LITERATURE CITED


CORROSION DAMAGE IN THE MATERIAL AND THE VARIATION
OF THE CRITICAL BRITTLENESS TEMPERATURE

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Corrosion-mechanical failure is one of the most frequent and dangerous types of failure of machine components and structural members. Corrosion cracking and corrosion fatigue are the main problems in examining the relationships governing the failure of materials and components in the conditions of combined loading (static or cyclic) and the effect of the corrosive medium [1, 2]. At present, there is no united theory of the corrosion-mechanical strength of the materials, and the reduction of strength in the corrosive media is explained in most cases by the following mechanisms: by the adsorption reduction on the surface energy, by hydrogen embrittlement of the material as a result of the penetration of hydrogen from the corrosive media, and by the electrochemical dissolution of the material. It is assumed that the metal in corrosion-mechanical failure is in the embrittled state.

The critical brittleness temperature (CBT) $T_{br}$ is one of the main complex mechanical characteristics reflecting the susceptibility of the metal to transfer to the brittle state. This characteristic depends strongly on the processing and design features of the components and also on the service conditions. The corrosive medium must also be considered in this concept. For example [3], atmospheric corrosion of low-carbon steels over a period of one month increases CBT by 1-2°C; under the effect of tensile stresses, the build-up of corrosion damage doubles this increase. The corrosion damage is represented by the results of the effect of one (or several) mechanism of the reduction of the strength of the materials in the corrosive media, such as hydrogen-charging of the local volumes of the metal, formation of the corrosion products leading to the formation of micro- and macroheterogenieties on the surface of metallic components, and crack formation in local electrochemical dissolution of the metal. The following data can be used as an indirect confirmation of the effect of the corrosion damage on CBT: electrolytic hydrogen charging of the steel [2], macro- and microheterogenieties on the surface [4], crack propagation [3] shifting CBT to positive values. Thus, the brittle premature failure of machine components and structural members in the conditions with corrosion damage can be determined to a large extent by the shift of CBT.
We shall examine the kinetics of corrosion damage on the basis of the theory of damage cumulation [5, 6]. Corrosion damage is described by the scalar 1 ≥ ψ ≥ 0 which can be interpreted as integrity. In the absence of damage ψ = 1; during corrosion, the degree of damage in the material increases with increasing duration of the effect of the corrosive medium. Therefore, the variation of integrity ψ can be described by the kinetic equation

\[ \frac{d\psi}{dt} = -F(\psi, \ldots). \]  

(1)

Function F depends on ψ and other variables important for the process of corrosion and damage cumulation. These variables include \( T_{br} \), the extent of micro- and macroheterogeneities, the stress tensor, time, composition of the medium, concentration of active components of the medium, temperature, etc. It is very difficult to take all these variables into account and a detailed analysis of experimental data must be carried out for this purpose. Therefore, we shall examine a simple variant of the kinetic equation (1) assuming that the parameters of loading and the corrosive medium are constant. We also assume that the material does not age with time (and there are no other similar processes). Consequently, the time is not included in the explicit form in the right-hand part of Eq. (1). The main parameters determining the extent of corrosion damage are assumed to be the shift of CBT of the material (component) \( \Delta T_{br} \) per sum unit time, and also the service time of the structure \( \tau \). Consequently, the rate of reduction of integrity ψ which characterizes the variation of the surface and volume properties of the metal as a result of corrosion damage cumulation can be approximately written in the form of, for example, an exponential dependence

\[ \frac{d\psi}{dt} = -A (\Delta T_{br}/\psi)^n, \]  

(2)

where A > 0 is a coefficient, n ≥ 0 is an exponent. The dependence (2) should be regarded as some suitable approximation and not a physical relation. In clarifying the physical nature of the phenomenon associated with the variation of \( T_{br} \) under the effect of corrosion damage, the type of dependence (2) can be determined more accurately.

In the initial state in the absence of corrosion damage in the metal \( \Delta T_{br} = 0 \) and \( \psi = 1 \); when the critical level of damage is reached, the integrity also reaches the critical value \( \psi_c \)

\[ \psi_c^{1+n} = 1 - (1 + n) A \int_0^{\tau_c} (\Delta T_{br})^n d\tau. \]  

(3)

The critical level of corrosion damage corresponds to the limiting shift of CBT, i.e., the transition of the material to the brittle state

\[ \Delta T_c = T_s - T_{br}, \]  

(4)

where \( T_s \) is the service temperature of the structure. On the other hand, we assume that the critical damage level can be reached within the time \( \tau^* \ll \tau_c \). Quantity \( \tau^* \) refers in this case to some normalized time (or unit time) during which the critical level of corrosion damage is reached in, for example, more severe corrosion conditions. Thus, we can write the following relation

\[ \psi_c^{1+n} = 1 - (1 + n) A (\Delta T_c^n)^n \tau^*. \]  

(5)

Equating the right-hand part of (3) and (5), we obtain an equation describing the shift of the CBT as a result of corrosion damage

\[ \int_0^{\tau_c} (\Delta T_{br})^n d\tau = \Delta T_c^* \tau^*. \]  

(6)

Assuming that the shift of CBT during the normalized time \( \tau^* \) is independent of the service time of the structure \( \tau \), we obtain the equation

\[ \Delta T_{br} (\tau_c/\tau)^{1/n} = \Delta T_c. \]  

(7)

Equation (7) should be regarded as a criterion of the transition of the metal of the structure to the brittle state as a result of the corrosion damage. When the shift of CBT reaches its limiting value \( \Delta T_c \), premature brittle failure of the structural member can take place. According to Eq. (7), in the intermediate moments of service of the structure the shift of \( T_{br} \) is