Design of Octo-Strain Device for Sheet Metal Testing using Neutron Diffraction

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Motivation

- Automotive lightweighting Research
  - Meet demand to develop automobiles with increased fuel efficiency
  - Improvements in crash test ratings
  - Create material models that accurately represent mechanical properties of material
    - Saves cost by producing correct metal forming dies that require zero rework because of incorrect modeling

*Figure 1: Chart displaying steel development [1]*
Motivation - Continued

• Traditional uniaxial testing is not an accurate enough measurement for the prediction of complex multiaxial deformation

Figure 2: Various Strain Paths for Octo-Strain Device

Figure 3: Strain Paths when Forming Automotive Parts
Introduction- What is Octo-Strain?

- A device used for multi-axial sheet metal testing
- Designed for specialized test specimens with eight arms
- Eight linear actuators apply tensile or compressive forces to the test specimen

Figure 4: Assembled Octo-Strain Ring

Figure 5: Strain Space for Octo-Strain

[2]
Introduction- Why use Neutron Diffraction?

• Unlike traditional tensile testing, cross-sectional area is difficult to calculate for complex geometries

• Neutrons are non-destructive with high penetration depth (cm)
  • X-ray Diffraction penetrates surface millimeters in comparison

\[ \sigma = \frac{F}{A} \]

Cross-sectional Area and forces that act on the gauge area is unknown

Figure 6: Comparing traditional tensile test specimen to Octo-Strain test specimen
**Introduction - Stress-Strain Relationship**

![Image of sample with lights and camera's highlighting](image)

**Figure 7: Speckle Pattern Used for Strain [3]**

\[
\varepsilon = \frac{\Delta L}{L}
\]

**Figure 8: Finding Strain using Digital Image Correlation**

\[
\lambda = 2d_{hkl} \sin \theta
\]

**Figure 9: Finding Stress using Neutron Diffraction**

\[
\sigma_x = \frac{E}{(1 + \nu)(1 - 2\nu)}[(1 - \nu)\varepsilon_x + \nu(\varepsilon_y + \varepsilon_z)]
\]

\[
\sigma_y = \frac{E}{(1 + \nu)(1 - 2\nu)}[(1 - \nu)\varepsilon_y + \nu(\varepsilon_x + \varepsilon_z)]
\]

\[
\sigma_z = \frac{E}{(1 + \nu)(1 - 2\nu)}[(1 - \nu)\varepsilon_z + \nu(\varepsilon_x + \varepsilon_y)]
\]

**Bragg’s Law**

\[
\lambda = 2d_{hkl} \sin \theta
\]

**Lattice Strain**

\[
\varepsilon = \frac{d - d_0}{d_0}
\]

**Hooke’s Law**

\[
\varepsilon = \frac{\Delta L}{L}
\]
Introduction - Stress-Strain Relationship

Figure 10: CAD model of Octo-Strain Test Specimen

Figure 11: Neutron Beam Path Location
**Introduction- Benefits of test specimen geometry**

- Increased failure strain by over 2x

- Increased strain homogeneity within gauge area

- Early failure due to sample geometry of Cruciform

*Figure 12: Strain Path of Octo-strain test specimen and cruciform*
Design Requirements

• 50 kN force applied to each of the eight loading arms
  • Allows for testing of High-Strength Metals
• Easy to assemble and make adjustments
• Keep weight of design under 500 pounds
  • Max. Capacity of 3-axis measurement table
• Stepper Motors cannot protrude from device
  • This will allow for an increased range of measurable scattering angles

Figure 13: Previous 10 kN design
CAD Modeling

• Creo Elements direct drawing CAD software was used to model all components of Octo-Strain
• From 3D models, engineering drawings were made and sent to machine shop

Figure 14: Isometric and Front View of Octo-Strain Device
Drive System

- Determined a timing belt would work best for driving screw-jack
- Calculated Torque of 26.3 Nm to drive screw-jack
- 1:1 gear ratio, 25 tooth, 30 mm wide pulley
- Bearing eliminates radial load on motor shaft

Figure 15: Free-body diagram of forces acting on screw-jack [4]

Figure 16: CAD model of completed drive assembly
Design Requirements - Continued

- Transmission and Reflection beam paths are possible
- Provides Measurement of all three principle directions

Figure 17: Top and Side View of BT8 Beam Path
FEA Results

- Determined max deflection of test stand when Device is assembled into base

Figure 18: FEA Result of Max. Deflection due to gravity (0.37mm)

Figure 19: Assembled Octo-Ring without Test Stand
FEA Results - Continued

- Determined max deflection with loading condition of 50 kN (Compression)

Figure 20: FEA Result of deflection due to 50 kN load in compression on Octo-Ring (0.04 mm)

Von Mises Stress
47.76 MPa
Yield Strength of Aluminum 6061 = 276 Mpa
FEA Results - Continued

- Determined max deflection with loading condition of 50 kN (Tension)

Figure 21: FEA Result of deflection due to 50 kN load in tension on Octo-Ring (0.04 mm)

Von Mises Stress
47.76 MPa
Yield Strength of Aluminum 6061 = 276 Mpa
FEA Results- Continued

• Determined max deflection with worst case loading condition of 50 kN

Figure 22: FEA Result of deflection due to 50 kN load on Octo-Ring (0.40 mm)

Von Mises Stress 55.14 MPa
Yield Strength of Aluminum 6061 = 276 Mpa
Figure 23: CAD model of 50 kN redesign compared to existing 10 kN design

Comparison of Designs

- Timing Pulley Drive system
- Increased Load Capacity and larger Load cells
- Larger diameter Octo-ring with slim profile
- Bearing to aid in sample alignment
- Redesigned Grips for faster sample changes
Conclusions

• With this device, material property data will be collected that will lead to the adoption of generation three high strength steels in the automotive industry

• Increased load capacity
  • Allows for testing of high-strength metals

• By using pulley and drive system, significant space is saved
  • Increased range of measurable scattering angles

• FEA was performed to verify structural integrity of device
Future Work

• Get all parts machined from engineering drawings

• Assemble Octo-Strain device

• Begin Testing of high-strength metals
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