Fracture 1977, Volume 2, ICF4, Waterloo, Canada, June 19 - 24, 1977

FATIGUE CRACK GROWTH IN STEEL IN AIR AND SEA WATER UNDER CONSTANT AMPLITUDE AND RANDOM LOADING

P. J. Haagensen*

INTRODUCTION

Fatigue crack propagation data has been accumulated, in recent years, in ever increasing amounts for various materials. However, much of the data comes from tests that are carried out at relatively high stress amplitudes giving crack propagation rates that correspond to short fatigue lives. In addition, most of the published data is obtained at constant amplitude loading which is quite different from the type of loading experienced by actual structures in service conditions. In fixed offshore structures, which have a design life of 30-50 years, most of the fatigue damage is caused by low to medium stress amplitudes [1], ($10^8 \leq N_f \leq 10^{10}$). Very little data is available for this life range and there is a 3-4 log cycle spread between the various S-N design curves [2], [3].

The lack of design data in the high-cycle part of the S-N curve, for steels in sea water is due to the fact that reliable corrosion fatigue results can only be obtained from tests that are carried out at the same frequencies as those experineced by the actual structure. This, however, imposes severe limitations on the amount of data that can be generated because of the long testing times involved. Typical North Sea waves have a frequency of approximately 0.17 Hz. Nineteen years would be required to obtain one data point on the S-N curve at 10^8 cycles! For welded structures, the dominant part of the fatigue life is spent in propagating a crack-like defect to the critical crack size. In this case it is possible to compute the life, N, by integration of crack growth relations of the form

$$\frac{da}{dN} = f(\Delta K) \tag{1}$$

In particular, Paris' equation

$$\frac{da}{dN} = C(\Delta K)^m \tag{2}$$

where C and m are material constants, is often used to predict life.

The purpose of the present investigation was to establish fatigue crack growth data for a type of steel, in a corrosion environment, that is a candidate material for offshore structures. The effect of irregularly varying stress amplitudes was also studied.

---

*SINTEF (The Foundation of Scientific and Industrial Research at the University of Trondheim), Trondheim, Norway.

MATERIAL AND TEST CONDITIONS

The test peices were made from a medium strength carbon steel, details of which are given in Table 1.

Single Edge Notch (SEN) specimens, with a cross section of 15 mm by 60 mm, were used. Two specimens in series were tested at the same time in a Schenk electrohydraulic closed-loop fatigue machine. A machined notch, 20 mm deep and 3 mm wide, was sharpened by electroerosive machining to give a slot at the root of the notch that was approximately 2 mm deep and 0.25 mm wide. The notch was further sharpened by fatigue loading in air at 20 Hz prior to testing in sea water. The reference crack growth tests in air were also carried out at 20 Hz.

Due to limitations imposed by the random noise generator/narrow band filter set, all tests in sea water were carried out at 6.5 Hz. The random loading was of the narrow band type with a Rayleigh distribution of peak amplitudes. The test section of the specimen was surrounded by a plexiglass test chamber through which aerated natural sea water was circulated. All tests were performed with a mean stress level of 240 MPa.

The crack lengths were measured visually with a 60 power microscope mounted on a micrometer screw. Crack length measurements were also made with a clip gage, mounted across the notch opening, using compliance calibration curves. The agreement between results obtained by the two methods was excellent.

EXPERIMENTAL RESULTS

The recorded a vs. N data was transformed into da/dN vs. ΔK data by two different methods. The "manual method" involved fitting a curve to the given data, by eye, and subsequent fitting of tangents to this curve. The other method consisted of fitting a second order polynomial to five consecutive data points by the use of a computer program utilizing least squares regression. The results of the two methods are compared in Figure 1. All test results are summarized in Figure 2 using ΔK_{rms} as a basis for comparison.

DISCUSSION

The data given in Figure 2 seems to confirm Barsom's test results [4]. There is no large difference in crack propagation rates obtained from tests with constant amplitude loading and from those with variable amplitude loading when they are conducted in air (at least for da/dN > 10^{-6}). A similar conclusion can be made based on the data obtained from the tests in sea water. The results thus confirm that the average fatigue crack growth rates under constant amplitude and under random loading may be described by one equation with da/dN as a function of ΔK_{rms}, as in the Forman equation [5]. The effect of corrosion seems to be fairly strong at low values of da/dN, and no threshold is apparent in the sea water test results.

CONCLUSIONS

Due to the fact that there is large scatter in the test results caution is indicated in their interpretation. However, there does not appear to any major effects due to the variable amplitude loading. The effect of corrosion is large at low crack propagation rates. The data obtained from the tests in sea water does not show any tendency to reach a threshold.

ACKNOWLEDGEMENT

This paper is band on a preliminary investigation which was conducted as a part of a continuing research project dealing with fatigue of offshore structures. The financial support of the Royal Norwegian Council for Scientific and Industrial Research and the participating companies are gratefully acknowledged.

REFERENCES

1. MARSHALL, P. W., Proceedings, Welding in Offshore Construction, Welding Institute, Cambridge, 1974, 10.
2. API Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, API RP 2A, 4th ed., 1972.
3. AWS Structural Welding Code, AWS D1.1, 1972.
4. BARSOM, J.M., American Society for Testing and Materials, ASTM STP 536, 1973, 147.
5. FORMAN, R. G., et al., Trans. ASME, J. Basic Eng., Series D, Vol. 89, No. 3, September 1967, 459.

Table 1 Chemical and Mechanical Properties of the Test Material

Element, weight %								σ_y	σ_f	ε
C	Si	Mn	P	S	Al	Nb	Ce	(MPa)	(MPa)	
0,17	0,26	1,38	0,036	0,006	0,047	0,052	0,015	444	586	0,33

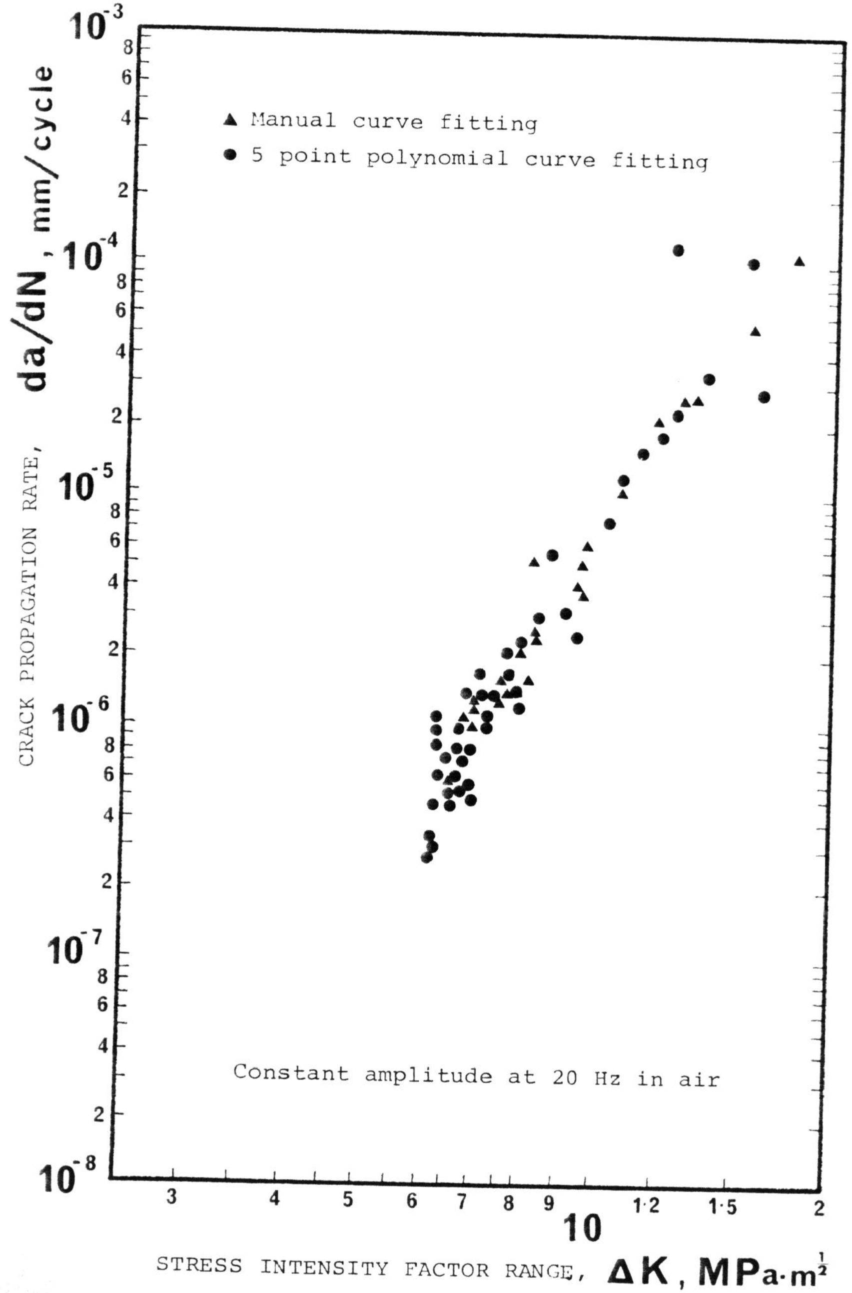

Figure 1 Crack propagation rate as a function of stress intensity range.

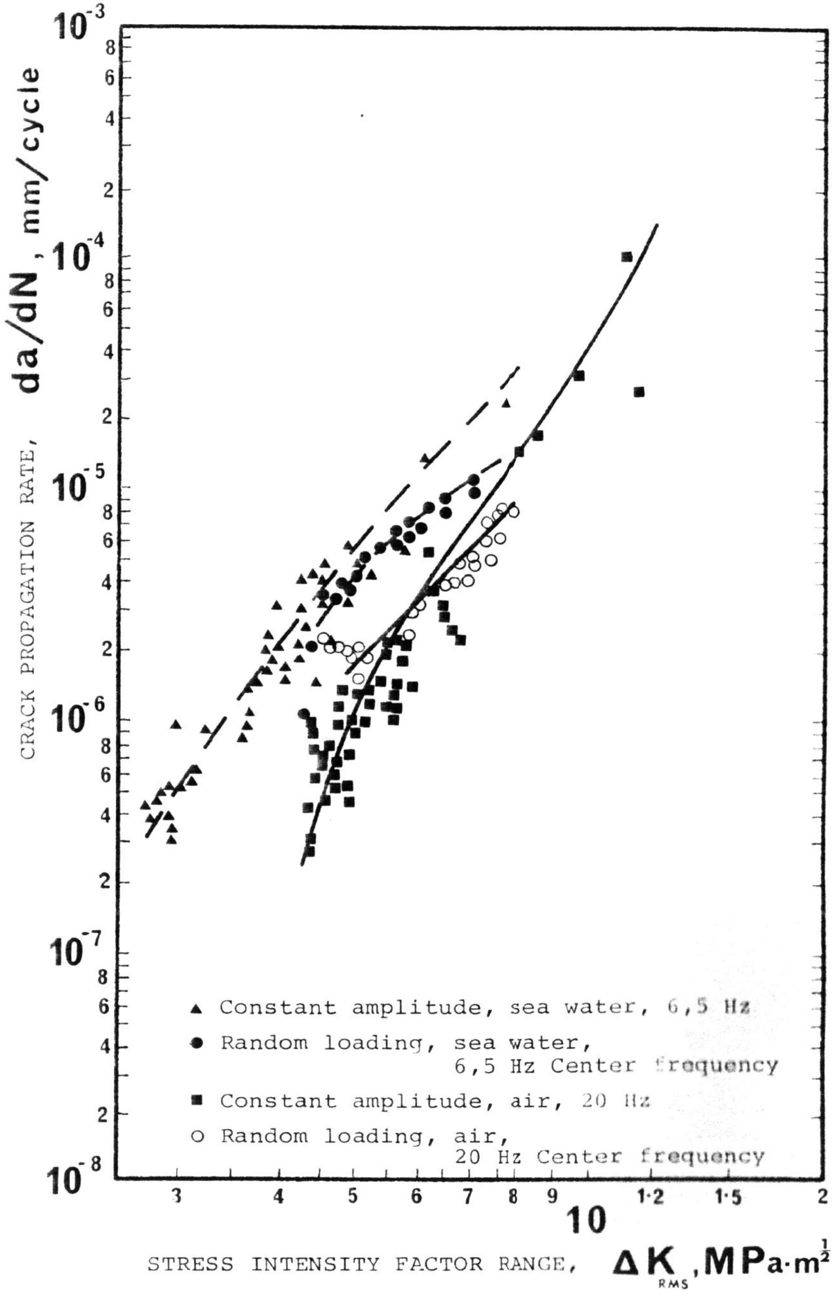

Figure 2 Crack propagation rate as a function of stress intensity range