PDV Measurements in the Electromagnetically Driven Expanding Ring Experiments

Dwight Landen, David Wetz, Sikhanda Satapathy, Scott Levinson

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Overview

• Background
  – High temperature material properties
  – Expanding ring experiment

• Apparatus
  – Primary circuit
  – Pre-heater
  – Instrumentation
    • IR Camera
    • PDV

• Data analysis in Matlab
  – Spectrogram
  – Error estimates
  – Comparison with VISAR (circa 1990?)

• Conclusion
High Temperature Properties

- Material strength is a function of temperature
  - Heating degrades strength
  - Short duration or pulsed heating different from equilibrium
  - Duration of heating event is much smaller than diffusion time thus assumed adiabatic

- Mechanisms
  - Moduli change
  - Microstructure change
  - Thermally activated dislocation motion
  - Precipitate growth...
High Temperature Properties

• Such data is critical to successful modeling of short duration high temperature events such as hypervelocity impacts and electromagnetic launch.

Simulation of a block armature
High Temperature Properties

• Lipkin, Swearengen, and Karnes (1973)
  – Measured strength with Hopkinson’s bar experiment
  – Pulse heating using electron beam
  – Results for 6061 T6

From Lipkin, Swearengen, and Karnes
"Mechanical Properties of 6061 Al-Mg-Si Alloy
After Very Rapid Heating"
Expanding Ring Experiment

• Needs
  – In-situ heating of material
  – Short loading duration to prevent heat dissipation
  – Measurement of deformation and temperature

• Choices
  – Split Hopkinson’s bar experiment
    • Stain rates ~ 1000/s
    • Heating not easily achieved
  – Electromagnetically driven expanding ring experiment
    • Strain rates > 1000/s
    • Built in heating
Expanding Ring Experiment

• Nirodson (1965)
  – Rotational symmetry => uniform tangential strain
  – Thin rings => negligible radial stress
  – No end effects
  – Fragmentation study

• Walling and Forrestal (1973)
  – Elastic vibration after initial plastic loading
  – Strain Gages
Expanding Ring Experiment

- Grady and Benson (1983)
  - Used MMF from solenoid to expand a ring sample
  - No pre-conditioning shock effects
  - Controlled loading rate
  - Conducive to lab environment compared to explosively driven experiment
  - Fragmentation study
  - Drawback- pre-conditioning effects of inductive heating
Expanding Ring Experiment

- Gourdin, Weinland, and Boling (1989)
  - Used MMF from solenoid to expand a ring sample
  - Used VISAR to measure surface motion.
  - Ignored thermal effects
  - Obtained stress-strain data (after load pulse)
Apparatus

- Setup is two RLC circuits
  - Inductive heater
  - Electromagnetic stress
  - Creates a low and nearly sinusoidal current for a programmable time followed by a 50 ms pulse

- Instrumentation
  - IR Camera
  - Photodoppler velocimetry (PDV)
  - Rogowski’s on primary and through solenoid and ring sample with active integration (PEM)
Apparatus
Inductive Heater

- Ten 450V, 3.2 mF electrolytic capacitors
- Switched in each positive half cycle microcontroller

Ring Current

IR Camera Containment

Heater

Ring Capacitor

Capacitor Bank
IR Camera

- Flir SC6000 IR camera
  - Up to 17 kHz with an 128x8 window
  - Integration time as low as 9 ms
- Using 128x64 window@ 1kHz and 9ms integration time
- Measurements with Al 6061, Al 7074, and ETP Cu
  - Al sample heated to near melting in < 15 ms
  - Cu heated to >700 °C in 40 ms.

Al 7075 @ 2ms and 15 ms
IR Camera

- Using 128x8 window@ 17kHz and 9ms integration time
- Can sometimes get expansion
- Problems
  - Surface emissivity varies for different surface finishes
  - ~3 pixel smear

Cu @20.64 ms

Cu @27.06 ms

Cu @27.12 ms

Cu @27.18 ms
Material strength is proportional to acceleration.

Any noise in the measurement is amplified by taking the numerical derivative.

Velocity measurement must have high signal to noise ratio.

Heterodyning enables PDV to amplify signal.
PDV

- Measures velocity using Doppler shifted light
- Ring sample reach peak velocity of about 180 m/sec in 20-30 ms
- Beat signal sampled at ~6 GHz or 12 GHz
  - 6 GHz; N=2^{13}; DV=0.591 m/s
  - 12 GHz; N=2^{14}; DV=0.591 m/s
- Velocity is extracted via spectrogram
Error Bounds

- Treat each column as a probability distribution
- Find 5%, 50% and 95% cumulative area under the probability curve
- Analogous to a confidence interval
- These are the minimum, average and maximum velocities
- Maximum uncertainty of ~5 m/s
PDV vs. VISAR

• Comparing experiments with the same impulse

• VISAR off by > 50% in previous experiments
  – Lost fringe?
  – Wrong etalon constant?
• PDV has been validated with other experiments
• Correction factor ~1.65
• Calculate acceleration using central difference
• Noise will swamp acceleration
PDV vs. VISAR

- Use FFT to filter VISAR help a little
- Still not a good as the PDV
  - Commercial components
  - Heterodyning!
Conclusion

- Expanding ring experiment is for measuring material strength
- PDV provides a very precise, accurate, and reliable velocity measurements
Conclusion

Questions