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Feasibility Study of Indirect Squeeze Casting For LM6 Aluminum Alloy Using Casting Process Simulation

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Abstract

In squeeze casting processes, molten metal must be filled into the die with lower speed comparing to that of conventional high pressure die casting processes in order to prevent the turbulence and air entrapment inside the casting. With this principle, applying squeeze casting processes to cast LM6 having freezing rang temperature between 576-578^{0}C is quite challenging.

In this study, a twin spacer, a 0.71 kg component used in the power transmission line, is used as a case study. Casting process simulation software is used to verify the design of die's gating system and process parameters used to cast the part. The results of the study shows that (1) angle of parts' layout position, (2) shape of runner and gates' position have the main effect to the temperature distribution on the die and casting, while plunger speed and ingate area have the direct impact on the melt's speed inside the cavity and directly affecting the gas porosity formation inside the casting.

***Keywords**:* squeeze casting, conventional high pressure die casting, die cavity, solidification, turbulent

1. Introduction

Gas porosities are the most common problems found in high pressure die casting processes [1]. The main cause of the problem is air entrapment resulting from the turbulence flow of liquid metal inside a cavity. At the end of cavity filling stage, high intensification pressure is usually applied to the cavity. Conceptually, the high intensification metal pressure is used to reduce or eliminate the porosity inside the casting. However, in reality, the liquid metal at the ingate area is solidified in a very short period of time. As a result, the effect of intensification pressure has less affect to the reduction of the porosity inside the casting.

Porosity affects the mechanical properties and hinders heat treatment process. In structural applications, porosity can act as a stress concentration creating an initiation site for cracks. When casting is heated, compressed air inside the porosity will be expanded and casing the blister on the surface.

To overcome limitations mentioned above, the amount of gas porosity must be eliminated or minimized as much as possible. Yulong et al. [4] reported that the as cast A356 part casted from squeeze casting process has higher mechanical properties than that of gravity die casting process. The ultimate tensile strength is improved from 154 MPa to 203 MPa and elongation is increase up to 9.5 %.

Two important characters of the squeeze casting process are: (1) laminar flow cavity filling pattern, and (2) solidify under high pressure. To achieve the laminar flow, the melt's front speed should not be more than 0.5 m/s [5]. This slow filling is controlled by the use of a large ingate area and slow speed of plunger. The large ingate area also helps to reduce turbulence during the filling stage [6,7] and increase solidification time of the molten metal at ingate. During solidification, high intensification pressure is applied to the solidifying liquid metal to minimize both gas and shrinkage porosities and also increase the cooling rate between the solidifying casting and the die [8]. The intensification pressure about 100 MPa are able to fully eliminate gas and shrinkage porosities [8,9,10]. Limitation of squeeze casting process is longer cycle time than conventional die casting because of slower filling speed and longer solidification time, high wear rate of die due to high die's and molten metal's temperature and coarse grains because of longer solidification time.

Squeeze casting process is classified in two types: direct squeeze casting and indirect squeeze casting [11]. Less oxide film contamination and better dimensions' control are the main advantages of indirect squeeze casting over the direct squeeze casting processes [4]. In Thailand, most of high pressure die casting machine are horizontal shot sleeve which can be applied for the indirect squeeze casting processes. So, we will develop knowledge in die design and parameters of squeeze casting process for horizontal high pressure die casting machine.

2. Experimental

In this study, aluminum alloy LM6 is selected. LM6 has a freezing range of 576-578 ^{0}C. The part used for this experiment is shown in fig. 1. This experiment use commercial software, MAGMASOFT, to simulate optimum condition of squeeze casting process.

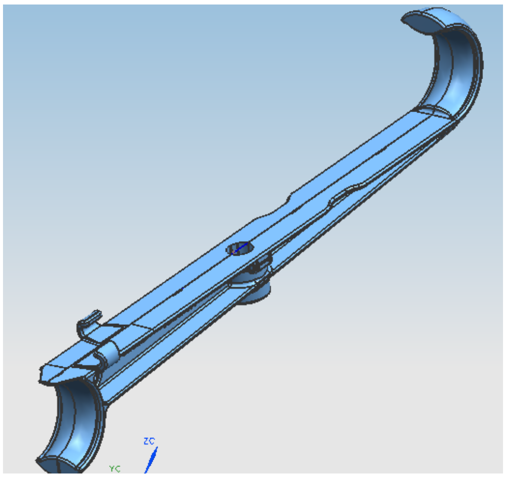


Fig. 1 Squeeze casting part

In this experiment, the cavity will be filled by injecting molten metal from bottom to the top with minimum speed in order to minimize air entrapment. This is called "distributed flow filling pattern". Filling with low speed from the bottom to the top, the distributed flow, increases effectiveness of air venting and also promotes directional solidification. Moreover, velocity of molten metal at gate needed to control for laminar flow by plunger speed and ingate area. With the same plunger speed, a smaller ingate area results in a higher speed of liquid metal at ingate and vice versa.

The experiment is divided into three parts. First, find suitable shape of runner, gates and biscuit position. Second, find appropriate of layout position and finally, find suitable velocity of molten metal at ingate. These experiments based on high pressure die casting machine which has an area for die installed 650*650 mm^2. Parameters of simulation in experiment are shown in Table. 1.

Table. 1 Indirect squeeze casting process parameter

Parameter	Value
Materials	LM 6
Die materials	H 13
Melt temperature at shot sleeve	660 ^{0}C
Die and plunger temperature	210 ^{0}C
Temperature of water in cooling channel	30 ^{0}C
Plunger diameter	70 mm
Biscuit height	40 mm
Slow velocity (v1)	0.225 m/s
Melt front speed	1-2 m/s

3. Results and Discussion

3.1 shape of runner, gates and biscuit position

Based on the part's shape, a slide core is required. As a result, the part must be placed horizontally or vertically. When the part is placed horizontally, the total length of the die is larger than the distance between two tie bars as shown in fig. 2. So, the part must be placed vertically.

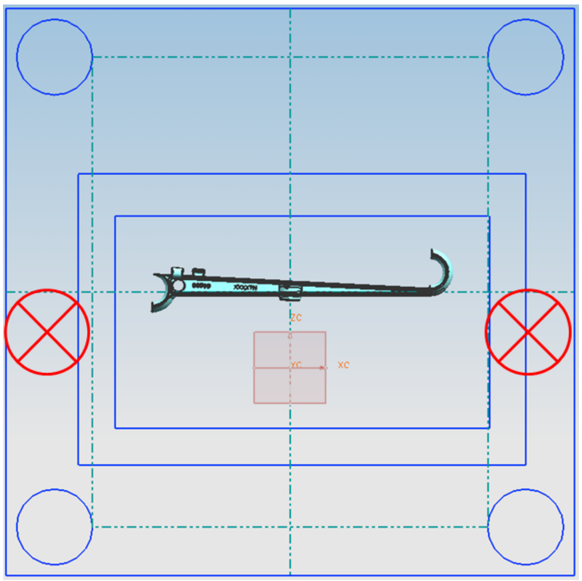


Fig. 2 Layout of part and gating system when placed at horizontal position

Two types of gate named; tangential gate, and fan gates are used. For the tangential gate (4a) it is difficult to control flow pattern and temperature drop of molten metal during the filling can observed. This can result in miss-run and flow-line problem. To minimize heat loss of the molten during the filling step, position of biscuit is placed at the center of part and uses multiple fan gates for control flow pattern as shown in fig. 4b. With the configuration shown in fig. 4b, die cannot be installed on the machine. The whole layout must be shifted to higher position in order to be able to install the die on the machine as shown in fig. 5. To minimized heat loss, runner cross section is designed in a circular shape.

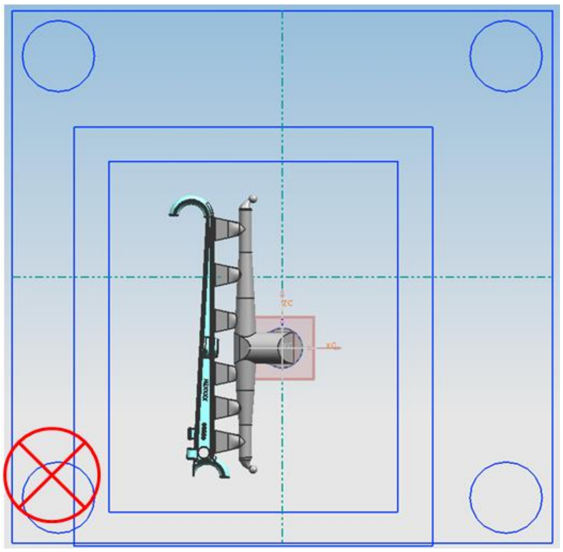
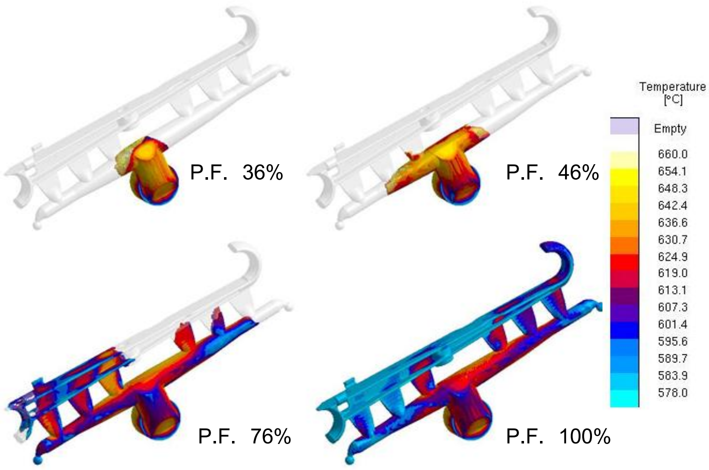
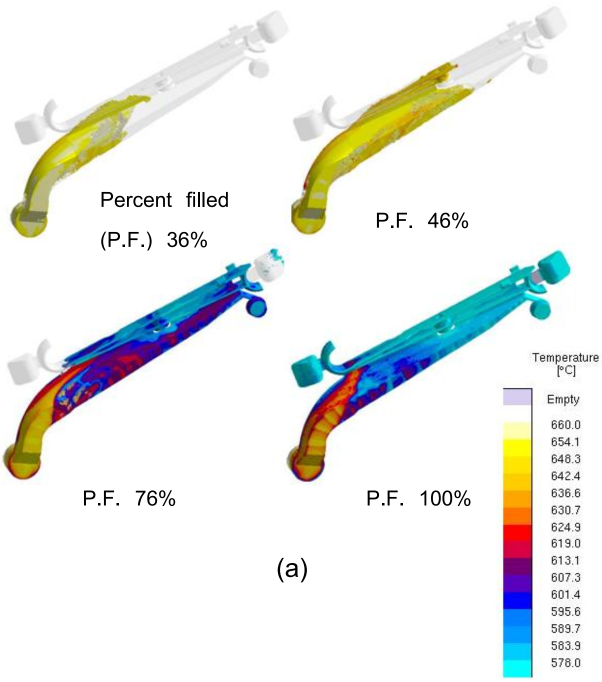


Fig. 3 Layout of part and gating system when placed at vertical position



(b)



(a)

Fig. 4 Shape of Gating system designs and temperature distribution during the filling of (a) Tangential gate (b) Multiple fan gates

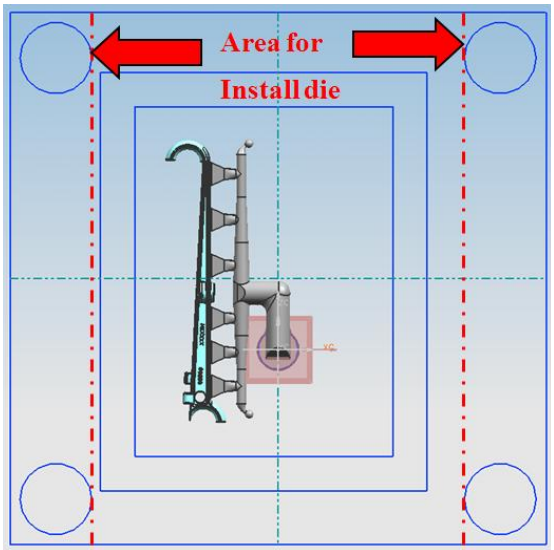


Fig. 5 Layout of part and gating system when move the part and gating system to higher position

3.2 layout position

To obtain the distributed flow pattern, the gating system is rotated from 0 to 90 degree. For each step of 5 degree's rotation, filling calculation is performed. Based on the calculation's results, angle of 90^0, 85^0, 80^0, 75^0 and 55^0 have the higher temperature distribution compared with the rest. At rotation angle of 55^0 and 90^0, contacted surface area of the melt with die and air is minimum resulting in the minimum heat loss.

From the filling pattern point of view, angle of 55^0 reveals the distributed flow pattern from bottom to the top as shown in fig.7. Fig.8 shows metal's temperature when molten metal fully filled at final section. It shows that at 55^0 has the highest metal temperature.

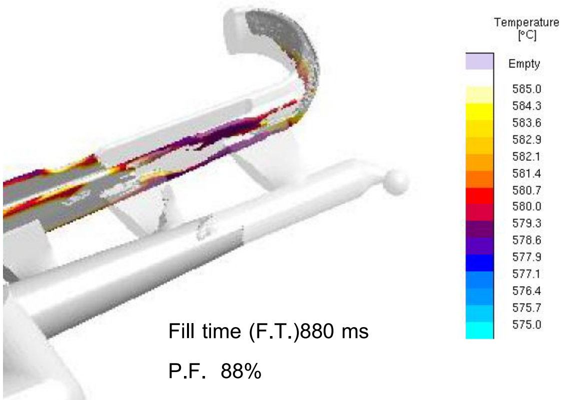


Fig. 6 Non distributed flow pattern when the part and gating system is higher position at 90^0

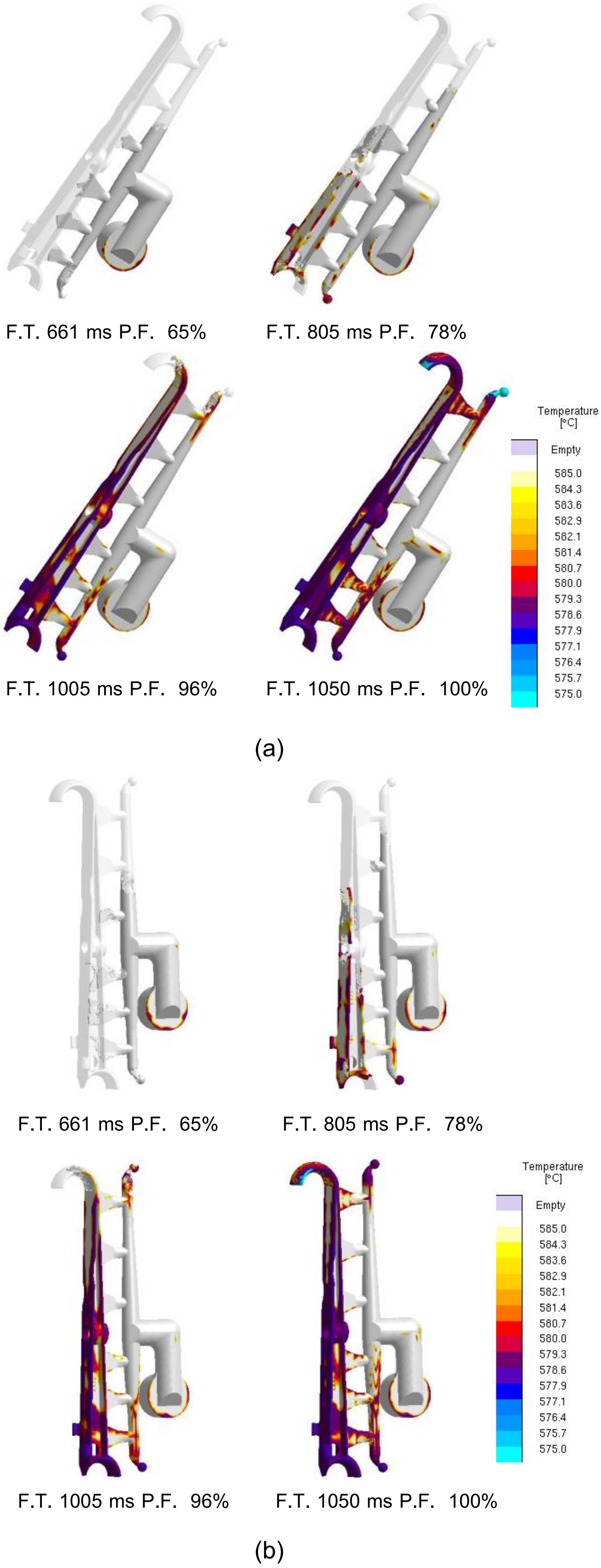


Fig. 7 Flow pattern of molten metal at layout of the gating system (a) 55 degree (b) 90 degree.

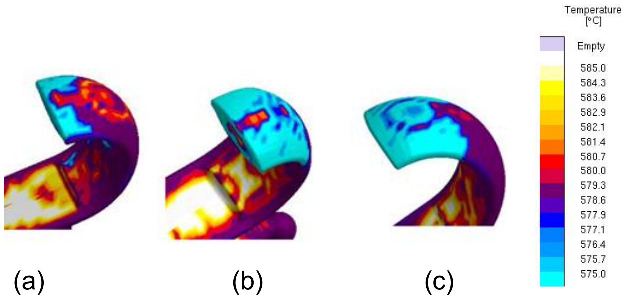


Fig. 8 Temperature distribution on the casting at cavity fully filled (F.T. 1050 ms, P.F. 100%) at (a) 55^0 (b) 65^0 and (c) 35^0 rotation angle.

3.3 Velocity of molten metal at ingate

Melt's speed at ingate is laminar when velocity is 0.5 m/s which calculate from Weber number [5] but 0.5 m/s are too slow, molten metal will solidifies before cavity is fully filled. To be able to fill the cavity on the shop floor, speeds of liquid metal in the range of 0.8 -2 m/s are investigated in this experiment.

At melt's speed of 0.8 m/s, molten metal is fully solidified before the cavity is fully filled as shown in fig. 9.

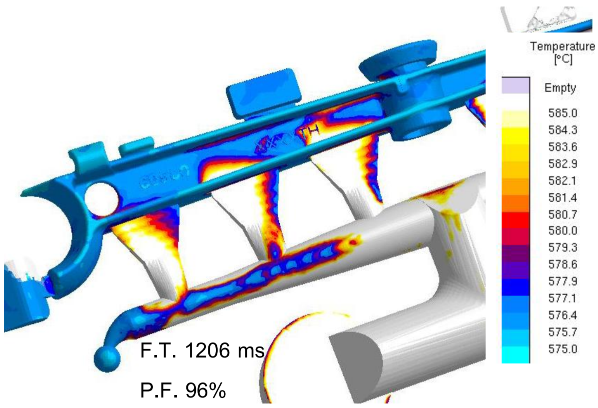
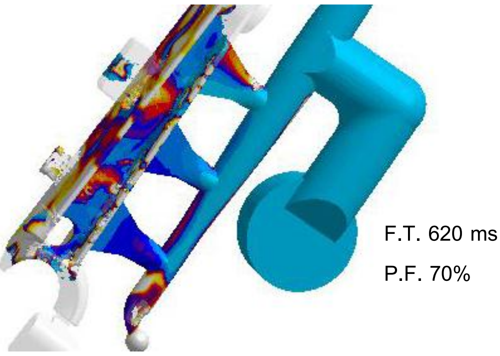


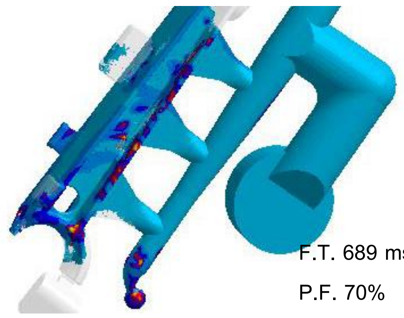
Fig. 9 At melt speed of 0.8 m/s complete solidification take place at the ingate area and casting part

At melt's speed of 2 m/s, air entrapment can be found between 2 fan gates when compared with those of 0.8, and 1m/s.

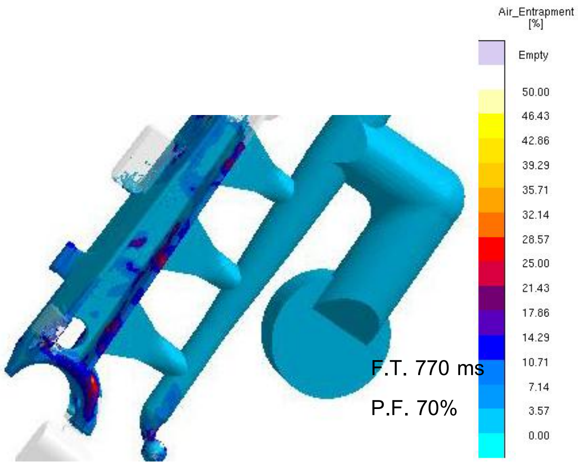
Based on the simulation, to minimize the air entrapment and achieve the best distributed flow pattern, melt's speed at ingate of 1 m/s is selected.



(a)



(b)



(c)

Fig. 10 Air entrapment in the cavity at different melt speed of (a) 2 m/s , (b) 1 m/s, and (c) 0.8 m/s, respectively.

4. Conclusions

This present study demonstrates that the production of LM6 aluminum alloy part via indirect squeeze casting is feasible with the optimal parameters.

(1) Optimum position of biscuit is at middle of the part because cavity can be filled by molten metal in the shortest path. Also the loss of temperature is minimized. Flow pattern can be easily controlled by using fan gates.

(2) The whole gating system must be configured at the 55 degree in order to achieve the best distributed flow pattern and minimize the heat loss at the last section filling.

(3) To minimize the air entrapment during the filling, speed of liquid metal passing through the ingate should be 1 m/s. The molten metal already solidifies at fill time 1206 msec.

5. Acknowledgement

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6. References

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