Engineering Fracture Mechanics 102 (2013) 15–31

Contents lists available at SciVerse ScienceDirect

Engineering Fracture Mechanics

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

Three-dimensional singular antiplane shear stress fields at the fronts of interfacial crack/anticrack/contact type discontinuities in tricrystal anisotropic plates

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ARTICLE INFO

Article history:
Received 29 August 2012
Accepted 28 January 2013

Keywords:
Three dimensional
Stress singularity
Tricrystal anisotropic plate
Monoclinic
Crack
Anticrack

ABSTRACT

A recently developed eigenfunction expansion technique, based in part on separation of the thickness-variable and partly utilizing a modified Frobenius type series expansion in conjunction with the Eshelby–Stroh formalism, is employed to derive three-dimensional singular stress fields in the vicinity of crack/anticrack/junction front of an infinite tricrystal plate, made of monoclinic/hexagonal/orthorhombic/cubic phases, of finite thickness and subjected to far-field antiplane shear loading. Such tricrystals are used in solar cells and superconductivity application among others. Crack/anticrack-face boundary and/or interface contact conditions and those that are prescribed on the top and bottom (free or fixed) surfaces of the tri-crystal plate are exactly satisfied. Five different through-thickness boundary conditions are considered: (i) slit crack, (ii) anticrack or perfectly bonded rigid inclusion, (iii) tri-crystal junction, and (iv and v) rigid inclusion located alongside a crack. Numerical results pertaining to the variation of the mode III order of stress singularity with various wedge aperture angles of the material 1 (e.g., scatterer in a solar cell), are also presented. Finally, results, pertaining to the through-thickness variations of mode III stress intensity factors or stress singularity coefficients for symmetric exponentially growing distributed load and their skew-symmetric counterparts that also satisfy the boundary conditions on the top and bottom surfaces of the tricrystal plate under investigation, also form an important part of the present investigation.

1. Introduction

Trimaterial bonded wedges made of anisotropic crystalline materials are common occurrences in many modern advanced technological applications, such as thin-film solar cells, superconductivity and so on. Thin-film solar cell technology has engendered considerable promise for GW- and TW-scale energy production, while reducing the bulk material costs of photovoltaic devices [1]. Toward this end, Nagel and Scarpulla [1] have recently utilized scattering from dielectric particles, such as SiO_2. These particles are embedded directly within the semiconductor absorber material with sizes on the order of one wavelength. Importantly, they have ensured that this geometry be fully compatible with the use of an anti-reflective coating (ARC) to maximize light capture, which results in a trimaterial bonded wedge; see the inset of their Fig. 1d.

Discovery of superconductivity in La–Ba–Cu–O system in the1980s by Bednorz and Muller [2] has spurred an enormous amount of activities in search for high (i.e., above the boiling point of liquid nitrogen) T_c superconductors such as monocrystalline YBCO (yttrium barium copper oxide), which is also called 1–2–3 superconductor (because of the presence of

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http://dx.doi.org/10.1016/j.engfracmech.2013.01.015

Nomenclature

$C_1^{(j)}$, $C_2^{(j)}$ constants related to stress intensity factors (crack) and stress singularity coefficients (anticrack) of the j^{th} anisotropic material of a tricrstal plate
$c_{i\ell}^{(j)}$ elastic stiffness constants of the j^{th} anisotropic material of a tricrystal plate, i, $\ell = 1, \ldots, 6$
h half-thickness of a tricrystal plate
k constant, called the wave number
$K_{IIIj}(z)$ mode III stress intensity factor of the j^{th} anisotropic material of a tricrystal plate
$K_{IIIjs}(z)$ symmetric (with respect to z) mode III stress intensity factor of the j^{th} anisotropic material of a tricrystal plate
$K_{IIIja}(z)$ antisymmetric (with respect to z) mode III stress intensity factor of the j^{th} anisotropic material of a tricrystal plate
r, θ, z cylindrical polar coordinate system
$S_{IIIjs}(z)$ symmetric (with respect to z) mode III stress singularity coefficient of the j^{th} anisotropic material of a tricrystal plate
$S_{IIIja}(z)$ antisymmetric (with respect to z) mode III stress singularity coefficient of the j^{th} anisotropic material of a tricrystal plate
s eigenvalue
s_3 mode III eigenvalue
u_j, v_j, w_j components of the displacement vector in x, y, z directions
x, y, z Cartesian coordinate system
λ order of stress singularity
θ_1 wedge aperture angle of material 1
$\sigma_{xj}, \sigma_{yj}, \tau_{xyj}$ inplane components of the stress tensor, in Cartesian coordinates, of the j^{th} anisotropic material of a tricrystal plate
$\tau_{xzj}, \tau_{yzj}, \sigma_{zj}$ out-of-plane components of the stress tensor, in Cartesian coordinates, of the j^{th} anisotropic material of a tricrystal plate

one yttrium, two barium and three copper atoms in its unit cell). It is known to crystallize in a defect perovskite structure consisting of layers. Practical applications of such mono-crystalline superconductors are, however, limited (at cryogenic temperature) by their poor fracture toughness [3,4].

Asymptotic behavior of two-dimensional stress fields at the tips of cracks, anticracks (through slit cracks filled with infinitely rigid lamellas) and junctions weakening/reinforcing homogeneous/bimaterial/trimaterial isotropic as well as anisotropic plates, has been studied extensively in the literature (see [5–10] and references therein). Anticracks have important applica-

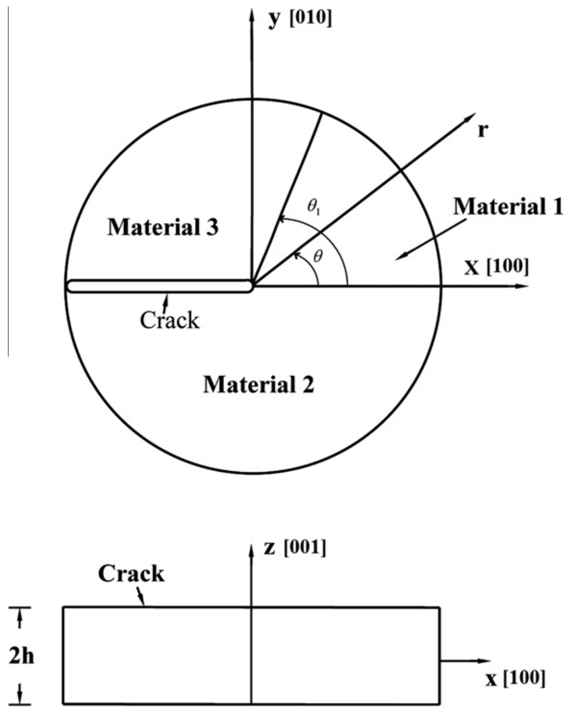

Fig. 1. Schematic of a trimaterial plate with a bimaterial interfacial crack.