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Simulated microstructure-sensitive extreme value probabilities for high cycle fatigue of duplex Ti–6Al–4V

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ABSTRACT

A newly developed microstructure-sensitive extreme value probabilistic framework to characterize the performance/variability for damage evolution processes is exercised to compare the driving forces for fatigue crack formation (nucleation and early growth) at room temperature for four different microstructure variants of a duplex Ti–6Al–4V alloy. The aforementioned probabilistic framework links certain extreme value fatigue response parameters with microstructure attributes at fatigue critical sites through the use of marked correlation functions. By applying this framework to study the driving forces for fatigue crack formation in these microstructure variants of Ti–6Al–4V, these microstructures can be ranked in terms of relative high cycle fatigue (HCF) performance and the correlated microstructure attributes that have the most influence on the predicted fatigue response can be identified. Nonlocal fatigue indicator parameters (FIPs) based on the cyclic plastic strain averaged over domains on the length scale of the microstructure attributes (e.g., grains, phases) are used to estimate the driving force(s) for fatigue crack formation at the grain scale. By simulating multiple statistical volume elements (SVEs) using crystal plasticity constitutive relations, extreme value distributions of the predicted driving forces for fatigue crack formation are estimated using these FIPs. This strategy of using multiple SVEs contrasts with simulation based on a single representative volume element (RVE), which is often untenably large when considering extreme value responses. The simulations demonstrate that microstructures with smaller relative primary α grain sizes and lower volume fractions of the primary α grains tend to exhibit less variability and smaller magnitudes of the driving forces for fatigue crack formation. The extreme value FIPs are predicted to most likely occur at clusters of primary α grains oriented for easy basal slip. Additionally, surrounding grains/phases with soft orientation shed load to less favorably oriented primary α grains, producing extreme value FIPs.

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1. Introduction

Variability of the fatigue life of engineered components arises from microstructure stochasticity. This is particularly true for the processes of fatigue crack nucleation and microstructurally small crack growth in ductile metallic material systems, which are driven by localized plasticity and the accumulation of dislocations against obstacles or the development of particular dislocation structures (e.g., persistent slip bands) (Suresh, 1998). In high cycle fatigue (HCF) of metals for which cyclic stress amplitudes are below the macroscopic yield stress, plasticity is quite heterogeneous and localized at microstructure

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