High temperature fatigue crack growth modeling in Ni-based superalloys using a gradient-enhanced elastic-viscoplastic damage model

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Fatigue crack growth prediction during both design and lifespan analysis of aeronautical structures still remains of great interest to ensure safety and reliability of critical components. Disregarding the conventional concepts from the Linear Elastic Fracture Mechanics (LEFM) theory, this study focuses on a new approach to evaluate the fatigue crack propagation in Nickel-based superalloys. It consists in assessing the capabilities associated with the local approach to fracture to simulate the propagation of a long fatigue crack in structural components [1]. To this end, a three-step approach is considered.

First, the cyclic non-linear behavior of the recently developed Nickel-based superalloy AD730™ is studied using dedicated characterization tests at three target temperatures (20, 550 and 700°C). The main strain-hardening mechanisms as well as complex viscosity effects are evidenced. A set of constitutive equations for the cyclic non-linear behavior of AD730™ is proposed and calibrated following the pioneer work of [2]. A good agreement between experimental and simulated results is achieved.

Next, high temperature fatigue and dwell-fatigue crack propagation tests on SEN-T specimens are performed in order to evidence the main crack driving mechanisms. A strong behavior-damage coupling is then settled – using the Continuum Damage Mechanics (CDM) concepts – hence leading to a time-incremental damage model for fatigue [3]. This model is implemented in a finite element code using a fully implicit resolution scheme. In order to solve for the spurious mesh-dependency effect, a non-local extension of the damage model is proposed using an implicit gradient formulation [4]. Several numerical tests of increasing complexity illustrate the ability of this non-local formulation to efficiently control damage localization and subsequently to ensure convergence of the numerical results upon mesh refinement.

Finally, an error-based mesh adaption procedure is considered in order to refine the mesh in the fracture process zone, close to the crack-tip where the non-linear phenomena occur. Once crack onset is achieved, a crack path tracking algorithm is used to evaluate the geometry and the direction of the crack increment [5]. Then, a damage-to-crack transition consisting in remeshing steps, fields transfer and equilibrium recovery is performed. This way, crack growth kinetics can be captured. The whole numerical loop is assessed on calculations conducted on a SEN-T specimen subjected to complex fatigue and creep-fatigue loading conditions. The capabilities of the proposed approach to relate the results from CDM to those from LEFM are emphasized, while its limitations are also discussed.

References

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