

# Modeling of Thermomechanical Fracture of Functionally Graded Materials with Respect to Multiple Crack Interaction

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**Abstract**—Different aspects of thermomechanical fracture of functionally graded materials (FGMs) are considered. Among them are the crack interaction problems in a functionally graded coating on a homogeneous substrate (FGM/H). The interaction between systems of edge cracks is investigated, as well as, how this mutual interaction influences the fracture process and the formation of crack patterns. The problem is formulated with respect to singular integral equations which are referred to the boundary equation methods. The FGM properties are modeled by exponential functions. The main fracture characteristics are calculated, namely, the stress intensity factors, the angles of deviation of the cracks from their initial propagation direction and the critical stresses when the crack starts to propagate. The last two characteristics are calculated using an appropriate fracture criterion. The problem contains different parameters, such as the geometry (location and orientation of cracks, their lengths, and the width of the FGM layer) and material parameters, i.e. the inhomogeneity parameters of elastic and thermal coefficients of the functionally graded material. The influence of these parameters on the thermo-mechanical fracture of FGM/H is investigated. As examples the following real material combinations are discussed: TiC/SiC,  $Al_2O_3/MoSi_2$ ,  $MoSi_2/SiC$ ,  $ZrO_2$ /nickel and  $ZrO_2$ /steel.

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**Keywords:** edge and internal cracking, thermal fracture, functionally graded coating, stress intensity factors, fracture criteria, fracture angle

## 1. INTRODUCTION

Functionally graded coatings (FGCs) are applied in thermal, wear and corrosion barriers which are used in different fields, such as, nuclear energy (e.g., nuclear reactor components), aerospace (e.g., rocket engine components, space plane body), engineering (e.g., turbine blade, engine components), energy conversion (e.g., thermoelectric generator, fuel cell) as well as many other applications [1–3]. 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 may 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.

Thermal fracture of FGCs is significantly affected by a complex crack interaction mechanism, e.g., inter-

acting cracks can enhance or suppress the propagation of each other. The crack patterns strongly depend on the microstructure of the materials and type of loading. Numerous experimental results (e.g., [4–6]) showed that when FGCs are subjected to thermal shock, multiple cracks often occur at the ceramic surface. The studies from laser thermal shock tests [7, 8] indicated that multiple surface precracks with a large density and short lengths reduce the crack driving force at the interface. At the same time very short precracks were most vulnerable to further surface cracking which in turn induced the interface crack. In [8] a functionally graded plate with an array of periodically spaced surface cracks of alternating lengths subjected to thermal shocks was considered. The crack morphology was described by the ratio of the length of the short cracks to that of the long cracks (initial crack length ratio) as well as by the crack spacing. The thermal properties

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