

## MECHANICS

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ON ONE FORMULA OF CORROSIVE STRENGTH  
OF METALS UNDER NON-STATIONARY CHANGE  
OF TEMPERATURE

## Abstract

*A formula is suggested for determining the time to corrosive failure of the body when in the corrosion process the temperature field changes in time.*

It is known that the corrosive medium temperature essentially influences on corrosive cracking velocity [1]. Temperature gain continuously and intensively increases the corrosive cracking velocity of metals. For example, at 20<sup>0</sup>C the time to cracking of the alloy *AL – ZN – MG* in 3% solution of *NaCl* on the average exceeds 100 hours, at 100<sup>0</sup>C it is about 1 hour [1]. Experimental investigation of corrosive cracking of the sheet aluminium alloys in 3% solution of *NaCl* showed that temperature gain reduces to sharp and continuous increase of corrosive cracking velocity [2]. The austenitic stainless steel of type 18-8 was subjected to corrosive cracking in 42% solution of *MgCl* [3]. Increase of solution's temperature from 120<sup>0</sup>C to 155<sup>0</sup>C continuously cancelled the time to cracking. Analysis of above mentioned experimental data shows that the time to cracking decreases due to temperature increase, and the process occurs continuously. Under experimental investigation of influence of corrosive medium temperature on corrosive cracking process, constant mechanical stresses were created in samples. Furthermore, the corrosive medium concentration and potential of the metallic sample were kept constant. The corrosive medium temperature essentially influences on the metallic sample temperature because of heat exchange between them. This says that the temperature of metallic structural element that function in aggressive media will depend not only on time but also on the body points coordinates. By [1], the problems on theory of temperature influence mechanism on metal's cracking velocity have not been studied. The existence of the formula allowing to determine the time to corrosion cracking under non-stationary change of temperature is not known to the author. In this connection, derive a formula that determines the time to corrosive cracking in the case when the mechanical stress under which the body is and also concentration of diffusing material and potential of the metal in the corrosion process don't change in time. Only temperature field of the body is subjected to time alternation.

We'll use damageability accumulation concept. By [4], we determine metals corrosive process as a process of accumulation of definite form of damages. We'll assume that the corrosive failure (fault of metal's continuity) happens when the accumulated corrosive damages achieve the definite level. Let the degree (depth) of corrosion in the metal be defined by a non-negative function  $\eta(t)$  that monotonically increases in time  $t$ . At initial moment  $t = 0$  we accept  $\eta(0) = 0$ . At corrosive failure moment  $t^*$  we assume  $gh(t^*) = 1$ . By [4], we'll suppose that accumulation velocity of corrosive damages  $\frac{d\eta(t)}{dt}$  depends on the achieved degree of corrodibility  $\eta(t)$ , mechanical

stress  $\sigma$ , absolute temperature of the body  $T$ , concentration of diffusing material  $C$ , potential of the metal  $U$ :

$$\frac{d\eta(t)}{dt} = \Omega[\eta(t), \sigma(t), T(t), C(t), U(t)]. \quad (1)$$

Notice that the quantities  $\sigma, T, C, U$  and also the function  $\eta$ , generally speaking, depend not only on time but also on the coordinate  $(x) = (x_1, x_2, x_3)$  of metallic body points that were omitted while writing formula (1). Here we'll consider a corrosive process that occurs under time independent stresses and concentration constants  $C = C_s = const$ , the potential  $U = U_s = const$ . Assume that the function is represented in the form

$$\Omega = \Psi(\eta) \varphi_1(\sigma, T(t), C_s, U_s) = \Psi(\eta) \varphi(\sigma, T(t)).$$

Take into account the represented relation in (1):

$$\frac{d\eta(t)}{dt} = \Psi(\eta) \varphi(\sigma, T(t)). \quad (2)$$

Integrate equation (2) under condition  $\eta(0) = 0$ :

$$\int_0^\eta \frac{d\eta}{\Psi(\eta)} = \int_0^t \varphi(\sigma, T(t)) d\tau.$$

Allowing for the condition  $\eta(t^*) = 1$ , we get

$$\int_0^{t^*} \Phi(\sigma, T(t)) d\tau = 1. \quad (3)$$

Here  $\Phi = \frac{\varphi}{A}$ ;  $A = \int_0^\eta \frac{d\eta}{\Psi(\eta)}$ .

Represent the function  $\phi(\sigma, T)$  in the form

$$\phi(\sigma, T) = \frac{1}{B(\sigma)} e^{\beta\left(\frac{T}{T_s} - 1\right)}, \quad (4)$$

where  $\beta = const$ ,  $B = B(\sigma)$ ,  $T_s$  is threshold temperature. Allowing for (4) we rewrite relation (3) in the form:

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

The quantities  $B(\sigma)$  and  $\beta$  may be determined from the corrosive failure experiments under different constant of temperature and stress:  $T = T_k = const$ ,  $\sigma = \sigma_m = const$  ( $k, m = 1, 2, \dots$ ) In the case  $T = T_k = const$ ,  $\sigma = \sigma_m = const$  we denote the time to corrosive failure by  $t_0$  i.e. we assume that in the considered case the time  $t^*$  passes to  $t_0$ . And from (5) we get:

$$t_0 = B(\sigma) e^{-\beta\left(\frac{T}{T_s} - 1\right)}. \quad (6)$$

Using the results of experiments represented in the form  $t_0 = t_0(\sigma, T)$ , from (6) by means of one of the mathematical approximation methods we find the function  $B(\sigma)$  and constant  $\beta$ . By [1], experimental dependences of time to corrosive failure on temperature in semi-logarithmic coordinates ( $\text{Im } t_0 \sim T$ ) are of linear character and this affirms validity of formula (6).

At the known law of change of temperature  $T$  on time  $t$  and under the known quantities  $B(\sigma)$  and  $\beta$ , the time to corrosive failure  $t^*$  may be determined from relation (5). However, determination of this law, especially for countinuum geometry bodies, represents some difficulties because of specific corrosive process. In the case when the temperature  $T$  changes in time  $t$  in the corrosion process, and the law  $T = T(t)$  is unknown, for determining the time to corrosive failure we use the method similar of [4].

We accept the function  $\eta(t)$  in the form

$$\eta(t) = 1 - e^{\alpha\left(1 - \frac{T(t)}{T_0}\right)}, \quad (7)$$

where  $T_0 = T(t)|_{t=0}$  is the initial temperature of the system "metal-corrosive medium". We assume that the quantity  $\exp\left[\alpha\left(1 - \frac{T(t)}{T_0}\right)\right]$  for  $t = t$  is a small quantity in comparison with a unit.

In a first approximation we accept  $\Psi(\eta) = 1$ . In this case we have:  $A = 1, \phi = \varphi$ . Now, consider (4) and (7) in (2). We get:

$$\frac{\alpha}{T_0} e^{\alpha\left(1 - \frac{T(t)}{T_0}\right)} \frac{dT(t)}{dt} = \frac{1}{B} e^{\beta\left(\frac{T}{T_S} - 1\right)}.$$

Integrate this relation:

$$\frac{t^*}{B(\sigma)} = \frac{\alpha}{T_0} e^{\alpha + \beta} \int_{T_0}^{T_b} e^{-\alpha \frac{T}{T_0} - \beta \frac{T}{T_S}} d\sigma. \quad (8)$$

Here  $T_b$  is temperature under which metal fails under mechanical stress.

Having calculated (8) and making some transformations, we get:

$$\frac{t^*}{B(\sigma)} = \frac{e^{\alpha\left(1 + \frac{\beta}{\alpha}\right)}}{1 + \frac{\beta T_0}{\alpha T_S}} e^{-\alpha\left(1 + \frac{\beta T_0}{\alpha T_S}\right)} \left[1 - e^{\alpha\left(1 + \frac{\beta T_0}{\alpha T_S} - \frac{T_b}{T_0} - \frac{\beta T_b}{\alpha T_S}\right)}\right]. \quad (9)$$

Accept the denotation:

$$e^{\beta} = D_1; \quad \frac{\beta}{\alpha} = d_1; \quad e^{\alpha - \beta \frac{T_b}{T_S}} = D_2; \quad \alpha \frac{T_b}{T_S} = d_2.$$

And from formula (9) we have:

$$t^* = \frac{D_1 B(\sigma)}{1 + d_1 \frac{T_0}{T_S}} = \left[ e^{-\beta \frac{T_0}{T_S}} - D_2 e^{-d_2 / (T_0 / T_S)} \right]. \quad (10)$$

Relation (10) is a formula for determining the time to corrosive failure under time independent stress and unstationary change of temperature field of the system "metal-corrosive medium". The constants contained in (10) may be determined from the experiment on corrosive strength under different constant temperatures.

### References

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