Investigation of Pore-Free Zone in Al Alloy Die Casting Auto Parts

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Abstract

The production of aluminium alloy die castings is increasing in the recent years, because of their low cost, high surface quality and high productivity.[7.2-1] In addition to these features, high internal quality is increasingly required by the users, particularly automobile manufacturers. To meet the requirement, it is necessary to reduce various types of casting defects, among which porosity is most harmful. Porosity occurs typically by air entrapment during mold filling, deteriorating mechanical properties and pressure-tightness.[7.2-2] Also the presence of porosity makes heat treatment for higher strength difficult, because pores may expand at high temperature, causing local deformation of the part. It has long been known that aluminium alloy die castings normally have a pore-free zone at and under the surface.[7.1-1] Problems in mechanical properties or pressure-tightness often occur only when the porous zone near the section center is exposed on the surface after the pore-free surface zone is removed by machining.[7.2-3] Therefore, some, though not all, of the problems may be solved, if the pore-free zone at a critical area can be made thicker than the machining allowance so that the surface remains sound after machining.[7.1-2] From this study, the trust that chilled zone has no porosities is not true. Small porosities can be found in the chilled zone as much as the magnification of the microscopy. Although, pore-free zone is not absent in the real casting but the definition of chilled zone would be redefined.

***Keywords**:* Pore-Free Zone, Aluminium Alloy Die Castings, Pressure Tightness

1. Introduction

The production of aluminium alloy die casting is increasing in the recent years, because of their low cost, high surface quality and high productivity. In addition to these features, high internal quality is increasingly required by the users, particularly automobile manufacturers.[7.2-4] To meet the requirement, it is necessary to reduce various types of casting defects, among which porosity is most harmful. Porosity occurs typically by air entrapment during mold filling, deteriorating mechanical properties and pressure-tightness. Also the presence of porosity makes heat treatment for higher strength difficult, because pores may expand at high temperature, causing local deformation of the part. One solution is to install expensive casting machines equipped with various new features such as vacuum casting or extra-high pressure squeeze casting. When such expensive methods are not feasible, however, we have to try to realize high quality casting with the conventional machines.

The project was conceived at MTEC in an intention to obtain some basic understanding of problems repeatedly arising in aluminium alloy casting industry. Many studies can be found in the literature dealing with the question of porosity in aluminium alloy die castings. Some of them use computer simulation to predict and control porosities. Most of them, however, are concerned with macroscopic porosities occurring near the section centers. On the contrary, we will mostly be dealing with microscopic porosities near the surface, on which only a few studies can be found. A specific feature of the present project is that it focuses on the pore-free zone rather than porous zone. It is, of course, the other side of the same phenomenon. Yet we feel that this change of view point may possibly result in a new finding so far not obtained.

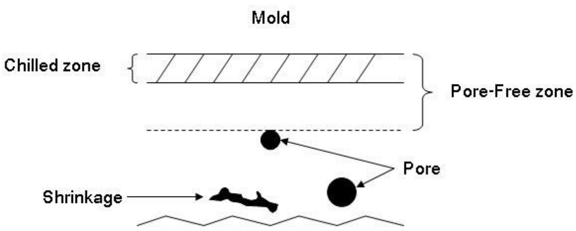

Figure 1 Schematic of Pore-Free Zone

Incidentally the concept of so-called chill zone has been well known in die castings. By definition it is a sub-surface zone consisting of exceptionally fine crystals. Although it is usually free from porosity, its definition is different from our pore-free zone, which may contain any types of crystals but no pores. Customarily the word chill zone has been often used wrongly in the meaning of pore-free zone. We feel the concept of pore-free zone is more productive in terms of engineering significance than that of the chill zone. One of the expected outcomes of the present project is to contribute to a wider recognition of the distinction of the two concepts.

By the way, the project as proposed is only a preliminary stage of an overall scheme to understand the whole picture of the pore-free zone. For instance, high pressure casting is not adopted in the laboratory test at this stage. Nevertheless we expect the results to be useful for obtaining suggestions for application to the practice. For instance, based on the knowledge obtained, it may become possible to locate in-gates for a casting in such a manner that mold filling flow is controlled to secure necessary thickness of pore-free zone at a critical area. The results will also be useful for planning further research.

2. Sample Parts

Quantitative examination of commercial castings was carried out to find out the structure and properties of the pore-free zones. A sample casting from the commercial production was chose to examine using density measurement, optical microscopy, penetration X-ray, heat treatment test, dye-penetrant test, and other methods. Mold-filling flow simulation will be performed to correlate the thickness of the pore-free zone to the flow and solidification behavior.

Figure 2. shows oil filter cover parts that was chose to be the study parts. This parts was formed by the conventional die casting method using a cold chamber die casting machine without any vacuum or a partial squeeze. A die casting mold used for this parts is two-cavity mold.

Figure 2 Study parts

3. Sample Parts Investigation

3.1 Density Measurement

Density measurement was carried out to measure the density of each die casting parts. First, bulk density was measured and each sample was cut to measure the density of each portion for calculation the porosities occurred in sample parts.

Density calculation was conducted by using below equation.

$$\rho = \frac{A}{A+B} \times \rho_0 + d \tag{1}$$

While;

ρ = Density of sample parts (g/cm^3)

A = Weight of sample parts in air (g)

B = Weight of sample parts in water (g)

ρ_0 = Water density (0.99841 g/cm^3 at 19°C)

d = Air density (0.001 g/cm^3)

Density measurement results show each sample part has an average density at 2.66 g/cm^3. That means each sample part contains porosities about 1 cm^3. However, density measurement method used in this study cannot be used to define the type of porosities. Therefore, shrinkage porosity and gas porosity cannot be judged by this method. Anyway, from X-Ray examination described later shows isolated porosities and can be considered as gas porosities.

Table 1 The density of sample parts A-E before blister test

Sample Parts	Density (g/cm^3)	Porosity (%)	Porosity (cm^3)
A	2.672	1.037	1.012
B	2.663	1.370	1.335
C	2.669	1.148	1.118
D	2.669	1.148	1.120
E	2.658	1.556	1.522

Remarks: Porosity (%) and Porosity (cm^3) are calculated from density measurement.

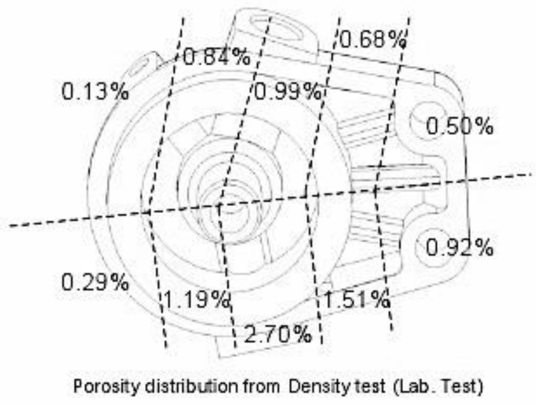

Figure 3 Porosities distribution at each portion

3.2 Optical Microscopy Observation

Figure 4 and 5 show the porosities distribution at thin portion and thick portion of sample parts. It can be understood easily that porosities occurred around the sample parts. Furthermore, porosities can be found more at near gate and center of sample parts. However, those porosities are not link together. Therefore, the harmful effect of leakage can be avoided.

Figure 4 Porosities distribution at thin portion

Figure 5 Porosities distribution at thick portion

Figure 6 shows the microstructure near casting surface. Fine microstructure can be observed near the casting surface and coarse microstructure can be found at the center of sample parts because of the cooling rate at casting surface is higher than at the center of sample parts. However, the depth of fine microstructure layer or chill layer is approximately around 0.1-0.2 mm from a casting surface.

Furthermore, most of porosities found in the casting are round shape and small size of porosities found near the casting surface and bigger size of porosities found far from the casting surface. Even though the small and big size of porosities is found, those porosities are not connected together. Therefore, the porosities found in the casting are not the shrinkage porosities but the porosities that caused from air entrapment or blow hole.

Besides, some porosities found at the fine microstructure called chilled zone that should be free from any type of porosities. Therefore, it can say that porosities can be occurred at rapid solidified zone or chilled zone. Anyway, the porosities found are very small that cannot be observed by visual observation and those small porosities are not connected together. Therefore, it will not affect to the quality of the casting.

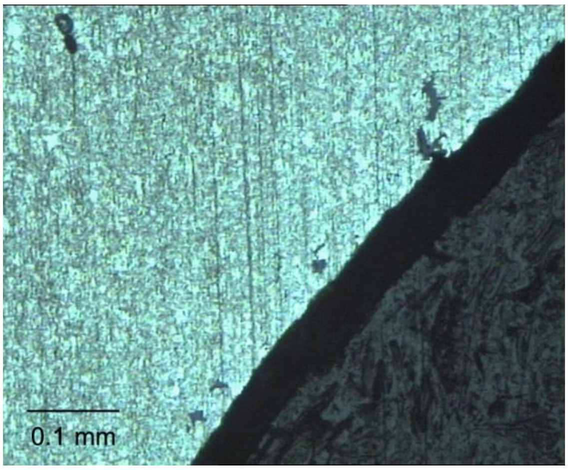

Figure 6 Microstructure of sample parts

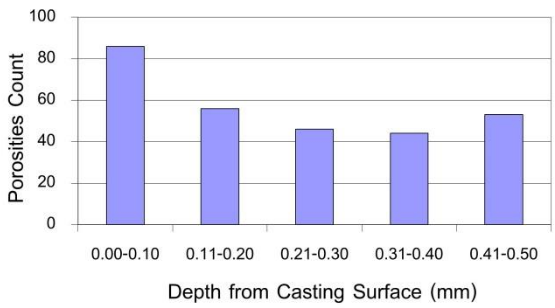

Figure 7 The relationship between porosities count and depth from casting surface

3.3 X-Ray Examination

X-Ray examination is one type of NDT (Non Destructive Testing). Both stable shots and first shots of production process were chose to be examined for the distribution of porosities and the size of porosities occurred in the casting parts.

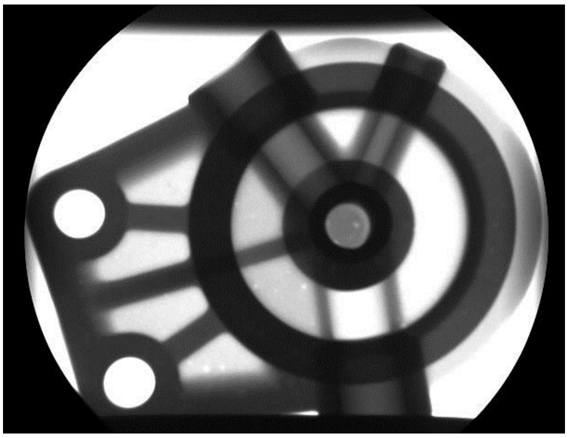

Figure 8 X-Ray examination result

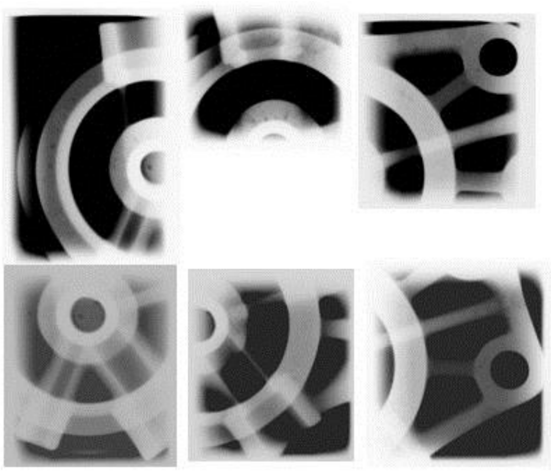

Figure 9 X-Ray examination results (Inversed)

The investigation result of sample parts obtained during mass production (stable shot) shows that even if the temperature of die was stable but the porosities in the casting were found. However, the amount of porosities in the casting during stable shot decreased obviously. That means the residual moisture on the surface of die was removed during die preheating process. And the porosities occurred was rising from residual gas in the melt, air entrapment during injection process and lubricants.

Furthermore, the pattern of porosities found both stable shot and first shot are quite similar. That is most of porosities found near gate and rib at the center of the casting.

3.4 Blister Test

The blister test analysis is the method of inspection process of cavities due to a gas within the work piece. Blister test was carried out at temperature during 200°C∼500°C to investigate the distribution of gas porosities near the casting surface. Figure 10 shows that the blister can be found obviously at 450°C and highly growth at 500°C or more as can be observed from a swelling of the expansion of the compressed gas within the work piece.

The result of the blister test analysis shown that there is some gas cavities under the surface of the work piece and does not occur only in the thickness part of the work piece but also occurs in the thinness part of the work piece.

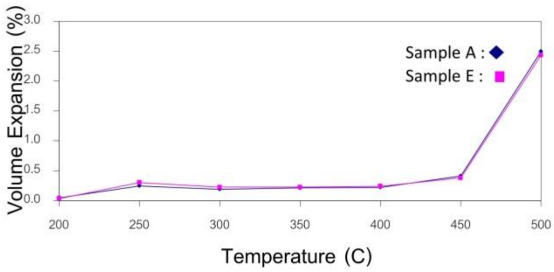

Figure 10 The relationship between volume expansion and temperature

Figure 11 The blister at the casting surface

Figure 12 The blister at the casting surface

Figure 11 and Figure 12 show the blister occurred all around the casting even if the front side or the back side of the casting. The size of blisters are various from 0.3 mm and can be found both the thick portion and the thin portion of the casting.

Furthermore, since this blister test analysis has no a clear definition, the results of this study can be summarized as the threshold temperature for aluminium alloy die casting. In case of aluminium alloy die casting went through the heat treatment process or welding or plating at high heat such as Teflon coating etc. If the work piece was produced by a common system die casting, it likely to cause a swelling of the work piece.

3.5 Die-Penetration Test

Die-penetration test is based upon capillary action, where surface tension fluid low penetrates into clean and dry surface-breaking discontinuities. After adequate penetration time has been allowed, the excess penetrant is removed and a developer is applied. The developer helps to draw penetrant out of the flaw so that an invisible indication becomes visible to the inspector.

Figure 13 Die-Penetration test result

Figure 13 shows the casting surface after a developer is applied. No penetrant found at the surface of the casting. That means the casting has a sound surface quality.

3.6 Flow and Solidification Analysis

Commercial casting simulation software “MAGMASOFT v4.1” was employed to calculate flow and solidification analysis of oil filter cover according to material properties, boundary conditions, and initial condition shown in Table 2, Table 3, and Table 4 respectively.

And the calculation results of melt flow and solidification of the casting was shown in Figure 14.

Table 2 Material Properties

Material	ADC12	SKD61
Density	2,438 kg/m^3 (at 595°C)	7,621 kg/m^3 (at 700°C)
Specific Heat	1,285-1,175 J/kg·K (T_S-T_L range)	1,400 J/kg·K (at 595°C)
Thermal Conductivity	146-73 W/m·K (T_S-T_L range)	26.2 W/m·K (at 595°C)
Latent Heat	476 KJ/kg	-
Liquidus	595°C	-
Solidus	555°C	-

Table 3 Boundary Conditions

Material - Material	HTC (W/m^2·K)
Casting - Mold	4,200
Casting - Cooling	10,000

Table 4 Initial Conditions

Initial Temp. of Casting ($T_{0\text{-cast}}$)	680°C
Initial Temp. of Mold ($T_{0\text{-mold}}$)	200°C
Initial Temp. of Cooling ($T_{0\text{-water}}$)	20°C
Initial Velocity (V_{inlet})	1.6m/s

Remarks;

- Free-slip boundary conditions on solid walls
- No back pressure consideration
- Casting mesh : 170,353 meshes
- Total mesh : 2,861,100 meshes

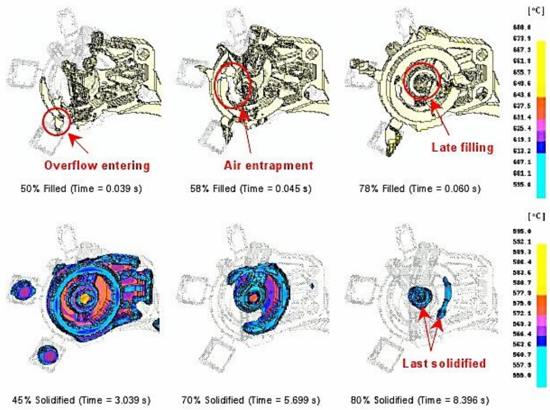

Figure 14 Melt flow and solidification analysis

As shown in flow pattern above, a turbulent flow was found in the runner and the cavity while melt is entering the cavity, result in the air entrapment defect in the casting. Furthermore, the last portion of molten metal filled was found at the cavity. Therefore, air pocket occurred in the casting, result in the lower density of the casting.

4. The Reproduction of Pore-Free Zone

The reproduction of the pore-free zone in the laboratory is to study the influence of significant parameters related to the pore-free zone including air entrapment, gravity effect, solidification velocity, alloy composition, and viscosity of the alloy melt.

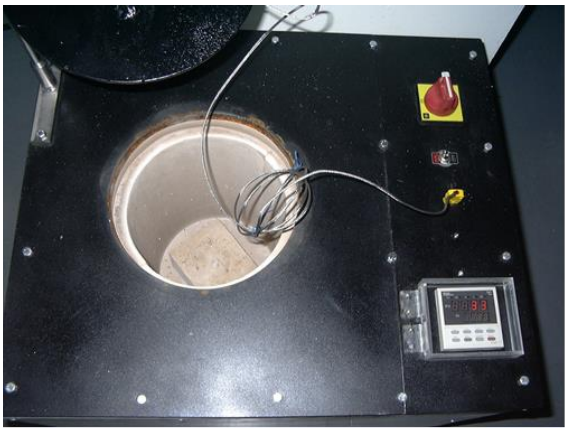

Figure 15 The electric furnace

Figure 15 shows the electric furnace was constructed for the experiment in this research project is an electricity resistance type. The section of providing temperature is a ceramic fiber heater type and the whole system can provide the highest temperature at approximately 1,200°C.

Figure 16 Step casting

Figure 16 shows the casting parts. Only a melt and pour liquid metal into the casting alone is not enough to cause the air bubbles inside the work piece. Therefore, the experiment in the laboratory for this research project was not successful to reproduce the production process of die casting.

5. Conclusion

The results of the test piece inspection found a cavity in the chilled zone which is generally known as the layer of micro structure with detailed and without cavity. Thus, the chilled zone can be defined as a layer with detailed structure and has opportunity to have completeness than the center of the work piece only. From the assumption to occur the complete layer which combined the thickness of the chilled zone and the next layer structure, it will not happen in reality in aluminium alloy die casting work piece produced by the conventional die casting process. Therefore, the trust that chilled zone has no porosities is not true. Small porosities can be found in the chilled zone as much as the magnification of the microscopy. Although, pore-free zone is not absent in the real casting but the definition of chilled zone would be redefined.

However, the skill of result analysis of cavity occurred within the work piece will improve a mold design to produce a high rate of good products in the production process.

6. Acknowledgement

We would like to express our gratitude to National Metal and Materials Technology Center (MTEC) in funding this project. We greatly appreciate CSP co., ltd for supporting a sample parts. In addition, we wish to thank Mr.FUJITA Masato who always gives the useful knowledge and suggestion to our team.

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