HIGH-CYCLE FATIGUE OF TURBINE ENGINE ALLOYS*

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Abstract: High-cycle fatigue (HCF) is a prime cause of military aircraft turbine engine failures. It results from fatigue-crack growth in blades and disks, initiated at small defects often associated with fretting or foreign object damage. Due to the high frequencies (>1 kHz) involved, design must be based on a HCF threshold, such that crack propagation cannot occur within $\sim 10^9$ cycles. In this work, the nature of the fatigue threshold is examined under representative high frequency and high load-ratio conditions, in a Ti-6Al-4V blade alloy with bimodal and lamellar microstructures, with emphasis on behavior following foreign-object damage (FOD) and under mixed-mode (modes I + II) loading conditions. It is shown that for all crack sizes, large or small, but of dimensions large compared to microstructural size-scales ("continuum-sized" cracks), a *worst-case fatigue threshold* can be defined (at load ratios where $R \rightarrow 1$ where crack closure is minimized) which represents a lower-bound stress intensity for fatigue-crack growth. This holds for mixed-mode loading (studied at $\Delta K_{II}/\Delta K_I$ ratios from 0 to 7, at load ratios from 0.1 to 0.8), provided the threshold is characterized under worst-case mode I conditions in terms of ΔG (incorporating both tensile and shear components). However, for crack sizes comparable with microstructural dimensions, i.e., < 10 µm in this alloy, as can be found in the vicinity of damaged regions due to FOD impacts, fatigue thresholds can be far lower, e.g., by a factor of two. In such instances where the critical condition for HCF must be defined in the presence of such microstructurally-small cracks, the Kitagawa-Takahashi diagram is more appropriate, where the limiting conditions are defined in terms of the 10^7-cycle fatigue limit (at microstructurally-small cracks sizes) and the "worst-case" ΔK_{TH} fatigue threshold (at larger, "continuum-sized" crack sizes).

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