7.1 THE ORIGIN OF STRAIN AVALANCHES IN SUBMICRON PLASTICITY IN fcc METALS - T. Crosby, G. Po, C. Erel, N.M. Ghoniem (University of California, Los Angeles)

EXTENDED ABSTRACT *- paper accepted with revisions in Acta Materialia (2014).*

In small-scale plasticity, single crystals experience a stress-strain relation that has at least three distinct characteristics: the flow stress is higher than in bulk materials, its magnitude is stochastic, and the post-yielding behavior is jagged rather than uniform. The flow stress is stochastic because at these length scales the individual behavior of dislocation lines (rather than the collective behavior in case of bulk crystals) leads to dramatic differences in the stress-strain relation, making the flow stress very sensitive to the initial distribution and initial density of dislocations in the material. This apparent stochasticity is not just present in the initial flow strength, but have also been reported in the later stages past the yield point (1, 2). The exact mechanisms behind size effect and the observed jerky stress past the yield point have been the subject of some controversy. In general, one may divide the factors influencing strength and hardening in nano- and micro-pillars into two main groups: extrinsic and intrinsic effects. In this work, we propose a different explanation for the observed jerky flow in stress-strain curves that is based on the dynamics of dislocation dipolar-loops, which act as debris inside the material.

Multiple three-dimensional discrete dislocation dynamics (3D-DDD) simulations, with different initial dislocation densities and distributions, were performed. In each, compression of a Nickel nano-pillar, Fig. 1, with a diameter of 250 nm and 3:1 aspect ratio, oriented with the loading axis is in the [111] direction, was carried out by applying a displacement on the top surface while fixing the bottom. Typical results at the end of simulations are shown in Fig. 2. The stress-strain curves showed both a stochastic flow stress and a jerky stress past the initial yielding point. Fig. 3 shows snap shots of the pillar microstructure.

The jerky behavior of the stress is intrinsic and a property of small-scale systems, and not the result of some external fluctuations or randomness. We suggest, based on the simulation results, that this is attributed to the nonlinear dynamics of formation and destruction of dislocation debris, which are dipolar-loops formed by cross-slip. The debris-mechanism for intermittent plasticity appears to be fundamental to the understanding of plastic flow in confined, submicron plasticity. An analysis for the evolution of dislocation densities that correspond to different dislocation families, confirms the role dipolar-loops play in dictating the onset of strain avalanches. The analysis suggests that the continuous shift in the peaks and valleys of the glissile and dipolar-loops densities correspond to the continuous space-time shifts of sources inside the material.

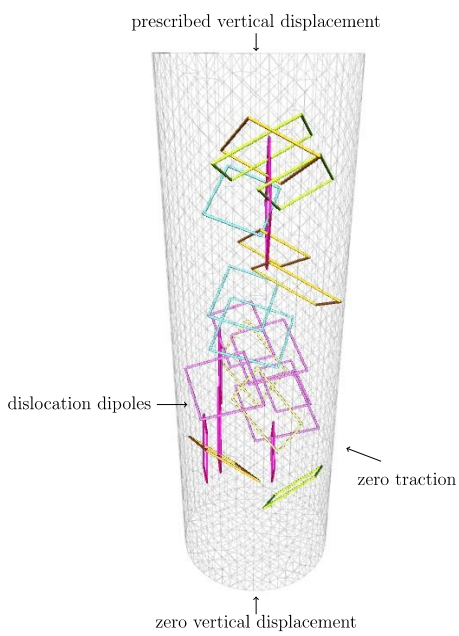


Figure 1. Nano-pillar considered in our DD simulations.

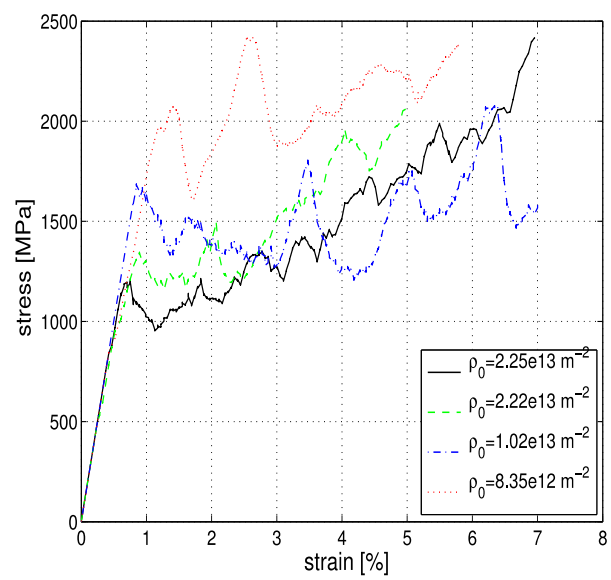
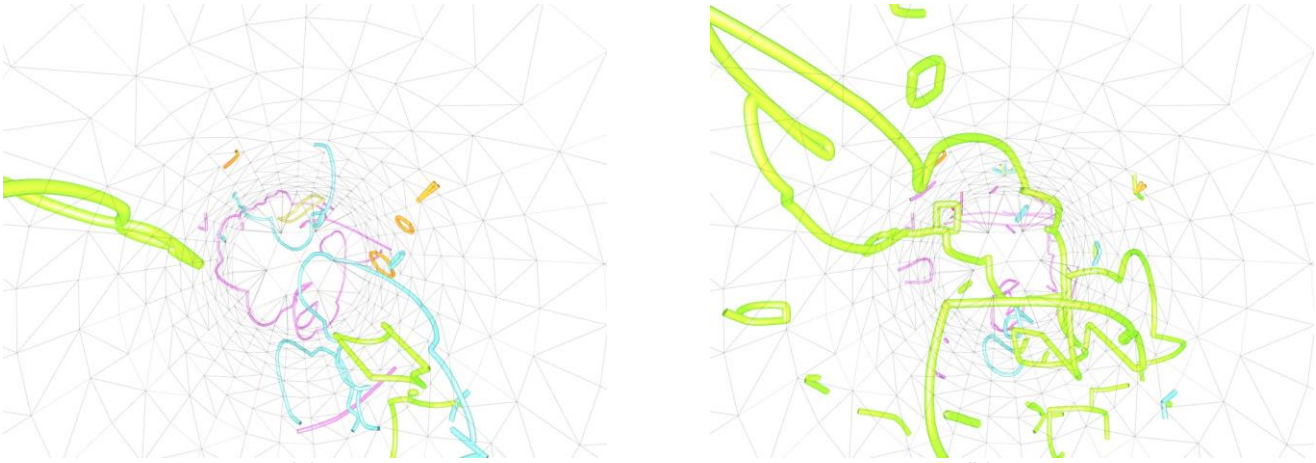


Figure 2. Stress-Strain curves for a D=250nm pillar under compression.



(a) (b)

Figure 3. Snap shots (top-view of the pillar) showing the evolution of dislocation microstructure inside the pillar. (a) Nearly starved (ε=0.08%), (b) Full (ε=1.95%).

References

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