Crystal plasticity analysis for temperature dependent fatigue crack propagation in a single crystal nickel-base superalloy

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Single crystal Ni-base superalloys are widely used as hot section components in advanced gas turbines for jet engines and land base power generation. In this study, fatigue crack propagation behavior in a single crystal nickel-base superalloy CMSX-4 was investigated experimentally and analytically. In the fatigue crack propagation tests, effects of temperature (room temperature and 450°C) and crystal orientations (four combinations of loading direction and propagation direction) were analyzed. At room temperature, the cracks showed crystallographic propagation along {111} slip planes in the FCC crystal, and crack propagation rates were significantly affected by crystal orientation. At 450°C, transitions from the initial model I cracking to the subsequent crystallographic cracking were observed, and the transition points depended on the crystal orientations. The higher strength of the precipitate phase at the higher temperature probably induced the transition cracking at 450°C, and crystal orientations led to different transition points. In order to interpret the effect of crystal orientations, crystal plasticity analysis was conducted using finite element method, considering some critical factors; elastic anisotropy, crystal orientations, 3-D geometry of the crack plane and intrinsic activities on all 12 slip systems in the FCC single crystal. Slip plane activity derived from the shear strains along 12 slip systems was introduced as a damage parameter to explain the crystal orientation effect. A series of numerical investigations showed that the crystallographic cracking took place along the specific slip plane with the highest slip plane activity, and the crack propagation rates increased with the increase of the slip plane activity at room temperature. It was also found from the analysis for 450°C that the transition from the mode I to crystallographic cracking was triggered when the slip plane activity reached a certain level.