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Jean Louis Chaboche
ONERA - The French Aerospace Lab

Frederic Feyel
ONERA - The French Aerospace Lab

Martine Poulain
ONERA - The French Aerospace Lab

Noemie Rakotamalala
ONERA - The French Aerospace Lab

Arjen Roos
ONERA - The French Aerospace Lab

See next page for additional authors

Authors
Jean Louis Chaboche, Frederic Feyel, Martine Poulain, Noemie Rakotamalala, Arjen Roos, Jean Roch Vaunois, Arnaud Longuet, and Pascale Kanaoute

LIFETIME ASSESSMENT TOOLS FOR THERMAL BARRIER SYSTEMS

Pascale Kanoute, ONERA, France

Jean-Louis Chaboche, Frédéric Feyel, Martine Poulain, Noémie Rakotomalala, Arjen Roos, Jean-Roch Vaunois, ONERA - The French Aerospace Lab F-92322 Châtillon, pascale.kanoute@onera.fr
Arnaud Longuet, Safran Group, Snecma Villaroche, 77550 Moissy-Cramayel, France

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The degradation of thermal barrier coatings (TBCs) used to limit the metal temperature of aeronautical turbine blades involves complex mechanisms. Multiple failure modes leading to TBC spallation can effectively be observed on coatings that have experienced service conditions. The lifetime assessment of TBC systems has been a challenge since their introduction in aircraft engines. This paper proposes two complementary approaches for the lifetime assessment of TBC systems.

The first one is an energetic based model developed and calibrated by means of adhesion tests. The model involves three steps: first, the mechanical fields inside the layers are computed by the semi-analytical model of the Balint and Hutchinson, which was improved by incorporating new possibilities. In addition to the 2D roughness description a 3D undulation shape is now available. Another important improvement relates to the capability to perform any kind of temperature and mechanical loadings. Given the thermo-mechanical history of the substrate (which can be derived from FE computations), the model computes the interface strains between the metallic substrate and the ceramic protection under a stress field induced by oxidation. The model has been identified and validated with respect to rumpling measurements for different ageing temperatures of the system. During a second step, the interface toughness is estimated through a damage model depending on the mechanical response of the multi-layered system. The damage parameters have been identified on toughness measurements. In order to characterize the TBC toughness, several shear mode interface crack propagation tests have been developed and carried out. Finally, an energetic approach allows to compute the system lifetime by comparing the decreasing interface toughness to the elastic stored energy. This lifetime assessment model is then applied as a post-processing of a finite element computation on a turbine blade and it will be shown that the experimental trends are consistent with the lifetime given by the model.

The second approach aims at modelling the spallation by means of a physically motivated, computationally efficient and complete thermo-mechanical cohesive zone model. The thermal and mechanical problems are solved in a coupled way to simultaneously consider the changes in load transfer due to crack propagation and the heat flow variations as a result of the mechanical damage of the interface. The mixed finite interface element for cohesive zone models is implemented in the finite element code Z-set to mesh the crack path located between the TBC and the substrate. The model accounts for the well-known fact that the fracture toughness of the interface is a function of the mode mixity. Continuum Based shell elements are used to mesh the TBC. The description of thermal transport includes a thermal cohesive zone model in which the degrees of freedom are the temperature jumps and the heat flow across the interface. This thermal cohesive zone can describe the decrease of the interface conductance together with its degradation. The thermal gradient through the thickness of the TBC also plays an important role in modelling the TBC delamination. A Continuum Based thermal shell element with a linear approximation of the temperature in the thickness is introduced to mesh the TBC in the thermal problem. A coupled numerical framework for modelling the TBC failure is presented and applied to a representative test case.