VARIANTS OF ANALYSIS OF THE PROPAGATION RATE OF THE CRACK TO THE AXIAL CYCLIC SOLICITATION FOR THE VARIATION OF THE WORK TEMPERATURE

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Abstract: Through this work, it is proposed the study of the increase rate of the crack da/dN, for a solicitation to fatigue through eccentric monoaxial straightening, in a sample made of steel for boilers and recipients mark R 520. There are analyzed variants for the cracking rate: the standardized polynomial method, the method of Paris' formula, the secant method and the simple polynomial method. The samples have been solicited with the asymmetry coefficient R=0.3, for the following temperatures: 293 K, 253 K and 293 K. The equipment used was a hydraulic installation with one pulsator, with the possibility of regulating the asymmetry coefficient R. For low temperatures was mounted on the machine a frigorific precincts cooled with liquid nitrogen. During the attempt we have noted the variation of the crack's length a_i and the numbers of solicitation cycles N_i with the data obtained and the solicitation tasks we have calculated the stress intensity factor ΔK and the tension σ at the top of the crack. With the parameters calculated above we passed to tracing some graphics for the cracking rate in report to SIF ΔK, $V(\Delta K)$, the rate in report to the durability N, V(N), respectively, in report to the tension σ, $V(\sigma)$. We have drawn these curbs for the three attempt temperatures.

Key words: crack, tension stress, cracking rate, stress intensity factor, cyclic load.

1. INTRODUCTION

The phenomenon of fatigue of the materials is defined as a physical process determined by the appearance of one or many cracks which advances in the material mass because of the repeated application of a cyclic load. Variable loads activates in general the surface defects. Those can be identified through visual contact, with penetrating liquids with magnetic powder or other techniques. At great parts thicknesses the defect's dimensions are estimated through ultrasonic control radiographic, acoustic emission, etc. In numerous cases it can be established if a crack (defect) resulted because of an fatigue process through the breaking surfaces analysis and the identification of some features common to breakings through the variable loads. At the microscopic scale it is noticed that the initiation of the fracture through fatigue takes place under the form of micro-cracks which are spreading in length of some slipping planes with an orientation of about 45° towards the main maximum tension.

The crack propagation process is characterized through the orientation change of the breaking towards a perpendicular plane on the direction of the main maximum tension. The fracture through fatigue doesn't occur suddenly in the entire section of a part or mechanical structure. The initiation of the crack phase and the spreading of this one respectively are successively covered.

The final fracture is produced when one of the cracks reaches the critical length, moment in which a frail breaking is released or a material overloading breaking from the remaining section. The evolution of the crack during its spreading it can be followed in the simplest way by a diagram of the form $a=a(N)$, where a is the length of the crack and N is the number of cycles loads. One of the basic parameters through which the breaking through fatigue is measured is the crack propagation rate *da/dN* which represents the length by which one cycle load crack is spread. This depends on the initial crack length and of the level or the extent of the applied tension.

These sizes come in the expression of another parameter of the fracture mechanics called stress intensity factor noted by *K*. The raise of the initial length of the crack and of the level of the stress determines a rising of the propagation rate of the fatigue crack. This can be colligated with the variation of the stress intensity factor *ΔK* through relations under the form *da/dN=f(ΔK).*

2. THE CRACK PROPAGATION RATE. CALCULATIONS EXPRESSIONS

On the basis of the Fracture Mechanics were produced empirical relations between the sizes *da/dN* and *ΔK* which controls the material's breaking process and which have been experimentally verified.

For the flat, compact tests, CT model with side notch, put to eccentric traction it calculates the variation of the stress intensity factor with the relation (1);/3/;/4/:

$$\Delta K = \frac{\Delta P}{B\cdot\sqrt{W}}\cdot\frac{2+\alpha}{\sqrt{(1-\alpha)^3}}\left(-5{,}6\cdot\alpha^4+14{,}72\cdot\alpha^3-13{,}32\cdot\alpha^2+4{,}64\cdot\alpha+0{,}886\right), \tag{1}$$

where α=a/W, and $0{,}2 \leq \alpha \leq 1$.

In the paper are highlighted few variants for the calculation of the crack propagation rate. These are presented in the order in which they are analyzed:
1. standardized polynomial method;
2. in accordance with Paris' formula;
3. the secant's method;
4. simple polynomial method.

In accordance with standard polynomial method, /1/, /4/, it is having in view the establishment of a second degree polynomial, through the polynomial interpolation of the values $\boldsymbol{a_i}$ in (2n+1) successive measure points (usually n=3). For a certain reading $\boldsymbol{(N_i, a_i)}$ it is written the expression of the interpolation polynom $\overline{a}(N)$:

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

where:

$$C_1 = \frac{N_{i-n}+N_{i+n}}{2};\quad C_2 = \frac{N_{i+n}-N_{i-n}}{2};\quad 1 \geq \frac{N_i-C_1}{C_2} \geq -1\ . \tag{3}$$

For each frequent, through the smallest square's method, it is determined the polynomial coefficients A_1, A_2 and A_3. For a crack length $\overline{a}_i$, the crack propagation rate through this method, $\mathbf{V_1}$, it is obtained through derivation of the expression (2):

$$V_1 \equiv (da/dN)_{\overline{a}_i} = \frac{A_2}{C_2} + 2\cdot\frac{A_1}{C_2^2}\cdot(N_i-C_1) \tag{4}$$

Based on the Paris' formula, the growth crack rate it is calculated with the relation (5):

$$V_2 \equiv \left(\frac{da}{dN}\right)_{\overline{a}_i} = C_P\cdot(\Delta K)^{m_P}\ . \tag{5}$$

Parameters $\boldsymbol{C_P}$ and $\boldsymbol{m_P}$ are material constants and they are determined using the above standard method with the condition that on the stabile propagation field of the defect the diagram should be in a straight line.
The secant method consists in calculation of the slope of the right line which unifies two consecutive points $(\boldsymbol{N_i, a_i})$ with $(\boldsymbol{N_{i+1}, a_{i+1}})$ **.** For this method the stress intensity factor is determined for an average length of the crack $\overline{a} = (a_{i+1} + a_i)/2$, and the cracking rate is calculated using the relation (6), /1/, /4/:

$$V_3 \equiv (da/dN)_{\overline{a}_i} = \frac{a_{i+1} - a_i}{N_{i+1} - N_i} . \tag{6}$$

Through the simple polynomial method it is resorted to approximations through parabolic of the second order of three consecutive points ($\boldsymbol{N_i, a_i}$):

$$\overline{\overline{a}}_i = B_3 + B_2 \cdot N_i + B_1 \cdot N_i^2 \tag{7}$$

The coefficients B_1, B_2, B_3, for each iteration are determined by applying the smallest square's method on by three point's successive groups. The cracking rate results through derivation of the relation (7) and it is calculated at the middle of the interval:

$$V_4 \equiv \left(\frac{da}{dN}\right)_{\overline{a}_i} = B_2 + 2 \cdot B_1 \cdot N_i . \tag{8}$$

The calculated values for the length of the crack $\overline{a}$, the stress intensity factor $\boldsymbol{\Delta K_i}$ respectively and the crack growth rates V_1,V_2,V_3 and V_4, are hold in the matrix with calculated data.

3. THE DEVICE AND THE PERFORMING OF THE TEST

For the suggested study have been executed flat samples CT types with side notch from general usage steel plate utilized for boilers and receptacles from chemical industry mark R520, /3/.

These have been subjected to a fatigue solicitation through eccentric stretching to an asymmetric coefficient R=0.3. There have been utilized three working temperatures: 293K (room temperature) and low temperatures 253K and 213K respectively. The trial installation is made out of an hydraulic pulsate with a maximum weight of 30 kN at 200 bars oil pressure, /3/.For low temperatures trials on the nose of the trial machine it was mounted a refrigerator precinct into which the test-tube is mounted, figure 1. As cooling agent it was used liquid nitrogen and the temperature measurement was made with a termometer with 1K precision.

Before starting the proper test it was done a pre-cracking of the samples at a crack length of $a_0 \approx 2{,}0$ mm keeping the initial number of cycles $\boldsymbol{N_0}$, too. This stage represents the touching of the limit stress intensity factor ΔK_{th}. From this moment on breaking crack enters in the stable propagation phase which usually

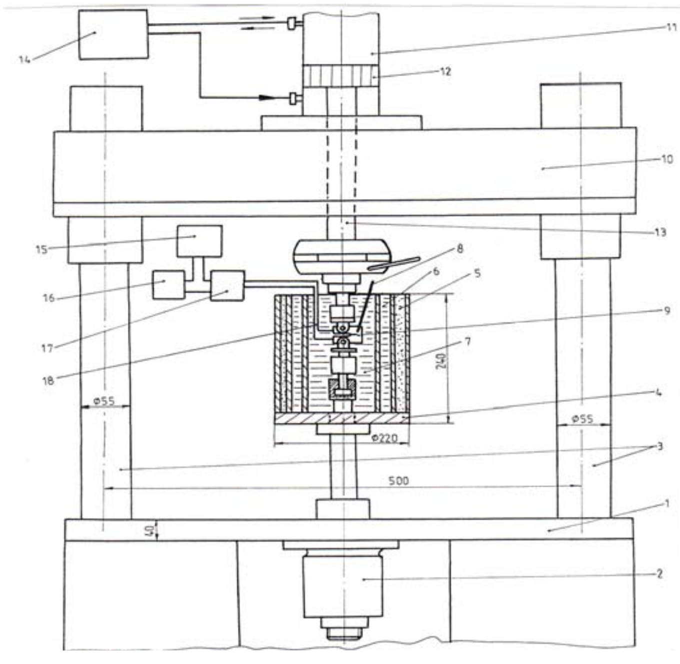


Fig.1. The test machine with frigorific precincts

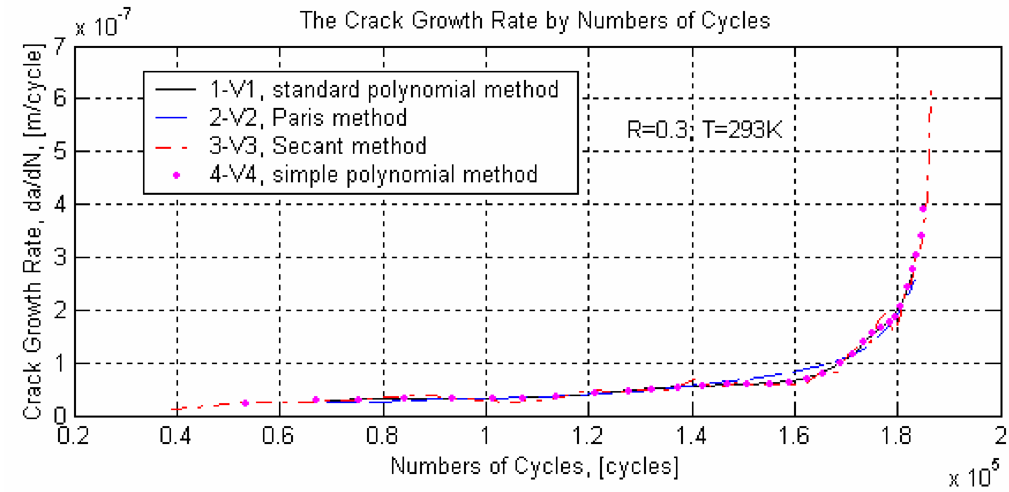
maintains a linear variation between the cracking propagation rate *da/dN* and the stress intensity factor *ΔK*. The variation of the crack length is followed with the help of an optical microscope fitted on the machine's frame. It was noted the crack length variation a_i at 0.25 mm intervals and it was retained the number of cycles adequate to N_i. For the lowered temperatures the variation for the crack length was determined through the elastic compilation method, /1/, /3/. These measures (N_i, a_i) are making the primary values which intervenes in the numeric calculation programme made for the chosen study. These elements were determined for all the samples tested at the load coefficient R=0.3 and at temperatures 293K, 253K and 213K.

4. EXPERIMENTAL DATA PROCESSING

In accordance with the study methodology of the Fracture Mechanics it was made a calculation programme for the purpose of determination of the imposed characteristics. As the entry measures experimental data (N_i, a_i) were used. There were calculated crack growth rates in accordance with the four variants (V_1, V_2, V_3 and V_4) stress intensity factor's variation ΔK_I respectively for the fatigue strain through the eccentric traction. The study was conducted at the asymmetric coefficient R=0.3 and for the 293K, 253K and 213K temperatures.

With the obtained results were made the following types of diagrams:
- cracking rates $\mathbf{V_1}$, $\mathbf{V_2}$, $\mathbf{V_3}$ and $\mathbf{V_4}$ related with **N** cycles, figure 2;
- cracking rates $\mathbf{V_1}$, $\mathbf{V_2}$, $\mathbf{V_3}$ and $\mathbf{V_4}$ according to the crack length ***a*** , figure 3;
- crack propagation rates $\mathbf{V_1}$, $\mathbf{V_2}$, $\mathbf{V_3}$ and $\mathbf{V_4}$ according to the variation of the tension intensity factor **ΔK**, figure 4;
- crack growth rate according to Paris' relation ($\mathbf{V_2}$) related to the tension intensity factor **ΔK** at the bilogarithmical scale, figure 5.

In each figure are shown the running for the three testing temperatures.



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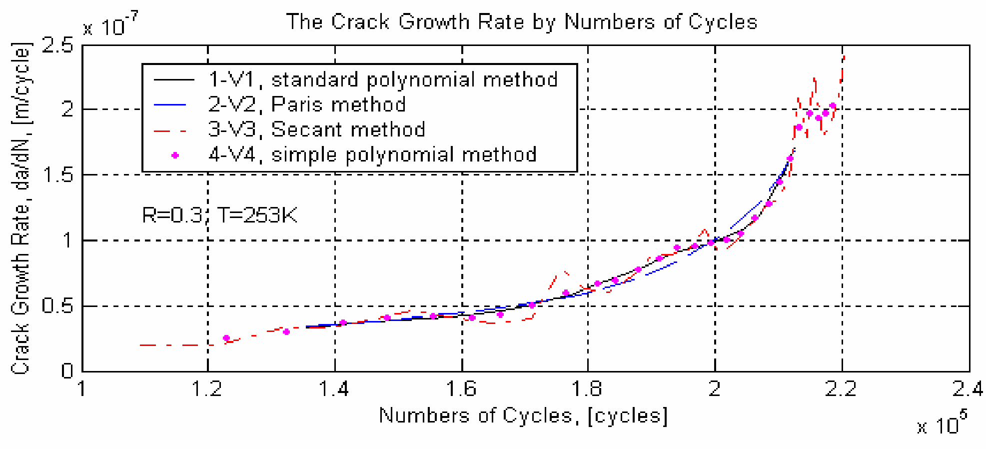

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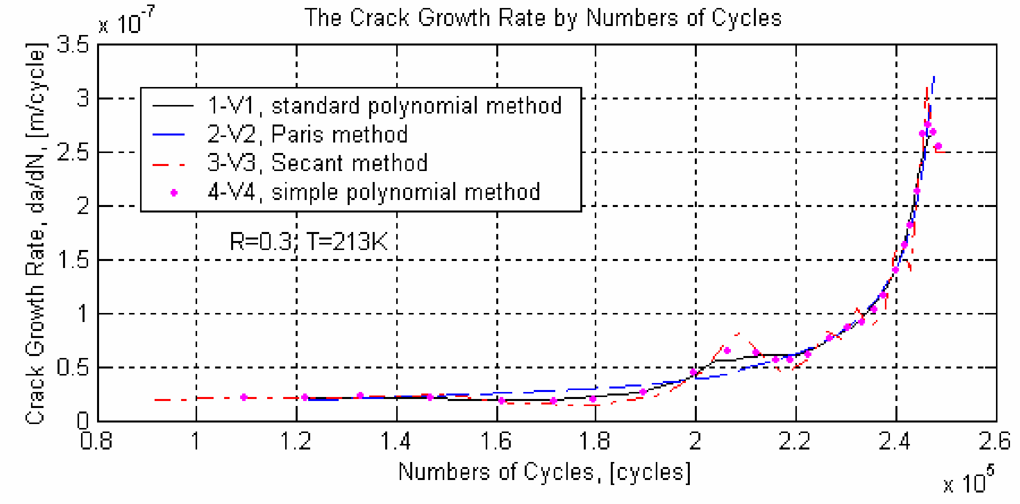
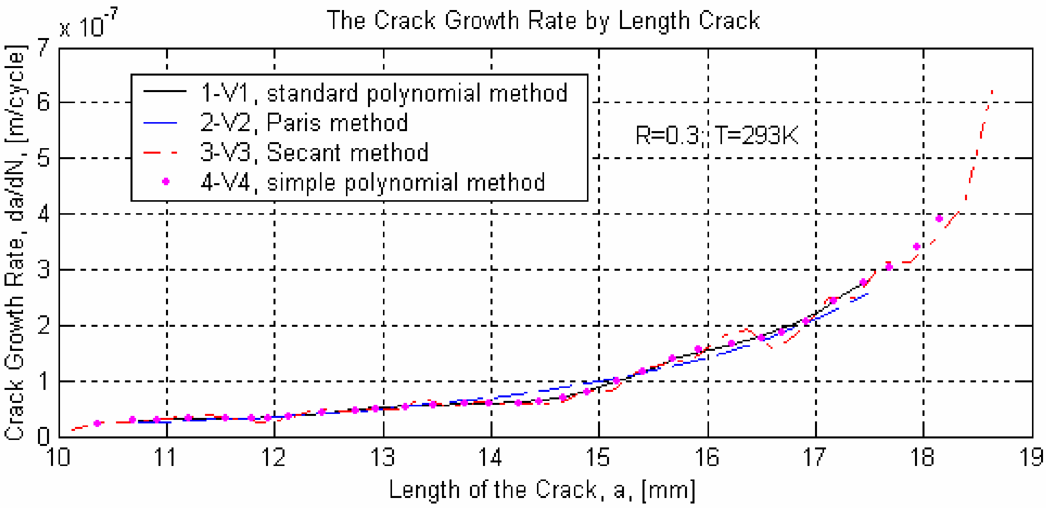


c.

Fig.2. The Crack Growth Rate Versus Durbility



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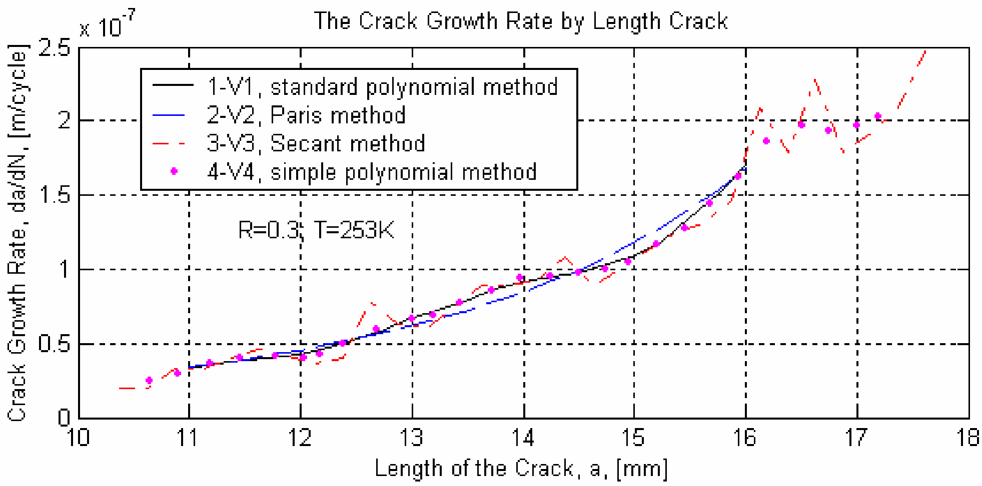

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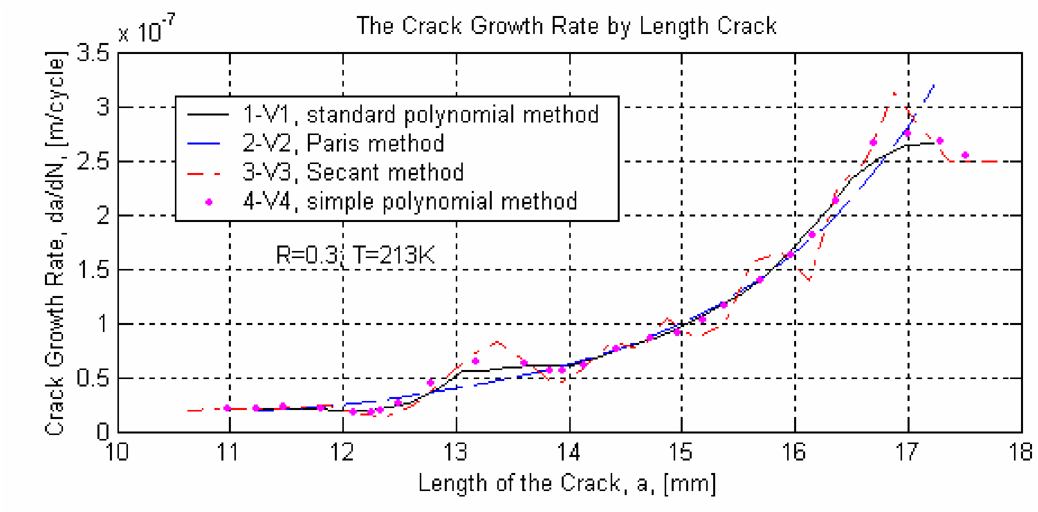

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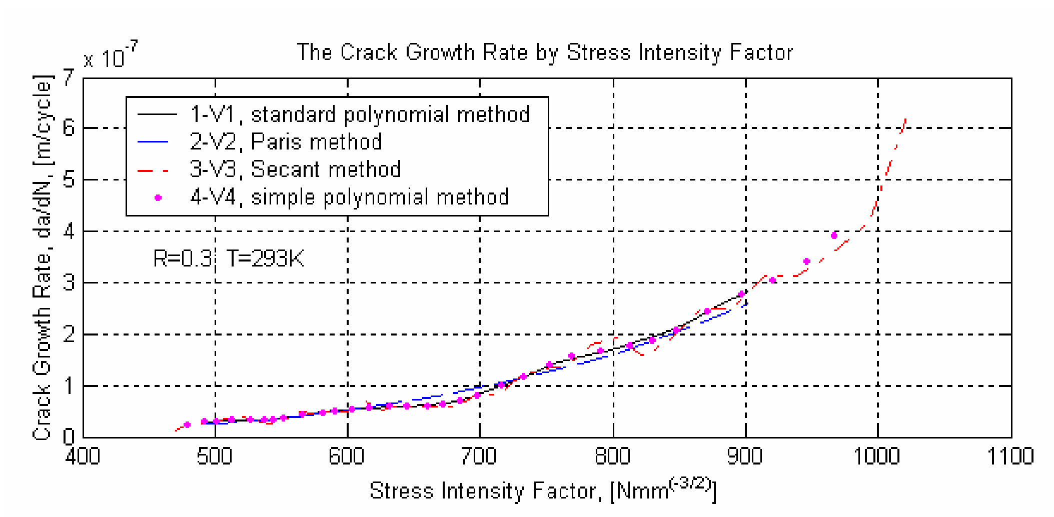
Fig.3. The Crack Growth Versus Length of Crack



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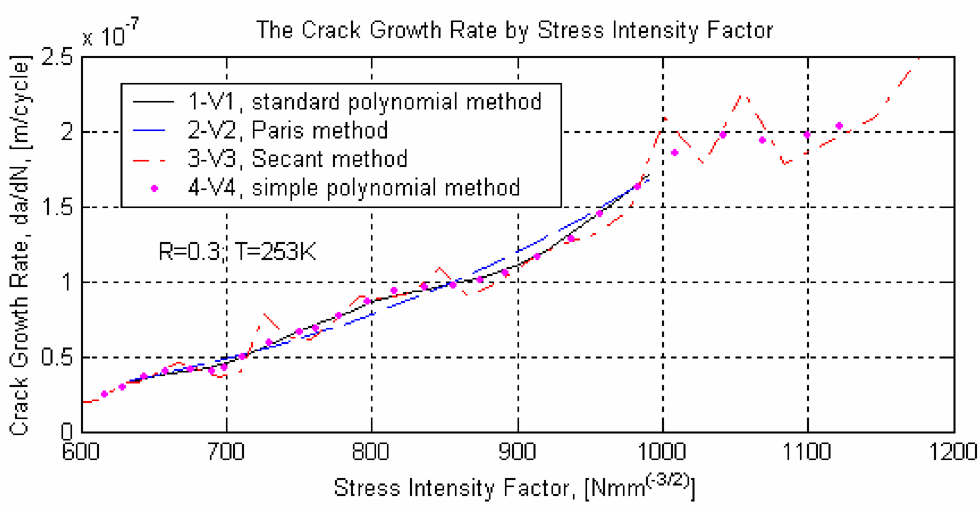

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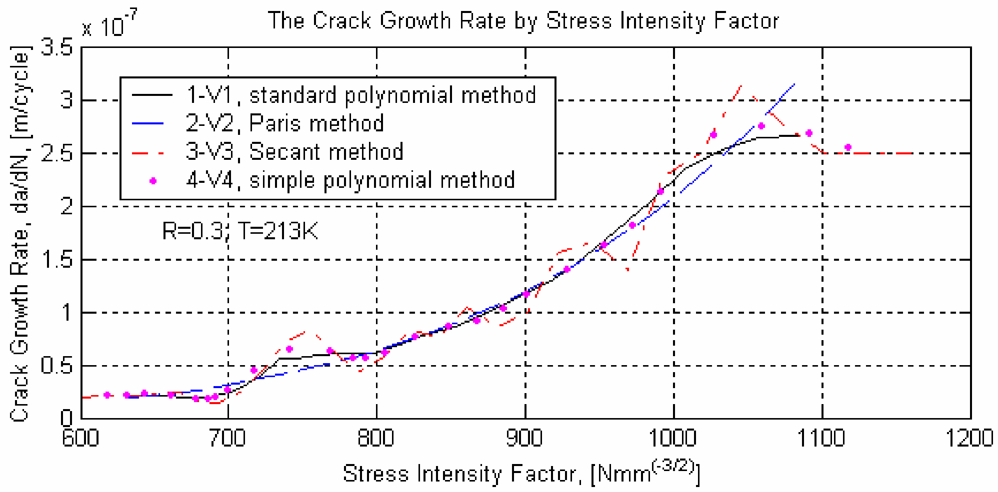

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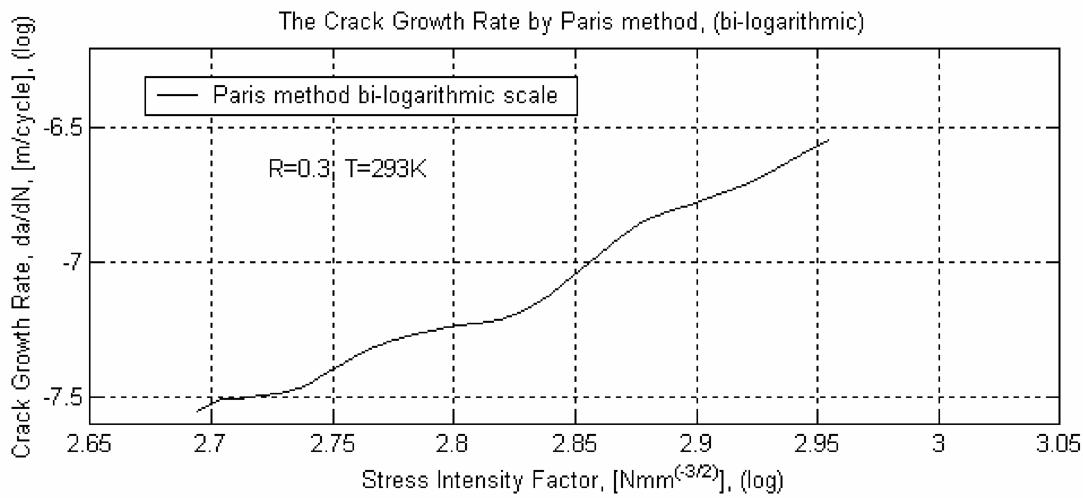
Fig.4. The Crack Growth Rate by Stress Intensity Factor



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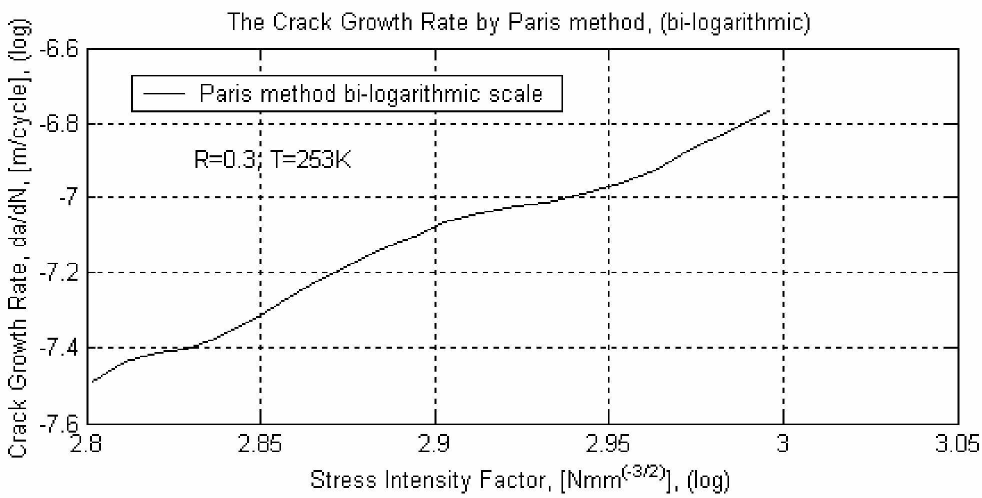

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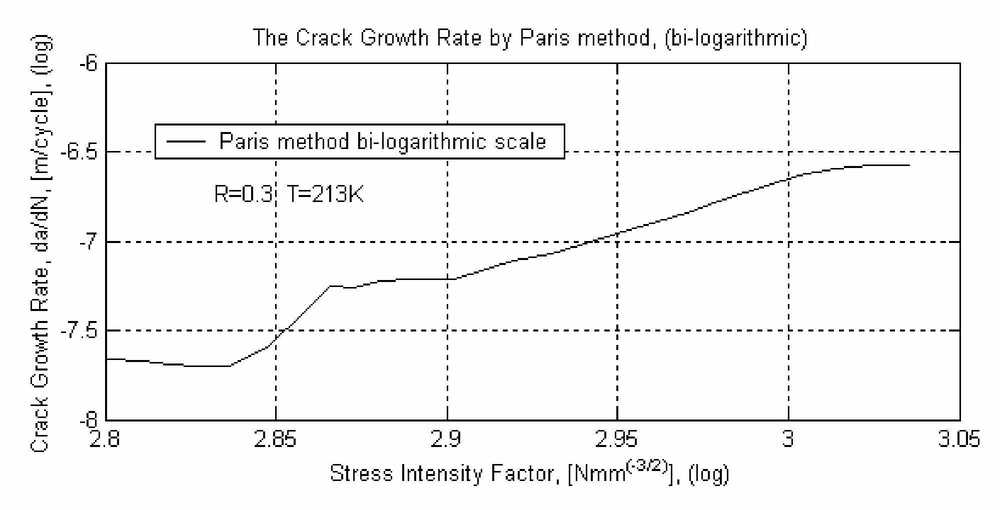

c.

Fig.5. The Crack Propagation Rate by Paris Method

5. CONCLUSIONS

From a brief analysis of all drawn diagrams it can be noticed that for the four calculation variants of the crack propagation rate the obtained values are slightly equal. For certain fields the runnings are overlapping or are very close to one another. For each temperature the cracking rate through the polynomial standard method (V_1) has greater values and through the secant method (V_3) resulting the smallest values.

At the 293K temperature the rates varies between $1{,}24\cdot10^{-8}$ m/cycle and $6{,}25\cdot10^{-7}$ m/cycle, for T=253K rates are between $2\cdot10^{-8}$ m/cycle and $2{,}5\cdot10^{-7}$ m/cycle, T=213K respectively, these increasing to the $1{,}83\cdot10^{-8}$ m/cycle and $3{,}21\cdot10^{-7}$ m/cycle. **N** durability oscillates in this way: between 39.000 and 186.300 cycles at normal temperature, between 109.000 cycles and 220.000 cycles for temperature of 253K, respectively the domain (91.800-250.000) cycles at T=213K. The domains for the stress intensity factor are depending as well of the testing temperature having the following values: (470-1020)$N\cdot mm^{-3/2}$ for the rooms' temperature, (600-1180)$N\cdot mm^{-3/2}$ at the 253K temperature, respectively (630÷1170)$N\cdot mm^{-3/2}$ related to T=213K.

All these aspects can be observed in the graphical part in the figures 2, 3 and 4.

In figure 5 for the three temperatures represented at the biologarithmical scale of the raising cracking rate related to the stress intensity factor is approximately linear. The slope of the respective straight lines is given by the value of the material coefficient and not from the Paris' formula.

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