A Study of Surface Crack Fatigue Propagation for BHW-35 Steel

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ABSTRACT

In this paper test results of BHW-35 steel concerning shape change and life of surface crack fatigue propagation were introduced.

KEYWORDS

Surface crack; fatigue propagation; safety assessment.

INTRODUCTION

Consider a structural component with through crack, the Paris relation (Paris et al., 1963) has been used commonly to describe the crack propagation:

$$da/dN = A(\Delta K)^m \tag{1}$$

Where a is half the crack length, N is the number of loading cycles, ΔK is the range of stress intensity factor, A and m material constants.

We can get the number of cycles from initial half crack length a_o to final half crack length a_e by integrating equ(1)

$$N = \int_{a_o}^{a_e} \frac{da}{A(\Delta K)^m} \tag{2}$$

As for a structual component with a plane surface crack, the surface crack is always assumed to be semielliptical with semiaxies a and c. The size and shape of the surface crack can be characterized by a and c, or more conveniently, by two dimensionless parameters a/t and a/c (t is the thickness of the plate). The shape (a/c) was always changing in the surface propagation. The change of shape would significantly affect the surface crack propagation rate. Therefore, it is very important to study the shape, life and the relationship between them of the surface crack. A great deal of work has been done and many research workers have addressed various solutions. One of them has adopted by "ASME BOILER AND PRESSURE VESSEL CODE" SECTION XI." The other solutions are adopted by other codes. There are grater difference among the results calculated by various methods. This needs further study.

EXPERIMENTAL INFORMATION

All the tests were conducted on a high frequency fatigue machine. All the tests were tension only, and the specimens used are snown in Fig(1). The initial notch was machined in the centre of the plate and extended by three points bending fatigue untill a total length 10mm was reached. The notch was aligned so that the crack growth was normal to the direction of rolling of the plate. The centre section was lightly polished to enable optical measurements of crack length in surface direction to be made.

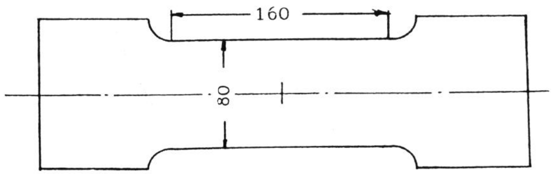

Fig. 1. The surface crack specimen geometry.

In order to leave the traces of a fatigue front line on the fracture surface. The so-called bèach marking methods was applied by keeping the average load at a given constant value and decreasing the range of load to half the given value. The surface crack propagation in surface direction in experiments was observed by the micrometer.

There is a plastic zone at the crack front when we applied a tensile load, if we unload, there is a closure load near the crack tip. This closure load resists the the crack propagation, if the tensile load is not enough to break the resistance, the friction will happen on the crack tip, and the dint will be made. The beach marking of the surface crack propagation is shown on Fig(2).

THE SURFACE CRACK FATIGUE PROPAGATION RATE

The surface crack fatigue growth rate can be described by Paris law. The first problem we should solve is the stress intensity fator of the surface crack. There is not any theoretical solution because of the complex three dimensional problems. The literature (FangYu-Yang, 1985) has summarised the sixteen surface crack stress intensity factor solutions, and Reju-Newman's solution (1979) be considered perfect.

$$K_I = (\sigma_t + H\cdot\sigma_b)\frac{F\sqrt{\pi a}}{\Phi}\left(\frac{a^2}{c^2}\cos^2\theta + \sin^2\theta\right) \qquad (3)$$

The range of stress intensity factor ΔK can be gotten in all directions using the equ(3). The surface crack growth rates in those directions can

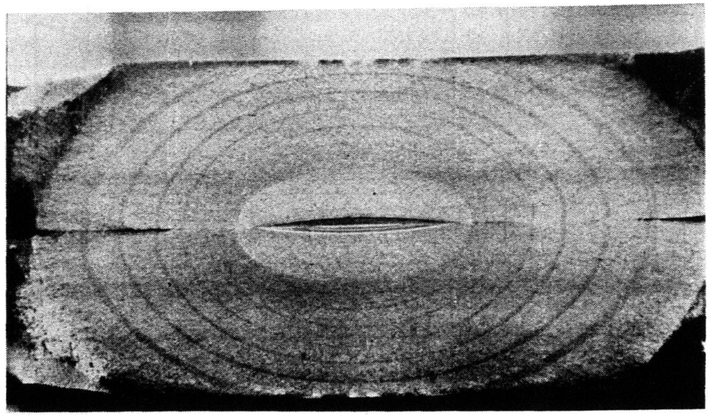

Fig. 2. The beach marking of the surface crack propagation

also be getten from the experiments. The Fig(3) and Fig(4) show the relationship between crack growth rate and the range of the stress intensity factors in surface and depth directions. We can see from the Fig(3) and Fig(4) the a log-log plot of the growth rate (da/dN) against the range of the stress intensity factor (Δk) was linear and can get the equations in depth and surface directions with the least square method.

$$da/dN = 1.08\times10^{-9}(\Delta k_a)^{2.50} \qquad (4)$$

$$dc/dN = 1.94\times10^{-10}(\Delta k_c)^{2.89} \qquad (5)$$

Where: Δk_a —— the range of the stress intensity factor in depth direction.

Δk_c —— the range of the stress intensity factor in surface direction.

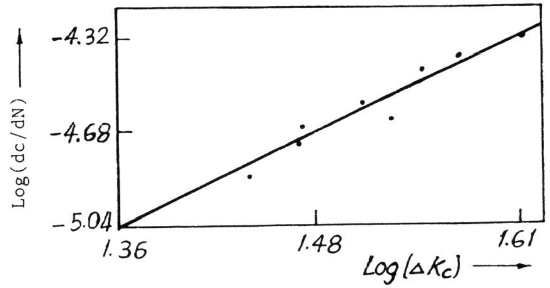

Fig. 3. The relationship between surface crack propagation rate and range of stress intensity fracture in surface direction.

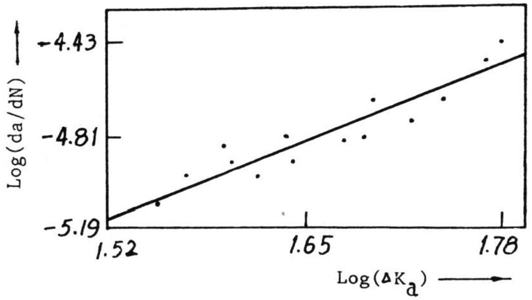

Fig. 4. The relationship between surface crack propagation rate and range of stress intensity fracture in depth direction.

We can gotten the Fig(5) combinating Fig(3) and Fig(4), and unique equ(6) using the least square method.

$$da/dN = 1.30\times10^{-9}(\Delta k)^{2.44} \quad (6)$$

The low line equation and high line equation can be shown as following:

$$da/dN = 9.95\times10^{-10}(\Delta k)^{2.44} \quad (7)$$

$$da/aN = 1.77\times10^{-9}(\Delta k)^{2.44} \quad (8)$$

The maximun deviation equal to 0.36

$$\delta = \{(1.77\times10^{-9}-1.30\times10^{-9}),(1.30\times10^{-9}-9.95\times10^{-10})\}_{max}/1.30\times10^{-9}$$
$$= 0.36$$

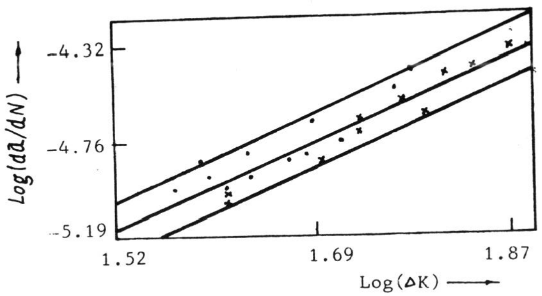

Fig. 5. The relationship between surface crack propagation rate and range of stress intensity factor
• experimental data in depth
x experimental data in surface

THE SHAPE CHANGE OF THE SHALLOW SURFACE CRACK

Fig(6) has shown the experimental shape change of the surface crack. There was not any crack growth in the surface direction at the begining of the crack fatigue growth for shallow surface crack. The crack growth in both directions happen when a/c was about 0.4. The a/c would increase because Δk_a in depth direction was greater than Δk_c in surface direction. The a/c would decrease when a/c was about 0.7 because Δk_a in depth direction was greatly affected by the back surface.

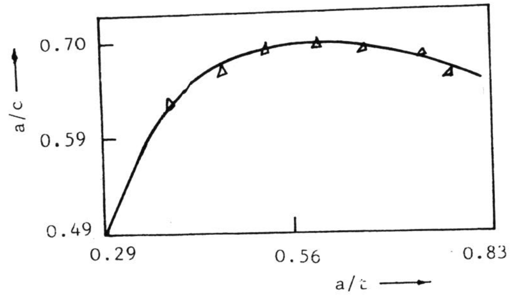

Fig. 6. The surface crack shape change.

Fig(2) has proved the assumption regarding the surface crack as semielliptical is correct. The shape change of the surface crack greatly affected the crack fatigue life, and much of work concerning the shape change of the surface crack has made. The literature (GauChong-Cha, 1985) has put forwards to a solution describing the surface crack shape change on assuming having same paris constants for the fatigue growth in depth and surface directions. Kawahara and Kunihara in Japan have summarised a greate of experimental data and proposed three empirical solutions for three kinds of surface cracks respectively.

Fig(8) has shown the comparision between results predicted by solution proposed by literature and our experimental data. Fig(7) has shown the comparision between results predicted by solution proposed by literature (Kawahara et al., 1975) and experimental data. The Fig(8) and Fig(7) have shown there was a certain of deviation between predicted results and experimental data. This was why the intensity factor in depth direction was largely affected by the back surface.

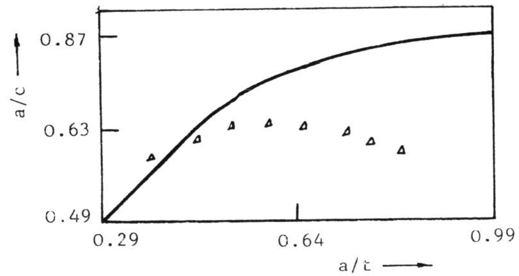

Fig. 7. Experimental data and predicted result by Kawahara.

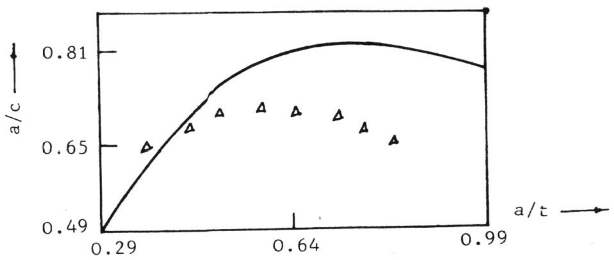

Fig. 8. Experimental data and predicted result by GauChong-Cha.

THE FATIGUE LIFE PREDICTION OF THE SHALLOW SURFACE CRACK

Some Codes of the pressure vessels have proposed the solution to calculating the fatigue life of the surface cracks. The solutions presented by the JWES-2805-1983 are more reasionable. It divided the surface cracks into three kinds and gave corresponding solutions. The surface crack fatigue life can be obtained above, and can also be obtained by definite integral. The table 1. provide two kinds of calculating results and experimental data, it has shown results predicted by JWES-2805 is more conservative.

Table 1. Fatigue life calculating results and experimental data

Specimen number	Range of stress	Initial crack dimension		Final crack dimension		Cycle number($\times 10^4$)		
	$\Delta\sigma/\sigma_Y$	a(mm)	c(mm)	a(mm)	c(mm)	N	N_1	N'
1	0.25	2.90	5.91	3.74	5.91	13.2	11.6	5.32
		3.74	5.91	4.54	6.83	10.0	9.78	3.22
		4.54	6.83	5.16	7.48	7.3	6.12	1.73
		5.16	7.48	5.90	8.48	7.1	6.35	1.65
		5.90	8.48	6.49	9.42	4.9	4.54	1.17
		6.49	9.42	7.28	10.72	5.2	4.63	1.15
		7.28	10.72	7.69	11.68	2.4	2.09	0.54
		7.69	11.68	8.27	12.97	2.7	2.57	0.76
		8.27	12.97	9.20	13.07	2.5	2.87	0.97
2	0.26	4.31	6.66	5.25	7.47	9.0	10.1	3.13
		5.25	7.47	6.14	9.10	7.5	8.61	2.40
		6.14	9.10	7.10	10.92	6.7	6.23	0.17
		7.10	10.92	8.64	12.96	4.1	6.91	0.21
3	0.27	3.91	6.72	4.95	7.51	7.7	12.7	4.79
		4.95	7.51	5.95	8.42	7.2	9.4	2.78
		5.95	8.42	7.03	9.96	7.0	8.4	2.23
		7.03	9.96	7.96	11.49	4.3	5.2	1.37
		7.96	11.49	9.12	13.60	3.8	4.4	1.25

N —— experimental data,
N_1 —— predicted results by definite integral,
N' —— predicted results by JWES-2805-1983.

CONCLUTION

The shallow and long surface crack made by BHW—35 steel would grow at the tensile fatigue load as a semielliptical. The shallow and long surface crack at tensile fatigue load have nearly same fatigue growth rate in surface and depth directions.

The solutions at present time describing the shape change of the surface crack have not much of agreement with the experimental data.

The solutions describing the surface crack fatigue life adopted by JWES-2805-1983 has enough safety.

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