Corrosion behavior of aluminum alloys 2024 and 6061 in rainwater

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Abstract: In the present work the corrosion behavior of both aircraft aluminum alloy 2024 and 6061 were studied by cyclic polarization test in Rainwater, before and after heat treatment at room temperature (25 °C). The corrosion resistance of both alloys decreases after these alloys were solution treatment at a temperature of 495 °C for 2hr for AA2024 alloy and artificial aging at temperature (150, 200, 250, and 300 °C) for 1 and 2 hours this decreasing was from 1.767×10⁻³ to 1.031×10⁻³ mm/y, and for solution treatment at a temperature of 530 °C for 2hr for AA6061 alloy and artificial aging at temperature (150, 200, 250 and 300 °C) for 1 and 2 hours this decreasing 6.279×10⁻³ to 1.204×10⁻³ mm/y.

Keywords: aircraft aluminum alloy; solution treatment, cyclic polarization curve, corrosion resistance.

1. Introduction

Aluminum (Al) is a non-pyrophoric, non-ferromagnetic, and non-toxic substance. It has a density equal to 2.70g/cm³; which is nearly 1/3 of the density of the steel. Several Al alloys are of more adequate strength/weight ratio values. Al is of adequate formability and malleability, high thermal and electrical conductivity, and high corrosion resistance and it is nonsparking. The tensile strength of the pure Al is approximately 90MPa and may be heat treated and alloyed to increase its strength to about 690MPa [1,2]. Those useful characteristics made the Al a significant material of engineering, and its utilization has considerably changed numerous engineering equipment and machines upon which life applications are dependent. Al isn't available purely in nature; it is instead discovered in the oxide form (Al₂O₃), which is also referred to as the alumina. Al is available in wrought and cast forms for a variety of applications. The principal elements of alloying specify the designation system of the cast and wrought aluminum [3]. Al is a greatly important consumer metal. Al and Al's alloys are utilized for beverage cans, foil, food processing, and cooking instruments, electrical and architectural applications, as well as structures for aircraft, boats, and additional transport vehicles. As a result of a naturally available tenacious surface oxide film (Al₂O₃), Cu, Si, Mg, Zn, Ni, and Mn are principal elements for alloying, which are added with the Al for increasing its strength in pure form. There are two Al alloy types considered, such as the wrought and cast aluminum alloys [4]. Al alloys may be categorized as heat-treatable (HT) and non-heat-treatable (NHT), based upon whether they are undergoing precipitation (i.e. age) hardening or not [5]. Usually, the Al alloys are categorized into three groups, namely: casting alloys, wrought NHT alloys, and wrought HT alloys. Each alloy incorporates a
particular quantity of alloying factors that provide the base aluminum with sure beneficial qualities. Numerous Al alloys ensure remarkable corrosion resistance in a wide range of chemical and atmospheric environments. Its resistance to corrosions and oxidations is of special importance in transport and architectural applications. With yield strength value which is equivalent to the mild steel yield strength [6, 7]. In AA 2024 alloy, those elemental amounts are 4.4% Cu, 1.5% Mg, and 0.6% Mn, nominally. This breakdown explains why 2024 aluminum is thought for its excessive strength due to the fact copper, magnesium, and manganese substantially raise the power of aluminum alloys. This strength comes at a disadvantage, however; the excessive percent of copper in 2024 aluminum substantially reduces its resistance to corrosion. 2024 aluminum is machined very without difficulty and has good workability, permitting it to be each severed and extruded if want be. AA2024 alloy is especially desirable and is used to make Aircraft fuselage, truck suspension parts, structural elements, truck, and plane wheels, and wing skins. Type AA6061 alloy is of the 6xxx aluminum alloys. Aluminum alloy 6061 is heat-treatable, easily formed, weld-able, and is excellent for corrosion resistance [8]. The 6061 aluminum alloy because easily welded and manipulated, and is very light and fairly strong, making it ideal for the fuselage, and wings are common in light aircraft, especially homemade ones. [9]. the primary alloying element in the precipitation strengthened Al 2024 alloy is Copper from 3.8 to 4.9 wt%. The precipitate particle in this alloy is Al2Cu because of a large amount of copper, these additions have a more noble potential than those in Al 6061[10].

2. Experimental procedure:

2.1 Aluminum alloys

The materials used in the present work are aircraft aluminum alloys grade (2024 and 6061). The chemical compositions of these alloys were analyzed by using spectromax and the results are listed in “Table 1” the results were match the standard v. This study was conducted at Rain Water. The method of water jet was used to cut the plate to fit sample holder dimensions the dimension and design of the sample holder are listed in “figure 1”. The specimens sample are disc shape with (Ø25 X 2 mm).

| Alloy | Cr% | Fe% | Ti% | Mn% | Si% | Mg% | Cu% | Ni% | Zn% | Pb% | Al% |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2024  | 0.0082 | 0.17 | 0.0240 | 0.515 | 0.0501 | 1.46 | 4.70 | 0.009 | 0.20 | 0.00 | 92.8 |
| 6061  | 0.121 | 0.53 | 0.132 | 0.124 | 0.596 | 0.990 | 0.257 | 0.009 | 0.02 | 0.01 | 97.2 |

Figure 1. Design and dimensions of the specimen holder. (All dimensions in mm)
2.2 Water media

In this study, Rain Water was selected as a corrosive medium to study the influence of solution treatment on the corrosion and hardness of both 2024 and 6061 aircraft aluminum alloys. The work was done at room temperature (25°C). With a salinity of (37.0 mg/L). The chemical analysis of rainwater media is listed in “Table 2”.

Table 2. Chemical analysis of Rain Water

| Type of analysis | percentage |
|------------------|------------|
| PH               | 5.7        |
| EC (µs/Cm)       | 65.03      |
| T.D.S. (mg/l)    | 37.0       |
| Ca²⁺ (mg/l)      | 4          |
| Mg²⁺ (mg/l)      | 4.8        |
| CaCO₃ (mg/l)     | 30         |
| Cl⁻ (mg/l)       | 1.15       |
| HCO₃⁻ (mg/l)     | 12.75      |
| SO₄²⁻ (mg/l)     | 2.83       |
| NO₃⁻ (mg/l)      | 0.88       |
| NO₂⁻ (mg/l)      | 0.003      |

2.3 Heat treatment

In this study, both 2024 and 6061 aircraft aluminum alloys were treating by solution treatment to study the impact of heat treatment on the corrosion resistance and hardness of these alloys. For solution treatment, the samples were placed in the lab furnace at a temperature of AA6061 alloy solution treated at 530 °C for 2hr. And AA2024 alloy solution treated at 495 °C for 2hr and then quenched in distilled water. Aging treatments are done for both alloys at temperatures (150, 200, 250, and 300 °C) for 1 and 2 hours.

2.4 Brinell hardness test

To investigate the effect of solution treatment and artificial aging heat treatment on the hardness of AA2024 and AA6061, a hardness test was conducted using the Brinell hardness unit.

2.5 Corrosion test

Polarization cycle test had been utilized to study the corrosion behavior of 2024 and 6061 aircraft aluminum alloys before and after heat treatment. Before these tests, all samples were grinding using emery papers with different grades (300, 500, 1000, and 2000) and then polished. Samples with 0.78 mm² surface area were exposed to rainwater media before and after solution treatment. The experimental work was carried out in three-electrode corrosion cell, 2024 and 6061 aluminum alloys are working electrode, graphite counter electrode, and calomel reference electrode.
3. Results and discussion:

3.1 Effect of solution treatment on BHN of 2024 and 6061 aircraft aluminum alloys

Figure 2 and figure 3 are showed the influence of heat treatment on of both aging temperature and Brinell hardness for 1h and 2h for AA2024 and AA6061.

In figure 2-a and figure 3-a are showed the relation between aging temperature and Brinell hardness for 1hr for AA2024 and AA6061 alloys from this figure the Brinell hardness increased to a maximum value(102.78) and then lower to a minimum value(100.37) for AA2024, and the Brinell hardness increased to a maximum value(78.52) and then lower to a minimum value(76.67) for AA6061, which means that at the beginning the deposition was of the identical type (coherent), and this does not change much of the microscopic composition, i.e. it appears as in the case before the heat treatment and the deposition increases and appears in the form of clear minutes when it reaches the maximum value (semi-coherent or incoherent) and then decreases again because the sediment grains grow larger their size and hardness decreases.

In figure 2-b and figure 3-b are showed the relation between aging temperature and Brinell hardness for 2hr for AA2024 and AA6061 alloys from this figure the Brinell hardness increased to a maximum value(105.5) and then lower to a minimum value(99.64) for AA2024 and the Brinell hardness increased to a maximum value(81.45) and then lower to a minimum value(77.13) for AA6061, which means that at the beginning the deposition was of the identical type (coherent), and this does not change much of the microscopic composition, i.e. it appears as in the case before the heat treatment and the deposition increases and appears in the form of clear minutes when it reaches the maximum value (semi-coherent or incoherent) and then decreases again because the sediment grains grow larger their size and hardness decreases.

![Figure 2](image1.png)

![Figure 3](image2.png)

Figure 2 showed the relation between aging temperature and Brinell hardness for a) 1h and b) 2h for AA2024.
3.2 Effect of solution treatment on the corrosion resistance of 2024 and 6061 aircraft aluminum alloys

“Figure 4, figure 5, figure 6, figure 7, figure 8 and figure 9” represents the typical polarization curve of both 2024 and 6061 aircraft aluminum alloys in Rainwater at a temperature of 25°C for as-received samples. AA6061 alloy solution treated at 530 °C for 2hr. And AA2024 alloy solution treated at 495 °C for 2hr and both alloys are artificial aging at temperature (150, 200, 250 and 300 °C) for (1 and 2) hrs. The potential of corrosion (E_{corr}) and corrosion rate of these alloys are listed in "Table 3" and in figure (10) and figure (11). From these figures and table, it is clear that 6061 have higher corrosion resistance than 2024; this difference in the corrosion resistance of these alloys is the result of the difference in the characteristics of precipitate particles of these alloys [11]. The aluminum alloys that containing copper are more susceptible to pitting and have lower resistance to general corrosion than those without copper. The localized corrosion phenomena show because the electrochemical activity associated with these IMP is different from the matrix and weakens the passive layer [10].

Figure (4), figure (5), and figure (6) are showing the Potentiodynamic polarization curves for AA2024 before and after heat treatment in rainwater from these figures showed the 2024 alloy is more prone to pitting corrosion and there is no re-passivation potential (E_{rep}), the rainwater compounds contain halogens that accelerate pitting corrosion.

Figure (7) and figure (8) are showing the Potentiodynamic polarization curves for AA6061 before and after heat treatment in rainwater from these figures showed the 6061 is less affected by pitting corrosion and gets re-passivation potential (E_{rep}), which means have high resistance to corrosion conditions. Except for the alloy 6061,150 °C, 1h is prone to pitting corrosion and there is no re-passivation potential (E_{rep}).

Figure (9) is showing the Potentiodynamic polarization curves for AA6061 with aging temperatures (150, 200, 250, and 300 °C) for 2 hr. These alloys are more sensitive to pitting corrosion at rainwater and no re-passivation potential (E_{rep}) because of the precipitate compounds that accelerate pitting corrosion.
Figure (4) Potentiodynamic polarization curves for AA2024 as received in rainwater

Figure (5) Potentiodynamic polarization curves for AA2024 after aging at temperatures (150, 200, 250 and 300 °C) for 1 hr in rainwater
Figure (6) Potentiodynamic polarization curves for AA2024 after aging at temperatures (150, 200, 250 and 300°C) for 2 hr in rainwater

Figure (7) Potentiodynamic polarization curves for AA6061 as received in rainwater
Figure (8) Potentiodynamic polarization curves for AA6061 after aging at temperatures (150, 200, 250, and 300°C) for 1 hr in rainwater

Figure (9) Potentiodynamic polarization curves for AA6061 after aging at temperatures (150, 200, 250, and 300°C) for 2 hr in rainwater.

Table 3. Corrosion rate and corrosion potential obtained from polarization curve of 2024 and 6061 alloys in rainwater
| Alloy | Temperature (°C) | $E_{corr}$ (mV) | Corrosion rate (mmpy) | $I_{corr}$ (µA) | $E_{rep}$ (V) | Epits (V) |
|-------|------------------|-----------------|------------------------|-----------------|--------------|-----------|
| 2024  | 25               | -0.570          | 1.767                  | 1.990           | -0.443       |           |
| 2024  | 150,1h           | -0.626          | 1.887                  | 2.130           | -0.449       |           |
| 2024  | 150,2h           | -0.518          | 2.392                  | 2.700           | -0.526       |           |
| 2024  | 200,1h           | -0.423          | 1.610                  | 1.820           | -0.591       |           |
| 2024  | 200,2h           | -0.636          | 1.244                  | 1.400           | -0.608       |           |
| 2024  | 250,1h           | -0.655          | 1.455                  | 1.640           | -0.575       |           |
| 2024  | 250,2h           | -0.655          | 2.43                   | 2.74            | -0.548       |           |
| 2024  | 300,1h           | -0.567          | 1.031                  | 1.160           | -0.476       |           |
| 2024  | 300,2h           | -0.525          | 1.969                  | 2.220           | -0.582       |           |
| 6061  | 25               | -0.720          | 6.279                  | 7.080           | -0.710       | -0.686    |
| 6061  | 150,1h           | -0.949          | 1.295                  | 1.460           | -0.591       |           |
| 6061  | 150,2h           | -0.725          | 1.462                  | 1.650           | -0.666       |           |
| 6061  | 200,1h           | -0.843          | 1.204                  | 1.360           | -0.760       | -0.737    |
| 6061  | 200,2h           | -0.642          | 11.16                  | 12.60           | -0.587       |           |
| 6061  | 250,1h           | -0.944          | 1.223                  | 1.380           | -0.749       | -0.855    |
| 6061  | 250,2h           | -0.612          | 10.55                  | 11.90           | -0.547       |           |
| 6061  | 300,1h           | -0.771          | 24.62                  | 27.80           | -0.797       | -0.697    |
| 6061  | 300,2h           | -0.716          | 3.490                  | 3.940           | -0.662       |           |
4. Conclusions

1- The Brinell hardness of AA6061 alloy solution treated at 530 °C for 2hr. And AA2024 alloy solution treated at 495 °C for 2hr and aging at (150,200,250 and 300 °C) increased to a maximum value and then decreased.

2- The corrosion resistance of 6061 and 2024 alloys decreases after heat treatment, which indicates that this heat treatment although improving hardness, but led to decrease corrosion resistance.

3- 6061 alloy has better corrosion resistance than 2024 alloy in rainwater.

4- Alloy 6061 gets re-passivation potential (E_{corr}) in cases 6061 as received and solution treated and aged at, 200, 250, and 300 °C for 1hr. which means that it is more resistant to corrosive conditions and less affected by pitting corrosion.
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