Characteristics degradation of gas transmission pipeline steel welded joints due to long-term operation

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Abstract

The mechanical and electrochemical properties of different zones of welding joint of 17H1S pipe line steel after 30 years of service were investigated. It was established that long-term service causes a decrease of plasticity and impact toughness, especially of the heat affected zone metal. The weld metal revealed synchronous decrease of strength, hardness and brittle fracture resistance. Operated material revealed a general regularity of the potential shift to the negative direction for all zones of welded joint in comparison with those in the initial state. For the base metal, the potential shifts least, and, for the weld metal, it shifts most. So, selective corrosion can be localized on the weld metal with the increase of gas transmission pipelines service time.

Introduction

Lately, the problem of properties degradation of gas transmission pipelines steels has become acute [1] in consequence of the long-term (30 years and over) service of their main networks. Comparative strength, plasticity, impact toughness, crack resistance, and corrosion cracking resistance tests of operated pipes steels and the as-received pipes metals [2-4] revealed primarily significant decrease the resistance to brittle fracture and resistance to hydrogen corrosion cracking. Electrochemical investigations in a solution modelling water condensate inside gas transporting pipelines showed that the hydrogenation of the pipe wall metal from its internal surface is possible due to corrosion, and, thus, its properties may degrade under the mutual action of mechanical stress and transported environments [5].

Welded joints of gas transmission pipelines are sensitive to the action of corrosive hydrogenating environments. The problem of the embrittling affect of welding as a result of relatively rapid cooling, which causes structural changes, redistribution of detrimental impurities, and residual stresses, is known. Moreover, welding joint is characterized by a high electrochemical heterogeneity, due to which local corrosion processes in both the heat affected zone metal and the weld metal are intensified.

In what follows, we investigate the mechanical properties and assess the corrosion resistance of different zones of the weld joint of 17H1S pipeline steel by electrochemical methods.

Materials and techniques of investigations

A field butt-welded joint of 17H1S pipe steel cut off from 1220 mm x 12 mm gas transmission pipeline after 30 years of service and butt-welded joint of 17H1S steel of the as-received pipes (reserve pipes) welded by the adopted welding practice for pipes under field conditions (electric arc welding at current strength 210 A by previously tempered at 560 K for an hour electrode UONI-13/55) were investigated. The weld width ranges from 3 to 4 mm, and the heat affected zone width is to 11 mm. The mechanical properties were determined by tension at a strain rate of $3{\cdot}10^{-3}$ sec^{-1} of cylindrical specimens with a working part 5 mm in diameter and 25 mm long, at the centre of which the investigated zone of the welded joint with a circular concentrator with a depth of 1 mm was located. In that case, conventional strength characteristics (yield strength $\sigma_{0.2}$ and ultimate strength σ_u) and plasticity characteristics (percentage reduction of area Ψ□) were obtained. The impact toughness (*KCV*) was determined by the Charpy method.

Electrochemical investigations were performed in a sulphuric acid solution (pH = 1) to prevent the camouflaging influence of the surface barrier films and obtain electrochemical characteristics of the metal. The stationary potential E_{st} (versus silver - silver chloride electrode) was determined and the polarization resistance R_p of the metal of different zones of the welded joint was calculated from the potentiodynamic polarization curves. A preliminarily polished surface of the welded joint, excepting a certain zone (with an area of about 5 mm^2) chosen for electrochemical investigations, were coating by a mixture of paraffin and colophony taken in the ratio 1:1. In some cases, where the fusion line was tested, the exposed area was decreased to 1mm^2.

Results and discussion

The mechanical properties of the base metal and the heat affected zone metal of the operated welded joint lightly differ (Table 1). In general, it is difficult to make a conclusion on the influence of long-term service on the strength of the welded joint metal based on the obtained data because of the difference in the initial properties of pipes of different heats.

The hardness of the metal of different zones of the welded joint changes in a symbate manner. The plasticity decreases for all zones of the welded joint, and it changes most intensively for the heat affected zone metal (Fig. 1). Though the plasticity of the weld metal remains the smallest, the difference in the values of reduction of area □for different zones of the operated welded joint decreases.

Table 1. Mechanical properties of different zones of a welded joint of 17H1S steel

Zones of the welded joint	State of the metal	$\sigma_{0.2}$, [MPa]	σ_u, [MPa]	*HB*	Ψ, [%]	*KCV*, [J/cm^2]
Base metal	Initial	653	796	187	62,5	274/260
	Operated	630	833	192	54	200/159
Heat affected zone metal	Initial	651	809	202	61	192/184
	Operated	665	835	207	50	122/86
Weld metal	Initial	753	942	207	51	232/192
	Operated	740	838	187	47	182/100

Comment: For *KCV*, the numerators correspond to mean values of test results of at least four specimens, and the denominators correspond to their minimum values.

The base metal is characterized by the highest impact toughness, its smallest value is typical for the heat affected zone metal (Table 1), and the scatter of experimental data is insignificant for welded joint of 17H1S steel in initial state. As a result of long-term service, the impact toughness of all zones of the welded joint decreases, and its decreasing is the largest for the metal of the heat affected zone. The scatter of experimental data increases abruptly for operated welded joint of

17H1S steel, especially for the heat affected zone metal and weld metal. This decrease in the impact toughness agrees with the decrease in the plasticity in terms of the percentage reduction of area, but often disagrees with the change in the strength. In particular, as a result of operation, the ultimate strength of the weld metal decreased from 942 to 838 MPa, which was to be accompanied by increases in the percentage reduction of area □and *KCV* indices. However, we observed their decreasing, which most probably corresponds to the earlier revealed phenomenon of simultaneous decrease in the strength and hardness, and, on the other hand, degradation of the resistance to brittle fracture of long-term operated low-alloy steels [2-4, 6]. Note that the metal of the heat affected zone degrades most intensively.

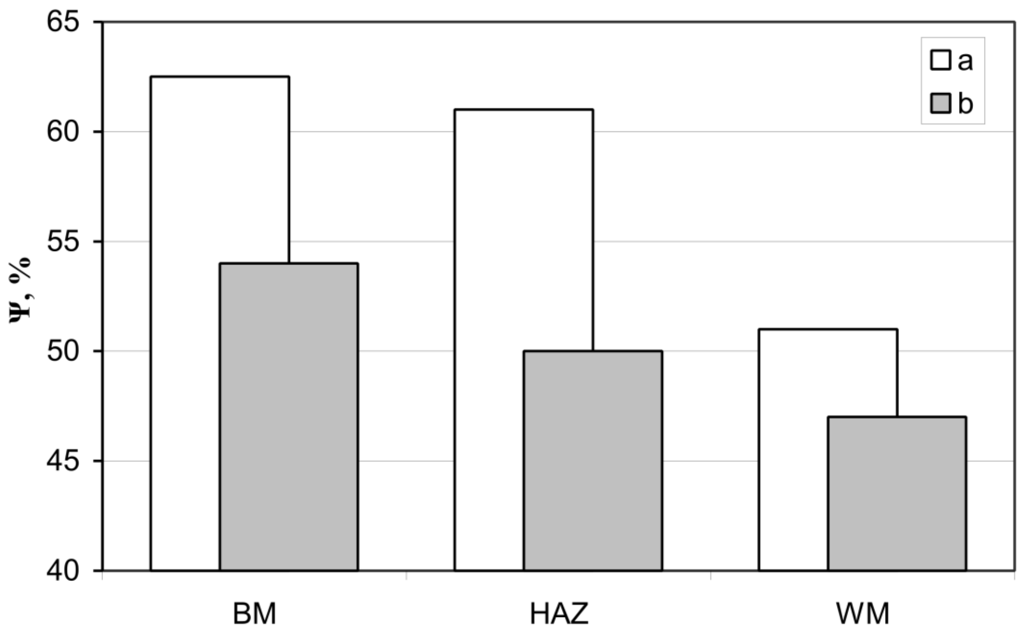

Fig.1. Influence of long-term service on the percentage reduction of area for different zones of a welded joint of 17H1S steel (BM – base metal; HAZ – heat affected zone; WM – weld metal): *a* - initial state, *b* - operated state.

The values of the polarization resistance calculated from polarization curves indicate that the weld metal in the initial state is characterized by a much higher corrosion resistance in comparison with those of the base metal and the metal of the heat affected zone (Table 2). The long-term service deteriorates practically equally the corrosion resistance of all zones of the welded joint.

Table 2. Polarization resistance R_p and stationary potential E_{st} of the welded joint in H_2SO_4 solution

State of the metal	Zones of the welded joint						
	Base metal		Heat affected zone		Weld metal		Fusion line
	R_p, [Ω·cm^2]	E_{st}, [V]	R_p, [Ω·cm^2]	E_{st}, [V]	R_p, [Ω·cm^2]	E_{st}, [V]	E_{st}, [V]
Initial	710	– 0.465	766	– 0.470	1048	– 0.445	– 0.435
Operated	513	– 0.480	509	– 0.495	822	– 0.490	– 0.455

However, the corrosion resistance of certain zones of the welded joint is determined by not only their polarization resistance, but also their mutual polarization if the electrode potentials of different zones differ, which is characteristic of the welded joint. This is why the electrochemical heterogeneity in electrode potential of individual zone is an important characteristic. In a corrosive medium they form galvanic couples, in which the base metal is hardly polarized because its area is much larger than those of other zones. Correspondingly, the heat affected zone metal and weld metal are polarized. Therefore, it is possible that a zone with a higher corrosion resistance (if it is considered separately) in galvanic couples with other zones of the welded joint will corrode more intensively then other ones.

Due to the specificity of the measurements of electrode potentials, which values do not depend on the metal area, we also studied regions on the weld metal – heat affected zone metal boundary with an area of about 1 mm^2. This enabled us to distinguish one more zone of the welded joint, namely the fusion line, which separates the weld metal and heat affected zone metal. On the whole, the difference in potentials of different zones of the welded joint in the initial state is not larger than 35 mV (Table 2). The heat affected zone metal is characterized by the most negative value of stationary potential, and the fusion line metal is characterized by the most positive value of one. Thus, for the welded joint in the initial state, two zones, namely the weld metal and fusion line metal, will be polarized in the negative direction, and the heat affected zone metal will be polarized in the positive direction, though by only 5 mV. Correspondingly, the cathodic polarization of the weld metal and fusion line metal will intensify cathodic reactions and retard anodic reaction. On the other hand, the anodic polarization of the heat affected zone metal will accelerate anodic reactions and retard cathodic reactions. Since the base metal due to the much larger area will hardly be polarized (Fig. 2a), its corrosion resistance will be determined by only the polarization resistance. At the same time, the corrosion resistance of other zones of the welded joint will depend on their polarization resistance and polarization. The weld metal is characterized by a higher polarization resistance, and, under an additional positive influence of cathodic polarization, its corrosion resistance will increase. The polarization resistance of the metal of the heat affected zone is slightly higher than that of the base metal, but as a result of the negative influence of anodic polarization in the galvanic couple of the welded joint on it, its corrosion resistance will decrease probably to (or below) the level of corrosion resistance of the base metal, and, definitely, below the corrosion resistance of the weld metal.

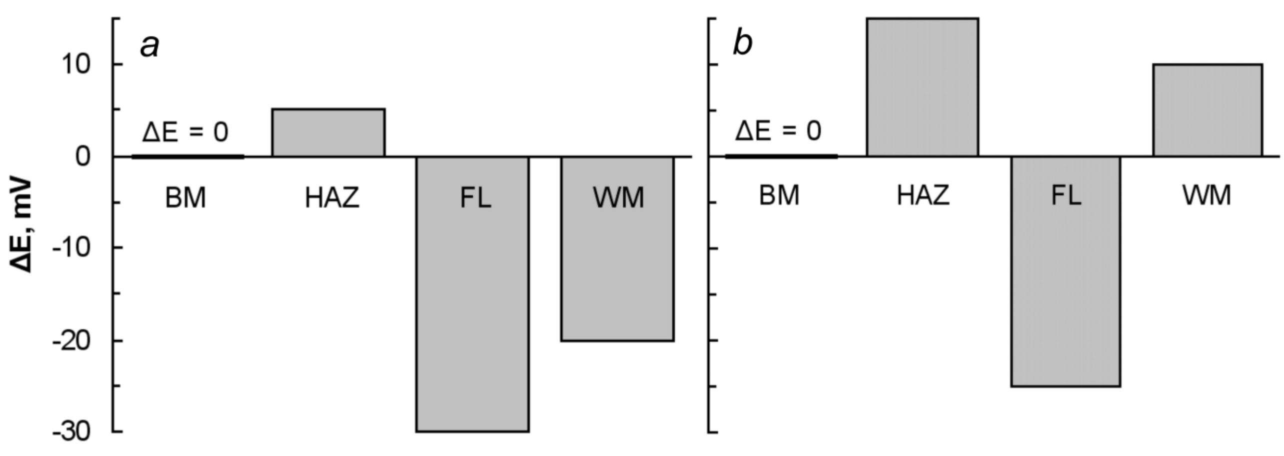

Fig. 2. Polarization of different zones of 17H1S steel welded joint in the initial state (a) and after long-term operation (b): (BM – base metal; HAZ – heat affected zone; FL – fusion line; WM – weld metal).

The general regularity of shift of the potential in the negative direction is observed for all zones of the operated welded joint. The potential shifts least for the base metal, and the potential of the weld metal becomes more negative than that of the base metal (Table 2). Thus, the heat affected zone and weld metal of the operated welded joint undergo anodic polarization, i.e., corrosion is intensified on its (Fig. 2b). In this case, the indicated effect is insignificant. However, this indicates the danger of occurrence of selective corrosion in the heat affected zone metal and, to a smaller extent, in the weld metal as the operation time of pipelines increases. In hydrogenating environment (soil, formation water, condensed water etc.), outside and / or inside a gas pipeline, a cathodic process occurs with the release of hydrogen [5, 7], in other words, hydrogenation of the metal is possible in cathodically polarized zones. The obtained results show that the metal must be hydrogenated particularly intensively along fusion lines. Taking into account the possible intensification of the selective corrosion of the heat affected zone metal and weld metal on the degraded welded joint, after the formation of corrosion pits in the zone of the weld metal, closer to the fusion line, hydrogenation may lead to the initiation of cracks in the weld metal zone closer to the fusion line by the hydrogen embrittlement mechanism. Further development of cracks from the fusion line will depend on whether the weld metal or heat affected zone metal will be characterized by the smallest resistance to brittle fracture.

Summary

Long-term operation affects slightly the strength characteristics of the welded joint of 17H1S pipe steel, but causes the degradation of the plasticity characteristics, impact toughness, and corrosion resistance. The potentials of all zones of the operated welded joint are shifted in the negative directions in comparison with those in the initial state. For the base metal, the potential shifts least, and, for the weld metal, it shifts most, which indicates the danger of selective corrosion of the weld metal as the operation time of gas transmission pipelines increases. In hydrogenating environment (soil, formation water, condensed water etc.) the metal is hydrogenated most along the fusion line. In the case where corrosion pits form as a result of selective corrosion, in the weld metal zone, closer to the fusion line metal, the initiation of cracks by the hydrogen embrittlement mechanism is possible. Their further growth from the fusion line metal is most probable in the heat affected zone metal, which is characterized by the smallest resistance to brittle fracture.

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