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Elastic fields of a core-spreading dislocation in anisotropic bimaterials

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ABSTRACT

A dislocation at an interface especially at a weak shear interface spreads its core associated with shearing the interface. Such core-spreading significantly reduces stress/strain concentration of the dislocation at the interface and thus traps the dislocation in the interface, correspondingly strengthening materials. Employing the Green's function for a single dislocation, we derived analytical expressions for the elastic fields associated with a core-spreading dislocation in anisotropic bimaterials. We proposed three fractional dislocation models to mimic the spreading core of a dislocation at an interface, i.e. uniform distribution (UD), linear distribution (LD) and cosine distribution (CD). The accuracy and efficiency of the three fractional models are validated by the continuity of both traction and displacement across the interface. Numerical results of the stress and displacement fields of the dislocation in the Cu/Nb bimaterial show that: (1) such core-spreading greatly reduces the stress intensity near the dislocation compared with the dislocation with a condensed core; (2) the distribution of the Burgers vector associated with the core spreading determines the magnitude and patterns of the elastic fields; (3) The influence of the core-spreading on the elastic fields can be negligible when the distance of a field point from the center of the dislocation core is greater than 2.17 times the width of the spreading core; (4) The LD model is simple while it is able to capture the interaction force acting on an incoming dislocation. The findings offer insights into understanding interface roles in strengthening materials and designing interfaces-dominated composites.

1. Introduction

Interfaces can greatly advance mechanical properties of polycrystalline aggregates and multiphase composites (Bai et al., 2001; Chen et al., 2008; Gromvo et al., 2010; Ghoniem et al., 2009; Pennycook, 2008; Anderson and Li, 2001; Püschl, 2002; Otsuka et al., 2003). Interface acting as sources, on the one hand, may nucleate and emit dislocations under mechanical loading, facilitating the propagation of plastic deformation from one grain to the adjacent grain (Yin,

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1998). On the other hand, because of the discontinuity of slip systems across an interface, interface acts as barriers to postpone or block dislocation transmission from one crystal to the other, which obviously strengthens the material (Zheng et al., 2015). Furthermore, interface dislocations may repel/attract incoming lattice dislocations with respect to the character of interface dislocations (Chu et al., 2013). There are several sources for interface dislocations. Firstly, misfit dislocations form in an interface associated with the lattice mismatch between the two adjacent crystals (Hull and Bean, 1992). Secondly, lattice dislocations after entering the interfaces become interface dislocation (Wang et al., 2008b). Thirdly, the emission or transmission of a lattice dislocation from an interface leaves residual dislocation at the interface (Jacques et al., 1990). These interface dislocations generate elastic fields which interact with incoming lattice dislocations (Demkowicz and Hoagland, 2008; Lu et al., 2009; Wang et al., 2008a,b; Wang and Misra, 2011). With decreasing the layer thickness in multilayered composites, interfaces are realized to be crucial in determining mechanical properties of multilayers based on the study of the dislocation–interface interactions (Akasheh et al., 2007a,b; Li and Ghoniem, 2009; Mara et al., 2008, 2010; Misra, 2008; Wang et al., 2009a,b; Wang and Misra, 2011; Shen and Anderson, 2006, 2007). The concept of the weak-interface strengthening mechanism has been proposed and demonstrated in metallic multilayers, where the interface is weak in terms of shear resistance (Hoagland et al., 2006; Wang et al., 2012; Chu et al., 2013).

When an interface shows a weak shear resistance, such as Cu/Nb metallic multilayers (Wang et al. 2008a, 2011) and metal/amorphous interfaces (Gao et al., 2002), interface dislocations show a spreading core at the interface. For instance, Gao et al. studied incoherent metal/amorphous interfaces using transmission electron microscopy (TEM), and disclosed the phenomenon that the contrast of dislocations under a strong electron beam may gradually disappear at the incoherent interface based on the concept of spreading-out dislocation (Gao et al., 2002). Using molecular dynamics simulations, Wang et al. demonstrated the core spreading of a dislocation in Cu/Nb bimaterial interfaces (Wang et al., 2008b, 2010) and the core-spreading influence on slip transmission (Wang et al., 2012; Wang and Misra, 2011). Chu et al. further developed a continuum scale model to study the influence of interface shear on the absorption of a lattice dislocation (Chu et al., 2013). However, less attention was paid on the elastic fields of a dislocation with a spreading core in interfaces.

Elastic fields associated with a dislocation determine interactions between the dislocation and other defects, thus influencing mechanical properties (strength and plasticity) and physical properties (optical and electric conductivity) of solids (Bai et al., 2001; Chen et al., 2008; Gromov et al., 2010; Kurzic, 2009; Ohno et al., 2012; Otsuka et al., 2003; Pennycook, 2008; Püschl, 2002; Zhu and Li, 2010). For example, strength and plasticity in a crystalline material are greatly determined by dislocation activities including nucleation, motion, and reactions. Dislocations can nucleate at interfaces, such as grain boundary, phase boundary, and free surface etc. (Beausir and Fressengeas, 2013; Beltz and Rice, 1992; Zhang et al., 2011; Salehinia et al., 2014a, 2014b, 2015), misfit dislocation intersections (Shao et al., 2015; Wang et al., 2014; Wang, 2015) and even homogenously nucleate in crystals (Hirth and Lothe, 1982). The elastic fields of a dislocation determine the energy barrier of nucleating the dislocation in such circumstances. The elastic fields associated with a dislocation were studied for several decades, including Aderogba's theorem (Aderogba, 1976), dislocation dynamics simulations (Zbib et al., 2000, 2011; Ghoniem and Han, 2005; Wang et al., 2004, 2006; Cai et al., 2004; Bulatov et al., 2001), correspondence theorem of couple stress elasticity (Lubarda, 2003), heterogeneous anisotropic elasticity theory (Vattréand Demkowicz, 2014), and Stroh formalism (Chu and Pan, 2014; Chu et al., 2011; Pan, 2002, 2003). Recently, we developed a simple integration method to evaluate the elastic fields of dislocation loops where the complex surface integral for the elastic fields in an isotropic infinite media could be simplified by the means of Stokes' theorem (Mura, 1987) and consequently turns into a line integral along the dislocation line (Chu et al., 2011, 2012). This method has been validated in studying elastic displacements and stress fields of a polygonal dislocation loop in anisotropic elastic crystals.

In this paper, we derived the elastic fields associated with a dislocation with a spreading core at an interface of anisotropic bimaterials. Three different core spreading models, i.e. uniform, linear and cosine distributions are considered and the corresponding analytical/semi-analytical expressions for elastic fields are obtained based on Stroh formula. This paper is organized as follows. In the second section, we briefly review the elastic fields for a single dislocation and deduce the fields for a dislocation with a spreading core in an anisotropic bimaterial. In the Section 3, we examined our theoretical models in the Cu/Nb bimaterial. Finally, conclusions and discussions are drawn in the Section 4.

2. Elastic fields of a dislocation with a spreading core in an anisotropic solid

Fig. 1 shows an interface dislocation with a spreading core in an anisotropic bimaterial. We denote the upper half space ($z > 0$) by material 1 and the lower half space ($z < 0$) by material 2. The dislocation has a spreading core with a width of w in the interface.

2.1. Green's function for a dislocation in bimaterials

The elastic fields associated with a single dislocation in bimaterials have been studied by Barnett and Lothe (1974), Dundurs and Mura (1964), and Ting (1996). For a dislocation with the Burgers vector $\boldsymbol{b}$ in a bimaterial, in terms of the Stroh