ŠÍRENIE POVRCHOVEJ ÚNAVOVEJ TRHLINY VO VEĽKÝCH ROPNÝCH PLOŠINÁCH

SURFACE FATIGUE CRACK PROPAGATION IN LARGE OIL PLATFORMS

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Abstrakt

Rast povrchových trhlín s výsledným, aj katastrofickým, zlyhaním zvarových spojov používaných na zariadeniach na voľnom mori je v posledných rokoch predmetom značného záujmu. Tento článok sa pokúša popísať, ako sa dá takáto porucha predpovedať použitím lineárnej lomovej mechaniky. Tento prístup vyžaduje dáta o únavovom raste trhliny pre materiály čela zvaru, zvarového materiálu, teplom ovplyvnenej zóny, zváraného materiálu ako aj koreláciu súčiniteľa intenzity napätia šírenia semi-eliptickej trhliny po povrchu a v smere hrúbky materiálu.

Kľúčové slová: povrchové trhliny, zvárané spoje, lomová mechanika.

Abstract

The growth of surface cracks with resulting, possibly catastrophic, failure in welded joints used for offshore purposes has been of considerable concern in recent years. The present report attempts to describe how such failure can be predicted using linear fracture mechanics. The approach requires fatigue crack growth data for the materials associated with a butt-welded joint, weld metal, HAZ, and parent material as well as a correlation for the stress intensity factor of semi-elliptical crack propagation both on the surface and in the through-thickness direction.

Keywords: surface craks, welded joints, fracture mechanics.

RESULTS A DISCUSSION

These and other properties were found for BS4360-50D, class 6 weld metal, and HAZ associated with the parent metal and weldment, as currently used for construction of North Sea oil platforms. The effects of stress ratio, loading frequency, specimen geometry, and salt-water environment were investigated. The stress intensity factor calibration for semi-elliptical cracks that gave the best correlation with the data from through-thickness cracks was found from the literature.

To obtain basic crack propagation data, tests were conducted on standard compact type specimens. Fatigue crack growth tests were also performed on surface-notched plates in bending. These tests covered the full subcritical range of growth rates from ΔK_{th} to high values of ΔK . The results showed that the growth rates of surface cracks in the weldment were higher than for the parent plate and that in general the fatigue crack growth rates increase with increase in stress ration and decrease in frequency. The use of an A.C. potential drop microgauge for crack depth measurements was also investigated. It was found that th variation of the digital voltage with crack

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depth is linear, and that increasing the gain results in a corresponding increase in sensitivity without affecting the linearity.

A model which can accommodate the fatigue crack propagation on the surface as well as for the crack in the through-thickness direction was developed to predict the growth of semi-elliptical cracks. The influence of initial flaw size on the shape and size of growing fatigue cracks was investigated, together with the effect of different width and thickness, using this model.

Finally an attempt was made to suggest ways to improve the fatigue properties of butt-welded joints. Preliminary tests showed that the technique developed to fabricate the butt-welded specimens reduced the rate fatigue crack growth when compared to the weldments fabricated by conventional methods.

A fracture mechanics approach was successfully applied in the investigation of surface crack growth in BS4360-50D low alloy structural steel and class 6 weld metal. This investigation differed from its predecessors in a number of ways. Both for the through-thickness direction and at the free surface, carck growth rates were obtained, the model proposed not being limited to fatigue crack propagation of the ddepest point alone; the crack both in the through-thickness direction and across the width can be accommodated.

Although the fields of fracture mechanics and of failure in thick plates ahve both been the subjects of active research at Imperial College for some years, attempts to describe the behaviour of surface cracks more accurately have been made only very recently. This investigation is one of the first and may perhaps be viewed as a forerunner in this field. Nevertheless, when compared with previous work on fatigue properties of low alloy structural steel, this investigation has provided considerable data on the surface crack behaviour of steel and weld metal used in the fabrication of North Sea oil platforms. This chapter draws together the main conclusions of the investigation, followed by recommendations of areas in which further work may be beneficial.

GENERAL CONCLUSIONS

The main conclusions drawn from this investigation are as follows:

1. The A.C: potential drop microgauge is suitable for crack depth measurements in a bending stress field. The main advantages of the microgauge are that it can measure the crack depth along the crack front for the surface notched plated tested and that its accuracy can be varied for different positions of the crack front by varying the gain value. Increasing the gain was found to increase the sensitivity of the microgauge without affecting the linearity of the digital voltage with the crack depth.
2. Fatigue crack growth rates are generally found to increase with increase in stress ration and decrease in frequency. The effect of stress ration is most pronounced at low growth rates, especially in the base metal and welded joints containing compressive residual stresses (i.e., CT geometry). At high growth rates and frequencies, however, no appreciable effect of stress ratio was observed for both HAZ and weldment. The effect of frequency in general was most significant at high stress ratios for a given frequency.
3. The stress intensity factor solution proposed by Koterazawa and Minamisaka for semi-elliptical surface cracks in a bending stress field was demonstrated to be a simple and fast way of finding the stress intensity factor range, ΔK , and was found to yield accurate data when compared with data obtained from compact-type specimens. However, the disagreement between the results for weldments obtained from different types of specimen tested was due to the different residual stress distributions produced by welding. When the sign and magnitude of the welding residual sstresses around the crack tip are unknown, the data obtained for surface-notched welded plates will be conservative, and no further deterioration factor need be considered to accound for tensile

mean stresses. However, if the welding residual stresses are compressive, the fatigue data for the base metal will be conservative. In this case it will be necessary to take into account the deterioration of these properties at high growth rates ($\rangle\, 10^{-4}$ mm/cycle) due to the existence of the tensile mean stress.

4. Upper bound for growth rates using SNP geometry in air

   $$\frac{da}{dN} = 2{,}3 \times 10^{-8} \left(\Delta K\right)^{3{,}2} \qquad \text{at 30 Hz,}$$

   $$\frac{da}{dN} = 1{,}35 \times 10^{-8} \left(\Delta K\right)^{4{,}2} \qquad \text{at 0,25 Hz.}$$

5. Crack growth rates can also be modelled from threshold to the high crack growth rate regime in terms of material fatigue properties:

   $$\frac{da}{dN} = A \left\{ \frac{\left(1 - R^2\right)\left(\Delta K^2 - \Delta K \cdot \Delta K_{th}\right)}{K_{1c}^2 \left(1 - R\right)^2 - \Delta K^2} \right\}^{\alpha},$$

   for BS4360-50D where $A_c = 4{,}69 \times 10^{-4}$, $A_a = 2{,}49 \times 10^{-4}$ a $\alpha_c = 1{,}00$, $\alpha_a = 0{,}94$ at 30Hz, and $A_a = 2{,}02 \times 10^{-3}$, $A_c = 1{,}43 \times 10^{-3}$ and $\alpha_c = 1{,}17$, $\alpha_a = 1{,}19$ at 0,25 Hz; for weldment using SNP geometry, $A_c = 5{,}22 \times 10^{-3}$, $A_a = 3{,}34 \times 10^{-3}$ and $\alpha_c = 1{,}26$, $\alpha_a = 1{,}23$ for 30 Hz, and $A_c = 7{,}08 \times 10^{-2}$, $A_a = 3{,}34 \times 10^{-2}$ and $\alpha_c = 1{,}48$, $\alpha_a = 1{,}65$ for 0,25 Hz. These results are confined to an air environment.

6. Using assumed values of initial flaw size, a prediction of the development of the shape of the surface crack in a bending sstress field was made; differing values for initial flaw size and shape, and geometric variables, were considered. The main conclusion drawn from these simulations is that initial elliptical flaws with low aspect ratio will cause earlier failure since they appear to develop to a stavble crack shape more quickly. This is the case assuming the initial aspect ratio is a function of crack depth, a, only. Considering the case in which the aspect ratio is a function of crack length, 2c, the converse is true.

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