COMPARATIVE STUDIES OF STRESS-CORROSION CRACKING OF LONG-TERM OPERATED MAIN GAS PIPELINE PIPE AND STORAGE PIPE MADE OF X70 STEEL

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The susceptibility to stress-corrosion cracking of the pipe metal of a long-term operated for 40 years main gas pipeline made of X70 steel and an emergency reserve pipe during cathodic protection in NS4 was investigated. A tendency towards some increase in susceptibility to stress corrosion cracking at a potential shift of -0.75 to -1.05 V was found for the serviced pipe compared to stock pipe metal. It is shown that the value of K_S is slightly higher for the operated pipe, which indicates the possible embrittlement of the steel with long-term exposure to external cathodic polarization.

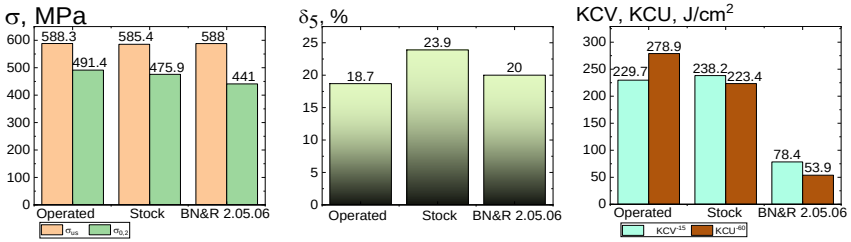
Keywords: pipe steel X70, long term operation, stress-corrosion cracking, electrolytic hydrogenation, voltammetry, slow strain test method, optical microscopy, SEM

Introduction. Underground main gas pipelines, during operation under conditions of complex anti-corrosion protection (protective polymer coatings and electrochemical), are exposed to mechanical and corrosive factors. The susceptibility of cathodically protected pipe steel to hydrogen degradation increases, which contributes to the expansion of stress-corrosion cracking. A significant factor in the degradation of main gas pipeline steels is believed to be deformation aging, which increases strength and reduces plasticity [1]. There is also data showing that volume microdamages develop in long-term operated steels [1]. But in many cases, long-term-operated gas pipelines' base metal and welded joints retain satisfactory performance [2–5]. The question arises as to the probability of the development of corrosion cracking and its intensity in the conditions of cathodic protection of the metal of long-term operational gas pipelines. The work aims to investigate the susceptibility to stress-corrosion cracking under cathodic polarization of pipe steel that has been in use for a long time compared to the emergency reserve pipe that has not been subjected to operational factors.

Research methods. The object of the study is pipe steel X70 after operation for 40 years and after the same period of storage. The chemical composition of the metal of the operated pipe and the reserve pipe is typical for steel of this class and corresponds to TS 14-3-995 [6]. Electrochemical and corrosion-mechanical studies were carried out in NS4, g/l solution: 0.122 KCl + 0.483 $NaHCO_3$ + 0.181 $CaCl_2$ + 0.131 MgSO4, pH 8.2 [7]. The mechanical properties of the base metal were determined by stretching full-thickness

samples on the ZDM 4 machine. Corrosion-mechanical studies were carried out by the slow strain rate method of specimens (10^{-6} c^{-1}) on the AIMA-5-1 breaking machine with a periodic wetting for 50 min in the solution, 10 min in the air at cathodic polarization potentials of -0.75 V, and -1.2 V (relative to the chloride-silver reference electrode) using a PI-50-1.1 potentiostat, simulating cathodic protection applied on an underground gas pipeline. Susceptibility to stress-corrosion cracking was assessed by the K_S coefficient (the ratio of the relative narrowing under the influence of the corrosive factor). Polarization curves were measured on an MTech PGP-550F potentiostat with a potential sweep speed of 1 mV/sec.

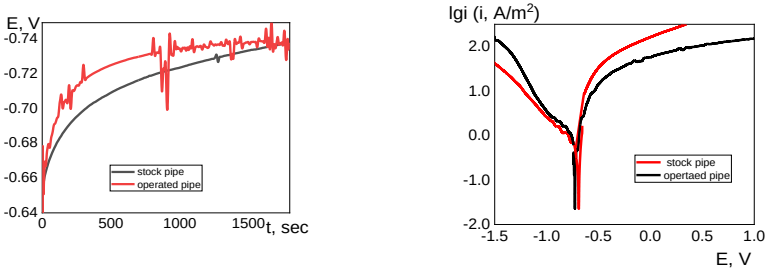
Results and discussion. The microstructure of the operated pipe is ferrite-pearlite with a ferrite grain size of 7-20 μm according to DSTU 8972. The microstructure of the stock pipe is ferrite-pearlite, more homogeneous than that of the operated pipe, the size of the ferrite grain 14-20 μm. The structure of the metal of both pipes has pronounced banding of the pearlite component, and corresponds to 4 points. The specified features of the structure contributed to obtaining a reduced value of the strength limit of the stock pipe (Fig. 1) compared to the standard value (588 MPa). All other indicators of mechanical properties meet the requirements of TU 14-3-995 (Fig. 1).



a b c

Fig. 1. Mechanical properties of the specimens of exploited pipe and stock pipe: a – ultimate strain and yield stress, b – relative elongation; c – impact toughness.

The stationary values of the corrosion potentials of the operated pipe and the reserve pipe coincide (Fig. 2, a). The nature of the anodic and cathodic curves is similar. The limiting diffusion current of oxygen reduction on the specimens of both pipes is close: i_{O2} 2.19×10^{-4} A/m^2 for the operated pipe and 2.19×10^{-4} A/m^2 for the reserve pipe, but the hydrogen reduction potentials on the specimen of the reserve pipe are negatively than those on the operated pipe: -0.930 V and -0.850 V, respectively (Fig. 2, b).



а б

Fig. 2. Corrosion potentials (a) and polarization curves (b) in NS4 solutions of X70 steel specimens.

Presumably, differences in the electrochemical properties of pipe specimens are conditioned to differences in their chemical composition. The anodic curves' slopes, determined at a section of 50 mV from the corrosion potential, are 0.020 V and 0.046 V, respectively. That is, in the NS4 model soil environment, the corrosion of X70 steel is described by the laws of diffusion kinetics.

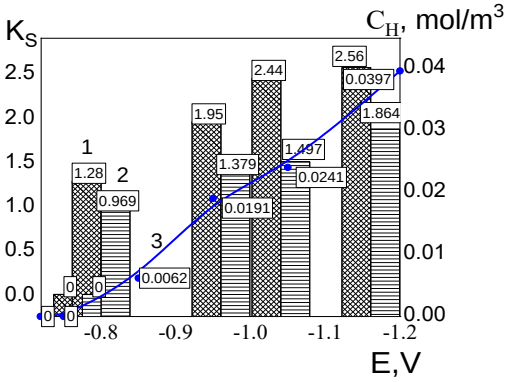


Fig. 3. Tendency to stress-corrosion cracking of metal of long-term operated pipe (1) and storage pipe (2), and susceptibility to hydrogenation (3) at different potentials.

According to the results of electrolytic hydrogenation of steel in NS4, it was established that the amount of hydrogen capable to penetrate into steel under cathodic polarization (with a shift in the polarization potential from -0.75 V to -1.05 V) increases from 0 to 0.0241 mol/m³.

In the range of cathodic polarization potentials from -0.75 V to -1.05 V in the NS4 solution, the coefficient of susceptibility to stress-corrosion cracking for the metal of the operated pipe, increases from 1.02 to 1.53, which correlates with an increase in the susceptibility to hydrogenation (Fig. 3, curve 3). For the reserve pipe at potentials -0.75 V → -0.95 V → -1.05 V coefficient K_S changes non-monotonically, such as 1.02 → 1.55→ 1.32 (Fig. 3). The tendency to increase susceptibility to stress-corrosion cracking when the potential shifts from -0.75 V to -1.05 V for the operated pipe may indicate some embrittlement of the steel under prolonged exposure to external cathodic polarization.

Conclusions. The tendency to increase the susceptibility to stress-corrosion cracking when shifting the polarization potential to the maximum protective potential for the operated pipe and the reserve pipe is the same. But the determined values of K_S are greater for the operated pipe, which possibly indicates on the embrittlement of the steel during long-term exposure to external cathodic polarization. An increase in the susceptibility to stress-corrosion cracking correlates with an increase in the susceptibility to hydrogenation with a shift in the polarization potential.

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