CORROSION FATIGUE OF TUBULAR WELDED JOINTS

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ABSTRACT

A series of random load fatigue tests have been conducted on Tubular Welded T-joints in air and simulated sea water. These tests have provided data on crack shape evolution and shown that the crack depth growth rate in seawater can increase by from 2 to 6 times the equivalent air crack growth rates. These results confirm the prediction made from earlier precracked plate specimen test results.

KEYWORDS

Corrosion fatigue; seawater; tubular welded T-joints; fracture mechanics; crack shape; random loading.

INTRODUCTION

During the last seven years a large fatigue test programme has been conducted in the UK with the aim of providing information for designers concerned with the design of offshore platforms for the Northern North Sea. One of the areas studied was the problem of corrosion fatigue and this work included the effect of cathodic protection level, oxygen content, temperature, frequency, periodic immersion and pH. This work has been fully reported (1981) and has formed the basis for the New Fatigue Design Guidance notes to be issued by the Department of Energy (1983). The experimental work conducted in this programme was mainly based on precracked plate specimens and also welded cruciform specimens all manufactured from BS 4360:50D. The precracked specimens were used to provide data on fatigue crack growth rates in this material, the cruciform specimens were used to provide S/N curves. In general these tests showed that for fatigue crack growth tests the growth rate was influenced by the level of cathodic protection (enhanced growth rates of between 2 and 6 for CP in the range -0.85 to -1.1V) but that for fatigue life tests (the cruciform specimens) the CP level had little effect. The Guidance Notes appear to have been more influenced by the results from fatigue life tests and recommend for the free corrosion conditions for
RESULTS AND DISCUSSION

The four tests conducted were monitored to give details of the crack shape evolution but until all the tests are completed a full analysis will not be possible. A small fraction of the data already available is shown in Fig. 2 and this data was obtained from air and free corrosion tests conducted at a hot spot r.m.s. stress of 112 MPa and 106 MP respectively. It can be seen that the crack front is irregular and this partly stems from the fact that the very early crack growth stage was from a series of semi-elliptical surface cracks. It would appear that the corrosion fatigue test produced an even more irregular crack front than the air test. For both tests the average crack growth rate varied along the length of the crack and for the air test it would seem that the crack shape was growing towards a stable shape governed by the tubular joint geometry and the mechanical stress distribution. For the corrosion fatigue test the preliminary conclusion was that a similar characteristic crack shape was also being produced but that local distortion occurred probably due to variations in the electrochemical conditions. This aspect of the study will be considered in more detail after completion of the fatigue test program.

One of the problems encountered in this work has been the choice of the method for analysis of the data. For example from Fig 2 it can be seen that the crack depth does not have a unique value and instead one has to choose from say

(a) A point by point analysis along the crack front.
(b) A best fit curve through the data.
(c) An average depth over the deepest portion.
(d) The deepest measured point along the complete crack front.

Option (a) and (b) are currently being studied; (c) has been used previously but (a) is the method chosen for this paper. A further problem relates to the fact that several different r.m.s. levels have been used and two slightly different tubular dimensions. Thus for the purposes of comparison a non-dimensional analysis is required.

In earlier work (Dover, 1982) it has been suggested that the stress intensity factor for cracks in tubular joints may be deduced from an expression of the form:

$$K = Y(s) \sigma^{\frac{3}{2}}$$

(1)

where a is the crack depth and Y(s) is the calibration factor that takes into account the local stress redistribution that takes place during crack growth.

It was further suggested that if one used the Paris Law for this material:

$$\frac{da}{dN} = 4.5 \times 10^{-12} (2K)^{3.3}$$

(2)

then experimentally measured crack depth growth rates could be interpreted in terms of the effective stress intensity factor (K_{exp}).

If it is assumed that for any crack depth the value of K_{exp} can be determined then

$$Y(s) = \frac{K_{exp}}{\sigma^{\frac{3}{2}}}$$

(3)
and a plot of $Y(t) \times a/t$ would give the variation of the calibration factor with crack depth.

This non-dimensional plot would only hold for a particular geometry, type of loading and environment but should be independent of stress level, wall thickness etc. In the present case only the environment has been varied which means that any differences in the $Y(t)$ plot reflect the use of the wrong constants in Eq. (2). The $Y(t)$ if used for both, the air and corrosion fatigue data should indicate the influence of environment on the growth rate. Figure 3 shows the crack growth curve for the free corrosion fatigue test using the maximum recorded crack depth at each interval. This was the first corrosion fatigue test on a tubular joint and consequently the test conditions were modified periodically in order to determine the effect of frequency. The test was a random load test and the two frequencies were 1.69Hz and 0.169Hz. These are average frequencies based on range counting. In terms of da/dt the crack growth slowed down each time the frequency was reduced. For da/dt however the growth rate was higher at the lower frequency.

Figure 4 shows the crack growth curve for the test with the cathodic protection, again using the maximum recorded crack depth at each interval. The test was conducted at an average frequency of 0.169Hz throughout but after 300000 cycles the r.m.s. stress was reduced from 120 to 90 MPa. From Figs. 3 and 4 it can be seen that for the major part of the crack growth period tests on T-joints subject to out-of-plane bending but now appears to be a characteristic of all tubular joints and has led to the proposal of a bi-linear fracture mechanics model to describe fatigue crack growth in tubular joints (Dover, 1983). The behaviour is quite different from cruciform specimens where it is found that the crack growth rate increases rapidly as the crack becomes deeper. The data from Figs. 3 and 4 and the air tests reported earlier (Dover, 1981b) have been analyzed to produce the $Y(t)$ vs $a/t$ plot shown in Fig. 5. It can be seen that the high frequency portion of the free corrosion test and the air data tend to fall on one curve and that the curve fitted to this data can be described by the following equation:

$$Y(t) = 0.5 \frac{a(t)}{t^{0.46}}$$

(3)

The remainder of the data fail on curves above this air data indicating that the corrosion fatigue growth rate is higher than the equivalent air growth rate and that Eq. (2) is not applicable.

The free corrosion data can be fitted by the following expression. (Note that the data for the final portion of the free corrosion test at low frequency has been omitted from the analysis because it was felt that too few depths had been recorded.)

$$Y(t) = 0.59 \frac{a(t)}{t^{0.51}}$$

(4)

Finally the two portions of the data from the G.P. test have also been analyzed. The test period at 120 MPa gave the expression shown below.

$$Y(t) = 0.82 \frac{a(t)}{t^{0.50}}$$

(5)

The test period at 90 MPa gives almost a continuation of this curve but the data is not sufficient for a firm conclusion. Comparing expressions (3), (4) and (5) shows that for free corrosion the growth rate in a tubular joint is 2.1 times higher than the air whilst for CP at -1050V the growth rate is approximately 6x higher. These enhanced growth rates are similar to those predicted from precracked plate specimens (Thorpe, 1983) which means that the crack growth portion of the fatigue life of a tubular joint could probably be predicted from the data already available for a wide range of conditions. The results from UNDSRF I (Dept of Energy, 1983) showed that the crack initiation period could occupy between 10-60% of the life to chord wall penetration, depending on wall thickness and mode of loading. In general the percentage of life involved in crack initiation decreased as the chord wall thickness increased. Thus for a 75mm wall thickness T-joint, subjected to axial loading, the initiation period need only be 10%. For this worst case if one also used the most deleterious environmental condition, say CP at -1.05V, then the life to wall penetration would be reduced by a factor of 6x. Even with the correct CP or for free corrosion one would predict a reduction of about 2x.

These predictions, if confirmed, would seem to indicate that the Dept. of Energy Guidance Notes may need modification for use with tubular joints. The Notes are probably more relevant to Tee-but welds or cruciform joints rather than Tubular joints. The behaviour of cracks in these two types of component is very different. These initial results show that one should be able to predict tubular joint behaviour from the results obtained on precracked plate specimens. These preliminary findings can only be confirmed when the programme is completed. The remainder of the programme is to be funded by the Dept. of Energy.

CONCLUSIONS

1. It is now possible to monitor automatically fatigue crack shape evolution in both air and seawater tests on tubular welded T-joints.

2. Preliminary results from two corrosion fatigue tests on tubulars suggest that earlier precracked plate specimen test data could be used to predict the effect of environment on the fatigue crack growth behaviour in tubular joints.

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![Fig 1a & 1b](image)

![Fig 2. CRACK SHAPE COMPARISON.](image)

$f_{1} = 1.69 \text{ Hz.}$

$f_{2} = 0.169 \text{ Hz.}$

![Fig 3 CRACK GROWTH - Free corrosion.](image)
Fig 4. CRACK GROWTH - cathodic protection.

Fig 5. $\gamma_0$ v. $\theta/\tau$