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Study of the Crack's Propagation Using Experimental Models for Cracking Rate in a Stainless Steel

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Abstract

*Using a stainless steel 10TiNiCr175 type, some flat samples, CT model with a lateral notch, have been tested. These were tested for a positive oscillatory load by eccentric tensile with an asymmetry coefficient **R** = 0.3. The testing temperature was **T** = 253K. Using the polynomial method, according to the ASTME 647 standard, the propagation speed of the crack **da/dN**, and the stress intensity factor noted by **ΔK** have been determinated.*

Key words: *fatigue, crack propagation rate (**da/dN**), stress intensity factor (SIF), asymmetry coefficient.*

Theoretical Approach

The applied loads to solid bodies can determinate the elastic or remanent strains. When the stress field progressively growth, the deformation process can be finalised with the fracture. So, the body is divided in two or more parts. Before the fracture phenomenon, some default inside the body material, crack type, because of the crystalline network irregularities, are occurs.

In these favourable conditions, the cracks begin to propagate and, as results, the body destroyed is occurs. The fracture process presents two distinctive phases: the crack initiation and its propagation for each specifically conditions.

Among the late study elements of the fracture, according to the Fracture Mechanics concepts, it is remember here the crack propagation speed and stress intensity factor, SIF. This parameter incorporates both the loading effect and sample geometry and can utilised to describe the fatigue crack growth.

Using an analytical theory of the fatigue phenomenon, more researchers, i.e. Paris and Erdogan, showed the fact that the crack propagation speed, **da/dN**, can be formulated as function of maximum value of the stress intensity factor, **ΔK**, as result of the cyclic load and asymmetry coefficient of the cycle, **R**..

In terms of the mode I of the fracture, when the crack is propagated through abruption, in the **stable propagation domain** of the default, the fatigue crack propagation speed can be calculated using Paris's relation:

$$da/dN = C\cdot(\Delta K)^{m} \, , \tag{1}$$

where: $\Delta\mathbf{K} = \mathbf{K}_{max} - \mathbf{K}_{min}$, and **C** and **m** are the constants which depends not only the material, but also the loading conditions (asymmetry coefficient, **R**), and work temperature, respectively.

Experimental Studies

The object of this study was to analyse a stainless steel, 10TiNiCr175 type, in fatigue stress conditions by eccentric tensile at 253K low temperature.

The selected samples were the plate type with a lateral notch, CT model [5]. In order to test the samples, a hydraulic pulsated machine, with 30 kN, maximum load, was used. Also, in order to cool the sample during the test, a cooling box, mounting on the hydraulic pulsated machine, was used [3, 4]. The cooling agent was nitrogen in liquid state. This was added in a petrol ether medium, Figure 1. In order to determinate the deformations using the elastic compliance method, a strain-measuring device (extensometer) with elastic lamellae was used. The samples was eccentric uniaxial loaded, with the asymmetry coefficient **R** = 0.3.

Was denoted the crack length variation $\mathbf{a_i}$, and the corresponding numbers of cycles, $\mathbf{N_i}$. These quantities were the primary elements of the study.

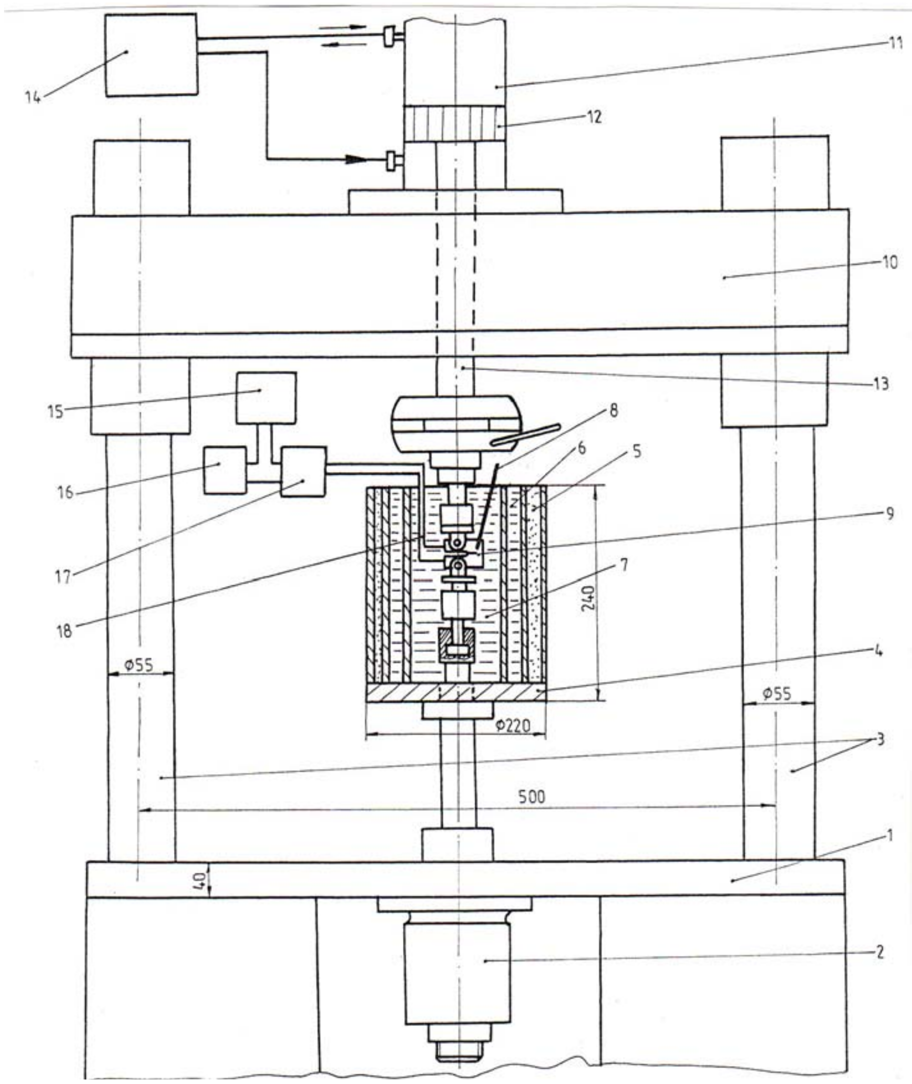

Fig. 1. The trial machine with the refrigerating precinct

Processing of the Experimental Data

Using the Matlab software and an adequate numerical program, the stress intensity factor, **ΔK**, according to the ASTM, [3, 5, 6, 7], and the crack propagation speed, **V1=da/dN**, for the polynomial model, [4, 7], was calculated.

These values were utilized as referential quantities for other proposed mathematical models for crack speed calculus, useful in this domain.

Hereby, the used variants and whose results can be observed in the followings are:

- the Paris formula:

$$da/dN = V2 = C2 \cdot (\Delta K)^{m2}; \tag{2}$$

- the Forman formula:

$$da/dN = V3 = C3 \cdot \frac{(\Delta K)^{m3}}{(1-R) \cdot K_c - \Delta K}; \tag{3}$$

- the Weertman relation:

$$da/dN = V4 = C4 \cdot \frac{(\Delta K)^4}{K_c^2 - \left(\frac{\Delta K}{1-R}\right)^2}; \tag{4}$$

- the Walker formula:

$$da/dN = V5 = C5 \cdot \frac{(\Delta K)^{m5}}{(1-R)^{r5}}; \tag{5}$$

- the Donahue relation:

$$da/dN = V6 = C6 \cdot (\Delta K - \Delta K_p)^{m6}; \tag{6}$$

- the Mc Evily relation:

$$da/dN = V7 = C7 \cdot (\Delta K - \Delta K_p)^2 \cdot \left(1 + \frac{\Delta K}{K_c - K_{max}}\right); \tag{7}$$

- the Erdogan-Ratwani generalized formula:

$$V8 = C8 \cdot (1+\beta)^{m8} \cdot \frac{(\Delta K)^{n8} \cdot (\Delta K - \Delta K_p)^{n8}}{K_c - (1+\beta) \cdot \Delta K}. \tag{8}$$

where: $\beta = \frac{K_{max} + K_{min}}{K_{max} - K_{min}}$.

For the testing material, a stainless steel, 10TiNiCr175 type, at the 253K temperature and **R**=0.3, asymmetry coefficient, the propagation variation of SIF, $\mathbf{\Delta K_p}$ = 675.6 MPa$\cdot\sqrt{mm}$, and the stress intensity critical factor, $\mathbf{K_c}$ = 915.14 MPa$\cdot\sqrt{mm}$, was obtained.

The parameters from Paris relation are: **C2 =** $1.763 \cdot 10^{-14}$ and **m2 =** 3.45.

It were determined all constants from (3) to (8) relations, then the graphical variation of the crack speed, in certain combinations of the above relations, was obtained.

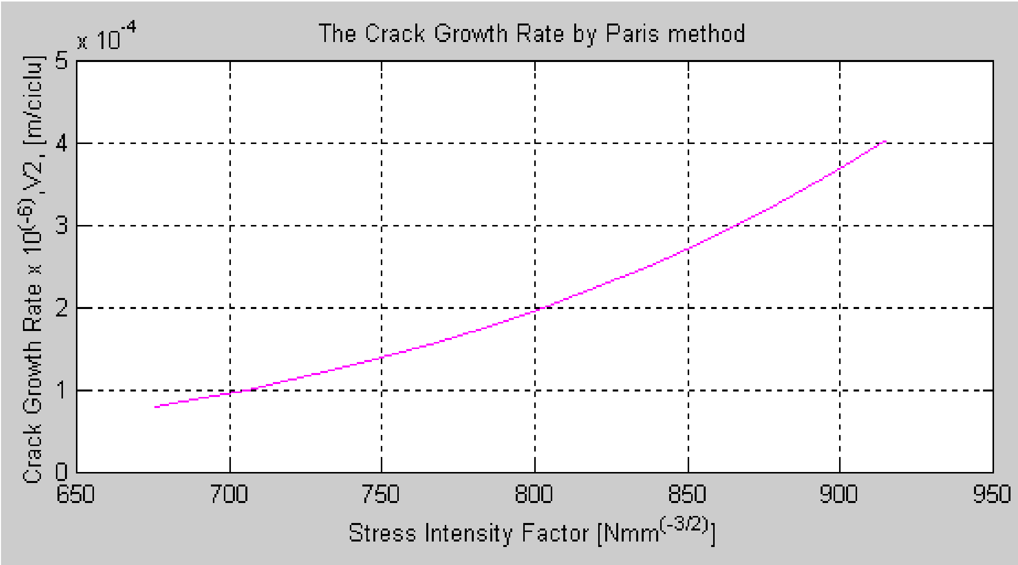

Fig. 2. The crack speed using Paris formula, normal coordinates

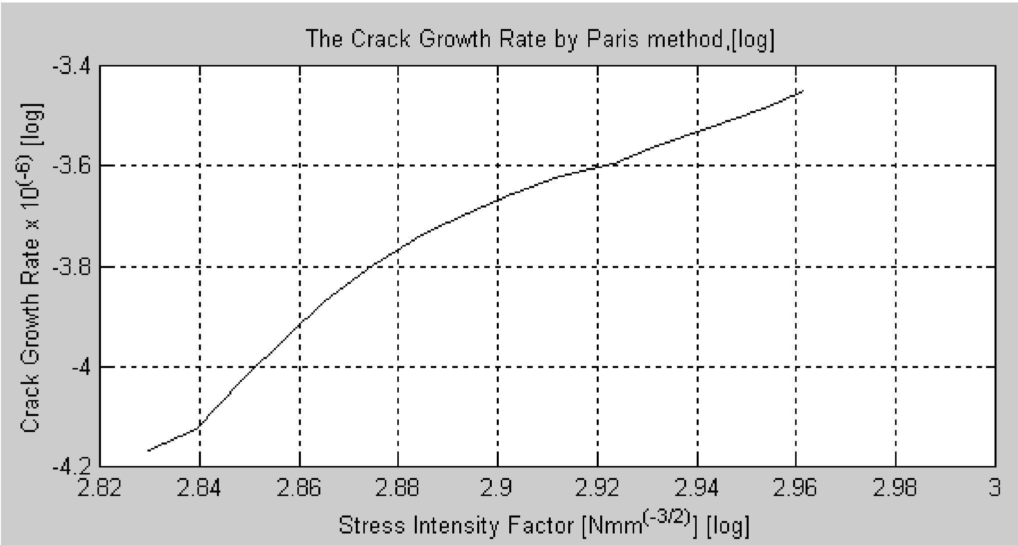

Fig. 3. The crack speed using Paris formula, bi-logarithmic coordinates

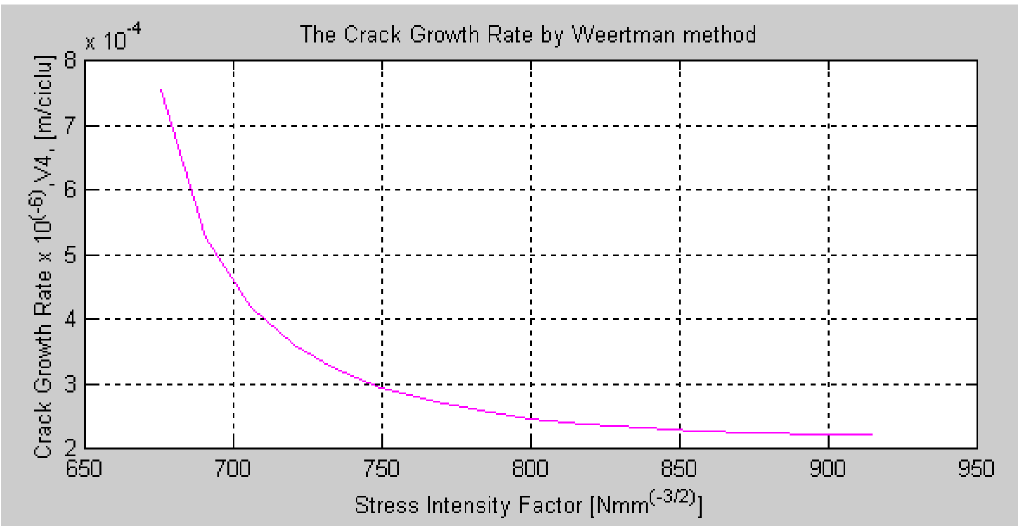

Fig. 4. The crack speed using Weertman formula

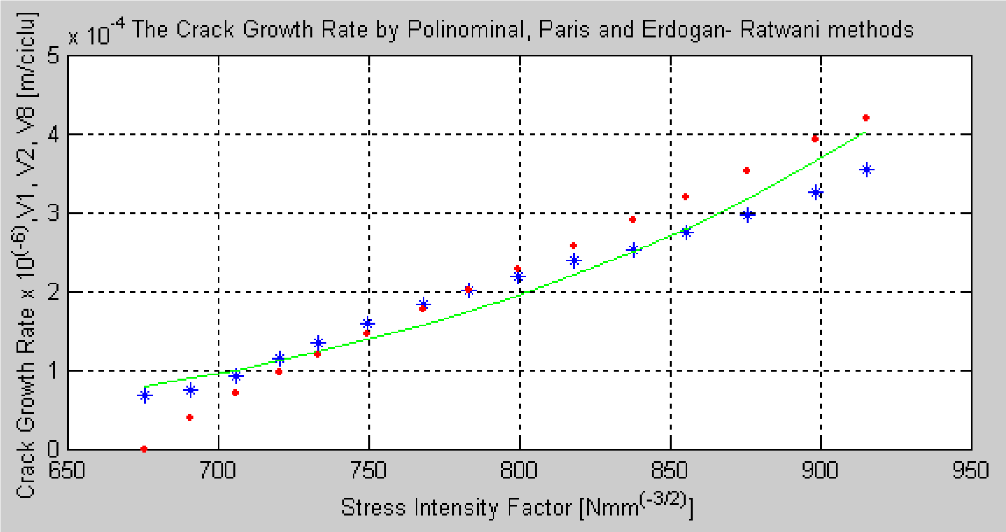

Fig. 5. The crack speed using the methods:
Polynomial (**), Paris (--) and Erdogan- Ratwani (..)

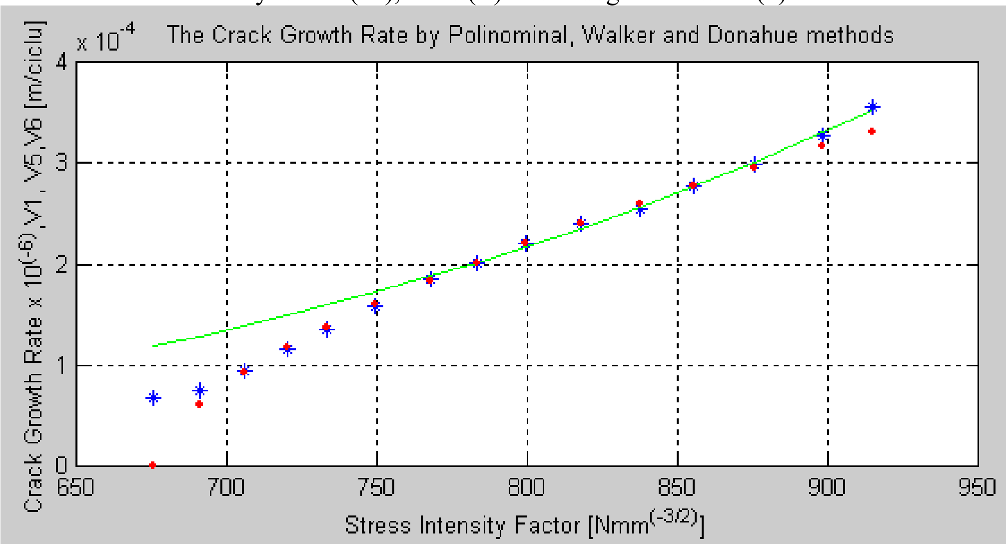

Fig. 6. The crack speed using the methods:
Polynomial (**), Walker (--) and Donahue (..)

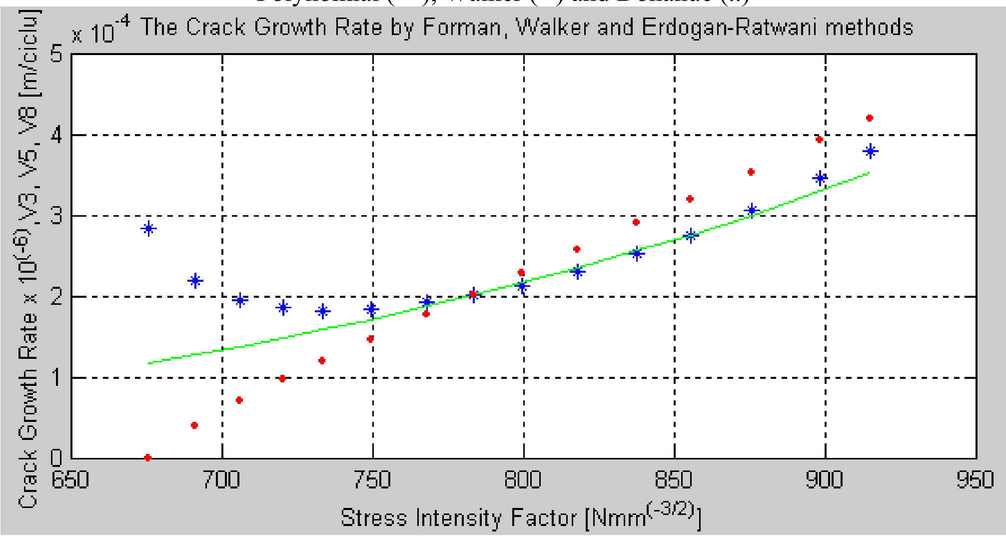

Fig. 7. The crack speed using the methods:
Forman (**), Walker (--) and Erdogan- Ratwani (..)

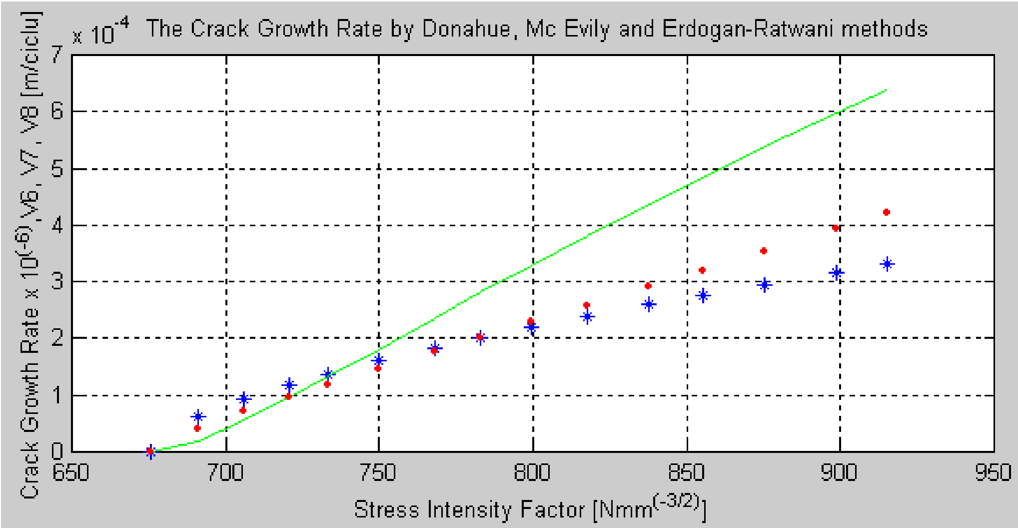

Fig. 8. The crack speed using the methods:
Donahue (**), Mc Evily (--) and Erdogan- Ratwani (..)

Commentaries

For all graphical representations, the variation domain of the SIF is between $\mathbf{\Delta K_p}$ and $\mathbf{K_c}$, i.e. between 676 $MPa\cdot\sqrt{mm}$ and 915 $MPa\cdot\sqrt{mm}$. This represents the stable propagation domain of the crack.

- According to the Paris formula, the speed **da/dN** = **V2**, varies between $1.144\cdot10^{-4}$ m/cycle and $2.673\cdot10^{-4}$ m/cycle, when the suddenly fracture of the sample is occurred. The graphical representations are presented in Figures 2 and 3, respectively, in bi-logarithmic coordinates.
- In Figure 5 the graphical representations of the crack propagation speeds using the polynomial methods, Paris formula, and Erdogan-Ratwani are presented. It can observe a group of the obtained values around the Paris curve, with a very low dispersion of the results. The variation boundaries are about $70\cdot10^{-6}$ m/cycle and approximate $360\cdot10^{-6}$ m/cycle.
- Simultaneously are, also, represented, in Figure 6, the polynomial variation, Walker variation, and Donahue model. It can observed that the propagation, according the Walker models, is more fast, between **ΔK**=670 $MPa\cdot\sqrt{mm}$ and **ΔK**=780 $MPa\cdot\sqrt{mm}$. After that, the three curves are, approximate, identical.
- An acceptable distribution it can be observed in Figure 7, where are represented the graphical representations according Forman formula, Walker formula, and Erdogan-Ratwani relation, respectively. There it can be an observation, namely, after the Forman model, the speed **da/dN** ≡ **V3** decreases with the factor **ΔK** increasing to 780 $MPa\cdot\sqrt{mm}$, then it begin to increase slowly, as the other two variants.
- In Figure 8 are represented, jointly, the crack propagation speed, according to Donahue formula, McEvily relation, and Erdogan-Ratwani model. There, the curves it can reciprocally supply to the **ΔK**=750 $MPa\cdot\sqrt{mm}$ value. After that the McEvily model impose a much more speed like the other two. The variation it is corresponding to a straight line.
- In Figure 4, a different situation that corresponds to the speed variation **da/dN** = **V4**, according to the Weertman model. There it is continuously decreasing, following the exponential function, from a $7.5\cdot10^{-6}$ m/cycle to a $2{,}2\cdot10^{-6}$ m/cycle value, in the sample fracture moment.

It can be mentioned that these variation are in contradiction with all, above presented, variants. For this reason, it is not recommended to use the Weertman model for the 10TiNiCr175 steel.

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Studiul propagării fisurii folosind modele experimentale pentru viteza de fisurare într-un oțel inoxidabil

Rezumat

*Folosind un oțel inoxidabil marca 10TiNiCr175, au fost încercate câteva epruvete plate, model CT, cu crestătură laterală. Acestea au fost solicitate prin cicluri de încărcare oscilante pozitive de tracțiune excentrică, cu coeficientul de asimetrie R=0,3. Temperatura de încercare a fost T=253K (-20ºC). Folosind metoda polinomială, în concordanță cu standardul ASTM E647, s-a determinat viteza de propagare a fisurii **da/dN** şi factorul de intensitate a tensiunii **ΔK**.*