CURRENT VALUE OF THE FATIGUE CRACK TIP OPENING DISPLACEMENT
AS AN EXPERIMENTALLY SUBSTANTIATED CRITERION OF CRACK GROWTH

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On the basis of the experimental data, we show that the effect of crack closure disappears at low ambient temperatures (213 K). This effect is preceded by the phenomenon of the natural pulsation of the degree of crack closure with permanently decreasing amplitude and duration of pulses to the minimum values of the stress intensity factor in a cycle $K_{\text{min}}$ at room and low ambient temperatures. The practical analysis of the accumulated data on the presence and absence of the effect of crack closure at different temperatures and for different types of asymmetry of the cycles demonstrates that an adequate description of the kinetics of fatigue cracks can be obtained on the basis of the experimentally substantiated criterion of their growth based on the evaluation of the current value of the crack tip opening displacement.

Nomenclature

$K_{\text{min}}$ = the minimal value of the stress intensity factor in a cycle
$K_{\text{max}}$ = the maximal value of the stress intensity factor in a cycle
$K_{\text{op}}$ = the stress intensity factor of crack opening in a cycle
$K_{\text{fcI}}$ and $\Delta K_{\text{fcI}}$ = respectively, the critical value of the stress intensity factor and the range of the stress intensity factor of vanishing of the effect of crack closure
$K_{\text{fcI}}^{293}$ and $\Delta K_{\text{fcI}}^{293}$ = respectively, the critical value of the stress intensity factor and the range of the stress intensity factor of vanishing of the effect crack closure at room temperature
$K_{\text{fcI}}^{213}$ and $\Delta K_{\text{fcI}}^{213}$ = respectively, the critical value of the stress intensity factor and the range of the stress intensity factor of vanishing of the effect crack closure at low ambient temperature
$\Delta K_{\text{eff}}$ = the range of the effective stress intensity factor in a cycle
$\Delta K$ = the range of the stress intensity factor in a cycle
$\Delta K_{\text{th}}$ = the threshold range of the stress intensity factor in a cycle
$\Delta K_{\text{theff}}$ = the effective threshold range of the stress intensity factor in a cycle
$\Delta K_{\text{op}}$ = the range of the stress intensity factor of pulsating crack closure in a cycle
$\Delta K_{\text{op}}^{293}$ = the range of the stress intensity factor of pulsating crack closure at room temperature
$\Delta K_{\text{op}}^{213}$ = the range of the stress intensity factor of pulsating crack closure at low ambient temperature
$\Delta K_{\text{eff}}^{*\text{inv}}$ = the critical range of the stress intensity factor of cyclic loading corresponding to the loss of invariance of the kinetic diagrams of fatigue fracture

\(\Delta \delta\) = the maximum range of the crack tip opening displacement in a cycle
\(\Delta \delta_{\text{eff}}\) = the effective range of the crack tip opening displacement in a cycle
\(\Delta \delta_{\text{fcl}}\) = the critical range of the crack tip opening displacement corresponding to the complete absence of the effect of crack closure
\(\Delta \delta_{\text{th}}\) and \(\Delta \delta_{\text{theff}}\) = respectively, the threshold and effective threshold ranges of the crack tip opening displacement in a cycle
\(\delta\) = the current value of the crack tip opening displacement
\(\delta_{\text{op}}\) = the crack tip opening displacement in a cycle
\(P\) = the value of the load
\(P_{\text{op}}\) = the load corresponding to the crack tip opening displacement
\(R\) = the load ratio

**Introduction.** The improvement of the concepts, approaches, and methods as well as the development of physically meaningful models and criteria for the estimation of the fracture resistance of structural materials are important problems of materials science and mechanics of materials. It is customary to analyze these problems on the basis of phenomenological criteria originating from the Griffith theory [1,2]. As applied to the study of the growth of fatigue cracks, the concept of critical stress intensity factor proposed by Irwin [3] enabled Elber [4,5] to experimentally discover the phenomenon of fatigue crack closure. This phenomenological result intensified profound investigations of the process of fatigue crack growth taking into account the effects of the crack closure and crack opening in each loading cycle characterized by the range of the effective stress intensity factor \(\Delta K_{\text{eff}}\). In this connection, we must mention the very important (both from the theoretical and practical points of view) problem of comprehensive experimental investigation of the kinetics of fatigue crack growth on the basis of the analysis of the effect of crack closure.

In [6], Krasovskii, Pinyak, and Morozov indicated that metals are characterized by the effect of vanishing of crack closure and experimentally established the characteristics of cyclic crack-growth resistance for which this effect is observed. The effect of vanishing is preceded by the phenomenon of natural pulsations of the degree of crack closure characterized by permanently decreasing amplitude and duration of pulses to the minimum stress intensity factor in a cycle \(K_{\text{min}}\) depending on the maximum stress intensity factor in a cycle \(K_{\text{max}}\) for all materials, load ratios \(R = K_{\text{min}}/K_{\text{max}}\), temperatures, and other service factors.

The aim of the present work is to study the influence of the load ratio and low temperatures on the distinctive features of the effect of closure of fatigue cracks for two types of structural steel.

**Experimental Results.** We tested compact specimens for eccentric tension with a thickness of 12.5 mm made of 30L-1 and D9H steels produced abroad and used in industrial tractors designed for service in the North. The chemical compositions of the investigated types of steel are presented in Table 1. We studied the characteristics of cyclic crack-growth resistance of 30L-1 steel for the load ratio \(R = 0.1\). For D9H steel, the load ratio \(R\) varied within the range 0.1–0.75. Both types of steel were tested at room and low ambient temperatures according to the methodical recommendations presented in [7] by using the data presented in [8] for a loading frequency of 15 Hz.

The crack opening displacement was continuously measured on the surface of the specimens at a constant distance of 14 \(\mu\)m behind the crack tip in the process of crack propagation under the conditions of cyclic loading with a loading frequency of 0.1 Hz according to the methods proposed in [9–11] and by the author in [12–14].

We obtained the dependences of the fatigue crack growth rate on \(\Delta K_{\text{eff}}\) and the range of the stress intensity factor \(\Delta K\) at room (293 K) and low ambient (213 K) temperatures for 30L-1 and D9H steels and \(R = 0.1\) (Fig. 1). The quantity \(\Delta K_{\text{eff}}\) is defined as the difference

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\Delta K_{\text{eff}} = K_{\text{max}} - K_{\text{op}},
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where \(K_{\text{op}}\) is the stress intensity factor of the crack opening displacement.