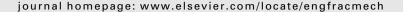
FISEVIER

Contents lists available at SciVerse ScienceDirect

## **Engineering Fracture Mechanics**





# Stress intensity factor analysis of a three-dimensional interface crack between dissimilar anisotropic materials under thermal stress

Masaki Nagai, Toru Ikeda\*, Noriyuki Miyazaki

Department of Mechanical Engineering and Science, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

#### ARTICLE INFO

Article history: Received 15 June 2010 Received in revised form 2 March 2012 Accepted 9 April 2012

Keywords:
Stress intensity factor
Interfacial crack
Anisotropic material
Stroh formalism
M<sub>1</sub>-integral
Moving least-square approximation
Thermal stress

#### ABSTRACT

A numerical method for evaluating the stress intensity factors (SIFs) of a three-dimensional interface crack between dissimilar anisotropic materials subjected to thermal and mechanical stresses is proposed. The  $M_1$ -integral method was applied to an interfacial crack between three-dimensional anisotropic bimaterials under thermal stress. The moving least square approximation was utilized to calculate the value of the  $M_1$ -integral. The  $M_1$ -integral in conjunction with the moving least square approximation can be used to calculate the SIFs from nodal displacements obtained by finite element analysis. SIF analyses were performed for double edge cracks in jointed dissimilar isotropic semi-infinite plates subjected to thermal load. Excellent agreement was achieved between the numerical results obtained by the present method and the exact solution. In addition, we computed the SIFs of an external circular interfacial crack in jointed dissimilar anisotropic solids under thermal stress and showed the distributions of SIFs along the crack front. The distribution of stress and the crack opening displacement obtained by the asymptotic solution using the computed SIFs were compared with those obtained by the finite element analysis with fine mesh. They were almost identical to each other, except for the minor component of SIFs that is much smaller than the major component of SIFs. These results indirectly demonstrate the accuracy of the obtained SIFs.

© 2012 Elsevier Ltd. All rights reserved.

#### 1. Introduction

Electronic devices and micro-electro-mechanical systems (MEMSs) are composed of many different materials and have many interfaces. The thermal stress resulting from the mismatch of the coefficient of thermal expansion between different materials often causes delamination along the interface. The delamination of the interface between different materials is one of the main causes of the malfunction or the reliability degradation of electronic devices.

The stress intensity factors (SIFs) of an interface crack are important for evaluating the fracture at interfaces. Gotoh [1], Clements [2], Willis [3], Bassani and Qu [4], and Wu [5] have investigated the stress field around interfacial cracks between dissimilar anisotropic materials. Hwu [6] has proposed an asymptotic solution for stress around an interface crack between dissimilar anisotropic materials using the Stroh formalism [7], and defined the SIFs of an interface crack. Few analytical solutions of the SIFs of interface cracks between dissimilar anisotropic materials have been proposed due to the mathematical difficulty. The energy release rate of an interfacial crack can be obtained using an energy method such as the virtual crack extension method, the *J*-integral method or the crack closure integral method. Sun and Qian [8] and Ikeda et al. [9] proposed

<sup>\*</sup> Corresponding author. Tel.: +81 75 753 5215; fax: +81 75 753 5719. E-mail address: ikeda@solid.me.kyoto-u.ac.jp (T. Ikeda).

```
Nomenclatures
A and B Stroh's eigenvectors matrices of a material
          elastic stiffness tensors
C_{ijks}
D and W bi-materials constant matrices
          bi-materials constant matrix
E
          bi-materials constant tensors
E_{ii}
f
          function vector
G
          energy release rate
          I-integral
              stress intensity factors
       K_I
L and S
          Barnett-Lothe tensors
l_k
          characteristic length
L_c
          small segment along a crack front
\mathbf{M}^*
          bi-materials matrix
          unit normal vector on the boundary
N_1 and N_3 functions of elastic constants
          linear basis
q_k (k = 1, 2, 3) test functions
          distance from the crack-tip
S_o and S_t surfaces of Tubular domain V
          boundary tractions
t_i
          displacement vector
u_i (i = 1, 2, 3) displacements
          tubular domain surrounding the crack segment
W^e
          elastic strain energy density
          weight function
x_i (i = 1, 2, 3) rectangular coordinate system
\alpha_{ii} (i = 1, 2, 3; j = 1, 2,3) coefficients of thermal expansion tensors
\delta_{\alpha} (\alpha = 1, 2, 3) eigenvalues
          oscillation index
          virtual crack advance
η
          shape function
          eigenvector matrix
\lambda_i (i = 1, 2, 3) eignevectors
\varepsilon_{ij} (i = 1, 2, 3; j = 1, 2,3) elastic strain tensors
          arbitrary contour pass on the x_1 - x_2 plane enclosing the crack tip
\mu_k
          shear modulus
\sigma_{ij} (i = 1, 2, 3; j = 1, 2, 3) stress tensor
          temperature
\xi_k (k = 1, 2, 3) crack advanced vectors
          area surrounded by the contour pass \Gamma
\Omega
ψ
          stress function
```

numerical methods to calculate the mode-separated SIFs of a two-dimensional interfacial crack between dissimilar anisotropic materials subjected to mechanical loads. Nagai et al. [10] and Nomura et al. [11] presented computational methods to determine the SIFs of a two-dimensional interfacial crack and corner between dissimilar anisotropic solids under thermal stress, respectively. Nagai et al. [12] proposed the modified  $M_1$ -integral method, which is a combination of the J-integral method and the superposition method, to obtain the SIFs of a three-dimensional crack between anisotropic bimaterials. However, there is still no numerical method based on the energy method to determine the SIFs of a three-dimensional interfacial crack between dissimilar anisotropic materials subjected to thermal stress.

We extended the  $M_1$ -integral to determine the SIFs of a three-dimensional interface crack between dissimilar anisotropic materials under thermal stress. In this method, the moving least-square approximation is employed to calculate the value of the  $M_1$ -integral, and the stress and strain in the  $M_1$ -integral are approximated from the nodal displacements obtained by the finite element analysis. Therefore, in the computation of the  $M_1$ -integral, this method does not need to extract any elemental data from the finite element analysis. The  $M_1$ -integral method presented here can calculate the SIFs easily and requires less time for the data preparation than other procedures.

### Download English Version:

# https://daneshyari.com/en/article/775275

Download Persian Version:

https://daneshyari.com/article/775275

<u>Daneshyari.com</u>