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Cracking characteristics of a moving screw dislocation near an interfacial crack in two dissimilar orthotropic media

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ABSTRACT

Investigated is the problem of the interaction between a moving screw dislocation and an interfacial crack in two orthotropic materials. The closed form solutions of this problem is obtained by using Riemann-Schwarz's symmetry principle integrated and the analysis singularity of complex functions. The stress intensity factors and the strain energy density factors have been investigated, the angle of crack initiation has been found. The results show that the shielding effect of dislocation for crack tips decreases with the increase of the distance between dislocation and crack tip and tends to zero at infinite, in additional, larger dislocation velocity leads to shielding effect waning. The normalized minimum SEDF increases with decrease of the velocity of dislocation and the distance between dislocation and crack tip and the ratio of shear modulus. The presented solutions contain previously known results as the special cases.

1. Introduction

The interaction between dislocations of heterogeneous material and interfacial defects of multiphase media is very important in studying the mechanical behavior of crystal materials. The study of dislocations interacting with interfacial cracks in the mechanics and materials science is motivated by the need of a better understanding of the mechanism of strengthening and toughening of materials. Many researchers have studied the effect of dislocations [1,2]. But under most dynamic conditions, the static solutions cannot replace the dynamic solutions. The solution of interaction between the moving dislocation and perfect interface in two dissimilar isotropic media can be found in [3]. The solution of displacement field of moving dislocation in anisotropic material has been obtained in [4,5]. Recently, the image force on moving dislocation has been investigated in [6]. The problem of a moving screw dislocation near a surface crack using dislocation modeling has been investigated in [7]. The problem of a dislocation starting from rest and moving with constant velocity in a general anisotropic solid was considered in [8]. A moving screw dislocation in a transversely isotropic piezoelectric was dealt with in [9]. An explicated closed form solution for a moving dislocation in an anisotropic piezoelectric solid has been presented in [10]. The problem of a horizontal moving screw dislocation near interfacial crack in two dissimilar anisotropic media has been discussed in [11]. The solution of electro-elastic fields of a moving screw dislocation near a circular cavity has been obtained in [12].

The investigation of fracture initiation and propagation is very important for the development of the theory of fracture mechanics. Many achievements have obtained successively, the problem of initiation and growth characterization of corner cracks near circular hole has been discussed in [13]. The problem of micro/macro crack growth due to creep-fatigue dependency on time-temperature material behavior has been investigated in [14]. But the investigation of the influence of the dislocation movement effect on crack initiation is not abundant yet. This work considers the problem of a moving screw dislocation near an interfacial crack in two dissimilar orthotropic media. A new solution has been obtained.

The elastic interaction between a moving screw dislocation and an interfacial crack in two orthotropic media is solved. The closed form solution of this problem is obtained by using Riemann-Schwarz's symmetry principle integrated and the analysis singularity of complex functions. The stress intensity factors and strain energy density factor has been discussed, the angle of crack initiation has been found. The influence of the velocity of dislocation and the distance between dislocation and crack tip and the ratio of shear modulus on minimum SEDF has been investigated. The presented solutions contain previously known results as the special cases.

2. Basic formulation and problem description

For an orthotropic material with three mutually perpendicular symmetry planes, the anti-plane deformation can be decoupled from the in-plane deformation, then there are only nontrivial

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displacement u_3, stresses σ_{13} and σ_{23} in the Cartesian coordinates. All components are only functions of variables x_1 and x_2. The mechanical constitutive equations can be expressed as

$$\sigma_{13} = G_{13}u_{3,1}, \quad \sigma_{23} = G_{23}u_{3,2} \tag{1}$$

where G_{13} and G_{23} are elastic constants, $u_{i,j} = \frac{\partial u_i}{\partial x_j}$.

In the absence of body forces, the governing equation for an transversely isotropic elastic medium is

$$\sigma_{13,1} + \sigma_{23,2} = \rho\ddot{u}_3 \tag{2}$$

where $\ddot{u}_3 = \partial^2 u_3/\partial t^2$, and ρ is the mass density of the medium. Substituting Eq. (1) into (2) will yield

$$G_{13}\frac{\partial^2 u_3}{\partial x_1^2} + G_{23}\frac{\partial^2 u_3}{\partial x_2^2} = \rho\ddot{u}_3 \tag{3}$$

The problem to consider is as follows. Referring to Fig. 1, let orthotropic medium I occupy the upper half-plane, while orthotropic medium II occupy the lower half-plane. An interfacial crack lie along a part L of the interface between two materials, where L is a crack segment L with the end points $-a$ and a. The crack surfaces are considered traction-free. L' is the remainder of the interface which two dissimilar materials are perfectly bonded. Without loss of generality, at time $t = 0$, assume the transient location of the screw dislocation z_0 (here, z_0 is a complex variable which will be adopt in the following text and $z_0 = x_{10} + ix_{20} = re^{i\varphi}$, $x_{20} > 0$) in the upper half-plane. The dislocation is characterized by Burgers vector b, and moving with uniformly subsonic velocity v in the horizontal direction.

The boundary conditions of displacements and stresses for the present problem can be expressed as follows

$$\sigma^+_{23(1)} = \sigma^-_{23(2)} \quad \text{on } L' \tag{4}$$

$$u^+_{3(1)} = u^-_{3(2)} \quad \text{on } L' \tag{5}$$

$$\sigma^+_{23(1)} = \sigma^-_{23(2)} = 0 \quad \text{on } L \tag{6}$$

where the subscripts 1 and 2 denote the quantities defined in the upper and lower half-planes, with the superscripts + and − used to denoting the boundary values of the physical quantities as they approached from the upper and lower half-planes, respectively. From Eq. (5), there results

$$u^+_{3,1(1)} = u^-_{3,1(2)} \quad \text{on } L' \tag{7}$$

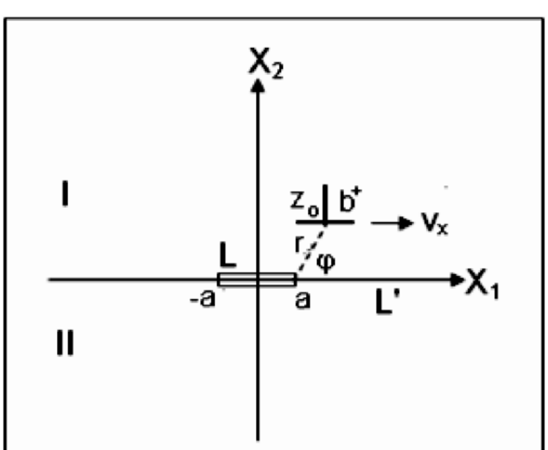

Fig. 1. A moving screw dislocation near an interfacial crack in two orthotropic media.

From Eq. (6), it is found that

$$\sigma^+_{23(1)} - \sigma^-_{23(2)} = 0 \quad \text{on } L \tag{8}$$

$$\sigma^+_{23(1)} + \sigma^-_{23(2)} = 0 \quad \text{on } L \tag{9}$$

In addition, assume that the loads at infinity are zero.

3. General solution of problem

By a coordinate translation, introduce a new coordinate system (x, y) as

$$x = x_1 - v_x t, \quad y = x_2 \tag{10}$$

then Eq. (3) can be transformed to the following equation in the new coordinate system

$$\overline{G_{13}}\frac{\partial^2 u_3}{\partial x^2} + G_{23}\frac{\partial^2 u_3}{\partial y^2} = 0 \tag{11}$$

with $\overline{G_{13}} = G_{13} - \rho v_x^2$.

The secular equation of Eq. (11) can be expressed as

$$\overline{G_{13}}dy^2 + G_{23}dx^2 = 0 \tag{12}$$

the result of Eq. (11) is as follow

$$x \pm i\sqrt{\frac{\overline{G_{13}}}{G_{23}}}y = c \tag{13}$$

the eigenvalue is found to be

$$\xi = x, \quad \eta = \sqrt{\frac{\overline{G_{13}}}{G_{23}}}y \tag{14}$$

We denote that

$$\zeta = \xi + i\eta \tag{15}$$

Eq. (11) can be expressed as

$$\overline{G_{13}}\frac{\partial^2 u_3(\zeta)}{\partial \xi^2} + \overline{G_{13}}\frac{\partial^2 u_3(\zeta)}{\partial \eta^2} = 0 \tag{16}$$

The general solution of Eq. (16) can be expressed in terms of a single holomorphic function $\varphi(\xi)$ as follows

$$u_3 = \frac{1}{2}[\varphi(\zeta) + \overline{\varphi(\zeta)}] \tag{17}$$

Then, the displacements(derivative) and stresses of the upper and lower half-planes can be written, respectively, in terms of a complex potential function of variables ζ_k $(k = 1,2)$ as

$$u_{3,1} = \frac{1}{2}[\Phi_k(\zeta_k) + \overline{\Phi_k(\zeta_k)}] \tag{18}$$

$$\sigma_{13(k)} = \frac{G_{13}}{2}[\Phi_k(\zeta_k) + \overline{\Phi_k(\zeta_k)}] \tag{19}$$

$$\sigma_{23(k)} = \frac{\beta_k[\Phi_k(\zeta_k) - \overline{\Phi_k(\zeta_k)}]}{2i} \tag{20}$$

where $\beta = -\sqrt{G_{23}\overline{G_{13}}}$, $\Phi(\zeta) = \varphi'(\zeta)$ and the superscript prime stands for derivative with respect to ζ_k.

Referring to the works in [15,16], the generalized analytic functions $\Phi_1(\zeta_1)$ and $\Phi_2(\zeta_2)$ in the upper and lower half-planes, respectively under consideration can be written as

$$\Phi_1(\zeta_1) = \frac{b}{2\pi i}\cdot\frac{1}{\zeta_1 - \zeta_0} + \Phi_{10}(\zeta_1) \quad \zeta_1 \in S^+ \tag{21}$$

$$\Phi_2(\zeta_2) = \Phi_{20}(\zeta_2) \quad \zeta_1 \in S^- \tag{22}$$

Noting that the boundary line is x-axis, the solution procedure of the function with argument ζ_k $(k = 1, 2)$ can be translated into the corresponding function with argument $z = x + iy$.