Mekanika: Majalah Ilmiah Mekanika

The Effect of Stirrer Depth And Electroless Coating of Hardness And Tensile Strength in Aluminium Matrix Composite AL6061-AL_2O_3

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Metal matrix composite (MMC) are composite materials that are widely used in the industrial sector. Examples of metal matrix composites are Al6061 as matrix alloys and Al_2O_3 as reinforcement. In general, making Al6061-Al_2O_3 composites using the stir casting method. The stirring parameter in the stir casting affects the physical and mechanical properties of the composites. The physical and mechanical properties of composites can be improved by increasing the wettability of the reinforcement. This research was conducted to determine the effect of the depth of stirring and electroless coating treatment on the hardness and tensile strength of Al6061-Al_2O_3 composites. The process of making composites with Al_2O_3 reinforcing particles with 6% weight fraction mixed with aluminum alloys and 2.5% magnesium powder as a wetting agent. Variations of this study were the depth of the stirrer and electroless coating treatment. The depths of stirring used for the experiment were 30%, 45%, and 60% of the height of the fluid. The testing phases in this study were the density and porosity test, metallographic observation, hardness test, and tensile test. The most efficient variation of the mixer depth was obtained at a mixer depth of 30% of the fluid height. The highest hardness and tensile strength test results are hardness value of 72.43 HBN and tensile strength of 182.19 MPa with electroless coating reinforcement treatment.

1 Introduction

Innovation in the field of advanced materials has developed very rapidly in recent years. This is evidenced by the use and utilization of materials in the industrial sector. However, the required material properties are lacking, such as hard, strong, tough, ductile, and high temperatures resistance in the industrial sector. So that the Metal Matrix Composite (MMC) was developed to deal with this problem. MMC is a combination of metal as a matrix and other materials as reinforcement.

MMC has been used in various industrial fields, such as the aircraft industry, railroad industry, and the automotive industry. MMC which is commonly used in the automotive industry is Aluminum Matrix Composite (AMC). One example of AMC is the Al6061 matrix alloy with Al_2O_3 as reinforcement. Al6061 alloy which is composed of Al, Mg, Si has superior mechanical properties such as tensile strength, good

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hardness, and ease of fabrication [1]. Al_2O_3 or alumina reinforcement has good oxidation resistance and chemical stability [2].

In general, the manufacture of Al6061-Al_2O_3 composites uses the stir casting method. The stir casting method is widely used because it is cost-effective and simple. The stir casting method aims to mix the pure liquid metal with the composite, stirred at a certain speed and time. In the stir casting process, there are several stirring parameters that play a role in determining the physical and mechanical properties of the metal. The parameters of stirring include stirring speed, stirring time, depth of stirring, size of the stirrer, and position of the stirrer [3].

The stirring parameter in the stir casting has an effect on increasing the wettability of the reinforcing particles so that the reinforcing particles can be evenly distributed in the metal [4]. The even distribution of reinforcing particles in the Al matrix can improve the physical and mechanical properties of the composite material. The physical and mechanical properties of the composite material are influenced by the distribution of the Al_2O_3 reinforcing particles to the Al matrix.

The problem that is often faced in composite manufacturing with the stir casting method is the poor distribution of Al_2O_3 particles to the Al matrix. To get a good particle distribution, it is necessary to know the position of the stirring which is efficient in making Al6061-Al_2O_3 composites. Besides, it can increase the wettability or wettability of the Al_2O_3 amplifier to the Al matrix. Increasing wettability can be done with electroless coating treatment. The electroless coating is a treatment used to make the interface layer of reinforcing particles to get good wettability. Good wettability affects the physical and mechanical properties of the material [4].

The description above discusses the position of stirring in the Al6061-Al_2O_3 composite which can affect the even distribution of particles in the metal. Good particle distribution can improve the physical and mechanical properties of composite materials. Therefore, it is necessary to know the most efficient stirring position of the Al6061-Al_2O_3 composite so that it can improve its physical and mechanical properties.

2 Experimental Methods

This study used Al6061-Al_2O_3 composites with electroless coating treatment and without treatment on reinforcing particles. The Al6061-Al_2O_3 composite was prepared using the stir casting method. This stir casting process uses a ¼ HP stirrer motor with a heater power of 3500 watts. This stir casting process uses a stirring temperature of 720°C-740°C with a stirring speed of 600 rpm and a stirring time of 10 minutes. The mixer used is in the form of a four blades impeller with a tilt angle of 45°, an impeller diameter of 50 mm, and a thickness of 18 mm. The stirrer used is made of stainless steel with a TiO_2 coating. Kowi is used for smelting metal made from clay graphite with a permanent mold made of iron. The positions of the stirring depth were varied at 30%, 45%, and 60% of the liquid level. Composite characteristics can be determined by testing the density and porosity, metallographic observation, hardness testing, and tensile strength testing.

The resulting specimens are tabulated in Table 1 and variations in the depth of stirrer in Figure 1.

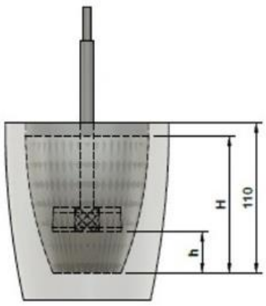


Figure 1. Variations in the depth of stirrer

Table 1. Composite specimen tabulated Al6061-Al_2O_3

Depth stirrer	Particle treatment	Specimen code
30%	No treatment	NP-30
	Electroless coating	EP-30
45%	No treatment	NP-45
	Electroless coating	EP-45
60%	No treatment	NP-60
	Electroless coating	EP-60

2.1 Density and porosity test

The density test is a comparison between the actual density and the theoretical density where the density calculation uses Archimedes' law. The density and porosity testing phase is to prepare the specimen by weighing the dry specimen and weighing the wet specimen. Weighing the weight of the wet specimen in the measuring cup by inserting the specimen into the measuring cup until the entire surface of the specimen is immersed in water. After that, record the numbered scales and calculate the actual density and theoretical density of the test result specimen. The density and porosity test scheme is shown in Figure 2 with the density and porosity equations.

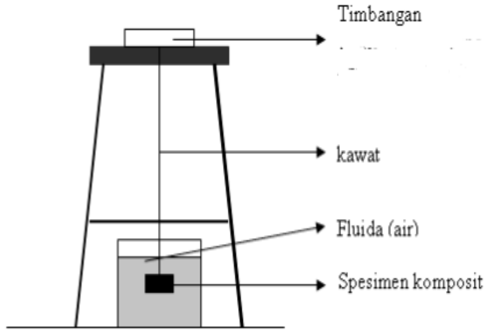


Figure 2. The density and porosity testing scheme [5]

$$\rho a = \frac{ms}{ms-mg} \; x \; \rho H_2O \qquad (1)$$

Where,
ρ_a = the actual density (g/cm^3)
ρH_2O = the water density (g/cm^3)
m_s = the dry sample mass (g)
m_g = the mass of the sample suspended in water (g)

$$\rho_{th} = \rho_m V_m + \rho_p V_p \qquad (2)$$

Where,
ρ_c = the theoretical density (g/cm^3)
ρ_m = the density of matrix (g/cm^3)
ρ_p = the density of reinforce (g/cm^3)
V_m = matrix volume fraction (%)
V_p = reinforce volume fraction (%)

$$P = (1 - \frac{\rho_a}{\rho_{th}} x \; 100\%) \qquad (3)$$

Where,
P = porosity percentage (%)

ρ_a = the actual density (g/cm^3)
ρ_{th} = the theoretical density (g/cm^3)

2.2 Metallograpic observation

Metallographic observation aims to determine the distribution of the aluminum oxide (Al_2O_3) reinforcing particles during the stir casting process. Metallographic observations in research refer to the ASTM E407 standard using a Keller reagent etching solution, 2 ml HF + 3 ml HCl + 5 ml HNO_3 + 190 ml distilled water. The specimens are immersed in the etching solution for 10 to 25 seconds and then washed under running water.

2.3 Hardness test

Hardness testing aims to determine the hardness of a material. Hardness testing in research refers to the ASTM E10 standard. Hardness testing is carried out at 3 points for each specimen. Indenter steel ball with a diameter of 2.5 mm with a load of 62.5 kg and a loading time of 30 seconds. The Brinell hardness testing scheme is shown in Figure 3 and the hardness test specimen is shown in Figure 4.

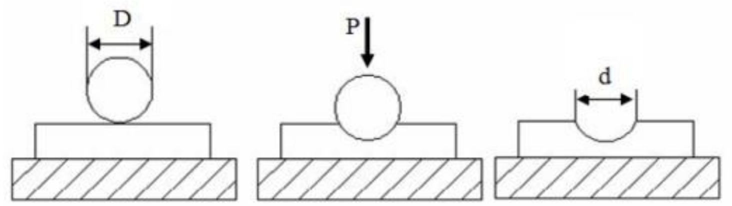


Figure 3. The Brinell hardness testing scheme [6]

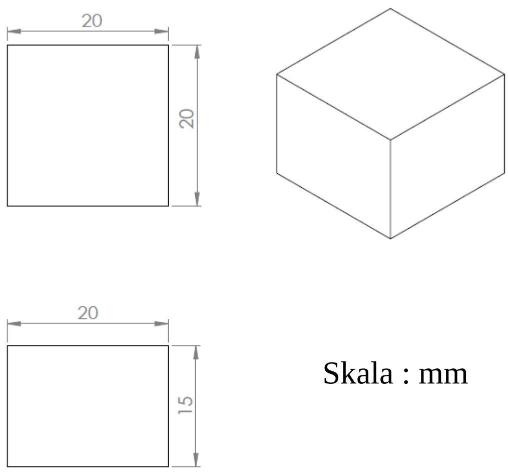


Figure 4. The hardness test specimen

2.4 Tensile strength test

Tensile testing aims to determine the strength of the material against the tensile force. The tensile test in this study refers to the JIS Z2201 standard. The tool used is the Universal Testing Machine (UTM). Tensile testing was carried out by preparing a dog bone-shaped specimen measuring 126 mm in length, 15 mm in radius and 56 mm in thickness. Then place the tensile test specimen on the UTM chuck, click the start button on the computer and the machine will pull the specimen until it breaks. The tensile test specimen is shown in Figure 5.

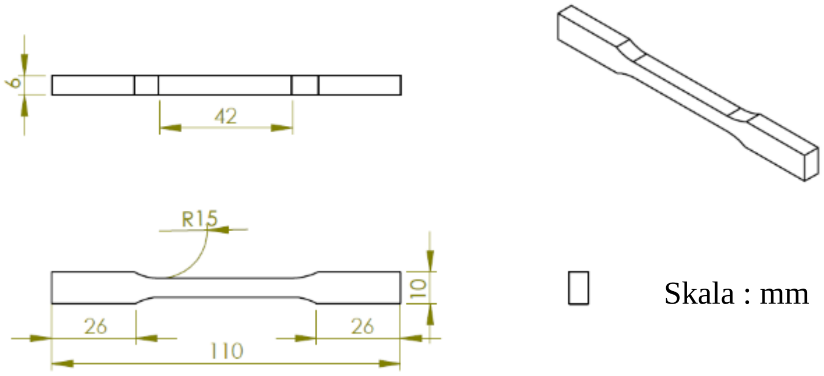


Figure 5. The tensile test specimen

3. Result and Discussion

3.1 Result of density and porosity test

The result of the density test is shown in Figure 6. The average density value shows the effect of stirring depth and electroless coating treatment. The density in the 30-NP specimen was 2.68 g / cm^3 while in the 30-EP specimen the density value was 2.71 g / cm^3. The density in the 45-NP specimen was 2.65 g / cm^3, while in the 45-EP specimen the density value was 2.66 g / cm^3. The density in the 60-NP specimen was 2.62 g / cm^3 while in the 60-EP specimen the density value was 2.64 g / cm^3.

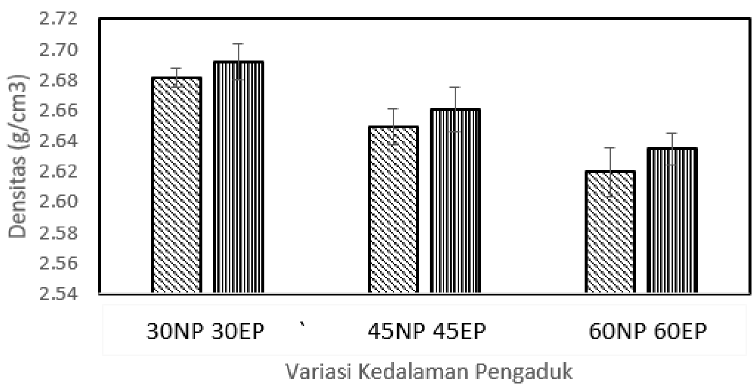


Figure 6. Graph of the relationship between the depth of stirrer and density

Figure 6 shows that the highest density value is obtained at a stirring depth of 30% of the fluid level. This can occur because the lower the stirring position will create an even distribution of Al_2O_3 reinforcing particles. The fluid flow that is formed produces a vortex that can attract particles both at the base of the kowi and on the surface of the liquid metal [7].

Figure 6 also shows the effect of electroless coating on density values. Electroless coating treatment can increase the density value of each stirring depth. This can occur because of the increased wettability or wettability of the Al_2O_3 reinforcement. The increase in wettability is due to the formation of the $MgAl_2O_4$ phase on the Al_2O_3 surface with an Al matrix [4].

The density test for each depth of stirrer is used to determine the percentage of the porosity of the material. The porosity value of a material has a value inversely proportional to the density value. The porosity value of the Al6061-Al_2O_3 composite can be shown in Figure 7.

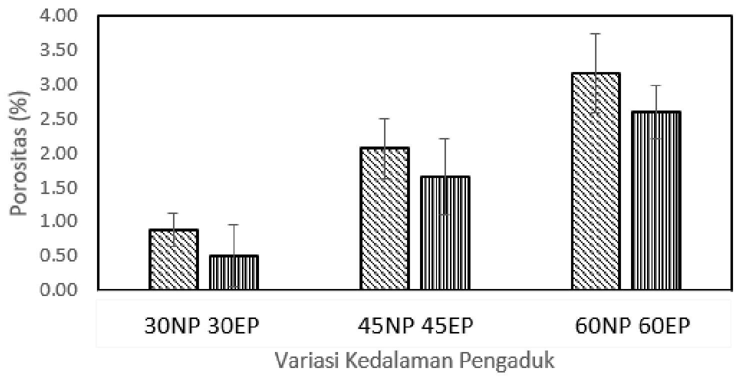


Figure 7. Graph of the relationship between the depth of stirrer and porosity

Figure 7 shows that the highest porosity value was obtained in the 60-NP specimen of 4.67% while the 60-EP specimen was 4.11%. The porosity value of 45-NP specimens was 3.59% while 45-EP specimens were 3.18%. The lowest porosity value was obtained in the 30-NP specimen of 2.42% while the 30-EP specimen was 1.54%.

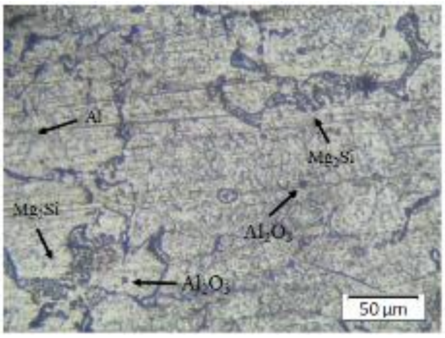
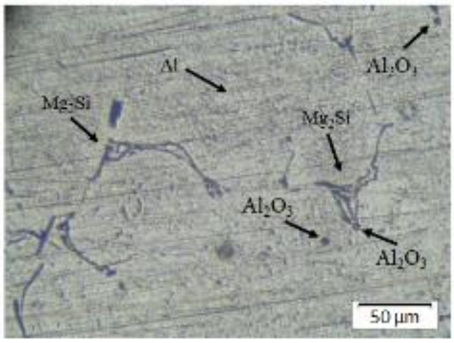
Porosity can occur due to the trapped gas in the stirring process in composite fabrication [8]. The closer the stirring position to the surface of the liquid causes the porosity value increase. The presence of porosity causes a decrease in the mechanical properties of the material [9].

Figure 7 also explains the effect of electroless coating treatment on the porosity value of the composite. It can be seen that the porosity value in the NP specimen has a greater value than the EP specimen. This is due to the fact that the electroless coating treatment can reduce the porosity at each position of the depth of the stirrer. The electroless coating is able to increase the wettability between reinforcement and matrix [4]. Good wetness of the reinforcing particles can reduce the porosity value at each variation of the stirring depth position.

3.2 Result of metallographic observation

Metallographic observation aims to determine the microstructure contained in each specimen. The microstructure shows the distribution of the reinforcing particles and the percentage of porosity in the composite. The specimens used for metallographic observations are ground and etched first. Metallographic observations were carried out using a microscope. Figure 8 shows the microstructure of the variation in the depth of stirrer and Al_2O_3 reinforcement treatment.

Figure 8 shows the microstructure of the Al6061-Al_2O_3 composite in the non-electroless coating treatment variation, the highest Al_2O_3 dispersion was obtained at the stirring depth of 30% and there was no porosity. At 45% and 60% stirring depth, the composite was porous, this is following the density and porosity test which showed that the stirring depth of 45% and 60% in non-electroless coating had higher porosity. A similar phenomenon occurs in a variety of electroless coatings. The increased porosity value is due to trapped air due to increased contact with the liquid metal so that the air is trapped in the liquid metal [10].

<table>
<tr><th>Variation of depth stirrerr</th><th>Non-electroless coating</th><th>Electroless coating</th></tr>
<tr><td>30 %</td><td>
</td><td>
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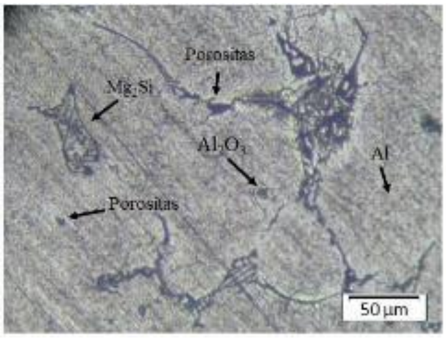
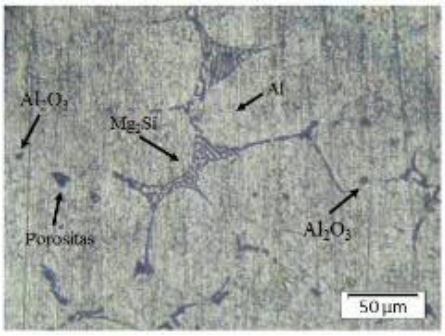
<tr><td>45 %</td><td>
</td><td>
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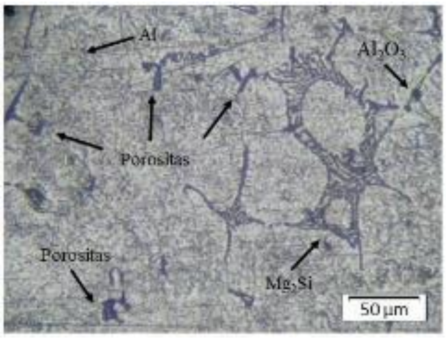
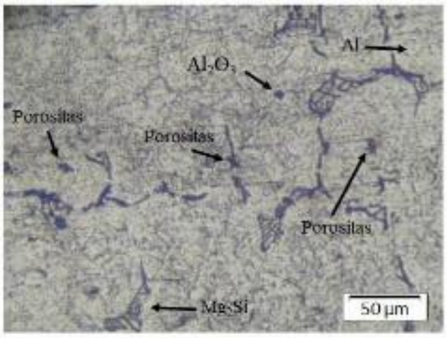
<tr><td>60 %</td><td>
</td><td>
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Figure 8. Comparison of the microstructure of variation of depth stirrer and Al_2O_3 reinforcement treatment

In Figure 8 the position of the stirrer depth of 30% shows an even distribution of Al2O3 particles rather than 45% and 60%. This is because the right stirring position can evenly distribute the reinforcing particles. The fluid flow that is formed produces a vortex that can attract particles both at the base of the kowi and on the surface of the liquid metal [7].

Figure 8 also shows the comparison of the results of the microstructure observation between the electroless coating and non-electroless coating treatment for each variation of the depth of the stirrer. It can be seen that the porosity that occurs in specimens with electroless coating treatment has the lowest porosity. The effect of electroless coating treatment on the microstructure of the composite shows that the specimens with electroless coating treatment produce better wettability. This happens because the electroless coating can increase wettability so that Al2O3 can bind better to the Al matrix [4]. Good wettability will result in lower porosity and increase the mechanical properties of the composite.

It can be concluded that the combination of 30% insertion depth and electroless coating treatment resulted in the best Al2O3 dispersion on the Al matrix compared to other combinations.

3.3 Result of hardness test

Hardness testing is useful for knowing the hardness of a material. This test uses the Brinell method using a steel ball indenter with a diameter of 2.5 mm with loading of 62.5 kg in a loading time of 30 seconds. This hardness test is carried out at 3 points of emphasis for each specimen. The graph of the relationship between the depth of stirring in the material with electroless coating and non-electroless coating treatment on the hardness value can be seen in Figure 9.

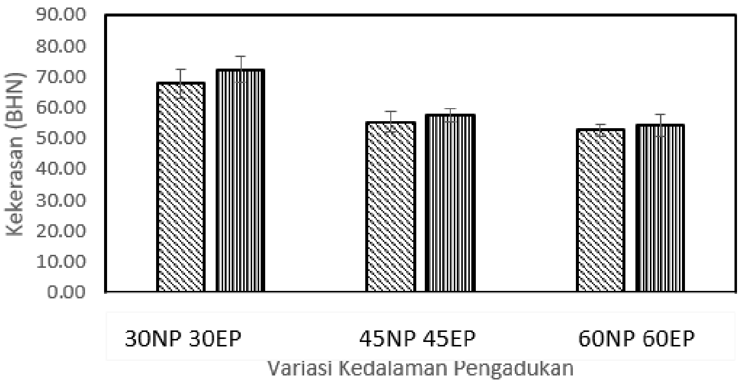

Figure 9. Graph of the relationship between the depth of stirrer and the hardness value

Figure 9 shows the Brinell hardness value against the depth of the stirrer and the electroless coating treatment. The hardness for the 30-NP specimen was 67.88 BHN and the 30-EP specimen was 72.33 BHN. The hardness for the 45-NP specimen was 55.47 BHN and the 45-EP specimen was 57.71 BHN. The hardness for the 60-NP specimen was 52.67 BHN and the 60-EP specimen was 54.37 BHN. The highest hardness value is obtained from the variation of the depth of 30% and the lowest hardness value is obtained from the variation of the depth of 60%.

Figure 9 shows that the hardness value decreases with the proximity of the stirring position to the surface of the liquid. The highest hardness is achieved at a stirring depth of 30% of the fluid level. This is due to the increased density and reduced cavity in the composite which causes the composite to become harder [11]. The right stirring position can evenly distribute the reinforcing particles so that the hardness of the material will increase. An increase in the value of hardness is associated with an increase in the value of density and a decrease in the value of porosity [11] which is by Figure 6 and Figure 7. High porosity values will result in low mechanical properties [9].

Figure 9 also shows the effect of the electroless coating treatment on the reinforcing particles. The hardness value of materials with electroless coating treatment is greater than that of non-electroless coating materials. Electroless coating treatment can increase the wettability or wettability of the Al2O3 amplifier so that it can produce a good particle distribution so that the hardness value of the composite will increase [4].

3.4 Result of tensile test strength

Tensile testing is useful for determining the strength of the material against tensile forces. The data observed in this tensile test is the relationship between tensile strength, elongation, and modulus of elasticity on the depth of stirring and the electroless coating treatment. The results of the tensile strength test are shown in Figure 10.

Figure 10 shows the effect of stirring depth on the tensile strength of the composite. Based on the test results, the average tensile strength for 30-NP specimens was 177.41 MPa and 182.19 MPa for 30-EP specimens. The tensile strength of the 45-NP specimen was 158.94 MPa and 159.69 MPa for the 45-EP specimen. The tensile strength of the 60-NP specimen was 151.05 MPa and 156.86 MPa for the 45-EP specimen. The highest tensile strength value obtained from the variation of the depth of 30% and the lowest tensile strength value obtained from the variation of the depth of 60%.

The results of the tensile test in Figure 10 show that the depth position of the stirrer affects the distribution of the reinforcing particles [7]. The uneven distribution of particles affects the tensile strength of the material, the more evenly the distribution of the reinforcing particles, the greater the value of the tensile strength [12].

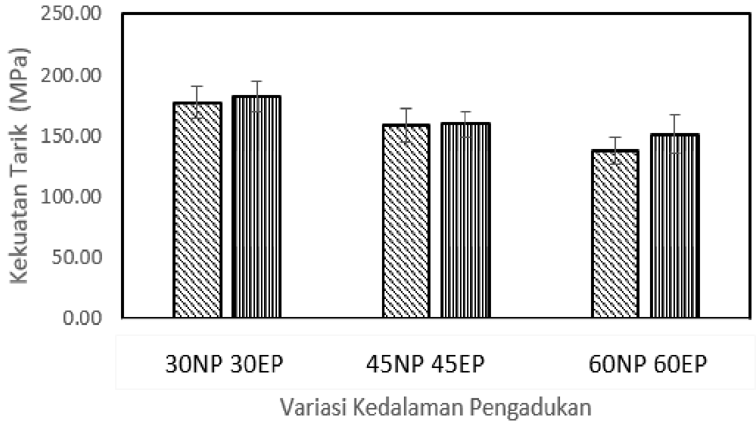

Figure 10. Graph of the relationship between the depth of stirrer and the tensile strength value

Electroless coating treatment at each variation of the stirrer depth can increase the tensile strength value. Electroless coating treatment can increase the wettability of the Al2O3 amplifier so that it can produce even particle distribution. The spread of the reinforcing particles makes the tensile strength value increase [12]. Besides, the presence of porosity affects the value of the tensile strength of a composite [9].

The graph of the relationship between the depth of stirring in the material with electroless coating treatment and non-electroless coating on elongation can be seen in Figure 11. The value of tensile strength is related to the elongation of the composite material.

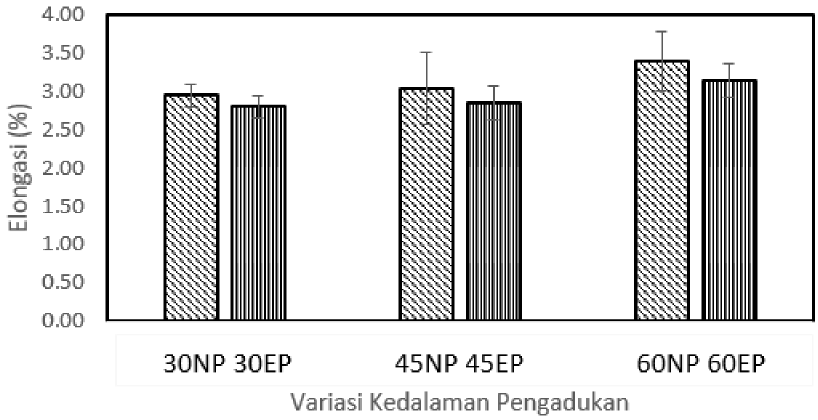

Figure 11. Graph of the relationship between the depth of stirrer and the elongation value

Based on the test results shown in Figure 11, the average elongation value for the 30-NP specimen was 2.95% and 2.80% for the 30-EP specimen. The elongation values for 45-NP specimens were 3.05% and 2.85% for 45-EP specimens. The elongation values for the 60-NP specimens were 3.39% and 3.15% for the 60-EP specimens. The highest elongation value was obtained from the 60% depth variation and the lowest elongation value was obtained at the 30% depth variation.

The tensile strength and elongation value of the composite affect the modulus of elasticity. The effect of stirrer depth on the modulus of elasticity is shown in Figure 12.

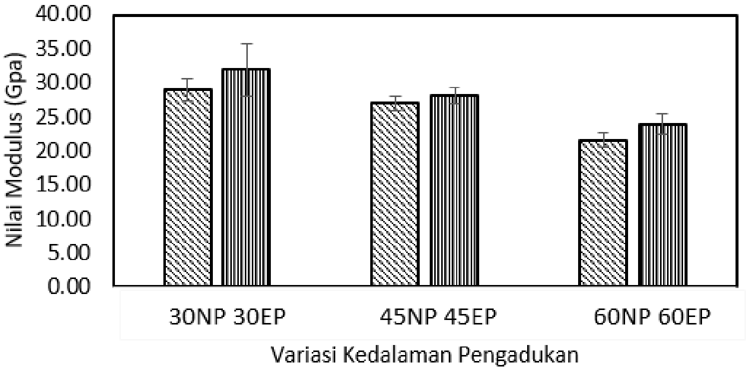

Figure 12 Graph of the relationship between the depth of stirrer and the modulus of elasticity

Based on the test results shown in Figure 12, the average modulus of elasticity for the 30-NP specimen was 29.02 GPa and 31.89 GPa for the 30-EP specimen. The modulus of elasticity for 45-NP specimens was 26.96 GPa and 28.12 GPa for 45-EP specimens. The modulus of elasticity in the 60-NP specimen was 21.51 GPa and 23.88 GPa for the 60-EP specimen. The highest modulus of elasticity is obtained from the variation of the depth of 30% and the lowest modulus of elasticity is obtained from the variation of the depth of 60%.

The results of the tensile test as listed in Figure 12 show that the variation in the depth of the stirrer affects the dispersion of the reinforcing particles [7]. The uneven distribution of particles affects the modulus of elasticity, the more evenly distributed Al2O3 particles on aluminum, the greater the value of the modulus of elasticity [12].

4. Conclusion

Based on the testing process, observations, and the results of the discussions that have been carried out in the study, it can be concluded that:

1. The position of the stirrer depth to the stir casting process affects the hardness and tensile strength values of the Al6061-Al_2O_3 composite. The variation of the stirrer depth of 30% from the fluid level is the best position to improve the mechanical properties of the composite.
2. Electroless coating treatment on the Al_2O_3 reinforcement can increase the hardness and tensile strength of Al6061-Al_2O_3 composites.

5. Acknowledgement

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