MINIMUM CRITICAL LENGTH OF A MICROCRACK AS A CONSTRUCTION MATERIAL CRITERION

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The micronon-uniformities of the stressed condition having decisive significance for crack initiation and pre-critical crack growth stages are obviously not taken into consideration sufficiently in modern theories. In the microvolumes with the sufficiently high level of stresses (e.g. near the cracktip) the potential energy can reach values, critical in the sense of Griffith's fracture criterion. It is known (1,2), that Griffith's conditions for macroscopic and microscopic fracture coincide, in such a case the realization of these conditions at the level of microstructural elements is connected (2) with the reducing of crack critical size by three to four orders and corresponding increasing up to two orders of critical stresses, acting in separate microvolumes of material.

The account of micronon-uniformities of the stressed condition in mechanics of cracks can be successfully carried out on the basis of energy criterions. As a critical value of strain energy density it is expedient to apply maximum value of the workhardening latent energy. Metals have several threshold levels of workhardening latent energy (3). Value U_s^{max} realized in the material given is specified by alloying and thermal treatment and can be determined easily by experiment, because U_s^{max} equals full specific work of uniform strain A_e (4). The most important feature of the fracture processes taken place at microvolumes level is their discrete character. If this feature to be taken into consideration, then during the development of the above ideas a new approach can be used, e.g. for the solving of the short cracks problem.

In general case for specimens of different geometry criterion K_{Ic} is determined from expression

$$K_{Ic} = Y \sigma_p \sqrt{\pi a_p}\ , \qquad (1)$$

where Y - calibration coefficient, that takes into account the specimen geometry with the crack and loading type; σ_p - critical stress, at which crack of length a_p

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starts to spread. On the other hand for the plane-strain condition Griffith-Orowan equation can be written as

$$\sigma_p = \sqrt{\frac{2E\gamma_{eff}}{\pi(1-\nu^2)a_p}} \qquad (2)$$

or

$$\sigma_p\sqrt{\pi a_p} = \sqrt{\frac{2E\gamma_{eff}}{1-\nu^2}}, \qquad (3)$$

where γ_{eff} - effective surface energy including the work of plastic strain near the cracktip for quasi-fragile materials, E - Young's module; ν - Poisson's coefficient. Product $\sigma_p\sqrt{\pi a_p}$ is just K_{Ic} for plate of infinite dimensions. For the specimens of finite dimensions with expression (1) taken into consideration we have

$$Y\sigma_p\sqrt{\pi a_p} = \sqrt{\frac{2E\gamma_{eff}}{1-\nu^2}} \qquad (4)$$

Assuming in accordance with (1,2) that equation (4) is correct at the microvolumes level, we transform it with several correlations taken into consideration. Having accepted $2\gamma_{eff}$ = 0.8LA_e (4) and $\sigma_p=\sqrt{2A_eE/3(1-2\nu)}$(5), we obtain

$$Y\sqrt{\frac{2A_eE}{3(1-2\nu)}}\cdot\sqrt{\pi a_o} = \sqrt{\frac{0{,}8LA_eE}{1-\nu^2}} \qquad (5)$$

from where

$$a_o = \frac{1{,}2L(1-2\nu)}{\pi(1-\nu^2)Y^2}, \qquad (6)$$

where a_o - minimal critical length of the growthable microcrack; L - constant with dimension of length.

For an example see Table with values a_o (mm): a) for plane specimens of width W with single side through crack at extension test (1) and pure flexure (2); b) for round specimens of diameter D with ring crack at extension test (3) and with segment-like crack at flexure test (4).

TABLE 1 - Estimated Values a_o of Construction Materials

ν	Specimen width, mm				Specimen diameter, mm			
	10		100		10		100	
	(1)	(2)	(1)	(2)	(3)	(4)	(3)	(4)
0.25	0.162	0.166	0.162	0.162	0.175	0.181	0.161	0.163
0.30	0.133	0.137	0.133	0.133	0.145	0.150	0.134	0.136
0.35	0.104	0.106	0.104	0.104	0.113	0.117	0.104	0.105
0.40	0.073	0.074	0.072	0.073	0.080	0.082	0.073	0.073

It is seen from the table that value a_0 for the material given (γ = const.) does not depend practically on specimen shape and size, crack geometry, and loading type. Values a_0 will differ from the table ones during presence of residual stresses in material since in such a case the effective energy spent on crack growth will change.

It is expedient to apply constant a_0 first of all during analysis of threshold conditions. The threshold growth condition of fatigue cracks within frames of linear fracture mechanics is represented as

$$\Delta K_{th} = Y \Delta \sigma_{th} \sqrt{\pi a}, \qquad (7)$$

where ΔK_{th} - threshold intensity of stresses; $\Delta \sigma_{th}$ - threshold stress for arbitrary crack of length a. Value $\Delta \sigma_{th}$ increases with the reducing of crack length and for very short cracks it approaches endurance limit $\Delta \sigma_w$. In this case with constant a_0 taken into consideration we have

$$\Delta K_{th} = Y \Delta \sigma_w \sqrt{\pi a_0} \qquad (8)$$

Out of expression (8) it follows, that cracks of length $a < a_0$ do not influence on endurance limit of smooth specimen. Recently Lykáš P. et al (6) have conducted the estimation research of maximum length of non-spreading short crack on fatigue limit of smooth specimens made of Cu (99.98%) and steel (2.25 Cr - 1 Mo) and obtained values a_0 respectively 90 and 100 μm. Calculations according to equation (8) give values a_0 close to them: 104 and 128 μm.

If the behaviour of specimens with cracks of different length up to $a = a_0$ is described by the linear mechanics of fracture, then parameter ΔK_{th} should be invariant to the crack size. However, the experiments showed, that parameter ΔK_{th} determines correctly the endurance limit only for specimens with crack the length of which considerably exceeds a_0 . Several hypotheses were suggested to support this fact (7-9), but remaining within the frames of these hypotheses it is impossible to explain the new experimental results (10), testifying about the discrete character of change $\Delta \sigma_{th}$ according to crack length. With these results taken into account it is possible to suggest that the reason of the above discrepancy is different: during analysis of fracture process in microvolumes (short cracks) the discrete character of the phenomenon wasn't taken into consideration. And then, with the results of this paper taken into account equation (7) would be more correctly represented as

$$\Delta K_{th} = Y_N \Delta \sigma_{th}^N \sqrt{\pi N a_0}\ , \qquad (9)$$

where N = 1,2,3..., $N a_0 = a$, and values of equation parameters when N = 1 characterize the test process of the smooth specimen. From where

$$\Delta \sigma_{th}^N = \frac{\Delta K_{th}}{Y_N \sqrt{\pi N a_0}} = \frac{Y_1 \Delta \sigma_w}{Y_N \sqrt{N}} \qquad (10)$$

The comparison with experimental data showed (Figures 1 and 2), that expression (10) reflects correctly dependence $\Delta \sigma_{th}$ on crack length.

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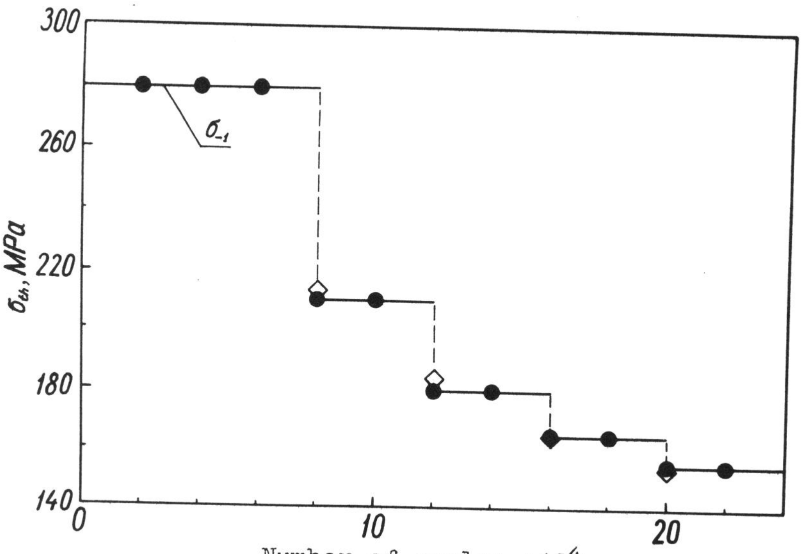

Figure 1 Change of threshold stress σ_{th} during cyclic overloading ($\sigma = 1.3\sigma_{-1}$): ● – experimental data (10); ◇ – values σ_{th} , calculated according to expression (10).

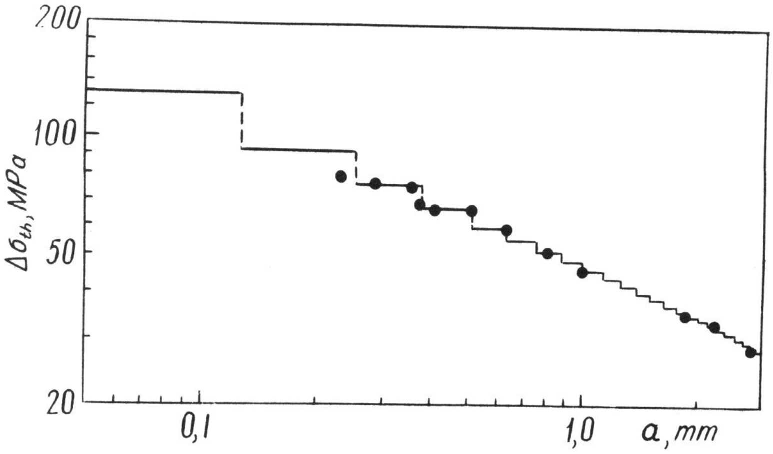

Figure 2 Influence of short cracks on endurance limit of Al alloy AMg-61 (7). Stepped curve calculated according to expression (10).