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Fatigue Torsion Test On Allumunium Alloy 7075 Under T6 Heat Treatment

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Abstract:
Fatigue testing is a material testing method that aims to evaluate how a material or structure reacts to cyclic loads or stress variations over time. The main goal of fatigue testing is to understand the behavior and resistance of materials to cyclic loads, which can cause the failure of materials or structures over long periods. Fatigue testing was carried out on AA 7075 material which has gone through a series of activities starting from turning the material according to ASTM in cylindrical shape, heating as solution treatment at a temperature of 475 ^{0}C for 5 hours, and then heating T6 artificial aging at a temperature of 120 ^{0}C for 4, 6 8 hours. The results of testing the NHT specimen at a load of 4 degrees, the material broke in cycle 14316 at a shear stress of 910.8 MPa. At a load of 5 degrees, the material broke in cycle 9316 at a shear stress of 1138.6 MPa, whereas at a load of 6 degrees, the material broke in cycle 6533 at a shear stress of 1366 MPa. The results of testing the HT specimen for 4 hours at a load of 4 degrees, the material broke in 18166 cycles at a shear stress of 894.1 MPa. At a load of 5 degrees, the material broke in cycle 15166 at a shear stress of 1117 MPa, whereas at a load of 6 degrees, the material broke in cycle 9863 at a shear stress of 1341 MPa. The results of testing the HT specimen for 6 hours at a load of 4 degrees, the material broke in 38683 cycles at a shear stress of 903 MPa. At a load of 5 degrees, the material broke in cycle 22850 at a shear stress of 1129 MPa, whereas at a load of 6 degrees, the material broke in cycle 17166 at a shear stress of 1355 MPa. The results of testing the HT specimen for 6 hours at a load of 4 degrees, the material broke at 78200 cycles at a shear stress of 1004 MPa. At a load of 5 degrees, the material broke in cycle 46250 at a shear stress of 1255 MPa, whereas at a load of 6 degrees, the material broke in cycle 29133 at a shear stress of 1506 MPa. From the test results, the greater the load applied, the faster the fracture will occur in the sample. This is by the S-N graphic pattern from Wahler which shows an exponential relationship. On the other hand, Mayer showed that the greater the stress, the faster the material's fracture.

Key Word: *Non-Heat Treatment, Heat Treatment, Fatigue Test, Siklus, stress.*

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I. Introduction

At this time, developments in the industry are becoming more advanced, therefore it requires industry players to improve every product they produce. (Suwardi and Daryanto, 2018). This means that the use of aluminum and metal alloys in the industrial world continues to grow, requiring humans to carry out engineering to meet increasingly complex needs. If you pay attention, many pieces of equipment that are often used every day, such as airplanes, ships, cars, motorbikes, and automotive parts, use aluminum as the basic material (Surdia and Saito, 1999). Aluminum is the third most widely used element in the world after oxygen and silicon, but until the late 1800s, it was still very expensive and very difficult to make. However, aluminum is now widely produced, now 25% of its use is for the needs of the transportation industry, 25% for making drink cans or other forms of packaging, 15% is used in the construction sector, another 15% is used in the electrical industry, and 20% is used in other fields (Askeland et al. al, 2011).

Aluminum is a non-ferrous metal that is generally divided into two, namely pure aluminum and aluminum alloy. One of the aluminum alloys that is often used in the aircraft industry today is Aluminum Alloy 7075 (AA7075). AA7075 is aluminum which has the main composition, namely Al, Zn, Mg, Cu, and a small amount of other metals (ASM Handbook Vol 2, 1992). This combination produces AA7075 which has the highest strength among other aluminum alloy series and can additionally be strengthened by heat treatment after processing (Surdia and Saito, 1999).

Heat treatment is a process to improve the properties of a material by heating the material to a certain temperature, then cooling it to a lower temperature, softening, normalizing, hardening, and tempering. In T6 heat treatment, artificial aging is carried out after dissolution treatment (Surdia and Saito, 1999). Based on the book (ASM Handbook Vol 2, 1992), the recommended T6 heat treatment temperature for AA7074 is 120oC and the recommended solution temperature is 465°C – 480°C.

One type of failure that occurs in material components is caused by dynamic loads (repeated loading). This failure is undesirable because the characteristics of failure or fracture cannot be known directly. This failure starts from an initial fine crack which continues to grow until the crack propagates until it breaks. It is estimated that 50 - 90% of mechanical failures are caused by fatigue (Tawaf, et al., 2014).

The types of loads on machine components generally consist of two types, namely pure torsion loads and pure bending loads. These two types of load greatly determine the life of the material. Apart from that, machine elements can also receive a combined load between them.

To determine the mechanical properties of the material, tests are needed. One of the tests that can be carried out is the fatigue test. This test is expected to be able to estimate fatigue and obtain data that can be used to predict the fatigue resistance of materials.

II. Material And Methods

The first stage of this research was collecting data obtained from previous research and relevant literature. The data collected includes:

a. Composition of aluminum alloy (AA) 7075 material
b. Data from thermogravimetry analysis (TGA) testing of aluminum alloy (AA) 7075 material Fatigue test rules or methods for metal follow JIS Z 2273, while for torsion test specimen dimensions follow Torsee's Repeated Torsion and Bending Fatigue Testing Machine (type FTS-4) - Instruction Manual. The testing steps using the Repeated Torsion and Bending Fatigue Testing Machine are as bellow :

1. Preparation of tools and materials. Make sure the specimen or material to be tested has been machined to the shape desired in the fatigue test.
2. The material or specimen that has been turned is then heat treated at a temperature of 480° C with a holding time of 5 hours.
3. Then quenching (quick cooling) is carried out with water for 4-5 seconds
4. After that, Artificial Aging is carried out at a temperature of 120° C with varying holding times of 4, 6, and 8 hours.
5. Each specimen is then subjected to fatigue testing using a Repeated Torsion and Bending Fatigue Testing Machine with differences in distance deflection, namely 4°, 5°, and 6°.
6. After the specimen is broken, record the data results, both time and number of cycles, then enter the data into the calculation table.
7. After the testing process is complete, analyze and discuss the fatigue resistance of the specimens tested.

III. Result

This test result data was obtained after carrying out fatigue testing in the Materials Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Sriwijaya University using a Repeated Torsion and Bending Fatigue Testing Machine. The fatigue test results were carried out on AA 7075 material which has gone through a series of activities starting from turning the material according to ASTM in a cylindrical shape, heating as solution treatment at a temperature of 475 °C for 5 hours, and continuing heating T6 artificial aging at a temperature of 120 °C for 4 hours. 6 and 8 hours.

Result Fatigue Test

Following are the test results on AA 7075 material without heat treatment.

Table 1. Fatigue Test Non-Heat

Specimen	Angle (°)	Time (s) SAMPEL 1	Time (s) SAMPEL 2	Time (s) SAMPEL 3
Sampel NHT1	4	248	345	266
Sampel NHT2	5	183	175	201
Sampel NHT3	6	125	129	138

Table 2. Fatigue Test with Heat Treatment for 4 Hours

Specimen	Angle (°)	Time (s) SAMPEL 1	Time (s) SAMPEL 2	Time (s) SAMPEL 3
Sampel HT1	4	360	344	386
Sampel HT2	5	305	283	322
Sampel HT3	6	182	194	205

Table 3. Fatigue Test with Heat Treatment for 6 Hours

Specimen	Angle (^{0})	Time (s) SAMPEL 1	Time (s) SAMPEL 2	Time (s) SAMPEL 3
Sampel HT1	4	720	835	766
Sampel HT2	5	420	503	448
Sampel HT3	6	300	370	360

Table 4. Fatigue Test with Heat Treatment for 8 Hours

Specimen	Angle (^{0})	Time (s) SAMPEL 1	Time (s) SAMPEL 2	Time (s) SAMPEL 3
Sampel HT1	4	1440	1572	1680
Sampel HT2	5	840	1025	910
Sampel HT3	6	540	620	588

From the fatigue test results on the above material, when heated for 4, 6, and 8 hours, twisting (torsion) was carried out at an angle of 4 degrees with the result that it took longer until the material broke. Meanwhile, with a twist of 6 degrees, the time required for the material to break is faster. On the other hand, a longer heating time makes the material stronger compared to heating at a faster time. When heating the material for 8 hours, it was found that the material broke at a longer time compared to heating for 4 and 6 hours.

Result Tensile Test

Tensile testing is carried out to determine the tensile strength of the material, the data of which is needed as initial data for calculating the fatigue fracture of each specimen. The following are the tensile test results for AA7075 material which did not receive heat treatment (Non Heat Treatment) and received heat treatment (Heat Treatment) for 4 hours, 6 hours, and 8 hours.

Table 5. Tensile Test Non-Heat Treatment

No	Material	Area mm^2	Yield Point N	Yield Stress MPa	Max. Load N	Max. Stress MPa	Break N	Break MPa	Extension mm	Elongation %
1	SAMPE	28.274	15697.028	555.169	17437.519	616.726	670.246	23.705	9.738	32.458
2	SAMPE	28.274	15287.988	540.702	16965.862	600.045	760.031	26.881	9.113	30.375

Table 6. Tensile Test with Heat Treatment for 4 Hours

No	Material	Area mm^2	Yield Point N	Yield Stress MPa	Max. Load N	Max. Stress MPa	Break N	Break MPa	Extension mm	Elongation %
1	120 / A	28.274	14304.302	505.911	15877.679	561.558	792.660	28.035	9.975	33.250
2	120 / A	28.274	14934.116	528.186	16571.949	586.113	811.950	28.717	9.175	30.583

Table 7. Tensile Test with Heat Treatment for 6 Hours

No	Material	Area mm^2	Yield Point N	Yield Stress MPa	Max. Load N	Max. Stress MPa	Break N	Break MPa	Extension mm	Elongation %
1	120 / A	28.274	14499.288	512.807	16094.319	569.220	803.104	28.404	10.775	35.917
2	120 / A	28.274	14438.993	510.675	16026.155	566.809	762.518	26.969	10.300	34.333

Table 8. Tensile Test with Heat Treatment for 8 Hours

No	Material	Area mm^2	Yield Point N	Yield Stress MPa	Max. Load N	Max. Stress MPa	Break N	Break MPa	Extension mm	Elongation %
1	120 / A	28.274	14136.286	499.969	15704.660	555.439	762.274	26.960	8.512	28.375
1	120 / A	28.274	14267.961	504.626	15831.674	559.931	785.483	27.781	9.400	31.333

Result Cycle and Strain Calculations

After knowing the data from fatigue testing, calculations are then carried out to determine the cycles and stresses that occur in AA7075 aluminum based on the predetermined angle. The result calculation can be seen in the table below from non-heat treatment material and heat treatment material.

Table 9. Tabulation calculations on cycle and strain on non-heat treatment materials

Specimen	Angle (^{0})	Max (Mpa)	Yield strength (Mpa)	G (Mpa)	Shear Stress (Mpa)	Siklus (N)
Sampel NHT1	4	227,72	455,44	2561824,69	910,87	14316,67
Sampel NHT2	5	227,72	455,44	2561824,69	1138,59	9316,67
Sampel NHT3	6	227,72	455,44	2561824,69	1366,31	6533,33

Kurva S-N

From the data fatigue testing calculations that have been carried out, the cycles that occur (N) and stress (MPa) for each specimen are known, then the data is plotted into an S-N curve for fatigue testing to determine the fatigue strength limit of the material.

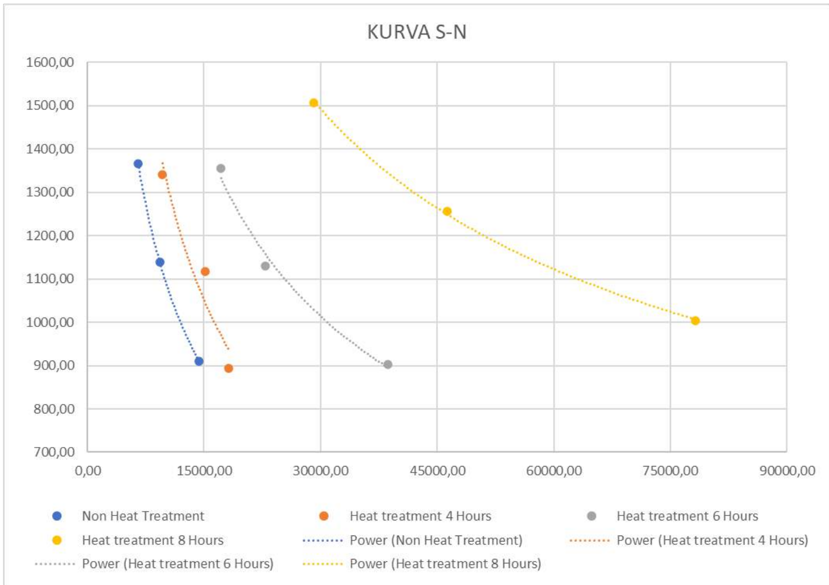

Figure 1. Kurva S-N from all material

From the combined S-N graph above, it can be analyzed that the longer the specimen receives heat treatment, the more likely the specimen experiences fatigue fracture in the long cycle and has a high shear stress. In the 4-hour NHT and HT samples, the 6-hour shear stress values are similar while the cycle is longer. From this the greater load applied, the faster the fracture will occur in the sample. This is in accordance with the S-N graphic pattern from Wahler which shows an exponential relationship. On the other hand, Mayer showed that the greater the stress, the faster the material's fracture.

Visual Observation Result

Visual observations were carried out using a microscope at the Engineering Materials Laboratory, Department of Mechanical Engineering, Sriwijaya University. This observation was carried out to see or predict the beginning of cracks in samples without heat treatment (Non Heat Treatment) and those treated with heat (Heat Treatment), whether these samples have differences. To show the beginning of the crack in the specimen, a graphic image of the angle is needed as shown in the following image.

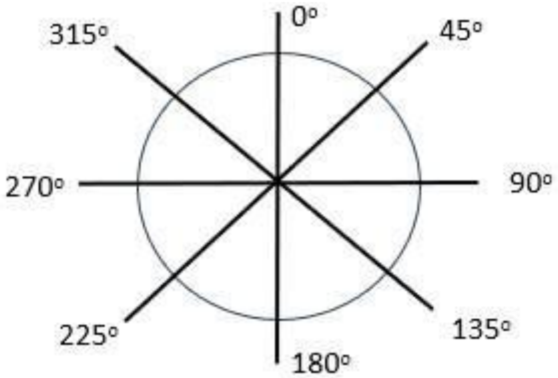

Figure 2. Graphis angle

This is one of the specimens which observation using macro analysis to see the fracture begin, that picture can be in below.

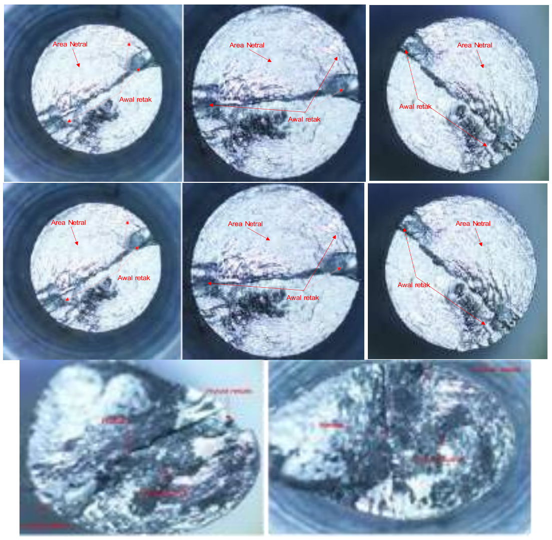

Figure 3. Specimen Non-Heat Treatment and give torsion 4,5,6 degrees.

The image above is a specimen that received a 5-degree twist angle. Visually, there are cracks at corners 45°, 90°, 210°, and 310°, which indicates that this point is the beginning of a crack. The surface on the broken side looks uneven because there is a crack line dividing the two sides of the surface and spreading downwards because of repeated rotation.

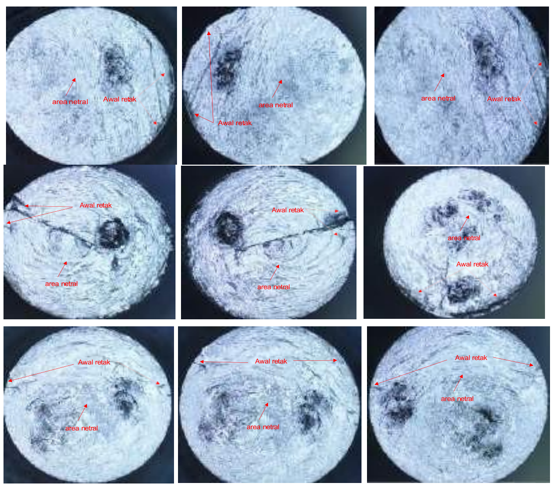

Figure 4. Specimen Heat Treatment for 8 hours and give torsion 4,5,6 degrees.

From the picture above, the 8-hour HT sample shows a crack pattern similar to the 6-hour HT sample, namely that there is an uneven surface occurring at angles of 90^o, 180^o, 270^o and 330^o. The 90^o and 120^o angles are estimated to be the starting point of the crack, while the middle area is caused by the last fracture before the material breaks. This cracking process also occurs in the 5 and 6-degree HT samples whose surfaces are uneven at angles 90^o, 270^{o,} and 330^o which are estimated to be the points where the cracks occur, while the uneven surfaces occur quite a lot in the side areas which form quite lumps. many, uneven surfaces occur, especially in the middle part, this is caused by a sequence of fractures that occur at the very end before the material breaks and the condition of the material is already weak. There is a slight difference in the 5-degree HT specimen because there is a crack line that spreads from angles of 45^o and 310^o to the middle side which is thought to occur when a fracture occurs at the base and is immediately followed to the middle side. Of course, the resulting fracture patterns are quite diverse, but it can be observed that the density of materials that have undergone heat treatment increases because straight fractures do not appear from top to bottom like materials without heat treatment.

IV. Discussion

Based on the fatigue test results on the above material, when heated for 4, 6, and 8 hours, twisting (torsion) was carried out at an angle of 4 degrees with the result that it took longer until the material broke. Meanwhile, with a twist of 6 degrees, the time required for the material to break is faster. On the other hand, a longer heating time makes the material stronger compared to heating at a faster time. When heating the material for 8 hours, it was found that the material broke at a longer time compared to heating for 4 and 6 hours. Then base on From the combined S-N graph above, it can be analyzed that the longer the specimen receives heat treatment, the more likely the specimen experiences fatigue fracture in the long cycle and has a high shear stress. In the 4-hour NHT and HT samples, the 6-hour shear stress values are similar while the cycle is longer. From this the greater load applied, the faster the fracture will occur in the sample. This is in accordance with the S-N graphic pattern from Wahler which shows an exponential relationship. On the other hand, Mayer showed that the greater the stress, the faster the material's fracture.

V. Conclusion

1. The results of the fatigue fracture test were obtained and plotted into an S-N curve. From the calculation results it can be concluded that the greater the load applied, the faster the fracture will occur in the specimen. This is following the S-N graphic pattern from Wahler which shows an exponential relationship. On the other hand, Mayer showed that the greater the stress, the faster the material's fracture.
2. In tensile testing, the yield stress value of specimens that receive heat treatment is lower than specimens that do not receive heat treatment. In addition, the longer the specimen receives heat treatment, the lower the yield stress value of the material.
3. The fatigue strength of aluminum alloy AA7075 tends to increase when heat treated.

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