FATIGUE CRACK PROPAGATION RATE OF ZG35 STEEL WITH SEMI-ELLIPTICAL SURFACE CRACK①

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ABSTRACT On a bowl body the occurrence frequency of surface crack which affectd the safety of the centrifuge has been evaluated scientifically. The growth rate of surface crack on the centrifuge bowl body(ZG35) has been determined, and the results of the experiment have been specifically analysed.

Key words growth rate surface crack centrifuge bowl body

1 INTRODUCTION

Because of the 3D characteristic of the surface cracks, a comparatively accurate stress-intensity factor equation is lacking. Thus it brings about difficulty to the study of surface crack growth rate. In 1981, Newman and Raju put forward a universally acknowleged and comparatively accurate stress intensity factor equation on basis of a large amount of 3D finite-element calculations[1].

$$K_{\rm I} = M_{\rm I}(\sigma_t + H\sigma_{\rm W})\sqrt{\frac{\pi a}{Q}} \quad (1)$$

$$(\frac{a}{c} \leqslant 1,\ \frac{a}{B} < 1,\ \frac{2c}{w} < 0.5,\ 0 \leqslant \varphi \leqslant \pi)$$

where

$$M_{\rm I} = [M_1 + M_2(\frac{a}{B})^2 + M_3(\frac{a}{B})^4] f_\varphi \cdot g \cdot f_w$$

$$M_1 = 1.13 - 0.09(\frac{a}{c})$$

$$M_2 = -0.54 + \frac{0.89}{0.2 + (a/c)}$$

$$M_3 = 0.5 - \frac{1.0}{0.65 + (a/c)} + 14(1.0 - \frac{a}{c})^{24}$$

$$g = 1 + [0.1 + 0.35(\frac{a}{B})^2](1 - \sin\varphi)^2$$

$$f_\varphi = [(\frac{a}{c})^2\cos^2\varphi + \sin^2\varphi]^{1/4}$$

$$f_w = [\sec(\frac{\pi c}{w}\sqrt{\frac{a}{B}})]^{1/2}$$

$$H = H_1 + (H_2 - H_1)\sin^P\varphi$$

$$P = 0.2 + \frac{a}{c} + 0.6\frac{a}{B}$$

$$H_1 = 1 - 0.34\frac{a}{B} - 0.11\frac{a}{c}(\frac{a}{B})$$

$$H_2 = 1 + G_1(\frac{a}{B}) + G_2(\frac{a}{B})^2$$

$$G_1 = -1.22 - 0.12\frac{a}{c}$$

$$G_2 = 0.55 - 1.05(\frac{a}{c})^{0.76} + 0.43(\frac{a}{c})^{1.5}$$

$$Q = \{E(k)\}^2$$

$$E(k) = \int_0^{\pi/2}[1 - k^2\sin^2\varphi]^{1/2}d\varphi,$$

$$k = (1 - a^2/c^2)^{1/2}$$

Being the second kind of complete elliptical integral, there is the empirical formula:

$$Q = 1 + 1.464(\frac{a}{c})^{1.65},\ (a/c \leqslant 1)$$

Equation (1) has been adopted by many defect evaluation standards home and abroad. Thus, with the aid of equation (1), suppose Paris relationship tenable, the crack growth rate at points A and B at the crack front (see Fig. 1) can be determined through experiment:

$$da/dN = C_A \Delta K_A^{n_A} \quad (2)$$

$$dc/dN = C_B \Delta K_B^{n_B} \quad (3)$$

where ΔK_A and ΔK_B are the stress intensity factor ranges of Points A and B.

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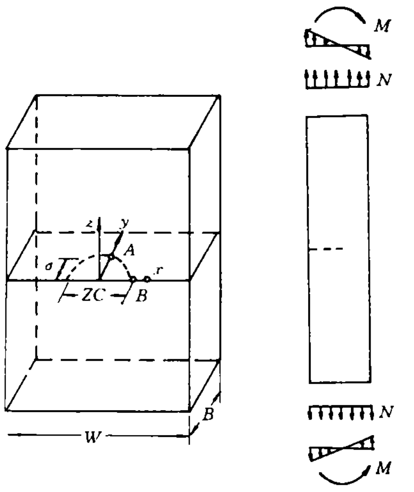

Fig. 1 Surface crack in a plate

According to a few results of experiment, Newman and some others imposed many restrictions on the constants in equation(2) and equation(3), i. e.

$$n_A = n_B = n \quad (4)$$

$$C_B = 0.9^n C_A \quad (5)$$

which have been adopted by many authors. In our opinion, because of the complication of the surface crack growth rate, the growth rates at point A and B are completely different, at the same time, equation(4) and equation(5) drawn from a few experimental results are not enough to show the universality. Therefore they should not turn to be the premise of our experimental study.

2 EXPERIMENT

2.1 *Specimen*

Cast a plate in the material(ZG35) identical to that of the centrifuge bowl body, after quench and temper, then made it into a needed size according to the state standard. The yield stress of the material has been determined to be $\sigma_{0.2} = 359.2$ MPa, and its ultimate stress $\sigma_b = 631.18$ MPa. Made some artificial cracks of various sizes as crack starter with the electric-discharge machine.

2.2 *Experimental Equipment*

The whole experiment was done under the American Material Test System (MTS), whose maximum load is 200 kN. Through repeated loading and unloading, the performance proved to be steady and the work went on smoothly. The maximun load, minimum load and numbers of cyclic loading were automatically displaied and recorded. An extra computer system was needed in addition to the whole experiment equipment.

2.3 *Experimental Process*

In the experiment, under the action of the bend cyclicloading, certain numbers of cyclic loading N_i as well as the corresponding crack length C_i and crack depth a_i were to be determined, while the accurate determination of the crack depth was the key of the whole experiment. Although many methods to determine the crack depth have been put forward at present, the method of lowering load marker is still regarded as a simple and reliable method. However, because the crack surface of ZG35 is rough, clear fatigue crack growth rate cannot be obtained by general method of lowering load marker. By trial and error, we have discovered that after load-lowering each time, soaked the cotton yarn with water and made the water be seeped into the newly cracked surface till fracture, thus, clear crack growth patterns could be shown, see Fig. 2. If some small amount of salt was put in the water, there would be an extraordinary effect.

Applying $P_{f\max} = 0.53\,\sigma_{0.2} \cdot (WB/S)$ to assess maximum load, maximum load should increase a littlee when the crack grew too slow. Using $R = P_{f\max}/P_{f\min} = 0.1$, when lowering load, average load maintained the same, load range went down by 2/3, load circulated 10 000～250 000 times.

2.4 *Sorted Out of Data*

Because, equation(1) is complicated, we make use of equation(2) and (3), and process data according to N_i, C_i, a_i determined in the experiment, then we have C_A, n_A, C_B and n_B. The work of numerical calcuiation is quitegreat. By using least square method and liner regression analysis, we worked out "The Surface Crack Analysis System Program-SCAS". Input all the effective specimen data (C_i, a_i, N_i) determined through experiment, specimen parameter (B, W) and load parameter ΔP to the computer, finally we get:

$n_A = 3.717\,708\,0$

$C_A = 0.281\,450\,1 \times 10^{-3}$

$n_B = 2.236\,972\,00$

$C_B = 0.202\,308\,6 \times 10^{-3}$

The above results of values have something to do with the unit of load, but they do not effect the expected result of the final fatigue life. the load unit here is K_N.

3 RESULT ANALYSES

(1) According to the result of the experiment, $n_A = n_B$, while

Fig. 2 Clear crack growth patterns

$$0.9^{n_A}C_A = 0.9^{3.717708} \times 0.281\,450\,1 \times 10^{-3} = 0.190\,234\,1 \times 10^{-3}$$

$$0.9^{n_B}C_A = 0.9^{2.236972} \times 0.281\,450\,1 \times 10^{-3} = 0.222\,353 \times 10^{-3}$$

if $n = (n_A + n_B)/2 = 2.977\,34$, then

$$0.9^{n}C_A = 0.9^{2.97734} \times 0.281\,450\,1 \times 10^{-3} = 0.256\,68 \times 10^{-3}$$

So, equation(3) is unsatisfactory, while equation(4) is tenable for the most part.

(2) When the specimen thickness $B \geqslant 16$ mm, after a certain amount of load circulation, there appears instable growth, see Fig. 2. In the state of instable growth, the crack depths a_c of six effective specimens are as in Table 1.

Table 1 The crack depths a_c of six effective specimens

number	1	2	3	4	5	6
Thickness B /mm	19.8	20	17.8	17.2	18	20
Depth a_c /mm	14.5	14	12.3	14.4	13	15
a_c /B	0.732	0.7	0.69	0.84	0.72	0.75

So, practically, for the bowl body with cracking under the action of alternating load in a long period of time, the appearance of instable growth of the crack is possible and cannot be overlooked.

(3) It is neither scientific nor practical that certain existing standards and technical requirements about centrifuges deny any surface cracks on bowl bodies of centrifuges. It is demanded to lay out a more scientific "Standards for the Evaluatlon of Centrifuge Defect" to make the design of the centrifuge laid on the basis of modern science and technology.

REFERENCE

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