Applications of Casting Process Simulation in Tooling and Process Design for Squeeze Casting Processes

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Abstract

To achieve the laminar flow filling pattern in squeeze casting processes, many literatures [1,2,3,4] have reported that ideal velocity of liquid metal passing through the ingate should be between 0.1 – 0.5 m/sec. Campbell [1] reported that melt front speed should be less than 0.4 m/sec in order to achieve the laminar flow and minimize gas porosities. However, such slow speed requires the higher temperature of liquid metal and die. This results in not only the longer cycle time but also a coarser microstructure of the casting. In addition, the sample castings used in the literature are simple form castings which do not reflect the real castings used in daily life.

In this study, the indirect squeeze casting processes is adopted to cast a motorcycle's component originally produced by a high pressure die casting process. Based on shape and dimensions of the casting to get the real casting out for the mass production, melt's speed must be higher than the level reported by the literatures. As a result, a full laminar flow may not be achievable. Casting process simulation software is used to verify the design of die's gating system and process parameters. Results from simulation are used to evaluate the possibility of defects and minimize them.

***Keywords**:* squeeze casting, high pressure die casting, laminar flow, casting simulation, gas porosity

1. Introduction

Be able to cast very complex castings in a very short cycle time are the advantages of a high pressure die casting process. However, [5] gas porosities inside a casting are the main disadvantage of the process directly affecting the quality of a casting. Because of the gas porosities, die casting parts are not heat treatable, which further limits achieve performance.

Squeeze casting process is developed from conventional die casting [5,6,7] for produced near net shape casting without gassing or blistering, resulting in the ability to solution treat. Hamadri and J.R.Morton [8, 9] have been reported that mechanical properties of a squeeze casting can be as good as wrought products of similar composition. Chen [10] studies squeeze casting of Al-Cu alloy and reports that castings from squeeze casting process have finer microstructure, higher density, toughness and hardness than those of gravity die casting process.

Recently, an investigation of the possibility to use a squeeze casting technique to fabricate a metal-matrix composite has been reported in [11, 12].

Two types of squeeze casting process have been developed based on metal's movement during a die filling. These have been given the name "direct squeeze casting" and "indirect squeeze casting" [11].

For a direct squeeze casting process, molten metal is poured directly into an open die, and hydraulic ram is moved down into the melt to apply the pressure. This technique does not control the die filling state which leads to turbulent flow and the entrapment of brittle surface oxide films.

For an indirect squeeze casting process, the metal flow can be controlled by the injection speed, and an intensification pressure can be applied as soon as the die is fully filled. The dimensions of casting are easier to control [13, 14]. As a result, the indirect squeeze casting process has been use more than the direct squeeze casting process in commercial.

2. Experimental procedures

The goal of this experiment is to apply the concept of the indirect squeeze casting process to cast part which has minimum gas and shrinkage porosities. A motorcycle's component is used as a case study. Cast material is ADC12.

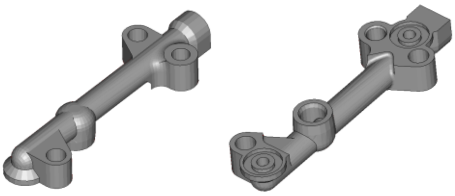
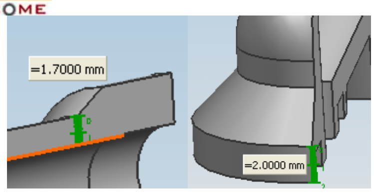


Fig. 1 part in this study.

2.1 part analysis

Shape of a casting is cylinder with different thickness. With the constraint of the long hole inside the casting, part must be layout vertically for the slide core movement. The thickness of casting is not uniform. For this casting, ingates are planned to place at two positions; (1) at the middle of the casting (thickness of 1.7 mm) and, (2) at the bottom of the casting (thickness of 2.0 mm) as shown in fig 2. The thickness of castings wall at these two positions directly confines the thickness of ingate.



(a) (b)

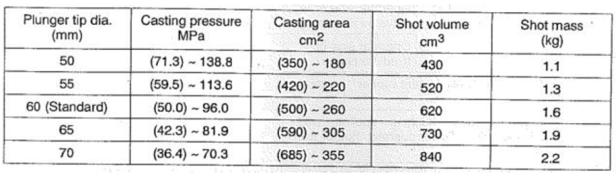
Fig. 2 Thickness of part (a) middle , and(b) bottom position.

2.2 Modeling and simulation

Commercial casting process simulation software are used to analyze both filling and solidification behaviors.

PROCAST is used to simulate flow inside shot sleeve and MAGMASOFT, is used to simulate filling and solidification inside the cavity.

Table. 1 Plunger size

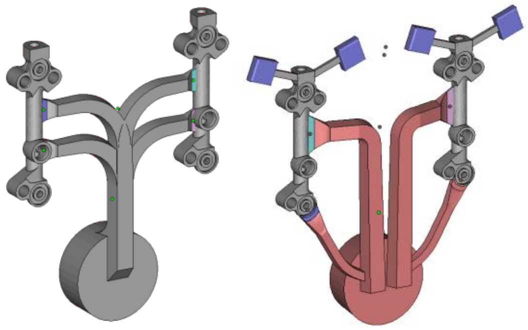


Plunger tip dia. (mm)	Casting pressure MPa	Casting area cm^2	Shot volume cm^3	Shot mass (kg)
50	(71.3) ~ 138.8	(350) ~ 180	430	1.1
55	(59.5) ~ 113.6	(420) ~ 220	520	1.3
60 (Standard)	(50.0) ~ 96.0	(500) ~ 260	620	1.6
65	(42.3) ~ 81.9	(590) ~ 305	730	1.9
70	(36.4) ~ 70.3	(685) ~ 355	840	2.2

3. Results and Discussion

3.1 Design of gating system

Two design of gating systems are evaluated in this work. Gating system No.1 is designed based on following flow pattern. First, liquid metal fills at center of casting and then and flow to top and bottom of the casting. For gating system No.2, molten metal is first fed to the cavity from the bottom and then when it reach the center of the casting, liquid metal at the center gate takes control the flow.



(a) (b)

Fig. 3 gating system design (a) No.1 (b) No.2

Shot weight is estimated to be around 0.3 kilograms. Plunger's diameter of 50 mm is selected based on the shot mass and casting pressure as shown in table 1. The thickness of biscuit is 20 mm. Other parameter of squeeze casting simulation is shown in Table. 2.

Table. 2 Parameter in simulation

Parameter	Squeeze casting
Material	ADC12
Die material	H13
Plunger diameter	50 mm
Biscuit thickness	20 mm
Melt temperature	680 ^{0}C
Die temperature	150 ^{0}C
Shot sleeve	280 mm

3.2 Analysis of simulation result

3.2.1 Flow analysis

Flow analysis is done into 2 parts: (1) shot sleeve and (2) inside cavity.

At low speed filling step, velocity of plunger is defined in 2 steps. Firstly, plunger moves by constant velocity of 0.2 m/s for 0.5 second. After that, plunger moves by acceleration of 0.2 m/s^2 from 0.5 to 1.09 second. Flow inside shot sleeve can be observed from Fig.4. Fig.5 shows temperature distribution of liquid metal in shot sleeve. Loss of liquid metal temperature inside the shot sleeve is around 30^0C.

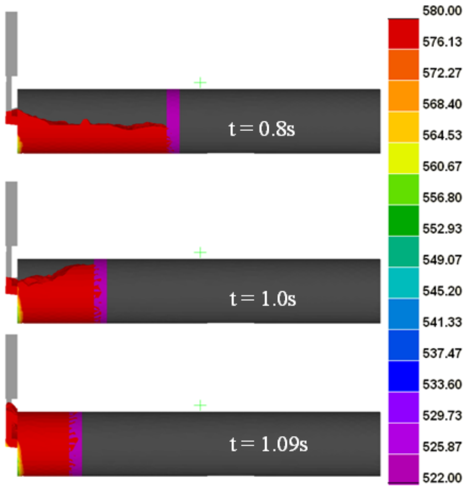


Fig. 4 Flow of liquid metal in the shot sleeve.

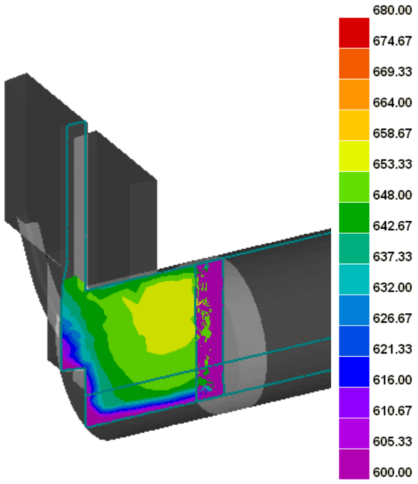


Fig. 5 Temperature distribution of liquid metal inside the shot sleeve at time =1.09 s

The profile of plunger's velocity for gating system No. 1 and No. 2 are shown in Fig. 6 and Fig. 7 respectively.

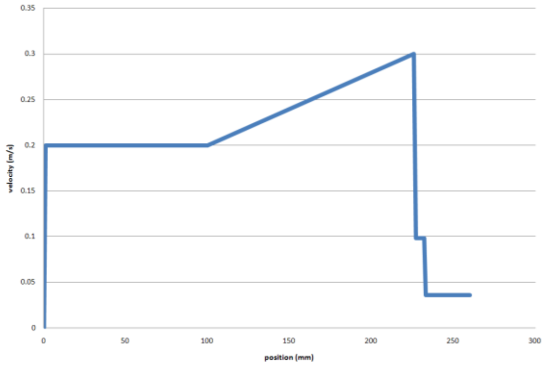


Fig. 6 Profile of plunger's velocity used for gating system No. 1.

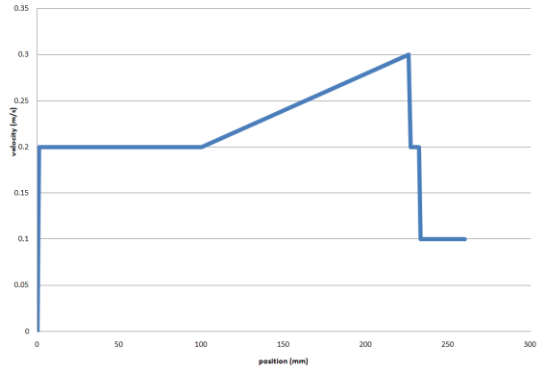


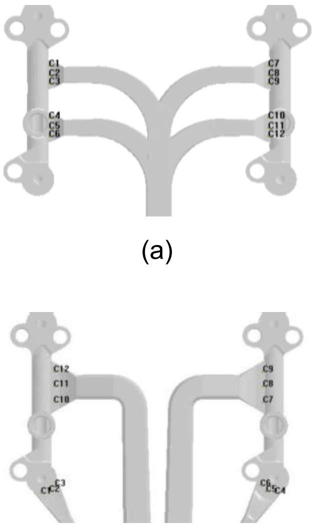
Fig. 7 Profile of plunger's velocity used for gating system No. 2.

In the simulation, virtual speed sensors are placed at the ingates and virtual thermocouples are placed on die's surface as shown in Fig. 8 and Fig. 9, respectively.

Flow pattern of two gating system are shown in Fig. 10 and 11. Flow pattern of gating system No. 2 is distributed flow than gating system No. 1. It is support by flow behavior, profile velocity and result of percent of air entrapment.

Result of velocity is shown in Fig. 12 and Fig. 13. For gating system No. 1, velocity of molten metal is around 1.1 m/s at upper gate (point 1-3 and 7-9) and 0.6 m/s at lower gate (point 4-6 and 10-12). For gating system No. 2, velocity of molten metal is around 1.1 m/s at the bottom gate (point 1-6) and velocity of molten metal is around 2.3 m/s at the middle gate (point 7-12). Profile velocity of gating system No. 1 and 2 showed that molten metal flow thought gate not fully uniform, so air entrapment can be founded in the cavity. Percent of air entrapment in the cavity of gating system No. 1 is higher than gating system No. 2 which shown in Fig. 14. Even molten metal's velocity of gating system No. 1 is lower than gating system No. 2 but flow of molten metal in the cavity of gating system No. 1 is not distributed flow so, air entrap in the cavity of gating system No. 1 is higher than gating system No. 2.

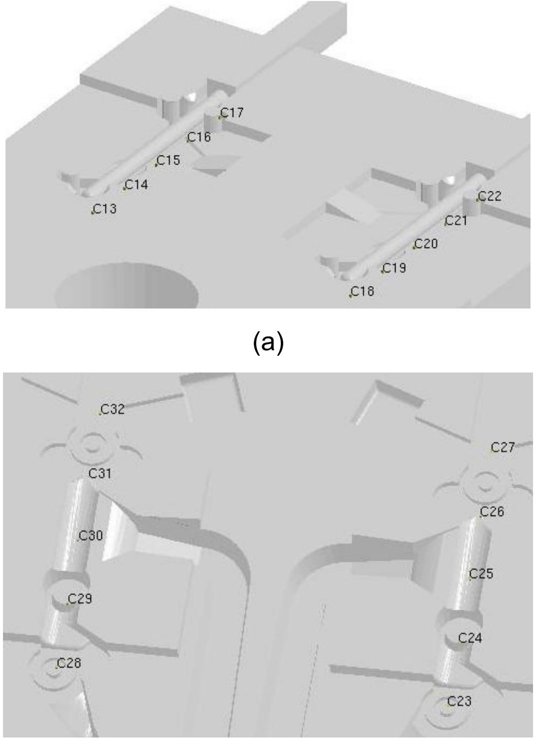
Temperature distribution of molten metal is around 572 – 580 ^{0}C at the cavity fully filled.



(a)

(b)

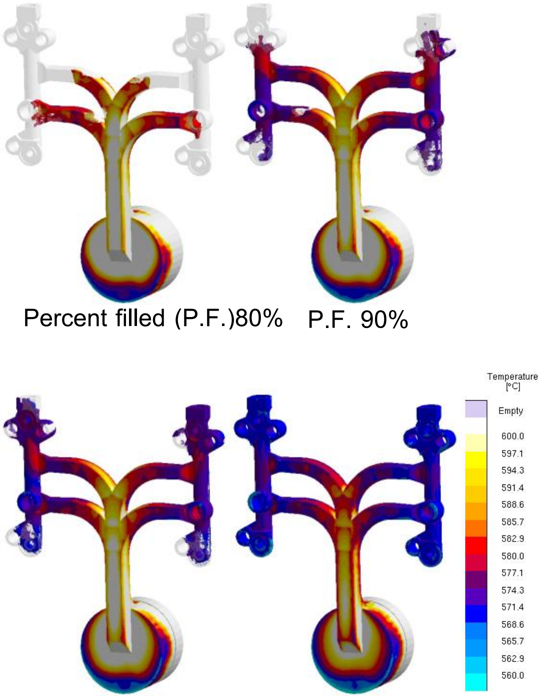
Fig. 8 Position of virtual speed sensors for (a) gating system No. 1 (b) gating system No. 2



(a)

(b)

Fig. 9 Position of virtual Thermocouples at mold (a) fix die (b) move die



Percent filled (P.F.)80% P.F. 90%

P.F. 95% P.F. 100%

Fig. 10 Flow pattern of gating system No. 1

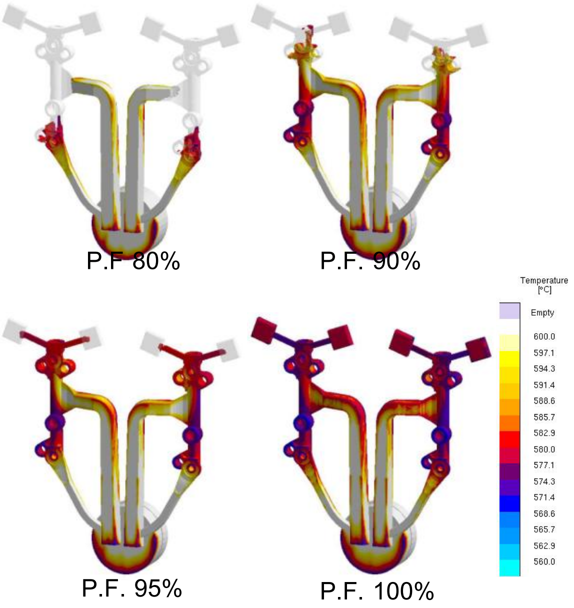
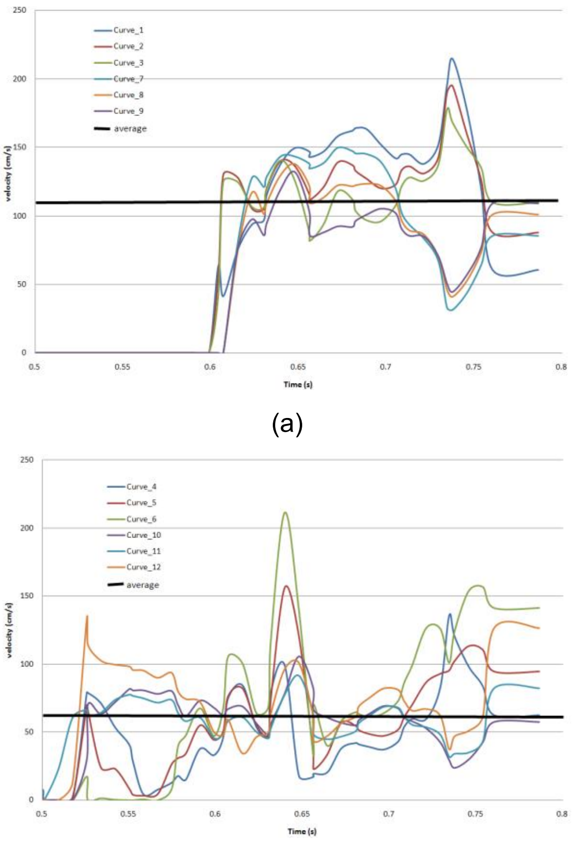


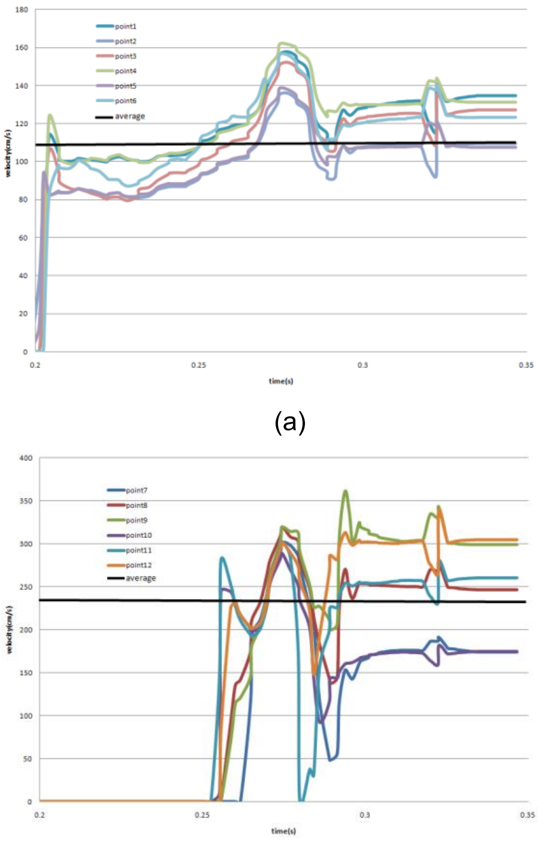
Fig. 11 Flow pattern of gating system No. 2



(a)

(b)

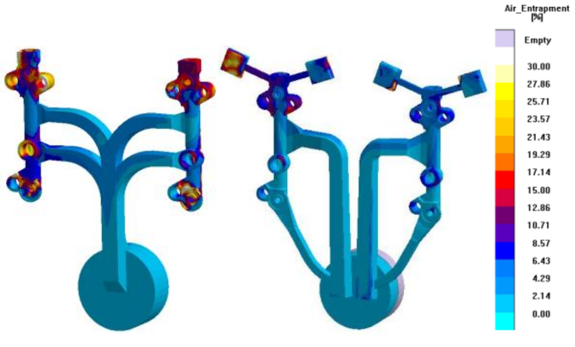
Fig. 12 Profile velocity molten metal of gating system No. 1 at (a) thermocouple point 1-3 and 7-9 (b) thermocouple point 4-6 and 10-12



(a)

(b)

Fig. 13 Profile velocity molten metal of gating system No. 2 at (a) thermocouple point 1-6 (b) thermocouple point 7-12



(a) (b)

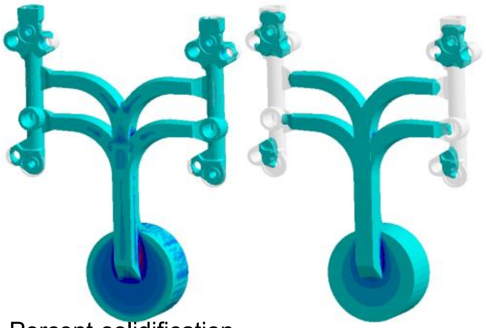
Fig. 14 Comparison air entrapment in the cavity between two gating design

3.2.2 Solidification analysis

Solidification of the part occurs faster than that of the runner. Solidification of the parts started at thin section and finished at the thickest of the part. Gating system No. 2 is proper than gating system No. 1 because pressure can intensify at the bottom of the part before molten metal becomes solid for reduce shrinkage porosity. Solidification behavior of two gating system are shown in Fig. 15 and 16.

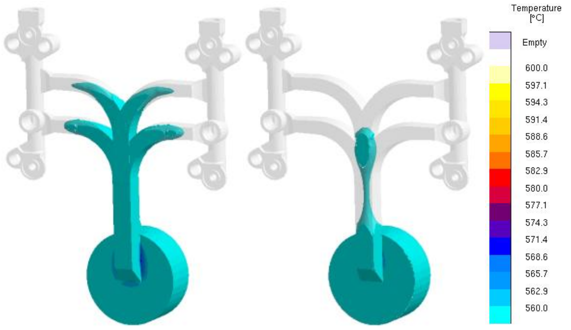
To identify the location of the shrinkage porosity, hot spot criteria is used. The part at this position has long solidification time lead to shrinkage problem which shown in Fig. 17. This area will use water channel for cooling die temperature.

To obtain the temperature of die's surface, 8 cycles of simulation are run. It is found that at the steady state, temperature on the surface of fix die and move die are around 210 ^{0}C and 270 ^{0}C, respectively.



Percent solidification (P.S.)25%

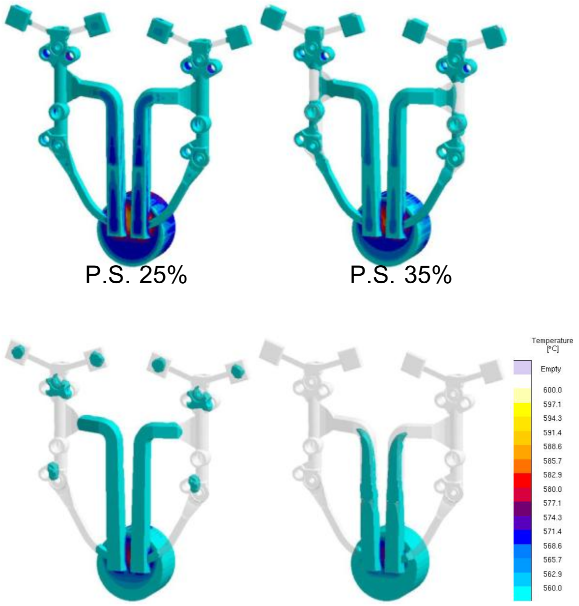
P.S. 35%



P.S. 45%

P.S. 55%

Fig. 15 Solidification of gating system No. 1



P.S. 25%

P.S. 35%

P.S. 45%

P.S. 55%

Fig. 16 Solidification of gating system No. 2

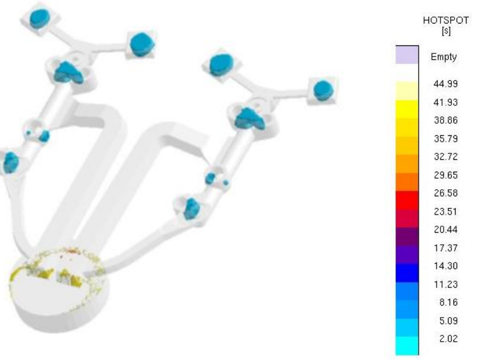
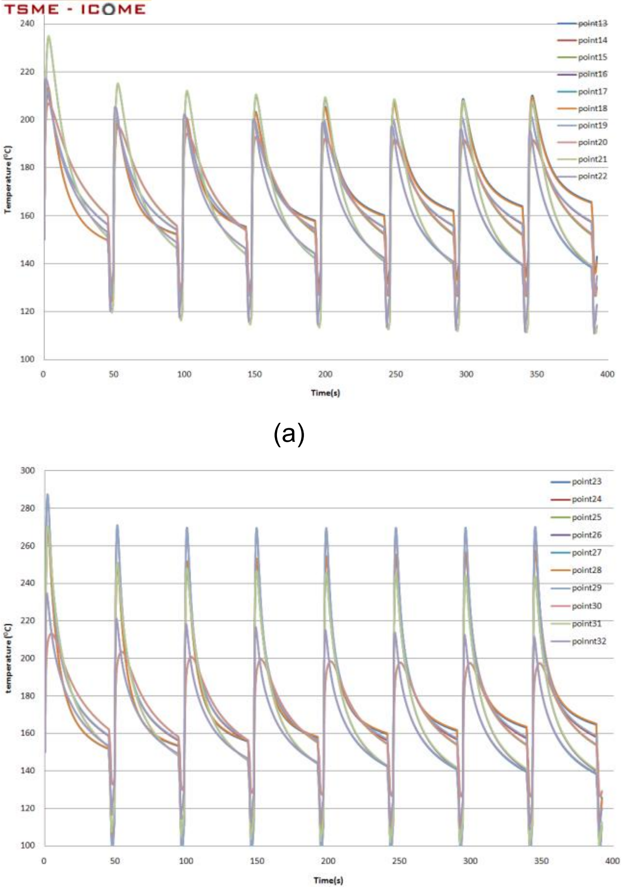


Fig. 17 Hot spot of casting part



(a)

(b)

Fig. 18 Temperature distribution at die (a) virtual thermocouple point 13-22 (b) virtual thermocouple point 23-32

4. Conclusion

Squeeze casting has many advantages over other casting processes. Thought the gating system design in mass production using computer aided engineering to develop the following results were obtained.

- The proper gating system of the pipe oil in mass production has been obtained by filling and solidification simulation.
- Gating system gating system No. 2 is proper filling behavior than gating system No. 1 because molten metal is distributed flow and air entrapment in the cavity is less than gating system No. 1.
- The behavior of solidification is important for pressure intensification in the cavity and shrinkage porosity. If the position of gate is correct, it can improve quality of the part by intent pressure after fully filled. Cooling channel must be used at hot shot zone for reduce die temperature.

5. Acknowledgement

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