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Testing Process of Density and Porosity of Aluminium 7075 and Aluminium 6061

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Abstract: Aluminium is a lightweight metal with good corrosion resistance and electrical conductivity properties. Testing the density and porosity of aluminium is important for its development in various applications, including household appliances, aircraft industry, automotive, ships, and construction. The purpose of this research is to determine the density and porosity values of aluminium 7075 and aluminium 6061 samples. Experimental methods, such as the Archimedes method and the Fujitsu FSR A 300g x 0.001g analytical balance, are used to collect data and measure the mass density of the test specimens. The results show that aluminium 6061 has a higher density measurement value (3.302 g/cm3) compared to aluminium 7075 (2.144 g/cm3). The theoretical density calculation results also indicate that aluminium 7075 has a higher value (3.26 g/cm3) compared to aluminium 6061 (3.18 g/cm3). Additionally, aluminium 7075 has a higher porosity calculation value (34.2%) compared to aluminium 6061 (27.6%). These differences in density and porosity can affect the mechanical and physical properties of the materials, including strength, hardness, deformation resistance, and thermal conductivity

Keywords: Aluminum 7075, Aluminum 6061, Density, Porosity.

INTRODUCTION

Aluminium is a lightweight metal that has good corrosion resistance and electrical conductivity properties. It is widely used in various industries, such as household appliances, aircraft, automotive, ships, and construction, due to its abundance on Earth (Royal Society of Chemistry, n.d.). Aluminium can be produced through casting and forming processes, resulting in products such as cast wheels, pistons, engine blocks, profiles, and plates (American Society for Metals, 1967). Aluminium alloys are also used to improve mechanical properties by adding elements such as copper, silicon, magnesium, manganese, nickel, and zinc (Van Vlack & Djaprie, 1992).

Understanding the physical properties and structure of a material is important, with density and porosity being important factors in material characterization (Lowell et al., 2012). Density is a measure of mass per unit volume, while porosity refers to the amount and size of pores or empty spaces in a material (Alim, 2017; Satria, 2021). These properties are important in various fields, such as manufacturing, material engineering, and material science, and can contribute to the selection of materials, product development, and scientific research (Smith, 1996).

Aluminum is a versatile metal that can be cast, melted, formed, worked, and extruded, making it a popular choice for many industries (American Society for Metals, 1967). In this study, the testing of density and porosity of aluminum materials was conducted to comprehend the characteristics and distinctions between aluminum 7075 and aluminum 6061. The density of the material refers to the extent to which its particles are compact or closely packed, while porosity refers to the quantity and size of pores or empty spaces within the material (Lowell et al., 2012).

This testing can be conducted using methods such as relative density measurement and calculation of density differences between solid and porous materials. One standard method used is the ASTM D792 procedure, which utilizes displacement techniques to determine density and specific gravity (ASTM International, 2020; Intertek, n.d.-b). Additionally, porosity testing can be performed by examining cell structures and pore sizes within the aluminum material, such as using porosity measurement modules in laboratory settings (Ratnaningsih & Sumantri, n.d.). By comparing the results of density and porosity tests between aluminum 7075 and aluminum 6061, a better understanding of their characteristic differences can be obtained. This can be valuable in selecting the appropriate material for specific applications, depending on the desired density and porosity requirements.

RESEARCH METHOD

Experimental methods can be employed as a research approach to test the density and porosity of aluminum. Data collection methods involve the use of the Archimedes method and measuring the mass density of test specimens using the Fujitsu FSR A 300g x 0.001g analytical balance with testing dimensions of 1x1x1 cm. The testing process is depicted in a testing process flowchart, outlining the steps from the initial testing phase to completion, as shown in Figure 1.

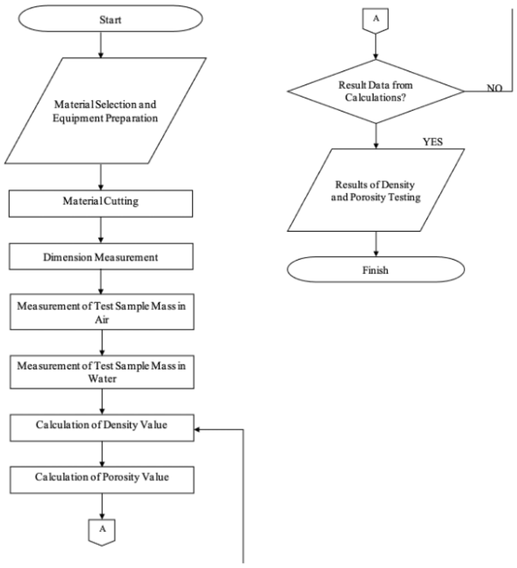


Figure 1. Flowchart of Density and Porosity Testing for Aluminum 7075 and Aluminum 6061

Material Selection and Equipment Preparation

In this test, we used aluminum materials, namely aluminum 7075 and aluminum 6061. Aluminum 7075 is an aluminum alloy with zinc as its primary alloying element. This alloy is known for being one of the strongest with excellent mechanical properties, including high strength, toughness, resilience, and fatigue resistance. However, its weakness lies in being more susceptible to embrittlement compared to other aluminum alloys due to microsegregation. The typical composition of this alloy consists of 94.1% aluminum, 5.8% zinc, 2.3% magnesium, 1.4% copper, 0.5% silicon, 0.5% iron, 0.5% manganese, 0.5% titanium, and 0.5% chromium, although these numbers may vary depending on manufacturing factors.

The density of aluminum 7075 is approximately 2.81 g/cm3 (0.102 lb/in^3), making it relatively lightweight for a metal. The copper content in this alloy increases its susceptibility to corrosion, but this sacrifice is necessary to create a strong yet workable material. Aluminum 7075 is commonly used in high-stress applications, such as aircraft parts or components subjected to high pressure. Additionally, this alloy is utilized in applications requiring a high strength-to-weight ratio, like transportation (automotive, aerospace, and marine). However, due to its higher cost compared to other aluminum alloys, it is typically used only when cheaper alloys are insufficient for the job.

Figure 2. Aluminum 7075

Aluminum 6061 is an aluminum alloy belonging to the 6xxx series of aluminum alloys, which uses magnesium (Mg) and silicon (Si) as its primary alloying elements. The nominal composition of aluminum 6061 includes 1% magnesium, 0.6% silicon, 97.2% aluminum, 0.195% chromium, 0.275% copper, 0.7% iron, 0.15% manganese, and 0.15% titanium. This alloy has a density of 2.7 g/cm3 (0.0975 lb/in^3) and is heat-treatable, easily formable, weldable, and corrosion-resistant.

Aluminum 6061 is widely used in various applications, including automotive parts, bicycle frames, electrical fittings, marine fittings, and structural components. This alloy is known for its weldability, machinability, corrosion resistance, and success in fabrication processes. Overall, aluminum 6061 is a versatile and extensively used aluminum alloy.

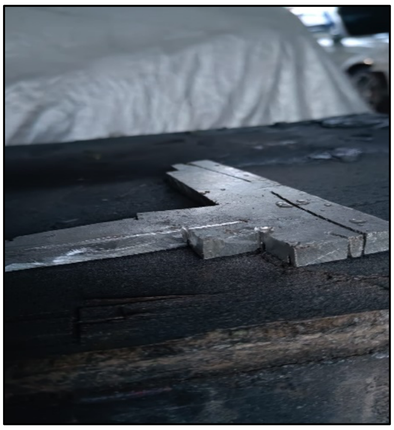


Figure 3. Aluminum 6061

Then, for the preparation of equipment and materials that will be used, they are as follows:

1. Fujitsu FSR-A 300g x 0.001g Analytical Balance
2. Distilled Water (Aquadest)
3. Bowl Container

4. Specimen Holding Container

Material Cutting

Material cutting of test specimens can influence density testing in some cases. Specimen cutting is performed to achieve uniform sizes and to ensure that test specimens fit within the boundaries of the immersion container used in the study.

Dimension Measurement

The material's dimensional size has a significant impact on density and porosity testing. The proper size will affect the accuracy of measurements and overall representation of material characteristics. Size that is too small or too large can lead to errors in density and porosity measurements. Additionally, the dimensional size also affects access to material pores and the adjustment of testing methods used. Therefore, selecting the appropriate dimensional size is crucial in density and porosity testing to ensure accurate and reliable results. For this testing, the specified dimensional size is 1 cm x 1 cm x 1 cm.

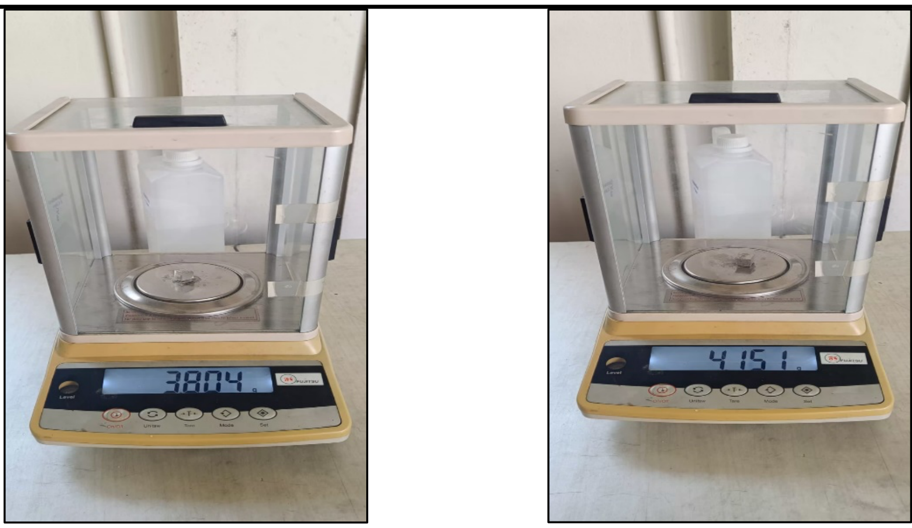
A

B

Figure 4. Dimensional Size of Test Material (A) Aluminum 7075 (B) Aluminum 6061

Measurement of Test Sample Mass in Air

The measurement of the test sample mass in the air was conducted using an analytical balance. The measurement results for aluminum 7075 showed a mass of 3.804 g, while for aluminum 6061, the measurement results showed a mass of 4.151 g.

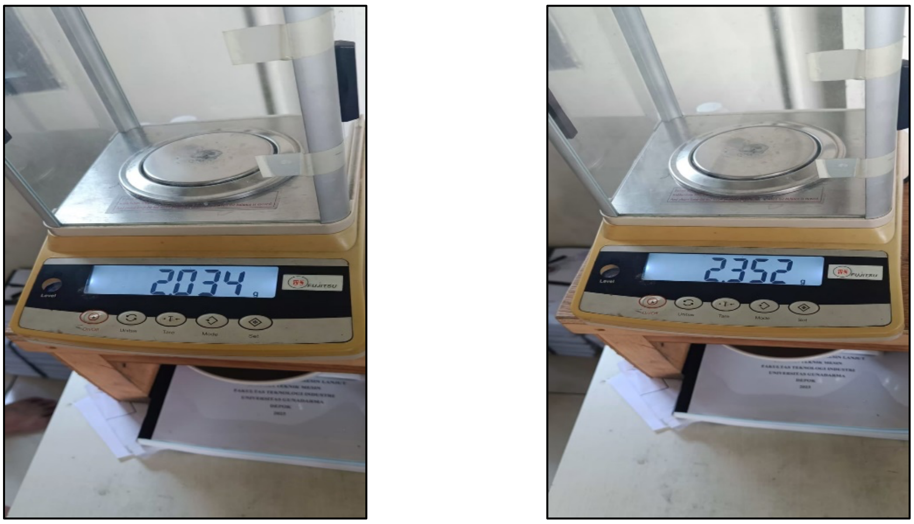


A B

Figure 5. (A) Measurement Results of Aluminum 7075 Specimen Mass in Air.
(B) Measurement Results of Aluminum 6061 Specimen Mass in Air.

Measurement of Test Sample Mass in Water

The measurement of the test sample mass in water was conducted using an analytical balance, resulting in a measurement of 2.034 g for aluminum 7075 and a measurement of 2.352 g for aluminum 6061.



A B

Figure 6. (A) Measurement Results of Aluminum 7075 Specimen Mass in Water.
(B) Measurement Results of Aluminum 6061 Specimen Mass in Water.

Density Calculation

Density calculation is carried out to estimate the specific mass or density of a material. Density is a value that describes the physical characteristics of a substance and is measured in grams per cubic centimeter or kilograms per cubic meter. The density calculation involves measuring the mass of components forming a mixture and the total mass of the mixture to obtain the density or specific mass of the material. Additionally, highly accurate analytical balances can be used in density calculations. Density calculation is useful in determining the quality and strength of a material. To find the density value, two types of calculations are conducted: measurement density and theoretical density using the following equations [10]:

1. Measurement Density

$$\rho_m = \frac{dry\ mass,(g)}{wax\ mass\ (g) - underwater\ mass\ (g)} \times \rho_{water} \tag{1}$$

Description:

ρ_m = *Measuremenet Density* (gram/cm^3)
W_{wax} = Wax mass (gram)
W_{water} = Specimen Mass in Water (gram)
ρ_{water} = Density of Water. (0.997 gram/cm^3)

2. Theoretical Density

$$\rho_{th} = \left(\rho_{Element} \times V_{f\ Element}\right) + \cdots \tag{2}$$

Description:

ρ_{th} = Theoretical Density (gram/cm^3)
ρ = Density(gram/cm^3)
V_f $= \frac{Volume\ per\ element}{Total\ material\ volume}$

Porosity Value Calculation

Porosity calculation is performed to estimate the percentage of pore volume within a material. Porosity is a value that describes the physical characteristics of a substance and is measured in the form of a percentage. Porosity calculation is useful in determining the quality and strength of a material. To calculate the porosity value, the following formula equation is used:

$$P_0 = \left(1 - \frac{\rho_m}{\rho_{th}}\right) \times 100\% \tag{3}$$

Description:

ρ_0 = Porosity (%)

ρ_m = Measuremenet Density (gram/cm^3)

ρ_{th} = Theoretical Density (gram/cm^3)

RESULT AND DISCUSSION

Test Data

The following is the test data that has been conducted and the data is further processed in the form of a table to facilitate data processing:

Table 1. Test Sample Mass Testing Data

Specimens	Air Method (g)	Water Method (g)
Aluminum 7075	3.804	2.034
Aluminum 6061	4.151	2.352

Calculation and Testing Process

1. Calculating Measurement Density

Aluminum 7075

Known:

Dry Mass (g) : 3.804 g

Mass in Water (g) : 2.034 g

Water Density (ρ_{water}) : 0.997 g/cm^3

Answer:

$$\rho_m = \frac{dry\ mass,(g)}{wax\ mass\ (g) - underwater\ mass\ (g)} \times \rho_{water}$$

$$= \frac{3.804\ g}{3.804\ g - 2.034\ g} \times 0.997\ g/cm^3$$

$$= 2.144\ g/cm^3$$

Aluminum 6061

Known:

Dry Mass (g) : 4.151 g

Mass in Water (g) : 2.034 g

Water Density (ρ_{water}) : 0.997 g/cm^3

Answer:

$$\rho_m = \frac{dry\ mass,(g)}{wax\ mass\ (g) - underwater\ mass\ (g)} \times \rho_{water}$$

$$= \frac{4.151\ g}{4.151\ g - 2.353\ g} \times 0.997\ g/cm^3$$

$$= 2.301\ g/cm^3$$

So, the results obtained for aluminum 7075 are 2.144 g/cm^3 and for aluminum 6061 are 2.301 g/cm^3.

2. Calculating Theoretical Density

Aluminum 7075

Known:

Density of Aluminum (g/cm^3) : 2.7 g/cm^3

Aluminum Composition (%) : 94.1%

Density of Zinc (g/cm^3) : 7.14 g/cm^3

Zinc Composition (%) : 5.8%

Density of Magnesium (g/cm^3) : 1.738 g/cm^3

Magnesium Composition (%) : 2.3%

Density of Copper (g/cm^3) : 8.96 g/cm^3

Copper Composition (%) : 1.4%

Density of Silicon (g/cm^3) : 2.329 g/cm^3

Silicon Composition (%) : 0.5%

Density of Iron (g/cm^3) : 7.874 g/cm^3

Iron Composition (%) : 0.5%

Density of Manganese (g/cm^3) : 7.21 g/cm^3

Manganese Composition (%) : 0.5%

Density of Titanium (g/cm^3) : 4.506 g/cm^3

Titanium Composition (%) : 0.5%

Density of Chromium (g/cm^3) : 7.15 g/cm^3

Chromium Composition (%) : 0.5%

Answer:

$$\rho_{th} = (\rho_{Element} \times V_{f\ Element}) + \cdots$$

$$= (\rho_{Al} \times V_{f_{Al}}) + (\rho_{Zn} \times V_{f_{Zn}}) + (\rho_{Mg} \times V_{f_{Mg}}) + (\rho_{Cu} \times V_{f_{Cu}}) + (\rho_{Si} \times V_{f_{Si}}) + (\rho_{Fe} \times V_{f_{Fe}}) + (\rho_{Mn} \times V_{f_{Mn}}) + (\rho_{Ti} \times V_{f_{Ti}}) + (\rho_{Cr} \times V_{f_{Cr}})$$

$$= (2.7\ g/cm^3 \times \frac{94.1\%}{100\%}) + (7.14\ g/cm^3 \times \frac{5.8\%}{100\%}) + (1.738\ g/cm^3 \times \frac{2.3\%}{100\%}) + (8.96\ g/cm^3 \times \frac{1.4\%}{100\%}) + (2.329\ g/cm^3 \times \frac{0.5\%}{100\%}) + (7.874\ g/cm^3 \times \frac{0.5\%}{100\%}) + (7.21\ g/cm^3 \times \frac{0.5\%}{100\%}) + (4.506\ g/cm^3 \times \frac{0.5\%}{100\%}) + (7.15\ g/cm^3 \times \frac{0.5\%}{100\%})$$

$$= 3.26\ g/cm^3$$

Aluminum 6061

Density of Aluminum (g/cm^3) : 2.7 g/cm^3

Aluminum Composition (%) : 97.2%

Density of Chromium (g/cm^3) : 7.15 g/cm^3

Chromium Composition (%) : 0.195%

Density of Copper (g/cm^3) : 8.96 g/cm^3

Copper Composition (%) : 0.275%

Density of Magnesium (g/cm^3) : 1.738 g/cm^3

Magnesium Composition (%) : 1%

Density of Silicon (g/cm^3) : 2.329 g/cm^3

Silicon Composition (%) : 0.6%

Density of Iron (g/cm^3) : 7.874 g/cm^3

Iron Composition (%) : 0.7%

Density of Manganese (g/cm^3) : 7.21 g/cm^3

Manganese Composition (%) : 0.15%

Density of Titanium (g/cm^3) : 4.506 g/cm^3

Titanium Composition (%) : 0.15%

Answer:

$$\rho_{th} = \left(\rho_{Element} \times V_{f\ Element}\right) + \cdots$$

$$= (\rho_{Al} \times V_{f_{Al}}) + (\rho_{Cr} \times V_{f_{Cr}}) + (\rho_{Cu} \times V_{f_{Cu}}) + (\rho_{Mg} \times V_{f_{Mg}}) +) + (\rho_{Si} \times V_{f_{Si}}) + (\rho_{Fe} \times V_{f_{Fe}}) + (\rho_{Mn} \times V_{f_{Mn}}) + (\rho_{Ti} \times V_{f_{Ti}})$$

$$= (2.7\ g/cm^3 \times \frac{97.2\%}{100\%}) + (7.15 \frac{g}{cm^3} \times \frac{0.195\%}{100\%} + (8.96\ g/cm^3 \times \frac{0.275\%}{100\%}) + (7.14\ g/cm^3 \times \frac{5.8\%}{100\%}) + (1.738\ g/cm^3 \times \frac{1\%}{100\%}) + (2.329\ g/cm^3 \times \frac{0.6\%}{100\%}) + (7.874\ g/cm^3 \times \frac{0.7\%}{100\%}) + (7.21\ g/cm^3 \times \frac{0.15\%}{100\%}) + (4.506\ g/cm^3 \times \frac{0.15\%}{100\%})$$

$$= 3.18\ g/cm^3$$

So, the results obtained for aluminum 7075 are 3.26 g/cm^3 and for aluminum 6061 are 3.18 g/cm^3.

3. Calculating Porosity Value

Aluminum 7075

Known:

Measurement Density (ρ_m) : 2.144 g/cm^3

Theoretical Density (ρ_{th}) : 3.26 g/cm^3

Answer:

$$P_0 = \left(1 - \frac{\rho_m}{\rho_{th}}\right) \times 100\%$$

$$= \left(1 - \frac{2.144\ g/cm^3}{3.26\ g/cm^3}\right) \times 100\%$$

$$= 34.2\ \%$$

Aluminum 6061

Known:

Measurement Density (ρ_m) : 2.301 g/cm^3

Theoretical Density (ρ_{th}) : 3.18 g/cm^3

Answer:

$$P_0 = \left(1 - \frac{\rho_m}{\rho_{th}}\right) \times 100\%$$

$$= \left(1 - \frac{2.301\ g/cm^3}{3.18\ g/cm^3}\right) \times 100\%$$

$$= 27.6\ \%$$

So, the results obtained for aluminum 7075 are 34.2%, and for aluminum 6061 are 27.6%.

Testing Process

In this stage, we conduct the testing process of the previously calculated test data. The data is then transformed into tables and graphs for the testing process. Below is the table showing the results of the measurement density, theoretical density, and porosity values of aluminum 7075 and aluminum 6061 materials:

Table 2. Results of Density and Porosity Testing for Aluminum 7075 and Aluminum 6061

Specimens	Measurement Density (ρ_m)(g/cm^3)	Theoretical Density (ρ_{th})(g/cm^3)	Porosity Value (%)
Aluminum 7075	2.144	3.26	34.2
Aluminum 6061	2.301	3.18	27.6

Then, the results from the table are presented in the form of graphs showing the measurement density, theoretical density, and porosity values. Below are the graphs of the testing results for aluminum 7075 and aluminum 6061.

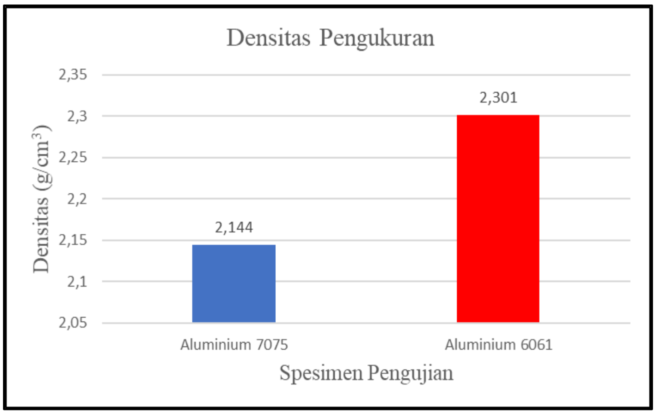


Figure 7. Graph of Measurement Density Calculation Results.

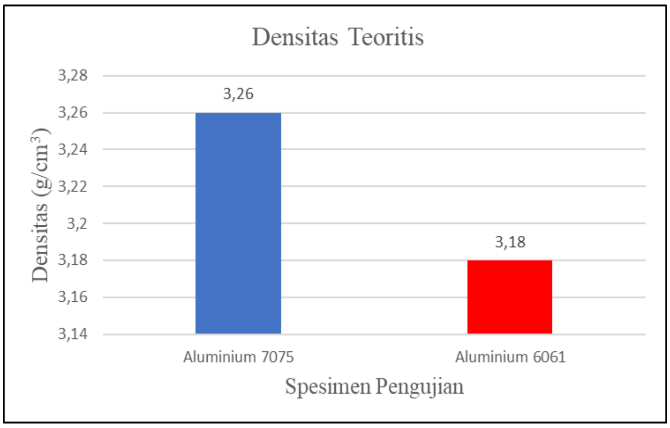


Figure 8. Graph of Theoretical Density Calculation Results

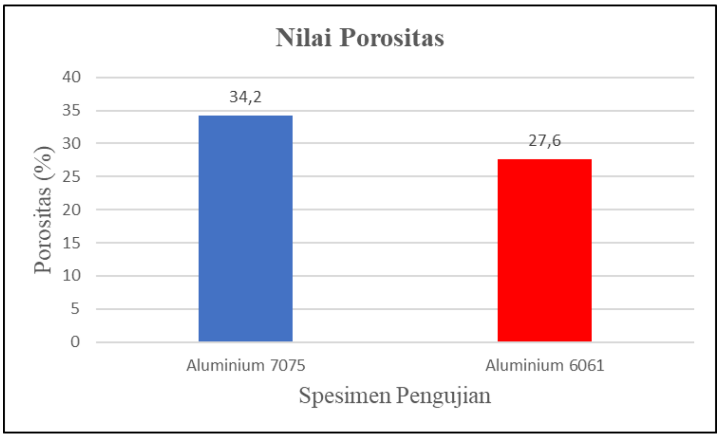
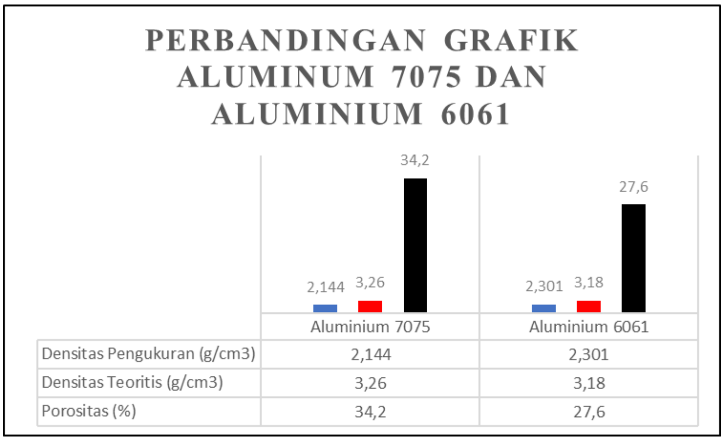


Figure 9. Graph of Porosity Value Calculation Results



Fugure 10. Comparison of Graphs for Aluminum 7075 and Aluminum 6061

After the calculations, the results for both specimens of aluminum 7075 and aluminum 6061 were obtained. The highest measurement density value was found in aluminum 6061 with a value of 3.302 g/cm^3, while the lowest value was in aluminum 7075 with 2.144 g/cm^3. For the theoretical density, the highest value was in aluminum 7075 with 3.26 g/cm^3, and the lowest value was in aluminum 6061 with 3.18 g/cm^3. Lastly, the highest porosity value was found in aluminum 7075 with 34.2%, and the lowest value was in aluminum 6061 with 27.6%.

CONCLUSION

Here are the conclusions from the density and porosity testing of aluminum 7075 and aluminum 6061 specimens:

1. The density of aluminum 7075 and aluminum 6061 materials indicates that the particles inside them are not perfectly compact or dense. The lower measured density compared to the theoretical density suggests the possibility of pores or empty spaces between the particles, indicating a less dense structure. Further analysis is needed to understand the factors causing these differences, such as imperfections in the measurement process or sample contamination.
2. Aluminum 7075 material has a porosity level of 34.2%, which affects its mechanical properties and density. High porosity reduces tensile strength and thermal conductivity. Aluminum 6061 material has a porosity level of 27.6%, indicating better mechanical properties and higher density compared to aluminum 7075. Its thermal conductivity is also superior.
3. Aluminum 7075 has lower density and higher porosity compared to aluminum 6061. These differences can impact the mechanical and physical properties of both materials, including strength, hardness, deformation resistance, and thermal conductivity.

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