Thermal fatigue failure analysis and life prediction of Ni-based single crystal film cooling hole structure under cyclic oxidation

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Abstract Aircraft engines and gas turbine hot end components work in harsh environments with high temperatures and loads for a long time. During the cyclic processes of starting, load changes, and stopping, components may experience severe cyclic oxidation and significant cyclic thermal stress, which can easily lead to damage and failure. This study combines experimental and finite element simulation methods to investigate the cyclic oxidation and thermal fatigue behavior of Ni-base single crystals with thin-walled cooling hole structures at different peak temperatures (25°C→ 980°C and 25°C→ 1050°C). The initiation position and propagation direction of thermal fatigue cracks in both single hole and multi-hole specimens exhibit the angles of ±45◦ with respect to the horizontal direction at the four corners of the holes.Octahedral slip failure mainly occurred at the crack initiation location and crack tip. The cyclic oxidation around the film cooling hole promotes the initiation and propagation of cracks. A cyclic oxidation kinetics model was established based on thermodynamics and oxidative diffusion theory. Based on the crystallographic theory, the strain–stress constitutive equation of the Ni-based single crystal superalloy under transient thermal shock was established. The location and evolution of thermal stress around the hole at different temperatures were obtained by finite element calculation. Finally, a thermal fatigue crack initiation life model considering cyclic oxidation, heating temperature and transient thermal stress has been established. The simulation results are in good agreement with the tests.

Keywords cyclic oxidation; Ni-based single crystal superalloys; film cooling hole; thermal fatigue