# FATIGUE-CREEP-ENVIRONMENT INTERACTIONS IN A DIRECTIONALLY-SOLIDIFIED NI-BASE SUPERALLOY

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Directionally solidified (DS) GTD-111 is a Ni-base superalloy designed to withstand creep damage occurring in the first and second stage blades of gas-powered turbines. The service conditions in these components, which generally exceed 600ºC, facilitate the onset of one or more damage mechanisms via fatigue, creep, and environmental corrosion. Under these conditions microstructural damage mechanisms operate interactively and independently to initiate cracks that lead to the eventual reduction of service life. Because of the distinctive microstructure of DS GTD-111, the manner in which these mechanisms interact to initiate cracks is related to grain structure and chemical composition. In addition to fatigue cycling, certain sections of these high temperature components are subjected to sustained dwell periods (i.e., creep) either in tension or compression. Experiments have been carried out to simulate a variety of thermal, mechanical, and environmental operating conditions endured by longitudinally (L) and transversely (T) oriented DS GTD-111. In some case, tests in extreme environments/temperatures were needed to isolate one or at most two of the damage mechanisms. Assuming a unique relationship between the damage fraction and cycle fraction with respect to cycles to crack initiation for each damage mode, the total crack initiation life has been represented in terms of the individual damage components (fatigue, creep-fatigue, creep, and oxidation-fatigue respectively), and is based on that developed by Neu and Sehitoglu [1] and modified by Gordon et al. [2]:

$$\frac{1}{N_i^{tot}} = \frac{1}{N_i^{fat}} + \frac{1}{N_i^{c-f}} + \frac{1}{N_i^{cr}} + \frac{1}{N_i^{ox}} \tag{1}$$

Observations from micrographs (Fig. 1) of sections of oxidized, fatigued, and crept samples have been incorporated to develop damage mechanism maps (DMMs). The DMMs, which quantify the transitions between damage mechanism regimes, have been applied to develop physically-based relationships for each of components of a crack initiation model.

A crystal plasticity based model has been formulated by Shenoy et al. [3] to capture the stress strain behavior in the material. Fatigue (Fig. 2) and creep data were used to calibrate the model which was implemented as an UMAT in ABAQUS. Using numerical simulations of experiments, damage and crack initiation life predictions have been made. It was determined that under high frequency and isothermal conditions with large plastic strain ranges and low temperatures, fatigue damage dominates. The contribution of the coupled creep-fatigue mechanism appears by increasing either the temperature or cycle time. Tests with small plastic strain range including those with superimposed thermal cycling, are subject to environmental-fatigue damage since the surface-related mechanisms are active at long exposure times.

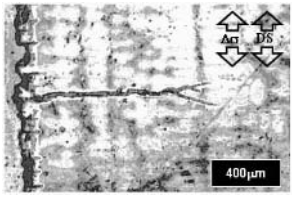


FIGURE 1: Oxide spiking observed in L-oriented DS GTD-111 with 982°C, $\Delta\varepsilon$=0.5%, R=-1, and 2min compressive holds.

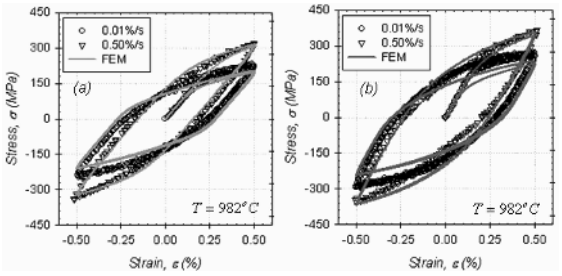


FIGURE 2: Simulated and actual experimental responses of DS GTD-111 under isothermal LCF in (a) L-orientation and (b) T-orientation at two strain rates. For each case 982°C (1800°F), $R_\varepsilon$=-1, and $\Delta\varepsilon$ = 1.0%.

## References

1. Neu, R. W., and Sehitoglu, H., *Metallurgical Transactions A*, vol. 20, 1769-1783, 1989.
2. Gordon, A. P., Shenoy, M. M., and Neu, R. W. (2005). In *Proceedings of 11th International Congress of Fracture (ICF11)*, Turin, Italy, Elsevier Science.
3. Shenoy, M. M., Gordon, A. P., Neu, R. W., and McDowell, D. L., In press for publication in the Journal of Engineering Materials and Technology, 2005.