NUMERICAL SIMULATION OF ENERGY RELEASE RATE FOR INTERFACE CRACK INITIATION DUE TO THERMAL STRESS IN ENVIRONMENTAL BARRIER COATINGS FOR SILICON CARBIDE (SIC) FIBER REINFORCED SIC MATRIX COMPOSITE

Emi KAWAI, The University of Tokyo
kawai@ulab.iis.u-tokyo.ac.jp
Yoshitaka UMENO, The University of Tokyo

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1. Introduction

In order to apply silicon carbide (SiC) fiber reinforced SiC matrix (SiC/SiC) composites as high-pressure turbine materials, environmental barrier coatings (EBC) is essential. EBC consists of several materials and thermal stress occurs by the difference in thermal property of EBC layers and SiC/SiC substrate during the fabrication process and usage environment. If energy release rate (ERR) exceeds interface fracture toughness, the interface crack can be initiated (Griffith theory). For structure design to maintain the property of EBC, it is necessary to theoretically predict ERR for interface crack while fracture toughness is obtained in experiments. This study is to perform numerical simulation of ERR for interface crack initiation due to thermal stress in EBC.

2. Theoretical equation for predicting ERR for interface crack in multi-layered structure

In 1990's, Suo and Hutchinson revealed that ERR for interface crack initiation in single-layered structure (isotropic elastic material, biaxial stress state) is written by strain energy of the layer multiplied by a dimensionless constant factor. To predict ERR for interface crack initiation in a multi-layered structure, we regard the coating layers above the objective interface as one layer and the other layers below the interface as a substrate. Then, ERR (G) is expressed by $G = Z'\Pi_{\mathrm{T}},\ \Pi_{\mathrm{T}} = \sum \sigma_i^2 h_i \left(1-\nu_i^2\right)/E_i$. Here, Z' is a dimensionless factor, σ_i, E_i, ν_i and h_i are thermal stress, Young's modulus, Poisson's ratio and thickness of the coating layer above the objective interface, respectively. Note that Z' is dependent not only on elastic properties of the components but also on thicknesses of the coating layers and substrate because ERR should be governed by the 'effective' mismatch between the layers above and below the objective interface. In order to examine the dependence of Z' EBC layer thicknesses, we calculate ERR (G_{F}), which is released strain energy per crack propagation area, by using thermal stress finite element method (FEM) analysis to be compared with Π_{T}.

3. ERR for interface crack under fabrication process

Figure 1 shows the FEM analysis model. The EBC model consisted of mixed layers of Ytterbium (Yb)-monosilicate (Yb_2SiO_5; 215) and Yb-disilicate ($Yb_2Si_2O_7$; 227) (215:227 =100:0, 80:20, 50:50, 20:80, 0:100), Mullite (Mu), Si-based bond coat (BC) and CVD-SiC (CS) layers. In this analysis, Mu, BC and CS layer thicknesses were changed as 5, 15 and 25 μm while the other layer thicknesses were fixed to be 20 μm. The displacement constraint in the y-direction was imposed on the bottom end of the model. The temperature difference upon cooling was 1375 K. The objective interfaces were Crack A, B and C as shown in Fig.1. The crack was initiated from the right side of the model and its length was 900 μm. The analysis was conducted for the models with and without the interface crack to calculate released strain energy.

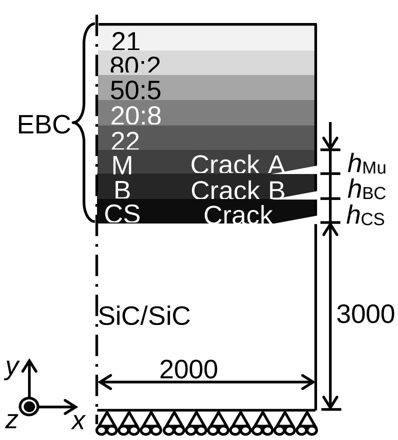

Fig. 1 Schematic illustration of FEM analysis model with interface

4. ERR for interface crack under thermal fatigue

Under the usage environment, SiC/SiC composites with EBC are subjected to thermal fatigue. The mechanical properties of EBC and SiC/SiC composites are changed due to thermal fatigue. Therefore, Z', which is dependent on the mechanical properties, is also changed during thermal cycles. Considering the change of material properties, we examine the dependence of Z' on EBC layer thicknesses by FEM analysis.

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