Creep-induced subsequent fatigue crack retardation and acceleration in wrought nickel-based superalloy GH4169: Competing mechanism of creep damage and creep deformation using DIC technique

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Abstract

Wrought nickel-based superalloy GH4169 (i.e., IN 718) is widely used in aero engine turbine disks. During operation, these disks experience alternating and sustained loads, leading to significant creep-fatigue interactions. Precise life prediction for these critical components requires quantitatively understanding the creep-fatigue interaction mechanisms during the crack propagation of GH4169.

Previous studies on creep-fatigue interaction have mainly used trapezoidal waveforms with dwell at maximum load to investigate the effect of creep on fatigue crack propagation rate. These investigations have attributed increased crack propagation rates to creep cavitation resulting from creep damage, while decreased rates have been linked to stress relaxation or crack tip blunting due to creep deformation. However, the quantitative mechanisms governing strain and damage development around the crack tip remain unclear.

In this study, the influence of prior creep on subsequent fatigue crack propagation behavior in nickel-based superalloy GH4169 was investigated, with a focus on the relationship between strain evolution and damage accumulation around the fatigue crack tip and fatigue crack propagation rate after applying the dwell loads based on digital image correlation (DIC). Crack propagation tests were conducted using compact tension (C(T)) specimens by introducing a single tension dwell at 650 ∘C into fatigue loading at ambient temperature. Various single dwell loads with different dwell times (600 s, 6000 s and 50000 s) were introduced into triangular cyclic loads at a similar initial stress intensity factor (25 MPa·m1/2) to introduce different creep effect on fatigue crack propagation, thereby revealing creep-induced retardation and acceleration effects. The results showed that the fatigue crack propagation rate, after applying dwell loads, demonstrated three distinct scenarios compared to the pure fatigue crack growth rate: 1) an instantaneous retardation for 600 s, 2) an instantaneous acceleration followed by retardation for 6000 s, or 3) an instantaneous rapid acceleration followed by slow acceleration for 50000 s. Ultimately, all scenarios converge to the pure fatigue propagation rate. Additionally, the cyclic strain distribution characteristics ahead of the crack tip and the crack opening and closure responses behind the crack tip using the DIC technique were analyzed. These analyses aimed to understand how creep deformation and damage influence the fatigue crack propagation rate and to obtain fracture parameters that quantitatively characterize the intrinsic mechanisms of creep-induced retardation and

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acceleration. The findings demonstrated that: 1) More evident strain and an increasing plastic strain region around the crack tip cause correspond to creep-induced acceleration. 2) A higher increasing rate in CTOD (crack tip opening displacement) and a larger severe strain (strain $> 3.6\%$) zone correspond to reduced fatigue crack growth (FCG) resistance due to creep damage, leading to a more pronounced acceleration effect. 3) The crack surface may be destroyed in certain regions after creep due to oxidation, suggesting that creep-induced retardation may be related to the oxidation-induced crack closure effect and the decrease in stress concentration due to oxidation-induced CTOD acceleration. Furthermore, the uniform manifold approximation and projection (UMAP) algorithm was used to analyze the difference between different strain fields associated with different creep damage and creep strain from a unique perspective.