Does discreteness matter in plasticity?

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Introduction

Continuum plasticity theories are incapable of predicting the formation of pile-ups at hard obstacles which a Discrete dislocation analysis can predict with relative ease. The question then arises: How important is the underlying discreteness at larger scales? Is there a directional dependence of this discreteness? Do we need to incorporate discreteness in a continuum setting, and if so how?

Fully Discrete Analysis

For illustration, we evaluate infinite walls of like dislocations piling up in an infinite medium (Figure 1). Discrete dislocation analysis is performed as a benchmark for comparison with continuum approximations. Non-linear equations are solved numerically to evaluate the equilibrium position of the walls under a constant, externally applied shear stress (Figure 3).

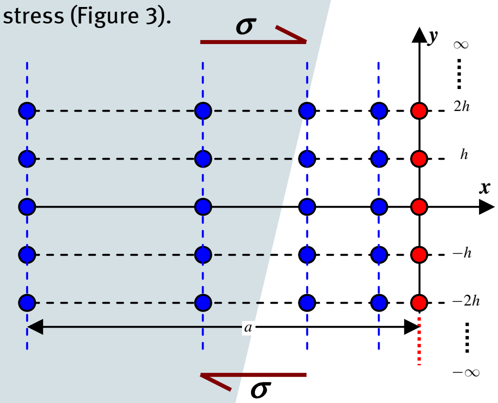

Figure 1 *Discrete dislocation representation of a pile-up in an infinite medium. Slip plane separation is "h". The red circles represent the immobile wall at x=0.*

Interestingly, we observe that there is no analytical limit on the number of pure edge dislocation walls (and hence pile-up length) that may be accommodated under a constant stress (Figure 2). The limit is governed by the pile-up domain, *a*. On the other hand an analytical limit exists for pure screw dislocation walls depending on the externally applied stress.

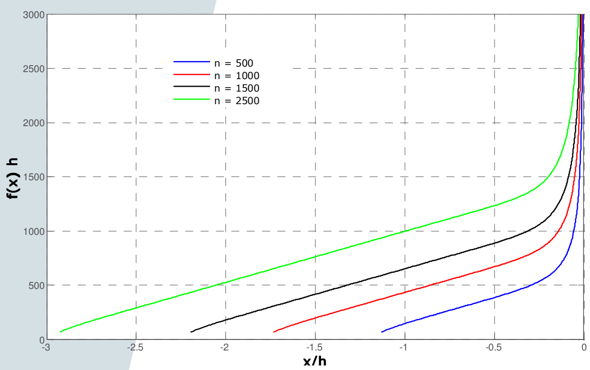

Figure 2 *Dislocation density profiles for different number of Edge dislocation walls, n. The external stress is kept constant.*

Discrete in y and Continuous in x

Here, the dislocation wall distribution in the slip plane direction is represented by a continuous function with the wall discreteness in the *y* - direction maintained as before. A converged solution on the density profile is obtained which matches exactly with the fully discrete analysis performed before (Figure 3).

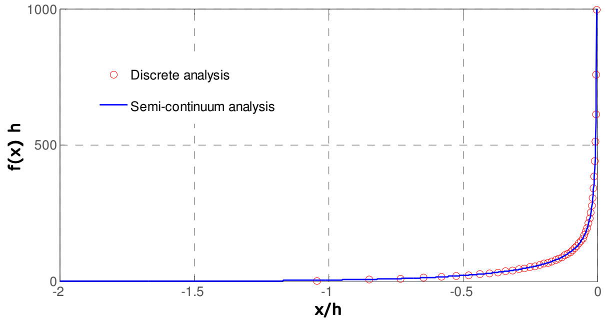

Figure 3 *Comparison of dislocation density distribution for positive Screw dislocation infinite walls .*

Continuous in y and Discrete in x

Analytically, if the internal discreteness (in the *y* direction) of a single infinite wall is replaced by a continuous function of infinitesimal dislocations the stress fields lose all variation in the slip plane direction and in most cases reduce identically to zero (Figure 4). Formation of pile-ups is not observed when multiple walls are considered.

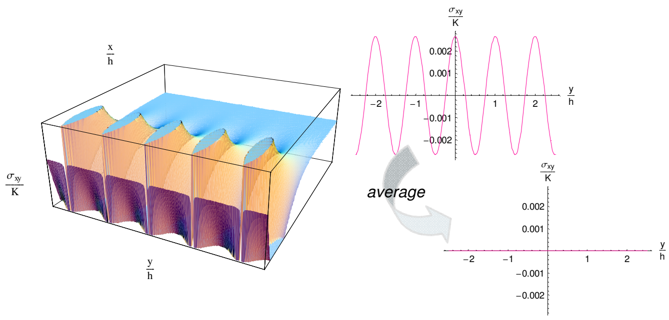

Figure 4 *Shear stress profile of an edge dislocation wall. Stress variation along the y-axis and consequence of averaging.*

Conclusion

- A pile-up length depending on the externally applied shear stress field can be predicted for like screw dislocation walls but not for dislocation walls of pure edges.
- Discreteness cannot be ignored in the direction perpendicular to the slip direction.
- "Smudging" of dislocations is allowed in the slip direction.

Future Work

Formulating techniques to characterize this unique directional dependence on discreteness using gradient terms in a continuum plasticity framework.

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