

INFLUENCE OF THE KINETICS OF PROCESSES ON THE BEHAVIOR OF THIN STRUCTURES IN A CONTINUOUS MEDIA

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Abstract. Hydrogen embrittlement of materials is one of the important factors at an estimation of serviceability of designs. In spite of the fact that many works are devoted to research of hydrogen influence on properties of metals and alloys, there are enough 'white' spots in this problem, in particular, the influence of kinetic processes inside a material, giving rise to hydrogen redistribution, on the basic strength characteristics at static and dynamic loading. Absence of authentic mechanical model, which description is based on the basic fundamental principles of rational mechanics, makes a problem rather actual, since, inherently, presence of such model would allow to describe influence of internal kinetics on macroparameters of a material, what is today extremely important in view of huge amount of hypotheses which are ready to confirm only concrete experiments and do not allow to use them in other cases.

Present work offers the model based on experimental data on decrease in break energy of internuclear bonds at landing particles of hydrogen, i.e. decrease in a level of free energy. The offered model allows to explain the localization of hydrogen in the field of the increased concentration of stresses and change of material properties.

1. INTRODUCTION

It is generally recognized, that hydrogen is one of the most dangerous contamination for the overwhelming majority of metals and alloys. A lot of papers analyze the hydrogen influence on various service properties of materials. However, there are enough open questions in this problem, in particular, a question on influence of kinetic processes inside a material, resulting in redistribution of hydrogen, on the basic strength characteristics at static and dynamic loading. Absence of authentic mechanical model, basing on fundamental principles of rational mechanics, makes this problem rather actual, since, inherently, the presence of such model would allow to describe the influence of internal kinetics on macroparameters of material. This possibility is extremely important in view of huge amount of hypotheses confirming concrete experi-

ments only; for this reason they are not acceptable for more common cases.

Main hypothesis incorporated in of the offered model are based on the experimental data specifying the decrease of the break energy of internuclear bonds at landing of hydrogen particles on a bond, i.e. the decrease of the free energy level. It should be mentioned that this effect takes place also for a congestion of lattice defects: dislocations, vacancies, *etc.*

Thus, it is possible to expect that basic equations derived below should be applicable for other cases of easing of internuclear bonds of a lattice.

2. RESULTS AND DISCUSSION

Basic principles of the above mentioned hypothesis can be illustrated via the analysis of one-dimensional chain consisting of identical particles – dots with a

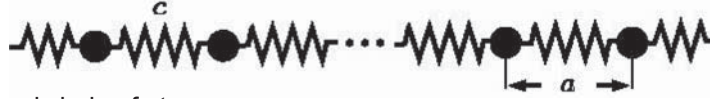


Fig. 1. One-dimensional chain of atoms.

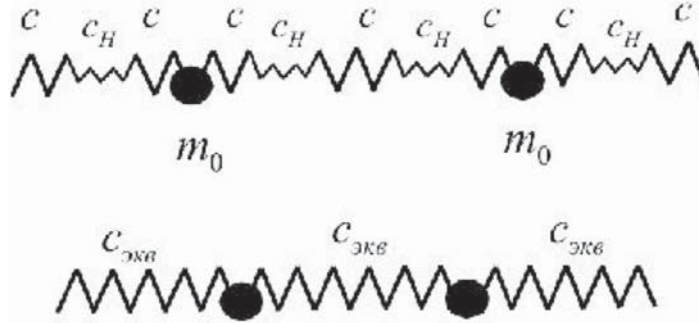


Fig. 2. Model of a chain with hydrogen atoms planted on the bonds.

mass of m_0 (mass of atom in a crystal lattice of a material) and are connected with each other by identical nonlinear springs with the lengths a , Fig. 1.

The basic equation of movement in long-wave approximation looks like [1]

$$m_0 \ddot{u} = -a[f(a(1+u'))] \quad (1)$$

Obviously, for small deformations $\varepsilon = \partial u / \partial x$, we come to the equation of a kind

$$\ddot{u} - \vartheta_0^2 u'' = 0, \quad \vartheta_0^2 = \sqrt{\frac{c}{m}} a, \quad (2)$$

$$\text{since } f[a(1+\varepsilon)] \approx -Ca\varepsilon = -Ca \frac{\partial u}{\partial x}.$$

The easing of internuclear bonds caused by 'landing' of hydrogen (or other mobile internal elements of structure) particles to it can produce the circuit formations of new internuclear bonds, see Fig. 2, as consecutive connections of elastic bonds of the basic lattice and the introduced elastic bonds of new elements (e.g. hydrogen particles). Obviously, such circuit is possible at the assumption that the mass of particles of a mobile structure is small, i.e.

$$m_0 \ll m_H.$$

Equivalent rigidity of the new bond can be found from the equation

$$\frac{N_{\Sigma}}{C_{\Sigma}} = \frac{N_0}{C_0} + \frac{N_H^+}{C_H} \quad N_{\Sigma} = N_0 + N_H^+ \quad (3)$$

The constitutive equation for this medium should be

$$\sigma^{(1)} = E_{\Sigma} \varepsilon, \quad E_{\Sigma} = \frac{E_0 E_H}{n_0 E_H + n^+ E_0}, \quad (4)$$

$$n_0 = \frac{N_0}{N_{\Sigma}}, \quad n^+ = \frac{N_H^+}{N_{\Sigma}}, \quad n_0 + n^+ = 1.$$

Here N_{Σ} is the full number of particles in elementary volume, N_0 – the number of the particles connected by unspoiled bonds, N_H^+ is the number of hydrogen particles attached to a lattice with the bonds by rigidity C_H , n_0, n^+ are the concentrations of the above mentioned particles, respectively.

The nonlinear force f in Eq. (1) can be accepted for small deformations as

$$f = -C_{\Sigma} a \varepsilon = -E_{\Sigma} \varepsilon. \quad (5)$$

The equivalent module of a lattice E_{Σ} , see Eq. (4), can decrease essentially, since $E_H = E_0$ ($c_H = c_0$), and has a strong dependence on the concentration of the attached particles n_+ .

The number of the lattice settled hydrogen particles depends on the stress state of the lattice in every point and, generally, on time. The unknown functional dependence of E_{Σ} on $n_+(\varepsilon, x, t)$ should be determined from model of the two-component continuum.

Substantive provisions of the theory of two-component continuum can be found in work [1]; there-

fore, we are presenting only final equations with necessary explanatories of the script of occurring processes. Considering one-dimensional case for the first components (later we shall analyze the basic bearing design, i.e. a crystal lattice with internal structures containing attached hydrogen or other mobile element particles), one can derive the equation for dynamics (Euler's first equation) as:

$$\frac{\partial \sigma^{(1)}}{\partial x} = \rho^{(1)} \frac{\partial v^{(1)}}{\partial t} + J_{12} v^{(1)} + R_{12}, \quad (6)$$

$$\rho^{(1)} = \rho^{(0)} + \rho_H^{(1)}.$$

Eq. (6) is again the classical continuum equation; therefore, it has new force items in the right hand part. As it was specified above, connection of mobile particles practically does not influence the change of inertial characteristics of the bearing medium, i.e. $\rho_H^+ = m_H \cdot N^+ = \rho_0^{(0)}$ is the continuum density. However, the rapid change of this characteristic J_{12} gives rise to a jet force $J_{12} \cdot v^{(1)}$; this effect is quite important and can not be neglected.

Internal force R_{12} determines the interaction between the first and second components of the considered continuum; its definition essentially depends on the character of processes proceeding inside a material structure.

The mobile structure of the internal structure of a material should be related to the second component; in the discussed case it means that the attached particles are not attached.

The equation determining dynamics of such particles looks like:

$$-\frac{\partial p}{\partial x} = \rho^{(2)} \frac{\partial v^{(2)}}{\partial t} + J_{21} v^{(2)} + R_{21}, \quad (7)$$

$$\rho^{(2)} = \rho_H^- = m_H \cdot N^-.$$

Here N is the number of mobile hydrogen particles.

Similarly to a case of compressed liquid, the state equation determining a connection between pressure p and density $\rho_H^{(-)}$ [2] will be

$$\tilde{p} = p - p_0 \cong \rho_H^- c_H^2 = m_H N^- c_H^2. \quad (8)$$

It is necessary to add the equation of mass balance or Eqs. (6) and (7),

$$\frac{\partial \rho^{(1)}}{\partial t} + \frac{\partial(\rho^{(1)} v^{(1)})}{\partial x} = J_{12} \quad (9)$$

or take into account an invariance of $\rho^{(0)}$

$$\frac{\partial \rho_H^+}{\partial t} + \frac{\partial(\rho_H^+ v^{(1)})}{\partial x} = J_{12}. \quad (10)$$

Eq. (10) determines the balance of hydrogen particles attached to a lattice of the bearing material

$$\frac{\partial N_H^+}{\partial t} + \frac{\partial(N_H^+ v^{(1)})}{\partial x} = J_{12} / m_H.$$

Expression for mass balance for non-attached particles looks like

$$\frac{\partial \rho_H^-}{\partial t} + \frac{\partial(\rho_H^- v^{(1)})}{\partial x} = J_{21} \quad (11)$$

or

$$\frac{\partial N_H^-}{\partial t} + \frac{\partial(N_H^- v^{(1)})}{\partial x} = J_{21} / m_H.$$

There are, meanwhile, uncertain reactions $R_{12} = -R_{21}$ and source terms $J_{12} = -J_{21}$.

Suggesting that the stream of non-attached hydrogen particles flow through the lattice of a bearing design can be described within the approach used for the stream of compressed liquid [2], R_{12} should be accepted in the following representation

$$R_{12} = k \frac{\rho_H^-}{D(\varepsilon)} [v^{(2)} - v^{(1)}]. \quad (12)$$

This formula is similar to the formula frequently used in hydraulics [2], where the square-law law of resistance is passed; however, a linearization of this law is done here and factor k is entered. In addition, it is important that the term $D(\varepsilon)$ - the size of through passage section, which depends on deformation ε - is introduced in Eq. (12). The source terms $J_{12} = -J_{21}$ is introduced in a form similar to those used in [3], i.e.

$$J_{12} = \alpha N_H^- - \beta N_H^+, \quad (13)$$

where α and β are positive factors determining interaction between attached and free particles of hydrogen. Their role can be easily seen from the following model equations of balance of particles in a design

$$\frac{dN_H^+}{dt} = \alpha N_H^- - \beta N_H^+ \quad \frac{dN_H^-}{dt} = -\alpha N_H^- + \beta N_H^+. \quad (14)$$

Initial conditions here are

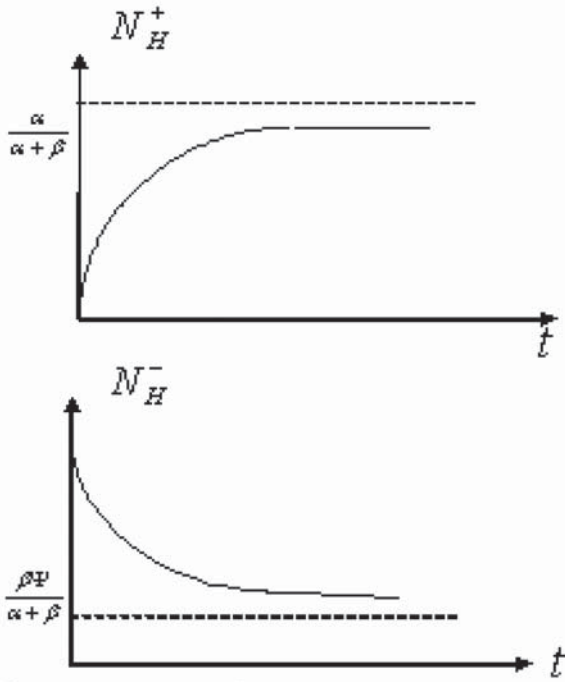


Fig. 3. Dependences of the bonded and mobile hydrogen on time.

$$N_H^+(0) = 0, \quad N_H^-(0) = \Psi,$$

The solution of system (14) will be (Fig. 3)

$$N_H^+ = \frac{1}{\alpha + \beta} \alpha \Psi (1 - e^{-(\alpha + \beta)t}),$$

$$N_H^- = \Psi \left[1 - \frac{\alpha}{\alpha + \beta} (1 - e^{-(\alpha + \beta)t}) \right]. \quad (15)$$

Parameters α and β should be determined experimentally because they determine the rate of hydrogen saturation of a bearing design and its rate of hydrogen loss.

It should be noted that Eq. (14) describes interchange of hydrogen particles (bonded and mobile) under the condition mobile hydrogen particles have zero moving speed. As follows from Eq. (12), this is realized under condition of $D(\varepsilon) = 0$, i.e. easy access of free hydrogen particles is excluded. Obviously, in this case all free hydrogen passes in the connected condition; hence $\alpha \gg \beta$.

For the one-dimensional case, the full system of the equations looks like:

$$\frac{\partial \sigma^{(1)}}{\partial x} = \rho^{(1)} \frac{\partial v^{(1)}}{\partial t} + J_{12} v^{(1)} + R_{12}, \quad \rho^{(1)} = \rho^{(0)} + \rho_H^+,$$

$$\rho_H^+ = m_H \cdot N^+ \quad \sigma^{(1)} = \frac{E_0 E_H}{n_0 E_H + n^+ N_0} \varepsilon,$$

$$n_0 = \frac{N_0}{N_0 + N_H^+}, \quad n^+ = \frac{N_H^+}{N_0 + N_H^+},$$

$$-\frac{\partial p}{\partial x} = \rho^{(2)} \frac{\partial v^{(2)}}{\partial t} + J_{21} v^{(2)} + R_{21},$$

$$\rho^{(2)} = \rho_H^- = m_H \cdot N^-,$$

$$\tilde{\rho} = p - p_0 \cong \rho_H^- c_H^2 = m_H N^- c_H^2,$$

$$\frac{\partial \rho^{(0)}}{\partial t} + \frac{\partial(\rho^{(0)} v^{(1)})}{\partial x} = 0, \quad (16)$$

$$\frac{\partial \rho_H^+}{\partial t} + \frac{\partial(\rho_H^+ v^{(1)})}{\partial x} = J_{12} \sim \frac{\partial N_H^+}{\partial t} + \frac{\partial(N_H^+ v^{(1)})}{\partial x} = J_{12} / m_H,$$

$$\frac{\partial \rho_H^-}{\partial t} + \frac{\partial(\rho_H^- v^{(1)})}{\partial x} = J_{21} \sim \frac{\partial N_H^-}{\partial t} + \frac{\partial(N_H^- v^{(1)})}{\partial x} = J_{21} / m_H,$$

$$R_{12} = -R_{21} = k \frac{\rho_H^-}{D(\varepsilon)} [v^{(2)} - v^{(1)}],$$

$$J_{12} / m_H = J_{21} / m_H = \alpha N_H^- - \beta N_H^+.$$

The derived system of equations (16) is full and strongly nonlinear, therefore let's limit our consideration by a simple case: a statics at adjusted uniaxial tension-compression with the first (basic) component test deformation ε .

The value of the stress σ is of essential interest here. In case of absence of hydrogen in a structure of a material, its linear - elastic behaviour is described by $\sigma_{st} = E \cdot \varepsilon_{st}$. When hydrogen presents in the material, the change of the sizes of through passage sections $D(\varepsilon)$ occurs giving rise to structure redistribution. In other words, when free hydrogen becomes bonded that results in a change of the effective module and stress value. From the state equation $\sigma = \sigma(\varepsilon, n^+(\varepsilon, x, t))$, which can be presented as

$$\sigma = E_0 \varepsilon \left[1 - \frac{n^+}{n^+ + n^{(0)} E_H / E_0} \right], \quad (17)$$

the essential dependence of stress state on concentration of the bonded hydrogen is evident.

It is necessary to note here that the concept of a static stress state is rather conditional since it is necessary to attribute the bearing component of medium with regard for Eq. (6) stating that the movement of the second component is determined by kinematics. In other words, reorganization of a material structure at the time level possesses its own dynamics. Therefore, it is natural to search for the solution of the task in view as:

$$\begin{aligned} \varepsilon &= \varepsilon_{st} + \tilde{\varepsilon}(x, t), \quad v^{(1)} = 0 + \tilde{v}^{(1)}, \\ v^{(2)} &= 0 + \tilde{v}^{(2)}. \end{aligned} \quad (18)$$

Here ε_{st} is a homogeneous static field of deformations. It is obvious that $N^+ = N^+(x, \varepsilon, t)$ can be submitted as

$$\begin{aligned} N^+(x, \varepsilon_{st} + \tilde{\varepsilon}, t) &= N^+(x, \varepsilon_{st}, t) + \\ \frac{\partial N^+}{\partial \varepsilon} \Big|_{\varepsilon=\varepsilon_{st}} \tilde{\varepsilon}(x, t). \end{aligned} \quad (19)$$

It is naturally to present stresses σ as

$$\begin{aligned} \sigma &= \sigma + \tilde{\sigma} = E_0 \varepsilon_{st} - \\ E_0 \varepsilon_{st} \left(\frac{n^+}{n^+ + n^{(0)} E_H / E_0} \right) &+ O(\tilde{\varepsilon}). \end{aligned} \quad (20)$$

Note that σ here is advisedly combined with $\tilde{\varepsilon}$, emphasizing that there are the induced deformations due to reorganization of internal structure, which generate a stress $\tilde{\sigma}$. Complex dependence σ on deformation converts the first equation of system (16) into:

$$\begin{aligned} \frac{\partial \sigma^{(1)}}{\partial \varepsilon} \frac{\partial \varepsilon}{\partial x} + \frac{\partial \sigma^{(1)}}{\partial n_H^+} \left[\frac{\partial n_H^+}{\partial \varepsilon} \frac{\partial \varepsilon}{\partial x} + \frac{\partial n_H^+}{\partial x} \right] = \\ \rho^{(1)} \frac{\partial v^{(1)}}{\partial t} + J_{12} v^{(1)} + R_{12}. \end{aligned} \quad (21)$$

Being limited to the first approach, one can write (16) as

$$\begin{aligned} \frac{\partial \sigma_0}{\partial \varepsilon} \frac{\partial \varepsilon_{st}}{\partial x} &= 0 \\ \frac{\partial \tilde{\sigma}^{(1)}}{\partial x} &= \rho^{(1)} \frac{\partial \tilde{v}^{(1)}}{\partial t} + J_{12} \Big|_{\varepsilon=\varepsilon_{st}} \tilde{v}^{(1)} + R_{12} \Big|_{\varepsilon=\varepsilon_{st}} - \\ \frac{\partial \sigma_0}{\partial n_H^+} \Big|_{\varepsilon=\varepsilon_{st}} \frac{\partial n_H^+}{\partial x} \Big|_{\varepsilon=\varepsilon_{st}}. \end{aligned} \quad (22)$$

Here

$$\begin{aligned} \sigma &= E_0 \varepsilon_{st} \left\{ 1 - \left[\frac{n^+}{n^+ + n^{(0)} E_H / H_0} \right] \Big|_{\varepsilon=\varepsilon_{st}} \right\}, \\ \tilde{\sigma} &= E_0 \tilde{\varepsilon} \left\{ 1 - \left[\frac{n^+}{n^+ + n^{(0)} E_H / H_0} \right] \Big|_{\varepsilon=\varepsilon_{st}} \right\}, \\ R_{12} \Big|_{\varepsilon=\varepsilon_{st}} &= k \frac{\rho_H^-}{D(\varepsilon_{st})} v^{(2)}. \end{aligned} \quad (23)$$

The second equation in (22) serves for definition of an induced field of deformations $\tilde{\varepsilon}$ when the main approach term $\partial \sigma_0 / \partial n^+ \cdot \partial n^+ / \partial x \Big|_{\varepsilon=\varepsilon_{st}}$ is known.

For the second component we can state that:

$$\begin{aligned} -\frac{\partial \rho}{\partial x} &= k \frac{m_H N_H n_H^-}{D(\varepsilon_{st})} v^{(2)}, \\ \rho - \rho_0 &= \tilde{\rho} = m_H N_H n_H^- c_H^2. \end{aligned} \quad (24)$$

Here $\rho_H = m_H N_H$ is hydrogen density, $N_H = N_H^- + N_H^+$ is the number of hydrogen particles in elementary volume, n_H^- is a concentration of free hydrogen $n_H^- = N_H^- / N_H$.

Eq. (24) can be transformed into:

$$c_H^2 \frac{\partial n_H^-}{\partial x} = -k \frac{n_H^-}{D(\varepsilon_{st})} v^{(2)}. \quad (25)$$

Eq. (25) is similar to formula Darcy, but has the generalized factor of diffusion dependent on the deformation field ε_{st} .

Thus, we have

$$v^{(2)} = -\frac{1}{k n_H^-} \cdot c_H^2 \cdot D(\varepsilon_{st}) \frac{\partial n_H^-}{\partial x}. \quad (26)$$

Above mentioned equations should be added by the balance equation for the number of bonded and free hydrogen particles:

$$\begin{aligned} \frac{\partial n_H^+}{\partial t} &= \alpha n_H^- - \beta n_H^+ \\ \frac{\partial n_H^-}{\partial t} + \frac{\partial n_H^- v^{(2)}}{\partial x} &= -(\alpha n_H^- - \beta n_H^+). \end{aligned} \quad (27)$$

Eqs. (27) can be combined relative to n_H^+ , the result accounting Eq. (26) looks like

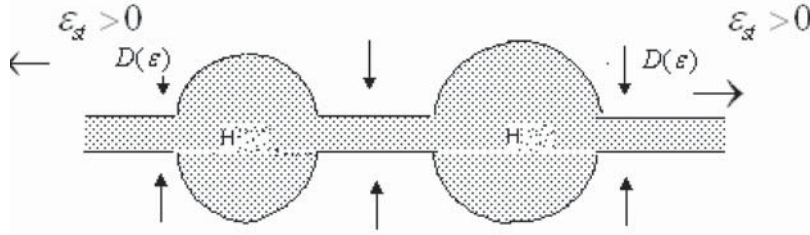


Fig. 4. Model of closing of channels and places of a congestion of hydrogen.

$$\frac{\partial^2 n_H^+}{\partial t} + (\alpha + \beta) \frac{\partial n_H^+}{\partial t} - A \cdot D(\varepsilon_{st}) \left[\beta \frac{\partial^2 n_H^+}{\partial x^2} + \frac{\partial^3 n_H^+}{\partial t \partial x^2} \right] = 0. \quad (28)$$

Here $A = c_H^2 k j$.

Eq. (28) is the equation of the mixed type, it contains terms inherent in the hyperbolic equation, i.e. $\partial^2 n_H^+ / \partial t^2$, $\partial^2 n_H^+ / \partial x^2$, and also terms of a parabolic kind $\partial n_H^+ / \partial t$, $\partial^3 n_H^+ / \partial t \partial x^2$. The last means that at the detailed analysis of a non-stationary problem at the assignment of the finite initial perturbation one should expect a characteristic front of movement of increase (or decrease) in a bonded hydrogen concentration, i.e. an exposed strong dispersion.

Let us consider the possible simplified solution of the problem. For the initial Eq. (28) we can analyse a problem at the initial conditions of a kind

$$n_H^+(0, x) = 0, \quad n_H^-(0, x) = \frac{1}{2} \cdot \Psi^{(-)} \cdot \left(1 + \cos \frac{2\pi x}{\lambda} \right), \\ \dot{n}_H^-(0, x) = \alpha \frac{1}{2} \cdot \Psi^{(-)} \cdot \left(1 + \cos \frac{2\pi x}{\lambda} \right). \quad (29)$$

Let us suggest that the solution can exist in a following form:

$$n_H^+ = \frac{1}{2} q(t) \cdot \Psi^{(-)} \cdot \left(1 + \cos \frac{2\pi x}{\lambda} \right). \quad (30)$$

where λ is the characteristic size of internal structure and $q(t)$ satisfies the equation:

$$\ddot{q} + \dot{q}(\alpha + \beta + G(\varepsilon_{st})) + \beta G(\varepsilon_{st}) q = 0, \quad (31)$$

In turn, its solution looks like:

$$q(t) = \frac{\alpha}{\alpha + G(\varepsilon_{st})} \cdot \Psi^{-1} \cdot \left(e^{\beta \frac{G(\varepsilon_{st})}{\alpha + G(\varepsilon_{st})} t} - e^{-(\alpha + G(\varepsilon_{st})) t} \right), \quad (32)$$

$$G(\varepsilon_{st}) = -\frac{1}{3} \cdot \frac{c_H^2}{k} \cdot D(\varepsilon_{st}) \cdot \left(\frac{2\pi}{\lambda} \right)^2.$$

It is important to note that

$$\frac{\partial n_H^+}{\partial \varepsilon} = -\frac{1}{3} \cdot \frac{c_H^2}{k} \cdot \left(\frac{2\pi}{\lambda} \right)^2 \frac{\partial D}{\partial \varepsilon_{st}} \frac{\alpha \Psi^{(-)}}{\alpha + G(\varepsilon_{st})}. \quad (33)$$

At $D(\varepsilon) = D_0 + D_1 \cdot \varepsilon$ and $D_1 < 0$ there is a closing channel that promotes an increase in concentration of bonded hydrogen, (see Fig. 4).

It is possible to receive simplified enough formula

$$\frac{\partial n_H^+}{\partial \varepsilon} > 0, \quad \text{если} \quad \frac{\partial D}{\partial \varepsilon_{st}} = D_1 < 0, \\ \frac{\partial n_H^+}{\partial \varepsilon} < 0, \quad \text{если} \quad \frac{\partial D}{\partial \varepsilon_{st}} = D_1 > 0. \quad (34)$$

Let's accept the following values of parameters: $\beta = \alpha$, $\varepsilon_{st}^* = D_0 / D_1$ - limiting concentration for the 'closed' channels and $\Psi \kappa^{(-)}$ limiting concentration of the tied hydrogen.

$$\Psi^{(-)} \gg \kappa = \frac{\zeta_H c_H^2}{\zeta_0 c_0^2}, \quad (35)$$

In particular, for steel, we have:

$$\Psi^{(-)} \approx 10^{-6}, \quad \kappa \approx 10^{-7} \div 10^{-8},$$

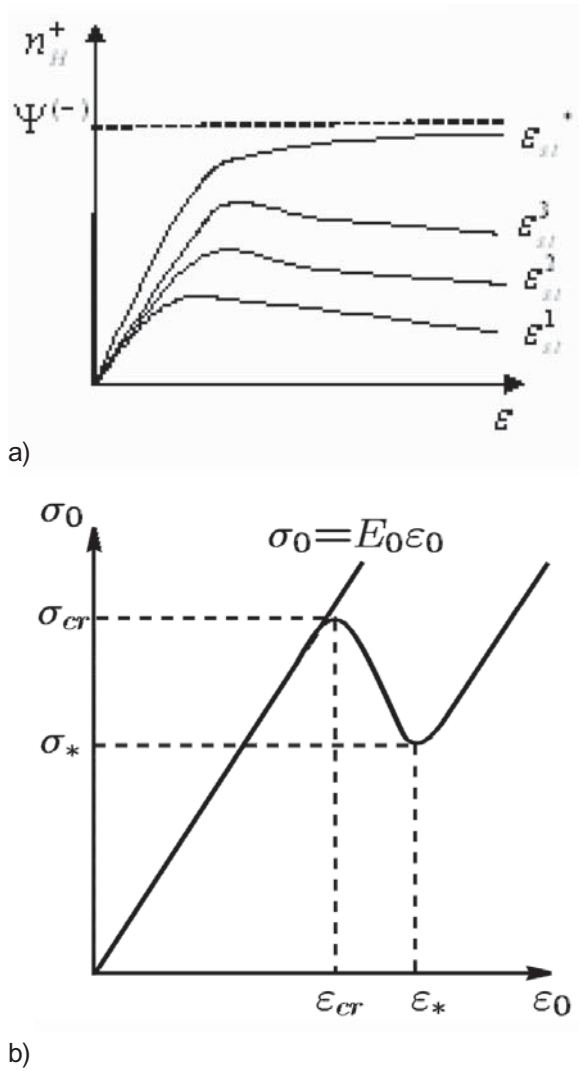


Fig. 5. Behaviour of concentration of the bonded hydrogen at a tension of a sample depending on the enclosed deformation-(a), the diagram a deformation - stress in view of influence of the bonded hydrogen - (b).

and for titan:

$$\Psi^{(-)} \approx 10^{-4}$$

Considering that ϵ_{st} is a homogeneous static field of the deformations, which is strongly increased

under the induced deformations connected to reorganization of internal structure, we can derive rather simple formulas for the equation of a condition and for the conditions of loss of stability of deformation, characteristic at fracture.

$$\sigma_0^{(1)} = E_0 \cdot \epsilon_{st} \cdot \frac{\kappa}{\frac{\alpha \Psi^{(-)}}{\alpha + D_0 - D_1 \epsilon_{st}} + \kappa},$$

$$\left. \frac{\partial \sigma_0^{(1)}}{\partial \epsilon} \right|_{\epsilon = \epsilon_1} = 0, \tag{36}$$

$$\epsilon_1 \cong \epsilon^* \cdot \left(1 - \sqrt{\alpha \cdot \frac{\Psi^{(-)}}{\kappa} \cdot \frac{\kappa}{c_H^2 D_0} \lambda^2} \right).$$

The behaviour of concentration of the bonded hydrogen at a tension of a sample depending on the enclosed deformation is shown in Fig. 5a. In Fig. 5b, qualitative representation of loss of stability of deformation is given at achievement of critical initial deformation, i.e. fracture.

3. SUMMARY

Thus, the model is constructed, which allows to describe the kinetics of hydrogen in metals, in particular: to estimate hydrogen transition from mobile into bonded state depending on the stress state and to describe the localization of the connected hydrogen resulting in the destruction of a material such localization places.

REFERENCES

- [1] A.M. Krivtsov and N.F. Morozov // *Doklady Physics* **40** (2001) 825, in Russian.
- [2] L.G. Loitzyansky, *Fluid and gas mechanics* (Nauka, Moscow, 1978), in Russian.
- [3] G.B. Whitham, *Linear and nonlinear waves* (J.Wiley – Interscience Publ., NewYork, 1974).