HiRadMat Beryllium Thermal-Shock Test

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- Provides high-intensity pulsed beam where material samples can be tested (4.9e13 ppp)
- Short pulse lengths suited for thermal shock tests (7.2 µs)

Objectives

- Collaboration with RAL HPTG
- Fracture Beryllium with one or multiple beam pulses
- Experimentally deduce the onset of plastic deformation
- Benchmark numerical simulations currently based on scarce literature data
- Potential post irradiation analysis
Conceptual test design

Fall 2014?

- Thick/thin Be specimens
- Incident beam at different radial locations
- One or multiple beam pulses per specimen

- Measurements
  - Radial vibrations - Laser Doppler Vibrometer (LDV)
  - Image fracture – High speed camera
HRMT-14 experiment

Radial Velocity Measurements

- Radial measurements performed with a Laser Doppler Vibrometer equipped with:
  - Targeting laser (green).
  - Infrared laser for measurements
  - Long range lens
  - In-line video camera with reticle overlay

Customized system developed in collaboration with Polytec® for this application!

HRMT-14 experiment

High Speed Camera

High Speed Camera Specifications:

- Distance: ~42 m,
- Optical Circuit: 3 mirrors + 1 window,
- Lens: Nikkor 1000 mm,
- Resolution: 224x224 px,
- Observable area at 42 m: ~100x100 mm,
- Pixel Dimensions: 1 px ~ 0.45x0.45 mm,
- Frame rate: 20000 fps,
- Shutter time: 5 μs.

HiRadMat maximum intensity beam parameters:

- Beam energy: 440 GeV
- Bunch intensity: 1.7e11 protons
- Number of bunches: 288
- Maximum pulse intensity: 4.9e13 protons
- Pulse length: 7.2 µs
- $\sigma_{\text{rms}} = 1$ mm

- Scaled MARS energy deposition up to 10 times to obtain peak temperatures close to melting (~ 1100 °C)
- Radial displacements resulting from 1 beam pulse
- Radius: 5 mm
- Elastic and bilinear kinematic plastic material model

- Axisymmetric model
- Incident beam at \( r/R = 0 \)

- 3D model
- Incident beam at \( r/R = 0.5 \) & \( 0.75 \)

- Radial displacements at window edge
Displacements - beam at $r/R = 0$

- Frequency $\sim 0.75$ MHz
Displacements - beam at $r/R = 0.5$

- Maximum plastic strain at window edge
Displacements - beam at r/R = 0.75

- Maximum plastic strain at window edge
Maximum displacement as a function of Edep (Tmax)

- Incident beam at $r/R = 0.75$ shows largest deviation in displacement for elastic and plastic behavior ($\sim 30 \mu m$).
Ability to crack/fracture Be?

- Large enough tensile stress at window edge may initiate cracks
- 3.1% plastic strain at RT may lead to fracture
- Dependent on temperature

$r/R = 0.5, \ 10x \ E_{dep}, \ Edge \ T = 120 \ ^\circ C$
BUT...

Temperature of Be at max. equiv. plastic strain of 3.1% ~ 622 °C
ε\text{fracture} ~ 20% at 600 °C

- Possibility of melting before any cracking occurs
  - Failure due to fatigue need to be investigated

Maximum principal stress at edge
Further work

- More numerical simulations
  - Optimize specimen size and incident beam location
  - Multiple beam pulses
  - Other specimen geometries to induce larger plastic strain

- Be material properties
  - Strain rate dependency
  - Plasticity model for $T > 600$ °C

- Damage/fracture model using LS-DYNA/Autodyne

- Pre-cracked zone at edge of specimens?

- Further analysis for thin window tests
Some results from HRMT-14

- LDV and high speed camera measurements fairly comparable with numerical simulations
- **Goal**: make similar comparisons for Beryllium
Thank you