A STUDY OF CASTING DIE DESIGN OF BRAKE MASTER CYLINDER USING SOFTWARE SIMULATION

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Abstract.
The die design process for casting requires repeated testing in order to get a good die and produce a product that is as planned, which takes a long time and costs a lot for die making in this trial. The purpose of this study is to determine a more efficient process in die design by conducting a casting analysis using a MagmaSoft simulation. The sample part used in this study is a motorcycle brake master cylinder which will be made by the Gravity Casting process with aluminum material. The basic method used is die design using CAD by calculating Shrinkage allowance, and casting simulation using MagmaSoft software to find out various possible defects during the casting process, such as filling, air trap, solidification, hot spots, and shrinkage porosity. The simulation results show that in the filling process there is no indication of cold shot and no air trap problem, solidification and hot spots are good and occur in the part area, and there is little porosity. In general, the simulation results show that the die design has met the requirements, although there is porosity, this porosity occurs in the area that will be lost after the machining process.

Keywords: Die design, Gravity casting, Simulation
INTRODUCTION

The traditional design process used various tools such as rulers, pencils, drawing pens and drawing paper using manual techniques with a process that took a long time [1,2]. The recent development of technology in engineering design and drawing, allows computer applications such as CAD to assist the design process become easier and simulation software to solve the difficulties that exist in the design calculations and simulating manufacturing process, to minimize failures in the manufacture of a product [3-5].

In die casting design, the die design must be made with a high level of precision to produce a uniform and efficient mass product. Without simulation, to get a good die it needs several trials that are usually carried out repeatedly so that it is expensive, takes a long time, and causes rejected material to be wasted [6,7]. Therefore, the die making must be done in a way that an analysis can be performed right after the design is made and prior to production trial.

The simulation technology allows the design to be analyzed in advance, so that the potential product failure can be reduced and the die manufacturing process can be more efficient [8,9]. By using simulations, the die design can be checked for the possibility of porous products due to air traps, incomplete filling due to too fast solidification resulted from incorrect gate, sprue, and runner positions, and inaccurate dimensions due to miscalculation of the shrinkage of molten metal in the cavity.

This paper presents a study of die design for gravity casting process in making brake master cylinders using MagmaSoft simulation. The simulation was carried out to analyze the die design so that the casting results are good and in accordance with the specifications.

THEORETICAL BACKGROUND

In comparison to high pressure die casting (HPDC) processes, production rate of gravity die casting (GDC) processes are much lower but are able to make a more complex parts, such as brake master cylinder and caliper, wheels, cylinder heads, and engine blocks. However, compared to sand casting process, GDC offers lower cost, shorter cycle times, better surface finish and internal quality [8].

For modelling interfacial flows, volume of fluid (VOF) methods is the most popular and widely used method for mold filling simulation because it is relatively easy in implementation. Several commercial simulation software for casting analysis, such as MAGMAsoft use the VOF technique [8]. MAGMAsoft is a three-dimensional package used to do modeling the flow and solidification of molten metal in dies [9]. The finite difference method is used in MagmaSoft to solve the heat and mass transfer and it is useful to simulate the flow of liquid metal in a permanent mold. MAGMAsoft can provide accurate data on solidification, velocity distribution, runner and gate effectiveness, and air entrapment.

Solidification Mechanism

In general, solidification is initiated by pouring the high temperature molten metal into the mold cavity and it flows with a certain velocity and releases heat to the mold. The heat transfer between the mold and the cast is purely conduction due to complete thermal contact. At the time the cast metal reaches the liquidus point during the cooling process, the cast releases latent heat and at the same time also releases a number of metal oxides. This metal oxides generate an air gap between the mold and the cast. Once the whole molten metal fills the mold cavity, the temperature drops to the liquidus temperature (TL), this phase is called liquid cooling, as it is shown in Fig. 1 [10]. The liquidus temperature (TL) is the point at which the solidification begins.
As the time lapse, the solidification progresses till reach the liquidus point and the mold temperature significantly increases to maximum. Later on the outer cast surface forms a solid skin and the cast shrinks causing an air gap between the mold and the cast. As the cast temperature gradually reaches a solidus (TS) temperature of the alloy, the cast to releases a large quantity of latent heat to the mold.

Further solidification reduces the cast surface temperature, but the inner cast continues to release the heat to the mold and causing the rise in the mold temperature as shown in Fig. 2 [10]. During the release of heat in the inner cast metal, the inner cast shrinks and there is a possibility of releasing metal oxides which causes an air trapped inside the cast and is called shrinkage porosity. The third phase of solidification occurs as the cast temperature decreases after the solidus point (Ts) till the end of solidification.
METHOD

The method of this study is exhibited in the flowchart presented in Fig 3.

Part Design

The part under study is brake master cylinder of motor cycle and the casting method used to produce the master cylinder is gravity die casting, made of Aluminum alloy (ADC12) material [13]. The 3D model is exhibited Fig 4.

The design of part for casting process should consider the shrinkage factor. The shrinkage allowance for Aluminum alloy is between 1.3 % – 1.6 % [14], and for this study the shrinkage allowance was taken at 1.5 %. Therefore, the part dimension was scaled accordingly became 1.015 from original dimension. The direction of shrinking normally to the reference point inside the dies.

![Flowchart of the methodology](image_url)
Die Design

The casting die was designed with two cavity model. The distribution of material volume is shown in Fig 5 and the calculated volume is presented in Table 1.
Table 1 Part Volume

| No. | Item Name                          | Volume       | Percentage |
|-----|------------------------------------|--------------|------------|
| 1   | Total casting volume               | 378.103 Mm³ | 100%       |
| 2   | Part volume                        | 192.543 Mm³ | 51%        |
| 3   | Gate, Runner & Over Flow volume    | 185.560 Mm³ | 49%        |

The detailed die design includes Runner, Over Flow, Plate Ejector and other die components are shown in Fig 6.

![Fig 6 Die Design of Gravity Die Casting](image)

**Casting Process Simulation**

After design process was completed, the simulation was then performed using MagmaSoft to study the casting performance and anticipate the possibility of defects. The simulation was done with the variable setting data shown in Fig 7. MagmaSoft optimize a comprehensive and effective casting process, optimize process condition, and reduce production cost. By using virtual experimental design and autonomous optimization, the strong process parameters and optimum casting layout can be determined for all materials and casting process[9].
The simulation allows evaluation of metal cooling and effective critical speed during filling. The progress and forming of porosity can be monitored and displayed continuously during solidification process.

RESULT AND DISCUSSION

The simulation result is exhibited in Table 2

| No | Defect types         | Simulation                                                                 | Result of simulation                                                                 | Remarks                                                                 |
|----|----------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| 1  | Filling              | ![Diagram](https://via.placeholder.com/150)                               | Aluminum casting for 6 seconds at temperature of 712°C suitable for part area       | No indication of cold shot problem                                     |
| 2  | Entrapped Air Mass   | ![Diagram](https://via.placeholder.com/150)                               | There was 8.8% air trap inside the part                                             | Indication of entrapped air mass was small, no problem.               |
| 3  | Solidification       | ![Diagram](https://via.placeholder.com/150)                               | The last solidification was inside the part                                         | In accordance with the good practice where last solidification should be inside the part |
| 4  | Hot Spot             | ![Diagram](https://via.placeholder.com/150)                               | The hot spot fraction solid occurs, indicate the last solidification was inside the part. | There was a hot spot area inside the part, no problem                 |
| 5  | Shrinkage Porosity   | ![Diagram](https://via.placeholder.com/150)                               | There was a potential of porosity around 11.3 mm³                                   | If the potential of porosity is less than 10%, the risk is very small and there is a possibility of removed by machining process |

### Variable setting data

| Alloy         | ADC12 |
|---------------|-------|
| Part weight   | 750 g |
| Alloy temperatur | 710°C |
| Initial Temperatur of the steel | 300°C |
| Time Jumping  | 5.5 s |
| Angle Jumping | 70°   |
| Solidification time | 120 s |
The simulation result shows a potency of small volume of porosity of 11.3 mm$^3$ inside casting part. To cater the porosity inside the part, a machining process at the center of the part can be performed after the casting process, so that the porosity area will be removed. Hence, this part is safe to be produced without the need to modify the part design. The illustration of this process is shown in Fig 8.

**CONCLUSION**

The dies that has been designed with two cavity model for gravity die casting of brake master cylinder, has an efficiency of 51 % where 49 % of material wasted in the form gate, runner & overflow. The design can be implemented into actual production by taking into consideration the variable parameters suggested by the simulation.

The simulation result indicated that filling, solidification, and hotspot are good. Meanwhile, there was a small air trap detected and also a shrinkage porosity defect. Fortunately, the porosity occurs inside the part where the machining will take place, so that the porosity will be removed and the part is safe for mass production.
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