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Study of Fatigue Life on Aluminium Composites – Fly Ash Received T6 Heat Treatment and Artificial Aging

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Abstract - *In the manufacture of aluminium composites, reinforcement in the form of coal base ash, which has been through an electroless process, is needed, which functions to coat the fly ash so that it sticks to the aluminium metal during casting. The strength of the aluminium alloy material does not only depend on the concentration of the alloy metal but also how the process is treated until the aluminium is ready for use. Heat treatment of T6 with a dissolving temperature of 510 ° C for 1 hour and 2 hours and continued with artificial aging at 120 ° C, 140 ° C and 160 ° C was held for 2 hours. Fatigue is a major cause of the malfunction. From the fatigue test, the highest fatigue life with a load of 087 σu can be seen in the specimens that received heat treatment of T6 510 ° C with a dissolving hold time of 1 hour and an aging temperature of 120 ° C for 2 hours, namely 3. 466 cycles and the lowest fatigue life in specimens that received heat treatment of T6 510 ° C with a dissolving hold time of 2 hours and an aging temperature of 160 ° C for 2 hours, namely 440 cycles. The highest fatigue life with load σy is seen in the specimens that received heat treatment of T6 510 ° C with a dissolving time of 1 hour and an aging temperature of 140 ° C for 2 hours, namely 32,566 cycles and the lowest fatigue life in specimens that received heat treatment T6 510 ° C with a dissolving hold time of 2 hours and an aging temperature of 160 ° C for 2 hours, namely 11,333 cycles.*

Keywords: *Aluminium, fly ash, Composite, Electroless Platting, Fatigue*

I. INTRODUCTION

Metal materials are technical materials that are often applied in various fields. In engineering or engineering applications, metal is the material that dominates its use when compared to other engineering materials, especially as the main material in the design machine. In addition, metal is widely used in industry and other household needs

Aluminium, for example, the basic material that is often found in the form of pure aluminium and aluminium alloys (composites). The composite material is a material consisting of a combination of two or more materials that remain separate and differ in a macroscopic level when forming a single component [1].

The composite material is composed of two parts, namely a matrix and a reinforcement. The matrix is the largest part of the composite structure and can be made of metal, ceramics, or polymers. Aluminium metal matrix composites are one of the most widely developed composite materials in the industry. Some of the advantages of aluminium as a matrix of composites are because it has a relatively low density, relatively high strength, corrosion resistance, and cheaper assembly costs so that it can be used as a construction material for machines that use aluminium as the basic material, one of which is ship propellers. The properties of aluminium metal, which are relatively ductile as a composite matrix, need to be combined with reinforcement in the form of particles that have a higher level of hardness and strength than aluminium so that an aluminium composite with better mechanical strength can be obtained and can be applied as a moving construction material for machinery.

Use of silica-based ceramic materials as reinforcing aluminium composites is often used because it can improve mechanical performance and corrosion resistance [3]. The reinforcing material in aluminium composites generally uses bottom ash, which contains relatively high oxides such as SiO2 and Al_2O_3, abundant amounts, high levels of hardness, resistance to high temperatures with a melting point above 2000°C, and cheap so it can be used as an alternative in manufacturing metal composites with an aluminium matrix (Ahmad and Santoso, 2015). The SiO2 content in the bottom ash of coal is estimated to be around 41.73%, and Al_2O_3 is around 24.3%, so that it can be used as an alternative material in the aluminium metal composite [2].

The stir casting method used for mixing the composites resulted in a uniform distribution of the reinforced fly ash particles, with the increasing content of fly ash reinforcement, increasing tensile strength, compressive strength, and decreasing with increasing fly ash particle size [23]. Metal Matrix Composite containing Fly Ash can be used in Automobile, Aerospace, and other applications in the Engineering field where lighter weights with higher strength are expected. [24]. Fly ash as reinforcement also increases the tensile strength by reducing the ductility of the composite [25]. The results showed that the increase in the biomass content of fly ash resulted in increased microhardness but decreased tensile strength and impact strength [26-32].

The main problem of using SiO_2 ceramic material as reinforcement in composites with an aluminium metal matrix is the relatively low level of surface adhesion of the two materials, so that it does not provide effective reinforcement to the composite system. The adhesion property of the two material surfaces can be done by providing a coating or coating on the SiO_2 ceramic surface with magnesium metal. The coating method is carried out using the electroless platting technique. The electroless plating technique is a coating process that does not use an electric current in the coating. Coating occurs due to oxidation and reduction reactions on the surface of the material so that a metal layer is formed from the metal salt. Electroless plating functions to wet the surface of the coal base ash particles (wettability) itself with metal before combining it with other metals in the melting or casting process. Electroless plating is carried out on SiO2 particles contained in the bottom ash of the coal, which is expected to increase the adhesion force leading to an increase in the mechanical properties of the composite material with an aluminum metal matrix [3].

The strength of the aluminium alloy material does not only depend on the concentration of the alloy metal but also how the process is treated until the aluminium is ready for use. The heat treatment process is the final stage of a series of metalworking processes before they are used according to their needs. The heat treatment process is an important step in the metalworking process in terms of improving mechanical properties such as hardness, ductility, and toughness. In the heat treatment process, the obstacles that are often faced are the emergence of distortion, changes in shape and size. The surface hardening process is carried out by raising the metal temperature to its austenitizing temperature, then holding it at that temperature for a certain time, and then rapidly cooling it into the oil. This rapid cooling of the austenite produces a martensite structure that is hard and brittle. To overcome this, it is necessary to do aging, namely, reheating it below its austenitizing temperature and holding it for a certain time for homogenization. After that, proceed with air cooling. In the end, it will produce ductile material properties, although the hardness is slightly reduced [4]. Ship propellers are one of the ship's propulsion and are included in the ship's machining system. If the ship uses the engine as propulsion, the role of the propeller will be very important. For this reason, the propeller is expected to have a high fatigue resistance limit because it always experiences dynamic loads that suddenly breaks and cannot function anymore.

The failure of construction caused by the dynamic load is known as fatigue failure. Fatigue failure is a form of failure that occurs in the structure due to dynamic loads that fluctuate under the yield strength that occurs for a long time and repeatedly. Fatigue is a major cause of the malfunction. A fatigue failure is characterized by the onset of a crack. This crack will spread towards the inside of the material to a certain extent where the material is no longer able to withstand loads and will break. The heat treatment process is the best alternative for increasing the fatigue strength of the propeller. Other natural fiber composites can be found in [33-37].

II. EXPERIMENTAL PROCEDURE

A. Material

Metal Matrix Composite with Aluminium matrix and Fly Ash reinforcement with weight percentage 89%, 10%, and added Magnesium by 1%.

B. Coal Base Ash Electroless Platting Process

The steps for the electroless plating of coal base ash are as follows:

1. Sieving the coal bottom ash to produce a particle size of 200 mesh using a 225-250 mesh sieve size.
2. Washing the coal base ash using 96% technical alcohol.
3. Electroless plating process:
   a. Put the HNO_3 solution into the Erlenmeyer glass, then rotate the HNO3 for 5 minutes using a magnetic stirrer.
   b. Next, enter the coal base ash into the Erlenmeyer glass.
   c. After the coal bottom ash is added, wait 30 minutes until the coal bottom ash is mixed with the HNO3 solution.
   d. Then put Mg (magnesium) into the Erlenmeyer glass and wait for 5 minutes.
   e. After 5 minutes, turn on the heater and set it to 100 ° C for 1 hour.

4. The oxidation process is up to a temperature of 250 ° C for 2 hours.

C. Composite Casting Process

After weighing the composite materials, the casting process is continued with the Gravity Casting Method. The steps of the casting process are as follows:

1. Prepare tools and materials for the composite casting process.
2. Turn on the burner for the healing process of the furnace.
3. Enter the piston into the kowi as much as 89%.
4. Heat the smelting furnace to the melting point of 660 ° C, if it is above 660 ° C, add 1% Mg (magnesium), stir for 5 minutes, then add 10% electroless coal base ash, stir for 5 minutes.
5. Before the composite castings are poured into the mold, preheat the mold to a temperature of 300 ° C so that there is no porosity (air cavity) in the cast to be poured.
6. Pour the castings into the mold and wait for 1 hour.

D. Test Object

Tensile Testing to determine the value of tensile strength with a standard tensile test specimen ASTM E 8 / E 8M. While Fatigue testing to find out the failure Fatigue withThe fatigue test specimen uses the ASTM E466 standard as shown in Figure….

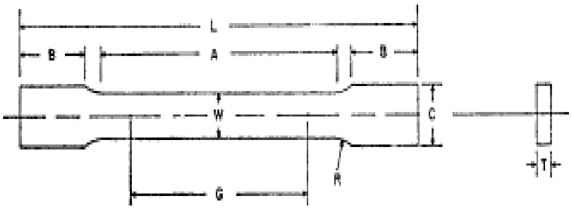

Figure 2.1 ASTM E 8 / E 8M standard tensile test specimens

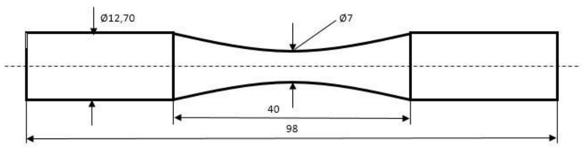

Figure 2.2 Fatigue test specimens using ASTM E466 standards

E. Heat Treatment process

The steps of the T6 heat treatment process are as follows:

1. Carry out solution heat treatment at a temperature of 510 ° C for 1 hour and 2 hours.
2. Furthermore, fast cooling with SAE40 oil is carried out.
3. The artificial aging process with temperature variations of 120 ° C, 140 ° C, and 160 ° C for 2 hours.

III. DISCUSSION

From Table 3.1, it is known that the addition of basic coal ash and heat treatment of T6 gives an increase in the average value of tensile strength compared to the material before the T6 process with a tensile strength value of 270 MPa. After the heat treatment process T6 510ºC 1 hour 120°C, the tensile strength value is 298 MPa, then at T6 5106C 1 hour 140ºC the tensile strength value decreases to 272 MPa, but at T6 510ºC 1 hour 160ºC the tensile strength value has increased again to 284 MPa.

Heat treatment T6 510ºC 2 hours 120ºC the tensile strength value increased to 307 MPa but at T6 510ºC 2 hours 140ºC, the tensile strength value decreased to 290 MPa and at T6 510ºC 2 hours 160ºC the tensile strength value decreased again to 274 MPa. It can be seen that the value of the highest tensile strength in the T6 510ºC 2 hours at a temperature of 120ºC with a strength value of 307 MPa. And the lowest strength value is in the T6 510ºC 2 hours at a temperature of 160ºC with a strength value of 274 MPa. The stress levels on the SN curve given in this Fatigue test are 0.87σ_u and σ_y.

Table 3.1 Tensile Testing Results

Data (MPa)	T6 510 ° C 1 Hour			T6 510 ° C 1 Hour		
	Aging 2 hours			Aging 2 hours		
	120 ° C	120 ° C	140 ° C	160 ° C	140 ° C	160 ° C
σ u	298.1	298.1	310	307.5	290.1	273.7
σy	222.3	222.3	225	209.4	204.6	199.9

Based on the data from the fatigue test, it can be seen that there is a fairly large spread of data for each given stress level. This shows that the actual fatigue life of a material is uncertain. Therefore, in making the SN curve, first, a statistical approach is made based on the probability of fracture theory, namely, the probability of fracture of the specimen in a certain number of cycles for a given stress level. The probability of fracture used is P 10%, P 50%, and P 90% with the following functions:

$$F(N) = \text{Log } N = a + b * \arcsin \sqrt{P}$$

$$b = \frac{\Sigma^n (\log Ni\ Zi) - [\Sigma^n \log Ni * \Sigma^n Zi]/n}{\Sigma^n Zi^2 - (\Sigma^n Zi)^2/n}$$

$$a = [\Sigma^n \log Ni - b\ \Sigma^n Zi]/n$$

where:
N = Number of cycles,
n = Number of specimens, Z = arcsin √6,
Z = arcsin √6,
P = probability of breaking

The number of cycles of fracture probability for P 10%, P 50%, and P 90% was obtained then analyzed with a linear regression function to obtain the equation of the infinite fatigue lifeline of the material.

$$\text{Log } N = c + d\,\sigma$$

$$\text{Log } N = c + d\,\sigma$$

$$d = \frac{\Sigma^n (\log Ni\ \sigma i) - [\Sigma^n \log Ni * \Sigma^n \sigma i]/n}{\Sigma^n \sigma i^2 - (\Sigma^n \sigma i)^2/n}$$

$$c = [\Sigma^n \log Ni - d\, \Sigma^n \sigma i]/n$$

From the SN curve of the test results of coal-bottom ash aluminum composites that received T6 heat treatment and artificial aging from the remelting of the used piston in Figure 4.1, it can be seen the comparison between the cycle (N) and the stress (S). The SN curve graph above shows that the red line with P10% has a voltage (upper limit) of 18,780 lb / in2 with a cycle of 2,770 turns, the voltage (lower limit) of 16,097 lb / in2 with a cycle of 12,968 turns. The green line with P50% has a voltage (upper limit) of 18,780 lb / in2 with a cycle of 3,299 turns, a voltage (lower limit) of 16,097 lb / in2 with a cycle of 16,622 turns and the blue line with P90% has a voltage (upper limit) of 18,780 lb / in2 with 3,930 cycles, voltage (lower limit) 16,097 lb / in2 with a cycle of 21,305 revolutions. So the smaller the stress applied to the specimen, the greater the cycle value obtained, and vice versa; the greater the stress applied to the specimen, the smaller the cycle obtained. The data above shows that heat treatment of T6 510 ° C for 1 hour and aging at 120 ° C for 2 hours has the highest cycle, namely 3,466 revolutions. 4.1x of heat treatment of T6 510 ° C for 1 hour and aging 140 ° C for 2 hours and 1.6 times of heat treatment of 510 ° C for 1 hour and aging 160 ° C for 2 hours.

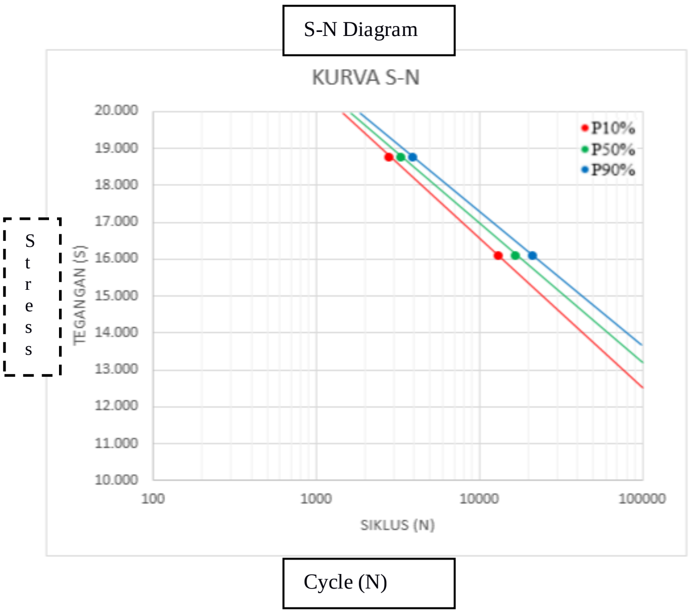

Figure 3.1 SN curve of specimens with heat treatment of T6 510 ° C for 1 hour and an aging temperature of 120 ° C for 2 hours

From the SN curve test results of coal-based aluminium ash composites that received T6 heat treatment and artificial aging from the remelting of the used piston above in Figure 4.2, it can be seen the comparison between the cycle (N) and the stress (S). The SN curve graph above shows that the red line with P10% has a voltage (upper limit) of 19,512 lb / in2 with a cycle of 424 turns, the voltage (lower limit) of 15,609 lb / in2 with a cycle of 23,104 turns. The green line with P50% has a voltage (upper limit) of 19,512 lb / in2 with a cycle of 706 turns, a voltage (lower limit) of 15,609 lb / in2 with a cycle of 30,102 turns and the blue line with P90% has a voltage (upper limit) of 19,512 lb / in2 with 1,177 revolutions cycle, voltage (lower limit) 15,609 lb / in2 with 39,228 revolutions cycle. So the smaller the stress applied to the specimen, the greater the cycle value obtained, and vice versa; the greater the stress applied to the specimen, the smaller the cycle obtained. From the data above, it shows that heat treatment of T6 510 ° C for 1 hour and aging at 120 ° C for 2 hours has the highest cycle, namely 633 revolutions. 1.4 times of heat treatment of T6 510 ° C for 1 hour and aging of 140 C ° for 2 hours and 1.5 times of heat treatment of 510 ° C for 1 hour and aging of 120 ° C for 2 hours.

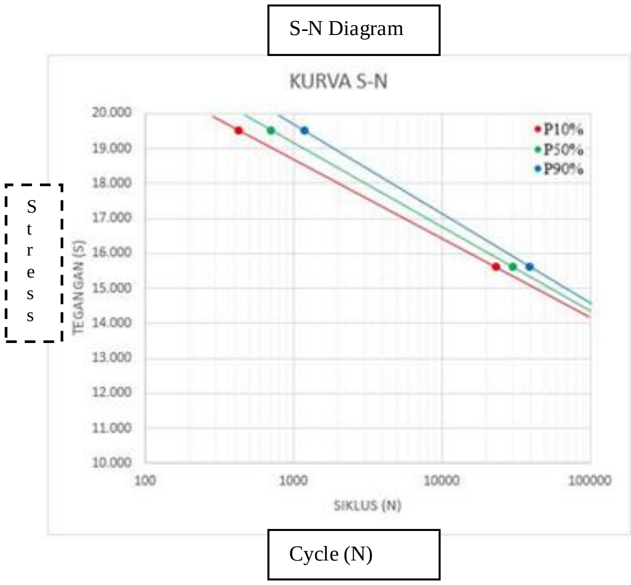

Figure 3.2 SN curve of specimens with heat treatment of T6 510 ° C for 1 hour and an aging temperature of 140 ° C for 2 hours

From the SN curve of the test results of coal-bottom ash aluminium composites that received T6 heat treatment and artificial aging from the remelting of the used piston in Figure 4.3, it can be seen the comparison between the cycle (N) and the stress (S). The SN curve graph above shows that the red line with P10% has a voltage (upper limit) of 18,048 lb / in2 with a cycle of 1,784 turns, the voltage (lower limit) of 16,341 lb / in2 with a cycle of 10,473 turns. The green line with P50% has a voltage (upper limit) of 18,048 lb / in2 with a cycle of 2,183 turns, a voltage (lower limit) of 16,341 lb / in2 of a cycle of 11,142 turns and the blue line with P90% has a voltage (upper limit) of 18,048 lb / in2 with 2,671 revolutions cycle, voltage (lower limit) 16,341 lb / in2 with a cycle of 11,830 revolutions. So, the smaller the stress applied to the specimen, the greater the cycle value obtained, and vice versa; the greater the stress applied to the specimen, the smaller the cycle obtained. The data above shows that heat treatment of T6 510 ° C for 1 hour and aging at 140 ° C for 2 hours has the highest cycle, which is 32,566 revolutions. 1.8x of heat treatment of T6 510 ° C for 1 hour and aging at 120 ° C for 2 hours and 2.8x of heat treatment of 510 ° C for 1 hour and aging 160 ° C for 2 hours.

From the SN curve test results of coal-based aluminium ash composites that received T6 heat treatment and artificial aging from the remelting of used pistons in Figure 4.4, it can be seen the comparison between the cycle (N) and the stress (S). The SN curve graph above shows that the red line with P10% has a voltage (upper limit) of 19,512 lb / in2 with a cycle of 379 turns, the voltage (lower limit) of 15,121 lb / in2 with a cycle of 19,169 turns. The green line with P50% has a voltage (upper limit) of 19,512 lb / in2 with a cycle of 560 turns, a voltage (lower limit) of 15,121 lb / in2 with a cycle of 20,290 turns and the blue line with P90% has a voltage (upper limit) of 19,512 lb / in2 with 828 revolutions cycle, voltage (lower limit) 15,121 lb / in2 with 21,473 revolutions cycle. So, the smaller the stress applied to the specimen, the greater the cycle value obtained, and vice versa; the greater the stress applied to the specimen, the smaller the cycle obtained. The data above shows that heat treatment of T6 510 ° C for 1 hour and aging at 140 ° C for 2 hours has the highest cycle, which is 25,400 revolutions. 1.2 times of heat treatment of T6 510 ° C for 1 hour and aging of 120 ° C for 2 hours and 1.6 times of heat treatment of 510 ° C for 1 hour and aging of 160 ° C for 2 hours.

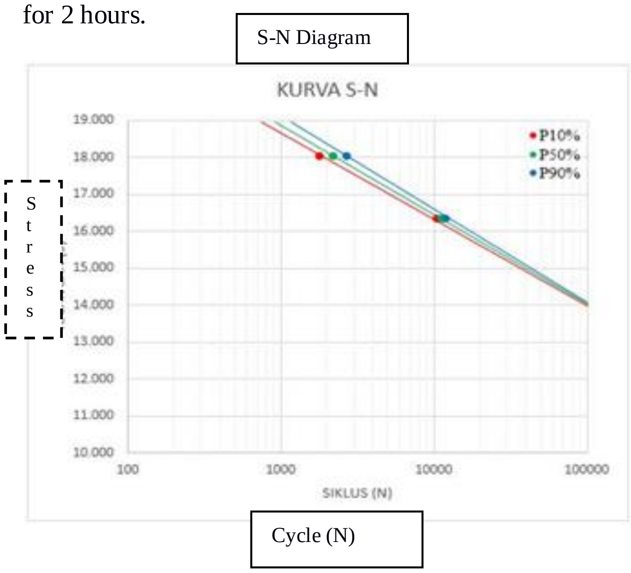

Figure 3.3 SN curve of specimens with heat treatment of T6 510 ° C for 1 hour and an aging temperature of 160 ° C for 2 hours

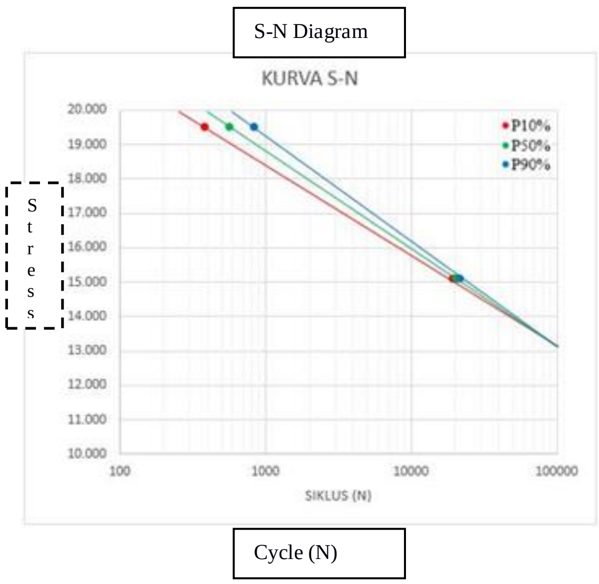

Figure 3.4 SN curve of specimens with heat treatment of T6 510 ° C for 2 hours and an aging temperature of 120 ° C for 2 hours

In Figure 4.5, it can be seen the comparison between the cycle (N) and the voltage (S). The SN curve graph above shows that the red line with P10% has a voltage (upper limit) of 18,292 lb / in2 with a cycle of 200 turns, the voltage (lower limit) of 14,878 lb / in2 with a cycle of 22,950 turns. The green line with P50% has a voltage (upper limit) of 18,292 lb / in2 with a cycle of 357 turns, a voltage (lower limit) of 14,878 lb / in2 with a cycle of 24,854 turns and the blue line with P90% has a voltage (upper limit) of 18,292 lb / in2 with cycle 636 turns, voltage (lower limit) 14,878 lb / in2 with a cycle of 26,853 turns. So the smaller the stress applied to the specimen, the greater the cycle value obtained, and vice versa; the greater the stress applied to the specimen, the smaller the cycle obtained. In Figure 4.6, the SN curve graph shows that the red line with P10% has a voltage (upper limit) of 18,292 lb / in2 with a cycle of 225 turns, the voltage (lower limit) of 14,878 lb / in2 with a cycle of 14,295 turns. The green line with P50% has a voltage (upper limit) of 18,292 lb / in2 with a cycle of 349 turns, a voltage (lower limit) of 14,878 lb / in2 with a cycle of 14,849 turns and the blue line with P90% has a voltage (upper limit) of 18,292 lb / in2 with 540 cycles, voltage (lower limit) 14,878 lb / in2 with a cycle of 15,420 revolutions. So, the smaller the stress applied to the specimen, the greater the cycle value obtained, and vice versa; the greater the stress applied to the specimen, the smaller the cycle obtained.

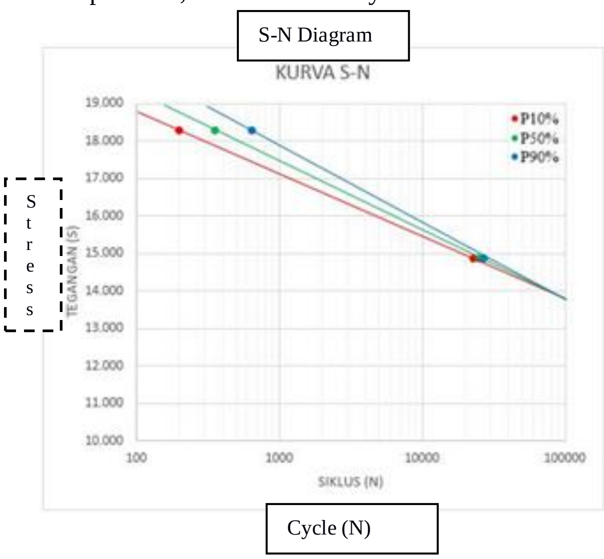

Figure 3.5 SN curve of specimens with heat treatment of T6 510 ° C for 2 hours and an aging temperature of 140 ° C for 2 hours.

After obtaining the SN curve of each T6 heat treatment and aging, the probability of breaking for P50% is taken as in Figure 3.7. Heat treatment of T6 with variations in dissolving resistance time and giving different aging temperatures affects the fatigue life of coal-based ash aluminium composite materials. From the test results of all specimens with the same cooling medium, namely SAE40 oil, the highest fatigue life with a load of 0.87 σ_u was seen in the specimens that were heat-treated with T6 510 ° C with 1 hour dissolution resistance time, and 120 ° C aging temperature for 2 hours, namely 3,466 cycles and the lowest fatigue life in the specimens that received heat treatment of T6 510 ° C with a dissolving hold time of 2 hours and an aging temperature of 160 ° C for 2 hours, namely 440 cycles. The highest fatigue life with σ_y load can be seen in the specimens that received heat treatment of T6 510 ° with a dissolving time of 1 hour and an aging temperature of 140 ° for 2 hours, namely 32.

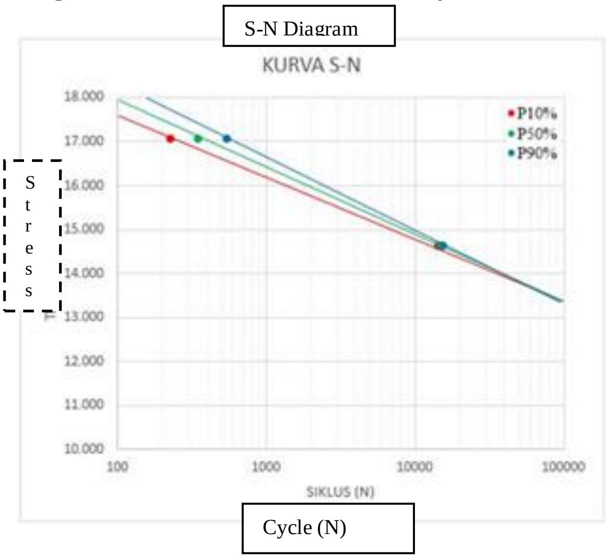

Figure 3.6 SN curve of specimens with heat treatment of T6 510 ° C for 2 hours and an aging temperature of 160 ° C for 2 hours

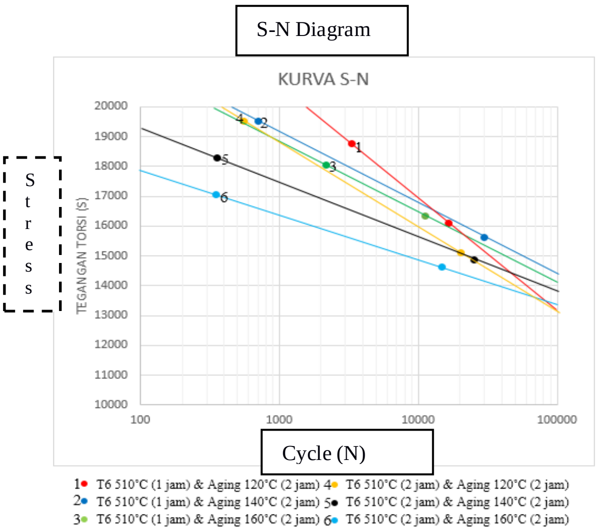

Figure 3.7 S-N curves of the heat-treated specimens with multiple variations of T6.

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IV. CONCLUSION

From the fatigue test with variations in the dissolving resistance time and giving different aging temperatures, it appears that the lower the stress on the test material, the higher the number of fracture cycles of the material is obtained and vice versa. As well as the SN curve of the test material has no predictable fatigue limit so that failure due to fatigue can appear suddenly even with a small cyclic load. Suggestions for future research of a similar type would be better if further studies were carried out on other factors that could affect the fatigue life of coal-based ash aluminium composite materials. For example, heat treatment methods, cooling media, and others can affect the fatigue resistance limits of coal base ash composite materials. So that later, it is expected to produce a new coal-based ash aluminium material with a better fatigue value.

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