# FATIGUE CRACK GROWTH BEHAVIOUR IN AIR AND SEA WATER OF GS13MnNi6.4 WELD JOINT FOR OFFSHORE STRUCTURES

K. MATOCHA AND M. TVRDÝ
*VÍTKOVICE – Research and Development*
*70602 Ostrava 6, Czech Rep.*

## INTRODUCTION

The design of large steel welded offshore structures must necessarily take into account the risk of failure by corrosion fatigue because the sea is both the aggressive environment and the principal source of cyclic stresses through wave action [1]. By the joint action of cyclic loading and aggressive environment ( sea water ) fatigue crack growth rate can be accelerated significantly. The welded joints will provide the most likely initiation sites for corrosion fatigue crack growth because of the concentration of stress and the prior existence of crack-like defects.

Fatigue crack growth behaviour in steel/seawater environment system can be influenced by many factors which can be separated into:

1. mechanical factors ( cyclic frequency, waveform, R ratio and $\Delta K$ ).
2. environmental factors ( water temperature, electrochemical potential )
3. metallurgical factors ( chemical composition , microstructure )

In this paper the effect of artificial sea water at laboratory temperature on fatigue crack growth behaviour in Paris law region of GS13MnNi6.4 weld joint ( base material, HAZ, weld metal ) has been studied. As a cathodic protection is a part of the overall corrosion protection system of the offshore structures [2], the effect of cathodic polarization ( -1000 mV vs. the Ag/AgCl electrode ) on fatigue crack growth behaviour in sea water has also been investigated.

## TESTING MATERIAL AND EXPERIMENTAL PROCEDURE

The cast plate 80 mm thick was used as a welding base metal. The chemical composition of the steel, the production of cast plates and their heat tratment are described in detail in [3]. The welding material was chosen concerning the wire and the flux. The wire was of ø 4 mm , represented by the OK Autrod 13.27, AWS A 5.23.80:EN2. The flux chosen was OK Flux 10.26, AWS A 5.523-80F8 A10 – F7 P10-ENi2-Ni2. The technology was submerged arc welding, the products were of ESAB Vamberk. The tensile properties of base metal and weld metal are shown in Tab. I.

**Tab. I Tensile properties of the studied weld joint at laboratory temperature**

| | $R_e$ [MPa] | $R_{p0.2}$ [MPa] | $R_m$ [MPa] | A [MPa] | Z [MPa] |
|---|---|---|---|---|---|
| Base material | 408 | | 571 | 21 | 51 |
| Weld metal | | 434 | 547 | | |

Centre cracked plate specimens were used for the investigation of fatigue crack growth behaviour of base material, weld metal and coarse grained heat affected zone.

All tests were carried out according to the ASTM standard [4] on INOVA 100 kN servohydraulic testing machine at a constant load range, with an R ratio of R = 0 and a sinusoidal loading waveform. Testing in artificial sea water was carried out using local environmental cells. The cells of plexiglas, provided with a rubber sealing, were attached to both sides of the test specimen and fixed by means of elastic clamps. The lengths of the fatigue cracks were measured optically with an accuracy of 0.01 mm.

## RESULTS AND DISCUSSION

Results of fatigue crack growth rate measurements have been plotted against $\Delta K$. The effect of laboratory air on fatigue crack growth behaviour is shown in Fig. 1. The materials follow a Paris laws over $\Delta K$ investigated with an exponent m = 3.25 (base material), m = 3.09 (HAZ) and m = 2.86 ( weld metal ). However, no significant differences were found among fatigue crack growth behaviour of the base material, course grained heat affected zone and weld metal ( $v_{HAZ}/v_{BM}$ ~1.3 , $v_{WM}/v_{BM}$ ~ 1.4 in the range of $\Delta K$ investigated ). Fig. 2 summarizes the results obtained in artificial sea water. At these tests the increase in crack growth rates, compared with air, was observed first of all in HAZ.

The appearance of corrosion fatigue crack growth behaviour is in general conformity with the stress corrosion cracking under cyclic loading [5] and is characterized by

1. Occurrence of a dynamic threshold $K_{ISCC(f)}$ ~ 12 $MPa.m^{1/2}$.
2. Occurrence of two periods characterized by different dependencies of fatigue crack growth rate on $\Delta K$.

At the first period ( when the threshold $K_{ISCC(f)}$ is reached ) fatigue crack growth rate is dependent on $\Delta K$. At the second stage the crack growth rate starts to be independent on $\Delta K$ untill it reaches the crack growth rate in air.

The effect of cathodic polarization ( -1000 mV vs Ag/AgCl electrode ) on fatigue crack growth behaviour in artificial sea water is summarized in Fig. 3. The appearance of da/dN vs. $\Delta K$ dependence is again in conformity with the stress corrosion cracking under cyclic loading. In spite of the fact that cathodic polarization was not found to affect the dynamic threshold $K_{ISCC(f)}$ and fatigue crack growth rates in the second stage , it was found to affect significantly crack growth behaviour in the first stage. However, in this range of $\Delta K$ fatigue crack growth rates in a base metal are significantly lower compared with those in weld metal and HAZ.

Fractographic analysis of the fracture surfaces produced by the fatigue crack growth in artificial sea water exhibited both fractographic features typical for cyclic loading of cast steels in air and transgranular quasicleavage areas. No intergranular fracture mode was observed.

The enhancement of fatigue crack growth rates in artificial sea water , compared with air, can be attributed to hydrogen embrittlement of microvolumes ahead of the propagating crack front. Cathodic polarization increases the hydrogen concentration ahead of the crack tip. Due to the extent of plastic zone into which the flow of hydrogen atoms is rectified, the cathodic protection affects first of all the first stage of da/dN vs. $\Delta K$ dependence obtained in water environment.

## CONCLUSIONS

From the study of fatigue crack growth behaviour in air and in artificial sea water of GS13MnNi6.4 weld joint it follows:

1. No significant differencies were found in Paris law region among fatigue crack growth behaviour in air of base metal, course grained heat affected zone and weld metal.
2. The appearance of corrosion fatigue crack growth behaviour in artificial sea water is in general conformity with the stress corrosion cracking under cyclic loading.
3. Cathodic polarization has affected first of all the fatigue crack growth behaviour in weld metal and course grained heat affected zone.
4. The enhancement of fatigue crack growth rates in artificial sea water, compared with air, can be attributed to hydrogen embrittlement of microvolumes ahead of the propagating crack front.

## REFERENCES

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GS13MnNi6.4 weld joint
cast plate 80 mm in thickness
laboratory temperature
centre cracked plate specimens,W = 60 mm, B = 3 mm
R = 0, sinus, f = 1 Hz

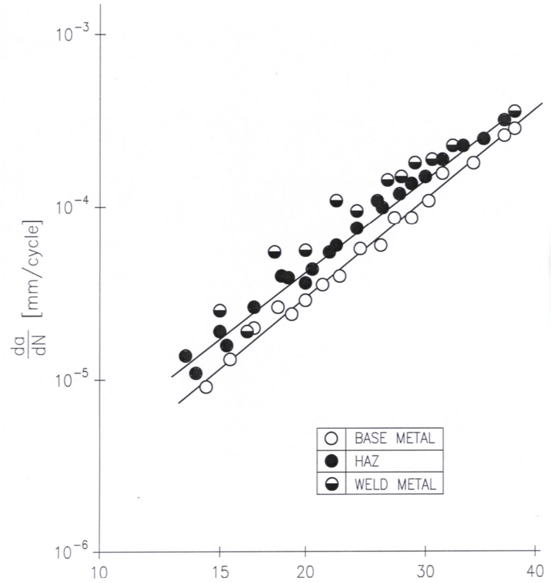


**Fig.1 Fatigue crack growth** behaviour in air

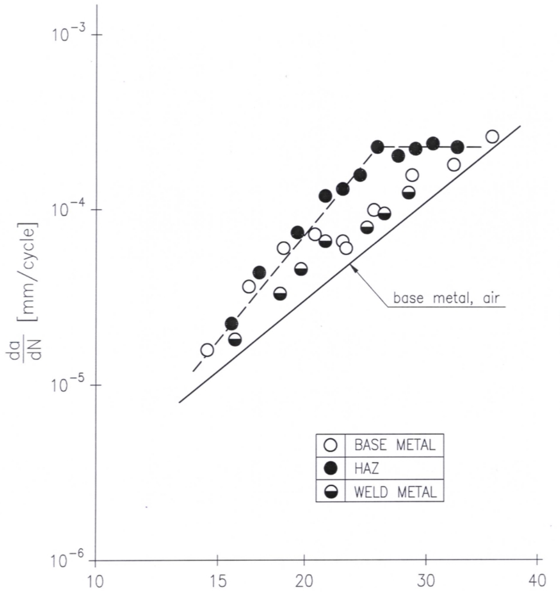


**Fig.2 Fatigue crack growth** behaviour in sea water

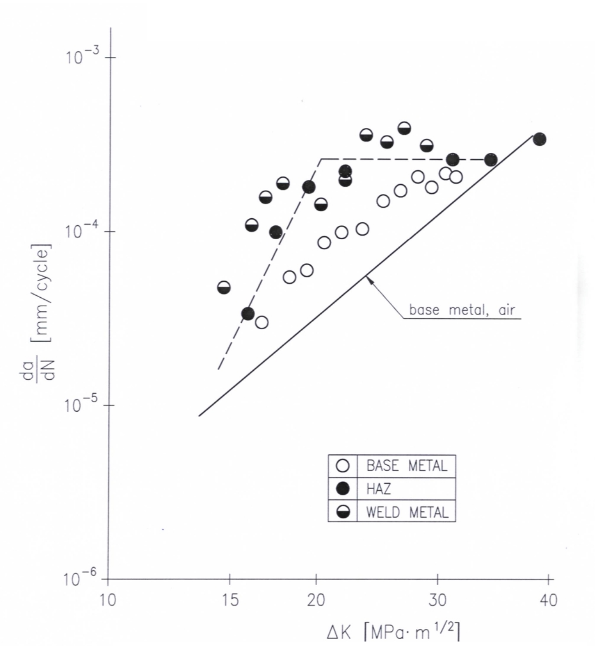


**Fig.3 Fatigue crack growth** behaviour in sea water under cathodic protection (-1 V)