Introduction and Objectives

Many accelerator facilities are currently being limited in beam power by their target facilities. When exposed to high-energy proton beams, target systems experience radiation damage, mechanical stress, and extreme temperatures, altering their physical properties.

For example, due to defects induced in materials by high-energy protons, the physical properties of materials will change during irradiation. Conducting PIEs (Post Irradiation Examinations) can help us understand how the materials can change.

Analyzing the strain field across an irradiated sample can help identify where defects have been created, how the hardness of materials have changed, and where they will experience failure.

Experimental Set-Up and DIC

- DIC is a non-contact optical technique used in tensile testing to measure and analyze deformation throughout sample.
- Samples of suitable shape and size for the test were cut and a stochastic speckle pattern was painted on them using black spray paint.
- Tensile stress was applied to samples using the Shimadzu AGS-X Tensile Tester and their in-plane deformation was recorded in video format using a mobile phone (iPhone XR).
- MATLAB Ncorr and GOM Correlate were used to perform DIC Analysis.
- “Subsets” or “ROIs” (Regions of Interest) of the stochastic pattern were tracked based on the following correlation criteria:

\[
C_{sys} = \frac{\sum (u_i(u_i) - \bar{u})(v_i(v_i) - \bar{v})}{\sum (u_i(u_i) - \bar{u})^2 + \sum (v_i(v_i) - \bar{v})^2}
\]

Normalized Cross-Correlation [1]

For optimization of the correlation algorithm, we use FA-GN and IG-GN (Forward Additive and Inverse Compositional Gauss Newton methods, respectively):

- FA-GN: Manipulates reference image with initial guess warp, calculates residuals and Jacobian, updates parameters until error is minimized.
- IG-GN: Manipulates deformed image with initial guess warp, calculates residuals, gradients, and Hessian, updates parameters until error is minimized.
- Interpolation is performed to compute grayscale pixel values and gradients at subpixel locations (bicubic for MATLAB, biquintic for GOM Correlate).

Results and Analysis

Displacement Fields

- Full-field displacements are calculated by observing the sum of least squares values of neighboring cells.
- Full-field engineering strain is calculated using a least squares plane to fit a local group of data points (for MATLAB).
- Aluminum sample experiences the greatest V-displacement above the necking point.
- Sample experiences almost no U-displacement, except for a contraction near the circumference of the circle when necking.

Linear Transformation of Subsets [2][4]

\[
\begin{align*}
\varepsilon_{xx} &= \frac{1}{2} \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) \\
\varepsilon_{yy} &= \frac{1}{2} \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \\
\gamma_{xy} &= \frac{1}{2} \left( \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right)
\end{align*}
\]

Green-Lagrange Strain Calculation [2]

Displacement Field (GOM Correlate)

- Aluminum sample experiences the greatest Green-Lagrange Strains near the circumference of the center hole.
- This makes sense as this is the region where the material experiences a decrease in cross-sectional area, therefore, there is a higher stress concentration.
- Physically, this is also where the sample began to experience “necking,” proving that the algorithm can accurately keep track of strain fields.

Strain Over Time

- Keeping track of the Green-Lagrange strains change with time (and stress) can help monitor how specific points experience deformation.

Future Goals

- Incorporating DIC algorithm into Python.
- Studying irradiated samples.
- Analyzing out-of-plane motion using 3D DIC algorithms.

References