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Impact of the non-homogenous temperature distribution and the coatings process modeling on the thermal barrier coatings system

M. Ranjbar-Far [a], J. Absi [a,*], S. Shahidi [b], G. Mariaux [c]

[a] GEMH, Ecole Nationale Supérieure de Céramique Industrielle, 47, Avenue Albert Thomas, 87000 Limoges Cedex, France
[b] LIUPPA, University of Pau, Avenue de l'Université, 64013 Pau Cedex, France
[c] SPCTS, University of Limoges, 16 Rue Atlantis, 87068 Limoges Cedex, France

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ABSTRACT

The present study deals with a numerical investigation of the residual stresses arising during the plasma-sprayed coatings process and their effects on the final stress state of the thermal barrier coatings system (TBCs) during service. A new thermo-mechanical finite element model (FEM) has been designed to function using a non-homogenous temperature distribution. Several phenomena are taken into account in the model such as: residual stresses generated during the spraying of coatings, morphology of the top-coat/bond-coat interface, oxidation at the top-coat/bond-coat interface, thermal mismatch of the material components, plastic deformation of the bond-coat and creep of all layers during thermal cycling. These phenomena induce local stresses in the TBCs that are responsible of micro-crack propagation during cooling and thermal cycling, specifically near the ceramic/metal interface.

The results of the non-homogenous temperature model have been compared with those of the homogenous temperature one. As a result, more stress relaxation in the hotter area due to creep and different oxide growth rate are founded in the non-homogenous temperature model.

1. Introduction

Air Plasma Sprayed (APS) thermal barrier coatings (TBC) protection is widely used to prolong the lifetime of turbine components. Due to the low thermal conductivity of the top-coat, this layer can decrease the substrate temperature by some hundred degrees (Fig. 1) [1,2]. The functionality and reliability of plasma spray coatings are strongly related to their microstructure, porosity [3] and residual stresses of thin films and coatings [4,5]. Amongst these factors, the effect of residual stress associated to a non-homogenous temperature functioning is the main objective in this study.

Residual stresses in a plasma-sprayed TBC are generated through four events; namely grit blasting of the substrates prior to bond-coat (BC) deposition, phase transformation, rapid contraction of sprayed splats (quenching stresses) and mismatch of thermal expansion coefficients of the substrate and coatings (thermal stresses) [4–6].

Bengtsson and Persson [4] and Widjaja et al. [5] described the development of residual stresses during spraying of zirconia-based thermal barrier coatings by finite element analysis. Their results were compared to experimental data and revealed a good agreement. However, the effect of coating residual stresses on the TBC behaviour during service has not been studied and to simplify the approach, authors assumed a flat interfaces hypothesis between dissimilar materials. The stress state during service depends crucially on the ratio of the loading rate caused by growth and swelling of the oxide layer, different thermal expansion, interface morphology and the unloading rate by creep and plastic relaxation. Hsueh and Fuller [7] examined the effect of curvature and height of the interface asperity on stresses formation during the service. Bialas [1], Sfar et al. [8] and Ranjbar-Far et al. [9] modelled the top-coat/bond-coat interface roughness, the volume growth of the oxide layer, the cyclic loading and the creep relaxation to predict their effects on the stress distribution. However, in all of these cited works, the temperature distribution was only assumed to be homogenous, the residual stresses appearing in the elaboration stage (during plasma spraying coatings) were not considered and finally, in certain of these works, the lateral growth of the Thermal Grown Oxide (TGO) layer was neglected.

In this paper, we present a new step in the objective to continue the development of the TBCs performance. A non-homogenous temperature model, using the finite element code ABAQUS, is proposed to study the thermo-mechanical behaviour of the thermal barrier coatings system. The distribution of the non-homogenous temperature among the model considers thermal transfer between the different layers by conduction and to the surrounding environment by convection. The first step focuses on

* Corresponding author. Tel.: +33 5 55 45 22 23.
E-mail address: joseph.absi@unilim.fr (J. Absi).

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