DFG Project SCHM 746/139-2

Analytical modeling and analysis of fracture of functionally graded coatings

Summary

Functionally graded coatings (FGCs) are applied in thermal, wear and corrosion barriers which are used in different fields, such as, nuclear energy, aerospace, engineering, etc. They are subjected to different thermal and mechanical loading and have to resist high temperature, wear and aggressive environments. However, cracks can initiate from initial defects or microcracks appear during manufacturing or service. Therefore, the study of fracture of FGC structures is important for a better understanding of the fracture resistance of graded coatings.

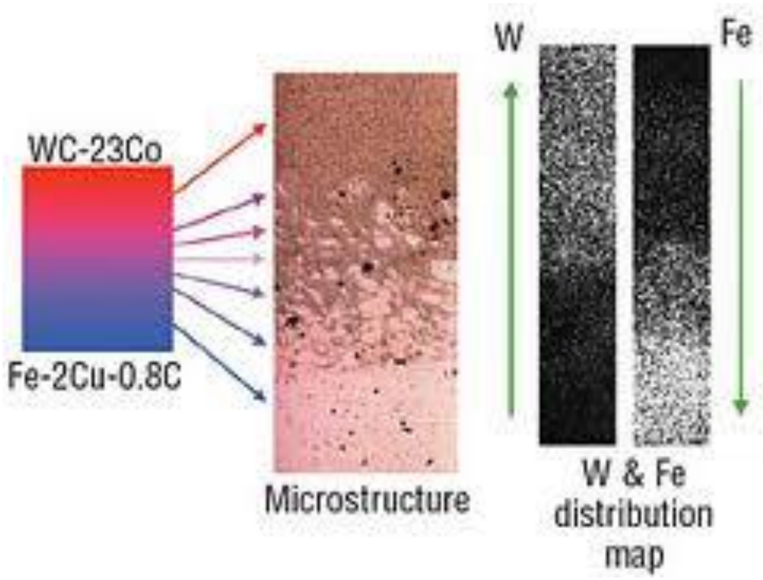

Fig. 1. Functionally graded material Fe(alloy)-WC/Co (industrialheating.com)

The primary objective of the project is to develop a computational semi-analytical model for the fracture analysis of functionally graded thermal barrier coatings on a homogeneous substrate (FGC/H) subjected to thermo-mechanical loading with plasticity incorporated in the model. The problem of fracture of FGC/H structures (semi-infinite isotropic medium) will be investigated under the influence of thermal and/or mechanical loads (e.g., a heat flux, residual thermal stresses caused by cooling-heating, tension). These problems reflect the most important cases which arise during the exploitation of FGC/H structures. The problem for FGC/H structures with pre-existing systems of cracks (edge cracks, interface cracks between the coating and substrate or internal cracks in the FGC) will be formulated in general by means of integral equations and with accounting for plastic zones (in the frame of the Dugdale model) at the cracks. Then, typical crack patterns for FGCs resulting from experiments available in the literature will be studied in detail on the basis of the derived model. The thermal and elastic properties of FGMs will be modeled from the point of view of its applicability to problems of cracks in FGCs under thermal and mechanical loadings. In order to simplify the problem relevant functional forms, such as, exponential or power law functions, will be used to simulate the non-homogeneous properties of FGCs.

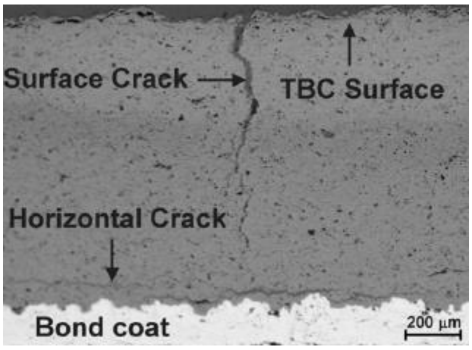

Fig. 2a Typical crack morphology for YSZ coating after thermal shock experiment (Gilbert et al 2008)

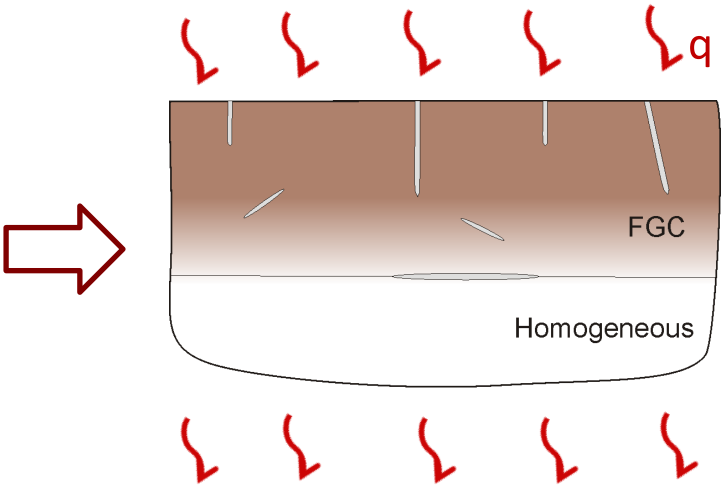

Fig. 2b The geometry of FGC/H structure with arbitrary located cracks

On the basis of this semi-analytical model the simulation of fracture processes in FGC/H structures will be performed for different real material combinations (ceramic/ ceramic, ceramic/ metal) and material property variations in the FGC. This simulation will provide knowledge for choosing appropriate material combinations and the gradation profile of FGCs in order to optimize the fracture resistance of the FGC/H structures.

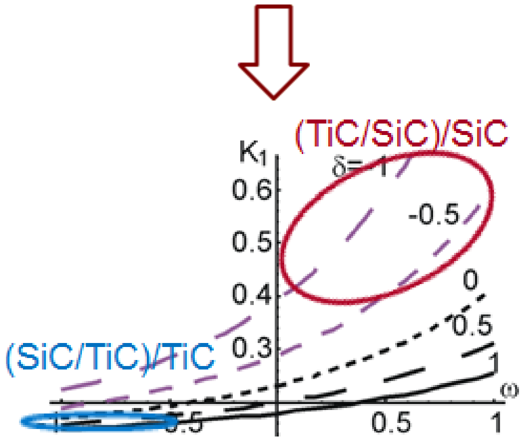

Fig. 2c Stress intensity factors Mode I K_1 at the interface crack tip (results for an infinite functionally graded/homogeneous bimaterail, Petrova, Schmauder, 2014)

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Publications

[1] Petrova V and Schmauder S 2012 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** 171–177

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

[3] Petrova V and Schmauder S 2015 Crack closure effects in thermal fracture of functionally graded/homogeneous bimaterials with systems of cracks *ZAMM* **195** 1027–36

[4] Petrova V and Schmauder S 2017 Modeling of thermo-mechanical fracture of FGMs with respect to multiple cracks interaction *Phys. Mesomech.* **20** 241–249