Analysis design of the gating system on high-pressure die casting process for production effectiveness

Lukas Dwi Purnomo, Dwi Rahmalina, A. Suwandi*
Mechanical Engineering Department, Faculty of Engineering Universitas Pancasila
*agrisuwandi@univpancasila.ac.id

Abstract. The purpose of this study is to improve the efficiency of production time for the manufacture of radiator components by performing gating system design optimization. The production data obtained is used as data to examine cases that occur on the production floor. The method of analysis is used to perform simulations on the design of the gating system that already exists, and then compare the results with the new design. The existing gating system design has two cavities while the new design has one cavity. Based on the simulation results, the two cavity gating system has a cooling time of 5 seconds longer than gating one cavity. As a result of longer cooling time, the product can be attached to the mould so difficult removable and can lead to defective products. The percentage of air trapped in the new design is 3.12%, whereas, from the previous design 19.29%, this can cause a reduction in potential defects in porosity in the product.

1. Introduction
The manufacturing industry has a very broad coverage. Almost all sectors need a manufacturing industry to support their activities. These sectors include agriculture, transportation, economy, trade, and many other sectors. In the transportation sector, the easy to find manufacturing industry is the automotive field that produces vehicles with a variety of shapes and uses. Vehicles produced include motorcycles, cars and trucks [1]. One of them is a component made of aluminium material. This material was chosen because of its low price and lightweight. Besides, that aluminium can be easily obtained, and the production process that is often found is casting. Casting is the formation of a product by melting the main material into molten then put into die. The casting process for aluminium material usually uses a high-pressure die casting, sand casting and gravity casting process.

The design of a casting product in high pressure die casting has several parts including biscuit, runners, sub-runners, gates, products, overflow, gas vent and chill event. A well-designed runner and gating system is very important to produce good quality die castings by providing a homogenous mould filling pattern. Flow analysis of the component is done in order to analyse the cavity filling process visibly [2]. One of the key elements to make a metal casting of high quality is the design of a good gating system. The gating system refers to those channels through which the metal flows from the ladle to the mould cavity [3]. For the optimum design of the gating system, the study of the filling process is of great significance since it directly affects casting quality. The goal of proper mould filing cannot be achieved without proper gating design which influences the flow pattern, further affects the temperature distribution and modifies the progression of solidification [4]. Beside that when manufacturing HPDC mould, generally, the casting layout design should be considered based on the relation among injection
system, casting condition, gate system, and cooling system [5]. Gating system design must be very effective in actual manufacturing facilities to avoid the occurrence of such defects [6]. Based on the research, the gating system has an important role not only in the smooth production but also in the manufacturing process.

This study aims to improve the efficiency of the radiator component production time by changing the gating system. The part production uses high pressure die casting method. Data is obtained based on the actual results of production during 2017 to provide an explanation of the condition of the part's production. The data is obtained from a gating system that uses two cavities in a single production process. The focus of this research is to design the gating system of one cavity due to the use of the existing gating system, production efficiency is not achieved and the waste in terms of molten material used in the casting process. In addition, the construction of dies also plays a role in contributing problems during production. This is evidenced by the percentage of downtime, the type of problem and the production capacity that does not reach the target. Calculated based on existing conditions, the same as producing with the number of cavity one.

2. Method and Materials
Investigate that die casting is a versatile manufacturing technique where liquid metal is poured into die. The tie consists of core and cavity is the main challenge in die casting design and manufacture of dies. Design and analysis integration results in better results [7]. Perform computer simulations to analyze liquid metal flow and analyze effective die designs. Optimal conditions are calculated through simple equations that are examined using experimental output [8]. Focusing research on the design phase of dying for car components made of aluminium alloy (ADC12). The design phase for die casting involves the selection of discrete design parameters namely, the gate area, gate speed, gas vent position and also the defect properties of the casting [9]. Investigate gating systems that are very important for die casting, but designing a gating system is an iterative process that can be very time consuming and expensive. The aim is to develop a design system that helps realize the automatic generation of geometry gating systems by applying parametric designs. With such capabilities, die designers can combine their expertise into the design process at an early stage and make the initial gating system design more like their final design [10].

2.1. Modelling of Case Comp Thermo
Case comp thermo (see Figure 1) is the part used as a radiator component in the car. This part will be assembled with a Thermo Cover which has several other parts in electrical terms. The initial design of Case Comp Thermo uses Solidworks. The parting line is made to separate parts from the fixed and movable die. Then, the appropriate draft angle is given on both sides of the parting line to ensure the part easy removal from the die.

![Model of Case comp thermo](image)

**Figure 1. Model of Case comp thermo**

2.2. Die Design Calculations
There are several things that must be calculated to design the gating system for simulation, among others part projected area, overflow area, runner area. Beside that calculate the filling ratio for injection and also machine tonnage [9].

- Total Part Projected Area = (Part Projected area) + (Overflow Projected Area) + (Slide Projected Area)
• Runner Projected Area = (Part Projected Area) + (30-40% More)
• Total Projected Area = (Total Part Projected area) + (Runner Projected Area)
• Tonnage of Machine = (Total Projected Area) + (Casting Pressure) + (Die Locking Force)
• Shot Weight = (Weight Per Cavity) + (Runner + Biscuits)
• Filling ratio = \( \frac{\text{Shotweight}}{(\text{Plunger Area})(\text{Active Length})(\text{Density})} \)
• Cavity Fill Time \( (t) = KT \frac{T_i-T_f+sz}{T_f-T_d} \)

Where \( K \) is Empirical constant; \( T \) is casting thickness (mm); \( T_i \) is a temperature of moulded metal as it enters the die (°C); \( T_f \) is Minimum flow temperature (°C); \( T_d \) is temperature of die cavity surface (°C); \( S \) is allowable % solid fraction (%), its selection depends upon casting thickness, and \( Z \) is units conversion factor.

2.3. Data preparation

Data is taken from the production during 2017 which is related to production downtime and the types of problems that exist in the die and compared with the calculation of capacity made in planning the production of the part. Table 1 is downtime data which has obtained.

| NO | Month | Break Down Machine | Dies Problem | Process Problem | Molten Problem | Another Problem |
|----|-------|-------------------|--------------|-----------------|----------------|----------------|
| 1  | January| 795               | 960          | 1085            | 675            | 0              |
| 2  | February| 135              | 1160         | 590             | 30             | 0              |
| 3  | March  | 130               | 1575         | 1410            | 10             | 0              |
| 4  | April  | 40                | 1025         | 605             | 0              | 0              |
| 5  | May    | 385               | 1000         | 1690            | 155            | 70             |
| 6  | June   | 215               | 1200         | 1165            | 375            | 70             |
| 7  | July   | 240               | 1700         | 1670            | 235            | 0              |
| 8  | August | 480               | 930          | 275             | 895            | 0              |
| 9  | September| 400              | 860          | 1900            | 55             | 130            |
| 10 | October| 200               | 1905         | 1640            | 80             | 0              |
| 11 | November| 270              | 5170         | 1110            | 15             | 0              |
| 12 | December| 470              | 2730         | 1075            | 565            | 20             |
| Total | 3760            | 20215         | 14215         | 3090            | 290            |

In Table 1, the highest downtime type is dying problem which reaches 20,215 minutes a year or around 55.4 minutes per day. Almost every month, die problems become the highest problem experienced by Cases Comp Thermo die and the biggest in November is 5,170 minutes. Below will be explained about the type of problem die that often occur. In table 2, the highest problem is that the core problem reaches 5,430 minutes. Casting product design will determine the construction of dies to be made. To find out whether the design has been maximized it can be simulated in advance so that it can minimize the problems that will occur during production.

From the production capacity on table 3, there are 254 units of production per day. Total downtime per day is 80.22 minutes or 4,813 seconds. Cycle time for casting 47 seconds. Because in one casting cycle there are 2 parts, the cycle time is considered 94 seconds. Part wasted due to 4,813 production downtime: 94 = 51.2 or 51 pieces. So that the parts produced were 254 - 51 = 203 pieces. In other words, the achievement of production is only 79.9% of the needs. So that to meet production targets, companies need additional time to produce part casting by increasing working hours or shifting production schedules of other parts that can disrupt its production schedule and pay for overtime manpower and the use of supporting resources such as casting machines, melting machines, electricity, etc. Besides that
the next process will be disturbed, such as machining, painting and assembling, not to mention the defects that will be generated from the process that can reduce achievement and disrupt delivery to customers.

**Table 2. Type of case comp thermo die problem**

| No  | Month       | Over He at | Part Stick y at Cavity | Cavity y surface not flat | Cooling Dies | Core Problem | Flash | Adapt or | Chipped | Insert Pin | Thic k Scra ps | Under cut |
|-----|-------------|------------|------------------------|--------------------------|--------------|--------------|-------|----------|---------|------------|----------------|----------|
| 1   | January     | 155        | 70                     | 0                        | 10           | 145          | 105   | 41       | 170     | 180        | 50             | 75       |
| 2   | February    | 120        | 15                     | 390                      | 0            | 180          | 0     | 31       | 290     | 0          | 0              | 165      |
| 3   | March       | 260        | 330                    | 0                        | 20           | 425          | 0     | 40       | 10      | 430        | 0              | 100      |
| 4   | April       | 115        | 0                      | 10                       | 160          | 30           | 25    | 370      | 30      | 355        | 0              | 30       |
| 5   | May         | 205        | 40                     | 0                        | 30           | 180          | 0     | 35       | 30      | 355        | 0              | 160      |
| 6   | June        | 130        | 315                    | 0                        | 135          | 110          | 120   | 26       | 100     | 200        | 0              | 0        |
| 7   | July        | 145        | 185                    | 10                       | 170          | 0            | 34    | 360      | 500     | 270        | 60             |          |
| 8   | August      | 185        | 420                    | 0                        | 30           | 0            | 24    | 0        | 220     | 0          | 25             |          |
| 9   | September   | 55         | 205                    | 0                        | 35           | 235          | 0     | 31       | 50      | 125        | 155            | 0        |
| 10  | October     | 15         | 230                    | 0                        | 880          | 30           | 37    | 85       | 210     | 375        | 75             |          |
| 11  | November    | 150        | 785                    | 0                        | 65           | 2350         | 30    | 380      | 780     | 80         | 540            |          |
| 12  | December    | 135        | 655                    | 170                      | 0            | 595          | 40    | 43       | 345     | 600        | 20             | 110      |
|     | Total       | 167        | 3250                   | 560                      | 345          | 5430         | 355   | 413      | 2055    | 397        | 0              | 950      |

**Table 3. Calculation of case comp thermo production capacity**

| No  | Part Name             | Depreciation setting | Basic Calculation Capacity (Depreciation Setting Base) | Production Capacity vs Depreciation Setting (%) | Initial MAX Production Unit per Day | HWI delivery day |
|-----|-----------------------|----------------------|------------------------------------------------------|------------------------------------------------|-----------------------------------|------------------|
|     |                       |                      | CT (s) Working Time (H) Daily Production Capacity (unit) Working Days Monthly Production Capacity (unit) |                                                  |                                   |                  |
| 1   | CASE COMP THERMO      | 2AG                  | 91,350 2,538 15% 115 21.25 254 21 8 5334 52.43% 203.2 181 |                                           |                                   |                  |
| 2   | CASE COMP THERMO      | 2CF                  | 103,950 2,888 15% 115 21.25 254 21 8 5334 45.87% 254 206 |                                           |                                   |                  |
| 3   | CASE COMP THERMO      | 2MD                  | 239,481 6,652 15% 115 21.25 593 21 8 12453 46.58% 593 475 |                                           |                                   |                  |
| 4   | CASE COMP THERMO      | 2AG                  | 91,350 2,538 15% 115 21.25 236 21 8 4956 48.80% 188.8 181 |                                           |                                   |                  |
| 5   | C.C. WATER OUTLET     | 2CF                  | 103,950 2,888 15% 55 21.25 236 21 8 4956 41.74% 236 206 |                                           |                                   |                  |
| 6   | C.C. WATER OUTLET     | 2MD                  | 239,481 6,652 15% 55 21.25 532 21 8 11172 40.46% 532 475 |                                           |                                   |                  |
| 7   | C.C. WATER OUTLET     | 2MD                  | 239,481 6,652 15% 55 21.25 650 21 8 13650 51.27% 520 475 |                                           |                                   |                  |
| 8   | SLIDER COMP TENSIONER | 2CF                  | 103,950 2,888 15% 65 21.25 280 21 8 5800 50.89% 224 206 |                                           |                                   |                  |
| 9   | COVER THERMO          | 2AG                  | 91,350 2,538 15% 32 21.25 304 21 8 6384 60.25% 243.2 181 |                                           |                                   |                  |
| 10  | COVER THERMO          | 2CF                  | 103,950 2,888 15% 32 21.25 304 21 8 6384 54.77% 304 206 |                                           |                                   |                  |
| 11  | COVER THERMO          | 2MD                  | 239,481 6,652 15% 32 21.25 609 21 8 12789 47.98% 487.2 475 |                                           |                                   |                  |

Note: Rejection rate of 15% is the total process from beginning to end
3. Results and Discussion

3.1 Draft Angle Analysis
Draft angle analysis is done to ensure that sufficient drafts are provided when designing casting parts (see Figure 2). The minimum draft angle from 1 to 1.5 degrees is given in the parts on both sides of the parting line.

![Figure 2. Draft angle analysis of case comp thermo](image)

3.2 Die Calculations
Table 4 shows the results of calculations from equation 2.4 calculation results are used as input from the magma simulation parameters.

| No | Item                | Value   | No | Item                | Value     |
|----|---------------------|---------|----|---------------------|-----------|
| 1  | Weight Part         | 0.704 kg| 6  | Sleeve length       | 380 cm    |
| 2  | Total Projection Area | 266,273 cm² | 7  | Volume Sleeve       | 14624.11 cm³ |
| 3  | Shot weight         | 1408 gr | 8  | Filling ratio       | 40%       |
| 4  | Ø Plunger tip       | 70 mm   | 9  | Metal Pressure      | 700 Kgf   |
| 5  | Area Tip            | 36.32 cm² | 10 | Machine Tonnage     | 233.34 Ton |

![Figure 3. Shot weight](image)

Figure 3 as shown the gating system for 1 cavity or the shot weight. The runner is the path or groove through which the metal liquid from the distributor reaches the product area which has the role of giving direction to the metal liquid to fill the entire cavity area. Biscuit is the formation of liquid metal that will change solid or freeze in the area between the die sleeve and the distributor. The chill vent is a part to efficiently remove the remaining air or gas from the inside out of the cavity.

3.3 Simulation Analysis
The simulation results of the two cavity gating system and one cavity describe on Figure 4 and 5. This simulation uses Magmasoft which is used for mould filling and solidification analysis [11]. From the simulation results of the gating system (see figure 4 and 5), it was found that in two cavities, the molten flow at the end of the shot, the product has several areas that are potentially hot and other areas are already cold.
This can also affect the quality of the product that will be made. The solidification process that occurs in the two cavity gating system takes longer to occur; this can be seen in the colour of the simulation results due to the runner's longer distance compared to one cavity in passing the product part. So that potential defects in the product can occur. Whereas when viewed from the results of the simulation of one cavity, the results tend to be better which is shown from a fairly stable colour.

Solidification is an integral part of the casting process. During compaction, the casting structure is generated. Because many castings are used in as-cast conditions (that is, without further thermal or mechanical processing), the structure resulting from solidification, the as-cast structure, is often also the final structure of the casting. It also follows that the mechanical properties of casting, which are a direct consequence of microstructure, are controlled through a process of solidification [10].

4. Conclusion

Research and simulations have been carried out to obtain the results of a new gating system design that will be used to improve the production efficiency of radiator component products with simulation results on a one-cavity gating system that is better than the current design for production. This can be seen from the colours produced by the simulation. In two cavities the simulation results have many colours that explain instability during the casting process where cycle time and solidification are not concurrent so that the potential problems in the product are more numerous. The results in one coloured cavity are more stable, so there is less potential for problems in the production.

5. References

[1] Information at https://www.astra.co.id/Business/Automotive, 2018.
[2] Ramnath, B. V., et al., Analysis and Optimization of Gating System for Commutator End Bracket, 2014. pp: 1312 – 1328.
[3] Ezparza, C. E., et al., Optimal design of gating systems by gradient search methods, 2006. pp: 457-467.
[4] Ingle, P. D., Narkhede, B. E., A Literature Survey Of Methods To Study and Analyze The Gating System Design for Its Effect on Casting Quality, pp : 5421-5429, 2017.
[5] K.K. Seo , H.K. Kwon , Simulation study and application on HPDC process with automobile part, Adv. Mater. Res. 658 (2013) 281–286.
[6] Lee, B. D., et al., Optimization of Gating System Design for Die Casting of Thin Magnesium Allot Based Multi Cavity LCD Housings, 2011.
[7] M. R. Bodhayana, N. Ramesha. Tool design for pressure dies casting of Housing Component. Int J Theor and Appl Res in MechEngg, 3:(2), pp. 30-33, 2014.
[8] B.S. Sung, I.S. Kim. The moulding analysis of automobile parts using the die-casting system. JMateriprocetech, 20-I, pp: 635–639, 2008.
[9] Vispute P. R., et al., Utilizing flow simulation in the design phase of a die casting die to optimize design parameters while validating through experimentation during trials, 2017. Volume 1 Issue 8, pp: 263-269.
[10] Stefanescu, Doru Michael, Science and Engineering of Casting Solidification, Second Edition, Ohio, Springer, 2009.
[11] Dabade, Uday A., Bhedasgaonkar, Rahul C., Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique, pp: 616-621, 2013