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Effect of hydrogen concentration on strain behaviour of pipeline steel

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ABSTRACT

The specificity of strain behaviour of pipeline steel depending on the hydrogen concentration in bulk of metal was studied. The existence of some characteristic value of the hydrogen concentration at which the mechanism of hydrogen influence changes, namely: below this value the enhanced plasticity (decreasing of the yield stress value) takes places and above – the hydrogen embrittlement occurs, was shown. This value can be considered as an important engineering parameter for strength and fracture assessment of materials and structural components in hydrogenous environments and also at the development of technology of hydrogen treatment of materials with the aim of improvement their service properties.

Introduction

The hydrogen effect on the mechanical behaviour of structural steels and alloys is well known and the numerous records on this topic are stored in literature [1,2]. Nevertheless the contradicting data can be found in some number of issues. For example, the strengthening effect of hydrogen on material [3] as well as the weakening of material (decreasing of yield stress limit) [4] was observed. This circumstance is caused by the difficulty to take into account all possible factors, such as the specimen size and conditions of their hydrogenation, control of hydrogen concentration in material, loading conditions, etc., which have an influence on studying phenomenon.

It should be noted that in the majority of conducted studies the actual value of hydrogen concentration in the material was unknown and the level of material hydrogenation was assessed indirectly [5]. This is some limitation of used methods and received results.

The presented work is dedicated to evaluation of the strain behaviour of hydrogen charged pipeline steel under known hydrogen concentration in a bulk of metal. Here the changing of mechanical parameters of steel under influence of hydrogen was determined as the function of hydrogen concentration.

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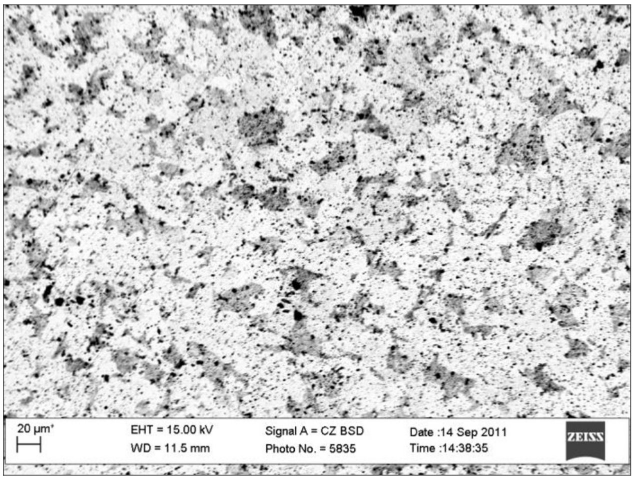

Fig. 1 – Structural specificity of studied pipeline steel (×500).

Experimental procedure

The object of study was low alloyed pipeline steel (σ_Y = 260 MPa and σ_U = 440 MPa) with nominal chemical composition (in weight %): C = 0.17–0.24; Si = 0.17–0.37; Mn = 0.35–0.65; S < 0.04; remainder Fe. This material consists of grains of ferrite-pearlite, typical in all carbon steels (Fig. 1). The standard tensile specimens (Fig. 2) were manufactured with real pipe.

The hydrogenation of specimens was made by electrochemical method under cathodic polarisation at some constant potential E_{cath} = const. With the aim to simulate the hydrogen entry at real operating conditions of the buried pipeline, the following procedure has been applied [6–10]. The special deoxygenated, near-neutral pH NS4 solution, which is the model of underground water, was chosen as the electrolyte for hydrogen charging of steel. The chemical composition of the NS4 solution is given in Table 1.

Taking into account the situation of freely corroding system that exists for the real pipeline, the potential of polarisation E_{cath} was slightly more negative than the free corrosion potential E_{corr} for given steel, i.e.: E_{corr} = −600 mV (SCE) and E_{cath} = −800 mV (SCE).

Hydrogen concentration in a bulk of steel has been determined on the base of hydrogen discharging process under anodic polarisation with using of hydrogen electrochemical oxidation method proposed in work [11]. The detailed description of the application of this method for the pipelines hydrogenation problems can be found in works [10,12].

Table 1 – Chemical composition of NS4 solution (gram/litre) [10].

$NaHCO_3$	KCl	$CaCl_2$	$MaCl_2 \cdot H_2O$
0.483	0.120	0.137	0.131

For realisation of experimental studies on the hydrogen charging of specimens and determination of the hydrogen concentration in a bulk of steel the special testing stand was developed, which based on the dynamic electrochemical laboratory VoltaLab40 [13]. The general view of developed facility is presented in Fig. 3. Here the standard three-electrode electrochemical cell was used where the auxiliary (counter) electrode has a form of cylindrical shell. The mutual location of working (specimen) and auxiliary (counter) electrodes is given in Fig. 4.

As preliminary stage of study the experimental dependence "hydrogen concentration C_H in specimen – time of exposure τ" was received. Following to work [10] these experimental data were described by power relation:

$$C_H = A \cdot 10^{-6} \cdot \tau^m, \ [\mathrm{mol/cm^3}]$$

where A and m are some constants that depend on system "material – environment" and testing conditions. For our case the values of these constants are: $A = 0.28 \cdot 10^{-6}$ and $m = 0.65$. This analytic relation served as the reference curve under hydrogen charging of the specimens for tensile test.

The specimens, which hydrogen charged to assigned level of C_H, were subjected to uniaxial tensile loading to failure. During tests, in automatic mode, the dependencies "applied load – elongation of specimen" were recorded as well as the reduction of cross section area of specimens.

Results and discussion

Based on received experimental curves "applied load – elongation of specimen", the dependencies "stress σ – strain ε" were constructed for different values of the hydrogen concentration C_H. Here it should be noted that calculation of stresses σ were made with taking into account the real values of cross section area of specimens, i.e. so called "true" stress–strain diagrams of were received. These diagrams served as the basis for determination of the true values of the

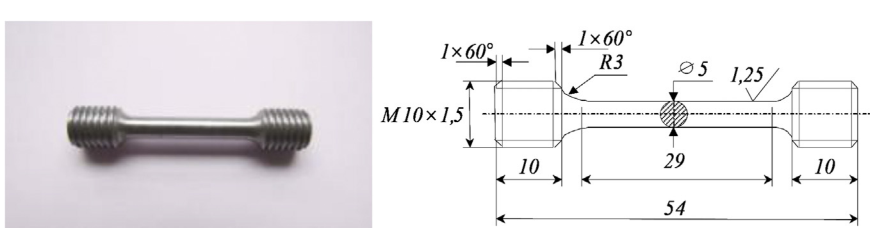

Fig. 2 – Geometry of the tensile specimen.