ON THE MODELING OF THE STOP-HOLE CRACK REPAIR METHOD[1]

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Abstract

The stop-hole method is a simple and economic repair technique widely used to retard or even to stop the propagation of a fatigue crack in structural components that cannot be replaced immediately after the detection of the crack. Its principle is to drill a hole at or close to the crack tip to transform the crack into a notch, reducing in this way its stress concentration effect. The fatigue life increment that can be achieved with this technique can be modeled by assuming that it is equal to the number of cycles required to re-initiate the crack at the resulting notch root, which depends at least on the crack size and on the hole diameter. To study the effectiveness of this repair method, classical εN techniques are adapted to explain the results of several experiments carried out on aluminum plates, taking into account short crack concepts. The comparison among the experimental and the calculation results show that the life increment caused by the stop-holes can be effectively predicted in this way.

Key words: Stop-hole; Crack repair; εN method; Short cracks.

SOBRE A MODELAGEM DO MÉTODO DO FURO DE PARADA PARA REPARO DE TRINCAS

Resumo

O método do furo de parada é uma técnica simples e econômica muito usada para reparar ou até mesmo para parar a propagação de uma trinca de fadiga em componentes estruturais que não podem ser substituídos logo após a detecção da trinca. O seu princípio é introduzir um furo na ou próximo à ponta da trinca para transformá-la num entalhe, reduzindo assim seu efeito concentrador de tensões. O aumento na vida à fadiga que pode ser conseguido desta forma pode ser modelado assumindo-o igual ao número de ciclos necessários para reiniciar a trinca na raiz do entalhe resultante, o qual depende pelo menos do tamanho da trinca e do raio do furo. Para estudar a eficácia deste método de reparo, técnicas εN clássicas foram adaptadas para explicar os resultados de vários testes feitos em chapas de uma liga de alumínio, levando em consideração conceitos de trincas curtas. A comparação entre os resultados experimentais e dos cálculos mostram que o aumento de vida causado pelos furos de parada pode ser eficazmente previsto desta forma.

Palavras-chave: Furo de parada; Reparo de trincas; Método EM; Trincas curtas.

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1 INTRODUCTION

The stop-hole method is a popular emergency repair technique to extend the fatigue life of cracked structural components.[1] In its simplest form, this method consists of boring a hole in the vicinity of, or centred at the crack tip, to transform the crack into a notch, increasing in this way the residual fatigue life of the cracked structure in comparison to the life it would have if not repaired. However, the parameters and the location of the stop-hole are usually decided in an arbitrary way, dependent on the crew experience and skill. In consequence, sometimes the stop-hole works very well, but in other cases their results can be disappointing, or even harmful. Therefore, a simple and reliable calculation method to predict beforehand the results of this practical emergency repair technique can be quite useful in real-life situations.

However, the appropriate modelling of this problem is not that simple. Several parameters can influence the fatigue life increment caused by the stop-hole. Among them, at least the radius, the position and the surface finish of the hole; the type and the size of the crack; the geometry and the mechanical properties of the component; the history, the type and the magnitude of the load; and the residual stresses around the stop-hole border can all influence the effectiveness of the repair.

As a general rule, the increase of the stop-hole diameter contributes to decrease the value of the stress concentration factor K_t of the resulting notch, but it also increases the nominal stresses in the residual ligament of the repaired component. But small stop-hole diameters are associated with smaller notch sensitivities q, which decrease the resulting K_t effect in the fatigue crack (re)initiation life. This effect is quantified by the so-called fatigue stress concentration factor K_f, classically defined by Peterson[2] and Shigley, Mischke e Budynas.[3]

$$K_f = 1 + q \cdot (K_t - 1) \tag{1}$$

However, when a long crack is repaired by a relatively small stop-hole, it forms an elongated notch with a high K_t, which is associated with a steep stress/strain gradient around its root. Consequently, its notch sensitivity q cannot be well predicted by the classical Peterson recipe.[4] Therefore, the model for predicting the residual fatigue life of repaired cracked structures must take this fact into account, as shown below.

2 EXPERIMENTAL PROGRAM

A set of experiments was carried out on SE(T) specimens of thickness $B = 8$ mm and width $W = 80$ mm, see Figure 1, to measure the delays associated with the re-initiation of a fatigue crack after drilling a stop-hole centred at the crack tip of length a. The tested material was an Al alloy 6082 T6, with yielding strength $S_Y = 280MPa$, ultimate tensile strength $S_U = 327MPa$, Young's modulus $E = 68GPa$, and area reduction $RA = 12\%$. The specimens were cut on the LT direction, and the fatigue tests were carried out under constant load range ΔP at $R = P_{min}/P_{max} = 0.57$. This high R-ratio was chosen to avoid any crack closure interference on the crack propagation behavior.

The 2, 5 or 6 mm stop-holes were carefully centered and drilled at the fatigue crack tips: the specimen was removed from the testing machine, fixed and positioned on a milling machine, drilled at low feedings with plenty refrigeration and then reamed to achieve a 1.5μm diameter accuracy, and finally re-mounted on the test machine. Great care was taken to avoid introducing residual stresses by any means during this process, designed to generate notches with a same length $a_n = a_0 + \rho = 27.5$ mm ⇒

$a_n/W = 27.5/80 = 0.344$. The load range ΔP was always maintained constant, before and after the drilling of the stop-holes, see Table 1.

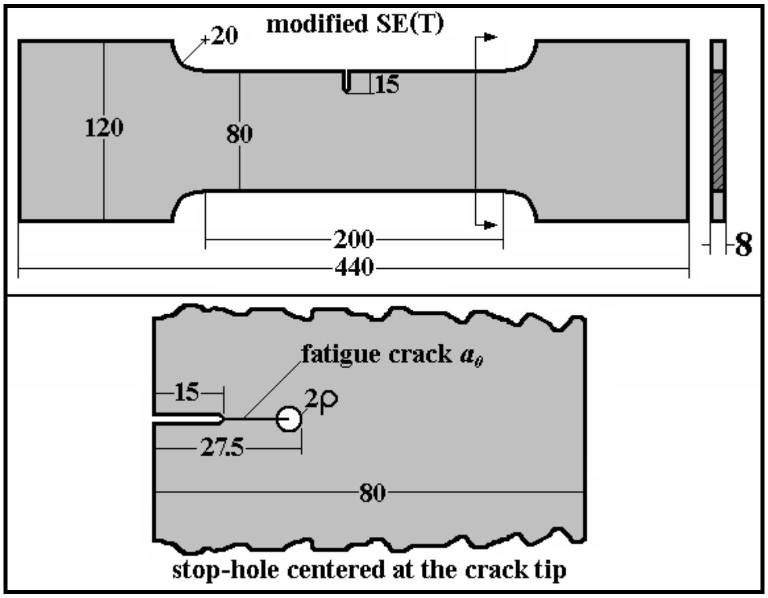

Figure 1: The tested specimens.

Table 1: Loads and nominal stresses $\sigma = P/B(W - a_n)$ associated with the applied pseudo stress intensity range $\Delta K^* = 0.838 \cdot \Delta P$ (in MPa√m, calculated using $a_n/W = 0.344$ and ΔP in kN[5]) after introducing the stop-hole.

ΔK^* (MPa√m)	6	7.4	7.5	8	8.1	9	10.1	13.5	14
ΔP (kN)	7.163	8.835	8.954	9.551	9.671	10.75	12.06	16.12	16.71
P_{min} (kN)	16.66	20.55	20.82	22.21	22.49	24.99	28.04	37.48	38.87
P_{max} (kN)	9.496	11.71	11.87	12.66	12.82	14.24	15.98	21.37	22.16
$\Delta\sigma$ (MPa)	17.06	21.04	21.32	22.74	23.03	25.58	28.71	38.38	39.80
σ_m (MPa)	31.14	38.40	38.92	41.52	42.03	46.70	52.41	70.06	72.65

Twenty-three specimens were tested, and in all of them a number of (delay) cycles N_d had to be spent until a new crack was able to reinitiate from the stop-hole edge. Fig. 2 shows typical crack propagation curves measured in 3 specimens with different stop-hole radii, all tested under the same loading conditions; and the beneficial influence of the stop-holes and of their diameter. Table 2 summarizes the number of delay cycles N_d caused by the stop-holes under the several testing conditions studied in this program. Note that $N_d > 2 \cdot 10^6$ cycles means that the tests were interrupted if a fatigue crack was not detected at the stop-hole root after this life.

Table 2: Number of measured delay cycles N_d after introducing the stop-hole.

$\rho = 1$ mm		$\rho = 2.5$ mm		$\rho = 3$ mm	
ΔK^* MPa√m	N_d ×10^3 cycles	ΔK^* MPa√m	N_d ×10^3 cyc.	ΔK^* MPa√m	N_d ×10^3 cyc.
6.0	*> 2000*	*7.5*	*> 2000*	*8.5*	*> 2000*
7.4	*980, 724, 580*	*8.1*	*1800*	*9.0*	*1150, 960*
8.0	*600, 560, 510*	*10.1*	*355, 270*	*10.1*	*611, 580*
10.1	*119, 84*	*13.5*	*65, 58, 37*	*14.0*	*60, 32*

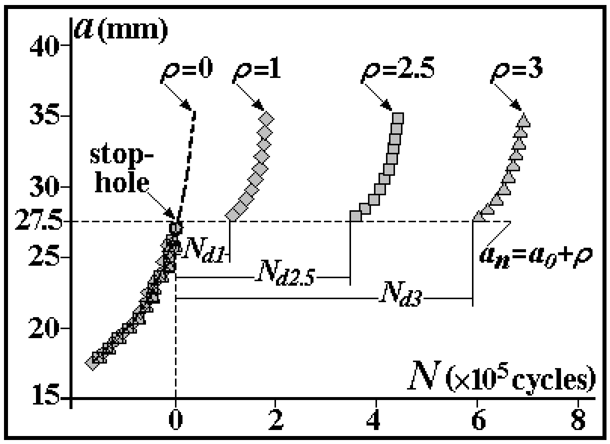

Figure 2: Typical effect of the stop-hole on the subsequent fatigue crack propagation.

3 THE BASIC STOP-HOLE MODEL

The fatigue crack re-initiation lives at the stop-hole roots can be modeled by εN local strain procedures, using (i) the cyclic properties of the 6082 T6 Al alloy, $H' = 443$ MPa, $h' = 0.064$, $\sigma'_f = 485$ MPa, $b = -0.0695$, $\varepsilon'_f = 0.733$, $c = -0.827$, where σ'_f, b, ε'_f and c are the Coffin-Manson parameters and H' and h' are the coefficient and the exponent of the cyclic stress-strain curve fitted by Ramberg-Osgood; (ii) the nominal stress history (see Table 3); and (iii) the stress concentration factor K_t of the notches generated by repairing the cracks drilling a stop-hole at their tips. Such factors can be estimated by Inglis, giving for hole radii $\rho = 1$, 2.5 or 3 mm, respectively

$$K_t \cong 1 + 2\sqrt{(a/\rho)} = 11.49,\ 7.63 \text{ or } 7.06 \tag{2}$$

The classical εN models neglect hardening transients, supposing that the fatigue behavior can be described by an unique Ramberg-Osgood cyclic stress/strain $\sigma\varepsilon$ curve, whose parameters H' and h' can also be used to describe the elastic-plastic hysteresis loop $\Delta\sigma\Delta\varepsilon$ curves. These equations should model both the nominal and the notch root cyclic stress/strain behavior, to avoid the logical inconsistency of using two different models for describing the same material (Hookean for the nominal and Ramberg-Osgood for the notch root stresses), and also the significant prediction errors that can be introduced at higher nominal loads by such a regrettably widespread practice [6]. Moreover, as all the studied stop-hole radii were much bigger than the cyclic plastic zones which followed the original fatigue crack tips, it is also reasonable to suppose that they did remove all the damaged material ahead of the cracks and

that the material at the resulting notch root can be treated as virgin.
The stop-hole can be modeled by first calculating the stresses and strains maxima and ranges at the notches roots according to a proper stress/strain concentration rule, which should then be used to calculate the crack re-initiation lives by an $\Delta\varepsilon \times N$ rule, considering the influence of the static or mean load component. Neglecting this effect could lead to severely non-conservative predictions, as the *R*-ratio used in the tests was quite high. All the required fatigue life calculations were made using the ViDa software, as summarized in Figures 3-5, which show that the lives predicted by Morrow El, Morrow EP and SWT are similar in this case (but it must be emphasized that such a similarity cannot be assumed beforehand, since in many other cases these rules can predict very different fatigue lives!), whereas the Coffin-Manson predictions are highly non-conservative, thus absolutely useless.

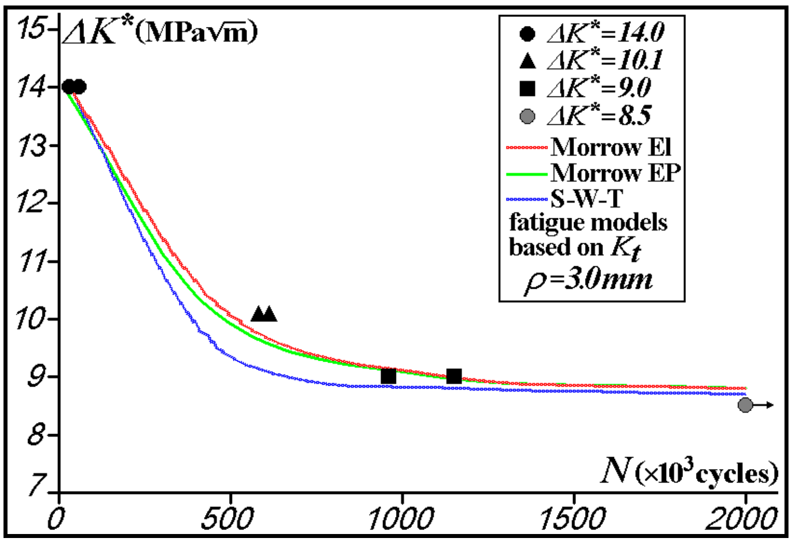

Figure 3: Predicted and measured crack re-initiation lives at the stop-holes roots of radius ρ = *3.0mm*, using the K_t of the repaired crack.

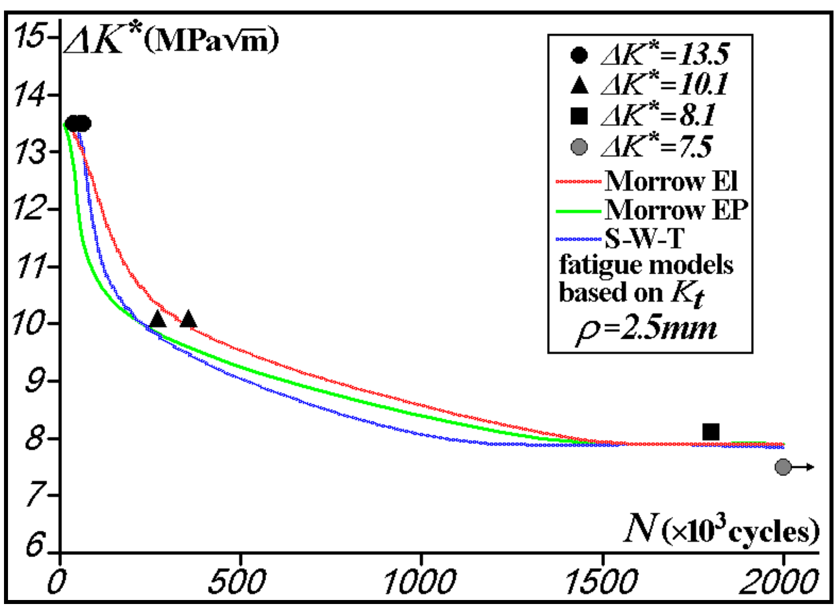

Figure 4: Predicted and measured crack re-initiation lives at the stop-holes roots of radius ρ = *2.5mm*, using K_t of the repaired crack.

For the two bigger stop-holes (with radii $\rho = 3.0$ and $\rho = 2.5mm$) the predictions reproduce quite well the measured fatigue crack re-initiation lives. In fact, so well that it is worth to point out that the curves in those plots result from calculated life predictions, not from data fitting. But the predictions obtained by the same calculation procedures for the smaller stop-hole with $\rho = 1.0mm$ are much more conservative. This behavior is a little bit surprising, but since for design purposes this performance is not really that bad, and based on the limited but representative data measured, the relatively simple procedure used above could probably be recommended as a useful design tool.

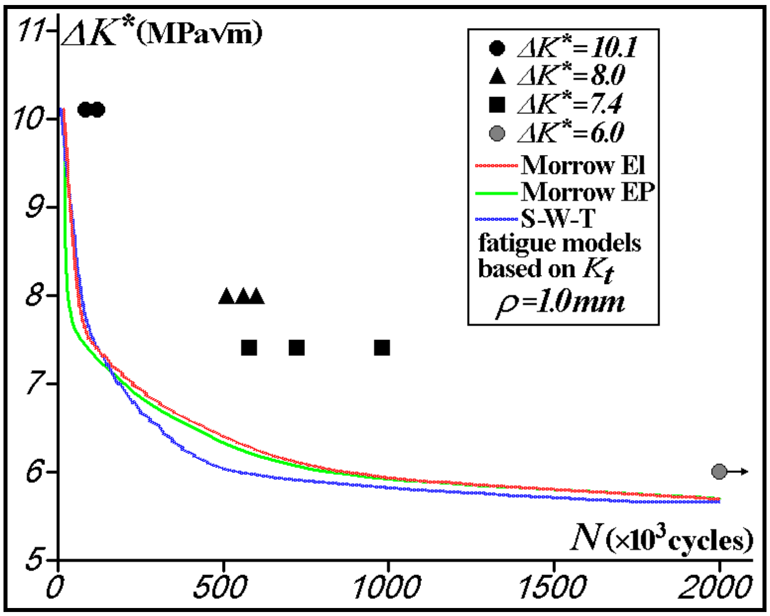

Figure 5: Predicted and measured crack re-initiation lives at the stop-holes roots of radius $\rho = 1.0mm$, using the K_t of the repaired crack.

There are few mechanical reasons which can explain the better than expected fatigue lives obtained from the specimens with the $\rho = 1mm$ stop-holes. Significant compressive residual stresses could be one of them. But all the holes were drilled and reamed following identical procedures, and the bigger stop-hole lives were well predicted supposing $\sigma_{res} = 0$. Therefore, it is difficult to justify why high compressive residual stresses would be present only at the smaller stop-holes roots. The same can be said about the surface finish of the stop-holes. However, the smaller stop-holes generate a notch with a bigger K_t and with a much steeper stress gradient near their roots. This effect can significantly affect the growth of short cracks and, consequently, the fatigue notch sensitivity [6], mechanically explaining the measured behavior, as follows.

4 ANALYTICAL PREDICTION OF THE NOTCH SENSITIVITY

Long cracks grow under a given $\Delta\sigma$ and R set when $\Delta K = \Delta\sigma\sqrt{(\pi a)}\cdot f(a/w) > \Delta K_{th}(R)$, where $\Delta K_{th}(R)$ is the propagation threshold at that R-ratio. Therefore, short cracks (which have $a \cong 0$) must propagate in an intrinsically different way, as otherwise $\Delta K(a \to 0, R) > \Delta K_{th}(R) \Rightarrow \Delta\sigma \to \infty$, which is a non-sense, as a stress range $\Delta\sigma > 2S_L(R)$ can generate and propagate a fatigue crack, where $S_L(R)$ is the fatigue limit of the material at R. To conciliate the fatigue limit (e.g.) at R = 0, $\Delta S_0 = 2S_L(0)$, with the propagation threshold under pulsating loads $\Delta K_0 = \Delta K_{th}(0)$, a small "short crack characteristic size" a_0 can be summed to the actual crack size a to obtain[7]

$$\Delta K_I = \Delta\sigma\sqrt{\pi(a+a_0)}\text{, where } a_0 = \frac{1}{\pi}\left(\frac{\Delta K_0}{f(a/w)\cdot\Delta S_0}\right)^2 \tag{3}$$

These equations correctly predict that the biggest stress range which does not propagate a microcrack is the fatigue limit: if $a << a_0$, $\Delta K_I = \Delta K_0 \Rightarrow \Delta\sigma \rightarrow \Delta S_0$. However, when the crack departs from a notch, as usual, its driving force is the stress range at the notch root $\Delta\sigma$, not the nominal stress range $\Delta\sigma_n$, which is generally used on the ΔK expressions. As in these cases the factor $f(a/w)$ includes the stress concentration effect of the notch, it is better to define $f(a/w)$ separating it in two parts: $f(a/w) = \eta\cdot\varphi(a)$, where $\varphi(a)$ quantifies the stress gradient effect near the notch, with $\varphi(a\rightarrow 0)\rightarrow K_t$, while the constant η quantifies the free surface effect, to obtain

$$\Delta K_I = \eta\cdot\varphi(a)\cdot\Delta\sigma_n\sqrt{\pi(a+a_0)}\text{, where } a_0 = \frac{1}{\pi}\left(\frac{\Delta K_0}{\eta\cdot\Delta S_0}\right)^2 \tag{4}$$

Using the traditional definition $\Delta K = f(a/w)\cdot\Delta\sigma\sqrt{(\pi a)}$, an alternate way to model the short crack effect is to suppose that the fatigue crack propagation threshold depends on the crack size, $\Delta K_{th}(a, R = 0) = \Delta K_{th}(a)$, through a function given by

$$\frac{\Delta K_{th}(a)}{\Delta K_0} = \frac{\Delta\sigma\sqrt{\pi a}\cdot f(a/w)}{\Delta\sigma\sqrt{\pi(a+a_0)}\cdot f(a/w)} = \sqrt{\frac{a}{a+a_0}} \Rightarrow \Delta K_{th}(a) = \frac{\Delta K_0}{\sqrt{1+(a_0/a)}} \tag{5}$$

However, an additional adjustable parameter γ in the $\Delta K_{th}(a)$ expression allows a better fitting of the experimental data:[8]

$$\Delta K_{th}(a) = \Delta K_0\left[1+\left(a_0/a\right)^{\gamma/2}\right]^{-1/\gamma} \tag{6}$$

If S'_L and $S_L = S'_L/K_f$ are the fatigue limits measured in standard (non-notched, polished) and in similar but notched SN specimens, $K_t \geq K_f = 1 + q\cdot(K_t - 1)$, where q is the notch sensitivity factor, which can be modeled using the short crack behavior, since it can be associated to tiny cracks which can initiate at the notch root but do not propagate if $2S'_L/K_t < \Delta\sigma < 2S'_L/K_f$.[6] E.g., the stress intensity factor of a crack that departs from a circular hole of radius ρ in a Kirsh (infinite) plate loaded in mode I is given by Tada, Paris and Irwin[9]

$$\Delta K_I = \eta\cdot\varphi\left(a/\rho\right)\cdot\Delta\sigma\sqrt{\pi a} = 1.1215\cdot\varphi\left(a/\rho\right)\cdot\Delta\sigma\sqrt{\pi a} \tag{7}$$

where $\varphi(a/\rho) \equiv \varphi(x)$ is given by:

$$\varphi(x) = \left(1+\frac{0.2}{(1+x)}+\frac{0.3}{(1+x)^6}\right)\cdot\left(2-2.354\frac{x}{1+x}+1.206\left(\frac{x}{1+x}\right)^2-0.221\left(\frac{x}{1+x}\right)^3\right) \tag{8}$$

Note that $\lim_{a\to 0} \Delta K_I = 1.1215 \cdot 3 \cdot \Delta\sigma\sqrt{\pi a}$ and $\lim_{a\to\infty} \Delta K_I = \Delta\sigma\sqrt{\pi a/2}$, exactly as expected. Thus, if $a_0 = (\Delta K_0/\eta\Delta S_0\sqrt{\pi})^2$, any crack departing from a Kirsh hole will propagate when

$$\Delta K_I = \eta \cdot \varphi(a/\rho) \cdot \Delta\sigma\sqrt{\pi a} > \Delta K_{th} = \Delta K_0 \cdot \left[1 + (a_0/a)^{\gamma/2}\right]^{-1/\gamma} \tag{9}$$

The propagation criterion for these fatigue cracks can then be rewritten as Meggiolaro and Castro[6]

$$\varphi\left(\frac{a}{\rho}\right) > \frac{\left(\dfrac{\Delta K_0}{\Delta S_0\sqrt{\rho}}\right)\cdot\left(\dfrac{\Delta S_0}{\Delta\sigma}\right)}{\left[\left(\eta\sqrt{\dfrac{\pi a}{\rho}}\right)^{\gamma} + \left(\dfrac{\Delta K_0}{\Delta S_0\sqrt{\rho}}\right)^{\gamma}\right]^{1/\gamma}} \equiv g\left(\frac{a}{\rho}, \frac{\Delta S_0}{\Delta\sigma}, \frac{\Delta K_0}{\Delta S_0\sqrt{\rho}}, \gamma\right) \tag{10}$$

Therefore, $K_f = \Delta S_0/\Delta\sigma$ can be calculated from the material fatigue limit ΔS_0 and crack propagation threshold ΔK_0, and from the geometry of the cracked piece by

$$\begin{cases} \varphi(a/\rho) = g(a/\rho, \Delta S_0/\Delta\sigma, \Delta K_0/\Delta S_0\sqrt{\rho}, \gamma) \\ \dfrac{\partial}{\partial a}\varphi(a/\rho) = \dfrac{\partial}{\partial a} g(a/\rho, \Delta S_0/\Delta\sigma, \Delta K_0/\Delta S_0\sqrt{\rho}, \gamma) \end{cases} \tag{11}$$

This system can be solved for several combinations of materials and hole radii, given by $\Delta K_0/\Delta S_0\sqrt{\rho}$ and γ, to obtain the Kirsh plate notch sensitivity as a function of the hole radius ρ and material fatigue properties. Figure 6 compares the q values calculated in this way with the traditional Peterson curves.[6]

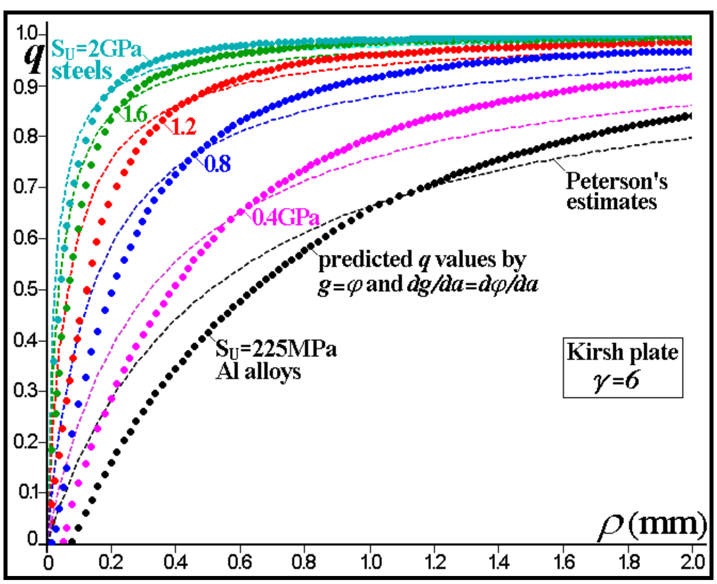

Figure 6: Notch sensitivity q as a function of the Kirsh hole diameter ρ, estimated using mean ΔK_0, ΔS_0 and S_U from 450 steels and aluminium alloys for $\gamma = 6$.

This analytical approach includes the γ exponent which allows a better fitting of the short crack propagation data, and it can be generalized to deal with other notch geometries, an important step here, since the stop-hole repaired cracks are similar to an elongated semi-elliptical notch, not to a Kirsh hole. The stress intensity factor of a crack *a* which departs from such a notch with semi-axes *b* e *c*, with *a* and *b* in the same direction perpendicular to the (nominal) stress $\Delta\sigma$, is given by:

$$\Delta K_I = \eta \cdot F\,(a/b\,,c/b) \cdot \Delta\sigma\sqrt{\pi a} \tag{12}$$

where $\eta = 1.1215$ is the free surface correction factor and $F(a/b,\ c/b)$ is the geometric factor associated to the notch stress concentration, which can be calculated as a function of the non-dimensional parameter $s = a/(a + b)$ and of K_t, given by Tada, Paris and Irwin[9]

$$K_t = \left(1 + 2\frac{b}{c}\right) \cdot \left[1 + \frac{0.1215}{(1 + c/b)^{2.5}}\right] \tag{13}$$

An analytical expression for the $F(a/b,\ c/b)$ of deep semi-elliptical notches with $c \le b$ was fitted to a series of finite element numerical calculations

$$F(\frac{a}{b},\frac{c}{b}) \equiv f\,(K_t\,,s) = K_t\sqrt{\frac{1 - exp(-K_t^2 \cdot s)}{K_t^2 \cdot s}}\text{, for } c \le b \tag{14}$$

Making $g = \varphi$ and $\partial g/\partial a = \partial\varphi/\partial a$ in (11), one can calculate the smallest stress range $\Delta\sigma$ required to initiate and propagate a crack from the notch root at a given combination of γ and $\Delta K_0/\Delta S_0\sqrt{\rho}$, which can be used to calculate $K_f = \Delta S_0/\Delta\sigma$ and *q*. Indeed, in the lack of compressive residual stresses at the notch border, the mechanical reason for stopping a crack initiated at that border (when it reaches a size a_{st}) is the stress gradient near the notch root: to stop the crack it is necessary that the stress range decrease due to the gradient near the border overcomes the effect of increasing the crack size: a short crack $a < a_{st}$ departing from the notch boundary stops when it reaches

$$\Delta K_I = \eta \cdot \varphi(a_{st}) \cdot \Delta\sigma\sqrt{\pi a_{st}} = \Delta K_0 \cdot \left[1 + (a_0/a_{st})^{\gamma/2}\right]^{-1/\gamma} \tag{15}$$

Traditional notch sensitivity estimates suppose that the sensitivity *q* depends only on the notch root ρ and the material ultimate strength S_U. However, as shown in Fig. 7, the sensitivity of semi-elliptical notches, besides depending on ρ, ΔS_0, ΔK_0 and γ, is also strongly dependent on the *c/b* ratio. Moreover, there are reasonable relationships between ΔS_0 and S_U, but not between ΔK_0 and S_U. This means that, e.g., two steels with same S_U but different ΔK_0 can behave in a way not predictable by the traditional estimates. The curves in figure 8 are calculated for typical Al alloys with mean ultimate strength $S_U = 225MPa$, fatigue limit $S_L = 90MPa \Rightarrow \Delta S_0 = 2S_LS_R/(S_L + S_R) = 129MPa$, propagation threshold $\Delta K_0 = 2.9MPa\sqrt{m}$, and $\gamma = 6$. Note that the corresponding Peterson's curve is well approximated by the semi-circular $c/b = 1$ notch.

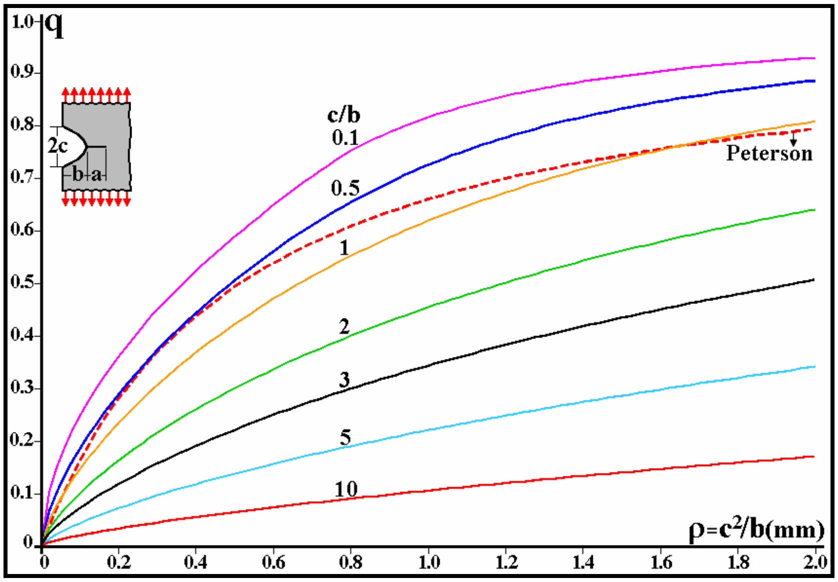

Figure 7: Notch sensitivity *q* versus the semi-elliptical notch tip radius ρ for plates of typical Al alloys ($\Delta S_0 = 129MPa$, $\Delta K_0 = 2.9MPa\sqrt{m}$, $\gamma = 6$) loaded in mode I.

5 THE IMPROVED STOP-HOLE MODEL

An improved model for predicting the effect of the stop holes on the crack re-initiation fatigue lives can be generated by using: (i) a semi-elliptical notch with $b = 27.5mm$ and $\rho = c^2/b = 1$, *2.5* or *3mm* to simulate the stop-hole repaired specimens; (ii) the mechanical properties of the 6082 T6 Al alloy studied in this work; (iii) equation (11) to calculate the notch sensitivity and equation (15) for the stress intensity factor of the repaired specimens; and finally (iv) K_f instead of K_t in the εN model.

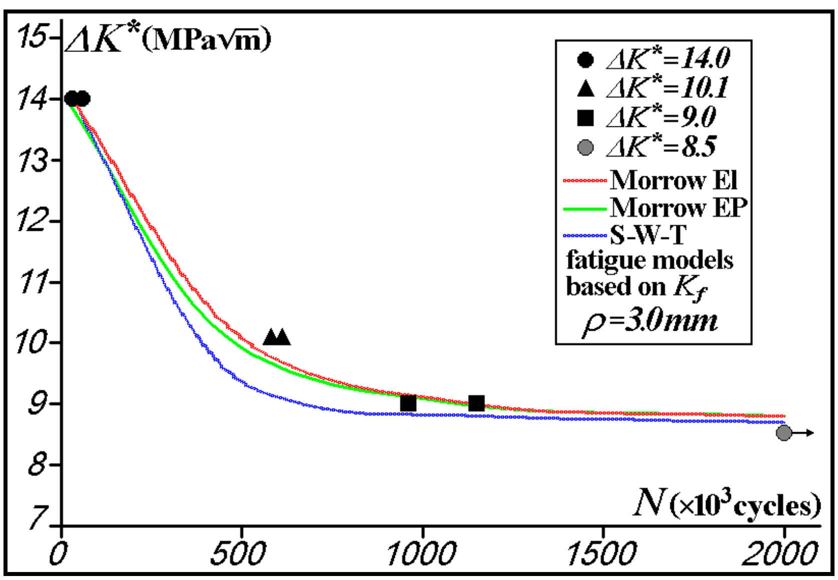

Figure 8: Predicted and measured crack re-initiation lives at the stop-holes roots of radius $\rho = 3.0mm$, using the K_f (instead of K_t) of the repaired crack.

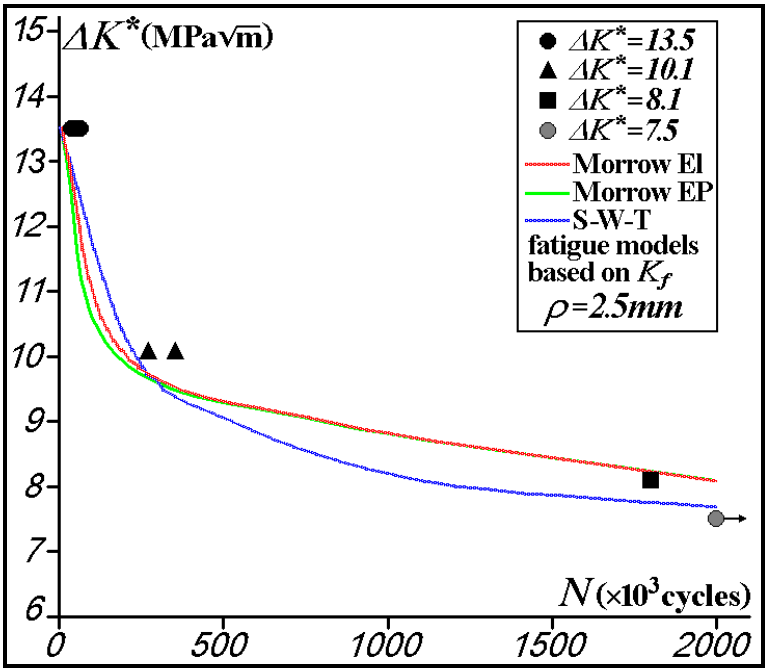

Figure 9: Predicted and measured crack re-initiation lives at the stop-holes roots of radius $\rho = 2.5mm$, using the K_f (instead of K_t) of the repaired crack.

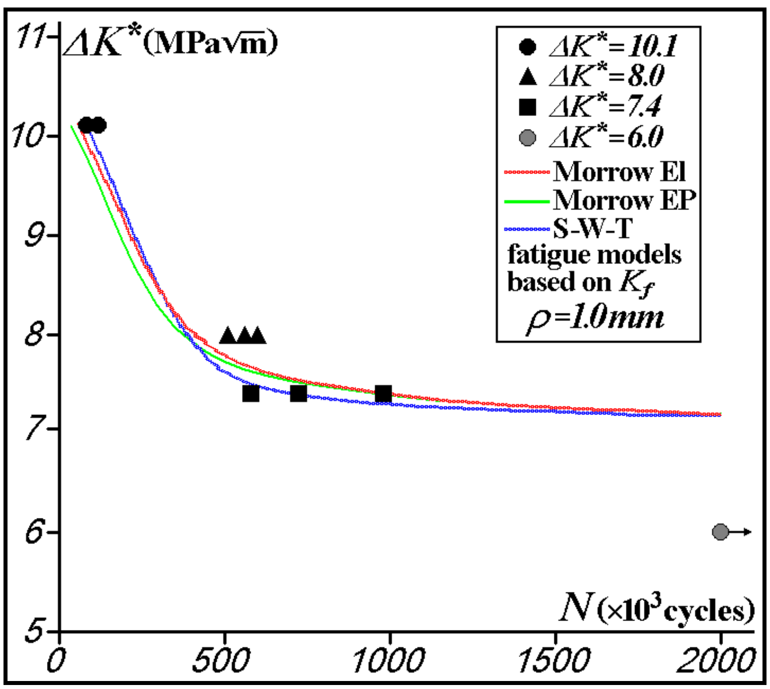

Figure 10: Predicted and measured crack re-initiation lives at the stop-holes roots of radius $\rho = 1.0mm$, using the K_f (instead of K_t) of the repaired crack.

The predictions generated by such an improved model are presented in Figures 8-10. Since $q \cong 1$ for the $\rho = 3.0$ and $\rho = 2.5mm$ stop-holes, the predictions obtained using their calculated $K_f = 7.0$ and $K_f = 7.2$, respectively, are as good as those obtained using their estimated K_t. However, the overly conservative initial predictions for the smaller $\rho = 1mm$ stop-hole, which were generated using its estimated $K_t \cong 11.5$, are much improved when the notch sensitivity effect quantified by its properly calculated

$K_f = 8.3$ (considering the important influence of the elongated involving notch geometry) is used in the fatigue crack re-initiation calculations.
The Al 6082 T6 fatigue limit and fatigue crack propagation threshold under pulsating loads required to calculate K_f are estimated as $\Delta K_0 = 4.8\ MPa\sqrt{m}$ and $\Delta S_0 = 110MPa$, following traditional structural design practices,[3] and the Bazant's exponent was chosen, as recommended by Meggiolaro and Castro,[6] as $\gamma = 6$.

6 CONCLUSION

Classical εN techniques were used with properly estimated properties to reproduce the measured fatigue crack re-initiation lives after stop-hole repairing several modified SEN(T) specimens. The predicted lives were not too dependent on the mean load εN model, and the larger stop-hole measured lives could be well reproduced using the stress concentration factor K_t in the Neuber/Ramberg-Osgood system. But such an approach yielded grossly conservative prediction for the smaller stop-hole life improvements. This problem was solved using the fatigue stress concentration factor K_f of the resulting notch instead of K_t in that system. However, the notch sensitivity q required to estimate K_f must be calculated in a proper way, considering the very important effect of the elongated notch geometry, since classical q estimates are only valid for approximately semi-circular notches.

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