Crack propagation kinetics at the substrate/thermal barrier interface under complex thermomechanical loading

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Abstract

Thermal barrier systems provide essential protection for the High-Pressure turbine blades of aircraft engines. Current engine development aims to increase the turbine's thermal efficiency, leading to a significant rise in the surface temperatures of turbine blades. During the design process, it is critical to ensure the durability of the thermal barrier coating under the extremely severe thermomechanical and environmental conditions applied. In particular, it is necessary to evaluate the adherence of the thermal barrier and its evolution during operation in order to estimate the number of cycles until spallation. Numerous tests for determining interface toughness exist in the literature (1), but they are destructive. This destructive aspect makes the characterization of interface toughness at various aging stages prohibitively expensive, thereby hindering the identification of clear trends and the isolation of inherent scatter in the thermal barrier spallation mechanism.

This study introduces a recent method for in-situ monitoring of crack propagation at the substrate/thermal barrier interface and called Laser Shock Damage Monitoring (LASDAM) (2-3). It leverages the ability to process a controlled-sized initial crack at the interface through a laser shock. Due to the evolution of the compressive stress level, the interfacial crack induces blistering of the ceramic layer. Subsequently, instrumentation of tests and analysis tools were developed to monitor, in a non-destructive manner, delamination and buckling of this blister during complex thermomechanical tests. The methodology has been validated under cyclic oxidation tests in furnace (homogeneous temperature), burner rig tests (with thermal gradients) (4) and in thermomechanical fatigue tests. More recently, this method has been applied to thermal gradient mechanical fatigue tests (TGMF). A synthesis of the results obtained in terms of delamination kinetics at the interface will be presented, as well as an analysis of the different regimes observed based on the applied loading conditions.

The cyclic evolution of the blister is modeled through finite element model accounting for nonlinear creep of metallic layer during thermomechanical cycles. This modeling is used to

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assess the local mechanical state at the crack tip. Then, equivalent quantities derived from fracture mechanics are calculated and analyzed to explain the stable delamination propagation during cycles. In a nutshell, the stable growth of a ceramic blister on a metallic surface can be studied for a large variety of load cases. It includes those where the viscoplastic behavior of the multi-layered system and progressive oxidation influence each other.

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