CORROSION-FATIGUE CRACK GROWTH RESISTANCE TESTING

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ABSTRACT

A new methodology of static and cyclic corrosion crack growth resistance testing of material under constant electrochemical conditions at the crack tip and under variation of these conditions are given. The methods of the investigation results presentation are considered. A new methodology of plotting the basic cyclic corrosion crack growth resistance diagrams of materials for calculation of lifetime of construction are proposed.

KEYWORDS

Fatigue, aqueous environment, crack tip, materials testing, crack propagation, corrosion crack growth resistance, electrochemical conditions, stress intensity factors, hydrogen index of environment, electrode potential of metal, basic diagram.

INTRODUCTION

In corrosion fracture mechanics (Romaniv O.M., 1981), which deals with fracture of materials under corrosion environment effect, the concepts and approaches of fracture mechanics are used. The corrosive environments are considered by it as one of the factors which considerably influences the crack growth resistance of material. It is supposed that a sufficient condition for such testing is provision of stability of electrochemical parameters of environment in a chamber. The methodology of crack growth resistance of material determination in inert and corrosive environments at present time is essentially similar. The results of specimens testing under static and cyclic loandings in corrosive environment as in inert one are represented by respective static and cyclic corrosion crack growth resistance (SCCGR and CCCGR) diagrams of material.

Due to this approach for estimation of crack growth resistance of material in corrosive environment without taking into account the peculiarities of its interacts with metal in the vicinity of the crack tip, the SCCGR and CCCGR diagrams of material were noninvariant. For one and the same material-environment system under initial testing conditions variation we can obtain quite different SCCGR or CCCGR values of material that exceed a permissible scatter band, and also other variations of diagrams of the material (Ratych, 1984).

It was established (Ratych,1984), that the noninvariant SCCGR and CCCGR diagrams of material were caused by nonidentical electrochemical conditions at the corrosion-fatigue crack (CFC) tip during growth. Taking this circumstance into account a new approach to estimation of the crack growth resistance of materials in corrosive environment (Panasyuk et al, 1984; Ratych, 1984) was proposed. According to this approach the CFC growth rate is determined by the parameters, which characterize not only the stress-strained state at the crack tip, but also the physico-chemical processes in time and the state of the fracture surface at the crack tip. For the widespread aqueous environments within the scope of the developed model the parameters were accepted: (i) the stress intensity factor (K) to characterize the stress-strained state;(ii) the hydrogen index of the environment (pH) and the electrode potential of the metal (E) at the CFC tip (pH_t and E_t) to characterize the electrochemical conditions. The invariant SCCGR and CCCGR diagrams of material are obtained due to stabilization of the electrochemical parameters at the crack tip in corrosion crack growth resistance testing.

Subsequent testing shows that the CFC growth rate depends not on the absolute pH_t and E_t values but on the electrochemical criteria ΔE_A and ΔE_H which chracterize the intensity of mechanisms of local anodic dissolution and hydrogen embrittlement of metals in the vicinity of the crack tip. Those criteria are determined by pH_t and E_t parameters.

Thus, SCCGR and CCCGR of material should be evaluated taking into account electrochemical conditions at the crack tip. Therefore a new methodology of corrosion crack growth resistance testing both under constant electrochemical conditions at the crack tip and taking into account their change was worked out.

NEW METHODOLOGY OF CORROSION CRACK GROWTH RESISTANCE TESTING

A new methodology of corrosion crack growth resistance testing accounting for the electrochemical conditions at the CFC tip is based on testing of the specimens with a hole (Panasyuk et al, 1982) in plane of the given crack growth direction to locate circulating or measuring capillaries (Dmytrakh et al, 1982) for estimation of the electrochemical parameters immediately at the crack tip.

Some methods of corrosion crack growth resistance testing which differ by the specimen geometry and loading mode were worked out.

The equipment for corrosion crack growth resistance testing taking into account electrochemical conditions at the CFC tip according to different methods are similar (Fig. 1). A specimen (1) with chamber (2) were mounted in grips (3) of testing machine and loaded by moment M or force P. The load was measured by a resistance strain gauges (4) fixed to the machine grips and recorded by a KSP4 automatic potentiometer (5). In the chamber on both sides of the specimen in the plane of crack propagation the auxiliary platinum electrodes (6) and control capillaries (7) and (8) to measure pH and E respectively on the surface of the specimen were located. In one hole the circulating or measuring capillary (9) for estimation of pH_t was installed and in the other hole a measuring capillary (10) for estimation of E_t was inserted. Capillaries (8) and (10) were connected electrolytically [by a saturated solution of KCl in vessel (11)] with standard reference chlor-silver electrode (12). Depending on future tests, specimen (1),reference electrode (12), platinum electrode (6) as well as control (7), (8) and measuring (9), (10) capillaries were connected according to the known schemes to a P-5827M potentiostat (13) and high-resistance voltmeter (14). Measured parameters are recorded continuously by a KSP4 automatic potentiometr (15). As the crack grows the capillaries (9) and (10) are moved by mechanism (16).

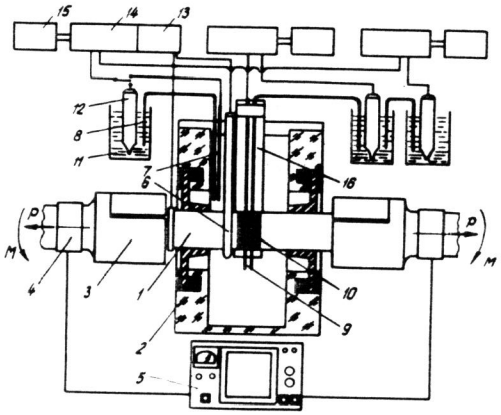

Fig.1.Scheme of equipment for corrosion crack growth resistance testing of rectangular section with edge crack specimens by axial tension or plane bending taking into account the electrochemical conditions at the crack tip.

The static and cyclic corrosion crack growth resistance tes-

ting can be performed on the presented equipment: (i) under constant electrochemical conditions at the tip of stationary and propagating crack; (ii) under variable electrochemical conditions at the tip of stationary and propagating crack with synchronous measurement of electrochemical parameters on the surface of the specimen and the crack tip; (iii) under external polarization of specimen with synchronous measurement of electrochemical parameters at the crack tip. Besides, similar tests can be carried out under stress-strained state at the crack tip on the specimen, which sizes were chosen taking into account the "testing machine-specimen" system compliance, by the method proposed by Panasyuk et al (1978).

The constant electrochemical conditions at the CFC tip were provided by stabilization of the values of electrochemical parameters in it. This is obtained: (i) for E_t by means of change of the current in a circuit "platinum electrodes (6) - specimen (1)" and control of its value by reference electrode (12) which is connected electrolytically with the crack tip by a measuring capillary; (ii) for pH_t by forced continuous drawoff of corrosion environment from the crack tip into the discharge capacity by circulating capillary. Such drawoff provides equality of pH values at the crack tip and its values in the chamber.

The values of pH_t were determined according to the registered by voltmeter (14) potential value between the antimonyoxide indicator [which was located in a measuring capillary (9) and contacted with corrosion environment only at the crack tip] and reference electrode (12) [which was connected electrolytically by measuring capillary (10) with the crack tip]. For this purpose at first pH-calibration of capillaries (9) by buffer solution was made.

A main feature of the used specimens for this test is presence of the holes for measuring capillaries in the crack plane. In this case, the specimens for static and cyclic crack growth resistance testing can be used, but it is necessary to drill two through holes in the plane of crack propagation. Diameter of holes should not influence the K values. Usually this is achieved if the netto section of a specimen with holes is not more than by 10% lower than the initial values. In other cases it is necessary to carry out K-calibration of these specimens.

The most suitable for SCCGR and CCCGR testing of material taking into account electrochemical conditions at the crack tip are two geometries of specimens: (i) prism with an edge crack for plane bending testing; (ii) rectangular or round compact with edge crack for testing on accentric tension. The first specimen has a considerable advantage: on its work part the chamber can be installed thus removing contact between environment and machine grips. That is very important when electrochemical parameters at the crack tip are measured.

To carry out a test on a thin material sheet a specimen with cover plates was proposed (Ratych and Dmytrakh, 1986). It consists of a prism specimen with an edge crack for plane bend testing and two cover plates of a corrosion resistant elastic material made fast to its sides. In these covers the holes for measuring capillaries, connected with a crack were made. In this case, cover plates material strength is substantially lower than the strength of the specimen, while the cover plates do not greatly influence the crack kinetics.

The three main constructions of capillaries were worked out by Dmytrakh et al (1982): (i) for estimation of pH_t; (ii) for estimation of E_t; (iii) for drawoff of environment from the crack tip. The capillaries represent the thinwalled elastic tube from chemically resistant dielectric material. Two holes were drilled in the tube wall: (i) for contact of environment at the CFC tip with indicator in it (in case of estimation of pH_t) or with filled electroconductive solution (in case of estimation of E_t); (iii) for drawoff of environment from the CFC tip into a sink vessel.

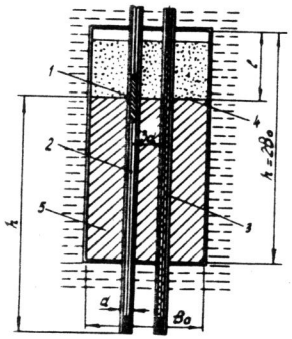

Fig.2. Graphical presentation of the measuring capillaries at the CFC tip.

The capillaries are inserted into the hole of a specimen and moved as CFC grows in such a way (Fig. 2), that the axes of holes (1) in the capillaries walls (2) and (3) coincide with a crack front (4) of the specimen (5). Special marked dashes are made on the capillary tube surface.

METHODS OF PRESENTATION OF TESTING RESULTS

In SCCGR and CCCGR testing of material taking into account electrochemical conditions at the CFC tip electrochemical parameters (pH_t and E_t at the CFC tip; pH_s and E_s on the specimen surface) synchronously with parameters of crack growth (crack length a and corresponding time τ under static loading or number of cycles N under cyclic loading) are recorded.

There are two methods of the testing result presentation depending on the SCCGR and CCCGR testing methods: (i) under constant or (ii) under variable electrochemical conditions at the CFC tip.

In the first case the testing results are presented as the invariant SCCGR or CCCGR diagrams of material (Fig. 3) with obligatory indication of the constant electrochemical parameters values at which the data for their plotting were recived. As far as for each material-environment system the electrochemical parameters change in a rather wide range (Ratych, 1984) than many such invariant diagrams can be plotted. Therefore, to limit their necessary number for complete characteristics of the system, SCCGR and CCCGR should be performed under certain boundary states. Such boundary states can be electrochemical conditions at the CFC tip under which pH_t is equal: (i) the pH value in a chamber pH_s; (ii) the minimum pH value for a stationary statically loaded crack tip $pH_{ts\ min}$; (iii) the minimum pH value for a propagating cyclically loaded crack tip $pH_{tc\ min}$. Definite invariant SCCGR and CCCGR diagrams of material correspond to each boundary state (Fig. 3). They are shifted to the left the more the lower is pH_t values at which the investigations were performed. In this case region A presents the influence of environment on crack growth resistance in comparison with air; region B shows the influence of the initial electrochemical conditions variation at the starting crack tip; region C presents the influence electrochemical conditions variation at the CFC tip. Sine the dependence occurs:

$$pH_{tc\ min} < pH_{ts\ min} < pH_s \qquad (1)$$

the most "extreme" (which corresponds to the maximum possible CFC growth rate) is the diagram plotted according to the testing results under electrochemical conditions at the CFC tip

$$pH_t = pH_{tc\ min} = constant \qquad (2)$$

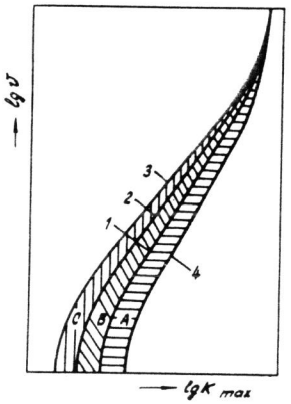

Fig.3. Invariant CCCGR diagrams of material under different boundary state at the CFC tip: (1) - pH_s; (2) - $pH_{ts\ min}$; (3) - $pH_{tc\ min}$; (4) - in air.

Invariant diagrams unambiquously characterize SCCGR and CCCGR of material at the given electrochemical conditions at the CFC tip. They can be used in lifetime calculation when estimating workability of structural elements in environment.

In the second case the testing result presented as the noninvariant SCCGR or CCCGR diagrams of material with obligatory indication of values of the electrochemical parameters at which the corresponding values of the CFC growth rate were

received. Such diagrams characterize rather SCCGR or CCCGR of the tested specimen than the material. Therefore they can not be used for evaluation of structural elements workability in corrosive environments. However, such tests are necessary and the method they use for results presentation is handy in study of the influence of electrochemical conditions at the CFC tip on a process of materials fracture, in investigation of the accelerated crack growth mechanism in corrosive environment, in developing the mathematical model of corrosion-mechanical fracture of a "material-environment" system etc.

A NEW METHODOLOGY OF PLOTTING BASIC DIAGRAMS

At present, lifetime of the construction elements taking into account the crack growth resistance of material is estimated using the basic curve (Bamford, 1979), which presents the "worst case" of a given metal-environment system. For a concrete material it is its boundary noninvariant CCCGR diagram, plotted according to the maximum values of CFC growth rate taking into account the effect of different structural, mechanical and physico-chemical factors. For this the presence of a large mass of experimental data is necessary, but as the new data are obtained, it should be replotted again. Therefore, it is impossible to build the basic CCCGR diagram of material during limited time and especially of a new material.

For solution of this problem we proposed a new more physically grounded methodology of basic CCCGR diagram plotting which uses the material invariant diagrams, received taking into consideration the influence of the extremal operation factors and extremal elecrtochemical conditions at the CFC tip. According to this methodology:

$$(da/dN)_{ec} = (da/dN)_{es} \times a_t \times a_e \qquad (3)$$

where $(da/dN)_{ec}$ is growth rate of CFC on the basic CCCGR diagram of material; $(da/dN)_{es}$ is growth rate of CFC for a basic specimen under action of extremal operation factors (frequency, stress ratio and cycle shape, temperature) and constant electrochemical conditions at the CFC tip, which correspond to the conditions in the chamber ($pH_t = pH_s = constant$); a_t and a_e are coefficients which take into account possible influence of stress-strained state and electrochemical conditions variation at the crack tip of the structure as compared with their values in a specimen.

The methodology is based on an assumption, that change of the stress-strained state, caused by transition from a specimen thickness to a structure thickness, does not essencially influence the electrochemical conditions at the CFC tip for equal K values. This allows to determine the a_t coefficient

on the basis of cyclic crack growth resistance diagrams of material in air, plotted according to the test results of basic B_o and the maximum B_{max} specimen thickness that corresponds to plane strain conditions, and it is assumed that this value will be the same as in case of corrosive environment effect. Thanks to this fact it is not necessary to carry out testing in corrosive environment on very thick specimens. The a_e coefficient is determined on the basis of invariant CCCGR diagrams of material, plotted according to the results of basic B_o thick specimens testing under effect of the extremal operation factors (frequency, stress ratio and cycle shape, temperature) in the given environment with $pH_t = pH_s = constant$ and in the environment with $pH_t = pH_{tc\ min} = constant$, that simulates the extreme electrochemical conditions at the CFC tip. Values of the a_t and a_e coefficients are determined for each region of the inital CCCGR diagram of material in the given environment.

The methodology has been used by us for plotting of basic CCCGR diagrams of vessel steels and their velds in reactor water of boron regulation, disk steel 34KhN1M in conditions of phase transaction of water, etc.

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