Low-Cycle Fatigue of Notched Specimen under Biaxial Unsymmetrical Stress

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ABSTRACT

This paper reports prograss to date in the evaluation of methods for predicting low-cycle fatigue life and site of notched specimen under biaxial unsymmetrical stress.

Low-cycle fatigue tests have been performed using thin-walled tube specimens with two kinds of notch subjected to inphase torsion. Unsymmetrical stress state and stress-strain gradients exist in the notch root. Local biaxial stress-strain fields were determined by means of an elasto-plastic shell finite element model.

A new criteria based on equivalent stress and its gradient for predicting life and site to "crack initiation"(0.1mm sized cracks) has been proposed. The correlated results compared with the testing datas show an agreement.

I. Experimental Study

Until now, much research work has been done under the condition of simple loading or symmetrical stress field near notch root. Though practically, around the notchs of the components or specimen, its stress-strain field is complicated. No matter what the applied load is, the condition can be divided into two kinds, symmetrical and unsymmetrical stress. From experiments it is known that these two kinds crack initiation rules are different from each other greatly. For the later one, crack does not initiate at the place of the maximum stress. So choosing unsymmetrical stress field near the root of notchs to investigate elasto-plastic fatigue is more general for the cracking rules.

This experiment was done by way of unsymmetrical loading,i.e. use thin-walled tubes with circular holes and long holes as shown in Fig. 1 (a) (b), to bear the torsion. From the calculation it is got that the unsymmetrical stress field of the two kinds of notchs are quite different. For each kind, three loading ratios were chosen, R=-1,-0.5, 0.1. Among them, again R=-1 two loads, big and small were chosen. In this way, for the both kinds, altogather eight loading ways were used. The aim for it is to test the identify between the experimental result and the predication of theoretical criterion.

The experiment was done by using MTS809 testing machine. As the experiment was being carried out, the loading ratio was fixed and the crack initiation life was measured. After this, the specimens were restored and the cracking site angle θ and cracking direction were measured. The results are given in list 1.

List 1

notch pattern	Specimen number	turning moment M(Nm)	initiation life Ni	test cracking site θ°	calculating cracking site θ°
circular hole	A	-650-650	960	25	22.8
	B	-500-500	23000	33.8	30.1
	C	-300-600	7410	29.2	27.3
	D	65-650	69250	38.5	31.5
long notch	A	-500-500	8410	20.5	23.1
	B	-400-400	11080	26.6	25.9
	C	-300-600	3710	16.8	20.3
	D	65-650	26390	27.9	26.6

II. Investigation about Cracks Initiation

The stress-strain field of the notched specimens in the article was calculated with curved shell elasto-plastic finite element model.

The calculation was done by the IBM-PC family computer. The program was implemented by the author (It has been proved to be correct). The cyclic constitutive equation and cyclic yield stress used in the calculation comes from the result of cycle experiment in which the same material was used.

Since the cracking site of unsymmetical stress field does not appear at the site of maximun stress (or strain), the gradient of unsymmetical stress in plastic region affect crack initiation effect greatly. A reasonable criterion must be at least reflect the rules of cracking site and cracking lifetime. The article gives out the following criterion.

$$\text{Cracking site criterion: } \triangle R(S)=\triangle R_{max} \qquad (1)$$

$$\text{Cracking lifetime criterion: } \triangle R_{max}=A.(Ni)^{n} \qquad (2)$$

where S is arc-length coordinate of the notch boundary; A,n is material factor, Ni is initiation life, ΔR is called as fatigue growth stress. It is given by the following equation:

$$\triangle R= \Delta\bar{\sigma} - \frac{C}{\sigma_{max}}\left(\frac{d\sigma}{dr}\right)^2 \qquad (3)$$

the influence of stress gradient on "crack initiation" was considered. In formulation (3),$\Delta\bar{\sigma}$ is equivalent stress amplitude. C is notch parameter which is a constant area-coefficient for a given notch. In the article, A=125.95, n=-0.08685, C=0.80mm^2 for circular hole and C=1.20mm^2 for long notch. $d\sigma/dr$ is stress gradient in the normal direction of notch boundary.

The datas of two kinds of notchs are correlated with formulation (2), and shown in fig. 2. With the double-logarithmic coordinate, the data of eight kinds of loading situation in the neighbourhood of the straight line, precisly this shows that test datas accord with the cracking lifetime criterion.

Fig. 3 shows the relationship between R(S) and hole edge angle θ, where the angle θ corresponding to the maximum $\triangle R$

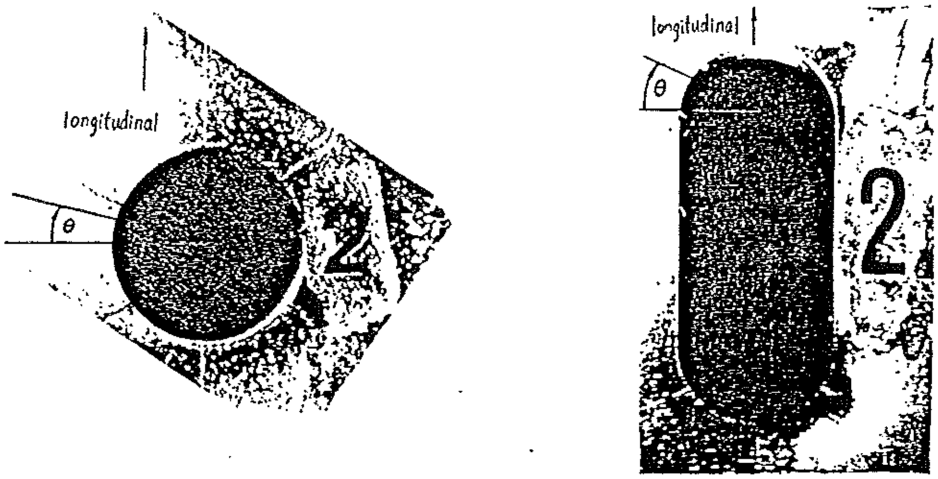
is the cracking site predicting by formular (1). The results are also given in list 1, and are compared with the experimental results. An agreement is found.

Thus, criteria (1) and (2) show that, under biaxial unsymmetrical stress (strain) the fatigue crack initiation site in a notched specimen corresponds the site where the growth stress ΔR reaches its maximum value and the initiation lifetime can be predicted by equation (2).

III. Conclusion

For the notched specimen, no matter the applied load is simple or complicated one, stress field around the notch can be divided into two kinds, symmetrical and unsymmetrical. The cracking phenomena of the two are different obviously. For the later one, the cracking site does not appear at the site of the maximum stress (strain).

For the low-cycle fatigue of the notched specimen under biaxial unsymmetrical stress, the maximum growth stress criterion is proposed here. The general influence of the stress gradient in plastic region has been taken into consideration. All the cracking site and cracking lifetime predicted in the criterion are the same with the result of the experiment. This can reflect the characters of the fatigue crack of the stress concentration component.



(a) circular hole (b) long notch

Fig.1

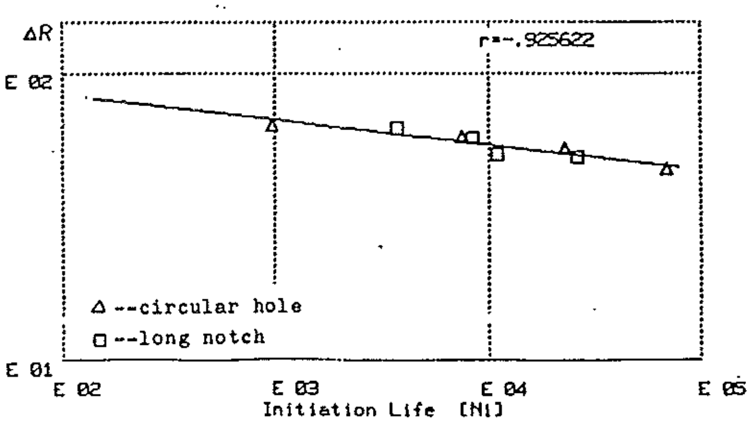
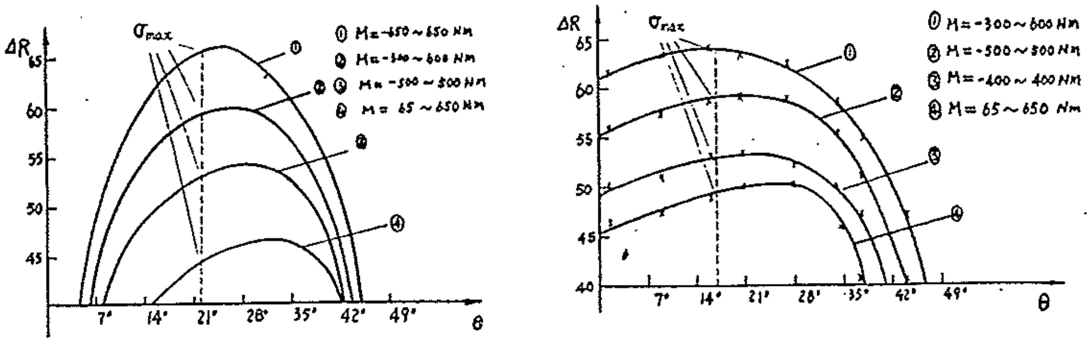


Fig.2



(a) circular hole (b) long notch

Fig.3