



Wedge indentation into elastic–plastic single crystals, 1: Asymptotic fields for nearly-flat wedge

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ARTICLE INFO

Article history:

Received 12 August 2010

Received in final revised form 19 October 2010

Available online 4 November 2010

Keywords:

Indentation

Single crystal plasticity

Asymptotic fields

Kink-shear

Glide-shear

ABSTRACT

Asymptotic stress and deformation fields under the contact point singularities of a nearly-flat wedge indenter and of a flat punch are derived for elastic ideally-plastic single crystals with three effective in-plane slip systems that admit a plane strain deformation state. Face-centered cubic (FCC), body-centered cubic (BCC), and hexagonal-close packed (HCP) crystals are considered. The asymptotic fields for the flat punch are analogous to those at the tip of a stationary crack, so a potential solution is that the deformation field consists entirely of angular constant stress plastic sectors separated by rays of plastic deformation across which stresses change discontinuously. The asymptotic fields for a nearly-flat wedge indenter are analogous to those of a quasistatically growing crack tip fields in that stress discontinuities can not exist across sector boundaries. Hence, the asymptotic fields under the contact point singularities of a nearly-flat wedge indenter are significantly different than those under a flat punch. A family of solutions is derived that consists entirely of elastically deforming angular sectors separated by rays of plastic deformation across which the stress state is continuous. Such a solution can be found for FCC and BCC crystals, but it is shown that the asymptotic fields for HCP crystals must include at least one angular constant stress plastic sector. The structure of such fields is important because they play a significant role in the establishment of the overall fields under a wedge indenter in a single crystal. Numerical simulations—discussed in detail in a companion paper—of the stress and deformation fields under the contact point singularity of a wedge indenter for a FCC crystal possess the salient features of the analytical solution.

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1. Introduction

The elastic–plastic properties of materials have long been probed using various indentation methods. Mechanics analyses of the indentation process are employed to interpret the results of indentation experiments in order to extract values of mechanical properties. The fidelity of these models depends upon how accurately the mechanics models reflect the actual stress and deformation fields in the material under the indenter.

It has traditionally been challenging to characterize stress and deformation states within an opaque material underneath an indenter. Recent diffraction-based methods, though, have made it possible to measure the rotation of the crystal lattice associated with elastic–plastic deformation under an indenter tip, as well as to characterize the state of the elastic (or lattice) strain. One such method is Laue x-ray diffraction which can resolve lattice orientation and elastic strain with a spatial resolution of about 1 μm within a volume of crystalline material (Larson et al., 2004; Ohashi et al., 2009). This method is capable of measuring the three-dimensional fields associated with an indentation (Yang et al., 2004; Feng et al., 2008),

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