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To Prediction Of Corrosive Failure Of Materials In Nonstationary Temperature Field

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Abstract: - A problem on corrosive failure of arbitrary size metallic constructions with regard to influence of temperature of corrosive medium is considered. The corrosive process is determined as a process of continuous accumulation of certain form of damages. It is assumed that the corrosive failure happens when the accumulated corrosive damages attain certain level. It is assumed that as a result of heat-exchange between the corrosive medium and metallic structural elements, at each point of the element there occurs non- stationary change of temperature by the unknown law. The deformation of the element of the construction is assumed to be stationary. Subject to this condition and for the known initial value of the temperature field a formula that enables to predict the time to corrosive failure of arbitrary geometry structural elements, is derived. The given formula in addition to initial value of temperature and stress contains some constants that are defined by the results of experiments on corrosive failure of prototypes in corrosive media.

Key words: **corrosion, failure, temperature, mechanical stress, time to corrosion, damage accumulation.**

I. INTRODUCTION

Corrosive-mechanical failure is one of the varieties of failure of constructions made of metals. Such form of failure of materials and articles holds as is known at joint action of load and corrosive medium. A lot of investigations of different authors, for example the papers [1-6] have been devoted to identification of the character and mechanism of the action of mechanical stress on the process of corrosive failure of metals. In these papers it is shown that in great majority of cases the corrosive failure happens under the action of tensile stresses. Corrosive cracks propagate perpendicularly to the direction of action of tensile stress at small deformations or almost without them. The authors of the papers [3, 4] believe that the corrosive failure occurs only in the case if the applied tensile stress higher than some critical threshold stress. At the same time some researchers deny the possibility of existence of critical stresses under which corrosive failure doesn't happen. On the opinion of the author of the paper [6], even very small tensile stresses cause failure if there is sufficient time to form stress concentrator. Whether there exists or doesn't exist critical threshold stress, the mechanical tensile stress has a significant influence on corrosive failure process, besides when the stress increases the time to failure decreases. Influence of temperature of corrosive medium on corrosive failure process for metals and corrosive media has also been studied [2,3]. Most studies in this direction is of experimental character. The references show the experimental curves of long-term corrosive strength on time to failure-temperature planes. When temperature increases, time to corrosive failure decreases. Influences of temperature of corrosive media on corrosive failure process were studied in samples where constant mechanical stresses were created [2,3]. As a result of heaf exchange between the corrosive medium and metal, in the corrosion process there happens non-stationary change of metal's temperature. Complexity of the corrosion process doesn't permit to define the temperature field of the corroding metallic body as a result of statement of a mathematical problem. Here it is considered the case when in the corrosion process the stress remains constant and we try to derive theoretical formula that permits to predict the time to corrosive failure without solving the boundary value problem on determination of non-stationary temperature field of a metallic body. Note that while maintaining deformation of the metallic body constant, with some approximation one can accept that in the part of the metal where the corrosion process has not penetrated, the stress can be considered constant [7].

II. DETERMINATION OF TIME TO CORROSIVE FAILURE

Following [8] we determine the corrosion process as a process of continuous accumulation of certain form of stresses. We'll consider that corrosive failure occurs when the accumulated corrosive failures achieve certain level. According to [8], we introduce the non-negative function $\eta(t)$ that monotonically increases with respect to time t and characterizes the corrosiveness degree. At initial time the function $\eta(t)$ equals zero: $\eta(0)=0$. Failure happens at time t_* at which $\eta(t_*)=1$. Let the velocity of accumulation of corrosive failures be a function of the applied constant stress σ and temperature field $T=T(x,t)$ of the corroding body, and also of the function $\eta(t)$:

$$\frac{d\eta}{dt}=F(\sigma,T(x,t),\eta(x,t)). \tag{1}$$

It is assumed that

$$F(\sigma,T,\eta)=\varphi(\sigma,T)\psi(\eta).$$

Allowing for this, we rewrite equation (1)in the form

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$$\frac{d\eta}{dt} = \varphi(\sigma, T(x,t))\psi(\eta(x,t)).$$

(2)

Taking into account the condition $\eta(t_*) = 1$, we get:

$$\int_0^{t_*} \phi(\sigma, T(x,\tau))d\tau = 1,$$

(3)

where $\phi = \frac{\varphi}{A}$, $A = \int_0^1 \frac{d\eta}{\psi(\eta)}$.

We accept the function $\phi(\sigma, T)$ in the form:

$$\phi(\sigma, T) = \frac{1}{B(\sigma)} e^{\beta\left(\frac{T}{T_s} - 1\right)}.$$

(4)

Here $B(\sigma)$ is some experimentally defined function, $\beta = const$, T_s is the temperature reduced to dimensionless quantity of temperature field of the body that is chosen from the range $T : T_s = const.$

Using (4), from relation (3) we have:

$$\frac{1}{B(\sigma)} \int_0^{t_*} e^{\beta\left(\frac{T(\tau)}{T_s} - 1\right)} d\tau = 1.$$

(5)

Let t_0 be the time to corrosive failure of the body under consideration at constant temperatures $T = T_k = const$. In this case the quantity t_* passes to t_0 and from relation (5) we have:

$$t_0 = B(\sigma) e^{-\beta\left(\frac{T_k}{T_s} - 1\right)}.$$

(6)

Formula (6) determines the time to corrosive failure at $\sigma = const$ and $T = const$. Experiments on corrosive failure at $\sigma = const$ and $T = const$ are in references, for example in [2]. By using the data of these experiments, according to formula (6) for each system "metal-corrosive medium" one can determine the function $B(\sigma)$ and constant β. According to formula (6), the function $B(\sigma)$ corresponds to the time of corrosive failure of the body at constant stresses $\sigma = \sigma_k = const$ for $T = T_s$: $B(\sigma) = t_0(\sigma, T_s)$. On the basis of analysis of experimental curves $t_0 \sim \sigma$ for $T = T_s = const$, in the paper [9], the function $B(\sigma)$ is approximated in the form of power function:

$$B(\sigma) = t_{os}\left(\frac{\sigma}{\sigma_s}\right)^{-\alpha},$$

(7)

where σ_s is the stress reduced to dimensionless quantity of stress that should be chosen from the range of the stress σ; $t_{os} = const$ is the time to corrosive failure at $\sigma = \sigma_s$, $T = T_s$; $\alpha > 0$ is a constant to be defined. Allowing for (7) formula (6) takes the form:

$$t_0 = t_{os}\left(\frac{\sigma}{\sigma_s}\right)^{-\alpha} e^{-\beta\left(\frac{T}{T_s} - 1\right)}.$$

(8)

In the paper [9], formula (8) was subjected to experimental verification for some systems "metal-corrosive medium" using the experimental data introduced in [10]. For example, for α – brass in ammonia solution (density 0,94) for $T_s = 293\ K$ and $\sigma_s = 2$ МПа the following results were obtained: $t_{os} \approx 15{,}6$ hour, $\alpha \approx 0{,}7$, $\beta \approx 1$.

Now let $T = T(x,t)$. In further notations we'll omit the arguments x: $T = T(t)$. Under unknown law $T = T(t)$, for determination of the time to corrosive failure t_*, we use the method suggested in [8]. According to [8], we represent the function $\eta(t)$ in the form:

$$\eta(t) = 1 - \frac{T}{T_0} e^{1 - \frac{T}{T_0}},$$

where T_0 is the initial value of temperature T: $T_0 = T(0)$. It is easy to be convinced that the quantity

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$\frac{T}{T_0}\exp\left(1-\frac{T}{T_0}\right)$ for great values of T, i.e. as $t \to t_*$ is a small quantity compared with a unit.

Let $\psi(\eta)=1,$ that may hold in a first approximation. Therewith $A=1,\quad \phi=\varphi.$ With regard to what has been noted and using relations (4) and (9) in equation (2), we get:

$$\frac{1}{T_0}\left(\frac{T}{T_0}-1\right)\exp\left(1-\frac{T}{T_0}\right)\frac{dT}{dt}=\frac{1}{B(\sigma)}e^{\beta\left(\frac{T}{T_s}-1\right)}.$$

Integrate this relation:

$$\frac{t_*}{B(\sigma)}=\frac{\exp(1+\beta)}{T_0}\int_{T_0}^{T_b}\left(\frac{T}{T_0}-1\right)\exp\left[-\left(\frac{1}{T_0}+\frac{1}{T_s}\right)T\right]dT, \quad (10)$$

where T_b is the value of temperature at $t=t_*: T_b=T(t_*)$.

After calculating the integral, relation (10) is transformed into the form:

$$t_*=B(\sigma)\frac{\exp(1+\beta)}{(1+T_{os})^2}\left\{\exp\left[-(1+T_{os})\right]+\left[T_{os}-D\left(1+\frac{1}{T_{os}}\right)\right]\exp\left[-D\left(1+\frac{1}{T_{os}}\right)\right]\right\} \quad (11)$$

Here $T_{os}=T_{os}(x)=\frac{T_o(x)}{T_s}$ is the known function only of the coordinates of the body's point. Furthermore, $D=\frac{T_b}{T_s}$ is a new constant to be defined from experiments on corrosive failure, for example at constant velocity of temperature change? The obtained formula (11) is a formula that admits to define the time to corrosive failure of structural elements in the case when $\sigma=const,\ T=T(x,t)$.

III. CONCLUSION

We obtained a formula permitting to find the time to corrosive failure of materials at no stationary change of temperature field of the corroding body under the action of constant mechanical stress.

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