

CORROSION OF ALUMINIUM ALLOY EN AW-2024 IN  
SELECTED ENVIRONMENTS

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Received on August 28, 2020

Presented by Ch. Roumenin, Member of BAS, on February 24, 2022

**Abstract**

Aluminium alloy 2024 is widely used in heavy industry. The aim of this study was to report on the corrosion behaviour of this alloy when exposed to selected environments of different acids and salts containing chloride, nitrate and sulphate ions and measure the corrosion rate by using the weight loss method at room temperature. The results obtained indicate that, under the conditions employed in the present work, the corrosion rate of this alloy depends on the specific ions present in the solution. Gravimetric analysis confirmed that with varying the exposure periods the weight loss of the alloy decreases and the corrosion rate can be described as an initial steep rise followed by subsequent fall.

**Key words:** aluminium alloy EN AW-2024, corrosion resistance

**1. Introduction.** Aluminium alloy 2024 is one of the highest-strength *2xxx* alloys that contain copper as the primary alloying element which reduces their corrosion resistance [1]. This alloy is widely used in many structural aircraft applications, screw machine products, automotive parts, cylinders and pistons [2]. Due to its widespread industrial applications in natural or technological environments, it frequently comes into contact with different electrolytes: acids, alkalis and salts and the interaction with them leads to its progressive corrosion.

Corrosion is the spontaneous destructive attack on a metal by a chemical or an electrochemical reaction with its environment [3,4] which leads to changes in

its properties and can often cause damage to the metal, its environment or the technical system [5].

Aluminum shows good corrosion resistance when exposed to the atmosphere and many aqueous environments due to the formation of a resistant oxide layer [6-8]. The protective oxide film which forms in water and atmosphere at ambient temperature is amorphous and only a few nanometers thick.

When aluminium and its alloys are exposed to environments that contain aggressive ions, such as chloride, these ions activate the corrosion process, impair their stability and damage the oxide layer [9].

The corrosion study of aluminium and aluminium alloys is of immense technological importance due to their growing industrial application. So far no systematic study of the corrosion behaviour of aluminium alloy 2024 in various electrolytes has been found in scientific literature. Most of the reported studies deal with some aspects of corrosion behaviour of aluminium alloy 2024 in contact with NaCl solutions [10-12].

The objective of this research was to investigate the corrosion behaviour of aluminium alloy EN AW-2024 in selected environments of different solutions of acids (1 M HCl, HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>) and salts (1 M NaCl, NaNO<sub>3</sub>, Na<sub>2</sub>SO<sub>4</sub>) and to determine the corrosion rate by using weight loss method and a digital microscope.

**2. Experimental. 2.1. Materials.** The tested material was 2024-T3 aluminium alloy (EN AW-2024) with a density of 2.78 g/cm<sup>3</sup> and with the following chemical composition (wt %): Si 0.5; Fe 0.5; Cu 3.8-4.9; Mn 0.3-0.9; Mg 1.2-1.8; Cr 0.25; Zn ≤ 0.30; Ti ≤ 0.15 and balance Al. The surface area of the cylindrical samples exposed to the electrolytes was 8.54 cm<sup>2</sup>. Prior to each experiment, the aluminum electrodes were mechanically polished with emery paper, washed in detergent for 5 min and then rinsed with distilled water and dried.

**2.2. Test environment.** 1 M solutions of HCl, HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, NaCl, NaNO<sub>3</sub> and Na<sub>2</sub>SO<sub>4</sub> were used throughout the experiment.

**2.3. Weight loss measurements.** The effects of corrosion on the alloy were evaluated by using the weight loss method at room temperature (≈ 25 °C). The experimental samples were weighed with an analytical balance Acculab ATILON, accurate to ± 0.0001g, and were then placed in 100 ml of a test solution of 1 M HCl at room temperature. The system was lightly covered with parafilm. The weight loss of each sample was first determined after 4 h of immersion and after that in every 192 h of exposure. The maximum period of exposure was 768 h. After immersion time, the samples were taken out from the solution and cleaned of corrosion products. Then the samples were rinsed with tap water, dried under a stream of air, and weighed. The same process was repeated with different 1 M solutions of HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, NaCl, NaNO<sub>3</sub> and Na<sub>2</sub>SO<sub>4</sub>. For each of the immersion periods, the corrosion rate (*Km*) of the alloy was calculated by using the following equation:

$$(1) \quad Km = \frac{m_1 - m_2}{S.t},$$

where  $m_1$  is the weight of the sample, g;  $m_2$  is the weight of the sample after the corrosion test, g;  $S$  is the area of the sample,  $m^2$  and  $t$  is the test time, h.

**2.4. Surface analysis.** The structures of the corroded surface of EN AW-2024 was investigated by digital microscope (Digi Micro Scope 2.0M Pixels).

**3. Results and discussion.** The obtained corrosion rate data of EN AW-2024 are given in Table 1 and Table 2, respectively.

Observation of the results shows an initial increase in the corrosion rate of aluminium alloy EN AW-2024 with respect to time. During the first 4 h of immersion in the test solutions of acids and salts the values of  $Km$  reach their maximum level, which is followed by a sudden decrease in the corrosion rate of the aluminium alloy. After 192 h of immersion the corrosion rate stayed relatively constant till the 768th h of exposure in the test solutions.

The behaviour of this process can be attributed to the formation of the protective layer on the alloy surface which occurs gradually resulting in increase in corrosion rate with respect to time. The corrosion rate decreases with the formation of a protective oxide layer. When exposed to an environment with aggressive ions, this oxide layer breaks down at some places, causing corrosion on the aluminium surface [14]. The corrosion rate of aluminium alloys depends on the specific ions present in the environment.

The solutions of most inorganic salts cause insignificant corrosion of aluminum alloys at room temperature [8]. The experimental samples showed better corrosion

T a b l e 1

Corrosion rate of aluminium alloy EN AW-2024 in 1 M salt solutions

Solution,	4 h	192 h	384 h	576 h	768 h
1 M	$Km, g/m^2.h$	$Km, g/m^2.h$	$Km, g/m^2.h$	$Km, g/m^2.h$	$Km, g/m^2.h$
NaCl	0.180	0.080	0.020	0.019	0.018
NaNO <sub>3</sub>	0.070	0.003	0.002	0.013	0.011
Na <sub>2</sub> SO <sub>4</sub>	0.050	0.002	0.001	0.010	0.010

T a b l e 2

Corrosion rate of aluminium alloy EN AW-2024 in 1 M acid solutions

Solution,	4 h	192 h	384 h	576 h	768 h
1 M	$Km, g/m^2.h$	$Km, g/m^2.h$	$Km, g/m^2.h$	$Km, g/m^2.h$	$Km, g/m^2.h$
HCl	7.75	1.72	1.20	0.85	0.66
HNO <sub>3</sub>	5.24	1.10	0.81	0.64	0.61
H <sub>2</sub> SO <sub>4</sub>	2.34	0.90	0.75	0.63	0.57

resistance in salt solutions containing sulphate ( $\text{Na}_2\text{SO}_4$ ) and nitrate ( $\text{NaNO}_3$ ) ions even after 768 h of immersion. In the salt solutions containing chloride ions ( $\text{NaCl}$ ) the corrosion rate was higher and there was an increasing trend of weight loss (Table 1, 2).

This aluminium alloy is most resistant to sulphuric acid and nitric acid solutions but hydrochloric acid solutions are definitely corrosive to it. In acid solutions, chlorides greatly stimulate attack on the protective layer [8] and the samples showed very high corrosion rate. Furthermore, as shown in Table 2, the samples immersed in 1 M solutions of HCl have the highest corrosion rate of about  $7.75 \text{ g/m}^2\cdot\text{h}$  after 4 h of exposure. This is followed by the aluminium alloy sample immersed in 1 M solution of  $\text{HNO}_3$  with a corrosion rate of  $5.24 \text{ g/m}^2\cdot\text{h}$  and  $\text{H}_2\text{SO}_4$  with a corrosion rate of  $2.34 \text{ g/m}^2\cdot\text{h}$ . These findings primarily suggested that 1 M solutions of HCl can be an aggressive medium to induce corrosion in the aluminium alloy. Alloy EN AW-2024 is less susceptible to corrosion attack when immersed in a  $\text{H}_2\text{SO}_4$  solution as compared to  $\text{HNO}_3$  even after 768 h of immersion.

Comparison of the corrosion rates of EN AW-2024 from gravimetric analysis proved that the solutions of acids and salts containing sulphate and nitrate ions are found to be less aggressive to the alloy, which showed relatively lower corrosion rates than those containing chloride ions.

The nitrate ions present in these acids and salts caused a moderate weight loss. The sulphate ions in the solutions appeared to impart passivity to the alloy and reduce corrosion rates. The presence of sulphate ions in the environment is likely to produce aluminium sulphates which are less soluble than the other aluminium salts formed in the presence of nitrate and chloride ions and may effectively retard the surface degradation [15]. The highest corrosion rate in the presence of chloride ions is indicative of the high penetrating power of these aggressive ions into the barrier oxide layer [16].

The surface analysis carried out to investigate the aluminium alloy surface and describes the changes that will happen. In general, the surface morphology of aluminum alloy EN AW-2024 in aggressive media has attracted considerable attentions due to its importance in corrosion. The rate of attack growth is dependent mainly on the chemical composition of the material, the microstructure of the material, temperature, the specific ions present in the solution, and the state of stress [17].

Figure 1 presents the micrographs on the surface of aluminium alloy EN AW-2024 at conditions used in the present work.

The surface morphology of the Al samples was examined after 768 h of immersion in environments of different solutions of acids and salts. Pits can be seen on the surface of specimens corroded in the solutions of salts (Fig. 1a) and acids containing chloride ions (Fig. 1d) indicating that the aluminum alloy undergoes pitting corrosion in these environments. Pitting is more extensive and localized in

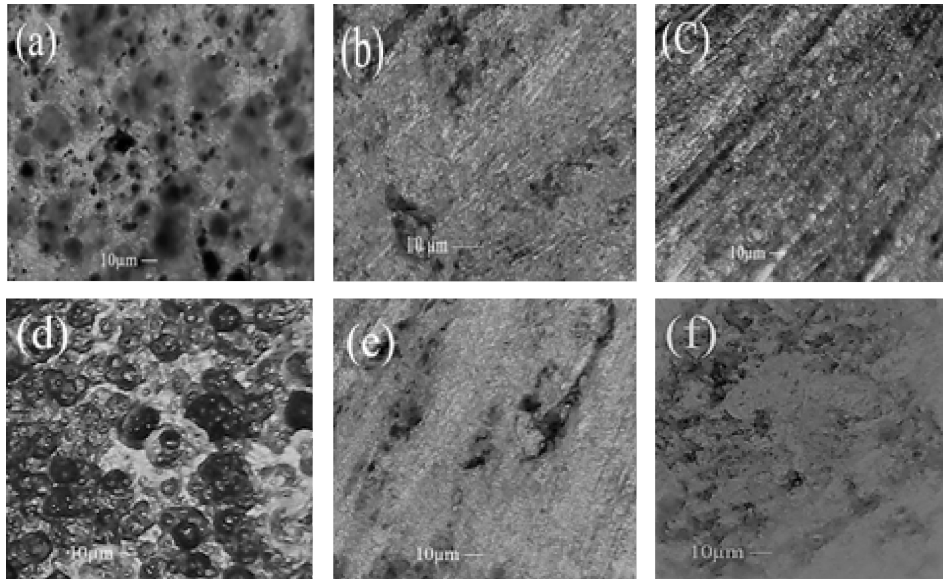


Fig. 1. Micrography of EN AW-2024 surface immersed in 1 M (a) NaCl, (b) NaNO<sub>3</sub>, (c) Na<sub>2</sub>SO<sub>4</sub>, (d) HCl, (e) HNO<sub>3</sub>, and (f) H<sub>2</sub>SO<sub>4</sub> from digital microscope

the solutions containing chloride ions than those containing sulphate and nitrate ions. Under extended immersion period of 768 h in medium containing nitrate ions, pits on the surfaces were found to be elongated and grown in size as shown in a micrograph (Fig. 1b, e). The micrographs of the samples immersed in 1 M solutions of salts (Fig. 1c) and acids (Fig. 1f) containing sulphate ion showing very few pits on the surfaces as compared to that in the chloride medium.

**4. Conclusions.** From the findings of the investigation of the corrosion behaviour of aluminium alloy EN AW-2024 can be concluded that the corrosion resistance of this alloy depends on the specific ions present in the solution. This alloy is less susceptible to corrosion attack in acid and salt environments containing sulphate and nitrate ions than to solutions containing chloride ions. Under the conditions of exposure in the present study, the corrosion rate reaches its maximum level during the first hours of immersion. The micrographs of the samples immersed in solutions of acids and salts containing nitrate and sulphate ions show very few pits on the surfaces as compared to that in the chloride medium.

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