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The Temperature – Influence Factor over the Crack Growth Rate in R520 Steel Specimens

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Abstract

The defects that exist in the body of certain products or the ones that appear during their working grow continuously, determining in the end the element fracture. There were made fatigue testings eccentric tensile on CT model specimens, with side notch made from R520 general steel. The loading asymmetry coefficient was R = 0.3, and the loading temperature were:293K, 253K and 213K, (+20℃, -20℃ and -60℃). The studies for the crack propagation rate variation, versus the defect length, respectively versus the stress intensity factor, were made by using some empirical mathematical models, presented by the researchers in this field. The variation graphics were drawn for the three temperatures, simultaneously considered.

Key words: *crack, crack growth rate, stress intensity factor, fatigue*

Analysis Preparation

A full study regarding the material behaviour during the product working, by making a qualitative assessment of its mechanical characteristics can be made by using the new concepts of Fracture Mechanics. The fracture of a strength element can exist or appear because of a micro-crack that grows in the product surface, as a result from an applied variable loading. The defect propagation involves the existence of three phases: the fracture crack initiation, the crack stable and slow propagation, respectively its fast propagation, stage that leads to the element or specimen fracture, [4, p.205].

The most important parameter that characterizes the defect (crack) propagation is the crack propagation rate, **d*a*/d*N***, which represent the defect length variation marked with *a* in a variable loading cycle.

In order to achieve the proposed target by the paper title, oscillatory fatigue testings were made, by axial-eccentrical tensile. The loading material was R520 general steel, the specimens were CT type, with side notch, Figure 1 [7]. In the beginning, there were determined the mechanical characteristics at a static tensile, R_m and R_{p02}, at an universal testing machine.

The loading testing was made on a hydraulic device SCHENK type with maximum loading of 30 kN. The loading frequency was 5Hz. The loading asymmetry coefficient was R=0.3, meaning F_{max}=4835N and F_{min}=1433N. Three loading temperatures were used: T=293K (20°C)

– room temperature, T=253K (-20°C) and T=213K (-60°C) – negative temperatures. For these a cool storage room was mounted on the testing machine, Figure 2 [7].

An initial crack was firstly made for all the loaded specimens, with a defect initial length a_0≈2.0mm, sided in the notch plane, that correspond and initial cycle number N_0. From this moment it can be considered that the crack propagation is placed in the second domain, the stable propagation domain, Figure 2.11/46/[5]. The crack length variation a_i is marked at 0.25 mm gaps and the corresponding N_i loading cycles.

The Test

Alongside the **d*a*/d*N*** crack growth rate, another fracture mechanics parameter that includes the stress state σ that exist at the crack peak and the defect length variation a, is the stress intensity factor variation, marked with ΔK, that can be determined with a general relation like (4.34)/59/[4]:

$$\Delta K = C \cdot \Delta\sigma \cdot \sqrt{\pi a}\ . \tag{1}$$

For different specimen shapes and certain loading ways, various authors have given calculus empirical relations for the stress intensity factor. So, a calculus relation that is mostly used for the CT specimens loaded to eccentrically tensile test is given in relation (2), [5, p. 36]/[7, relation 4]:

$$\Delta K = \frac{\Delta F}{B \cdot W^{1/2}} \cdot \frac{2+t}{\left(1-t\right)^{3/2}} \cdot \left[-5,6 \cdot t^4 + 14,72 \cdot t^3 - 13,32 \cdot t^2 + 4,64 \cdot t + 0,886\right]. \tag{2}$$

In the above relation, $t=a/w$ is the crack length relative variation; B – the specimen thickness; W – the specimen width; ΔF – the loading force variation.

For the design and furthermore for following a product during the working time, it is very important to analyze the defect increase rate in its body, **d*a*/d*N***. Two studying directions can be highlighted:

- the **d*a*/d*N*** rate variation versus crack length a variation;
- the **d*a*/d*N*** rate variation versus the stress intensity factor (S.I.F.) ΔK.

For a comparative study of the crack propagation rate **d*a*/d*N***, we have limited to three models:
1 – sequential polynomial method presented in the ASTM E647 standard [9], used also in [5, p.82]/[8, p. 146];
2 – method based on Paris formula [3, p. 191]/[4, p. 204]/[8, p. 42];
3 – method based on Walker empiric formula [4, p. 209]/ [1, p. 145].

According to the American ASTM E647 standard, the **sequential polynomial method** impose to determine a second degree polynom for crack length variation $a(N)$, by successive interpolation through (2n+1) consecutive measuring points (n=3is used), relation given in (3):

$$a_i(N) = A_3 + A_2 \cdot \frac{N_i - C_1}{C_2} + A_1 \cdot \left(\frac{N_i - C_1}{C_2}\right)^2 \equiv a_1(N)\,. \tag{3}$$

The indirect variables C_1 and C_2 are determined with (4):

$$C_1 = \frac{N_{i+n} + N_{i-n}}{2};\ C_2 = \frac{N_{i+n} - N_{i-n}}{2} : -1 \le \frac{N_i - C_1}{C_2} \le 1\ . \tag{4}$$

The interpolation polynom factors A_1, A_2 and A_3 are determined for each iteration by using the least-squares method. Finally, at the middle of each gap, the crack growth rate is successively calculated, by the relation (3) derivation:

$$\frac{da}{dN} = V_1 = \frac{A_2}{C_2} + 2 \cdot \frac{A_1}{C_2} \cdot \frac{N_i - C_1}{C_2} \quad . \tag{5}$$

For the followed domain at the loading machine, with the stress intensity factor variation **ΔK** determined with (2), the crack rate **d*a*/d*N*** is approximated with the **Paris formula**, relation (6):

$$\frac{da}{dN} = V_2 = C_2 \cdot (\Delta K)^{m_2} \ , \tag{6}$$

and the C_2 factor is determined and the m_2 degree. In the same way, for the same domain, the propagation rate **d*a*/d*N*** is approximated with the **Walker relation** (7):

$$\frac{da}{dN} = V_3 = \frac{C_3 \cdot (\Delta K)^{m_3}}{(1-R)^{\gamma}} \quad . \tag{7}$$

Also, the material parameters C_3, m_3 and γ are determined and are continuously further needed for V_3 rate calculus.

Graphical Adaptation and Comments

In the experimental phase, according to paragraph 1 methodology, the next measures were set: a_i – the defect length read in 0.25 mm steps and its corresponding loading cycles numbers marked with N_i. With these primary data, a numerical calculus program was realized, in which, following the 2 paragraph course, there were computed:

- stress intensity factor variation ΔK, with relation (2);
- crack theoretical length a_1, with relation (3);
- cracking rate V_1 according to **polynomial method**, with relation (5);
- cracking rate V_2 using **Paris formula**, with relation (6);
- crack growth rate according to **Walker relation**, marked with V_3, by relation (7).

With the numerically obtained values, the next curves are drawn:

- V_1, V_2 and V_3 rates variation on the same graphics, in comparison with crack theoretical length variation a_1, for asymmetry coefficient R = 0.3, at temperatures: T = 293 K, Figure 1, T = 253 K, Figure 2, T = 213 K, Figure 3;
- V_1, V_2 and V_3 rates variation on the same graphics, in comparison with stress intensity factor variation ΔK, at asymmetry coefficient R = 0.3 for temperatures: T = 293 K, Figure 4, T = 253 K, Figure 5, T = 213 K, Figure 6;
- V_1 cracking rates variation, according to **standard method**, for the **three temperatures** on the same graphic, at the asymmetry coefficient R = 0.3, depending on stress intensity factor ΔK, Figure 7;
- Similarly for V_2 rates, according to **Paris formula**, Figure 8;
- Similarly for V_3 rates, according to **Walker relation**, Figure 9.

From the drawn graphics and tables with computed values for crack propagation rates, V_1, V_2 and V_3, it is observed that the stress intensity factor ΔK ranges between 615 $N \cdot mm^{-3/2}$ and 965 $N \cdot mm^{-3/2}$, at T = 293 K, between 634 $N \cdot mm^{-3/2}$ and 991 $N \cdot mm^{-3/2}$, at T = 253 K, respectively between 646 $N \cdot mm^{-3/2}$ and 1084 $N \cdot mm^{-3/2}$, namely a curve displacement to bigger values, when testing temperature decreases.

Generally, V_1, V_2 and V_3 rates increase from near $23 \cdot 10^{-6}$ m/cycle, to near $300 \cdot 10^{-6}$ m/cycle, with a bigger increase for V_3 rate, when Walker variant. This increase is a lot bigger for the same rate when the testing background temperature decreases at 213 K, Figures 2 and 6.

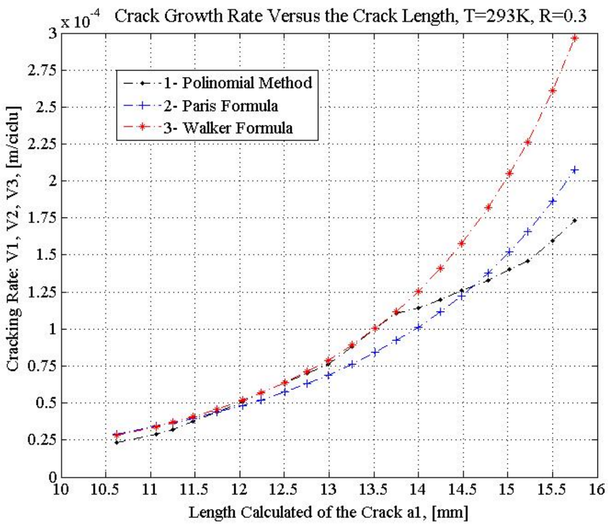

Fig. 1. The crack growth rates versus the crack length for $T = 293$ K

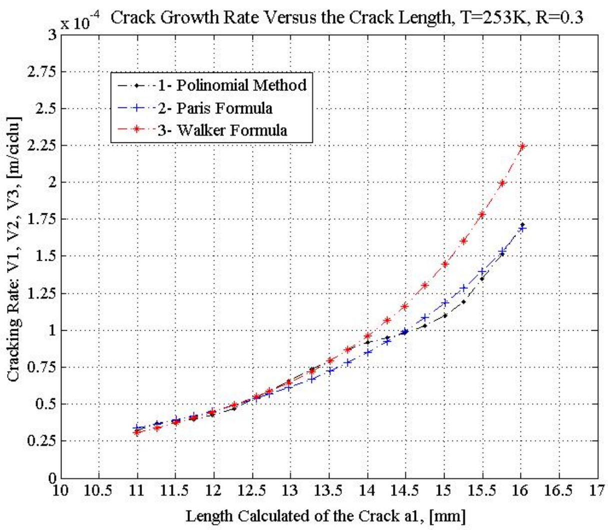

Fig. 2. The crack growth rates versus the crack length for $T = 253$ K

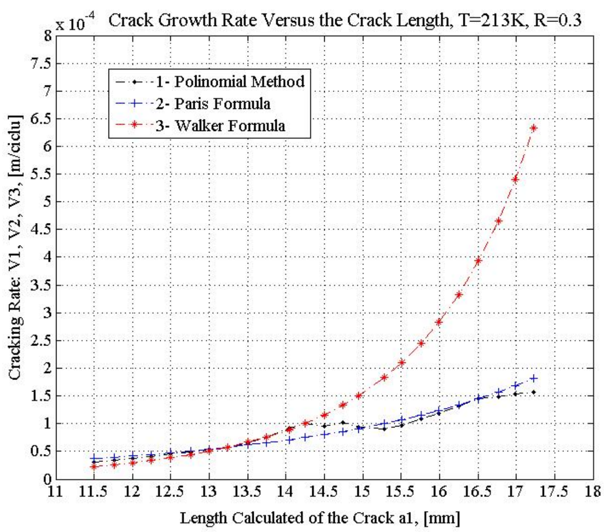

Fig. 3. The crack growth rates versus the crack length for $T = 213$ K

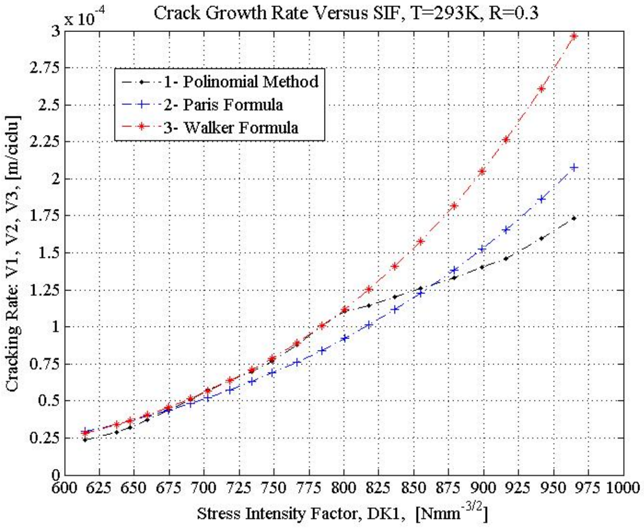

Fig. 4. The crack growth rates versus the SIF ΔK for $T = 293$ K

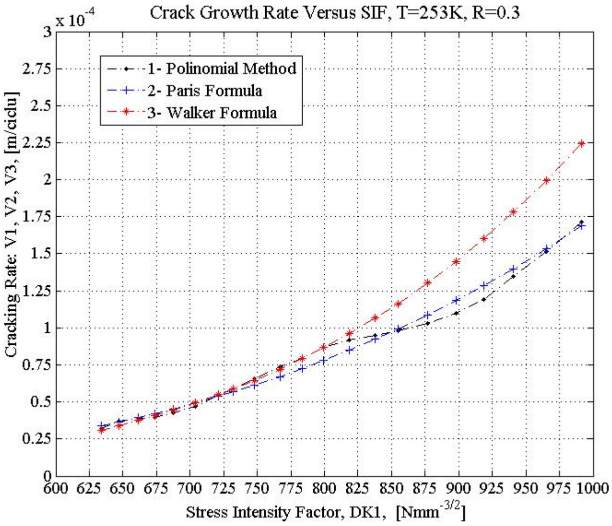

Fig. 5. The crack growth rates versus the SIF ΔK for $T = 253$ K

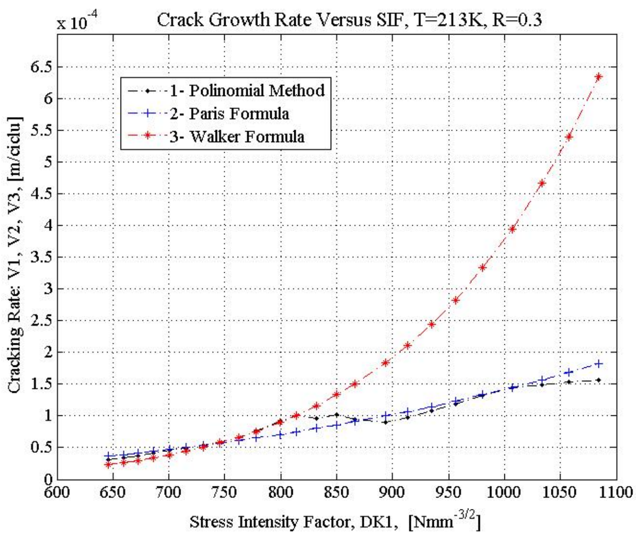

Fig. 6. The crack growth rates versus the SIF ΔK for $T = 213$ K

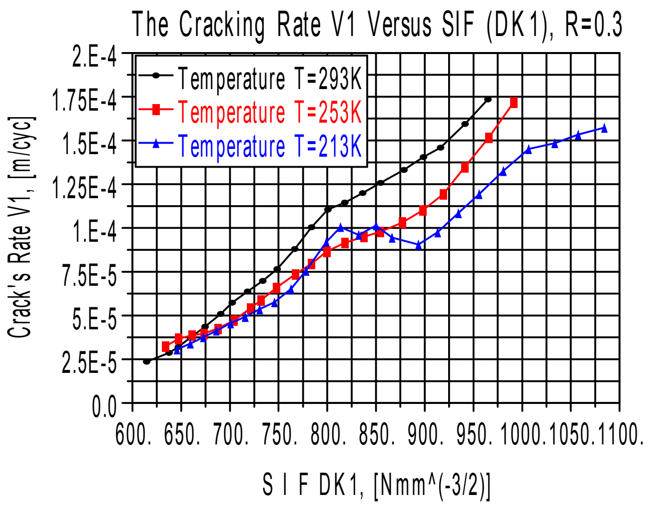

Fig. 7. The crack growth rates V_1 versus SIF ΔK

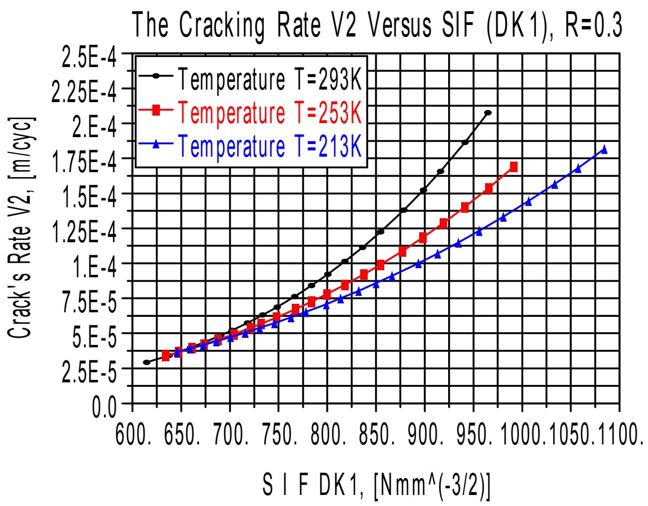

Fig. 8. The crack growth rates V_2 versus SIF ΔK

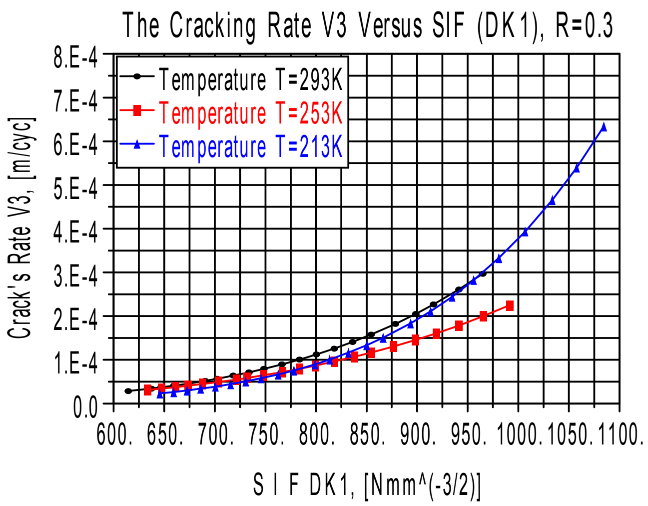

Fig. 9. The crack growth rates V_3 versus SIF ΔK

For crack smaller lengths, to $a_1 \approx 14$ mm, the propagation rate **d*a*/d*N*** has good values in all the three variants, afterwards V_3 rate more rapidly increases (see all drawn graphics).

Concerning Figures 7, 8 and 9, where V_1, V_2 and V_3 rates are severally presented, but for all three simultaneously temperatures, a value grouping is observed to $\Delta K \approx 850$ N·mm$^{-3/2}$ factor. Afterwards, a light dispersion of the respective curves parted by temperature is produced.

By a general conclusion, it can be said that, for crack smaller lengths, the comparable and satisfying results are obtained for all three suggested models: ASTM method, Paris method and Walker method.

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Temperatura – factor de influenţă asupra vitezei de creştere a fisurii în epruvete din oţel R520

Rezumat

Defectele existente în corpul anumitor piese, sau cele care apar în timpul funcţionării acestora, se dezvoltă continuu, determinând în final ruperea elementului respectiv. Au fost efectuate încercări la oboseală prin întindere excentrică pe epruvete model CT, cu crestătură laterală, executate din oţel de uz general R520. Coeficientul de asimetrie al solicitării a fost R = 0,3 pentru temperaturile de încercare 293K, 253K şi 213K, (+20℃, -20℃ şi -60℃). Studiile pentru variaţia vitezei de propagare a fisurii, în raport cu lungimea defectului, respectiv în funcţie de factorul de intensitate a tensiunii, au fost realizate în baza mai multor modele matematice empirice, propuse de cercetătorii în domeniu. Graficele de variaţie au fost trasate pentru cele trei temperaturi, considerate simultan.