Cornell University
Cornell High Energy Synchrotron Source

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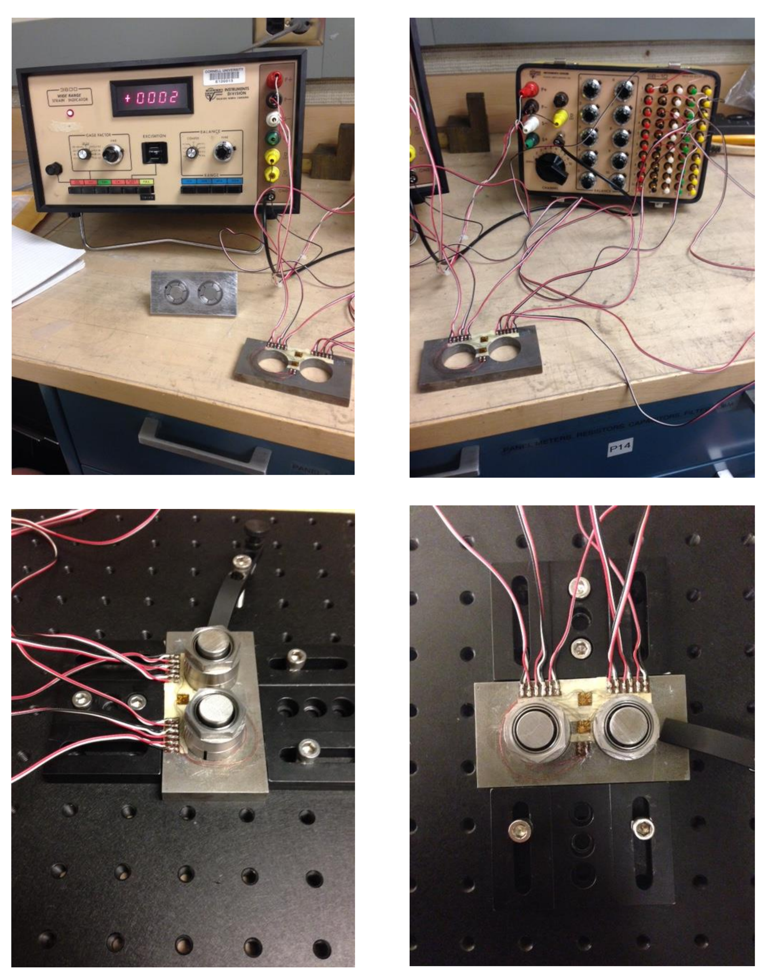
Calibrating Diffraction-Based Residual Stress Measurements Using Strain Gages

Introduction

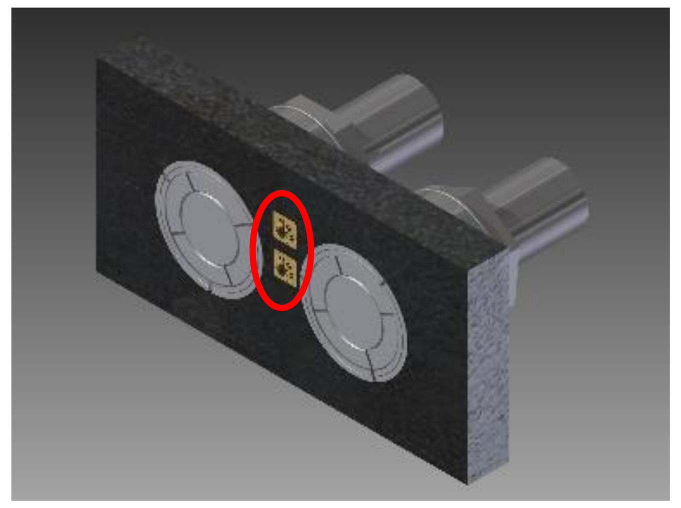
Residual stress is a state of stress that exists in the bulk of a material without the application of an external load. Residual stresses exist in most manufactured parts therefore it is important to investigate how they will affect a component in the long run. Residual stress is hard to measure/compute therefore at CHESS, within the InSitμ Center, Chris Budrow and Professor Armand Beaudoin, the Industrial Liaison for the InSitμ Center, are working with Caterpillar Corporation to develop a new diffraction-based method for measuring lattice strains and computing residual stress. With any new experiment, it is always best to first analyze a problem where the answer is known therefore the goal is to develop a classical mechanical technique to calibrate X-ray diffraction based residual stress measurements.

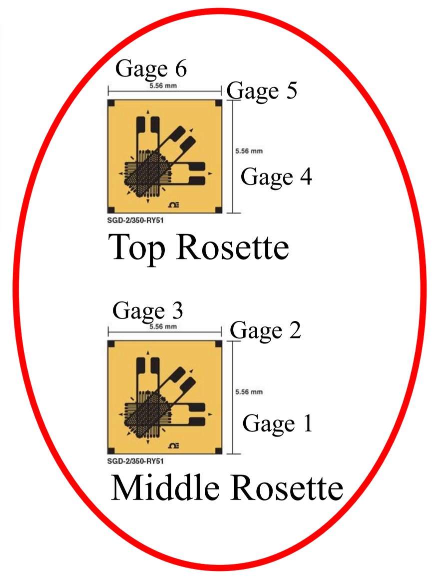
Experiment



- Steel Plate Test Specimen
  - 90 mm base, 45 mm height, and 10 mm thickness
  - 26 mm diameter holes for fittings
- During testing both of the trantorque fittings were adjusted using a torque wrench
- The change in strain was measured using two strain gage rosettes and observed using a strain indicator
- Once the measurements were taken the torque was released to perform the test again.

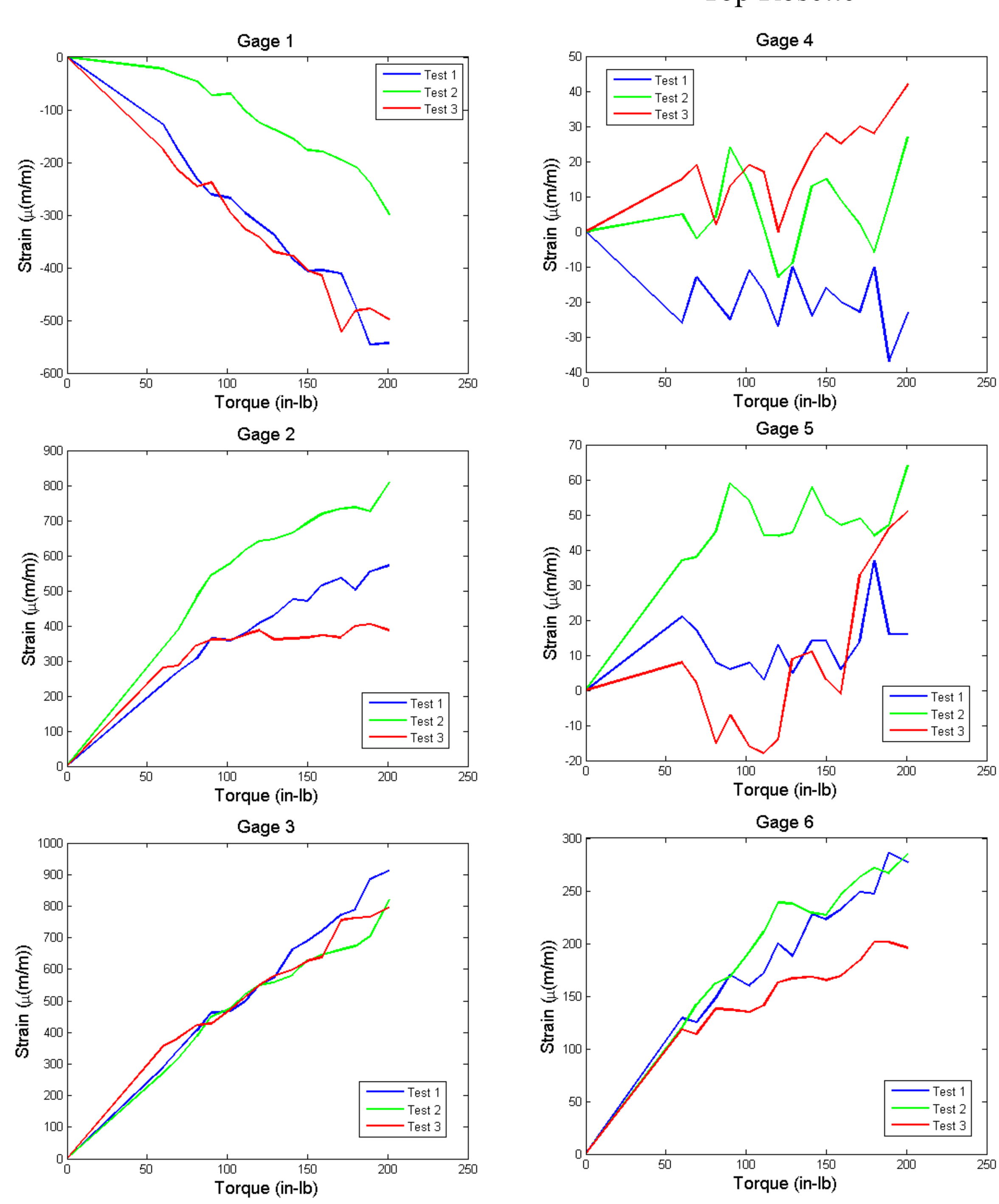
Results





Middle Rosette

Top Rosette



The plots above show the relationship between the torque applied to both of the trantorque fittings and the strain. Both fittings were adjusted to 200 in-lb three separate times (Test 1, Test 2, and Test 3).

Results

- Data reduction equations, shown below, were used to determine the principal stresses (σ_1 and σ_2), and the principal angle (ϕ_1).
- Stress components change as the reference coordinate system changes.
- The x axes are aligned with gages 1 and 4 and the y axes are aligned with gages 3 and 6.
- The principal coordinate system is where the extreme values of normal stress occur: the maximum (σ_1) and minimum (σ_2) principal stresses.
- The principal angle is the orientation of the axis associated with the maximum principal stress relative to the x axis.

For three element rectangular rosette with $\theta_A = 0°, \theta_B = 45°, \& \ \theta_C = 90°$:

$$\epsilon_A = \epsilon_{xx} \qquad \epsilon_C = \epsilon_{yy} \qquad \epsilon_B = \frac{1}{2}(\epsilon_{xx}+\epsilon_{yy}+\gamma_{xy}) \qquad \gamma_{xy} = 2\epsilon_B - \epsilon_A - \epsilon_C$$

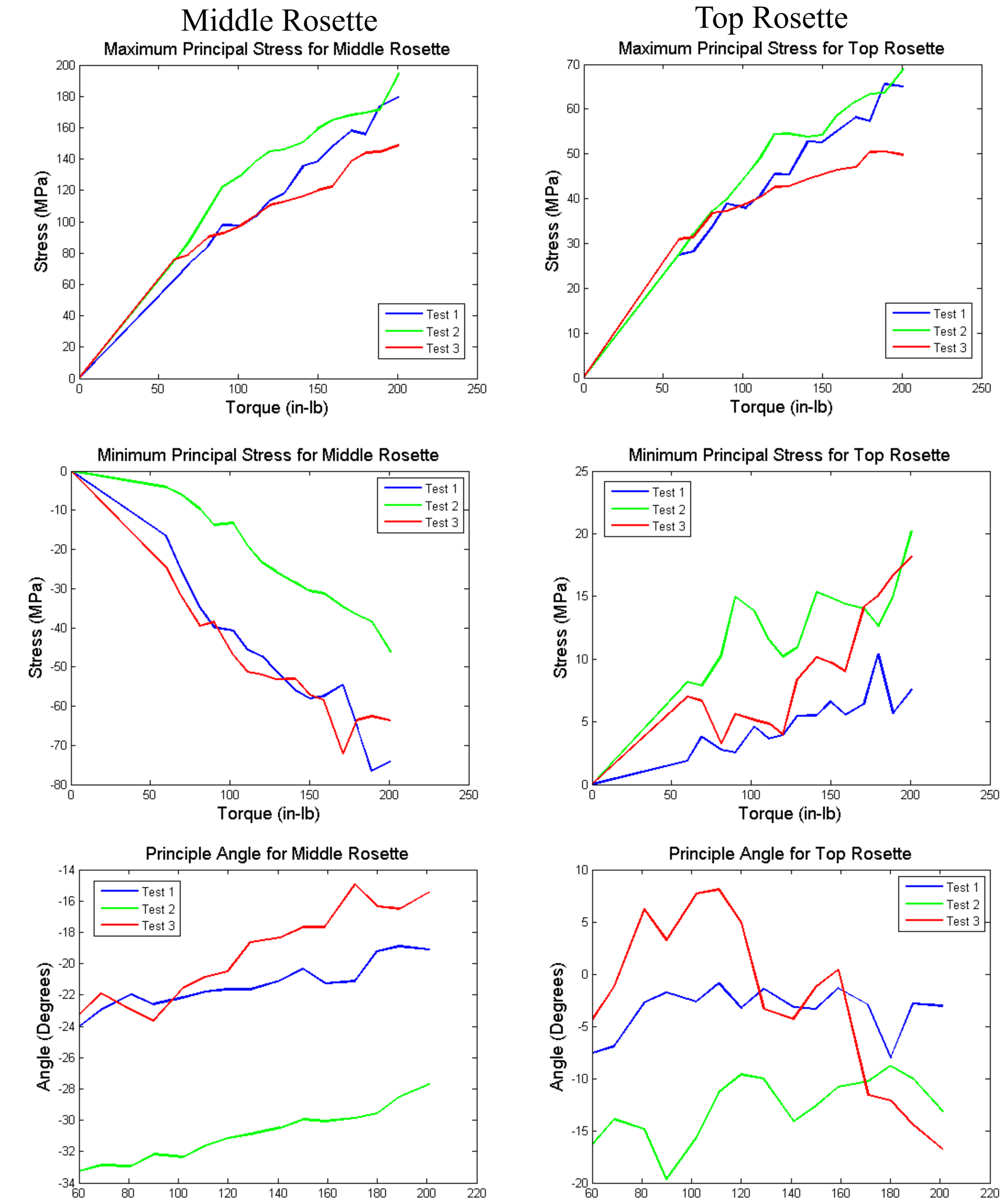
$$\phi_1 = \frac{1}{2}\tan^{-1}\frac{\epsilon_{xx}+\epsilon_{yy}+\gamma_{xy}}{\epsilon_A-\epsilon_C}$$

$$\sigma_1 = E\left(\frac{\epsilon_A+\epsilon_C}{2(1-\nu)} + \frac{1}{2(1+\nu)}\sqrt{(\epsilon_A-\epsilon_C)^2+(2\epsilon_B-\epsilon_A-\epsilon_C)^2}\right)$$

$$\sigma_2 = E\left(\frac{\epsilon_A+\epsilon_C}{2(1-\nu)} - \frac{1}{2(1+\nu)}\sqrt{(\epsilon_A-\epsilon_C)^2+(2\epsilon_B-\epsilon_A-\epsilon_C)^2}\right)$$

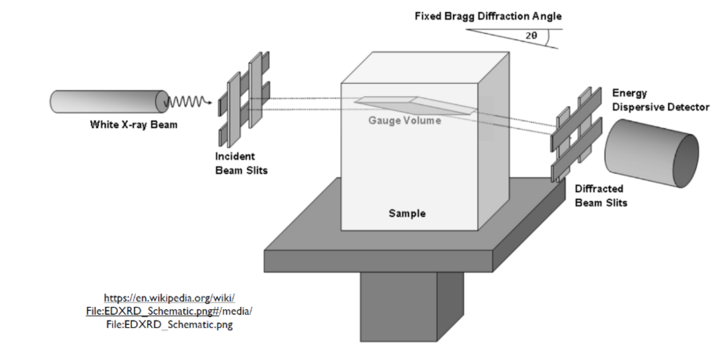
Middle Rosette

Top Rosette



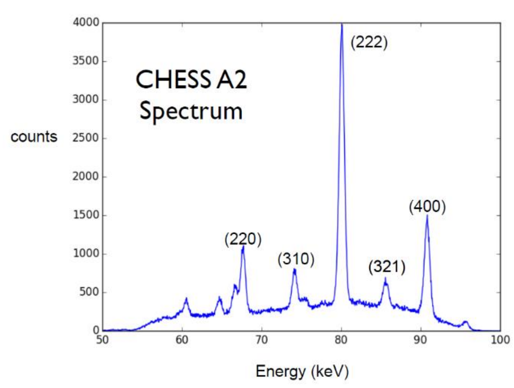
The plots above show the relationship between the torque applied to the fittings and the principal stresses and principal angle.

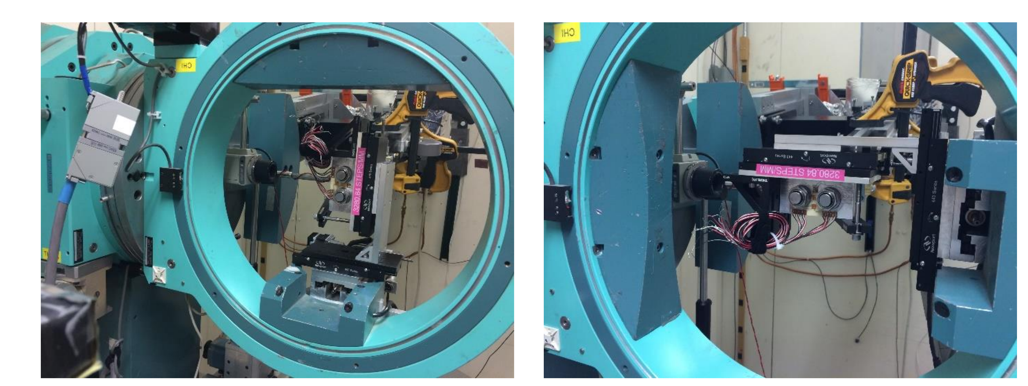
X-Ray Diffraction Experiment



- Energy Dispersive Diffraction (EDD)
- The polychromatic (white) beam has the advantage of going all the way through the steel plate.
- The idea is to measure the stresses within the specimen at the exact location of the rosettes and compare those stresses to the stresses found using the strain gages.

The location of the peaks are known therefore when there is a shift in the peaks it indicates a strain within the material.





The test specimen mounted in the frame located at the A2 Beamline at CHESS.

Conclusion

The goal of this project was to begin the development of a classical mechanical technique to calibrate synchrotron data. Data was successfully collected using strain gages and trantorque fittings that can be used to compare to synchrotron data. The strains from the middle rosette gages are consistent from one test to the next, especially tests 1 and 3, and seemed to be changing linearly with torque. The strains from the top rosette were more erratic, especially gages 4 and 5. The strains were also very low for those gages. This could be due to the stress state or a problem with the gages. This will be further investigated. The next step is to compare the stresses found in this experiment to the measurements made at the beamline.

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