# CORROSION FATIGUE OF STRUCTURAL STEEL IN ARTIFICIAL SEAWATER

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Experiments to verify the new model for corrosion fatigue of structural steel (FeE355-KT) in sea water, proposed by van der Wekken, are discussed. Crack length measurements performed with the potential drop method are shown to be reliable and accurate during corrosion fatigue tests in both air and sea water. The presence of a ∅2.2 mm hole in the compact tension specimen for inserting a micro pH-electrode, does not lead to different crack growth rates as a function of the stress intensity range $\Delta K$, if the effective width of the specimen is reduced by the diameter of this hole.

## INTRODUCTION

Corrosion fatigue may be defined as the combined effect of an aggressive environment and a cyclic stress during one or more of the progressive stages of damage accumulation that constitute fatigue failure. The combined effect leads to a crack growth rate, which is higher than the sum of the rates resulting from the individual mechanical and chemical influences.

An aggressive environment of special interest is sea water. Structural steels used for offshore structures are susceptible to corrosion in sea water. A new model describing the corrosion fatigue behaviour of steel in sea water has been proposed by van der Wekken (1-3). The basis of the model is an enhanced diffusion transport mechanism for $H^+$-ions towards the crack tip. At the crack tip $H^+$-ions are reduced and hydrogen embrittlement can occur. To study the model, corrosion fatigue experiments are performed on structural steel (FeE355-KT, according to Euronorm 113-72) in deaerated artificial sea water under anodic polarisation. During anodic polarisation $H^+$-ions are produced at the crack mouth and can be transported to the crack tip.

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Electrochemical conditions at the crack tip (pH and crack tip potential) can be determined by inserting a micro pH-electrode and a salt bridge into a central hole towards the crack tip, see figure 1. The model assumes a two dimensional problem and thus an infinite crack width. Therefore, the sides of the used compact tension specimen are covered with silicone shields in order to eliminate sidewards transport and to approximate the two dimensional model, see figure 1. This paper discusses the experimental aspects which have to be taken into account when verifying the model.

## EXPERIMENTAL SET-UP

Corrosion fatigue tests are performed on compact tension specimens made of FeE355-KT ($\sigma_{ys}$= 386 MPa and $\sigma_{uts}$=557 MPa) according to the ASTM E-647 procedure. Specific dimensions are W=100 mm, B=25 mm and H=60 mm. A chevron notch is used to facilitate crack initiation, see figure 2. Tests are performed in laboratory air, in aerated and in deaerated artificial sea water. Artificial sea water is prepared according to ASTM D-1141.

The crack length is monitored with the DC pulsed potential drop technique using two potential pick-ups $V_1$ and $V_2$. Optimal current input positions and potential probe positions were determined by means of the finite element method (4) and are given in figure 2. The generated potential differences in the compact tension specimen are of the order of 0.1 mV (4) and are assumed not to affect with occurring electrochemical reactions and vice versa. The following dimensionless polynominal for the crack length, a, divided by the specific parameter W, see figure 2, was obtained by optical calibration:

$$\frac{a}{W} = -0.0013 \cdot \left(\frac{V_1}{V_2}\right)^3 + 0.0263 \cdot \left(\frac{V_1}{V_2}\right)^2 - 0.275 \cdot \left(\frac{V_1}{V_2}\right) + 1.443 \qquad (1)$$

Crack tip solution pH and electrode potential can be determined in the following way. A ∅2.2 mm hole is drilled through the ligament of the compact tension specimen. From the back side of the specimen a micro pH electrode is inserted and from the front side of the specimen a micro salt bridge, see figure 2. To prevent sea water to enter the crack from the side of the specimen, silicone shields are attached to the side of the compact tension specimen.

The method for determining the crack growth rates da/dN is that used by Zuidema (4). Starting at a certain crack length $a_i$ (and corresponding number of cycles $N_i$), a distinct crack increment $\Delta a$ is defined, related to the experimental error involved with the potential drop apparatus. The first data point corresponding to a crack length larger than $a_i+\Delta a$, i.e. $a_{i+n}$, is used to calculate da/dN:

$$\frac{da}{dN}=\frac{a_{i+n}-a_i}{N_{i+n}-N_i} \quad \text{and} \quad \Delta a \approx a_{i+n}-a_i \tag{2}$$

The value of da/dN corresponds to a crack length of $(a_{i+n}+a_i)/2$. The procedure is repeated for all successive data points.

## RESULTS

### Influence of the Potential Drop Technique

Using the potential drop technique in air or in sea water it was found that the environment did not affect the measured ratio of the potentials, $V_1/V_2$. The accuracy of the obtained crack length data in sea water is comparable with the accuracy obtained in air. No evidence was found for an influence of the crack length measurements on the electrochemical reactions.

### Influence of the Hole for the pH-electrode

Tests are performed in air to investigate a possible effect of the ∅2.2 mm hole used for inserting the pH electrode. In figure 3 the crack growth rate da/dN is presented for tests on specimens with and without a hole (R=0.1, f = 30 Hz), as a function of ΔK. As can be seen from this figure, crack growth rates for a test specimen with a hole were about 8% to 10% higher compared to specimens without a hole. This increase is in agreement with the reduction of the crack area due to the presence of the hole (8.8%). Instead of calculating ΔK for a specimen width of 25 mm, a reduced width of 22.8 mm (original specimen width minus the diameter of the pH hole). In figure 3 da/dN versus ΔK using the reduced specimen width is shown. The crack growth rates for specimens with and without a hole are found to be almost identical if the "effective" width of the specimen is used.

### Influence of the Silicone Side Shields

Tests were also performed in air to see if there was any mechanical effect when silicone side shields were attached. Results are presented in figure 4. As can be seen from this figure no influence was found on the crack growth rate. However, in sea water first results show a rather large difference in crack growth rates found on specimens with and without silicone side shields: without shields the crack growth rates were about 10% higher. Although the silicone side shields have no mechanical effect, they certainly had an influence on the transport process.

## CONCLUSIONS

1. The potential drop method using two potential differences is a reliable and accurate method to monitor the crack length during corrosion fatigue testing in sea water.
2. The presence of a ∅2.2 mm central hole in the compact tension specimen for inserting a micro pH-electrode, does not lead to incorrect representations of the crack growth rate if $\Delta K$ is determined on the basis of a width of the specimen, decreased by the diameter of this hole.
3. No mechanical adjustments have to be made when silicone side shields are attached to the specimen.

## ACKNOWLEDGEMENT

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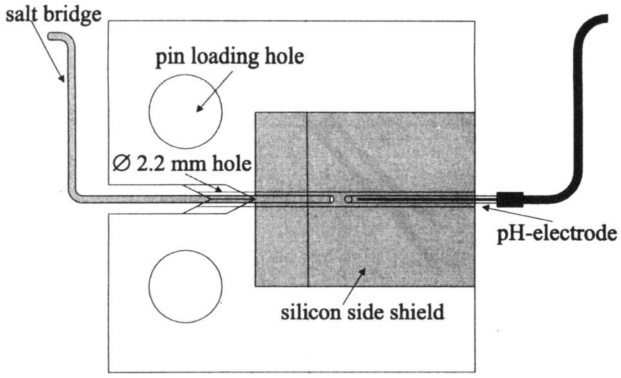

Figure 1 Representation of the compact tension specimen with silicone side shields, micro pH electrode and salt bridge to measure the crack tip potential

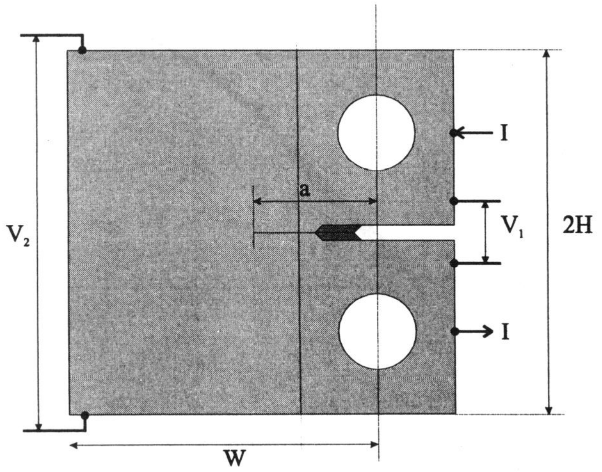

Figure 2 Compact tension specimen showing chevron notch, potential drop current input and potential probe positions

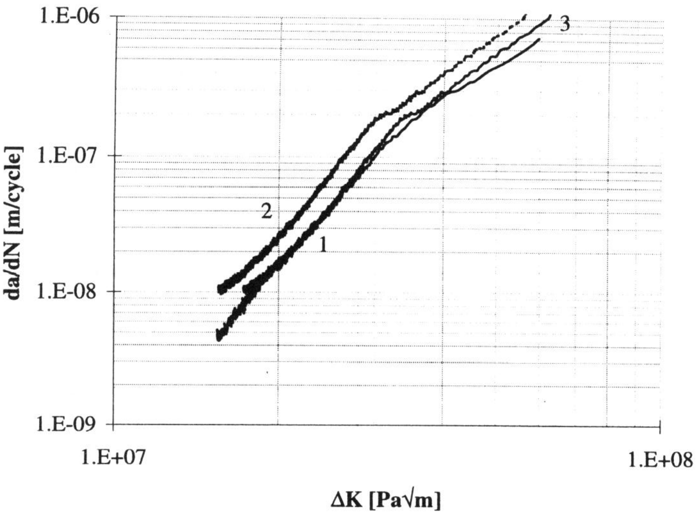

Figure 3 Influence of 2.2mm pH hole on the crack growth rate in air R=0.1, f=30 Hz: without hole (1), with hole (2) with hole and corrected width (3)

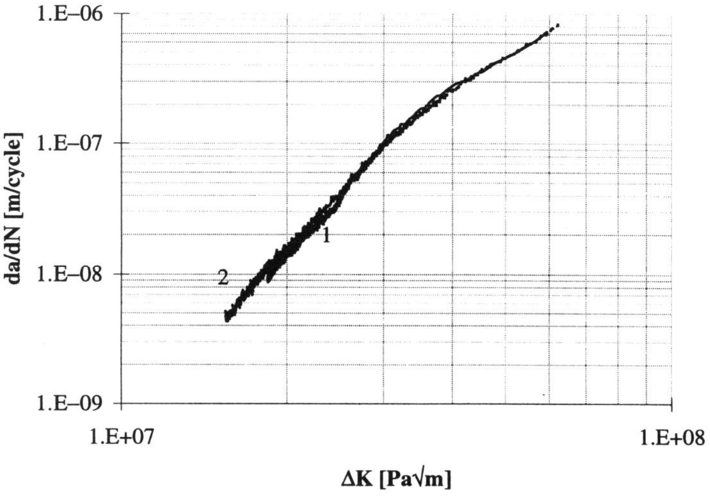

Figure 4 Influence of the silicone side shields on the crack growth rate of in air, R = 0.1, f = 30 Hz, without silicone shields (1) and with silicone shields (2)