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Strength and Dislocation Structure Evolution of Small Metals under Vibrations

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It is well-known that ultrasonic vibration can soften metals, and this phenomenon has been widely exploited in industrial applications concerning metal forming and bonding. In this work, we explore the effects of a superimposed small oscillatory load on metal plasticity, from the nano- to macro-size range, and from audible to ultrasonic frequency ranges. Macroscopic and nano-indentation were performed on aluminum, copper and molybdenum, and the results show that the simultaneous application of oscillatory stresses can lower the hardness of these samples. More interestingly, EBSD and TEM observations show that subgrain formation and reduction in dislocation density generally occurred when stress oscillations were applied. These findings point to an important knowledge gap in metal plasticity – the existing understanding of ultrasound softening in terms of the vibrations either imposing additional stress waves to augment the quasi-static applied load, or heating up the metal, whereas the metal's intrinsic deformation resistance or dislocation interactive processes are assumed unaltered by the ultrasound, is proven wrong by the present results. Furthermore, in the case of nanoindentation, the Continuous Stiffness Measurement technique for contact stiffness measurement assumes that the imposed signal-carrier oscillations do not intrinsically alter the material properties of the specimen, and again, the present results prove that this can be wrong. To understand the enhanced subgrain formation and dislocation annihilation, Discrete Dislocation Dynamics (DDD) simulations were carried out and these show that when an oscillatory stress is superimposed on a quasi-static applied stress, reversals of motion of dislocations may occur, and these allow the dislocations to revisit repeatedly suitable configurations for annihilation. DDD, however, was unable to predict the observed subgrain formation presumably because the number of dislocations that can be handled is not large enough. Subgrain formation was directly predicted by a new simulation method of dislocation plasticity based on the dynamics of dislocation density functions.