

The Fracture Peculiarities of Trunk Pipeline Steels after their Long Term Service

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ABSTRACT. Long term service of oil and gas trunk pipelines in corrosion and hydrogenated environments can cause a degradation of the mechanical properties and correspondingly a decrease its lifetime.

Effect of service about 30 years on the impact strength and hydrogen cracking of oil and gas trunk pipeline low alloyed steels is considered.

In the case of the “bottom” section of the oil pipe being in service, it has been not possible to evaluate the impact strength, due to the deflection into cracking parallel to the pipe wall. 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-reduction bacteria. The different susceptibility to hydrogen cracking and impact strength for the upper and bottom of parts of exploited pipe has been explained as a result of hydrogen charging and hydrogen degradation of steel during the service.

The results discussed in the paper show that inspection of the surfaces of installations to find corrosion or mechanical damage alone may not be sufficient for proper evaluating risk of failure. Since material can loss its initial mechanical properties, a thorough investigation of the properties of the metal being in service under the hydrogenation conditions for the long time is suggested.

INTRODUCTION

It is considered that corrosion damages of external surfaces of pipes are the main factors of a decrease of trunk pipelines workability. Since a special attention is paid to a reliability and lifetime of protective coatings and electrochemical protection. However, the degradation of steels as a result of the internal corrosion is not less dangerous [1] since this phenomenon worsens their “in bulk” mechanical properties after about 30 years of operation [2]. As was established, the most intensive degradation takes place at the lower part of a pipe due to residual water [1]. Investigations of hydrogen permeation

show [3] that the steel of the lower part of a pipe after operation is substantially microdamaged as compared with the initial state, which can be explained by the joined action hydrogen absorbed by metal and long-term operation. The operational degradation of the metal was also corroborated by a sharp decrease in its impact strength, including weld joints [2], although the corrosion factor was not considered especially, and the upper and lower part of a pipe were not distinguished.

The aim of the present work is to clarify changes in the resistance of the steels of trunk pipelines to brittle fracture after long-term operation.

MATERIALS AND TESTING METHODS

We studied 10GS-type (0.1C-Mn-Si) steel after 28 years of operation on an oil-trunk pipeline and 17G1S (0.17C-1Mn-Si) steel after 30 years of operation on a gas-trunk pipeline. The specimens were cut out in parallel to the tangent line of the pipe (Fig. 1). The resistance to brittle fracture was evaluated by Charpy impact strength and sensitivity to hydrogen cracking (HC) under tension of cylindrical specimens of 3 mm in diameter of working part. We distinguished the upper (“top”) and lower (“bottom”) parts of the pipe at investigation of the 10GS-type steel. In this case the specimens were tested for HC sensitivity in residual water taken from a working storage tank at the strain rate 10^{-6} s^{-1} and cathodic charging during loading with a current density of 0.05 mA/cm^2 . For comparison we also carried out in air but with a strain rate of $3 \cdot 10^{-3} \text{ s}^{-1}$. The 17G1S steel was tested in air with a strain rate of $3 \cdot 10^{-3} \text{ s}^{-1}$ after preliminary hydrogenation in the H_2SO_4 solution with pH0 under current density of 10 mA/cm^2 . In the both cases sensitivity to HC was evaluated by changes in the relative elongation and reduction of area by the corrosive environment. These quantities were characterised by the factors:

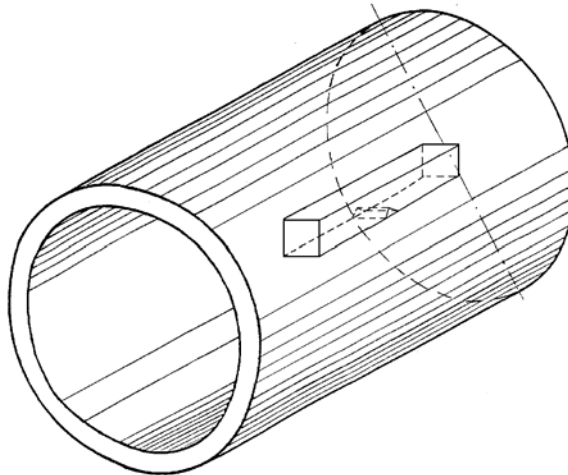


Figure 1. Scheme of a pipe and cutting out of specimens

$$K_{\delta} = \delta^c / \delta \text{ 100\% and } K_{\Psi} = \Psi^c / \Psi \text{ 100\%,} \quad (1)$$

where δ^c and δ , Ψ^c and Ψ are the relative elongation and reduction of area of the specimens in the corrosive environment and in air, respectively.

RESULTS AND DISCUSSION

In the initial state, the 10GS steel possesses the highest Charpy strength (180 J/cm^2), but long term operation of the pipeline decreases it. For the metal “top”, it is half as great (95 J/cm^2). Such a sharp drop is in a good agreement with a data of similar tests [2], which shows that the general problem of deterioration of the mechanical properties of pipeline steel after long-term operation (first of all, of its resistance to brittle fracture) is quite timely. It was impossible to determine quantitatively the Charpy strength of the part “bottom” since, in all cases (we tested three specimens), fracture was reoriented along the tangent line of the pipe (Fig. 2), which is a consequence of hydrogen exfoliation, characteristic of pipelines for the transportation of oil with a high content of hydrogen sulfide and sulfide-reduction bacteria [4]. The results of hydrogen permeation studying [3] corroborate the possibility the hydrogen pickup of the pipeline metal in residual water and the important role of hydrogen in the degradation of the steel of pipelines of not only crude but also refined oil.



Figure 2. Typical Charpy tests fracture surfaces of the top (on the left) and the bottom (on the right) parts of exploited pipe

Table 1. Plasticity of the 10GS steel after slow strain rate tension

Material	Environment	δ (%)	Ψ (%)	K_{δ} (%)	K_{Ψ} (%)
Initial state	Air	36	77	39	55
	Water	14	42		
“Bottom”	Air	28	56	25	5
	Air	7	3		

Slow strain rate tension in residual water under conditions of cathodic polarisation also decreases the resistance to brittle fracture of the metal after long-term operation (Table 1). The relative reduction of area is more sensitive to the embrittlement action of the environment than the relative elongation. The specimens “bottom” proved to be especially sensitive to HC: the factors of influence of the environment are $K_{\Psi} = 55\%$ and 5% for the specimens in initial state and “bottom”, respectively. Comparison of the relative reduction of area of the specimen in the initial state ($\Psi = 77\%$) and after long term operation from the part “bottom” under cathodic polarisation ($\Psi^c = 3\%$) demonstrates the possible catastrophic drop of the resistance to brittle fracture of the metal if conditions of its hydrogenation pickup are created in the course of operation, which corresponds to the laboratory tests.

Thus, the given results allow establishing the intensive corrosion-hydrogen degradation of trunk pipeline steels, caused by the processes of interaction of its internal surfaces with residual water. It can intensify not only corrosion damages on internal surfaces (it can be revealed, in principle, during periodical inspection of object) but also cause a danger of hardly predicted brittle fracture because of a loss of plasticity and an appearance of sensitivity to HS.

Concerning to the trunk gas pipeline 17G1S steel the effect of the service degradation on the its sensitivity to HS in dependence of combinations of the preliminary hydrogenation and loading conditions was investigated. We realised the following order of hydrogenation and loading: a) the specimens were preliminary electrochemically hydrogenated (PEH) 1 hour and after 5-10 min were loaded to fracture – such scheme allowed to study the effect of hydrogen absorbed by metal on the mechanical behavior of steel; b) the specimens were loading in air to the certain level in elastic or plastic region, PEN 1 hour at this level and after that we continue a loading in air to fracture – it was possible to evaluate an effect of exploited stresses and deformations on HS; c) the specimens were loaded in air to the certain plastic deformation, after that unloaded, hydrogenated and loaded to fracture – to evaluate the effect of preliminary plastic deformation (PPD).

The 17G1S steel in the initial state demonstrated the high plasticity (Fig. 3). Hydrogenation of the steel under the regime a) practically does not effect on its strength and plasticity (pos. 1 on the curve 1). Concerning to the regime b) the specimens were loaded lower of the yield stress (200 to 400 MPa), on the yield stress level just after yield drop (455 MPa) and after essential plastic deformation (490 MPa). These levels of loading are showed in the Figure 3 by vertical lines with marking 1, 2...6. The PED of the specimens loaded in the elastic region decreases already the plasticity of metal and

more with the stresses σ increase ($\psi^H = 70\%$ and 63% , $K_\psi = 0,89$ and $0,8$ respectively for $\sigma = 200$ and 400 MPa). It indicates about the principally different conditions for hydrogen absorption by stressed (regime b) and unstressed (regime a) metal. It means that hydrogen accumulated by metal is enough only in the first case for HS of investigated ductile steel. And just it is corresponded to the stationary regime of service of gas pipeline under an action of the static loading (due to gas pressure) and hydrogenated environment.

Test in accordance to the regime b) with hydrogen charging at stresses equal to yield stresses increased HS of the metal ($\psi^H = 50\%$, $K_\psi = 63\%$). However the metal is the most sensitive to embrittlement at hydrogenation under stresses 490 MPa, close to yield strength ($\psi^H = 36\%$, $K_\psi = 46\%$).

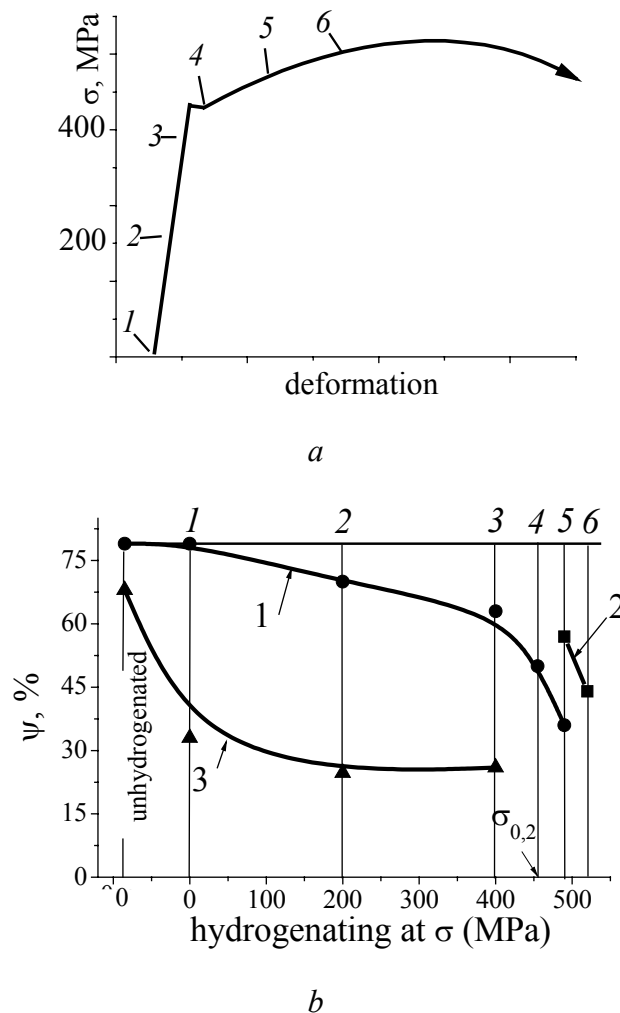


Figure. 3 – The typical curve of loading of the 17G1S steel (a) and change its plasticity under PEH (b): 1 – the initial state, hydrogenation at constant loading; 2 – the initial state, hydrogenation after PPD); 3 – the steel after 30 years of service, hydrogenation at constant loading.

The slight stress relaxation was observed in the PPD specimens during hydrogenation as on the regime b) but later during further loading it was deformed elastically to higher level of stress then the preliminary one (Fig. 4). This effect can be explained as more trouble plastic deformation caused by hydrogen influence.

The specimens were hydrogenated after loading to the stresses 490 and 520 MPa (regime c) and unloading for an apportionment of the PPD role. Its effect was higher for more intensive PPD - $\psi^H = 57\%$ and 44% , $K_\psi = 0,72$ and $0,52$ (Fig. 3, curve 2). However the effect of hydrogenation is less at these conditions then jointly with stresses and deformation (regime b, curve 1).

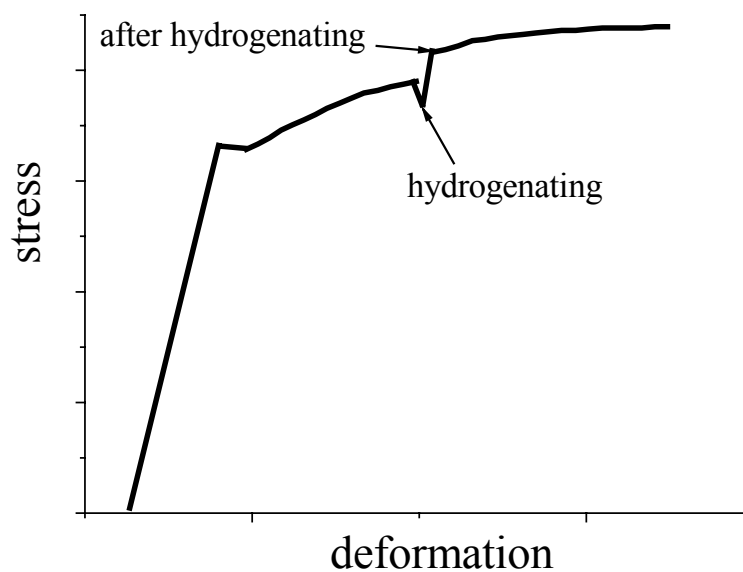


Figure. 4 – The typical curve of stress-deformation curve after hydrogenation at constant loading in the plastic region (scheme).

The exploited 17G1S steel like the oil pipeline one is characterised by lower plasticity comparatively with the initial state. In spite of the initial state of material it is sensitive to HS already at hydrogenation of unloaded specimens (Fig. 3, curve 3). It corresponds to the HS sensitivity level of material in the initial state but for more rigid conditions of hydrogenation (stressed specimens or PPD). In essence, a usage of more conditions of hydrogenation concerning to the exploited steel practically does not strengthen its sensitivity to HS. It means that the service degradation of material exhausts its reserve of plasticity and, correspondingly, a resistance to brittle fracture of steel in the same measure like PPD.

The obtained results show for a prospect of a usage of the corresponding combination loading-hydrogenation for modeling of service degradation of steels.

CONCLUSIONS

After long-term operation of trunk pipelines, the resistance of the steels of the pipes to brittle fracture decreases, first of all, the impact strength and resistance to hydrogen cracking.

The effect of in service steel degradation of trunk pipelines is connected with the combined action of exploited stresses and hydrogen absorbed by metal from the technological environments and can cause the anisotropy of its the brittle fracture resistance, especially, impact strength.

Inspection of the presence of surface defects and damages only is insufficient for the substantiation of serviceability. It is also necessary to evaluate the possible changes in mechanical properties, first of all, resistance to brittle fracture.

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