Effect of the Processing Parameters on the Shrinkage Defect Using A High-Pressure Die-Casting Process

by Dwi Rahmalina

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Abstract. Effects of the processing parameters of a high-pressure die-casting (HPDC) process on the shrinkage defect of housing block compressor (HBC) were examined in this research. Because of the reduction of defect can increase the productivity of HBC that representing a good quality product, the processing parameters determining the quality of product must be optimized. In this study, the processing parameter of high speed in the range of 3.97 to 4.97 m/s and that of fast start point in the range of 293 to 333 mm were calculated and then the HBC samples of using the Al alloy of ADC12 were produced through the HPDC process. The shrinkage defects on HBC were characterized by visual inspection, radiography testing and microstructure examination. The result showed that the best parameters for reducing shrinkage defect of HBC by the HPDC process are 4.97 m/s of high speed and 313 mm of fast start point. The optimum parameters of high speed and fast start point were verified to contribute to producing a high quality of the HBC for the applications in automotive engine.

Keywords: High pressure die casting; Fast start point; High speed; Shrinkage defect.

1. Introduction

Quality of the casting product is an important factor in producing a superior manufacture product, due its competitiveness in the market. This has motivated the manufacture world doers to compete in innovating and to strive for various ways to achieve this goal. One of the ways to increase productivity of the production line is to increase the good quality products and reduce the ratio of not good quality products (*NG In-Process*). The casting technology has been developed to optimize the parameter of the casting process. High Pressure Die Casting (HPDC) is a shape manufacturing process and has been used to produce many automotive components. The molten metal is injected into metal mold at high speed and solidified under high pressure [1-2]. The HPDC products have high dimensional precision and elevated production efficiency, also significant financial profit for automotive industries [3-6]. However, components manufactured by HPDC contain defects, such as shrinkage defects, that could decrease their mechanical properties [7,8]. Shrinkage defect is the existence of cavity or trapped air inside a product produced from cast in HPDC production line. The mechanical properties is influenced by filling process and solidification conditions, particularly depends on HPDC parameters such as the condition as pressure applied and the gate velocity [9].

Automotive component, particularly compressor is functioned as an equipment to compress the refrigerant in a car cooler system (Fig. 1). This block compressor consists of 4 main components; they are Front Housing, Front Cylinder, Rear Cylinder, and Rear Housing. This block compressor is using ADC12 material as the raw material. There is a need to decrease NG (Not Good) product ratio value of compressor dies on 10SRE11 Rear Housing model with minimum standard as much as 1% [10,11]. Therefore a deeper and thorough study on getting the method in reducing the "Not Good" product is required. One thing to achieve is by examining the injection parameter needed to reduce cavity defect on the product, especially high speed and fast start point. High speed (HS) is defined as injection speed of material into mold, while fast start point (FSP) is beginning point of implementing high speed. This research is aiming to study the effect of high speed parameter concerning shrinkage defect on RH 10SRE11 block compressor metal casting; to examine the effect of fast start point parameter toward shrinkage defect occurred on RH 10SRE11 block compressor metal casting; also to investigate the characteristic of shrinkage defect.

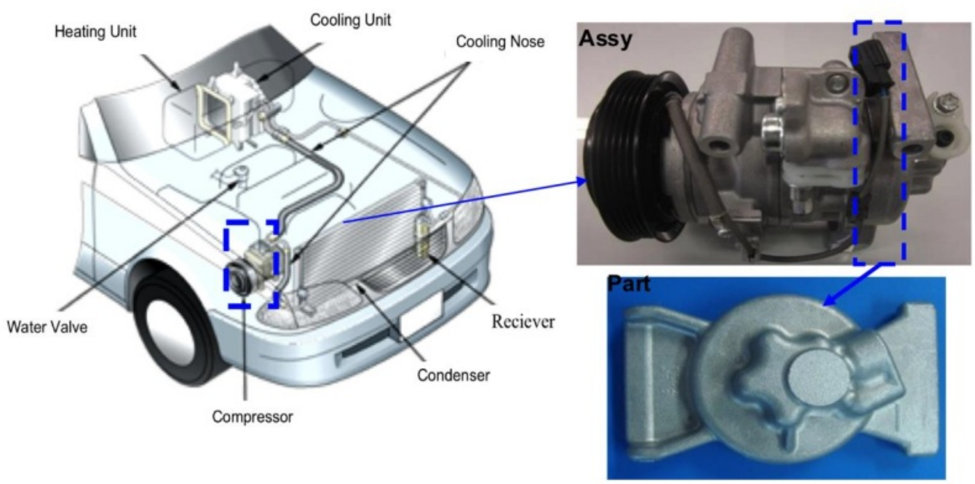

Figure 1. Housing block compressor type 10SRE11.

2. Experimental method

The block compressor was produced using aluminum alloys of ADC12. The steps of processing and research are described in two steps. First, re-calculation of casting aspects so that beginning parameter can be identified, which will be used to prove the formulation. Gating system on the cast in HPDC process consists of 3 cast cavities, as seen in Figure 2 and 3. To achieve an optimum parameter determination, a calculation of high-speed value and fast start point is conducted. Furthermore, a method to determine HPDC parameter in order to obtain optimum parameter will be discussed.

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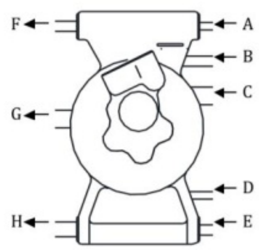

Figure 2. Input and output gating systems of Al alloy on the Cavity produced by block compressor.

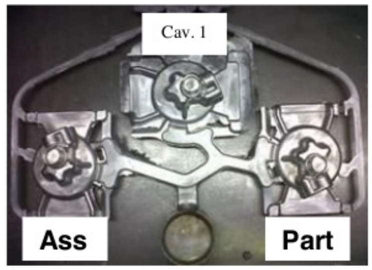

Figure 3. Number of Cavity.

Second step is conducting an experiment on production process of casting RH 10SRE11 with injection systems as shown as Fig. 4, that is by using the beginning parameter re-calculation result, particularly high speed and fast starts point. High-speed effect is presented in Figure 5, showing a schematic picture of a plunger tips movement of injecting the liquid Al material into the die cast. Fast start point (FSP) is the beginning of high-speed point application during the process of pushing the molten aluminum into the cast. Fast start point will be trialed on 3 positions; of which before gate, on the gate, and after the gate (Fig. 6).

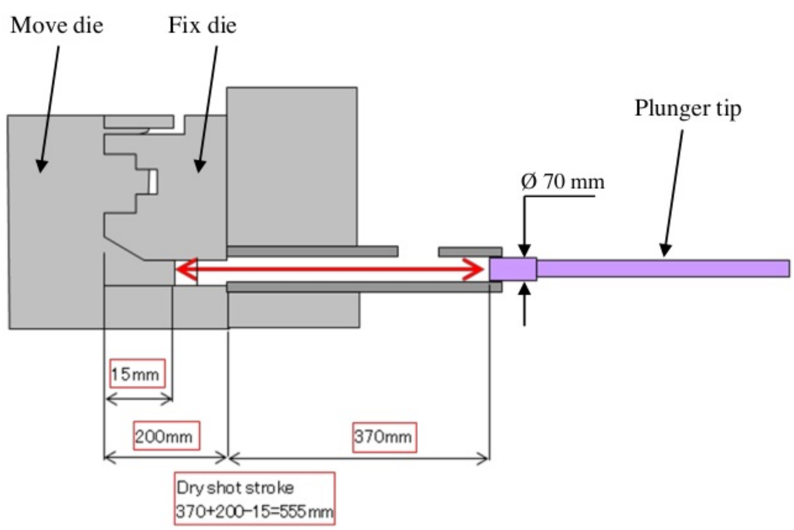

Figure 4. Injection system of molten Al alloy into metal mold using HPDC process.

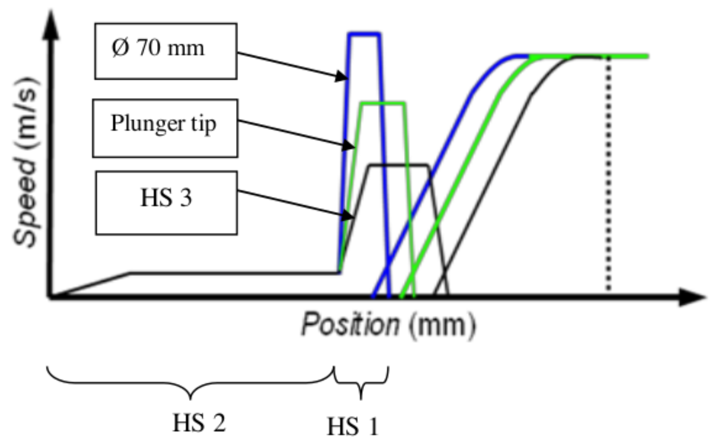

Figure 5. Illustration of high-speed variation of HPDC process on compressor product.

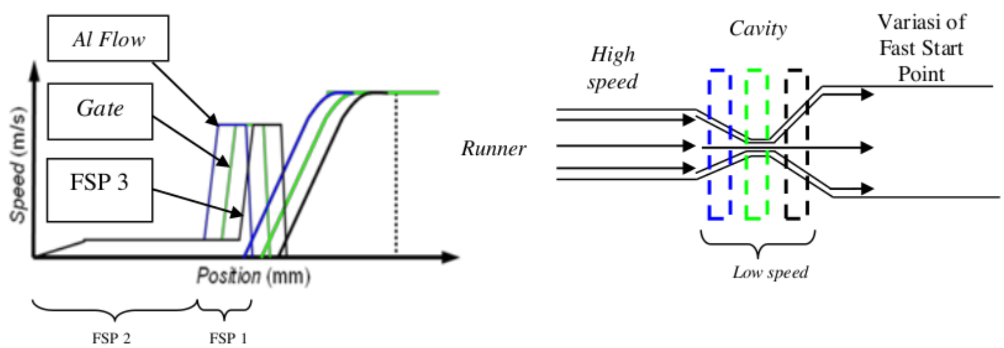

Figure 6. Fast start point on the gate of HPDC process on compressor product.

The parameters of HPDC process are cross section area of gate of 91 mm^2/ cavity; over flow (O/F) of 43.5 mm^2/cavity; diameter of plunger tip of 70 mm, cross section area of plunger tip of 3846.5 mm^2, product weight of 1600 gr (3 cavity); over flow weight of 450 gr; ρ (density melt Al) of 2.4 gr/cm^3 and charging volume of. 284.7 cm^3. Based on these parameters, charging time can be calculated as shown in equation (1).

t (*Charging time lower limit*) $$= k \cdot \left(\frac{T_i - T_f + S \times Z}{T_f - T_d} \right) \cdot X \quad (1)$$

= 0.05206 sec = 52.06 msec

t = *Charging time* (s)
k => 0.0346 s/mm
T_i = Melting temperature on *Gate* (°C) = 632 °C
T_f = Pouring Temperature = 570 °C
T_d = Dies Temperature = 150 °C
S = *Solid rate* = 20 %

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Z = Coefficient of Conversion Unit = 4.8 °C / %
X = Thickness of product = 4 mm

Vp (*lower limit speed injection value*) $= \dfrac{V \times W}{A_{tip} \times t}$ (2)

= 4.27 m/s

Setting lower limit = - 0.2 m/s
Speed requirement = Vp – (setting lower limit)
= 4.47 m/s

Vg (*Gate speed*) $= \dfrac{V_{requirement} \times A_{section\_tip}}{A_{section\_gate} / Cavity}$ (3)

= 62.9 m/s

FSP (*Fast start point*) = Dry shot stroke – biscuit thickness - $\dfrac{W_p(Part + O/F)}{\rho_{Al} \cdot A_{tip}}$ (4)

= 313 mm

Therefore from the beyond calculation, it can be concluded that high-speed value needed is 4.47 m/s and Fast start point value needed is 313 mm.

In this section, the result of the experiment of the research will be addressed by comparing the result of inspection process (visual inspection, radiographic inspection, and microstructure inspection), so that the best result shall be obtained. Parameter 1 will use High speed parameter at 3.97 m/s and fast start point at 293 mm. Parameter 2 will use high speed parameter at 3.97 m/s and fast start point at 313 mm, and so forth until all the parameter are examined.

3. Results and discussion

Below is a summary table of result of visual inspection. Figure 7 shows an example of visual checking result under a condition where a defect is present (O) and no defect (X). From the above observation, it can be seen that speed value with the most no defect condition (O) is (high speed, fast start point) parameter, respectively, (3.97 m/s, 293 mm), (3.97 m/s, 333 mm), (4.47 m/s, 293 mm), (4.97 m/s, 293 mm), (4.97 m/s, 313 mm), and (4.97 m/s, 333 mm). Whereas, parameter with least no defect (O) is (*high speed, fast start point*) parameter, respectively, (4.47 m/s, 313 mm), and (4.47 m/s, 333 mm).

Table 1. Summary of visual inspection examinations.

Fast Start Point		293 mm			313 mm			333 mm		
Cavity No.	.	1	2	3	1	2	3	1	2	3
High speed	3.97 m/s	X	X	O	X	X	X	X	X	O
	4.47m/s	X	X	O	X	X	X	X	X	X
	4.97m/s	X	X	O	X	O	X	X	O	X

Note: X = Defect is Present on compressor
O = No Defect

In the following, radiographic examination will be explained. On this radiographic examination, a comparison of void sizes resulting from each measurement is conducted. The standard used is the values below 15 mm^3 by using reference from the standard of the housing block compressor manufacturer. From the observation, it can be concluded that parameter of the smallest void value is high-speed 3.97 m/s with 333 mm fast start point. Figure 8 explains (a) is a product with minimum void value, and figure (b) is the product with maximum void value.

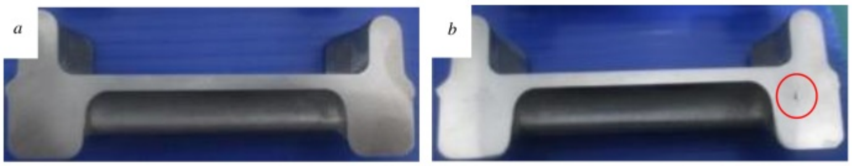
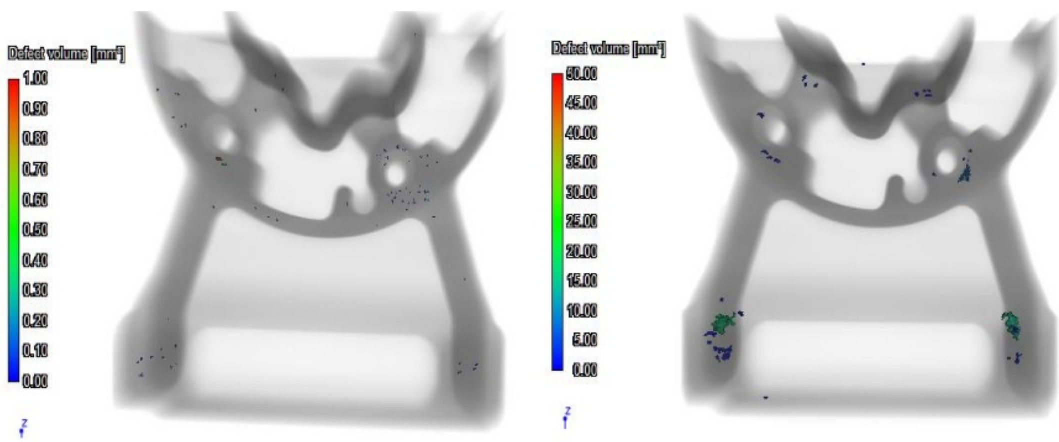


Figure 7. Visual inspection of the block compressor: (a) No defect. (b) Defect is Present.

Table 2. Summary of Radiographic analysis result (in mm^3).

Parameter FSP		293 mm			313 mm			333 mm		
Cav No.	.	1	2	3	1	2	3	1	2	3
Parameter *High speed*	3.97 m/s	56.9	29.9	16.7	50.4	29.2	15.4	39.9	20.9	6.3
	4.47m/s	35.9	36.1	21.0	49.2	42.7	9.9	35.3	28.8	24.7
	4.97m/s	21.1	12.4	12.4	24.5	13.8	10.2	24.3	23.3	13.7



(a) (b)

Figure 8. Radiographic observation image: (a) minor defect, (b) major defect.

In the following, the result of structure micro observation will be explained. From the result, morphology shapes of a microstructure of each parameter will be compared. Figure 9 shows the sample position on which a microstructure observation will be conducted. Each of the samples is observed using 2 types of magnification, which are 100x and 500x. Figure 10 is resulted from 100x magnification. From this figure, it can be seen that the structure on figure (b) is more uniform and homogenous than the structure in figure (b). This explains that figure (b) has an evenly distributed Si Eutectic structure than figure (a). Also from figure (a), it can be seen that a micro shrinkage, which is spread almost every location in figure (b).

Figure 11 describes that the present of dendritic sizes between figure (a) and figure (b) are almost similar. Moreover, micro porosity is also can be seen, which explains that micro porosity is still formed in each of the parameters. Therefore, it can be concluded that this parameter has effect on porosity and shrinkage, which occurred on the sample.

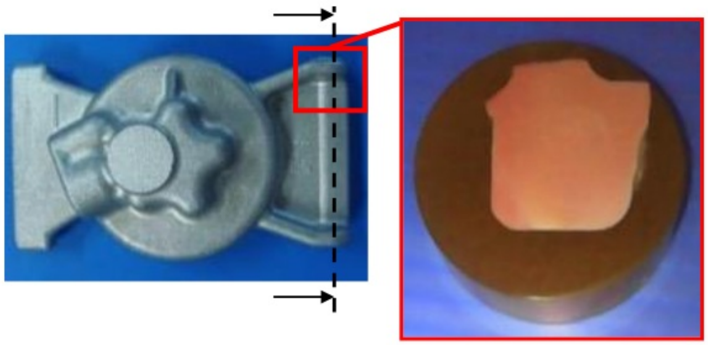


Figure 9. Sample position to examine the microstructure.

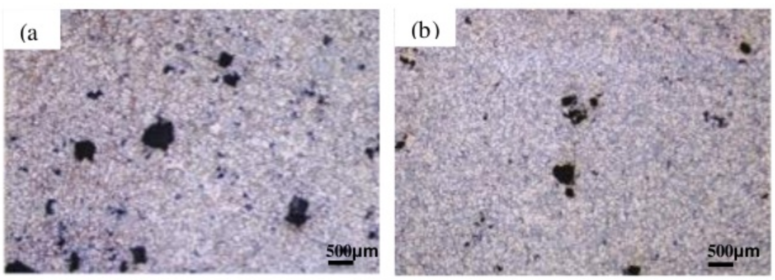


Figure 10. Microstructure of block compressor with HPDC parameters of: (a) 3.97 m/s with 293 mm, (b) 4.97 m/s with 313 mm.

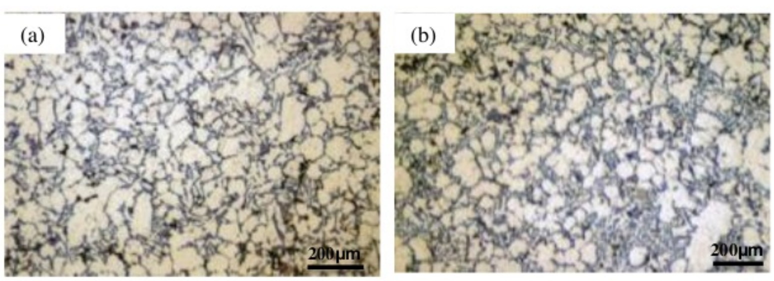


Figure 11. Microstructure of block compressor with HPDC parameters of: (a) 3.97 m/s with 293 mm, (b) 4.97 m/s with 313 mm.

4. Conclusion

From the research in previous chapter, it can be concluded that the result of visual inspection is the parameter with minor defect is 4.97 m/s high speed and 293 mm, 313 mm, and 333 mm fast start point. Radiographic analysis result is the parameter with the small void volume (under 15mm^3) is high-speed

4.97 m/s with 293 mm and 313 mm fast start point. The result of microstructure analysis is the parameter with distributed eutectic silicon grain size is 4.97 m/s with 313 fast start point. Generally the dendritic size is not much different from each of the parameters. The best parameter for manufacturing block compressor is the parameter of 4.97 m/s high speed with 313 mm fast start point.

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