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Effect of stress state and simultaneous hot corrosion on the crack propagation and fatigue life of single crystal superalloy CMSX-4

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Abstract

Operating conditions within industrial gas turbines are changing in response to pressures to reduce environmental impact and enable use of renewable sources. This is driving an increase in the operational temperatures and pressures of combustion in turbine systems. Additionally, diverse operating environments can result in higher sulphur and trace metal contaminant levels, exacerbating hot corrosion in GT systems. Low cycle fatigue (LCF) cycling can also be intensified as a result of increased start/stop shutdowns. The combined effects of hot corrosion and stress are experimentally studied on CMSX-4 single crystal (SC) γ/γ' system under both fatigue and static stress conditions, with either a multi-axial bending or uniaxial stress state. The associated stress intensity thresholds (K_{TH}) under the various stress conditions were evaluated using finite element analysis (FEA). Cracking was observed both under static and fatigue stress conditions in a hot corrosion environment. Crack morphologies were analysed using SEM techniques. Bending stresses and fatigue cycles demonstrated increased crack propagation in the presence of hot corrosion with static uniaxial stresses showing the longest nucleation times and lowest propagation rates.

Keywords: Hot Corrosion, Fracture Mechanics, FEA, Single Crystal Superalloys

Nomenclature and Units

K – Stress intensity (Pa·m$^{1/2}$)

K_{TH} – Fatigue stress intensity threshold

K_{cr} – Critical stress intensity threshold

K_I – Mode I Stress intensity

σ – Stress (Pa)

Y – Linear elastic fracture mechanics geometry factor

C – Paris law constant

n – Paris law exponent

J – J-integral (J/m^2)

r – Arbitrary contour path around the crack tip

w – Strain energy density (J/m^3)

T_i – Traction vector (N/m^2)