A SYNTHESIED METHOD IN DURABILITY ANALYSIS

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Abstract

In this paper a synthesied method in durability analysis is proposed by combining the advantages of probability fracture mechanics analysis (PFMA) and definite crack growth analysis (DCGA). It provides not only crack's growth law as time of structural details under a certain relieability and degree of confidence but also the growth situation of leading crack. Thus, it could make us understand the damage situation exactly. It also improves the accuracy of durability analysis. By comparing with testing results, it has been proven to be in good accordance with those.

I. Introduction

Durability analysis is a important link in aircraft structral durability design. The durability analysis method will directly affects the precision of durability design. It is of great significance to improve the durabilityanalysis method.

At present, there are two methods used(1)(2) in durability analysis: probability fracture mechanics analysis (PFMA) and definite crack growth analysis (DCGA). In PFMA method, structral details as a whole are regarded as study object. Initial flaws existing in these details are assumed. Then based on this, the law of crack growth as time is established. Thus the structral durability is evaluated by determining the number of crack size greater than given crack size under given service time in the structral details. In DCGA method, it is based on damage tolerance, by determining the initial crack size with a certain possibility, and making it in accordance with initial equalent crack size of a given possibility, then the growth law of crack as time is studied. Hence, the structral durability is evaluated by determineing the the growth time frow initial crack size to critical size.

Obviousely, in the two methods above, the former one has a consideratin with all crack details, but it is blind to the leading crack growth. Thus it is disadvantageous to control the leading crack growth. Otherwise, the later one has a consideration with the leading crack growth, but it doesn't take the damage of crack detailes as a whole into account. So, it is unknown to the damage situation of the structre.

A synthesized method in durability analysis is thus developed by combining the advantages of the two methods above. In this method, not only is the growth of crack details as a whole considered, but also is the leading crack growth considered. So this method could avoid the disadvantages of PFMA and DCGA methods and improve the precision of durability analysis.

The synthesized method in durability analysis is also divided into two steps: ① determining structral initial crack size. This step is compatible with PFMA method. By means of IFQ model, building general EIFS distribution, making parameters optimization, determining the EIFS value of the structure, and using it as the initial value of DCGA method with a certain probability. ② determining the minimum macro-crack size, which could be accepted in engineering and observed easily in test. Taking the size as dividing point, the crack growth is divided into two stages. At first stage, the growth life is calculated by small crack growth fomula from the initial crack size to the minimum macro-crack size. At the second stage, the growth life is calculated by long crack growth formula from minimum macro-crack size to economical repairing limit size. In the calculation of crack growth life, by using crack growth parameters with a certain probability and a certain degree of confidence, the crack growth life is calculated from the initial crack size to the economical repairing limit crack size, and the number of details in which cracks surpassing the economical repairing limit size is also calculated. Hence, this method could be used to reach our aim.

In this paper, we adopt a multi-screw joined structure as example. (3) There are two arrangements of screw ranks: parellel arrangement and crisscross arrangement.

II. Determination of Initial Crack Size(4)

The initial fatigue quality (IFQ) of the multi-screw joined testing specimens is determined by 7 data collections and 5 different reference crack size. The specimen material is 7475 — T761 aluminium alloy. Only is one loading level considered. The stress level is 213. 8 MPa. The loading spectrum is a kind of simplified random spectrum, per 500 flight hours representing 9729 cycles. IFQ is indicated by EIFS. EIFS is not real crack existing in structral details. It could not be determined by non-damage detecting method. Therefore, EIFS distribution is often determined by reverse derivation from TTCI distribution when it is built by the fractographical data.

1. Determination of TTCI distribution

TTCI is the time when structral details reach to a given crack size under a certain loading spectrum . TTCI is a random varible ,it is concerned with loading spectrum and a_r. TTCI is subdued to three parameters Weibull distribution. Its accumulation distribution funtion is :

$$F_T(t)=1-\exp\{-[\frac{t-\varepsilon}{\beta}]^{\alpha}\} \qquad (1)$$

α is the shape parameter,

β is the proporitional scale parameter,

ε is the lowwer boundary of TTCI.

In the TTCI period , the small carck growth equation is

$$\frac{da}{dt}=Q[a(t)]^{b} \qquad (2)$$

Q, b are parameters independent on loading spectrum , structal details and material properties.

The TTCI average values are shown in Table 1.

a_r	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
PARALELL ARRANGEMENT	1934	2148	2299	2444	2592	2743	2883	3013
CRISSCROSS ARRANGEMENT	2350	2589	2772	2925	3051	3194	3336	3467

TABLE 1 THE TTCI AVERAGE VALUE OF SPECIMENS (UNIT: FLIGHT HOURS)

2. Determination of general EIFS distribution

Equvalent initial flaw size (EIFS) is a imaginary carck . It is determined by fratographic examination . It is a random varible . Its prbability density could be derived by TTCI probability . The accumulative distribution funtion is:

When b=1

$$F_X(x)=\exp\{-[\frac{\ln(X_u/X)}{Q\beta}]^{\alpha}\} \qquad (3)$$

When b>1,

$$F_X(x)=\exp\{-(\frac{X^{-c}-X_u^{-c}}{cQ\beta})^{-\alpha}\} \qquad (4)$$

It is obvious that as for each data collection, there would be a TTCI distribution and crack growth parameters, thus a correspondent EIFS distribution is determined. Because EIFS isn't relative to stress level, loading spectrum, but just relative to matericals and manufacturing quality, it must be generalized. Its general parameters are x_u, b, Q; β, α. By calculating TTCI accumulative distribution probability under different stress level, and checking a set closest to testing results, the best set as EIFS distribution parameters would be obtained.

Integrating formula (2) and letting $\tau=0$, the initial crack size will be got:

Parallel rank case is 5.70×10^{-2}mm, cross rank case is 4.26×10^{-2}mm.

III. Life Calculation of Crack Growth

1. Calculation of Stress Intensity Factor

Stress intensity factor is a very important content in crack growth life calculation. It's precision directly affects the life value. Hence, it is very necessary to choose a proper formula to calculate stress intensity factor.

In this paper , a analytic formula[5] fitted by infinite calculation results of Newman is adopted to calculate the stress intensity factor of the corner crack at hole edge. The formula is of high precision , and appropriate for engineering use. When the crack length along the hole is longer than 0.8 times of its thickness, the stress intensity factor is calculated by the formula of through crack .

2. Determination of crack growth parameters

Crack growth life not only varies of initial crack growth size, but also corcerns with the crack growth parameters. After the crack growth formula is determined, the determination of its parametes will be a important thing.

In calculation of long crack growth life, Walker formula is used. By meansof the methods provided in reference[6], the crack growth parameters under a certain reliability and degree of confidence, could be obtained.

The key contents of the method above are: ① within a given error limit,determing number of the minimum specimens demanded in evaluating parent percentiles; ② fitting da/dN $-\Delta k$ curve and p$-$da/dN$-\Delta k$ curve; ③ fitting the crack growth parameters with a certain reliability under a certain degree of confidence.

It is should be pointed out that the crack growth area of the specimens used to determine crack growth parameters shuold be as close as possible to that of crack durability analysis concerning.

3. Life calculation of crack growth.

Because of the property's differences between the small crack growth and the long crack growth, the crack gowth life calculation must be divided into two stages.

In this paper, 0.3 mm is used as the seperating point of small crack and long crack. From initial crack size to 0.3 mm is small crack growth formula used. From 0.3 mm to 1.0 mm is the long crack growth formula used. Then, the gross crack growth life is got by adding the two results.

1) Small crack growth life calculation

At present threr is not appropriate formula to calculate small crack growth life. Here, the formula (2) is adopted.

Making using of data of multi-screw joined specimens, the crack growth parameters are given as:

Parallel arrangement: $Q=1.1020\times10^{-3}$(1/hour)

Crisscross arrangement: $Q=9.7975\times10^{-4}$(1/hour)

Changing $da/dt=Q[a(t)]^{b}$ and integrating gives

$$t=t_1+\frac{1}{Q}\ln[a(t_1)/a_0] \qquad (5)$$

Thus , the crack growth life is calculated as:

Parallel arrangement: 1505 flight hours

Crisscross arrangement: 1911 flight hours

2) Long crack growth life calculation

Since the loading spectrum is random, the effects of loading seqence and stress rate must be considered in crack life calculation. Thus, in this paper, J. B. Chang model is used which gives considerstions to overload tardiness and minus loading acceleration.

According to Walker formula, using numberical integration method, the growth life from 0. 3 mm to 1. 0 mm is 26616 cycles, that is 1350 flight hours.

Adding the growth life values of small and long crack, the total crack growth life is obtained.

Parallel arrangement : 1505 + 1350 = 2855 (flight hours)

Crisscross arrangement : 1911 + 1350 = 3161 (flight hours)

Because the calculation is done under 50% reliability and 95% degree of confidence, so the life value is middle value.

IV. Conclusion

Through analysis above, we can conclude that the synthesized method is a appropriate and pactical method to make durability analysis. It not only provides the damage situation of strutral details as a whole, but also gives the leading crack growth value. It is of high precision. Table 2 gives the comparion of analytic values and testing results.

	ANALYTIC VALUES	TESTING RESULTS
PARALELL ARRANGEMENT	2855	3013
CRISSCROSS ARRANGEMENT	3261	3467

TABLE 2 COMPARION OF ANALYTIC VALUES AND TESTING RESULTS

It is obviously seen from Table 2 that the analytic values are very close to the testing results . So the synthesized method is a practical, exact and effective to be used in durability analysis.

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