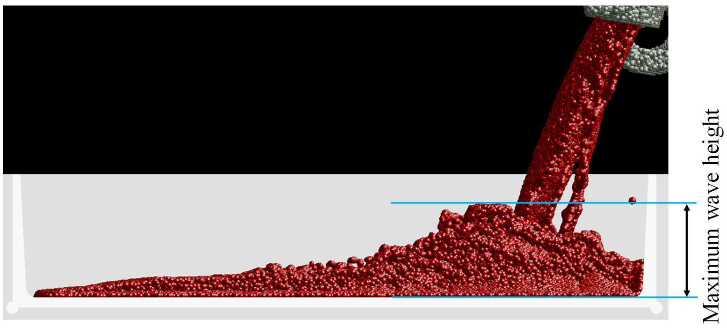


Figure 2: Illustration of the evaluation of wave height generated by pouring.

2.4 Wave simulated by COLMINA CAE

Figure 3 shows the dynamic behaviours of maximum wave height under the ladle tilting condition of speed change of the low-speed section shown in Table 3. The time 0s means the start time of ladle tilting. In the case of constant 0.66rad/s of the ladle tilting speed, maximum wave height rises rapidly from 1.4s at the start of pouring, and a peak is observed at 2.1s. Then, the maximum wave height is lower and pouring is finished in about 2.6s. For example, in the case of the tilting speed change from 0.66rad/s of the high speed to 0.26rad/s of the low speed, the rise in maximum wave height at the early 1.6s of pouring is the same, but the rapid rise in the maximum wave height thereafter is suppressed. Since the tilting speed is changed to low speed, the pouring finishing time is longer than in the constant case. The results of other conditions are the same trend.

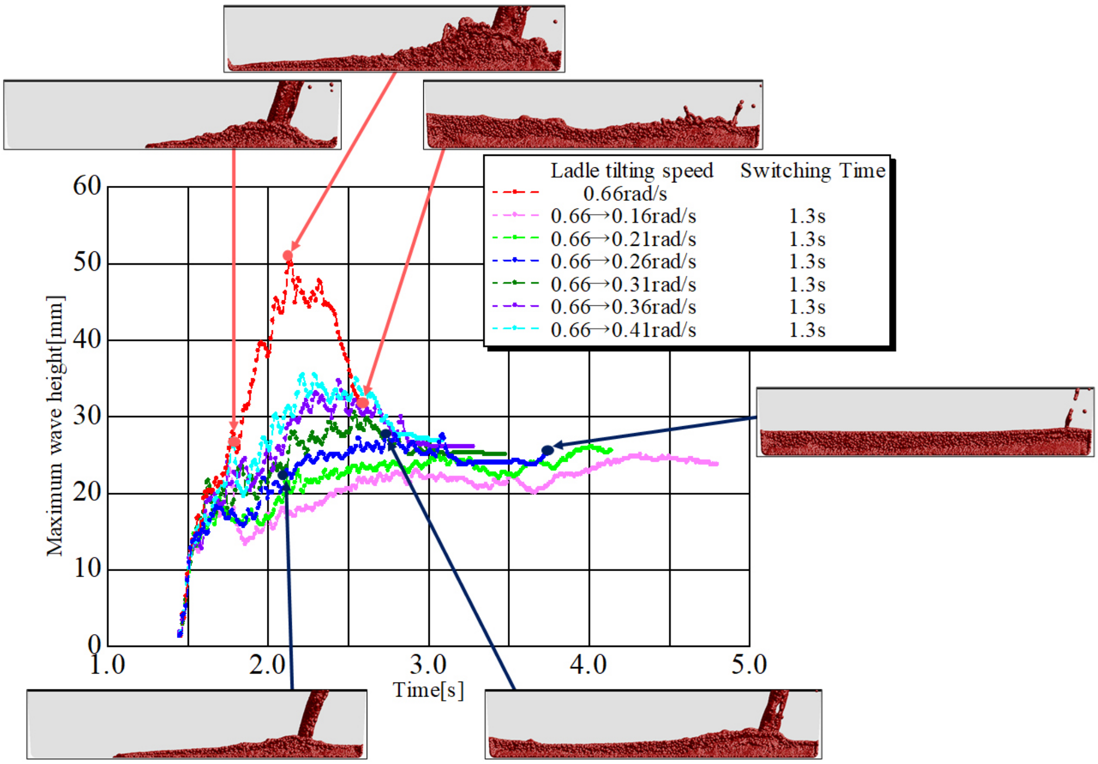


Figure 3: Dynamic behaviours of maximum wave height under the ladle tilting condition of speed change of the low-speed section.

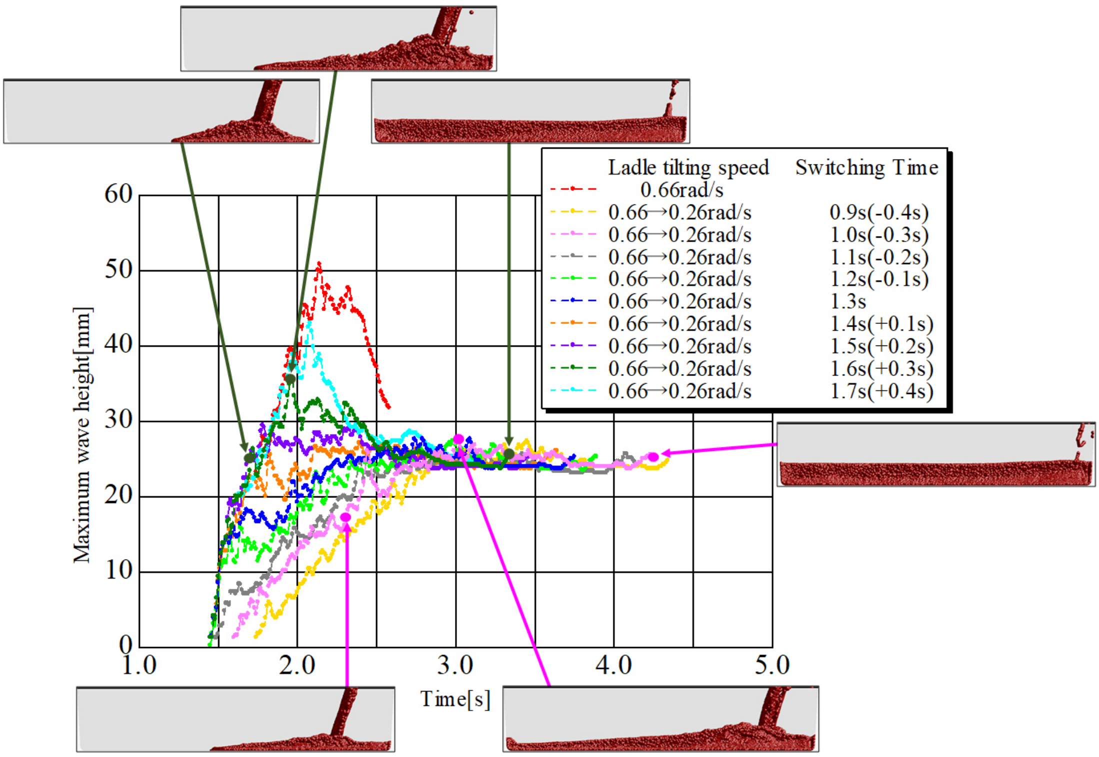


Figure 4: Dynamic behaviours of maximum wave height under the ladle tilting condition of switching time change from high-speed to low-speed.

Figure 4 shows the dynamic behaviours of maximum wave height under the ladle tilting condition of switching time change from high-speed to low-speed shown in Table 4. In the case of the switching time of 1.0s, which is 0.3s before the molten metal begins to outflow the ladle, the rise in maximum wave height from the start of pouring is slower than in the constant case, and the peak of maximum wave height is not observed and is suppressed. However, this condition is undesirable because the finishing time of pouring is very late about 4.2s, decreasing the temperature of molten metal and increasing the risk of cold flakes. In the case of the switching time of 1.6s, which is 0.3s after the molten metal begins to outflow the ladle, the dynamic behaviour in the early stage of pouring is the same as the constant case. The wave height suppression effect is observed after 2.0s, when the maximum wave height rises to some extent, but the finishing time of pouring is delayed. Then, this condition is also undesirable. From these above, it is better that the switching time of the ladle tilting speed is at the same time as or slightly before the molten metal begins to outflow the ladle.

2.5 Experimental verification

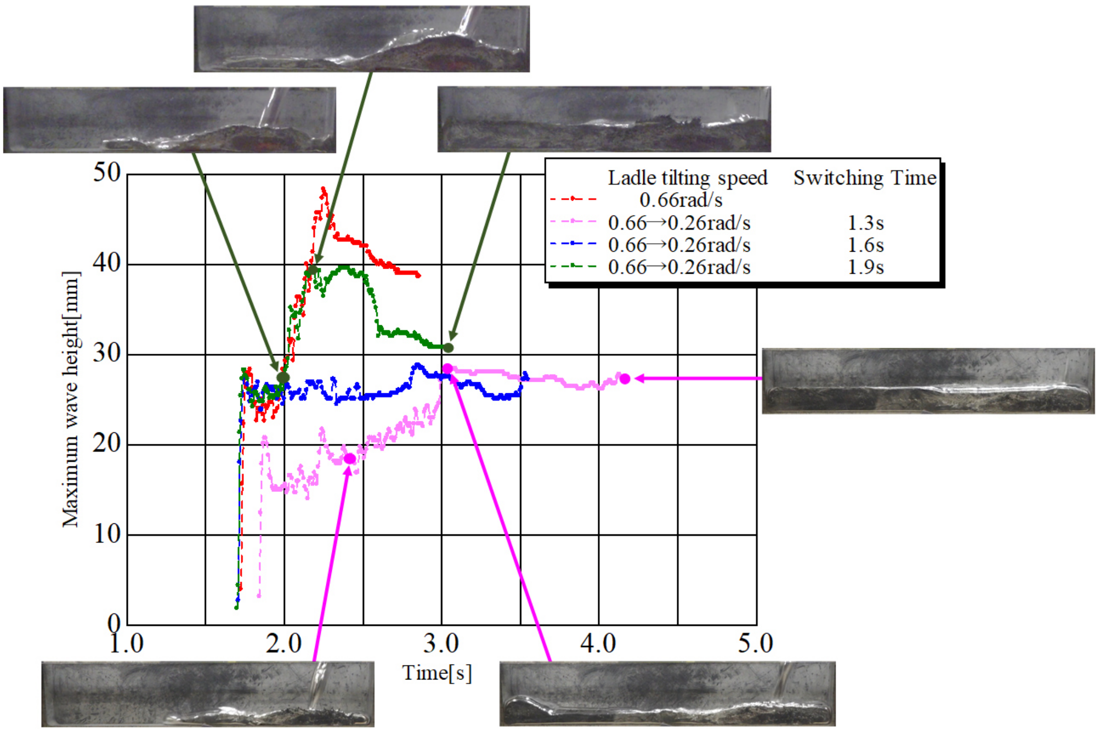


Figure 5: Dynamic behaviours of maximum wave height in the experiment.

The calculation results are verified using the visualization experimental setup shown in Figure 1. In the experiment, two video cameras are used to capture the front and top of the sleeve at 120 fps. The experimental conditions are almost the same calculation conditions in Table 1. The ladle tilting speeds of the high-speed and low-speed sections are 0.66rad/s and 0.26rad/s, respectively. The time when the molten metal begins to outflow the ladle is 1.6s in the experiment. Therefore, the switching time change from high-speed to low-speed is set to 1.3, 1.6, and 1.9s. The experiments are repeated three times under the same conditions.

Figure 5 shows the dynamic behaviours of maximum wave height in the experiment. In the case of constant 0.66rad/s of the ladle tilting speed, maximum wave height rises rapidly from 1.7s at the start of pouring, and a peak is observed at 2.2s. Then, the maximum wave height is slightly lower, and pouring is finished in about 2.8s. In the case of the switching time of 1.3s, which is 0.3s before the molten metal begins to outflow the ladle, the rise in maximum wave height from the start of pouring is slower than in the constant case, and the peak of maximum wave height is not observed and is suppressed. However, the finishing time of pouring is late. In the case of the switching time of 1.9s, which is 0.3s after the molten metal begins to outflow the ladle, the large peak of maximum wave height is observed and the dynamic behaviour is not improved. The finishing time of pouring also became to be long.

Comparing both results, the same trend of the dynamic behaviour of wave height is obtained in the experiment as in the analysis. Changing the ladle tilting speed from high to low at the same time as or slightly before the molten metal begins to outflow the ladle, the finishing time of poring is slightly long but the dynamic behavior of wave height is largely improved.

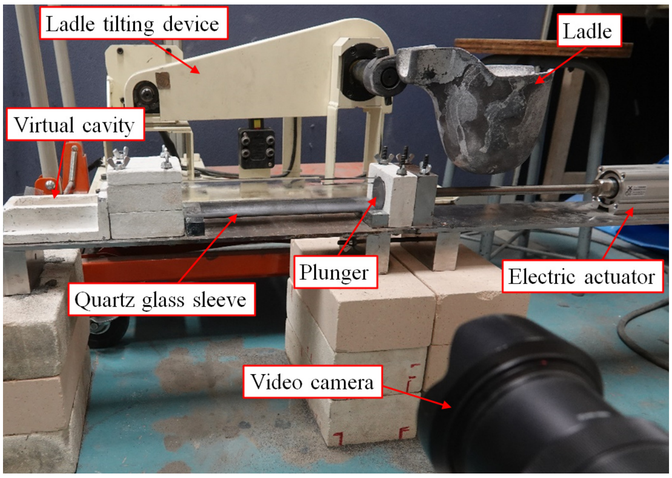


Figure 6: Experimental apparatus for ladle pouring and plunger advancing.

3 LADLE POURING AND PLUNGER ADVANCING

3.1 Experimental apparatus and conditions

Figure 6 shows the experimental apparatus for ladle pouring and plunger advancing [13]. A cylindrical sleeve made of quartz glass is used for the plunger advancing process. In a series of processes from ladle pouring to plunger advancing, it is possible to directly observe how the waves generated by ladle pouring behave during plunger advancing. K.

Takada et al.[13] carried out the experiments and simulation varying with the shot time lag, which is the interval from the finish of ladle pouring to the start of the plunger advancing, and plunger speeds. They investigated the wave behaviours generated by plunger advancing. Then, the ladle tilting speed is constant and a low speed of 0.26rad/s.

In this research, we focus on how the wave generated by the ladle pouring flows with the advance of the plunger. Table 5 shows the experimental and calculation conditions for ladle pouring and plunger advancing. The mass of molten metal inside the sleeve is 300g, and the sleeve filling rate is 33.7%. The ladle tilting speed varied from a slow speed of 0.26rad/s to a high speed of 0.66 rad/s in order to intentionally generate large waves. The switching time change from low speed to high speed is 4.3s in the experiment or 3.7s in the simulation, respectively. The shot time lag is 0s in order to start the plunger advancing in the presence of the waves generated by ladle pouring. The plunger advancing speeds are two kinds of is 120 and 180 mm/s.

Table 5: Experimental and calculation conditions for ladel pouring and plunger advancing.

Test material	Aluminum Alloy, JIS-ADC12
Amount mass of materials	300g
Pouring temperature	700℃
Ladle tilting speed of low-speed section	0.26rad/s
Ladle tilting speed of high-speed section	0.66rad/s
Switching time (Experiment)	4.3s
Switching time (Simulation)	3.7s
Shot time lag	0s
Plunger advancing speed	120, 180mm/s

3.2 Wave behaviour during ladle pouring and plunger advancing

Figure 7 shows the wave behaviour generated by ladle tilting pouring condition, shown in Table 5. From simulated results, a large wave is generated by the ladle tilting pouring, and it propagates to the biscuit position (opposite position to the plunger) when the ladle pouring finish at 5s.

The experimental and simulated results at a plunger advancing speed of 180mm/s or 120mm/s are shown in Figure 8 or Figure 9, respectively. The wave that is at the biscuit position when the plunger position is 0mm returns once in accordance with the plunger advancing and then propagates to the biscuit position again. A closed air loop is observed when the plunger is advanced to 160mm position. After that, the molten metal with air will be injected into the cavity, possibly. However, in the case of plunder advancing speed of 120mm/s, the wave that is at the biscuit position when the plunger position is 0mm makes a round and a way trip during the plunder is advancing to 160mm position. So, the wave exists in front of the plunger tip, then the air is ejected before molten metal injection into the cavity.

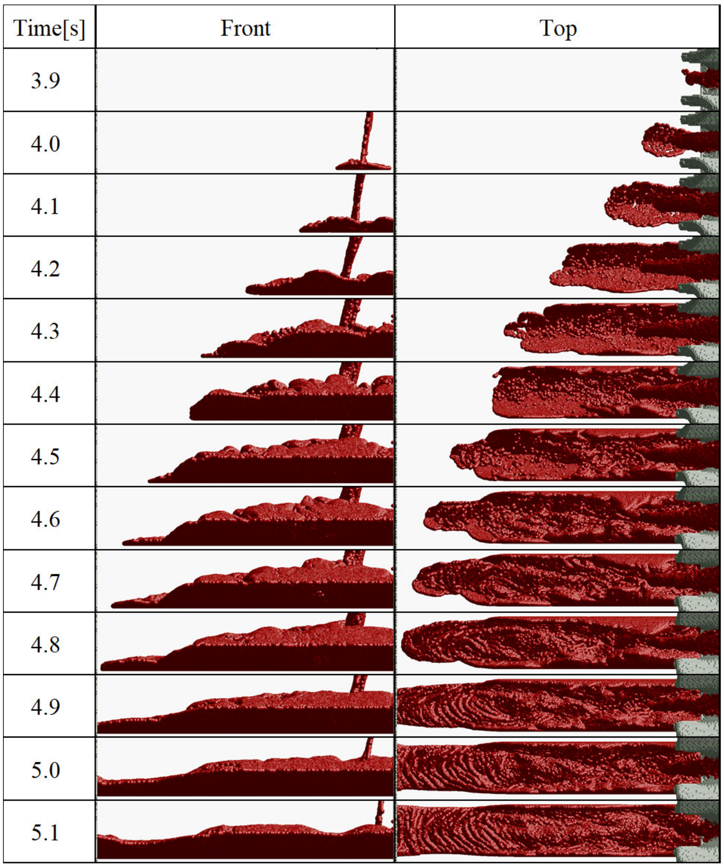


Figure 7: Wave behaviour generated by ladle tilting pouring.

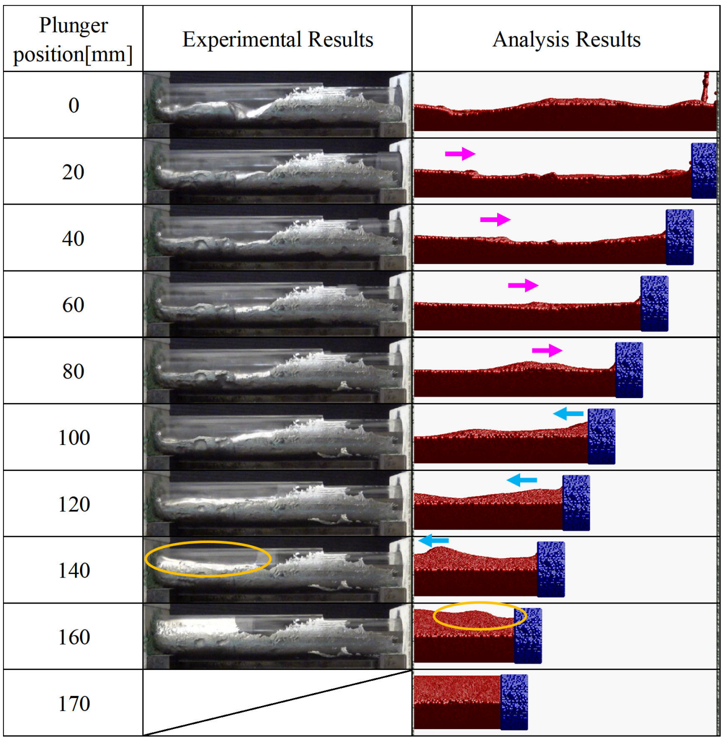


Figure 8: Wave behaviour during plunger advancing in 180mm/s.

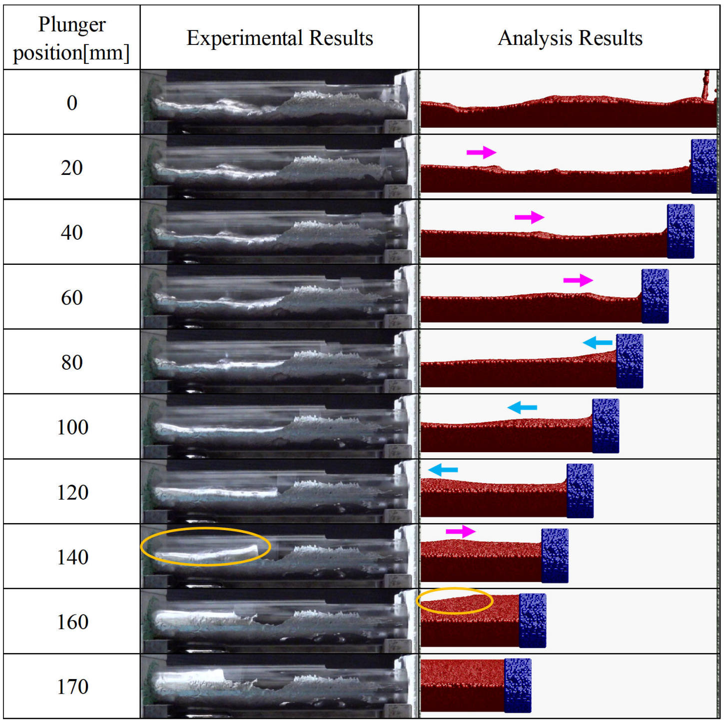


Figure 9: Wave behaviour during plunger advancing in 120mm/s.

4 CONCLUSIONS

A simulation and experimental verification of ladle pouring and plunger advancing processes of die casting using the particle-based SPH method are carried out, and the following results are clarified.

When the ladle tilting speed is changed from high to low, the pouring time becomes longer, but it has the effect of suppressing the generation of waves. The switching time is effective when the molten metal is outflowed from the ladle or slightly before. The wave generated by the ladle pouring propagates in accordance with the plunger advancing. In the future, it is necessary to search for comfortable die casting conditions in a series of processes from ladle pouring to plunger advancing using the simulation.

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ACKNOWLEDGMENT

The authors would like to thank Dr. M. Kazama and Dr. T. Suwa at Fujitsu Limited their technical support of COLMINA CAE.