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An Investigation of Alternate Behavior of Corrosion and Fatigue of LY12CZ Aluminum Alloy

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Abstract

The paper investigates the effect of pre-corrosion on mechanical properties of LY12CZ aluminum alloy and failure behavior of this alloy under alternate corrosion and fatigue. The alternate tests are designed as cyclic mode of corrosion–fatigue-corrosion-fatigue, and corrosion tests use equivalent environment spectrum simulating airdrome environment. It is shown that static strength and fatigue life decrease significantly with corrosion. In the results of alternate tests, after a same accumulated corrosion duration, fatigue loading cycles at last alternation (N_m)is usually less than remainder fatigue life after pre-corrosion (N_{re}), whereas accumulated fatigue cycles(ΣN_i) of alternate tests is larger than N_{re} significantly. In the alternate process, anti-corrosion strength increases while the LY12CZ alloy obtains a longer accumulated fatigue life.

1. Introduction

A considerable research has been made on the principle and effective factors of corrosion fatigue since the concept "corrosion fatigue" was brought up in 1926. Most of work has focused on the synergetic interaction between corrosion and fatigue. However, many mechanical products endure alternate actions of fatigue and corrosion, but not synergetic interaction. For example, aircrafts are always parked for a long time after short-time flights, in other words, aircraft materials usually endure alternate actions of corrosion and fatigue.

There are a lot of literatures on the corrosion fatigue of aircraft aluminum alloys [1-3]. The investigation of effects of corrosion on mechanical properties of aluminum alloys has also been carried out. Person [4] demonstrated that pitting corrosion reduces the fatigue life of 7075-T6 aluminum alloy. Pantelakis [5] investigated the influence of pre-corrosion on the static strength of 2024 aluminum alloy. In the latter paper, the authors consider that the decrease in static strength is due to hydrogen penetration and absorption. Obert [6] also carried out a study on the reduction in tensile strength and fatigue life of pre-corroded 7075-T6 aluminum alloy. But up to now, there is less information on alternate behavior of corrosion and fatigue. Rudd [7] studied the alternate process of environment—fatigue / environment—fatigue, and proposed that the alternate action plays an important role in the material degradation. Some tests have been made on alternate behavior of corrosion and fatigue of aluminum alloys in the Institute of Metal Research, Chinese Academy of Sciences, but no valuable results were reported.

Alternate test in this study simulates the cyclic damage mode of actual use of aircraft, which is park (corrosion)—flight (fatigue)--park (corrosion)—flight (fatigue). Some important results are obtained on corrosion and fatigue failure behavior of LY12CZ alloy after corrosion and fatigue alternate tests.

2. Experimental Procedures

2.1 Material and Corrosion Environment

The material used in this study is a 3mm thick sheet of LY12CZ aluminum alloy. The chemical composition (wt.%) of the major elements in the studied alloy was 4.4Cu, 1.5Mg, 0.53Mn, and Al (balance). Specimens are cut in the longitudinal direction. In this study, only the central section of these specimens is corroded. Therefore, the remainder of each specimen is protected from corrosion environment by means of coating. Corrosion test is conducted under equivalent environment spectrum simulating some airdrome environments. The equivalent environment spectrum consists of:

A: immersion in 50℃，5%NaCl+0.5%Na_2SO_4 solution for 24 hours,
B: exposure in 50℃，HR80% wet and hot air for 127 hours,
C: aging in 100℃ hot air for 17 hours.

The total corrosion duration is 168 hours (approximately one week). A corrosion cycle equals to half-year parking in some airdromes.

2.2 Pre-corrosion Test

The static strength and fatigue life are measured after specimens are subjected to the corrosive environments described above. Pre-corrosion tests include seven groups, which respectively corrode for 0, 1/3, 1, 2, 3, 6, 10 cycles. In each group, half of the samples are used for tensile tests and the other half for fatigue tests. The fatigue tests are conducted at a frequency of 10Hz with a maximum load of 336MPa. A sine wave function is applied and the stress ratio is 0.1.

2.3 Corrosion and Fatigue alternate Tests

Corrosion tests are performed under similar environments described above. The fatigue tests are conducted at a frequency of 10Hz with a maximum load of 336MPa and stress ratio of 0.1. In alternate tests, corrosion test and fatigue test are made in sequence. Each alternation cycle consists of a corrosion test of same corrosion cycle (T_i) and a fatigue test of same fatigue loading cycles (N_i). Alternate tests are separated into four groups, each consisting of 5 parallel specimens.

3. Results and Discussion

3.1 Mechanical Properties of Pre-corroded LY12CZ Alloy

The mechanical properties of the pre-corroded samples reduce significantly. The static strength and fatigue life are shown in figs.1, 2, and 3. It can be concluded from these figures that pre-corrosion has a notable effect on fracture failure of materials. With an increase in pre-corrosion duration, σ_b, $\sigma_{0.2}$, $\delta_{5\%}$, and N_{re} (remaining fatigue life after pre-corroded) all decrease. The effect of pre-corrosion on N_{re} is especially significant. As seen in Figure 3, there is a large initial drop in N_{re} from 73247 cycles (non-corroded) to 20178 cycles after a 1/3-cycle corrosion, and then N_{re} reduces slightly. This result shows that pre-corrosion affects the formation life of fatigue crack remarkably, and has a less effect on the extension life of fatigue crack.

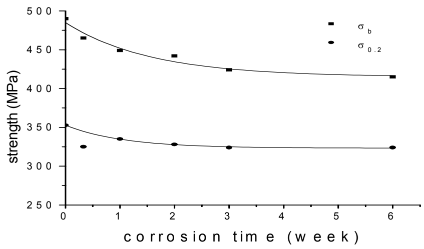

Figure1: Effect of pre-corrosion on tensile strength.

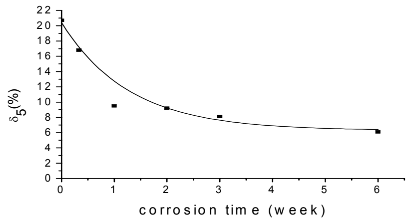

Figure2: Effect of pre-corrosion on elongation.

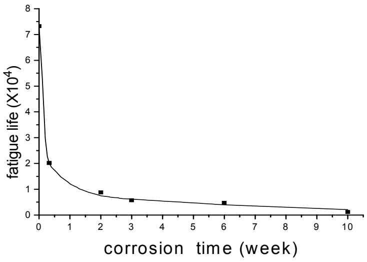

Figure 3: Effect of pre-corrosion on fatigue life.

3.2 Fractography of Pre-corroded Specimens

Corrosion characteristics on the specimen surface are different for samples with different corrosion durations, as shown in Figure 4. After pre-corroded for 1/3 cycle, pitting occurs in the corroded surfaces. Pitting increases with corrosion duration. After 6 weeks corrosion, pitting has spread all over the surface and exfoliation corrosion occurs.

Fractured surfaces of pre-corroded fatigue specimens were examined in SEM. The fatigue crack starts from the corrosion pits where multiple origins are present (Figure 4), and then extends and fractures under cyclic loading.

A corrosion product can be seen at the fatigue origin at high magnifications, Figure 5. The similar features of fracture are present in specimens with different corrosion duration.

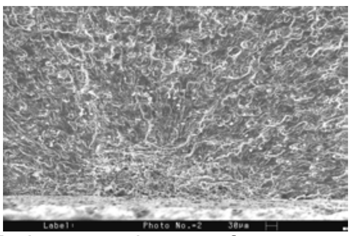

Figure 4: Fatigue crack starts from corrosion pit.

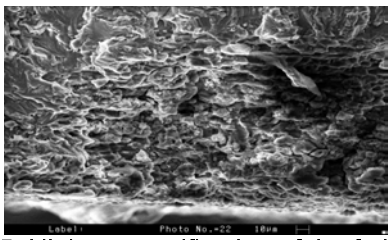

Figure 5: Higher magnification of the fatigue origin.

3.3 Alternate Behavior of Corrosion and Fatigue

Test parameters and results of four alternate test groups are presented in Table 1.

As seen in this table, when the corrosion duration in each alternate cycle is one week (one cycle), with a decrease in fatigue loading cycles N_i, the alternate number m increases gradually from 2 to 2～3,3～4,and 4～7 cycles, in other words, the accumulated corrosion duration time increases. Another trend is that there is less difference in the accumulated fatigue cycles ΣN_i when N_i decreases from 10500 to 5250.

Comparing the results of alternate tests with those from pre-corrosion tests, it can be observed that, under the condition of similar accumulated corrosion durations, N_m (fatigue loading cycles in the last cycle) is usually less than N_{re} (remaining fatigue life after pre-corrosion), whereas ΣN_i (accumulated fatigue cycles) of alternate tests is significantly larger than N_{re}, as indicated in Figs. 6, 7. It can also be observed that ΣN_i sometimes is larger than N_{re}, whereas the sample corrodes for a longer time accumulatively than pre-corrosion duration ($\Sigma T_i > T_p$).

Table 1 Results of corrosion and fatigue alternate tests

Test series	T_i	N_i	m	N_m	ΣT_i	Total fatigue life	
						ΣN_i	Average
A	One cycle /one week	10500	2 2 2 2 2	7580 4230 3730 5101 1103	2 cycles	18080 14730 14230 15601 11603	14849
B	One cycle	7000	2 2 3 3 3	6362 4400 2000 460 523	2～3 cycles	13362 11400 16000 14460 14523	13949
C	One cycle	5250	3 3 3 4 4	3965 2400 1629 2601 375	3～4 cycles	14465 12900 12129 18351 16125	14794
D	One cycle	1300	4 4 5 5 7	1024 476 499 339 521	4～7 cycles	4924 4376 5699 5539 8321	5772

Nomenclature:

- T_i Corrosion duration in an alternate cycle
- N_i Fatigue loading cycles in an alternate cycle
- m Alternate number
- N_m Fatigue loading cycles at last alternate cycle
- ΣT_i Accumulated corrosion duration
- ΣN_i Accumulated fatigue cycles

For example, ΣT_i of samples in C group is three or four cycles, but the average ΣN_i of C group is larger than N_{re} of samples pre-corroded for two cycles. Therefore, the results described above show that anti-corrosion strength of LY12CZ alloy increases and the alloy obtains a longer accumulated fatigue life in the alternate process.

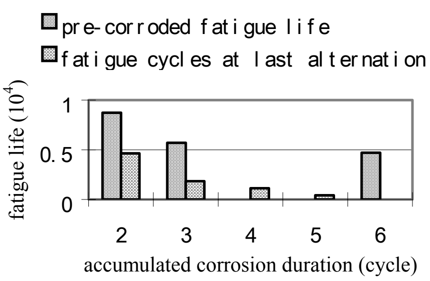

Figure 6: Comparison between pre-corroded fatigue life and fatigue cycles in the last alternate cycle.

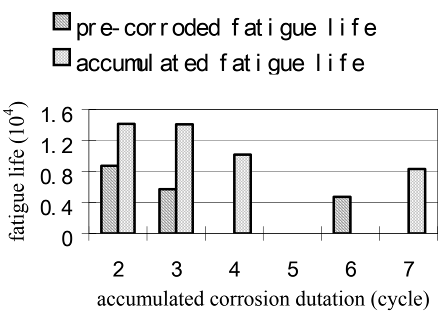

Figure 7: Comparison between pre-corroded fatigue life and accumulated fatigue life in alternate tests.

In Figure 11, the fatigue striations are clearly visible in the fatigue propagation region.

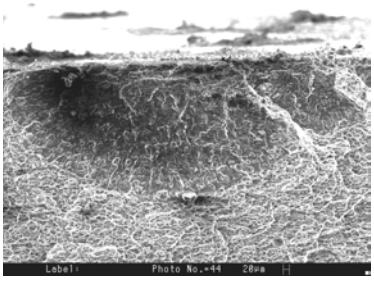

Figure 8: SEM micrograph of fracture surface.

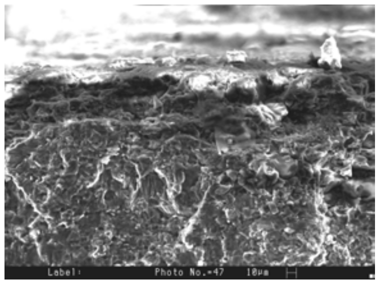

Figure 9: Corrosion product in the fatigue origin.

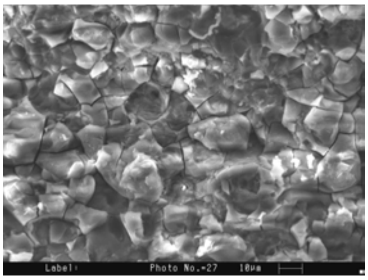

Figure 10: Fatigue striation in mud-crack pattern.

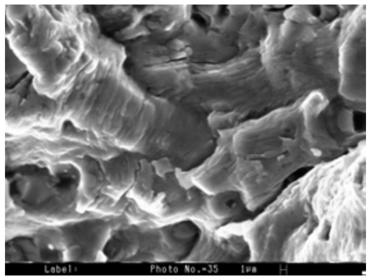

Figure 11: The fatigue striation.

4. Conclusions

(1) With an increase in pre-corrosion duration time, σ_b, $\sigma_{0.2}$, $\delta_{5\%}$, and the remaining fatigue life after pre-corrosion N_{re} all decrease. Pre-corrosion affects remarkably the formation life of fatigue cracks, and has a less effect on the extension life of fatigue crakes.

(2) Under the condition of similar accumulated corrosion durations, N_m (fatigue loading cycles in the last alternation cycle) is usually less than the remaining fatigue life after pre-corrosion N_{re}, whereas accumulated fatigue cycles ΣN_i of alternate tests is significantly larger than N_{re}.

(3) In the alternate process, anti-corrosion strength increases and the LY12CZ alloy obtains a longer accumulated fatigue life.

(4) When the corrosion duration in an alternate cycle is one week (one cycle), the alternate number m increases gradually with decreasing fatigue loading cycles N_i, in other words, the accumulated corrosion duration increases.

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