SAND2020-9149C

Shock wave interaction and fracture growth in polymethyl methacrylate (PMMA)

Sivana Torres
Michael J. Hargather

Mark C. Grubelich
Joseph Pope
Richard E. Robey

Oleg Y. Vorobiev
J. P. Morris

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

Sandia National Laboratories

Lawrence Livermore National Laboratory

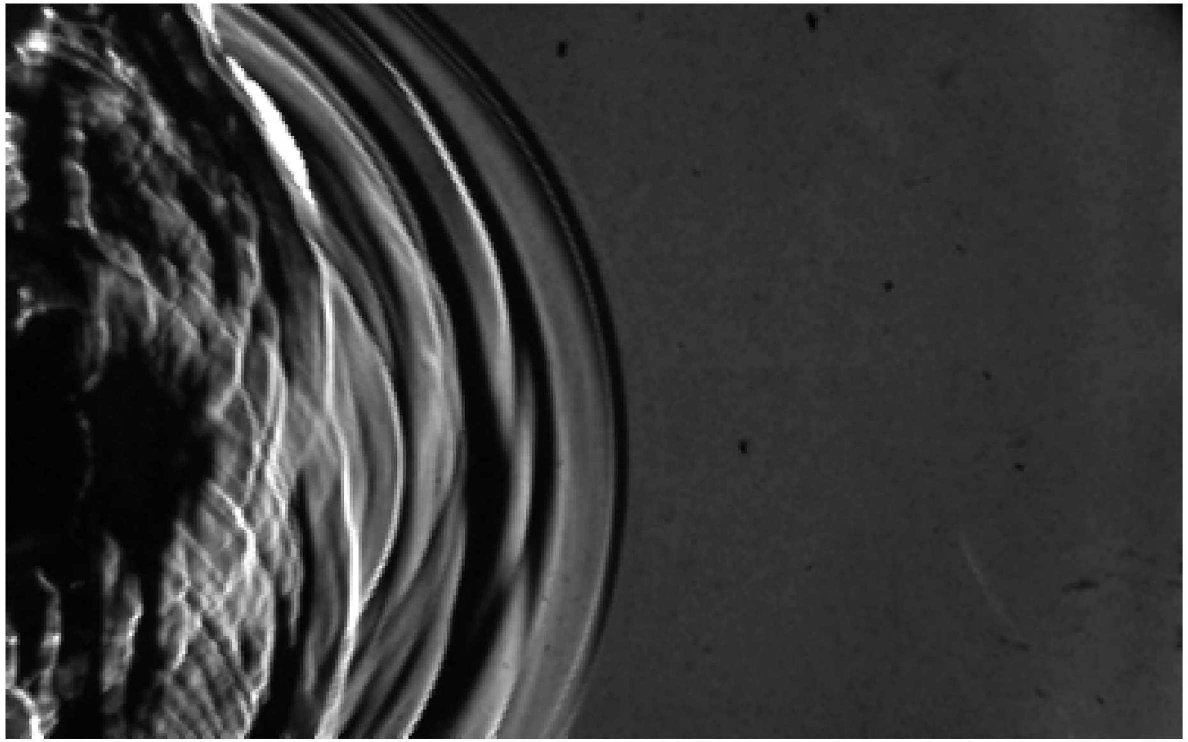
Virtual SEM XIV International conference September 14th, 2020

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Research was conducted to study shock wave propagation and fracture growth in PMMA samples

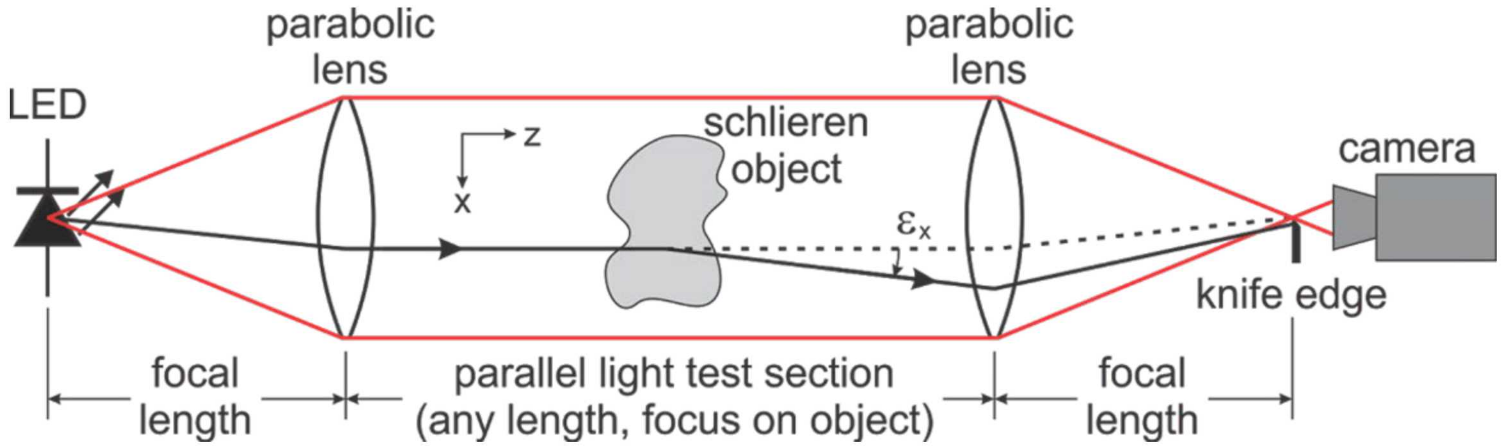
NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

- Quantitative schlieren techniques are well defined for shock waves in air
- Schlieren and shadowgraphy have been used to quantify shock Hugoniots in optically clear materials
- Goal of this work:
  - Apply quantitative schlieren techniques to shock waves propagating through optically clear materials
  - Extract Hugoniot parameters using quantitative schlieren techniques

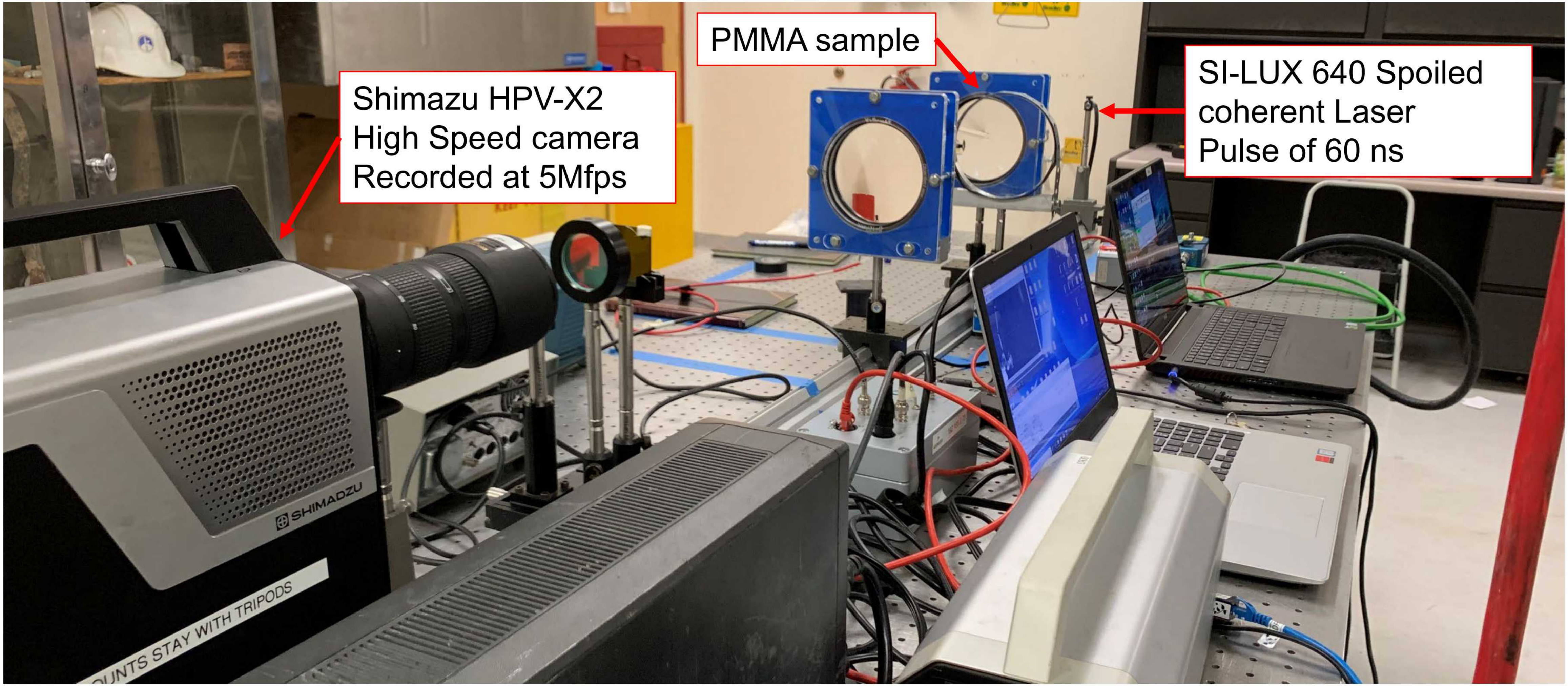


Schlieren imaging was used to capture shock wave propagation through PMMA samples

- Light from a point source is collimated through a parabolic lens
- Second lens brings light to a focal point
- Knife edge is placed at the focal point
- Density gradients within test section cause variations in refractive index which distort the light beam

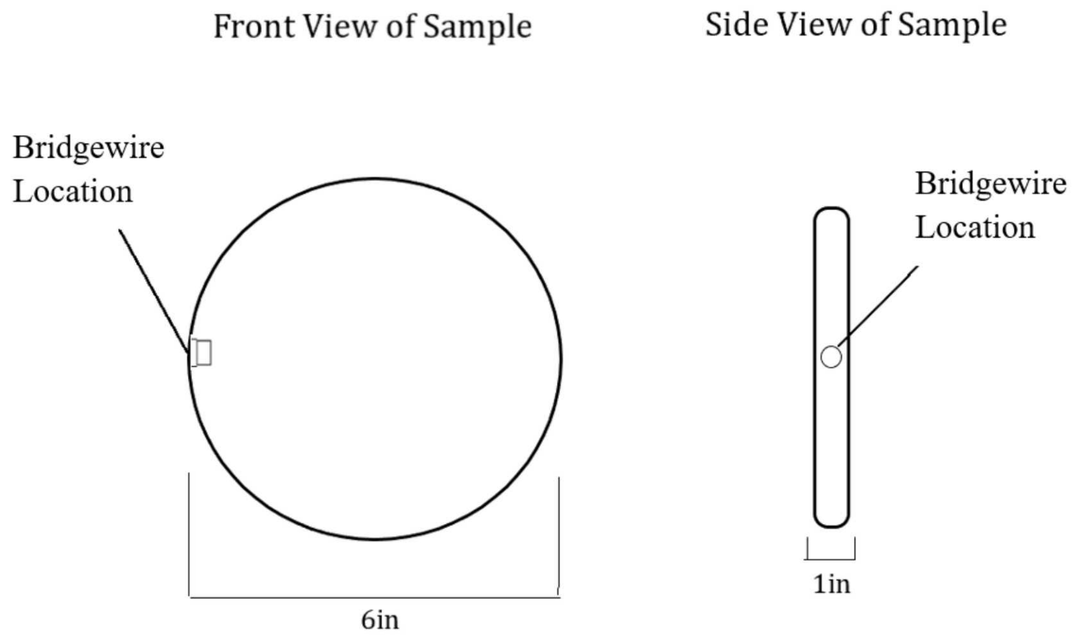


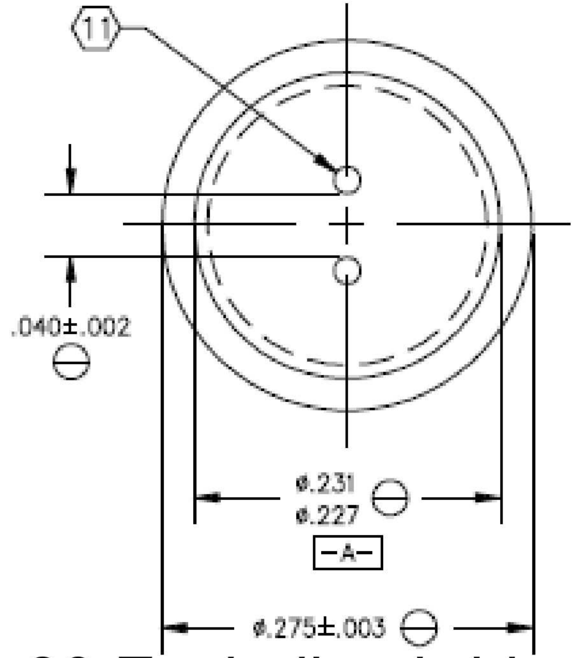
High speed imaging was used to image the shock wave propagation through the PMMA samples



Detail of PMMA samples used

- PMMA details:
  - Density: 1.19 g/cc
  - Acoustic sound speed: 2710 m/s

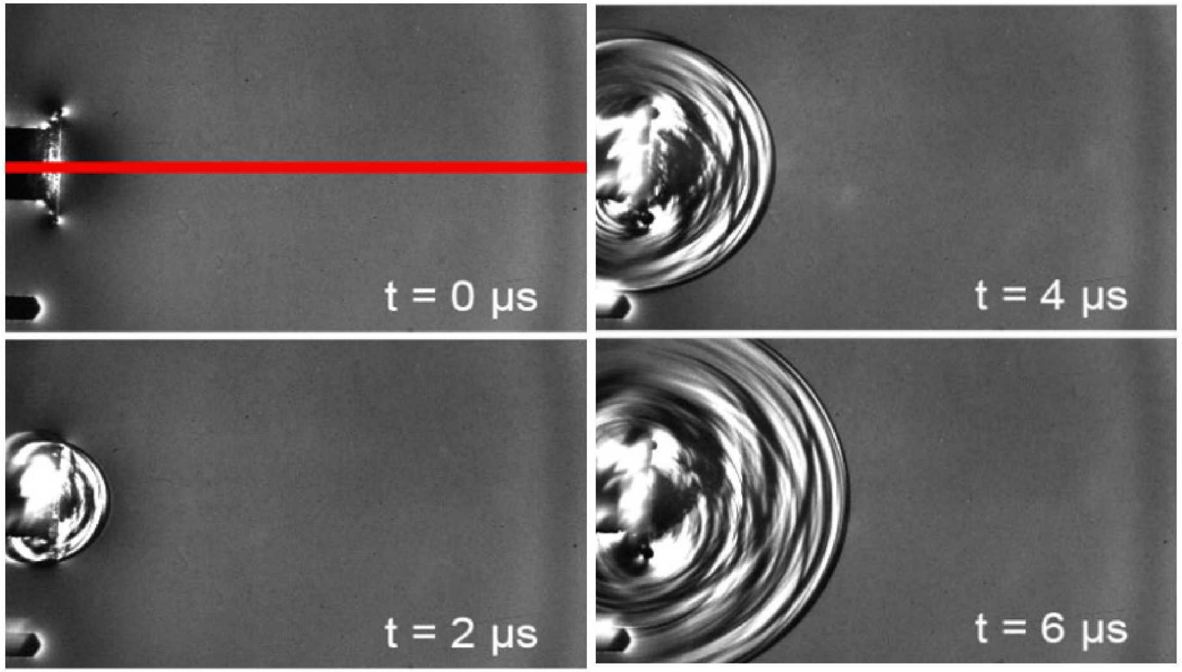


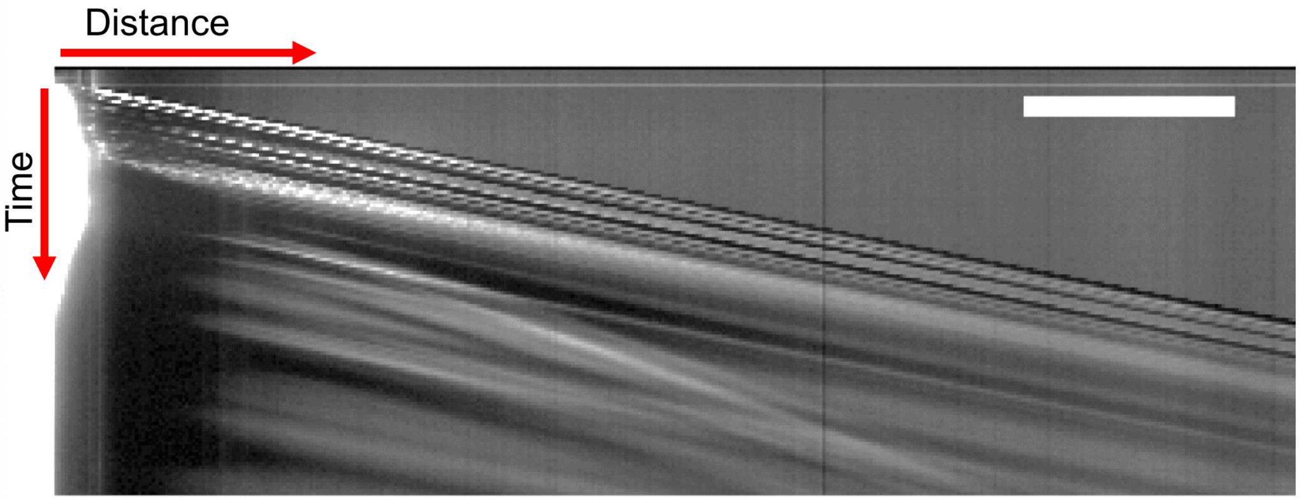


- RP – 80 Exploding bridgewire:
  - Bridge Diameter: 2.7 mil
  - Bridge material: Gold (Au)

Image processing was used to extract a row of pixels from each frame to create a time vs distance graph – a streak image

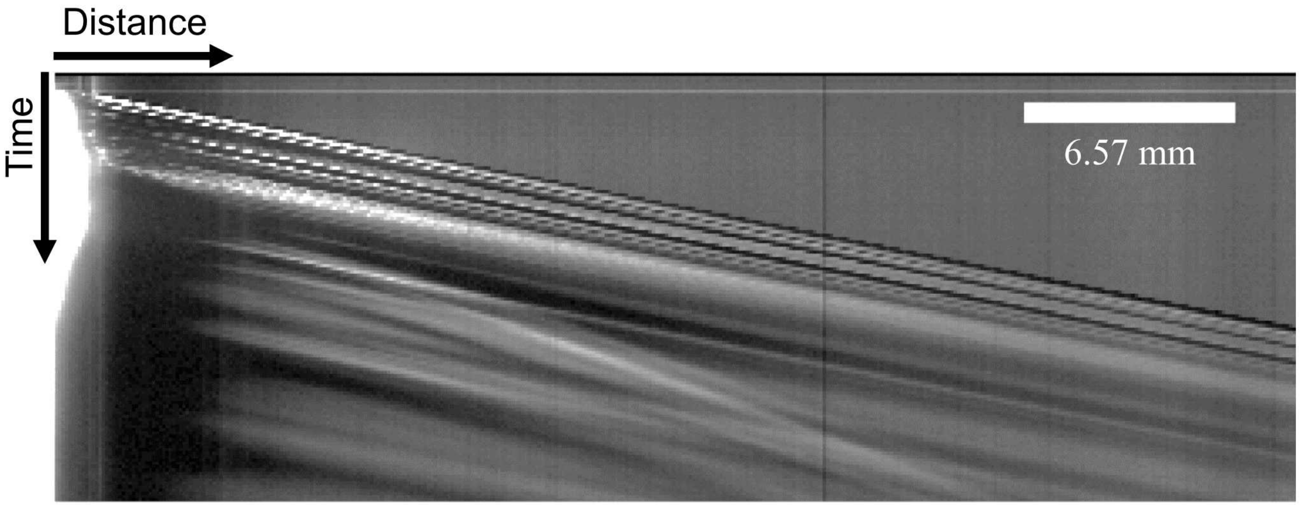
- Streak images are created to determine shock velocities
- Shows temporal evolution of processes



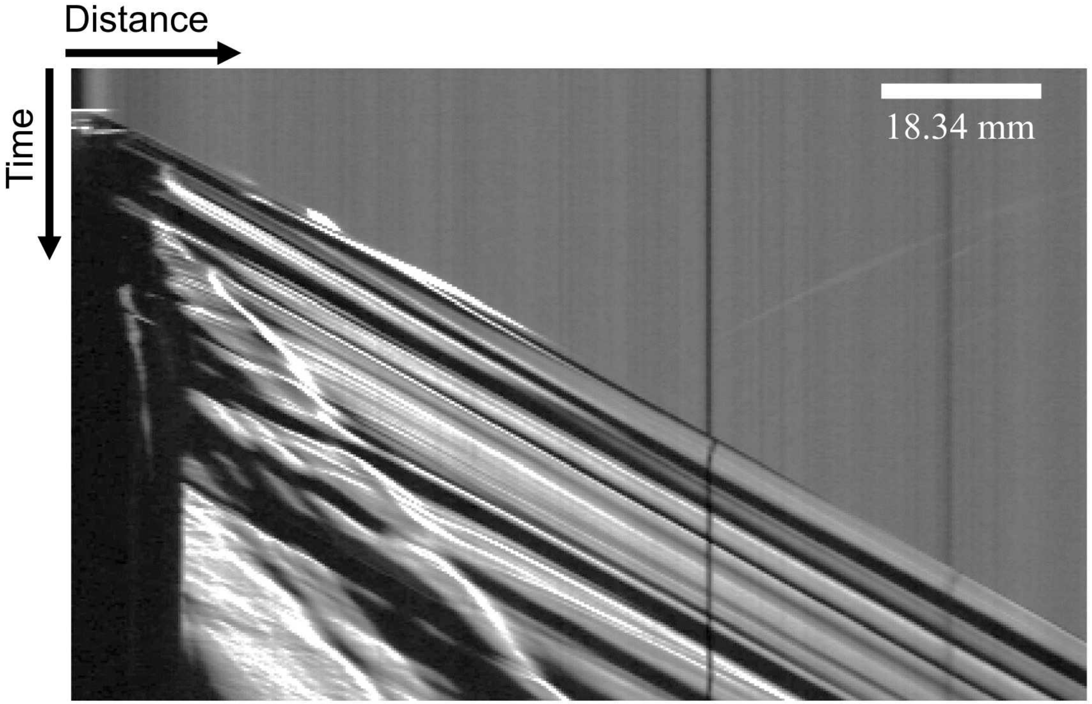


Streak images show difference between tests of different shock loading scenarios

- RP – 2 Detonators and RP – 80 bridgewires were used to induce shock waves into the PMMA samples
- The shock wave induced by the bridgewire quickly attenuates into a weak pressure wave



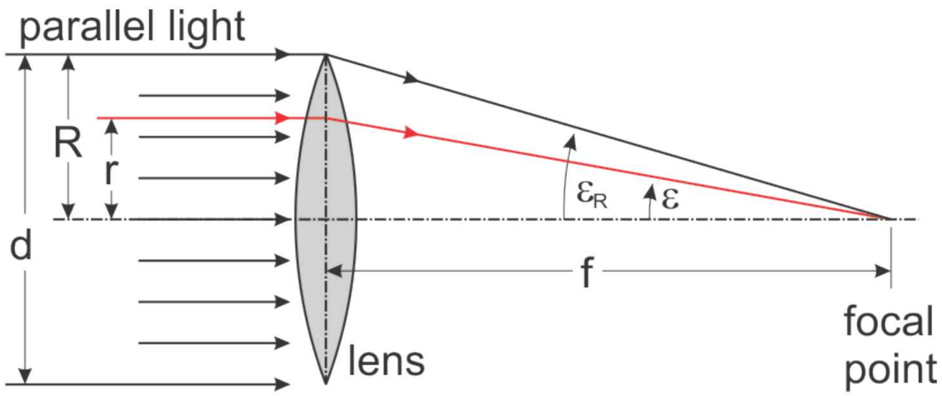
RP – 80 bridgewire, 5Mfps, 128 frames



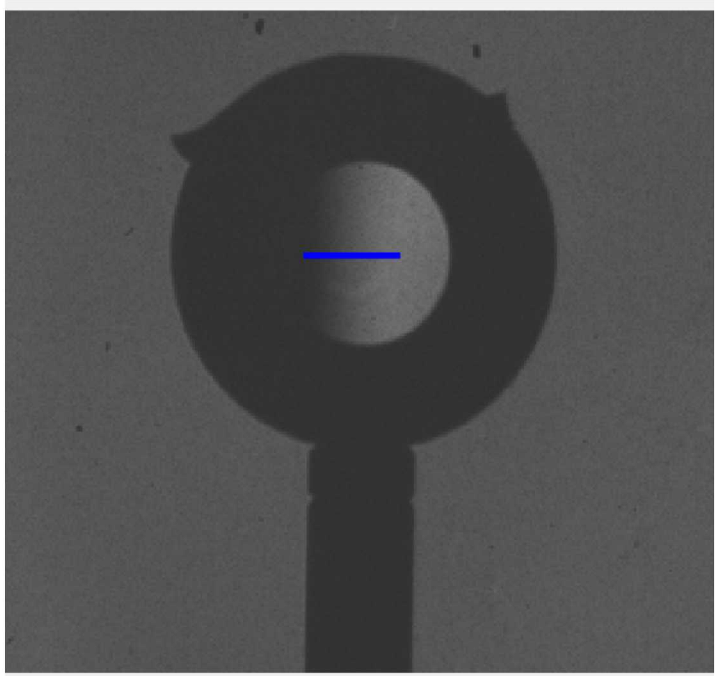
RP – 2 detonator, 5Mfps, 256 frames

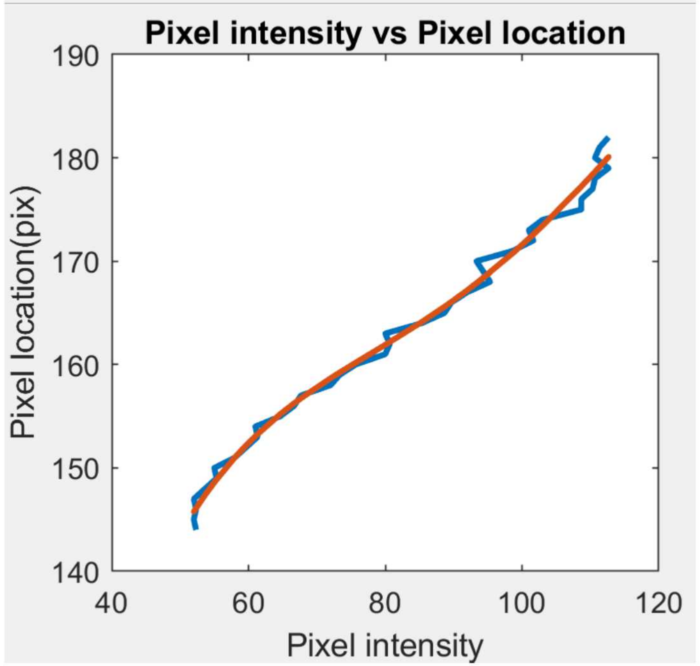
Quantitative schlieren imaging is a method to relate refraction angle to a density gradient in a schlieren image

- The grayscale intensity value in a schlieren image is proportional to the local refractive index gradient
- A lens is used as a calibration object to quantify intensity to refractive index gradient
- Vertical knife-edge schlieren resolves horizontal refractions
- Once refractive index gradient field is obtained, it can be integrated and related to a density field



$$\varepsilon_y \cong \int_{\zeta} \frac{1}{n} \frac{\partial n}{\partial y} dz$$



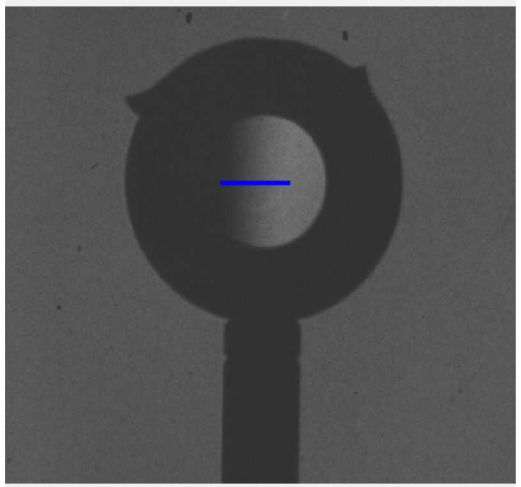


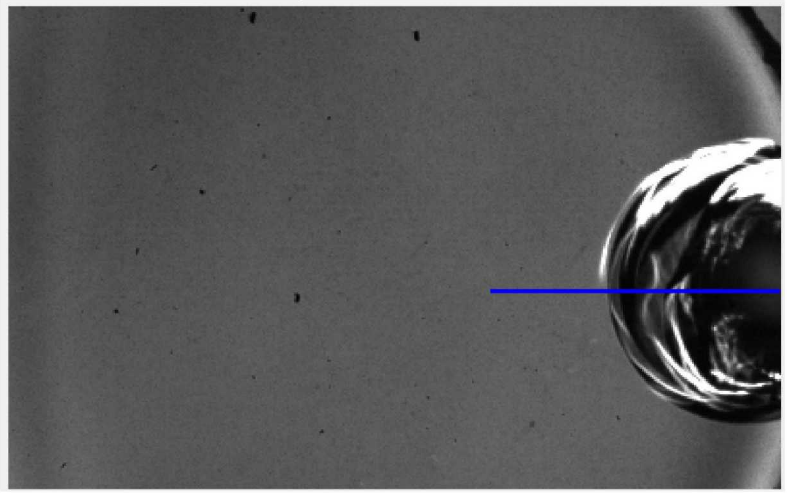
Process for performing quantitative schlieren analysis

1. Image schlieren object of interest and weak lens
2. Relate pixel intensity in schlieren object to location in lens
3. Lens location gives refraction angle, ε
4. Refraction angle is converted to a refractive index gradient
5. The refractive index gradient is integrated to yield the refractive index field throughout space
6. Refractive index can be converted to density via the Gladstone Dale Law

$$\varepsilon_y \cong \int_\zeta \frac{1}{n}\frac{\partial n}{\partial y}\,dz$$

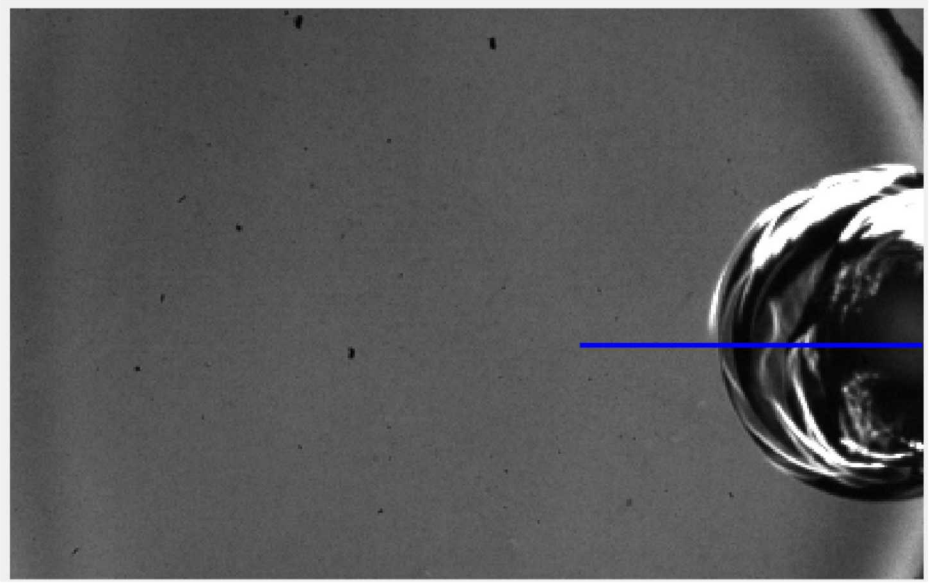
$$n = k\rho + 1$$

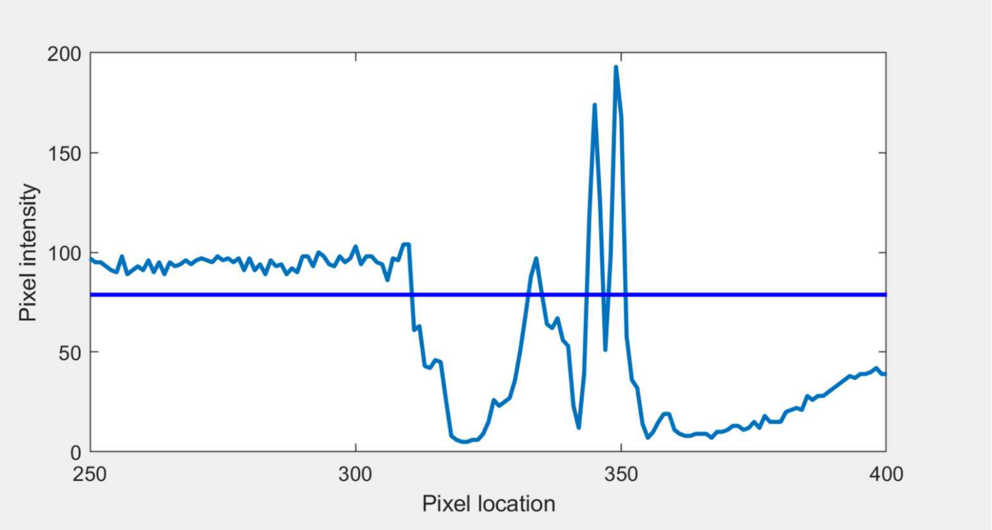


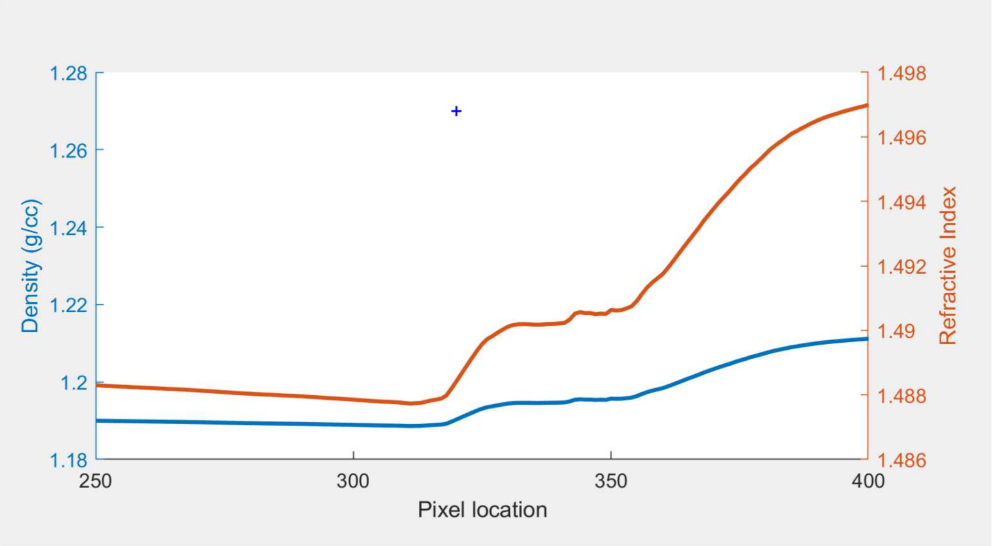


The density field across the shock wave from an RP – 2 detonator was measured at early time

- The extracted pixel intensity is converted to the refractive index field and thus density
- The shock wave was assumed to be two dimensional, planar due to the thickness of the acrylic and to simplify the analysis

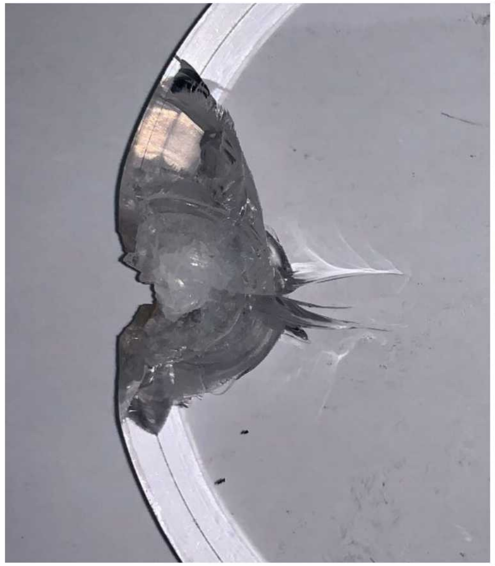






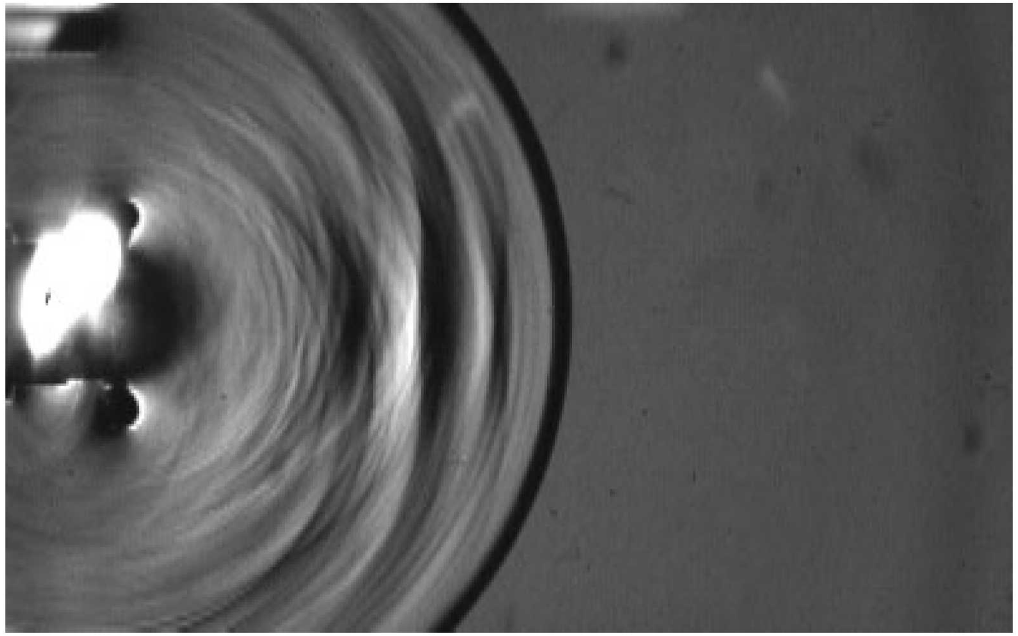
The PMMA fractures locally near the explosive loading

- One goal of the optical measurement is to infer the state at the interface with the explosive to learn more about the fracture process
- Localized fracture growth is visualized in the schlieren images



Fracture due to RP – 2 Detonator

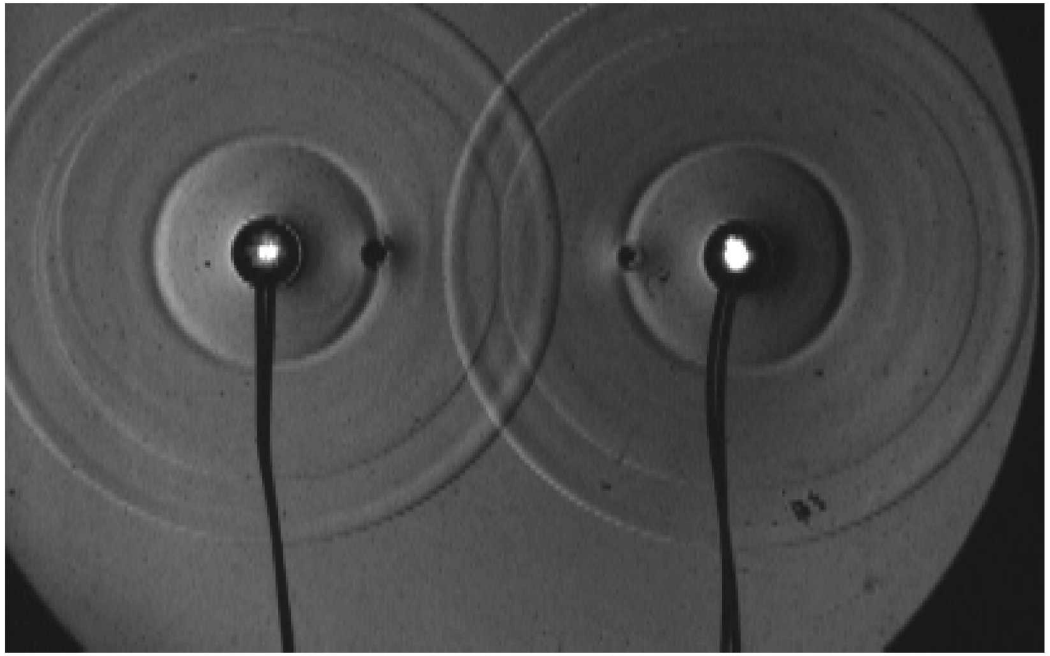
Fracture due to RP – 80 Bridgewire



Fracture growth using an RP – 80 bridgewire

The quantitative techniques being developed will be applied to more complicated geometries and to investigate shock interactions

- Quantitative measurement of density change across the shock waves is not in agreement with steady state hugnoiot calculations
- Current 2D assumption for quantitative analysis will be expanded in future work using Abel transform to account for 3D phenomena
- Larger scale tests will be done using PETN to produce stronger shock waves
- Experimental data will be used to validate computations models to be developed
- Future work will explore shock interactions and more complex loading scenarios



Thank you and Acknowledgements

Funding for this work at New Mexico Institute of Mining and Technology (New Mexico Tech) is provided by Sandia National Laboratories. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Shock and Gas Dynamics Lab:
www.nmt.edu/mjh/

sivana.torres@student.nmt.edu

michael.hargather@nmt.edu