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Magnesium Addition and Treatment of Reinforcement Particles in Al6061 – Sea Sand Composite on Coefficients Friction and Wear Rate

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Abstract

Aluminium Matrix Composite (AMC) is a composite material with an Al matrix and ceramic reinforcement particles such as SiC, Al_2O_3, B_4C, TiB_2, ZrO_2, SiO_2, graphite, and even sea sand can be used as reinforcement to increase the tribological properties of composite. The process of manufacturing the Al6061-Sea sand composite used the stir casting method with a stirring time of 10 minutes and a speed of 600rpm. Stir casting specimens were manufactured with a height dimension of 20 mm and a diameter of 10 mm. After that, the specimen was friction tested using the pin on disc method. The highest coefficient of friction was the specimen without electroless coating with the addition of 2% wt Mg of 0.634. The more mass fraction of sea sand, the higher the porosity, and the lower the density. To increase the friction coefficient and reduce porosity, an electroless coating process can be carried out on the reinforcing particles. This study aims to determine the effect of the addition of Mg and treatment of reinforcing particles on the Al6061-Sea sand composite on the coefficient of friction and wear rate. The coefficient of friction, the density of the specimen increased, the porosity and the wear rate, decreased. This occurred because the reinforcement particle size of sea sand bonded more strongly to the aluminium matrix. The highest coefficient of friction was the electroless coating with the addition of 2% wt Mg of sea sand, which was 0.646.

1. Introduction

From year to year, the demand for developing new materials that are strong but light is increasing. Materials that can have superior properties and are currently being developed are composites. Composite is a material that is formed from a combination of two or more macroscopically different materials, where one material functions as a reinforcement and the other as a matrix so that we can produce new materials that have better properties than other materials [1]. Metal Matrix Composite (MMC) is an example of a composite that is widely used in engine components such as pistons, cylinder heads, and many more [2].

One of them is Metal Matrix Composite (MMC) including Al-alloy, Al6061 alloy is widely used in engineering applications such as the transportation and construction sectors because of its superior

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mechanical properties such as hardness and tensile strength [2]. One example of Metal Matrix Composite (MMC) is Aluminium Matrix Composite (AMC). AMC is a composite material that has an Al matrix andceramic reinforcement particles such as SiC, Al_2O_3, B_4C, TiB_2, ZrO_2, SiO_2, and graphite [3]. Sea sand can also be used as a reinforcement to improve the properties of the Al6061 alloy due to their content of oxide [4].

The use of ceramic and oxide particles has the disadvantage of being expensive to produce. Previous research has innovated in the use of ceramic and oxide particles as reinforcement by employing natural resources and industrial waste, such as bamboo leaf ash, coal ash, and others. The reinforcing particle to be used is sea sand. The main manufacturing process for AMC that is often used is the stir casting method and it falls into the category of liquid-state processes. Economical costs and simple manufacturing are the reasons why this stir casting method is used. Factors that need to be considered when manufacturing aluminium matrix composites (AMC) with the stir casting method include the homogeneous distribution of the 2 reinforcing particles, the wettability of the reinforcing particles and the chemical reactions that occur between the reinforcing particles and the aluminium matrix [5].

The distribution of reinforcing particles to the Al matrix is one of the common problems that occur in composite manufacturing using the stir casting method. The distribution of reinforcing particles to the Al matrix is greatly influenced by the wettability of the reinforcing particles by the molten metal. One way to increase wettability is to use electroless coatings. Electroless coating is a treatment used to make the interfacial layer of reinforcing particles in order to obtain good wettability, which will affect the mechanical properties of the composite [6]. This makes it necessary to know the effect of electroless coating treatment on reinforcing particles on the mechanical strength of the composite.

This study aims to determine the friction coefficient and wear rate of the Al6061-Sea sand composite with different variations in the addition of Mg and the treatment on sea sand. At the next level, the AA6061-Sea sand composite material is expected to be a substitute for disc brake material in the braking system which has superior properties. Braking using a disc brake creates friction between the brake pad and the disc which generates heat and then the heat is released into the air. Because braking occurs repeatedly, the disc brake will rub and gradually wear out. Therefore, the coefficient of friction and wear rate are material characteristics that are of great concern in the manufacture of disc brakes [5].

2. Literature Review

Stir casting is a commonly used method of making metal composites. This is because the stir casting method is a simple, economical, and flexible method [7]. This method is widely used in industry as well because it follows conventional process paths [8]. Stir casting uses mechanical stirring to vigorously stir the aluminium melt with the simultaneous addition of reinforcement [6]. Mechanical stirring was carried out for 10 minutes at a speed of 600 rpm [9].

The stir casting method is always tied to the wettability of the reinforcing particles in the process. A good wettability level will cause a more even distribution of particles [10]. The use of the electroless coating method for reinforcing sea sand is carried out to increase the wettability of the reinforcing particles. The electroless coating process is carried out by mixing HNO_3 and Magnesium (Mg) in sea sand reinforcement particles. This process will form a $MgAl_2O_4$ spinel phase on the surface of the reinforcing particles. This phase causes the composite hardness to increase due to increased wettability [6]. The stir casting process has a weakness, namely the wettability between the reinforcing particles and the metal matrix. Wettability affects interfacial bonding. Good interfacial bonding occurs if the matrix can completely wet the reinforcing particles. To increase the wettability of the reinforcing particles, they are given electroless coating treatment. Electroless coating is a particle coating method based on the oxidation of the substrate to be coated and a reduction process by metal ions from the coating solution. The electroless coating layer that is formed is relatively thin due to the coating process stopping when the entire surface has been coated [11].

The addition of Mg during the molten metal stirring process has the effect of combining the reinforcing particles in the melt and improving the particle distribution. The optimal addition of Mg to obtain the best particle distribution and mechanical strength is 1%wt [12]. The use of heavy fractions also influences wettability. Sharma examined Al6061 composites with variations in graphite reinforcement and found that the hardness decreased along with the addition of graphite weight fraction. The most optimal weight fraction of graphite reinforcement is 4%wt [13].

3. Experimental Methods

The initial step taken in the manufacture of aluminium matrix composites by treating the reinforcement was an electroless coating on the reinforcement. Al_2O_3 powder was cleaned using 96% alcohol, then dried in the furnace at a temperature of 100 ℃ for 10 minutes. Then, the electroless coating treatment employed 40 ml of 68% HNO_3, 20 g of Al_2O_3 powder, 0.5 g fine Al powder, and 0.1 g Mg powder, stirred in the magnetic stirrer at 70 ℃ for 45 minutes.

The Al_2O_3 powder was then dried in the furnace at 200 °C for 60 minutes after being electroless treated. Raise the temperature to 400 °C and keep it there for 120 minutes. The results of the treatment were then cooled to room temperature and then stored in a container. Next step was the casting process under stir casting method. The 91.5% wt of matrix Al 6061 melted at 700°C, the, added 6% wt the Al_2O_3 electroless coated powder and 2.5% wt magnesium powder as wetting agent with variation of 0, 1, 1.5, and 2% wt. Melt Al6061 in the furnace with a melting temperature of 720-740 °C. The agitation process used a four-blade impeller at 600-620 rpm for 10 minutes, the stir casting equipment is shown in Figure 1. After that, the molten composite poured into heated permanent moulding. The wear test conducted with pin on disc according to ASTM G-99 with 2 kg normal force and rotational speed at 2 m/s with a track long is 2000 m. The friction coefficient was calculated using Eq. 1, while the specific wear was calculated using Eq. 2. The friction test scheme is shown in Figure 2 with F is the Normal force on the specimen, R is the radius of the specimen trajectory, d is the Diameter of the specimen, D represents the disc diameter and W represents the disc speed. Friction test apparatus is shown in Figure 3.

$$\mu = \frac{F\ friction}{N} \quad (1)$$

$$K = \frac{\Delta V}{FL} \quad (2)$$

Figure 1. Stir casting equipment

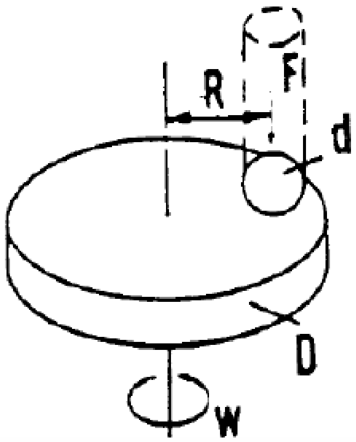

Figure 2. Scheme of friction test

Figure 3. Friction test apparatus

4. Result and Discussion

4.1 Density and Porosity Test Results

The density of the composite showed the effect of the addition of Mg and the electroless coating treatment of reinforcing particles on the Al6061-Sea sand composite shown in Figure 4. The density of the specimen NE-0 is 2.611 g/cm^3, while the EC-0 specimen had a density of 2.622 g/cm^3. The density of the NE-1 specimen was 2.613 g/cm^3, while the EC-1 specimen had a density of 2.623 g/cm^3. The density of the NE-1.5 specimen was 2.616 g/cm^3, while the EC-1.5 density was 2.627 g/cm^3. The density of the NE-2 specimen was 2.621 g/cm^3, while the EC-2 specimen had a density of 2.629 g/cm^3.

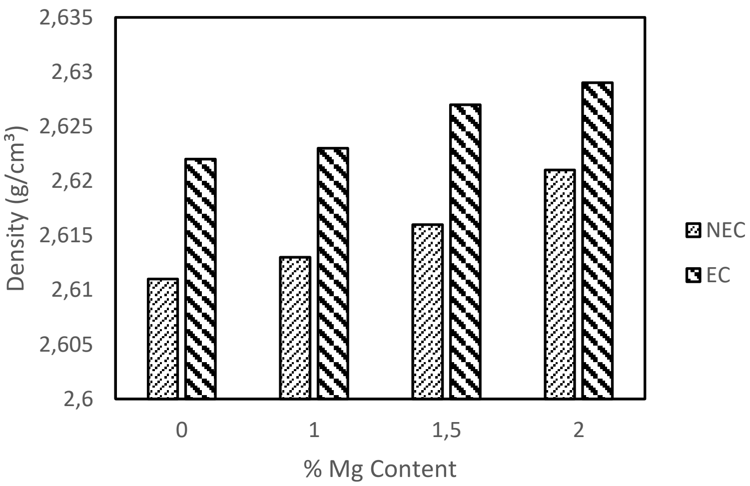

Figure 4. Density of composite

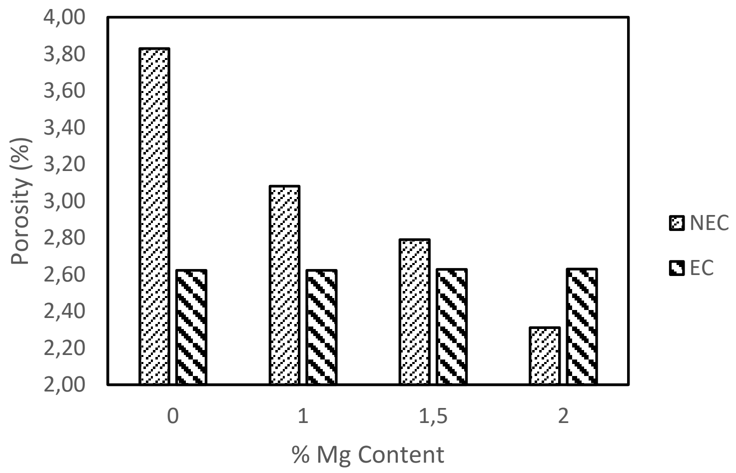

Figure 5. Porosity of composite

The electroless coating treatment of the reinforcing particles caused an increase in the composite density. Electroless coating treatment on sea sand can increase the wettability of sea sand, so that sea sand reinforcing particles bind more strongly to the aluminium matrix [6]. The addition of Mg during the manufacturing process of the Al6061-Sea sand composite caused an increase in the density of the composite. The addition of Mg when manufacturing the Al6061-Sea sand composite lowered the surface tension of the aluminium matrix, so that the reinforcing sea sand particles could bond more strongly to the aluminium matrix [6]. The density of the specimens for each variation was used to determine the percentage of porosity in the specimen. Porosity was obtained from the comparison between the density of the specimen and the theoretical density.

Figure 5 shows that the porosity decreased in the composite through the electroless coating treatment of reinforcing particles and addition of Mg on the Al6061-Sea sand composite. The porosity of the NE-0 specimen was 3.83%, NE-1 was 3.08%, NE-1.5 was 2.79%, and NE-2 was 2.31%. While the porosity of the EC-0 specimen was 3.44%, EC-1 was 2.80%, EC-1.5 was 2.37%, and EC-2 was 2.01%. Based on the data above, it shows that the electroless coating treatment caused a smaller porosity than the porosity found in composites with reinforcing particles without electroless coating treatment. The addition of Mg also caused the resulting porosity decrease.

4.2 Wear Test

The coefficient of friction is the ratio between the friction force and the normal force. The friction coefficient test was carried out using a pin on disc tribometer with a normal force of 2 kg and a rotational speed of 2 m/s. The results of the friction test for each specimen are shown in Figure 6. The friction coefficients on the NE-0 and EC-0 specimens were 0.542 and 0.556, the friction coefficient s on the NE-1 and EC-1 specimens were 0.572 and 0.583, the friction coefficient s on the NE-1.5 and EC-1.5 specimens were 0.602 and 0.616, and the friction coefficient s for the NE-2 and EC-2 specimens were 0.634 and 0.646. The addition of sea sand to aluminum caused the friction coefficient to increase. This happened because sea sand contains Magnesioferrite ($MgFe_2O_4$). Magnesioferrite is composed of MgO and Fe_2O_3 ceramic particles which have a higher hardness than aluminum [7]. As a result, the strength of the Al6061-Sea sand composite improved, as did the coefficient of friction. The EC-2 specimen had the greatest friction coefficient.

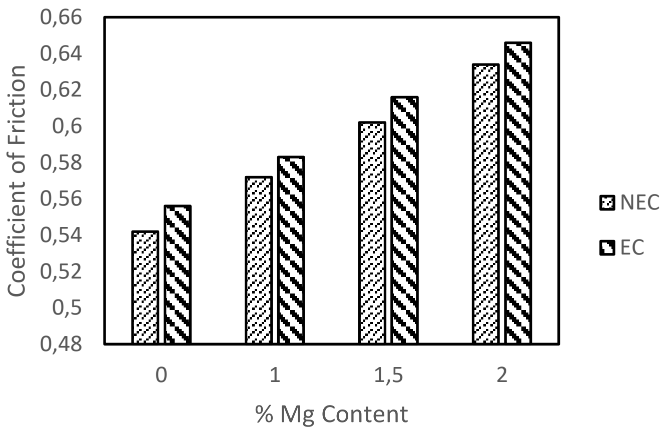

Figure 6. Coeffocient of friction composite

Electroless coating treatment of sea sand reinforcing particles can increase wettability so that sea sand reinforcing particles can bind more strongly to the aluminium matrix [6]. The addition of Mg when manufacturing the Al6061-Sea sand composite lowered the surface tension of the matrix and reinforcing particles, so that the reinforcing particles bonded more strongly to the aluminium matrix [6]. Good bonding of reinforcing particles with aluminium increases the coefficient of friction of the composite.

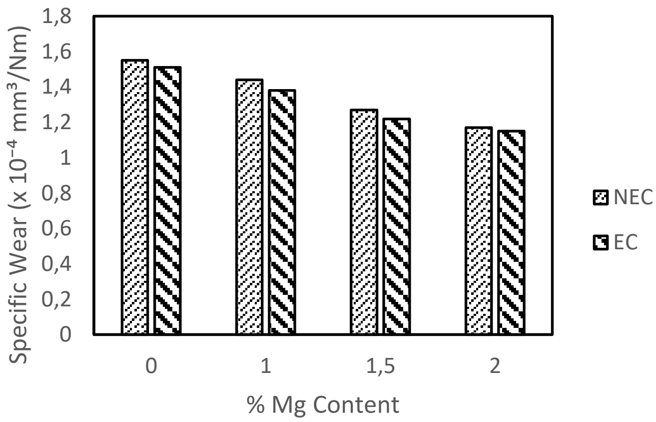

Figure 7. Specific wear of composite

The specific wear on the composite specimen is shown in Figure 7. The specific wear on the NE-0 and EC-0 specimens was 1.55 x 10^{-4} mm^3/Nm and 1.51 x 10^{-4} mm^3/Nm, the specific wear s on the NE-1 and EC specimens -1 which is 1.44 x 10^{-4} mm^3/Nm and 1.38 x 10^{-4} mm^3/Nm, the specific wear on the specimen NE-1.5 and EC-1.5 was 1.27 x 10^{-4} mm^3/Nm and 1.22 x 10^{-4} mm^3/Nm, and the specific wear s on the NE-2 and EC-2 specimens were 1.17 x 10^{-4} mm^3/Nm and 1.15 x 10^{-4} mm^3/Nm. The specific wear of the EC-2 specimen was lower than the specific wear of NE-1 because less porosity was found in the EC-2 specimen. In the NE-1 specimen there was more porosity because the reinforcing sand particles did not bind well to the aluminium matrix. Whereas in the EC2 specimen, less porosity was found due to the electroless coating treatment on sea sand and the addition of Mg during composite fabrication. Electroless coating on sea sand increase wettability so that sea sand reinforcement particles can bind more strongly to the aluminium matrix [6].

The addition of Mg when manufacturing the Al6061-Sea sand composite lowered the surface tension of the matrix and reinforcing particles, so that the distribution of reinforcing particles bonded more strongly to the aluminium matrix [6]. High magnesium content increases the amount of magnesium silicide precipitates formed during aging, these deposits strengthen the aluminium matrix by suppressing the atomic lattice and making dislocation movements difficult, so that the strength will increase [15]. Porosity causes the specific wear rate to decrease so that the wear resistance increases [16]. Lower wear rate indicates that the material has high wear resistance. This could be related to the increase in material hardness. The lower the specific wear, the higher the friction coefficient [17].

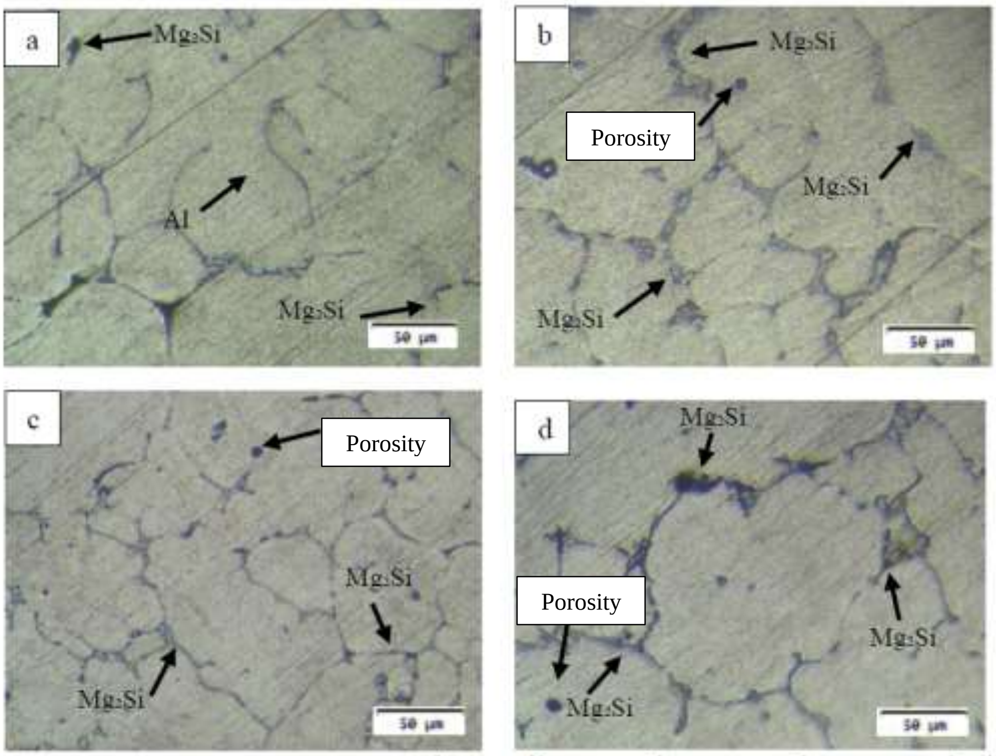

Figure 8. Microstructure observations on non-electroless coated specimens: (a) Without addition of Mg (b) Addition of Mg 1%wt (c) Addition of Mg 1.5%wt (d) Addition of Mg 2%wt.

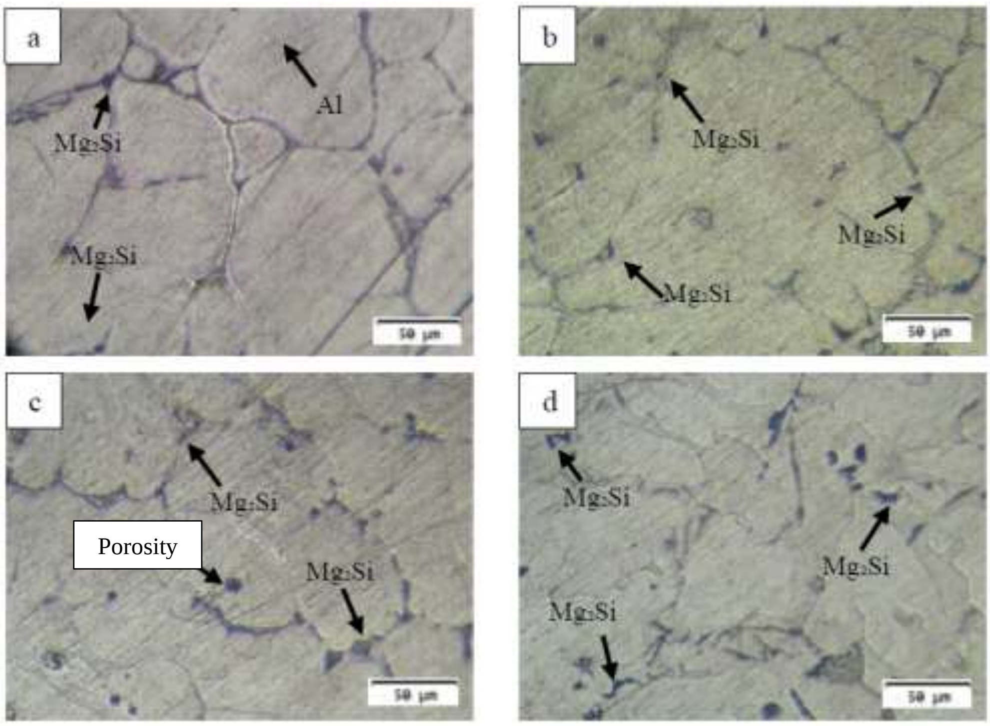

Figure 9. Microstructure observations on electroless coated specimens: (a) Without addition of Mg (b) Addition of Mg 1%wt (c) Addition of Mg 1.5%wt (d) Addition of Mg 2%wt.

Observations of the microstructure of the specimen are shown in Figure 8 and Figure 9, showing the effect of adding Mg to the Al6061-Sea sand composite. Observations of the micro and macro structure of non-electroless specimens showed that the distribution of sea sand was the worst in the NE-0 specimen and the best in the NE-2 specimen. Observing the micro and macro structure of the electroless coating specimens, it was found that the distribution of sea sand was the worst in the EC-0 specimen and the best in the EC-2 specimen. The addition of Mg to the Al6061 composite reduced the surface tension in the composite so that a strong interfacial bond between the aluminium matrix and reinforcement [6].

5. Conclusion

Based on the results of the tests and discussions that had been carried out, it can be concluded that the addition of Mg to the Al6061-Sea sand composite was able to increase the coefficient of friction in specimens whose particles had undergone electroless coating treatment or not through electroless coating treatment. The addition of Mg in the stir casting process decreased the porosity that occurred, so that the density of the Al6061-Sea sand composite increased.

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