THE ANALYSIS OF THE DURABILITY WITH THE VARIATION OF THE TEMPERATURE TO AN ECCENTRIC AXIAL SOLICITATION FOR R=0.5 IN THE STEEL 10 TiNiCr 175

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Abstract: The durability of a first part submitted to fatigue during the service is a very important parameter in the safety of a mechanic structure's functioning. This thing is necessary both the environmental temperature and to low temperatures. For a stainless steel, mark 10 TiNiCr 175 fatigue attempts were made through eccentric straightening, with the asymmetry coefficient R=0.5, on the temperatures T=293 K, T=253 K and T=213 K. For the low temperatures (253 K and 213 K) we mounted on the attempt machine a frigorific chamber cooled with liquid nitrogen. During the attempt we have kept in mind the variation of the crack's length a_i and the durability N_i. The samples tested had type CT, with lateral notch. We calculated according to the ASTM norm the stress intensity factor ΔK at the top of the crack. The fracture is produced after the mode I of solicitation, by opening the crack. Through a numeric calculation program we have then calculated and then drawn graphics for the durability N in report to the calculated length a, respectively in report to stress intensity factor N(ΔK).

Keywords: crack, variable load, durability, stress intensity factor, crack propagation rate.

1. A MODALITY OF DURABILITY ESTIMATION

Within an element submitted to a cyclic load, there can appear cracks that will spread until at least one of them reaches a critical length. At this moment, due to the maximal charge of stress, it can happen the rude breaking of the piece. After the analysis of the propagation of a tiredness breaking, there can be established quantitative patterns concerning the estimation of the **life-cycle** of certain mechanical structures submitted to complex cyclic loads. This represents the number of cycles from the structure service outlet, or from a certain moment, until the rude breaking of the structure. Life-cycle or durability can be also defined between two certain values of the crack length. The relation ***dN/da*** represents the accumulation rate of the ***N*** cycles, for an increase of the ***a*** crack length. The estimation of life-cycle can be made in two ways:
- by linear integration, applied for cracks with constant amplitude, with continuous control of the loading;
- by cycle to cycle integration, or on interval loads with constant amplitude.

In the area of crack top, tensions and shifts in certain points depend on the complex variable ***z*** of the point and on a constant ***K*** named **stress intensity factor**, [3], § 4.2. This is used for establishing designing patterns that avoid the total crack, and also for evaluating the stubbornness at breaking, meaning their capacity to resist to rude breakings. The stress intensity factor depends on the length of the crack ***a*** and on the tension stress ***σ***, through a relation as:

$$K = \sigma \cdot \sqrt{\pi a} \cdot F(a), \tag{1}$$

where ***F(a)*** is a coefficient that rectify the value of ***K*** and it is established on the basis of the tension status at the top of the crack, depending on the geometry of the piece or sample, and also on the way of stressing this tension.

A fundamental parameter that, generally, evaluates fracture, and, especially fatigue fracture , is **the propagation rate of the crack *da/dN***, parameter that represents the length of crack propagation on a load cycle. Once with the increase of crack length, as well as with the increase of load level, it increases the propagation rate of fatigue fracture. It results that the propagation rate of the crack ***da/dN*** can be correlated with the variation of the stress intensity factor Δ***K***, relation (2):

$$\frac{da}{dN} = f(\Delta K, R, T, ...) . \tag{2}$$

For the field II, of the constant propagation of crack, [3], [5], the rate ***da/dN*** can be expressed depending on Δ***K*** by a relation named **formula of Paris**, rendered in (3),

$$\frac{da}{dN} = C \cdot (\Delta K)^m , \tag{3}$$

with ***C*** and ***m*** material constants. From the relations (1), (2) and (3), it results:

$$\frac{dN}{da} = \frac{1}{\frac{da}{dN}} = \frac{1}{f(\Delta K, R, T, ..)} = \frac{1}{C \cdot (\Delta K)^m} = \frac{1}{C \cdot \left(\Delta\sigma \cdot \sqrt{\pi a} \cdot F(a)\right)^m} . \tag{4}$$

For the increase of the crack with constant rate, the calculation of **life-cycle** can be made by integrating relation (4) between the initial length of the crack a_i and the final length of the crack a_f,

$$N_{if} = N_f - N_i = \int_{N_i}^{N_f} dN = \int_{a_i}^{a_f} \frac{da}{C \cdot (\Delta K)^m} . \tag{5}$$

On a finite interval of the crack length increase, included between the values a_i and a_f, the function F(a) can be considered constant and equal with its value from the beginning of the interval. In this situation, the variation of the cycles number Δ***N*** is obtained by integrating expression (5) and it is obtained:

$$\Delta N = N_f - N_i = \frac{2 \cdot a_i}{(m-2) \cdot C \cdot (\Delta K_i)^m} \cdot \left(1 - \sqrt{\left(\frac{a_i}{a_f}\right)^{m-2}}\right) . \tag{6}$$

It results the life-cycle N_f until reaching the final length of the crack a_f:

$$N_f = N_i + \Delta N . \tag{7}$$

2. EXPERIMENTING BASE

For elaborating the proposed study, there were made cyclic testings through eccentric traction loads. The material used was an austenitic steel of the class V2A, type 10TiNiCr175. There were tested flat samples, with lateral notch, of model ASTM 647, type CT, figure 1.

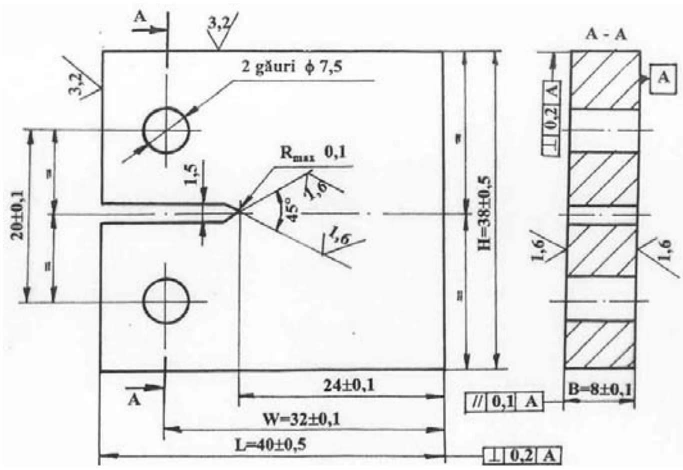


Fig.1. Sample model CT with lateral notch

The machine, having the possibility to set the asymmetry coefficient R, develops a maximal charge of 30 kN, and the pressure within the installation is of 200 bars. The load frequency was of 5Hz. The asymmetry coefficient of trials, for all test-pieces, is R= 0.5. The trials were made at three temperatures: the room temperature T=293K and the low temperatures T=253K and T=213K. For the trials at low temperatures, on the trial machine a cooling room was mounted, [5], § 5.3. The cooling environment is ether oil, and the liquid nitrogen was used as cooling agent (N_2L). The temperature of the working environment was measured with a thermogen of a precision of 1K. The variation of the crack length is followed with an optic microscope of an increasing power of 50x, by with a continuous following of the deficit. For low temperatures, the measurement of the crack increase was made through the method of elastic compliance, using an extensometer with elastic slides, that is inserted in the working place, [5], § 5.3.

3. RESULTS AND PROCESSING OF RESULTS

With the parameters and conditions of trial, previously rendered, there were made the trials of proofs for the charging coefficient R= 0.5 at the three temperatures: 293K, 253K and 213K. First, it was made an initial crack $\mathbf{a_0} \approx \mathbf{2,0}$ mm for the initial number of cycles $\mathbf{N_0}$, moment that corresponded to the passing threshold from the initiation stage of the crack to the stage of the crack constant propagation, field II of propagation, [5], § 5.1.

From this moment, the testing is continued and it is noticed the variation of the crack length with the values a_i at intervals of 0.25 mm and the number of cycles afferent to these, noted with N_i. These are sets of basic values. The load is continued until the test-piece yields, the crack length reaching the critical value a_c, and if the trial will be continued, we would be in the field of the unstable propagation of the crack.

With these input data, it is aimed the establishment of patterns for evaluating the material's durability proportional to the variation of the length of the crack ***a*** or of the stress intensity factor ΔK.

We created a numerical calculus program in order to accomplish the above-mentioned objective that crosses the following steps:
- establishment of the expression of the approximation parabola for the crack length proportional to the durability N, ***a(N)*** according to the standard polynomial method, [1], [5], [6], through successive parabolic approximations of seven successive points;
- through the derivation of the obtained relation, it is obtained the variation of the propagation rate of the crack ***da/dN***, as function of the number of experimental cycles N_I;
- it is calculated the variation of the stress intensity factor ΔK_i, that corresponds to every iteration, with relation (8), [1], [3], [5], [7];

$$\Delta K_i = \frac{\Delta F}{B \cdot \sqrt{W}} \cdot \frac{2 + \frac{a_i}{W}}{\sqrt{\left(1 - \frac{a_i}{W}\right)^3}} \cdot \left(-5{,}6 \cdot \left(\frac{a_i}{W}\right)^4 + 14{,}72 \cdot \left(\frac{a_i}{W}\right)^3 - 13{,}32 \cdot \left(\frac{a_i}{W}\right)^2 + 4{,}64 \cdot \left(\frac{a_i}{W}\right) + 0{,}886 \right) \quad (8)$$

- requiring that, on the analyzed field of the deficit's unstable propagation, the variation of the crack rate observed by the law of Paris, relation (3), there are established, for every trial, the material parameters ***m*** and ***C*** ;
- it is required the application of relation (5) on every interval **(i, i+1),** where f = i+1, it is established the durability N_2, calculated on every subfield with expressions like:

$$N_2(i) = N_i + \frac{2 \cdot a_i}{(m-2) \cdot C \cdot (\Delta K_i)^m} \cdot \left(1 - \sqrt{\left(\frac{a_i}{a_{i+1}}\right)^{m-2}} \right); \quad (9)$$

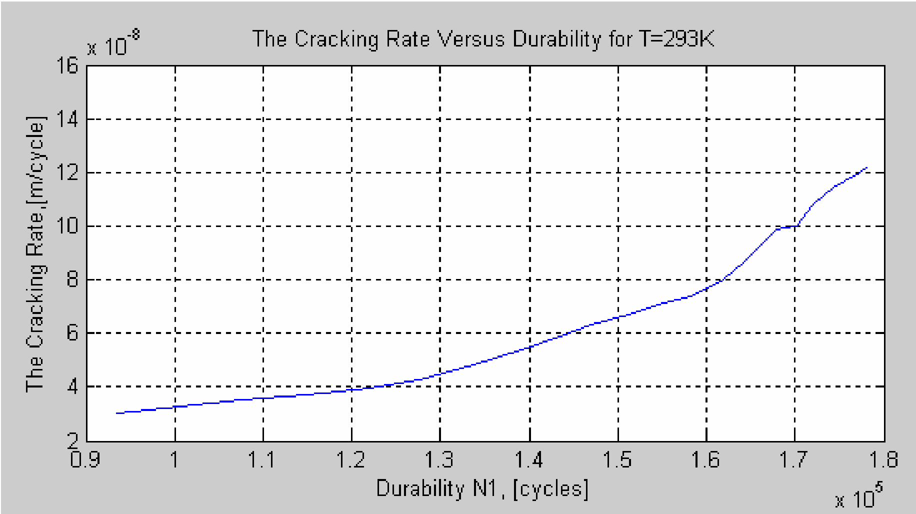
- with the experimental and the calculated data, we pass to the drawing of the following graphs: - crack rate ***da/dN*** versus to the experimental durability N_1, figure 2;
- compared durabilities N_1 (experimental) and N_2 (calculated) depending on the length of the crack ***a***, figure 3;
- durabilities N_1 and N_2 in function to the stress intensity factor ΔK, figure 4.
These determinations were made for the three testing temperatures, T = 293K, T = 253K and T = 213K.

4. COMMENTS

From the analysis of the drawn diagrams in the figures 2, 3 and 4, some conclusions can be rendered:
- the propagation rate of the crack ***da/dN***, for the three trial temperatures, proportional to the experimental durability N_1 is shown in figure 2. As for the temperature 293K, it has an uniform, continuous increase from $3{,}03 \cdot 10^{-8}$ m/cycle to $12{,}25 \cdot 10^{-8}$ m/cycle. At the temperature of 253 K, the tendency is also of increase, from $3{,}23 \cdot 10^{-8}$ m/cycle and $15{,}56 \cdot 10^{-8}$ m/cycle, but with a slow decrease around the durability of 160.000 cycles.

Variation rate ***da/dN*** at the temperature of 213K has two stages: - from $4{,}7 \cdot 10^{-8}$ m/cycle it decreases to $3{,}78 \cdot 10^{-8}$ m/cycle, then increasing to $10{,}5 \cdot 10^{-8}$ m/cycle, corresponding to the durability of 178.000 cycles;
- it follows again a decrease of the rate to $8{,}31 \cdot 10^{-8}$ m/cycle for the durability N_1 = 190.000 cycles, continuing with a continuous increase until $17{,}3 \cdot 10^{-8}$ m/cycle, at fracture, for the critical durability N_{cr} = 211.300 cycles;
- a first modality of analyzing the durability is highlighted in figure 3. There are presented the experimental durability N_1 and the calculated durability N_2, in function to the variation of the length of the crack ***a***. There were noted with 1 – the curve of experimental numbers N_1 and with 2 – the curve of the calculated cycles number N_2.

Between them, it can be noticed an outlined approaching, and on certain parts even a superposition. For the temperature of 293K, the durability N_2 varies between 92.730 cycles and 188.900 cycles, at 253K N_2 is included between 125.500 cycles and 197.700 cycles, and at T = 213K, the field of N_2 is (445450 ÷ 214130) cycles;
- variation of the durabilities N_1 and N_2 in relation to the stress intensity factor ΔK is rendered in figure 4. The variation type is the same with the diagrams ***N(a),*** of figure 3, adding that the fields for SIF were the following: (410-722) $N \cdot mm^{-3/2}$ for T = 293K, (440-670) $N \cdot mm^{-3/2}$ for T = 253K, and (450-700) $N \cdot mm^{-3/2}$ for T = 213K.



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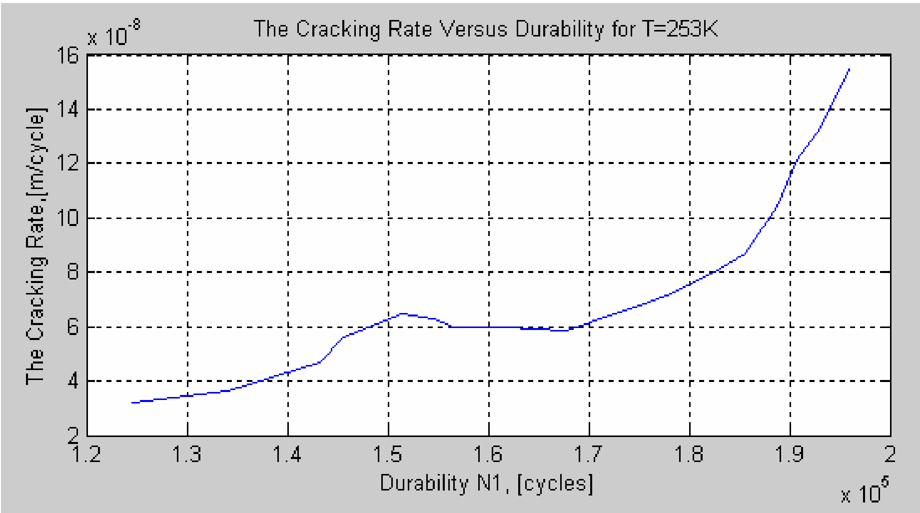

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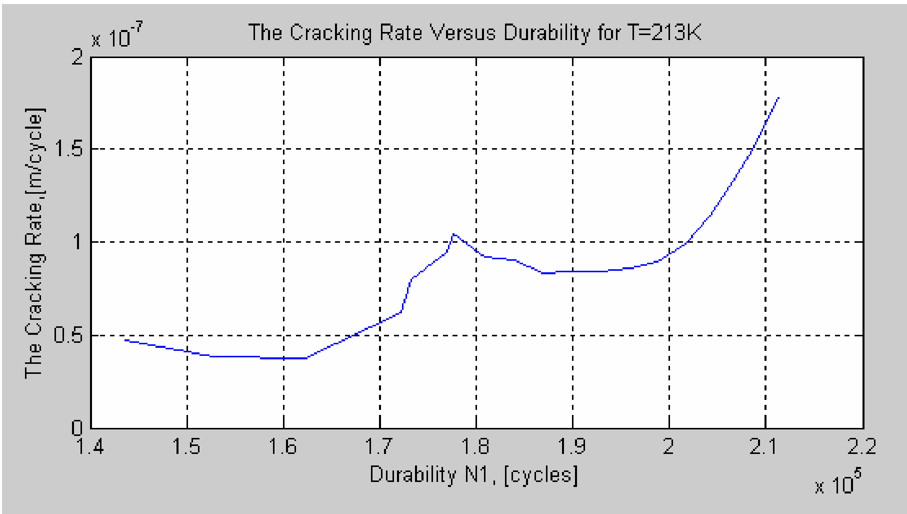

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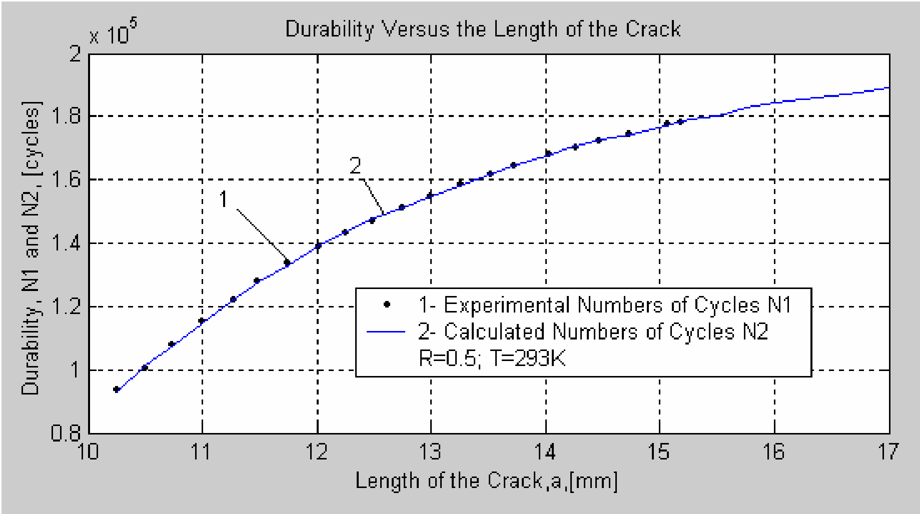
Fig.2. The Cracking Rate Versus Durability



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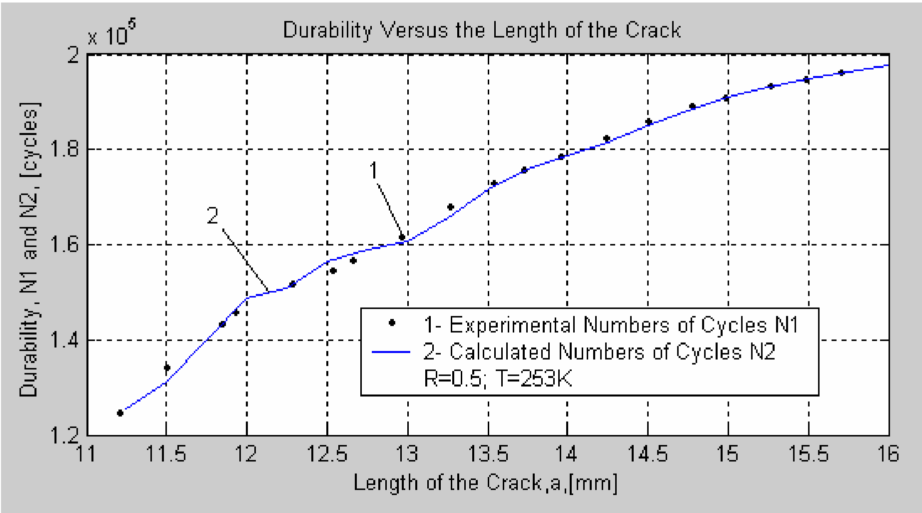

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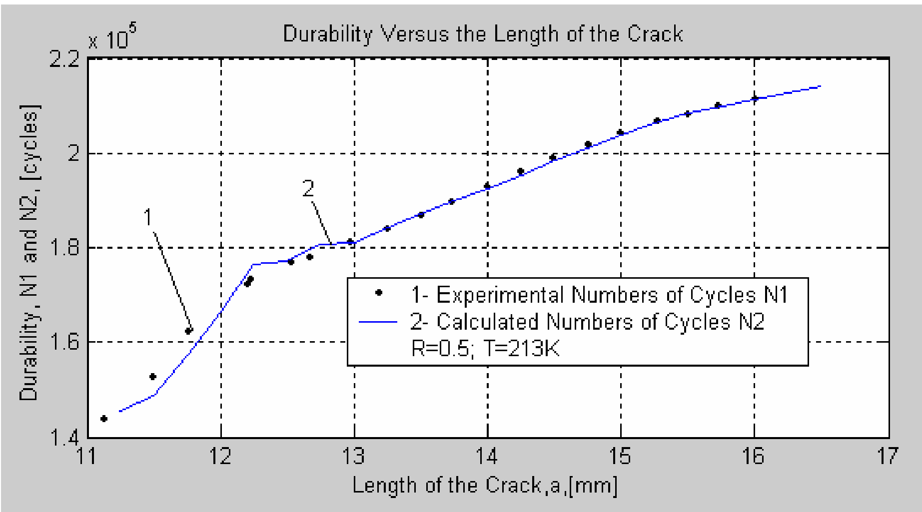

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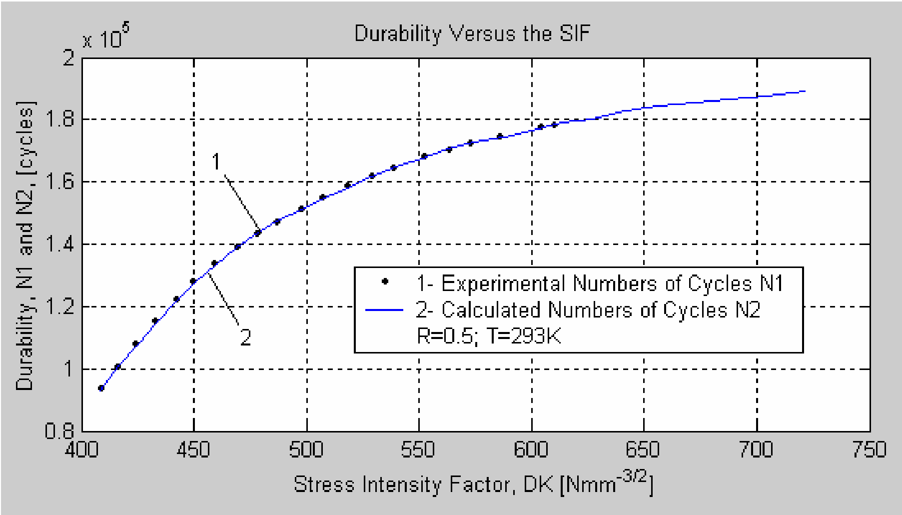
Fig.3. Durability Versus the Length of the Crack



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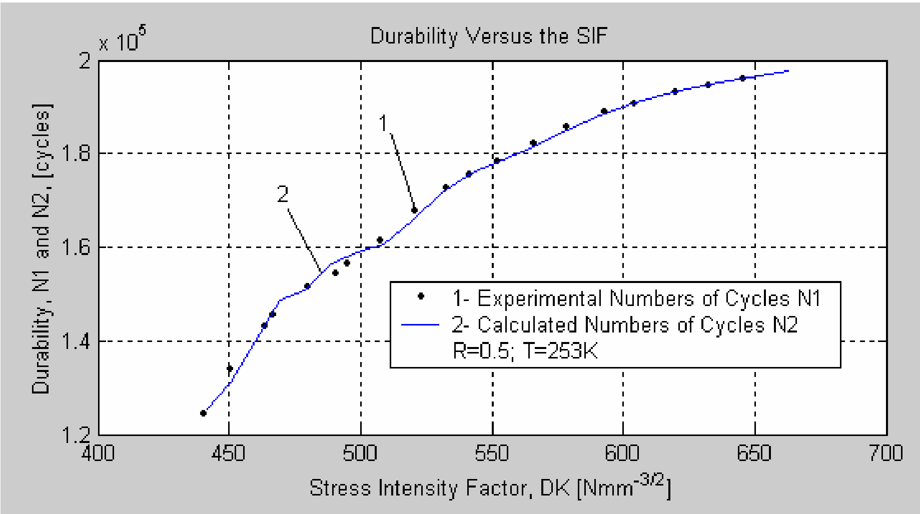

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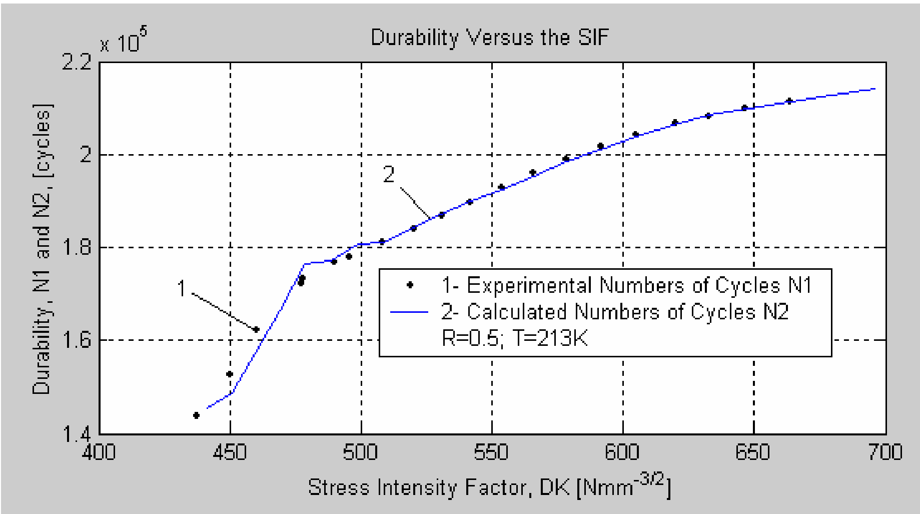

c.

Fig.4. Durability in function to Stress Intensity Factor

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