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Mechanical and Metallurgical Properties Assessment for High Strength AA2024 After Annealing Heat Treatment

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Abstract: - In the present investigation, the impact of the annealing procedure on the mechanical and metallurgical properties of the 2024 alloy, was studied. To assess the metallurgical, a bending test was conducted, while the mechanical and metallurgical properties were analyses through tensile, hardness, microstructure, and corrosion tests. The test specimens were annealed by heating them to 300 and 400°C in an electrical furnace for two hours, followed by cooling to room temperature. The results showed a decrease of about 40% in the tensile strength and hardness. However, the bending strength increased by roughly 25%, and the specimens were able to bend at a high angle without cracking or breaking, unlike the base metal. The annealing heat treatment stabilized the microstructure and released the second phase precipitate particles. Consequently, the annealing process, when carried out at suitable procedures and temperatures, enhanced the metallurgical, ductility, and corrosion resistance of the Al 2024 alloy.

Keywords: metallurgical, mechanical properties, annealing heat treatment, wear rate.

I. Introduction

Aluminium and alloys are considered one of the most important engineering materials because it is widely used in many different applications [1]. Aluminium alloys are highly versatile materials, used in a variety of applications owing to their unique properties including low density, high ductility, corrosion resistance, high reflectivity, adequate strength, and low cost. They offer a beneficial combination of strength and ductility, while being non-toxic and recyclable [2].

In 2xxx collection alloys, copper is the basic alloying element, frequently with magnesium as a secondary addition [3, 4]. To get the best characteristics, these alloys need solution heat treatment; mechanical property is like mechanical property in the solution heat-treated state, and sometimes exceeds low-carbon steel. In certain states, the treatment of precipitation heat (aging) is employed to increase mechanical properties [5, 6]. In this treatment, with the attendant lack of elongation, yield strength increases; its effect on tensile strength is not as significant. AA2024 is a precipitation hardening aluminium alloy that contains copper (5.1-5.5 wt.%), magnesium (2.1-2.9 wt.%), and zinc (1.2-2.0 wt.%), making it a popular choice in the aerospace and automotive industries because of its high strength-to-weight ratio [7]. In order to enhance the ductility, and microstructure stability of heat-treatable alloys like the Al 2024, a proper and effective annealing treatment is necessary [8]. The microstructure of the AA 2024 contains three types of second-phase particles: intermetallic particles made from elements such as Zr, Cr, and Mn, constituents such as Fe or Si impurities, and strengthening precipitates such as $MgZn_2$ [9]. Proper annealing treatment stabilizes the microstructure and releases the second-phase precipitates from the matrix. Understanding the effect of second-phase particles on the recrystallization of the alloy is crucial for regulating the grain size and texture during thermo-mechanical processing 10]. However, large particles with deformation heterogeneities may initiate recrystallization during annealing of materials with high alloying content. For example, closely spaced particles may pin grain boundaries [11, 12]. The corrosion resistance of AA 2024 can be evaluated using corrosion tests, and pitting corrosion is the most common type of corrosion that affects aluminium.

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Pitting corrosion leads to haphazard pit formation, which varies depending on the alloy's composition and external factors [13]. Purer alloys generally have higher resistance to pitting because pitting results from galvanic interaction between different components on the alloy. This type of corrosion can be the most harmful since it pierces the metal to its depth, causing greater stress concentrations in those areas.
The most harmful type of corrosion for aluminium is pitting, which occurs when the oxide layer breaks down and creates small pits with localized chemistry that lead to an immediate attack on the exposed metal. Researchers have studied the heat treatment of AA 7075, such as cryocooling followed by annealing treatment, which reduces tensile strength and hardness [14, 15]. Cold rolling increases yield strength but lowers ductility, while subsequent annealing at high temperatures increases elongation values and metallurgical. This study aims to investigate and establish appropriate annealing heat treatment procedures for AA 2024, and to analyse their impact on mechanical and metallurgical properties, as well as ductility.

II. EXPERIMENTAL WORK

The selected alloy is Al 2024. Using the ARL spectrometer to analyze the chemical composition, Table 1 shows the results.

TABLE I
CHEMICAL COMPOSITION OF AA2024 - ALLOY

Element	Measured
Mg	1.04
Cu	5.5
Mn	0.62
Zn	0.11
Cr	0.008
Fe	0.25
Al	Balance

The tensile, bending, and corrosion test specimens were manufactured according to the ASTM (A370-11), ASTM (E 190-92), and ASTM (G 70-30) standards, respectively. The tensile specimens were circular and met the required dimensions, while the bending specimens were of typical dimensions specified by the ASTM (E 190-92) standard, to determine the ease of manufacturing sheet metal, a bending test is conducted. The three-point method is used to investigate the exterior face bending at room temperature. The corrosion specimens were produced with a 1cm diameter and 3cm mm length. The specimens were divided into three groups, designated by symbols (Pa, Pb, and Pc). The specimens in group A were not subjected to annealing heat treatment, while those in groups Pb and Pc were annealed by heating to 250°C and 400°C, respectively, for two hours, followed by cooling to room temperature in the furnace.
The samples were prepared for microstructural analysis by grinding with Emery sheets of different mesh sizes (600, 1000, 1400,1800 and 2400), polishing with 2μm Diamond paste, and then etching for about 30 seconds with Keller's Etch.

III. RESULTS AND DISCUSSION

A. *microstructure*

The purpose of conducting a microstructural examination is to demonstrate the alterations in the microstructure that result from heat treatments. In Figure (1, 2 and 3) optical microscope images display samples that have been hardened through precipitation via quenching in room-temperature water. The alloy contains somewhat soft particles. When subjected to precipitation hardening, numerous phases with varying distributions and ratios of (Al) and (Si) components appear, including the small, relatively soft particles of the precipitated compound ($CuMg_2Si$). This compound undergoes precipitation in three stages: the first being GP-zones, the second being the (β') phase, which is a ($CuMg_2Al$) compound with an (F.C.C) crystal structure, and the third being the ($CuMg_2Si$) compound, which is a (β) phase with the same crystal structure.

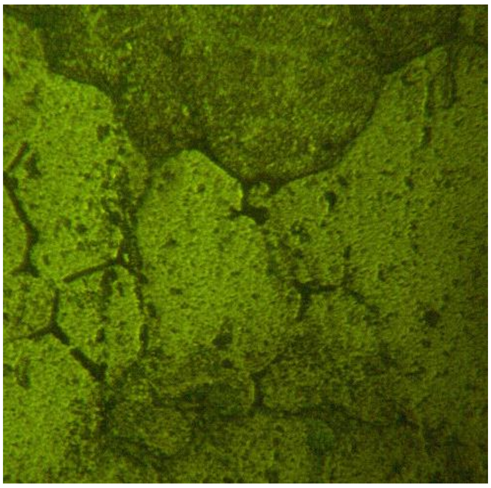

Fig. 1 Microstructure test for specimens 0 °C (100x)

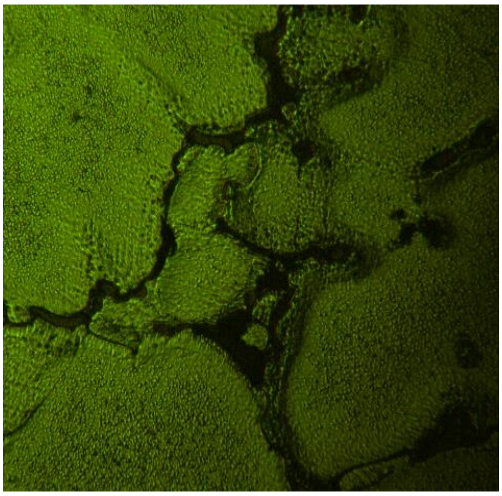

Fig. 2 Microstructure test for specimen's 300°C (100x)

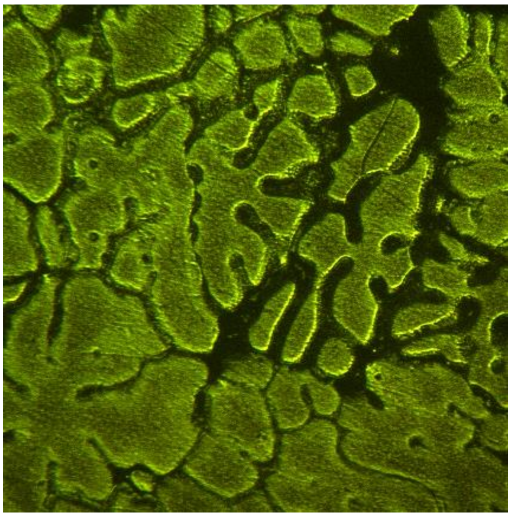

Fig. 3 Microstructure test for specimens at 400°C (100x)

B. mechanical properties

The Yield, ultimate tensile strength, and percentage elongation data were obtained at room temperature and a crosshead speed of 0.5 mm/min. The results of the three tests were averaged, and the values are presented in Figure 4 The mechanical properties of AA 2024 changed due to annealing, with an increase in ductility by about 30%, and a decrease in yield strength, ultimate tensile strength, and hardness by about 50%. Recrystallization occurred quickly at these temperatures, and the precipitate particles lost their ability to harden. Bending tests showed the increase in ductility The findings are shown in Figure 5. At (300) ºC, the tensile properties were found to decrease when the time interval was increased from two to ten hours. This finding is consistent with the results reported by M. Abdulwahab and colleagues in their study [16].

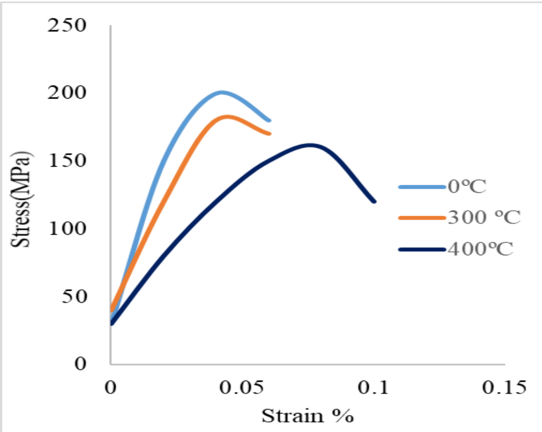

Fig. 4 Stress-strain curves for specimens A, B, and C.

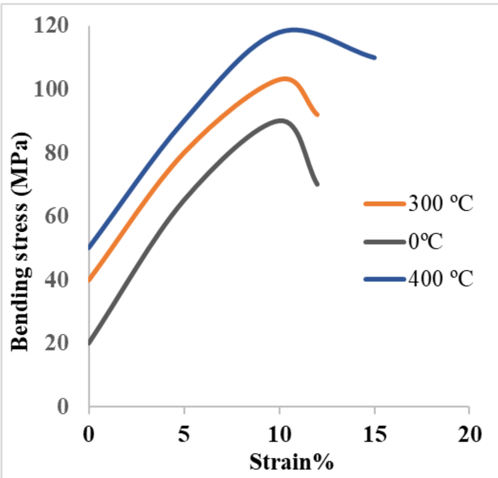

Fig. 5 Stress-strain curve for bending test for specimens A, B, and C

To determine the hardness of the specimens, the Rockwell B hardness test was conducted, with measurements taken perpendicular to the longitudinal axis. The average hardness was determined by taking three separate measurements at various randomly selected locations, and the outcomes are presented in figure 6. The micro-structure following the process of aging can be specified as precipitation hardening. Throughout aging duration, a few alloys complexes precipitate; also end up at the boundaries of the grain for increasing the strength of the material through the interference with the slip planes. The microstructure test indicated somewhere else, specifying that the solution treatment for AA 2024 at a temperature of 400°C for two hours all the alloying elements have been dissolved in aluminum matrix. In the case when solution treated samples are aged at different temperatures, the process of precipitation regarding secondary phase has been started on the basis of sequence. In the case when aging temperature has been a temperature of 200°C, the precipitates regarding secondary phase have been developed. In the case when the samples are age hardened at low and high temperatures, the precipitation related to the secondary has been commenced because of the enhancement in hardness [17,18].

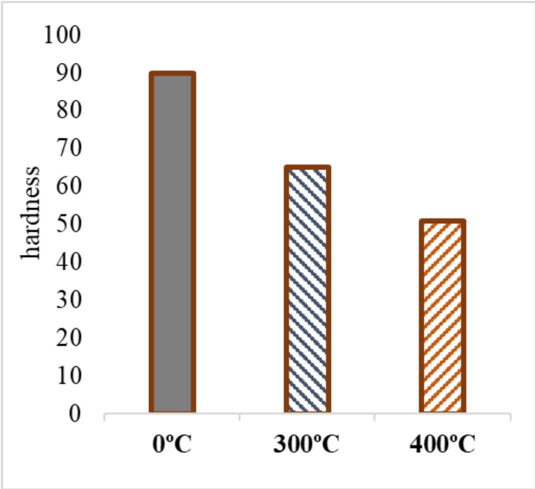

Fig. 6 hardening test for specimens 0, 300, and 400.

c. Wear rate

The graph in Figure 7 shows how changing the annealing temperature affects the wear rate of the samples. The highest wear rate, which is 810-8 gm/cm, is observed after 2 hours of annealing at 300°C. However, when the annealing temperature is increased to 400°C, the wear rate decreases to 7.710-8 gm/cm. This decrease in wear rate indicates an increase in wear resistance. Furthermore, an increase in surface hardness can also lead to a rise in wear resistance by reducing the contact area between the alloy surface and the disc used. The results suggest that the optimal annealing temperature for achieving the best wear resistance is 300°C according to the curves in the graph [19,20, 21].

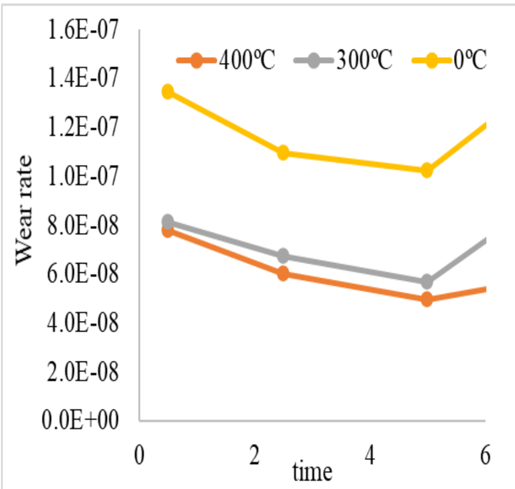

Fig. 7 Wear rate results for specimens 0, 300 and 400.

Conclusions

Annealing heat treatment, when conducted with properly selected procedures and temperatures, was able to stabilize the microstructure and release the second-phase precipitate particles. However, mechanical properties (strength and hardness) were shown to decrease by about 40% with annealing treatment. On the other hand, formability and ductility were found to increase by about 25% with the annealing treatment. Annealing heat treatment, enhanced the wear characteristics contributing to the development of a stable trilateral with self-lubricating features

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