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Oxide induced crack closure in the near threshold regime: the effect of oxide debris release

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Abstract. Within this work the influence of oxide particle transport during fatigue loading on the fatigue propagation rate was investigated in detail by means of load-shedding tests in the near threshold region (crack propagation rate between 0.1 and 10 nm per cycle). To this purpose, standard fatigue specimens (SENB - single edge notch bending) were machined. At selected specimens, a stretchable nitrile rubber patch was glued onto the sample surfaces in the ligament region. This patch was expected to prevent the emergence of iron oxide particles near the sample surface, and indeed subsequent fracture surface analysis showed obvious differences in the shape of the arising oxide debris layer. It is shown that the build-up of oxide debris on the fracture surface is higher in the specimen with the nitrile rubber patch applied. This leads to increased oxide induced crack closure and, in turn, to a higher fatigue crack growth threshold. In this context, also the influence of the specimen thickness on the fatigue crack growth threshold is examined. Finally, also the influence of the load ratio on the oxide debris layer is briefly discussed.

1. Introduction

The crack propagation rate da/dN for cyclically loaded components is proportional to the effective stress intensity factor range ΔK_{eff}, because a crack is only able to propagate when the crack flanks are separated [1]. This implies that the maximum applied load $K_{\max}$ must be greater than the stress intensity factor for crack opening K_{op}, where the crack is fully opened:

$$\frac{da}{dN} \propto \Delta K_{\mathrm{eff}} = K_{\max} - K_{\mathrm{op}} \tag{1}$$

The value of K_{op} depends on the applied load ratio R, on the residual stresses that may be present in some cases (e.g., due to heat treatment or mechanical surface treatment), and on the resistance against crack propagation due to crack closure mechanisms. There exist different crack closure mechanisms promoting retardation of fatigue crack growth [2, 3, 4]. The most important contributions to crack closure – at least for steels – are plasticity-induced, roughness-induced and oxide debris induced crack closure. To describe the crack closure contribution in dependence of the crack extension Δa, the cyclic crack resistance curve (R-curve) is commonly used [5, 6, 7, 8]. The R-curve describes the build-up of the fatigue crack growth threshold ΔK_{th} over the crack extension Δa. After a certain crack extension the resistance against crack propagation ΔK_{th} remains constant for constant load amplitudes. The point when this 'steady-state' is reached is the so called long crack threshold $\Delta K_{\mathrm{th,LC}}$.

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