Here's the English translation of your sentence:
"At potentials from –0.75 V to –1.05 V, the fracture remained predominantly ductile, but the proportion of brittle areas gradually increased."
Would you like me to also translate the rest of your summary into English for consistency?

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Susceptibility to stress-corrosion cracking of long-operated gas pipeline steel in a model soil electrolyte

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INTRODUCTION & AIM

Underground main gas pipelines, after long-term operation under the combined influence of comprehensive anticorrosion protection and mechanical loads, may experience a reduction in properties, leading to deterioration of their service performance. Some researchers believe that the degradation of pipe steels is caused by strain aging, which results in increased strength and reduced ductility. Others have shown that the base metal and welded joints of gas pipelines, after prolonged operation, retain a complex of mechanical properties due to the high reserve of impact toughness and ductility of the metal in its initial state. However, despite extensive research, data on the resistance of pipes after long-term operation to stress corrosion cracking under conditions of cathodic polarization remain insufficient.

The aim of this work was to conduct comparative studies of stress corrosion cracking under cathodic polarization of the pipe metal of a 1020 mm diameter main gas pipeline made of X60 steel after 50 years of service, using samples from both an intact section and a section where a damage zone was detected.

METHOD

The study was conducted on samples of the base metal from a pipe made of X60 steel after the accident of a 1020 mm diameter main gas pipeline that had been in operation for 50 years. Samples were taken from an intact section (Sample 1) and from a section where a damage zone was detected (Sample 2).

Stress corrosion studies were carried out on specimens (Figure 2) by slow strain rate (10^{-6} s^{-1}) test method (SSRT) on an AIMA-5-1 machine, in NS4 solution (0,037 g/l KCl + 0,559 g/l $NaHCO_3$ + 0,008 g/l $CaCl_2$ + 0,089 g/l $MgSO_4$, pH 8.2) [1] under cathodic polarization potentials of –0.750, –0,950 and –1.050 V.

Susceptibility to SCC was estimated by the dimensionless coefficient K_S [2]:

$$K_S = \frac{S_0 - S_1^{air}}{S_0 - S_1^{sol}} = \frac{\psi^{air}}{\psi^{sol}}$$

S_0 – cross-sectional area of the specimens before testing, mm²;
S_1 – cross-sectional area after testing, mm²;
ψ – relative narrowing of specimens;
air and sol – belong to tests in air and in solution.

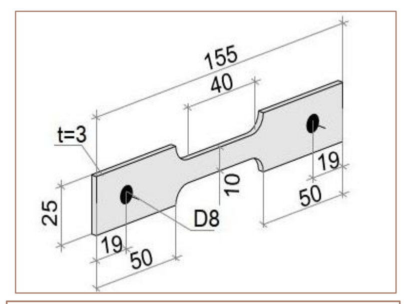

Figure 1. Specimen for SSRT.

RESULTS & DISCUSSION

The results of the chemical composition analysis (**Table 1**) confirmed that the base metal of both investigated pipes belongs to low-alloy steel with vanadium additions and, by its chemical composition, meets the requirements of the technical specifications under which these pipes were manufactured. No significant deviations in the chemical composition of the base metal of pipe Sample 1 compared to the intact pipe Sample 2 were detected.

The mechanical properties (σ_{ts} and σ_y) of pipe Sample 2 are slightly higher than those of Sample 1, but remain within the limits specified by the TU-40-68 (**Figure 2**). Differences were observed in Sample 1 compared with the certificate data: lower tensile strength and higher yield strength. For Sample 2, the tensile strength corresponds to the certificate, while the yield strength is slightly higher. The toughness properties of both pipes, despite deviations from certificate data, are within the TU-40-68 requirements. It can be concluded that after long-term operation, the strength and plasticity of the base metal, both in the intact pipe and in the pipe with a detected damage zone, meet the technical conditions.

The microstructure of Sample 1 and Sample 2 is typical for the steel manufactured in the XX century – ferritic-pearlitic with fine ferrite grains (20-25) microns in size (**Figure 3**). The share of the pearlite component was (50-60)% and is approximately the same for both pipes.

Table 1. Chemical composition of the investigated samples in comparison with the pipe certificate data and technical requirements.

Sample characteristic	Mass part of the elements, %							
	C	Mn	Si	S	P	V	Ti	Nb
Sample 1	0,17	1,32	0,45	0,021	0,009	0,096	0,002	<0,01
Sample 2	0,21	1,40	0,40	0,020	0,015	0,064	0,002	<0,01
Pipe certificate	0,19-0,21	1,40-1,42	0,40-0,43	0,024-0,026	0,016-0,020	V+ Nb+ Ti 0,09		
Technical requirements TU 40-68	0,22	1,60	0,55	-	-	V+ Nb+ Ti 0,12		

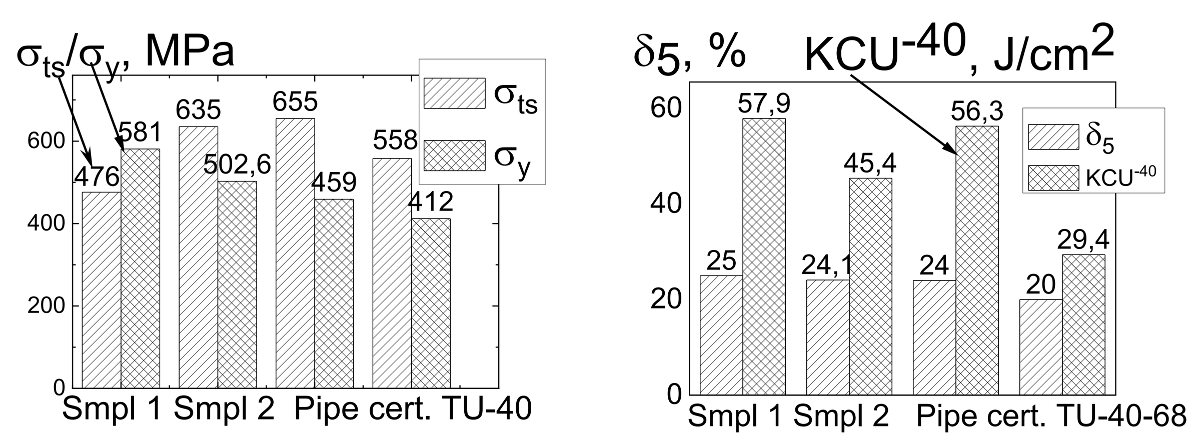

Figure 2. Mechanical properties of the investigated samples in comparison with the pipe certificate data and technical requirements.

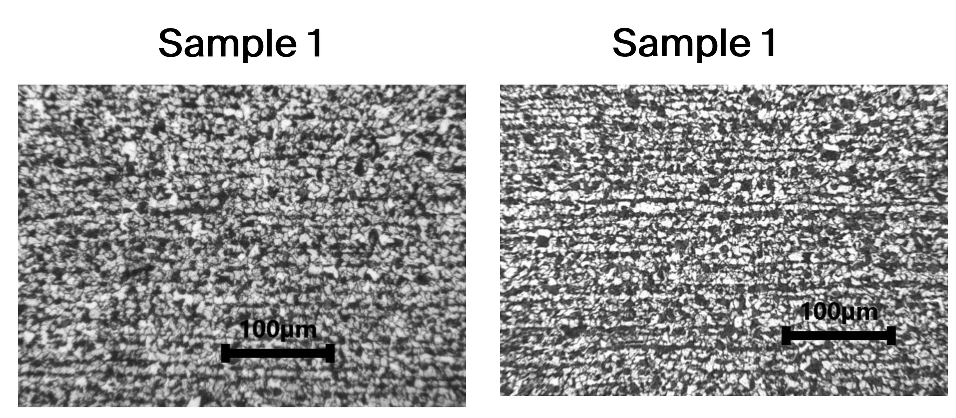

Figure 3. Microstructure of the base metal of the investigated pipes.

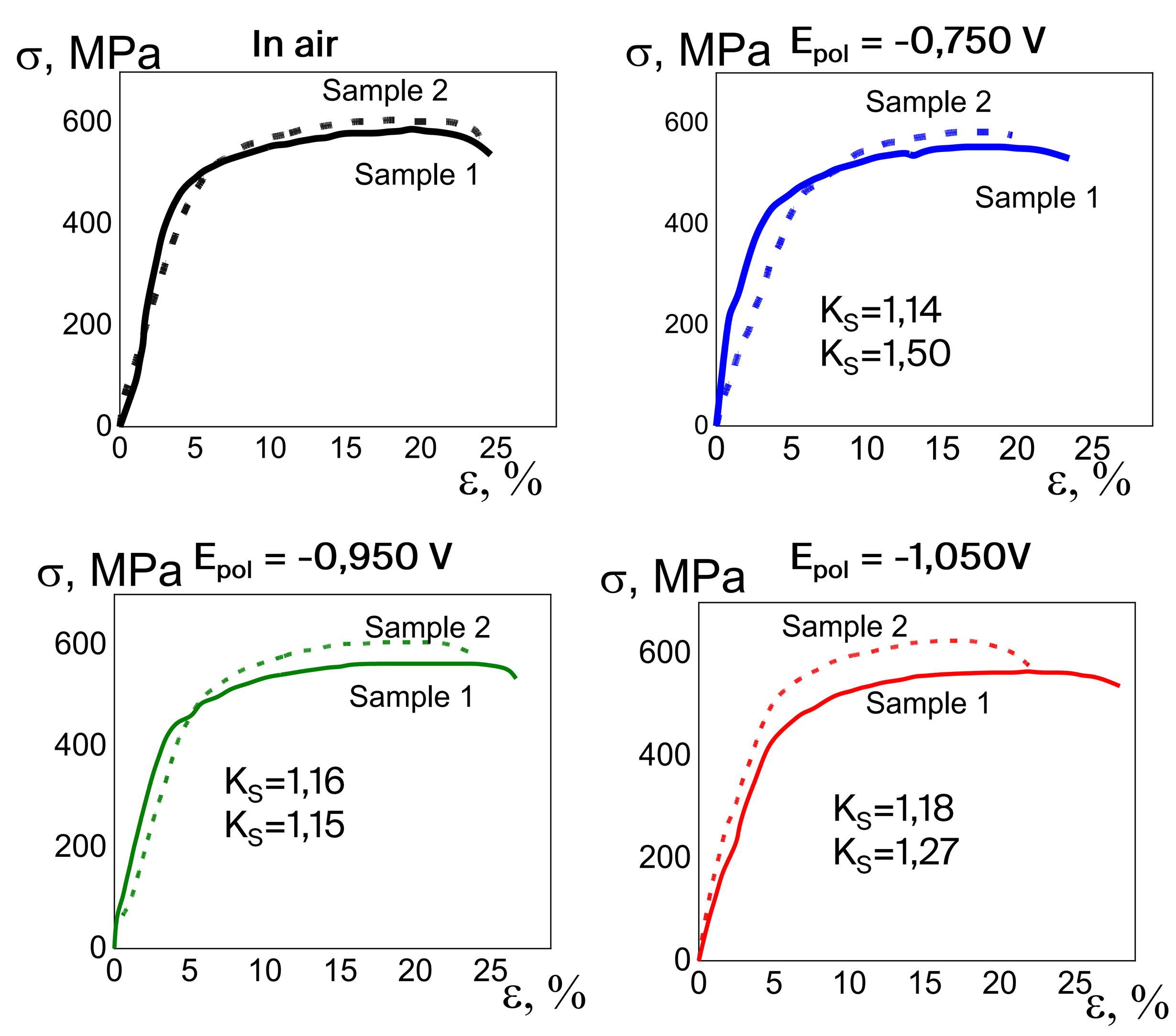

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Figure 4. Breaking diagrams of the investigated samples during long-term tensile tests in air and in NS4 solution under conditions of cathodic polarization potentials.

Susceptibility to stress-corrosion cracking coefficient K_S for the metal of an undamaged pipe (Sample 1) at the polarization potential range from -0.75 V to -1.05 V (relative to the saturated silver chloride electrode) in NS4 increases from 1.14 to 1.18 (**Figure 4, Figure 5**). For specimens of damaged pipe (Sample 2), the maximum K_S value 1.5 is observed at -0.75 V, and it decreases to 1.27 at -1.05 V (**Figure 5**).

It was found that specimens of damaged pipe demonstrated higher maximum stress, lower relative elongation and relative narrowing at the potential of -1.05 V than specimens from an undamaged pipe (**Figure 4**). Such patterns may be due to pipe deformation during the accident and the influence of local anodic dissolution.

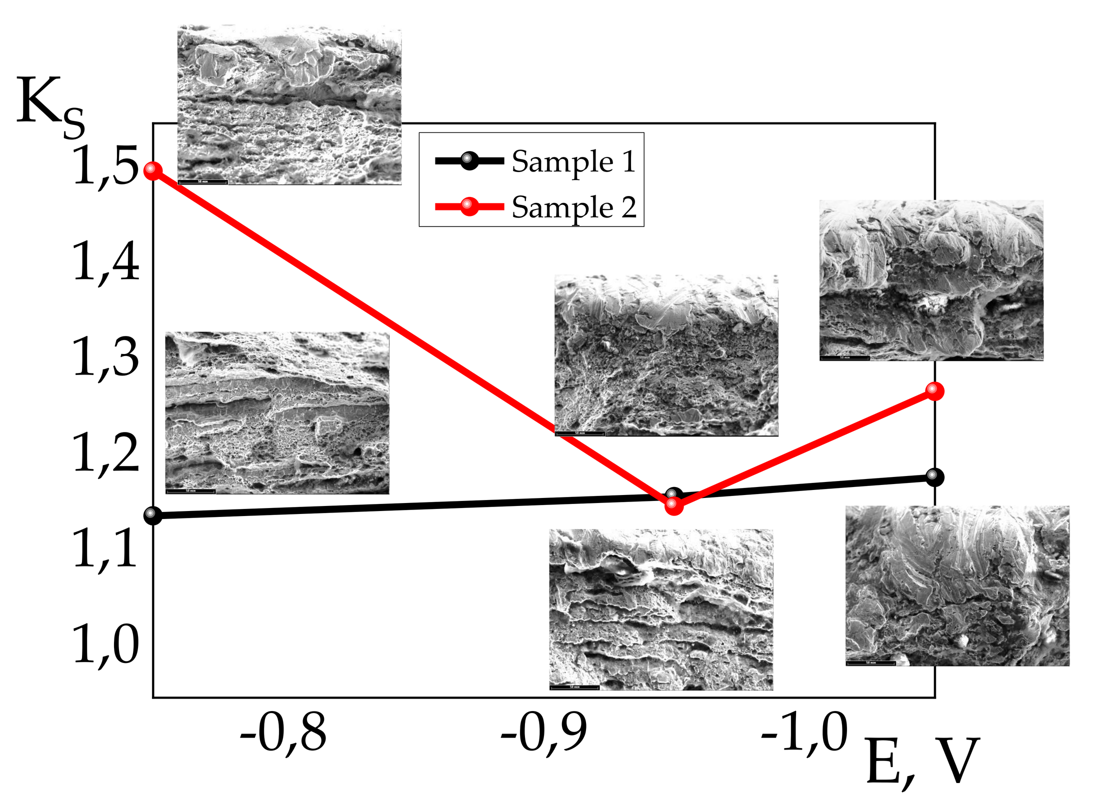

Figure 5. Susceptibility to stress-corrosion cracking of the investigated samples within the range of protective potentials normalized by National Standard 4219 and SEM images of fracture surface.

The fracture analysis of both undamaged and damaged pipes under cathodic polarization in the range –0.75 V to –1.05 V demonstrates a progressive increase in brittle features despite the overall ductile fracture mode. In the undamaged pipe (Sample 1), this transition occurs gradually, whereas in the damaged one (Sample 1) the brittle component intensifies more sharply, accompanied by higher KS values and a greater presence of faceted fracture surfaces. These findings indicate that prior mechanical damage significantly accelerates susceptibility to stress-corrosion cracking under protective potentials, underscoring the critical role of structural integrity in determining fracture behavior.

CONCLUSIONS

1. The base metal of both pipes is low-alloy steel with vanadium additions, meeting technical specifications without significant deviations between intact and damaged samples.
2. Despite minor differences in tensile and yield strength compared to certificate data, both pipes maintain strength and toughness values within TU requirements, confirming acceptable performance after long-term operation.
3. Under cathodic polarization (–0.75 V to –1.05 V), both pipes show increasing of brittle features, but the damaged pipe demonstrates sharper intensification of brittle fracture, higher K_S values, and greater faceted fracture surfaces, highlighting the critical impact of prior mechanical damage on stress-corrosion cracking resistance.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

FUTURE WORK FOCUS. Further research should focus on investigating of stress-corrosion cracking in long-term operated pipes under thin-film corrosion conditions.

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