DEGRADATION OF CORROSION FATIGUE CRACK GROWTH RESISTANCE OF A POWER PLANTS PIPE-LINE STEEL UNDER OPERATING CONDITIONS

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The comparative data of a corrosion fatigue crack growth resistance (corrosion fatigue crack growth rate versus stress intensity factor range) are presented for a new and used metals of the feeding pipe-lines of the power plant over critical pressure units (OCPU). The received data for a new and exploited metals from Uglegorska and Ladyghynska Power Plants (Ukraine) are significantly distinguished, that show on degradation of an initial metal properties under long term influence of the operating conditions, and also on a different level of this degradation which depends on a given power plant conditions. The admissible depths of the crack-like defects in pipe-line walls were determined with taking into account of a statistic data about the OCPU work. These values have the range 3...7mm, which depend on a planned term of work, a metal state, an environment composition and, also on a cracks form.

INTRODUCTION

The reliability assessment of power plant units is actual engineering problem especially for which the planned operation term expire (1). Such assessment consist of different stages among which one of most important is detection of the basic structural components. This detection includes the determination of real mechanical state of the components materials that may be significantly degraded during exploitation.

In frame of this problem the presented studies are focused on determination of a corrosion fatigue crack growth resistance of new and used metals of the feeding pipe-lines of the power plant over critical pressure units (OCPU). The tested materials have been received from real tubes from Uglegorska and Ladyghynska Power Plants (Ukraine).

EXPERIMENTAL PROCEDURE

A typical power engineering steel 16HS ($\sigma_{YS} = 250MPa$ and $\sigma_{UTS} = 480MPa$) was investigated. Steel chemical composition (in weight %): C=0.12-0.18; Si=0.4-0.7; Mn=0.9-1.2; Cr<0.3; Ni<0.3; Cu<0.3; S<0.04; P<0.03; As<0.08; remainder Fe.

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The standard beam specimens by thickness of 10mm and with V-shape notches were machined from metal of tubes. Three different materials were used: metal from new tube, metal from Uglegorska Power Plants pipe-lines (metal U) and metal from Ladyghynska Power Plants pipe-lines (metal L).

Two types of the environments were used. First - an environment of nominal composition according to rules of power plants exploitation. It was the high purity water under $pH = 7 \pm 0.5$ and conductivity $\chi \leq 3 mS/m$. Second - the same environment but with organic additions, namely a formic acid (C=3000 μg/kg) and a 2,4-dinitrophenyl (C=400 μg/kg). It should be noted that these additions were chosen on the base of the preliminary investigations. These electrochemical studies showed that formic acid and 2,4-dinitrophenyl are the most corrosion aggressive additions with respect to tubes metal among others which were detected in natural reservoir for given power plants.

Corrosion fatigue crack growth tests were carried out under frequency of cyclic loading $f = 1.0Hz$ and stress ratio $R = 0.7$ that imitate the real operating pulsation for the OCPU pipe-lines. During tests the constant environment composition in the crack tip area was provided by continuous sucking out of the environment from the crack cavity using a specially designed technique (2).

RESULTS AND DISCUSSION

The corresponding series of the corrosion fatigue crack growth tests were conducted both for different metals and environment composition. The received results were presented as scatter plots of crack growth rate da/dN versus stress intensity factor range ΔK_I (so-called the corrosion fatigue crack growth resistance diagrams (3)). The given plots have been described analitically using well-known Paris equation:

$$da/dN = C(\Delta K_I)^n, \tag{1}$$

where C and n are the constants of the tested "material-environment" system.

These dependencies are shown in Figure 1 and numerical values of constants C and n and also the threshold intensity factor range ΔK_{th} are given in TABLE 1.

TABLE 1 - Corrosion fatigue crack growth resistance characteristics of a metal (16HSsteel) of the power units feeding pipe-lines.

"Material-environment" system	n	C	$\Delta K_{th}, MPa \cdot \sqrt{m}$
New metal - nominal environment	11.21	$8.71 \cdot 10^{-16}$	6.32
New metal - organic additions	10.55	$3.02 \cdot 10^{-15}$	6.36
Metal U - nominal environment	14.07	$1.66 \cdot 10^{-18}$	6.89
Metal U - organic additions	10.66	$3.24 \cdot 10^{-15}$	6.11
Metal L - nominal environment	32.87	$1.66 \cdot 10^{-33}$	6.83
Metal L - organic additions	18.36	$4.36 \cdot 10^{-22}$	6.86

The main observation to be made from these results is decreasing of the corrosion fatigue crack growth resistance characteristics of used metal with comparison to new that show on degradation of materials properties under given operating conditions. Especially it can be seen for metal from Ladyghynska Power Plants pipe-lines for which crack growth rate curve have the highest steep slope (see Figure 1, curves 3). It is inauspicious for providing of the pipe-lines durability because any negligible operating overload may lead to significant increasing of corrosion fatigue crack growth rate.

The presented above data were used for estimation of the admissible depths of the crack-like defects in pipe-lines walls. Under observations of the used tubes two main types of the corrosion fatigue damages have been discovered. First type may be determined as corrosion furrow and second as corrosion ulcer. These defects were modeled by semielliptical cracks with different ratio of their axises a and b (see Figure 2). For furrow-type defect this ratio was accepted as $a/b = 1/10$ and for ulcer-type defect - $a/b = 2/3$.

For calculation a stress intensity factor for semielliptical crack in tube wall the needed expression was used from previous work (4):

$$\Delta K_I = \Delta\sigma \cdot \sqrt{\pi a} \cdot \left\{ \frac{1}{\sqrt{\pi}} \cdot \frac{1.12 - 0.48\beta + 0.13\left(\frac{2\theta}{\pi}\right)^2 \cdot \beta(3\beta - 2 - \alpha)}{1 - \alpha(1 - 0.75\beta)} + \right.$$
$$\left. + 1.13k_f\left[\beta\left(\frac{2\theta}{\pi}\right)^2 \cdot (\alpha - 0.4 + 0.6\beta) + \beta(1 - 1.4\alpha) + 0.62\lambda(1 - \beta) \cdot \psi(\alpha)\right]\right\} \quad (2)$$

where $\alpha = a/S$; $\beta = a/b$ $(0 \le \beta \le 1;\ \ 0 \le \alpha \le 0.4)$;

$$\psi(\alpha) = (\alpha)^{-1/2} \cdot \sqrt{(1-\alpha)^{-3} - (1-\alpha)^3}; \qquad \lambda = \begin{cases} 1, \alpha \ge 1/20 \\ 1.15 - 60(\alpha)^2; 0 \le \alpha \le 1/20 \end{cases}$$

where b is a crack half length; a is a crack depth; S is a thickness of tube wall; θ is an angle from small axis semielliptical crack; k_f is a coefficient which take into account the tube cross section form; $\Delta\sigma$ is a tensile stress range per loading cycle. The parameter $\Delta\sigma$ was determined from relation:

$$\Delta\sigma = (\Delta p \cdot d)/S, \quad (3)$$

where Δp is pulsation of a pressure p in pipe-line and d is an internal diameter of tube.

For calculations of the parameter ΔK_I as function of the crack depth a, the next numerical values were used: $d = 285mm$; $S = 40mm$; $p = 35MPa$; $R = p_{min}/p_{max} = 0.7$; $k_f = 1$. These calculations showed that the furrow-type defects are more dangerous than ulcer-type, because for them the same value of ΔK_I achieves under lesser meanings of the crack depths a. As result the furrow-type crack will grow mainly in depth direction whereas the ulcer-type cracks have the equal potential for growth in both directions.

The estimation of the admissible crack depths in pipe-lines walls have been realized on the base of limitation of corrosion fatigue crack growth rate, i.e.:

$$da/dN \le (da/dN)_*, \qquad (4)$$

where $(da/dN)_*$ is the maximum crack growth rate that may be admitted in the wall of pile-lines during planned service life T_*.

TABLE 2 - Statistic data on the exploitation regimes of power plant units.

Power plant	Exploitation term, thousands hours	Number starting of unit	Number cycles of loading
U	120-150	170-350	850-17506
L	135-145	360-455	1800-2275

Using the statistic data on the exploitation of the OCPU (see TABLE 2) the range of the maximum crack growth rate was chosen as $(da/dN)_* = 2 \cdot 10^{-4} \div 2 \cdot 10^{-3}\, mm/cycle$. Under this suggestion and on the base of the equations (1) and (2) the calculations of the admissible crack depths a_* were performed. These results are shown in Figure 3 and it can be seen that for studied cases the meanings of parameter a_* depend on a planned service life, a metal state, an environment composition and, also on a crack form.

CONCLUSIONS

Corrosion fatigue crack growth resistance tests were carried out for a new and used metals of the feeding pipe-lines of the power plants over critical pressure units (OCPU).
The received results reflect the degradation of the initial metal properties under long term influence of the operating conditions, and also on different level of this degradation which depends on conditions for given power plant. From these reasons the admissible depths of the crack-like defects in pipe-line walls are within the range $a_* = 3 \div 7\, mm$ and depend on different factors such as real metal state, operating environment and their form.

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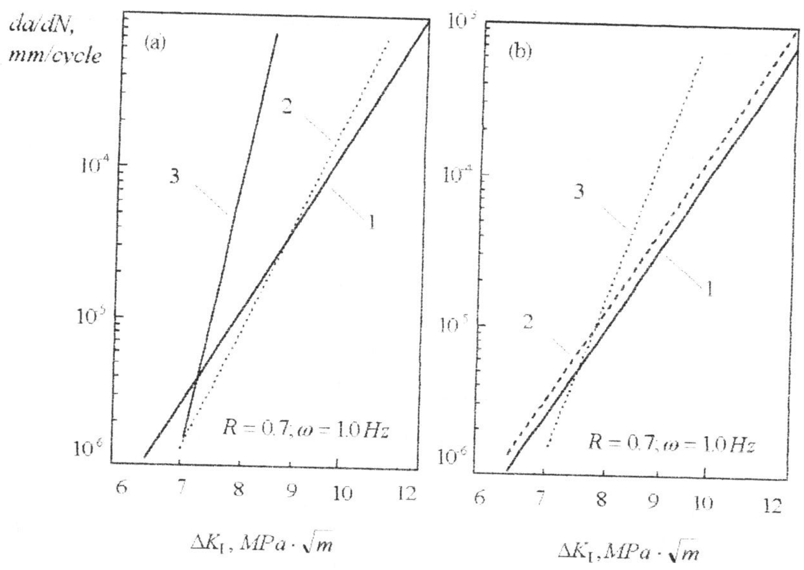

Figure 1 Comparison of the corrosion fatigue crack growth resistance diagrams of new metal (1) and used pipe-line metals from Uglegorska Power Plant (2) and Ladyghynska Power Plant (3) for operating environments of different composition: (a) - environment of nominal composition; (b) - with organic additions.

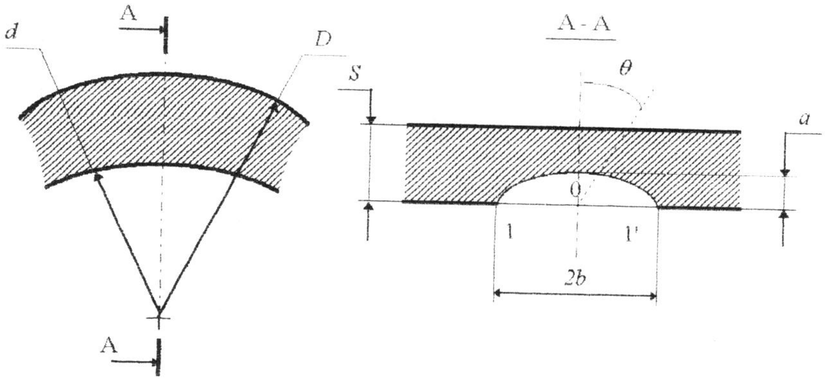

Figure 2 Schematic representation of a crack-like defect in a walls of the pipe-line.

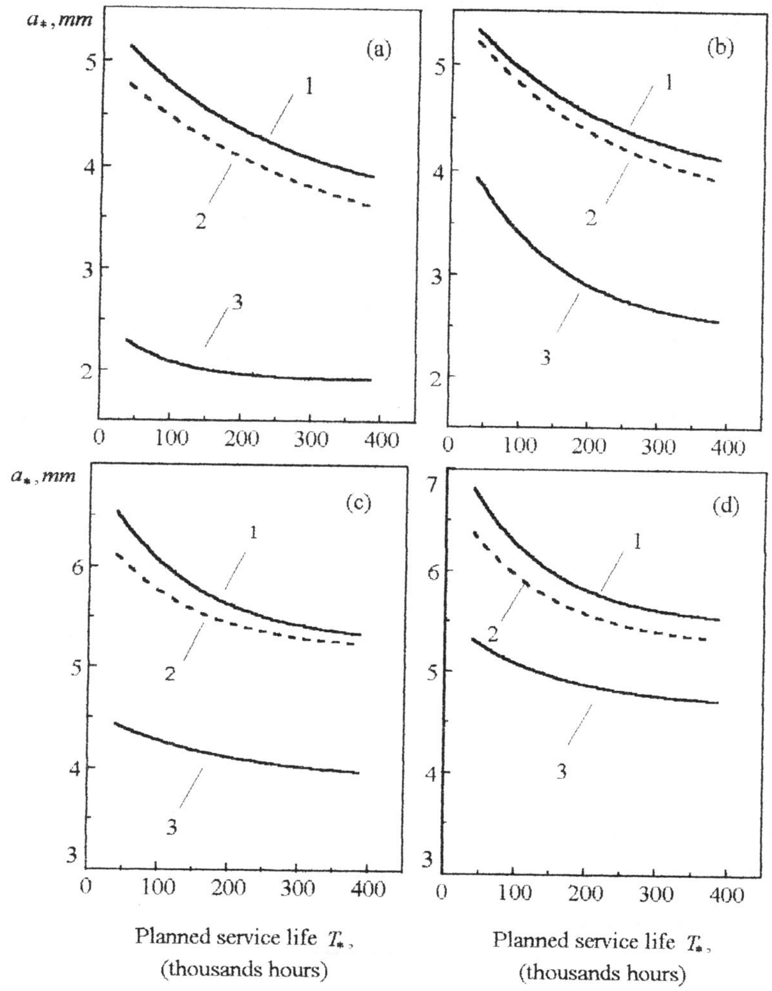

Figure 3 Dependencies of admissible crack-like defects depth a_* on the planned service life T_* for new metal (1) and used pipe-line metals from Uglegorska Power Plant (2) and Ladyghynska Power Plant (3).
Environment: (a) and (c) - nominal composition; (b) and (d) - with organic additions.
Type of crack-like defect: (a) and (b) - furrow-type; (c) and (d) - ulcer-type.