A Brief Survey of High-Speed Image Analysis

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Acknowledgements

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- Prof J.E. Field - support throughout
- Funded by – EPSRC, AWE, QinetiQ, [dstl] amongst others
- References/Articles at end of talk

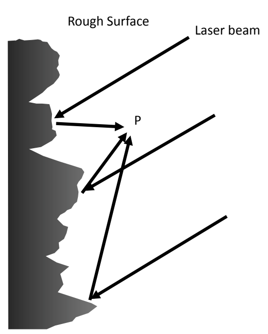
High-Speed Photography

- Current State (ultra-fast)
- 5 ns exposure
- 500 x 500 pixel
- Image-Intensified
- 2-32 frames
- OR
- 1000's frames
- minutes

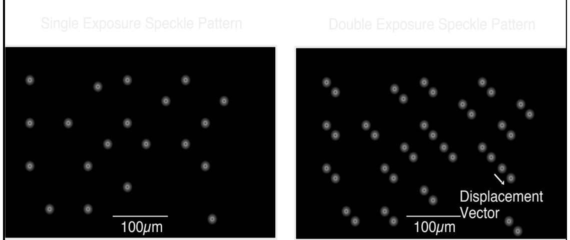
Techniques

- Double-pulsed ruby speckle photography
- Fine Grid (low-rate)
- Fine Grid (high-rate)
- Flash Radiography
  - shaped charge
  - sand

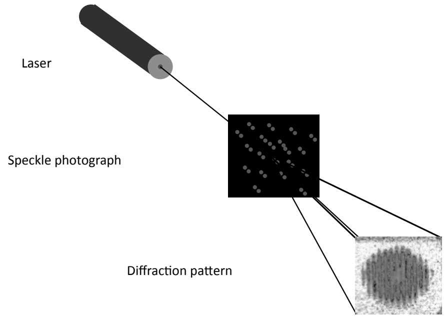
Speckle Patterns



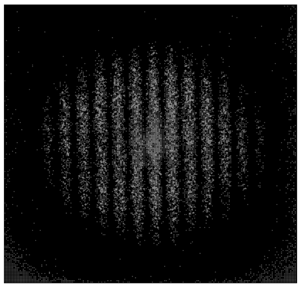
Speckle Patterns



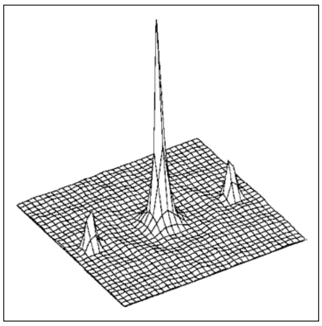
Speckle Photography Analysis



Fringe Pattern



2D Fourier Transform

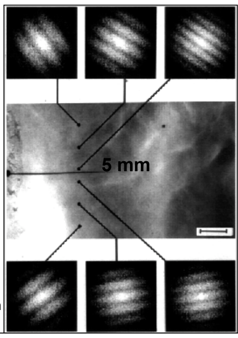


Double-Pulsed Ruby Laser Speckle Photography

- Use two closely spaced flashes of a ruby laser as light source
- Use crack running in PMMA as specimen

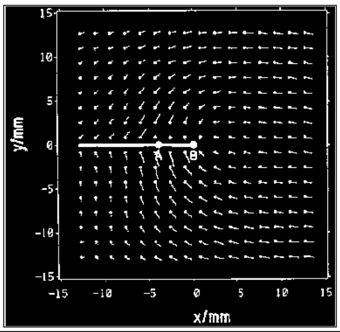
Diffraction patterns around crack

Crack v = 290 ms^{-1}
15 μs between pulses

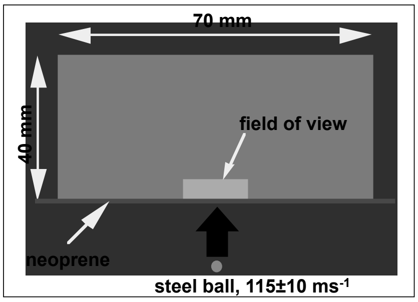


5 mm

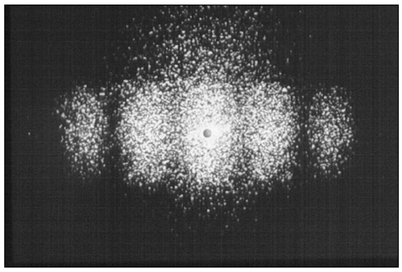
Displacement field × 40



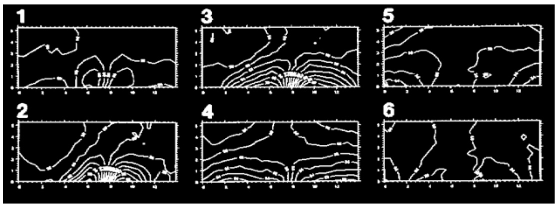
Sample Geometry



Diffraction Pattern



u_x Displacement Maps



IFT=1.65 μs, FOV 14 × 5.5 mm^2, Contour interval 2 μm

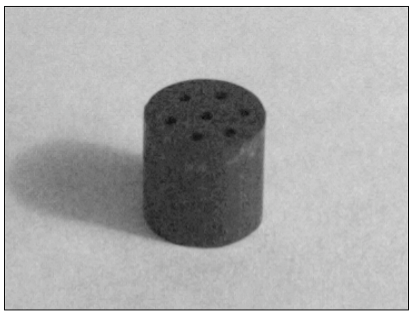
Speckle Photography

- Widely applicable
- Complicated post-processing
- Sign ambiguity in displacements
- Modern alternative — Digital Speckle Pattern Photography (using cross-, rather than auto-correlation…)

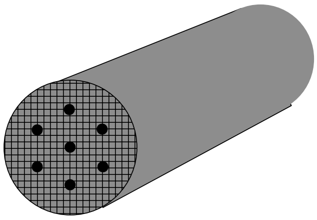
Fine Grid Method

- *Whole–Field* displacement measurements
- *Both* components of in-plane displacement
- Experimentally simple
- Widely applicable

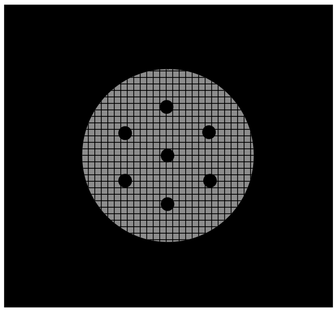
Propellant grain



In The Laboratory

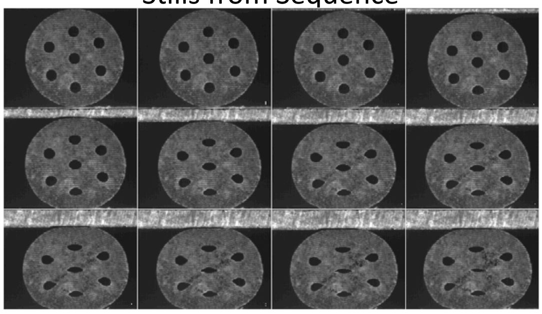


The Experiment



Load / Time Curve

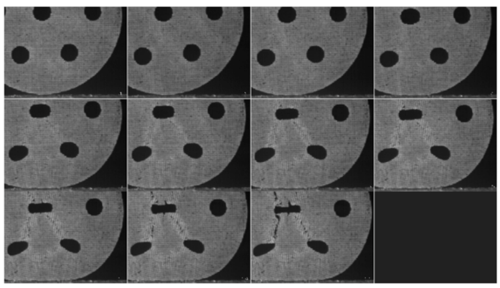
Deformation Experiment
Stills from Sequence



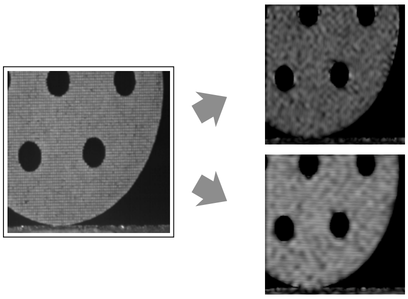
Further Processing

- This "Time-Lapse" photography gives some insight, but…
- To be really useful, data must be processed to give:
  - Displacement maps in x and y.
  - Strain maps in e_{xx} , e_{xy} , e_{yy}.

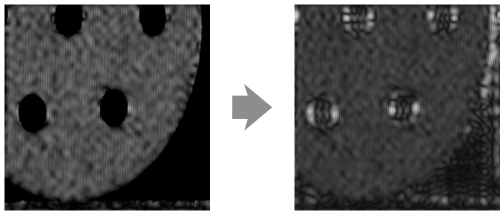
Raw Data

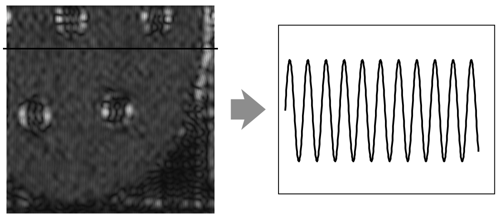


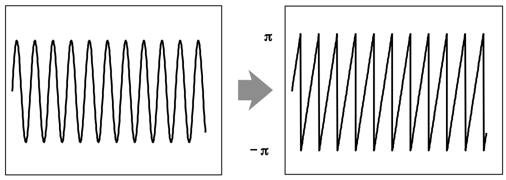
Spatial Filtering

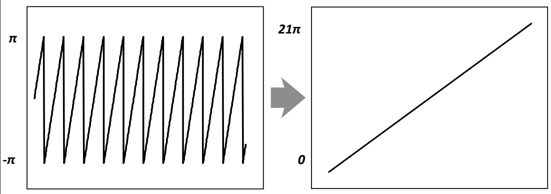


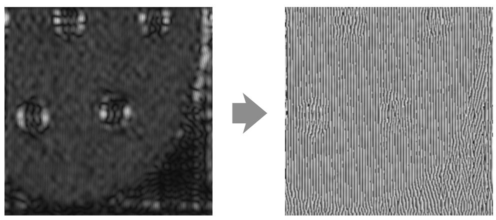
Gerchberg Iteration

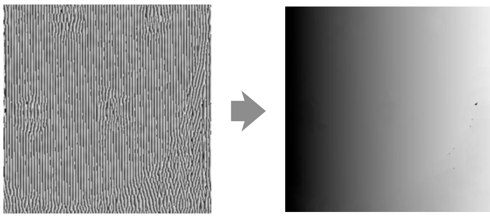








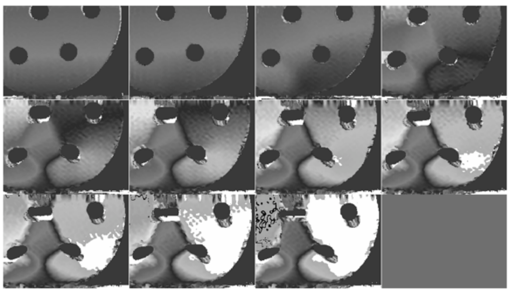




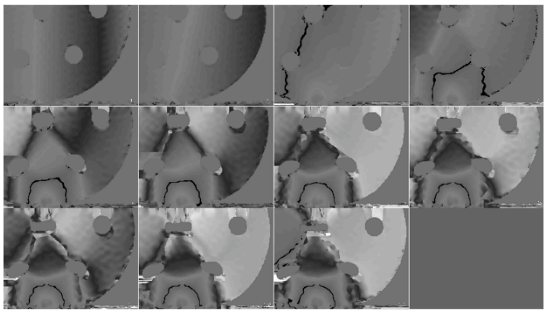
Calculations for each frame:

- For *x* and *y* in turn:
  - Gerchberg Iteration → Wrapped phase maps without discontinuities
  - Phase Unwrapping → A co-ordinate plane fixed to the sample
- For each point on the sample:
  - Find the x and y phase co-ordinates on the sample
  - Find x′ and y′ where these phase co-ordinates occur on the deformed sample
- Follow (*x* , *y*) to (*x′* ,*y′*) to calculate the displacement

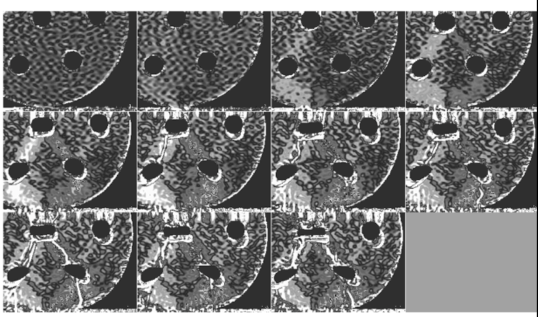
X displacements



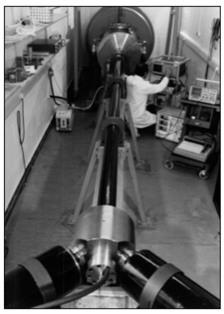
Y displacements

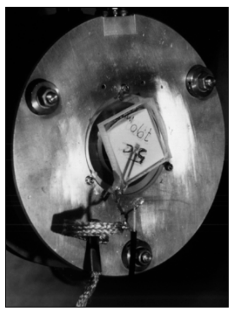


XY displacements

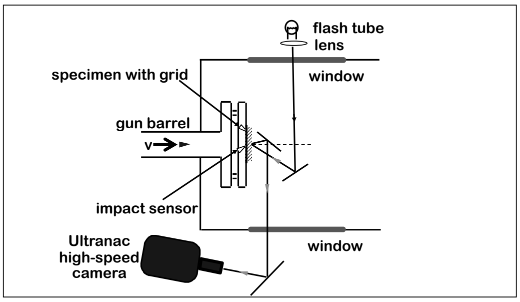


The Gas-Gun Facility

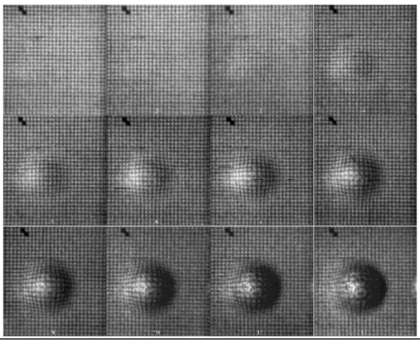




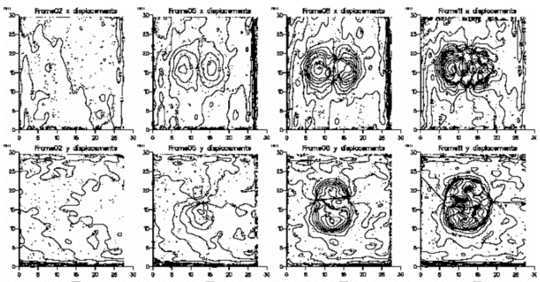
Fine Grid Setup



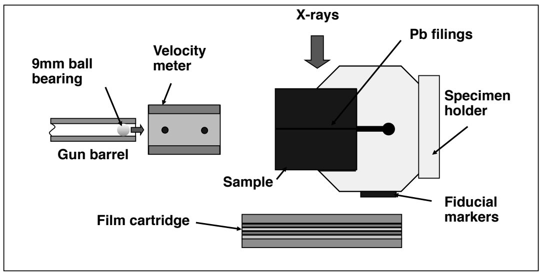
$532\ m\ s^{-1}$ impact on Al plate
Raw Images



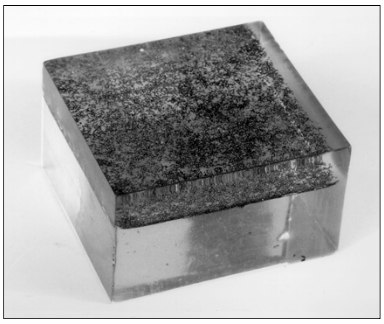
Strain / Displacement Maps



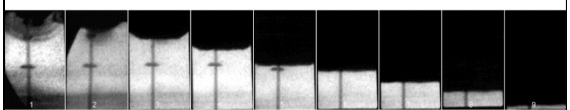
Flash X-ray Radiography



X-ray specimen



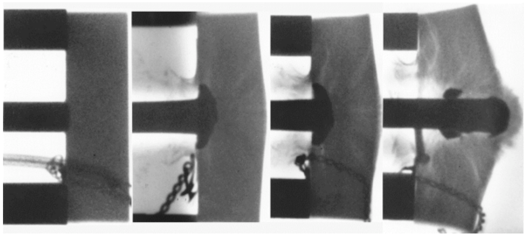
High-speed photography



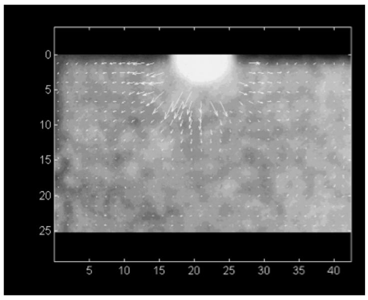
Inter-frame time = 20 μs

You can see crack front and velocity but not what is happening behind….

X-radiographs

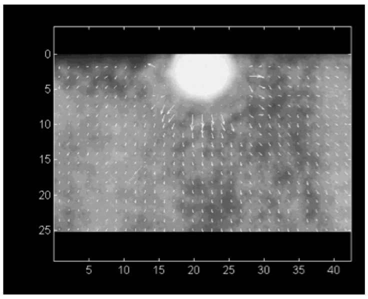


X-ray displacements, 20μs



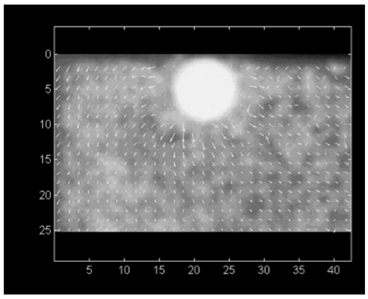
1 mm displace-ment

X-ray displacements, 30μs



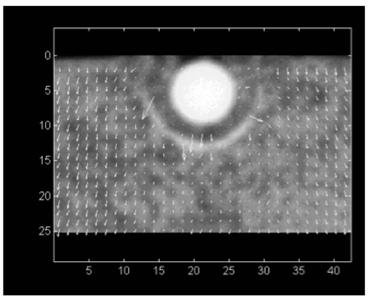
1 mm displace-ment

X-ray displacements, 41μs



1 mm displace-ment

X-ray displacements, 53μs



1 mm displace-ment

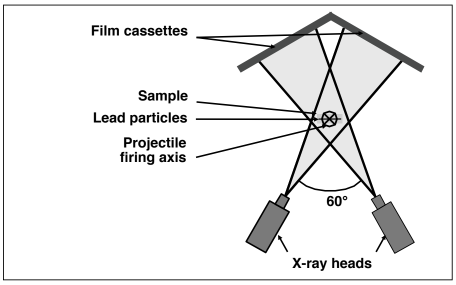
The next step…

- This analysis:
  - 2D
  - ~1 mm spatial resolution
  - ~0.1 mm displacement resolution
- We can:
  - Use 2 X-ray heads, at 60°
  - Use 3D DSP algorithm

…get all three components of displacement, all through specimen

Increase accuracy as well!

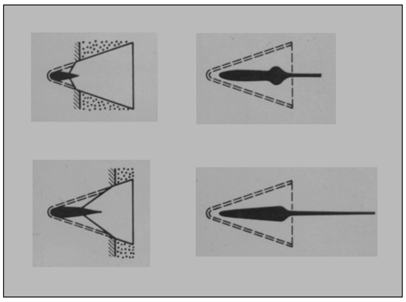
Stereoscopic DSR



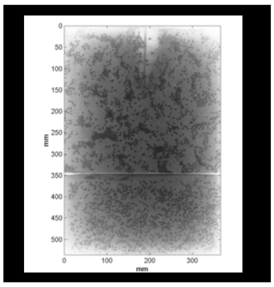
3-D Experiment

- 2 × 450 keV X-ray heads
- Cement specimen 20 × 20 × 10 cm^3
- Lead shot speckles
- Shaped charge jet projectile
  - Cylinder filled with explosive
  - Detonator
  - Hollow lined cavity
  - Jet travelling in excess of 10 Km s^{-1}

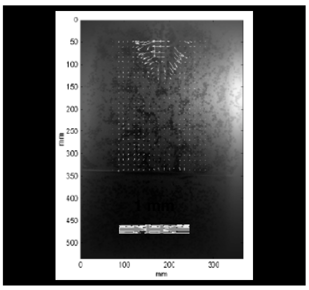
Shaped charge jet



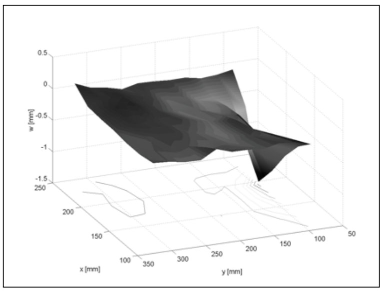
X-ray image



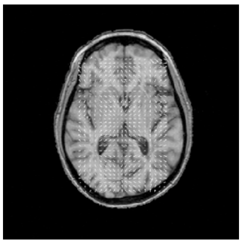
In-plane measurements

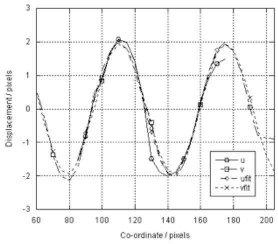


Out-of-plane measurements



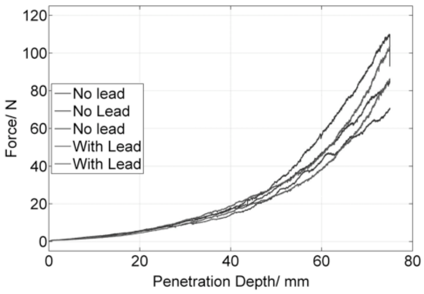
Cerebral



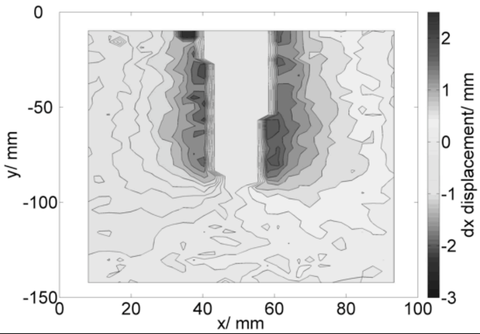


Sand – Low rate - High Rate

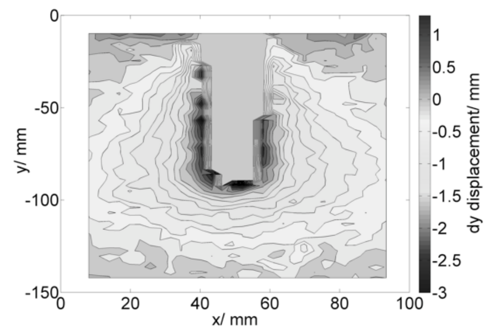
Sand – Low rate - High Rate



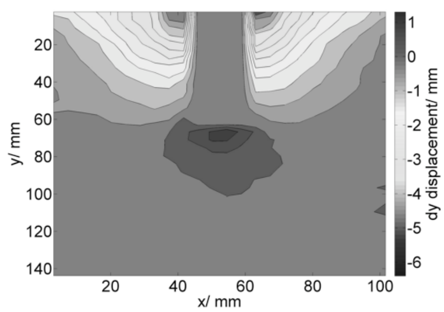
550 m s-1 - Impact



550 m s-1 - Impact



1.5 mm / min “impact”



1.5 mm / min “impact”

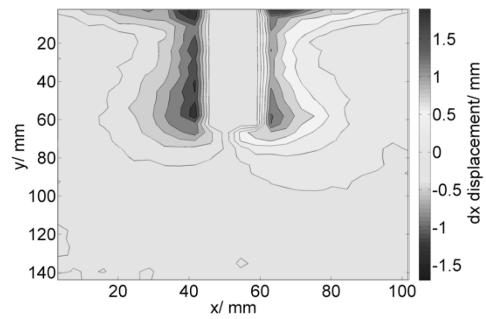
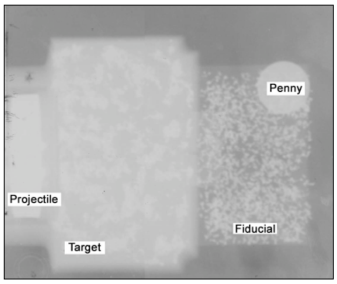
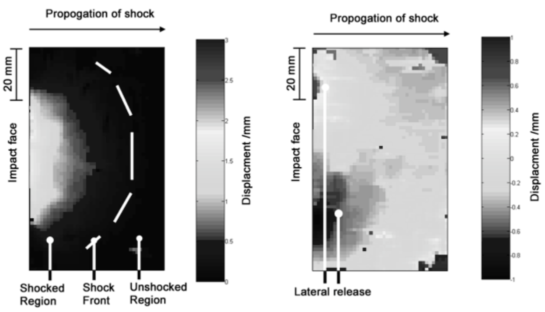


Plate Impact - Description of setup



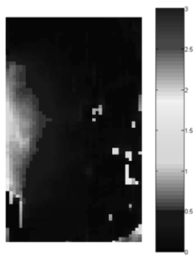
Penny diameter 20.32 mm
150 KeV x-ray flash of 70 ns duration

Results: general form

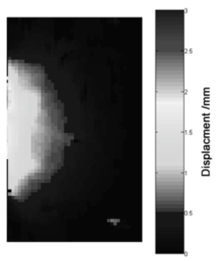


300 ms^{-1}, 17μs after impact

Results: 300 ms^{-1}

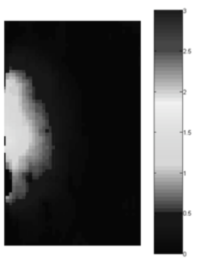


8 μs

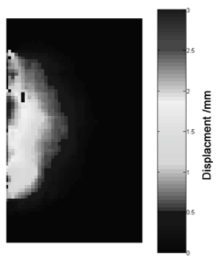


17 μs

Results: 600 ms^{-1}



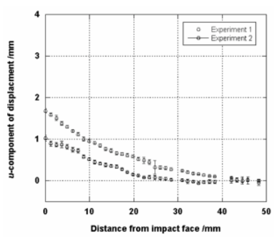
6 μs

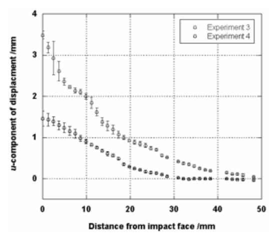


13 μs

Results: cross-section

Averaged displacements over 10 mm front (centred about projectile axis)

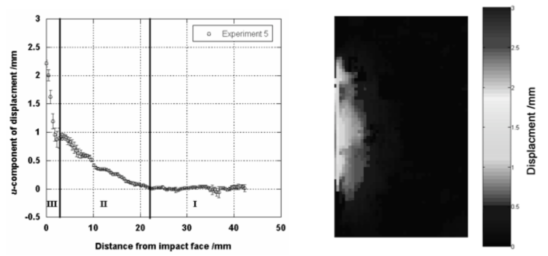




300 ms^{-1}:
Shock speed ~1.6 km s^{-1}
Strain 4.0 ± 0.1 %

600 ms^{-1}:
Shock speed ~2.4 km s^{-1}
Strain 7.3 ± 0.1 %

Results: double shock



Strain:
Region III = 0 %
Region III = 5.5 ± 0.1%
Region III = 60 ± 5%

Conclusions

- High-Speed photography – powerful tool
- Used in combination with image analysis
- Cross-compare results
- Often need to balance counter-acting factors
- Resolution – Reproducibility

Thank you!

Selected References

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