ELLIPSOIDS, COLLECTIVE MOTION OF DISLOCATIONS, AND RATE DEPENDENCE

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AT ‘NORMAL’ STRAIN RATES, THERE IS VERY LITTLE RATE DEPENDENCE

Slip bands spread like avalanches, displaying incessant intermittency. Earlier models were dislocation pile-ups on a single slip plane. In a pile-up, all dislocations experience the same stress. The trouble with this model is that it has no volume fraction – it’s just a planar configuration. It can be generalised using Eshelby’s famous theorem, that the strain inside an ellipsoidal elastic inclusion is uniform in any linearly elastic medium. The stacking of ellipsoids can then be used to estimate the volume fraction eligible for slip, and the ellipsoids can be stabilised by a forest of secondary slip, which brings the avalanche to a halt, overwriting previous structures. The only rate dependence in such a model is the very slight temperature dependence of forest hardening. The hardening is essentially independent of temperature and strain rate.

BREAKDOWN OF COLLECTIVE MOTION AT HIGH RATES

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PALIMPSEST!

- ‘Slip eligible volume fraction’ – ψ – only (1 - *f)* at low rates
- SOC requires the system to be *slowly driven*
- Acoustic emission suggests critical time corresponds to strain rate 10^{-4} s^{-1}
- Longest timescale is between two avalanches: a ‘synchronisation time’
- Larger bands take longer to synchronise
- Collective motion remains in increasingly smaller, eventually ceases
- Strength must progressively increase as more avalanches are frozen out
- Bands overwrite each other: palimpsest!

Overview of Metal Constitutive Modelling in QinetiQ - Summary

- Research Applications driven in impact and explosive loading regime
- Customer requirements for one-off full-scale trials
- Need for integrated modelling, experiments and material theory to derisk trials and provide better understanding
- Developed predictive material and ductile fracture algorithms based on interrupted tensile test and continuum mechanics
  - Based on modified Armstrong Zerilli model for bcc metals and alloys
  - Goldthorpe Path Dependent Deformation (PDD) model for fcc, hcp metals and alloys
  - Goldthorpe Path Dependent Fracture (PDF) Model for ductile fracture
- Extensive validation over may years on high rate tests
- Proven capability and extension of ‘predictive modelling’ envelope – including EFPs, ballistic penetration etc.
- Models shown to be applicable to Additive Manufactured (AM) materials – case study on maraging steel
  - Unique tensile Hopkinson bar capability at Cambridge
  - Good agreement between model and experiment
- Future challenges are behaviour close to melt, anisotropy, fracture of multi-phase alloys

QINETIQ

Dislocations in Shock - B Gurrutxaga-Lerma

- Using elastodynamics, we can extend dislocation theory to model the behaviour of crystallographic dislocations under high strain rates.
- Dislocation fields become propagating wave fields, asymmetrical, and heavily dependent on past history ("*haunted by their past*").
- We can build a discrete dislocation dynamics methodology based on elastodynamics to study high strain plasticity.
- This requires accounting for a wide number of poorly understood phenomena: kinematic and homogeneous nucleation of dislocations, dislocation mobility at high strain rates, temperature effects at high strain rates.
- We rely on molecular dynamics and lattice theory to model some of them (mobility and instabilities, generation mechanisms).
- We find that the elastic precursor decay is caused by the interference of the dislocation's own elastic fields with the shock front. The dislocation must be generated at the front. Homogeneous nucleation is set to dominate at high strain rates over Frank-Read sources, because FR sources are found to be too slow relative to the rise time of the shock front.

HCP metals under Shock Loading: Magnesium single crystals Shock response over temperature

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1 page SUMMARY

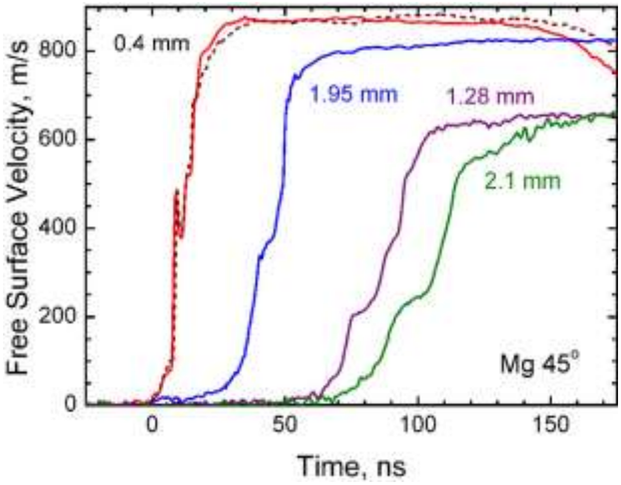
The general area of shock loading of HCP metals was outlined and then the results of a series of impact on magnesium single crystals were reported. The samples ranged from 0.2 to 3mm thick and were shock loaded in directions parallel or perpendicular to the c-axis of the hexagonal closed packed structure. Additionally 45^{o} to the c-axis, was also investigated.

Shock compression along the c-axis is associated with the largest Hugoniot elastic limit (HEL) and. microscopic observation of recovered c-cut samples demonstrated intense twinning with a greater density of twins near the impact surface.

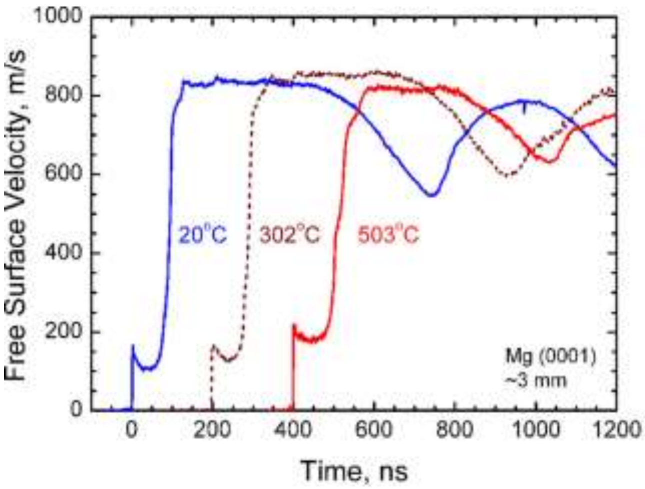
The low-energy basal slip was activated by shock loading along the inclined direction and has the smallest HEL. In all cases, we observe the decay of the elastic precursor wave and growth of the HEL with increasing temperature.

For the inclined shock compression after the HEL, two plastic waves were found where the stress level of the first plastic wave depends on the peak shock stress. Finally, the largest spall strength was along the transversal direction and the smallest in the off-axis direction. The fracture surface of the sample of transversal orientation contains numerous groves oriented along the base planes of the crystals.

This bulk of the Mg research is reported in a more complete fashion in G. I. Kanel, G. V. Garkushin, A. S. Savinykh, S. V. Razorenov, T. de Resseguier, W. G. Proud, and M. R. Tyutin. JOURNAL OF APPLIED PHYSICS 116, 143504 (2014)



Evolution of shock compression waves in the samples at 45 orientation under different peak stresses.



The free surface velocity histories for 3-mm-thick magnesium single crystals impacted on (0001) plane (shock compression along the **c**-axis) at normal and elevated temperatures.

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Metallic armour systems

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1. Introduction
2. Why metals?
3. Steel armour
    1. Rolled Homogeneous Armour (RHA)
    2. High-hardness steel (HHS)
    3. Ultrahigh-hardness steel (UHS)
4. Aluminium armour
    1. Al5083
    2. Al7039
5. Other interesting metals
6. Q&A

Simultaneous high-speed imaging of temperature & deformation fields in dynamically deforming of granular material and metal

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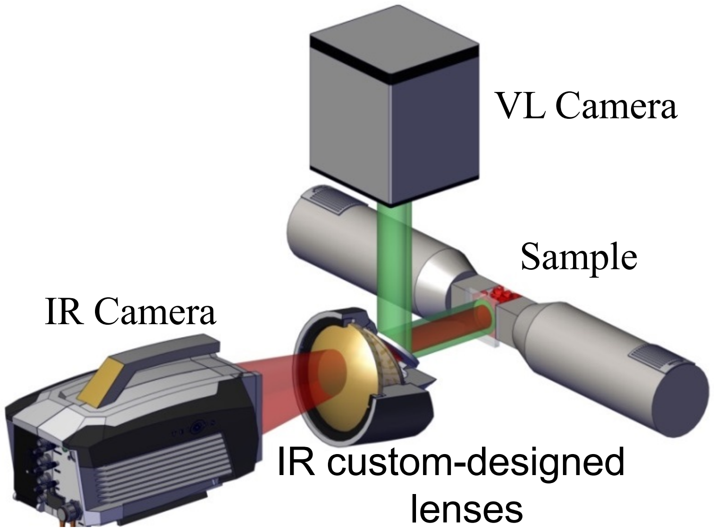
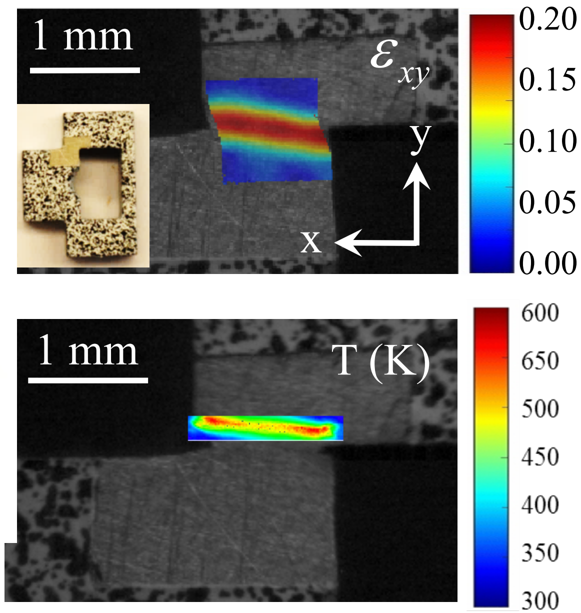
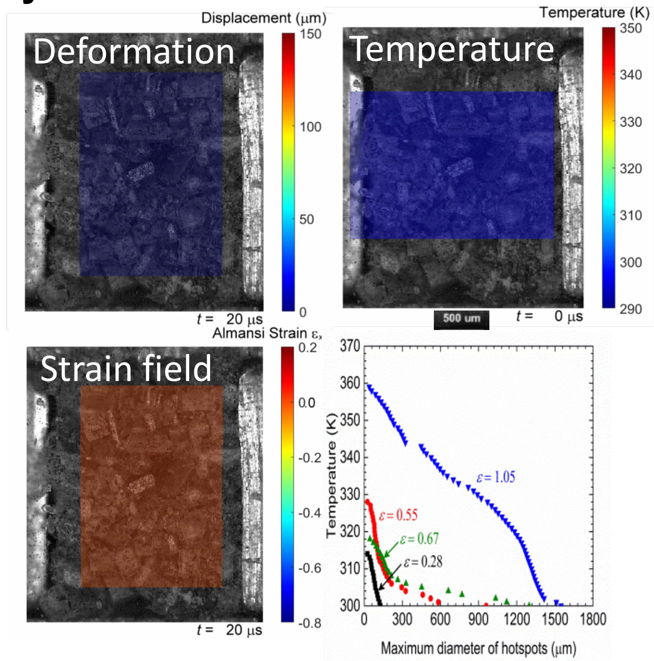
Cavendish Laboratory, Cambridge, 20th July 2018



Simultaneous Mesoscale Optical & Infrared Diagnostics





Novel capability for simultaneous measurement of microscale deformation and temperature fields with 13.15 μs and 7.06 μm resolutions developed.

High temperature (~600 K) in shear bands of Ti6Al4V samples, slower IR camera compare to the deformation process.

Deformation in granular sugar test: temperature increase in first stage is insignificant (< 315 K). Significant temperature increase occurs after crushing(~ 360 K).

Large strains, strain rates and temperatures in predicting chip formation in metal cutting of carbon and low alloy steels, Tom Childs, University of Leeds