PRE-CORROSION FATIGUE NOTCH FACTOR

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Abstract: The notched and smooth specimens of aluminum alloy LC4CS soaked in EXCO solution for different time are tested under the constant amplitude cyclic loading to obtain S-N curves and fatigue notch factors with different pre-corrosion time. By analyzing the corrosion process of LC4CS specimens in EXCO solution, the influence mechanism of corrosion on fatigue notch factor is expounded. Then, a two-parameter model used to describe the change of corrosion fatigue notch factor with time is established and verified by experiment. The results show that the pre-corrosion fatigue notch factor of LC4CS material decreases at first and then increases with the increasing pre-corrosion time. The inflection point appears at the beginning of denudation stage.

Key words: pre-corrosion; EXCO solution; fatigue notch factor; LC4CS; fatigue experiments

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INTRODUCTION

Aluminum alloy has become the main materials of aircraft structure due to its inherent high specific strength, specific stiffness and superior fatigue property. Although the ratio of titanium alloy and composite has increased in the new generation aircraft, aluminum alloy has remained the main structure material. As the problem of calendar life of aircraft structure has become more critical, corrosion and corrosion fatigue of aluminum alloy have become one of the key problems on the life assessment of aircraft structure.

A large amount of research on corrosion and corrosion fatigue behavior of aluminum alloy are conducted[1-3]. A seven-stage model of corrosion fatigue process which is proposed by Pan and Mahadevan Sankaran[4] is pit nucleation, pit growth, transition from pitting to fatigue crack nucleation, short crack growth, transition from short crack to long crack, long crack growth, and fracture. Yanlin Hu[5] explained the evolvement of pitting attack damage by occluded cell autocatalytic principle. Additionally, Z Khan and M Younas[6] predicted the corrosion fatigue life for notched components based on the local strain and linear elastic fracture mechanics concepts. However, there is little literature about pre-corrosion fatigue notch factor.

The stages of corrosion failure of aluminum alloy LC4CS in the atmospheric environment are pitting, intergranular corrosion and denudation. Because the specimens of aluminum alloy LC4CS soaked in EXCO solution could reappear this corrosion damage mode better, we adopt EXCO solution to research the variation of fatigue notch factor with corrosion time. Based on experimental observation, we explain the mechanism of variation of pre-corrosion fatigue notch factor with time, and then, identify a model of pre-corrosion fatigue notch factor verified by experiment.

1 EXPERIMENT

1.1 Specimen

The specimen is LC4CS aluminum sheet with thickness 2 mm. Specimen size is shown in Fig. 1

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and Table 1. The clamping segment and transition segment are protected by silica. The surface of the experimental segment is cleaned by ethanol.

Table 1 Specimen specification

Specimen	Diameter/mm	Number
Smooth	Null	88
Central hole	3	17
Central hole	6	18

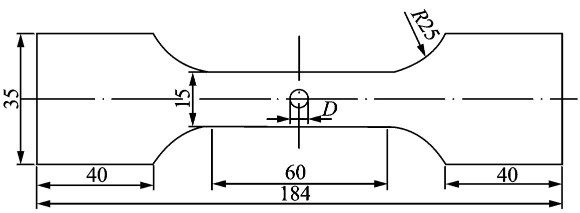


Fig. 1 Specimen size

1.2 EXCO solution

EXCO solution is prepared according to HB5455-90. The ratio of solution volume and specimen surface area is 20 ml/cm^2. Due to the long corrosion time, check the concentration of solution every 48 h and add proper amount of HNO_3 to insure that pH is 0.4.

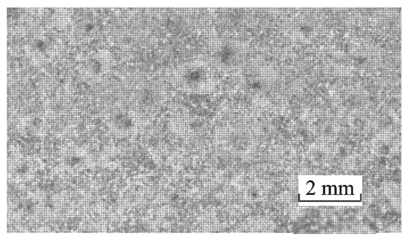
1.3 Experimental process

Smooth specimens are tested by the MTS809 fatigue test machine after being soaked in EXCO solution and the pre-corrosion S-N curves of aluminum alloy LC4CS are determined. Fatigue life of pre-corrosion notched specimens under one stress level is also determined.

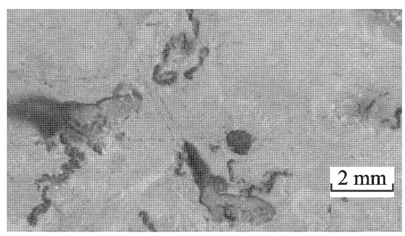
2 EXPERIMENTAL RESULT AND DISCUSSION

2.1 LC4CS corrosion process

The corrosion process of specimens in EXCO solution is similar to the description in Ref. [7]. After specimens are soaked in EXCO solution, air bubbles appear on the surface and then, the surface slightly changes color. However, due to the protection of passive film, there is no appearance of pitting and denudation. Then, as the failure of passive film, corrosion pitting appears and the edge of notch upswells slightly. The corrosion pitting expands along the directions which are parallel and perpendicular to surface and then, it makes the surface serrated. At this stage, because the corrosion pitting is shallow and the corrosion medium is adequate, corrosion rate is relatively high (Fig. 2(a)). With additional soaking time, the corrosion rate declines, and bubbles on the surface of specimens appear and then ruptures. There is a denudation layer on the surface of the specimen after the bubbles ruptured. After specimens soaked for a specific period of time, the surface of the specimen is clearly delaminated and the color is clearly changed. Corrosion extends to the interior of matrix, and the surface metal completely denudes while serration is not obvious (Fig. 2(b)).



(a) Pre-corrosion 50 h



(b) Pre-corrosion 150 h

Fig. 2 LC4CS specimen after pre-corrosion

2.2 Variation of stress distribution in root of notch due to corrosion

Pre-corrosion fatigue notch factor K_{fC} is defined as

$$K_{fC} = \frac{S_{0C}}{S_{NC}} \tag{1}$$

where S_{0C} is the pre-corrosion fatigue strength of smooth specimen and S_{NC} the pre-corrosion fatigue strength of notch specimen.

It is assumed that there is a corrosion pitting i near the notch, and the coupling effect is neglected because the pitting is rather small. This corrosion pitting i would cause a local stress field (Fig. 3). Based on force balance, we can get

$$P = \sum_{i=1}^{n} \int_0^b \sigma_i(y)\mathrm{d}x + \int_0^b \sigma(y)\mathrm{d}x \qquad (2)$$

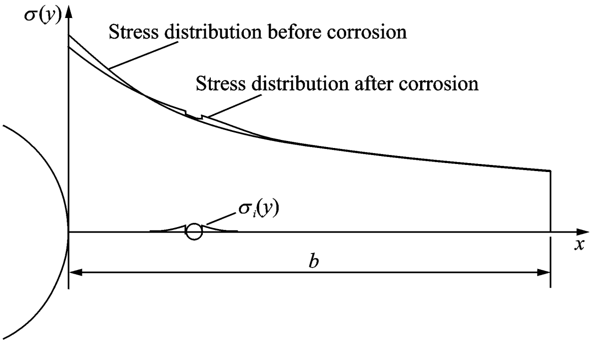


Fig. 3 Stress distribution when pitting near notch

For specimen without corrosion pitting, its force balance equation is

$$P = \int_0^b \sigma(y)\mathrm{d}x \qquad (3)$$

where $\sigma_i(y)$ is the stress distribution in $y=0$ caused by corrosion pitting i, n the number of corrosion pitting, $\sigma(y)$ the stress distribution in $y=0$ caused by load P before corrosion, and b the ligament width.

Deduced from Eq. (3), if external load P is kept constant, the maximum stress value of the notch would decrease because corrosion pitting would lead to the increase of its ambient stress. Therefore, the stress concentration factor of notch specimen after corrosion would reduce with the increasing of number and depth of corrosion pitting.

In the stage of denudation, surface of specimen tends to smooth and the weaken effect of maximum stress value caused by corrosion pitting will decrease. So, the maximum stress value of notch will increase and finally tends to the maximum stress value of smooth specimen.

2.3 Experimental result

Four S-N curves, in which pre-corrosion time is different, are obtained based on the fatigue experiment. In this paper, the model of S-N curve found in Ref. [8] is used to fit the experimental data (Fig. 4).

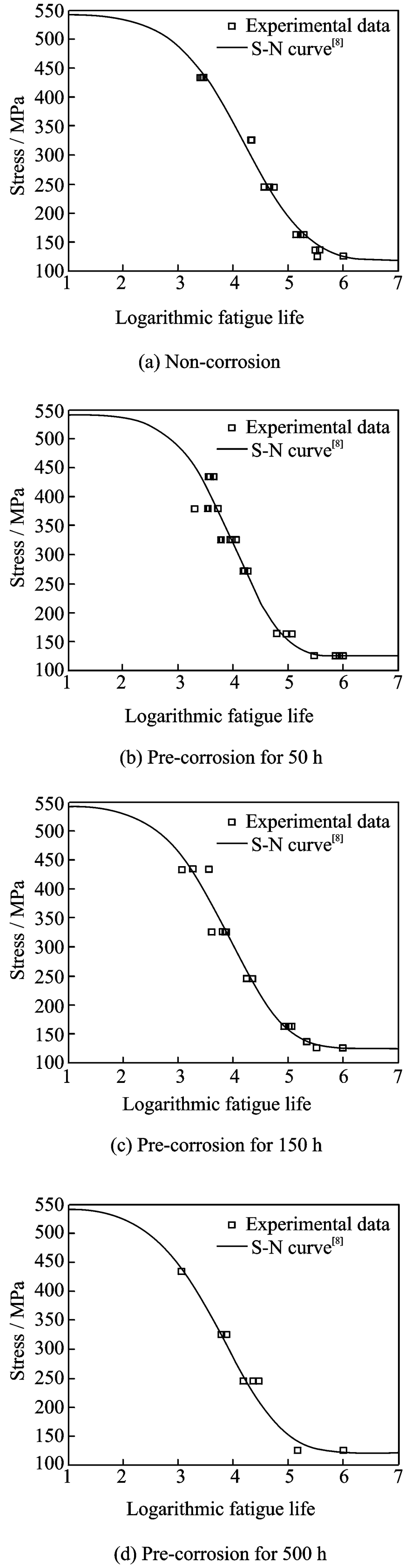


Fig. 4 S-N curves with different pre-corrosion time

Fatigue strength of notch specimen S_{NC} and its corresponding mean life N_C are obtained by experiment. From Fig. 4, we obtain corrosion fatigue strength S_{0C} relative to mean life N_C. Then, pre-corrosion fatigue notch factor is calculated by Eq. (1). Experimental values of pre-corrosion fatigue notch factor of specimen with central hole are shown in Table 2.

Table 2 Pre-corrosion fatigue notch factor of specimen with central hole

Diameter/mm	3	3	6	6
Corrosion time/h	Pre-corrosion fatigue notch factor	Regularization pre-corrosion fatigue notch factor	Pre-corrosion fatigue notch factor	Regularization pre-corrosion fatigue notch factor
50	1.42	0.68	1.39	0.68
150	1.63	0.78	1.52	0.74
500	1.44	0.69	1.53	0.75

2.4 Pre-corrosion fatigue notch factor model

Field intensity method[9] is based on the idea that fatigue notch factor depends on stress distribution of notch root. The pre-corrosion fatigue notch factor K_{fC} of specimens does not decrease obviously at the beginning of corrosion. However, its value declines quickly when a large number of corrosion pittings appear. At the stage of denudation, pre-corrosion fatigue notch factor K_{fC} increases slowly and tends to pre-corrosion fatigue notch factor K_{fC} of the smooth specimen. So, pre-corrosion fatigue notch factor $K_{fC}(t)$ is the function of time t, it meets three basic conditions:

(1) $K_{fC}(0)=K_f$, non-corrosion fatigue notch factor;

(2) $K_{fC}(\infty)=K_f$, ideal uniform corrosion fatigue notch factor;

(3) $K_{fC}(t)<K_f$.

where K_f is conventional fatigue notch factor.

According to the corrosion mechanism of aluminum alloy, the regularization pre-corrosion fatigue notch factor model is

$$C(t) = \frac{K_{fC}(t)}{K_f} = \frac{1-K_{fC_{\min}}}{2}\cos\left(\frac{2\pi b^c}{(t+b)^c}\right) + \frac{1+K_{fC_{\min}}}{2} \tag{4}$$

where $C(t)$ is the regularization pre-corrosion fatigue notch factor, $K_{fC_{\min}}$ the minimum of pre-corrosion fatigue notch factor, b the position parameter, which mainly relates to corrosion sensitivity of material and is determined by the time that pitting transformed into denudation, c the change rate of K_{fC} and influenced mainly by corrosion character of material.

3 EXPERIMENTAL VERIFICATION

In order to verify the applicability of this model for different notch geometries simultaneously, we chose LC4CS aluminum sheet with slot and its thickness is 2 mm. The total number is 18. Geometry size of specimen is shown in Fig. 5.

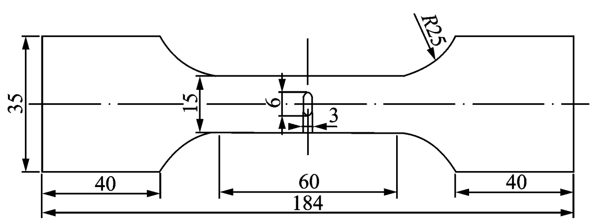


Fig. 5 Geometry size of specimen with slot

The experimental values of pre-corrosion fatigue notch factor of specimens with slot are obtained by the same way as in Section 2.3. Pre-corrosion fatigue notch factor and regularization pre-corrosion fatigue notch factor of specimens with slot in three different corrosion time are shown in Table 3. The fatigue notch factor, which is calculated according to the Peterson formula, is 2.43. The values of b, c and $K_{fC_{\min}}$ of three different notch specimens are shown in Table 4. The change curve of pre-corrosion fatigue notch factor of specimens with slot and central hole are shown in Fig. 6.

Table 3 Precorrosion fatigue notch factor of specimens with slot

Corrosion time/h	50	150	500
Pre-corrosion fatigue notch factor	1.805	1.945	2.126
Regularization pre-corrosion fatigue notch factor	0.743	0.800	0.875

Table 4 Parameter value of regularization pre-corrosion fatigue notch factor

Notch	b	c	$K_{fC_{min}}$
3 mm central hole	3.3	0.297	0.68
6 mm central hole	3.2	0.265	0.68
Slot	3.6	0.290	0.73

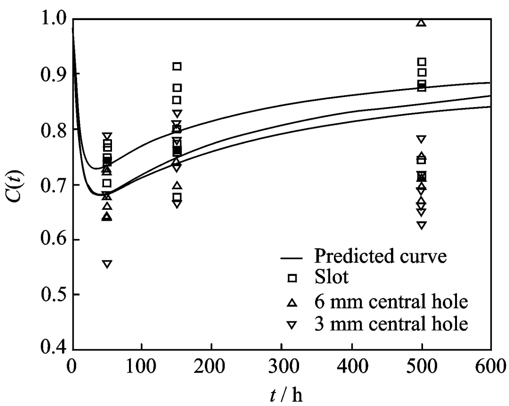


Fig. 6 Comparison between experimental result and prediction result

The curve of specimens with slot is in good agreement with experimental data. However, the curves of specimens with central hole are not in good agreement with experimental data at the point of 500 h. This result might be caused by dispersion of corrosion and fatigue experiment.

The coefficients of variation of pre-corrosion fatigue notch factor of specimens are shown in Table 5. The data are all large and do not have any law. So, we cannot give any definite conclusion about dispersion of pre-corrosion fatigue notch factor as the function of time.

Table 5 Coefficient of variation of pre-corrosion fatigue notch factor

Notch	Time/h		
	50	150	500
3 mm central hole	0.182	0.110	0.083
6 mm central hole	0.064	0.034	0.159
Slot	0.037	0.110	0.077

4 CONCLUSIONS

The pre-corrosion fatigue notch factor model describes the variation of fatigue notch factor that decreases at first and then increases with the increasing pre-corrosion time. Finally, this model is verified by experiment. The results show that:

(1) Variation of model fits the actual corrosion process and interprets the change mechanism very well;

(2) This model could be obtained by a few experimental data;

(3) This model demonstrates that the pre-corrosion fatigue notch factor reaches the lowest point at the significant pitting stage when the number of corrosion pitting reaches the maximum. However, the significant pitting stage is just a conceptive time and does not have a precise definition. So, the definite time that pre-corrosion fatigue notch factor reaches the lowest point needs further research.

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预腐蚀疲劳缺口系数

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摘要:对在EXCO溶液中预腐蚀后的LC4CS光滑试件和缺口试件进行疲劳试验,得到不同预腐蚀时间的S-N曲线及预腐蚀疲劳缺口系数。通过分析腐蚀过程,阐述了腐蚀对疲劳缺口系数的影响机理,建立了描述预腐蚀疲劳缺口系数的两参数模型,并进行了试验验证。结果表明:LC4CS材料的疲劳缺口系数随预腐蚀时间呈现出先降后升的变化趋势,其拐点出现在剥蚀开始阶段。

关键词:预腐蚀;EXCO溶液;疲劳缺口系数;LC4CS;疲劳试验

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