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by Budiarto Budiarto

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Effect of vacuum system on porous product defects and micro structures on the ADC-12 aluminum material with cold chamber die casting machines

B Budiarto* and T D Kurniawan

Mechanical Engineering, Faculty of Engineering, Indonesian Christian University, Jakarta, Indonesia

*budidamaz@gmail.com

Abstract. Research on the effect of the vacuum system on porous product defects and microstructure on the ADC-12 aluminum alloy material with cold chamber die casting machine has been carried out. In the injection process in cold chamber die casting, the aluminum material commonly used is namely ADC-12. The ADC-12 aluminum alloy has better resistance to corrosion, is lightweight, has ease of casting, good mechanical properties, and dimensional stability. The purpose of this study is to compare the vacuum system with overflow system using ADC-12 aluminum alloy material with observed parameters are porosity, trapped air pressure, hot spot level, hardness level of Vickers Hardness, XRD analysis, and microstructure analysis with Light Optical Microscope (LOM). The results of the analysis using the Magma flow software, the vacuum system is better than the overflow system in terms of porosity and product yield, which is influenced by the amount of air trapped and the hot spot level. The level of hardness in a product with a vacuum system is better than a product with an overflow system. The average hardness in the vacuum system is 162,235 while in the overflow system is 147,615. Thus, the use of a vacuum system can increase the level of hardness in products by around 9%. With the change in usage from the overflow system to the vacuum system, it shows an increase in dislocation density followed by an increase in lattice strain and a decrease in the level of crystal size of the product.

1. Introduction

Die casting is the process of inserting molten metal under high pressure into the mold cavity. Die casting serves to produce a large number of products with short lead times and good surfaces with high injection pressure from cast alloys, product design, flow and gate design, and others [1].

In the production process of die casting injection, there are problems that occur in the results of the injection. These problems can occur on the visual side and its functions such as scratch, abnormal shrinkage in the dimensions of the product, burry or flashing, the materialis formed apart from the cavity, and porous [2].

One problem that still often occurs in the die casting injection process today is porosity. Porosity problems are caused by air trapping before the aluminum liquid injection process enters the cavity so that the air causes the microstructure of the aluminum to become less dense and causes cavities that affect the strength and lifetime of the product [3].

There are several things that must be considered and several ways to reduce porous problems, that is raising the die temperature, metal liquid. Speed up the gate speed, to shortenthe charging time. Installing over flow or gasvent [1], in terms of the production process can be considered on the results of machining by looking at the surface cavity structure, then in terms of design can look carefully to the area of the gate runner, overflow thickness, and the placement of runners. In addition, porous problems can be overcome by using a vacuum system [4].

1.1. Porosity in aluminum
There are several studies on porosity analysis by optimizing design changes and gate dimensions on products to reduce product defects. Based on Krisbianto's et al., whichis about optimizing the design of the gating system die casting cold chamber process to reduce product defects, shows that changes in gate design can reduce porosity in the product, but not only from the gate shape but also from some adjustment parameters during injectionor in terms of the design and addition of the system to the mold [5-7].

It is expected that in the research the effect of the influence of the vacuum system on porous product defects and microstructure on the ADC-12 aluminum material with a cold chamber die casting machine can reduce the level of porosity and the addition of system options to reduce product defects

1.2. Vacuum system in cold chamber machines in die casting
The function of a vacuum system can remove air-trapped cavity, so that during the processof injection of material, no air-trapped in cavity [3]. The vacuum system is usually used in cold chamber machines. This machine works by melting the first material in a separate furnace, and put it into a chamber and then shot with heat (or injection cylinders). This firing process is driven into cavity by a hydraulic or mechanical piston.

1.3. Analysis with Magmasoft simulation software
To see the final results of the design prior to the injection phase, design simulation will be carried out with Magmasoft simulation. Based on Putra and Ifansah [8] using software is to determine the effect of the cavity runner gate system design on HPDC (high pressure die casting) on the turbulance effect, it results in an indication of turbulence flow which is worth 7974 and 6375 based on the calculation of the Reynolds number on segment one and two. Onthe center hole cover left which has been simulated with Z-Cast experiencing shrinkage dueto the absence of overflow where the thickness at the center hole is 5.52 mm greater than the average thickness of 2.5 mm so that the problem solving in shrinkage defects should be placed overflow to avoid gas trapped inside the inject part. Comparison of cooling time on inject parts 366.5 sec and 292.1 sec, high temperature variance 21.46 0 C and 23.16 0 C, high cooling quality (green areas) 15.0% and 19.6% [8]. It is expected that the influence of the vacuum system on porous product defects and microstructure on the ADC-12 aluminum material with a cold chamber die casting machine can determine the level of air trapped in themold to reduce turbulance in the injection process and compare the effectiveness of the overflow system with the vacuum system with using magmasoft simulation software simulation.

The natural injection process in cold chambers usually uses materials from metals such as aluminum, zinc with the largest composition of aluminum, magnesium and copper. One of the materials commonly used is aluminum, ADC-12 [4]. This material is easy to find in the market and has good mechanical properties compared to other types of aluminum [6]. The ADC-12 aluminum has an Al-Si alloy.

1.4. Al-Si aluminum micro structure
Al-Si is a type of aluminum alloy, Aluminum-Silicon has properties that are easy to pour / cast and are resistant to corrosion. Strengthening Al-Si is done by adding a small amount of other elements, such as Cu, Mg, or Fe. The higher the iron content, the Al-Si will be more brittle [9].

Al-Si has mild characteristics, good specific-strength, good thermal conductivity, good machineability and corrosion resistance [10]. Al-Si complexes are commonly used for commercial parts

casting and are used in the automotive, aerospace, transportation anddefense industries. Hypereutectic Al-Si is used to make brake shoes. Hypereutectic is an area or zone above the eutectic temperature or melting point of iron, whereas hypoeutectic is an area below the eutectic temperature [11].

1.5. X-Ray Diffraction (XRD) analysis

The X-Ray Diffraction (XRD) technique is very important in the process of analyzing crystalline solids. XRD is a characterization method that serves to determine the main characteristics of crystals, such as lattice parameters and structure types. In addition, XRD is also used to determine the arrangement of various types of atoms in a crystal, the presence of defects, orientation, and crystal defects [12].

X-rays were first discovered by Wilhelm Rontgen in 1895. X-rays have shorter wavelengths ($\lambda \approx 0.1$ nm) than light waves ($\lambda = 400\text{-}800$ nm) [4]. These X-ray wavelengths are used as the basis for X-ray diffraction techniques to determine the microscopic structureof a material [12].

According to Bragg, a beam diffracted by a crystal will occur if the reflection by the plane parallel to the atom produces a constructive interference. The reflection of X-rays by a group of parallel fields in a crystal should be a reflection of the diffraction of the crystal atoms. Diffraction of crystal atoms as reflected by X-rays by a group of parallel fields in the crystal. The direction of diffraction is largely determined by the geometry of the lattice, which depends on the orientation and distance between the crystal fields.

This statement is Bragg's law. Bragg reflection occurs if $\leq 2d$, so that it cannot use visible light, where n is an integer = 1,2,3, ... [13]. The direction of the beam reflected by atoms in a crystal is determined by the geometry of the crystal lattice which depends on the orientation and distance of the crystal plane. A crystal that has cubic symmetry (a = b = c, $\alpha = \beta = \gamma = 90°$) with the lattice parameter size, a = b = c, then the beam angles that are diffracted from the crystal fields (hkl) can be calculated with the formula of the distance between fields as follows:

$$\frac{1}{d^2} = \frac{h^2 + k^2 + l^2}{a^2}$$

The crystal structure is determined by X-ray diffraction. Interplanar distances can be calculated up to four or more significant figures by measuring the diffraction angle. This can be used to base determining interatomic distances and counting radii [14]. Determination of crystal orientation is done by observing the X-ray diffraction beam pattern reflected by the crystal. For XRD, the diffraction pattern is observed as a 2-angle function. The diffraction patterns that occur are then compared with JCPDS as standard data.

1.6. Hardness of material in Vickers scale

Hardness is one of the faster and cheaper methods for determining the mechanical properties of a material. Hardness is not a physical constant, its value does not only depend on the material being tested, but is also influenced by the test method. If the test method used is different, the results of the mechanical properties will be different [15].

There are several types of violence, namely, Ball Identation Test (Brinnel), Pyramid Identification (Vickers), Cone and Ball Identation Test (Rockwell), Micro Hardness Test or Knoop Hardness [16]. This method is distinguished by the Indenter and the test load used.

Vickers Method, aims to determine the hardness of a material in the material resistance to diamond indenter which is quite small and has a pyramid shaped geometry as shown in Figure 2 [17]. Vickers micro hard value is the quotient between the maximum static compressive load and the penetrator area [18-20].

1.7. Analysis with Light Optical Microscope (LOM)

Microscopes are devices that are often used to see objects or samples that cannot be seen by the eye without help. Various microscope models such as optical microscopy, Scanning Electron Microscopy (SEM), and Transmission Electron Microscope (TEM) have different ways of using [21].

Optical microscopes involve diffraction, reflection, or refraction of electromagnetic radiation or electron beams that interact with specimens and collections of scattered radiation to produce images [21].

Light Optical Microscope, abbreviated as LOM, is a microscope using a light source with a lens system that serves to enlarge images in small samples. Images from an optical microscope can be captured with normal light-sensitive cameras to produce micrographs. Initially, photographs were captured by film photography, but with modern developments in metal-oxide-semiconductors and charge-coupled device (CCD) cameras it was possible to capture digital images.

The purpose of this study was to identify the ADC-12 Aluminum alloy characterization on the effect of using the overflow system and the vacuum system during the injection process with several tests, specifically; Physical properties testing for porosity, testing of mechanical properties for hardness, and testing structure crystal for crystal size (D), stretch grid (ε), and density (L)

2. Methods

To analyze the effect of the vacuum system on porous products and microstructure on ADC-12 material with a cold chamber die casting machine, the following methods are used:

The samples used are samples that do not use a vacuum system (overflow system) and samples that use a vacuum system.

- Each sample is cut into two parts with benshaw to simplify the testing process.
- Porosity testing was carried out to determine the level of porosity, air pressure in the mold, and the level of hot spots in both samples using Magmaflow software.
- Vickers Hardness mild testing to identify the nature of the material used and the change in properties that occur due to the process
- XRD analysis to determine crystal size, lattice strain and dislocation density.
- Metallographic examination with Light Optical Microscope (LOM) to identify the presence of porous defects in the material.

3. Results and discussion

3.1. Porosity analysis using Magmaflow software

3.1.1. Porosity level. Identification of the level of porosity of the material using Magmaflow software is listed in Figure 1.
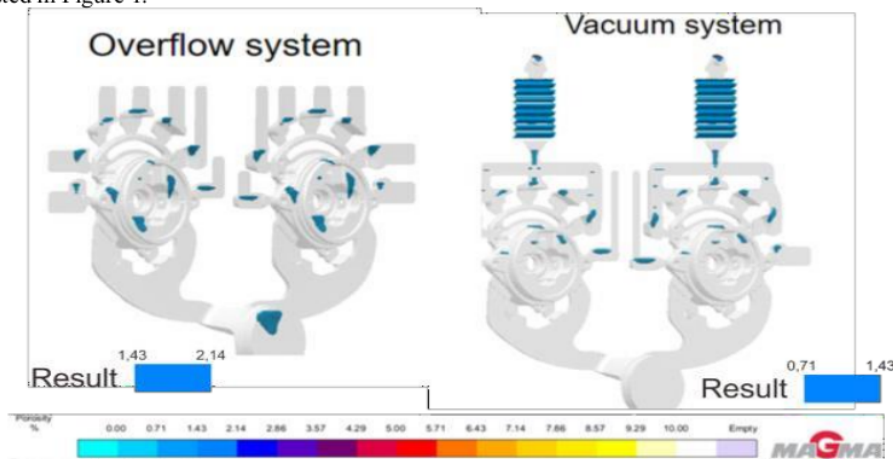

Figure 1. The degree of porosity in overflow and vacuum systems.

Figure 1 shows the porosity conditions in the vacuum system model having a smaller porosity ratio which ranges from 0.71% to 1.43%. In addition, the area of porosity in products with vacuum systems looks smaller and less. In the overflow system model, the range level of porosity is greater, from 1.43% to 2.14% and theposition of the porosity is very large and is located in vital parts of the product such as product connectors. The porosity that occurs can be caused by a blowholeon the product. This blowhole is caused by the air trapped in dies or product forming molds [5].

3.1.2. Levels of air pressure in the mold. The level of air pressure during the injection process, inhibits the flow ofliquid ADC-12 to enter the product profile in cavity. By using a vacuum system, there is a very drastic decrease in the level of air pressure in the mold (Figure 2).
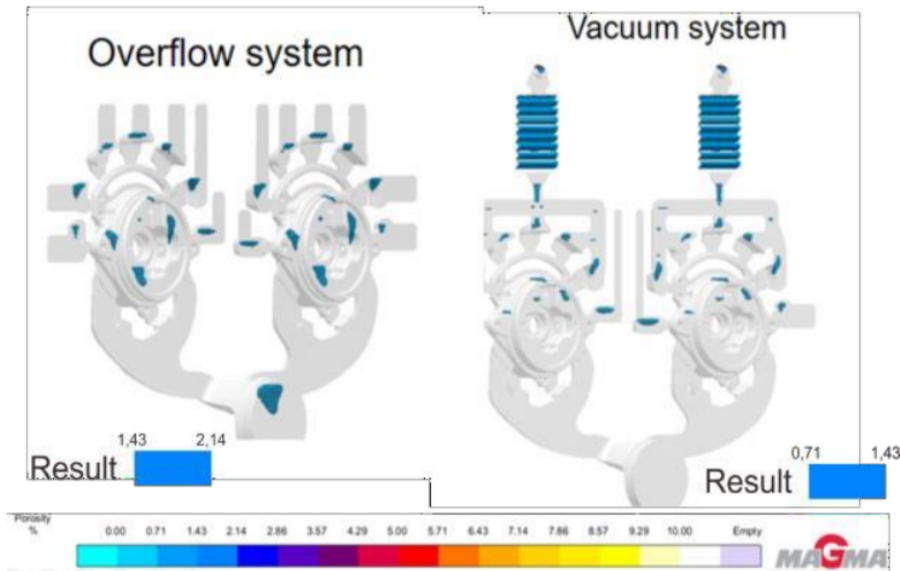

Figure 2. The level of air pressure in a mold on an overflow system and a vacuum system.

It can be seen that the result of the level of air pressure in the mold in the vacuum system has decreased which ranges from 5082 mbar to 6438 mbar, while in the overflow system ranges from 13219 to 14575 mbar. The decrease that occurs may be due to the vacuum system being able to draw air trapped in cavity when in a closed position so that trapped air does not affect the pressure which reduces the rate of fluid transfer.

3.1.3. Hot spot level. Air pressure greatly affects the running of the ADC-12 liquid where the pressure and velocity of the injection fluid will slow down, causing a hotspot during the casting process and eventual buildup. Analysis of hot spot levels in overflow and vacuum systems shown in Figure 3.
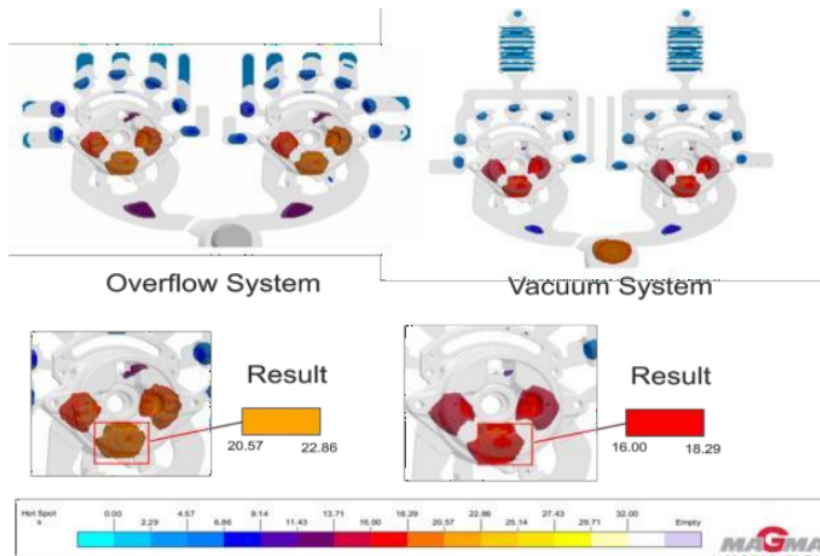
Figure 3. The hot spots level on overflow and vacuum systems.

The use of a vacuum system shows low hotspot levels ranging from 16.00 to 18.29s, when compared to overflow systems which show results of hotspot levels from 20.57 to 22.86 s. The decrease in hot spots level that occur in the vacuum system can be caused because the air contained in the print cavity is pulled out when the molten metal is poured, so that the friction of liquid ADC-12 with air becomes very minimal.

3.2. Vickers hardness analysis

Hardness level in the product determines the product lifetime and strength of aproduct. The results of the analysis of product hardness can be seen in Figure 4.
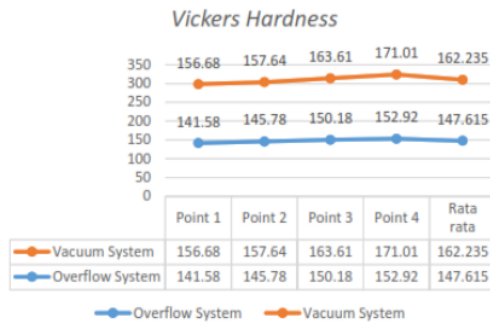

	Point 1	Point 2	Point 3	Point 4	Rata rata
Vacuum System	156.68	157.64	163.61	171.01	162.235
Overflow System	141.58	145.78	150.18	152.92	147.615

Figure 4. Comparison of Vickers Hardness between the vacuum system and the overflow system.

Based on the analysis of the level of hardness Vickers Hardness, shows that the use of vacuum systems has a better level hardness compared to overflow systems. Taking on several points, the use of a vacuum system has a higher average hardness level of 162,235 HV compared to an overflow system which has a lower average of 147,615 HV. The use of a vacuum system can produce the products with good lifetime and strength. This increase in hardness occurs along with a decrease in porosity. Decreased

porosity due to trapped air is very minimal because air in the print cavity is pulled out when liquid metal is poured [4].

3. *Analysis of crystal size, dislocation density, and lattice strain of ADC-12 alloy*
Analysis of crystal size, dislocation density, and micro lattice strain were carried out using the XRD method. This aims to determine the microstructure and phase containedin the sample overflow system and vacuum system. The results of the analysis on the vacuum system and overflow system can be seen in figures 5 and 6.
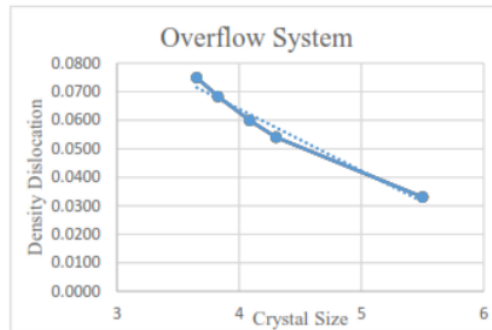

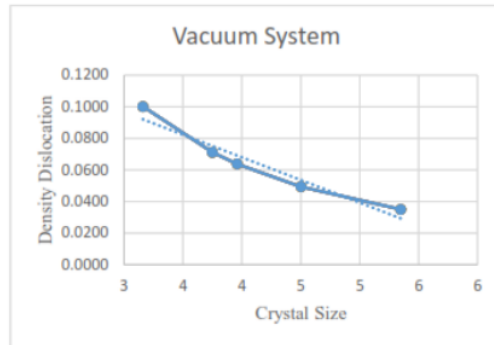**Figure 5.** Graph of XRD analysis on ADC-12 alloy with Overflow system.

Figure 6. Graph of XRD analysis on ADC-12 alloys with a vacuum system.

Table 1. Peak list of XRD for overflow systems.

No Peak	Θ (°)	B FWHM 2Θ(°)	D Crystal Size (nm)	P Density Dislocation	E Lattice Strain
1	56,11	0,43	3,6539	0,07490	20,17%
2	78,235	0,467	3,8268	0,06829	14,36%
3	38,522	0,35	4,1964	0,05679	25,04%
4	76,35	0,41	4,3019	0,05404	13,04%
5	87,897	0,35	5,5024	0,03303	9,08%
Average			4,29627	0,05741	16,34%

Table 2. Peak list of XRD for the vacuum system.

No Peak	Θ (°)	B FWHM 2Θ(°)	D Crystal Size (nm)	P Density Dislocation	E Lattice Strain
1	69,13	0,61	2,7602	0,13125	22,14%
2	44,759	0,4	3,7487	0,07116	24,29%
3	38,51	0,371	3,9588	0,06381	26,55%
4	42,02	0,33	4,5009	0,04936	21,48%
5	76,39	0,33	5,3462	0,03499	10,49%
Average			4,06295	0,07011	20,99%

The size of the crystals and the correlation between the results of the lattice strain and the dislocation density of the variation of the type of system used in the mold are shown in Figures 5 and 6 and Table 1 and 2. Based on the results, it shows that there is an effect of differences in the use of vacuum systems with overflow on crystal size (D), lattice strain (ε), and dislocation density (ρ). Treatment with a vacuum system can cause a decrease in crystal size and increase the density of the dislocation and latticestrain.

3.4. Analysis using Light Optical Microscope (LOM)

Analysis using Light Optical Microscope (LOM) aims to see the surface structure of an object by using a light microscope at certain vehicles. In this study, this analysis is used to see the surface of the material that shows the parts that have porosity. LOM micrographs on the use of vacuum systems and overflow systems against the porosityof the material surface can be seen in the following figure.
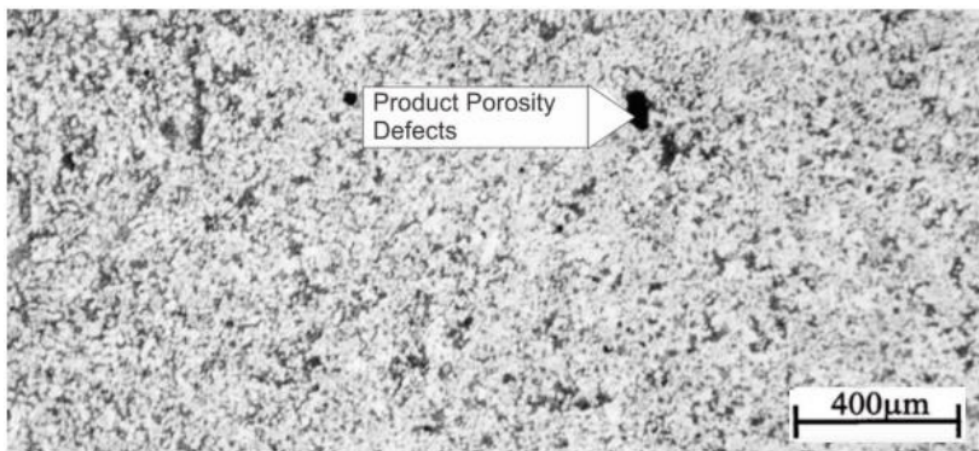
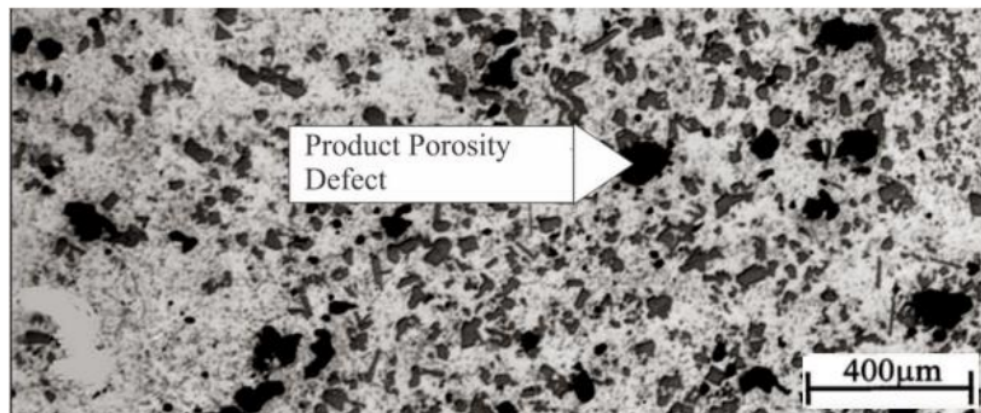**Figure 7.** ADC-12 alloy LOM micrograph with a vacuum system.

Figure 8. ADC-12 alloy LOM micrograph with overflow system.

Based on Figure 7 and Figure 8 with a magnitude of 400 μm using an optical microscope, showing the results that the level of porosity in the vacuum system (Figure 6) looks less compared to the use of overflow systems where the amount of porosity is very high (Figure 7).

4. Conclusion

Based on the research, it can be concluded that:

- The analysis using the Magma flow software, the vacuum system gives better results than the over flow system in terms of porosity and product yield, both of which are affected by the amount of air trapped and the level of hot spots.
- The level of hardness in a product with a vacuum system is better than an overflow system. The average hardness in the vacuum system is 162,235 while in the overflow system is 147,615. Thus, the use of a vacuum system can increase the level of hardness in products by around 9%.
- With the change in usage from the overflow system to the vacuum system, it shows an increase in dislocation density followed by an increase in lattice strain and a decrease inthe level of crystal size of the product.

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