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STRESS CONCENTRATIONS CAUSED BY DISLOCATIONS AT THE FREE SURFACE

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Summary In this contribution discrete edge dislocation simulations (static and dynamic) are used to verify the analytical solution of Brown and Ogin (1984) for the stress state caused by the intersection of the persistent slip band with the free surface. Static and dynamic results show that, only in a rather unphysical limiting situation, the singular stress fields of the discrete dislocations lead to a logarithmic stress singularity at the free surface.

INTRODUCTION

In fatigue the key to predict and understand the nucleation of the crack lies in the stress concentrations at the free surface. Dislocations play an important role in the initiation of a crack through their long range stresses. During fatigue they cluster and form first the channel-vein and later the ladder-like structure found in persistent slip bands (PSBs). The PSB emerges at the free surface as an extrusion of material. The geometry of extrusions themselves can be the origin of stress concentrations, but the dislocations below the surface have long been recognized as potential sources for high stresses near the surface. Brown and Ogin [1] proposed an analytical model for PSB-induced stresses, which will be described in the following section. Subsequently, static and dynamic simulations are presented to verify the accuracy of this model.

BROWN'S ANALYTICAL MODEL

Dislocations in a persistent slip band are on primary slip planes. Areas of high dislocation density form walls which are separated by regions that are almost dislocation free. The Burgers vector of the dislocations in a single wall can be added up to form a 'super dislocation dipole' representing the wall. These super dislocation dipoles are then spaced uniformly along the PSB as shown in Figure 1.

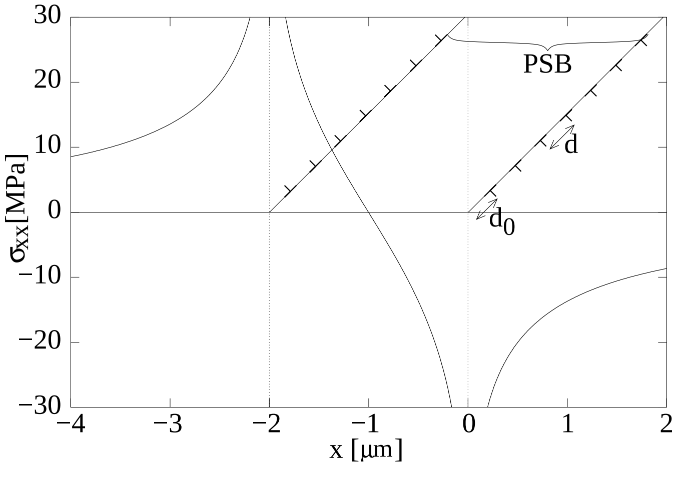

Figure 1. Idealized dislocation distribution in a PSB according to Brown and Ogin [1] and logarithmic singularity in the stress component σ_{xx} parallel to the surface at the root of the PSB.

The super dislocations are then 'smeared' out along the persistent slip band direction. The resulting stress field has been calculated analytically [1] and the resulting stress profile is shown in Figure 1. The stress profile reveals a logarithmic stress singularity at both sides of the PSB emerging at the free surface. The positive stress singularity supposedly leads to the initiation of a mode I crack along the interface between the PSB and the surrounding matrix.

STATIC DISLOCATION CALCULATIONS

To verify the above-mentioned results for a smeared dislocation distribution, discrete dislocation dipoles are placed at both ends of the wall in a PSB. Their stress profile fields are calculated as a function of the distance of the first dislocation to the surface, d_0, and the results are shown in Figure 2.
The stress σ_{xx} parallel to the surface has a maximum at $x \approx -2\mu m$ and a minimum close to $x = 0\mu m$. In this simulation with discrete dislocations the stresses remain finite. In addition, the stresses are not symmetric, i.e. the absolute value of the maxima is smaller than that of the minima and the position of the maxima is shifting with increasing spacing of the first dislocation to the surface.

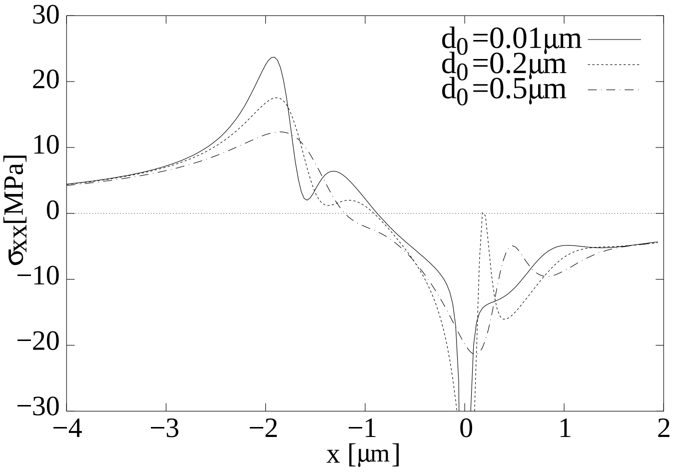

Figure 2. Stress profile at the free surface for different spacings of the first dislocation to the free surface.

DYNAMIC DISLOCATION CALCULATIONS

In addition to considering static dislocation structures, we also perform dynamic simulations where the dislocations can move along predefined slip planes in a single grain near the free surface [2]. This grain has three slip systems (60° from each other) with the primary slip system oriented favorably at 45° to the applied load direction. Dislocations are generated from randomly placed two dimensional Frank-Read sources. Their movement is governed by a linear drag relation and they can annihilate with each other or move out at the free surface. Their movement is hindered by obstacles, representing forest dislocations or precipitates. The stress profile after 1897 cycles in a zig-zag fashion is shown in Figure 3.

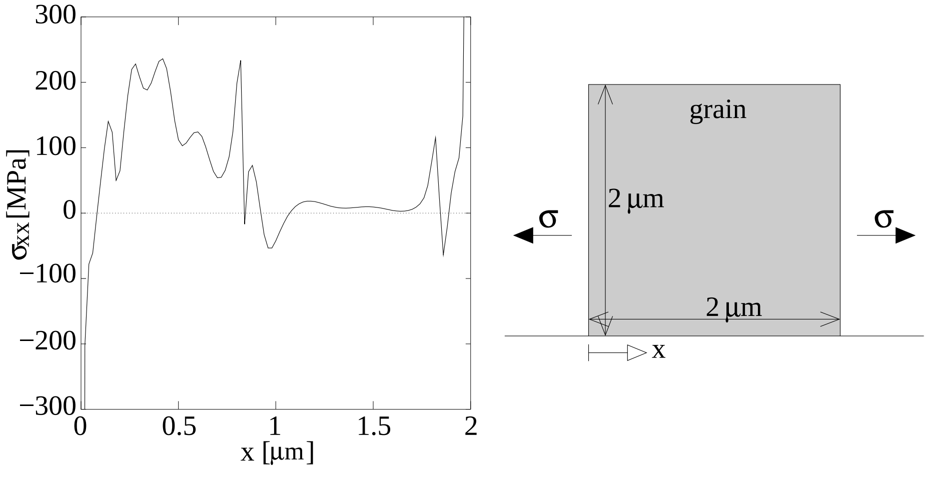

Figure 3. Stress profile at the free surface of a $2 \times 2\mu m$ grain after 1897 cycles.

DISCUSSION

Brown and Ogin [1] assume that the dislocations forming a wall can be smeared out along the persistent slip band. This leads to a dislocation with a Burgers' vector of b/d (d is the spacing of the dislocation dipoles, Figure 1) at the surface. A dislocation cannot stay at the free surface because of the image stress, pulling the dislocation out of the grain. Without a dislocation at the free surface the static dislocation calculations show no singular stress at the free surface. The dynamic simulations confirm the finite stresses at the free surface. The values of the stresses are expected to change with continuing load cycles.

References

[1] Brown, L. M. and Ogin, S. L.: Role of internal stresses in the nucleation of fatigue cracks. In: Bilby, Miller, Willis, *Fundamentals of deformation and fracture*, Eshelby memorial symposium, 501–528, 1984.

[2] Van der Giessen, E. and Needleman, A.: Discrete dislocation plasticity: a simple planar model. *Modelling and Simulation in Materials Science and Engineering*, **3**: 689-735, 1995.