INFRARED IMAGING TO QUANTIFY TEMPERATURE CHANGES DURING RAPID MATERIALS DEFORMATION

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W.J. Wright, M.W. Burke, W.O. Miller*, and S.J. DeTeresa
Manufacturing and Materials Engineering Division
*New Technologies Engineering Division

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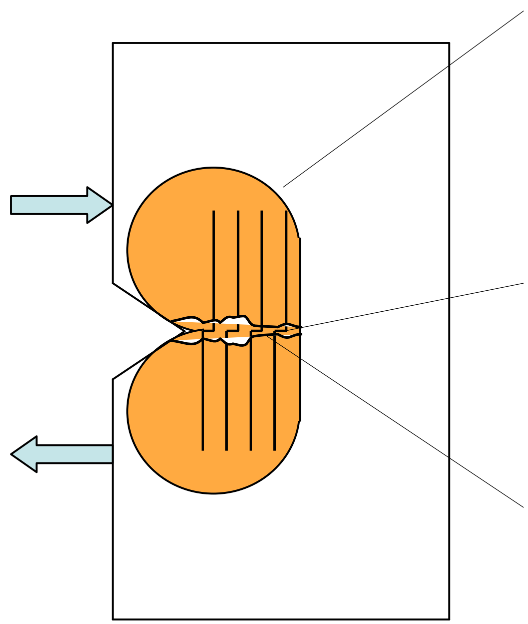
Temperature Measurement and Thermal Analysis to Study the Progressive Stages of Dynamic Failure

During deformation of materials, mechanical work is converted to other forms of energy:



Notched material under shear loading

Plastic deformation:

- energy dissipated as heat, [illegible]
- energy stored (e.g., dislocations)
- ΔT~50°-100°C

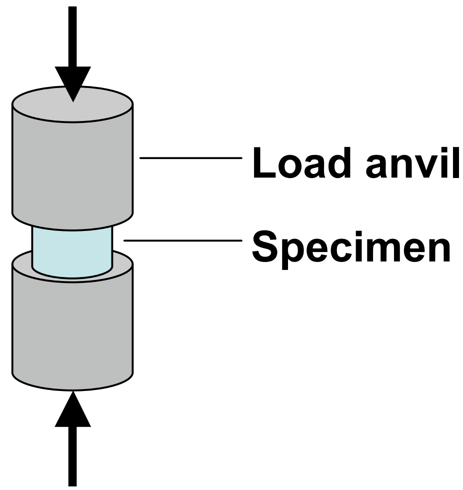
Shear bands:

- localized plastic deformation
- ΔT~500°C (phase change)

Fracture:

- energy consumed by free surfaces
- microfracture

Intermediate and High Strain Rate Uniform Deformation



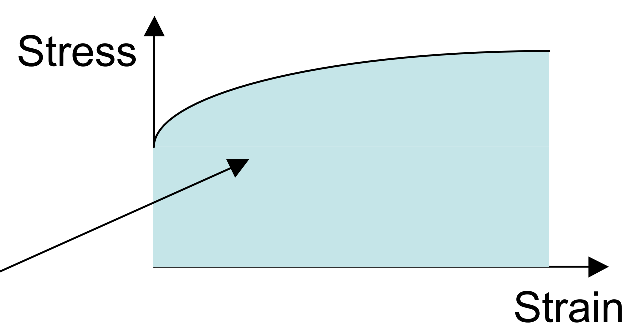
Intermediate Strain Rate: 10 s^{-1}
High Strain Rate: 3000 s^{-1}

Materials of Interest:
Pure Tantalum and Kel–F

- **Reported values of ß range from 0.6 – 1.0**

$$\Delta T(\varepsilon) = \frac{\beta}{\rho C_v} \underbrace{\int_0^{\varepsilon_m} \sigma \, d\varepsilon}_{\text{Plastic work}}$$

Taylor-Quinney coefficient



Available Temperature Measurement Techniques

- **Contact Measurement Sensors**
  - Well–calibrated
  - Finite response time
  - Point measurement
  - May influence sample temperature

- **Infrared Sensors**
  - Remote temperature measurement
  - Improved response time (250 nanoseconds possible)
  - Full field measurement possible
  - Gradients easily detected
  - Every material of interest must first be calibrated due to differences in emissivity

$$\mathcal{E} + \mathcal{R} = 1$$

$\mathcal{E} \equiv$ emissivity

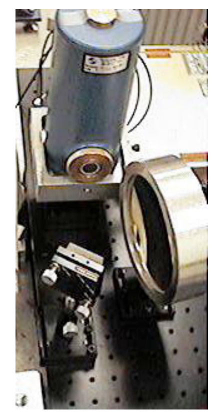
$\mathcal{R} \equiv$ reflectivity

Available Technology for Dynamic Infrared Temperature Measurement

- **Phoenix InSb**
  - — Full field sensing
  - — 640 x 512 pixels @ 100 Hz, 128 x 12 pixels @ 10 kHz, currently using 128 x 76 pixels @ 2 kHz
  - — 25 μm resolution
  - — 3–5 μm MWIR
  - — Built–in optics

Phoenix InSb

- **Fermionics HgCdTe**
  - — 250 ns rise time, multi–frame
  - — 16 detectors in linear array, 80 x 80 μm spot size, 20 μm spacing
  - — 8–12 μm LWIR
  - — Cassegrain optics



Fermionics HgCdTe

- **Single point temperature measurement using fast response thermocouples (~2°C/μs – M.M. LeBlanc)**
  - — For work in uniform plastic deformation (no gradients)

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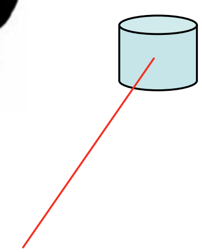
Experimental Issues in Infrared Temperature Measurement

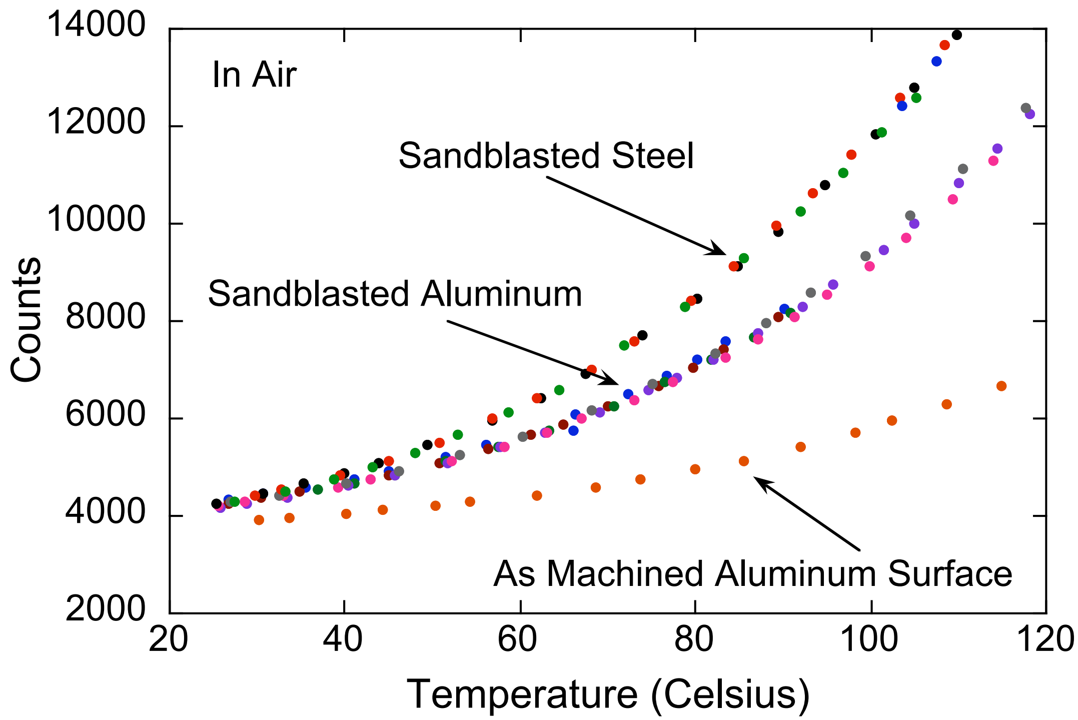
- Ideally calibration conditions are identical to test conditions
- Surroundings contribute an infrared signal – therefore, want extraneous sources hidden or removed from view
- Emissivity is different for each material and varies as a function of surface treatment
- Emissivity may change during mechanical deformation due to evolution in surface texture or surface oxidation
- Narcissus effect and optical vignetting
- Lens heating during static calibration
- Cylindrical versus cubic samples

Phoenix InSb



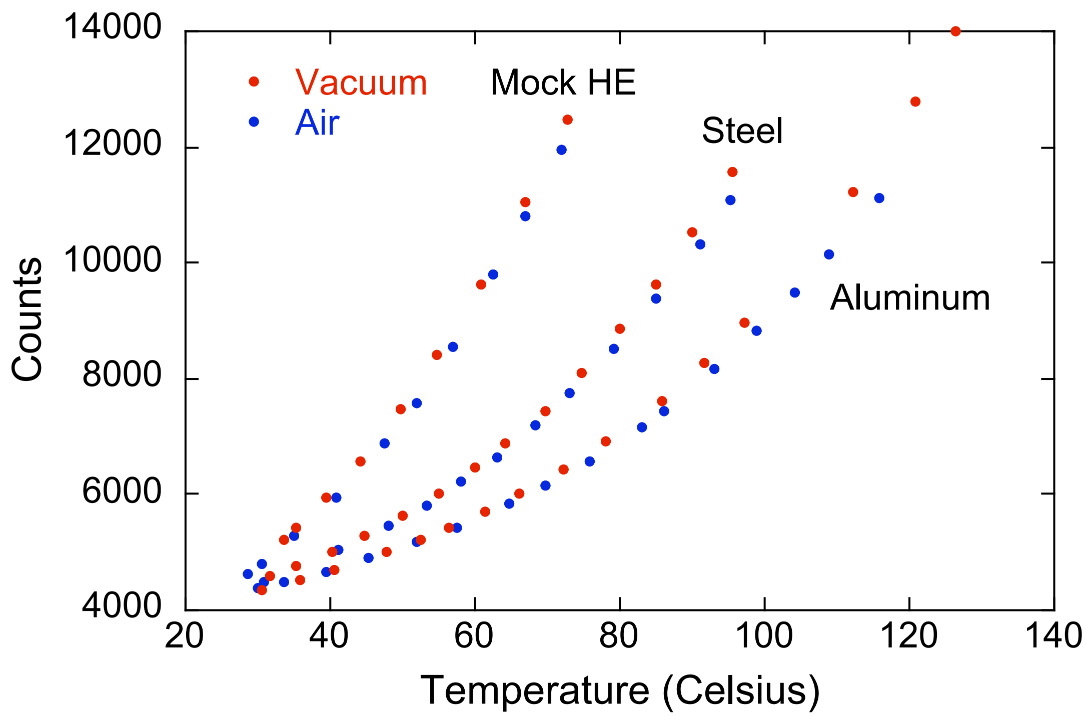
Bonded TC

Emissivity and Surface Texture



- **Calibrations were highly repeatable and followed expected trends**
  - **No evidence that emissivity changed with exposure to these temperatures**
- **Surface texture was modified to increase emissivity**
- **High emissivity coatings gave mixed results**
  - **Higher emissivity, but problems with coatings flaking off during dynamic deformation**

Emissivity and Environment



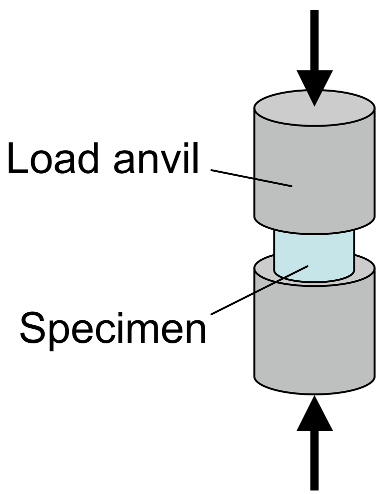
- Calibrations performed in air and vacuum (75 mTorr) under otherwise identical conditions

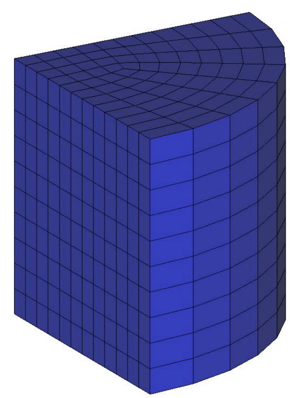
- There is a small, but repeatable difference between air and vacuum, but not sufficient to account for published discrepancies in

- Mock High Explosive (HE) yields high signal

Numerical modeling is used to determine when adiabatic conditions are met in uniform deformation

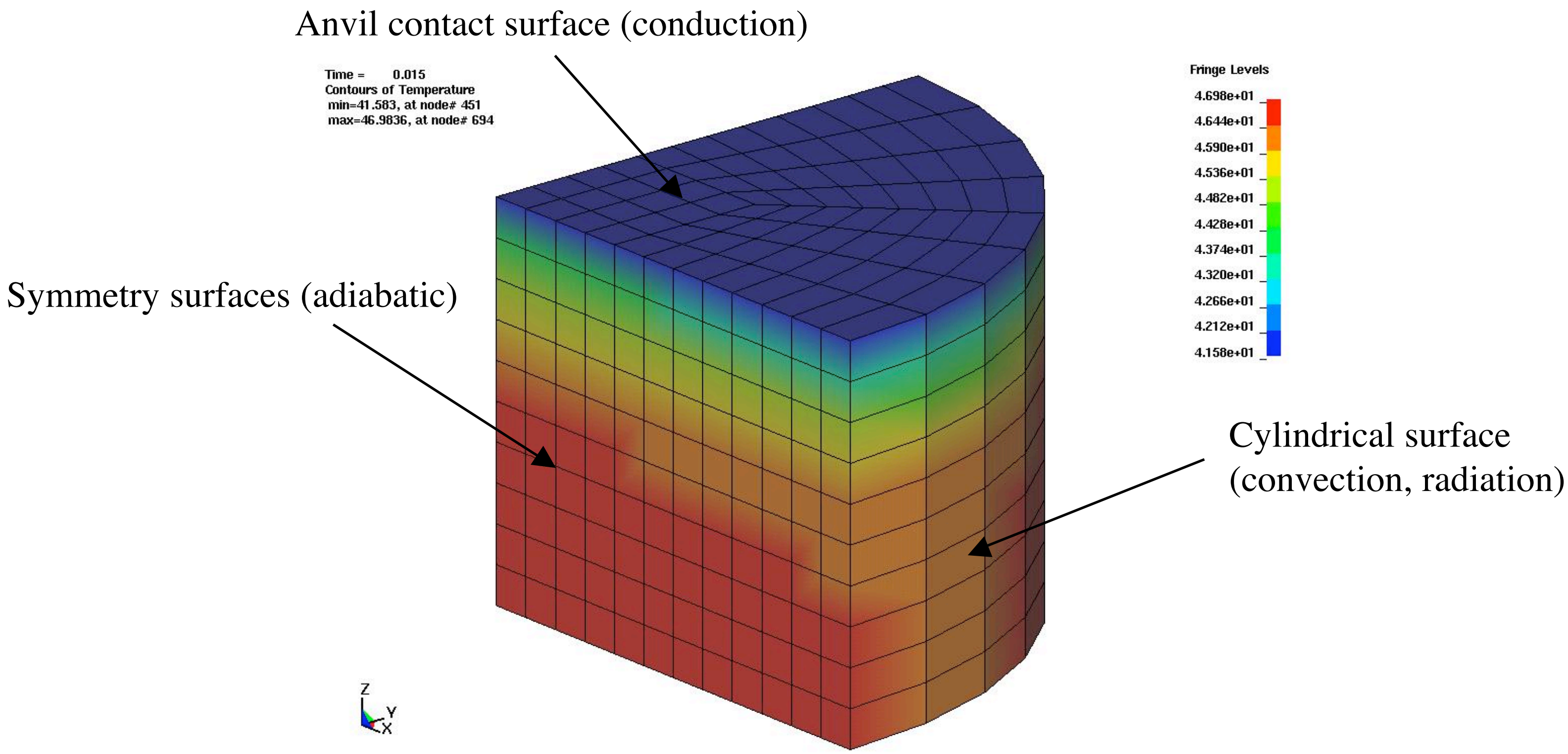
- **LS-DYNA was used to simulate a uniaxial compression test with annealed tantalum**
- **Model includes plastic work-to-heat conversion and surface heat transfer to surroundings**
- **A 1/8 symmetry model was developed for a specimen that was plastically deformed to 15% true strain**
- **Deformation time of 15 ms (strain rate = 10 s^{-1}) was used to determine effect of rate on surface heat loss**





0% strain

Results show that adiabatic conditions prevail away from specimen ends during intermediate rate deformation



10 s^{-1} strain rate shows 46 °C average temperature rise, cooling to 42 °C at anvil contact surface

Can compare IR and thermocouple measurements for intermediate rate tests

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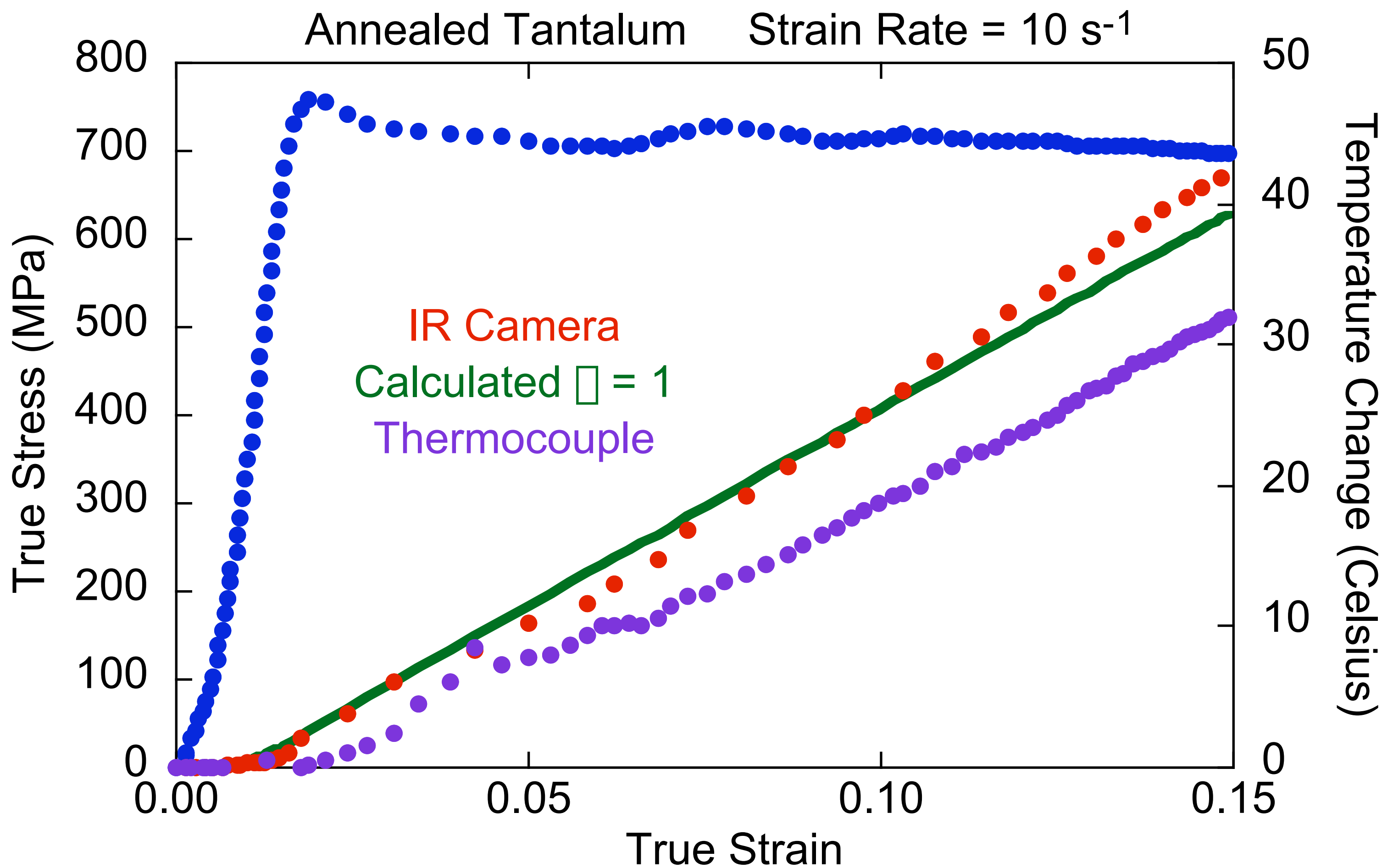
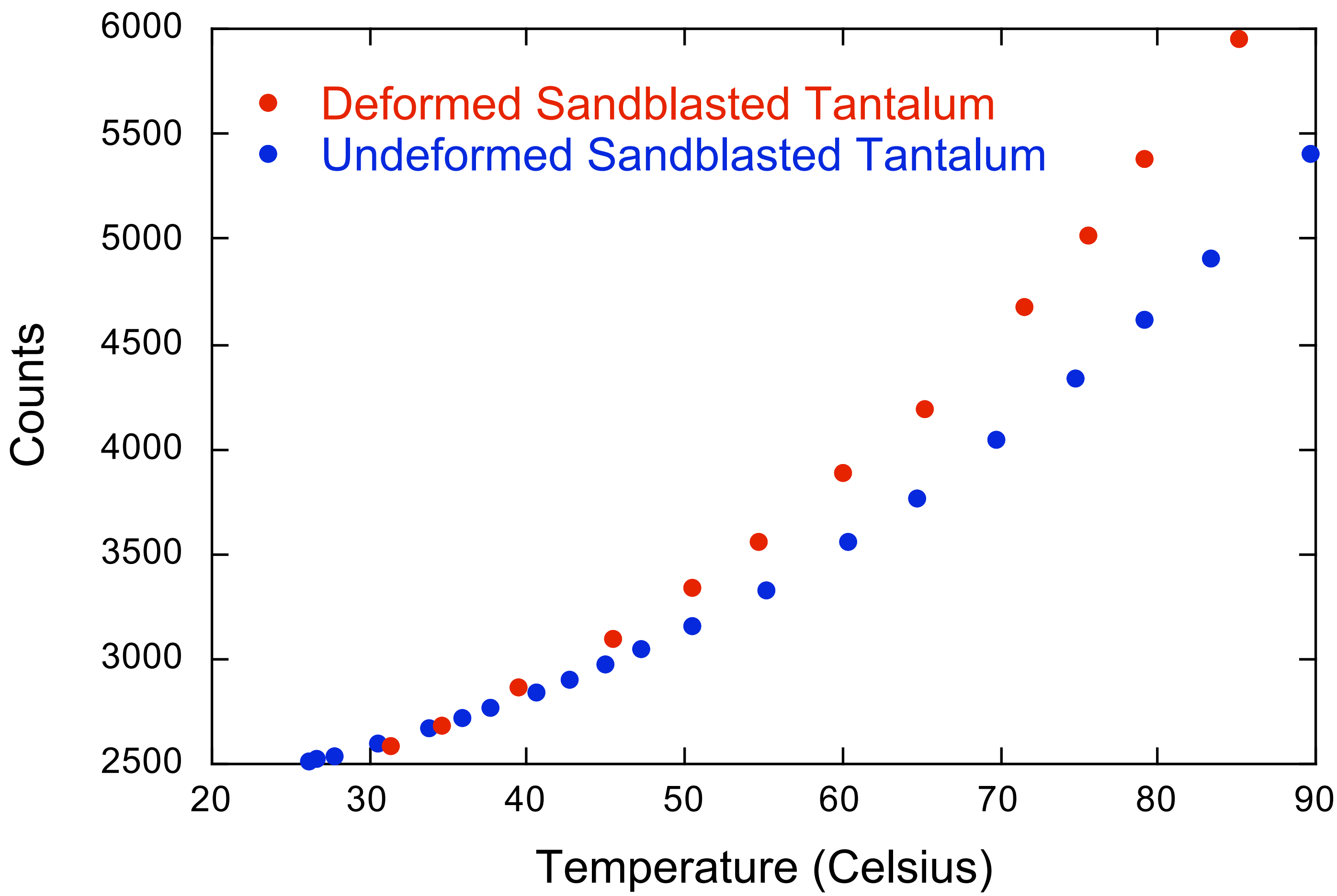
Preliminary Results for Annealed Tantalum



Emissivity increases with strain as surface texture changes



Summary

- Our goal is to use infrared thermography to study dynamic deformation and failure of materials.

- Material emissivity is the most challenging experimental issue when determining the absolute temperature of an object.

- IR thermography is a powerful materials and process characterization tool.