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DISCRETE DISLOCATION PLASTICITY SIMULATIONS OF ROUGH SURFACE CONTACT

L. Nicola[⋆], **A. Needleman**[⋆], **A.F. Bower**[⋆] **and E. Van der Giessen**[†]

[⋆]Division of Engineering, Brown University, Providence, RI 02912, USA
e-mail: lucia@daisy.engin.brown.edu

[†]Department of Applied Physics, University of Groningen, Nyenborgh 4, 9747 AG Groningen,
The Netherlands

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Summary. *The effect of surface roughness on contact is studied by analyzing indentation of a single crystal by a rigid indenter with a square wave profile. Calculations are carried out using discrete dislocation plasticity and, for comparison purposes, conventional continuum crystal plasticity. A size independent response is obtained using conventional crystal plasticity whereas discrete dislocation plasticity gives a distinct size effect with smaller being harder.*

1 INTRODUCTION

Surface roughness is almost always unavoidable and, even under relative light loading, plastic deformation tends to occur at the contacts. When the loading is removed the non-uniform plastic deformation gives rise to the development of a residual stress state that can promote crack nucleation. Therefore the study of plasticity in rough surface contact is of significance for understanding friction and wear, as well as contact and fretting fatigue. We carry out simulations of indentation of an infinitely large two dimensional deformable single crystal by a rigid indenter. The surface of the crystal is taken to be flat but to simulate rough contact the profile of the indenter is taken to be a square wave. Plane strain calculations are carried out with plasticity in the crystal occurring by the collective motion of discrete dislocations. This allows the effect of possible organized dislocation structures on the stress distribution at the contact to be analyzed. The simulations track the evolution of the dislocation structure and stress state during loading and unloading. For comparison purposes, calculations are also carried out using conventional continuum crystal plasticity.

2 FORMULATION

The deformable body is modelled in two-dimensions as an infinitely long single crystal of height h, see Fig. 1. To simulate rough contact the profile of the rigid indenter is taken to be a rectangular wave function. The dislocations are modeled as line singularities in an otherwise isotropic linear elastic solid. Plane strain conditions are assumed. A set

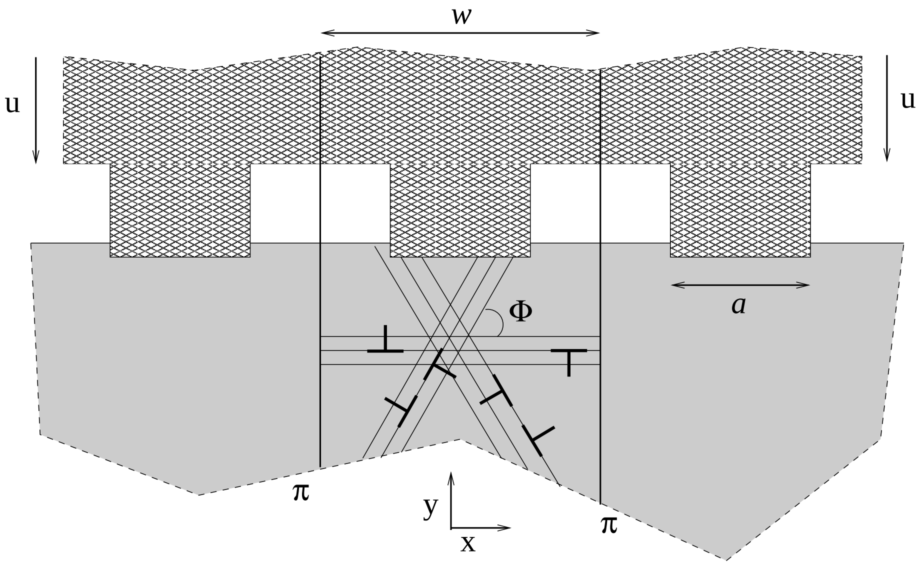

Figure 1: Two-dimensional model of the indented body. The calculations are performed for the unit cell of width w.

of constitutive rules is supplied for the glide of dislocations as well as their generation, annihilation and pinning at point obstacles. The solution for the state of stress and deformation is at every increment given as a superposition of two contributions: the known, analytical solution for individual dislocations in infinite space and a non-singular linear elastic, finite element solution that enforces the proper boundary conditions as described in [1]. The deformation history is calculated incrementally. At time t, the stress and displacement fields are known at each material point along with the positions of all dislocations. An increment of the applied displacement u is prescribed (see Fig. 1) and calculation of the state at time $t + dt$ involves: (i) determining the Peach-Koehler forces on the dislocations; (ii) determining the rate of change of the dislocation structure caused by the motion of dislocations, the generation of new dislocations and their mutual annihilation; and (iii) determining the stress and strain state for the updated dislocation arrangement.

3 RESULTS

To investigate the effect of the roughness period of the indenting surface, simulations are performed for three values of size of the contact, $a = 0.33\mu$m, $a = 0.66\mu$m and $a = 1.33\mu$m, with the contact area fraction kept constant, $a/w = 1/3$. The calculated values of hardness measured at $u = 0.1\mu$m are plotted versus the contact area in Fig. 2 together with results obtained from conventional crystal plasticity theory. The hardness,

H, is defined as

$$H = f/a, \qquad f = \int_{-a/2}^{a/2} T_n dx, \tag{1}$$

where T_n is the normal traction and H pertains to a unit(1 m) thickness.

The crystal plasticity results give a size independent response whereas a distinct contact size dependence is predicted by discrete dislocation plasticity with smaller being harder. The slight size dependence of the conventional crystal plasticity results is a consequence of the calculations being carried out for a finite size region, with the region size being the same for all contact sizes. A discrete dislocation analysis of an isolated contact subject to shear loading gave rise to a size dependence with smaller being harder, [2].

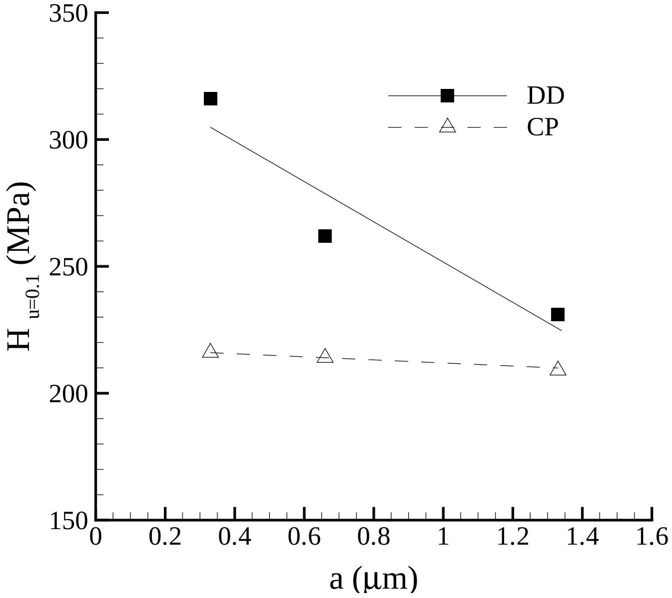

Figure 2: Size effect: hardness at $u = 0.1\mu$m versus the area of the single contact a. Solid squares are the discrete dislocation plasticity results while the hollow triangles are the predicitions obtained using conventional crystal plasticity theory. Straight lines are fit to the data using the standard least-squares algorithm.

The stress distributions on unloading as predicted by discrete dislocation plasticity and by conventional continuum plasticity will also be presented.

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