Corrosion Fatigue Strength of VVER-440 RPV-Steel Base and Weld Metal

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INTRODUCTION

At present the reliability of reactor materials is mainly determined on the basis of quantitative evaluation of their ability to resist brittle failure at the crack iniatiation stage. However, the practical experience obtained in NPP shows that it is necessary to check the structural elements for cracks or similar sharp-ended defects which may emerge either in the course of manufacture or in service. Such cracks, when subjected to operational loads and corrosive environment, can grow and achieve critical dimensions. Therefore to develop the methodology for prolongation of reactor service life one needs information on crack propagation rate which would allow one to predict crack behavior in the specific conditions of pressure vessel operation.
In modern practice extensive experience has been gained on fatigue crack growth of A533B and A508 steels in light water reactor environments and it has been established the effect on the crack growth rate such factors as stress ratio, frequency, wave form, environmental such temperature, dissolved oxygen, flow rate and material such sulfer content in steels (Tice, 1985). There are only few publications (Timofeev et al, 1987; Giginyak et al, 1988) on the properties of USSR-type reactor materials. Therefore the object of the article was not only the fatigue crack resistance investigation in high temperature water environment of structure materials used in the USSR for reactor case production, but also the determination of temperature and previous neutron irradiation effect on a crack growth rate in water environment.

MATERIALS AND EXPERIMENTAL PROCEDURE

The chemical composition of the studied materials is given in Table 1.

Table 1

Material	Element content, wt									
	C	Si	Mn	Cr	Ni	Mo	V	S	P	Cu
15X2MFA	0.15	0.22	0.38	2.50	0.18	0.63	0.29	0.013	0.012	0.14
15X2MFA	0.17	0.18	0.37	2.59	0.16	0.70	0.28	0.016	0.019	0.09
15X2MFA	0.15	0.29	0.45	2.65	0.07	0.64	0.25	0.008	0.011	0.06
Cb10XMFT weld metal	0.06	0.45	1.13	1.34	0.20	0.53	0.23	0.012	0.021	0.09

Fatigue tests were conducted in the Technical Research Centre of Finland (VTT) and Central Research Institute of Structural Mate-

rials (ZNII KM) at Leningrad. At VTT, CT50 specimens were fabricated from base and weld metal in T-L orientation. At ZNII KM, both CT50 and CT25 specimens were used for the base and weld metal. CT50 specimens were tested at a constant amplitude of the stress intensity factor and water temperatures of 20, 80, 140, 200, 250 and 290°C. Irradiated specimens (F = 1.0...1.5 10^{24} or 8 10^{23} n/m^2, E 0.5 Mev) were tested simulating shut-down conditions in 90°C water at ZNII KM. Both CT16 and center cracked tension specimens with 3 mm thickness were used. The experiments were carried out in autoclave facilities. Both the autoclave systems are much alike, and detailed description of the system at VTT is given in the report (Chanfreau et al, 1987).
The test procedure was according to ASTM E647-78T and its subsequent revisions. The loading condition was that with the stress ratio R=0.2 and R=0.7, the loading frequency f=1 cpm (17 mHz) with the sinusoidal wave form. In some cases, stress ratio were R=0.5 and R=0.65, frequency was 0.5 cpm (8.5 mHz). The water chemistry, temperature and pressure used were simulating those in use at Loviisa NPS primary circuit.

EXPERIMENTAL RESULTS AND DISCUSSION

Crack growth rate results for base and weld metals are shown in Fig.1 and 2.

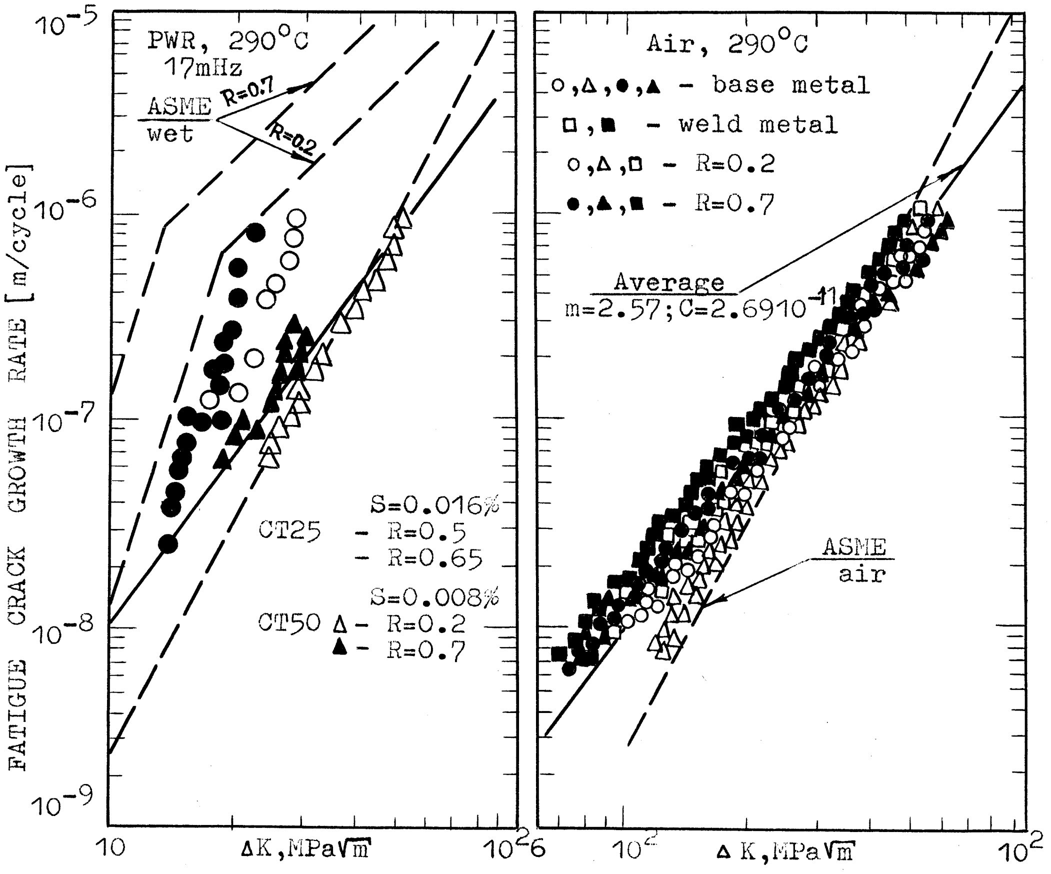

Fig.1. Crack Growth Rate of 15X2MFA Base Metal and its Weld.

In Fig.1, data from several experiments performed in air at 290°C with 15X2MFA base metal and its weld metal are shown, compared with the ASME Code Section XI reference line. The clear difference in the slope of lines can be seen. The slope observed in the experiments performed at ZNII KM with the materials used in this study is quite close to that recently proposed for A533B and similar steels (Eason et al,1987).

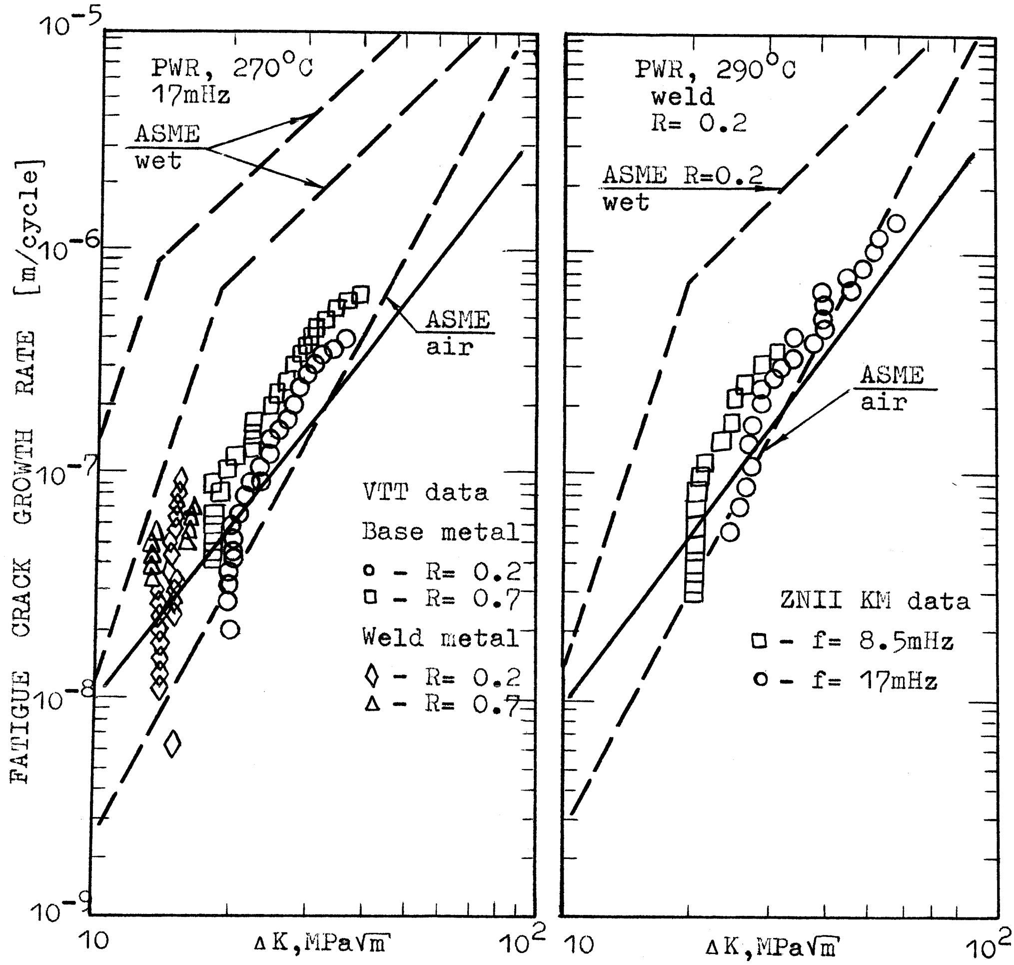

Fig.2. Crack Growth Rate of 15X2MFA Weld Joint.

A pronounced environmental influence on the crack growth rate is found only in 15X2MFA steel base metal containing a high level of sulphur(Fig.1). The data show that at sulphur content of 0.016% a ten fold increase in fatigue crack growth rate is observed in comparison with test results in air. All the obtained crack growth rate values were located within the ASME Code reference curve in water at stress ratio R=0.2 and air test results line. As illustrated in Fig.1 and 2 steels with low bulk sulphur content show very little enhancement (similar results have been found in weld metal). Crack growth rates for weld metal at 290°C in pure water are almost equal to those in base metals.

The effect of pre-irradiation was studied at 90°C in ZNII KM with two different specimen geometries, CT16 and CCT3. The results (Fig.3) show that pre-irradiation does not have a marked influence on corrosion fatigue crack growth rate. This is in accordance with other earlier results (Cullen et al, 1981).

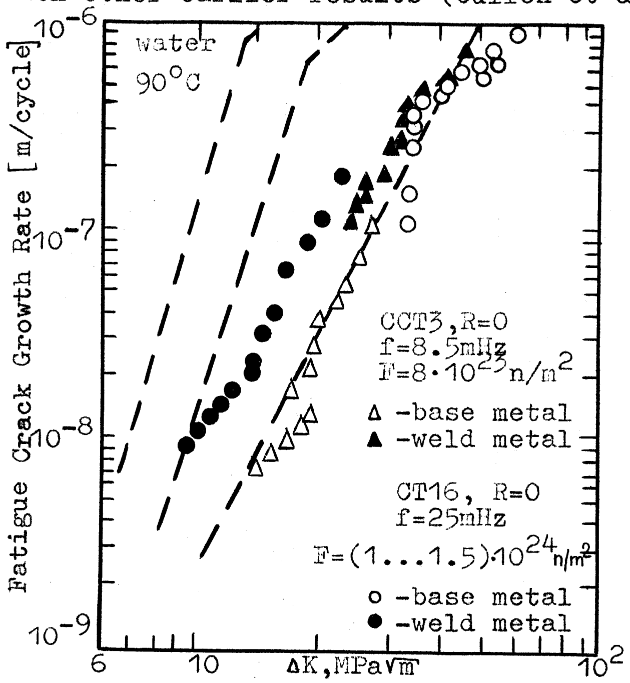

Fig.3. Effect of neutron fluence on fatigue crack growth rate.

As is shown in Fig.4 , the temperature dependence of the crack growth rates in a range from room temperature to 290°C indicated a complicated behaviour. Similar trends can be noted in these relations for the two stress ratio considered. In both cases the maximum value is recorded at 140°C and the minimum one at 200°C, the rate values varuing practically by an order of magnitude. The fact that the crack growth rate in reactor steels in PWR water environment is the lowest at 200°C in the temperature range considered, was treated in literature (Atkinson and et al, 1986; Katada et al, 1985). For BWR conditions a similar effect is observed at 175°C and the highest crack growth rates are registered at 100°C (Cullen et al). Temperature dependence of the crack growth rate for PWR and BWR conditions seems to be similar. In addition, it is of interest to note that the crack growth rate in PWR environment at 290°C in both cases does not exceed the values registered at 20°C.

The fractographic examination of the specimen fracture surfaces has shown that the crack propagation at 20, 200, 250 and 290°C is of purely transcrystalline nature. Yet, for temperatures of 80 and 140°C some intercrystalline fracture sites have been observed (Fig.5). In this case it should be emphasized that the intergranular fracture percentage was low and actually similar for both temperatures. As is shown in article (Pohmursky et al,1983), the typical elements of the fracture surface are cleavage and quasi-cleavage facets, when hydrogen-charged specimens are tested to evaluate the fatigue crack growth. Besides, the presence of cleavage facets and intergranular fracture elements in fracture surface of specimens in A533 steel is mentioned in work (Atkinson et al, 1981), where fatigue crack resistance was studied under the effect of water environment of 93°C. Such brittle fracture elements are usually related in corrosion-fatigue tests with the hydrogen mechanism of the crack growth acceleration. Grain boundary hydrogen concentration increases with temperature in the range of $T < T_{cr}$, when it is considered that for iron and ferrous alloys there is a critical temperature T_{cr} (Borisova et al, 1976) below which it is a temperature rise-enchanced regular diffusion which is the main

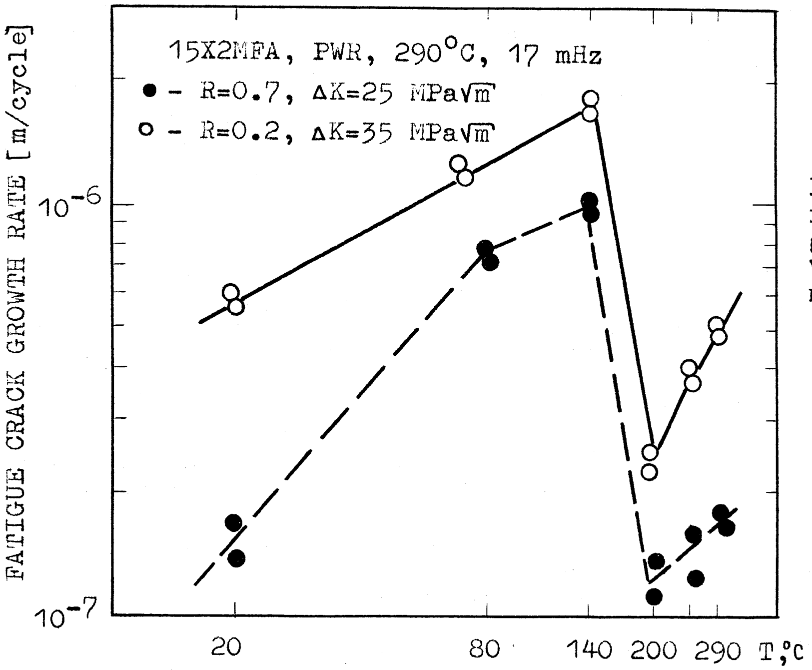

Fig.4.

Effect of temperature on crack growth rate in water environment

mechanism of hydrogen diffusion and dislocations and clusters under these conditions are hydrogen traps. Irrespective of further increase in hydrogen diffusion factor dislocations cease to contribute to hydrogen segregation and become its additional transfer ways when $T > T_{cr}$. According to work (Geld et al,1979)T_{cr} is in the range of 150...200°C.

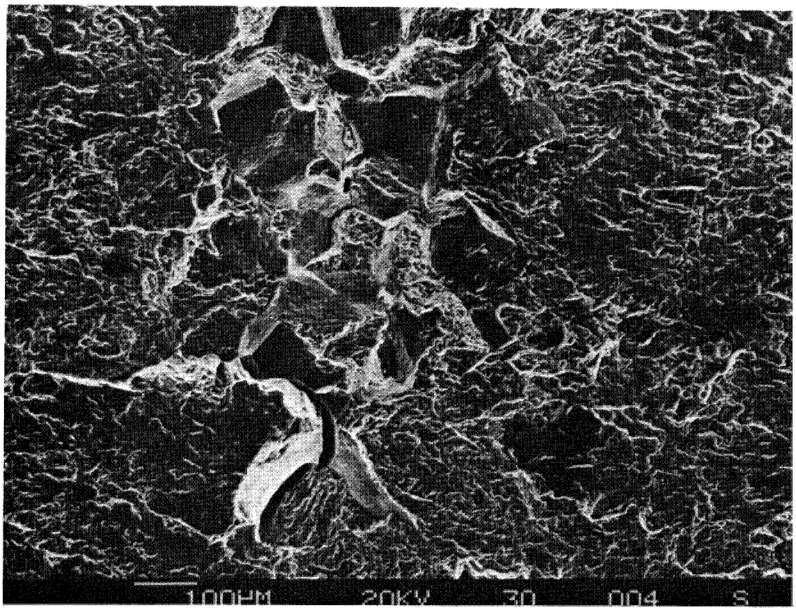

Fig.5.

Scanning electron micrograph of the fracture surface after testing at 140°C.

Thus it is felt that the greatest temperature dependence of the crack growth rate for reactor steels can be attributed to the change in the mechanism of the crack grow acceleration.

CONCLUSIONS

The results of this work are summarized as follows: 1. Corrosion fatigue crack growth rate of 15X2MFA steel is markedly lower of ASME Code Section XI reference curves. 2. Crack growth rate for weld metal in PWR water at 290°C are almost equal to or lower than that of base metal. 3. Neutron fluence does not cause essential changes in corrosion fatigue crack growth rate of pre-irradiated VVER-440 base and weld metal. 4. The crack growth rates vary with test temperature: a maximum is observed at 140°C while a minimum at 200°C.

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