7.5 LOADING CONTROLLED TRANSITION OF PLASTIC FLOW FROM DISLOCATION AVALANCHE TO QUASI-PERIODIC STRAIN BURST BEHAVIOR—Y.N. Cui, G. Po, N.M. Ghoniem (University of California, Los Angeles)

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Numerous studies suggest that collective dislocation dynamics during plastic flow can self-organize to exhibit power law scaling avalanche behavior [1]. Here we demonstrate a dynamical regime transition toward quasi-periodic strain burst when the driving force changing rate is comparable to internal relaxation rate. Through three-dimensional discrete dislocation dynamics we can access different driving force rate of change by tuning system stiffness and directly correlate the measured intermittent plastic events with internal dislocation activities (see Figure 1). When the system stiffness is extremely soft ($\alpha=0$, pure stress control), system response is much slower than the internal relaxation, and the power law scaling avalanche behavior is reproduced (see Figure 2(a)). However, when the system stiffness is extremely high ($\alpha=\infty$, pure stress control), system response rate is comparable to internal relaxation rate, quasi-periodic strain burst is observed (see Figure 2(b)).

Careful analysis of the simulation results reveals that the dislocation mechanisms of avalanches/burst under different loading modes are significantly different. Under pure strain control, the rapid decrease of the driving force (see Figure 3(a)) inhibits the correlated dislocation activity, prevents the strain burst from continuously growing and makes it difficult to self-organize to exhibit scale free power law burst size distribution. Compared with pure strain control, finite system stiffness can promote the correlated dislocation motion. For the case of extremely soft system stiffness, each strain avalanche under pure stress control is induced by the highly correlated motion of dislocations. Multiple dislocation sources are activated correlated and simultaneously. In Figure 3(b), the autocorrelation function r_k of the dissipated energy rate is given to illustrate the apparent contrast correlation extent of dislocation motion under different loading modes.

These results are faithfully reproduced by a simple dislocation-based branching model, including the stepped or serrated burst features, and the power law scaling behavior under pure stress control. Furthermore, the branching model clearly shows as the system stiffness increases, the power law tails gradually becomes too heavy to recognize the power law scaling.

The current research presents the first systematic three-dimensional discrete dislocation dynamics investigation on the statistical properties of dislocation avalanches and strain bursts, accounting for the effects of the interaction with an external loading system. The finding raises new possibility of controlling the correlated extent of dislocation behavior and the dynamical regime transition of avalanche statistic by tuning the interaction with outer system. The importance of often-neglected interaction with outer system on intermittent plastic flow or other complex system has now come to light.

References

[1] D. M. Dimiduk, C. Woodward, R. LeSar, and M. D. Uchic, Scale-free intermittent flow in crystal plasticity, Science, 312 (2006) 1188-1190.

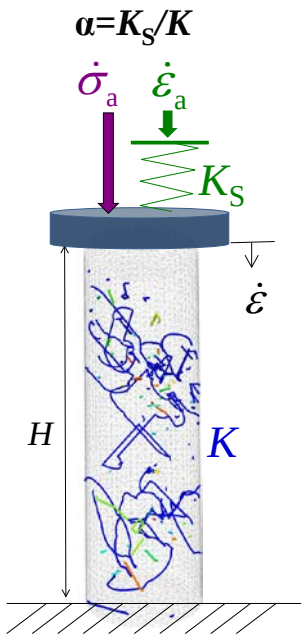

***Figure 1**. Simplified sketch of pillar compression with an open loop (directly applying some force) and close-loop control (connecting a spring with finite system stiffness K_s). One typical dislocation configuration in pillar with d=3000b is shown as an example.*

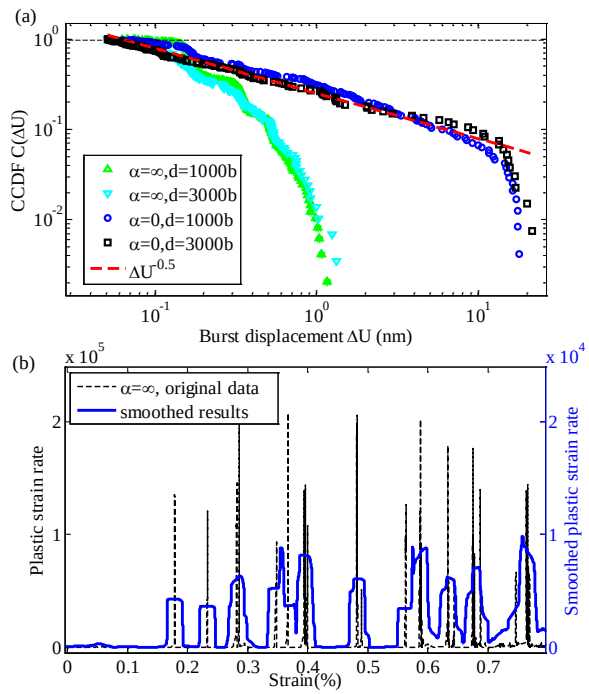

Figure 2. (a) Statistical properties of burst displacement under pure strain and stress control for pillar with diameter d=1000 b and 3000 b, showing power-law scaling avalanche under pure stress control; (b) Typical result of the evolution of plastic strain rate and its averaged value showing quasi-periodicity strain burst under pure strain control.

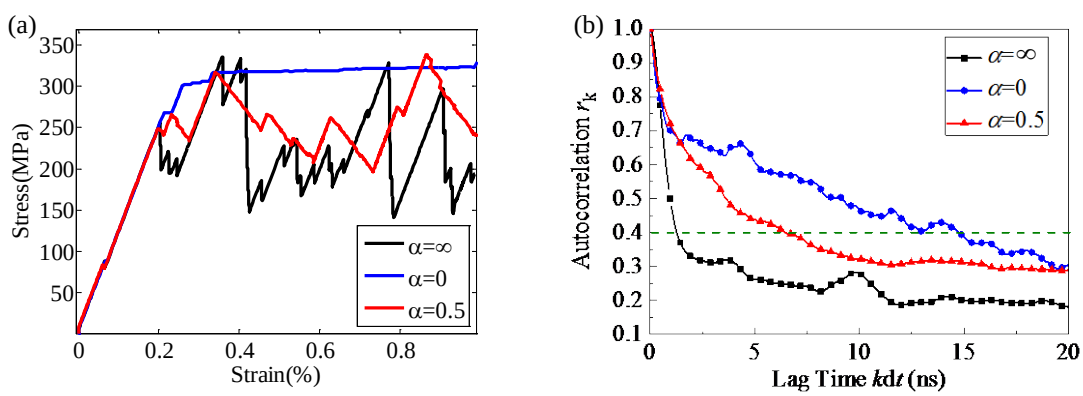

Figure 3. Typical simulation results under different loading modes for pillar with d =1000 b, (a) stress-strain curve, showing stepped or serrated burst features; (b) Autocorrelation function for dissipated energy rate showing different correlated extents of dislocation activities under different loading modes, where the dotted green lines are plotted to help visualization, which corresponds to 0.4.