Manufacturing of Ceramic Reinforced Metal Matrix Composites (Al/Sicp) And Their Characterization Through Powder Metallurgy Methods

Jepriandi Ginting
Department of Physics, Faculty of Mathematics and Natural Sciences, University of North Sumatra, Medan, Indonesia

ABSTRACT
Metal Matrix Composites is two or more combination material with aluminum metal as matrix and devolved to fix metal act, strength, high temperature stability and hardness. Metal matrix composites have been developed so many because it has low density, corrosion proof, cheap and easy fabrication. Powder metallurgy technique is one of metal matrix composites fabrication process in solid state that is still developed because more economic, doesn't need difficult equipment. Aluminum that use in this research is Al alloy type 2124. Metal matrix composites fabrication process with powder metallurgy method using wet mixing with pure ethanol, cold compaction 300 MPa and inert gas atmospheric using Nitrogen gas (N2) at sintering process. Variation of sinter temperature that used is 450, 500, 550, and 600 °C with highly temperature average 5 °C/min and holding time for 1 hour and with speed flow Nitrogen gas (N2) 5 lt/min with pressure 1000 kgf/cm2. From research result can be concluded the mechanical properties and physical properties from metal matrix composites reinforced ceramics Al/SiCp increase with sinter temperature highly and with reinforcement particle addition SiC can increase mechanical properties and physical properties such as: hardness, wear resistance, coefficient of thermal expansion and corrosion resistance. From microstructure analysis, particle Sic distributed homogeneously at test specimen based on SEM analysis, and structure crystal analysis test result XRD show that dominant phase appear is Al, and Sic.

INTRODUCTION
Materials that are cheap and easily available will certainly be able to reduce the selling price and reduce manufacturing costs (manufacturing). Metal-based industries (such as: motor vehicle wheels, turbines for power generation, pistons for the automotive industry, mechanical equipment, etc.) in Indonesia generally still import from abroad, in addition to the relatively high price of raw materials. In general, the constituent materials for pistons, wheels, and other applications in motor vehicles are made of ferrous (ferrous)-based casting materials. However, the application of metal composite
materials in the industrial world in Indonesia has not been significant, perhaps due to fabrication engineering barriers or other technical constraints. But the advantages of composite materials when applied in the industrial world in the long term will provide various advantages, such as: weight reduction of components, anti-corrosion, resistance to friction (friction material), low thermal conductivity, and other mechanical and physical advantages. Metal composites that are often used today are aluminum-based metal matrix composites because they are one of the most abundant and inexpensive mineral materials in the world. While the reinforcement used is usually ceramic-based from various groups (carbides, nitrides, and oxides), such as: SiC, B₄C, TiC, in the form of particles, whiskers, or in the form of short Al₂O₃ fibers. (Zainuri, 2007) Metal composites that are often used today are aluminum-based metal matrix composites because they are one of the most abundant and inexpensive mineral materials in the world. While the reinforcement used is usually ceramic-based from various groups (carbides, nitrides, and oxides), such as: SiC, B₄C, TiC, in the form of particles, whiskers, or in the form of short Al₂O₃ fibers. (Zainuri, 2007) Metal composites that are often used today are aluminum-based metal matrix composites because they are one of the most abundant and inexpensive mineral materials in the world. While the reinforcement used is usually ceramic-based from various groups (carbides, nitrides, and oxides), such as: SiC, B₄C, TiC, in the form of particles, whiskers, or in the form of short Al₂O₃ fibers. (Zainuri, 2007)

Powder metallurgy (powder metallurgy) is a fabrication technique that has a very wide application in various material technology innovations today. In the industrial world, this technology can be applied to various material characteristics, such as physical properties including electrical, magnetic, optical or mechanical properties (Angelo and Subramanian 2008). The advantages of applying powder-based technology include being able to combine various material properties with different characteristics, so that they become new properties as planned (design) (Gibson, Kvan, and Ming 2002). Composite material with the basic forming material in the form of a matrix and reinforcement in the form of a powder, including: isotropic composite group in which all reinforcement directions have the same magnitude.

Metal Matrix Composites (MMC’s) with aluminum matrix and powder-based SiC reinforcement or also known as isotropic Al/SiC composites are materials that have a potential role with wide application and development. This composite has advantages in strength and resistance to wear. This composite is also widely used as a basic material for automotive product components such as gears, pistons, disc brakes and other automotive product components.

Composites are one of the alternative materials that are widely used to replace conventional materials which are decreasing in terms of quantity and quality (Pandey et al. 2010). One of these conventional materials is aluminum (Al), which has been known as a material that has light physical properties, is plastic, and is resistant to corrosion by utilizing a composite of powder metallurgy manufacturing process system. With this manufacturing system, Aluminum material which has plastic properties, when reinforced with SiC ceramic material with hard properties, will have new properties that are between plastic and hard. This can happen if there is a bond between the surface of the aluminum powder and the SiC powder. The quality of the interfacial bond that occurs between Al and SiC is influenced by the amount of pressure (compact) during the process of making composite materials. Pressure that is too small will cause the initial bond between the Al and SiC surfaces to be weak, therefore during the sintering process the bonds will be released. For bonds that are too large, well above the yield strength (yield point) of the matrix, it will cause gas trapping or solid release after the pressing process, so during sintering this will cause cracks in the composite. To avoid unexpected events, it is necessary to apply the right pressure so that the bonds between the surfaces are not too weak and not too strong, thus the diffusion process that occurs between the surfaces of the matrix and reinforcement can occur perfectly. In addition, the problem that is often faced in the manufacture of aluminum matrix composites with powder metallurgy is the problem of wettability, because the wettability of the reinforcing particles (reinforcement) against the matrix is the main factor in the formation of bonds (diffusion). Factors that affect wettability include: uniformity (homogeneity) when mixing matrix and reinforcing powders, sintering process, time, and...
atmospheric environment. All of these factors determine the quality of the composite manufacturing process. (Khaerudini, 2008) among others: uniformity (homogeneity) when mixing matrix and reinforcing powders, sintering process, time, and atmospheric environment. All of these factors determine the quality of the composite manufacturing process (Fung 2003). (Khaerudini, 2008) among others: uniformity (homogeneity) when mixing matrix and reinforcing powders, sintering process, time, and atmospheric environment. All of these factors determine the quality of the composite manufacturing process. (Khaerudini, 2008)

In the manufacture of composites using a powder metallurgy process, Al matrix powder and SiC reinforcing particles are mixed (wet mixing) and then put into a mold and compacted using a hydraulic press with a pressure of 300 MPa and held for 5 minutes to get a green body with a sample density of around 80%. After the process, the sintering process is carried out, the sintering process is carried out in a nitrogen atmosphere (inner gas) and the sintering temperature is varied to a limit of 600 °C (below the melting point of aluminum) and held for 1 hour. In this study, SiC ceramic particles were wetted (wettability) using Al(NO3)3.

The aims of this study were: To determine the characterization of the Al/SiCp ceramic-reinforced metal matrix composite. 1. To determine the mechanical and physical properties of Al/SiCp metal matrix composites for various test parameters. 2. To take advantage of Indonesia’s abundant natural resources for industrial development, especially in the manufacture of metal matrix composites. 3. To find out the application of Al/SiCp ceramic-reinforced metal matrix composites in various industries and in everyday life. Benefits The research that has been carried out is expected to increase knowledge and insight into the manufacturing process and characterization of Al/SiCp ceramic-reinforced metal matrix composites for various applications in industrial sectors such as: automotive industry, aviation (aerospace),

RESEARCH METHOD

2.1 Flow diagram

2.1.1 Diagram of Pre Treatment Electroless Coating SiC

![Diagram of Pre Treatment Electroless Coating SiC](image)

**Figure 1.** Schematic of SiCp electroless coating process to increase ceramic wettabiliy (wettability)
2.1.2 Al/SiCp Matrix Composite Flowchart Schematic

![Flowchart Schematic](Image)

Figure 2. Schematic flow diagram of aluminum alloy 2124-SiCp metal matrix composite fabrication through powder metallurgy process

2.2 Experimental Variables
2.2.2 Research variable
a. Sintering temperature variation starts from 450, 500, 550, up to 600 °C.
b. The ratio of weight composition between Al alloy matrix and SiCp reinforcement is 70 : 30 %wt and 80 : 20 %wt.

2.2.3 Experimental Variables Tested
a. Physical Properties
b. Mechanical Properties
c. Microstructural Analysis

2.3 Research procedure
2.3.1 Powder Preparation
SiC particles were sieved through a < 50 m (200 mesh) sieve, then washed with acetone solution to clean the dirt contained in the powder. After washing, the SiC particles were evaporated (pre-heated) at 100 °C for 4 hours in a dry oven to avoid oxidation reactions.

2.3.2 Mixing (mixing)
The next process is the mixing process between the matrix raw material (aluminum alloy powder) measuring 38–50 μm (200 mesh) and the SiCp particle reinforcement until evenly distributed (homogeneous). Mixing was carried out in a glass beaker using a magnetic stirrer as the stirring medium.

2.3.3 Test Sample Making

The test samples were made by cold compaction using a hydraulic press with a capacity of 100 tons. Before the sample is put into the mold, the mold wall is first coated (smeared) with stearic acid (stearic acid) to facilitate the compaction process (emphasis), reduce friction between metal powder (aluminum alloy 2124) against the mold wall, and avoid the Al/SiCp specimen from sticking on the mold wall. The addition of the amount of stearic acid (lubricating agent) is about 0.2 – 1% wt. A mixture of matrix raw materials (Al alloy 2124 powder) and reinforcement (SiC particles) weighing 10 g was put into a mold and compacted at 300 MPa with a pressure speed of 10 cm/min.

2.3.4 Sintering Process

Sintering is a process of burning composite materials so that the granules bind to each other (diffusion) and there is a decrease in the value of porosity. In this study, the sintering temperature variations were 450, 500, 550, and 600 °C (Shao, Zhou, and Zhu 2012).

2.4 Test

The tests carried out in this study include: porosity, density, coefficient of thermal expansion, corrosion resistance, compressive strength, hardness (Vickers hardness), erosion resistance (wear resistance), microstructure testing and crystal structure analysis.

2.4.1 Physical Properties

2.4.1.1 Density

The purpose of density measurement is to obtain the results of metal matrix composites which have a density in accordance with the theoretical density of 2.6 – 3.1 g/cm³ and the density test refers to the ASTM C 373 standard. Density measurements in the manufacture of metal matrix composites are carried out using Archimedes’ principle. Measurements were carried out in two stages, namely: pre-sintering and post-sintering density measurements.

2.4.1.2 Porosity

The purpose of the porosity measurement is to find out whether the metal matrix composite has the desired porosity and the porosity test refers to the ASTM C 373 standard. The measurement of the coefficient of thermal expansion was carried out using a Harrop Laboratories T-70 Dilatometer with the measurement temperature range set from 30 – 300 °C and referring to the ASTM E 228 standard.

2.4.1.3 Corrosion Resistance Testing

The purpose of corrosion testing is to determine the corrosive nature of the test sample, corrosion testing refers to the ASTM G103 standard.

2.4.2 Mechanical Properties

Compressive Strength

The compressive strength test is to measure the compressive strength of the material (test sample) against mechanical stress. The tools used to test the compressive strength are Universal Testing Machine (UTM) and Hydraulic press. ASTM C-773.

2.4.2.1 Hardness (Vickers Hardness Test)

A tool for testing hardness using a Microhardness Tester, Matsuzawa brand type MXT-50, with a diamond pyramid as a support and this test refers to the ASTM E18-02 standard

2.4.2.2 Erosion Resistance Testing (Wear Resistance)

The purpose of the erosion resistance test is to determine the resistance of the test sample to repeated friction on the surface of a material with a certain grit (roughness) and period. Erosion resistance testing in this study refers to the ASTM G-99. Standard

Microstructural Analysis

SEM (Scanning Electron Microscope)
The shape and size of the Al/SiC metal matrix composite particles can be identified based on the data obtained from the SEM (Scanning Electron Microscope) measuring instrument.

2.5 Crystal Structure Analysis

2.5.1 X-Ray Diffraction (X-Ray Diffraction)

In this study, the characterization of the crystal structure of the test sample was carried out using the x-ray diffraction method. The purpose of testing the crystal structure analysis is to determine the phase changes in the structure of the material and to know what phases are formed during the process of making the test sample.

RESULTS AND DISCUSSIONS

2.4 Physical Properties

3.1.1 Density and Porosity

From the results of the research that has been carried out, the pre-sintering and post-sintering density and porosity values can be determined using equations 2.8 and 2.9 which refer to the ASTM C 373 testing standard using the Archimedes method.

3.1.1.1 Presintering Density and Porosity

From the calculation results, a table for measuring the density and porosity values of pre sintering can be made as follows:

Table 4.1 Presintering density and porosity measurements for composition 80 : 20 %wt Al/SiCp

| Code Sample | mo (g) | your (g) | mA (g) | mK (g) | Density (g/cm³) | Porosity (%) |
|-------------|--------|----------|--------|--------|-----------------|--------------|
| I           | 7.52   | 7.62     | 3.99   | 0.52   | 2.50            | 3.43         |

Table 4.2 Presintering density and porosity measurements for composition

| Code Sample | mo (g) | your (g) | mA (g) | mK (g) | Density (g/cm³) | Porosity (%) |
|-------------|--------|----------|--------|--------|-----------------|--------------|
| I           | 7.86   | 7.96     | 4.23   | 0.52   | 2.52            | 3.22         |

3.1.1.2 Post sintering density and porosity

From the calculation results, a table for measuring the density and porosity values after sintering can be made as follows:

Table 4.3 Measurement of post sintering density and porosity at composition 80 : 20 %wt Al/SiCp

| Temperature (oC) | Sample | mo (g) | your (g) | mA (g) | mK (g) | Density (g/cm³) | Porosity (%) |
|------------------|--------|--------|----------|--------|--------|-----------------|--------------|
| 450              | I      | 8.22   | 8.28     | 4.75   | 0.52   | 2.79            | 2.12         |
|                  | II     | 8.13   | 8.19     | 4.69   | 0.52   | 2.78            | 2.09         |
| 500              | I      | 8.17   | 8.23     | 4.72   | 0.52   | 2.78            | 2.11         |
|                  | II     | 8.09   | 8.14     | 4.69   | 0.52   | 2.81            | 1.83         |
|                  |        | 7.96   | 8.01     | 4.61   | 0.52   | 2.81            | 1.71         |
|                  |        | 8.03   | 8.08     | 4.65   | 0.52   | 2.81            | 1.77         |
Sintering in the process of making composites using the powder metallurgy method is an interesting phenomenon to be considered more closely, because the final bonding process between SiCp reinforcement and Al Alloy matrix greatly determines the mechanical and physical properties of the composite material to be made. The sintering process is a diffusion phenomenon between particle surfaces on an atomic scale which is very dependent on the surface reactivity between the interacting particles, in the process of making Al/SiCp metal matrix composites, it is highly expected that Al Alloy matrix materials and SiCp reinforcement interact perfectly. Therefore, coating SiCp particles with metal oxide Al(NO3)3 is expected to increase the interaction between SiCp reinforcement and Al Alloy matrix.

**Thermal Expansion Coefficient**

From the results of the research that has been done, the value of the coefficient of thermal expansion can be found using equation 2.10 by adjusting the equation generated by the plotter tool. From the table of results of testing the coefficient of thermal expansion (Appendix A), it can be made a graph of the relationship between changes in sample length and the increase in test temperature.
Testing the thermal expansion properties of a composite material is very important because it is related to the application of the composite. The purpose of testing the coefficient of thermal expansion is to determine the change in length relative to the initial length of the sample related to temperature (T). The measurement of the coefficient of thermal expansion (CTE) was carried out using the Dilatometer Harrop T-70 measuring instrument. The coefficient of thermal expansion is measured from 30 oC to 300 oC. From Figures 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, and 4.11, the values for the coefficient of thermal expansion are determined based on the slope of the graph of the relationship between temperature increase and sample length increase. The slope of the coefficient of thermal expansion can be found by equation 4.1 below.

| Sintering Temperature (oC) | m1 (oC-1) | m2 (oC-1) | m3 (oC-1) | average (oC-1) |
|---------------------------|-----------|-----------|-----------|----------------|
| 450                       | 0.14000   | 0.12267   | 0.10667   | 0.12311        |
| 500                       | 0.13600   | 0.13810   | 0.17222   | 0.14877        |
| 550                       | 0.12014   | 0.13467   | 0.15000   | 0.13494        |
| 600                       | 0.10063   | 0.13889   | 0.16667   | 0.13539        |

| Sintering Temperature (oC) | m1 (oC-1) | m2 (oC-1) | m3 (oC-1) | average (oC-1) |
|---------------------------|-----------|-----------|-----------|----------------|
| 450                       | 0.1111    | 0.14167   | 0.14035   | 0.13104        |
| 500                       | 0.14085   | 0.13433   | 0.13443   | 0.13653        |
| 550                       | 0.11776   | 0.12763   | 0.13810   | 0.12783        |
| 600                       | 0.08940   | 0.11806   | 0.15319   | 0.12022        |

### 3.1.3 Corrosion Resistance

From the results of the corrosion resistance test on the test sample carried out for 168 hours (7 days) using a 6% NaCl solution, a table of changes in the mass of the test sample can be made as follows:

| Temperature (oC) | Time (Hour) 0 | 24 | 48 | 72 | 96 | 120 | 144 | 168 |
|----------------|---------------|----|----|----|----|-----|-----|-----|
| 450 oC         | 7.896         | 7.879 | 7.880 | 7.887 | 7.894 | 7.872 | 7.891 | 7.897 |
| 500 oC         | 7.791         | 7.808 | 7.803 | 7.777 | 7.787 | 7.791 | 7.791 | 7.803 |
| 550 oC         | 8.050         | 8.056 | 8.027 | 8.059 | 8.057 | 8.070 | 8.048 | 8.049 |
| 600 oC         | 7.789         | 7.798 | 7.791 | 7.793 | 7.787 | 7.797 | 7.790 | 7.793 |

| Temperature (oC) | Time (Hour) 0 | 24 | 48 | 72 | 96 | 120 | 144 | 168 |
|----------------|---------------|----|----|----|----|-----|-----|-----|
| 450 oC         | 8.290         | 8.300 | 8.240 | 8.181 | 8.282 | 8.290 | 8.271 | 8.293 |
3.2 Mechanical Properties

3.2.1 Strong Press

From the calculation results, a table for measuring the compressive strength value can be made as follows:

| Temperature (°C) | Diameter (cm) | Large (cm²) | Maximum Load (kgf/cm²) | Strong Press (MPa) |
|-----------------|---------------|-------------|------------------------|---------------------|
| 450             | 1.53          | 1.83        | 11.67                  | 91.25               |
| 500             | 1.53          | 1.84        | 13.33                  | 103.84              |
| 550             | 1.53          | 1.83        | 18.33                  | 143.40              |
| 600             | 1.53          | 1.83        | 19.67                  | 153.83              |

| Temperature (°C) | Diameter (cm) | Large (cm²) | Maximum Load (kgf/cm²) | Strong Press (MPa) |
|-----------------|---------------|-------------|------------------------|---------------------|
| 450             | 1.53          | 1.84        | 10.83                  | 84.37               |
| 500             | 1.52          | 1.81        | 12.33                  | 97.32               |
| 550             | 1.52          | 1.81        | 13.33                  | 105.21              |
| 600             | 1.53          | 1.83        | 17.33                  | 135.58              |

From tables 4.9 and 4.10, a graph of the relationship between the compressive strength value and changes in the sintering temperature can be made as shown in the following figure:

Thus, the addition of SiC particle composition in the process of making aluminum metal matrix composites can reduce the value of the compressive strength of the composite material, but with the addition of SiC particle composition it can increase mechanical properties such as: hardness and friction resistance, as well as thermal properties of metal matrix composite materials. Therefore, during the manufacturing process, it is necessary to pay attention to the addition of the right SiCp composition so that the physical and mechanical properties of the sample are as expected (planned).

3.2.2 Vickers Hardness

From the calculation results, a hardness test table can be made as follows:

| Temperature (°C) | d1 (µm) | d2 (µm) | daverage (µm) | daverage (mm) | d² (mm)² | HV (kgf/mm²) | VHN (MPa) |
|-----------------|---------|---------|---------------|---------------|----------|--------------|-----------|
| 450             | 139.68  | 137.00  | 138.34        | 0.138         | 0.019    | 99.42        | 994.4     |
| 500             | 139.30  | 121.94  | 130.72        | 0.130         | 0.017    | 108.74       | 1087.8    |
Manufacturing of Ceramic Reinforced Metal Matrix Composites (Al/Sicp) And Their Characterization Through Powder Metallurgy Methods (Jepriandi Ginting)

Table 4.12 Hardness Test on composition 70 : 30 %wt Al/SiCp

| Temperature (ºC) | d1 (µm) | d2 (µm) | daverage (µm) | daverage (mm) | d² (mm) | HV (kgf/mm²) | VHN (MPa) |
|-----------------|---------|---------|---------------|---------------|--------|-------------|-----------|
| 450             | 122.64  | 111.40  | 117.02        | 0.117         | 0.013  | 136.50      | 1365.2    |
| 500             | 116.72  | 114.28  | 115.50        | 0.115         | 0.013  | 139.20      | 1391.7    |
| 550             | 106.74  | 107.40  | 107.07        | 0.107         | 0.011  | 166.04      | 1660.4    |
| 600             | 107.50  | 92.72   | 101.11        | 0.101         | 0.010  | 187.78      | 1924.1    |

From tables 4.11 and 4.12 above, a graphic image of the relationship between changes in the hardness value to changes in the sintering temperature can be made as shown in the following figure:

The measurement results show that the hardness value of the sample with a composition of 70 : 30 %wt Al/SiCp has a higher hardness value than that of a composition of 80 : 20 %wt Al/SiCp, the highest hardness value for the composition of 80 : 20 %wt is 1860.50 MPa, while the composition of 70 : 30 %wt Al/SiCp is 1879.67 MPa. From Tables 4.9 and 4.10 it is obtained that the hardness values for composition variations have significant differences. In addition to changes in sintering temperature, density, and porosity, the hardness value is also influenced by the composition of the SiC reinforcing particles.

3.2.3 Erosion Resistance (Wear Resistance)

From the calculation results, it can be made a table measuring the value of erosion resistance (wear resistance) as follows:

Table 4.13 Test of erosion resistance (Wear Resistance) at the composition of 80 : 20 %wt Al/SiCp

| Temperature (ºC) | Diameter (mm) | Tall (mm) | mbeginning (g) | mend (g) | m (mg) | Sliding Distance (cm) | Wear Rate (kg.m⁻¹) |
|-----------------|---------------|-----------|----------------|---------|-------|-----------------------|-------------------|
| 450             | 8             | 10        | 5.714          | 5.708   | 6.0   | 0.100                 | 6.00              |
| 500             | 8             | 10        | 5.720          | 5.714   | 5.8   | 0.098                 | 5.91              |
| 550             | 8             | 10        | 5.768          | 5.762   | 5.4   | 0.092                 | 5.86              |
| 600             | 8             | 10        | 5.780          | 5.775   | 4.9   | 0.090                 | 5.44              |

Table 4.14 Testing of wear resistance at composition 80 : 20 %wt Al/SiCp

| Temperature (ºC) | Diameter (mm) | Tall (mm) | mbeginning (g) | mend (g) | m (mg) | Sliding Distance (cm) | Wear Rate (kg.m⁻¹) |
|-----------------|---------------|-----------|----------------|---------|-------|-----------------------|-------------------|
| 450             | 8             | 10        | 6.022          | 6.018   | 4.0   | 0.092                 | 4.34              |
| 500             | 8             | 10        | 6.094          | 6.090   | 3.9   | 0.091                 | 4.28              |
| 550             | 8             | 10        | 6.130          | 6.126   | 3.4   | 0.087                 | 3.90              |
From tables 4.13 and 4.14, a graph of the relationship between changes in the value of erosion resistance (wear rate) can be made to changes in the sintering temperature as shown in the following figure:

### 3.3 Microstructural Analysis

#### 3.3.1 SEM (Scanning Electron Microscope)

In the process of making metal matrix composites using powder metallurgy, it is hoped that the SiC reinforcing particles are evenly distributed on the Al matrix and no agglomeration occurs, because if this happens it can reduce the mechanical and physical properties of the metal matrix composite. In addition, the process of making metal matrix composites using powder metallurgy methods generally involves engineering the coating of SiC reinforcing particles using metal ions Al(NO₃)₃. This aims to increase the wettability between reinforcing particles with a low matrix. In the SiC reinforcing particle coating process, it is expected that the entire surface of the SiC particles is perfectly coated on the micron-order scale. If the coating process of SiC reinforcing particles is not perfect, it can affect the interlocking of the SiC reinforcing particles with the Al matrix. This also causes the composite to become brittle and easily corroded because it is more reactive with water. So, in the process of making metal matrix composites using the powder metallurgy method, it is expected that all SiC reinforcing particles are evenly distributed with the Al matrix and the SiC bonding particle coating process also occurs perfectly to obtain the desired results.

#### 3.3.2 XRD (X-Ray Diffraction)

XRD analysis test aims to observe the elements (phases) formed in the test sample after the sintering process in the manufacture of metal matrix composites. As a result, positions 1, 2, 3, 4, 5, 6, 7, and 8 are positions where the dominant phases appear in the post-sintering Al/SiCₚ fabrication process with a composition of 70: 30 %wt. Based on the calculations, each phase is at an angle of 2Θ or the x-axis, including: position no. 1 which is 34.1890, no. 2 is 35.3750, no. 3 is 38.2100, no. 4 is 44.6950, no. 5 is 59.6750, number 6 is 64.9400, number 7 is 71.4200, and number 8 is 77.9000. Based on these d values, the dominant phases (compounds) that appear can be known, including: position no 1 is SiC, no 2 is SiC, no 3 is Al, no 4 is Al, no 5 is SiO₂, No. 6 is Al₄C₃, No. 7 is Al₂O₃, and No. 8 is Al.

### CONCLUSION

From the results of research on the manufacture of Al/SiCₚ ceramic-reinforced metal matrix composites and their characterization through powder metallurgy methods, it can be concluded that:

1. From the results of testing the physical properties for the composition of Al/SiCₚ 80: 20 %wt, it was obtained: the density and porosity of pre sintering were 2.50 g/cm³ and 3.43 %, the density and porosity after sintering were 3.05 g/cm³ and 0.98 %, and the coefficient of thermal expansion is 13 x 10⁻⁶/oC. For the composition of Al/SiCₚ 70 : 30 %wt, the pre sintered density and porosity were 2.52 g/cm³ and 3.22 %, the post sintered density and porosity were 3.11 g/cm³ and 0.87 %, and the coefficient of thermal expansion is 12 x 10⁻⁶/oC.

2. From the results of testing the mechanical properties for the composition of Al/SiCₚ 80 : 20 %wt obtained: the compressive strength value is 153.83 MPa, the hardness value is 1865.3 MPa, the erosion resistance value is 5.44 kg.m⁻¹. For the composition of Al/SiCₚ 70 : 30 %wt is obtained: the compressive strength value is 135.58 MPa, the hardness value is 1924.1 MPa, and the erosion resistance value is 3.52 kg.cm⁻¹.

3. From the results of microstructural analysis using the SEM (Scanning Electron Microscope) test equipment, it shows that the SiC reinforcing particles are evenly distributed during the mixing process of the reinforcing particles with the Al matrix.
4. From the results of crystal structure analysis using XRD (X-Ray Diffraction) test equipment, the phases formed during the process of making Al/SiCp ceramic-reinforced metal matrix composites are as follows: SiC, Al, SiO2, Al4C3, and Al2O3.

ACKNOWLEDGEMENTS

We would like to thank all those who have contributed to this research, so that the research can be carried out properly.

REFERENCES

(Zainuri, Struktur Komunitas Copepoda di Perairan Jepara, 2007)
(Khaerudini, 2008)
Angelo, P. C., and Ramayyar Subramanian. 2008. Powder Metallurgy: Science, Technology and Applications. PHI Learning Pvt. Ltd.
Fung, Chin-Ping. 2003. "Manufacturing Process Optimization for Wear Property of Fiber-Reinforced Polybutylene Terephthalate Composites with Grey Relational Analysis." Wear 254(3-4):298–306.
Gibson, Ian, Thomas Kvan, and Ling Wai Ming. 2002. "Rapid Prototyping for Architectural Models." Rapid Prototyping Journal.
Pandey, Jitendra K., S. H. Ahn, Caroline S. Lee, Amar K. Mohanty, and Manjusri Misra. 2010. "Recent Advances in the Application of Natural Fiber Based Composites." Macromolecular Materials and Engineering 295(11):975–89.
Shao, Zongping, Wei Zhou, and Zhonghua Zhu. 2012. “Advanced Synthesis of Materials for Intermediate-Temperature Solid Oxide Fuel Cells.” Progress in Materials Science 57(4):804–74.