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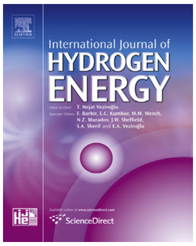

Effect of hydrogen concentration on fatigue crack growth behaviour in pipeline steel

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ARTICLE INFO

Article history:
Received 23 September 2016
Received in revised form
15 November 2016
Accepted 29 November 2016
Available online xxx

Keywords:
Pipeline steel
Hydrogen charging of metal
Hydrogen concentration
Cyclic loading
Enhanced plasticity
Hydrogen embrittlement

ABSTRACT

The ambiguous relationship between fatigue crack growth rate and hydrogen concentration C_H in the bulk of metal under cyclic loading of the ferrite-pearlite low-alloyed steel in hydrogen-contained environments has been found: there is a certain C_H value at which the crack growth resistance of steel increases. At these test conditions fracture surface demonstrates some increasing of the plastic component on relief. The received results point on key importance of the determining of such threshold hydrogen concentration values, which correspond the transition "enhanced plasticity – embrittlement".

Introduction

The phenomenon of hydrogen embrittlement of metallic materials, which lead to the loss of their plasticity, decreasing of fracture toughness and degradation of fatigue properties is well-known and the numerous records of such effects can be found in the literature [1–3]. Despite of that, there is the number of works where the positive hydrogen effect, i.e. the hydrogen-induced plasticity, was shown [4–14]. For example, in work [12] the dramatic phenomenon was found in which charging a supersaturated level of hydrogen into specimens of austenitic stainless steels of types 304 and 316L drastically improved the fatigue crack growth resistance, rather than accelerating fatigue crack growth rates. Results presented in Ref. [14] confirmed the existence of a hydrogen-induced plasticity effect within a particular range of cathodic polarization of X70 pipeline steel. The possible explanation for the contradictory results of hydrogen effects on macroscopic deformation and the model to interpret the criterion for the application of local softening concept can be found in work [13].

Therefore it is important and actual problem to study and to clarify all aspects of specific hydrogen effects of metallic structural materials with the aim to establish the conditions for the transition "enhanced plasticity – embrittlement". This may be the crucial key factor for deeper understanding of the hydrogen influence mechanism and also it will promote to review the existed conceptions where the hydrogen is

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http://dx.doi.org/10.1016/j.ijhydene.2016.11.193
0360-3199/

Please cite this article in press as: Dmytrakh IM, et al., Effect of hydrogen concentration on fatigue crack growth behaviour in pipeline steel, International Journal of Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.11.193

considered as a negative agent. Some disputable aspects of this problem are currently discussed and considered [15–18].

Within the frame of above-mentioned problem the presented paper is dedicated to evaluation of the fatigue behaviour of hydrogen charged pipeline steel under known hydrogen concentration in a bulk of metal. Here the parameters of fatigue crack growth resistance of steel were assessed as the function of hydrogen concentration. This work can be considered as further development of our previous work [19] where the specificity of strain behaviour of pipeline steel depending on the hydrogen concentration in bulk of metal was studied. There 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.

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 for all carbon steels (Fig. 1). The rectangular cross-section beam specimens (Fig. 2) were manufactured with real pipes, which were supplied from two different manufacturers (test series A and test series B). The longitudinal cracks were studied and cut off of specimens from pipe was corresponded to this case.

For realisation of experimental studies on the hydrogen charging of specimens, determination of the hydrogen concentration in a bulk of steel and the fatigue crack growth under joint action of the cyclic loading and hydrogenation environmental conditions the special testing stand was developed, which based on the fatigue testing machine for pure bending of specimens at the environmental conditions [20] and the dynamic electrochemical laboratory VoltaLab40 [21]. The general view of developed facility is presented in Figs. 3 and 4. Here the standard three-electrode electrochemical cell was used where the auxiliary (counter) electrode consists of four round bars. The mutual location of working (specimen) and auxiliary (counter) electrodes is given in Fig. 5.

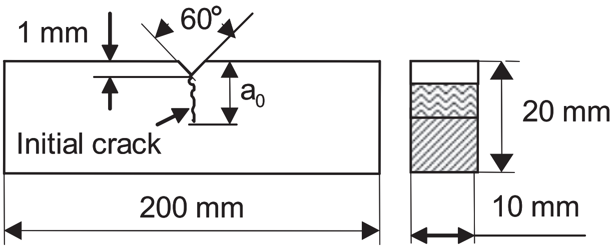

Fig. 2 – Geometry of the beam specimen.

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 [22–26]. 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 the hydrogen electrochemical oxidation method proposed in work [27]. The detailed description of the application of this method for the pipelines hydrogenation problems can be found in works [27,28].

As preliminary stage of study the experimental dependence "hydrogen concentration C_H in specimen – time of exposure τ" was received. Following to work [26] these experimental data were described by power relation:

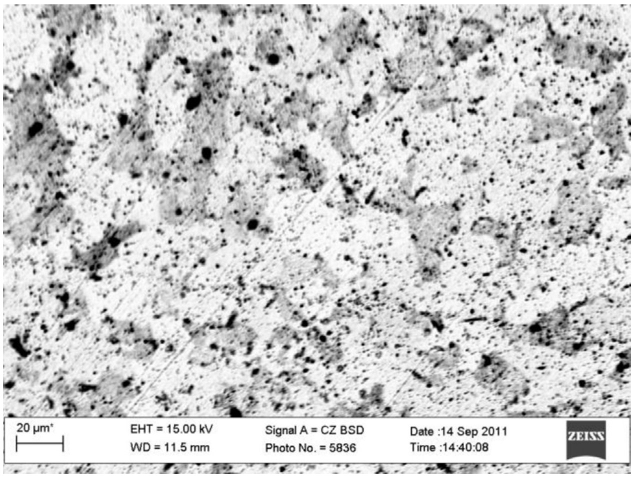

Fig. 1 – Structural specificity of studied pipeline steel (x 1000).

Fig. 3 – Special fatigue testing stand.

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