Engineering Fracture Mechanics 116 (2014) 31–40

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Weight functions for multiple edge cracks in a coating

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ARTICLE INFO

Article history:
Received 25 May 2013
Received in revised form 10 September 2013
Accepted 8 December 2013

Keywords:
Weight function
Finite element analysis
Fracture mechanics
Stress intensity factor

ABSTRACT

In this paper, the weight function for multiple edge cracks located in a segmented coating has been investigated. The stress intensity factors (SIFs) for two reference loading configurations were computed via the finite element (FE) method. Dimensional analysis was used to reveal the scaling relationships between the weight function and some important parameters such as dimensionless crack depth, crack spacing and material constants. The sensitivity analyses were carried out through a parametric study and the results were presented in graphical forms. A simple approach for fitting the computational results was given and the fitting formulas for weight functions were obtained.

1. Introduction

In many practical applications, protective coatings are usually deposited onto the surface of an underlying substrate to improve a certain surface properties, for example hardness, corrosion and thermal resistance [1]. These protective coatings in most cases work in severe environments. If the magnitude of mechanical and/or thermal load is high enough, a single or several cracks may be caused within the coating. When, under cyclic loading, the crack further extends and reaches the interface, delamination along the interface usually occur as a consequence, which would result in the final removal of coating [1,2]. Therefore, it is of great significance to delay or avoid such failure and hence to retain the integrity of the coating-substrate system.

From the point view of fracture mechanics, this requires the calculation of the driving force for crack propagation, in which the stress intensity factor (SIF) needs to be quantified for given loads as a function of crack depth and material constants. By correlating the computed SIF with the fracture toughness of materials, one can predict the crack growth rate and fatigue life of components. Thus, a large amount of research has been focused on using different methods to determine the SIFs for various crack geometries and load cases [3–5]. In practice, the distribution of stress in coating is sometimes highly inhomogeneous (e.g. in case of thermal loading problems), which makes the evaluation of SIF difficult or inefficient. Under such circumstances the weight function method provides a powerful and cheap means to do this work.

It is well known that the weight function is a unique property of geometry. Once the weight function for a particular cracked body is determined, the SIF for any stress distribution can be calculated by implementing a simple quadrature procedure [6]. For homogeneous materials, the weight functions have been derived for a wide variety of crack geometries [7–11]. To name a few, Petroski and Achenbach [7] employed a simple representation for the crack-face displacement to compute a weight function solely from the stress intensity factors for a reference loading configuration. The accuracy of their procedure was improved by Fett and Mattheck [8] by expanding the crack opening displacement field in a power series. A method of deriving weight functions for cracks subjected to mode I loading was discussed by Shen and Glinka [9]. Wu [10]

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0013-7944/$ - see front matter
http://dx.doi.org/10.1016/j.engfracmech.2013.12.012

Nomenclature

a	crack depth
E_1, E_2	Young's modulus
F_P, F_σ	dimensionless shape factors
$f(z)$	the formula for a decoupled fitting method
G	shear modulus
$h(x,a)$	weight function
K, K_{IP}, $K_{I\sigma}$, K''_{IP}	stress intensity factor
l	crack spacing
P	a single pair of force per thickness loaded at the crack mouth $x = 0$
r_q	distance from quarter point to the crack tip
t	thickness of coating
u_y^q	y-component displacement for the quarter point on the free face of the crack
μ_1, μ_2	Poisson's ratio
σ	constant stress loaded at the crack-face
α, β	Dundurs' elastic mismatch parameters

presented approximate weight functions for cracks in finite bodies with or without prescribed displacement boundaries. A closed-form weight function was derived by Oliveira and Wu [11] for one and two internal and external axial cracks in hollow cylinders subjected to thermal shock.

Compared to the case of homogeneous materials, the similar study concerning the layered composite materials seems relatively limited. Fett et al. [12] developed weight functions for a single edge crack within the thin surface layer. However, in an actually encountered coating/substrate system, multiple cracking in coating is a common phenomenon (especially in case of thermal shock) [13]. More importantly, recently the multiple cracks perpendicular to the interface were intentionally generated in the coating to alleviate the misfit strain between the coating and substrate [14–18]. Both experimental observations and theoretical predictions [14–20] suggested that the segmented coating has higher crack growth resistance than the intact counterpart. This new concept coating and multiple cracks are usually called segmented coating and segmentation cracks, respectively. Some typical segmented coating examples are shown in Fig. 1, for which the details of preparation process can be found elsewhere [15,17]. However, to the best knowledge of the authors, no previous work has been done to address the weight function for multiple cracks located in a segmented coating. Therefore, it is the main objective of the present paper.

This paper is organized as follows. In Section 2, the computational model of the segmented coating/substrate system is established and some assumptions are made to simply the analysis. The procedure of three-parameter approach is outlined to determine the weight functions for multiple edge cracks in a segmented coating. Dimensional analysis is carried out in Section 3 to reveal the scaling relationship between the weight function and a certain material and geometrical parameters. Section 4 addresses the finite element (FE) model to calculate SIFs for two reference loading conditions. In Section 5, the numerical results for weight functions are obtained for a specific coating/substrate system and sensitivity analysis is carried

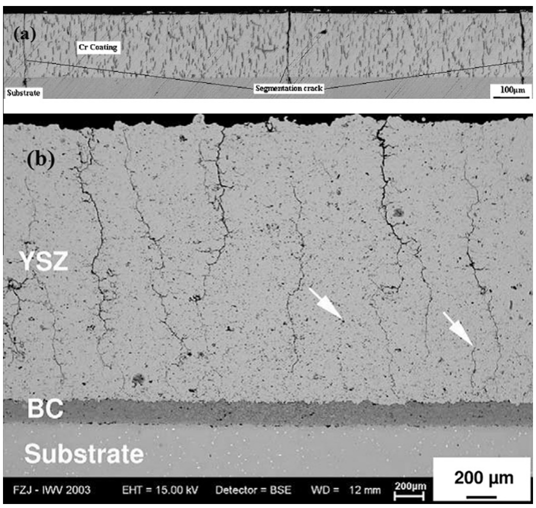

Fig. 1. The segmented coating formed by (a) hybrid laser pre-quenching plus post-electroplation [19] and (b) atmospheric plasma spraying [17].