Fracture risk assessment of trunk oil pipeline by corrosion fatigue mechanism of service defects development

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Abstract. Engineering estimations of the corrosion fracture velocity of oil pipelines have been given, which include both mechanical and physical-chemical interaction operation factors of strained material with workspace. Characteristics of cyclic corrosion crack resistance of a pipe metal of the exploited oil-trunk pipeline with the regard for operating production factors have been defined.

New data about corrosive and fatigue failure of pipes in dependence on the initial sizes and forms of their detected defects have been obtained. Cyclic used and unused pipe investigated steel crack resistance charts have been compiled. Also, it has been established, that aqueous corrosive environments (soil and distilled water) essentially influence the fatigue failure propagation process in the investigated steel.

Key words: trunk pipeline, corrosive fissuring defect, corrosive environment, cyclic corrosive crack resistance chart, crack growth rate, threshold (K_{th}) and critical (K_{fc}) stress intensity factor.

I. Introduction

The problem of materials fatigue is one of the central problems of fracture mechanics. Technical diagnostics of responsible constructions exploited in the conditions of combined power load and corrosive aggressive media is an actual scientific and technical problem, particularly, for definition of long-term exploitation (durability) objects. Pipes, used for oil production and transportation, are in constant contact with corrosive and deleterious substances which cause intensive internal corrosion of pipes, whereas their abrasion is accompanied with great material losses and severe ecological consequences [1, 5, 6].

As demonstrated by multiple researches, processes of wear-out failures of industrial constructions under the influence of combined action of mechanical loadings and corrosive workspaces are caused by a number of physical and chemical localised processes of formation and development of fissuring troubles in the material [2 –4]. Besides, alongside with places of enhanced exertion concentration (openings, cuttings, cracks and other technological and constructive exertion raisers), these processes often arise on smooth distorted surfaces, which is due to heterogeneity of their physical and chemical condition. This has been affirmed by the latest statistical data [8 – 10], namely, that almost 80 % of all oil pipelines failures are caused by primary corrosion-mechanical damage and by progressing surface fissuring troubles in places of corrosive caverns and welding joints. In this connection, there appears an acute problem in development of effective methods of evaluation of these phenomena and adequate loading diagrams for engineering practice.

Thus, definition of features and evaluation criteria of technical state of trunk oil pipelines and the interrelation between parameters of physical-mechanical state of their material and operating environment corrosion mechanisms is an actual scientific and applied engineering task.

II. Problem setting

It is possible to prolong durability and provide reliable exploitation of trunk pipelines by diagnosing the actual state of metal and characteristics of its resistance to fissuring troubles expansion, taking into consideration a number of exploitation factors (such as static, cyclic and dynamic loads, corrosive media) which influence probable development of the detected damages.

In order to carry out these engineering evaluations, today they use modern approaches to fracture mechanics [1 – 3], which enables the definition of regularities of corrosion cracks expansion under the influence of fatigue failures that are represented in the form of cyclic corrosive crack resistance charts, which are dependences of fracture growth rate on stress intensity factor K_I. Such charts are arranged between its two boundary values: bottom threshold value K_{th} corresponding to the value of K_I at which there occurs no corrosive fatigue failure growth, and upper K_{fc} corresponding to the value of K_I at which there occurs spontaneous (catastrophic) growth of a fracture. The average amplitude part of such charts is analytically described by Paris power dependence [7].

III. Purpose of research

Grounding on charts of cyclic corrosive crack resistance of the oil-trunk pipeline material to substantiate a comparative evaluation of the influence of corrosive media on corrosive fatigue failures developing in it for different “material – environment” systems.

The investigations have been carried out for both unused (new) metal (steel 10Г2БТЮ3, $\sigma_{0,2}$ = 423,7 mPa, δ = 26,9 %, d_{ext} = 530 mm, t = 8 mm) and used metal (steel 10Г2БТЮ3, $\sigma_{0,2}$ = 438,9 mPa, δ = 25,6 %, d_{ext} = 530 mm, t = 7mm) of oil pipeline “Druzhba”. Mechanical characteristics of steel have been defined after a standard testing procedure of cylindrical samples for stretching.

All basic physico-mechanical investigations of corrosive fatigue failures' developments have been conducted on prismatic models. The intermediates for samples of 10 mm × t × 40 mm in size have been cut out from fragments of real pipes. The total length of the sample add up to l = 200 mm.

The diagrams of cycle crack resistance of unused metal of the pipeline have been received by way of testing of approbation beam samples with rectangular section (8 × 10 mm) with the initial edge crack c = 1,5 ... 2,0 mm.

Also, investigations have been conducted of cyclic crack resistance of used metal of an 81 km long “Druzhba” oil-trunk pipeline segment, which have been in operation for 41 year. What should be underlined is, that as a result of metal abrasion during operation process the thickness of the pipe wall lessened from 8 mm to 7 mm, and the most typical operational defects are corrosion defects, caused by joint action on metal of working loadings and environments.

The investigations for cyclic crack resistance have been conducted on special experimental equipment in pure bend conditions of the models with 1 Hz frequency at the sinusoidal form of loading cycle ($R \approx 0,8$). They have been tested in laboratory air, in distilled water (pH 6,7), as well as in 0,1 % NaCl solution (pH 6,5), which served as a soil water model. Environment temperature $T = 25°C$.

The models have been tested to final fracture with the subsequent analysis of fracture surfaces. The computerized fracture surface images, that correspond to different stages of corrosive fatigue failures development, can be used as models at identification of fracture conditions of real elements of pipelines in operation.

IV. Investigation results

Approbation results have been represented as diagrams of cyclic crack resistance. The analysis of the final results testifies to the following. With the growth of test media corrosiveness (laboratory air – distilled water – soil water), cyclic crack resistance of both new and used metal declines.

For all analysed cases the cyclic crack resistance of used metal of “Druzhba” oil-trunk pipeline is lower, than for the metal of the new pipe. The exploited metal is more sensitive to the environmental influence.

In particular, during the tests of used steel in soil water, the value of exertion intensity factor K_{th} declines in 1,5 – 1,7 times, whereas critical value K_{fc} declines in 1,3 – 1,6 times in comparison with the analogical data for new metal in the air.

Thus, we have defined the degree of influence of aggressive corrosive media on propagation of fatigue failure in the indicated steel.

Conclusion

New data on character and peculiarities of fatigue and corrosive fatigue failure of pipes in dependence on the initial size and form of the detested in the pipeline defects have been obtained.

It has been established, that the exploited over 40 years (degraded) metal of “Druzhba” oil-trunk pipeline (steel 10Г2БТЮ3) in corrosion medium has smaller resistance to propagation of cracks in comparison with unused metal.

It has also been found out, that aquatic corrosive media (soil and distilled water) essentially influence the process of a fatigue failure propagation in steel 10Г2БТЮ3. The most dangerous corrosive medium is 0,1 % NaCl solution, that is, model soil water.

Practical importance of the results

With the purpose of determination of the mechanism of corrosive-mechanical damages and developing of the recommendations for their preventive maintenance, the data obtained on cyclic crack resistance a pipe material will further be used in computed estimations of durability and longevity of pipeline elements taking into account the subcritical development of corrosion fissuring defects.

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