Performance Deregulation Rule of Aircraft Fatigue Critical Components in Consideration of Calendar Environment

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Abstract The 2A12-T4 aluminum alloy specimens were studied with accelerated environment test to simulate different parking calendar years. Afterwards, these specimens were implemented with fatigue test to fracture. Through analyzing the test data, the relationship between S-N shape parameter and parking calendar years was caculated with dynamic S-N curve method. Then, the performance deregulation rule of aircraft fatigue critical components in consideration of calendar environment was established. In addition, the rule between Detail Fatigue Rating (DFR) and parking time was also set up. Compared with the similar specimens' life from retired aircraft, the life with S-N curve and DRF method was in good agreement with actual value. The result shows that aircraft fatigue cirtical components' performance declines with the prolonging parking calendar time.

Keywords 2A12-T4 aluminum alloy, fatigue critical component, calendar environment, dynamic S-N curve, Detail Fatigue Rating

1. Introduction

Currently, the service life index of aircraft component in China includes fatigue life denoted by flight hours and calendar life denoted by calendar life. The first repair, major repair and total life are controlled according to the principle of first reach of service life index [1]. The calendar life mainly aims at the corrosive critical component and the degree of corrosive damage is the basic premise whether the component is in good working order [2]. The fatigue life mainly aims at the fatigue critical component and the remaining life depends on the degree of fatigue damage and the number of repair. Aimed at the corrosive fatigue critical component, the method of corrosive influence coefficient is usually used for the general engineering purpose to revise the attenuation of fatigue life because of the corrosive effect during service life [1,3,4]. Generally speaking, the corrosive effect of componen is mainly considered for the calendar life, however, the remaining fatigue life of component is that the design target subtracts the consumed fatigue life and don't take the effect of environment into account. Because the calendar life of aircraft at present are over 20 years [4], the representative aircraft—B-52, the calendar life are over 50 years. The effect of environment for a long time can result in the corrosion of component and reduce the anti- fatigue performance of material [1-10]. The fatigue critical component is exposed to the parking environment for a long time, which can't result in the obvious corrosion of component but can cause the microscopic damage. However, the instance that the performance is degrading for the fatigue critical component of parking aircraft because of environmental effect is never reported at home and abroad.

Aimed at the problem of performance decline for the fatigue critical component in parking environment, the accelerated environment test of different parking calendar time was carried out by using the 2A12-T4 aluminum alloy standard specimen until the specimen fracture, then the relation was calculated between the shape parameters and the parking calendar time, the model for life decline was established about the fatigue critical component under the parking condition. The model for Detail Fatigue Rating (DFR) and accelerated time were calculated and compared with the fatigue life of the same material from the retired aircraft. The result shows that the model is reliable. The result indicates that the parking environment can cause the fatigue performance decline for the fatigue critical component, and more attention should be paid to the usage and life-saving for the old aircraft.

2. The test method and result

2.1. Manufacture of the specimen

The material of specimen is 2A12-T4 aluminum alloy with the thickness of 4 mm and the size is shown in Fig.1. The tensile strength σ_b is 450 MPa, the yield strength σ_s is 325 MPa, the extensibility δ is 15%.

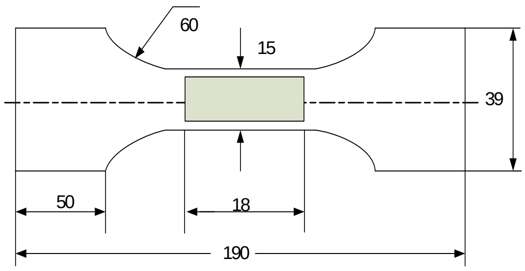

Figure 1. Specimen size

The old specimen came from fuselage slab component of some no- corrosive retired aircraft (2A12-T4 aluminum) and was machined as picture 1 according to the loading direction.

2.2. The test method

The accelerated environment test was processed in the environment box and the environment spectrum as shown in Fig.2, was used to simulate the natural environment. At present, a mount of tests on the accelerated corrosion in laboratory were aimed at the corrosive fatigue critical component and the effect of environment on the no- corrosive fatigue critical component didn't be considered [5]. Consequently, on the basis of accelerated environment spectrum of the metallic material and organic material in laboratory, the accelerated corrosive environment spectrum used on engineering at present was modified in this paper and then was applied to the accelerated test of the fatigue critical component. The fatigue critical component would suffer the environment of high temperature and humidity as the corrosive fatigue critical component was suffered, the corrosive factor could weaken as far as possible.

The accelerated environment spectrum:

①Temperature:(40±2) ℃;
②Humidity: 90%~95%RH;
③Corrosive liquor: 5%NaCl liquor;
④The time for soak every period: 7.5min, the time for exterior: 22.5min;
⑤Under the glare of the far infrared lamp, keep the surface of specimen dry.

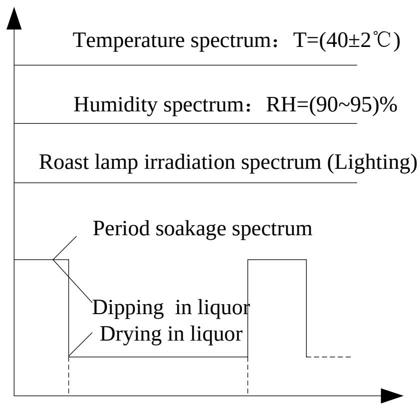

Figure 2. Accelerated environment spectrum

The surface of specimen was airproofed by the aviation silica gel.

One hour in the environment box was equal to 0.135 years in the natural environment [5], the 4 years、12 years and 20 years were simulated separately in the natural parking environment. After the accelerated environment test, the specimen of no- corrosion surface was chose to test.

The fatigue test was carried out by the MTS810 500KN fatigue test machine at room temperature with sine wave, the frequency was 20Hz, the stress ratio R was 0.06, every group would be picked up 4 valid data and the stress level had 3 groups.

2.3. The result of test

Provided that the result of test obeyed the lognormal distribution [7], the median-fatigue life could be calculated by the formula (1).

$$N_{50}(\mathrm{t}) = 10^{\frac{1}{n_t}\sum_{i=1}^{n_t}\lg N_i(t)} \tag{1}$$

Where, n_t is the number of accelerated specimen, $N_{50}(\mathrm{t})$ is the median-fatigue life, $N_i(\mathrm{t})$ is the fatigue life for the i specimen.

Table 1. Specimens' median-fatigue life

		Stress/MPa	$N_{50}(\mathrm{t})$ /10,000 cycle
Accelerated environment test	4	250	26.68
		310	12.93
		372	6.48
	12	240	26.54
		310	12.22
		372	5.97
	20	265	20.73
		310	11.83
		372	4.60
The specimen of retired aircraft		250	14.28
		290	7.83
		320	6.53

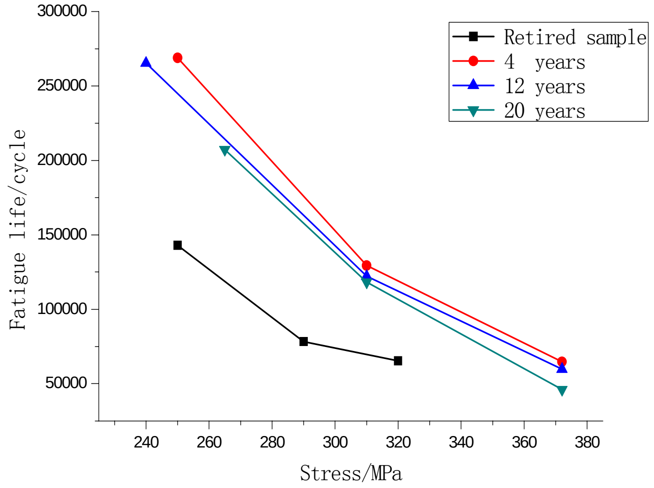

Figure 3. Specimens' stress-life curve

The Fig.3 indicated that the S-N curve moved down along with the increase of parking time, and the fatigue life declined.

3. The life analysis model for the fatigue critical component

3.1. The life model based on the dynamic S-N curve

Using the S-N curve:

$$SN^{\alpha} = C \tag{2}$$

Where, C and α are the shape parameters of material. With the service time prolonging, if the loading was not changed, the effect of environment could result in the performance decline of component. That is to say, C and α could alter with the change of time, as the formula (3) and Fig. 4 shown [10].

$$\begin{cases} C = C(\text{Parking Time}, T) \\ \alpha = \alpha(\text{Parking Time}, T) \end{cases} \tag{3}$$

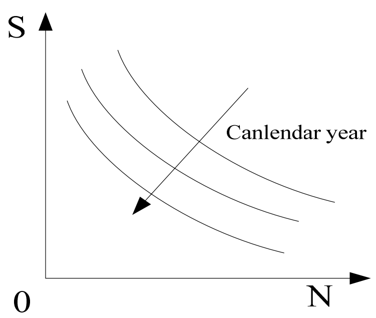

Figure 4. Dynamic S-N curve

Assuming the stress level for component was n at some loading spectrum, according to the linear accumulated damage theory, the fatigue life N could be shown as followed:

$$N = \frac{1}{\sum_{i=1}^{n} D_i} = \frac{1}{\sum_{i=1}^{n} N_{\mathrm{i}}} = \frac{1}{\sum_{i=1}^{n} (\frac{C}{S_i})\frac{1}{\alpha}} = \sum_{i=1}^{n} (\frac{C}{S_i})^{-\frac{1}{\alpha}} \tag{4}$$

Where, N_0 is the initial life of component and N_1 is the remaining life after parking for certain time, according to the formula (4), the formula (5) could be gotten:

$$\begin{cases} N_0 = \sum_{i=1}^{n} (\frac{C_0}{S_{0i}})^{-\frac{1}{\alpha_0}} \\ N_1 = \sum_{i=1}^{\mathrm{n}} (\frac{C_1}{S_{1i}})^{-\frac{1}{\alpha_1}} \end{cases} \tag{5}$$

Where, S_0 and S_1 respectively is the loading level. And more:

$$\frac{N_1}{N_0} = \frac{\sum_{\mathrm{i}=1}^{n} (\frac{C_1}{S_{1\mathrm{i}}})^{-\frac{1}{\alpha_1}}}{\sum_{\mathrm{i}=1}^{n} (\frac{C_0}{S_{0\mathrm{i}}})^{-\frac{1}{\alpha_0}}} = (\frac{C_1}{C_0} \cdot \frac{S_{0i}}{S_{1i}})^{\frac{\alpha_0}{\alpha_1}} = (\frac{C_1}{C_0})^{\frac{\alpha_0}{\alpha_1}} \tag{6}$$

Where, $\mathbf{C_0}$ and α_0 respectively means the shape parameter of S-N curve for the intact component, $\mathbf{C_1}$ and α_1 respectively is the shape parameter of S-N curve after parking for some time, other parameters are the same as above.

Therefore, the model for the remaining life was set up for the component that had parked for different T years.

$$N(T+1) = \frac{N(T)}{[\frac{C(T)}{C(T+1)}]^{\frac{\alpha(T+1)}{\alpha(T)}}} \qquad (\mathrm{T} = 0, 1, 2, \ldots\ldots) \tag{7}$$

The deregulation rule for fatigue life of component at different parking time was set up in the formula (7).

The environment influence for the performance of fatigue critical component was only considered. After considering the condition of service, the formula (7) could be revised as followed:

$$N(T+1) = \frac{[N(T) - G(T)]}{[\frac{C(T)}{C(T+1)}]^{\frac{\alpha(T+1)}{\alpha(T)}}} \qquad (\mathrm{T} = 0, 1, 2, \ldots\ldots) \tag{8}$$

Where, G(T) is the flight frequency for every year.

Aiming at the current usgue situation of aircraft, the two-aparameter life prediction model could be set up based on the local environment and the test data, which considered the influence of environment for fatigue critical component.

3.2. The way of Detail Fatigue Rating

The Detail Fatigue Rating (DFR) is usually used to analyze the fatigue quality for detail component. It is the inherent fatigue performance and is the measurement for component quality and ability of enduring repeating load. That is to say, the Detail Fatigue Rating (DFR) is the max stress at the constant loads for R=0.06, the cycles are for 10^5 cycles, the confidence level is 0.95 and the reliability ratio is 0.95 [11].

$$\sigma_{DFR} = \frac{\sigma_{m0}(1-R)}{0.94\frac{\sigma_{m0}}{\sigma_{\max}}X - 0.47(1+R)X + 0.53(1-R)} \tag{9}$$

Where, σ_{DFR} is the Detail Fatigue Rating; $\sigma_{m0} = 310$ MPa; R is the stress ratio; S is the pitch coefficient, $S = 2$; $X = S^{5-\lg N}$; N is the safe life $N_{95/95}$ for the confidence level 0.95 and the reliability ratio 0.95. If three parameters are known, then the other can be calculated among the other parameters.

First, the character life β for test data of every group should be calculated according to the Weibull distribution:

$$\beta = \left[\frac{1}{n}\sum_{i=1}^{n} N_i^{\alpha}\right]^{1/\alpha} \tag{10}$$

Where, $\alpha = 4$.

Then, the life should be calculated for the confidence level 0.95 and the reliability ratio 0.95:

$$N_{95/95} = \frac{\beta}{S_{\tau}S_{R}S_{C}} \tag{11}$$

Where, the specimen coefficient $S_{\tau} = 1$, the reliability coefficient $S_R = 2.1$ for the aluminium alloys, the confidence level coefficient S_C =1.175 for the confidence coefficient 0.95 and n=4.

4. Analysis and validation

4.1. The confirmation of model parameters

The standard S-N curve was fitted based on the test data from table 1 after accelerated environment test as Table 2 shown.

Table 2. S-N curve under different accelerated time

accelerated time /a	S-N curve	confidence level /%
4	$SN^{0.2796} = 8.2725\times10^{3}$	0.998
12	$SN^{0.296} = 9.7538\times10^{3}$	0.992
20	$SN^{0.2243} = 4.1727\times10^{3}$	0.986

The change rule of the shape parameters C and α was gained along with time according toTable 2, as the formula (12) shown.

$$\begin{cases} \alpha(T) = 0.238 + 0.01317\times T - 0.000695\times T^2 \\ C(\mathrm{T}) = 4883 + 1067.96\times \mathrm{T} - 55.175\times T^2 \end{cases} \tag{12}$$

The change rule of the shape parameters of S-N curve was established in the formula (12) for different parking calendar year. Therefore, the declining degree of S-N curve could be calculated at different parking time according to formula (12), and then the life of fatigue critical component could be reasonablly analysed and forecasted.

In the same way, the S-N curve was fitted according to the fatigue life of retired aircraft.

$$SN^{0.2698} = 6.1298 \times 10^{3} \tag{13}$$

The specimen value of DFR was calculated based on the fatigue life corresponding with a group data from the table 1, the result was shown in Table 3.

Table 3. Detail Fatigue Rating/MPa

	Stress/MPa	Life/10,000 cycle		DFR/MPa
Accelerated 4a	310	12.004 11.860	15.187 13.580	214.1635
Accelerated 12a	310	11.613 12.454	12.616 13.286	210.8297
Accelerated 20a	310	12.280 10.654	12.642 11.802	209.8210
Retired specimen	320	7.025 5.969	5.501 7.906	187.5407

The DFR in Table 3 was fitted by the exponential form and the change rule of DFR along with the calendar year was gained.

$$\sigma_{DFR}(T) = 207.937 + 8.479 \times e^{-0.0747T} \tag{14}$$

4.2. The example

Accoding to the actual service condition, the fatigue life was only consumed about 10% when the aircraft was retired.

Aimed at the status of consumed life and combined the formula (8) with (12), the theoretical calendar life was calculated by the dynamic S-N curve as the shape parameters were same as the formula (13); The calendar life was calculated by using the DFR method according to the formula (14) as the DFR value was same as Table 3. Compared with the actual fatigue life of retired aircraft, the result was shown in Table 4.

Table 4. Comparison of theoretical value and actual calendar life

	Theoretical value /a	Actual calendar life /a	Error /%
Dynamic S-N curve method	23.17	25	-7.32
DFR method	26.009	25	4.04

The results gained from Table 4: the error was not large between the calendar life calculated by the two models and the actual life, the two models could be used to predict the rule of life deregulation for the fatigue critical component at the parking environment.

5. The result

(1) The accelerated environment test for the 2A12-T4 aluminum alloy is carried out. though comparing the fatigue life after environment test with the fatigue life of retired aircraft, the rule

of life deregulation for the fatigue critical component is analysed with the calendar parking time prolonging.

(2) According to the test results, the change rule that the shape parameter changed with the parking time is calculated by the dynamic S-N curve; the calculating model for deregulation rule of the fatigue life has been established for the fatigue critical component. The error between the predicted calendar life and the actual value is about 7.32%.

(3) The rule that the DFR changes with the parking time is gained and the error between the theoretical calendar life and the actual value is about 4.04%.

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