CREEP CLOSE TO CRACK TIP UNDER STRESS CORROSION

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ABSTRACT

The present work is dealt with a research of the local creep near the crack tip in same steels, with a relevant method presented for processing the obtained experimental data. In testing materials for stress corrosion (in the case of absence of crack propagation) due to local thermally activated flow near the crack tip it may be recommended to estimate the behaviour of the material in the terms of the crack opening in the process of the tests and the stress intensity factor.

KEYWORDS

Stress corrosion, local creep, crack tip, local plastic flow.

INTRODUCTION

The overwhelming majority of articles operating in corrosive media experience, besides, the effects of external loads. Structure of any material is thought to contain such defects as cracks which in the course of time under the action of applied stresses either start spreading, which may result in damage to the article concerned, or tend to open without spreading, which may invite untolerable deformation of the respective member. Such an opening of the crack is caused by creep of some volume of the material in the zone of the crack tip (with the loading held constants), i.e. local creep. Cracking of a loaded material possessing an initial crack and placed in an aggressive medium occurs only in the case of fairly strong materials, while opening of the crack tip without growing lengthwise, i.e. local creep, is usually characteristic of rather plastic materials under comparatively minor loads due to thermally activated flow.
The present work is dealt with a research of the local creep in

some steels, with a relevant method presented for processing the obtained experimental data.

METHOD OF TESTS

The tests for study of the local creep were carried out at room temperatures with the use of prismatic specimens measuring 80x20xIO mm. One of the lateral faces of the specimens was provided with a fatigue crack, 3 mm long, preliminarily grown from an acute notch.

Due to a higher plasticity of the material under test the application of a load gives rise to a plastic zone near the crack tip, an opening of the tip and its sticking in the plastic zone as a consequence of strengthening of the material and also owing to the fact that the crack mouth tends to become blunt. As the result, in the case of a long-acting load applied to the specimen (the tests were performed with a three-point bend) no start of crack growth arises, however, the process of its opening begins and tends to increase in the course of time.

The local creep takes place only in a small local zone close to the crack tip, provided this zone is much less that the total length of the crack with the notch, and the crack opening is negligible, therefore the approaches of linear mechanism of failure are found to be well applicable. The experimental stress in the net section did not exceed 0.8 of the bending yield point.

The processing of the experimental data has allowed: (A) determination of kinetics of the local creep, i.e. a change of the crack opening with time under the predetermined load corresponding to the value of the stress intensity factor K;

(b) determination of the relationship between the crack opening as a measure of the local creep and the value of factor K as applied to the particular test base (20 hours, 50 hours, etc.)

(c) determination of the value of the stress intensity factor corresponding to K^t_δ - the start of the local creep, i.e. the start of the crack tip opening δ for any pre-assigned time of the tests;

(d) determination of the values of factor K corresponding to K^0_δ - the start of the local creep upon removal of the load applied (t = 0).

The information derived from the like experiments makes it possible to estimate both the force criteria of local creep in the terms of factor K (K^t_δ , K^0_δ) and the tendency to a plastic flow with time, that is characterized by the parameter L:

$$L = (K^0_\delta - K^t_\delta) \cdot t^{-1}$$

The value of the stress intensity factor can be calculated by the following formula:

$$K = 108\,\frac{P\sqrt{a}}{B \cdot W} \cdot Y$$

$$Y = 1.93 - 3.07\lambda + 14.53\lambda^2 - 25.11\lambda^3 + 25,8\lambda^4$$

where P is the axial load applied to the centre of the specimen; B is the thickness of the specimen; W is the width of the specimen; a is the total length of the crack and notch; $\lambda = a/W$.

The specimens were tested in a 3% solution of sodium chloride with photographing (at regular intervals) the notch area and the crack opening by the use of the fiber optics.

Subjected to the tests were specimens fabricated from low-alloy steels, type Cr - Mn - Si with 0,3%C after hardening and tempering at a temperature of 600 C, and type Cr-Mo-V with 0,I2%C. The steel of the first type was obtained as a product of: (a) an ordinary industrial smelting (steel I); (b) a smelting with a higher frequency for the admixtures (steel 2); and (c) a smelting under slag fluid bed (steel 3).

The steel of the second type was tested in two states: (a) in the initial state after a cold rolling, a heating up to 950-I030°C, a 30-minute holding, a cooling and a repeated heating to 720-750°C with a holding for one hour (steel 4); (b) after an additional preliminary deformation (I2%) and an annealing for 24 hours at a temperature of 600°C (steel 5).

TEST RESULTS

The primary dependences were obtained in the form of a function reflecting the increment of the crack tip opening ($\Delta\delta$) versus time t during which the specimen was held under the specified load, in other words, the original value of the stress intensity factor (K). In this case the initial opening ($\Delta\delta$) directly at moment of loading the specimen (i.e. the process of varying the applied load from zero to the prescribed level) was not taken into account, while the value of $\Delta\delta$ indicated the increment resulted from a prolong action of the load, i.e. it was in conformity with the process of its aftereffect. The values of $\delta_0 + \Delta\delta$ lay within the limits enabling the approaches of the linear mechanics of failure to be practically used.

Fig.I illustrates the relations between the crack opening increments and the value of the initial stress intensity factor K on the expiration of 20 hours (Fig.I, a,c) and I00 hours (Fig.I, b) of application of the load.

From Fig.I (a,b) it will be obvious that the crack opening increases with rise of the initial value of factor K. The intensity of the crack opening growth is determined by the angle of inclination of the straight lines to the X-axis:

$$\frac{d(\Delta\delta)}{dK^2} = i.$$

It is clear that the value i is a substantially sensitive parameter with respect to different methods of smelting of a steel of the same grade.

The intersection of the strength lines with the X-axis gives the value of K^t_δ corresponding to the start of the crack opening in a definite lapse of time. Steel 3 features the highest sensitivity of i to the crack opening, however, it also has the greatest value of the stress intensity factor K^t_δ (the parameter of the opening start $\Delta\delta$). The more the time t of the load application the less is the factor K^t_δ at which the crack opening starts ($\Delta\delta$).

The said relations of " δ - K^2 " for the steel of type Cr-Mo-V in the initial state (curve 4) and after the deformation and annealing (curve 5, Fig.I, c) show a high sensitivity of the criterional estimation of the local creep to the

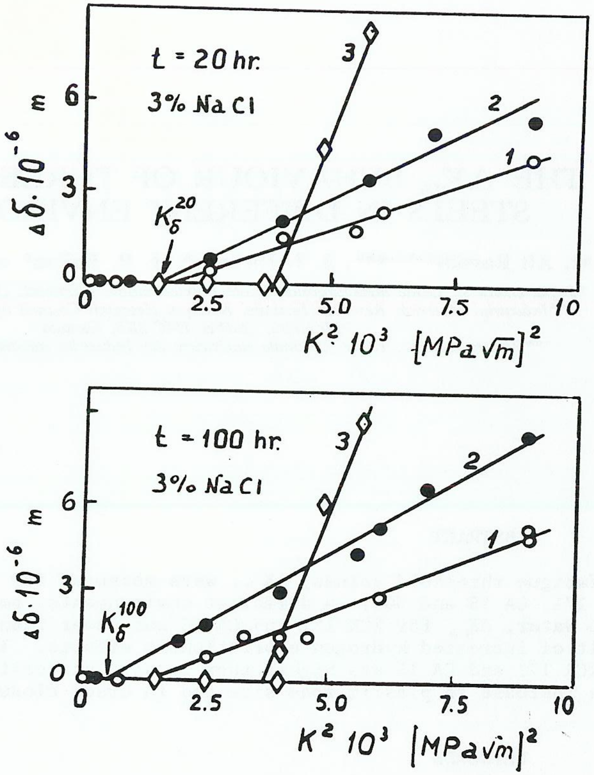

Fig. I. (a) Increment of crack tip opening versus initial value of stress intensity factor K (and K^2) in 20 hours of holding under load. I - steel I; 2 - steel 2; 3 - steel 3; (b) Same, in I00 hours of holding under load.

structural state of the steel concerned.
The dependences presented in Fig.I (a,b) for different holding durations make it practicable to plot the curves showing the factor K_δ^t at a function of time t (Fig.2). It is evident from these curves that steel 3 is found most advantageous as compared to the other two versions at any time of experimental holding of the specimens under load (up to I00 hrs). The intensity of diminishing of K_δ^t with time for this steel is least as compared with that of the other steels.
The results of the experiments are tabulated below.
From the particulars presented in Table I it transpires that the criterion of K_δ^t may vary within rather wide ranges and serve as a characteristic of the local creep resistance as a

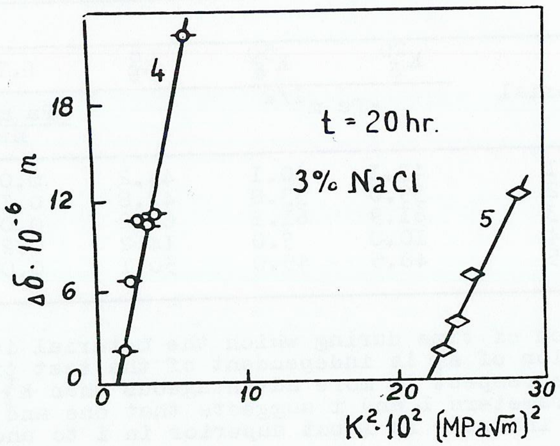

Fig.I. (c) Same, in 20 hours of holding under load; 4 - steel 4; 5 - steel 5.

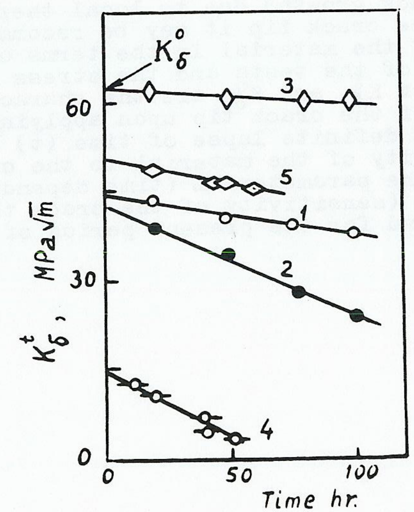

Fig.2. Effect of time of holding of specimen under load exerted on criterion K_δ^t characterizing value of stress intensity factor K at which crack tip opening starts to develop within particular period of time (t).

TABLE I Criteria of Local Creep of Tested Steels

Material	K_δ^{20}	K_δ^{50}	K_δ^{0}	$L.IO^{-3}$	$i\ IO^{-9}$
	MPa $m^{I/2}$			$\frac{MPa\ m^{I/2}}{hr}$	$(MPa)^{-2}$
Steel I	43.I	40.I	44.2	0.067	0.54
Steel 2	39.0	33.8	42.8	0.I88	0.67
Steel 3	6I.9	6I.I	62.2	0.030	I.I5
Steel 4	I0.0	3.0	I4.2	0.2I0	3.28
Steel 5	48.5	45.0	50.I	0.083	0.42

function of time during which the material is held loaded. The criterion of K_δ^0 is independent of the test time and therefore in this respect is more advantageous than K_δ^t . Comparison of the parameters L and i suggests that one and the same steel may be inferior in L but superior in i to another type of steels.

CONCLUSION

In testing materials for stress corrosion (in the case of absence of crack growth) due to local thermally activated plastic flow near the crack tip it may be recommended to estimate the behaviour of the material in the terms of the crack opening in the process of the tests and the stress intensity factor. The parameters of K_δ^t and K_δ^0 are the characteristics of the start of opening of the crack tip upon applying the load, respectively after a definite lapse of time (t) and at t = 0. The sensitivity of the material to the crack opening is characterized by the parameters L (time dependence of the opening start) and i (sensitivity of the crack tip opening to the change of the load for the present period of time).