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THE EFFECT OF HEAT TREATMENT AND SURFACE ANODIZATION ON WEAR AND FRICTION COEFFICIENT OF 2024 ALUMINUM USING PIN-ON-DISK METHOD

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Abstract

The use of aluminum alloys as a material for engineering components that rub against each other is increasing, so it is important to know the friction characteristics of these aluminum alloys. In this study, 2024 aluminum was given heat treatment with variations in aging time or an anodization process. Then, the wear and friction coefficient tests were carried out using a pin tool on the disc. The effect of aging time and surface anodization on wear tests are carried out to determine the amount of wear, and the coefficient of friction test is carried out to determine the coefficient of friction of the material when it rubs against a pin made of AISI 52100 steel. The coefficient of friction test is carried out by adding lubrication type as a parameter. The test results showed that the aluminum alloy given heat treatment had better resistance than that not heat treated. This is because the heat treatment creates precipitates that can increase aluminum's hardness and wear resistance. Whereas for anodized aluminum alloy, the alumina layer can act as an abrasive grain when continuously given a high enough friction and load. Hence the wear testing mode changes from dry sliding wear to three-body abrasive wear and decreased wear resistance. From the friction coefficient test results, the aging time affects the hardness of the aluminum alloy, which leads to the value of the coefficient of friction. The harder the aluminum alloy surface, the smaller the coefficient of friction obtained. Furthermore, applying lubricant to the aluminum alloy will also decrease the value of the friction coefficient of the alloy. Lubricating oil will provide a more significant reduction in friction coefficient than air. Finally, the anodizing surface on the aluminum alloy will act as a lubricant reservoir when it occurs.

Keywords: *Aluminum 2024, wear resistance, coefficient of friction, pin-on-disk test*

1. INTRODUCTION

Technological advancements in engineering components constantly need suiting material to function efficiently. Aluminum alloys are one of the most widespread base materials and have had an important role in the aerospace and automotive industry [1]. Aluminum has a lower density than ferrous metal's [2]. Furthermore, aluminum's melting point is much lower than that of ferrous metal. The low melting point lowers aluminium's the processing energy and costs, and its low density makes aluminum-based components lightweight [3].

The 2xxx series aluminum alloys are one of the most commonly used alloys in the industry. This series incorporates copper (Cu) and magnesium (Mg) as alloying metals to get new and better properties [4]. The presence of Cu and Mg provides higher strength for aluminum alloy due to the precipitation strengthening phenomenon [5]. Precipitation strengthening is one of the most common strengthening methods in aluminum alloys. Precipitation strengthening occurs when alloys are subjected to a specific heat treatment; the different heat treatment processes will yield different strengthening

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results. The presence of precipitate also increases the hardness of the material [6].

Furthermore, increasing the hardness of aluminum alloys can also be done by surface treatment such as anodization. Anodization creates an oxide layer on the surface that will increase the hardness of the aluminum surface [7]. The oxide layer formation has been proven effective in tribological applications, as it can act as a reservoir for lubricants, thus increasing the friction and wearability of the component [8].

The increase of hardness in aluminum alloys, heat treatment and anodizing provides the alloys with better wearability [9]. This is why aluminum alloys are commonly used in applications such as cylinder block components and piston insert rings, which require good tribological properties [10]. Wearability is a very critical property in tribological applications. By thoroughly engineering wearability, it is estimated that one can save 1,6% of GDP, which equals more than 100 billion USD yearly in the United States [11]. Nevertheless, material choice is not the only variable determining wearability. Velocity and load are also important variables of wearability [12].

Moreover, two surfaces that rub against each other produce frictional force, which is determined by the friction coefficient. Frictional forces are sometimes wanted in one application but need to be minimalized in another. Thus, it is important to decide on the alloy's friction coefficient value so that it can be well-suited according to the application demands. Therefore, research needs to be conducted to determine these coefficient values.

This research observes the effect of the aging time and anodization on the wearability and friction coefficient. The tests are conducted with the pin-on-disk method.

2. MATERIALS AND METHODS

2.1 Materials

The aluminum alloy used in this research was 2024 aluminum (2024 Al) plate provided by PT GMF Aero Asia. Table 1 shows the chemical composition of 2024 Al. The 2024 Al sample used was in the form of a 65×65×2 mm plate. The sample plate was subjected to heat treatment or anodization before being tested for wearability and friction coefficient. There are five samples of 2024 Al, each subjected to different treatments. The first sample was not subjected to any treatment, coded T0. The samples coded T3, T6, and T9 were subjected to various heat treatment processes.

Table 1. Chemical composition of 2024 aluminum

Element	% Weight
Al	97.508
Cr	0.003
Cu	1.394
Fe	0.221
Mg	0.531
Mn	0.160
Si	0.097
Ti	0.025
Zn	0.042
Ni	0.005
Sn	0.003
Sb	0.008

The sample TA was subjected to anodization.

2.2 Sample Preparation

The sample used in this experiment was in the form of a 65×65×2 mm plate. To accommodate the shape and dimension of the samples in order to be fit in the pin-on-disk test equipment, the sample was cut into 20×20×2 mm.

Figure 1. Sample being held by a 3D printed sample holder

Next, the sample holder was made using a 3D printer from PLA material. The sample was fixated on the sample holder using an M2 bolt and ring, as shown in Fig. 1.

2.3 Heat Treatment and Anodization

In the heat treatment, heating was done to form supersaturated solid solution, followed by artificial aging. Both processes were done using SAKAE electrical furnace provided by PT GMF Aeroasia. There were three 2024 Al samples subjected to heat treatment with variation aging time. All three samples were heated at 490 °C for 35 minutes. After that, the samples were rapidly cooled to room temperature to form a supersaturated solid solution. Then, the samples were artificially aged at 190 °C for 3 hours for T3, 6 hours for T6, and 9 hours for T9.

The TA sample was anodized in H_2CrO_4 solution for 55 minutes at 35 ºC. Then, the sample was sealed at 90 ºC for 28 minutes.

2.4 Hardness Test

The hardness test was conducted using the Mituyo Rockwell hardness testing machine, provided by PT GMF AeroAsia, at room temperature using a steel ball indentor (1/16 in) and 100 kgf load.

2.5 Wear Test

A wear test was performed using 540 grams of load and an average rotational speed of 1370-1400 rpm for 120 minutes.

Figure 2. Pin-on-disk wear test machine

The test machine used a 150Watt DC motor and was powered by AC electricity, thus creating fluctuation in rotational speed at 1370-1400 rpm range. Nonetheless, the deviation in test results was still relatively negligible. The wear test machine used was a pin-on-disk test machine designed by an undergraduate student of Materials Engineering, Institut Teknologi Bandung, as shown in Fig. 2. The pin used in the test was 5 mm in diameter, made from AISI 52100 steel ball.

Sample mass loss was used to calculate sample wear. The greater the mass loss, the greater the wear. As a result, sample weighing must be done with care.

2.6 Coefficient of Friction Test

In this experiment, the coefficient of friction was determined from the friction test using the previous pin-on-disk test machine.

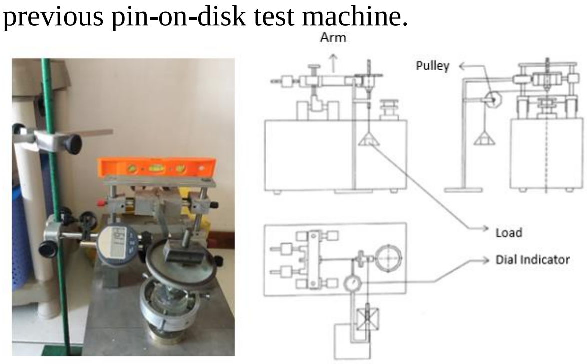

Figure 3. Coefficient of friction test tool

Calibration was carried out as an empirical approach to this friction test. The purpose of this step was to obtain valid data from the friction test. In this test, the frictional force between the sample and the pin will cause a deflection in the arm (Fig. 3). The amount of deflection was then converted into the coefficient of friction. In the tool calibration process, the frictional force will be replaced by the weight of the load, which will cause deflection. Several additional tools were needed to support the calibration process, such as pulleys, steel wires, wire clamps, load containers, level indicators, dial indicators, and loads with varied values (the load is weighed, and the time is recorded). Then, the tool was prepared according to the scheme in Fig. 3.

This research was carried out with a fixed load of 100 grams with variations in lubricant: water lubricant, oil lubricant, and without lubricant. The lubricant oil used in this test was AHM Oil MPX 2 (SAE 10W-30) engine oil. Before testing, all samples except the anodized sample were sanded with 800 grit sandpaper to uniform the surface roughness of the samples. The anodized sample was not sanded because the sanding process would remove the anodized layer formed on the sample surface.

3. RESULT AND DISCUSSION

Figure 4 shows that after three hours of aging, the hardness value of 2024 Al increased to 60.3 HRB. The hardness value, however, decreased with increasing aging time of 6 and 9 hours. Over aging occurs when aging is performed for between 6 and 9 hours.

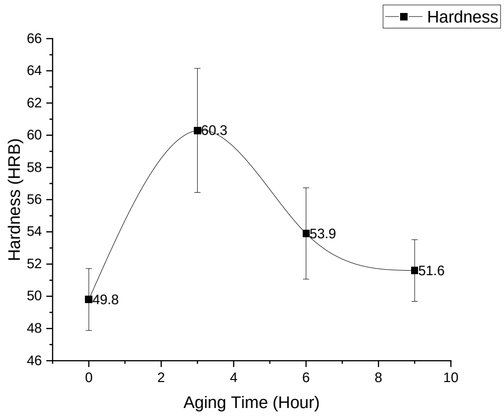

Figure 4. The hardness value (HRB) of 2024 Al with various aging time

The increase in hardness when the aging time was carried out for 3 hours was due to the strengthening of the precipitate, which hindered the dislocation motion. At this maximum hardness value, the precipitate is in a semi-coherent phase. This semi-coherent arrangement of atoms will produce a significant lattice distortion, so a greater force is needed for the dislocations to move through the existing strain field. If aging is left longer, for example, 6 hours and 9 hours, the precipitate atoms will have time to arrange themselves into a more stable phase, namely the incoherent phase. In this phase, the lattice distortion is reduced so the strain field that arises is smaller. This phenomenon will cause decreasing the hardness value. This finding is also in line with the study [14], where the hardness will increase until it reaches a maximum and then decrease if we hold the aging process longer.

3.1 Wear Test Results

The wear test in this study was carried out by providing a load of 540 grams. The average rotational speed was in the range of 1370-1400 rpm for 120 minutes. The wear test uses a 150-watt DC dynamo.

Figure 5 shows that the anodized material has the greatest mass loss. Several things can cause this; first, the oxide layer formed is not optimal, so this layer is easily damaged when subjected to continuous friction. The cause of the non-optimal layer formation is the high anodization temperature so that the pores formed are large and coarse, and the structure of the oxide layer formed is random [13]. The second point, using an indenter as a ball, causes the pressure on the surface to be significant. The sliding motion makes the easily damaged oxide layer more easily lost and eroded. The damaged oxide layer can become wear debris and then become abrasive. The wear debris is between the pins, forming a three-body abrasive wear mechanism [13]-[14].

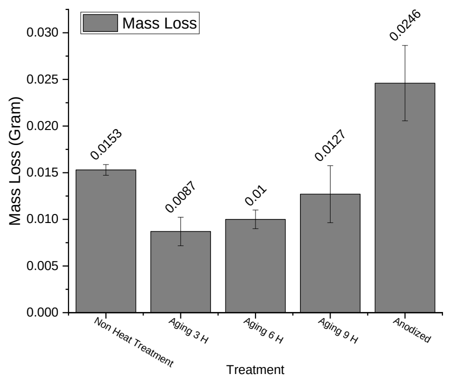

Figure 5. Average mass loss of 2024 Al with various treatments

The last point is that a continuous oscillating load on the same path supported by abrasive materials can create fatigue wear which causes micro-cracks on the surface so more material wears out. According to research [8], where the hard alumina layer becomes wear debris, it can cause micro-cracks so that wear occurs more quickly, as in [14], where the abrasive wear mechanism also occurs.It can be seen in Fig. 6 that the wear value is inversely proportional to the hardness value of the heat-treated 2024 Al.

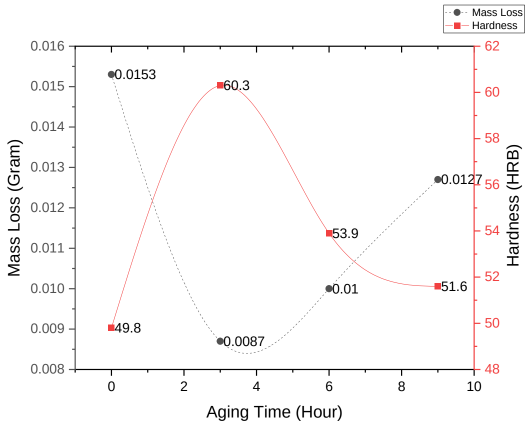

Figure 6. Effect of hardness value on mass loss in heat treated 2024 Al

The material with the highest hardness value will have the lowest wear value. According to the study [15], the heat-treated 2024 Al will increase their wear resistance and are directly proportional to their hardness.

3.2 Friction Coefficient Test Results

As explained in section 2.6, the pin-on-disk coefficient of friction test tool is calibrated before testing the coefficient of friction. Varied masses are weighed and converted to weight, and the resulting deflection values are recorded. The calibration process results will be plotted into a graph, and linear regression is performed on the calibration curve to obtain the calibration equation.

By using linear regression, the linear equation of the curve is obtained, namely:

$$F_{\text{friction}} = 0.2282x + 0.177 \tag{1}$$

Where x is the deflection in mm and F is friction in N. Then, the frictional force is converted to a coefficient of friction using the following equation.

$$\mu = \frac{F_{\text{friction}}}{N} \tag{2}$$

It can be seen in Fig. 7 that the 2024 Al with different aging times without using lubricants have different coefficients of friction. This shows that the aging time carried out on 2024 Al will affect the value of the coefficient of friction. As explained in the previous sub-chapter, the aging time on 2024 Al will affect its hardness value.

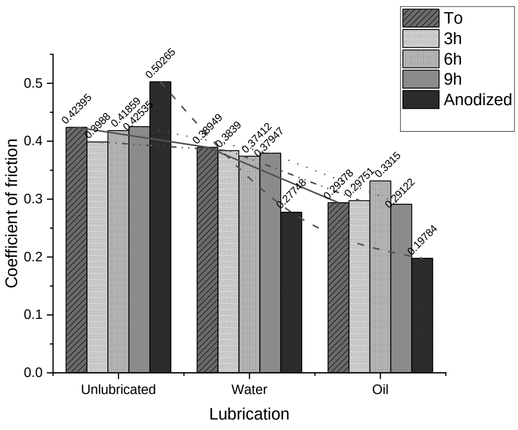

Figure 7. Graph of 2024 Al coefficeint of friction value

As shown in Fig. 8, the 2024 Al with an aging time of 3 hours has the highest hardness value and the lowest coefficient of friction. The harder the alloy surface, the smaller the coefficient of friction obtained, and vice versa. Material with lower hardness will make the penetration of the pin caused by normal forces deeper than the harder material.

Thus, in softer materials, the real contact area of the pin that rubs against the 2024 Al will be greater. When the contact area becomes wider, the adhesion force on the contact surface becomes greater, and it causes the friction that occurs will be even greater.

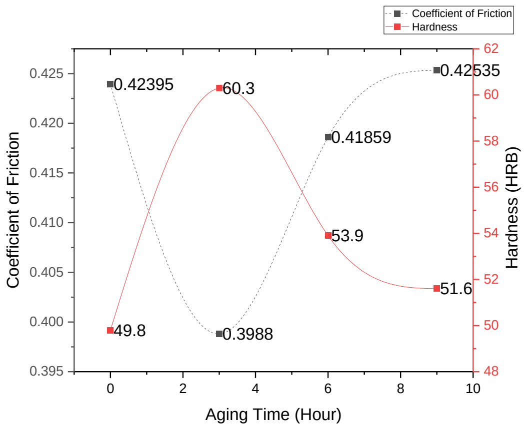

Figure 8. Hardness and coefficient of friction unlubricated 2024 Al curve

It can be seen in Fig. 7 that the coefficient of friction of the anodized 2024 Al has a different value than the other four samples. It means that the anodized surface will affect the coefficient of friction for 2024 Al. The coefficient of friction for the anodized 2024 Al is higher than the others. It is because the surface of the anodized is not polished. It is feared that this process can remove the anodizing layer that has formed. Thus, the surface roughness of the 2024 Al anodized will be different, and the coefficient of friction will be higher than the others. It can also be seen that the friction coefficient value of anodized 2024 Al lubricated during testing had a much lower coefficient of friction than the other four samples. It could be seen that applying lubricants could significantly reduce the coefficient of friction compared to the others. That happens because the presence of an anodized layer in the form of a pore can be a place for storing lubricants. Thus, the lubrication process at the contact of the two materials that takes will be better than in samples that do not have pores as a lubricant reservoir [14].

4. Conclusion

The wear resistance and coefficient of friction of 2024 Al are obtained by testing with the pin-on-disk tool. Heat treatment will affect the hardness value of 2024 Al. The highest hardness value of 2024 Al that have gone through the heat treatment process is achieved by giving aging treatment for 3 hours around 60.3 HRB. The 2024 Al with the highest hardness value has the best wear resistance value (lowest mass loss) and the lowest friction coefficient. The wear resistance and hardness are directly proportional. When the hardness increases, the wear resistance of 2024 Al will also increase. Furthermore, the friction coefficient of 2024 Al is inversely proportional to its hardness value; the harder the 2024 Al, the lower the friction coefficient value. Imperfect formation of the anodizing layer will cause the wear resistance to be lower.

The addition of lubricants can reduce the friction coefficient of 2024 Al. Lubricating oil will reduce the coefficient of friction more significantly than water lubricants. This is because the oil's viscosity is around 170 cP, while the viscosity of water at the same temperature is only about 1,0005 cP. Lubricants with higher viscosity will produce a thicker layer at the contact between the two surfaces. Therefore, the oil can create a thick layer on the contact surface so that the non-uniformity of the surface is not too influential when the friction occurs. The presence of a shaped oxidation layer will be useful as a lubricant reservoir so that the coefficient of friction of the anodized 2024 Al and added with lubricant will produce the smallest value.

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