

Research of main gas pipeline (steels X65, X60, 17G1S) susceptibility to stress corrosion cracking, hydrogen uptake and ST 37-2 steel fatigue testing

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Abstract. According to the data from the slow strain rate stress corrosion cracking test, two histograms were constructed that shows an increase in the susceptibility of metals to stress corrosion and hydrogen charging due to the rise in temperature (+ 25°C to +50°C). Consequently, susceptibility to stress corrosion increased from 0.85 to 0.87 for steel X65 and rose to 0.9 for steel X60, respectively. The same trend was observed for hydrogen charging (from + 25°C to + 50°C, the hydrogen charging increased from 1 to $2 \frac{(\text{mol} \cdot \text{H})}{\text{m}}$) for steel X65 and (from 1.2 to $3.5 \frac{(\text{mol} \cdot \text{H})}{\text{m}}$) – for steel X60. In the second study, for the low-cycle fatigue under varying strain conditions, V-shaped shear specimens of ST 37-2 steel were used. It shows that grain-boundary steel has a crack width of 1.3 µm, whereas steel with an initial and cellular structure – 0.34 and 0.42 µm. Comparing the data obtained from Severgazprom, a histogram of the dependence of corrosion-stressed defects in the pipeline segments in front of the compressor station was constructed. The sections of the 115 km of the underground gas pipeline infrastructure were surveyed. In case of steel grade 17G1S, the diameter of the pipes ranged from 1020 mm to 1420 mm. Graphs were constructed for the dependence of the density of corrosive destruction in winter or summer seasons. The range of temperatures during operation of main gas pipelines was from 60°C to 25°C in summer and from 30°C to -30°C – in winter.

1. Introduction

Over the period of many years of operation, the main gas pipeline is subjected to a large number of internal and external influences, which leads to various defects.

The paper presents a study of the effect of temperature and hydrogen charge on stress-corrosion cracking as separate factors. This will help to understand the process of occurrence of stress corrosion on gas mains.

Previous research [1-3] has established that one of the primary defects of gas pipelines was stress corrosion cracking, which led to the failures of up to 50% of all failures of main gas pipelines.

By 2000, the amount of destruction due to corrosion defects had been 30%. In 2001, 41.93% of the main gas pipelines were not operating due to stress corrosion, while it was shown only on the main



large-diameter pipe (720-1420 mm). The fundamental research issue is that stress-corrosion cracking occurs only at the specific moment under the circumstances.

With variable loads during a long period of operation, the material of the main gas pipeline significantly changes its mechanical properties, i.e. another cellular structure with dense grain boundaries formed, which subsequently can lead to the nucleation of a defect and its development with the consequences of the destruction of the pipe segment [4, 5].

2. ST 37-2 steel fatigue testing

Long-term operation of pipelines and tanks leads to the gradual formation of a homogeneous cellular structure with dense boundaries. The average size of the cells is about 1 μm , and the angles of misorientation between them do not exceed 1-2 °. A similar structure formed for large plastic deformations with monotonous loading [6]. Let us note that inside the ferrite grains deformation is uneven. There are separate areas where the initial phase of cell boundary formation is observed, as well as areas where individual dislocations are not allowed. Longer work leads to a fragmented structure characterized by very subtle and extreme boundaries. These borders create large disorientation of surrounding areas. This structure can be formed as a result of simultaneous rotation of cells mainly in one direction, and as a result of their disordered rotation.

The fatigue test was carried out to determine the impact of different dislocation structures on durability with 2 samples. Two symmetrical V-notch shear specimens used for this purpose.

Fatigue tests were carried out under conditions of low-cycle deformation. The results are presented in Figure 1.

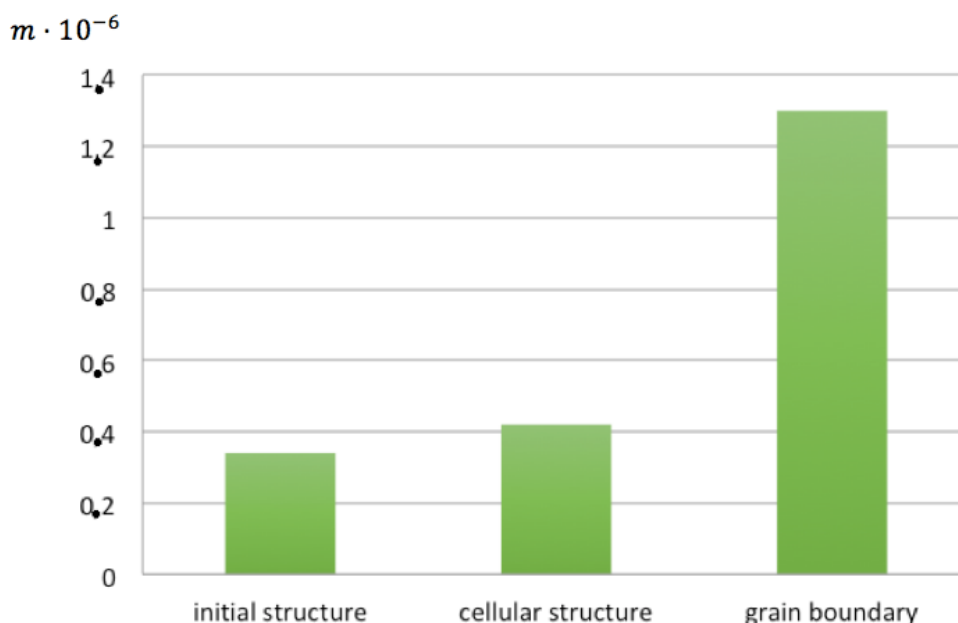


Figure 1. Cracks width.

It is evident from the figure that cracks of grain-boundaries steel are 3 times wider than in steels with an initial and cell structure.

3. Comparison of the susceptibility of steel grades to stress corrosion under the influence of different temperatures

The next point of the work was the construction of two graphs (Figures 2, 3), based on the results of the slow rate of deformation test of longitudinal welds of steel X60 and X65 in an electrolyte solution saturated with H₂S at a temperature of + 25 °C, + 37 °C and + 50 °C.

According to the first schedule, when the temperature is changed from + 25 °C to + 50 °C, the susceptibility to stress corrosion grows from 0.85 to 0.87 for steels X65 and increases from 0.85 to 0.9 for steels X60.

Susceptibility to stress corrosion was calculated using the following formula (1):

$$I_{SCC} = \frac{R_{air} - R_{H_2S}}{R_{ai}} \cdot 100 \quad (1)$$

Where R_{air} and R_{H_2S} – loss of metal in air and in H_2S solution [7].

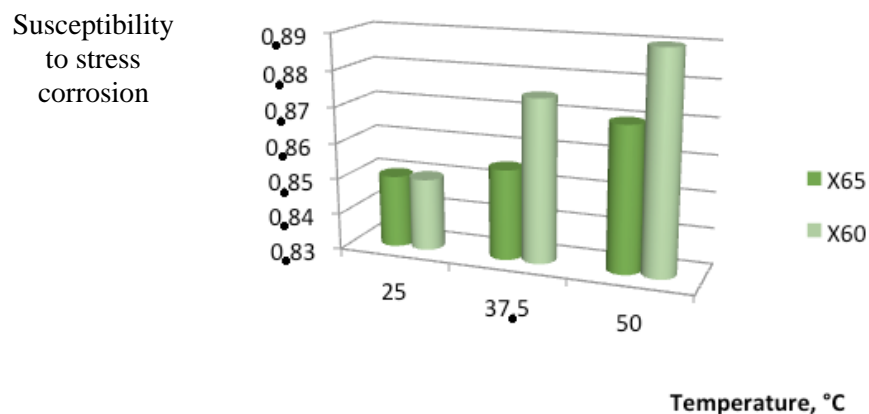


Figure 2. Susceptibility to stress corrosion versus temperature characteristic.

The second graph shows increasing ability of hydrogen charge due to the temperature growth from + 25°C to + 50°C 2 times for steels X65, and for X60 steel – 2.5 times. Thus, the risk of stress-corrosion cracking increased.

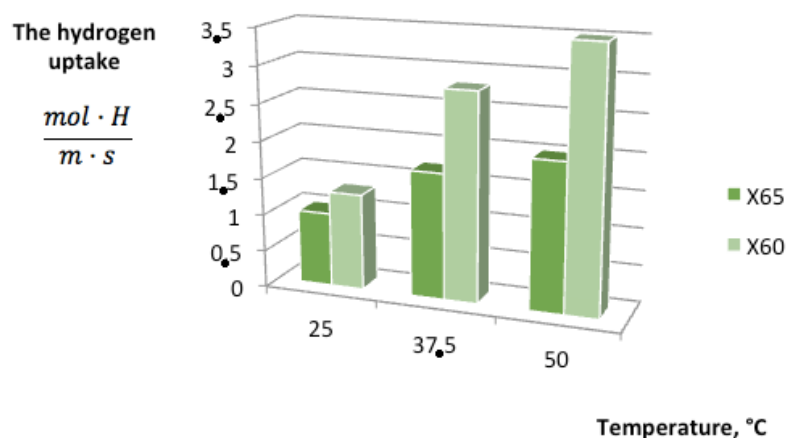


Figure 3. Hydrogen uptake versus temperature characteristic.

4. The analysis of thermal effect on stress corrosion failures of the main gas pipelines according to “Severgazprom” Company

According to data on the distribution of failures in the gas pipeline infrastructure of Severgazprom [8-10], a histogram of the dependence of the number of failures due to stress corrosion from the distance to the compressor station was constructed (Figure 4). The failures were registered by the inspectors of Severgazprom. The length of the infrastructure of the underground main gas pipeline of 115 km was examined. In case of steel grade 17G1S, the diameter of the pipe ranged from 1020 mm to 1420 mm [11].

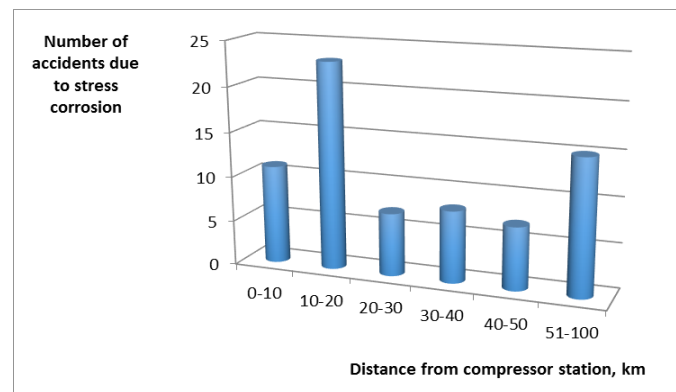


Figure 4. Stress corrosion defects vs. distance from the compressor station

Analyzing the temperature distribution along the length of the main pipeline in the winter and summer seasons, graphs of the dependence of the number of corrosion stress on temperature were plotted. The range of temperatures during operation of main gas pipelines was from 60°C to 25°C in summer and from 30°C to -30°C – in winter (Figure 5, 6).

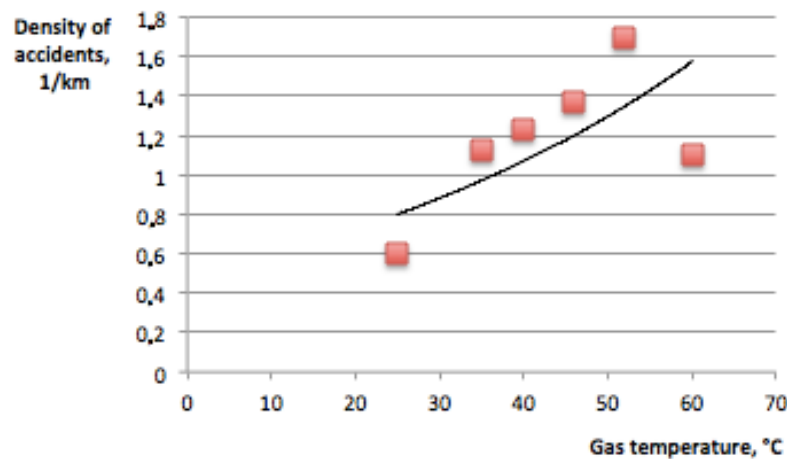


Figure 5. Exponential approximation of stress corrosion failure density vs. temperature in summer

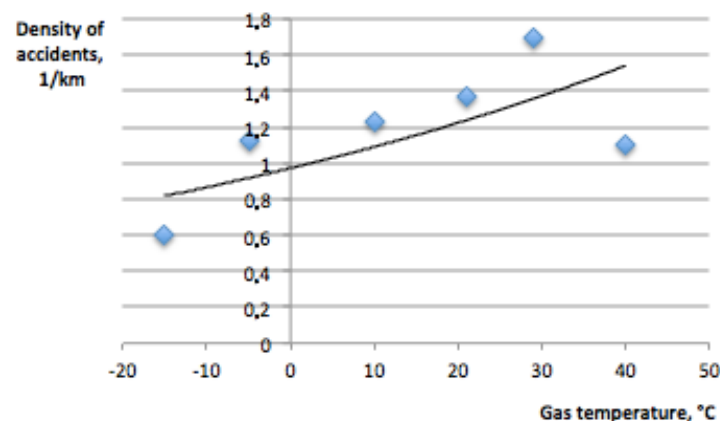


Figure 6. Exponential approximation of stress corrosion failure density vs. temperature in winter

From the above-mentioned chart review, it seems that high temperatures have significantly affected the condition of pipelines, particularly gas pipelines operating at high temperatures are much more susceptible to stress corrosion.

5. Conclusion

As a result of the first study, it was found that during operation, there is a significant degradation of the structure within the ferrite grains of steel ST 37-2, the state of which can affect the origin of defects and the development of destruction processes.

For the next experiment, a clear connection of the occurrence of corrosion stresses in the steels of the main gas pipelines X60 and x 65 was established depending on the temperature and the ability of hydrogen to charge the pipe metal.

The results of comparing the sensitivity of steels to stress corrosion under the impact of different temperatures show an increase in the propensity of metals to stress corrosion and hydrogen charging with increasing temperature. The analysis of the thermal effect on the failures of the main gas pipelines in comparison with the corrosion stress shows a reduction in the number of failures as the temperature decreases. On pipeline sections, located close to compressor stations, where the main gas pipelines have the maximum operating temperature, the fracture density reaches 1.6 km, and 115 km – from the compressor station; the fracture density is more than 0.8.

References

- [1] FangB, EadieR, ElboujdainiM, ChenW, Han E-H 2008 *The Effect of Microstructure on Pit-To-Crack Transition and Crack Growth in an X-52 Pipeline Steel in Near-Neutral pH Environment* (7th International Pipeline Conference, vol 2) IPC 2008-64112 (Calgary: ASME) Paper No. IPC2008-64112, pp 215-225
- [2] Contreras A, Salazar M, Albiter A, Galván R and Vega O 2011 *Arc Welding*.pp. 143-144
- [3] Craig B 1998 Calculating the lowest failure pressure for electric resistance welded pipe, *Welding Journal***77**(1) 61-63
- [4] NEB 1996 *Stress Corrosion Cracking on Canadian Oil and Gas Pipelines Report of the Inquiry*
- [5] CEPA 1997 *The CEPA Report on Circumferential Stress Corrosion Cracking Submitted to the National Energy Board*. pp 4-10
- [6] NACE TM 0177-2005 *Laboratory testing of metals for resistance to sulfide stress cracking and SCC in H₂S environment*
- [7] Bulger J & Luo L 2000 *Effect of microstructure on near-neutral pH SCC Proceedings in the International Pipeline Conference ASME* (Calgary: ASME)
- [8] Chuchkalov M V 2015 Doctoral dissertation. pp 97-99
- [9] Teplinskii YA 2007 *CenLitOilGas*. p 400
- [10] Gareev AG., Nasibulina OA, Rizvano RG 2012 *Oil and Gas Business***6** 126-146
- [11] Silvestrov AC, Bulkin VA, Anvarov AD 2011 *Bulletin of Kazan State Technological University***18** 169
- [12] Ivancivsky VV, Skeebe VY, Bataev IA, Lobanov DV, Martyshev NV, Sakha OV, Khlebova IV 2016 The features of steel surface hardening with high energy heating by high frequency currents and shower cooling. *IOP Conference Series: Materials Science and Engineering* **156**(1) 012025