FATIGUE CRACK GROWTH BEHAVIOUR OF A USI-SAC-50 HOT-ROLLING STEEL IN THICKNESS DIFFERENTS

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Abstract *The fatigue fracture is the most common type of structural failure and through the years it has been a challenging problem. It is caused by the initiation and propagation of a crack through the component with the two processes occupying different proportions of fatigue life.*
The objectives of this research are the determination of the mathematical expressions for the rate of propagation of a crack by fatigue versus the stress-intensity factor range, the quantification of thickness effect on the propagation of a crack and the evaluation of anisotropy effect according to the directions TL and LT for this same propagation. To achieve these objectives, samples of a USI-SAC-50 hot-rolling steel with thickness of 12 and 19 mm, according to rolling directions LT and transversal TL, were submitted to fatigue test on INSTRON machine model 8802 after pre-crack of 3mm. The samples showed a weak texture on both rolling direction and transversal to rolling and the stronger crystallographic directions in each direction: normal direction (DN), longitudinal direction (DL) and transversal direction (DT) are respectively [111], [101] and [111]. The obtained results showed that on stage II, the material obeys the Paris equation for appliance on both transversal and longitudinal direction. However, a linear correlation between the parameters C and m_f *was verified. There was no variation on the rate of propagation of a crack by fatigue on stage II, for thickness of 12 and 19 mm direction LT.*

Keywords: Fatigue, Texture, Structural Steel

1. Introduction

The USI-SAC-50 steel is applied on the mechanical industry for manufacture of structures. These steels are known as acclimate steels, witch have the properties of to develop a protective layer of oxide at his surface, compact and adherent to the metallic substrate, when exposed to industrial environment. Another attractive of this steel is the high mechanical strength and good weldability. His high strength allows a substantial reduction of weight of the structure resulting in economy of weld, transport, and others.

In project of this kind, a confidence evaluation of the structure in service depends, beside the conventional properties as yield stress and strength stress, on other factors, as fracture resistance and fatigue crack (Ratnapuli & Melo, 1998).

Fracture fatigue is the most common form of structural fail. This fracture is caused by the beginning and propagation of a crack in a component. The knowledge of the impact resistance and fracture of the material, mainly of the steels, has being since several times one of the main objective of mechanical engineering.

Through elasticity and plasticity theory it can found a mathematical relationship between toughness, crack size and applied stress to the material to prevent the behavior of a structure or component to crack growth resistance (Godefroid, 1999).

The actual tendency of the mechanical designers is works based on the characteristic values of fracture toughness of the materials. These results obtained on fracture mechanic tests are applied in projects for determination of the lifetime of structures and components. The conditions which these stresses and strains will be result in crack propagation are not yet well established. In general, it is assumed that the crack propagation will be to occur, when the stresses at the crack tip to exceed a critical value. It has being suggested the use of the mean strain or stress at a certain distance from the tip crack as a fracture criteria (Anderson, 1995). The crack propagation and non-propagation conditions are meaningful affected by variables as stress ratio, microstructure and environment.

The microstructure can be characterized by different techniques and defines the anisotropy properties of the material through texture. This crystallographic texture can be or not aleatoric and characterized by techniques as x-ray diffraction or electron back scattering diffraction (EBSD).

The dependence of mechanical properties with the direction is called of anisotropy. The crack propagation in steel at rolling direction and at the transversal direction occurs respectively by the mechanism of striations and coalescence of micro voids (Godefroid, 1999) and can be a function of texture of the material according these same directions.

The purposes of this work are:

- Quantify the effect of the thickness on crack propagation;
- Evaluate the anisotropy effect according the TL and LT directions for this same propagation;
- To study the fracture at tension, impact properties and fatigue of the USI-SAC-50 steel.

2. Methodology

The chemical analysis was made in specimens with dimensions 50x50x19 mm in an optical spectrometer emission. The specimens for metallographic analysis were cut at the rolling direction and perpendicular to this direction. The cut was made according the parallel and perpendicular to rolling directions. For the microstructure analysis these specimens were etching with nital 5%, and after this, analyzed in an optical microscopy Leitz, with 200X magnification.

The fracture surface of the specimens for 12 mm and 19 mm in thickness, on LT and TL orientations, were analyzed on SE, Phillips, with 20 kV in tension and 100, 200 and 500X in magnification.

The software Quantikov (Pinto, 1996) for the determination of pearlite and ferrite in volumetric percentage, and the mean grain diameter was used.

The technique of electron back scattering diffraction for characterization of the grain structure and micro texture for surface and the center of the plate with 12 mm and 19 mm in thickness was used. For measurement of ferritic grain size the boundary measure with 5º minimum disorientation were adopted as criteria. A machine instrumented Charpy INSTRON Wolpert PW30, 40 kN of minimum capacity was used. It were used nitrogen, water and ice as a ambient of cooling to guaranty the test temperatures which were: -197ºC, -90ºC, -70ºC, –50ºC, -40ºC, -30ºC, -20ºC, -10ºC, 0ºC, 6ºC, 17ºC, 23ºC, 50ºC, 70ºC, 97ºC, 125ºC e 140ºC.

The Charpy machine is endowed of interface, mark Impact 95, with data acquisition frequency of 1MHz. This load signal versus time, F(t), is used for calculation of the pendulum velocity through the expression:

$$v(t) = v_0 - \left(\frac{1}{m}\right)\int_0^t F(t)dt \qquad (1)$$

where: v_0= velocity of the pendulum impact;

m= mass of the pendulum;

t= time.

The deflection of the specimen as a function of the time, s(t), was determined from the integration of the curve velocity versus time:

$$s(t) = \int_0^t v(t)dt \qquad (2)$$

The absorbed energy by the specimen as a function of the displacement, EW(s), was determined by integration of the curve load versus displacement:

$$E_W(s) = \int_0^s F(s)ds \qquad (3)$$

The equipment used for the tension test was a universal machine INSTROM, model 1125, with driving mechanism servo-hydraulic and load cells of 98 kN and 295 kN.

The yield point value was obtained from the graph of stress-strain , from 0.2% of deformation. To obtain the normal coefficient anisotropy (R), it was used two strain gages, one on the transversal direction and one on the longitudinal direction. The calculation of R_1 and R were made through the bellow expressions:

$$R_1 = \frac{\varepsilon_W}{\varepsilon_T} \tag{4}$$

$$R_1 = \frac{\ln\left(\frac{W_0}{W_f}\right)}{\ln\left(\frac{l_0 W_O}{l_f W_f}\right)} \tag{5}$$

$$\bar{R} = \frac{(R_0 + 2R_{45} + R_{90})}{4} \tag{6}$$

From these values it was calculated the mean value and the standard deviation associated with these measurements.

The equipment used for fatigue test was the universal machine INSTRON, model 8802 (CDTN) composed of a dynamical system, 250 kN in capacity gripe head and hydraulic raising with maximum extension 1515 mm, and load digital electronic controller. The machining of the specimens was made according the standard ASTM E-647-00 (2000), as shown in Fig. 1, for 12 mm and 19 mm thickness plates.

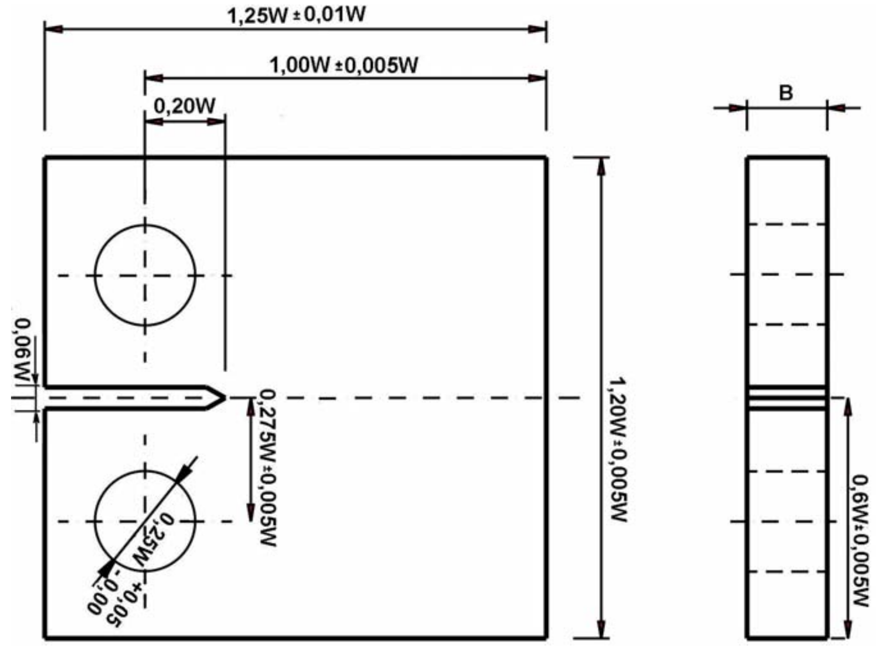


Figure 1 – Dimensions of the specimens type compact tension, C(T), for fatigue crack propagation, according the standard ASTM E 647-00 (2000).

For fatigue crack propagation test a fatigue pre-cracking with 0.06W minimum in length was made. For the opening of this pre-cracking, the value of f(a/W), function of the geometrical parameter of the specimens was calculated. The specimen parameters, the amplitude, the initial crack length and the crack growth rate were informed to the software Max of the machine control. The crack length measured by the clip gauge and the number of cycles are registered on the computer. At the end of the test, the graph da/dN versus ΔK was obtained.

3. Results and Discussion

On the Tab. bellow is shown the chemical analysis of the material in weight percent.

Table 1 – Chemical composition of steel type USI-SAC-50 used on the experiments, in percent and weight

C	Mn	Si	P	S	Cr	Ni	Cu	Ti	Nb	V	Al	N(ppm)
0.11	1.13	0.33	0.024	0.013	0.44	0.18	0.27	0.010	0.010	0.005	0.035	53

On the Fig. 2 is shown the metallographic analysis obtained according TL and LT orientations were the presence of ferrite and pearlite on the microstructure can be observed. The volumetric fraction of pearlite and ferrite were, respectively, 18.63 % and 81.37%, with 1.21 of standard deviation. The ferritic grain size measured by linear intercept mean was 7 μm, with 0.5 of standard deviation.

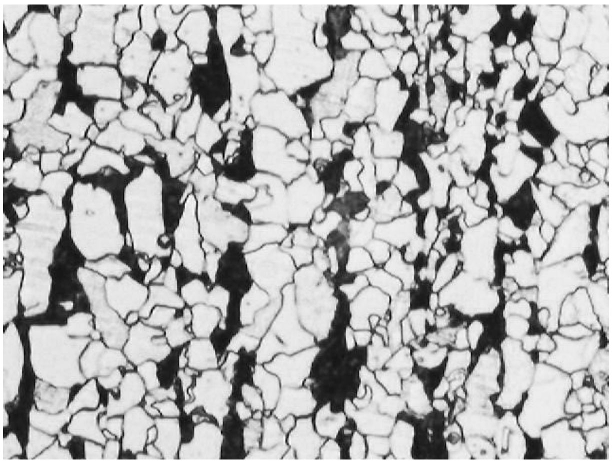


Figure 2 – Microstructure of the steel USI-SAC-50 in longitudinal section (a) and transversal section (b), where it can see the presence of ferrite and pearlite. Etching: Nital 5%, magnification: 200X.

On Fig. 3 is shown the histogram of the disorientation angle with the fraction of ferrite grains for the 12 mm thickness plate. It can be observed that more than 9.5% of the specimen presents the disorientation angle of ferrite less than 5º. This fraction of ferrite corresponds to the part of the hot rolling material that is already recovered.

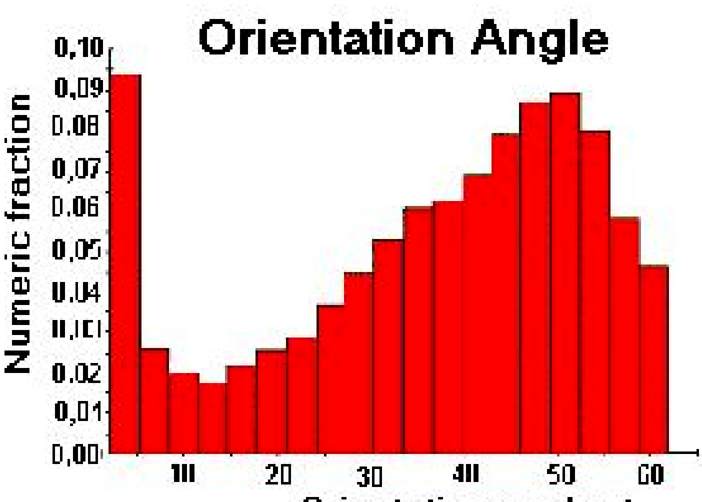


Figure 3 - Histogram of the disorientation angle with the fraction of grain ferrite for 12 mm-thickness plate

It is shown on Fig. 4 the orientation fraction distribution (ODF) for USI-SAC-50 steel, with 12 and 19 mm in thickness, at the position correspondent to the plate center. For the plate of 12 mm in thickness, the section φ_2=45º of the Euler space evidences a typical texture of hot rolling of low killed carbon steel, with fibber [110]//DL or fibber α with peak of major intensity in (112)[110], and fibber [111]//DN or fibber γ. The Fig. 4 revealed also component of diffuse texture with maximum intensity of 2.4.

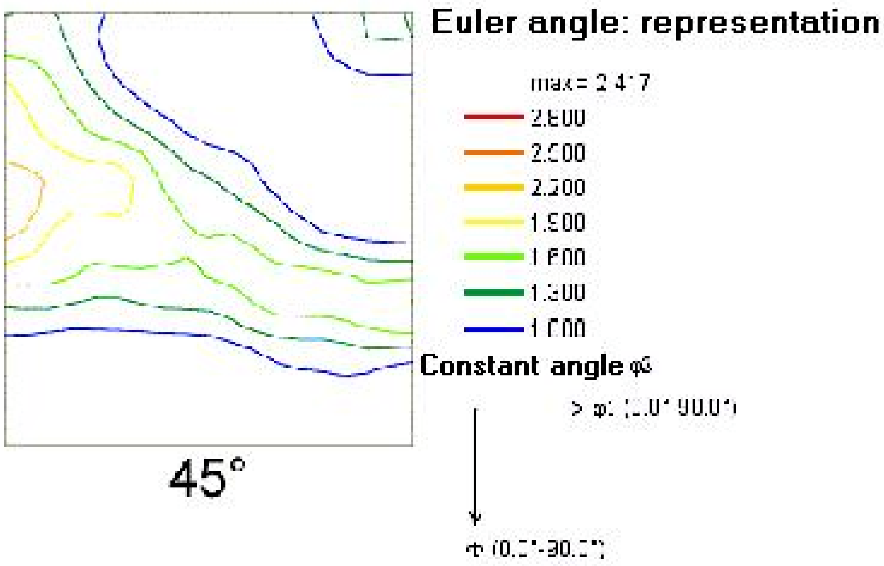


Figure 4 – Orientation distribution function (ODF) for USI-SAC-50 steel, with 12mm in thickness at the center position

Wherein, during hot rolling, the deformation mode changes through the plate thickness, it can be to obtain homogeneity of the texture thorough the thickness (Park, 1996). To verify this possibility, it is shown on Fig. 5 the ODF corresponding to the 12 mm in thickness plate surface. Thought the surface orientation being practically random and weak texture for 12 mm thickness plate, it can be observed a tendency to typical shear preferential orientation, with [110]//DN and peak in (110)[001] and (112)[111] and maximum intensity of 1.4.

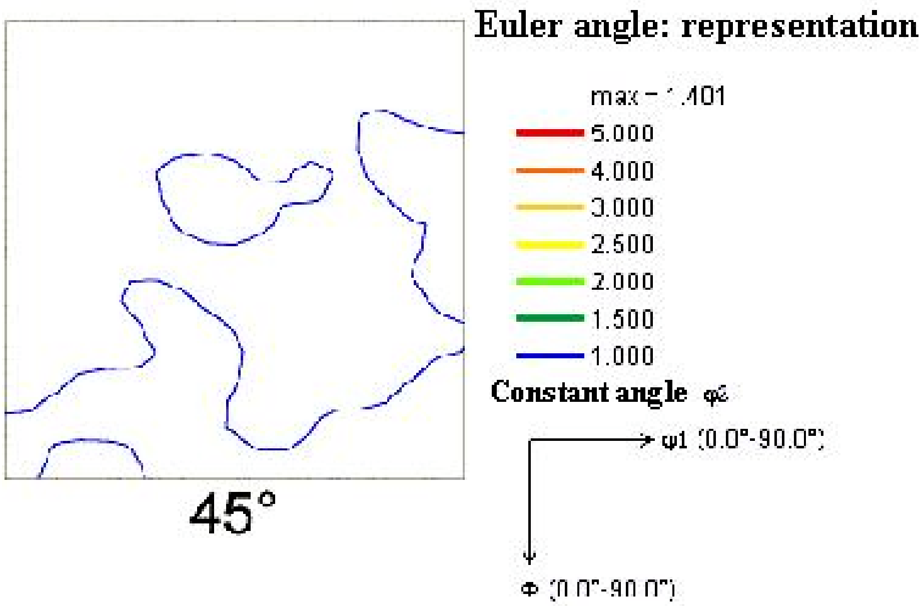


Figure 5 – Orientation distribution function (ODF) for USI-SAC-50 steel with, 12 mm in thickness, at the position corresponding to the surface

For the knowledge of the preferential crystallographic orientations according to transversal and short transversal rolling directions, it were obtained the inverse pole figure in a longitudinal section (DL-DN) with dimensions 0.42 x 1 mm² (Fig. 6). The orientations corresponding to DN [001], DL [100] and DT [010] directions become evident that the texture is weak and the more strong crystallographic directions in each direction DN, DL e DT are respectively [111], [101] e [111] and maximum intensity of 1.7, for the plate of 12 mm in thickness.

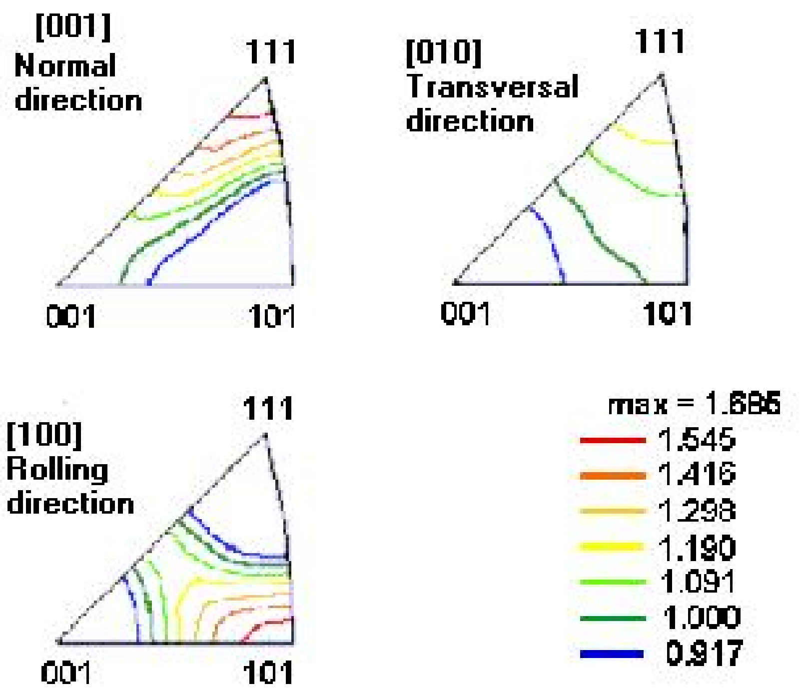
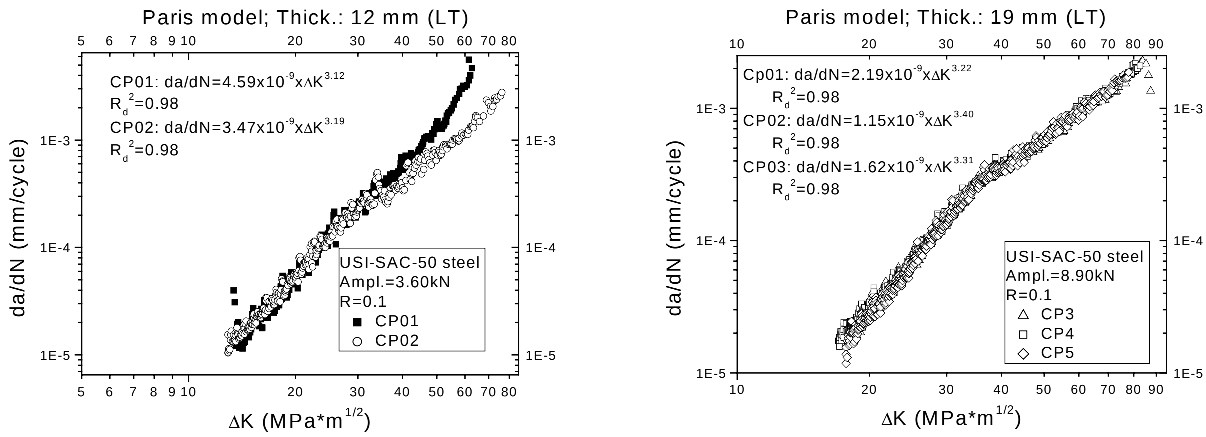


Figure 6 – Inverse pole figures with orientations corresponding to the directions DN [001], DL [100] and DT[010], for the plate of 12 mm in thickness

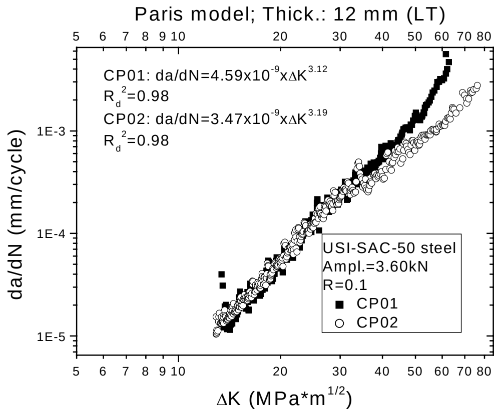
On Fig. 7 (a) and (b) it is shown the graphs d*a*/dN versus ΔK, for the specimens of 12 e 19 mm in thickness respectively, to LT orientations, stage II, for load ratio R = 0.1 and frequency of 20 Hz. The coefficients and exponents of ΔK found according with proposed by Lal (Lal, 1994) and in disagreement with the proposed by Barsom (Rolfe & Barsom, 1987), for ferritic-pearlitic steels. It were observed that the coefficients C and exponents m_f were near and simultaneously the coefficient of determination was high, becoming in evidence a good statistical adjust.



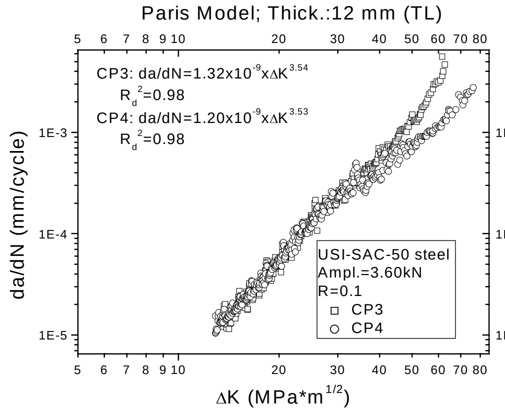
(a) (b)

Figure 7 – Evolution of the curve d*a*/dN versus ΔK, for the thickness of 12 mm (a) and 19 mm (b), orientation LT, on stage II, for USI-SAC-50 steel.

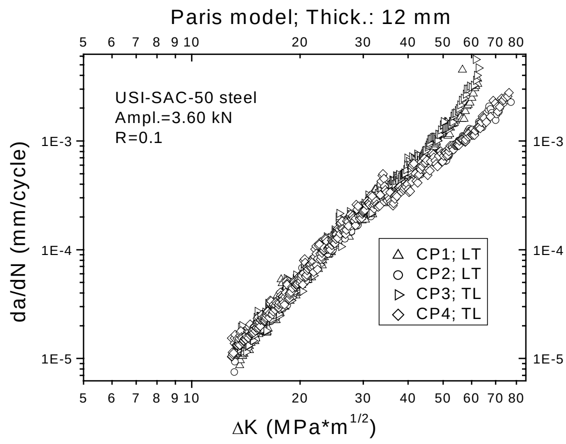
On Fig. 8 (a), (b) and (c) it is shown the graphs d*a*/dN versus ΔK, for 12 mm in thickness specimens, orientations LT and TL, stage II, load ratio R = 0.1 and frequency 20 Hz. It was observed that the coefficients C and exponents m_f were near and simultaneously, the coefficient of determination was high, evidencing a good statistical adjust and that not had variation on the crack propagation rate for the 12 mm in thickness for LT and TL orientations.



(a)



(b)



(c)

Figure 8 - Graphs d*a*/dN versus ΔK, for one 12 mm in thickness specimen, orientation LT (a), TL (b) and LT and TL (c), stageII, for load ratio R = 0.1 and frequency 20 Hz

4. Conclusions

- The crystallographic orientation of USI-SAC-50 steel, evaluated by EBSD, shown aleatoric at the TL and LT orientations, that is, weak texture. The more strong crystallographic orientations in each one of the directions DN, DL and DT were respectively [111], [101] e [111] with maximum intensity of 1.7, for the plate of 12 mm in thickness.
- There was not variation of texture between the surface and the center of the plate with 12 mm in thickness demonstrating thus weak texture for the USI-SAC-50 steel.
- The coefficients C and exponents m_f, of the Paris model, for the specimens of 12 and 19 mm in thickness, on LT orientation, were near and simultaneously, the coefficient of determination was high, becoming evidence a good statistical adjust. It was observed that there had not variation on the crack propagation rate for both thickness 12 e 19 mm on the orientation LT, region II.
- The coefficients C and exponents m_f, of the Paris model, for the specimens with 12 mm in thickness, orientations TL and LT, were near and simultaneously, the coefficient of determination was high, becoming evident a good statistical adjust. It was observed that there had not variation on the crack propagation rate for the specimens whit 12 mm in thickness, on the orientations LT and TL, region II.

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