CORROSION CRACKING IN SHEET WELDED STRUCTURES

S.K. FOMICHOV, V.M. PROKHORENKO, O.I. STEKLOV and V.A. VELIGIN

Kiev Politechnic Institute, 37, Prospect Pobedy, Kiev, 252056, Ukraine

ABSTRACT

This paper presents an algorithm of calculation - based prediction of stages of corrosion cracking in sheet welded structures. The conditions of initiation and propagation of tiny surface cracks have been established. The calculation of initial and final lengths of a crack which propagated across the field of residual stresses is given. The conditions of propagation of the main crack in a welded structure have been also covered.

KEYWORDS

Corrosion cracking, welded structures, calculation - based prediction, stress' intensity coefficient.

The experience of more than twenty years of operation of aluminium plants in the Urals and Southern Ukraine shows that in service of sheet welded structures made of low - carbon steels (e.g. decomposer) in boiling alkaline solutions the following four conditions of metal (BMC3 steel) are possible: no corrosion cracking; tiny surface cracks; through cracks; propagation of the main crack. Through cracks, as a rule, occur in weldments in circumferential seams in the direction transverse to the weld axis. Such cracks cause trickle leakage of the solution. Cracks are welded up when decomposer is being repaired. Propagation of the main crack results in failure of decomposer and in leakage of alkali and causes a great material and ecological damage. let us consider an algorithm for calculation - based prediction of the above stages of corrosion cracking in welded structures (Fig. 1).

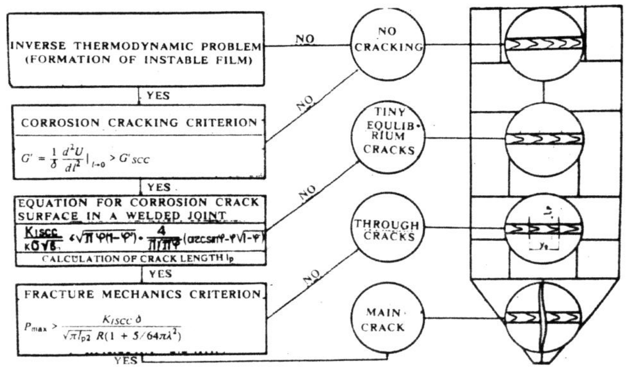

Fig. 1. Algorithm for calculation - based prediction of stages of corrosion cracking in welded structures.

According to the film theory, the prerequisite for corrosion cracking is the formation of thermodynamically instable passivating surface films or breaking of surface films as a result of mechanical action (first of all, in cyclic loading). For a "low - carbon steel - boiling alkaline solution" system which has a wide industrial application, it is thermodynamically instable γ-FeOOH that performs the function of such film (Beliayev et al., 1984). In order to determine the probability of formation of the film it is sufficient to consider all the reactions possible under given conditions and to choose the most probable one from thermodynamic point of view.
With reference to low - carbon steels in boiling alkaline solutions, such approach has been taken by Beliayev et al. (1984). Of practical importance is the solution of inverse problem - determination of conditions (the range of stationary potentials) under which the corresponding reactions proceed. For a "low - carbon steel - boiling alkaline solution" system the range of stationary potentials of formation of instable passivating film is −900 to −500 mB i.h.e. (Hour and Jones, 1973). Stationary potential of low - carbon steel in a pure alkaline solution with a concentration of 20 per cent by weight at 60 °C is beyond the area of susceptibility to cracking /4/. Under certain conditions (for instance, when sulphorous impurities, such as sulphide ions, with a concentration of $5 \cdot 10^{-4}$ g-ion/l and higher, thiosulphate with a concentration of $3{,}2 \cdot 10^{-3}$ g-ion/l and sulphite with a concentration of 2,22 g-ion/l are found in aluminate solutions) the potentials may be shifted to the zone of susceptibility to cracking (Artemiyev et al., 1979), that is, the surface film is destroyed.
Depending on the level of stresses and strains, discontinuities in the surface film may either propagate or not propagate into the metal. The tendency in propagation of a crack at the initial stage of its existence in the form of a microcrack can be described in terms of the corrosion cracking criterion (Fomichev, 1993). The corrosion cracking criterion is determined as the second derivative of the elastic deformation energy with respect to crack length, provided the length tends to zero.
Thus, the necessary and sufficient conditions of the initial stage of cracking (i.e. formation of tiny surface cracks) are as follows: physico - chemical condition (formation of a thermodynamically instable passivating surface film), and energy condition, according to which the corrosion cracking criterion should exceed its critical value. If at least one of these conditions is not satisfied, no cracking takes place. In case when both conditions are satisfied, the possibility of initiation of through cracks at the level of welded joint should be considered.
Through cracks are initiated as a result of the action of the total residual welding and working stresses. Crack propagation in a weldment is related with two simultaneous processes: on the one hand, stress intensity coefficient increases as a result of increase in crack length; on the other hand, as the level of longitudinal residual stresses decreases, the structure is relieved in the areas of close proximity to the propagating crack. Crack propagation depends on the relation between these processes. Length of an arrested crack at the state of equlibrium l_p allowing for the work was determined by Kasatkin et al. (1987) from the following equations:

$$K_{ISCC} / (\sigma_y \sqrt{b_n}) = \sqrt{\pi\varphi(1-\varphi^2)} + 4 / (\pi\sqrt{\pi\varphi}) (\arcsin\varphi - \varphi\sqrt{1-\varphi^2}); \quad 0 \le \varphi \le 1, \quad (1)$$

$$K_{ISCC} / (\sigma_y \sqrt{b_n}) = 3/8 \sqrt{\pi\varphi} \, [(2-\varphi^2) \arcsin 1/\varphi_p + \sqrt{\varphi^2 - 1}]; \quad \varphi > 1; \; \varphi = l_p/b_n, \quad (2)$$

where K_{ISCC} is corrosion cracking resistance; σ_y is yield strength; b_n is width of the plastic zone of the weldment.
Equations (1) and (2) have two solutions - l_{p1} and l_{p2} . A set of solutions (Fig. 2.) determines the boundaries of the above stages of corrosion cracking. At the first stage, tiny cracks are formed. This stage has been described above. At the second stage crack propagates due to a welding factor (residual welding stresses). At this stage, $K_I > K_{ISCC}$. Crack grows abruptly from l_{p1} up to l_{p2}. As a result of crack propagation, welding stresses are relieved and further propagation of a crack stops.

Experimental check of validity of the method of calculation of l_{p2} for an arrested crack was carried out using a set of seven butt - welded plates made of 3 steel with 0.18% of carbon. Each plate measured 300×300×5 mm. Plates were submerged arc welded using AH - 348 flux and C - 08A wire. Welding conditions used (I_w = 450 A, U_a = 30 V, vw = 38 m/h) predetermined

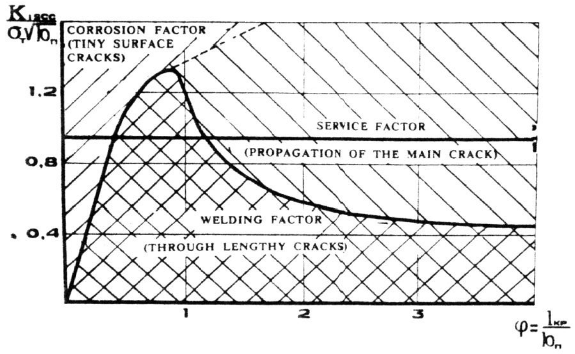

Fig. 2. Stages of corrosion cracking in welded structures.

the width of plastic zone $2b_n$ as equal to 58 mm. The width of plastic zone was calculated by Trochun method (Kasatkin et al., 1987).
Plates were boiled during 500 hrs in a 45% ammonium nitrate solution. The mechanism and pattern of corrosion cracking in low - carbon steel in this solution are similar to those in corrosion cracking in boiling alkaline solutions. In this case cracking proceeds much more rapidly, and boiling for more than 500 hrs results neither in further propagation of a crack nor in initiation of new cracks (Schreier, 1981). according to the results of experiments, the average length of arrested cracks is $2l_{p2}$ = 98 mm. Corrosion cracking resistance of BMC3 steel in a 45% boiling ammonium nitrate solution K_{ISCC} is equal to 68 MPa$\cdot\sqrt{m}$. The length of a crack in the state of equlibrium determined when solving rquations (1) and (2) $2l_{p2}$ is equal to 122 mm. The error in calculation of the expected length of an arrested crack is 24%.
Further propagation of a crack above l_{p2} (stage 3 in Fig. 1 - the main crack at the level of welded structure) takes place due to the service factor (working stresses). In this case the condition of crack propagation is determined in terms of traditional approaches of fracture mechanics by selecting an appropriate criterion and a calculation procedure. For cylindrical sheet structures the solution suggested by Folias (1970) may be used. Of practical importance is the maximum permissible pressure which does not cause propagation of a series of cracks in case of their initiation

$$P_{max} = K_{ISCC}\delta / [\sqrt{\pi l_{p2}} \, R(1 + 5/64\pi\lambda^2)]; \quad (3)$$
$$\lambda = 12(1-\nu^2) \, l_{p2}^4/(R^2\delta^2),$$

where R is radius of structure; ν is Poisson's ratio. The value of l_{p2} in (3) is determined from (1) and (2).
Thus, the algorithm of calculation - based prediction of stages of corrosion cracking in welded structures is based on determination of the possibility of formation of an instable passivating surface film and on calculation of the corrosion cracking criterion (stage of initiation of tiny surface cracks), on solving the equations of equlibrium of corrosion crack in a welded joint (stage of formation of lengthy through cracks at the level of welded joint), and, finally, on the calculation of the critical service parameters using the fracture mechanics criteria (stage of propagation of the main crack).

REFERENCES

Артемьев В. И., Серегин В. И., Жолобова Е. П., Беляев В. П., (1979), О коррозионном растрескивании под напряжением углеродистой стали в щелочно-алюминатных растворах, Защита мкталлов, №1, P. 62—65.

Беляев В. П., Парпуц И. В., Артемьев В. И., Сухотин А. М., (1984), Диаграмма потенциал–зР и пассивность железа в горячих щелочных растворах, Защита металлов, 20, №6, P. 914—918.

Hour T. P. et al., (1973), The mechanism of caustic cracking of carbon steels, Corrosion Science, No 13, p.p. 725 - 738.

Касаткин Б. С., Прохоренко В. М., Чертов И. М., (1987), Напряжения и деформации при сварке, Вища школа, Киев.

Folias E.S., (1970), On the theory of fracture of curved sheets, Eng. Pract. Mech., No2, p.p. 151 - 164.

Fomichov S.K., (1993), Corrosion cracking criterion, In: Advances in fracture research. Proc. 8th Int. Conf. Fract. (ICF8), Kiev, 8 - 13 June, P. 272.

Шрайер Л. Л., (1981), Коррозия: справочное издание, Металлургия, Москва.