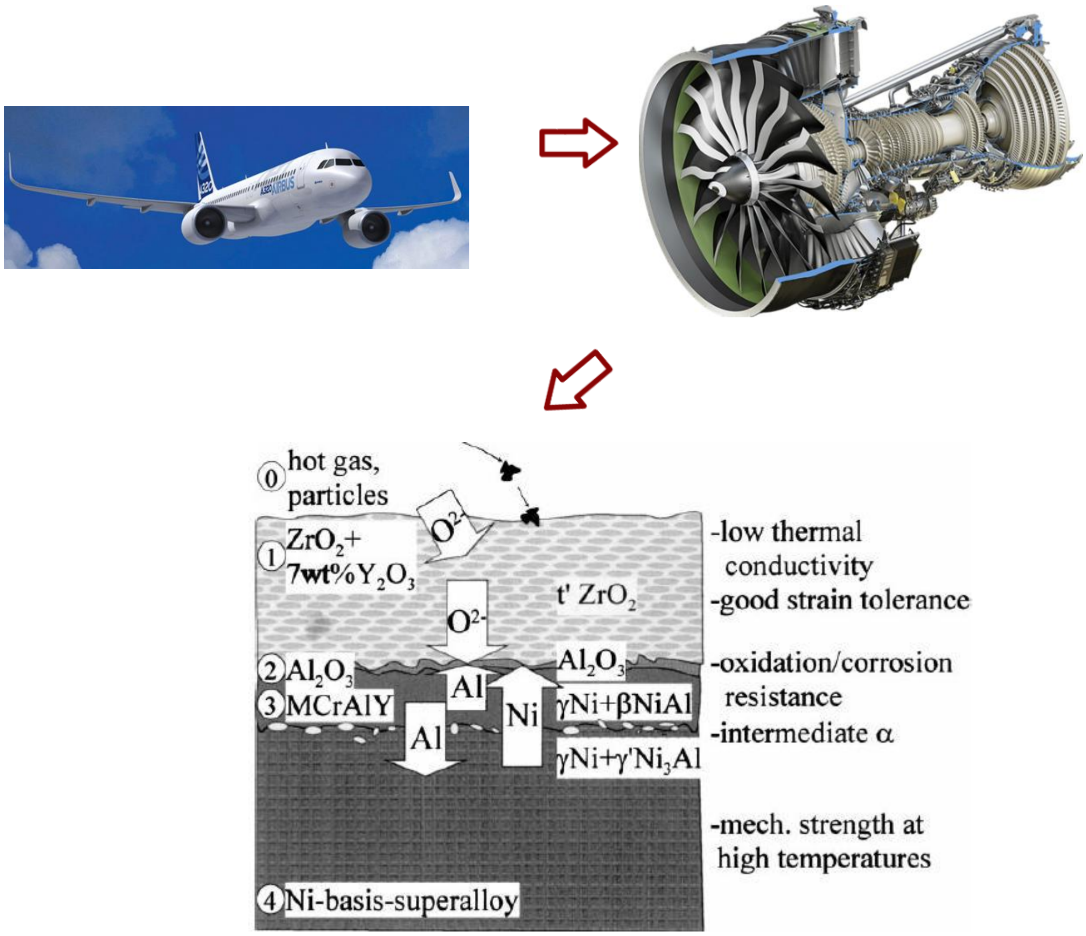
DFG Project SCHM 746/209-1

Modeling of fracture of functionally graded thermal barrier coatings under high heat fluxes

Functionally graded thermal barrier coatings (FGCs) are used in energy producing engineering and aircraft applications in the hottest parts of gas-turbine engines, and they protect the inner metallic parts from overheating and melting. Increasing the capacity of these engines requires increasing the operating temperature, and this relies on further improvement of FGCs with respect to improvement of temperature durability and fracture resistance. During manufacturing and service small defects appear in FGCs and then the cracks can initiate from these defects; the defects and cracks change both the thermal conductivity and fracture resistance of FGCs. In this context, a study of thermal fracture of functionally graded coatings on a homogeneous substrate (FGC/H) under the influence of high heat fluxes is of great demand.

The ***main goal*** of the project is to develop a computational semi-analytical model for the fracture analysis of functionally graded coatings on a homogeneous substrate FGC/H (with an additional oxidation layer between the coating and substrate which is formed as a result of oxidation processes) under thermal and mechanical loading. A number of new issues arising with increased temperatures and with high heat fluxes will be addressed, such as, thermal conductivity problems for FGC/H with pre-existing systems of interacting cracks; the cracks will be considered as partially thermal permeable due to the thermo-conductivity of gas inside the cracks. The material properties vary significantly with temperature and this will be accounted for in the model. The thermal and elastic properties of FGCs will be modeled from the point of view of its practical application to the specific problem of cracks in FGCs under thermal and mechanical loadings. The thermal problem and thermo-elastic (plastic) problems will be formulated by means of integral equations. The solution will be obtained numerically, using special quadrature formulae for the integrals. Besides, new approximate analytical solutions will be obtained for some special cases, e.g. for the interaction of thermally permeable cracks. This semi-analytical approach allows to correlate the structural material parameters (material gradation, crack parameters) and the thermo-mechanical loading parameters with the main fracture characteristics. The model in combination with a detailed parametric analysis can help to optimize the gradation of the FGCs and their structure in order to improve the fracture resistance of FGC/H systems operating under elevated temperatures. In this regard, potentially desirable thermal and mechanical properties of FGCs will be analyzed as well as available real material combinations for advanced thermal barrier coating applications.



Physical processes in TBCs (Clarke et al., 2012)

Fig. 1. An application of TBCs and physical processes in TBCs

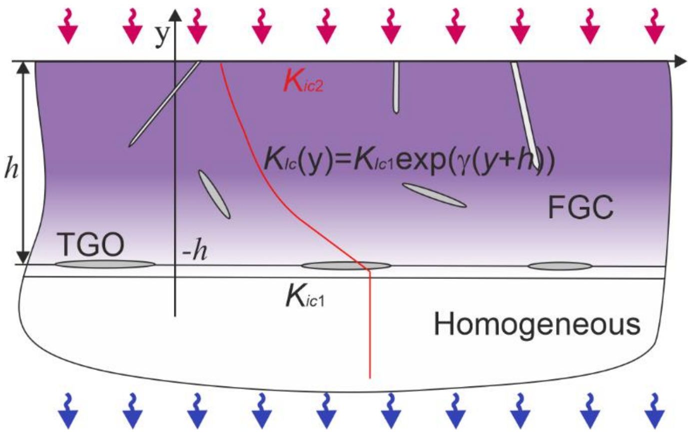


Fig. 2. FGC/H (with a thermally grown oxide layer, TGO) structure with a system of cracks; fracture toughness K_{Ic} varies from the ceramic on top to the metal as the substrate

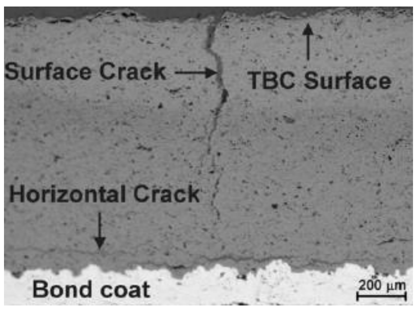


Fig. 3. Typical crack morphology for YSZ coatings resulting from laser thermal shock experiments (Gilbert et al., 2008)

Publications

[1] V. Petrova, S. Schmauder, Thermal fracture of a functionally graded/homogeneous bimaterial with a system of cracks, Theor. Appl. Fract. Mech. 55 (2011), 148-157

[2] V. Petrova, S. Schmauder, Mathematical modelling and thermal stress intensity factors evaluation for an interface crack in the presence of a system of cracks in functionally graded/ homogeneous bimaterials, Comput. Mater. Sci. 52 (2012), 171-177

[3] V. Petrova, S. Schmauder, FGM/homogeneous bimaterials with systems of cracks under thermo-mechanical loading: Analysis by fracture criteria, Eng. Fract. Mech. 130 (2014), 12-20

[4] V. Petrova, S. Schmauder, Crack closure effects in thermal fracture of functionally graded/homogeneous bimaterials with systems of cracks, ZAMM, Z. Angew. Math. Mech. 95 (10) (2015), 1027-1036

[5] V. Petrova, S. Schmauder, Modeling of thermomechanical fracture of functionally graded materials with respect to multiple cracks interaction, Phys. Mesomech. 20(3) (2017), 241-249

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