ANALYSIS OF FRACTURE MECHANICAL TESTS FOR STRESS CORROSION CRACKING

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A superposition based method is developed to obtain environmentally assisted crack growth rate, $(da/dt)_{EAC}$. The method applies for fracture resistance curves determined in an environment with different loading rates i.e. rising load test results. Constant load test results can be analyzed in the same manner. The verification with AISI 4340 - seawater stress corrosion cracking test results shows that $(da/dt)_{EAC}$ determined from J–R-curves is practically independent from loading rate. Furthermore, the environmentally assisted crack growth rate seems to be the same for all test types.

INTRODUCTION

Fracture resistance curve testing (or rising load testing) for obtaining stress corrosion cracking data has become increasingly popular compared to more conventional fracture mechanical tests, i.e. constant load and constant displacement tests. Fracture resistance curves determined in an environment with a low loading rate have so far been used for attempts to determine a stress corrosion threshold stress intensity value, K_{IEAC}. Selecting the proper loading rate for a fracture resistance test to reveal susceptibility for stress corrosion cracking has proved to be problematic. The environmentally assisted crack growth rate, $(da/dt)_{EAC}$, for a material–environment-system has been determined using more time consuming constant load or displacement tests.

Recently an analysis method has been developed to obtain environmentally assisted crack growth rate directly from fracture resistance curves determined in an environment i.e. rising load tests (Karjalainen-Roikonen (1)).

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BASIS OF THE ANALYSIS METHOD

It is assumed, according to the principle of superposition, that the environmentally assisted crack growth rate and the crack growth rate due to mechanical loading are separable. The mechanical part of the crack growth rate can thus be subtracted from the total crack growth rate and the remaining part represents the environmentally assisted crack growth rate, $(da/dt)_{EAC}$.

$$\left(\frac{da}{dt}\right)_{EAC} = \left(\frac{da}{dt}\right)_{TOT} - \left(\frac{da}{dt}\right)_{MECH} \qquad (1)$$

The method for the analysis of J–R-test (rising load) results is schematically presented in figure 1. A more detailed description of the method is presented in (1). Constant load test results can be analyzed analogically to the fracture resistance curves because a constant load test is actually a test with increasing stress intensity factor, K_I, too. The mechanical crack growth rate for this type of test is naturally quite small. For both types of tests the method should, however, yield the same value for $(da/dt)_{EAC}$ that is measured in constant displacement test.

APPLICATION OF THE ANALYSIS METHOD

The method has been verified with two material–environment-systems taken from the literature: AISI 4340 – seawater (Mayville et al (2)) and Al 2024 T351 – seawater (Dietzel et al (3)). The results of the former are analyzed here. Original J–R-curves from (2) determined in air and in seawater with different loading rates are presented in figure 2, constant load and constant displacement test results from (2) in figure 3.

In the present analysis, first, the total crack growth rates for J–R-curves were calculated. Second, on the basis of fracture resistance curve in air, the crack growth rates due to mechanical loading were evaluated for each of the curves. Finally, according to equation 1, $(da/dt)_{EAC}$ values were determined. Using the same principle, the environmentally assisted crack growth rate $(da/dt)_{EAC}$ for constant load tests was calculated as well.

The total crack growth rates for J–R-curves, figure 4, show remarkable dependence on the applied loading rate. This is due to the mechanical crack growth rate which increases with loading rate. The environmentally assisted crack growth rate $(da/dt)_{EAC}$, determined from the fracture resistance curves, figure 5, is, however, practically independent of loading rate. This is the case even for a loading rate variation of two orders of magnitude. Analysis of the constant load tests yields the same plateau value of $(da/dt)_{EAC}$. Furthermore, both cases give values similar to those measured in the constant displacement test, figure 5.

The threshold value K_{IEAC}, from the J–R-tests, according to the plot $(da/dt)_{EAC}$ vs. J-integral, figure 5, is approximately 10 kJ/m^2 in a J-scale or about 46 MPa$\sqrt{m}$ as K_{IEAC}. This is less than half of the value given in (2). The value obtained here is nearer to those around 40 MPa$\sqrt{m}$ reported by Yokobori et al (4) for similar material–environment-systems with constant displacement test.

The analysis method seems to work for the evaluation of the environmentally assisted crack growth rate. This would suggest that not only the crack growth rates but also the mechanisms are separable. The estimation of the stress intensity factor threshold for SCC is more controversial. The application of the method to other systems is required before final conclusions can be drawn.

SUMMARY AND CONCLUSIONS

The superposition based analysis method enables the determination of the environmentally assisted crack growth rate $(da/dt)_{EAC}$ from J–R-test (rising load test) results. The obtained environmentally assisted crack growth rate is fairly independent of loading rate. The method is equally well suitable for the analysis of constant load test results. Both test types yield the same $(da/dt)_{EAC}$ plateau value, which is similar to that measured in constant displacement test. The method sets all three test types on the same line. The use of the analysis for getting the stress intensity threshold value from J–R-curves is controversial.

ACKNOWLEDGEMENTS

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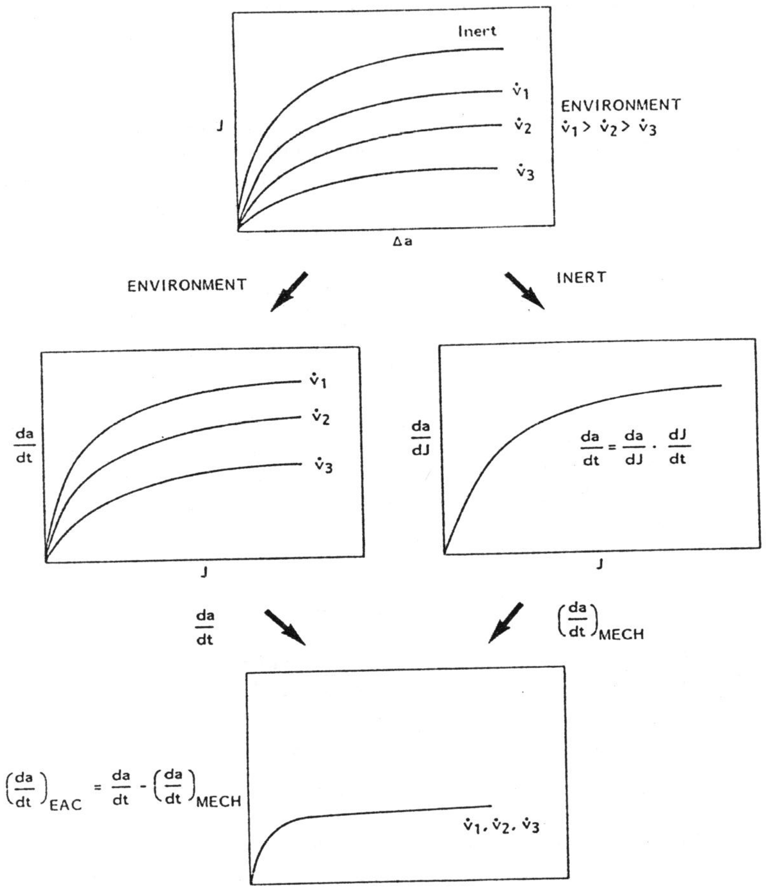

Figure 1 Schematic presentation of the analysis method for obtaining $(da/dt)_{EAC}$ from J–R-curves determined in an environment with different loading rates.

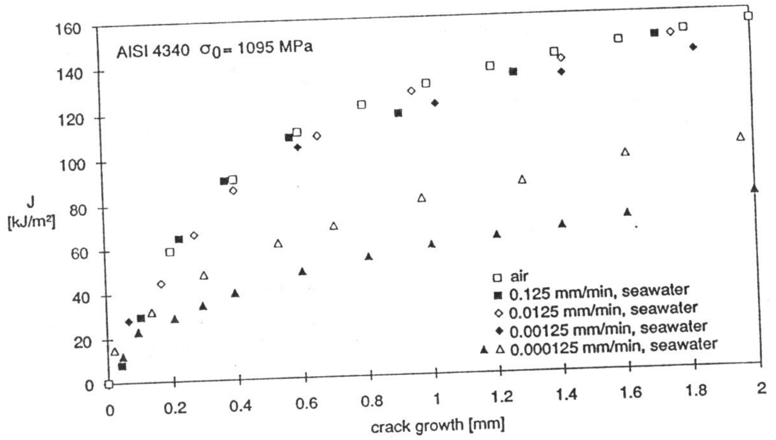

Figure 2 J–R-curves for AISI 4340 determined in air and in seawater with different loading rates, from (2).

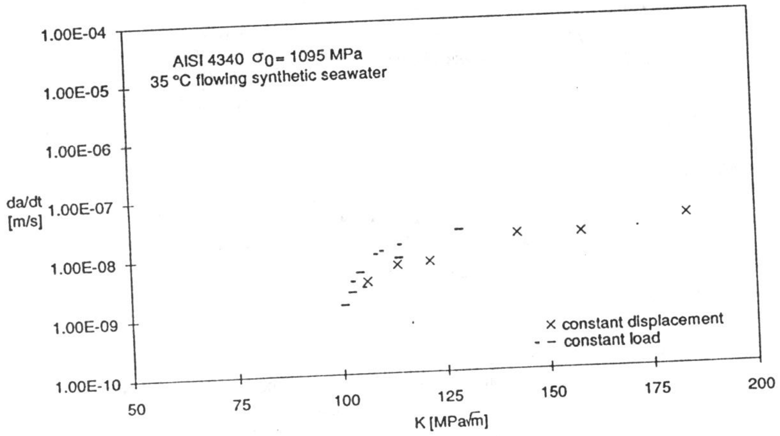

Figure 3 Constant load and constant displacement test results for AISI 4340 in seawater, from (2).

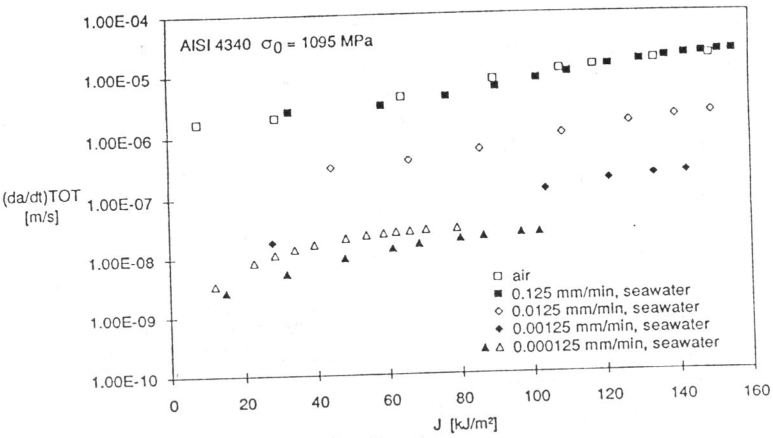

Figure 4 The calculated total crack growth rates for J–R-curves in fig. 2.

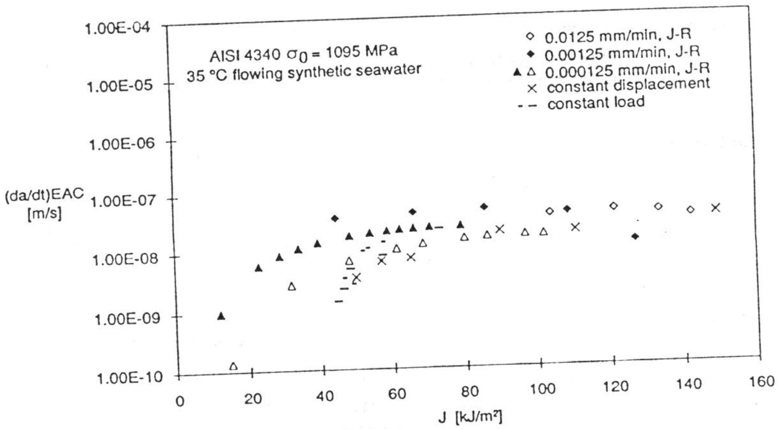

Figure 5 The $(da/dt)_{EAC}$ determined from the J–R-curves, fig. 2, and constant load tests, fig. 3, compared to the measured values of CMOD test.