doi:10.1017/S1431927616009508
Microsc. Microanal. 22 (Suppl 3), 2016

Prediction of Fatigue-Initiating Twin Boundaries in Polycrystalline Nickel Superalloys Informed by TriBeam Tomography

William C. Lenthe[1], Jean-Charles Stinville[1], McLean P. Echlin[1] and Tresa M. Pollock[1]

[1.] Materials Department; University of California, Santa Barbara; Santa Barbara, CA 93106

Fatigue is the life limiting property of polycrystalline nickel-base superalloys used for turbine disks. Alloys processed through advanced powder metallurgical routes have minimal concentrations of pores, inclusions, or other extrinsic defects that commonly serve as crack initiation sites. Instead, fatigue cracks initiate at intrinsic defects resulting in microstructurally sensitive and difficult to predict fatigue response [1]. Crack formation and short crack growth accounts for 80% of lifetime in the high cycle fatigue regime resulting in highly variable lifetimes spanning up to three orders of magnitude [1, 2]. Identifying and characterizing regions amenable to initiation and initial propagation of cracks is crucial for improving fatigue life predictions.

Fatigue cracks in René 88DT initiate due to strain localization near annealing twin boundaries in large grains with a high resolved shear stress. Cracks nucleate due to large incompatibility stresses generated by accumulation of irreversible cyclic dislocation slip [3]. Recently a criterion for fatigue crack initiating twin boundaries has been developed by surface investigations of interrupted fatigue tests [2]. The initiation criterion is defined by elastic modulus mismatch across the boundary, boundary length, and maximum boundary parallel Schmid factor.

Fatigue crack initiating microstructural features were characterized in three dimensions using TriBeam tomography. The TriBeam system couples a femtosecond laser with a dual beam focus ion beam (FIB) - scanning electron microscope, allowing rapid in-situ material removal rates 4-5 orders of magnitude faster than a Ga^+ FIB which enables the analysis of large mm^3-scaled three dimensional volumes [4]. Several volumes of René 88DT were collected with electron backscatter diffraction (EBSD) patterns indexed for each slice including volume surrounding a short crack shown in Figure 1.

The three dimensional volumes reveal complex twin networks and that most twin boundaries are coherent, allowing inference of twin boundary inclination from two dimensional cross sections. To investigate initiation site density for a statistically significant number of grains, EBSD was collected from mm^2 scale cross sections. Boundary parallel Schmid factors were computed for each twin boundary by assuming coherence. The length of each boundary was similarly computed by projection onto the coherent trace. The elastic modulus in the loading direction was found using average orientation of each grain with the single crystal elastic tensor for nickel. Combined, these calculations allow for the identification of all boundaries meeting the fatigue crack initiation criterion as shown in Figure 2 [2].

The convergence behaviour of fatigue crack initiating boundary length was interrogated using a subsampling method [5]. Areas of the two dimensional scan were randomly selected for a range of sizes and the length of crack initiating boundary measured. Multiple measurements were made for each size and the sample mean and variance calculated. Convergence of the 95% confidence interval width to 5% of the sample mean requires an area of 0.2 mm^2. Variance in initiation site density is inversely proportional to area, allowing variability predictions for smaller regions and providing a framework for estimating variability in fatigue crack initiation lifetimes for René 88DT.

References:

[1] TM Pollock and S Tin, J Propul Power, **22** (2006), p. 361.
[2] JC Stinville *et al*, Acta Mater, **103** (2016), p. 461.
[3] J Miao, TM Pollock and JW Jones, Acta Mater **57** (2009), p. 5964.
[4] MP Echlin *et al*, Mater Charact **100** (2015), p. 1.
[5] MP Echlin, WC Lenthe and TM Pollock, Integr Mater Manuf Innov **3** (2014), p. 1.

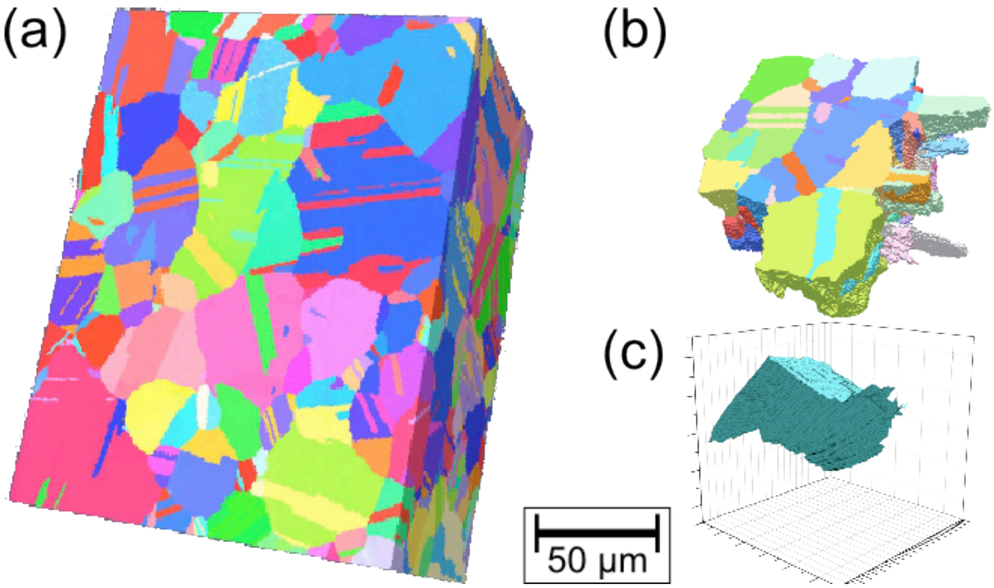

Figure 1. A 3D dataset of René 88DT collected around a crack is shown in (a). The grains surrounding the crack and the crack shape are shown in (b) and (c) respectively.

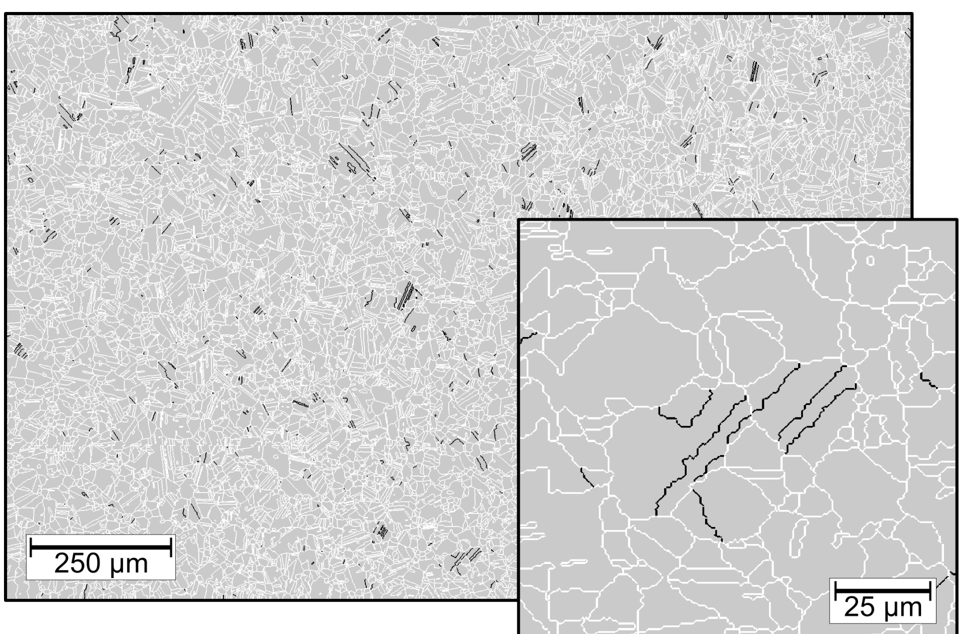

Figure 2. All grain boundaries for a mm^2 scale EBSD scan are shown in white with boundaries satisfying the fatigue crack initiation criterion highlighted in black.

https://doi.org/10.1017/S1431927616009508 Published online by Cambridge University Press