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CORROSION CRACKING OF RING SECTOR AT PURE CURVE

Abstract

Analytical formulae for time of precorrosive cracking of elastic isotropic ring sector which is subject to pure curve in corrosive medium are cited. Graphs of dependence of time of precorrosive crackings on a bending moment, in the case, when a material of ring sector is brass, and the medium is a corrosive-ammoniac medium.

Mechanical voltages and corrosive medium, acting interconnectively on metal structural elements, create in them corrosion damages. The accumulated corrosion damages at reaching of defined level, reduce metal elements to a cracking. Except for mechanical voltage, tempereture, concentration of active components of a corrosive medium and potential of corrosion have essential influences. On a process of accumulation of corrosion [12]. By solving a problem of a corrosion cracking of metals, one of the important moments is the establishment of the law, permitting to define time of precorrosive cracking from mechanical voltage, temperatures, concentration of the active components of a medium and a potential of corrosion. In [3] it has been theoretically derived and experimentally checked the formula which can be accepted as the mentioned above law of a corrosion cracking of metals.

The formula derived by L.H.Talybly in the work [3] has the form:

$$t_*(x) = Lt_0(\sigma_e,(x),T(x),C(x),U(x)) - Rt_0(k_1,k_2,k_3,k_4) \tag{1}$$

where L, R, k_1, k_2, k_3, k_4 are the constants. Besides, here $t_*(x)$, where $(x) = (x_1, x_2, x_3)$ are coordinates of points of a body is the time of precorrossive cracking of the given structural element, when during corrosion the equivalent voltage σ_e, defined through components of a tensor of mechanical voltage $\sigma_{ij}(i,j = 1.2.3)$ such, that it appears reduced to a unaxial voltage of a stretching, temperature T, concrentation of the active components of a medium C and a potential of corresion U or a part of these parameters vary in time on unknown laws peculiar to corrosive process, $t_0 = t_0(\sigma_e(x), T(x), C(x), U(x))$ is analogous time at stationary values of these parameters. Function t_0 is defined from experiments on the prolonged corrosive destruction at $\sigma_e = \sigma_{11}^{(k)} = const, T = T_k = const, U = U_k = const,\ (k = 1, 2, ...)$. In the case of a prime stretching $\sigma_e = \sigma_{11}$, where σ_{11} is a normal tensile stress. In the case of a common statement of the problem quantity σ_e is expressed by average voltage $\sigma = (\sigma_{11} + \sigma_{22} + \sigma_{33})/3$ and intensity of voltages

$$\sigma_+ = \frac{\sqrt{2}}{2}\left[(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2 + 6\left(\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{13}^2\right)\right]^{1/2} \ [4]:$$

$\sigma_e = \dfrac{1}{2}\left[(1-\lambda)\sigma + (1+\lambda)\sigma_+\right]$ where $\lambda = \sigma'_{\text{lim}}/\sigma''_{\text{lim}}$; σ'_{lim}, σ''_{lim} are limit stresses at a prime stretching and a prime compression, respectively, in the case of absence of action of the corrosive medium; $0 < \lambda \leq 1$.

For definition of quantities $\sigma_{ij}(x)$ $(i,j = 1,2,3)$, $T = T(x)$, $C = C(x)$, $U = U(x)$ it is necessary to take advantage of the corresponding statements of problems for definition of these quantities. The corrosion checking begins at the point x_α, in which quantity $t_*(x)$ takes a minimum value: $t_*(x_\alpha) = \min t_*(x)$.

The function t_0 is considered to be a universal function, quantities L, R, k_1, k_2, k_3, k_4 are universal constantans of a system of "metal-corrosive medium". The universal constants L, R, k_1, k_2, k_3, k_4 are defined from prime experiments on the prolonged corrosive destruction, in which in turn one of the parameters σ_e, T, C, U varies during corrosion in time, and others remain constant. Let's remark, that constants k_1, k_2, k_3, k_4 correspond to the limiting values of parameters σ_e, T, C, U at their modification in time during corrosion.

The function $t_0 = t_0(\sigma_e, T, C, U)$ is approximated as a concrete function depending on the form of the given experimental curves of the prolonged corrosive durability, obtained at parameters, which remain constant or approximately constant during the corrosion.

Some formulae for t_0 are cited in [3]. Here, by [3] we'll give one of the possible formulae for t_0:

$$t_0 = t_0(\sigma_e, T, C, U) = \left[\frac{1}{t_{os}} + B_1\left(\frac{\sigma_e}{\sigma_s} - 1\right)^{\beta_1} + \right.$$

$$\left. + B_2\left(\frac{T}{T_s} - 1\right)^{\beta_2} + \beta_3\left(\frac{C}{C_s} - 1\right)^{\beta_3} + B_4\left(\frac{U}{U_s} - 1\right)^{\beta_4}\right]^{-1}. \tag{2}$$

Here B_i, β_i $\left(i = \overline{1,4}\right)$ are material constants; $\sigma_s, T_s, C_s, U_s = const$ is a voltage, temperature, concentration and potential of reducing to the non-dimensional quantities. These quantities should correspond to the lower values of parameters σ_e, T, C, U in range of their changes, t_{os} is a time before cracking at $\sigma_e = \sigma_s, T = T_s, C = C_s, U = U_s$. Ordinary, $1/t_{os} \to 0$. If corrosion under the mechanical voltage σ_e at the fixed T, C, U, then taking $T = T_s, C = C_s, U = U_s$, form (2) we'll obtain

$$t_0 = t_0(\sigma_e, T_s, C_s, U_s) = B_1^{-1}\left(\frac{\sigma_e}{\sigma_s} - 1\right)^{-\beta_1} \equiv A\left(\frac{\sigma_e}{\sigma_s} - 1\right)^{-\beta_1}. \tag{3}$$

At $\beta_1 = 0,5$ and $\sigma_e = \sigma_1$, where σ_1 is a constant tensile stress, formula (3) coincides with the known formula of Rabotnov [5], which was checked by Zhucov [6] experiments on corrosive cracking of brass in an ammoniac medium at a constant deformation (with some approximation at a constant voltage).

At that: $\sigma_s = 46MPa, A = 3,67$.hrs.

As it is marked in [3], the concrete aspect of a function t_0 is not unique. The method of definition of constants contained in formula (1) is not unique also. Besides as we see from [3] formula (1) holds also in the case when corrosive process holds without participation of mechanical voltage. Now, using the above-stated formulae we'll define a time of precorrosive cracking of elastic isotropic ring sector which is subject to pure curve in a corrosive medium (fig.1)).

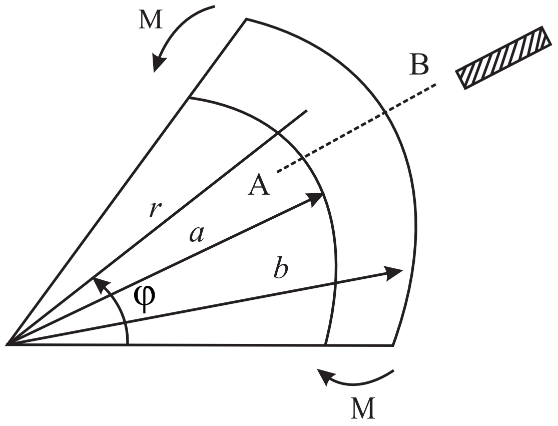

Fig. 1.
Pure curve of a ring sector.

Normal radial σ_r and tangential σ_φ voltages, at the absence of corrosive medium have the form [7]:

$$\sigma_r = \frac{4M}{N}\left(\frac{a^2b^2}{r^2}\ln\frac{b}{a} + b^2\ln\frac{r}{b} + a^2\ln\frac{a}{r}\right), \tag{4}$$

$$\sigma_\varphi = \frac{4M}{N}\left(-\frac{a^2b^2}{r^2}\ln\frac{b}{a} + b^2\ln\frac{r}{b} + a^2\ln\frac{a}{r} + b^2 - a^2\right), \tag{5}$$

where $N = \left(b^2 - a^2\right)^2 - 4a^2b^2\ln^2\frac{b}{a}$.

Now let's define the equivalent voltage. We'll assume, that $\lambda \approx 1$, that approximately holds for many alloys, including for brass. In this case

$$\sigma_e = \sigma_+ = \left(\sigma_r^2 - \sigma_r\sigma_\varphi + \sigma_\varphi^2\right)^{1/2} = \frac{4M}{N}\left(\frac{a^4b^4}{r^4}\ln^2\frac{b}{a} + 3b^4\ln\frac{r}{b} + 6a^2b^2\ln\frac{r}{b}\times\right.$$

$$\times \ln\frac{a}{r}+3a^4\ln^2\frac{a}{r}-3a^4\ln\frac{a}{r}-\frac{a^2b^4}{r^2}\ln\frac{b}{a}+\frac{a^4b^2}{r^2}\ln\frac{b}{a}-3a^2b^2\ln\frac{r}{b}+$$

$$\left.+3a^2b^2\ln\frac{a}{r}+b^4-2a^2b^2+a^4\right)^{1/2}. \tag{6}$$

We assume, that pure curve of the ring sector happens at $T=T_s, C=C_s, U=U_s$. Thus function $t_0=t_0(\sigma_e,T_s,C_s,U_s)$ can be selected as (3). According to the formula (1), the corrosion cracking will begin at a point, where $t_*(r)$ and from here, as a consequence, t_0 takes a minimum value.

The point, where quantity σ_e, defined by formula (6, takes a maximum value corresponds to this. It is clear, that these points $r=b$ (the equivalent voltage doesn't depend on the coordinate φ). At the points $r=b$ the quantity σ_e by (6) has the form:

$$\sigma_e\left|_{r=b}\right.=\frac{M}{a^2}\frac{N_2\left(\frac{b}{a}\right)}{N_1\left(\frac{b}{a}\right)} \tag{7}$$

where

$$N_2\left(\frac{b}{a}\right)=8\left[\ln^2\frac{b}{a}+\ln\frac{b}{a}-\left(\frac{b}{a}\right)^2\ln\frac{b}{a}+\frac{1}{4}\left(\frac{b}{a}\right)^4-\frac{1}{2}\left(\frac{b}{a}\right)^2+\frac{1}{4}\right]^{1/2} \tag{8}$$

$$N_1\left(\frac{b}{a}\right)=\left(\frac{b}{a}\right)^4-2\left(\frac{b}{a}\right)^2+1-4\left(\frac{b}{a}\right)^2\ln^2\frac{b}{a}. \tag{9}$$

The time of precorrosive cracking of the considered ring sector will begin at the points $r=b$ and (1), (3), (7) will be defined by the formula

$$\frac{t_*(b)}{A}=L\left[\frac{M}{a^2\sigma_s}\frac{N_2\left(\frac{b}{a}\right)}{N_1\left(\frac{b}{a}\right)}-1\right]^{\beta_1}-R\left(\frac{k_1}{\sigma_s}-1\right)^{-\beta_1} \tag{10}$$

where $N_2\left(\frac{b}{a}\right)$ and $N_1\left(\frac{b}{a}\right)$ will be defined by formulae (8) and (9).

For construction of the graph $\frac{M}{a^2\sigma_s}\sim\frac{t_*(b)}{A}$ we'll use numerical date, which are calculated in [3] on the base of experiments [6] on the prolonged corrosive destruction of samples of brass in an ammoniac medium at an action of the constant load: $A=3.67\ hrs;\ L=0.564,\ R=\left(\frac{k_1}{\sigma_s}-1\right)^{-\beta_1}=0.265,\ \ \beta_1=0,5;\ \ \sigma_e=46MPa$. The graphs of dependence $\frac{M}{a^2\sigma_s}\sim\frac{t_*(b)}{A}$ constructed on the base of equation (10), at the cited numerical date, and also at different ratios $b/a=2;3;4$ are presented in fig. 2. From these graphs it follows, that at fixed values of a bending moment

M with increasing of the ratio b/a the time t_* is increased. In all considered ratios b/a at increasing M the time t_* is decreased. Besides for each given ratio b/a there exists a quantity of the moment M, lower of which the phenomenon of a corrosion checking doesn't happen.

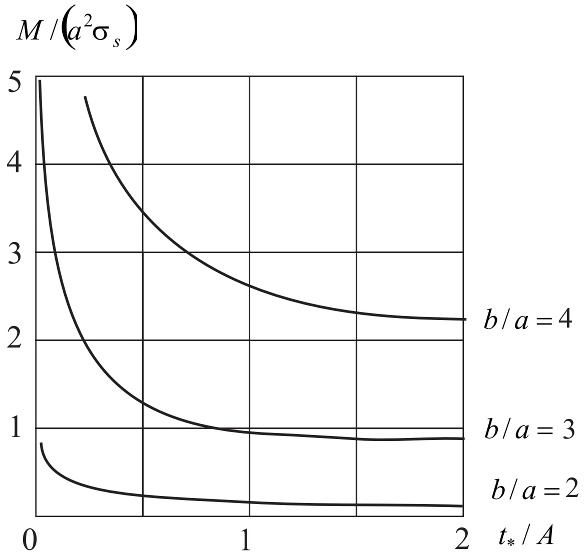

Fig. 2.

Dependence of time of precorrosive destruction of ring sector at pure curve in a corrosive medium.

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Received January 08, 2004; Revised May 25, 2004.
Translated by Mamedova Sh.N.