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The Crack Growth Rate for an Eccentric Tensile in Connection to the Asymmetry Coefficient for a Stainless Steel

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Abstract

The paper intends a study of the propagation speed for cracks of the ***da/dN*** *kind, into an Austen steel employed at the refrigerating plants from the chemical industry. The testing was made with flat test of the CT model, with a lateral notch, the stress being an eccentric stretch. The cycles were of the positive oscillatory kind, with the asymmetry coefficients R=0.1, R=0.3 and R=0.5, and the test was made at normal temperature. The crack lengths* ***a*** *and the corresponding cycles numbers* ***N*** *were noted. With the help of some numerical computation programs were determined* ***ΔK****, the stress intensity factor, and* ***da/dN****, the crack's propagation rate. In the end were traced the graphs of the variating* ***da/dN****, in connection with the defect's length* ***a****, respectively with the* ***ΔK*** *index, for the three asymmetry coefficients.*
Key words*: crack, stress intensity factor (SIF), asymmetry coefficient, crack growth rate (da/dN).*

Introduction

The action of environmental factors or the application of a repeated stress to a machine part or to a test board lead to the increase of the length of a defect already existing, quicker or slower, as a function of the states of deformation and tension wich act at the spike of the crack.

The state of tension is a function of the variation of the stress intensity factor ΔK, which implicitly controlls the variation of the crack length. The propagation of the crack is defined by the propagation speed, denoted $\mathbf{d}a/\mathbf{d}N$, and it represents the increase of the crack's length during a stress cycle.

Generally, for variable loadings, the analysis of the crack's propagation is performed with a constant amplitude, and its aim is to establish a connection between the crack's propagation speed $\mathbf{d}a/\mathbf{d}N$ and the variation of the stress intensity factor $\Delta K = K_{max}-K_{min}$, the connection having the general form $\mathbf{d}a/\mathbf{d}N=v(\Delta K)$.

The variation curve of the crack's propagation rate $\mathbf{d}a/\mathbf{d}N$, in respect to SIF ΔK, has averagelly of a sigmoid [4].

The Experiment's Initial Conditions

The study of the fracture phenomenon at cyclic axial stresses was performed in respect to the stipulations of the ASTM E 647 standard, by using flat test boards, with a lateral notch, of the CT model, [2, 5].

A hydraulic pulsating device WPM was used, with a top loading of 30 kN, bearing a test gear which had been adapted for the kind of the test board previously mentioned (figure 1).

The main composing elements of the pulsating outfit are: 1 - the body; 2 – the fixed frame; 3 – the columns; 4 – test board; 5 – gras-ping head; 6 – hydraulic cylinder.

The strain's frequency is of 5 Hz, and the precision in reading the load is up to 1 N of range. Before submitting the test board to a cyclic axial eccentric strain, we would apply on it pre – cracking stress, with a length of about 2 mm, and the number ***N*** of cycles corresponding to it is recorded.

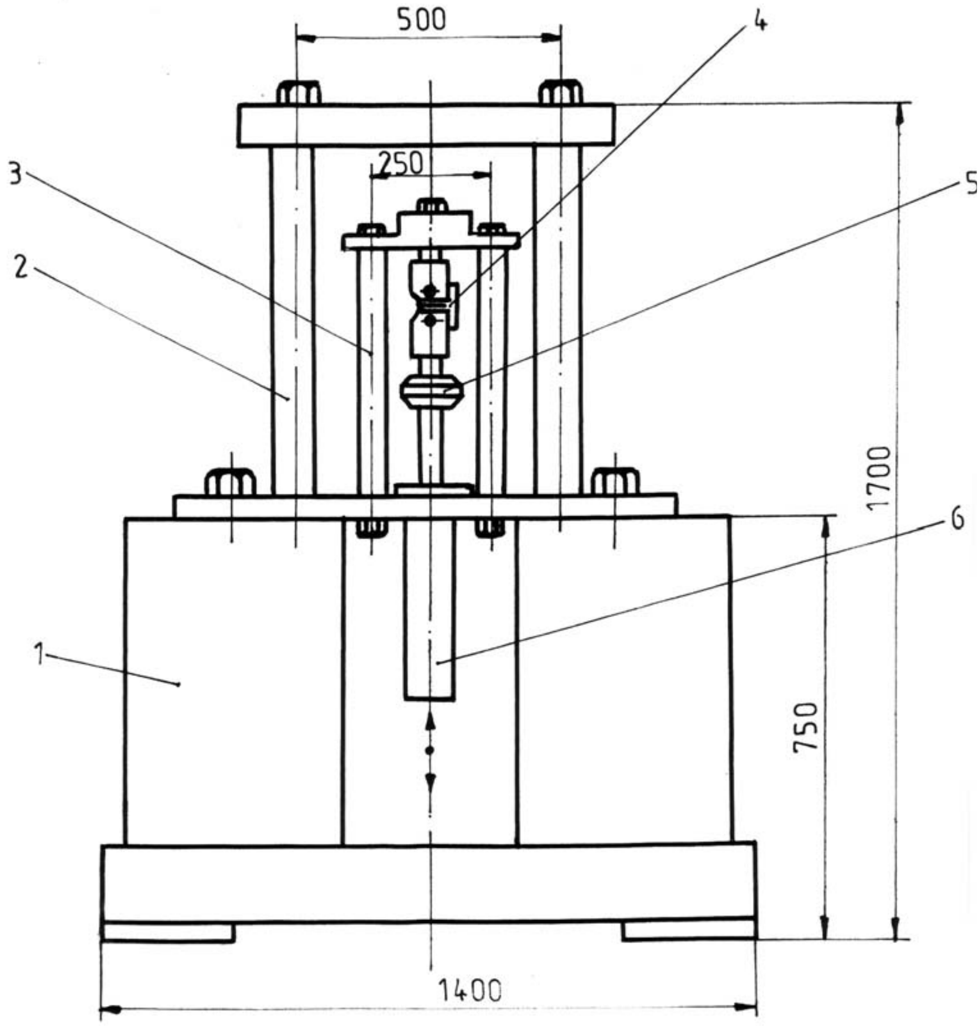

Fig. 1. Hydraulic pulsating device

Then the strain is continued, with the purpose of increasing the length ***a*** of the crack, measurements being performed at each progress of 0.25 mm, with the help of an optical microscope able to magnify 50 times, situated steady on the body of the testing machine. The numbers of cycles ***N*** are respectively recorded.

The operation is repeated for three asymmetry coefficients, $\boldsymbol{R=F_{min}/F_{max}}$, $\boldsymbol{R}$=0.1, $\boldsymbol{R}$=0.3 and $\boldsymbol{R}$=0.5 . The test boards were executed of a stainless steel with the trademark 10TiNiCr175.

The Computation of Experimental Data

The enlarging speed of the crack's length was studied through the polynomial method that has been developed in ASTM E 647, [3], [5]. According to this standard and using the data recorded during the experiment, (the cracks' lengths $\boldsymbol{a_i}$ and the cycles' numbers $\boldsymbol{N_i}$), an approximative parabola is determined, expressing the crack's length, calculated as $\overline{a}_i$ and given by the relation:

$$\overline{a}_i = A_1 \cdot \left(\frac{N_i - C_1}{C_2} \right)^2 + A_2 \cdot \frac{N_i - C_1}{C_2} + A_3 \ , \tag{1}$$

where A_1, A_2 and A_3 are the coefficients of the regression's polynominal, determined by the method of the smallest squares.

The crack's growth speed for the crack's length $\overline{a}_i$ and the number of stress cycles N_i is:

$$\left(\frac{da}{dN} \right)_{\overline{a}_i} = 2 \cdot A_1 \cdot \frac{N_i - C_1}{C_2^2} + \frac{A_2}{C_2} \ . \tag{2}$$

The variation of the stress intensity factor (SIF) is determined as a function of the variation of the strain force $\boldsymbol{\Delta F = F_{max} - F_{min}}$ and of the calculated crack's length $\overline{a}_i$. For test boards of the CT model, it is obtained through the expression:

$$\Delta K = \frac{\Delta F}{B \cdot \sqrt{W}} \cdot \frac{2 + a}{\sqrt{(1 - a)^3}} \cdot \left(0.886 + 4.64 \cdot a - 13.32 \cdot a^2 + 14.72 \cdot a^3 - 5.6 \cdot a^4 \right) . \tag{3}$$

In the expression above, the parameters have the following meanings [5]: B – thickness of the test board (8 mm); W – the width of the test board (32 mm); $\alpha = \overline{a} / W$ under the condition that $\alpha \geq 0.2$ for the elastic domain.

Through the application of the numerical computation program, under the form of a two-columns matrix, we obtain the following values' tables:
(a, N), (a,* d*a/*d*N), (ΔK, a), (ΔK,* d*a/*d*N), respectively **(lgΔ*K*, lg*(*d*a/*d*N*)).** Once these sets of values calculated, we trace the graphs: ***N=N(a),*** Figure 2, $\boldsymbol{v=v_1(a)}$, Figure 3, ***a=a(ΔK),*** Figure 4, $\boldsymbol{v=v_2(\Delta K)}$, Figure 5, respectively $\boldsymbol{\lg(v)=v_3(\lg(\Delta K))}$, figure 6.

On the same graphs, for the same temperature (293K) are drawn the curves corresponding to the three asymmetry coefficients: R=0.1, R=0.3 and R=0.5.

Comments

The analysis of the five graphs could lead us to a few conclusions:

1°. The durability ***N*** increases with the asymmetry coefficient ***R***, for the same crack's length ***a***, Figure 2. So, for ***R*=0.1**, the cycles' numbers variate between 47600 and 88000, for ***R*=0.3,** ***N*** is oscillating between 82000 and 154000, respectively for ***R*=0.5**, the durability ***N*** stands between 181400 and 483600.

2°. In Figure 3 is represented the propagation rate of the crack, (**d*a*/d*N***), function of the crack's length variation ***a*** . It is easy to notice that a higher asymmetry coefficient ***R*** leads to a decrease of the cracking rate. For any of the asimmetry coefficients, the cracking rate grows when the length of the defect increases too. So, for ***R*=0.1**, **d*a*/d*N*** is variating between $55.5 \cdot 10^{-6}$ m/cycle and $321.7 \cdot 10^{-6}$ m/cycle, for ***R*=0.3** it grows between $44.4 \cdot 10^{-6}$ m/cycle and $143.9 \cdot 10^{-6}$ m/cycle, respectively for ***R*=0.5** the crack's propagation rate stands between $7.7 \cdot 10^{-6}$ m/cycle and $81.1 \cdot 10^{-6}$ m/cycle.

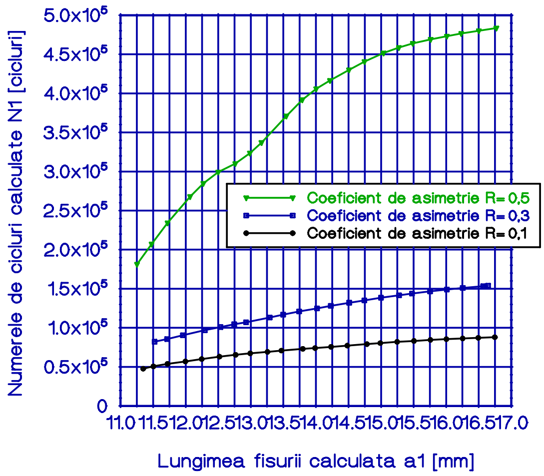

Fig. 2. Durability variation versus crack's length

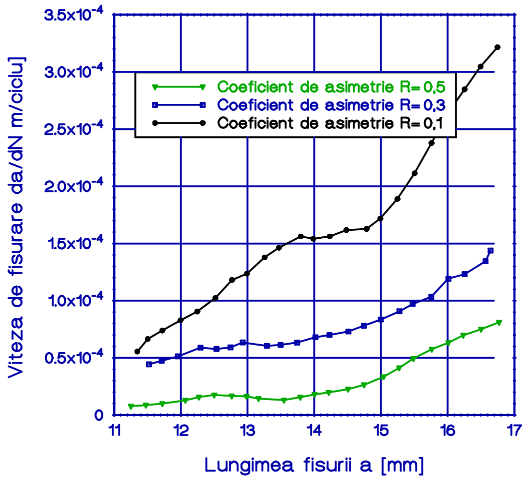

Fig. 3. Cracking rate versus crack's length

3°. Whatever could be the asymmetry coefficient, the increase of the stress intensity factor **Δ*K*** involves an increase of the crack's length ***a***, Figure 4. The stress intensity factor (SIF) decreases when the coefficient ***R*** gets higher, the graphs moving to their lowest values. So, when ***R*=0.1**, **Δ*K*** is located between 640 and 1028.5 $N \cdot mm^{-3/2}$, for ***R*=0.3** it oscillates between 512.4 and 803.6 $N \cdot mm^{-3/2}$, respectively for ***R*=0.5 Δ*K*** is situated between 353.6 and 572.3 $N \cdot mm^{-3/2}$.

4°. A modern way used in the analysis of the behaviour of a material submitted to cyclic stresses is the study of the variation of the cracking speed **d*a*/d*N*** , correlated to the SIF **Δ*K***, as in Figure 5. For all three asymmetry coefficient, SIF **Δ*K*** and the speed **d*a*/d*N*** have the same sense of variation expressed by an exponential function which folows Paris's formula

$\frac{da}{dN} = C \cdot (\Delta K)^m$. But, the increase of the coefficient ***R*** determines a movement of the curves towards their lowest values, for the abscissa as well for the ordinate. This fact is enlightened in Figure 5, under normal co-ordinates, respectively under bi-logarithmic ones in Figure 6.

For ***R*=0.1, Δ*K*** belongs to the interval (640; 1028,5) $N \cdot mm^{-3/2}$ and **d*a*/d*N*** is variating between $55.5 \cdot 10^{-6}$ and $321.7 \cdot 10^{-6}$ m/cycle; for ***R*=0.3**, **Δ*K*** stands between 512.4 and 803.6 $N \cdot mm^{-3/2}$, while the cracking rate goes from $44.4 \cdot 10^{-6}$ and $143.9 \cdot 10^{-6}$ m/cycle, respectively for ***R*=0.5,** the FIT strolls from 353.6 to 574.2 $N \cdot mm^{-3/2}$, while **d*a*/d*N*** variates inside the limits of $7.7 \cdot 10^{-6}$ and $81.1 \cdot 10^{-6}$ m/cycle, as in Figure 5.

5°. For their representation under logarithmic co-ordinates, as in Figure 6, the curves are approximated through first – degree functions, so being obtained the parameters ***m*** and *C* from Paris' formula, in the relation:

$$\lg \frac{da}{dN} = m \cdot \lg(\Delta K) + \lg C . \tag{4}$$

So, we come to: m=4.71 and C=7.94·10^{-18} for R=0.5, m=2.33 and C=2.15·10^{-11} for R=0.3, respectively m=3.23 and C=6.02·10^{-14} for R=0.1.

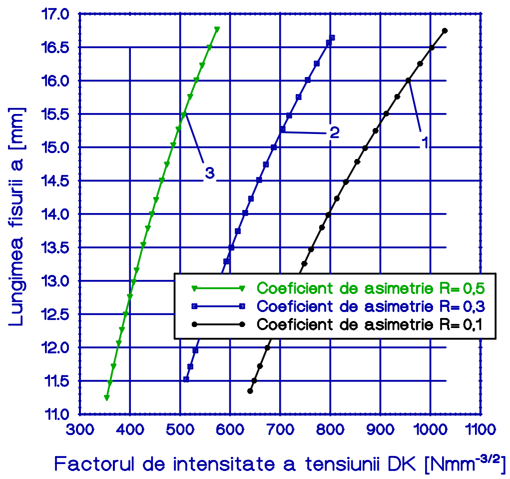

Fig. 4. Crack's length versus SIF Δ*K*

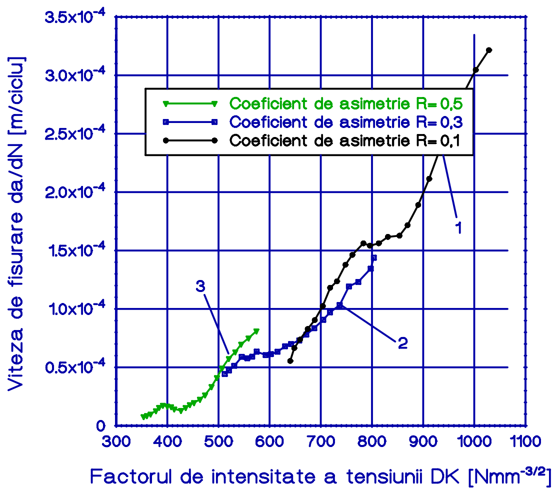

Fig. 5. Cracking rate in function SIF Δ*K*

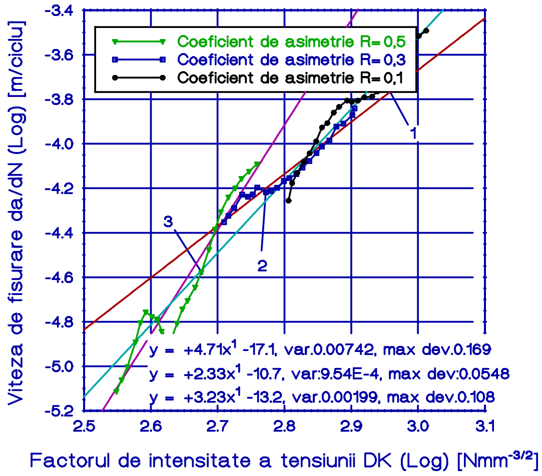

Fig. 6. Crack growth rate versus SIF ΔK (logarithmic co-ordinates)

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Viteza de creştere a fisurii pentru o întindere excentrică în raport cu coeficientul de asimetrie, pentru un oțel inoxidabil

Rezumat

*Lucrarea are ca scop un studiu al vitezei de propagare a fisurii notată cu **da/dN** într-un oțel inoxidabil folosit la instalațiile frigorifice din industria chimică. Încercările au fost efectuate pe epruvete plate model CT, cu crestătură laterală, iar solicitarea fiind de tracțiune excentrică. Ciclurile de solicitare au fost de tipul oscilante pozitive, cu coeficienții de asimetrie R=0,1, R=0,3 şi R=0,5. Încercările au fost realizate la temperatura normală. În timpul experimentărilor s-au notat lungimea fisurii **a** şi numerele de cicluri corespunzătoare **N**. Cu ajutorul unor programe de calcul numeric s-a determinat variația **factorului de intensitate a tensiunii ΔK** şi variația **vitezei de propagare a fisurii da/dN**. În final, cu aceste mărimi s-au trasat grafice de variație pentru viteza de fisurare **da/dN** în raport cu lungimea defectului **a**, respectiv în raport cu factorul de intensitate a tensiunii **ΔK**, pentru cei trei coeficienți de asimetrie.*