Manufacture of Aluminum-Magnesium Reinforced Metal Matrix Composite Silicon Carbide with Powder Metallurgy Method

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Abstract: Metal matrix composites (Metal Matrix Composites) are a combination of two or more materials with aluminium metal as the matrix and developed to improve metal properties, strength, high heat stability, and hardness. Powder metallurgy technique is one of the metal matrix composite manufacturing processes in solid condition which is still being developed because it is more economical, does not require complicated equipment. In this study, the manufacture of metal composites with aluminium-magnesium as the matrix and SiC as reinforcement was carried out using the powder metallurgy method of composition variation (75% Al : 15% SiC : 10% Mg, 80% Al : 15% SiC : 5% Mg). Then the results of the mixing are compacted at a pressure of 14 ton-force with a holding time of 4 minutes. After compaction in the form of a specimen, then sintered at various temperatures (500 °C and 550 °C) for 2 hours. After sintering with a furnance machine, the specimen is ready to be tested for mechanical properties and microstructure photos. The results of the bending and hardness test are obtained by increasing the composition of magnesium resulting in the bending strength and hardness also increasing successively. In mixing Al:SiC:Mg (80%: 15%: 5%) with a temperature of 550°C, the highest bending strength is 50.31 MPa and the highest hardness is 76.21 HV.

1 INTRODUCTION

The results of technology with good quality of course require processing of technical materials with the perfect combination so as to create new materials that have a high level of quality(Pasaribu, 2017). Material technology composite is one of the smart technology engineering to get a new material that is much better than the raw materials used(Ginting, 2009). There are several composite materials according to the type of matrix, including metal matrix composites (MMC), ceramic matrix composites (CMC), and polymer matrix composites (PMC).

Metal matrix composites have various advantages over other types of composites. Such as high strength, high modulus, high toughness and impact property, low sensitivity to temperature changes or thermal shock, high surface resistance and low sensitivity to surface flaws, high electrical conductivity.(Chandra, 2014).

Metal composites that are often used today are aluminium-based metal matrix composites because they are one of the most abundant and inexpensive mineral materials in the world. Al metal as monolithic, when viewed from the mechanical properties, such as hardness value (hardness) is very low. Therefore, Al metal as a monolithic material has many weaknesses, especially its mechanical strength, stiffness and coefficient of expansion(Sakti et al., 2009).

To increase the mechanical value of the metal, it is necessary to add other elements, one of which is magnesium. Magnesium has properties such as low density and light and strong when combined. The addition of magnesium in certain concentrations can increase the hardness and bending strength of aluminum alloys(Shomad & Jordanianshah, 2020).the addition of Mg in aluminum alloys increases the strength and hardness of aluminum, increases corrosion resistance and increases wettability(Supriyatma et al., 2016).

To increase the hardness value of metal composites, it is necessary to strengthen the metal, by adding hard materials, such as ceramics. Common types of ceramic materials used include: Al2O3, SiC, TiC, and ZrO2. Among these types of ceramics, the hardest is SiC(Idris et al., 2003).

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In addition to the matrix and reinforcement, another important thing is the fabrication technique used today. Powder metallurgy (powder metallurgy) has several advantages compared to liquid metallurgy. The temperature used in powder metallurgy processes can be lower, that is, below the melting point of the material. Meanwhile, in liquid metallurgical engineering, high temperatures are required to reach the melting point of the component materials (Ramadhonal, 2010).

(Risky, 2019)examined the effect of the addition of SiC on the properties of hardness and bending strength as well as the microstructure of aluminium composites. The studies varied between SiC (0%, 3%, 5%, 9%). The research proves that there is an increase in the results of the hardness test and bending test results for each addition of SiC. This proves that SiC can increase the strength of metal composites.

(Supriyatma et al 2016) examined the Effect of Magnesium Addition on Hardness, Impact Strength and Microstructure of Aluminium Alloy (Al-Si) Using Lost Foam Casting Method. In this study, there was an increase in the addition of Mg to Al-Si alloys based on used car alloy wheels using the lost foam casting method. The hardness number after the addition of Mg was 109.70 HRL, and before the addition of Mg was 99.8 HRL. It was concluded that the increase was 9.9%.

(Triadi, 2022)examined the effect of sintering temperature and material composition on the mechanical characteristics of composites made from waste aluminium and glass using powder metallurgy methods. This study found that the specimen with the highest compressive strength value was found at a sintering temperature of 590 C and a composition of 90:10, which was 235.59 MPa. While the lowest strength value is 45.11 MPa at a sintering temperature of 390 C and a composition of 70 :30. The results of the hardness test showed that the highest hardness value was obtained in specimens with a composition of 90: 10 and a sintering temperature of 590 C, namely 60 HRF, followed by temperatures of 490 C and 390 C. The same applies to the composition of other materials, namely the greatest hardness value is found at the highest sintering temperature.

1.1 Metal Matrix Composite (MMC)

Metal matrix composite (MMC) comes from a combination of metal-based materials with ceramics. MMC can also be called a material consisting of a matrix in the form of metal and its alloys which is reinforced by reinforcing materials in the form of continuous fiber, whiskers, or particulate. The manufacture of metal matrix composites can be done by several methods, including powder metallurgy, diffusion bonding, liquid phase sintering, squeeze infiltration and stir casting.(Risky, 2019).
The reasons why MMC has been attracting attention for nearly 30 years:

1. The MMC approach in metallurgical processes is the only way to produce a wide variety of these composites. So that the resulting product is very wide (varied). It is only in this way that we can combine aluminium, copper, magnesium with the carbide, oxide or nitride phase. Because the above material has a solubility to carbon, the nitrogen in the molten metal is too low.
2. MMC also provides significant changes to the properties of the material, such as resistance to high temperatures, does not react to chemicals, good hardness, and wear resistance.

Metal matrix composites can be made by the casting method or by the powder metallurgy method. However, the casting method has a problem, namely it is difficult to make homogeneous composites, because the reinforcing particles usually settle or float due to differences in specific gravity.

1.2 Powder Metallurgy

Powder Metallurgy (Powder Metallurgy) is the process of forming commercial workpieces from metal where the metal is in the form of a powder, then the powder is pressed in a mold and heated below the melting temperature of the powder to form a workpiece. So that the metal particles coalesce due to the mass transport mechanism due to atomic diffusion between the particle surfaces. Powder metallurgy methods provide precise control over the composition and use of mixtures that cannot be fabricated by other processes. As the size is determined by the mold and finishing touch. Basic steps in powder metallurgy (Demasya, 2018):

1. Powder maker.
2. Mixing.
3. Compaction.
4. Sintering.

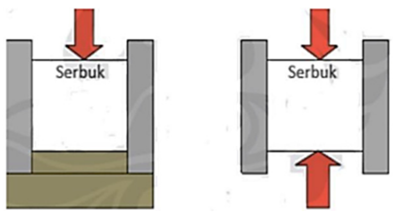

Figure 1: Compaction Process(Risky, 2019).

1.3 Hardness Test

Hardness is the ability of a material to withstand compressive loads. The hard test mechanism is to press the indenter to the surface of the test object so that the geometry of the indentation is obtained. The type of hard test based on the shape of the indenter is spherical (for Brinell test), pyramidal (Vickers and Knoop test), or conical (Rockwell test).

$$VHN = \frac{1{,}8544 \times P}{D^2} \tag{1}$$

VHN = Vickers hardness value (HV)

P = amount of load (kgf)

D = average diagonal (mm)

1.4 Bending Test

Bending test is one of the mechanical properties testing of materials that is carried out on specimens of materials, both materials to be used as construction or components that will receive loading. With this load it will even experience deformation with two opposing forces acting at the same time(Mahadi ST & Novri, 2017).

$$\sigma = \frac{3.F.L}{2.b.h^2} \tag{2}$$

Where:

= Bending Stress (MPa)

F = Load (N)

L = Length of span /Support span(mm)

b = Width (mm)

h = Thickness (mm)

2 RESEARCH METHODS

2.1 Research Flowchart

In conducting research, the stages are carried out referring to the flow chart shown in Figure 2

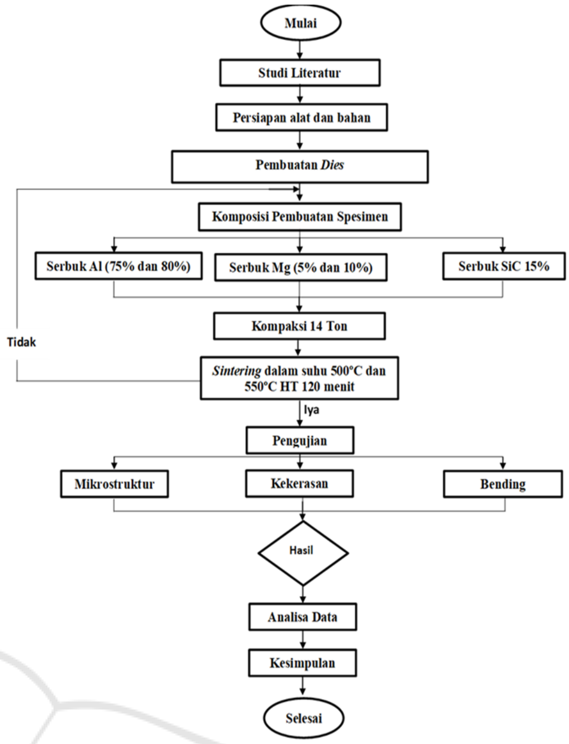

Figure 2: Research Flow Chart.

2.2 Tool

Details of the equipment used in this study are:

1. Universal Testing Machine

   Universal Testing Machinefor the process of making composites with cold compaction in 14 Tons of compaction that has been dies previously

Figure 3: Universal Testing Machine.

2. Furnance

Furnance used to carry out heat treatment during the sintering process with temperatures of 500 C and 550 C on Metal Matrix Composite specimens.

Figure 4: Furnance.

2.3 Ingredient

In this study, the main materials used are aluminium powder with a content of 85% and magnesium as the matrix of the metal composite, while the reinforcing material is silicon carbide.

2.4 Research Procedure

Prepare materials for the manufacture of composites with a composition (80%Al-5%Mg-15%SiC and 75%Al-10%Mg-15%SiC) then compacted with a loading of 14 tons and then held for holding time 4 minutes, then The specimen is removed from the mold for further sintering with a sintering temperature of 500 C and 550 C.

2.5 Vickers Hardness Test

The hardness test carried out in this study refers to ASTM E384. The hardness of the SiC-reinforced Al-Mg composite material was tested using a macro hardness tester, Innova test brand, with an indenter in the form of a diamond pyramid with a load of 1 kgf and indentation time of 30 seconds with 5 tests in one composite variation.

Figure 5: Vickers Hardness Test Tool.

2.6 Bending Test

The bending test carried out in this study refers to the ASTM D790, where the shape of the specimen used is in the form of a plate with sizes, P = 125 mm, l = 12.7 mm and t = 3.2 mm. With the test parameter compressive speed of 20 m/s and stops at 50% breaking.

Figure 6: Bending Test.

3 RESULTS AND DISCUSSION

3.1 Hardness Testing

In this study, the hardness test used was a hardness test using the Vikers method. Hardness testing using the Vickers method aims to determine the hardness of a material in the form of material resistance to pyramid-shaped diamonds with a peak angle of 136 degrees which is emphasized on the surface of the test material.

In this test the indenter load is 1 kgf with a holding time of 30 seconds for each hardness test specimen. The following is the Vickers hardness test process.

Table 1: Hardness Test Results.

Composition Variations	Temperature Variation	Hardness value (VHN)
Al 75% SiC 15% Mg 10%	500°C	53,824
	550°C	76.218
Al 80% SiC 15% Mg 5%	500°C	43,098
	550°C	65,464

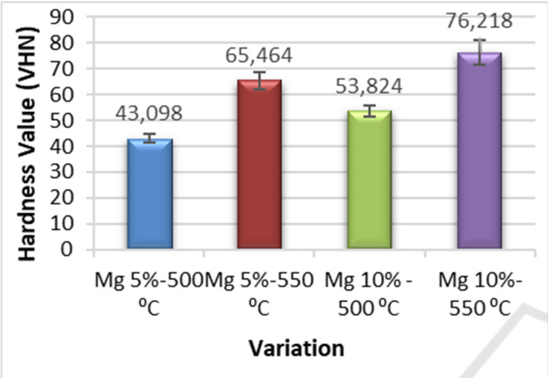

Figure 7: Vickers hardness chart.

The results of the Vickers hardness test show that with different compositions and sintering temperatures, we can conclude that the addition of magnesium and the effect of temperature variations on the manufacture of Al-Mg metal matrix composite (MMC) with silicon carbide reinforced with powder metallurgy method can increase the hardness value (VHN). This can be seen from the results of the Vickers Hardness Test on the 5% magnesium composition in the total mass of the SiC reinforced Al-Mg specimen at a temperature of 500 C the average value is 43,098 HV, at the 5% magnesium composition in the total mass of the Al-Mg reinforced specimen. SiC at a temperature of 550 C the average value is 65.464 HV, at a composition of 10% magnesium in the total mass of SiC-strengthened Al-Mg specimens at a temperature of 500 C the average value is 53.824 HV.

The results of this test are similar to the research(Mahadi ST & Novri, 2017)that the addition of magnesium can increase the value of hardness and in research(Triadi, 2022)The higher the sintering temperature, close to 90% of the melting matrix temperature, the higher the hardness value.

3.2 Bending Test

In this study, one of the mechanical properties testing is the bending test carried out to measure how strong the bending to fracture of a test specimen material is. In this test, all samples of Metal Matrix Composite (MMC) standard ASTM D790 with dimensions of length = 125 mm, width = 12.7 and thickness = 3.2 mm with a compression parameter of 20 m/s and stops at 50% breaking.

Table 2: Bending Test Results.

Composition Variations	Temperature Variation	Bending Value (Mpa)
Al 75% SiC 15% Mg 10%	500°C	36.07
	550°C	50.45
Al 80% SiC 15% Mg 5%	500°C	32.19
	550°C	42.72

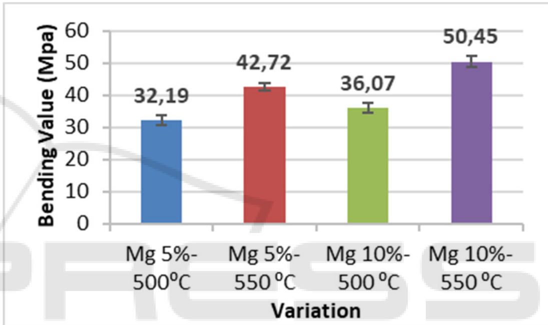

Figure 8: Bending Test Graph.

The results of the bending test show that with different compositions and sintering temperatures, we can conclude that the addition of Magnesium and the effect of temperature variations on the manufacture of Al-Mg metal matrix composite (MMC) with silicon carbide reinforced with powder metallurgy method can increase the value of bending strength. the results of bending tests on 5% magnesium composition in the total mass of SiC-reinforced Al-Mg specimens at a temperature of 500 C the average value is 32.19 Mpa, at 5% magnesium composition in the total mass of SiC-reinforced Al-Mg specimens at 550 C the average value is 42.72 Mpa, at 10% magnesium composition in the total mass of SiC-strengthened Al-Mg specimens at 500 C the average value is 36.07 Mpa,at 10% magnesium composition in the total mass of SiC-strengthened Al-Mg specimens at a temperature of 550 C the average value is 50.45 Mpa.

The results of the research above are similar to the research(Triadi, 2022)With the higher the sintering temperature, the value of the bending compressive strength increases.

4 CONCLUSION

The research that has been done can be concluded as follows:

1. The hardness value of the SiC-reinforced aluminium-magnesium matrix composite will increase along with the increase in the addition of magnesium (Mg) and the increase in the sintering temperature. The addition of 10% Mg at a sintering temperature of 550ºC has the highest hardness of 76.218 HV.
2. The value of the bending strength of the SiC-reinforced aluminium-magnesium matrix composite will increase along with the increase in the addition of magnesium (Mg) and the increase in the sintering temperature. The addition of 10% Mg at a sintering temperature of 550ºC has the highest bending strength of 50.45 Mpa.

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