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ENVIRONMENTAL STRENGTH EVALUATION OF WELDED STEEL JOINT IN SEAWATER

PART I : CORROSION FATIGUE CRACK GROWTH BEHAVIOUR FOR HIGH CYCLE

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A study on corrosion fatigue was experimentally conducted for the as-welded and PWHT specimens of the steels, HT80 and SM53B in 3.5% NaCl solution. Submerged arc welding was done. PWHTwas carried out at comparatively high temperature of 650° C. Besides, in order to simulate the residual stress in weld HAZ, the stress of 98MPa was applied during PWHT. Corrosion fatigue crack growth was dependent upon the materials and PWHT conditions. In the case of HT80, crack growth in corrosion environment was faster than that in air. However, the crack growth of the main crack for SM53B in 3.5% NaCl solution was decreased in comparison with that in air,unlike HT80. The sensitivity to corrosion environment was reduced due to PWHT. The applied stress in HAZ during PWHT acted to enhance the crack growth compared with that of the PWHT specimen without stress.

Key Words: Post Weld Heat Treatment (PWHT), Heat Affected Zone (HAZ), Corrosion Fatigue, Stress Intensity Factor Range, Crack Growth Rate, Secondary Crack.

1. INTRODUCTION

Post weld heat treatment(PWHT) of the weldments is carried out to remove the triaxial residual stresses and improve the fracture toughness in welds. It is well known that temper embrittlement depends on PWHT conditions, applied stresses during PWHT and microstructure(Lim, 1987). Speidel and Wei(1972) indicated that corrosion fatigue was an important fracture phenomenon for the structures. However, the data of PWHT specimens and the as-welded in corrosive environment are scarce. To establish the design criteria based on the fracture mechanics in designing weldments under the aggressive conditions mechanically and environmentally, it is necessary to evaluate the environmental effect of crack propagation in weld HAZ, and more data are needed.

In this study, the effects of PWHT and stress simulating the residual stress during PWHT in weld HAZ for SM53B and HT80 steels on corrosion fatigue crack growth were evaluated experimentally.

2. EXPERIMENTAL PROCEDURES

The materials used in this experiment were two steels, SM53B and HT80. Table 1 shows the chemical composition and mechanical properties obtained at room temperature. 4mm depth, 60°v grooves were machined perpendicular to the rolling direction of the plate, and submerged arc welding was conducted.

Figure 1 represents the locations of specimens which were oriented transverse to the welding direction, and centered on the fusion line. PWHT was done under the following conditions;temperature of 650℃, heating rate of 220℃/hr,holding time of 1/4hr, cooling in furnace. To simulate the residual stress, the stress of 98 MPa was applied to the HAZ during

Table 1 Chemical compositions, and mechanical properties

(a) Chemical compositions(wt %)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Ti	SolAl
SM53B	0.16	0.46	1.44	0.02	0.05	–	–	–	–	–	–	0.29
HT80	0.106	0.26	0.83	0.016	0.005	0.20	0.74	0.46	0.43	0.042	0.018	–

(b) Mechanical properties

	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
SM53B	413.5	560.5	27
HT80	760.4	828.1	24

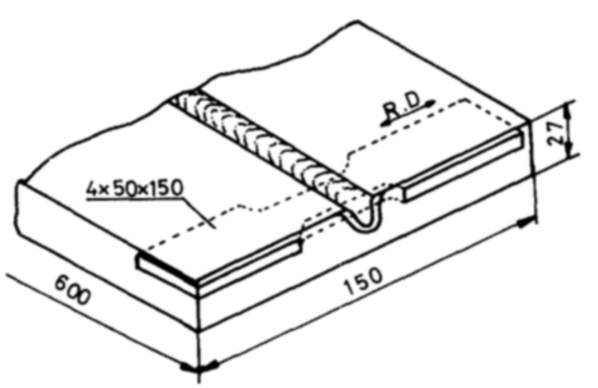

Fig. 1 Welding plate configuration and extraction of specimen

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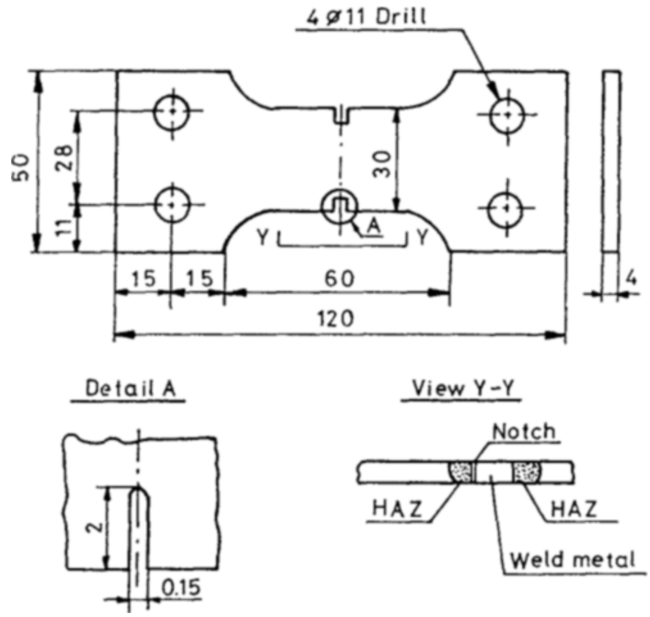


Fig. 2 Specimen dimensions and notch position for fatigue test

PWHT. Double edged notches (2mm) located on the fusion line were machined with the cut-off wheel of 0.15mm width as shown in Fig. 2.

The cyclic loading was provided by the out of bending fatigue machine with the cyclic frequency of 30 Hz. The specimens were tested under zero to tension. The applied stress to the center cross section was 196 MPa. When the corrosion fatigue testing was conducted, 3.5% NaCl water solution passed through the acryl cell at a flow rate about 200 ml/min. The measurement of crack growth was performed with the optical microscope($\times 40$).

3. RESULTS AND DISCUSSIONS

Figure 3 and Figure 4 are the semilogarithmic plots of crack growth rate (da/dN) and stress intensity factor range (ΔK) for the as-welded and parent of SM53B as well as HT80 steels in air. The value of K was calculated using the following equation proposed by Bowie(1967). $K = 1.005\sigma_b\sqrt{a}$. Where, σ_b, applied stress, a ; crack length. Regardless of SM53B and HT80, crack growth rate of the as-welded in air is slower than that of the parent. Kapadia(1987) reported that the compressive residual stress in HAZ resulted in reducing the crack growth rate in comparison with that of the base metal. Figure 5 represents the crack propagation path of the as-welded and the base metal for SM53B. However. The discontinuities of microstructure and irregularities of mechanical properties in HAZ make the crack propagation path complex, so it is reasonable to regard that the reduced crack growth in HAZ is due to the compressive residual stress as well as singularities in welded region.

Figure 6 shows the behaviour of corrosion fatigue crack growth for the as-welded and parent of HT80, including the air data. Crack growth rate of the parent and as-welded in 3.5% NaCl solution is increased in comparison with that in air. Besides, the maximum acceleration factor of (da/dN) corrosion/(da/dN) air for the as-welded is about 2, while that for the parent 1.5. This result can be explained by the

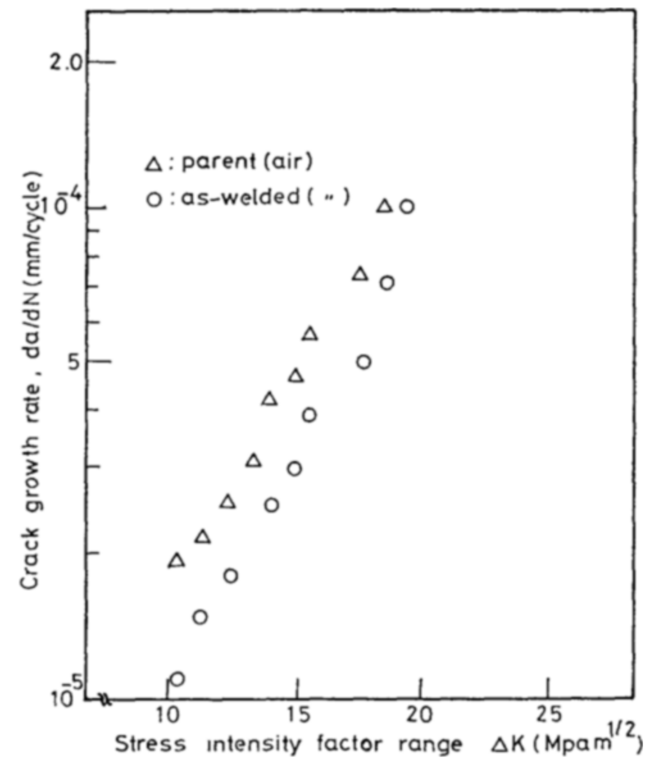


Fig. 3 Crack growth behaviours for SM53B in air

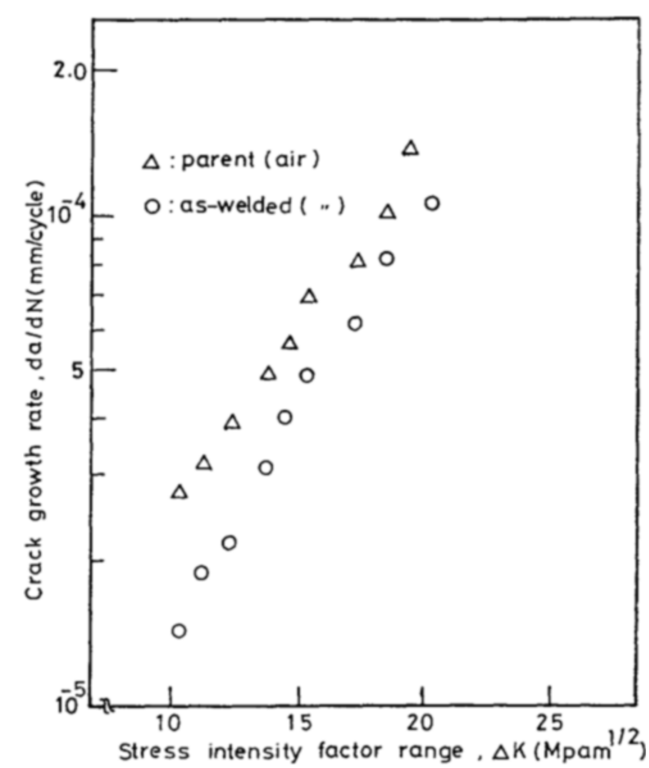


Fig. 4 Crack growth behaviours for HT80 in air

following facts. The microstructures of martensite and pearlidte formed at the welded region were very sensitive to corrosion environment. Besides, the microdefects of the welded region in corrosion environment cause to produce the local electric potential difference which promotes the corro-

(a) Parent

(b) As-welded

Fig. 5 path of fatigue crack propagation for parent and as-welded (SM53B)

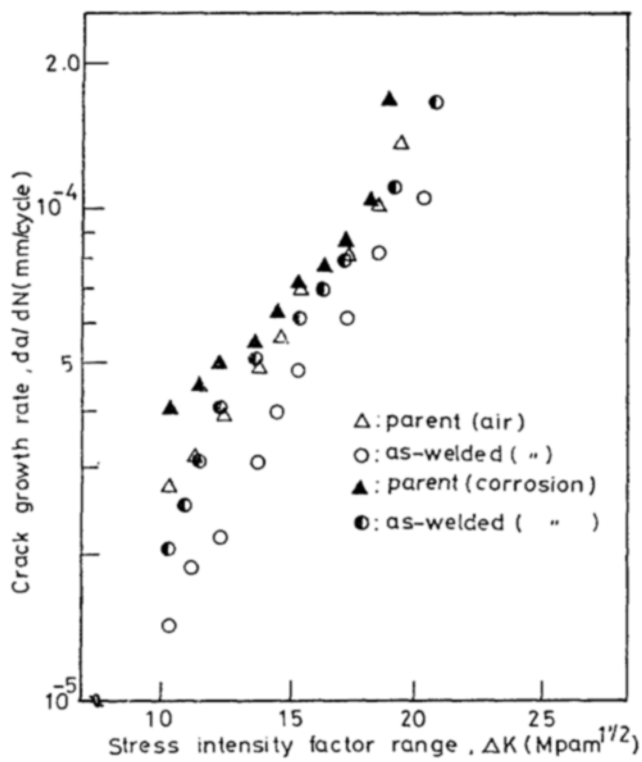


Fig. 6 Corrosion fatigue crack growth for parent and as-welded (HT80), including the air data

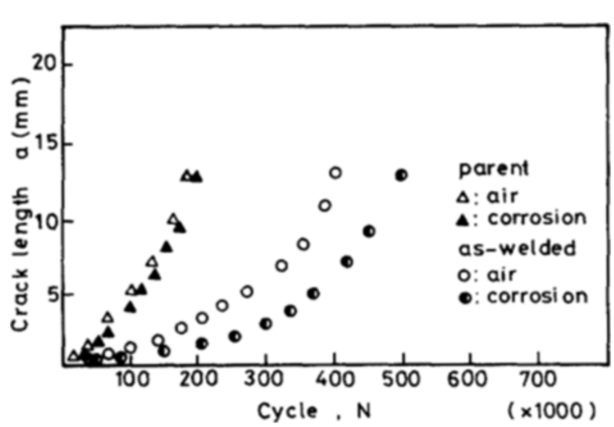
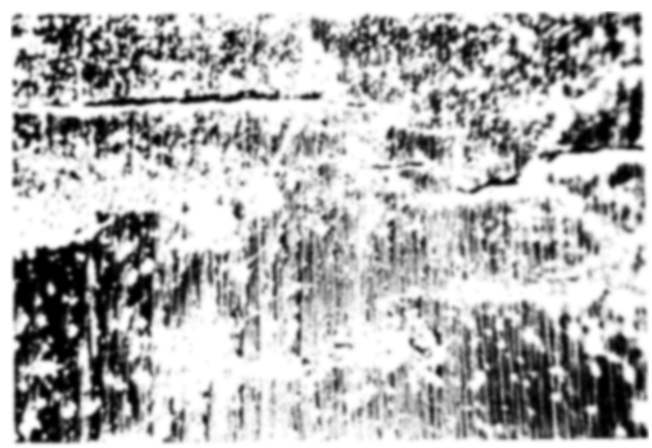


Fig. 7 Crack length versus a number of cycles for parent and as-welded of SM53B

(a) Parent



(b) As-welded

Fig. 8 Behaviour of crack growth for parent and as-welded in 3.5% NaCl Solution

sion rate remarkably. Figure 7 is the crack growth length versus a number of cycles for the as-welded and parent of SM53B in 3.5% NaCl solution and air. In this case, since it is meaningless to estimate the corrosion fatigue behaviour based on the stress intensity factor range because of the irregular branched cracks and secondary ones which are formed around the main crack, as shown in Fig.8, unlike HT80, the data was plotted on the *a-N* curve. In case of the parent, fatigue life for propagation of the main crack in 3.5% Nacl solution is a little longer. However, that for the as-welded in corrosive environment is considerably increased compared with the air data. These results are different from the past works(Davis, Czyryca, 1983) on the corrosion fatigue which showed that corrosion fatigue crack growth was faster than that in air generally. Figure 9 represents the relationship between da/dN and ΔK for the specimen (HT80) subjected to PWHT. Crack growth rate of the PWHT specimen in corrosive environment increases a little at the low ΔK region. That behaviour is different from the data of the as-welded mentioned above. From this result, it is considered that the improvement of microstructure in HAZ according to PWHT results in the reduction of the sensitivity to corrosive environment. Figure 10 shows the crack length versus the number of cycles for PWHT specimens without stress and with stress of 98MPa(SM53B) during PWHT. In

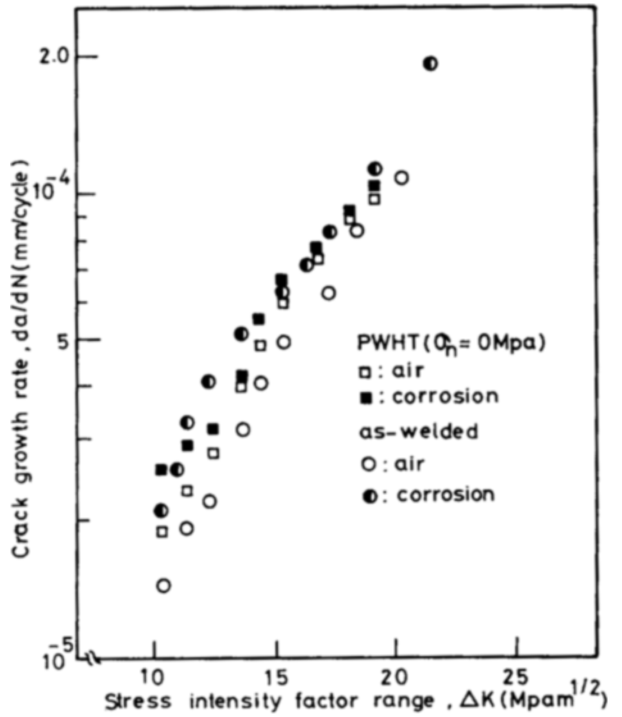


Fig. 9 Behaviour of corrosion fatigue crack growth for as-welded and PWHT Specimen (HT80) including the air data

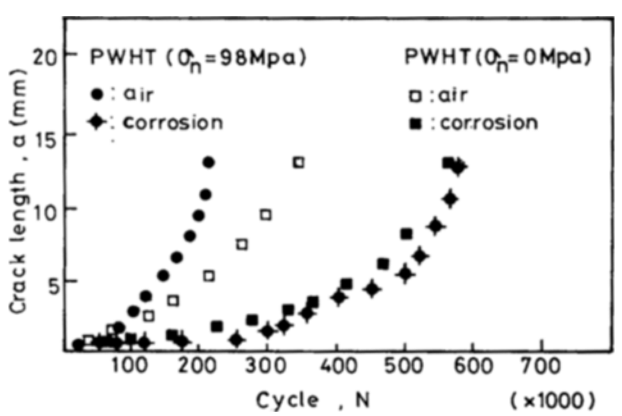


Fig. 10 Crack length versus a number of cycles for PWHT Specimens without stress and with stress of 98MPa(SM53B) during PWHT

the case of the data at ambient air, fatigue life for the PWHT specimen with stress of 98 MPa is decreased compared with that for the PWHT one without stress during PWHT considerably. Besides, fatigue life in 3.5% NaCl solution is increased in comparison with that in air. This tendency was similar to the result of the as-welded in corrosive environment. In the meanwhile, fatigue life for two PWHT conditions in corrosive environment is almost same, unlike the ambient air data. This means that applied stress during PWHT causes to increase the crack growth in weld HAZ in corrosive environment.

Figure 11 shows the behaviour of corrosion fatigue crack growth for the PWHT specimens (HT80) without stress and subjected to 98 MPa during PWHT, including the air

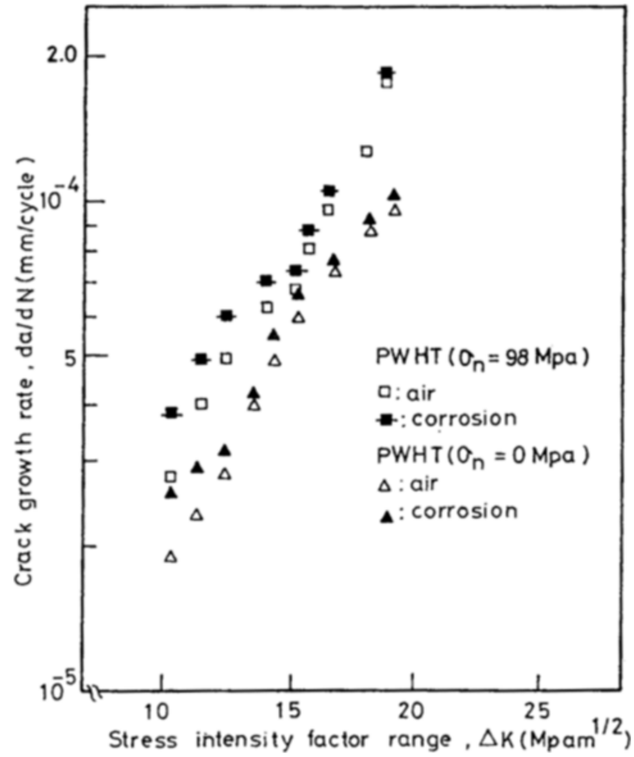


Fig. 11 Behaviour of corrosion fatigue crack growth for PWHT specimens (HT80) without stress and subjected to 98MPa during PWHT, including the air datea

data. Regardless of the data in air and corrosive environment, crack growth for the PWHT specimen with stress is faster than that for the PWHT one without stress over the all ΔK range. In the case of HT80 with the elements of carbides formation, such as Cr, Mo, Si, etc., the applied stress duridng PWHT is presumed to give a rise to the precipitation of the impurities and carbides which promote the crack growth. Meanwhile, crack growth rate in corrosive environment is faster than that in air at a constant ΔK value. Besides, in the low ΔK region, crack growth is greatly influenced by the corrosive environment. However, the corrosive effect is gradually reduced with the ΔK. The accelerated crack growth in corrosion environment is based on the electrochemical theory of the crevice corrosion.

That is, $M \rightarrow M^+ + e^-$

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

$$M^+Cl^- + H_2O \rightarrow MOH\downarrow + H^+Cl^-$$

At the low ΔK region which shows the slow crack growth, the following electrochemical reaction at the crack and corrosion environment occurs enough comparatively. The metals at the crack are dissolved and hydrogen gas which is absorbed at the plastic zone. However, as the crack grows, the net section area of the specimens is decreased. So, at the high ΔK region, the mechanical factors rather than environmental ones give the predominant influence to crack propagation.

As considered above, the behaviours of corrosion fatigue crack growth were dependent upon the materials and PWHT conditions. Especially, considering the past works on corrosion fatigue which showed the increased crack growth in corrosive environment generally, the opposite behaviours were observed for SM53B in this study. That tendency is caused by the following factors, it is thought.

Firstly, it is the branched cracks of the main crack which can be certified in Fig. 8. The production of the branched cracks is contributed to the singularities in HAZ and fast strain at the notch tip in this experiment. Owing to the presence of the branched cracks, the maximum value of K which plays important role in propagating the crack along the fusion line is decreased by the following equation, $K_{eff}=K_{max}(1-n)$. Where, n ; branching factor.

Secondly, it is due to the decreased ΔK because of the crack blunting by the corrosion products which are made from the electrochemical reations between corrosive environment and compositions of the material. The corrosion products (Fe_3O_4, Fe_3O_4, H_2O) which are accumulated at the crack side in the course of crack propagation act to decrease the ΔK (Velden, 1972).

Thirdly, since the branched cracks as well as decreased ΔK cause to decrease the crack growth considerably and the strained region around the main crack in HAZ is wide under the out of bending load, the secondary cracks are formed easily in corrosive environment. The secondary cracks on the surface of the specimen behave like the surface crack growth. Even if the crack growth of the main crack for SM53B in corrosive environment is retarded by those factors, it is serious that the secondary cracks can be produced in weld HAZ. In other words, the secondary cracks cause to originate and produce the unstable fracture of the weldments under the specific conditions such as low temperature or impact loading, etc. Accordingly, it is thought that careful observation must be given for the safety of the weldments subjected to the repetitive loads in corrosive environment.

4. CONCLUSIONS

The effects of PWHT and stress simulating the residual stress during PWHT in weld HAZ of SM53B and HT80 steels on corrosion fatigue crack growth were evaluated. In the case of HT80, 3.5% NaCl solution acts to accelerate the crack growth for all specimens, and the as-welded was very sensitive to corrosive environment. In the meanwhile, corrosion fatigue crack growth of SM53B was retarded in comparison with the fatigue crack growth in air because of the branched cracks,decreased ΔK due to the corrosion products and secondary cracks around the main crack in HAZ. Besides, the applied stress in HAZ during the PWHT acted to increase the crack growth compared with that of the PWHT specimen without stress.

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