EFFECT OF DAMAGE IN SERVICE OF 12Kh1MF STEAM-PIPE STEEL ON ITS CRACK RESISTANCE CHARACTERISTICS


The results of investigations of the effect of long-term service of steel on the characteristics of its static cyclic crack resistance are presented. The kinetic diagrams of fatigue failure for the whole range of fatigue crack rates (from the rates close to the threshold of $10^{-10}$ m/cycle to $10^{-3}$ m/cycle) are analyzed. It is shown that acceleration of fatigue crack growth as a result of a change in the state of the metal in service is most pronounced in the third and threshold regions of the effective kinetic diagrams of fatigue failure. The observed regularities are explained by structural transformations in the metal of a steam line under the effect of service factors.

Service specifications of steam lines of steam power plants specify operating temperatures (up to 550°C), steam pressure in a steam line (up to 14 MPa), and the content of impurities that are active in term of corrosion in a working fluid. The joint effect of these factors for a prolonged time causes structural changes in the metal of the steam line, the degradation of its properties [1], and, as a consequence, damages. In a critical case uncontrollable failure of the weakest member occurs.

It is well known that the action of compressed steam and its own weight in the walls of a steam pipe result in the development of a complex stressed state [2]. Insignificant pressure differentials in service or shutdowns and start-ups dictated by the technology cause conditions that correspond to multicycle low-amplitude fatigue with a high asymmetry of the loading cycle or to high-amplitude fatigue with a small number of cycles. Therefore, the failure of a steam line can be due to both a fatigue crack growth and a quasistatic one.

The aim of the work is to establish the regularities of the effect of changes in a metal of a steam line as a result of its service on the characteristics of its static and cyclic crack resistance.

Material and Procedure

We investigated a low-carbon 12Kh1MF steel which is widely used in the production of steam pipes of various steam power plants (the time of operation $\tau_{op}$ was from $48 \cdot 10^3$ to $19 \cdot 10^4$ h). Mechanical characteristics were determined by tensile testing cylindrical specimens 5 mm in diameter cut from a wall of a tube in the $C-R$ direction. The static crack resistance $J_{1c}$ was established by four-point bend-testing prismatic $C-R$ specimens $22 \times 15$ mm in section with a one-side edge notch following the standards [3]. Using the data of cantilever and four-point bend tests at $R = 0$, $\nu = 0.1-10$ Hz we constructed kinetic diagrams of fatigue failure (Kbff) from a nominal span and a critical one [4]. The effect of fatigue crack closure was estimated by a familiar procedure [5]. The gain in crack length was measured with an optical microscope with a resolution of 0.01 mm or calculated from the change in compliance of a specimen. Taking into account the high plasticity of the steel, the growth of a fatigue crack in the high-amplitude region of loading (the third region of the Kbff) was described by a graphic dependence $da/dN - J$ in logarithmic coordinates [6]. A running value of the $J$-integral was computed by the Rice formula [7], which is valid for the interval $0.55 \leq a_k \leq 0.75$:

$$J_k = \frac{2A_k}{B(W - a_k)}.$$
where $A_k$ is the total energy of failure, which is calculated by the area under the diagram force $P_k$—displacement of a point upon application of a force $u_k$; $a_k$ is the length of a crack after the $k$th cycle of loading; $B$ and $W$ are the thickness and width of a specimen. For the critical values we took the values $K_{ic}$ and $J_{fc}$ at which the rate of crack growth was equal or exceeded $10^{-3}$ m/cycle.

Results and Discussion

In spite of a significant spread of data, which is most probably caused by distinctions in service conditions at different steam power plants [8], the standard mechanical characteristics of the steel during tension depend slightly on the time of operation (Fig. 1a). A barely visible tendency for a decrease in strength characteristics within the first $5 \cdot 10^4$ h of service with a further stabilization of the process of loss of strength is observed. The characteristics of plasticity within the limits of the spread of experimental data practically do not depend on the failure of the material (Fig. 1a).

In distinction to the characteristics of strength and plasticity, the short-term static crack resistance $J_k$ is rather responsive to changes in the metal (Fig. 1b). Furthermore, the parameter $dJ/da$ [9], which is determined by the slope of the $R$-curves, responds more noticeably to the changes than $4 \cdot 10^4$ h. It drastically decreases after service of the steel for more than $4 \cdot 10^4$ h. These changes of the indexes $J_{ic}$ and $dJ/da$ (Fig. 1b) are explained by the different effects of the structural degradation of the metal after long-term service on the changes in the mechanisms of crack start and quasistatic crack growth. We determined by a fractographic method that, irrespective of $\tau_{op}$, a crack is initiated according to the ductile mechanism. At the stage of its quasistatic growth at the background of a ductile shell-like fracture, regions of transgranular failure form. Their quantity increases with time of operation. But the indexes $J_{ic}$ and $dJ/da$ (Fig. 1b) do not become worse as $\tau_{op}$ approaches the estimated service life ($10^5$ h) or to any other service time, which testifies to the attainment of critical failure and make it possible to use them as criteria for substantiating the danger of further service of the steel. It is very dangerous to assume that the reduction of these indexes down to zero will not affect the normal operation of structural members. The higher responsivity to failure in service of the crack growth parameter $dJ/da$ as compared to the parameter $J_k$ (which determines the crack start) gives grounds to expect more reliable results from investigations of the fatigue growth of a crack.