Thermo-mechanical fatigue crack growth of a coated superalloy

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Abstract

This study focuses on combustion chambers made of superalloys, coated with thermal barriers to offer protection against extreme heat. These chambers experience severe thermal gradients and out-of-phase (OP) cyclic loading, characterized by tensile stress at low temperatures and compressive stress at high temperatures. This induces significant mechanical stresses, leading to damage in the form of fatigue cracks. The aim of this work is to investigate the propagation of pre-existing cracks, with a particular focus on their path and speed, to evaluate the durability of combustion chambers, especially when Thermal Barrier Coatings (TBCs) are applied.

The component is subjected to complex thermo-mechanical loads, consisting of variable-amplitude cycles with significant temperature gradients, which can lead to large scale yielding deformation. Furthermore, the presence of a TBC, composed of a NiCrAlY bond coat layer and an yttria-stabilized zirconia ceramic layer applied by Air Plasma Spraying (APS), adds further complexity. The mechanisms of crack propagation under these conditions are not well understood. Previous work has characterized crack initiation (1) and propagation (2) on the substrate. The challenge of this study is, therefore, to develop experimental and numerical techniques that accurately represent the loads experienced by the component and replicate the crack propagation observed in coated combustion chambers.

Consequently, an experimental test series has been designed to understand the role of both coating layers in crack propagation, using image correlation techniques and infrared thermography. The purpose of these tests is to first analyze the impact of temperature conditions on crack propagation across different layers. To achieve this, thermomechanical fatigue (TMF) experiments are conducted on pre-notched specimens. One set of specimens is coated solely with a NiCrAlY layer and subjected to biaxial loading conditions, while another set is coated with an additional thermal barrier coating (TBC) and tested under uniaxial loading conditions. The tests are performed at a constant temperature of 900◦C and at varying temperatures ranging from 300◦C to 900◦C, incorporating different heating and cooling rates under OP conditions.

In parallel, finite element simulation methods, informed by experimentally measured fields, are being employed to analyze the forces driving crack propagation. In particular, a non-local

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remeshing method (3) adapts the mesh around the crack, simulating crack propagation and enabling precise computation of the energetic data associated with each increment of crack growth. This approach makes direct comparison with experimental data feasible. A complementary phase-field approach is also being developed to simulate the damage field induced by thermomechanical loading and to model its interaction with plasticity. The phase-field method is particularly valuable for capturing the coupled effects of damage and plasticity, especially near closed crack tip regions, where these interactions significantly influence the material response (4).