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Features of the influence of non-metallic inclusions on quality of oil and gas field equipment steels

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ABSTRACT: The increased accident rate of oilfield pipeline systems with full compliance of steel with the requirements of existing regulatory documents testifies to the fact that these requirements, as well as steel testing methods, are not sufficient to ensure the required corrosion resistance and operational reliability. Therefore, it is important to develop additional requirements to steels and their test methods to improve corrosion resistance and service life of oilfield pipelines and environmental safety of oil and gas production.

KEYWORDS: nonmetallic inclusions (NI), metal oxide, study of steel microstructure, aggressive environment.

I. INTRODUCTION

In terms of preventing significant loss of equipment and installations of their planned resource as a result of exposure to aggressive components in the working environment, the most important scientific, technical and economic task is to extend the life of the trouble-free operation of installations and equipment. This means not only maintaining their design level, but also technical and engineering improvement of systems, increasing their reliability and safety of objects exposed to corrosive exposure. One of the ways to achieve this is to strengthen the requirements for metal quality of equipment operated in aggressive environments, which will ensure the industrial safety of hazardous production facilities.

II. LITERATURESURVEY

The object of research is a metallographic structure - an interconnected configuration of solid body regions with a homogeneous or inhomogeneous crystal structure, separated from each other by incoherent interfaces.This makes it possible to determine possible changes in the metal of the equipment, which are the result of exposure to aggressive media. The reasons for the appearance of inhomogeneous crystal structure are presented in Table 1.

Table 1 - The causes of metal surface inhomogeneity

Common reason	Specific reason
Metalinhomogeneity	
Metallic phase inhomogeneity	a) macro- and micro-inclusions (non-metallic inclusions are cathode sites); b) alloyinhomogeneity.
Metal surface inhomogeneity	a) the presence of block boundaries and crystallite grains; b) the appearance of dislocations on the metal surface; c) anisotropy of a metal crystal.

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Metal surface atomic inhomogeneity	a) presence of inhomogeneous atoms in the solid solution.
Inhomogeneity of protective films on the metal surface	a) macro- and micro-pores in the oxide film (the bottoms of the pores are anodes); b) non-uniform distribution of secondary products on the metal surface.
Inhomogeneity of internal stresses in the metal	a) non-uniform deformation; b) non-uniformity of applied external stresses (the anode areas are more stressed).
Electrolyteinhomogeneity	
Liquid phase inhomogeneity	a) the difference in the concentration of the ions of a given metal in the electrolyte; b) difference in the concentration of neutral salts in the solution; c) pH differences; d) difference in oxygen concentration (more aerated are cathodic).
Inhomogeneityofphysicalconditions	
Inhomogeneity of physical conditions	a) temperature difference (the hotter areas are anode areas); b) non-uniform distribution of radiant energy; c) non-uniform overlapping of the external electric field.

It is also essential that steel is a heterogeneous material whose components in the form of oxides, sulfides, nitrides, etc. are part of complex and often multiphase corrosive-active nonmetallic inclusions (CANI).

Five groups characterize the most frequently observed types and morphological signs of inclusions:
- group A (sulfide-type inclusions) are strongly deformed individual particles of grey color, with a wide range of shape factor (length/width ratio) and usually with rounded ends;
- group B (aluminate-type inclusions) - numerous non-deformable particles (at least three), polygonal in shape, with a low shape factor (less than three), black or bluish in color, oriented in the direction of deformation;
- group C (silicate-type inclusions) - highly deformed individual black or dark gray particles, with a wide range of shape factors (at least three) and, as a rule, sharp ends;
- group D (globular oxide-type inclusions) - non-deformable, angular or circular, black or bluish, randomly distributed particles, with a low shape factor (less than three);
- group DS (single globular oxide type inclusions) - round or nearly round single particles with a diameter of at least 13 µm.

Such defects are associated with the harmful effects of non-metallic inclusions:
- point and spot inhomogeneity;
- soiling and hairlines;
- slate fracture;
- stone-like fracture and etc., the number and size of the defects increase with the content of harmful impurities in the steel (sulfur, phosphorus, etc.).

The localization of stresses at CANI in steel is due to:
- different thermal compression of the inclusion and matrix during material cooling;
- concentration of the applied stresses due to the difference in the elastic modules of the inclusions and the matrix, as well as the shape of the inclusions;
- the difference in coefficients of linear expansion of the inclusions and the matrix around the non-metallic inclusion (NI), which causes internal (structural) stresses.

The effect of inclusions is usually strongest on the impact toughness, which is particularly sensitive to metal notches and stress concentrators (Figure 1). The decrease in impact toughness, for example, in the presence of string inclusions in the fracture plane, can reach 30-70%. String non-metallic inclusions can cause delamination of metal under external loads. This causes rapid wear and rejection of steel products. Globular oxide nonmetallic inclusions located on the contact surface reduce the wear resistance and fatigue strength of steel.

At JSC“O'ZLITINEFTGAZ” fragments of oil and gas production and process pipes and equipment are tested to determine reasons for failures and possibility of their reuse taking into account destructive and corrosive processes in metal (Table 2).

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Table 2 - Set of studies of corrosion failures

Research	Device	Referencedocument
Parameters and sample defects	Ultrasonic: - thickness gaugeA1208 - flaw detector A1212 Master - hardness testerТЭМП-2	GOST 14782 GOST 28702 GOST 17410
Chemical composition of steel	Styloscope AH-7529-4	GOST 12344
Mechanicalproperties	Tensile testing machine ИР-100М-авто	GOST 1497 GOST 9012
X-rayphaseanalysis	X-raydiffractometerДрон-2,0	Handbook of X-Ray Analysis
Macro-microanalysis	Electron microscopeLeicaDM 2700-M	GOST 8233 GOST 5639 GOST 5640
Presence of non metallic inclusions		GOST 1778 ISO 4967

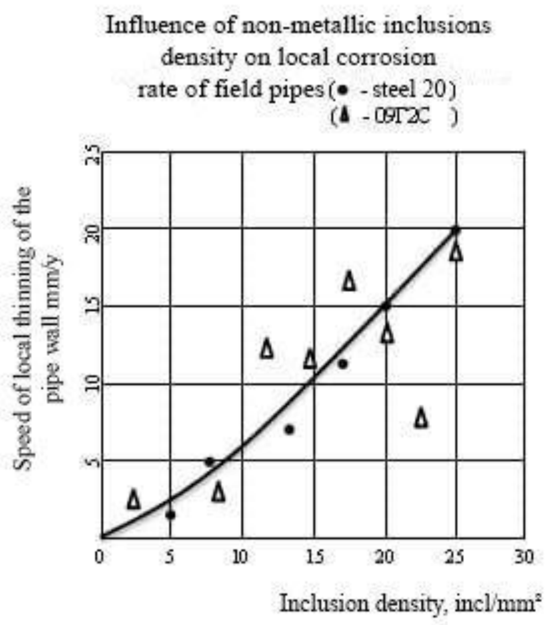

Figure 1 - Effect of CAVI on steel properties

III. EXPERIMENTAL RESULTS

Studies conducted at JSC "O'ZLITINEFTGAZ" showed changes in mechanical and corrosion resistance properties of the tested samples of steel 20 and steel 20C under the influence of real aggressive media of oil and gas fields, depending on the presence of CANI.

Studies of the microstructure, the presence of non-metallic inclusions were determined on a metallographic microscope Leica 2700M in one field by the methods outlined in GOST 1778, ISO 4967 [4] and the program "Steel Expert", which provides a color highlighting CANI.

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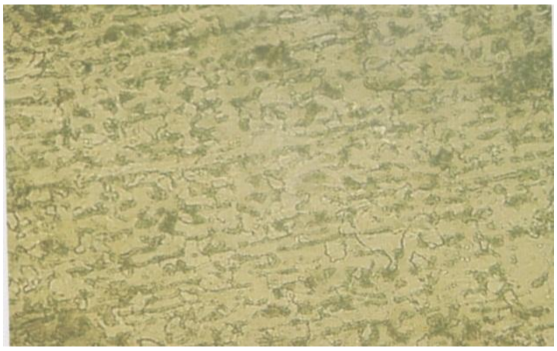
Figure 2a shows a general view of a fragment of MDEAcollector that has been in operation since 1996 (operating environment - MDEA medium with H_2S up to 0.027 mol, CO_2 0.1 mol per 1 mol of solution; temperature operation mode - up to 125 °C).

Figure 2b shows the microstructure of the steel massive of the fragment under test, and the globular-chain arrangement of CANI - sulfides is clearly distinguished in the swelling zone (Figure 2c).

X-ray patterns for phase analysis were performed on diffractometer Дрон-2.0 with radiation of iron anode at voltage of 25 kV on the X-ray tube, anode current 8-12 mA, speed of counter movement 4 o/min, speed of diagram tape movement 1800 mm/h. Wavelengths of characteristic radiation of iron anode K_α = 1,93728Å, K_β =1,75653 Å. [1-4].

a



b

c

Figure 2 - General view of the collection fragment (a);microstructures of the steel massive (b) and steel structure in the swelling zone (c); ×200

Table 3- the X-ray phase analysis of corrosion products from the surface of the collection fragment.

	Experimental results		Table data d/n, Å						
	θ	d/n, Å	Fe_2O_3	$\beta Fe_2O_3 \cdot H_2O$	$\gamma Fe_2O_3 \cdot H_2O$	FeS	FeS_2	Fe_3O_4	Fe_2SO_4
1	$19^0 4'$	2,2649				2,97(33)		2,97(28)	
2	$19^0 32'$	2,8975				2,88(4)			
3	21^0	2,7026					2,70(75)		
4	$21^0 12'$	2,6787	2,6(100)			2,65(33)			

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5	$21^0 36'$	2,6314		2,64(15)		2,65(33)			
6	$23^0 8'$	2,4659			2,47(100)				
7	$23^0 32'$	2,4264					2,42(45)	2,42(11)	
8	$23^0 44'$	2,4071							2,40(2)
9	$25^0 16'$	2,2690		2,29(25)					2,28(13)
10	$26^0 4'$	2,2044	2,20(18)				2,21(35)		
11	$27^0 4'$	2,1288						2,10(32)	
12	28^0	2,0631			2,085(16)	2,06(100)			
13	$28^0 12'$	2,0495				2,06(100)			
14	$29^0 4'$	1,9939							1,99(20)
15	$29^0 20'$	1,9772		1,96(25)	1,94(80)				
16	$30^0 36'$	1,9030					1,91(45)		
17	$31^o\ 56^1$	1,8314	1,84(63)		1,85(12)				1,83(16)
18	$32^o 24^1$	1,8078							
19	$33^o\ 44'$	1,7412			1,73(40)				
20	$34\ ^0 20'$	1,7174				1,71(33)		1,71(16)	
21	$35\ ^0 16'$	1,6775	1,69(63)	1,648(45)					
22	$36^0\ 28'$	1,6298					1,6(100)	1,61(64)	1,63(20)
23	$37^0 16'$	1,5997	1,60(13)						1,59(20)
22	$37^0\ 36'$	1,5876			1,57(11)		1,56(15)		
25	$40^0\ 4'$	1,5050					1,50(17)		
26	$40^o\ 24'$	1,4945		1,494(5)	1,49(6)				
27	$40\ ^0 44'$	1,4845	1,48(50)					1,48(80)	
28	$41\ ^0 56'$	1,4496	1,45(50)	1,45(25)			1,45(25)		
29	$42^0\ 12'$	1,4420	1,45(50)	1,45(25)			1,45(25)		1,44(6)
30	$42^0 32'$	1,4328			1,439(14)	1,449(9)	1,45(25)		1,44(6)
31	$42^0\ 52'$	1,4238			1,439(14)		1,45(25)		
32	44^0	1,3943		1,38(15)	1,39(8)				

X-ray diffraction analysis revealed the presence of all types of iron oxide Fe_2O_3 of various crystalline modifications, as well as large amounts of FeS and FeS_2.

The steel defect of the tested MDEA collection fragment is apparently caused by the process of hydrogenation by hydrogen released during hydrolysis due to CANI - sulfides.

Figure 3a shows a general view of a pipe fragment for acid gas transportation. In operation since 1998, the working environment contains H_2S+CO_2up to 45-55%, SO_2 - 35-45%, hydrocarbons - up to 0,1-1%, temperature operation mode - up to +60°C.

a b

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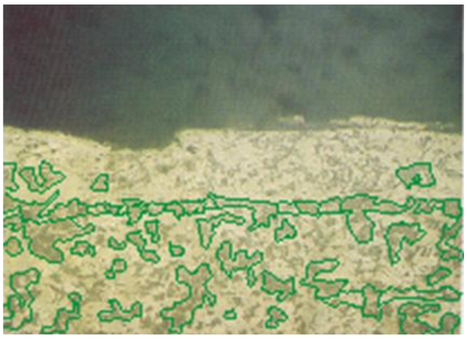
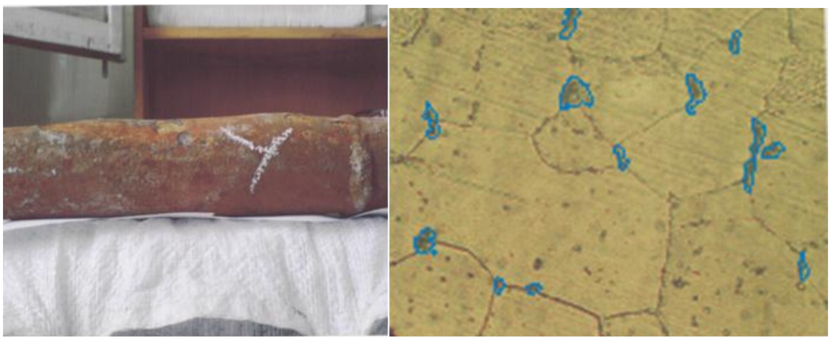


c

Figure 3 - General view of a fragment of acid gas transportation pipe (a), the microstructure of the steel massive (b) and the steel structure in the swelling zone (c) ;×200

The steel defect of the tested fragment of the acid gas transportation pipe is apparently caused by the process of hydrogenation by hydrogen released during hydrolysis due to CANI - string oxides.

Figure 4 shows a general view of the pipe fragment for transporting saline solutions. In operation since 1999, the working temperature inside the pipe - up to 150°C, outside - up to 1050°C.



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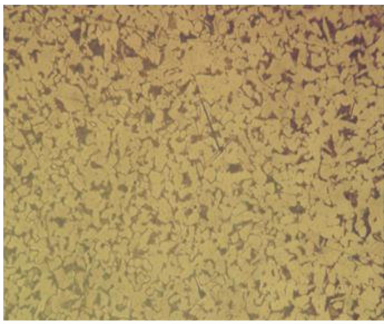

c

Figure 4 - General view of a fragment of saline solutions transportation pipe (a), the microstructure of the steel massive (b) and the steel structure in the swelling zone (c) ;×200

The defect in the steel of the salt pipe fragment is caused by the specific ferrite structure, with the location of cementite in the form of a grid along the grain boundaries (intergrain character) with the formation of small pores, which is due to the presence of NI-oxides and sulfides, as well as long-term heating at temperatures above 400 °C in pipes not fully loaded by the volume of the transported environment.

X-ray analysis of corrosion products showed the presence of all types of iron oxide Fe_2O_3 of different crystalline modifications, as well as FeS, FeS_2 and sulfuric iron Fe_2SO_4.

IV. CONCLUSION AND FUTURE WORK

According to the results of a complex research of mechanical properties, chemical composition, microstructure, and CANI contamination of steel fragments of destroyed sections of field pipelines, it was established that in the environments under consideration the main structural factor determining the corrosion resistance of steel is its CANI purity, the main reason for acceleration of corrosion processes is the presence of modified sulfide inclusions in steel.

Therefore, for the pipes and equipment operated in aggressive field and process media, the feasibility is obvious:

- application of heat treatment technology, which allows a significant increase in the corrosion properties of the metal due to structural methods of inhibition of hydrogen sulfide influence, because the combination of the cellular substructure of free ferrite, recrystallized sorbitol matrix and dispersed globular carbides prevents the formation of stress concentrators (CANI), thereby eliminating the reasons for the formation of atomic hydrogen accumulations formed due to CANI and transported by dislocations;
- to increase the resistance of pipes and fittings, it is necessary to use steels that are clean in NI and in nano-sized particles, resistant against hydrogenation and sulfide stress corrosion cracking;
- when designing oil and gas fields, construction of fields, especially when ordering pipe products of technological and field equipment, operated in aggressive environments, it is advisable to specify the allowable minimum number of inorganic inclusions in accordance with GOST 1778 and ISO 4967.

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