Effect of High Temperature Water Environment on Fatigue Crack Resistance of Carbon and Low Alloy Steels

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Keywords: power equipment, fatigue, steel, water environment, stress intensity factor, crack growth diagram

Abstract. The operating experience shows that corrosion-fatigue cracks are the most common type of damage to heat-power equipment components contacting with water heat coolant. Therefore the establishment of crack propagation mechanisms in metals under the influence of cyclic load and water environment is of great importance to the prediction of component's durability. The power equipment steels have been tested. Crack growth diagrams in corrosive water environment were obtained.

Crack defects in power equipment metals are frequently located on the surface of the element under stress. Whenever the element's surface interacts with the coolant water environment, defect propagation in metals is defined not only by stress conditions, but also by corrosive effects of "metal – water environment" system [1]. This paper presents the results of power equipment steel corrosion-fatigue crack resistance research taking into account the influence of cyclic load parameters and water environment's composition and temperature on the process kinetics.

The steels have been tested: low alloy piping steels 15ГС (Si-Mn), 12Х1МФ (Cr-Mo-V) and pressure vessel carbon steel 22К. The specimens were cut from the actual equipment components; 25 mm thick compact tension specimens (CT-1) were used. Investigations were carried out in distilled water (inert conditions); in hydrazine-ammonia solution (H_2O+NH_3 with up to pH9) and in hydrazine-ammonia solution with addition of organic acid (H_2O+NH_3 with up to pH9 + 10^{-5}mole/l CH_3CH_2COOH with up to pH5,9) at temperatures of 80, 150 and 280°C [2]. Customized testing equipment was used. In tested specimens, the developing crack length was determined using pliability measurement method with a custom inductive sensor [2]. For comparative evaluation the fatigue crack resistance tests in air were carried out at temperatures of 20 and 300°C.

Experiment results exhibit the significant activating effect of water environment on the crack growth rate (CGR) in investigated steels: crack growth rate increases in water environment up to one order of magnitude and higher – Fig.1. The largest accelerating effect observed in the stress intensity factor (SIF) range of 20÷40 MPa$\sqrt{m}$. Activating effect of distilled water has more impact on fatigue crack propagation than the effect of hydrazine-ammonia solution under the same conditions (Fig.1). Water environment with addition of organic (acetic) acid has the most accelerating effect on fatigue crack propagation in carbon and low alloy steels (Fig.1). Such negative effect of acetic acid additive on pearlite steels' fatigue crack resistance is probably induced by cathode electrochemical reaction mechanism activation in the fracture zone.

Impact of cyclic load parameters on corrosion fatigue crack resistance properties was investigated by variation of cycle frequency and asymmetry coefficient. Investigated steels have shown the overall trend towards decline of corrosion fatigue crack resistance with frequency decrease. For low alloy steels, however, such relation is of nonmonotonic nature. At the same time low load cycle frequency range (0,04 ÷ 0,0008 Hz) causes lower levels of corrosion crack resistance than that of medium frequency (1,0 ÷ 0,04 Hz). Further frequency decrease below 0,04 Hz, however, has virtually no effect on corrosion fatigue crack resistance – Fig.2.

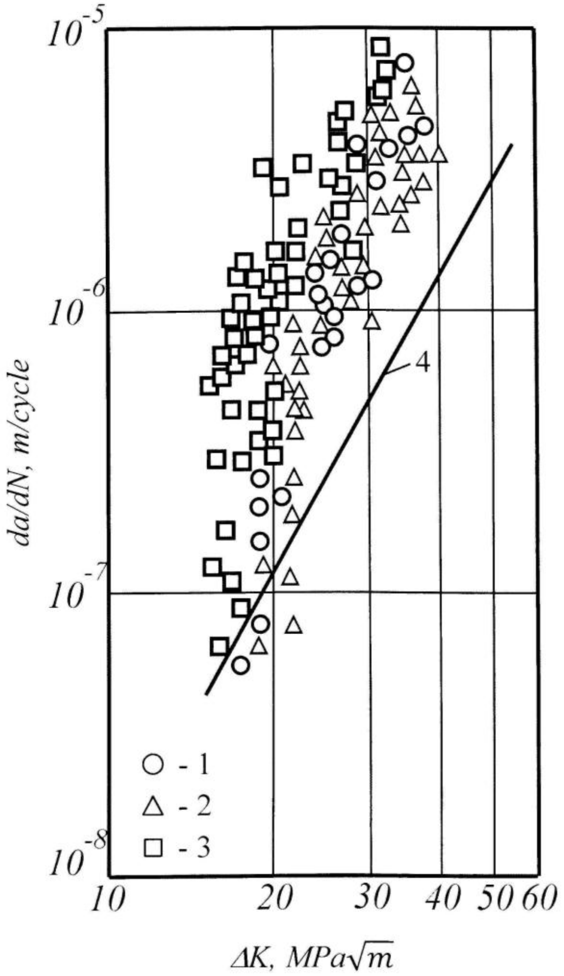

Fig.1. Effect of water chemical composition on corrosion fatigue crack resistance in steel 15ГС:
1 - distilled water; 2 - hydrazine-ammonia solution; 3 - hydrazine-ammonia solution with addition of organic acid; 4 – air.

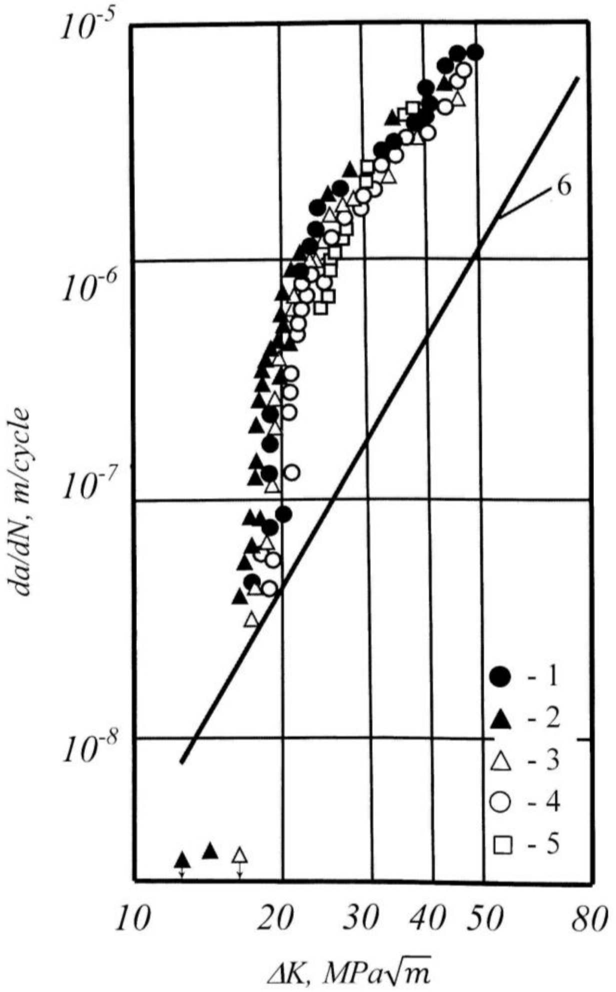

Fig.2. Effect of frequency on corrosion fatigue crack resistance in steel 12Х1МФ:
1, 2 - distilled water; 3, 4, 5 - hydrazine-ammonia solution; 6 – air. 1, 4 – f = 0,04Hz; 2, 3 – f = 0,008Hz; 5 – f = 0,0008Hz.

Impact of load cycle asymmetry on corrosion fatigue crack resistance of steel 15ГС is shown in Fig.3. It is evident that although the traditional «da/dN - ΔK» crack growth diagram (CGD) approximation is maintained, with asymmetry coefficient increase experimental data is shifted towards lower values of SIF range, i.e. higher levels of CGR. CGR approximation of CGD through effective SIF range parameter ($\Delta K_{ef} = (1-R)^{-0,25} \cdot \Delta K$) generally limits the set of experimental data for various kinds of asymmetry to a common scatter band – Fig.3. This pattern is consistent with all investigated steels.

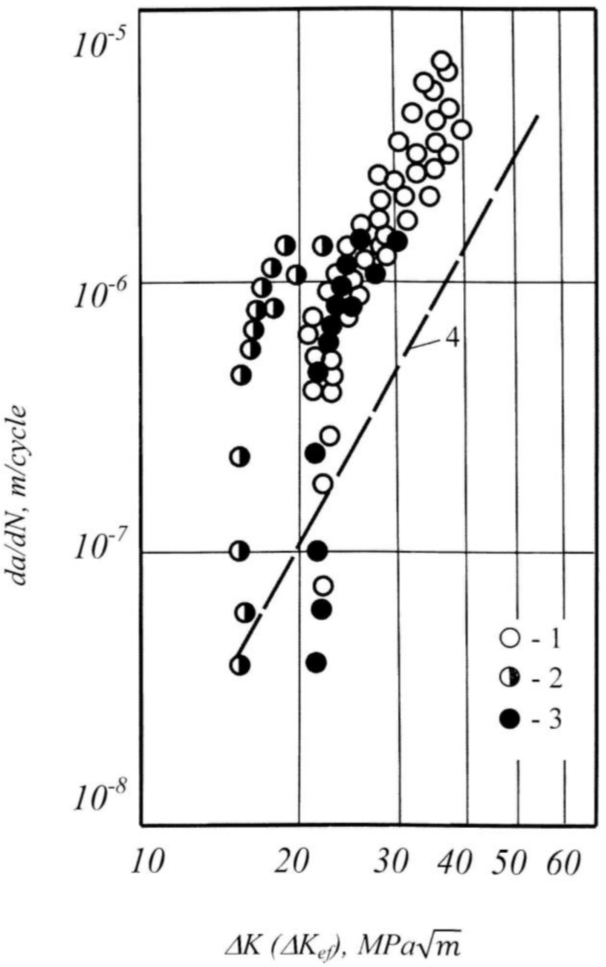

Fig.3. Corrosion fatigue crack resistance in steel 15ГС in hydrazine-ammonia solution with different load cycle asymmetry: 1 – R ≈ 0,05; 2, 3 – R ≈ 0,65. Approximation: 1, 2 – da/dN-ΔK; 3 – da/dN-ΔK_{ef}. 4 – air (R≈0).

Above mentioned results for influence of various factors on corrosion fatigue crack resistance were obtained at 80°C water environment temperature. Impact of temperature change on corrosion fatigue crack resistance was investigated in 80°C ÷ 280°C range – Fig.4 and 5. The increase of the corrosive water environment temperature from 80 to 280°C changes the type of CGD and does not increase CGR itself – Fig.4 and 5. Initial stages of CGD at temperatures of 80°C and 280°C are almost similar in shape. However when reaching SIF range of ~ 22÷25 MPa$\sqrt{m}$ CGD at 280°C deviates drastically to low range of CGR. At this point a virtually horizontal segment is formed and then (at $\Delta K \cong 40$ MPa$\sqrt{m}$) it continues rising similarly to CGD in air at 300°C (Fig. 4 and 5). CGD in water environment at 150°C is located between CGDs at 80 и 280°C (Fig. 5).

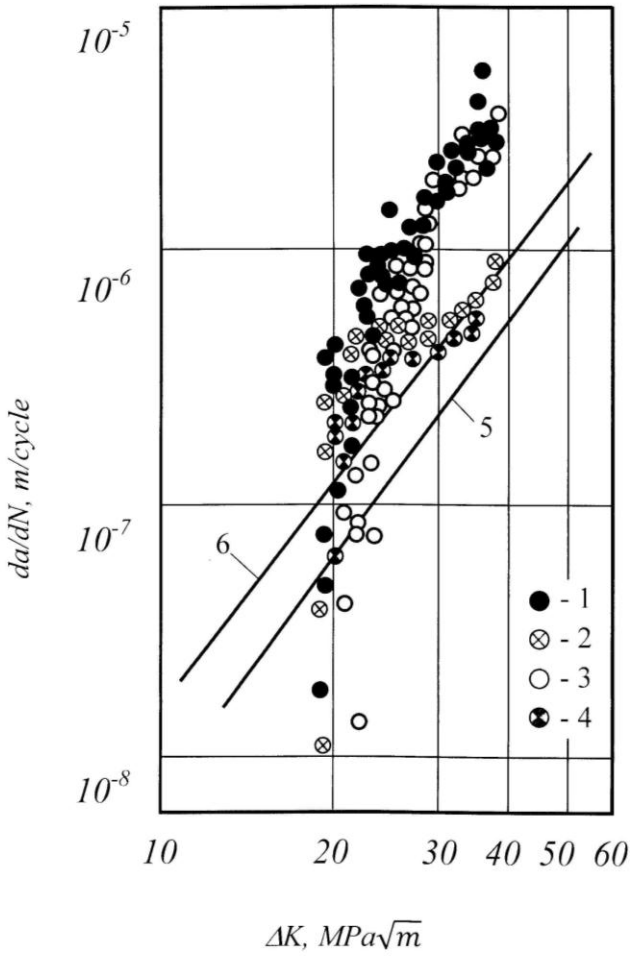

Fig.4. Effect of temperature on corrosion fatigue crack resistance of steel 22К (1, 2) with a welding joint (3, 4): 1, 3 – 80^{o}C; 2, 4 – 280^{o}C. 5 – air 20^{o}C; 6 – air 300^{o}C.

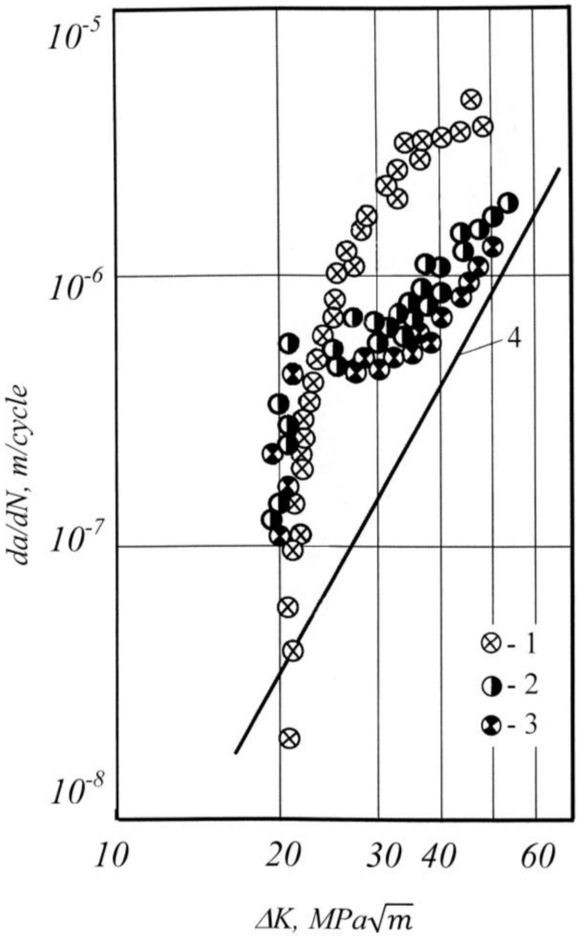

Fig.5. Effect of temperature of hydrazine-ammonia solution on corrosion fatigue crack resistance of steel 12Х1МФ: 1 – 80^{o}C; 2 – 150^{o}C; 3 – 280^{o}C; 4 – air.

This data shows, that corrosion fatigue crack resistance characteristics of investigated steels don`t vary greatly. Steel 15ГС, however, generally shows higher CGR levels, i.e. lower corrosion fatigue crack resistance.

References

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