

Fracture of Functionally Graded Materials



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FRAGMENTATION OF FUNCTIONALLY GRADIENT MATERIALS
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Fracture Of Functionally Graded Materials

Paul Steinmann



Fracture Of Functionally Graded Materials:

Fracture of Functionally Graded Materials G.H. Paulino,2002-10-23 Scientific research on functionally graded materials FGM s looks at functions of gradients in materials comprising thermodynamic mechanical chemical optical electromagnetic and or biological aspects This collection of technical papers represents current research interests with regard to the fracture behaviour of FGM s The papers provide a balance between theoretical computational and experimental techniques It also indicates areas for increased development such as constraint effects full experimental characterization of engineering FGM s under static and dynamic loading development of fracture criteria with predictive capability multiphysics and multiscale failure considerations and connection of research with industrial applications *Fracture of Functionally Graded Materials* G. H. Paulino,2002 *Special Issue on Fracture of Functionally Graded Materials* Glaucio H. Paulino,2002 *Fracture Mechanics of Functionally Graded Materials* ,1996 Functionally graded materials are generally two phase composites with continuously varying volume fractions Used as coatings and interfacial zones they help to reduce mechanically and thermally induced stresses caused by the material property mismatch and to improve the bonding strength In this project some basic problems concerning fracture mechanics of graded materials are identified general analytical methods for solving the related crack problems are developed the singular behavior of the solutions for typical material nonhomogeneities is examined and solutions of some benchmark problems are obtained The results are intended to provide technical support for material scientists and engineers who are trying to develop methods for processing these materials and for design engineers who are interested in using them in technological applications Typical applications of functionally graded materials include thermal barrier coatings of high temperature components in gas turbines surface hardening for tribological protection and as interlayers in microelectronic and optoelectronic components The results found show that by eliminating the discontinuities in material property distributions the mathematical anomalies regarding the crack tip stress oscillations for the interface cracks and the nonsquare root singularities for cracks intersecting the interfaces are also eliminated From the viewpoint of fracture mechanics the importance of this result lies in the fact that in analyzing the components involving functionally graded materials one can use the existing crack tip finite element modeling developed for ordinary square root singularities and apply the energy balance based theories of conventional fracture mechanics **Fracture Behaviour of Functionally Graded Materials** Prabhakar Marur,2012-05-30 Functionally graded materials FGMs are special composites consisting of two constituent phases whose composition change continuously along one direction The gradual transition in material properties alleviates thermal mismatch problems experienced by clad and coated components The microstructure of FGM is usually heterogenous and the dominant failure mode of FGM is the crack initiation and propagation from the inclusions The interface crack problem is studied by examining the asymptotic behavior of stress and displacement fields around the crack in FGM and by comparing the results with known solutions for bimaterial systems The focus is on characterizing the

influence of material nonhomogeneity on the fracture parameters and determining the fracture strength of FGM under quasi static and dynamic loading Experimental Fracture Measurements of Functionally Graded Materials Ray Douglas Carpenter,2013 The primary objective of this research was to extend established fracture toughness testing methods to a new class of engineering materials known as functionally graded materials (FGMs). Secondary goals were to compare experimental results to those predicted by finite element models and to provide fracture test results as feedback toward optimizing processing parameters for the in-house synthesis of a MoSi₂/SiC FGM. Preliminary experiments were performed on commercially pure CP Ti and uniform axial tensile tests resulted in mechanical property data including yield strength 268 MPa, ultimate tensile strength 470 MPa and Young's modulus 110 GPa. Results from 3-point bending fracture experiments on CP Ti demonstrated rising R-curve behavior and experimentally determined J_Q fracture toughness values ranged between 153 N/mm and 254 N/mm. Similar experimental protocols were used for fracture experiments on a 7-layered Ti/TiB FGM material obtained from Cercom in Vista, California. A novel technique for pre-cracking in reverse 4-point bending was developed for this ductile/brittle FGM material. Fracture test results exhibited rising R-curve behavior and estimated J_Q fracture toughness values ranged from 0.49 N/mm to 2.63 N/mm. A 5-layered MoSi₂/SiC FGM was synthesized using spark plasma sintering (SPS). Samples of this material were fracture tested and the results again exhibited a rising R-curve with K_{IC} fracture toughness values ranging from 2.7 MPa·m^{1/2} to 6.0 MPa·m^{1/2}. Finite Element Models predicted rising R-curve behavior for both of the FGM materials tested. Model results were in close agreement for the brittle MoSi₂/SiC FGM. For the relatively more ductile Ti/TiB material, results were in close agreement at short crack lengths but diverged at longer crack lengths because the models accounted for fracture toughening mechanisms at the crack tip but not those acting in the crack wake. The Mixed Mode Fracture of Functionally Graded Materials Xiang Long,2003 **Fatigue Fracture of**

Functionally Graded Materials Under Elastic-Plastic Loading Conditions Using Extended Finite Element Method Somanātha Bhaṭṭācārya,2018 In this chapter, extended finite element method (XFEM) has been used to simulate the fatigue crack growth problems in functionally graded material (FGM) in the presence of hole, inclusion, and minor crack under elastic and plastic conditions. The fatigue crack growth analysis of alloy/ceramic FGMs/alloy and equivalent composite is done by XFEM in the presence of multiple discontinuities under mode I mechanical load. The validity of linear elastic fracture mechanics (LEFM) theory is limited to brittle materials. Therefore, the elastic/plastic fracture mechanics (EPFM) theory needs to be utilized to characterize the plastic behavior of the material. A generalized Ramberg-Osgood material model has been used to model the stress-strain behavior of the material. Plasticity has been checked by Von Mises Yield criteria. J-integral has been used to calculate the SIF. Crack growth direction is determined by maximum principal stress criteria.

Cohesive Modeling of Fracture in Functionally Graded Materials Soma Sekhar Venkata Kandula,2004 *The Role of Interfaces in the Fracture of Functionally Graded Materials*,2005 The research focuses on establishing conditions when

interfaces between interlayers are important in governing fracture processes in composites with graded compositions A theoretical framework is sought that could ultimately quantify the role of interfaces when their presence dominates behavior Initial work is driven towards establishing general trends Experimentally multilayer composites have been fabricated by several techniques that aim at modifying interface characteristics The competition between fracture at notches of particular depth parallel to the interface and interface fracture is examined A numerical model is being constructed to obtain crack tip and interface free edge stress fields to better understand experimental trends Also models are being devised to examine how the presence of the interface modifies the stress field of an edge crack parallel to the interface Experiments in which cracks are extended from notches placed near interfaces have been conducted utilizing optical moir interferometry conducted at INEEL The crack driving force and mode mixity as a function of type of interface and proximity to interface are being determined

Optimizing Functionally Graded Materials to Resist Failure Under Dynamic Loadings, 2002 After three years of the project many of the proposed research topics have been completed and manuscripts were submitted for publication First for the dynamic crack propagation within functionally graded materials FGMs a novel fracture criterion was introduced It is based on energy concept and controls crack growth rate and associated plastic dissipation flow This model was implemented in dynamic failure analysis to investigate crack propagation within elastic plastic graded materials The new procedure was also implemented for the impact of graded protective layer The results confirmed the importance of modeling of cracking revealed the effects of compositional gradation through thickness In a subsequent analysis a procedure that utilizes an inverse analysis was developed to measure key fracture parameters These parameters are difficult to measure with conventional means Third in collaboration with materials science group material parameters of actual FGM were measured using the indentation and inverse method The specimens were thermal barrier coatings fabricated with zirconia and NiCrAlY This type of advanced scheme to post process experimental data is essential for obtaining properties of complex systems In addition preliminary fracture tests were conducted for thicker FGMs to determine its fracture behavior

Functionally Graded Materials Nathan J. Reynolds, 2012 Functionally graded materials FGMs are composites with gradually varying material content This book presents current research in the study of FGMs including the fracture and contact problems of functionally graded materials FGMs obtained by combustion synthesis techniques thermoplastic simulation of FGMs the thermal buckling analysis of functionally graded arbitrary straight sided quadrilateral plates the mechanical response of metal ceramic FGMs and simulation of quasi static crack propagation in FGMs *Evaluation of Crack Tip Fields and Fracture Parameters in Functionally Graded Materials* Carl-Ernst Rousseau, 2000 **Fracture**

Behaviour of Functionally Graded Materials Prabhakar R. Marur, 1999 Comprehensive Structural Integrity Ian Milne, R. O. Ritchie, B.L. Karihaloo, 2003-07-25 The aim of this major reference work is to provide a first point of entry to the literature for the researchers in any field relating to structural integrity in the form of a definitive research reference tool

which links the various sub disciplines that comprise the whole of structural integrity Special emphasis will be given to the interaction between mechanics and materials and structural integrity applications Because of the interdisciplinary and applied nature of the work it will be of interest to mechanical engineers and materials scientists from both academic and industrial backgrounds including bioengineering interface engineering and nanotechnology The scope of this work encompasses but is not restricted to fracture mechanics fatigue creep materials dynamics environmental degradation numerical methods failure mechanisms and damage mechanics interfacial fracture and nano technology structural analysis surface behaviour and heart valves The structures under consideration include pressure vessels and piping off shore structures gas installations and pipelines chemical plants aircraft railways bridges plates and shells electronic circuits interfaces nanotechnology artificial organs biomaterial prostheses cast structures mining and more Case studies will form an integral part of the work

Proceedings of the ASME Pressure Vessels and Piping Conference--2006: Materials and fabrication ,2007 **Advances in Mechanical and Industrial Engineering** Muhamad Mat Noor, Hoang Anh Tuan, Purna Chandra Mishra, 2022-07-01 The International Conference on ADVANCES IN MECHANICAL AND INDUSTRIAL ENGINEERING ICAMIE 2020 aims to solidify knowledge of sister branches of research on Mechanical Engineering applied to Industry Health Sectors Energy Sector Agricultural Sector etc Mechanical Engineering is a core branch of Engineering with its own peculiarities and very diverse areas of action ICAMIE 2020 will widen the scope of bringing together innovators researchers and industries under a common goal creating evaluating implementing and benefiting from innovations in the areas of engineering applications It will thus support innovative projects and bring benefits to all involved participants Participants from Universities Institutes Associations Companies Consultancies R Ds etc from India and abroad will be invited The aim of ICAMIE 2020 is to be one of the most influential channels for transferring innovative ideas from academia to industry thereby these ideas may start to generate consultancy projects and collaborations The novel idea to conduct this type of conference is to discuss social and industrial problems and try to find a way to resolve their solutions by advanced methods and methodologies like soft computing techniques Multi criteria decision making algorithms Internet of Things technologies Artificial intelligence Robotics etc ICAMIE 2020 will be successful being the multidisciplinary conference of its first kind and aims to be one of the most influential channels transferring innovative ideas from academia to industry thereby these ideas may start to generate consultancy projects and collaborations

Method for Determining Fracture Parameters of Functionally Graded Materials Hongwei Li, 1998 *IUTAM Symposium on Progress in the Theory and Numerics of Configurational Mechanics* Paul Steinmann, 2009-08-03 Configurational mechanics has attracted quite a bit of attention from various search elds over the recent years decades Having been regarded in its infancy of the early years as a somewhat obscure and almost mystic eld of research that could only be understood by a happy few of insiders with a pronounced theoretical inc nation configurational mechanics has developed by now into a versatile tool that can be applied to

a variety of problems Since the seminal works of Eshelby a general notion of configurational mechanics has been developed and has successfully been applied to many problems involving various types of defects in continuous media The most prominent application is certainly the use of configurational forces in fracture mechanics However as configurational mechanics is related to arbitrary material inhomogeneities it has also very successfully been applied to many materials science and engineering problems such as phase transitions and inelastic deformations Also the modeling of materials with microstructure evolution is an important field in which configurational mechanics can provide a better understanding of processes going on within the material Besides these mechanically physically and chemically motivated applications ideas from configurational mechanics are now increasingly applied within computational mechanics

Fatigue Crack Propagation in Functionally Graded Materials Brett Kenneth Hauber, 2009 Interest in the development and application of functionally graded materials FGM has increased in recent years leading to their limited use in a number of commercial and military products More recently interest in the use of FGMs in aircraft fuselage structures as integrated thermal protection systems has also begun to develop However our limited ability to predict the nucleation and fatigue propagation of cracks in these materials limits the application of FGMs to non fracture critical structures reducing the potential benefits of their incorporation A first step toward addressing this technology gap is to evaluate whether linear elastic fracture mechanics methods appropriately modified to account for material non homogeneity can be used to predict fatigue crack propagation in an arbitrarily graded metal ceramic FGM This dissertation documents new developments for characterization and modeling of fatigue crack propagation in FGMs Unique precracking and characterization methods and a Paris equation dependent upon stress intensity and material phase volume fraction and gradients are developed for FGMs Hybrid numerical experiments are used to develop and verify a multivariable regression MVR method for identifying the effective crack tip coordinates and accurately recovering stress intensity from 2 D crack tip displacement field measurements in FGMs Numerical and experimental results for Ti TiB FGM specimens validate the MVR method for recovery of stress intensity in FGMs when allowing for the presence of manufacturing induced residual stresses Predicted fatigue crack propagation rates also compare favorably with experimental results but are limited in accuracy by the effects of residual stresses Residual stresses modify crack tip stress intensities and their effects are only accountable here by using the MVR recovered stress intensities The results suggest that a Paris equation including material gradients as independent variables is viable However an accurate means of accounting for residual stresses in arbitrary FGM forms must be developed if linear elastic fracture mechanics methods are to be used effectively otherwise excessive experimental characterization of fatigue crack propagation properties would be required

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