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Parametric Study for Runner Modifications of Die Casted Part with Venting Systems

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Abstract: High-pressure die casting (HPDC) is a process used for creating complex components by injecting the molten metal inside the cavity at high pressure. Failure in die casting may reduce product mechanical properties, surface quality, and life cycle. In this paper, the die-casting process of an inspection instrument - test piece is investigated for parametric study and Computational fluid dynamics (CFD) analysis. Parameters used in the die-casting process are important since it affects the molten flow quality inside the cavity. Thus, a parametric study is done to investigate the optimum parameter use in the die-casting process of the test piece. Runner gating system design is also one of the important criteria to maintain the quality of products. This paper also investigated the effect of runner gating system design optimization in reducing gas porosity. The CT scan of the sample mold is included to compare the relationships between gas porosity occurrence with CFD results. This paper proposed a new runner design named outward curvature runner with an air vent that can improve velocity and temperature distributions in reducing die-casting defects. In addition to that, air vents are installed to extend the volume and promote higher suction, to eliminate gas bubbles entrapment inside the cavity.

Keywords: Porosity occurrence, parametric analysis, numerical analysis, design optimization

1. Introduction

Demand for metal injection molding (MIM) has been increasing for years, the growth is due to the capabilities of this manufacturing process to produce complex products while minimizing waste [1]. The advancement in technology and industrial revolution progress is important to manufacture die-casted parts economically and effectively in mass production. V-LINE®SYSTEM is a system used in the industrial injection molding process which separates plasticization and injection cylinders, filling the exact volume of molten metal, and providing heat and maintaining temperature for better fluid injection [2]. It is important for the manufacturer to confirm the quality of the die-casting process to minimize casting defects and improve productivity.

1.1 Casting Defects

High-speed injection of molten metal into the cavity in the die-casting process can cause backflow of molten metal which can lead to air bubble entrapment in the melt, forming pores or voids on the surface of the products. The air entrapment causes gas porosity defects in high-pressure die casts. As a result, the product is vulnerable to voids due to poor tensile strength and ductility [3]. Other than that, when the molten metal solidifies inside the mold, it always shrinks in volume. Shrinkage porosity happens when some part of the molten metal with high temperature solidifies

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later than other surrounding sections, and insufficient molten metal to completely fill the sections. As a result, high cooling rates cause shrinkage to the cast product [4]. Turbulent flow also affects casting defects. Turbulent flow happened due to the chaotic velocity flow of molten metal after passing through a small cross-sectional area of the runner gate. The curve generated at the runner gate helps better flowing of molten metal into the mold cavity [5]. Thus, the optimization of the runner gating system design could help to reduce the chaotic velocity flow of molten metal.

1.2 Factors Affecting Die Casting Process

Vacuum die casting theoretically can help to reduce gas entrapment during molten metal injection, because the low surrounding pressure can help to suck the air bubble out from the cavity. The reduction of gas entrapment can eliminate the porosity defect and produce high-quality products. As a result, the tensile strength and elongation of die-casting products will also be improved [6]. From this case study, the installation of overflow and air vents is crucial to optimize the volume fraction of air distribution. The parametric study will show the effect of low operating pressure on temperature and the percentage of air entrapment. Air vents are thin cross–sectional area cavity help to promote air circulation, where trapped air flows when the mold cavity is fully occupied. It helps to reduce air entrapment that causes porosity to die-cast parts. The larger the air vent gap, the better air circulation, and the greater reduction of porosity microstructure [7].

The runner gating system is an entrance for the molten metal flowing from the runner to the cavity. In designing a mold, the gating system should be optimized to allow better fluidity flow of molten metal into the cavity. Poor gating systems can cause porosity such as gas entrapment and shrinkage porosity [8]. Flat gating systems can lead to turbulent flow and non-uniformed filling of molten metal in the die cavity [9]. Lower thermal conductivity is the physical properties of Magnesium compared to Aluminum, making molten Magnesium transfer heat to the wall cavity relatively easier [10]. Magnesium alloy is chosen in the manufacturing industry due to its excellent fluidity behavior and high resistance towards hydrogen peroxide, thus it produces a better-quality casting over aluminum and copper [11].

1.3 Test Piece

In this paper, the sample used to run this study is a test piece shown in Figure 1. A test piece is an inspection instrument with a ladder shape to conform 90° angle edge. The test piece is in dimensions of 200 mm x 100 mm with 4 mm, 8 mm, 12 mm, and 16 mm thickness.

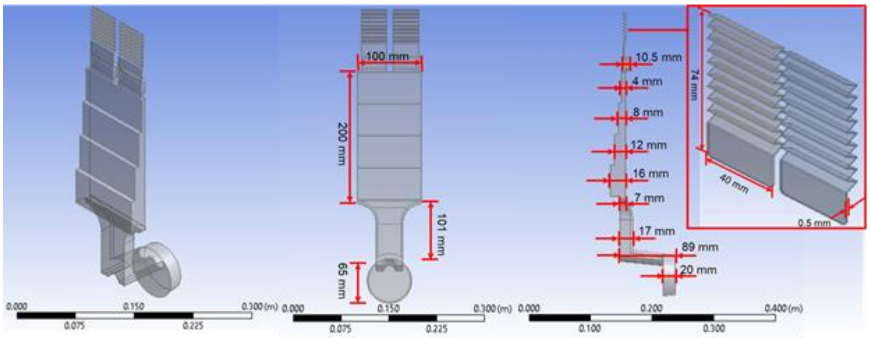

Fig. 1 - Test piece with air vents

2. Methodology

Figure 2 shows the experimental analysis using a non-destructive evaluation method using a Computed Tomography (CT) scan of the Magnesium die-cast sample mold retrieved from the Kyokuto die-cast [11]. The results of the experimental analysis in Figure 3 show purple dots indicate the porosity occurrence at 8 mm depth from the test piece surface. A higher percentage of porosity can be seen in the cross-sectional view of the 16mm thickness. The modification objective in this paper is to reduce the porosity formation at the critical point (8mm depth of 16mm thick part) and improve the fluidity of molten metal in the cavity. Table 1 shows the summarization of the experimental analysis results obtained by using the Nikon X-ray CT machine -XT: H225 Series Interior. The results conclude the defect results at 8 mm depth at a different thickness of the test piece. In this research, CFD software is used for designing and conducting parametric and numerical analysis. To optimize the molten metal fluid behavior in the mold cavity and reduce porosity defects as shown previously in Figure 3, the runner design is modified, and air vents are introduced. Using the optimization mold cavity design, a parametric study is implemented to analyze the optimal temperature, inlet velocity, and operating pressure during the die-casting process. Optimal input parameters such as die temperature and initial molten metal temperature and velocity do affect the good cast quality and promote a high production rate [12]. Input parameters used in the die-casting process of the test piece in the industry are presented in Table 2.

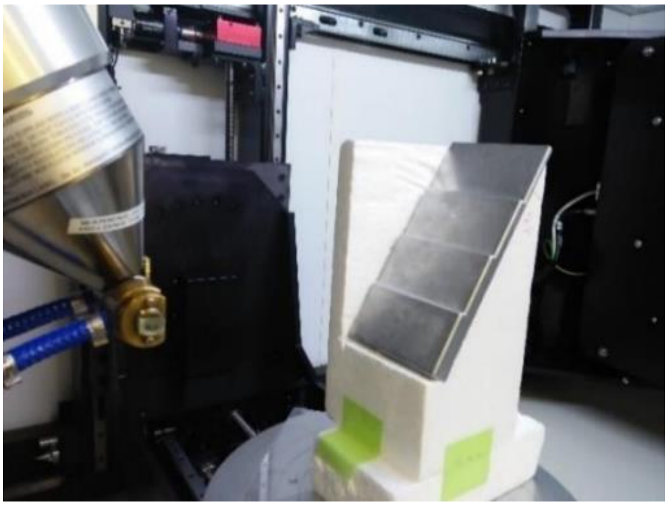

Fig. 2 - Nikon x-ray CT machine XT: H225 Series interior

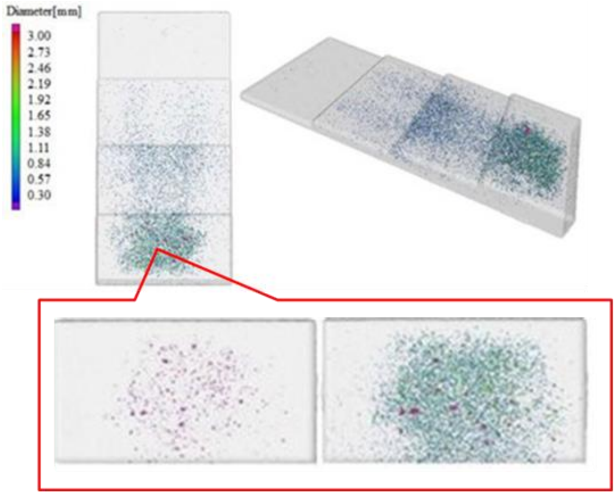

Fig. 3 - Sample mold CT scan

Table 1 -Test piece x-ray CT scan defect result

Test piece thickness	4 mm	8mm	12mm	16mm	Total
Material volume [mm^3]	20, 000	40, 000	60, 000	80,000	200,000
Defect volume [mm^3]	1.0174	0.1024	0.7129	47.73	49.56
Defect Percentage [mm^3]	0.0005	0.0001	0.0003	0.0239	0.0248

3. Parametric Analysis

24 simulations were conducted by modifying the parametric values that were selected. The selected parameters to be modified are the inlet velocity of molten metal and the operating condition. The operating condition represents the suction pressure from the venting systems and also represents vacuum assisted die-casting process. The lower the pressure of operating condition, means the greater the suctions. The low surrounding pressure inside the cavity will suck the gas bubbles out from the molten metal, leaving the location of high pressure of molten metal (the critical location point). Placing liquid metal as a vacuum medium also could cause the metal biofilm to expand and increase the buoyancy and allow the gas-form metal to float on the surface during melting, rather than be trapped inside the molten metal [13]. The outcome numerical results are tabulated into a set of data consisting of the pressure at the critical point and temperature at the critical point as shown in Table 3.

The collection of data from Table 3 is then plotted into a three-dimensional graph that represents them. Figure 4 illustrates how the modification of the inlet velocity of the molten metal and operating conditions could lead to changes in the pressure of the molten metal at the critical point. The manipulated variable in the study is the inlet velocity and operating condition. Based on Figure 3, as the inlet velocity of the molten metal increases, the pressure of the molten metal at the critical point increases too. This increasing amount of pressure of the molten metal at the critical point is more desirable as high pressure helps in dispersing the air bubble trap in the die cavity out toward the overflow and air vents. The high pressure also represented the high concentration of molten metal at the critical point, low air entrapment, thus the temperature also increasing. Meanwhile, Figure 5 shows the result of the temperature of the molten metal at the critical point when the modification of inlet velocity and operating condition takes place. The increasing inlet velocity of molten metal also results in the increasing temperature at the critical point, due to heat generation from high frictions. Despite of high pressure of molten metal at 100 Pa and 3.0m/s, the temperature is much lower than in operating pressure below 10 Pa, this help to reduce the solidification rate and manufacturing time.

Table 2 -Test piece die casting input parameters

Mold Material: H13 Steel (Hot Work Tool)	
Specific Heat Capacity	460 [J/kg·K]
Density	7800 [kg/m^3]
Thermal Conductivity	24.3 [W/m·K]
Die Temperature	438.15 [K]
Preheat temperature	473 [K]
Thermodynamic Parameters	
Temperature of fluid	971 [K]
Inlet velocity	2 [m/s]
Properties of the Molten Metal	
Cast Material: Mg	
Density	1740 [kg/m^3]
Dynamic viscosity	0.00123 [Pa·s]
Specific Heat Capacity	1020 [J/kg·K]
Thermal Conductivity	156 [W/m·K]
Modulus of Elasticity	45 [G·Pa]
Poisson's ratio	0.29
Melting Range	470-598 [°C] (AZ91)
Cast Material: ADC12	
Density	2820 [kg/m^3]
Dynamic viscosity	0.0013 [Pa·s]
Specific Heat Capacity	963 [J/kg·K]
Thermal Conductivity	92 [W/m·K]
Melting Range	525-570 [°C] (ADC12)

4. Numerical Analysis

According to the sample mold CT scan shown previously in Figure 3, a high percentage of porosity defects are focused on the area of the test piece part which has a thickness of 16 mm, the thickest part of the test piece. The porosity defects are affected by the uneven flow direction of the molten metal flowing out from the runner gating system which eventually reduces the molten velocity. Consecutively, gas bubbles are trapped in that area when solidification occurs. The modified design, outward curvature runner with air vent solved this issue. The outward curvature runner was designed with a generated curve and runner facing outward for better fluid flow out from the runner to the cavity. The flow of molten metal behavior is analyzed based on CFD flow simulation.

Figure 6 shows the temperature contour of the inner part of the test piece that was cut through at the midpoint of the 16mm test piece thickness, and 20 mm distance apart on both sides. Results obtained illustrated that the high localized temperature of molten metal in the sample mold is estimated to be around 722.7 K to 762.1 K. On the contrary, the high localized temperature of molten metal with the proposed outward curvature runner with air vents cavity has a much lower temperature range, which is 683.3 K to 722.7 K. The high-temperature region will solidify later than the remaining surrounding sections, trapping air bubbles. As a result, the different cooling rates can cause shrinkage to cast products and increase porosity defects due to un-uniformed solidifications. An incomplete fluid filling will cause gas bubbles and gas porosity. An extensive thermal difference of molten metal will also cause cracks, burn marks, and flow marks. Lowering the temperature value could avoid the molten to absorb unnecessary gas bubbles. The outward curvature proposed design promotes better solidification.

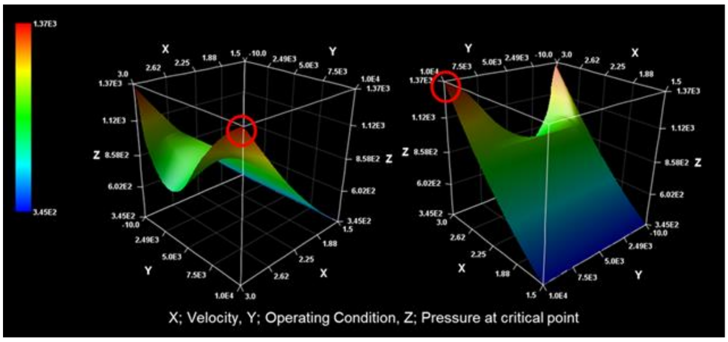

Fig. 4 - 3D graph of pressure at a critical point

Table 3 - Parametric analysis results from Ansys simulation

Velocity [m/s]	Operating condition [Pa]	Pressure at critical point [kPa]	The temperature at critical point [K]
1.5	-10	345,250	672.48
	-5	345,250	672.48
	10	345,250	672.48
	100	345,250	672.48
1.75	-10	468,847	686.01
	-5	468,850	686.01
	10	468,850	686.01
	100	468,850	686.01
2.0	-10	612,751	705.13
	-5	612,750	705.13
	10	642,750	705.13
	100	612,750	705.13
2.25	-10	773,571	721.35
	-5	773,570	721.35
	10	773,570	721.35
	100	773,570	721.35
2.5	-10	953,259	736.19
	-5	953,260	736.19
	10	953,260	736.19
	100	953,260	736.19
3.0	-10	1,345,780	751.36
	-5	1,345,800	751.36
	10	1,345,800	751.36
	100	1,371,800	733.05

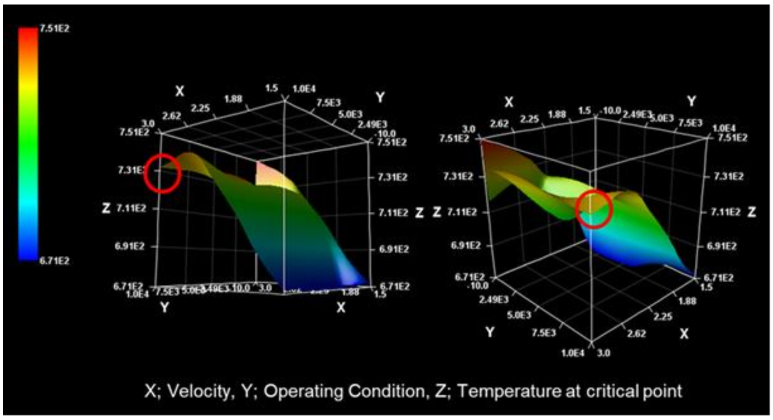

Fig. 5 - 3D graph of temperature at a critical point

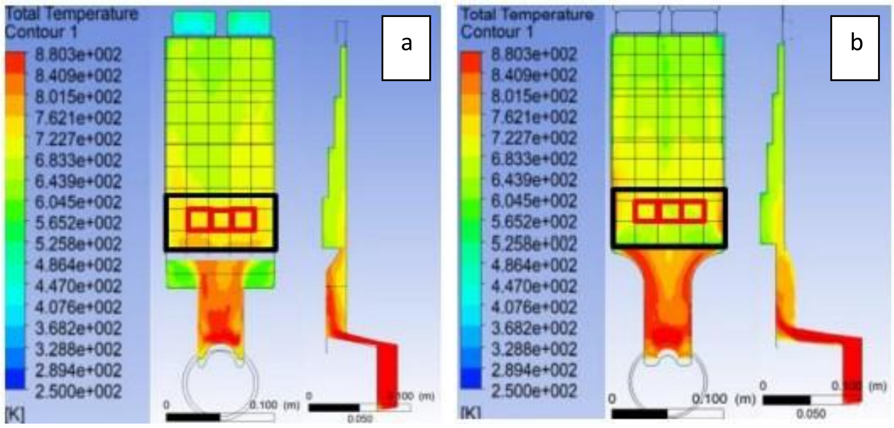

Fig. 6 -Temperature contour for (a) sample mold; (b) outward curvature runner with air vent

Shown in Figure 7(b) is the balanced filling of molten metal inside the cavity for outward curvature runner mold with air vent design. The velocity streamlines are more consistent and evenly distributed compared to the original sample mold design, shown in Figure 7(a). A well-distributed velocity allows a balanced total temperature distribution of molten metal inside the cavity. The modified design eliminates the vortex formation compared to the original sample mold. The modified design also promotes better filling of molten metal, improves the work done by fluid, and enables potential absolute filling. In addition to that, the high molten metal velocity indicated by the red region at the air vent at the top of the mold design shown in Figure 7(b) compared to Figure 7(a), allows fluid to disperse air from the main casting. Extended volume by introducing air vents also promotes higher suction due to the lower pressure inside the air vents. Installation of air vents helps to reduce turbulent flow while keeping the molten fluid velocity higher than in the sample mold which allows molten metal to disperse gas particles of the main casting. Reducing the turbulent flow in Figure 7(b) signifies molten metal flow in an improved direction, dispersing gas bubbles away from the cavity.

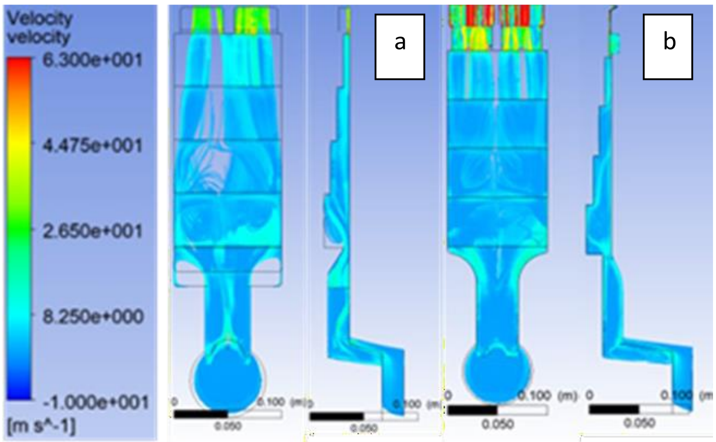

Fig. 7 -Velocity streamline distribution for (a) sample mold; (b) outward curvature runner with air vent

5. Conclusion

A parametric study has shown that, as the inlet velocity increase, the pressure at the critical point will also increase, thus the high pressure could help to disperse the air bubble from the molten metal leaving a high concentration of molten metal at the critical point. The higher the pressure at the critical point, the higher the temperature of molten metal since more friction heat is generated. The high temperature at the critical point will cause a slower solidification rate, however, at 100 Pa and 3.0 m/s, the temperature is slightly lower even though at high pressure, which can help in reducing the manufacturing times. At a certain condition, the vacuum-assisted die-casting process can reduce the pressure at the thickest point since a high vacuum can cause a turbulent flow of molten metal, which leads to backflow and gas entrapment. In numerical analysis, the high-localized temperature of molten metal will cause a crack, burn mark, and flow mark. The high-temperature difference will also lead to inconsistencies in solidification rates which may lead to incomplete filling when some part of molten metal starts to solidify without completely filling the mold cavity, as can be understood from the vortex formation of the sample mold analysis. The incomplete filling will cause gas bubbles entrapment which leads to gas porosity defects. The vortex formation also leads to reductions in molten metal velocity. Outward curvature runner shows a different approach to mold casting, with the runner facing outward, and the curve generated at the runner gate inlet. The runner effectively increases molten metal velocity and molten metal temperature distribution. Furthermore, air vents also promote higher suction due to lower pressure inside the air vents.

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