A model for high-cycle fatigue crack propagation

Marcela Angela Balbi, Rosario, Argentina

This paper deals with the prediction of high-cycle fatigue behavior for four different materials (7075-T6 alloy, Ti-6Al-4 V alloy, JIS S10C steel and 0.4 wt.-% C steel) using Chapetti's approach to estimate the fatigue crack propagation curve. In the first part of the paper, a single integral equation for studying the entire propagation process is determined using the recent results of Santus and Taylor, which consider a double regime of propagation (short and long cracks) characterized by the model of El Haddad. The second part of the paper includes a comparison of the crack propagation behavior model proposed by Navarro and de los Rios with the one mentioned in the first half of this work. The results allow us to conclude that the approach presented in this paper is a good and valid estimation of high-cycle fatigue crack propagation using a single equation to describe the entire fatigue crack regime.

Article Information

Correspondence Address
Dr. Marcela Angela Balbi
University of Rosario
2000 Rosario, Argentina
E-mail: balbi@ifir-conicet.gov.ar

Keywords
Fatigue crack propagation, short cracks, high-cycle fatigue, long cracks, crack growth equation

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on January 10, 2017
For personal use only.

The issue of fatigue strength estimation for materials or components that contain natural defects, inclusions or inhomogeneities is of great importance from both the scientific and the industrial point of view. Fatigue damage is one of the major life-limiting factors in most structural components subjected to variable loading during service. Hence, the containment of this damage is essential for intelligent design and selection of materials to minimize the total life-cycle costs.

For a component, the natural tendency in the implementation of a "damage tolerant" approach to fatigue life predictions to relate the remaining life to predictions of the crack propagation rate for cracks of a size, generally in the order of 1 mm, that can be observed by nondestructive inspection (NDI). In high-cycle fatigue (HCF), a relatively large fraction of component life is required to initiate an observable size crack. Generally, it is observed that a component in service spends about 80 % of its life-time in the region of short crack growth (crack length <1 mm) [1-12]. Consequently, further research to understand, identify, detect and estimate HCF damage in the early stages of total fatigue life becomes vitally important.

The long crack (a crack with a plastic zone size that is only a small fraction of the crack length) propagation rate can be described accurately by the Paris law [13], which relates the stress intensity factor range to subcritical crack growth under a fatigue stress regime. As such, the Paris law is the most popular fatigue crack growth model used in materials science and fracture mechanics. The basic formula reads:

$$\frac{da}{dN} = C\left(\Delta K\right)^m \qquad (1)$$

Where only two material parameters are required: C and m, which are be deduced by fitting experimental data. Several modifications of the Paris law have been proposed by different researchers [13]. The most popular variations are:

$$\frac{da}{dN} = C\left(\Delta K - \Delta K_{thR}\right)^m \qquad (2)$$

$$\frac{da}{dN} = C^*\left(\Delta K^{m^*} \Delta K_{thR}^{m^*}\right) \qquad (3)$$

which were proposed by Zheng and Hirt [14] (Equation (2)) and by Klesnil and Lukáš [15] (Equation (3)).

In addition, many efforts have been made to study short fatigue crack growth [16-18], and various kinds of models and approaches have been established [19-22]. Short crack growth models are valid when applied to the respective regime from which they were derived. A number of researchers has proposed models trying to find a growth law appropriate for all cracks, from short to long cracks [23, 24].

It is now well understood that the complex behavior of short cracks is related to the threshold for short fatigue crack propagation, which is a function of crack length.

Different models have been proposed for short cracks to estimate the variation of the propagation threshold as a function of crack length [3, 5, 6, 10]. For long cracks, this threshold tends to a constant value. For example, Chapetti [11] proposed that the threshold for fatigue crack propagation can be estimated as a function of crack length by using only the plain fatigue limit, $\Delta\sigma_{eR}$, the threshold for a long crack, ΔK_{thR}, and a dimension characteristic of the microstructure (e. g., grain size). The model estimates the material threshold for crack propagation from a depth given by the position d of the strongest microstructural barrier:

$$\Delta K_{th} = \Delta K_{dR} + \left(\Delta K_{thR} - \Delta K_{dR}\right)\left[1 - \exp\left(-k\left(a-d\right)\right)\right] \quad a \geq d \qquad (4)$$

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on January 10, 2017
For personal use only.

In terms of the threshold stress, it is obtained:

see Equation 5 (5)

with ΔK_{thR} and $\Delta\sigma_{eR}$ (and thus ΔK_{dR}): functions of the stress ratio R and k is a material constant. The microstructural threshold for crack propagation, ΔK_{dR}, is defined as follows [11]:

$$\Delta K_{dR} = Y\Delta\sigma_{eR}\left(\pi d\right)^{1/2} \quad (6)$$

with Y: geometrical correction factor (Y = 0.65, if the microstructurally small crack is semicircular [1-3]).

A total extrinsic threshold for crack propagation, ΔK_{CR}, is defined by the difference between the crack propagation threshold for long cracks, ΔK_{thR}, and the microstructural threshold, ΔK_{dR}, which is a function of the crack length. The parameter k is derived as follows [11]:

$$k = \frac{1}{4d}\frac{\Delta K_{dR}}{\left(\Delta K_{thR} - \Delta K_{dR}\right)} = \frac{1}{4d}\frac{\Delta K_{dR}}{\Delta K_{CR}} \quad (7)$$

The Kitagawa-Takahashi (KT) diagram, in its commonly used form, allows prediction of the allowable stress range for infinite life, for cracks of a given length. The KT diagram and the modification proposed by Miller [4] are shown in Figure 1.

The aim of this paper is to demonstrate that the approach proposed by Chapetti provides a valid estimation of high-cycle fatigue crack propagation behavior using only a single equation applied over the entire fatigue crack regime.

Fatigue crack propagation assessment: Choosing a simple fatigue crack propagation law

The effective driving force applied to the crack can be calculated as the difference between the total applied driving force, ΔK (which depends on the applied stress distribution corresponding to a given geometrical and loading configuration) and the threshold for crack propagation, ΔK_{th}, as expressed by Equation (4). For the applied driving force, ΔK, the following general expression can be used [12]:

$$\Delta K = Y\Delta\sigma_n(\pi a)^{1/2} \quad (8)$$

with $\Delta\sigma_n$: nominal applied stress range.

The analysis of fatigue crack growth requires a functional relationship of general validity to be established between the rate of fatigue crack growth, da/dN, the range of the applied stress intensity factor, ΔK, and the threshold for the whole crack length range, ΔK_{th}. The following relationships meet these requirements:

$$\frac{da}{dN} = C(\Delta K - \Delta K_{th})^m \quad (9)$$

$$\frac{da}{dN} = C^*(\Delta K^{m^*} - \Delta K_{th}^{m^*}) \quad (10)$$

with C, C^*, m and m^*: environmentally sensitive material constants obtained from long crack fatigue behavior (see Equations (2) and (3)). At first glance, Equations (2) and (3) seem to be the same as Equations (9) and (10), but in the former the parameter ΔK_{thR}, the fatigue crack propagation threshold for long cracks, appears, while in Equations (9) and (10), ΔK_{th} appears which is the material threshold for crack propagation proposed by Chapetti.

The fatigue crack propagation life for a given crack length range and a given material can be obtained by integrating Equation (9) or (10) and using Equation (4) to derive the material threshold, ΔK_{th}, and a proper expression for the applied driving force, ΔK. These latter parameters are obtained by analyzing the loading and geometrical configurations.

Experimental data from the references were used to determine the effects of applying the developed methodology of analysis and to select between Equations (9) and (10). It is proposed that these relations model crack-growth rate propagation behavior over the entire range of fatigue cracks, from short to long lengths. First, long crack data have been analyzed to obtain the constants C, C^*, m and m^*, which link Equations (2) and (3) with Equations (9) and (10). After that, short crack data was analyzed by using Equations (9) and (10), and thus, it was determined which equation is the most advantageous for predicting fatigue crack propagation behavior.

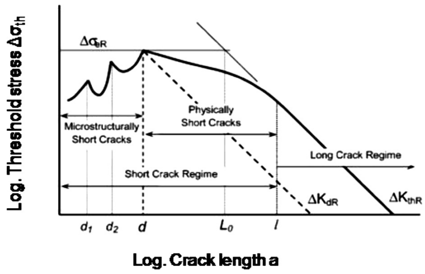


Figure 1: Threshold curve for fatigue crack propagation [11]

Three materials have been analyzed: the aluminum alloy 7075-T6 (R = -1), the titanium alloy Ti-6Al-4 V (R = 0.1) and the structural low carbon steel JIS S10C (R = -1). The data corresponding to the aluminum and titanium alloys refer to the work of Santus and Taylor [25] and those of the steel are obtained from Tokaji et al. [26]. The relations between da/dN and ΔK, and ΔK_{thR}, the propagation threshold for long cracks for this steel were obtained from a relation R = 0.05, the values of the constants C and m (corresponding to Equations (2) and (3)) and the threshold ΔK_{thR} for the particular material were obtained from reference [27] for R = -1. The principal properties of the material are listed in Table 1.

Long cracks. Figures 2a to 2c show the da/dN vs. ΔK plot of the materials in this study. In these figures, the so-called long crack growth behavior can be observed. For each material, by means of the experimental information that could be obtained corresponding to long cracks, the constants C, C^*, m and m^*, related to the Equations (2) and (3), were determined.

Table 2 summarizes the results. The curves correspond to the above aproximations for the propagation of a long crack.

As can be seen in Figure 2, Equations (2) and (3) agree very well with the experimental data corresponding to long cracks. They predict the same crack propagation rate at low and high values of ΔK, but, in the intermediate region, Equation 2 approximates the experimental data better than Equation 3. This is the relation

Material	σ_{ys} (MPa)	σ_{uts} (MPa)	$\Delta\sigma_{eR}$ (MPa)	R	Ref.
7075 T-6	512	572	335	-1	[25]
Ti-6Al-4V	915	965	460	0.1	[25]
JIS S10C	286	433	440	-1	[26]

Table 1: Mechanical properties of the materials used in this study

Equation 5

$$\Delta\sigma_{th} = \frac{\Delta K_{dR} + \left(\Delta K_{thR} - \Delta K_{dR}\right)\left[1 - \exp\left(-k\left(a-d\right)\right)\right]}{Y\left(\pi a\right)^{1/2}} \quad a \geq d$$

Material	ΔK_{thR} (MPa × $m^{1/2}$)	C (mm × $cycle^{-1}$ × MPa^{-1} × $m^{-1/2}$)	m	C* (mm × $cycle^{-1}$ × MPa^{-1} × $m^{-1/2}$)	m*
7075 T-6	3.5	9.094E-10	1.975	2.594E-10	2.271
Ti-6Al-4V	4.0	3.014E-10	2.369	2.156E-11	3.072
JIS S10C	13	4.11E-09	3.710	8.983E-13	5.368

Table 2: Results for the constants in the Equations (2) and (3)

Material	ΔKthR (MPa × $m^{1/2}$)	$\Delta\sigma_{eR}$ (MPa)	d (mm)	$\Delta\sigma_n$ (MPa)	ΔK_{dR} (MPa × $m^{1/2}$)	k (mm^{-1})
7075 T-6	3.5	335	0.018	610	1.642	12.279
Ti-6Al-4V	4.0	460	0.020	460	2.37	18.176
JIS S10C	13	440	0.024	480	2.483	2.348

Table 3: Experimental information and estimation of the materials studied

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on January 10, 2017
For personal use only.

which is chosen for modeling long crack propagation.

Short crack propagation. For short crack modeling, Equations (9) and (10) were selected to predict the crack growth rate propagation behavior of fatigue cracks, which are linked with Equations (2) and (3) by the constants C, C*, m and m*. These constants have been used to make the approximations of da/dN vs. ΔK, but to apply them for the whole range of cracks, Equations (9), (10) and (4) are used. Table 3 summarizes results from this approach.

Figure 3 shows a da/dN vs. ΔK plot with experimental data corresponding to long and short crack propagation. In the graphs, it can be seen that a short crack propagates faster than a long crack at a given ΔK, and propagates in a region below ΔK_{thR} (threshold for long cracks).

It is worth noting that both equations are valid to predict crack growth behavior, but Equation (9) agrees most closely with the experimental data.In addition, it is most similar to the equation of Paris and simpler to solve mathematically. Thus, Equation (9) has been chosen to implement in the model proposed in this paper, whose constants C and m are obtained from Equation (2).

For the materials 7075 T-6 and Ti-6Al-4V, it is possible to see a curve in Figures 3a nd 3b corresponding to an approximation using the model proposed by Santus and Taylor [25]. The model predicts propagation of short cracks given by the equation:

$$\frac{da}{dN} = C_S\left(\Delta K - \Delta K_{th,a}\right)^{m_S} \quad (11)$$

where the constants C_S and m_S are obtained from short crack data and $\Delta K_{th,a} = \Delta K_{thR}\left(\frac{a}{a+a_D}\right)^{1/2}$ corresponds to the thresh-old proposed by El Haddad [10].

Although the model proposed by Santus and Taylor [25] applies to the propagation

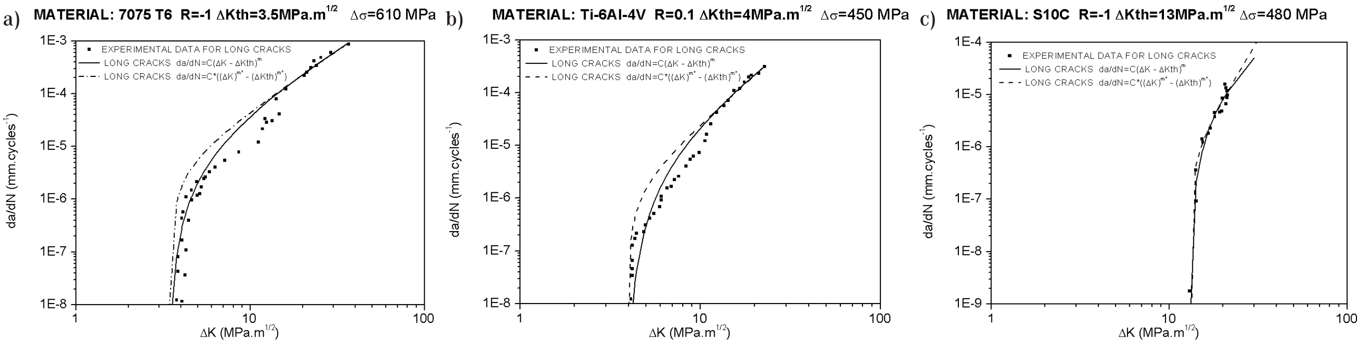


Figure 2: Plot of da/dN vs. ΔK showing experimental and the estimated data from long crack propagation behavior, a) 7075 T-6 [25], b) Ti-6Al-4 V [26], c) steel S10C [26]

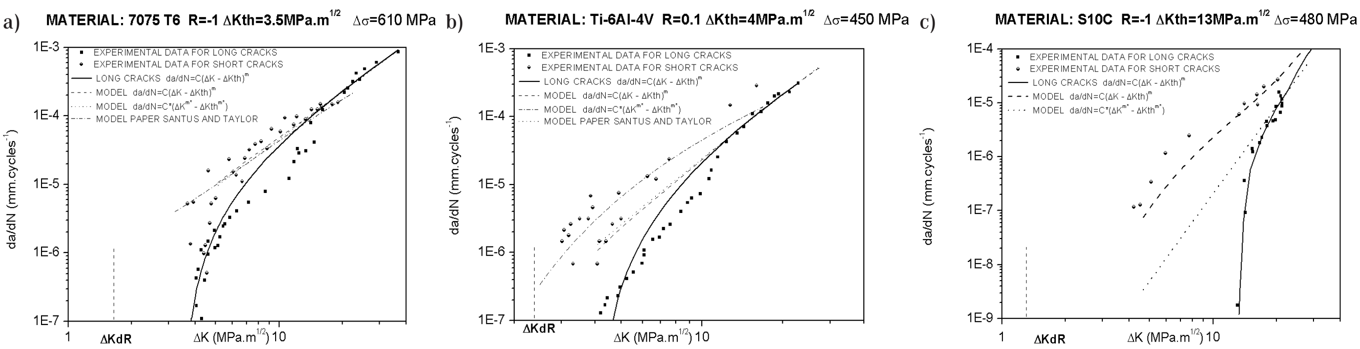


Figure 3: Plot of da/dN vs. ΔK showing experimental data from short and long crack propagation and the model proposed for the crack propagation behavior, a) 7075 T-6 [25], b) Ti-6Al-4 V [25], c) steel S10C [26]

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on January 10, 2017
For personal use only.

of short cracks, to obtain their estimation, they need to know experimental data for the exact crack lengths which they wanth to model. The model is also valid for only a short range of crack lengths. The model proposed here only needs long crack experimental data and some characteristical material properties. It can predict crack growth propagation behavior for the entire range of crack lengths.

Example, applications and discussion

It was demonstrated that the approach proposed in this paper agrees well with crack growth propagation behavior over the entire range of length scales. Here, it will be demonstrated that it is possible to calculate the number of cycles that a crack will spend to grow to a determined length by this approach.

Navarro and de los Rios proposed a model to estimate two limit curves (upper and lower bounds) for the crack growth rate starting from short to long cracks [24], and the possibility of calculating the fatigue lifetime.

In this part of the paper, the proposed approach using Equation (9) will be compared with the model proposed by Navarro and de los Rios [24] for crack propagation applied to the 0.4 wt.% C steel.

Table 4 summarizes the mechanical properties of the 0.4 wt.% C steel and, in Table 5, estimations of parameter values are given for the approach proposed in this paper.

In the model proposed by Navarro and de los Rios [24], the crack growth rate is assumed to be proportional to the plastic displacement at the tip of the crack that is the number of active dislocations within the plastic zone. This may be expressed as:

$$\frac{da}{dN} = f\Phi \tag{12}$$

with f: fraction of dislocations on the slip band which participates in the process of crack extension. This number depends on the level of applied stress. The plastic displacement Φ at the tip of the crack is determined for conditions where the applied stress σ is much higher than the friction stress:

$$\Phi = \frac{2\kappa}{G}\frac{\left(1-n^2\right)^{1/2}}{n}\sigma a \tag{13}$$

with G: shear modulus, and $\kappa = 1$ or $1-\upsilon$ (where υ is Poisson's ratio) depending on whether screw or edge dislocations are being considered.

The dimensionless parameter $n = a/c$ (where a is half the surface crack length and c is a length segment which incorporates both the crack length and the plastic zone) defines the location of the crack tip with respect to the grain boundary on which the leading dislocation is blocked. For a constant applied stress, the stress concentration ahead of the plastic zone depends solely on the parameter n. As the crack grows, but with the plastic zone still being blocked by the grain boundary, the parameter n increases toward a critical value $n = n_C$. At this point, the stress concentration reaches a level sufficiently high to activate dislocation sources, and consequently, the plastic zone extends across the next grain. When this occurs, the stress concentration ahead of the newly extended plastic zone decreases. This is an effect of the new lower value of n (n_S), which is related to the larger plastic zone.

For each surface crack length 2a (in the longer crack region) the value of the parameter $\overline{K} = (\pi a)^{1/2}$ was obtained. Parameter n_C was then determined by Equation (14):

$$n_C = \cos\left[\frac{\pi}{2}\frac{\sigma}{\sigma_{comp}}\left(1-\frac{K_{th}}{\overline{K}}\left(n_C\right)^{1/2}\right)\right] \tag{14}$$

where σ_{comp} is an appropriate comparison stress greater than the applied stress σ. Here, it is $\sigma_{comp} = \sigma_{UTS}$ and $K_{th} = \sigma_{FL}\left(\frac{\pi D}{2}\right)^{1/2}$, where σ_{FL} is the fatigue limit and D is the grain diameter.

This equation is solved readily in three or four iterations, taking the initial value of n_C equal to 1. The value of n_S is calculated from the following Equation (15):

$$n_S = \frac{n_C}{1+2n_C\left(\frac{\sigma}{\sigma_{FL}}\right)^2\left(\frac{K_{th}}{\overline{K}}\right)^2} \tag{15}$$

The calculation of φ can now be made using Equation (13). Finally, for each set of pairs (Φ,da/dN), a power law expression was determined:

$$f = 2.539.10^{-14}\,\Delta\sigma^{4.335} \tag{16}$$

With the value of f obtained from Equation (16), the upper and lower limit curves derived by using the values of n_S and n_C, respectively, where determined and have been plotted in Figure 4, together with the curve obtained using the proposed model.

Figure 5 shows the data corresponding to one of the short cracks, where the crack growth rate presents an oscillating pattern of accelerating and decelerating growth. This behavior is related to grain and phase boundaries which act like obstacles to short crack propagation.

If we want to calculate the number of cycles that a crack will need to grow to a determined length, we will have to integrate the curves shown in Figure 5, from an initial crack length a_0 ($a_0 \geq d$) to a final length a_f. In Figure 6, that integration is shown. Because of the validity of the proposed approach, the integrations can begin at a length of $a_0 = d$ and finish with a crack length of 1 mm, where, typically, the crack is considered to be long and propagating according to Paris's law. As can be observed, the approach is valid over the complete range of crack lengths and its prediction is between the two curves proposed by Navarro and de los Rios.

Table 6 summarizes the data needed for each model or approach. As can be seen, both models need only mechanical parameters of the steel. The difference is the simplicity of the approach proposed here, only

Table 4: Mechanical properties of the steel used in this study

Material	σ_{ys} (MPa)	σ_{uts} (MPa)	$\Delta\sigma_{eR}$ (MPa)	R	Ref.
0.4 wt.% C steel	392	683	486	-1	[14]

Table 5: Estimations of parameters of the model proposed for the steel investigated in this study

Material	ΔK_{thR} (MPa × m$^{1/2}$)	$\Delta\sigma_{eR}$ (MPa)	d (mm)	$\Delta\sigma_n$ (MPa)	C (mm × cycle^{-1} × MPa^{-1} × m$^{-1/2}$)	m	ΔK_{thR} (MPa × m$^{1/2}$)	k (mm^{-1})
0.4 wt.% C steel	6.0	486	0.097	815.9	4.961E^{-07}	2.028	5.515	29.278

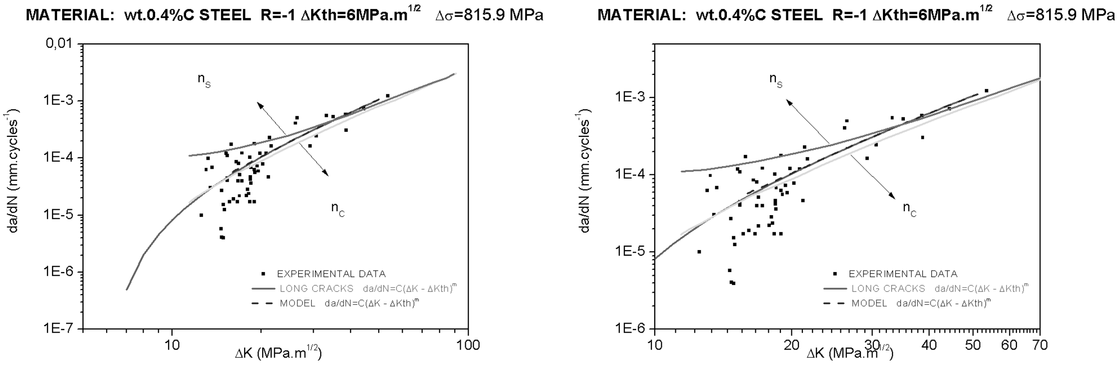
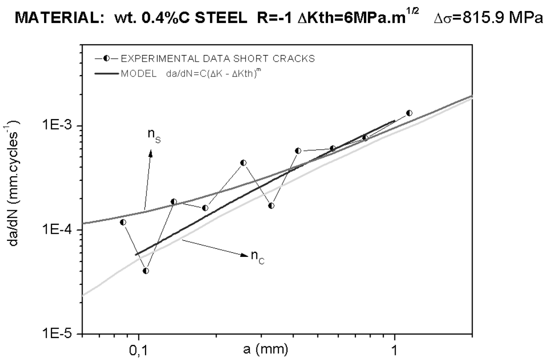


Figure 4: Plot of da/dN vs. ΔK showing experimental [24] and estimated data from crack propagation behavior from 0.4 % C steel, a) plot, b) zoom of the principal zone



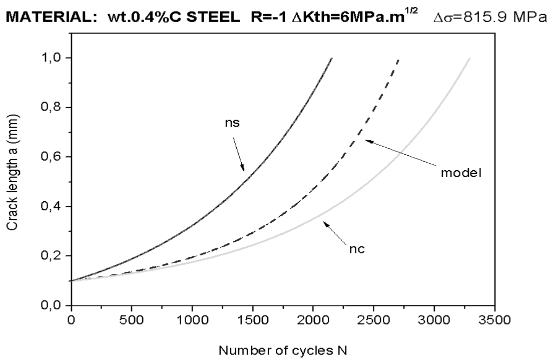


Figure 5: Experimental data of one crack together with the predictions of Navarro and De Los Rios [24] and the approach discussed in the present work (left)

Figure 6: Plot of the number of cycles spent from initiation of crack growth to a determined crack length (right)

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on January 10, 2017
For personal use only.

one equation must be solved and that without iterations.

Vallellano, Navarro and Domínguez [28] had recently proposed a model for crack growth prediction. It establishes two different thresholds to crack growth: one is associated with whether or not the monotonic plastic zone is able to overcome the barriers and the other threshold imposes the same condition but for the cyclic plastic zone. For applying this model, one needs to know a lot of parameters of the material and has to resolve iterations. The simplicity of the mathematical model proposed in this paper is the significant difference compared to the other approaches.

Conclusions

In this work, the approach previously proposed by Chapetti [11] was taken, but now, it was applied to estimate high-cycle fatigue crack propagation over the entire fatigue crack growth regime. The advantage of this work is that it needs only a single equation and the data required is simple to measure. No more than a straight forward test is required to obtain long crack data (ΔK vs. da/dN), the size of the microstructural barrier (usually the grain size) and the plain fatigue limit $\Delta\sigma_{eR}$.

This approach was applied to four different materials: 7075-T6 alloy, Ti-6Al-4 V alloy, JIS S10C steel and 0.4 wt.% C steel. In all cases, the approach presented in this paper allows an accurate and valid estimation of high-cycle fatigue crack propagation.

Acknowledgement

The author wants to thank the Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET) of Argentina.

Model	Range of applications	Necessary parameters
Navarro and de los Rios	from MSC to LC	• grain diameter • K_{th}, a vs da/dN, G, σ_{UTS}, E • conduct iterations
proposed here	from MSC (a ≥ d) to LC	• long crack data of ΔK vs da/dN • size of the critical defect or strong microstructural barrier (usually d) • plain fatigue limit $\Delta\sigma_{eR}$

Table 6: Comparison of the models

References

1 K. J. Miller, F. E. Ibrahim: Damage accumulation during initiation and short crack growth regimes, Fatigue of Engineering Materials and Structures 5 (1982), pp. 223-232 DOI:10.1111/j.1460-2695.1982.tb01250.x

2 M. D. Chapetti, T. Kitano, T. Tagawa, T. Miyata: Fatigue limit of blunt-notched components, Fatigue and Fracture of Engineering Materials and Structures 21 (1998), pp. 1525-1536 DOI:10.1046/j.1460-2695.1998.00115.x

3 K. Tanaka, Y. Nakai: Prediction of fatigue threshold of notched components, Journal of Engineering Materials and Technology, Transactions of the ASME 106 (1984), pp. 192-199

4 K. J. Miller: The two thresholds of fatigue behaviour, Fatigue and Fracture of Engineering Materials and Structures 16 (1993), pp. 931-939 DOI:10.1111/j.1460-2695.1993.tb00129.x

5 D. Taylor, J. K. Knott: Fatigue crack propagation behaviour of short cracks, the effect of microstructure, Fatigue of Engineering Materials and Structures 4 (1981), pp. 147-155 DOI:10.1111/j.1460-2695.1981.tb01116.x

6 J. Lankford: The influence of microstructure on the growth of small fatigue cracks, Fatigue of Engineering Materials and Structures 8 (1985), pp. 161-175 DOI:10.1111/j.1460-2695.1985.tb01201.x

7 A. J. McEvily, K. Minakawa: On crack closure and the notch size effect in fatigue, Engineering Fracture Mechanics 28 (1987), pp. 519-527 DOI:10.1016/0013-7944(87)90049-X

8 J. R. Yates, M. W. Brown: Prediction of the length of non-propagating fatigue cracks, Fatigue and Fracture of Engineering Materials

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on January 10, 2017
For personal use only.

and Structures 10 (1987), pp. 187-201
DOI:10.1111/j.1460-2695.1987.tb00477.x
9 M. D. Chapetti, T. Kitano, T. Tagawa, T. Miyata: Two small-crack extension force concept applied to fatigue limit of blunt notched components, International Journal of Fatigue 21 (1999), pp. 77-82
DOI:10.1016/S0142-1123(98)00057-7
10 M. H. El Haddad, T. H. Topper, K. N. Smith: Prediction of nonpropagating cracks, Engineering Fracture Mechanics 11 (1979), pp. 573-584
DOI:10.1016/0013-7944(79)90081-X
11 M. D. Chapetti: Fatigue propagation threshold of short cracks under constant amplitude loading, International Journal of Fatigue 25 (2003), pp. 1319-1326
DOI:10.1016/S0142-1123(03)00065-3
12 H. O. Fuchs: Metal Fatigue in Engineering, John Wiley and Sons, New York, USA (1980)
13 N. E. Dowling: Mechanical Behavior of Materials: Engineering Methods for Deformation Fracture and Fatigue, 3rd Ed., Prentice Hall, USA (2007)
14 X. Zheng, M. A. Hirt: Fatigue crack propagation in steels, Engineering Fracture Mechanics 18 (1983), pp. 965-973
DOI:10.1016/0013-7944(83)90070-X
15 M. Klesnil, P. Lukáš: Fatigue of Metallic Materials, Materials Science Monographs 7 (1980)
16 K. J. Miller, E. R. de los Rios: The behaviour of short fatigue cracks, EGF (ESIS) Publication 1 (1986)
17 R. O. Ritchie, J. Lankford: Small fatigue cracks: A statement of the problem and potential solutions, Material Science and Engineering 84 (1986), pp. 11-16
DOI:10.1016/0025-5416(86)90217-X
18 S. Suresh, R. O. Ritchie: Propagation of short fatigue cracks, International Metals Reviews 29 (1984), pp. 445-476
DOI:10.1179/imtr.1984.29.1.445
19 Zuyu Sun, E. R. de los Rios, K. J. Miller: Modelling small fatigue cracks interacting with grain boundaries, Fatigue Fracture Engineering Materials and Structures 14 (1991), pp. 277-291
DOI:10.1111/j.1460-2695.1991.tb00658.x
20 D. J. Nicholls, J. W. Martin: A comparison of small fatigue crack growth, low cycle fatigue and long fatigue crack growth in Al-Li alloys, Fatigue Fracture Engineering Materials and Structures 14 (1991), pp. 185-192
DOI:10.1111/j.1460-2695.1991.tb00652.x
21 P. H. Hobson: The formulation of a crack growth equation for short cracks, Fatigue Engineering Materials Structures 5 (1982), pp. 323-327
DOI:10.1111/j.1460-2695.1982.tb01241.x
22 K. S. Chan, J. Lankford: A crack tip strain model for the growth of small fatigue cracks, Scripta Metallurgica 17 (1983), pp. 529-532
DOI:10.1016/0036-9748(83)90346-0
23 R. W. Hamm, W. S. Johnson: A unification of small- and large- crack growth laws, Fatigue Fracture Engineering Materials and Structures 22 (1999), pp. 711-722
DOI:10.1046/j.1460-2695.1999.t01-1-00149.x
24 A. Navarro, E. R. de los Rios: A microstructurally-short fatigue crack growth equation, Fatigue and Fracture of Engineering Materials and Structures 11 (1988), pp. 383-396
DOI:10.1111/j.1460-2695.1988.tb01391.x
25 C. Santus, D. Taylor: Physically short crack propagation in metals during high cycle fatigue, International Journal of Fatigue 31 (2009), pp. 1356-1365
DOI:10.1016/j.ijfatigue.2009.03.002
26 K. Tokaji, T. Ogawa, Y. Harada: The growth of small fatigue cracks in a low carbon steel; the effect of microstructure and limitations of linear elastic fracture mechanics, Fatigue and Fracture of Engineering Materials and Structures 9 (1986), pp. 205-217
DOI:10.1111/j.1460-2695.1986.tb01207.x
27 Data Book – On Fatigue Crack Growth Rates of Metallic Materials, The Society of Materials Science, Japan (1983)
28 C. Vallellano, A. Navarro, J. Domínguez: Two-parameter fatigue crack growth driving force: Successive blocking of the monotonic and cyclic plastic zones at microstructural barriers, International Journal of Fatigue 46 (2013), pp. 27-34
DOI:10.1016/j.ijfatigue.2011.12.013

Bibliography

DOI 10.3139/120.110959
Materials Testing
59 (2017) 1, pages 35-40
© Carl Hanser Verlag GmbH & Co. KG
ISSN 0025-5300

Abstract

Ein Modell für den Rissfortschritt unter High Cycle Fatigue (HCF) Beanspruchung. Der vorliegende Beitrag behandelt die Vorhersage des High-Cycle-Ermüdungsverhaltens für vier verschiedene Werkstoffe (Aluminiumlegierung 7075-T6, Titanlegierung Ti-6Al-4V, Stahl JIS S10C und Stahl mit 0,4 wt.-% Kohlenstoff) unter Verwendung von Chapetti's Ansatz zur Abschätzung der Ermüdungsrissfortschrittskurve. Im ersten Teil des Beitrags wird eine einfache Integralgleichung zur Untersuchung des gesamten Fortschrittprozesses ermittelt, indem die neuesten Ergebnisse von Santus und Taylor berücksichtigt werden, die ein doppeltes Regime des Fortschritts (kurze und lange Risse) verwendet werden, das mit dem Modell von El Haddad charakterisiert wird. Der zweite Teil des Beitrags beinhaltet einen Vergleich des Rissfortschrittverhaltens, wie es von Navarro und de los Rios propagiert wird, mit dem im ersten Teil des Beitrags weiterentwickelten Ansatzes. Die Ergebnisse erlauben die Schlussfolgerung, dass der in diesem Beitrag postulierte Ansatz eine gute und zuverlässige Abschätzung des HCF-Rissfortschritts darstellt, indem nur eine einzige Gleichung zur Beschreibung des gesamten Ermüdungsrissregimes verwendet wird.

Nomenclature

a	crack length
d	position from the surface of the strongest microstructural barrier
da/dN	crack growth rate
ΔK	applied stress intensity factor range
ΔK_{thR}	fatigue crack propagation threshold for long cracks
MSC	microstructurally short crack
LC	long crack
R	stress ratio
$\Delta\sigma$	applied stress range
$\Delta\sigma eR$	plain fatigue limit
$\Delta\sigma th$	fatigue crack propagation threshold stress
ΔKth	fatigue crack propagation threshold
ΔKdR	microstructural threshold
ΔKCR	extrinsic component of ΔK_{thR}
k	material constant
$\Delta\sigma n$	nominal applied stress range

The author of this contribution

Marcela Angela Balbi, born 1980, received her MSc and PhD in Physics from the National University of Rosario, Argentina. She is currently Auxiliary Professor at the National University of Rosario, Argentina and a researcher of the National Council of Scientific Research and Technology (CONICET) of Argentina.