

Effect of Aqueous Medium Composition at Elevated Temperatures on Fatigue Strength of Carbon Steel

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Corrosion fatigue of metals is considered to be the result of simultaneous action of electrochemical processes and cyclic stresses. At the initial stage of surface fatigue damage development the environment has an adsorptional and electrochemical effect by inducing elemental slip, etching bare metallic zones and causing micropitting. At the next stage local electrochemical pairs are coming into action. This results in deepening the pits and conversion them into microcracks.

High temperature investigations of fatigue were usually restricted to tests in air or gas; in aqueous media at elevated temperatures no systematic investigations have been performed. At the same time the electrochemical corrosion processes in water at 250°C greatly differ from those at room temperature, and can lead to fatigue strength variation as compared to tests in air.

The present paper deals with fatigue strength of a carbon steel (C=0.20%) in aqueous media at 250°C. Tests were conducted utilizing a cantilever rotation bending technique with limited specimen deflection in bending moment plane. The specimen was bended by an

electromagnet rotating around a cylindrical autoclave. A 4mm diameter specimen was mounted inside the autoclave, which was then filled up with water. The aqueous medium was heated by resistance furnace located outside the autoclave.

Figure 1 shows the comparison of carbon steel fatigue strength at 250°C in air and in oxygen free aqueous media. In water of high purity ($O_2 < 0.05$ ppm, $Cl < 0.05$ ppm) at 250°C fatigue limit of steel based on 10^7 cycles decreases as compared to the endurance limit in air from 22 to 20 kg/mm². The presence^{of} chlorides 3 to 15% in oxygen free water results in further reduction of fatigue limit up to 18 kg/mm². Fatigue strength reduction at room temperature in similar aqueous media is not observed.

The reason of different carbon steel behaviour under cyclic loading in aqueous media at room and elevated temperatures resides in the variation of electrochemical corrosion rate and in the change of chemical composition and structure of corrosion products. It has been known, that at room temperature and in the absence of oxygen in water iron solubility is negligible (less than 1 mg/dm² per 24 hours). At elevated temperatures the corrosion rate during first tens of hours is constant exceeding 10 to 20 times corrosion rate in water at room temperature and, subsequently, solution becomes slower due to formation of dense protective magnetite layers on the metallic surface.

Corrosion fatigue of steel in a high temperature medium can be considered as a result of two competitive processes, namely: 1) Fatigue strength reduction due to elevated rate of metal solution at a high temperature and to fatigue damage increase; 2) Fatigue strength increase through the formation of strong protective oxide films which strengthen metal surface, decrease corrosion rate and heal fatigue damage.

Since the first process in oxygen free water at 250°C seems to dominate, one can observe a reduction of the fatigue limit, while at room temperature the fatigue limit in air and in aqueous medium is the same due to very low corrosion rate.

NaCl weakens crystalline structure of magnetite by intruding into an oxide and leads to the formation of magnetitic films of low protective force. This causes extensive metal solution and, consequently, further decrease in fatigue limit.

Experiments on the effect of loading frequency and oxygen dissolved in water on corrosion fatigue of steel in 3% NaCl at 250°C, as shown in Fig.1b, provide an additional support for this view. It is universally accepted that loading frequency reduction decreases corrosion fatigue strength of steel. In contrast, in oxygen free 3% NaCl at 250°C a 30-times decrease in loading frequency leads to an increase of fatigue limit of carbon steel. The result obtained can be explained as follows. It is a common

knowledge, that the main damages associated with the medium influence are originated at the initial stage of tests which corresponds to 20-30% fatigue life. In low frequency tests force factor contribution is reduced, and the magnetite film has a chance to develop, thus protecting metal from further damage. The development of dense magnetite films, as it is appearant from tests in air, raises fatigue strength of carbon steels. The effect of strain aging may also play a certain part in the case considered.

In the presence of oxygen dissolved in water magnetite is oxydized to form Fe_2O_3 , which results in damage of the protective layer. The increase in metallic corrosion rate in oxygen-containing water reduces both fatigue life and endurance limit as is shown in Fig.1b, and causes of nucleation of microcracks in large quantities.

Thus, as ^{it} is evident from test results, the peculiarities of high-temperature electrochemical corrosion of metals exert direct influence on their corrosion fatigue strength in aqueous media. The development of protective magnetite films raises fatigue limit of steels in high-temperature aqueous media, while the formation of loose corrosion product layers results in cyclic strength reduction.

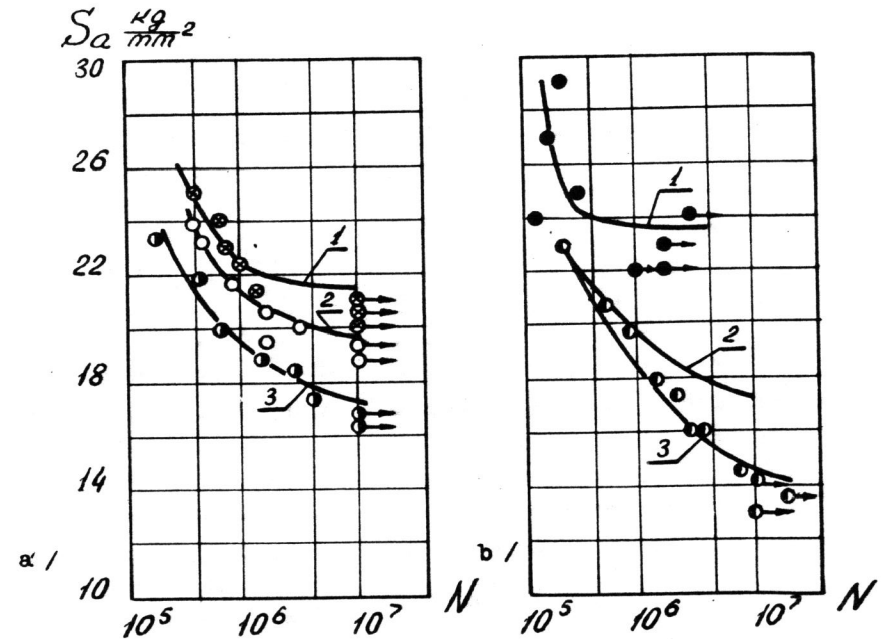


Fig.1. Fatigue curves of 0.20% carbon steel in aqueous media at 250°C.

- a/ 1- air
- 2- oxygen free distilled water
- 3- 3% NaCl solution ($0.2 \leq 0.05$ ppm), loading frequency - 1500 cycles/min
- b/ 3% NaCl solution
- 1- 50 cycles/min, $0.2 \leq 0.05$ ppm
- 2- 1500 cycles/min (similar to curve 3 in Fig. 1a), $0.2 \leq 0.05$ ppm
- 3- 1500 cycles/min, $0.2 \leq 0.05-50$ ppm