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THE PROPAGATING FATIGUE CRACK LENGTH ESTIMATION BASED ON THE CRACK OPENING AT THE SPECIMEN EDGE MEASUREMENT RESULTS

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The crack length measurement method on a flat specimen with single edge on crack (SEC) based the crack opening measurement results on the specimen edge is presented in this paper. This method was applied to tests of 18G2A steel specimens under constant amplitude load and also under load of constant amplitude with some singular overloadings applied at equal time intervals repeatedly.

1. Introduction

The propagating crack length (during fatigue test) measurement becomes a significant element of the present investigations.

The application of such methods as: optic, tensometric, eddy current or acoustic, requires, as a rule, an access to rather complicated measuring devices to achieve a high accuracy of measurement or to assure a good and steady standardization of the measured quantities. The crack length measurement method on a flat specimen with single edge crack (SEC) based the crack opening measurement results on the specimen edge is presented in this paper. This method was applied to tests of 18G2A steel specimens under constant amplitude load and also under load of constant amplitude with some singular overloadings applied at equal time intervals repeatedly.

2. Experimental techniques

A standard clip gauge (an usual equipment of strength and fatigue testing machines with a 10 mm base) was used to measure the crack opening width. The standardization and calibration of the gauge, with demanded accuracy, was assured by the testing machine.

The fatigue tests were carried out on flat specimens single edge cracked – with one–side edge notch. The specimens were cut out from the 18G2A steel sheet. On every specimen a fatigue crack with a length of some millimetres from the bottom of the crack was initiated under a constant amplitude cycling at 190 MPa (determined for the initial cross–section of the specimen).

After the crack initiation the appropriate fatigue tests were carried out. They consists of two investigation stages. The first one – at a constant amplitude loading (σ_{max} equals 160 MPa), and the other one – also at a constant amplitude loading but interrupted every 10000 half cycle with almost static (at frequency of 0.01 Hz) overloadings with $k_{ov} = 1.75$ (overloading coefficient). For both stages an asymmetry cycle coefficient $R = 0.3$ was accepted. The fatigue cycle number N, the force F and the opening of the fatigue crack during the tests were recorded. The fatigue rig INSTRON was used in these tests.

3. Tests results

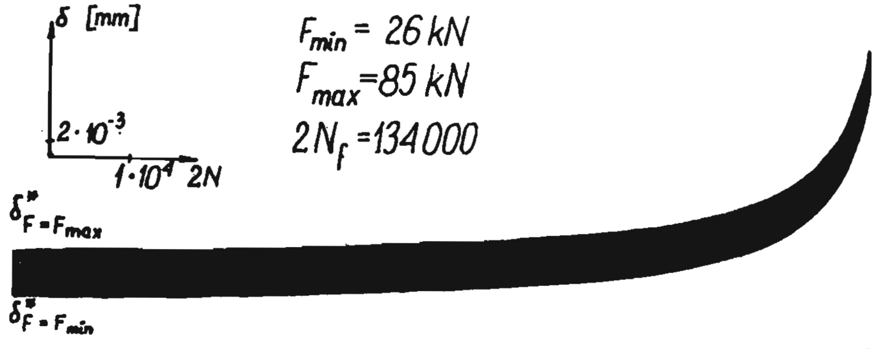

Fig. 1. The experimental record of the fatigue crack opening displacement versus the cycle numbers for specimen without overloading

The tests results in the form of parameter recordings for specimens of both stages are presented in Fig.1 and 2. There are presented the crack opening change charts in the successive loading cycles.

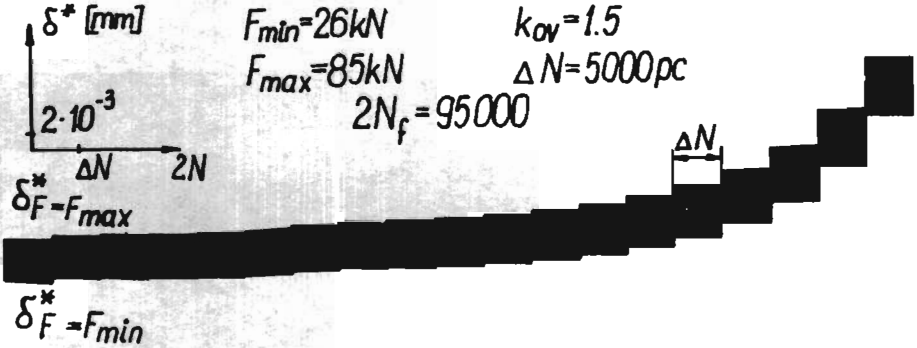

Fig. 2. The experimental record of the fatigue crack opening displacement versus the cycle numbers for overloaded specimen

In the case without overloading (Fig.1) a characteristic rise in the crack opening level from the initial value to the critical one was obtained. When the tests with overloading were carried out (Fig.2) the changes of the crack opening levels took place only during the overloading cycles and stayed approximately at a constant level between the initial and critical values, respectively, also for the subcritical crack development. Characteristic diagrams of the fatigue fracture micrographs in both cases are presented in Fig.3 and 4.

Fig. 3. Microfractograph of a SEC specimen tested without overloading

For the first case (test without overloadings) the picture of fatigue fracture shows a clear fatigue zone (with a different initiation part at the top of the crack) and also a brittle crack zone (Fig.3). For the second case (tests with overloadings) the fatigue fracture is characterized by the overloadings lines in the fatigue zone along the crack propagating path from the initial length to the critical one (Fig.4). The areas between the overloading lines on the fatigue fracture are systematically increasing with the rise in the crack length and the crossing of the damage zone takes place with the appearance of the last overloading cycle.

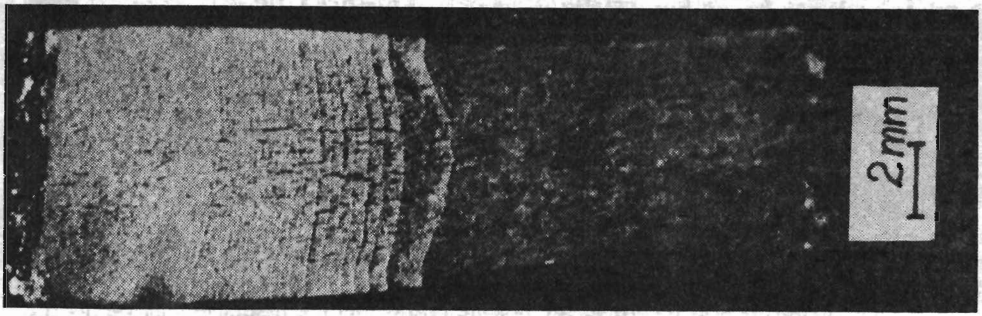

Fig. 4. Microfractograph of a SEC specimen tested under overloading

Since the overloading lines number on the fatigue fracture of the tested specimens is equal to the number of standed overloading cycles, one can draw a clear relation $a = f(N)$ using the measurement results of the overloading lines location on the fatigue fracture of the specimen.

Microphotographic analysis of the fatigue fracture with the aid of electron or scanning microscope shows that the development of the fatigue crack takes place not only during the overloading events but also between them, it can be seen in the form of fatigue striations between the overloading lines.

For the specimens without overloadings we can not expect the overloading lines on the fatigue fracture, therefore the experimental relation $a = f(N)$ can not be applied. For this case a method for estimation the value of the propagating crack length is proposed, based upon the crack opening changes – this parameter can be recorded during the both cases of the test.

This method was tested first on the specimens undergoing overloadings for comparison between the calculated crack lengths and the experimentally obtained ones. The changes of crack openings recorded during the tests versus the increasing force values during the overloading event applied at 0.01 Hz were used. The records during the half cycle of tensile and the reverse run of the curves force – crack opening, for the specified overloading cycles (and also for the corresponding crack lengths) are shown in Fig.5. As can be seen the crack opening after each overloading event increases and only up to the defined force level remains linear versus the force. The increase in the opening value (Fig.2) is caused by the permanent plastic deformations under the overloading events, it is shown by an increase of the extensometric signal value. After eliminating the permanent deformations from the crack opening record and estimating the zero value of the crack opening (based on the linear relationship between the force and the crack opening within the range from 0 to 50 kN) during each overloading event, the plot in Fig.5 can

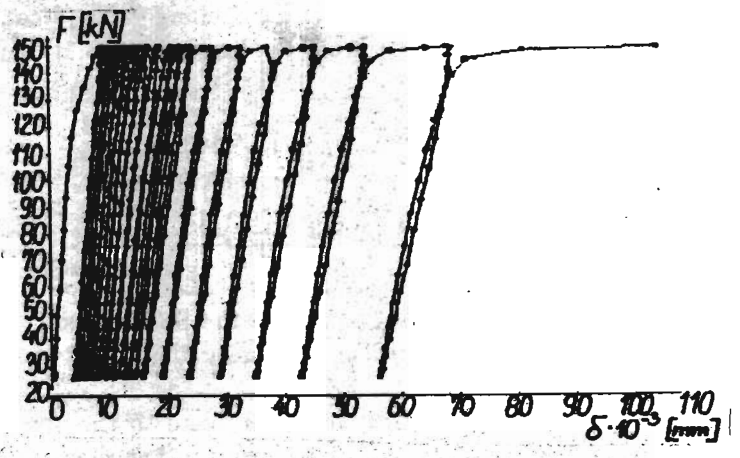

Fig. 5. Crack opening versus loading force recorded on a SEC specimen for successive overloading cycles

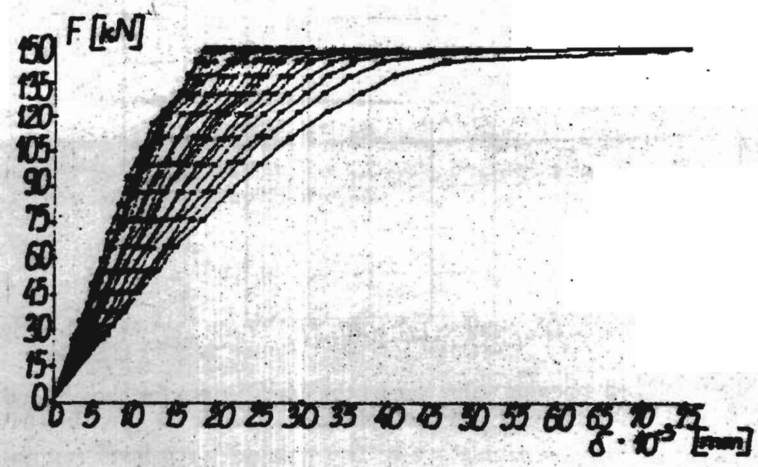

Fig. 6. Crack opening versus loading force recorded on a SEC specimen for succesive overloading cycles after elimination of plastic deformations

be transformed to the form shown in Fig.6 (to make sure that only the tensile half cycles are presented).

The specified curves correspond to the sequential overloading events and are equivalent in meaning assigned to the determined on a base of measurements of the fatigue crack lengths. The deflection of the crack opening value δ caused by the force F is presented by the well-known from the literature (cf [1]), equation $\delta = f(F,a)$

$$\begin{aligned}\delta &= \frac{4Fa}{SEt}\Big[1.46 - 0.70\Big(\frac{a}{W}\Big) - 25.93\Big(\frac{a}{W}\Big)^2 + 143.0\Big(\frac{a}{W}\Big)^3 - \\ &- 538.6\Big(\frac{a}{W}\Big)^4 - 907.5\Big(\frac{a}{W}\Big)^5 + 633.7\Big(\frac{a}{W}\Big)^6\Big]\end{aligned} \tag{3.1}$$

where W, t, S stand for width, thickness and cross-section area of the specimen, respectively, which marked the over crossing of the linear-elastic fracture mechanics area in the course of testing and also the essential fall of the plastic deformations in the tested material.

The run of the first overloading event (which correspond to the undeformed material under overload of the range $k_{ov} = 1.75$) shows another character which argues that in the linear-elastic range, the presented relation can bear a quite different character.

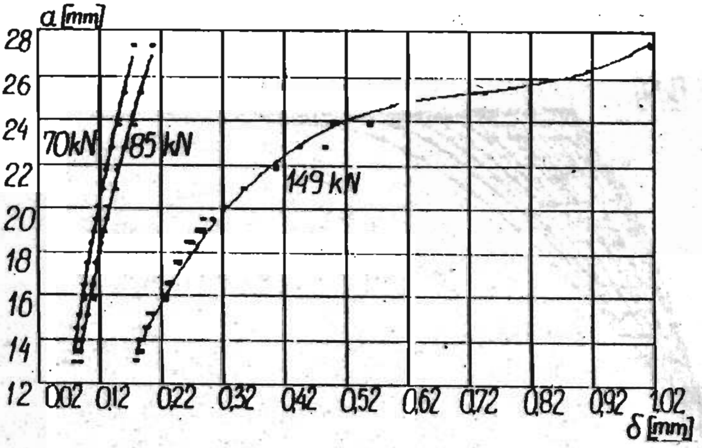

Fig. 7. The change of crack opening value versus the crack length for chosen load levels on a SEC specimen

From the charts obtained (Fig.6) one can easy, for given load level F = constant, express the relation: crack opening – crack length as the proper curves correspond univocally to the measured length. For example: for the load levels $F = 70$, 85 and 149 kN the relations obtained are presented in a consolidated plot in Fig.7.

The singular curves (for the assignment of load levels F = constant) can be easily approximated e.g. by means of the curvilinear regression method, which allows the direct calculations of the crack opening and the crack length to be made. Obtained in such a way, the regression equation $a = f(\delta)$ takes for F_{max} equal to 70, 85 and 149 kN, respectively, the following forms

$$\begin{aligned} a &= -2.451 + 231.484\delta - 370.062\delta^2 \\ a &= -2.148 + 201.482\delta - 296.304\delta^2 \\ a &= -0.308 + 97.477\delta - 127.924\delta^2 + 58.069\sigma\delta^3 \end{aligned} \tag{3.2}$$

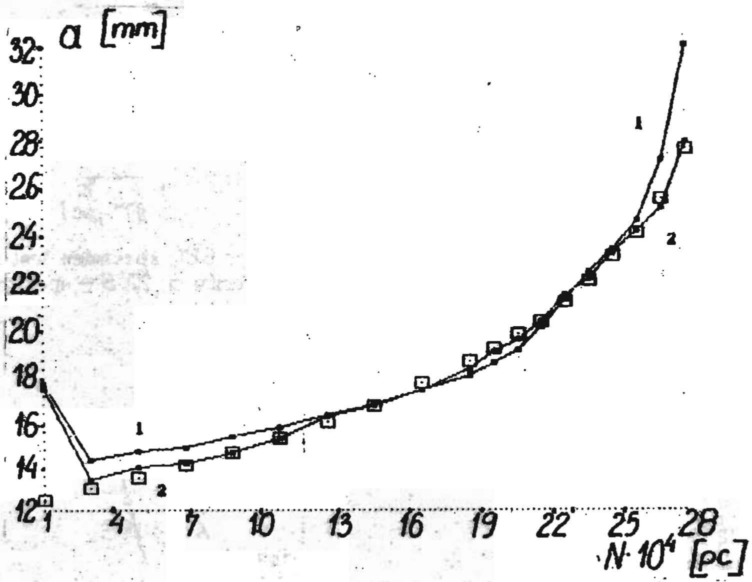

Fig. 8. Fatigue crack length estimation results based on the crack opening value for the SEC specimen; curve 1 – Eq (3.1) was used, curve 2 – Eq (3.2) was used, squares – measured crack lengths

The attempt to estimate the crack length, based both on the recorded experimental crack opening values for the load values on the level of the overloading event $F = 149$ kN and on well-known relations [1], leads to results presented in Fig.8 (curve 1), where squares denote the measured crack lengths.

The unfitness in the range of the initial crack lengths can be easily seen, together with the overestimation of the length near the critical value of it – which results from the crossing the nonlinear range of the relation $F-\delta$. Using the equation (3.2) in calculations gives, of course, a very good estimation (curve 2 in Fig.8) and the errors result only from the scattering of the applied curve approximation from Fig.7 for the loading level $F = F_{max} = 149$ kN.

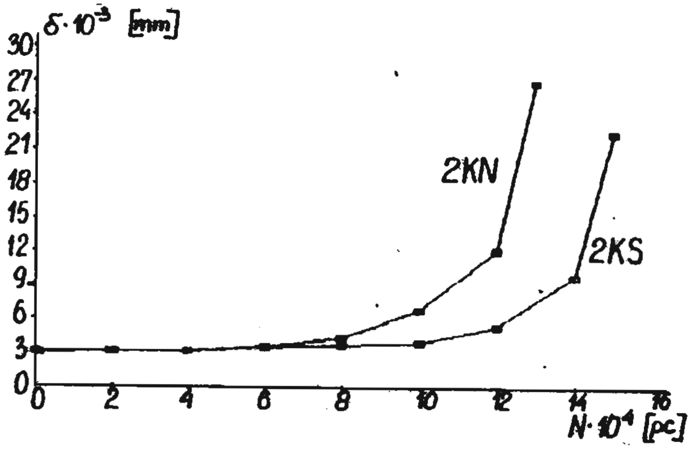

Fig. 9. The charts of recorded crack opening values for the SEC specimen tested without overloading under $F_{max} = 85$ kN; $2KN$ – unwelded specimen, $2KS$ – specimen with welded joint

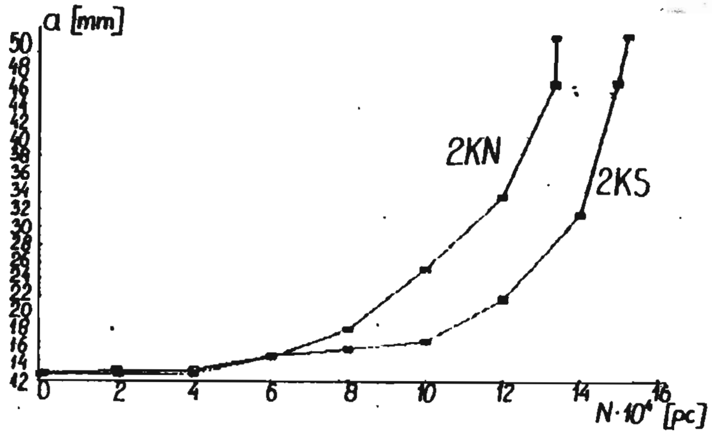

Fig. 10. Fatigue crack length estimation results based on the crack opening value for the SEC specimen tested without overloadings; $2KN$ – unwelded specimen, $2KS$ – specimen with welded joint

We claimed then, that the obtained relations $a = f(\delta)$, for the level of $F =$ constant load pertinent, allowed us to determine the fatigue crack length applying the measurements of this crack opening results, also at the first test stage (without overloading), when the possibility of measuring the crack length on the fractured area did not exist.

In Fig.9 the change of crack opening measured during the run of the tests of specimen made of 18G2A steel with a single edge crack without overloading is presented.

Respective calculations based on the foregoing relations (3.2) allowed us to determine the hypothetical curve of the fatigue crack development in those cases. The results are presented in Fig.10.

A good agreement can be seen between the values of crack length observed on the fracture area: the initial $a_0 = 12.5$ [mm] and the critical $a_{cr} = 49$ [mm] values, respectively.

4. Final conclusions

The fatigue crack length estimating method based on the measuring results of the crack opening displacement in flat opening specimen with a single edge crack presented here reflects good the size of the propagating crack.

This is confirmed by the verification of experimentally determined (based on the measuring results of the fracture specimen area – Fig.4) values of the crack (Fig.8) on specimens tested under overloadings together with the initial and critical crack lengths, respectively, determined from the measurements of the specimen fracture area tested without overloadings (Fig.3).

Applying the method mentioned above allows us to check the length of a propagating crack also in the case of the permanent plastic deformation appearance.

Reference

1. MURAKAMI Y., 1987, *Stress intensity factors handbook,* Pergamon Press

Ocena długości pęknięcia zmęczeniowego w oparciu o pomiar rozwarcia szczeliny na brzegu próbki

Streszczenie

W pracy została przedstawiona metoda pomiaru długości pęknięcia w płaskiej próbce z jednostronnym karbem krawędziowym na podstawie pomiaru rozwarcia szczeliny na brzegu próbki. Metodę tą zastosowano w badaniach próbek ze stali 18G2A przy obciążeniu stałoamplitudowym i stałoamplitudowym z przeciążeniami.

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