Effect of Environmental Factors on the Corrosion of 2024T3 Aluminium Alloy

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Keywords: 2024-T3 aluminum alloy, environmental factor, corrosion, alternate immersion

Abstract

Effects of environmental factors such as temperature, humidity, Cl^- and SO_4^{2-} on the corrosion of 2024T3 aluminum alloy were studied by alternate immersion tests. Since localized corrosion is a stochastic phenomenon, a statistical method was also used to process the data. The results indicate that pitting corrosion occurs after a short alternate immersion period and the maximum corrosion depth is consistent with the Gumbel distribution. Cl^-, SO_4^{2-} and temperature are the main factors affecting the corrosion of 2024T3 aluminum alloy while humidity has less effect on it. With the relative humidity increasing from 55% to 95%, the change of maximum corrosion depth is small. Cl^- and SO_4^{2-} have inverse influence on the corrosion of 2024T3 aluminum alloy when their concentrations vary from 0.5% to 5%. With an increase in the concentration of Cl^-, the corrosion becomes severe and SO_4^{2-} acts inversely.

1. Introduction

2024T3 aluminum alloy has been widely used as structural material of the aircraft. But it is susceptible to localized corrosion such as pitting. Generally, temperature, humidity and salinity are the main factors taken into considerations during the accelerated tests. But it was found that humidity had little effect on the corrosion of major structural materials on the commissioned naval aircrafts [1]. So in this article, alternate immersion tests were used to simulate the oceanic climate environment to study the influences of temperature, humidity, Cl^- and SO_4^{2-} on the corrosion of 2024T3 aluminum alloy. A statistical method was used in the data processing to get more confident results.

2. Experimental Methods

The material used in this work was 2024T3 aluminum alloy and its chemical composition (wt%) was shown as follows: 0.25 Zn,1.2~1.8 Mg,3.8~4.9 Cu, 0.50 Fe,0.50 Si,0.30~0.90 Mn,0.10 Cr and balance Al.

All specimens were prepared by cutting the rolled 2024T3 aluminum alloy into 48mm×20mm×2mm pieces and were cleaned with acetone.

They were subjected to alternate immersion test for 6 days. The process of the test was as follows: the specimens were immersed in test solution for 3 hours, then exposed in air for 9 hours, and repeated these steps till the test finished.

Different values of temperature, humidity, concentration of Cl^- and SO_4^{2-} were selected as Table1. According to the orthogonal experiment design of four factors and three levels (L_9（3^4））[2], there were nine experiments of different corrosion condition as Table 2.

Table 1: The factors and levels of L_9（3^4）orthogonal design

Factor	Level		
	1	2	3
Temperature (°C)	25	50	75
Relative Humidity (%)	55	75	95
Concentration of Cl^- (wt%)	5	3.5	0.5
Concentration of SO_4^{2-} (wt%)	3.5	0.5	5

Table 2: The experiments scheme of L_9（3^4）orthogonal design

Number	Temperature（°C）	Relative Humidity (%)	NaCl(wt%)	Na_2SO_4(wt%)
1	25	55	0.5	0.5
2	50	55	5	5
3	75	55	3.5	3.5
4	25	75	3.5	5
5	50	75	0.5	3.5
6	75	75	5	0.5
7	25	95	5	3.5
8	50	95	3.5	0.5
9	75	95	3.5	5

The maximum corrosion depth was used to evaluate the severity of corrosion in this article because it is most suitable to show the degree of localized corrosion such as pitting. But it is difficult to obtain exactly because the occurrence and distribution of localized corrosion are random [3,4]. So after tests listed in Table2, three parallel specimens were divided into eight parts as Figure1.The maximum corrosion depth was measured from profiles of the eight parts by optical microscope. Thus sixty corrosion depths of twenty-four samples can be obtained. Then the most probable maximum corrosion depth in different corrosion condition can be calculated based on statistical analysis of the data [5].

1	**2**	**3**	**4**
5	**6**	**7**	**8**

Figure 1: Schematic sketch of the divided specimen.

3. Results and Discussion

3.1 Corrosion Appearance of 2024T3 Aluminum Alloy Alternate Immersed for 6 Days

Pitting corrosion took place on the surfaces of 2024T3 aluminum alloy after they were tested for 6 days. A representative corrosion appearance of the specimen was shown in Figure 2. Some black corrosion spots and white corrosion products were found on the surfaces of all specimens.

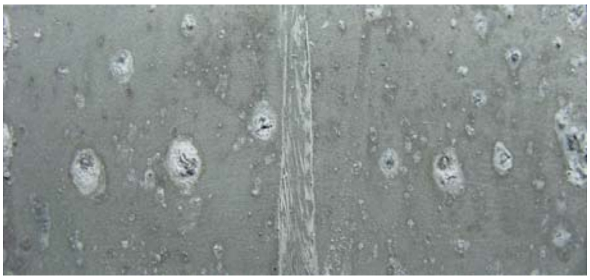


Figure 2: Corrosion appearance of a 2024T3 specimen. (T=25°C ,RH=55%,[Cl^-]=5% [SO_4^{2-}]=5%)

3.2 Statistical Analysis of the Maximum Corrosion Depth

The previous study [1,5,6] has showed that corrosion depth is consistent with the Gumbel distribution if pitting occurs, but it corresponds to not only Gumbel distribution but also normal distribution when exfoliation occurs for high strength aluminum alloy. The statistical analysis was performed for the data of corrosion depth obtained from the parallel measurements. According to the statistical theory, the character of normal distribution for parameter d is that the relation between accumulating probability $P(D \le d)$ and d must be linear, where D is random variable of d, $P = i / (N+1)$, N is the total number of the measurement value for d; i = 1,2,3,⋯⋯,N. If d corresponds to Gumbel distribution, the relation between $\ln(\ln 1/P(D \le d))$ and d must also be linear [7].

The testing of Gumbel distribution and Normal distribution for the corrosion depth was shown in Figure 3. The high relative coefficient(R) of Fig 3(a) reveals that d is fit with Gumbel distribution because the R (0.96 ～0.99)is higher than the R(0.75~0.78) of normal distribution.

The expression of the fitted regression line based on the Gumbel distribution by the least square method can be described as equation 1.

$$\ln(\ln 1/P(D \le d_m)) = A + B \cdot d_m, \tag{1}$$

where d_m is maximum corrosion depth, A and B are regressing constant. The values of maximum corrosion depth under different condition listed in Table 2 can be obtained by equation 1， When the corresponding accumulating probability P=0.95, the results were listed in Table 3.

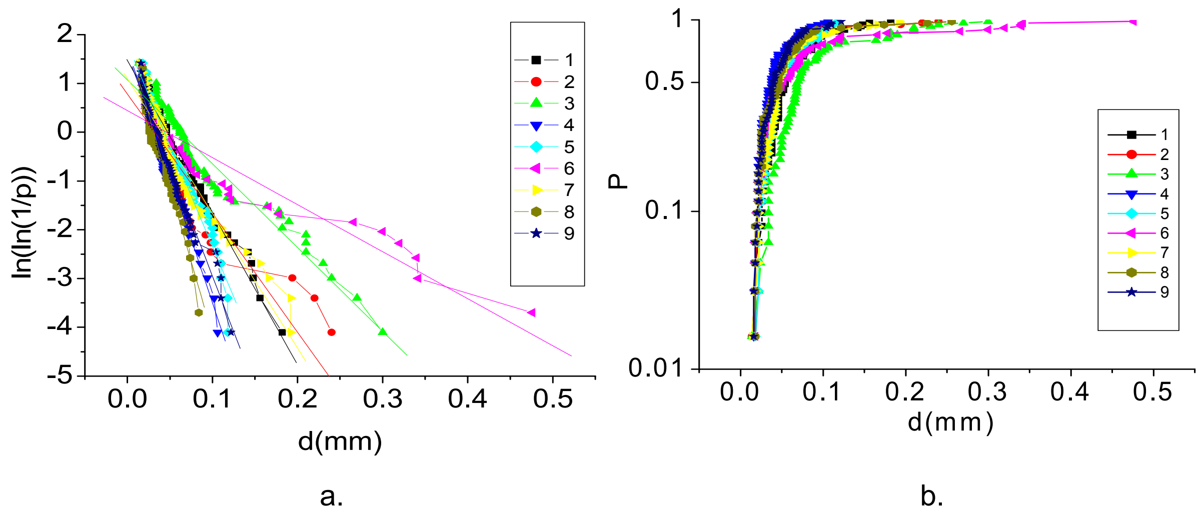


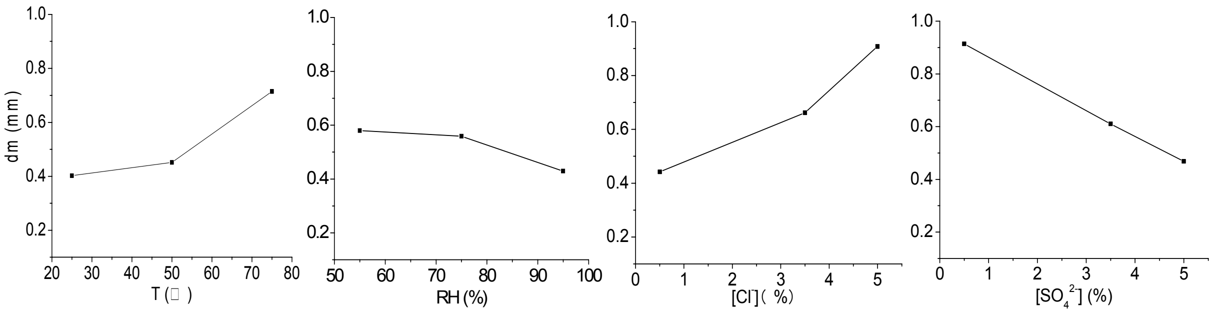
Figure 3: Testing of statistical distribution for d. (a) Gumbel distribution,(b) normal distribution.

Table 3: Results and analysis of the orthogonal experiment

Number	Temperature（□）	Relative Humidity（%）	NaCl (wt%)	Na_2SO_4(wt%)	d_m（mm）
1	25	55	0.5	0.5	0.1424
2	50	55	5	5	0.1773
3	75	55	3.5	3.5	0.2598
4	25	75	3.5	5	0.0899
5	50	75	0.5	3.5	0.1152
6	75	75	5	0.5	0.3542
7	25	95	5	3.5	0.1701
8	50	95	3.5	0.5	0.1589
9	75	95	3.5	5	0.1004
R_1	0.4024	0.5795	0.7016	0.5451	T=1.5682
R_2	0.4514	0.5593	0.5086	0.6555	
R_3	0.7144	0.4294	0.3580	0.3676	
S	0.3120	0.1501	0.3436	0.2879	

3.3 Effect of the Fours Factors on the Corrosion of 2024T3 Aluminum Alloy

The results from Table3 show that Cl^-, SO_4^{2-} and temperature are the main factors for the corrosion of 2024T3 aluminum alloy, but humidity is secondary. Figure 4(c) and (d) show that Cl^- and SO_4^{2-} have a distinct influence on the corrosion of 2024T3 aluminum alloy when their concentrations vary from 0.5% to 5%. With the increasing of Cl^- concentration, the corrosion becomes severe and SO_4^{2-} acts inversely. So both high content of SO_2 with low content of Cl^- and high content of Cl^- with low content of SO_2 in the atmosphere are dangerous to the corrosion of aluminum alloy.



(a) (b) (c) (d)

Figure 4: Variational tendency of d_m vs four factors.
(a) temperature (b) relative humidity (c) concentration of Cl^- (d) concentration of SO_4^{2-}

In addition, it can be found that the maximum corrosion depth decrease slightly with the relative humidity increasing from 55% to 95% and there is no critical humidity on which corrosion rate increase severely. It is possible that the higher the humidity is, the harder the liquid on the surface of the specimen evaporates. So there may be a thick layer of liquid film on the surface that can inhibit oxygen reduction corrosion because the diffusion of oxygen is difficult.

Some conclusions drawn from the above analysis are somewhat different from the previous research [8,9]. Generally for iron, steel, and zinc etc, when the humidity of the atmosphere exceeds the critical humidity (50~70%), their corrosion becomes obvious, and the corrosion rate grows rapidly with the humidity increasing. SO_2 or SO_4^{2-} are considered to be the most harmful contamination in the atmosphere in which some compound of soluble sulfate may form on the surface of many metals. The corrosion rate grows linearly with the content of SO_2 rising. The difference may be a character of the oceanic atmosphere corrosion for aluminum alloy. It is also possible that alternate immersion test can not simulate oceanic atmosphere environment of aluminum alloy exactly. This work is worthy of further study to get more information on the corrosion character of aluminum alloy.

4. Conclusions

1. Pitting occurs after the six-day alternate immersion test and the statistical maximum corrosion depth is consistent with Gumbel distribution for 2024T3 aluminum alloy.
2. Among the four factors representing oceanic atmosphere environment, concentration of Cl^- and SO_4^{2-} and temperature have great effect on the corrosion of 2024T3 aluminum alloy while humidity contributes less to it. Cl^- and SO_4^{2-} have distinct influence on the corrosion of 2024T3 aluminum alloy when their concentration varied from 0.5% to 5%. With the increasing of Cl^- concentration, the corrosion became severe and SO_4^{2-} acts inversely. With the relative humidity increasing from 55% to 95%, the maximum corrosion depth decrease slightly.

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