NATURE OF FATIGUE STRIATION AND EFFECTIVE THRESHOLD

Yu.I.Ragozin*

A hypothesis is presented that the fatigue striation spacing s for metallic materials is multiple to half-wavelength of electromagnetic vibrations emerging during the main crack propagation. With the author's results obtained earlier a formula is drawn for calculation the effective threshold value of stresses intensity ratio $\Delta K_{eff,th}$. The known dependence s on value ΔK is substantiated physically. Value ΔK is normalized by modulus of elasticity E of the corresponding materials.

INTRODUCTION

It's known (1) that for metallic materials the striation spacing at the crack development initial stage is about 10^{-7}m and it doesn't depend on strain conditions, temperature, media and frequency. It's supposed (1) that this is not by chance but specified by the universal parameter for all materials - cells or subgrains size forming at plastic zone ahead of the crack tip. On the other hand, however, it's unknown what specifies the size of forming fragments. A hypothesis is presented hereby enabling not only to clarify the fatigue striation nature, but to obtain a number of correlations describing perfectly the available experimental data as well.

*Polytechnical Institute, Perm, Russia.

PHYSICAL FOUNDATIONS OF HYPOTHESIS

The metals strain and fracture are accompanied by different physical phenomena, including emergence the electromagnetic radiation of wide wave range up to X--ray range (2,3). The study of radiation process may present valuable information concerning metal properties, so now the intensive investigations are carried out on problem of the radiation origin. In particular the authors of study (2) suppose that at least two mechanisms of high-frequency radiations emergence are possible: hemosorptious and "resonance", and in fact for realization of the latter it's necessary that the crack emergence and growth would take place on the boundaries of the dislocation blocks. And it's just the case when fracture happens (4). So it may be supposed that during fatigue crack propagation the high-frequency radiation emerges, that penetrates the metal and effects its fine structure. The passing of electromagnetic waves through crystal effects charges separation and hence electroneutrality violation that should facilitate dislocations formation cores of uncompensated charge. The volumes of maximum amplitude dislocations may become the locations of supposed formation of dislocation cells boundaries, while the cross size (step) of the cells would be equal to half-wavelength of penetrative radiation. As it known (5) the electromagnetic radiation penetrates the metal only when the radiation wavelength will not be less than $\lambda=2\pi c/\omega_p$ where c - speed of light, ω_p - plasma frequency. It may be admitted that fragments size forming ahead of the crack tip is specified by radiation with wavelength $\lambda=\lambda_p$ forming during metals fracture. The values of plasma frequency ω_p and wavelength λ_p for the most important metals are presented in Table 1.

TABLE 1 - Several constant values of metals.

Metals	Cu	Mg	Al	Ti	Fe
ω_p, 10^{16} rad/sec	2.32	1.61*	2.32*	2.54**	2.32
λ_p, 10^{-8} m	8.10	11.7	8.10	7.41	8.10

* experimental value (5)

** with correction for ion frame polarization taken into account

During fracture in plane strain conditions according to break-off mechanism and independent from load conditions the correlation between stresses σ_y in direction perpendicular to crack propagation and length r from the crack edge in accordance with linear fracture mechanics concept is expressed by equation:

$$\sigma_y = K / \sqrt{2\pi r} \tag{1}$$

It was assumed that the crack starts to spread close to effective threshold value of stress intensity ratio $K_{eff,th}$ ($\Delta K_{eff,th}$) at the moment when in plastic strain zone of size r_e near crack tip the energy is absorbed equal to one of energy threshold levels W_i for the material calculated on phonon fracture concept basis (6). Having estimated according to recommendations (7) fracture stress σ_f as $\sigma_f(\Delta\sigma_f) = \sqrt{2W_iE}$, where E - elasticity modulus, start-off condition may be expressed as:

$$\Delta\sigma_f\sqrt{2\pi r_e} = 2\sqrt{\pi W_i E r_e} = \Delta K_{eff,th} \tag{2}$$

Identifying value r_e in equation (2) with minimum striation spacing s_e and assuming in accordance with the above hypothesis that $s_e = \lambda_p/2$, we obtained expression for calculation of parameter $\Delta K_{eff,th}$:

$$\Delta K_{eff,th} = 2,50\sqrt{W_i E\lambda_p} \tag{3}$$

It's known that during ΔK (ΔK_{eff}) growth the striation spacing increases. Assuming that the mechanical energy absorption takes place discretely in local metal volumes and striation spacing s remains multiple to minimum step s_e then kinetic equation connecting striation spacing with ΔK_{eff} may be presented as

$$s = Ns_e = \frac{N\cdot(\Delta K_{eff,th})^2}{4\pi W_i E} \tag{4}$$

or

$$s = B\left(\frac{\Delta K_{eff}}{E}\right)^2 \tag{5}$$

where $N = 1,2,3...$; $B = E/4\pi W_i$; $\Delta K_{eff} = \sqrt{N}\,\Delta K_{eff,th}$

COMPARISON WITH EXPERIMENT

Before estimating parameter $\Delta K_{eff,th}$ by equation (3) for metals investigated we point out that value s_e is really turned out to be quite close to value $\lambda_p/2$. For example, as it follows from study results (8,9) minimum striation spacing for three steel grades in eight conditions is equal to $0.4\cdot10^{-8}$ m, that perfectly coincides with value $\lambda_p/2$ for Fe (Table 1).

Since alloying and thermal treatment change constants W_i, E and apparently λ_p only in small degree, then correlation (3) drawn for pure metals would be true for alloys on their base. For each metal and alloy on its base there is a characteristic discrete spectrum of energy threshold values W_i (6). Hence in accordance with correlation (3) there is a characteristic discrete spectrum of value $\Delta K_{eff,th}$ for them. Table 2 presents levels $\Delta K_{eff,th}$ calculated by equation (3) for Al, Ti and Fe (and alloys on their base). Necessary values W_i for calculation are taken from study (10), elastic constant values E were assumed to be equal to $7.06\cdot10^4$ MPa, $11.0\cdot10^4$ MPa and $20.6\cdot10^4$ MPa correspondingly for Al, Ti and Fe. The wide comparison of calculated values $\Delta K_{eff,th}$ (Table 2) with experimental values $\Delta K_{eff,th}$, obtained by different authors showed their close compliance.

TABLE 2 - Calculated levels $\Delta K_{eff,th}$ for several metals

Metals	$\Delta K_{eff,th}$, $MPa\sqrt{m}$					$K^m_{eff,th}/E$, 10^{-5} $m^{1/2}$
	1	2	3	4	5	
Al	0,72	1,02	1,06	1,24	1,50	1,57
Ti	1,18	1,33	1,64	1,93	2,30	1,59
Fe	2,23	2,73	2,86	3,30	3,40	1,36

Remark. $\Delta K^m_{eff,th}$ - mean value.

For example, it was proved (11) that for many alloys $\Delta K_{eff,th} = 1.6\cdot10^{-5}E$. If to take mean calculated value

$\Delta K_{eff,th}$ for all possible alloys on the base, then it'll be precisely equal (Table 2) to the above values for aluminium ($1.57\cdot10^{-5}E$) and titanium ($1.59\cdot10^{-5}E$) alloys. For the alloys on Fe base $\Delta K_{eff,th}$ is a bit lower - $1.36\cdot10^{-5}E$, that also perfectly agrees with the results of study (11): $\Delta K_{eff,th}=1.45\cdot10^{-5}E$.

Correlation (5) is plotted on Fig.1,a. For Al it's shown completely, for Ti and Fe only contours are shown. It's evident that normalizing ΔK_{eff} against E the differences in properties character during cycle load can be excluded to a great extent and a universal dependence between fatigue striation spacing and parameter $\Delta K_{eff}/E$ can be obtained for materials of different nature. Since ΔK_{eff} is a part of interval ΔK, then the above dependence should be equidistant to dependence s - $\Delta K/E$ (Fig.1,b) established earlier (12), that is universal for alloys of different nature. It can be seen (Fig.1) that in fact this correspondence takes place, though we find correlation between s and $\Delta K_{eff}/E$ more physically specified.

REFERENCES

(1) Grinberg,N.M., Phys.-Chem. Mech. Mater., No.2, 1985, pp.55-62.

(2) Tupik,A.A., Valuev,N.P. and Belenky,A.Ia.,Phys.-Chem. Mech. Mater., No.4, 1985,pp.51-57.

(3) Deriagin,B.V., Krotova,N.A. and Karasev,V.V., Vestnik of USSR AS, No.2, 1985, p.142.

(4) Wilsdorf,H.G.F., Krist. and Techn., Vol.14, No.10, 1979, pp.1265-1274.

(5) Platzman,P.M., Wolff,P.A.,"Waves and Interactions in Solid State Plasmas", Academic Press, New York and London, 1973.

(6) Ragozin,Yu.I., Proc. 7th Eur. Conf. on Fracture, Budapest, Vol.1, 1988, pp.109-111.

(7) Kator,A., Prob. Prochnosty, No.4, 1972, pp.42-53.

(8) Kitsunai,Y., Jap. Soc. Mech. Engng., Vol.44, No.378, 1978, pp.385-393.

(9) Kitsunai,Y. and Tanaka,M., Preprints, Jap. Soc. Mech. Engng., 760-2, 1978, 35p.

(10) Ragozin,Yu.I. and Antonov,Yu.Ya., Proc. of the C-MRS International'90, Beijing,China, 1990, "Mechanical Properties / Materials Design", Elsevier Publ.,Vol.5, Amsterdam, 1991, pp.141-144.

(11) Liaw,P.K., Leax,T.R. and Logsdon,W.A., Acta Met., Vol.31, No.10, 1983, pp.1581-1587.

(12) Bates,R.C. and Clark W.G., Jr., Trans. Quart., ASM, Vol.62, 1969, pp.380-389.

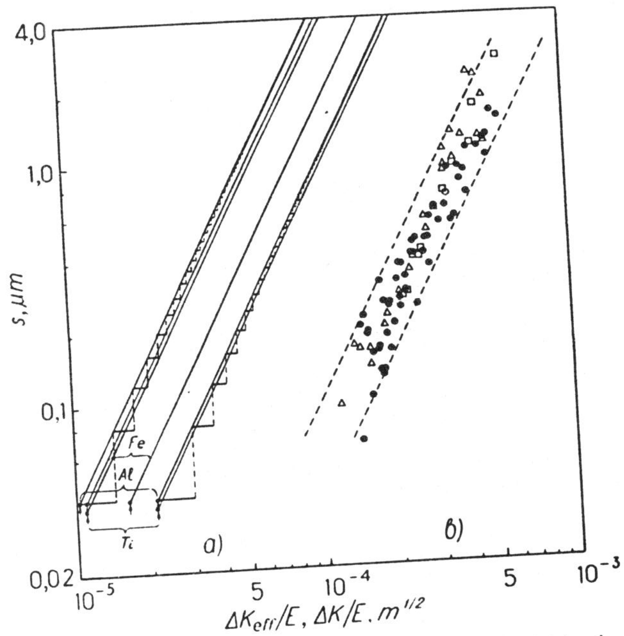

Figure 1 Fatigue striation spacing s plotted against value $\Delta K_{eff}/E$ (a) and $\Delta K/E$ (b): a - correlation (5); b-(12), ● - steels, Δ - aluminium alloys, □ - titanium alloy.