

The Effect of Argon Gas Use Discharge on Density, Porosity, and Hardness of Casting Products from Remelting Used Aluminum

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Abstract - Porosity is a defect that often occurs in aluminum alloy casting which is difficult to avoid, and is the most serious problem in aluminum casting. Porosity that occurs during the casting process results in decreased product quality or the product must be recycled. Generally, porosity in aluminum alloys is caused by dissolved and entrapped hydrogen, or underfeeding. Degassing is the process of binding hydrogen compounds that occur in the aluminum metal smelting process. Inert gases (Argon, Nitrogen, Helium) as inert gases are widely used for the degassing process in aluminum smelting. Its function is as a shielding gas to minimize the porosity that occurs when molten aluminum becomes solid. The process of smelting and manufacturing casting products using used aluminum is carried out using an LPG gas-fired smelting furnace. The degassing process in this study was carried out using Argon gas, which was put directly into the aluminum melt some time after the aluminum melted at 660°C. As long as Argon gas reacts with Hydrogen gas bubbles will form that appear to the surface. The test samples consisted of 6 cylinders with a diameter of 30 and a thickness of 20 mm, made from used aluminum castings, which in the process of making casting products used 500 grams of used aluminum with varying discharges of Argon gas, 0 ; 0.25 ; 0.5 ; 0.75 ; 1 ; 1.25 liter/minute. The test sample was initially observed visually, then several tests were carried out, including: hardness test, density and porosity test, morphology/microstructure test using an optical microscope, SEM-EDAX. Based on the results of observations and laboratory tests, it is known that the porosity of aluminum casting products decreases with increasing use of Argon gas in the degassing process, and also increases the density and hardness of casting products. The addition of Argon gas to melted aluminum increased the hardness of aluminum by 8,52 %.

Keywords: degassing, Argon gas, density, hardness, porosity, remelting, used aluminum.

I. INTRODUCTION

Aluminum is one of the most abundant metals in the earth's crust and is the third most abundant element after oxygen and silicon. The use of aluminum continues to increase from year to year, its applications include structural components, vehicles and transportation, packaging for food products and even the aerospace industry. The ability of aluminum to be recycled makes aluminum one of the materials developed to replace the use of primary aluminum.

Utilization and processing of aluminum waste, from an economic perspective, is much cheaper and can reduce energy consumption because it only requires 5% energy compared to primary aluminum bauxite production [1]. Recycling aluminum is also more environmentally friendly because it can reduce air pollution due to exhaust gases produced during the processing of aluminum from bauxite, especially CO₂ and greenhouse gases. Recycling aluminum is a concept for handling waste, becoming a possibility to limit the amount of metal waste and use natural resources efficiently [2].

Aluminum is widely used, causing the amount of metal waste due to industrial activities to also increase. The costs and energy required to produce primary aluminum are very expensive, besides that it also causes air pollution. One of the efforts made to overcome this is by recycling aluminum scrap. The limited availability of aluminum in the world due to its increasing use makes recycling aluminum scrap an option to reduce primary aluminum (bauxite) production. The use of recycled aluminum scrap for engine components is an alternative choice for the sustainability of the industrial world in the future, one of which is pistons.

Metal casting is one of the prospective manufacturing processes for automatic products and machine components. The advantage of metal casting is that it is able to produce goods that are similar to the product (net shape), using raw materials (ingots) and producing ingots from scrap metal so that pollution can be controlled [3]. One of the many casting products produced is pistons. Pistons from aluminum alloys

have good mechanical properties at high temperatures, approximately above 400 OC [4].

One of the problems that often arises from the aluminum remelting process is the presence of defects or porosity in the product (Figure 1). The defects in question are gas porosity defects or shrinkage porosity defects which are generally caused by the formation of gas when molten metal is poured and the presence of hydrogen which is also dissolved. To overcome this, a degassing process is usually carried out in the aluminum smelting process.



Figure 1: Porosity defects in aluminum casting results

Several previous researchers regarding degassing in the aluminum smelting process stated that the application of pressure during solidification in squeeze casting resulted in the hydrogen pressure being much lower than the external pressure so that the nucleation of gas bubbles did not occur and the hydrogen was trapped or dissolved in the liquid metal and forced out through the die ventilation. , Abdillah [5]. In this research, it was concluded that the direct squeeze casting method could significantly reduce porosity defects, namely by 85%.

Budiyono, et al [6], analyzed the mechanical properties of materials when treating aluminum alloys from recycled materials by extracting hydrogen gas (degassing aluminum alloys) with a rotary degasser and Argon gas degasser in liquid metal and then compared them with before treatment. The material used is aluminum scrap. The conclusion is that the highest increase in tensile strength was in the stirring treatment with a rotary degasser for 2.5 minutes, namely 159.4 MPa, likewise for stirring with Argon gas degassing for 2.5 minutes, namely 157.7 M.Pa.

The influence of Argon gas discharge on the porosity and hardness of aluminum remelting results based on used aluminum waste has been studied by Hernady and Sodiran [7]. This research was carried out to find out what volume of argon gas is used when aluminum is heated or to wait a while after the aluminum starts to melt. The research method used in this research was to directly test the aluminum melting process without protective gas, and using protective gas with spraying time intervals of 10 minutes, 15 minutes and 20 minutes. The

process of observing the porosity that occurs uses the SEM test. From the research results, it was found that melting aluminum takes approximately 25 minutes and argon gas can be used 10 minutes after the aluminum is heated. The use of argon gas is regulated in such a way that it covers the surface of the liquid aluminum. The porosity that occurs with a delay time of using argon gas of 10 minutes after the aluminum is heated is around 12.78%.

Lutiyatmi and Daryanto [8], researched and studied the effect of degassing on the formation of intermetallic compounds (IMC) which formed at the interface between molten aluminum and solid steel from the crucible furnace lining. The cylindrical test specimen was immersed in a bath of molten aluminum. Soaking the test specimens is in the range of 10 to 15 minutes. Two types of degassing, namely table salt degassing and sodium chloride (NaCl) degassing, were carried out to investigate the effect on IMC formation. The IMC was examined with an electron microscope, as well as the hardness of the IMC with microvickers hardness. Due to the high hydrogen content, the test specimens immersed in molten aluminum without a degasser had a thicker IMC layer than others. The NaCl degassing process is more effective than Grasak salt degassing in reducing IMC growth. Furthermore, the phases that appear in the IMC area, namely FeAl and FeAl₃ compounds, are formed in the specimen by a process without degassing and using NaCl degassing.

In this research, the influence of Argon gas discharge on the density, porosity and hardness of cast products resulting from the recycling of used aluminum, such as beverage cans, was investigated.

II. MATERIALS AND EXPERIMENTALS PROCEDURES

2.1 Materials and Equipment

The materials used in this research are: Used/waste aluminum, LPG gas and Argon gas.

The equipment used in this research is divided into two parts. The first part covers the equipment during the process of making Aluminum ingots. The second part includes equipment for characterization and testing of ingot cast products from used Aluminum.

1) Equipment used for the aluminum ingot process: metal melting furnace, steel stove, steel mold, burner, 12 kg LPG gas cylinder, LPG gas hose, LPG gas regulator, 1/2" LPG gas tap, gas cylinder 1 m³ argon, argon gas hose, argon gas regulator, 1/2" argon gas faucet, ceramic pipe Ø 15 mm x 50 cm, thermo gun, thermo couple, timer, clamping pliers, electronic scale, stirrer, ladle, mask and gloves.

2) Equipment for characterization and testing of ingot cast products from used aluminum: SEM and EDX test equipment, hardness test equipment, density and porosity test equipment.

The equipment used in this research is shown in figure 2.

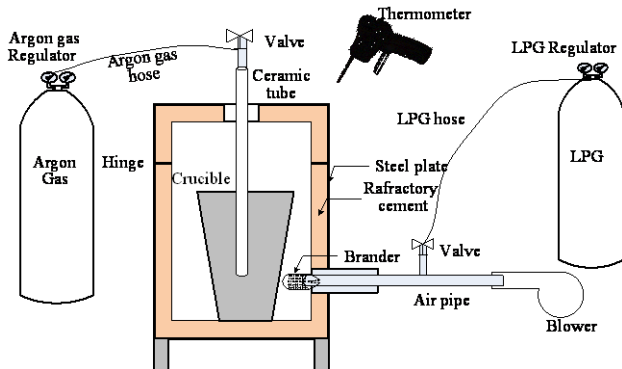


Figure 2: Equipment system design for making Aluminum ingots

2.2 Research Design and Procedures

2.2.1 Research Location

The research, which includes the tool making process, melting process, degassing and pouring process, was carried out at the Mechanical Laboratory of the Bali State Polytechnic Mechanical Engineering Department. The results of aluminum ingot casting products will initially be observed visually, then several tests will be carried out, including: density, porosity and hardness tests at the Metallurgical Laboratory, Department of Mechanical Engineering, Udayana University, Morphology/microstructure test using an optical microscope, SEM-EDAX at the Laboratory. Central State University of Malang.

2.2.2 Making Aluminum Ingots

The burner is turned on for initial heating of the crucible. The ingredients for ingot casting products from used aluminum are added gradually to the kowi in the melting furnace. Heating is carried out until all the aluminum in the kowi melts at a temperature of 660 °C. The slags formed during the melting process are removed with a spatula. The degassing process is carried out after the surface of the melted aluminum in the kowi is clean from slag.

During the degassing process, bubbles appear on the surface of the liquid aluminum, due to the reaction between Argon gas and Hydrogen gas which is formed during the aluminum melting process. After there are no more bubbles, the melted aluminum is poured into a box-shaped metal (steel) mold at room temperature.

Making Aluminum ingots is carried out in 6 processes (6 test samples).

2.2.3 Characterization Procedure

2.2.3.1 Density of Aluminum Ingot

Density measurement refers to (Birkeland, 1984): ASTM C 134 - 95, and performed using Archimedes' principle. The measurement of the density of the Aluminum ingot material is a test object resulting from the stir casting process. The procedure for measuring the density of the Aluminum ingot material is carried out in the following steps:

- The sample was dried in an oven at 100 °C with a drying time of 2 hours, then weighed its mass with a digital balance, called dry mass (m_s).
- Weigh the mass of the sample along with the hanger (using a wire) in the water using a digital balance, m_g .
- Weigh the mass of the hanging wire using a digital balance, m_k .

By knowing these quantities, the density of the Aluminum ingot material can be determined using the equation (Birkeland, 1984),

$$\rho = \frac{m_s}{m_s - (m_g - m_k)} \times \rho_{H_2O}$$

with,

ρ = bulk density (gram/cm³)

m_s = mass of the sample after drying in the oven (grams)

m_g = mass of sample suspended in water (grams)

m_k = mass of sample hanging wire (grams)

ρ_{H_2O} = density of water = 1 gram/cm³

2.2.3.2 Porosity of Aluminum ingot

Measuring the porosity of Aluminum ingot materials, refers to (Birkeland, 1984); ASTM C 373 - 88. The procedure for measuring the porosity of the Aluminum ingot material is carried out in the following steps:

- The samples were dried in an oven at a temperature of 100 °C with a drying time of 2 hours then weighed the mass with a digital balance, m_s .
- The sample is boiled in water at 110 °C, until the mass of the object is in a state of saturation (saturated), then wipe the surface with a cloth, and weigh the mass using a digital balance, m_b .
- Weigh the mass of the sample along with the hanger (using a wire) in the water using a digital balance, m_g .
- Weigh the mass of the hanging wire using a digital balance, m_k .

By knowing these quantities, the porosity of the Aluminum ingot material can be determined using the equation (Birkeland, 1984),

$$\rho = \frac{m_b - m_s}{m_b - (m_g - m_k)} \times 100\%$$

with,

ρ = bulk density (gram/cm³)

m_s = mass of the sample after drying in the oven (grams)

m_b = mass of the sample after soaking in water / saturated (grams)

m_g = mass of sample suspended in water (grams)

m_k = mass of sample hanging wire (grams)

2.2.3.3 Hardness of Aluminum ingot (Vickers Hardness Test)

The hardness of the Aluminum ingot material was tested at the Metallurgical Laboratory of Mechanical Engineering, State University of Malang using a Microhardness Tester (ESEWAY, Model EW421AAT), and the test refers to the standard (Dowling, E.N., 1999); ASTM E 18 - 02. The hardness test procedure is as follows:

- a) The surface of the test object is first sanded using sandpaper starting from the roughest to the smoothest.
- b) Place the sample in the holder, the given load is 100 grams and the identification time / dwell time is 10 seconds.
- c) After pressing, observe the resulting indenter, such as a diamond (figure 3) by adjusting the focus until the observed shape is quite clear.

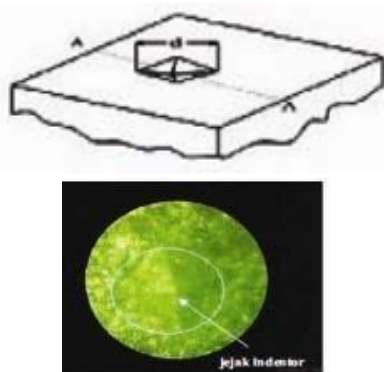


Figure 3: Vickers Hardness test results

- d) Measure the diagonal length of each pressing result and the hardness value of the tested sample can be read directly on the microhardness tester monitor, perform at least 3 repetitions for each sample tested.

The hardness value of the Aluminum ingot material can also be calculated using the following equation (Dowling, 1999).

$$VHN = \frac{2P}{d^2} \sin \frac{\alpha}{2} = 1,8564 \frac{P}{d^2}$$

with :

VHN = Vickers hardness value (kgf/mm²)

P = pressing load (kgf)

d = average diagonal length (mm)

α = angle between diamond faces (136°)

III. RESULTS AND DISCUSSIONS

3.1 Aluminum Ingot Products

The results of the used aluminum casting process with various Argon gas flow compositions are shown in Figure 4.



Figure 4: Products resulting from Aluminum Ingot casting

Next, the resulting Aluminum ingot casting product is shaped (lathe process) into a diameter of 30 mm and a thickness of 20 mm, for the process of testing physical properties and morphological characterization, figure 5.

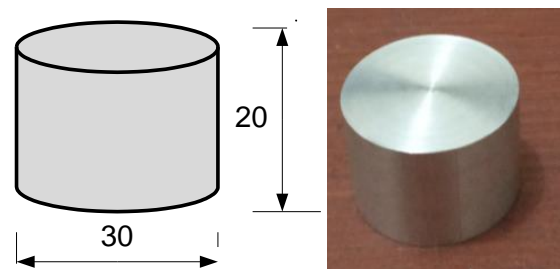


Figure 5: Products from casting used aluminum ingots after turning

3.2 Physical Properties of Aluminum Ingots

Based on the results of calculations using equation (1) for the density test, equation (2) for the porosity test, as well as testing the hardness properties of used aluminum casting products, which were carried out in the Lab. Udayana University Mechanical Engineering Metallurgy, data obtained as shown in table 1.

Table 1: Physical Test Data for Aluminum Ingots

| Debit gas Argon (liter/minute) | m _s (gr) | m _g (gr) | m _k (gr) | m _b (gr) | ρ H ₂ O (gr/cm ³) | ρ (gr/cm ³) | P % |
|--------------------------------|---------------------|---------------------|---------------------|---------------------|--|-------------------------|--------|
| 0 | 36,78 | 23,27 | 1 | 39,5 | 1 | 2,535 | 15,786 |
| 0,25 | 36,95 | 23,65 | 1 | 39,3 | 1 | 2,584 | 14,114 |
| 0,5 | 37,15 | 24,15 | 1 | 38,9 | 1 | 2,654 | 11,111 |
| 0,75 | 37,35 | 24,65 | 1 | 38,7 | 1 | 2,726 | 8,970 |
| 1 | 37,62 | 25,15 | 1 | 38,5 | 1 | 2,793 | 6,132 |
| 1,25 | 37,85 | 25,95 | 1 | 38,3 | 1 | 2,934 | 3,371 |

3.2.1 Effect of Argon Gas Discharge in Aluminum Ingots on Density

Based on Figure 6, it can be seen that with increasing Argon gas discharge in used aluminum smelting, the density of aluminum casting products tends to increase. The lowest density of aluminum casting products, 2.535 gr/cm³, occurs when the Argon gas flow rate is 0 liters/minute. Meanwhile, the highest density of aluminum casting products, 2.934 gr/cm³, occurred when the Argon gas flow rate was 1.25 liters/minute.

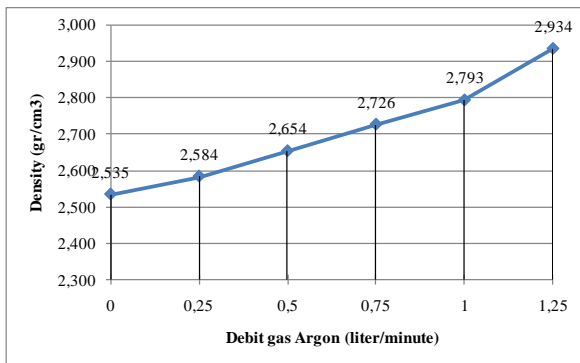


Figure 6: Relationship between density and Argon gas flow rate

3.2.2 Effect of Argon Gas Discharge in Aluminum Ingots on Porosity

Based on Figure 7, it can be seen that with increasing Argon gas discharge in used aluminum smelting, the porosity of aluminum casting products tends to decrease. The lowest porosity of aluminum casting products of 3.371% occurred when the Argon gas flow rate was 1.25 liters/minute. Meanwhile, the highest porosity of aluminum casting products was 15.786% when the Argon gas flow rate was 0 liters/minute.

3.2.3 Effect of Argon Gas Discharge in Aluminum Ingots on Hardness

As mentioned previously, spent Aluminum melt is added with variable discharge Argon gas into the aluminum melt using casting techniques. The aim is to improve the physical and mechanical properties, which were reported to be very poor in previous reviews [7]. Sample hardness was tested

using a Vickers hardness tester. Approximately 3 penetrations were performed on different areas of each sample.

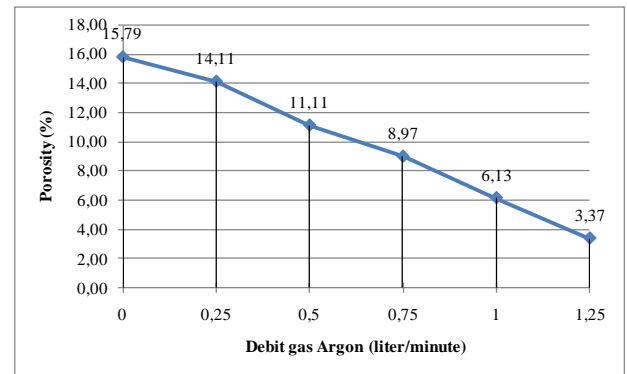


Figure 7: Relationship between porosity and Argon gas flow rate

The small variability of Vickers hardness between different indentations is an indication of the homogeneous distribution of Hydrogen gas in the aluminum matrix. The results of the Vickers hardness number and standard error (SE) for the percentage of Argon gas influence are presented in Table 2.

Table 2: Data on hardness test results for aluminum ingots

| Debit gas Argon (liter/minute) | Hardness (HV) | Deviation (%) |
|--------------------------------|---------------|---------------|
| 0 | 76,5 | 0,00 |
| 0,25 | 78,1 | 2,09 |
| 0,5 | 80,5 | 5,23 |
| 0,75 | 84,3 | 10,20 |
| 1 | 88,5 | 15,69 |
| 1,25 | 90,2 | 17,91 |

Based on Figure 8, it can be seen that with increasing flow rate of Argon gas in aluminum casting products, the hardness of aluminum casting products tends to increase. The lowest hardness of aluminum casting products, 76.5 HV, occurs when the Argon gas flow rate is 0 liters/minute. Meanwhile, the highest hardness of aluminum casting products, 90.2 HV, occurred when the Argon gas flow rate was 1.25 liters/minute.

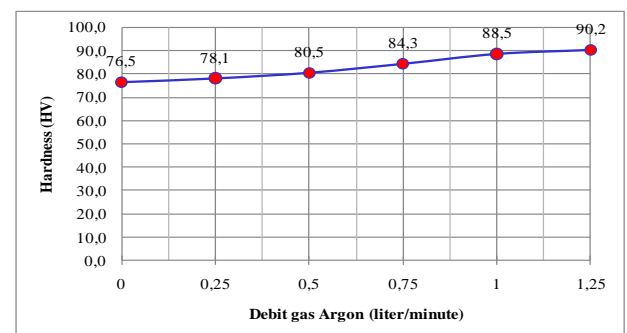


Figure 8: Relationship between hardness and Argon gas flow rate

It was found that by adding 0.25 Argon gas; 0.5 ; 0.75 ; 1 and 1.25 liters/minute into the spent Aluminum melt results in a significant increase in the Vickers hardness of the Aluminum casting product 0 ; 2.09 ; 5.23 ; 10.2 ; 15.69 and 17.91%. This confirms the potential of the process used in producing good quality Aluminum ingots by adding Argon gas to the Aluminum melt. Efforts are being made to optimize the casting process and to fully investigate the behavior of the physical and mechanical properties of Aluminum cast products.

3.3 Microstructure of Used Aluminum Casting Products

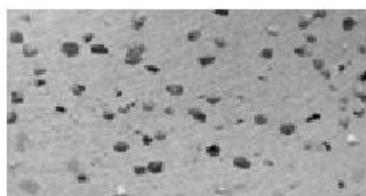
Based on the SEM test results, the following results were obtained, for testing aluminum melting by degassing using argon gas where argon gas was introduced when the aluminum was melting, shown in Figure 9. Testing aluminum melting by degassing using argon gas where argon gas was flowed for 10 minutes after the aluminum melted on 660 °C. Testing aluminum melting by degassing using argon gas where the Argon gas flow rate is 0.25; 0.5 ; 0.75 ; 1 and 1.25 liters/minute are shown in Figures 9a, 9b, 9c, 9d, 9e, 9f.



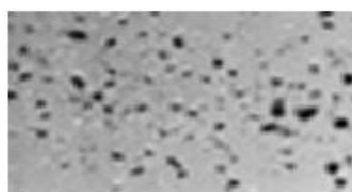
(a)



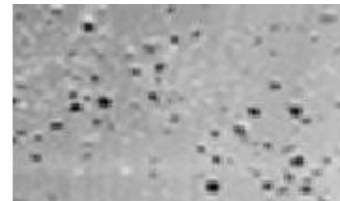
(b)



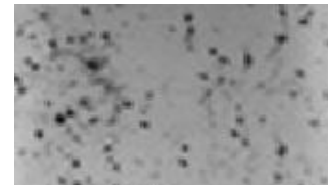
(c)



(d)



(e)



(f)

Figure 9: (a). Microstructure of used aluminum casting products with an Argon gas flow rate of 0 liters/minute (b). Microstructure of used aluminum casting products with an Argon gas flow rate of 0.25 liters/minute (c). Microstructure of used aluminum casting products with an Argon gas flow rate of 0.5 liters/minute (d). Microstructure of used aluminum casting products with an Argon gas flow rate of 0.75 liters/minute (e). Microstructure of used aluminum casting products with an Argon gas flow rate of 1 liter/minute. (e). Microstructure of used aluminum casting products with an Argon gas flow rate of 1.25 liters/minute

Providing argon gas in the process of melting aluminum metal is one of the degassing methods to reduce porosity. Porosity occurs due to the presence of hydrogen atoms dissolved in liquid aluminum. The hydrogen atoms dissolved in molten aluminum come from the dissociation of water vapor on the surface of the molten aluminum. These hydrogen atoms will form small cavitation bubbles due to pressure. Cavitation bubbles occur because changes in the partial pressure of hydrogen in molten aluminum become smaller than the partial pressure of hydrogen in the outside air. The hydrogen atoms in liquid aluminum diffuse into these bubbles easily and continuously, and at the same time interact with each other and turn into hydrogen molecules, that is, from 2H to H₂ gas

When the liquid aluminum freezes, the H₂ gas bubbles are trapped in the aluminum alloy forming cavities called porosity [11][12]. The maximum concentration of dissolved hydrogen in aluminum alloy is 0.6 ml H₂/100g. If the melting is done well, the solubility of H can be reduced to 0.2 -0.3 ml H₂/100g aluminum. The degassing process using inert gas can reduce the hydrogen solubility level to around 0.1 ml H₂/100g aluminum. The solubility of hydrogen in cast alloys is around 0.12 ml H₂/100g and it can be stated that the porosity that occurs is small. [13][14].

According to Haghayeghi, R [15], degassing argon gas that is fed into liquid aluminum affects the gas bubbles, because argon cannot dissolve in liquid aluminum, the argon

gas mixes and combines with the cavitation bubbles then brings them to the surface while lifting the existing dirt so that molten aluminum becomes clean and uniform.

The process of porosity in aluminum melting is also influenced by the speed of flow of liquid aluminum into the mold (dies), the faster the liquid aluminum enters the mold, the more H₂ gas bubbles will enter and be trapped in the mold [16]. Another influence is the characteristics of the shape of the mold itself, the more indentations it makes, the more difficult it will be for H₂ gas bubbles to be released into the outside air so that the possibility of porosity occurring is also greater [17] [18].

IV. CONCLUSION

In the process of making used aluminum ingots by flowing Argon gas into the melted aluminum (degasiing), it can be concluded that:

- a) The higher the Argon gas flow rate, the density of the aluminum casting product increases, while the porosity decreases.
- b) The higher the Argon gas flow rate, the hardness of aluminum casting products tends to increase, with an average increase in hardness of 8.52%.
- c) The distribution of hydrogen gas that is still trapped in the aluminum matrix is uneven and clustering occurs in several locations.
- d) The results of the research show that used aluminum ingot casting products which are supplied with Argon gas, improve the quality quite significantly.

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