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Effect of Heat Treatment on Some Mechanical Properties of AA2024 Aluminum Alloy

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Abstract. In this paper, the effect of heat treatment on the AA2024 aluminum metal matrix on fatigue properties was studied, microstructural, hardness, and x-ray. A stir casting technique was used to fabricate the aluminums alloy AA2024. These round cylindrical rods of material were formed into cast iron mold where some samples were cooled quickly to room temperature while others were aged. The heat treatment has been performed for 3 hours at a temperature of 500°C followed by quenching in water. It was then artificially aged at 170°C for 3 hours and quenched in air. The findings of this research reveal that the fatigue strength and Vickers hardness of the aluminum alloy AA2024 were improved after heat treatment. The improvement was 30% and 50% for fatigue stress and hardness, respectively. According to the results, the gradual chilling process leads to the creation of microscopic $MgZn_2$ segregations, whereas the rapid cooling process does not produce these types of segregations. In addition to this, it was discovered that the heat treatment operations of age hardening were able to eradicate these micro segregations and improve the mechanical properties of the AA 2024 Al alloy.

INTRODUCTION

Aluminum alloys are widely utilized in autos and a variety of other daily products. This group of metals is commonly employed due to their outstanding combination of light weight and high strength, as well as their good corrosion resistance and low cost [1].

While substituting light metals for heavy metals has been common practice in important aerospace structures for decades, it's now a key focus in other businesses, including those that make cars, trucks, military vehicles [2]. In applications where lighter weight and lower maintenance costs are required, aluminum alloys are taking the place of steel. Additionally, it is lightweight and has a good strength to weight ratio.

Structural materials must have good fatigue resistance. Some aluminum alloys are made stronger by precipitation hardening. Making aluminum more durable is one of the most significant strategies to do so [3, 4].

There are two types of aluminum alloys: wrought and cast compositions. Because each group's difference is based on the major property development procedure [5]. A further distinction for each group is based on the primary property development process.

Thermal treatment affects different alloys in different ways based on their solubility [6]. For example, precipitation, quench, and ageing and hardening are some of the processes that can be used. This alloy has been characterized as heat treatable for both wrought and casting alloy types [7, 8].

Mechanical reductions are used in a wide range of different-sized compositions to harden the work. In order to improve its properties, it is frequently used in conjunction with various annealing methods [9]. Heat-treatable alloys, on the other hand, benefit from the inclusion of alloying elements including copper, magnesium, zinc, manganese, and silicon.

These elements are more easily dissolved in aluminum as the temperature rises, which means they can be reinforced through heating [10,11]. The control of solution heat, the quenching of heat, and the ageing of heat are all

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examples of additional heat treatment procedures that are included among the many different heat treatment techniques. Combining solution heat therapy, quenching, and ageing results in the highest intensity and lowest ductility [12,13].

Alloy AA 2024 belongs to the 2xxx series of Al–Cu–Mg heat-treatable aluminum alloys and has replaced alloy 2017 as the predominant aircraft alloy [14]. Moreover, its widespread applications stem from the excellent combinations of specific strength and fatigue resistance of aluminum alloy AA 2024 in the form of sheet or plate [15,16].

We opted to investigate this aluminum alloy due to its significance in the aerospace sector and the fact that precipitation that occurs during solid solution treatment and ageing can significantly boost the alloy's strength. The aluminum alloy AA2024 was created using a stir casting process. In this in our work, the effect of heat treatment on the AA2024 aluminum metal matrix on fatigue properties was studied, microstructural, hardness, and x-ray. The fracture mechanisms were evaluated with the aid of scanning electron microscopy.

EXPERIMENTAL WORK

For this study aluminum alloys AA2024 were chosen. Aluminum samples were chemically analyzed at a temperature of 25°C in the Table 1, by Thermo ARL 34600, optical emission spectrometer.

TABLE 1. The chemical composition of AA2024 aluminum alloy

Si	Fe	Cu	Mn	Mg	Cr%	Ni	Ti	Zn	Al%
0.050	0.178	4.90	0.505	1.41	0.0082	0.0073	0.0260	0.239	92.7

Matrix material samples are preheated to 700 °C in a graphite crucible using an electric furnace to ensure the complete melting. After that, stirring is performed for about 4 minutes at 200 rpm, to achieve a homogenous mixing of the matrix, and the molten material was then poured into molds and preparation several specimens of the (AA2024) alloy as shown in Fig. 1.

(a) (b)

FIGURE 1. a) The Stir casting furnace, and b) Mold preparation

The samples have been classified into two main groups for heat treatments. For the first process, the samples were then solution treated at 500 °C for 3 hr. in an air circulated furnace and water quenched at room temperature and was followed by the aging process at 170 ºC for 3hr, and for the second process without the use of heat.

The samples were examined with the fatigue action of aluminum alloy AA2024-T3, which can be determined through laboratory testing. In this study, a HI-TECH alternate bending fatigue (HSM20). Testing equipment with a constant amplitude was utilized to assess the fatigue behavior of a cantilevered specimen under alternating or fluctuating bending loads. The samples' average values of fatigue have been carried out with the use of the fatigue scale. This test was done by 10 specimens for every case and evaluated the value to satisfy further accurate results. Figures 2 and 3 shows the samples.

$$\sigma_{\mathrm{a}} = \frac{32*P*L}{\pi*d^3} \tag{a}$$

For the fatigue machine test which we used:

$$\sigma_{\mathrm{a}} = \frac{32*P*L}{\pi*6} \tag{b}$$

Where P is the applied load in Newton's (N), L is the force arm in millimeters, and d is the minimum diameter of the specimen in millimeters. Tests have been done at room temperature, with a frequency of 50 Hz and a stress ratio of R = -1 for completely reversed loading and, R= 0 for tension release, R= 1 refers to static tensile loading.

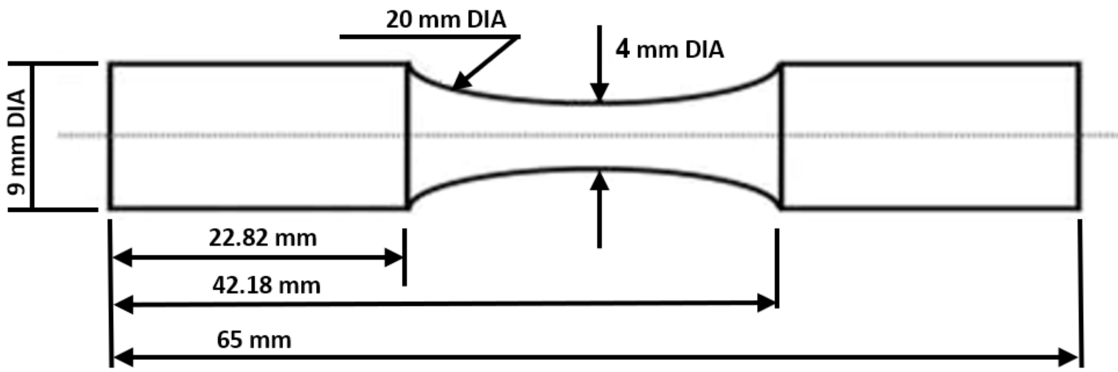

FIGURE 2. Schematic drawing of fatigue test sample (ASTM D638-10)

(a) (b)

FIGURE 3. Fatigue test samples; (a) before failure, and (b) after failure

The Vickers hardness test is performed by the Vickers tester. This test was conducted by polishing each test specimen with different wet silicon carbide papers, starting with (300) to (1500) mm. The samples were fired using a 294 N applied load and a 15 sec dwell time.

Average values of the hardness have been carried out with the use of the Vickers scale. This test was done to all specimens with different cases by three specimens for every case and evaluate the average value. These Scanning electron microscopy (SEM) is used to identify the microstructure of aluminum alloys. This test has been carried out at Russia's Samara technical university.

To calculate the distribution of the components and their quantities, the grinding is done with emery paper in six different degrees (180-300-600-800, 1500, and 2000). Polishing is done using a specific cloth and liquid alumina powder (1μm), after which the specimen is washed with water and alcohol.

The etching procedure was carried out using a suitable solvent (H_2O: HNO_3: HF = 92: 6: 2) to clarify the material's crystalline boundary, following which the specimen was dried, using transmission electron microscopy (JEOL JEM-2100) and STEM, the substructure of defects and the distribution of chemical elements were studied to figure out how the surfaces had been changed.

X-ray diffraction is a fast way to analyses something, the main thing it does is find phases. This analysis was done on samples with an x-ray diffract meter (model 6000 from Shimadzu). At 40 KV and 20 mA, the radiation's wavelength (λ) was 0.154 nm. The detector was moved from a 10-degree angle to a 90 degree angle. XRD analysis was performed, samara technical universities – Russia.

RESULT AND DISCUSSION

X- Ray Diffraction

The phase composition of AA 2024 samples treated with heat was investigated using X-ray diffraction. The initial sample is made up of a simple cubic lattice. Figure 4 depicts diffraction patterns found on AA 2024 samples before and after heat treatment.The similarity of the x-ray patterns in Fig. 4 shows that irradiating the AA 2024 with and without heat treatment does not result in a change in the phase composition of the material.

There is a shift of the AA 2024 diffraction lines after irradiation towards large angles, which indicates a possible decrease in the crystal lattice parameter of the alloy. Indeed, heat treatment causes a non-linear drop in the crystal lattice parameter. Irradiation, on the other hand, causes a decrease in the micro-distortions of the alloy crystal lattice and an increase in the size of the coherent scattering zones.

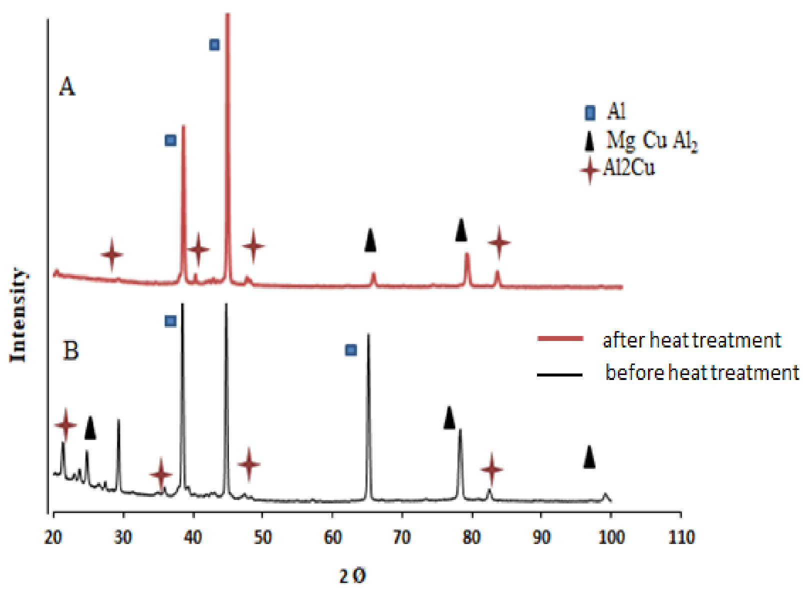

FIGURE 4. XRD patterns of the sample with and without heat treatment with the different energy densities

Fatigue Test

The Fig. 5 was conducted to evaluate the fatigue life for each case and to display the effect of the heat treatment on AA2024-T3. Also, the behavior regarding such test has been specified as fatigue stress with some numbers of cycles to failure curves (S–N curves), fatigue failure can be defined as a phenomenon result in fracture under repeated or fluctuating stresses which have been less in comparison to the material’s tensile strength.

The effect which is related to age hardening and solution heat treatments on fatigue characteristics regarding Al alloy is increased due to the increase in solution heat treatments time. Also, the solution heat treatment succeeded via age hardening (up to 170°C) increased the hardness and tensile strength of specimen that result in increasing the fatigue life. The improvement on fatigue performance was because of hardening phase were totally dissolved before quenching. Mg_2Si is participating to improve the fatigue properties [17, 18].

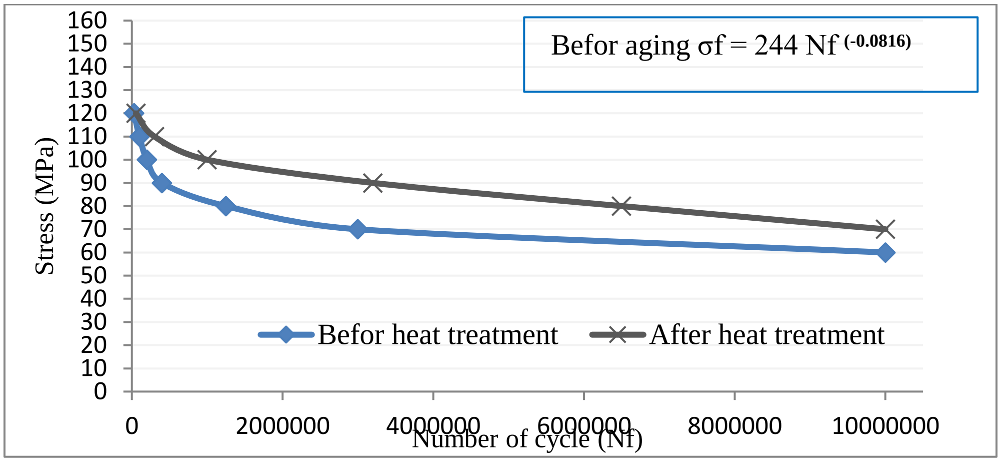

FIGURE 5. S-N curves for the AA2024 aluminum alloy

Figure 6 shows the nature of the fracture of the sample during the failure stage, where the fracture line can be observed across the grain boundaries significantly in the sample before thermal treatment, while there were small cracks in the heat-treated sample due to the deposition of Mg and Cu and the formation of $MgAl_2Cu$ and $MgAl_2$ compounds.

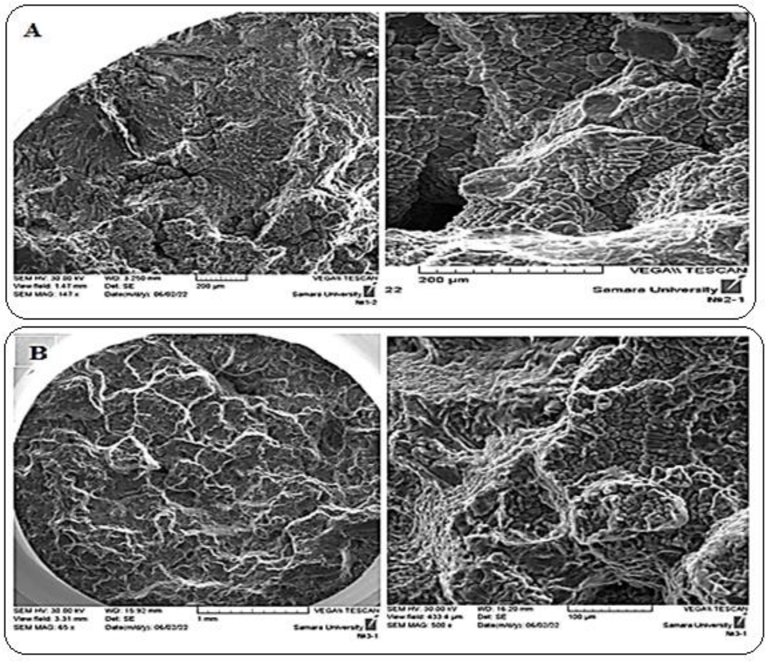

FIGURE 6. SEM images of the fracture surface; (A) before heat treatment, and (b) after heat treatment

Microstructure Results

The micro-structure following the process of aging can be specified as hardening of precipitation. Throughout aging duration, a few alloy 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 as shown in Fig. 7.

The microstructural examination indicated somewhere else, specifying that the solution treatment at a temperature of 500°C (for two hours) all the alloying elements have been dissolved in Al matrix.

In the case when solution treated samples are aged at various temperatures, the process of precipitation regarding secondary phase has been started on the basis of sequence.

In the presented work, it has been specified that the growth and initiation of the Mg_2Si were the function related to aging temperature. Also, it is indicated that at aging temperature of 170°C. as shown in Fig. 8.

The precipitates regarding secondary phase $AlMg_2Cu$ have been developed, the uniform distribution of these particles and less porosity led to improve mechanical and fatigue properties of $AlMg_2Cu$ in comparison with the as-cast matrix [19].

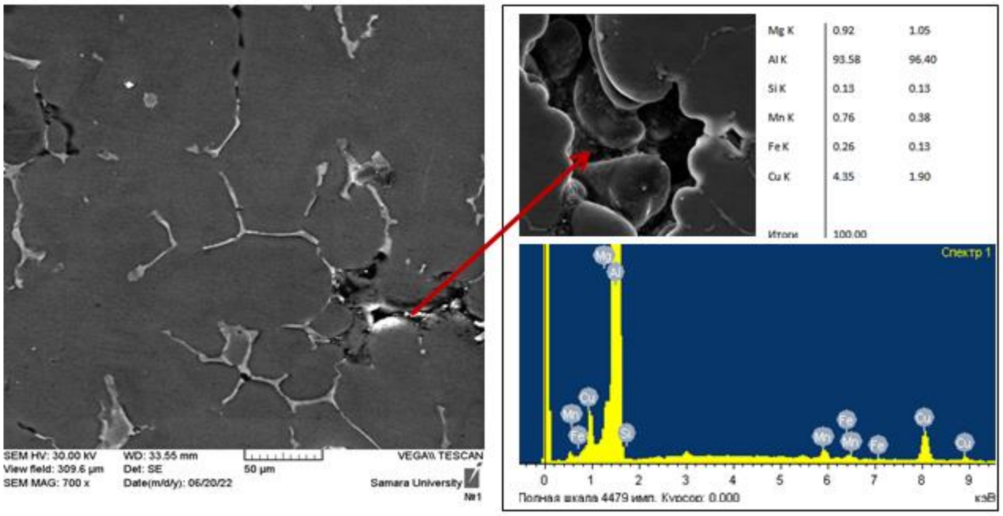

FIGURE 7. SEM micrograph and EDS of the Al alloy before heat treatment

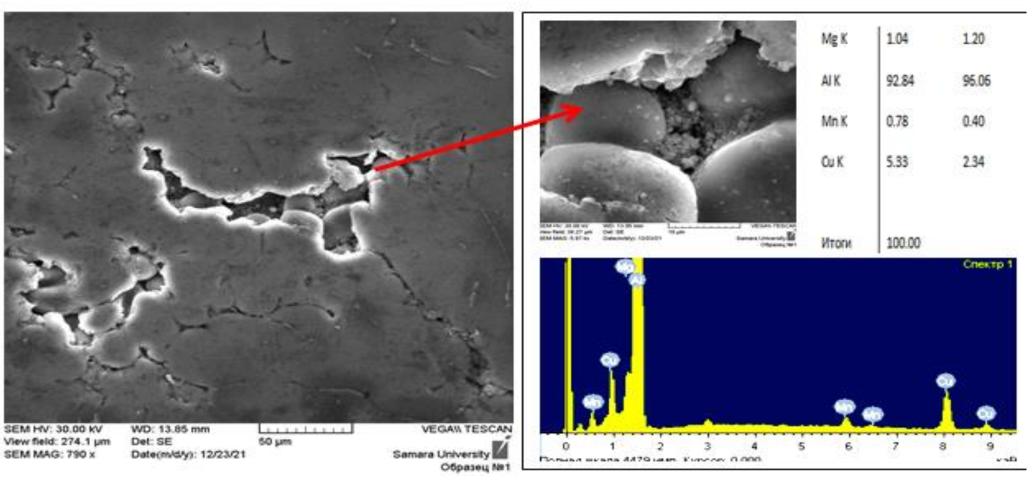

FIGURE 8. SEM micrograph and EDS of the Al alloy after heat treatment

Hardness Test

Figure 9 shows the test results, that increasing aging temperature will be increases the hardness of the specimen. The hardness of the composite has been further improved; it was 54 HRB after aging. Results showed that after the heat treatment process, hardness was improved significantly [19].

In addition, increasing the hardness is because of the secondary precipitation related to intermetallic phases. Throughout creating the intermediate phases, the lattice of the matrix will be strained, that will cause the value of the hardness to be increased.

The low aging temperature will cause the nucleation sites to be increased. The high hardness might be because of creating the well-distributed finer solute inter-metallic rich phases.

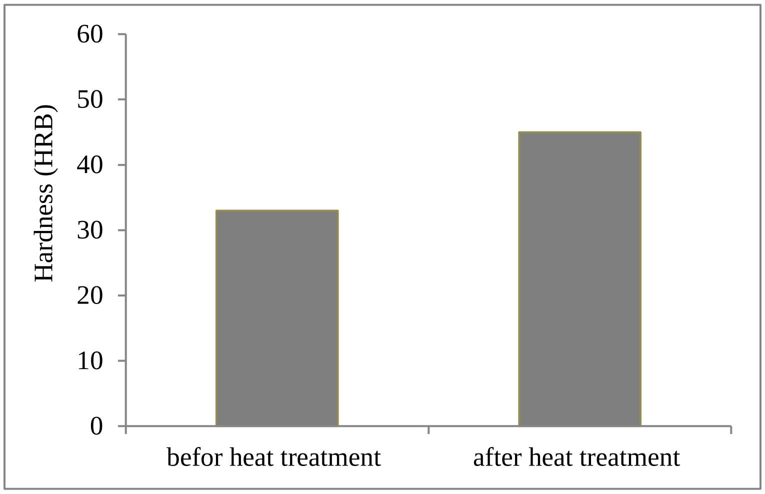

FIGURE 9. Effects of heat treatment on the hardness of AA2024

CONCLUSION

A stress ratio of -1 is used in this study to explore the influence of solution heat treatment on the mechanical properties of aluminium alloy AA2024-T3 and the fatigue life of this alloy. Fracture surfaces of samples subjected to low cycle fatigue testing revealed mostly precipitates and micro voids, whereas fracture surfaces of samples subjected to high cycle fatigue testing displayed surface crack initiation. The optical microscope and X-ray diffraction pattern confirms hardened samples by precipitation through quenching, precipitation, and hardening, resulting in the appearance of many phases with different distributions and ratios as (Al) and (Si) phases according to time and temperature of ageing, and the precipitated compound, (AlMg2Cu), is small soft particles, and the rate of precipitate nucleation increases when aged at 170 °C. The appearance of peaks is due to the creation of the Al_2Cu phase, which results from the solubility of Cu in a solid Al solution phase. As a result, it can be that heat treatment to the AA2024 alloy can significantly improve its physical qualities, allowing for a significant increase in the use of aluminum alloys in many industrial applications.

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