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Casting Layout Design using CAE Simulation with Automotive Part (Oil Pan)

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Abstract
Background/Objectives: One of the main methods for mass production in modern industry era is the die-casting process. The mold-filling process of aluminum die-casting is important and very complex because of the high speed of liquid metal. In fact, it is almost impossible to calculate the exact mold-filling performance using experimental knowledge in parts with complex features.

Methods/Statistical analysis: Casting Layout is a plan of a holistic casting method of how to design a cavity in a mold, how to design a runner, gating, etc. and how molten metal can smoothly fill the mold cavity with the proper over-flower and air-vent for gas extracts to obtain a complete product. In order to solve those casting problems, CAE simulation widely used at the industrial sites is applied in this casting layout study.

Findings: The system that fills the molten metal into the mold cavities is one of the most important factors that affects the quality of the casting and the various problems that occur in the casting processes. The filling analysis of CAE simulation found the gates size, their location, and the runner system design. And also internal porosities caused by air-isolated area were predicted and reduced with modifying the gate and runner system and the overflows configuration.

Improvements/Applications: The layout designs of a casting product had been used by the heuristic know-how based on a trial-and-error process. The solution achieved in this scientific calculation and analysis save a lot of the fabrication cost and time of the die casting mold and also are applied in the die casting mold design and fabrication process.

***Keywords:** Oil Pan, Gate System, Casting Layout, CAE Simulation, Flow Analysis*.

1. Introduction

In the latest global market competition, automotive parts technology had been developing with the goal of improving fuel economy, stability, convenience, durability and emissions reduction, and is also a technology-intensive industry that requires various requirements and technology convergence from consumers. The lightweight technology of automotive parts is critical for technology development as it is a key fundamental technology that improves fuel cell performance of future vehicles, such as hybrids and electric vehicles, to meet overseas emission regulations. The key technology for lightening of automotive parts is to apply alternative application technologies for steelmaking, which are traditionally used as automotive parts materials, to parts and materials such as non-ferrous metals such as aluminum and magnesium, and polymeric materials such as plastic materials [1,2,3].

The die casting technique is a mass production technology that minimizes the post process and can manufacture complex shaped parts in a single step. It is an important manufacturing technology that is widely applied to various industries with a focus on automotive parts as it is very advantageous in terms of cost. High dimensional stability, such as automotive parts and electronic components, and competitive high-quality, low-cost, and single-delivery equipment required for mass production are seen as the best manufacturing methods. However, such die castings require more advanced mold making techniques such as high temperature of molten metal, high pressure on the mold surface, complexity and precision of the product shape [3,4,5]. In addition, the basic quality problems can lead to poor appearance and internal defects due to the flow of molten metal and poor internal pressure. However, it should be avoided because the foundry system itself changes easily with these corrective actions, and it is desirable to modify the casting layout after careful consideration when other measures cannot be addressed in advance [6,7].

CAE technology, which is widely used at industrial sites to solve these problems, is widely applied to the die casting area. Casting methods should be designed in consideration of the mold layout, extrusion system relationships, casting conditions, design of the gating system of the mold, etc. In addition, the degree or location of product defects caused by castings are varied depending on different casting methods. Recent advances in CAE technology have allowed to omit many of the existing trial and error processes in the manufacture of casting molds. As a result, production costs and period of production were reduced and high quality casting parts could be produced [7,8,9].

As shown in Figure 1, an oil pan is an automotive part that attaches to the underside of an engine block. An oil pump pumps oil that lubricates the automobile engine and then is returned into the oil pan. The oil pan used in this study is generally applied with ADC12 types of aluminum, and the oil in the oil pan is heated by the automobile engine by lubricating the engine. In this study, to optimize the casting layout design of automotive oil pan, CAE simulations were performed with three layout designs using CAE simulation software (AnyCasting). Three casting layouts were reviewed using AnyCasting to minimize the internal air porosities of the casting part and ensure the stability of the quality. Analyzing the simulation results of the filling process, we are going to explore the method of fault control for filling defects, and derive the best casting layout for applying in the die casting mold design and fabrication process.

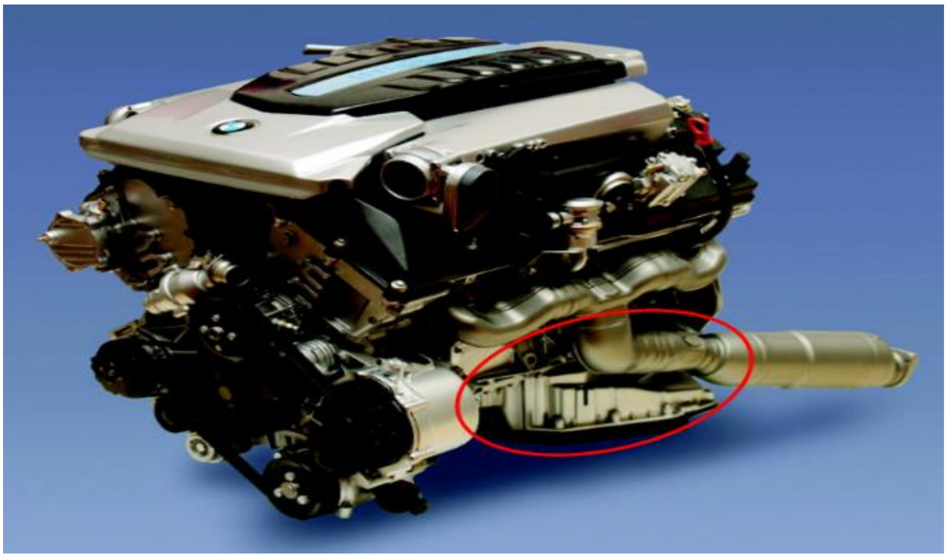

Figure 1. Image of the engine module with Oil Pan [10]

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2. CAE Simulation Of Die Casting Process

Commercial packages (Anycasting) used to optimize casting designs were developed by AnyCasting Co., LTD, and a hybrid method combining the PM (Porous Media) method and Cut-Cell method that complements the shortcomings of conventional FDM (finite difference method) rectangular mesh. More accurately improve mold filling analysis and improve calculation speed by 50% or more by reducing mesh number. [11]. Compared to several other commercial packages, AnyCasting has the ability to develop user-friendly routines that describe dependent boundary conditions. The CAE simulation process using AnyCasting is illustrated in Figure 2. During the pre-process by using converted STL files, groups of materials such as castings, overflows, runners, gates, and molds are formed.

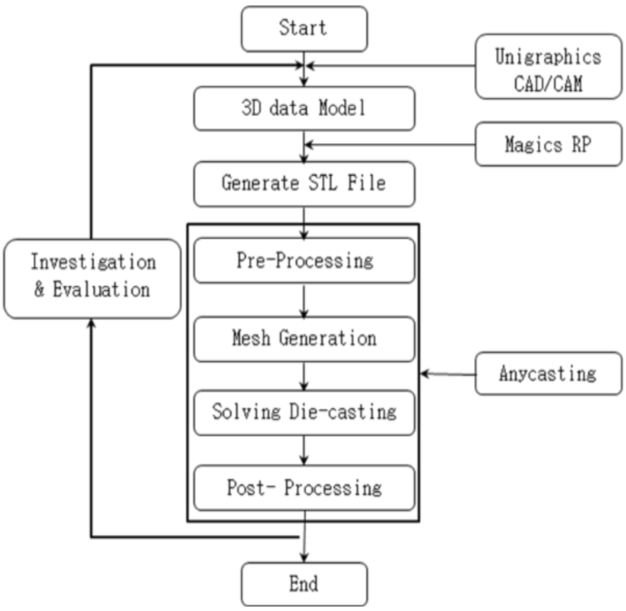

Figure 2. Flow-Chart of the die casting simulation

2.1. Numerical Model of Die Casting Process

The fast movement, the flow of the molten metal in the die-casting process, of plunge in the chamber generates the high pressure. AnyCasting, which employs a hybrid method to analyze the flow of the molten metal, had been designed for analyze 3D fluid flow with the free surface and boundary. Any non-Newtonian and non-linear rheological properties are generally applied on the flow of the molten metal. In making the modeling of the filling process, three phenomena are modelled with melt momentum balance, mass balance and energy balance [9, 12, 13]. The following governing equations describe the mentioned phenomena:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_j) = 0 \tag{1}$$

Momentum equation (Navier-Stokes):

$$\frac{\partial}{\partial t}(\rho U_i) + \frac{\partial}{\partial x_j}(\rho U_j U_i) = \frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}(\mu \frac{\partial U_i}{\partial x_j}) + \rho g_i \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial t}(\rho C_p T) + \frac{\partial}{\partial x_j}(\rho C_p U_j T) = \frac{\partial}{\partial x_j}(\lambda \frac{\partial T}{\partial x_j}) + Q \tag{3}$$

Volume of Fluid (VOF):

$$\frac{\partial F}{\partial t} + U_j \frac{\partial F}{\partial x_j} = 0, 0 \le F \le 1 \tag{4}$$

Where: t-time(s), x-space(m), p-density(Kg/m^3), u-kinematic viscosity(m^2/s), g-gravity(Kgf), C_p-heat capacity(J/K), λ-conductivity(W/m^{2}K), F-volume(m^3), U-velocity(m/s), T-temperature (^{o}C, K), T_s-solid temperature (^{o}C, K), and Q-heat source (^{o}C, K).

2.2. Geometry Model of CAE Simulation

STL formats are made by converting from CAD models as shown on the flow chart in figure 2. For the filling and solidification simulation, STL models are imported directly into AnyCasting software. Figure 3 shows 3 different gate designs used for finding out the best result. The case 1 comparing with case 2 and 3 has 7 ingates and 10 overflows. The case 2 has 5 ingates by removing and relocating some ingates and 10 overflows by relocating some overflows and overflow-lines on the both side of the part. With the further modification, the case 3 has 4 ingates and 12 overflows by changing their location and adding 2 overflows on the left side of the part.

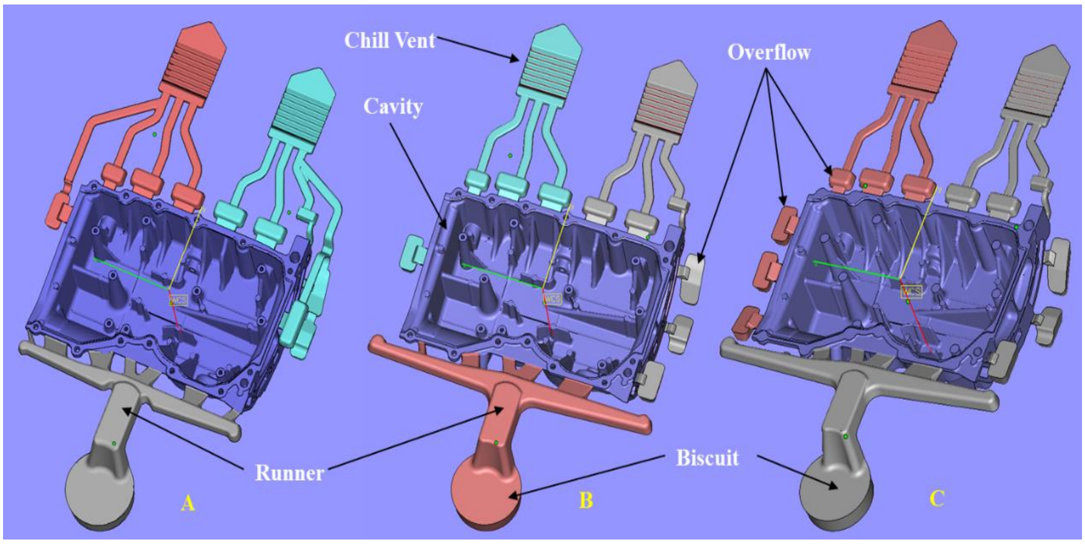

Figure 3. Casting model of Oil Pan. (A) Case 1, (B) Case 2, (C) Case 3

2.3. Condition of CAE Simulation

The casting material used in CAE simulation is ADC12($AlSi_9Cu_3$), and the detail analysis conditions applied in CAE simulation are shown in Table 1. The mold material is SKD61 described on Table 2. The initial temperature of the molten metal was set at 630^{0}c, the preheating temperature at the beginning of the mold was set at 180^{0}c, and the mold temperature during casting was set at 280^{0}c. The die-casting machine has a cold chamber type of 1,200 tons clamping force and a plunge of 120mm diameter(Φ). With a low-speed injection speed of 0.9m/s and a high-speed injection speed of 3.5m/s, the injection zone is set

Table 1: Condition for the CAE simulation

Part		Mold		Plunger	
Material	ACD12	Material	SKD61	Diameter	120mm
Liquidus Line	580°C	Initial Temperature	180°C	Slow Velocity	0.90 m/s
Solidus Line	515°C	Casting Temperature	280°C	High Velocity	3.50 m/s
Initial Temperature	630°C	…	…	Length	850mm
Weight for casting	5,502g	…	…	…	…

Table 2: Chemical composition (%) of SKD61

C	Si	Mn	P	S	Cr	Ni	Mo	V
0.32-0.42	0.80-1.20	<0.50	<0.03	<0.03	4.50-5.60	…	1.00-1.50	0.80-1.20
W	N	Cu	Co	Pb	B	Nb	Al	other
…	…	…	…	…	…	…	…	…

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to a two-stage injection condition. In the process of mesh formation, mesh generation was made by the unequal-interval element division, and the total number of mesh used in the analysis was 37,900,000.

3. Results and Discussion

A very important factor affecting the quality of the product and the life of the casting mold in the filling process is the flow velocity of the molten metal. If the filling speed is slow, high heat loss causes defects such as misrun, cold cut, etc. However, if the filling speed is too fast, the mold life is shortened by promoting abrasion in the mold cavity on the joint of the gates, runner, etc. In general, if the internal porosities of the product determine the quality of the product, the filling speed is slowed. This is to provide time for internal air to be discharged from the outside through overflow while the molten metal is filled inside the mold. On the other hand, if the appearance of the product determines the quality of the product, the speed of filling is accelerated to encourage the enhancement of the product appearance [13,14].

3.1. Flow analysis of CAE Simulation

Figure 4 shows the filling behavior of the molten metal for each casting layout. The two-stage injection velocity was established empirically by considering the optimal mass production conditions of similar products and the characteristics of the products. To minimize the internal porosity of the product, the point at which the speed from the low speed (0.90 m/s) to the high speed (3.50 m/s) is switched is set at the time when the mold cavity is completed about 5% after filling the runner and the ingates.

As shown in Figure 4, the melt filling process can be seen that the filling is smooth without the occurrence of the misruns and cold shuts of the molten metal. In case3 of casting layout, compared to other casting layouts, the flow of molten metal can be observed to flow uniformly. It can be seen that the air-isolated position, which

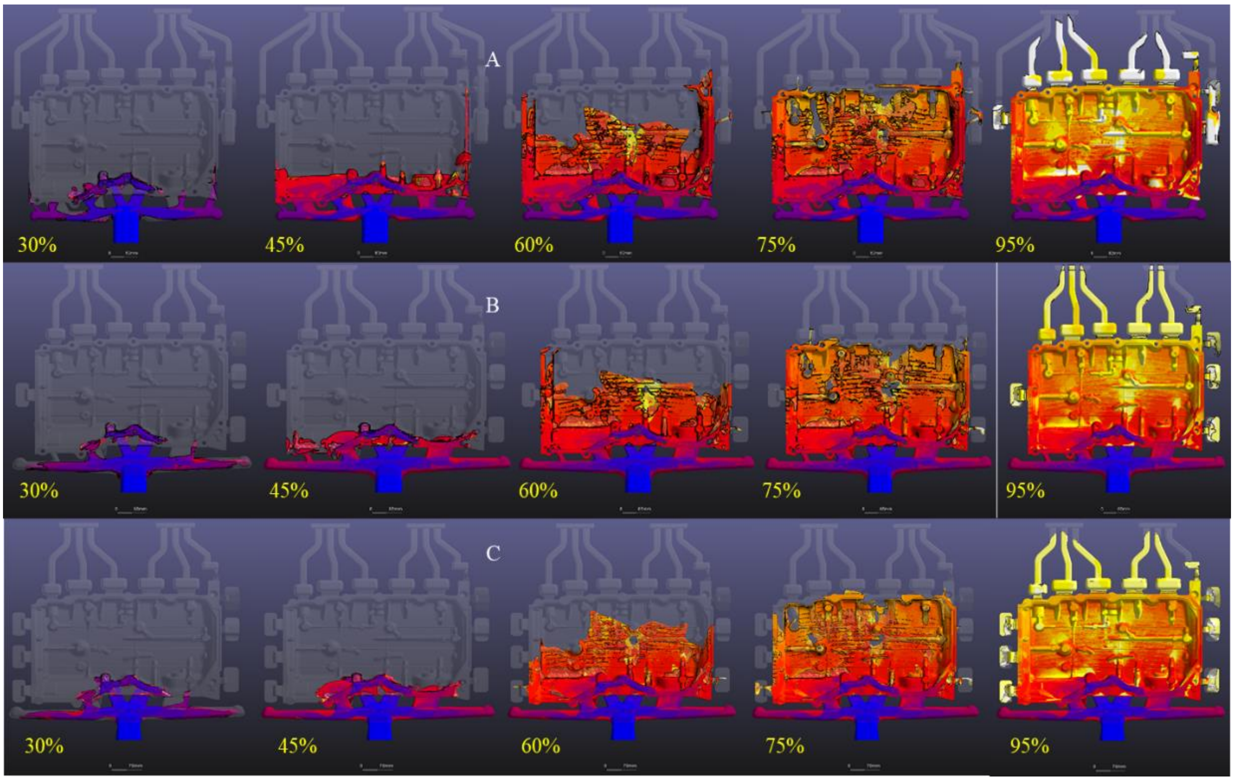

Figure 4. Simulation results of the melt filling process: (A) Case 1; (B) Case 2; (C) Case 3

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may occur during filling, is less visible in case 3 than in other casting layouts. We can also see that the filling is relatively even compared to other casting layouts.

flow. Therefore, casting layout 1 is considered to be inappropriate.

Based on the results of casting layout 1, the improving alternatives are produced on Figure 6.

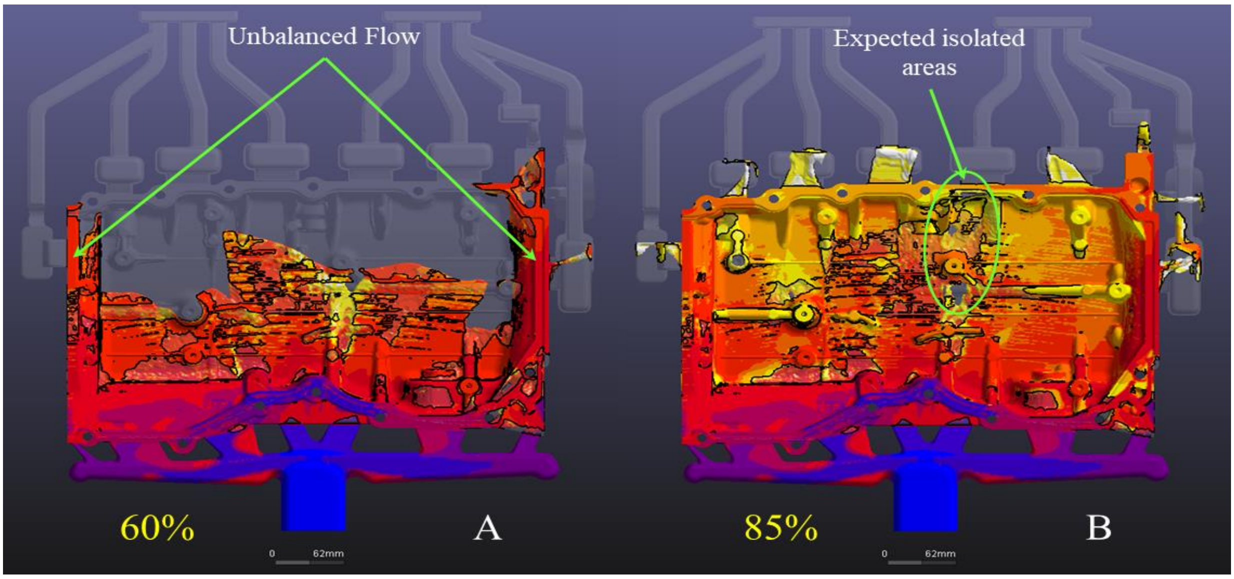

Figure 5. Simulation results for the melt flow of Case 1: (A) 60% filling; (B) 85% filling

3.1.1. Flow analysis and Improvement of Case 1

Figure 5 shows the results of 60% and 85% filling behavior in casting layout 1. As shown on figure 5A, the melt flow at both edges is not uniform with the internal melt flow and can generate an internal air-isolated area. As filling behavior shown in figure 5B, the internal air-isolated location is expected to 85% of filling behavior in casting layout 1 due to an imbalance in the melt

Figure 6A eliminates unnecessary overflows and their lines and also indicates modification of the runner corner. In order to improve the flow balance of the molten metal, figure 6B shows the correction of the ingate direction (G3 and G6) and the elimination of the unnecessary ingates (G1 and G7). Based on the improvement of figure 6, figure 3B of casting layout 2 was designed.

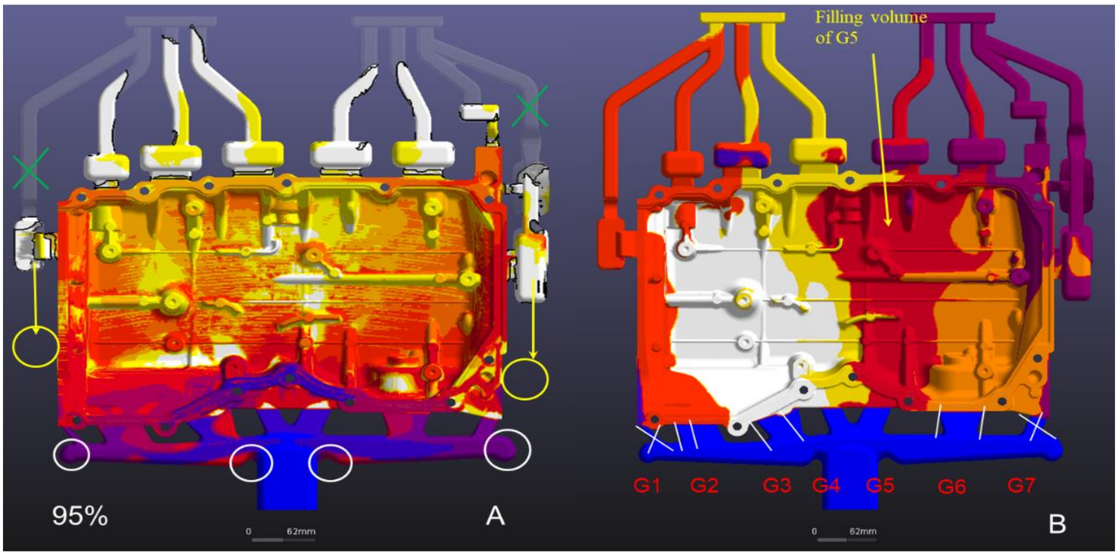

Figure 6. Modification of case 1: (A) Melt flow; (B) Flow tracking

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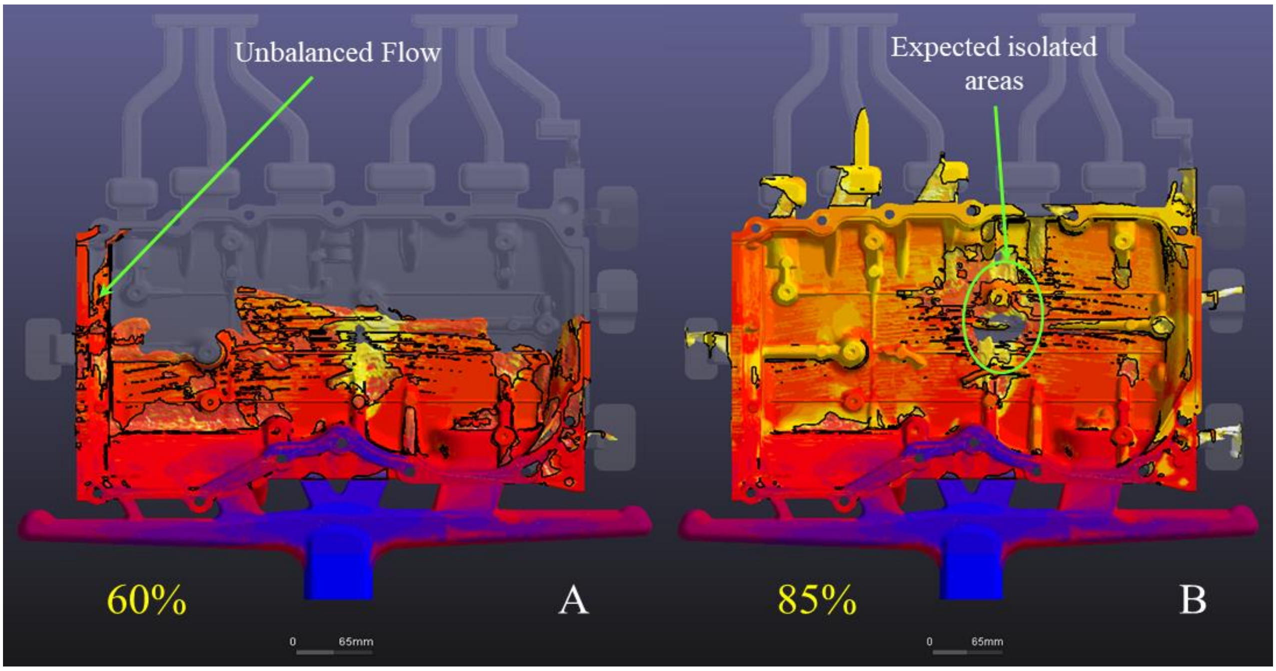

Figure 7. Simulation results for the melt flow of Case 2: (A) 60% filling; (B) 85%filling

3.1.2. Flow analysis and Improvement of Case 2

Figure 7 shows the results for the filling behavior in casting layout 2. Comparing the flow balance of the casting layout 1, the balance of the melt flow of casting layout 2 is much better but the imbalance of the melt flow is still present at the edge after 60% filling shown on Figure 7A. In addition, because of the imbalance in the melt flow, the inside air-isolated location is expected in a little area similar to case 1 shown 85% filling behavior of figure 7B. Therefore, it is deemed that casting layout 2 is not appropriate.

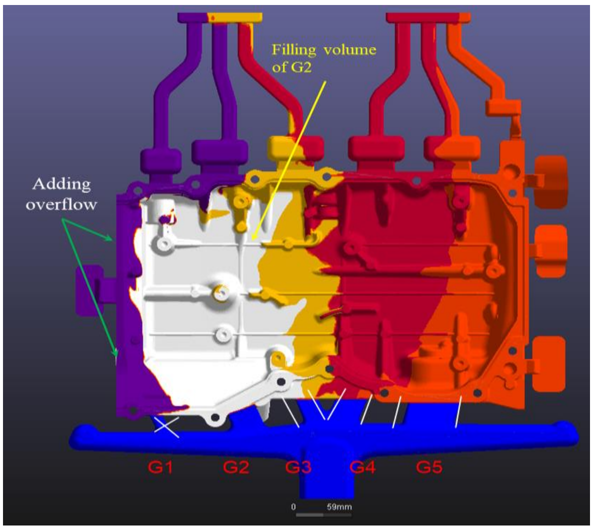

Figure 8. Simulation results of the flow tracking for case 2

Based on the results of casting layout 2 on figure 7, figure 8 shows the further improving alternatives of casting layout 2. For improving the air-vent for gas extracts on the melt filling, 2 overflows were added on the left side of the part. In order to improve the flow balance of the molten metal, the unnecessary ingate (G1) was removed, ingate size (G3) changed for 23.6mm to 32.5mm, ingate size (G4) changed for 31.8mm to 33.8mm, and ingate size (G5) changed for 32.9mm to 38.7mm. Based on the improvement of figure 8, figure 3C of casting layout 3 was designed.

As shown on figure 4C, relative to other casting layouts, the melt flow is relatively uniformly filled. In addition, it can be seen that the melt flow in casting layout 3 is uniformly flowing, resulting in less air-isolated location than other casting layouts that can occur when filling the molten metal.

4. Improvements of the final casting layout

According to the flow analysis on figure 4, the results of the casting layout 3 represent the best comparing to other casting layouts. Nevertheless, some improvements were observed in casting layout 3. Figure 9A shows the results of the filling behavior after 80 % filling on the fixed side. As

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shown in Figure 9A, it is observed that the air-isolated location appears weak at the center and edge end of the product. For further improving the problems associated with the air-isolated area observed in Figure 9A have improved significantly.

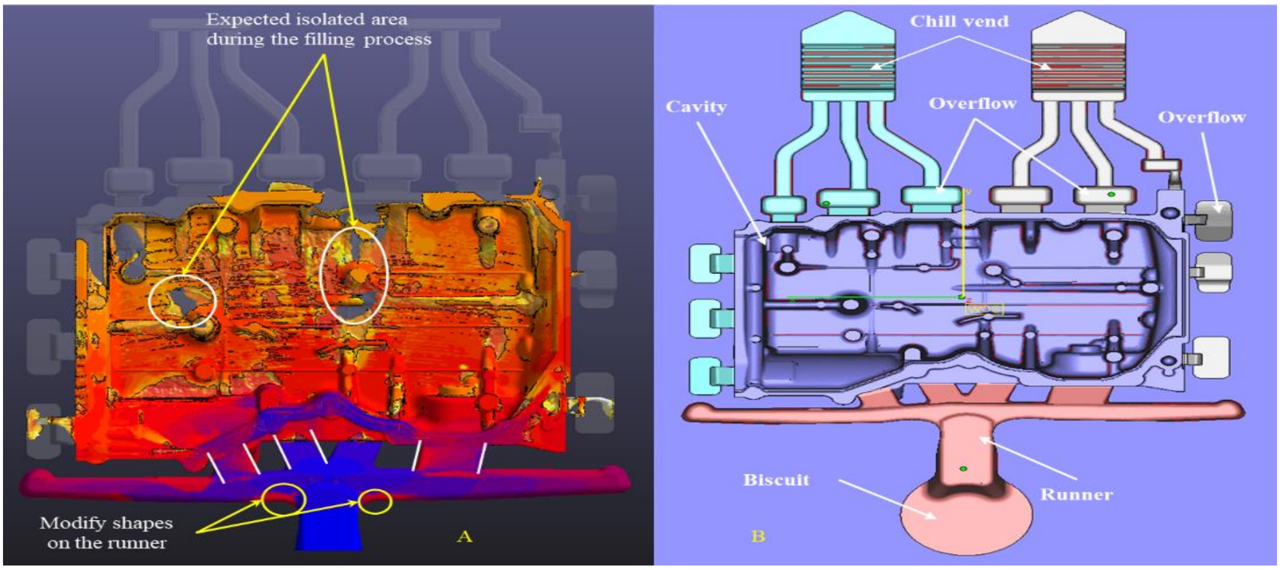

Figure 9. (A) 80% filling process on the fixed side of Case3; (B) Final casting design

flow balance, the size of the ingates (G1 and G4) were increased about 0.5mm to fill up the molten metal into the air-isolated area and also the size of the ingate (G2) was increased about 2.2mm to be similar to the size of the ingate (3). The design of the final casting layout is shown in figure 9B.

In the flow Analysis results with the final casting layout as shown in the figure 10, its judgement for the melt flow is more evenly than the casting layout 3. In addition, it is considered that the

5. Conclusion

Using the flow analysis program(Anycasting) with the several casting layouts of automobile part (Oil Pan), the following results are achieved through the flow analysis.

1) According to the flow analysis results, the air-isolated location and the melt flow are properly identified. The direction and the number of ingate are also distinguished properly based on the few casting layouts. It is deemed that the result can be

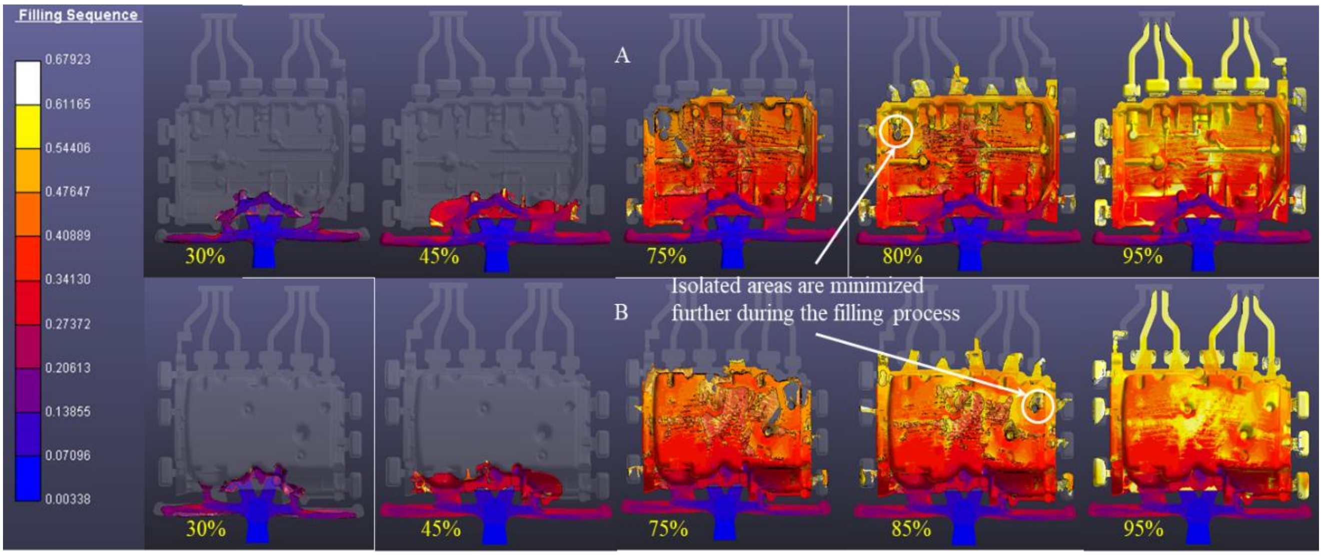

Figure 10. Simulation results with the final casting design: (A) Moving side; (B) Fixed side

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used to properly eliminate the problems caused by the imbalance in the melt flow.

2) According to the flow analysis result, the melt flow of the final casting layout is judged to be even and uniformly other than casting layouts (1, 2 and 3). The micro segmentation air-isolated location that occurs in the final casting layout was also identified. It is considered that establishing the proper position of the ejecting pin during the mold development process will greatly reduce the trial and error of the different types occurred on the casting processes and shorten the period of mold development.

3) According to the flow analysis result, the confluent location of a melt flow is properly identified and the installation positions of the overflow are optimized to discharge proper the inside air pockets. Applying the results can save time and cost of the post-process for the casting product.

6. Acknowledgment

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