Novel Capability for Microscale In-situ imaging of Temperature and Deformation Fields under Dynamic Loading (MINTED)

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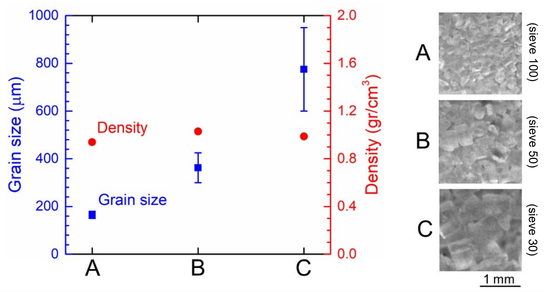
Objective

Develop a novel capability for simultaneous high-speed IR & VL imaging of temperature & deformation fields in dynamcailly deforming HEMs

- Resolutions of 15.6 microns in space and 1 microsecond in time via optical high-speed imaging and 12.5 microseconds via high-speed infrared imaging
- Grain size and type recognition, movement tracking, deformation and temperature analysis, and digital image correlation (DIC)

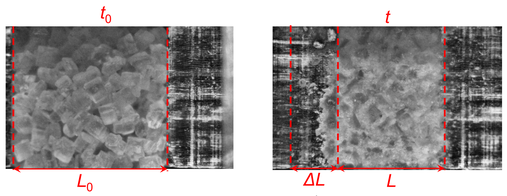
Materials

Sucrose is a common simulant of energetic crystals.



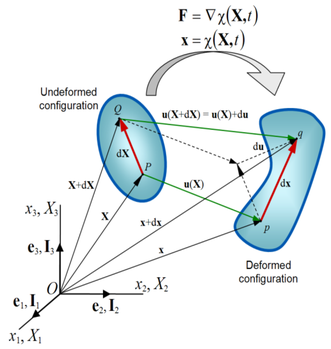
Measures for strain

Engineering strain and strain rate



$$\bar{\varepsilon} = \frac{\Delta L}{L_0} \qquad \dot{\bar{\varepsilon}} = \frac{\dot{L}}{L_0}$$

Almansi strain & rate of deformation



$$\mathbf{F} = \nabla\chi(\mathbf{X},t)$$
$$\mathbf{x} = \chi(\mathbf{X},t)$$

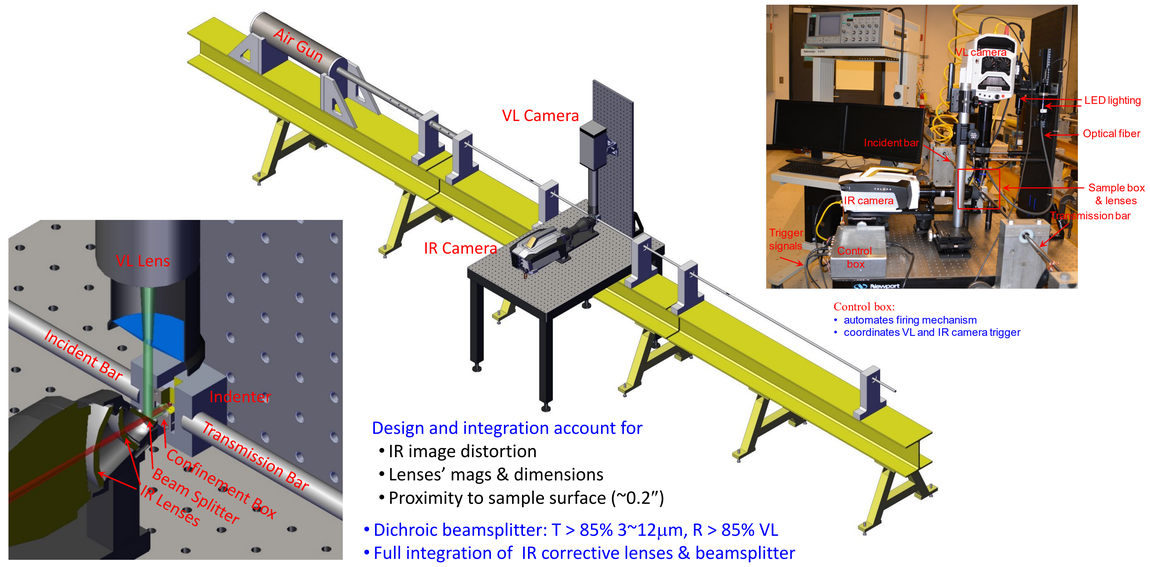
$$\boldsymbol{e} = \frac{1}{2}\left(\mathbf{I} - \mathbf{F}^{-T}\mathbf{F}^{-1}\right)$$

$$e_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j} - \frac{\partial u_i}{\partial u_j}\frac{\partial u_j}{\partial u_i}\right)$$

$$\dot{\boldsymbol{\varepsilon}} = \frac{1}{2}\left(\frac{\partial \dot{\mathbf{u}}}{\partial \mathbf{x}} + \left(\frac{\partial \dot{\mathbf{u}}}{\partial \mathbf{x}}\right)^T\right)$$

$$\dot{\varepsilon}_{ij} = \frac{1}{2}\left(\frac{\partial \dot{u}_i}{\partial x_j} + \frac{\partial \dot{u}_j}{\partial x_i}\right)$$

Experimental Layout



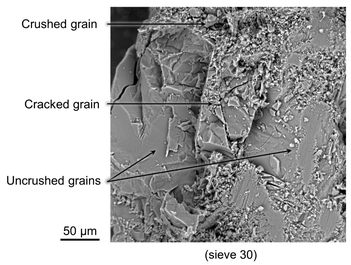
Design and integration account for
- IR image distortion
- Lenses' mags & dimensions
- Proximity to sample surface (~0.2")

- Dichroic beamsplitter: T > 85% 3~12μm, R > 85% VL
- Full integration of IR corrective lenses & beamsplitter assembly with camera

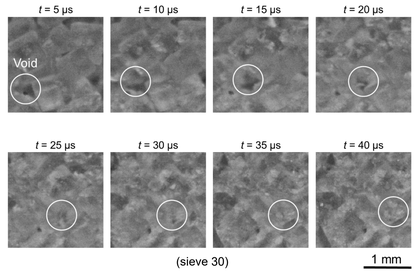
Deformation Mechanisms

Deformation mechanisms:

1. Bulk compression
2. Void collapse
3. Grain fracture/crushing
4. Frictional sliding



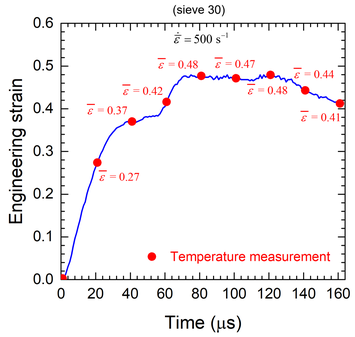
Void collapse

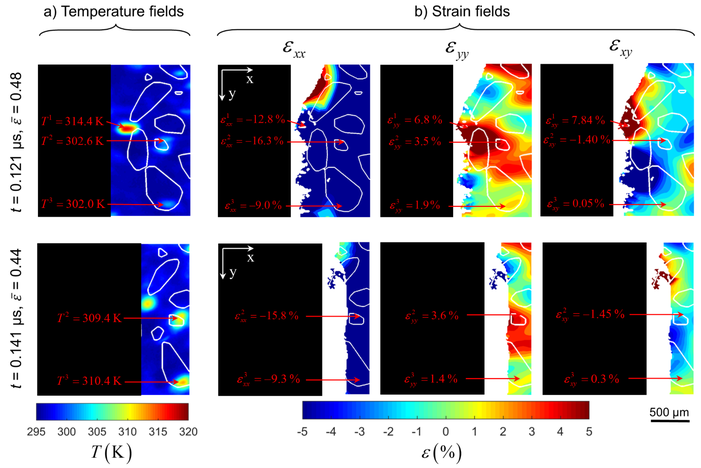


Simultaneous High-speed VL and IR Imaging

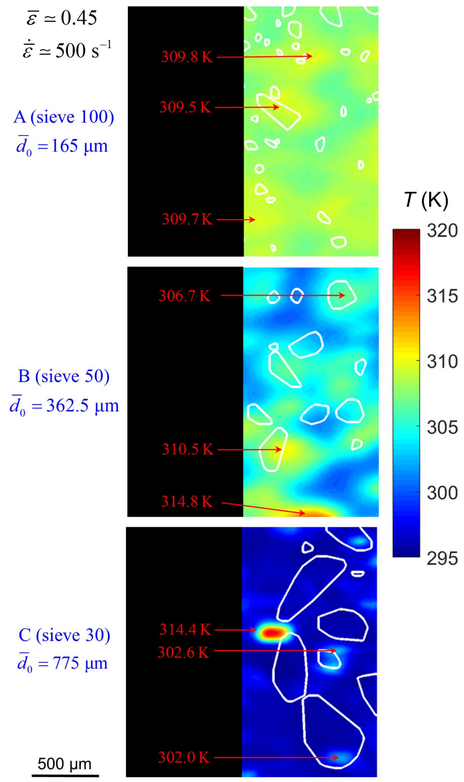
Stages of deformation:

1. Grain crush and void collapse: 0 ~ 60 μs
2. Recompression: 60 ~ 120 μs
3. Unloading: t > 120 μs





Grain Size Effect



Summary

1. A ground-breaking capability for simultaneous microscopic VL-IR imaging is developed.
2. Experiments are focused on effects of heterogeneities on thermo-mechanical behavior.
3. Hotspots emerge at the boundaries of relatively large grains as a result of frictional sliding.
4. Samples with larger initial grain size experience higher peak temperatures and more intense hotspots. Smaller grain sizes result in more widely spread heating.

References

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- Barua, A., Y. Horie, and M. Zhou. "Energy localization in HMX-Estane polymer-bonded explosives during impact loading." *Journal of Applied Physics* 111.5 (2012): 054902.
- Ravindran, Suraj, Addis Tessema, and Addis Kidane. "Multiscale damage evolution in polymer bonded sugar under dynamic loading." *Mechanics of Materials* 114 (2017): 97-106.

Acknowledgements

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