

# SUSCEPTIBILITY TO STRESS CORROSION IN TRANSPORT OIL PIPELINE STEELS EXPOSED TO LONG TIME SERVICE CONDITIONS

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## Abstract

Corrosion induced degradation of the steel in the oil trunklines exploited for up to 30 years has been found to be the most intensive in the bottom area of the inner surface of the pipes. The reason for that is the deposition of the water emulgated in the transport oil. Mechanical properties, hydrogen absorption and the hydrogen permeation parameters of the virgin steel were compared with those of steel from the “top” and “bottom” parts of the pipe being in service for 28 years. Decrease in the resistance to the brittle cracking under the low hydrogen charging in deposited water and decrease in the impact toughness of steel due to its longtime exploitation have been described. A conclusion has been drawn that the inspection of the working surface of pipelines to detect the corrosion damage and mechanical damage is not sufficient for comprehensive evaluation of pipe line degradation. Changes in the mechanical properties, need to be also take into account.

## Introduction

The life time assessment of the oil trunk lines exploited for a long time has been mostly based on the monitoring of corrosion damage of the outer surface of the pipes. As a result, the special attention has been paid to the reliability and durability of the protective coatings and the electrochemical protection. However, quite recently, the observations of the inner surface of the transport oil pipeline, done after the long-term operation have revealed by Slobodyan [1,2] the pits, especially numerous on the bottom of the pipe cross-section. Presence of the residual water has been the main reason for this corrosion damage. The difference between the bulk material corrosion resistance of the different parts of installations (upper and bottom parts of exploited and unexploited pipes, bottom and different wall height of the tank) has been detected in the residual water and has been accounted for the degradation of steels during their operation. The problem of the mechanical strength of the steel of pipelines being in service for up to 30 years, pointed by Krasowsky *et al.* [3] and Tsyurulnyk *et all* [4] also is of a great importance.

This paper is directed to an assessment of sensitivity to stress corrosion cracking under the low hydrogen charging conditions of the oil trunkline steel being in service for 28 years.

## Material and experimental methods

Specimens of the virgin (as received) 0.10C-1.6Mn-0.30Si pipeline steel and that cut from the upper (“top”) and lower (“bottom”) parts of the cross-section of pipe being in service for 28 years were tested.

The impact toughness (using the Charpy V-notch specimens) and the resistance to stress corrosion cracking have been evaluated. The specimens for the above tests were cut along the pipe axis. Sensitivity of investigated materials to stress corrosion cracking has been evaluated by slow strain rate ( $10^{-7} \text{ s}^{-1}$ ) tensile test, using cylindrical specimens, 3 mm in diameter. As a test solution, the residual water deposited in the oil storage tank, has been used. The moderate cathodic polarization (current density  $A = 0.5 \text{ A/m}^2$ ) has been applied. For comparison, the similar experiments have been performed in air at usual strain rate ( $3 \times 10^{-3} \text{ s}^{-1}$ ). Diagram “force  $F$  – displacement  $\Delta$ ” has been recorded in both cases. Susceptibility to stress corrosion cracking was determined by the ratio  $K_\varepsilon = \varepsilon^c / \varepsilon \text{ 100\%}$  and  $K_{RA} = RA^c / RA \text{ 100\%}$ , where  $\varepsilon$  and  $\varepsilon^c$ ,  $RA^c$  and  $RA$  – the relative elongation and reduction in area of specimens tensile tested in air and corrosion environment, respectively.

The amount of hydrogen ( $V$ ) and the hydrogen desorption rate were measured by vacuum extraction at  $560^\circ\text{C}$ . The hydrogen diffusion coefficient ( $D$ ) and the apparent coefficient ( $D^*$ ) were calculated in accordance to the paper of Devanathan and Stachurski [5] from the decay and build-up permeation transients recorded in the electrochemical permeation measurements through the membrane, 0.5 mm thick, cut from studied materials.

## Results and discussion

As it is shown in the Table 1, the total amount of hydrogen in the exploited steel is about two times higher than in as received material. The rate of the hydrogen desorption from the virgin steel is noticeably higher in comparison with the steel being in service (Fig. 1). This may point out on the more intensive hydrogen trapping by the material being in service. This assumption is supported by the results of hydrogen permeation measurements, presented in Table 1. Taking into account that in accordance to the paper of Iino [6] the ratio of  $D/D^*$  corresponds to the trapping efficiency of material, increase in hydrogen trapping intensity approximately for 7 times can be observed for the exploited steel. This confirms negative role of absorbed hydrogen in the process of steel degradation.

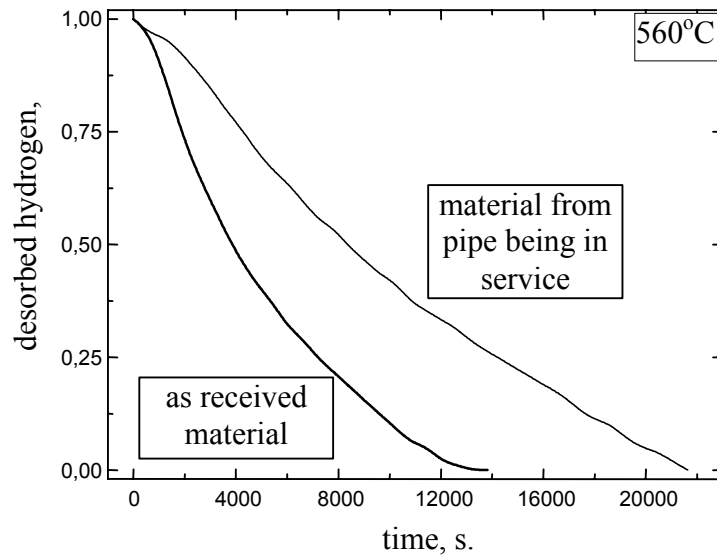


FIGURE 1. The hydrogen extraction curves recorded for the as received materials and for the being in service one.

As follows from the results of the impact toughness tests, the as received steel exhibits the maximum value of KCV ( $180 \text{ J/sm}^2$ ). In the case of material of the sections „top” being in service KCV is twice low ( $95 \text{ J/sm}^2$ ). Such a dramatic drop in the toughness is in agreement with the similar tests reported elsewhere [2] and indicates a general problem of the degradation of mechanical properties of the steels exploited in oil trunklines.

TABLE 1. Hydrogen quantity ( $V$ ), physical ( $D$ ) and apparent ( $D^*$ ) coefficient of hydrogen diffusion for ”as received” and “in service” steels

Material	$V$ , ppm	$D^*$ , $\text{cm}^2/\text{s}$	$D$ , $\text{cm}^2/\text{s}$	$D/D^*$
As received	1.6 +/- 0.5	$7.4 \cdot 10^{-6}$	$2.4 \cdot 10^{-5}$	3.2
In service	3.4 +/- 0.6	$2.9 \cdot 10^{-6}$	$4.3 \cdot 10^{-5}$	14.8

Drop in the resistance to the brittle cracking is one of the major consequences of the above mentioned degradations. In the case of the “bottom” section of the pipe being in service, it has been not possible to evaluate the impact toughness, due to the into cracking parallel to the pipe wall, cf. Figure 2. This is a symptom of so called hydrogen induced stratification, well known degradation phenomenon of industrial pipe lines transporting the crude oil containing the higher amount of the hydrogen sulfide and the sulfide reduced bacteria. The above findings, together with the results of the hydrogen extraction and permeation tests confirm the role of hydrogen in the degradation of steel of the oil trunklines.



FIGURE 2. Typical appearance of the fracture of specimens cut from the pipe being in service and subjected to the impact tests: (left) specimen from „top” section; (right) specimen from “bottom” section.

The results of stress corrosion cracking tests are presented in Figure 3 and in Table 2. In the case of testing in air, specimens of the as received material exhibit higher strength and plasticity than those from the bottom part of the exploited pipe.

The residual water, selected as a test solution is aggressive enough at moderate polarization to discriminate the susceptibility to stress corrosion cracking of the studied specimens. This has been confirmed by the abrupt decrease in plasticity of the as received steel (curve 3 in Figure 3). From the data in Figure 3 it also follows that the specimens cut from the “bottom” section of the pipe being in exploitation are especially sensitive to stress corrosion cracking (cf. curves 2 and 4).

TABLE 2. Plastic properties of tensile tested materials

Material	Test environment	$\varepsilon$ , %	RA, %	$K_E$ , %	$K_{RA}$ , %
As received	air	36	77	39	55
	water	14	42		
Being in exploitation	air	28	56	25	5
	water	7	3		

As seen in Table 2, the values of parameters  $K_{RA}$  is 55% and 5% for the specimens in the initial state and cut out from bottom section of the pipe correspondingly (the  $K_{RA}$  parameter is more indicative than the  $K_E$  parameter).

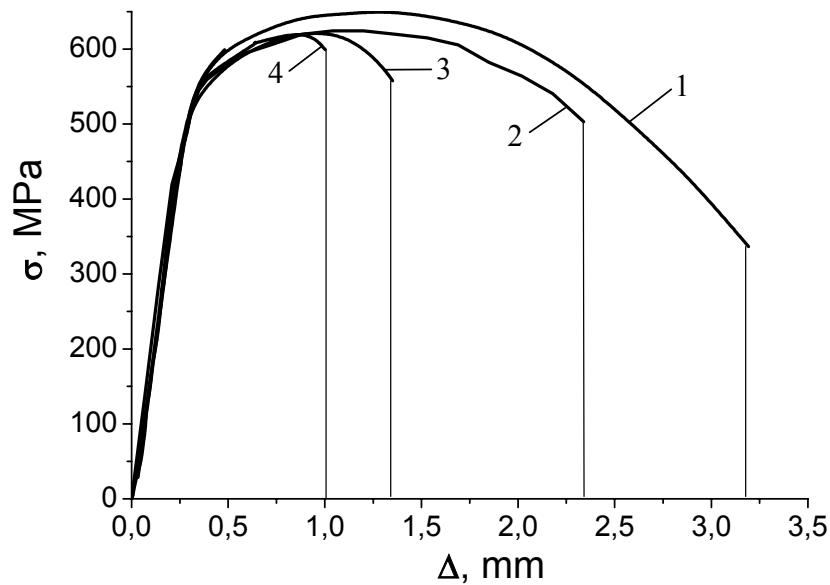


FIGURE 3. Stress ( $\sigma$ ) vs. elongation ( $\Delta$ ) relationships recorded for different parts of pipe as tested in air (1, 2) and in residual water (3, 4):

1, 3 – specimens cut from as received steel; 2, 4 – specimens cut from the “bottom” section of pipe being in exploitation.

Comparison of RA value estimated in air for as received material with that measured for the “bottom” section of exploited pipe in aggressive environment ( $RA = 77\%$  and  $RA^c = 3\%$ , respectively) shows the possibility of drastic decrease in the resistance to brittle fracture of metal if in the course of exploitation, the conditions for the hydrogen charging to the level, similar to that obtained in the laboratory tests could occur.

As follows from the above data, a signification in the resistance to stress corrosion cracking in the residual water of the exploited and of as received pipe steels has been found. The lower resistance of the bottom fragments of the pipe is a result of the in-service hydrogen induced degradation. It implies that inspection of the surfaces of installations to detect the corrosion and mechanical damages is not enough since also the mechanical properties of the material change over the time of service. This mainly refers to the susceptibility to the brittle cracking under the conditions pipe of contact with the residual water. It should be emphasized that the detrimental effect of the water would manifest itself not only during the pipeline standstill, when water can deposit on the pipe bottom, but also during the transport of oil, if the pipe bottom would be covered with the paraffin deposits. The break trough of the compact layer of deposits would result in the local penetration of the water to the metal surface causing the pitting and crevice corrosion, as well as the hydrogen charging of steel, and thus the further degradation of the pipe metal.

## Conclusions

The following conclusions can be drawn from the results presented in this paper.

Long time exploitation of the oil trunklines leads to the decrease in the resistance to brittle fracture of the pipe metal. This is manifested in particular by the drop in the impact strength tests and in increase in the susceptibility to hydrogen induced cracking.

The control of the pipelines limited the detection of the defects and damage is not sufficient to ensure the safety of operation of the oil trunklines.

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