Modelling shocks in metals
(or *real* dislocation dynamics)

Adrian Sutton[1], Daniel Eakins[1], Beñat Gurrutxaga Lerma[2], Daniel Balint[2], Daniele Dini[2]

[1] *Department of Physics, Imperial College London, UK;*
[2] *Department of Mechanical Engineering, Imperial College London, UK;*

During shocks metals deform at much higher strain rates than those normally encountered in plastic deformation, typically up to 10^{10} s^{-1}. Shock loading occurs during high speed car crashes, birds flying into the compressor blades of aircraft engines, missile strikes on tanks and ships, and more sinister weaponry.

Shocks are studied experimentally by firing projectiles in gas guns at stationary metallic targets at speeds of about 1 km s^{-1}, or pulsing the surfaces of metals with intense lasers. In both cases a shock wave enters the metal at the longitudinal speed of sound. As it travels through the metal, dislocations are generated at the shock front and travel at speeds approaching the shear wave speed. At such high dislocation speeds the finite time it takes for elastic signals to travel through the medium becomes significant. The force on a dislocation per unit length is still the Peach-Koehler force, i.e. the resolved shear stress on the slip plane in the direction of the Burgers vector. But by the time a dislocation experiences the stress wave emitted by another dislocation, that other dislocation is no longer at the position it was when it emitted the wave. This means that the *time-dependent* equations of elasticity have to be solved to describe the interactions between dislocations and their interactions with the shock wave. This is analogous to the distinction between electrostatics and electrodynamics, except that the relevant wave speed in elasticity is the shear wave speed rather than the speed of light.

Describing interactions between large numbers of moving dislocations is the purview of dislocation dynamics. But until our work [1-3] all dislocation dynamics codes were based on a quasistatic description of dislocation interactions: at each time step the instantaneous configuration of dislocations is frozen and their interactions are described in terms of their static, time-independent elastic fields. I will show in this talk how these methods fail spectacularly to model dislocation dynamics during shock loading. It was this discovery that motivated our development of *Dynamic discrete dislocation plasticity (D3P)* [1], the first fully elastodynamic treatment of dislocation dynamics.

In this talk I will show what is involved in an elastodynamic treatment of dislocation dynamics. I will then show its application to solving a long-standing mystery in shock physics, namely why the yield point, which is the stress at which the metal begins to deform plastically, decreases the further a shock wave travels into the metal. Our explanation [2] involves the destructive interference of elastic waves at the shock front - unusual concepts and language to use in the context of dislocations interactions.

This research was carried out in the Centre for Doctoral Training on Theory and Simulation of Materials at Imperial College, funded by EPSRC grant EP/G036888/1.

[1] *A dynamic discrete dislocation plasticity method for the simulation of plastic relaxation under shock loading*, B Gurrutxaga-Lerma, D S Balint, D Dini, D E Eakins, and A P Sutton, Proc. R. Soc. A 469, 20130141 (2013). http://dx.doi.org/10.1098/rspa.2013.0141

[2] *Attenuation of the dynamic yield point of shocked aluminum using elastodynamic simulations of dislocation dynamics*, B Gurrutxaga-Lerma, D S Balint, D Dini, D E Eakins and A P Sutton, Phys. Rev. Lett. 114, 174301 (2015) http://dx.doi.org/10.1103/PhysRevLett.114.174301

[3] *Dynamic discrete dislocation plasticity, B Gurrutxaga-Lerma, D S Balint, D Dini, D E Eakins, A P Sutton*, Advances in Applied Mechanics 47, 93-224 (2014).
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