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Assessment of subcritical crack growth in hydrogen-containing environment by the parameters of acoustic emission signals

Valentyn Skalskyi, Olexandr Andreikiv, Iryna Dolinska *

Karpenko Physico-Mechanical Institute of National Academy of Sciences of Ukraine, 5 Naukova Street, Lviv 79601, Ukraine

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ABSTRACT

Estimation models (differential equations, initial and final conditions) for determining the crack propagation kinetics in hydrogen-containing environments using the acoustic emission (AE) signal parameters are proposed. The formulation of these models is based on the main ideals of the AE method, dependence between the crack increment area and a sum of AE-signals amplitude, main criteria of fracture mechanics and laws of thermodynamics.

Introduction

The problem of hydrogen embrittlement and hydrogen fracture of metal materials in general for many years has been a central point of attention of physicists, material scientists and engineers–mechanics [1,2]. Important aspects of these problems were studied in the papers of scientists from different countries, and the obtained results of the studies have been applied successfully to hydrogen-resistant materials selecting, as well as to the assessment of the structural elements strength and durability for thermal, atomic and hydrogen energetics. The influence of gaseous hydrogen on crack growth in structure steels is analysed taking into account the thermal influences and effects of hydrogenation-degasation of metals in paper [3]. Significant attention is paid to the study of the hydrogen influence on the fatigue properties of pipelines steels [4], on the propagation of cracks under cyclic [5–9] and static loads [10,11]. A significant increasing of fatigue crack growth rate was observed under conditions of high pressure gaseous hydrogen action [5,6,9] and revealed to be higher in an order compared with air tests [6]. A formula for determining the rate of a crack propagation as dependence on the local hydrogen concentration near the crack tip, the hydrogen concentration in the bulk of the metal and the range of stress intensity factor has been obtained in the papers [7,8]. The physico-mechanical model for evaluation of internal hydrogen defects growth kinetics with the account for non-stationary thermal influences is proposed [3]. The influence of hydrogen on the parameters of the material stress-strain state was investigated in the papers [12–15]. On the basis of the theory of elasticity the appropriate system of equations for

* Corresponding author.
E-mail address: ira_dolinska@ukr.net (I. Dolinska).
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determining of the stress components caused by hydrogen in metal was built in the paper [12]. The observation of fracture surfaces a 15-5 PH martensitic stainless steel showed a change in fracture mechanisms depending on hydrogen pressure and loading condition, namely the stress intensity factor amplitude and the loading frequency [5]. The equation of changing of the fatigue crack sizes in the wall of the pipeline depending on time is obtained [16]. Here, the equation of state for the ideal gas was used, the solution of the problem of elasticity theory about the crack opening under gas pressure and the diffusion theory of gas diffusion into the crack cavity.

However, diagnostics of such process is of a special interest in engineering practice. Because crack propagation under hydrogen effect is of a jump-like character [17], one of the methods of such processes diagnostics is the AE method, since it gives the information about defect propagation [18,19]. The process of crack propagation and fracture creates, as a rule, rather high amplitudes of AE signals [20] that can easily be recognized on the hindrances background. For example [21], where cracks initiation and propagation in hydrogenated titanium specimens using the method of AE has been investigated. As mentioned above, such cracks generated high amplitudes of acoustic signals.

The AE method proved to be effective also in experimental investigations of corrosion fracture [20,22], induced very often by a hydrogen mechanism [23]. A long-term time of acoustic signals generation was related with the development of hydrogen bubbles in a corrosive environment [24–28]. In papers [17–20,22–28] it is shown that this method is effective in investigation of the subcritical crack growth under hydrogen effect. Application of the simplified model of hydrogen diffusion allowed interpreting the mechanism of crack propagation as a jump-like one, that was proved by the fractographic and AE analyses [17].

The authors of [29] demonstrated that AE can be the effective method for assessing hydrogen embrittlement. In papers [30,31] a number of experimental AE investigations on the dynamics of crack formation in the system surfacing - base metal, as a result of hydrogen effect, were carried out. It is established that the processes of crack initiation and propagation in specimens are develops by a jump-like character and recorded by the AE signals. The AE-testing of the processes of hydrogen cracking of tubular У8 steel specimens [31] showed that in specimens, hydrogenated to high concentration of hydrogen, cracking was caused mainly by the effect of gaseous hydrogen on steel. Presence of the dissolved hydrogen leads to a retarded cracking and causes discrete AE with high amplitudes that alternate with continuous AE at relatively small amplitudes.

However, for technical diagnostics it is important to build a theory of quantitative assessment of materials' life time by the AE parameters, i.e. the construction of mathematical equations for the description of crack propagation in hydrogen-containing environments by the AE parameters.

In connection with this, in the proposed paper the mathematical modeling of hydrogen fracture, caused by crack propagation of such species: hydrogen-mechanical, high-temperature creep cracks in hydrogen-containing environments, hydrogen cracks at super-high hydrogen concentrations in material are carried out. In this case the estimation models for above mentioned types of hydrogen propagation of cracks is formulated from the unified positions of the energy approach that is based on the laws of thermodynamics and basic principles of the mechanics of slow down fracture.

Kinetic equations of hydrogen-mechanical cracks propagation

Let us consider a 3-D body with a plane crack of initial area S_0, subjected to the effect of hydrogen-containing environment. At the infinitely remote points a body is tensioned by durable static forces p (Fig. 1) that form the stress-strain state symmetric with respect to the plane of the crack location. In the crack tip vicinity the stress-strain state is described by the stress intensity factor (SIF) K_I only. The crack surfaces are assumed to be coated by an oxide film, while on the juvenile surface of its moving tip the surface concentration of hydrogen C_H is formed. The problem is to determine the kinetics of crack propagation and to assess its subcritical growth period.

To solve the problem let us build a estimation model, i.e. mathematical equations that describe the process of crack propagation. Assume that a crack in the process of its growth moves discrete-continuous, by microjumps, where their areas ΔS are sufficiently small, and a time for jumps

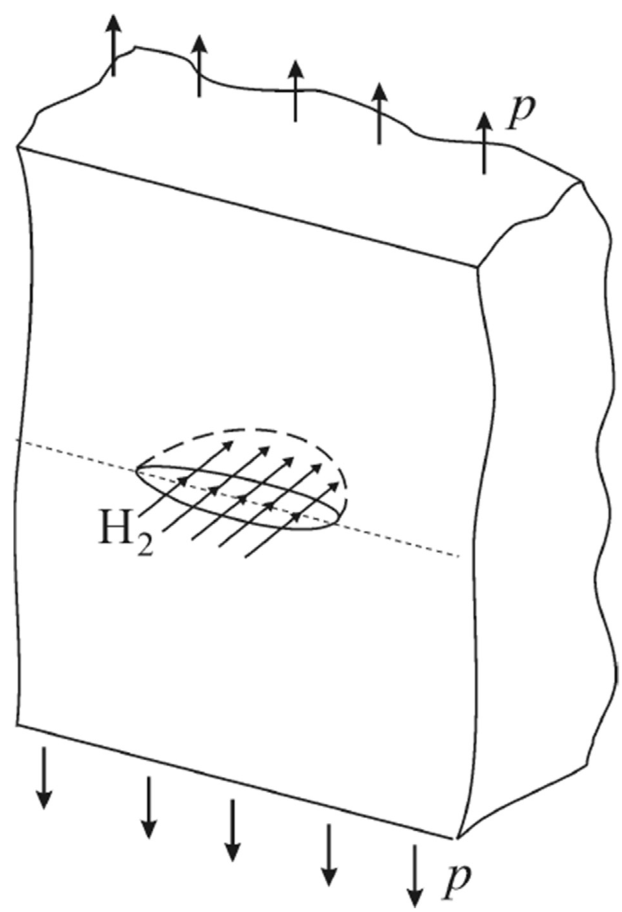

Fig. 1 – Loading chart of a body with a hydrogen-mechanical crack.

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