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The Effect of Holding Time Artificial Aging on Hardness and Microstructure of Al-2024

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Abstract: This study aims to determine the effect of holding time artificial aging on the hardness and microstructure of Al-2024. This study used a specimen in the form of Aluminum 2024 series, which was heat treated at a temperature of 500°C for 60 minutes, then quenched with a cooling medium in the form of water. Subsequently, it was reheated with variations in holding time, namely 3 hours, 5 hours, and 7 hours with a temperature of 190°C. Then the specimen is slowly cooled to room temperature. The results of the chemical composition test using Spectromax showed the percentage of Al was 90.6%, and Cu was 5.90%. The hardness test results using the Rockwell Hardness Tester obtained a hardness value without heat treatment which has a hardness value of 71.4 (HRB) and a hardness value after quenching of 66.9 (HRB). The highest hardness value is found in heating with a holding time variation of 5 hours with a temperature of 190°C, and the hardness value is 84.6 (HRB), where the hardness value at a holding time of 5 hours has increased by 8.48% from the hardness value of the material without heat treatment. Microstructure testing showed that the Al-Cu material after the artificial aging process at a holding time of 5 hours had a higher amount of precipitate phase (θ). The Al-Cu grain boundaries tended to be denser and more regular. It means that the material treated with artificial aging has precipitated deposits or the formation of a second phase which causes the material to be more rigid and have better mechanical properties.

Keywords: Aluminum 2024, artificial aging, hardness value, and microstructure

1. Introduction

Aluminum is the second most widely used metal after steel. That was because aluminum has several advantages, including its lightweight and resistance to corrosion. The heat treatment used on aluminum aims to produce a finer grain shape, as well as to make the formation of deposits on the aluminum structure. For the application, pure aluminum is too soft, so its ductility and hardness need to be increased. Heat treatment of pure aluminum with alloying elements is used to improve mechanical properties such as the hardness and ductility of aluminum. Meanwhile, pure aluminum is less effective if heat treatment is carried out because it does not have a precipitate-forming element. Then an effective way to increase the mechanical properties of pure aluminum is to combine it with other elements [1].

In recent years research on aluminum alloy Al-2024 has been widely used, especially in the aerospace industry (the outer fuselage lining of the Hercules C-130 aircraft), missile parts, and manufacturing bolts and nuts in other automotive industries. It happens because this alloy has advantages in the resulting strength, namely a higher structural weight than steel, good fatigue

resistance, ductility, and high mechanical properties. In addition to these mechanical properties, the most preferred property of this alloy is its age-hardening properties. [2].

Products produced with aluminum alloy are one of the most widely used in manufacturing and everyday life. Aluminum is widely used because it has a light and strong mechanical property. Then to increase the use of aluminum, there are advantages over other metal materials, including lightweight and good electricity conductors. However, aluminum also has many weaknesses, namely its poor mechanical properties. To improve its mechanical properties, aluminum is combined with Cu, Si, Mg, Zn, Mn, Ni, and other elements.

The aluminum alloy requires several treatment stages to increase the material's strength before being used. One of the most effective ways to increase the strength of a metal alloy is through the heat treatment stage.

After testing the hardness of the Rockwell method, the specimen was then continued with a microstructure test to know what phases were formed before and after precipitation hardening. For aluminum, based on previous studies, the initial phase formed is usually a single phase (α), and after hardening precipitation is performed, a precipitate is formed.

2. Materials and Methods

This study used the precipitation hardening process and continued with the artificial aging process with a specified holding time. After hardening precipitation with an artificial aging process, the hardness test is carried out, and observation of the microstructure with the shape of the Aluminum 2024 specimen, as presented in fig. 1

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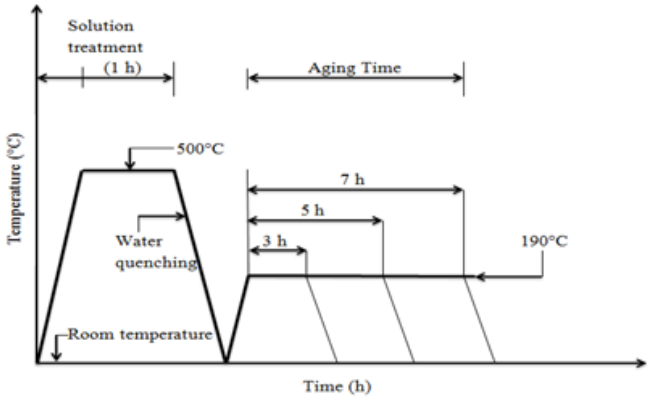

Figure 1. Hardening (Aging) precipitation process

Specimens given precipitation hardening treatment will be continued with a reheating process (artificial aging) at a holding time of 3 hours, 5 hours, and 7 hours which aims to improve the mechanical properties of the 2024 aluminum. The heat treatment process on 2024 aluminum where the preheating temperature in the kitchen furnace used is 500 o C and the holding time is 60 minutes. After 60 minutes, the specimen was removed, and then a rapid cooling process (quenching) was carried out, namely dipping into the water cooling medium. After the quenching process, the reheating or artificial aging process was carried out with a holding time of 3 hours, 5 hours, and 7 hours.

The test specimens that have been prepared will be distinguished based on no treatment and after heat treatment by quenching with water media, then reheating (artificial aging) with a holding time of 3 hours, 5 hours, and 7 hours. The tests carried out were hardness testing using the Rockwell method and microstructure observations with optical microscopes aimed at determining the mechanical properties and phase changes formed from the specimens before and after being heat treated. Artificial aging with cooling times of 3 hours, 5 hours, and 7 hours, as in Fig. 2.

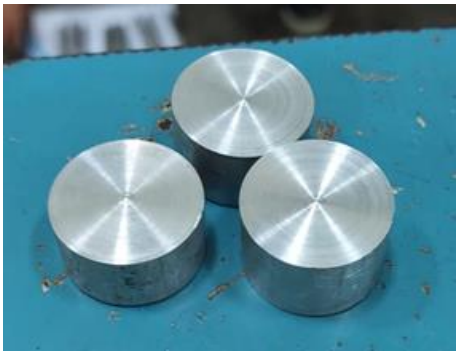

Figure 2. Aluminum 2024 specimen

3. Results Discussion

3.1 2024 Aluminum Composition Test Results

Data in table 6 obtained the results of testing the chemical composition of Aluminum 2024 carried out at the Laboratory of LIPI Tanjung Bintang, Lampung. Based on table 6, it can be seen that the total content of Cu (copper) is 5,90 %.

Table 1. Chemical Composition Data of Aluminum Test Results 2024

No	Element	Rate (%)
1	Cu	5.90
2	Mg	1.81
3	M N	0.793
4	Al	90.6
No	Element	Rate (%)

3.2 Rockwell hardness test analysis

Rockwell hardness testing, the greater the value of hardness in a material, the greater the value of the material's brittleness. In the process of hardness testing, a test specimen changed the form of a former indenter pressure used by a 1/16 steel ball indenter with a B scale. In this study, 25 specimens were tested for hardness. The test was carried out at the Engineering Materials Laboratory, Diponegoro University, Semarang.

Hardness tests have been carried out with variations without treatment, after quenching, and after artificial aging with holding times of 3 hours, 5 hours, and 7 hours. Each hardness test result is for the value of hardness without treatment equal to 71,4 (HRB); after quenching, the value is 66.93 (HRB). Then, after artificial aging with a holding time of 3 hours, the hardness value was 77.53 (HRB). At a holding time of 5 hours, the value was 84.63 (HRB), and at a holding time of 7 hours, a value of 83 (HRB) was obtained, as presented in figure 3.

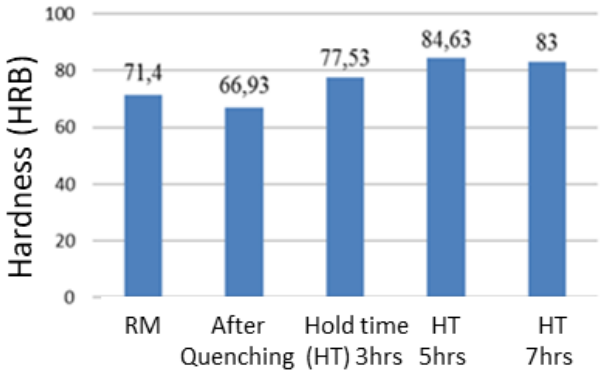

Figure 3. Graph of hardness test results

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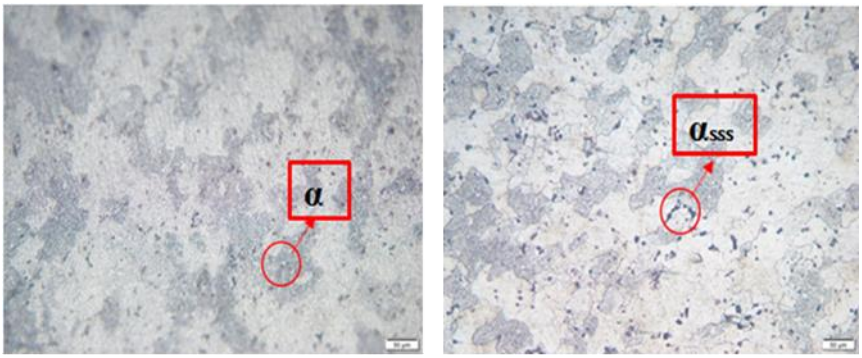
4. Discussion

4.1 Optical Microscopy (OM) test results

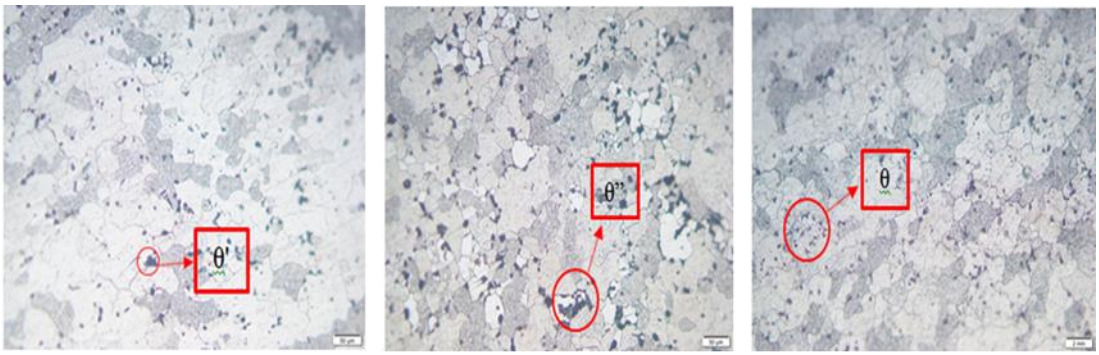
Figure 4 (a) shows a photo of the structure without heat treatment, and it can be seen that the structure formed is a single phase (α) with visible small granules spread evenly in large numbers. While in Figure 4 (b), observing the microstructure results after being given a quenching process, the phase formed, namely (supersaturated solid solution) αsss, shows that the granules formed are getting bigger with fewer numbers. The structure of the atomic granules is more tenuous, following the results of hardness testing. The Rockwell obtained is smaller in value than the Al-Cu material before the heat treatment process (raw material).



(a) (b)

Figure 4. Photo Results of Al-Cu Micro Structure Test. (a) Photo Results of Al-Cu Microstructure Test Before Heat Treatment Process (Raw Material); (b) Photo Results of Al-Cu Microstructure Test After Quenching Process.

The rapid cooling or quenching resulted in the solid soluble Cu atoms not having time to diffuse out of the phase. Thus the second phase of Al-Cu would not be formed. It follows the previous research [3], which states that the quenching stage will produce a supersaturated solid solution (Super Saturated Solid Solution), an unstable or non-equilibrium phase at ordinary or room temperature.



(a) (b) (c)

Figure 5. Photo Results of Al-Cu Micro Structure Test. (a) Photo Results of Al-Cu Micro Structure Test After Artificial Aging Process at a holding time of 3 hours; (b) Photo Results of Al-Cu Microstructure Test After Artificial Aging Process At a holding time of 5 hours; (c) Photo Results of Al-Cu Micro Structure Test After Artificial Aging Process At a holding time of 7 hours.

In Figure 5 (a), the microstructure results at a holding time of 3 hours show that tiny particles of precipitate begin to form. This is due to aging conditions, namely smaller precipitates, and the particles are spread unevenly so that the ' phase begins to appear. Then in Figure 5 (b), it can be seen

that the microstructure results at a holding time of 5 hours show that the precipitate grains began to enlarge, and the distribution of Al-Cu grain sizes began to be dense and regular. In this condition, the most optimal hardness results were obtained compared to the microstructure results at holding times of 3 hours and 7 hours. And in Figure 5 (c), the microstructure results at a holding time of 7 hours show that the size of the small particles formed is getting denser and spreading unevenly again. This is due to over-aging conditions with ' phase. As well as a larger precipitate size. During this over-aging condition, the size of the precipitate increases, and the distance is closer. It can even become an equilibrium condition if the holding time is extended and a phase is formed.

In the early stages of the artificial aging process, A GP Zone 1 will be formed. The GP 1 Zone is formed when the temperature is below 100°C or at room temperature. The formation of the GP1 Zone increased the hardness value of aluminum alloys [4,5]. When the artificial aging temperature is above 100°C, the formation of the phase or Zone GP 2, the optimal hardness value will be obtained if the temperature is above 100°C with the holding time fulfilled, as mentioned elsewhere [4]. When Zone GP 2 has been formed, and a delicate intermediate phase θ precipitation is formed, the artificial aging process stops. This happens because when it has passed through Zone GP 2, the alloy will become soft again. The formation of the θ phase or Zone GP 2 in the artificial aging process is called second hardening [6].

5. Conclusions

The hardness testing results of the Artificial aging treatment samples show that hardness with a holding time of 3 hours increased by 4.12 % to 77.53 HRB from the value of violence without treatment of 71.5 HRB. For materials with a holding time of 5 hours, the hardness value increased by 8,48 % to 84,63 HRB. For materials holding 7 hours, the hardness value becomes 83 HRB or 7.51% of the hardness value without treatment. This shows that the Artificial Aging treatment with a holding time of 5 hours is the most optimal. From the results, the test Rockwell violence showed that the hardness value decreased at a holding time of 7 hours. This happens because the holding time used for Al-Cu material is too long, so a precipitate is formed stable phase; at this stage, the precipitate and matrix are in a balanced state, causing larger particles formed which results in a decrease in the hardness of the material, or it can also be called over aged material.

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