QUANTITATIVE REPRESENTATION OF STRESS-CORROSION CRACKING
OF METALS

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A method is presented of quantitatively estimating the resistance of metals to stress corrosion on the basis of the reduction in the long-time strength \( \Delta \sigma_{sc} \) in a given medium. The calculation of \( \Delta \sigma_{sc} \) when the reduction in the long-time strength is associated not only with stress corrosion but also with general corrosion and hydrogen embrittlement is discussed.

Some of the problems associated with the quantitative estimation of the resistance of metals to stress corrosion on the basis of experimental determination of time-to-rupture were discussed previously [1]. Later we proposed a new method of quantizing corrosion fatigue [2], which is extended in this article to stress corrosion.

In choosing a quantitative criterion of stress corrosion of metals we start from the obvious fact that this process essentially consists in the destruction of the material and that the main manifestation of the latter phenomena is a loss of strength. When a metal loses its capacity to carry cyclic loads, one talks about corrosion fatigue; when there is a loss of static (long-time) strength, we are dealing with stress corrosion. Consequently, the reduction in strength is a direct and unequivocal measure of stress corrosion of metals.

Before considering methods of calculating the loss of metal strength which is a measure of stress corrosion, let us point out one of the typical characteristics of this process: the loss of strength due to a simultaneous action of stress and corrosive media is much larger than the sum of losses due to each of these factors acting separately.

It is shown below that this characteristic makes it possible to compute the specific contribution of each of the factors that, side by side with stress corrosion, may take part in reducing the strength of metals. These factors include ordinary corrosion* [3], hydrogen embrittlement [4], and, relatively less often, a specific form of pitting stress corrosion [5].

In other words, depending on the properties of the metal and the medium in question, the loss of strength of a metal under a static stress in a corrosive medium can be represented as

\[
\Delta \sigma = \Delta \sigma_{sc} + \Delta \sigma_{c} + \Delta \sigma_{e} + \Delta \sigma_{p}
\]

where \( \Delta \sigma_{sc} \) is the loss of strength due to stress corrosion, \( \Delta \sigma_{c} \) the loss of strength due to ordinary corrosion, \( \Delta \sigma_{e} \) the loss of strength due to hydrogen embrittlement, and \( \Delta \sigma_{p} \) the loss of strength due to pitting stress corrosion. Cases in which the loss of metal strength is due to the simultaneous action of all the factors taken into account in (1) are relatively rare. Cases in which the loss of strength is due only to stress corrosion, i.e., when \( \Delta \sigma = \Delta \sigma_{sc} \), are quite common; in these cases the stress corrosion takes place in media in which ordinary corrosion is insignificant and no hydrogen charging takes place. Media of this kind include atmospheric air, dilute solutions of neutral electrolytes, and, in the case of metals that are not susceptible to hydrogen embrittlement, dilute solutions of weakly acid electrolytes.

The quantity \( \Delta \sigma_{sc} \) is determined from long-time strength curves obtained by tests in corrosive media. A curve of this kind is shown schematically in the figure (curve I). It is easy to see that the loss of strength \( \Delta \sigma \) (related to the breaking stress \( \sigma_0 \) of the metal in the initial condition) increases with increasing rate of stress corrosion (i.e., the slope of the curve) and increasing test duration.

For any test duration \( \tau \), the loss of strength \( \Delta \sigma_{sc} \) due to stress corrosion is given by

\[
\Delta \sigma_{sc} = \sigma_0 - \sigma_{\tau}
\]
where \( \sigma_b \) is the breaking stress of the metal in the initial condition and \( \sigma_r \) is the stress at which the time-to-rupture of the metal is \( \tau \). Graphically \( \Delta \sigma_{\tau}^{sc} \) corresponding to \( \tau_1 \) is represented by the segment a-b. The segment b-r represents the remaining reserves of metal strength.

When the long-time strength is determined by tests whose duration is dictated by practical considerations, it constitutes an important structural characteristic, making it possible to select a material possessing the necessary reserve of long-time strength. For an equal test time base, the higher the initial strength of a metal and the lower the loss of strength due to stress corrosion, the higher the reserve of the long-time strength.

It is evident that the larger the magnitude of \( \Delta \sigma_{\tau}^{sc} \), the lower the stress-corrosion resistance of a metal. If the latter characteristic is denoted by SCR we obtain

\[
SCR = \frac{1}{\Delta \sigma_{\tau}^{sc}}.
\]

As a minimum, \( \Delta \sigma_{\tau} \) should be determined for the test time base used. To obtain a more complete picture, it is advisable to plot the relation \( \Delta \sigma(\tau) \) or SCR(\( \tau \)); these relations directly reflect the kinetics of stress corrosion of metals.

When a metal is stressed in a corrosive medium in which no hydrogen embrittlement takes place, the loss of strength due to stress corrosion may be accompanied by a loss due to a reduction in the specimen cross-sectional area resulting from the dissolution of the metal. In such media

\[
\Delta \sigma_{\tau}^{sc} = \Delta \sigma_{\tau} - \Delta \sigma_{\tau}^{l}.
\]

One of the methods of experimentally determining \( \Delta \sigma_{\tau}^{l} \), which are often used in studies of stress corrosion of metals [3], is to use short-time tensile tests to determine the breaking stress \( \sigma_{\tau}^{l} \) of specimens which were previously corroded under stress for a time \( \tau \) in a given medium.

It is evident that the change in \( \sigma_{\tau}^{l} \) in relation to \( \sigma_b \) is proportional to the corrosion-induced reduction in the specimen cross-section area. Having determined \( \sigma_{\tau}^{l} \), it is easy to calculate \( \Delta \sigma_{\tau}^{sc} \):

\[
\Delta \sigma_{\tau}^{sc} = (\sigma_b - \sigma_{\tau}) - (\sigma_b - \sigma_{\tau}^{l}) = \sigma_{\tau}^{l} - \sigma_{\tau}.
\]

If \( \sigma_{\tau}^{l} \) is marked on the ordinate axis (\( \sigma_{\tau}^{l} \) in the figure), \( \Delta \sigma_{\tau}^{sc} \) is graphically represented by the segment a-c. It is evident that the closer \( \sigma_b \) and \( \sigma_{\tau}^{l} \) are to each other, the smaller the reduction in the specimen cross-section area due to the dissolution of the metal.

It is advisable to determine \( \sigma_{\tau}^{l} \) for various \( \tau \) and to reproduce the results graphically (curve II). The difference \( \Delta \sigma_{\tau}^{l} \) (or curve II) makes it possible to determine the relative contribution of ordinary corrosion and stress corrosion to the overall loss of strength of metals under the influence of corrosive media.

The magnitude of \( \Delta \sigma_{\tau}^{sc} \) in atmospheric air or in neutral electrolyte solutions can be determined quite accurately. The determination of \( \Delta \sigma_{\tau}^{sc} \) in acid media will be less accurate, especially at high stress levels; this is because the rate of corrosion in such media increases nonlinearly with increasing stress [6].

The influence of stress on the corrosion rate in the latter case can be accounted for by calculating \( \Delta \sigma_{\tau}^{sc} \) from data on the maximum reduction in the cross-section area of specimens ruptured due to stress corrosion in a time \( \tau \).

Even more difficult is the accurate representation of the stress corrosion in acid media in which both ordinary corrosion and hydrogen embrittlement take place, i.e., when

\[
\Delta \sigma_{\tau} = \Delta \sigma_{\tau}^{sc} + \Delta \sigma_{\tau}^{l} + \Delta \sigma_{\tau}^{2}.
\]

Hydrogen embrittlement necessitates a different approach to the problem of selecting a quantitative criterion of stress corrosion. The point is that in this case the process of fracture is manifested also in a loss of ductility. This factor may be decisive when a metal has a sufficient reserve of strength after a period \( \tau \) but its ductility falls below a critical level.

It is therefore necessary before all to determine the relation \( \sigma_{\tau}^{l} = f(\tau) \) for specimens subjected to stress corrosion in media of this kind and to draw appropriate conclusions about factors governing the process of fracture. However, even if the fracture is due to a loss of the long-time strength (with the ductility remaining at an acceptable level), it is difficult to suggest a method of quantitatively estimating the contribution of stress corrosion in the process of fracture.

The contribution of the factor associated with pitting stress corrosion can be determined only under conditions of stepwise reduction in the specimen cross section area which is characteristic of fracture of this kind [5]. Failures of this kind are observed [3] in the absence of hydrogen embrittlement and stress-corrosion cracking, i.e., when

\[
\Delta \sigma_{\tau} = \Delta \sigma_{\tau}^{l} + \Delta \sigma_{\tau}^{3}.
\]