TEORIJSKA I PRIMENJENA MEHANIKA 17, pp 133–146, 1991, UDK 539.43

AN ANALYTICAL MODEL FOR DESCRIPTION OF FATIGUE DAMAGE

H. Pašić

(Received 20.05.1991)

1. Introduction

Fatigue crack propagation and fatigue damage of structural components have become subjects of unquestionable relevance. However, most of the research efforts are separated into several fields such as Fracture Mechanics, Damage Mechanics, Fatigue etc., while combined efforts are missing.

A large part of fatigue life of metallic structures is related to a sequence of processes during which localized strains, slip bands and microcracks initiate and develop until the macroscopic crack which leads to fracture is formed. The life is therefore controlled by a complex crack-growth phenomenon [1], [2]. It is very difficult to describe analytically such a complex phenomenon and, therefore, some global meassures are needed for its description. On this line many analytical models have been developed [3]. Unfortunately, most of them are purely phenomenological.

Depending on the point of view of the authors of fatigue-failure models which pretend to be based on physical grounds, they are founded on either microscopic or macroscopic variables. The first type is based on a crack length as a critical variable [4] while the second one uses a damage variable as a global measure of the material degradation [5]. The first approach is an attempt to extend the application of Fracture Mechanics to very short cracks, while the second one is an attempt to generalize Continuum Damage Mechanics [6].

In fact, as shown in [7] there could be implicit connections between the continuous damage parametrization and the crack lenght used in Fracture Mechanics. The model developed here may be considered as the combination.

2. Short to long crack transition

Long cracks are monitored in linear-elastic type specimens in such a way that a crack is inserted in a specimen before testing. The initial crack length is typically a few millimeters long and its further growth is obtained by integrating the crack growth rate described by the Paris law [8].

However, many engineering components do not contain big flaws such that the period of the first crack development may consume an important part of its life, before the crack becomes long. It has also been found that under the same driving force the growth rates of short cracks are greater than the corresponding rates of long cracks [9]. This suggests that the use of data for long cracks in defect tolerant lifetime predicitions for structural components can lead to considerable overestimates.

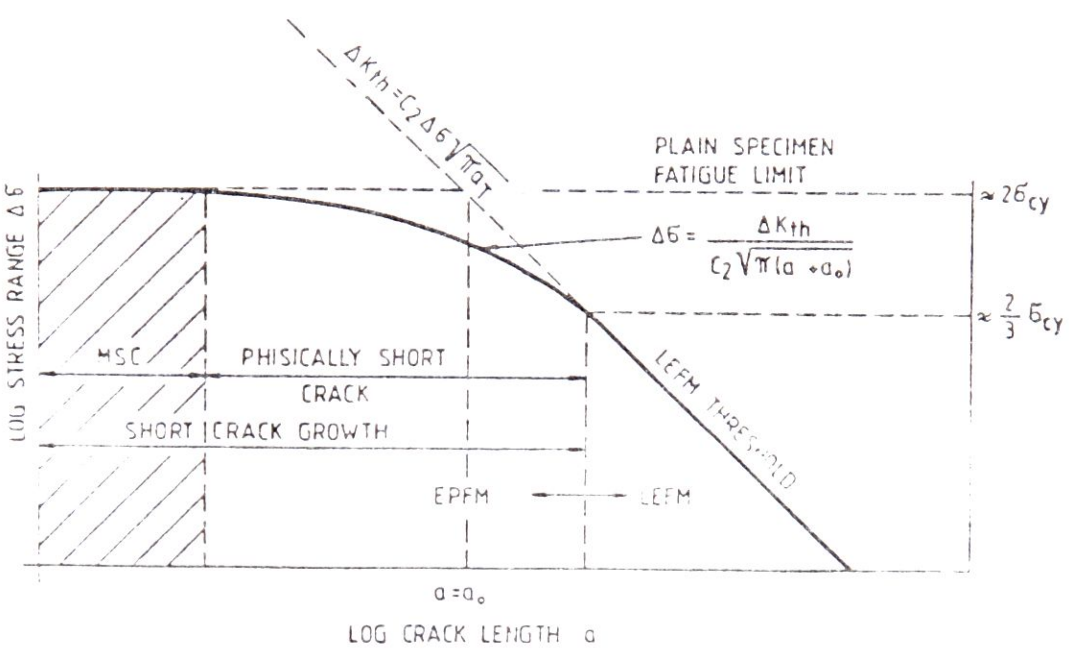

Fig. 1. Kitagawa-Takahshi diagram for short and long cracks

Recognizing the fact that the short crack behavior requires an elasto-plastic (EPFM) analysis Kitagawa and Takahashi [10] have proposed a single approach that combines both LEFM and EPFM at threshold, Fig. 1. The line given by ΔK_{th} represents the long crack threshold condition. But for shorter cracks to propagate higher loads are to be applied and small scale yielding conditions for validity of LEFM are violated. This happens to be the case when $\Delta\sigma$ exceeds about 2/3 of the cyclic yield stress σ_{cy} in a reversed stress test (when the stress ratio is $R = -1$). The horizontal bounding line in the diagram is the fatigue limit of the plane specimen $\Delta\sigma_e \cong \Delta\sigma_{cy}$. The shaded area in Fig. 1 corresponds to the so-called micro-structurally short nonpropagating cracks (MSC). Experimental studies indeed clearly show that threshold stresses for long and short cracks are different and the Kitagawa-Takahashi diagram shows that the threshold condition for long crack propagation is a constant stress intensity, while the same condition for short cracks is a constant stress $\Delta\sigma_e$.

In rationalizing the behavior of long and short cracks with respect to the threshold condition, El Haddad et al. [11] proposed redefinition of the stress inten-

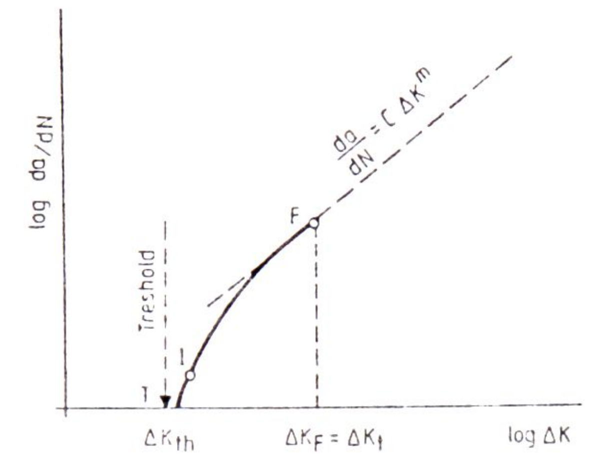

Fig. 2. Fatigue crack growth rate vs. stress intensity range

sity factor, such that for both long and short cracks at threshold, Fig. 1:

$$\Delta K = C_2 \Delta\sigma \sqrt{\pi(a + a_0)}\,. \tag{1}$$

The so called intrinsic crack length a_0 is then obtained from (1) from the condition that $\Delta\sigma$ tends to $\Delta\sigma_e$ as the crack length a approaches zero, Fig. 1, therefore being

$$a_0 = \frac{1}{\pi}\left(\frac{\Delta K_{th}}{\Delta\sigma_e}\right)^2. \tag{2}$$

The earliest crack growth experiments have shown that, in general, da/dN versus ΔK curves are of the form shown in Fig. 2, and that the Paris law does not hold at theshold below which cracks do not grow or grow very slowly, say at rates of the order of 10^{-10} m/cycle. Empirically growth rates in that region can be described as [12]:

$$\frac{da}{dN} = C_1(\Delta K - \Delta K_{th})^m \tag{3}$$

where the value ΔK_{th} strongly depends on the mean stress, i.e. the load ratio R. Xiulin [13] shows the applicability of (3) with $m = 2$ to such diverse materials as b.c.c. high strength low alloy steels, f.c.c. aluminium and h.c.p. titanium alloys.

In the threshold region sizes such as the plastic zone or the crack tip openings are of the same order as the microstructural features such as grain size, for example. Therefore the crack growth mechanisms and growth rates at threshold are strongly influenced by the microstructure. At the transition point $\Delta K = \Delta K_t$, Fig. 2, crack growth rate curve starts to deviate from the straight line in the logarithmic plot. Below $\Delta K = \Delta K_t$ the growth rate decreases rapidly and the crack stops its propagation at threshold. Liu and Liu [14] examined fifty fatigue crack propagation data for steels and aluminium alloys and found the empirical relation

$$\Delta K_{th} = (0.7 \mp 0.1)\Delta K_t. \tag{4}$$

Also, they took the net driving force at threshold as proportional to $(\Delta K - \Delta K_{th})^m$, such as in (3), with $m = 2$ as in [13].

Starting with the new definition (1) for the stress intensity factor at and close to threshold, then using (2) and (3) and introducing:

$$p = a_T + a_0, \quad r = a_F - a_T, \quad q = \frac{r}{p}, \quad \underline{a} = \frac{a - a_T}{r}, \quad \underline{a}_0 = \frac{a_I - a_T}{a_F - a_T} \tag{5}$$

where the indexes F, T and I stand for crack lengths at „failure", „threshold" and „initial", Fig. 2, such that the normalized crack length $\underline{a}_0 \leq \underline{a} \leq 1$, the following crack growth equation results:

$$d\underline{a} = A_m \left(\sqrt{\underline{a} + q} - \sqrt{q} \right)^m dN \tag{6}$$

where

$$A_m = C_1 \left(C_2 \sqrt{\pi} \right) r^{m/2-1} \Delta\sigma^m. \tag{7}$$

Double integration of (6) — once from the initial crack length $\underline{a}_0$ to an arbitrary crack length $\underline{a}$ while the number of cycles runs from N_I to N, and the second time-when $\underline{a}_I < \underline{a} < 1$ while $N_I < N < N_r$, Fig. 2, and taking $N_I = 0$, one obtains:

$$N = (1/B_m)(f(\underline{a}) - f(\underline{a}_0)) \tag{8}$$

$$N_F = (1/B_m)(f(1) - f(\underline{a}_0)). \tag{9}$$

Therefore the normalized life is:

$$\frac{N}{N_F} = \frac{f(\underline{a}) - f(\underline{a}_0)}{f(1) - f(\underline{a}_0)}. \tag{10}$$

The value of B_m is not given here and may easily be found by simple integration [15].

Eqn (10) could be numerically solved for the set of parameters m, $\underline{a}_0$ and q and an example of such a calculation is shown in Fig. 3.

A typical value for q may be judged from (1), (4) and (5). Namely, identifying the point F (failure) with the transition point, Fig. 2, equations (4) leads to $\Delta K_{th}/\Delta K_F = 0.7$. Taking $0.7^2 \cong 0.5$ there follows $a_F = 2a_T + a_0$ and $q = 1$. Integration of (6) beyond the transition point does not change the specimen life significantly.

3. Damage model

Let us assume that the series of stress controlled experiments is made on several specimens at different stress levels but all of them cycled up to the same number of cycles, Fig. 4. As the number of cycles N is increased from $N_0 = 0$ to $N = N_F$ at failure, the stress-strain diagram due to fatigue-creep strain accumulation will be of the form shown in Fig. 5. Assuming that the stress range exceeds its value at threshold — $\Delta\sigma_T$, the specimen will be eventually broken, for any $\Delta\sigma > \Delta\sigma_T$, sooner or later depending on stress level, after N_F cycles, Fig. 5.

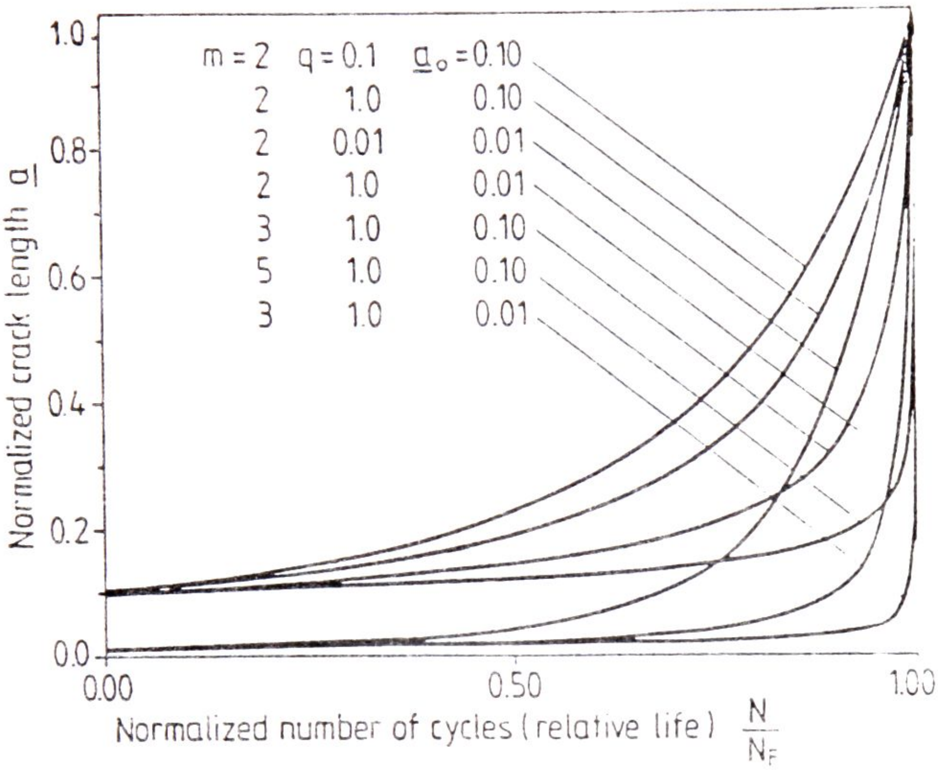

Fig. 3. Normalized crack length vs. normalized life

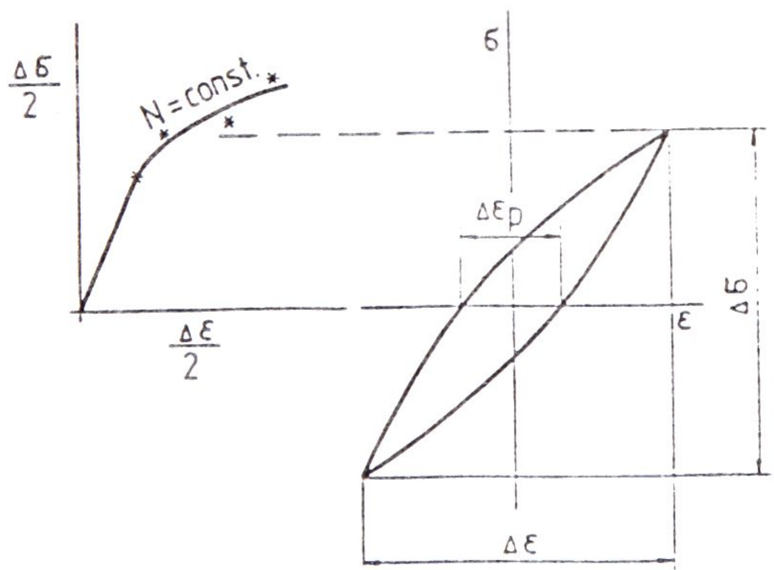

Fig. 4. Cyclic stress-strain range curve for $N = \text{const}$

Let us further assume that beyond the threshold (T) the stress-strain depen-

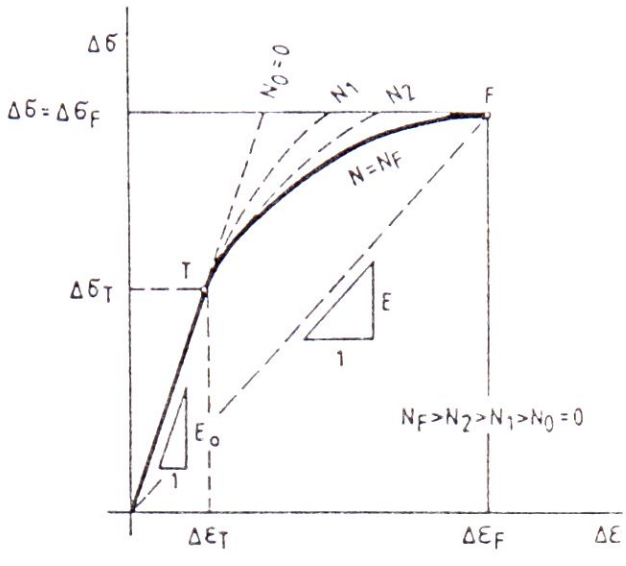

Fig. 5. Fatigue creep strain accumulation. Stress range vs. total strain range

dence, at a certain (constant) number of cycles N in a stress controlled experiment may be described by, Fig. 5:

$$\Delta\underline{\sigma} = E_0(1 - D)\Delta\underline{\varepsilon} \tag{11}$$

where

$\Delta\underline{\sigma} = \Delta\sigma - \Delta\sigma_T$ — applied (constant) stress range beyond threshold,

$\Delta\underline{\varepsilon}(N) = \Delta\varepsilon(N) - \Delta\varepsilon_T$ — total strain range beyond threshold,

$D = D(N)$ — damage

E_0 — virgin material Young's modulus. $E = E_0(1 - D)$ may be considered as being the new modulus of damaged material, Fig. 5.

Next, let us define the damage. Fatigue damage mechanisms are very complex but they generally start at the surface of the material. The crack initiation is closely related to the localized strain produced by cycling and then, depending on the microstructure, various mechanisms take place up to the failure. The possible crack sites are found to be persistent slip bands (PSB), second phase particles or, less frequently, at grain boundaries.

Lim et al. (1990) have recently studied surface fatigue damages in polycrystalline copper plain specimens at intermediate total strain levels (between low and high cycle fatigue). They found three types of damages: slip bands and twin and grain boundary microcracks-great majority of which being confined to surface grains. Even in the intermediate region the life fraction to nucleate a surface crack of the three-grain-facets length was 75 to 90 per cent, suggesting that a large fraction of the life is spent in nucleating a fatal crack on the surface. Finally, they found that at higher strain amplitudes fatal cracks are predominantly intergranular, while at low strain amplitudes most of fatal surface cracks are formed by linking the transgranular PSBs in the adjoining grains by grain boundary cracks.

The early growth of short fatigue cracks in polycrystalline materials follows the patern of repeated surface crack nucleation and linkage since near the free surface the PSB's produce very large (with a logarithmic singularity) surface stresses with localized plastic flow see Brown and Ogin [16]. Macroscopic internal stresses in PSB's change sign every half-cycle and the resulting shear stress between the band and the matrix always acts to increase slip near one side of the PSB, i.e. assists dislocation flow and the Stage I crack nucleation. Brown and Ogin have also found that the volume fraction of PSB's — associated with Stage I cracks, is closely related to the applied strain amplitude for variety of polycrystalline materials.

It has long been known that damage in high cycle fatigue is influenced by both surface crack lengths and surface crack density [2]. Final fracture occurs by coalescence of many randomly distributed micro cracks (not by growth of a single crack), but is governed almost exclusively by the behaviour of the major crack. However, Polak and Liskutin (1990) show that the same crack need not remain the longest one within the whole fatigue life. Therefore, the authors have defined "equivalent crack length" which is close to the temporary largest crack length with the growth rate similar to one in Fig. 3. This crack length can be obtained by averaging the dependence of the longest cracks on the cycle number measured in different specimens cycled at the same strain amplitude.

Having in mind the preceding discussion the damage model adopted here should include the longest surface crack or the averaged "equivalent crack length" as an important parameter; from now on it will be assumed that this crack grows in accordance with the rules described in Section 2. Since the final fracture is governed by the behaviour of the major crack the failure criterion will be the one when crack length reaches the transitional length, i.e. when $\underline{a} = 1$.

As it has already been discussed fatigue damage is influenced by the surface crack density as well. On the other hand the crack density is a function of the volume fraction of PSBs and, as shown in [16] is closely related to the applied strain amplitude. Having all this in mind, let us define damage as:

$$D = \gamma \underline{a}^k \Delta \underline{\varepsilon}^n \tag{12}$$

where γ is a constant while $\Delta\underline{\varepsilon}$ is a total strain rate beyond its threshold value — see (11). A similar form for damage, namely the product of the average flaw length and their number per unit volume is a characteristic measure of the loss of stiffness of brittle solids as well — see for example [18]. Socie et al. [19] have discussed variety of forms by which the damage parameter may be defined, such as in terms of the relative surface crack length $D = a/a_F$, in terms of stress drop in a strain-controlled test, or in terms of transient strain response in a stress-controlled test. In this light the damage model for the stress-controlled test described by (12) may be viewed as being a combination of the fristg and the third of these forms.

Hua and Socie [20] have evaluated four different damage theories in both high (HCF) and low cycle fatigue (LCF) regimes in 1045 steel under constant amplitude biaxial loading. They found that in the LCF region ($N_F < 10^4$) a number of damage nuclei were observed and that continuum damage theories should be applicable to this life regime. They also found that the surface-crack density parameter plays an important role but this parmeter alone is not a suitable measure for damage. On the other hand, in the HCF region a single dominant crack was used to represent fatigue damage and continuum damage models, such as Chaboche's [6], "are not expected to model the life regime dominated by the growth of a single large crack". It has also been concluded that in the HCF regime "none of the models can predict crack growth during the entire fatigue life" and, therefore, "surface crack length definitely can not be used as a damage prameter". This discussion also suggests that a damage model having the form (12) could be a compromising solution, because it includes both the longest crack length and crack density parameters.

The continuous damage models applied to fatigue processes have certain deficiences. First, due to its surface character damage is heterogeneously distributed and, second, during the propagation period the number of large defects is small at least in the last period of life, which is inconsistent with a continuum approach. However, in spite of that, CDM has been found to be a powerful tool in describing these complicated phenomena [21]. It is interesting to note that Popelar and Hoagland (1986) have found the damage model such as the one described by (11), where D is assumed to be linearly proportional to the strain, may even be used to analyze the fracture of a double-cantilever-beam specimen (with a single crack) and may successfully bridge the fields of Damage and Fracture Mechanics.

4. Results

From (11) and (12) the stress-strain relationship reads:

$$\Delta\underline{\sigma} = E_0(1 - \gamma\underline{a}^k\Delta\underline{\varepsilon}^n)\Delta\underline{\varepsilon} \tag{13}$$

while the stress and damage are related as:

$$\Delta\underline{\sigma} = E_0(\gamma\underline{a}^k)^{-1/n}(1 - D)D^{1/n}. \tag{14}$$

For a fixed value of the crack length $\underline{a}$ Fig. 6 depict (13) for several values of the yet unknown parameter n.

Extreme value of the curve in Fig. 6 corresponds to failure for which the crack length $\underline{a}_F = 1$, such that at this point:

$$D_F = \frac{1}{n+1} \tag{15}$$

$$\Delta\underline{\varepsilon}_F = \gamma^{-1/n}(n+1)^{-1/n} \tag{16}$$

$$\Delta\underline{\sigma}_F = E_0\gamma^{-1/n}\frac{n}{(n+1)^{(n+1)/n}} \tag{17}$$

while from (14), (15) and (16) there follows:

$$\gamma = \left(\frac{E_0}{\Delta\underline{\sigma}}\right)^n \frac{n^n}{(n+1)^{n+1}} \tag{18}$$

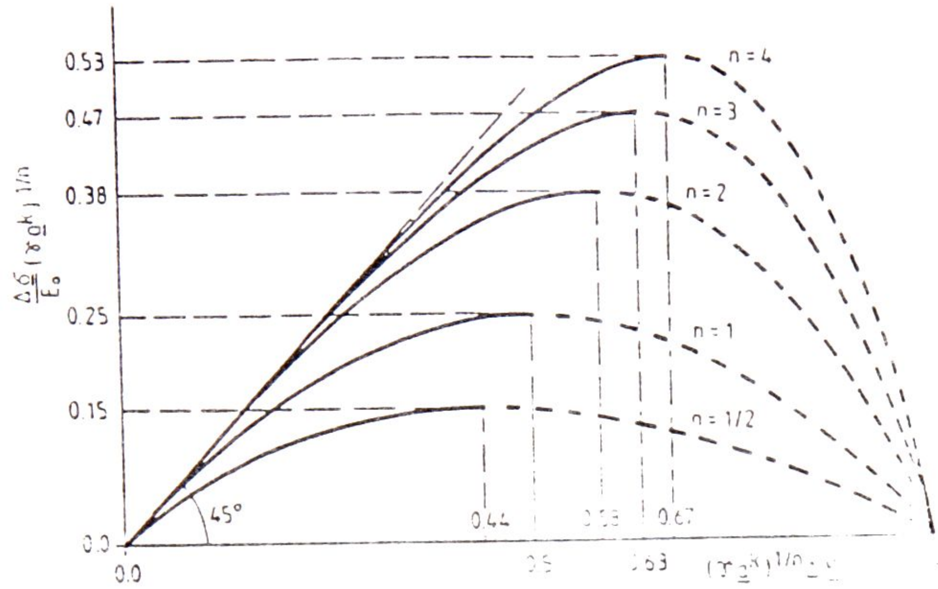

Fig. 6. Stress-strain dependence as a function of n

$$\Delta\underline{\varepsilon}_F = \frac{\Delta\underline{\sigma}}{E_0}\,\frac{n+1}{n}. \tag{19}$$

For real values of fatigue damage at failure $0.2 < D_F < 0.8$ [6], according to (15) the parameter n should range between $n = 4$ and $n = 0.25$, respectively. The value of the coefficient n may be found as follows. The total strain amplitude at failure $\Delta\varepsilon_F/2$ consists of its elastic and plastic parts and obeys the Manson's law [8]:

$$\frac{\Delta\varepsilon_F}{2} = \frac{\Delta\varepsilon_{Fe}}{2} + \frac{\Delta\varepsilon_{Fp}}{2} = \frac{\sigma'_F}{E_0}N_F^b + \varepsilon'_F N_F^c \tag{20}$$

where E_0 is modulus of elasticity of a virgin material, b and σ'_F/E_0 are the slope and one reversal intercept of the elastic part of the curve, while ε'_F is the fatigue ductility coefficient.

Since [8]:

$$E_0\frac{\Delta\varepsilon_{Fe}}{2} = \frac{\Delta\sigma_F}{2} = \sigma'_F N_F^b \tag{21}$$

and

$$\Delta\underline{\varepsilon} = \Delta\varepsilon - \Delta\varepsilon_T = \Delta\varepsilon - \Delta\varepsilon_E \tag{22}$$

where

$$\Delta\varepsilon_E = \frac{\Delta\sigma_E}{E_0} \tag{23}$$

while and σ_E is the endurance limit of a real (not ideally smooth) specimen, for a stress controlled test ($\Delta\underline{\sigma} = \Delta\underline{\sigma}_F$), (19) to (23) produce the following result:

$$n = \frac{2\sigma'_F N_F^b - \Delta\sigma_E}{2E_0\varepsilon'_F N_F^c}. \tag{24}$$

For example, for the SAE 4340 steel [8]: $\sigma'_F = 1200$ MPa, $\varepsilon'_F = 0.58$, $b = -0.09$, $c = -0.57$, $\sigma = 281$ MPa, assuming $E_0 = 2 \cdot 10^5$ MPa, depending on the stress level applied, i.e. depending on the number of cycles at failure, the coefficient n — eqn (24) is, for example: $n = 0.4$ at $N_F = 10^4$, $n = 0.88$ at $N_F = 10^5$ and $n = 2.93$ at $N_F = 5 \cdot 10^6$, while the corresponding values for damage — eqn (15), are: $D_F = 0.71$, 0.53 and 0.25. As it is seen values of $4 > n > 0.25$ estimated above and corresponding to $0.2 < D_F < 0.8$, respectively, are quite real.

From (12), (15) and (16) the strain range and normalized strain range are:

$$\Delta\underline{\varepsilon} = (\gamma \underline{a}^k)^{-1/n} D^{1/n} \tag{25}$$

$$\frac{\Delta\underline{\varepsilon}}{\Delta\underline{\varepsilon}_F} = \underline{a}^{-k/n} (D/D_F)^{1/n}. \tag{26}$$

From (14), (15) and (18) the normalized crack length is related to damage and normalized damage as:

$$\frac{n^n}{(n+1)^{n+1}} \underline{a}^k = (1-D)^n D \tag{27}$$

$$\left(\frac{n}{n+1}\right)^n \underline{a}^k = \left(1 - \frac{n}{n+1} \frac{D}{D_F}\right)^n \frac{D}{D_F}. \tag{28}$$

Definition of damage as given in (12) assumes that the initial damage is not equal to zero, since the initial crack length $\underline{a}_0 = 0$. From (27) the initial damage may be found as the solution of the following equation:

$$\frac{n^n}{(n+1)^{n+1}} \underline{a}_0^k = (1-D_0)^n D_0. \tag{29}$$

For small values of the initial damage $(1 - D_0) \cong 1$ such that, in that case:

$$D_0 \cong \frac{n^n}{(n+1)^{n+1}} \underline{a}_0^k. \tag{30}$$

Figures 7 to 9 present damage and strain accumulation diagrams in terms of the normalized life N/N_F and for various coefficients $\underline{a}_0$, q, m, k, n. For example, for given initial crack length $\underline{a}_0$, choosing m (typically $m = 2$) and q (typically $q = 1$), then using (10), normalized crack length $\underline{a}$ is found as a function of the normalized life N/N_F — such as in Fig. 3. The initial damage is found from (29) for a set of typical parameters n — say between $n = 1/2$ and $n = 4$. Finally, damage D, normalized damage D/D_F and normalized strain $\Delta\underline{\varepsilon}/\Delta\underline{\varepsilon}_F$ are found from (27), (28) and (26), respectively. Unlike damage curves given in Fig. 7, normalized damage curves in Fig. 8, for the same values of parameters used, almost overlap each other (especially for small initial flaws $\underline{a}_0$), indicating that this could be a better definition for damage. Shape of damage and strain curves shown in Figs. 7 to 9 are in a good qualitative agreements with well known experimental results of fatigue damage [5], [19].

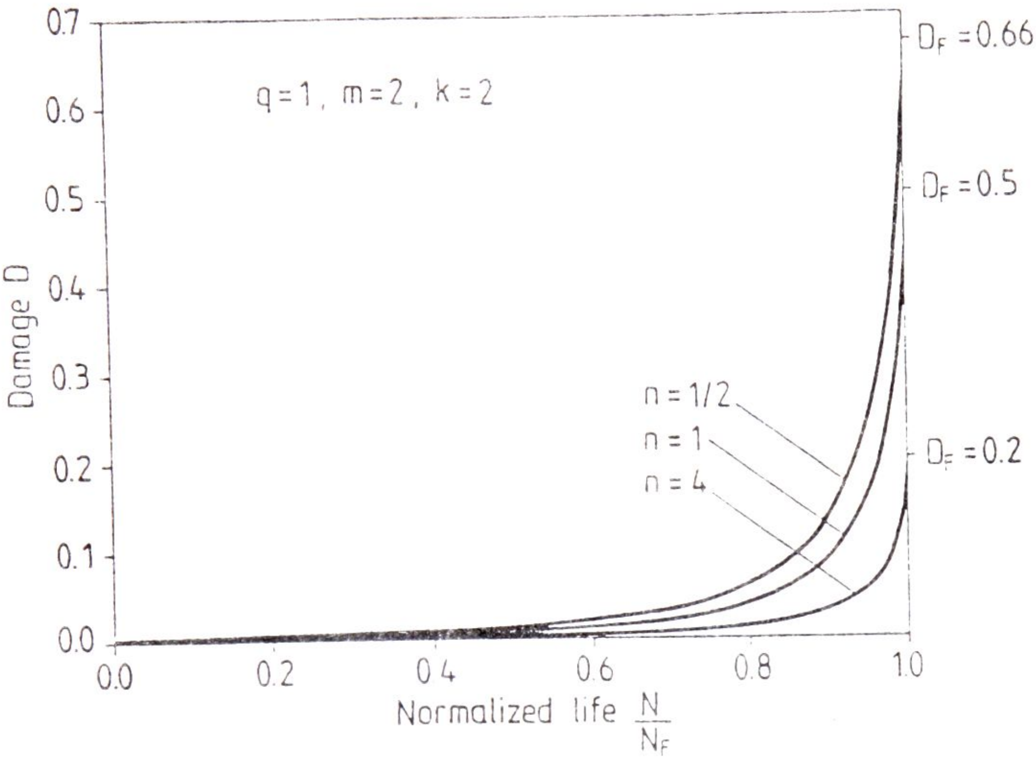

Fig. 7. Damage vs. normalized life for $\underline{a}_0 = 0.1$

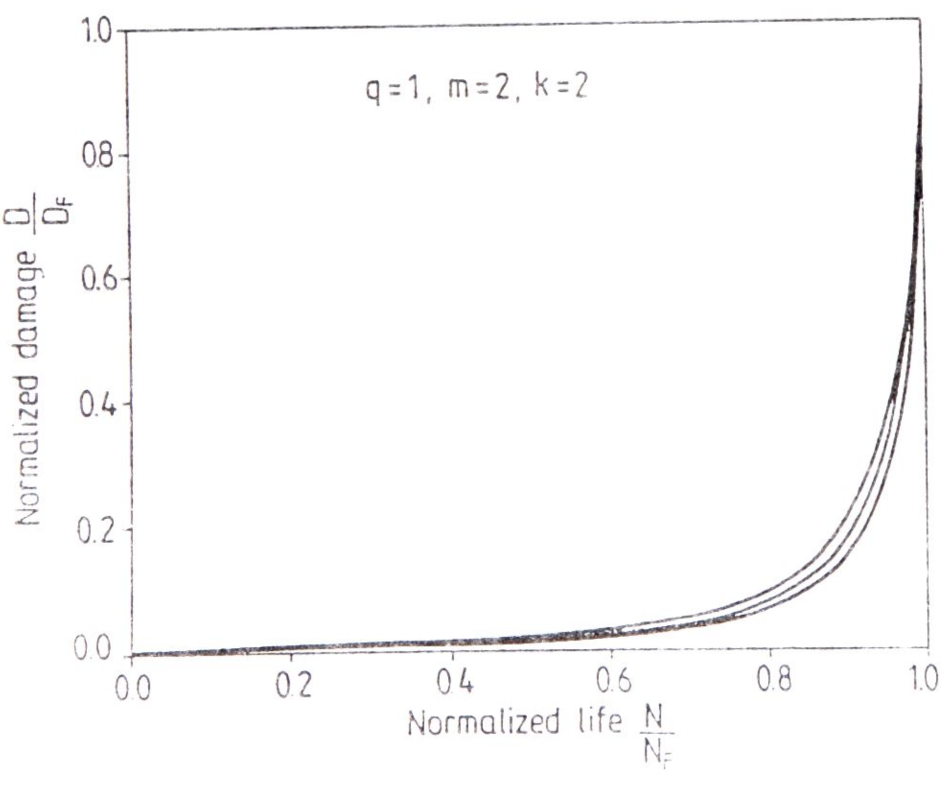

Fig. 8. Normalized damage vs. normalized life for $\underline{a}_0 = 0.1$

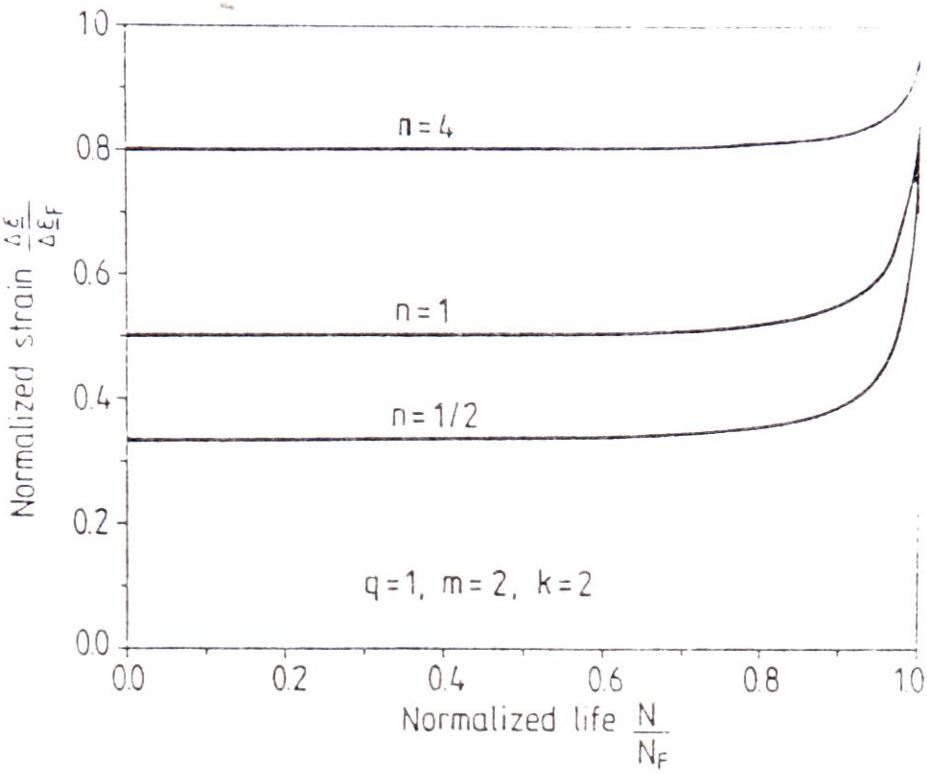

Fig. 9. Normalized strain vs. normalized life for $\underline{a}_0 = 0.1$

The damage model developed here includes both initiation and short crack propagation phases. Also the damage law has a nonlinear evolution and accumulation and, therefore, should be able to describe the cumulative damage under nonperiodic loading. However, a successful fatigue damage model should reflect the mean-stress influence and this remains to be done next. Also, values of some constants in the analytical model, such as ΔK_{th}, $\underline{a}_0$, m, etc., then possible inclusion of the crack closure concept are to be related to the experimental verification in further development of this model.

REFERENCES

[1] Kitagawa, H., Takahashi, S., Suh, C.M. and Miyashita, S., *Quantitative analysis of fatigue process-microcracks and slip lines under cyclic strains*, ASTM STP 675 (1979), 420–449.

[2] Suh, C.M., Lee, J.J. and Kang, J.G., *Fatigue microcracks in type 304 stainless steel at elevated temperature*, Fatigue Fract. Engng. Mater. Struct. **13** (5) (1990), 487–496.

[3] Collins, J.A., *Failure of Materials in Mechanical Design*, John Wiley and Sons, New York, 1981.

[4] Miller, K.J. and de los Rios, E.R., *Proceedings: The Behaviour of Short Fatigue Cracks*, Mechanical Engineering Publications, London, 1986.

[5] Chaboche, J.- L., *Continuum damage mechanics (Part I — General concepts and Part II — Damage growth, crack initiation and crack growth)*, Journal of Applied Mechanics **55** (1988), 59–72.

[6] Lemaitre, J. and Chaboche, J.-L., *Mécanique des Matériaux Solides*, Dunod, Paris, 1984.

[7] Cailletaud, G. and Levaillant, C., *Creep-Fatigue life prediction: what about initiation?* Nuclear Engng. and Design **83** (1984), 279–292.

[8] Hertzberg, W.R., *Deformation and Fracture Mechanics of Engineering Materials*, John Wiley and Sons, New York, 1988.

[9] Miller, K.J., *The short crack problem*, Fatigue Engng. Mater. Struct. **5** (3) (1982), 223–232.

[10] Kitagawa, H. and Takahashi, S., *Applicability of fracture mechanics to very small cracks or the cracks in the early stage*, Proceedings Int. Conference on the Mechanical Behaviour of Materials (ICM2), American Society of Metals, 1976, 627–631.

[11] El Haddad, M.H., Topper, T.H. and Smith, K.N., *Prediction of non-propagating cracks*, Engng. Fract. Mech. **11** (1979), 573–584.

[12] Allen, R.J., Booth, G.S. and Jutla, T., *A review of fatigue crack growth characterization by linear elastic fracture mechanics (LEFM), Part 1*, Fatigue Fract. Engng. Mater. Struct. **11** (1) (1988), 45–69.

[13] Xiulin, Z., *A simple formula for fatigue crack propagation and a new method for the determination of* ΔK_{th}, Engng. Fract. Mech. **27** (4) (1987), 465–475.

[14] Liu, H.W. and Liu, D., *A quantitative analysis of structure sensitive fatigue crack growth in steels*, Scripta Metallurgica **18** (1984), 7–12.

[15] Pašić, H., *High-cycle fatigue damage in polycrystalline materials*, Scientific report, JRC EURATOM — Institute for Advanced Materials, Ispra, Italy, 1990.

[16] Brown, L.M. and Ogin, S.L., *Role of internal stresses in the nucleation of fatigue cracks*, in: *Fundamentals of Deformation and Fracture*, Cambridge Univ. Press, 1985, 501–528.

[17] Polak, J. and Liskutin, P., *Nucleation and short crack growth in fatigued polycrystalline copper*, Fatigue Fract. Engng. Mater. Struct. 13 (2) (1990), 119–133.

[18] Budiansky, B. and O'Connell, R., *Elastic moduli of a cracked solid*, Int. J. Solids Struct. **12** (1976), 81–97.

[19] Socie, D.F., Fash, J.W. and Leckie, F.A., *A continuum damage model for fatigue analysis of cast iron*, ASME Conference in Life Predictions, Albany, New York, 1983, 59–64.

[20] Hua, C.T. and Socie, D.F., *Fatigue damage in 1045 Steel under constant amplitude biaxial loading*, Fatigue Engng. Mater. Struct. 7 (3) (1984), 165–179.

EIN ANALYTISCHES MODELL FÜR ERMÜDUNGSSCHADEN

In der Arbeit ist gezeigt wie man mit der Kombination der Mechanik des Bruches und der Schadenmechanik (Damage Mechanics) ein Modell für die Ermüdungsschaden in polykristalischen Material, der unter kontrolierter Spannung ist, entsteht. Der Defekt (damage) ist als Produkt von der längsten Spalte und der gespeicherten Deformation, (wobei beide Grössen mit einem Exponent genommen sind), definiert. Der Übergang von einer kurzen Spalte an eine lange ist mit Hilfe von El Haddads Intensitätsspannungfaktor für Anfangsspalte, der Bruch dagegen mit dem Verhalten der längsten Spalte definiert.

JEDAN ANALITIČKI MODEL ZA OPIS ZAMORNIH OŠTEĆENJA

U radu je pokazano kako kombinovane Mehanika loma i Mehanika oštećenja (Damage Mechanics) mogu da se iskoriste za uspostavljanje modela zamornih oštećenja polikristalnih materijala u eksperimentu sa kontrolisanim naponom (stress controlled test). Oštećenje (Damage) je definisano kao proizvod najduže dužine pukotine i akumulirane deformacije — pri čemu su obje veličine uzete sa

izvjesnim eksponentima koji se određuju iz uslova opterećenja i kriterijuma sloma materijala. Prelaz sa kratke na dugu pukotinu je opisan pomoću El Haddadovog redefinisanog faktora intenziteta napona kao praga (threshold), dok je slom određen ponašanjem najduže pukotine.

Hajrudin Pašić
Mašinski fakultet
71000 Sarajevo