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# Modelling of shock waves in fcc and bcc metals using a combined continuum and dislocation kinetic approach

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## ABSTRACT

Recent experimental data has revealed that, over short time scales (on the nanosecond scale), during formation of a shock in metals, amplitude of the ‘elastic’ precursor greatly exceeds the Hugoniot elastic limit (HEL), before decaying to the level of the HEL. Standard continuum scale material models are unable to reproduce this behaviour. To capture this aspect of material behaviour in metals, physical effects related to high rate dislocation mechanics must be taken into consideration (Mayer et al., 2013) and included into the continuum scale material model. The constitutive model developed here is defined at the continuum level, where the evolution of plastic deformation is controlled with a system of equations for three microscale state variables, for each slip system of a single crystal. These three state variables are the density of mobile dislocations, the density of immobile dislocations and the mobile dislocation velocity. The density evolutions of mobile and immobile dislocations are controlled by dislocation kinetic equations, which account for the generation of new dislocations, immobilisation of mobile dislocations and annihilation of dislocations. Dislocation velocity is determined by integration of the equations of motion of the mobile dislocations. The dislocation micromechanics is incorporated into the continuum model using the generalised Orowan equation, which relates plastic strain rate to the density of mobile dislocations and the velocity of mobile dislocations. Evolution of the yield surface is controlled by density of immobile dislocations.

The dislocation mechanics model (Krasnikov et al., 2011, Mayer et al., 2013) was combined with the orthotropic continuum scale material model (Vignjevic et al., 2012) with a vector shock equation of state (EOS) (Vignjevic et al., 2008), which was developed for modelling the response of orthotropic metals to high strain rate loading including presence of shockwaves. The continuum model was implemented in the LLNL Dyna3d (Liu, 2004) for linear solid elements.

Model validation was performed by comparison of numerical results with experimental data for plate impact tests (uniaxial strain state) for aluminium (fcc), copper (fcc) and tantalum (bcc). The numerical results show that during the first 50ns after impact, the pre-cursor wave has an amplitude similar to the stress level behind the shock front and relaxes to HEL with time (wave propagation). The difference between the experimental and numerical values of the compared variables (longitudinal stress, pulse length, elastic precursor relaxation time) was within 5% for the fcc materials, with the similar accuracy obtained for the bcc material, particularly for loading in the principal material direction.