Quantitative Correlation of 7B04 Aluminum Alloys Pitting Corrosion Morphology Characteristics with Stress Concentration Factor

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Abstract. The accelerated pitting corrosion test of 7B04 aluminum alloy specimen was carried out according to the spectrum which simulated airport environment, and the corresponding pitting corrosion damage was obtained and was defined through three parameters $A$ and $B$ and $C$ which respectively denoted the corrosion pit surface length and width and corrosion pit depth. The ratio between three parameters could determine the morphology characteristics of corrosion pits. On this basis the stress concentration factor of typical corrosion pit morphology under certain load conditions was quantitatively analyzed. The research shows that the corrosion pits gradually incline to be ellipse in surface and moderate in depth, and most value of $B/A$ and $C/A$ lies in 1 between 4 and few maximum exceeds 4; The stress concentration factor $K_f$ of corrosion pits is obviously affected by the its morphology, the value of $K_f$ increases with corrosion pits depth increasement under certain corrosion pits surface geometry. Also, the value of $K_f$ decreases with surface width increasement under certain corrosion pits depth. The research conclusion can set theory basis for corrosion fatigue life analysis of aircraft aluminum alloy structure.

1. Introduction
Aircraft aluminum alloy structure is easy to initiate pitting corrosion in airport environment during service process, and corrosion pit damage is susceptible to nucleate fatigue crack under fatigue loading spectrum which could eventually shorten fatigue life and reduce residual strength of structure [1-2], this phenomenon or behavior of aero aluminum alloy could bring catastrophe to flight safety of plane, and it is more serious to the aging aircraft which serves in coastal environment, so the behavior of pitting corrosion initiating fatigue crack is important foundation to corrosion fatigue analysis of aircraft aluminum alloy structure. Now more researchers think that the degeneration degree and degeneration probability of aluminum alloy structure fatigue property could be directly affected by its pitting corrosion damage morphology characteristics [3-4], and it is considered that the pitting corrosion damage morphology affect the roughness of structure surface which eventually change the stress distribution around the corrosion pit and bring stress concentration that lead to crack nucleation and propagation, researchers also quantitatively analyses the relationship between the corrosion pits damage morphology and the stress concentration factor [5-6].

But there are two shortcomings which lie in the above mentioned research. The first is that the pitting corrosion damage of aluminum alloy specimen is obtained through immersion in the 3.5% Nacl or EXCO solution, the corrosion damage morphology which is obtained in this way differs from the corrosion damage morphology that naturally nucleates in the airport environment. The second is the pitting corrosion damage morphology characteristics parameter usually choose the surface damage degree or open angle or corrosion pit depth and so on, these parameters are one dimension parameter
which couldn’t comprehensively reflect the corrosion damage characteristics, on the contrary, the corrosion pit propagation often follows constant volume rule [7-8], so the mentioned one dimension parameter could not precisely depict the correlation between morphology characteristics of corrosion pits and its corresponding stress concentration factor.

Aimed at the two shortcomings, the typical aircraft 7B04 aluminum alloy is chosen as research object, and the pitting corrosion test is carried out according to the accelerated corrosion environment spectrum which simulates the airport environment, then the corrosion pit damage data is obtained through microscope and is defined through three-dimensional parameters which reflect corrosion pit morphology characteristics, the quantitative correlation analysis between pitting corrosion morphology characteristics and stress concentration factor is followed through which we can know the rule of how the three-dimensional damage morphology characteristics of pitting corrosion affects stress concentration factor of corrosion pits, and this research context could set theory basis for corrosion fatigue life analysis of new aircraft aluminum alloy structure.

2. Pitting Corrosion Test

The dimension and the composition of 7B04 aluminum alloy specimen is respectively shown in Fig. 1 and Table 1, in order to get rid of the impurity of specimen surface, the specimen was cleaned with the absolute ethyl alcohol followed washing procedure with distilled water.

![Figure 1. Dimension of specimen (mm)](image)

| Table.1. Composition of the 7B04 aluminum alloys (%) |
|-------------------|--------|--------|--------|--------|-------|-------|-------|--------|----------------|
| Element    | Cu   | Mg    | Mn    | Zn    | Si    | Fe    | Ti    | Be     | Al          |
| Content (%)| 3.8-4.3 | 1.7-2.3 | 0.4-0.9 | <0.1  | <0.2  | <0.3  | <0.1  | 0.0002-0.005 | others       |

It is a long period method that putting the specimen in the true aircraft service environment to initiate natural pitting corrosion and obtain pitting corrosion damage morphology parameters, in order to reduce research time and simulate aluminum alloy pitting corrosion process in the true service environment, the accelerated pitting corrosion test of 7B04 specimen was carried out according to equal corrosion damage principle and the accelerated corrosion test environment spectrum which was statistically calculated through true data of service environment factors [9], the magnitude and frequency of accelerated pitting corrosion test environment spectrum was depicted in Fig. 2, the main way that spectrum acted was combination of immersion in solution and far infrared lamp raying, the solution was admixture of H₂SO₄ and 3.5%(wt.%)NaCl, the pH value of solution was 4.0±0.2, the exact immersion time and raying time respectively was 4.6 minutes and 12.3 minutes, one equivalent corrosion year included 255 loops which accounted for 71.82 hours. ZJF-75G periodic soaking tests cabinet was adopted to carry out pitting corrosion test, the HB5455-90 standard was referenced to control test process.

The accelerated pitting corrosion test lasted 1500 hours, which amounted to over 10 equivalent corrosion years, typical corrosion morphology of 7B04 specimen was shown in Fig. 3 which suggested that corrosion pits sites and pit corrosion density increased with the corrosion period prolongation.
**Accelerated corrosion time**

**Environment test condition**

- **Temperature**: $T = (40 \pm 2) ^\circ C$
- **Humidity**: $\text{RH} = 90\%-95\%$
- **Far infrared lamp raying**

**Solution soaking**

- 4.6min

**Raying out of solution**

- 12.3 min

5%NaCl + H$_2$SO$_4$

PH=4±0.2

(One equivalant corrosion year includes 255 loops which accounts for 71.82 h)

**Figure 2.** Accelerated pitting corrosion test environment spectrum

![Image of corrosion test environment spectrum](image1)

(a) 150h

(b) 750h

**Figure 3.** Corrosion morphology of typical 7B04 specimen surface in different corrosion period

3. Acquisition and Processing of Test Data

During test process, every specimen was picked under fixed period to be observed through KH-7700 three dimensional microscopy, and at the same time three-dimensional parameters of corrosion pits was gauged. The specific parameters were defined as following: firstly, the corrosion pit length was the pit surface length, which was vertical to the axial orientation of specimen and represented by parameter $A$. Secondly, the corrosion pit width was pit surface width that was parallel to the axial orientation of specimen and represented by parameter $B$. Lastly, the corrosion pit depth was the distance between the specimen surface and pit bottom which represented by parameter $C$. The unit of parameters was $\mu$m, and their schematic definition was depicted in Fig. 4.

Typical corrosion pits damage morphology parameters were successively measured, and part of three-dimensional parameters data were shown in Table 2.
Figure 4. Schematic diagram of corrosion pit morphology parameters

Table 2. Typical corrosion pits morphology parameters data of 7B04 specimen

| Corrosion period/a | 5     | 7     | 9     | 11    |
|--------------------|-------|-------|-------|-------|
| $A\times B\times C (\mu m^3)$ |       |       |       |       |
|                     | 2.6×5.5×8.7 | 2.5×6.0×15.0 | 2.5×9.6×7.8 | 3.5×15.5×18.5 |
|                     | 2.1×4.1×6.3 | 1.8×5.5×7.1 | 2.7×11.0×15.1 | 3.3×12.5×19.1 |
|                     | ...     | ...    | ...   | ...   |
|                     | 1.8×4.1×7.2 | 2.6×8.3×11.4 | 3.3×9.0×8.9 | 3.5×8.9×14.6 |
|                     | 2.2×4.4×1.01 | 2.4×5.6×7.3 | 3.6×6.6×11.2 | 3.6×17.3×15.3 |

Nowadays more researchers usually regard the corrosion pits as sphere or ellipsoid and so on [7-8,10], this paper depict the corrosion pits morphology characteristics according to the obtained data which were shown in Table 2, and the characteristics of corrosion pits morphology was determined by the $A, B, C$ three dimensional parameters, specifically, if the corrosion pit surface length $A$ served as reference, the value of $B/A$ and $C/A$ could determine the corrosion pits morphology characteristics. Similarly, if $B$ and $C$ served as reference, the analysis process was similar which was not mentioned and discussed here again.

Based on the above mentioned hypothesis, the corrosion pits morphology characteristics was quantitatively computed according to three dimensional parameters of corrosion pits and the results of typical corrosion year was shown in Fig. 5. The computation results showed that most value of $B/A$ and $C/A$ lied in the interval between 1 and 4 and seldom exceeded 8.
4. Computation of Stress Concentration Factor of Corrosion Pits

ABAQUS software was applied to compute the stress concentration factor corresponding to different corrosion pits morphology characteristics, which were detailedly depicted in previous section. The finite element mesh choose tetrahedron element method, the load condition was axial tension, and the meshing of specimen and local corrosion pits and stress distribution was respectively shown in Fig. 6 and Fig. 7.

The stress concentration factor was calculated through the following equation,

\[ K_f = \frac{M_{\text{stress \ max}}}{P}. \]  \hspace{1cm} (1)

In equation (1), \( K_f \) was stress concentration factor, \( P \) was tension load and its unit was Mpa.

Figure 5. Frequency distributing of corrosion pits morphology
Under certain load condition, the result of stress concentration factor \( K_f \) computation was shown in Table 3 and Fig. 8.

The conclusion, which was based on computation results could be made that \( K_f \) increased with corrosion pits depth deepening under certain corrosion surface morphology, on the contrary, \( K_f \) decreased with corrosion pits surface size increasing under certain corrosion pits depth. The ratio between maximum and minimum of \( K_f \) was 2.3, which could bring completely different influence on corrosion fatigue life analysis of aircraft aluminum alloy structure [11-15].

![Figure 6](image1.png)

**Figure 6** Meshing of finite element

![Figure 7](image2.png)

**Figure 7**. Stress distributing figure of typical corrosion pits morphology

| Results | \( B/A \) | \( C/A \) | \( C/A \) | \( C/A \) | \( C/A \) |
|---------|---------|---------|---------|---------|---------|
|         | 1       | 2       | 4       | 8       | 10      |
| 1       | 2.722   | 3.146   | 3.607   | 3.646   | 3.698   |
| 2       | 2.060   | 2.281   | 2.494   | 2.608   | 2.658   |
| 3       | 1.842   | 2.069   | 2.226   | 2.309   | 2.333   |
| 4       | 1.741   | 1.880   | 2.062   | 2.128   | 2.154   |
| 8       | 1.619   | 1.697   | 1.757   | 1.827   | 1.833   |

Table 3. Stress concentration factor results of different corrosion pit morphology characteristics
Figure 8. Stress concentration factor results of different corrosion pit morphology characteristics

5. Conclusion

Based on the accelerated pitting corrosion test results of 7B04 specimen and the ABAQUS software analysis, the quantitative relationship between pitting corrosion morphology characteristics and stress concentration factor is discussed, it is found that:

(1) Most of the value of $C/A$ and $B/A$ lies in the interval between 1 and 4, seldom exceeds 8 which suggests that the corrosion pits morphology characteristics inclines to be circle or ellipse geometry on the surface and be moderate deep in corrosion pits depth with the corrosion period prolongation.

(2) The stress concentration factor $K_f$ correlates with corrosion pits morphology characteristics, specific say, $K_f$ increases with corrosion pits depth increasing under certain corrosion surface geometry, on the contrary, $K_f$ decreased with corrosion pits surface size increasing under certain corrosion pits depth.
(3) The ratio between maximum and minimum of $K_f$ under different corrosion pit morphology characteristics is 2.3 which could bring completely different influence on corrosion fatigue life analysis of aircraft aluminum alloy structure.

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