Internal Stress Development Due to Deformation Twinning

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Donald W. Brown[1] and Sean R. Agnew[2]

[1]Los Alamos National Laboratory
[2]University of Virginia

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TMS2008
137th Annual Meeting & Exhibition

Symposium: Deformation Twinning: Formation Mechanisms and Effects on Material Plasticity

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Insights on Cyclic Twinning Deformation using Neutron Diffraction Measurements

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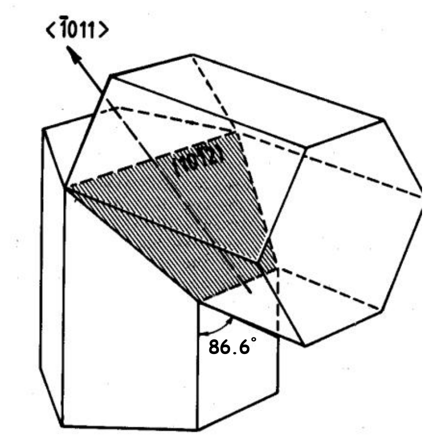
Why Investigate Twinning in Magnesium Alloys?

- Magnesium twins very easily
- Elastically isotropic
- Isotropic CTE's



Tensile Twin: $\langle 10\bar{1}1 \rangle \{10\bar{1}2\}$

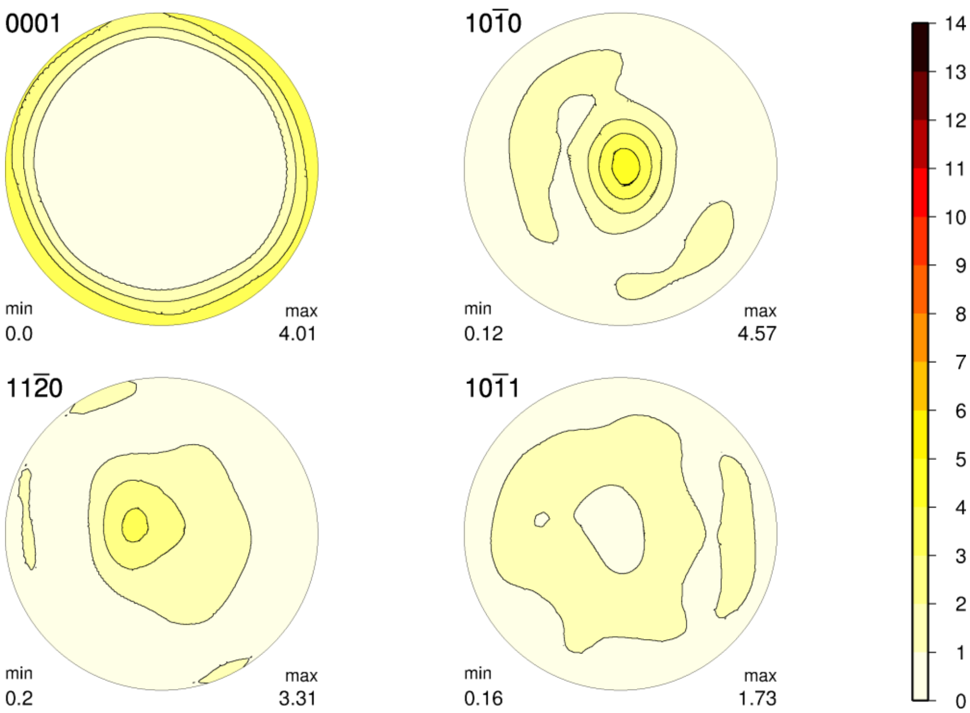
Relative low level of intergranular strain for a hcp material

$\Rightarrow$ Isolate the effects of twinning

Why Investigate Twinning in Magnesium Alloys?

- Magnesium twins very easily
- Elastically isotropic
- Isotropic CTE's
- Extruded, loaded in compression along the extrusion axis: All basal poles are perpendicular to the loading direction

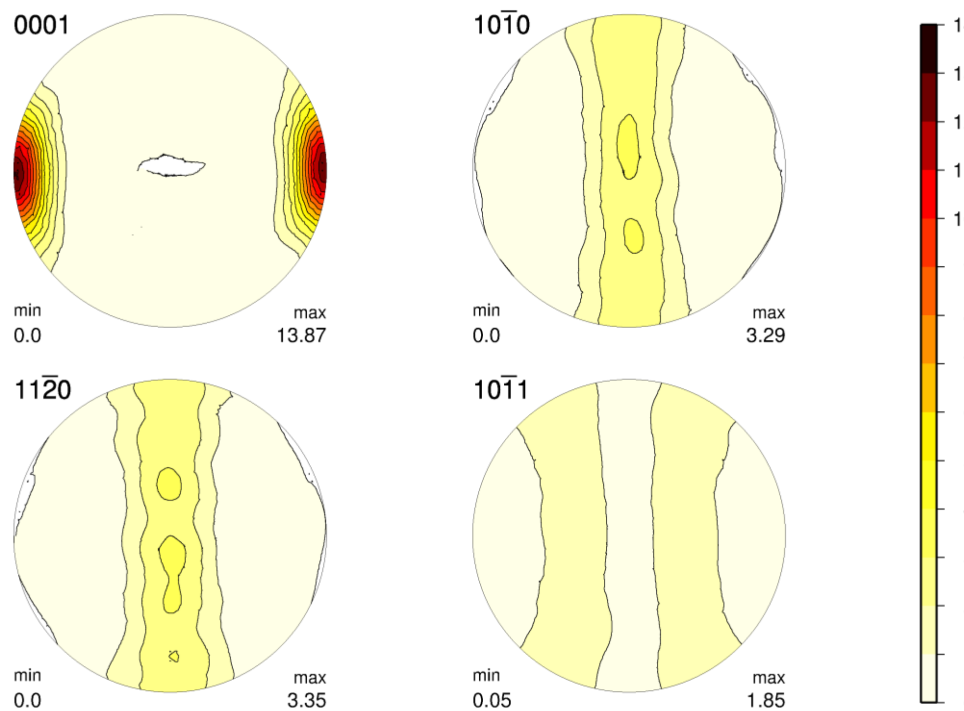
Extruded Mg, Initial



Why Investigate Twinning in Magnesium Alloys?

- Magnesium twins very easily
- Elastically isotropic
- Isotropic CTE's
- Extruded, loaded in compression along the extrusion axis: All basal poles are perpendicular to the loading direction
- Rolled, loaded in compression along the rolling direction: Basal poles are perpendicular to the loading direction as before, but concentrated along the normal direction

Rolled Mg, Initial



De-Twinning or Re-Twinning

- De-Twinning
  - Initial loading: Nucleation of twin followed by growth
  - Reverse loading: Collapse existing twin boundaries

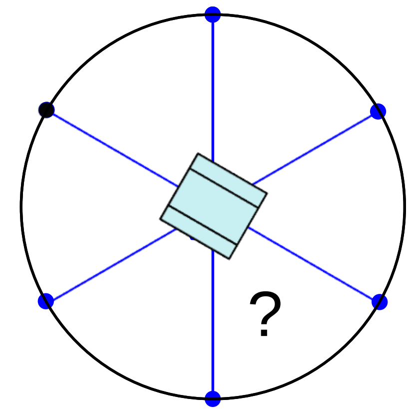
  $\Rightarrow$ Texture Memory Effect

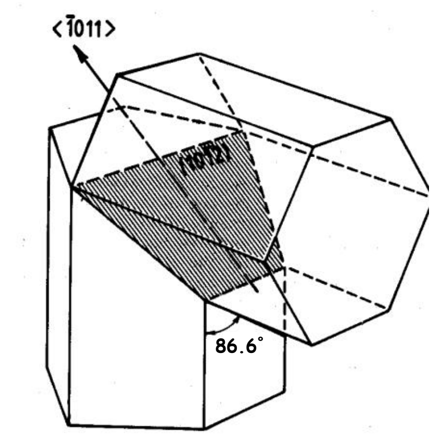
- Re-Twinning
  - Initial loading: Nucleation of twin followed by growth
  - Reverse loading: Nucleation of new twin followed by growth

- Wagoner et al. (2007) suggest de-twinning based upon acoustic emission measurements

De-Twinning or Re-Twinning

- Grain with c-axis in the transverse direction
- Upon loading along the center of pole figure, it will twin and reorient with its 6 prism poles in the transverse direction
- Which variant will it select when the load is reversed?
- Neutron diffraction provides the information to determine if it de-twins or re-twins



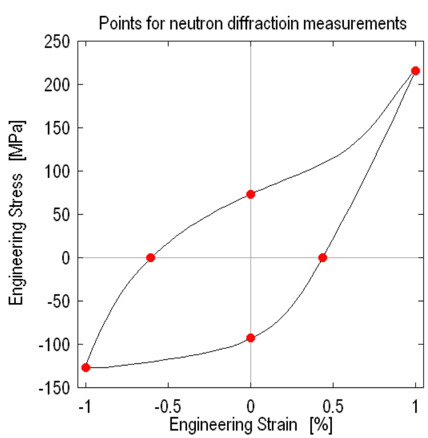


Low Cycle Fatigue Test

- Samples of Extruded and Rolled magnesium AZ31 alloy were subjected to low cycle fatigue
  - R = -1 at 0.5 Hz
  - Strain amplitude of 1%,
- In-situ neutron diffraction measurements were made for select cycles
  - Extruded: 1, 2, 5, 9, 13, 31, 51, 76, 101, 251 (Fail: ~450)
  - Rolled: 1, 2, 19, 49, 100, 150, 200, 250, 30(
  - Hold times were about 10 minutes
  - Most select cycles we measured at:

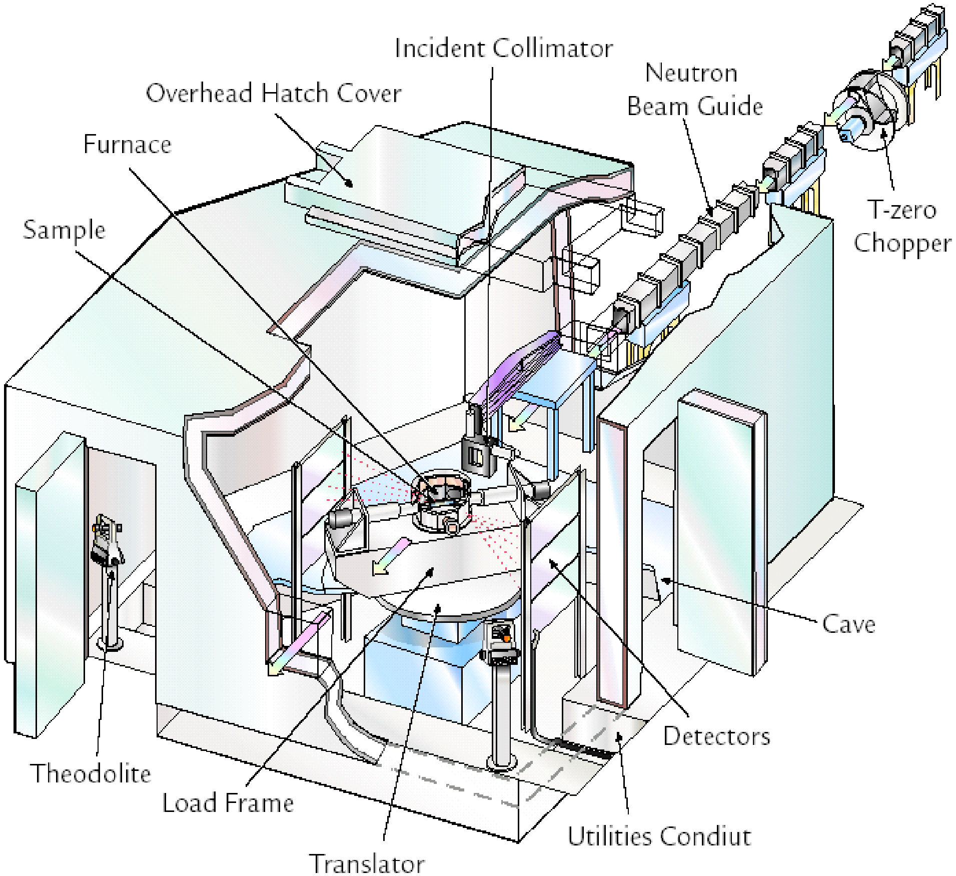
    ε = -1%, σ = 0 MPa, ε = 0%,

    ε = 1%, σ = 0 MPa, ε = 0%



SMARTS

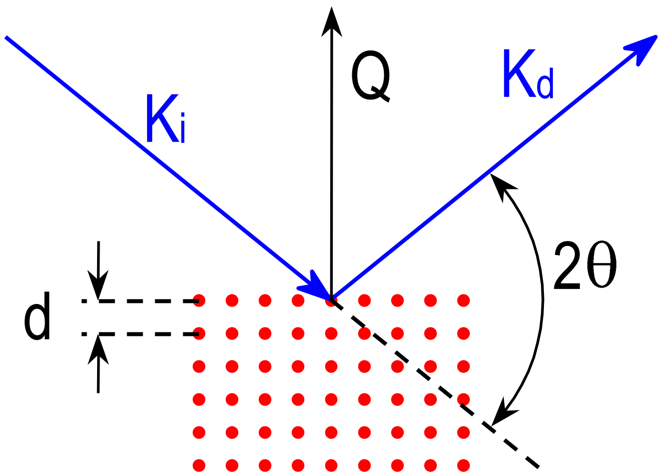
- **S**pectrometer for
  MAterials
  Research at
  Temperature and
  Stress



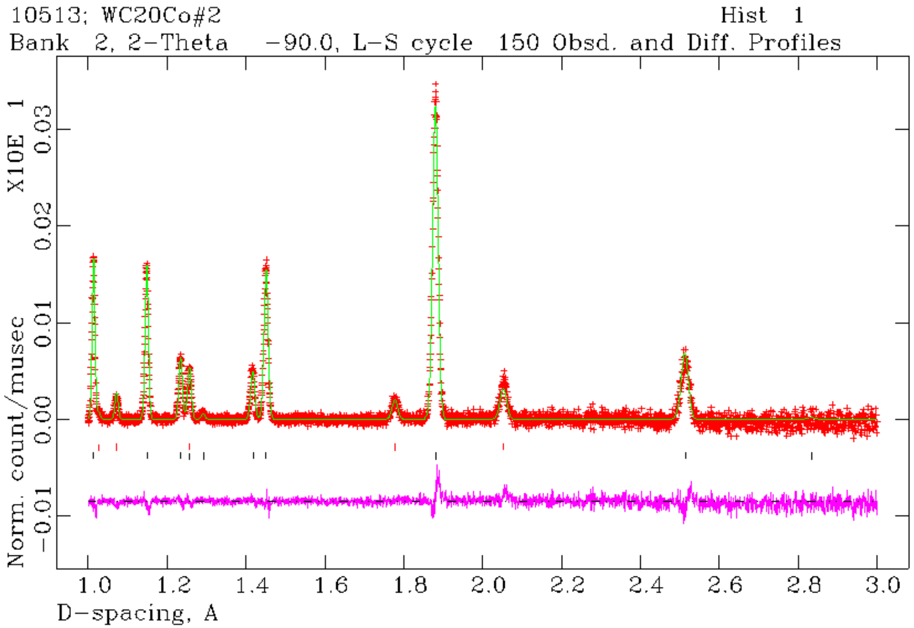
- Spatially resolved measurements
  - Residual strains in components
- *In situ* measurements
  - Strains as a function of stress, temperature, environment, …
- Instrument Scientists:
  - Donald W. Brown
  - Bjørn Clausen

https://lujan-proposals.lanl.gov/
Deadline: Monday, March 17, 2008

Information Obtained from Diffraction Measurements



$$\lambda = 2d\sin\theta$$

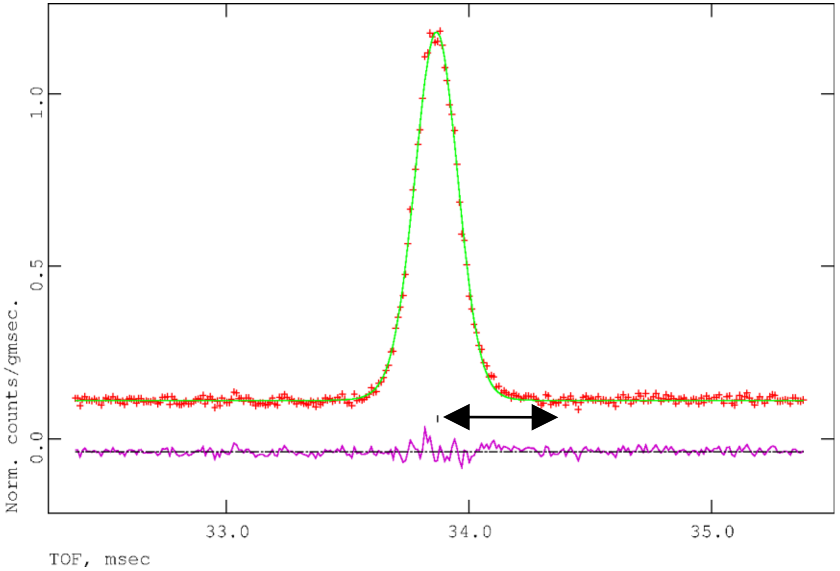


Phase specific: Important for composites

- Elastic Bragg scattering
  – Time-of-flight: Energy dispersive with fixed geometry

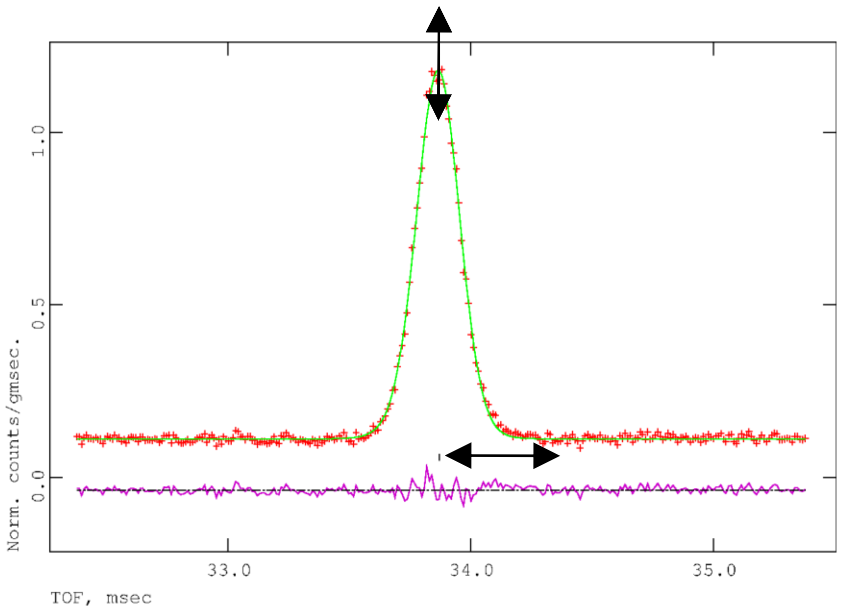
Information Obtained from Diffraction Measurements

- Peak position
  - Elastic lattice strain from changes in peak position
  - Intergranular strains



Information Obtained from Diffraction Measurements

- Peak position
  - Elastic lattice strain from changes in peak position
  - Intergranular strains
- Peak intensity
  - Texture change from changes in peak intensities



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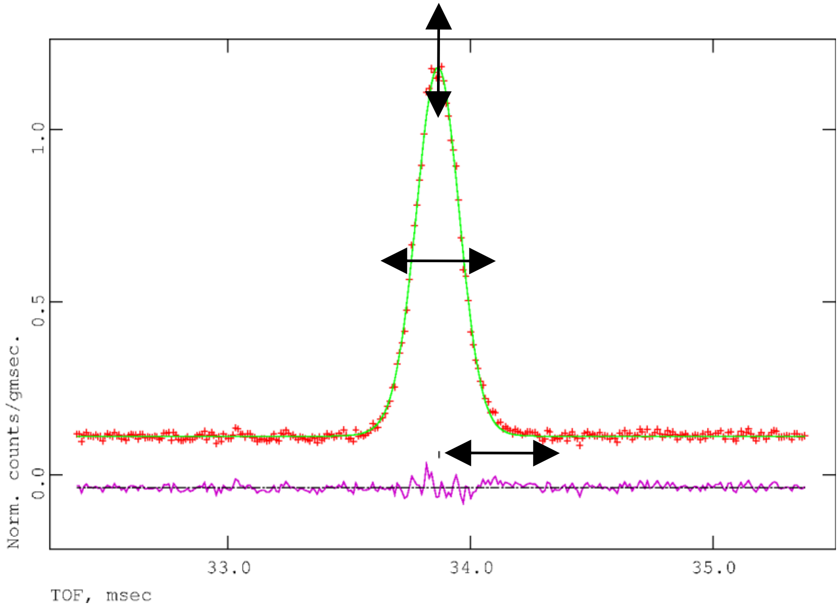
Information Obtained from Diffraction Measurements

- Peak position
  - Elastic lattice strain from changes in peak position
  - Intergranular strains
- Peak intensity
  - Texture change from changes in peak intensities
- Peak width
  - Depends on defect concentration
    - Generally increases with plastic deformation
  - SMARTS does not have the resolution for quantitative analysis



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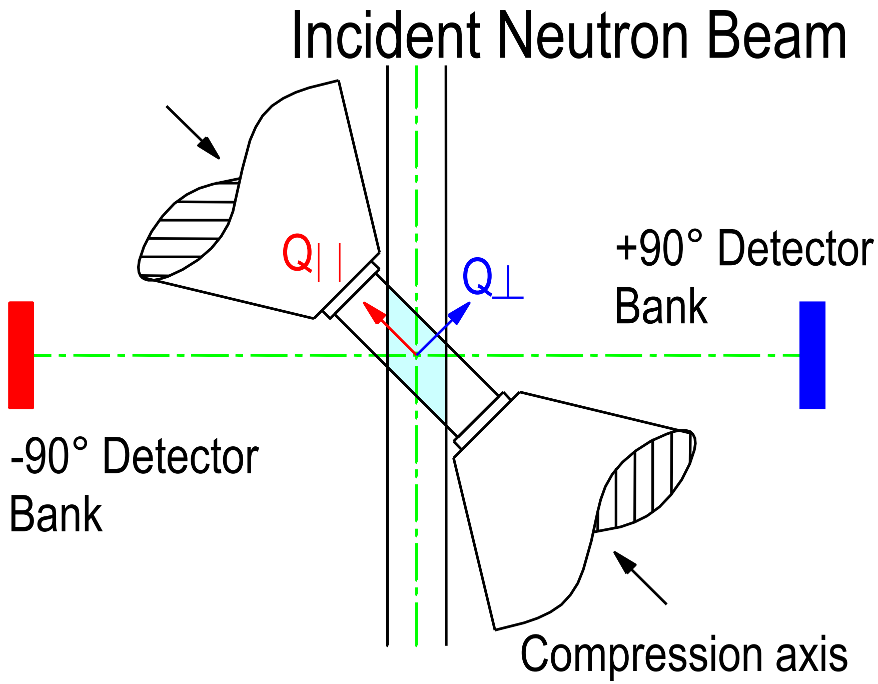
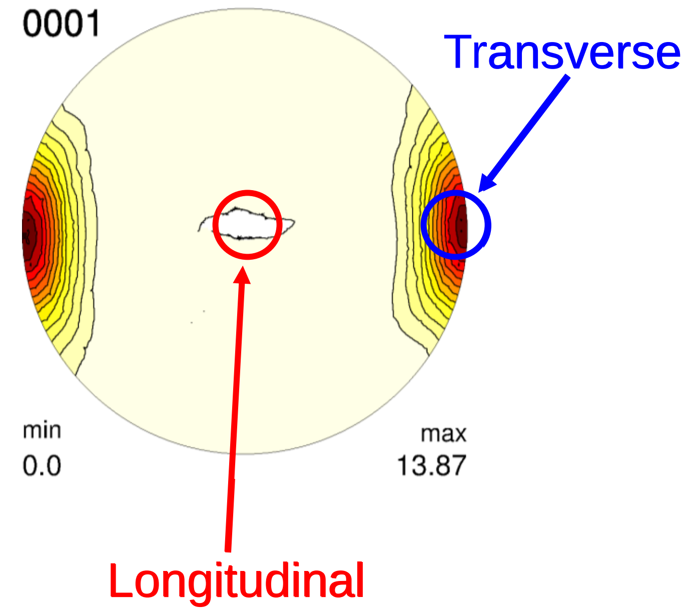
Geometry: Scattering Vectors





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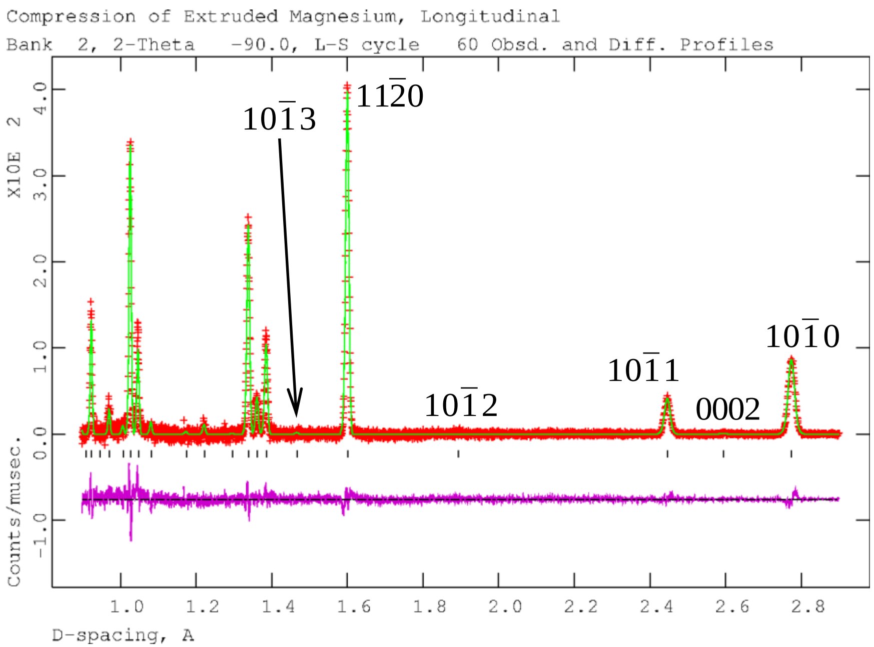
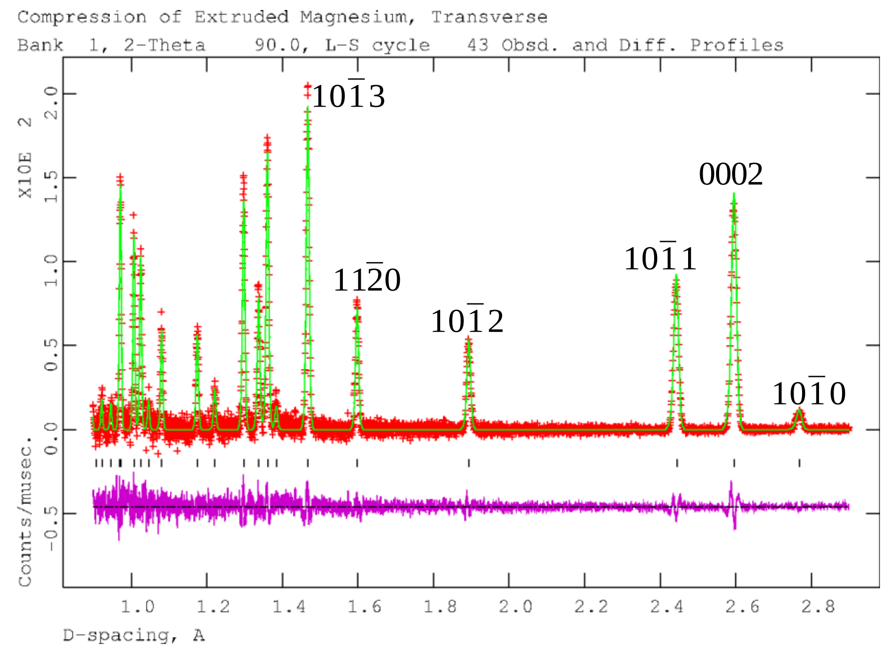
SMARTS Diffraction Patterns



Extruded Longitudinal

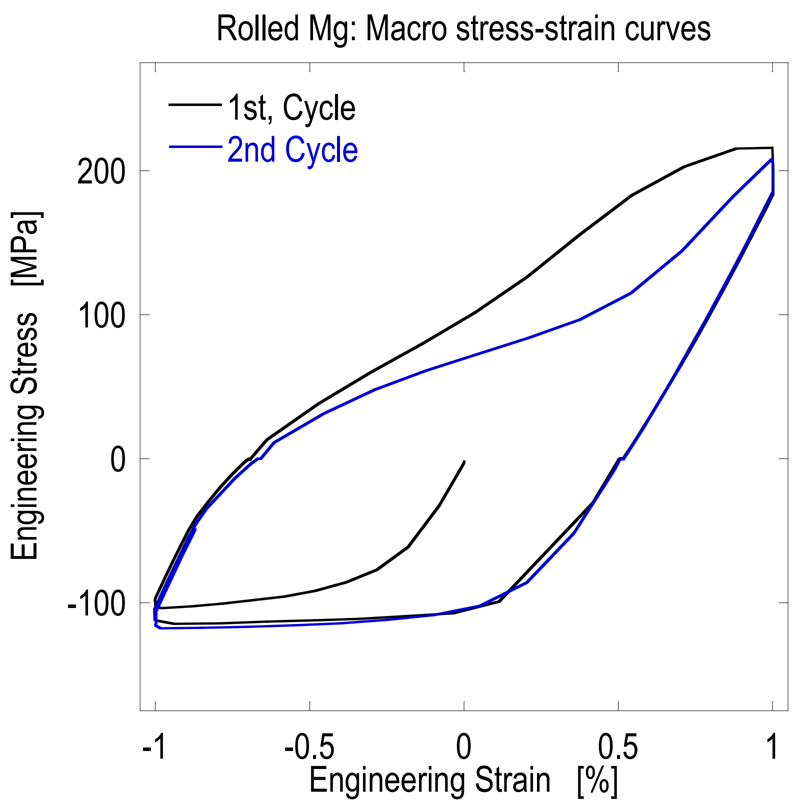


Extruded Transverse

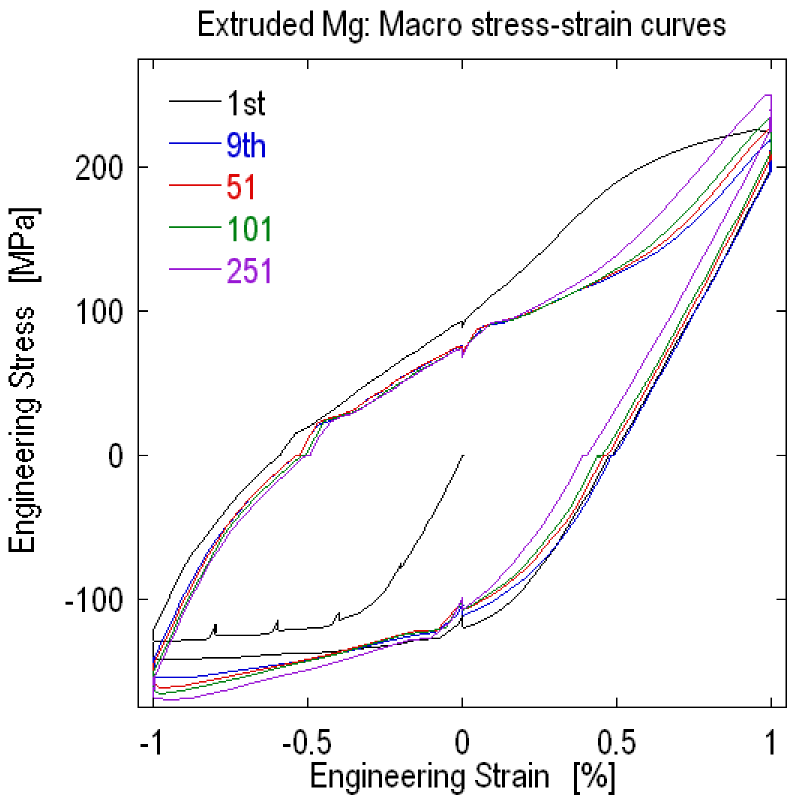
- Not all peaks are present in both banks due to the strong initial texture

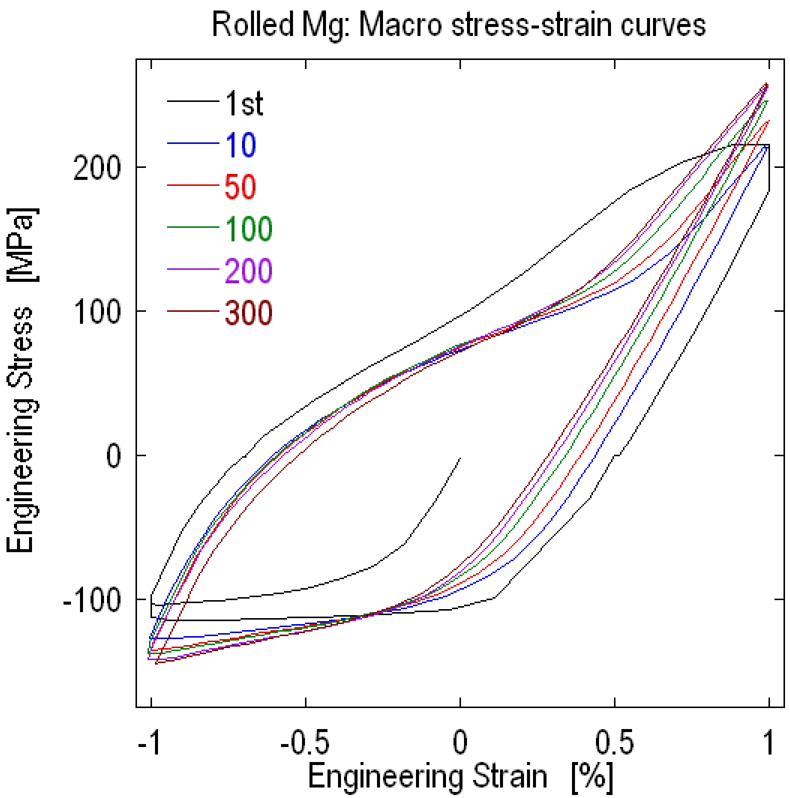
Macro Stress-Strain Curves

- 1^{st} Cycle
  - 1% Compression
  - 2% Tension
    - Run out of twins after 1% tension
    - Further deformation by slip with associated hardening
- 2^{nd} Cycle
  - 2% Compression
  - 2% Tension
    - De-twinning the entire way



Macro Stress-Strain Curves





- Only minor differences between Extruded and Rolled
  - Loop is very asymmetric due to twinning

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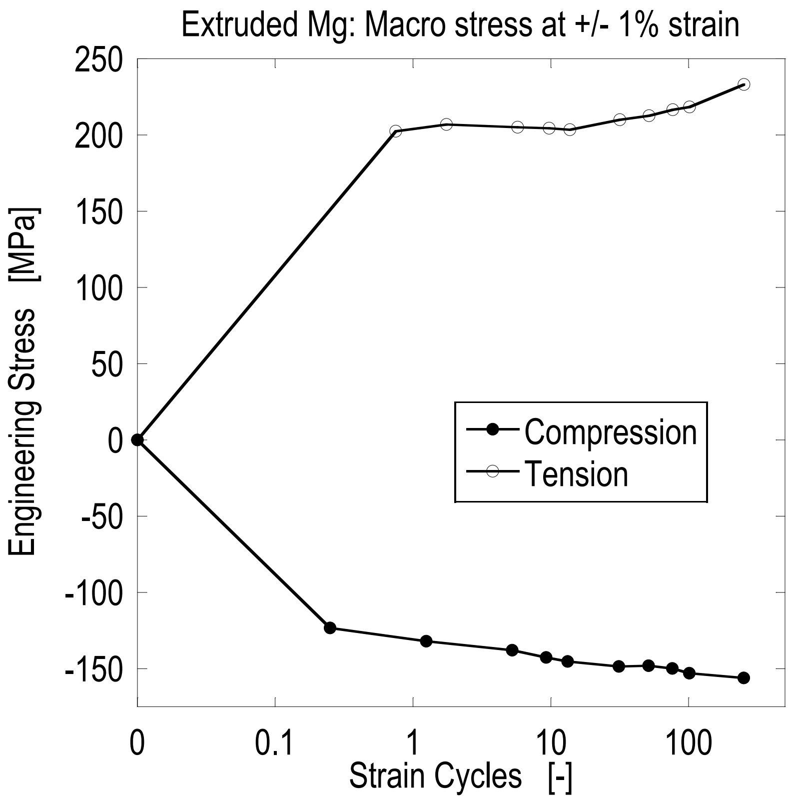
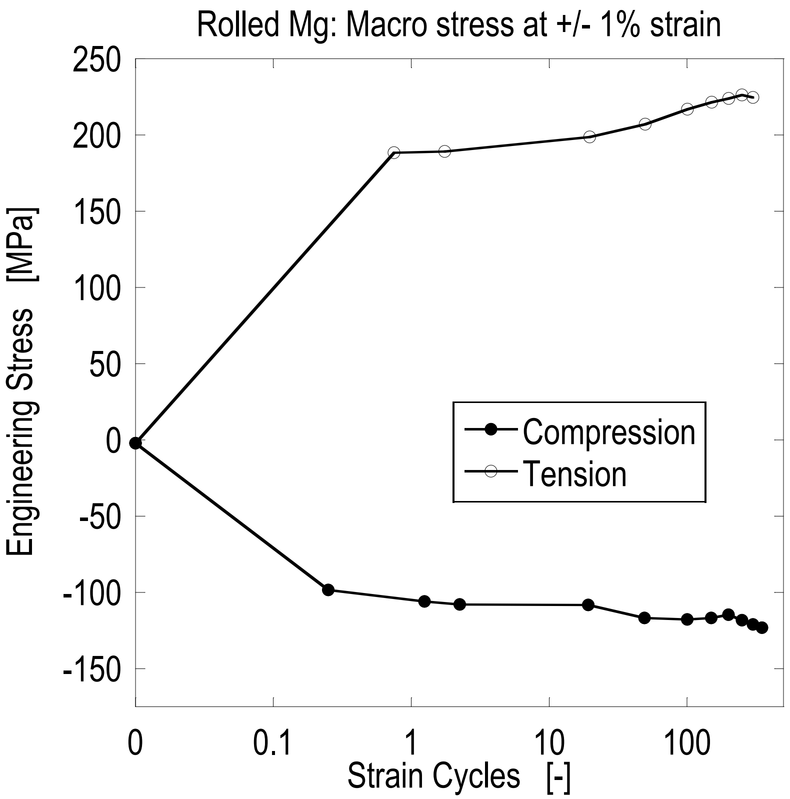
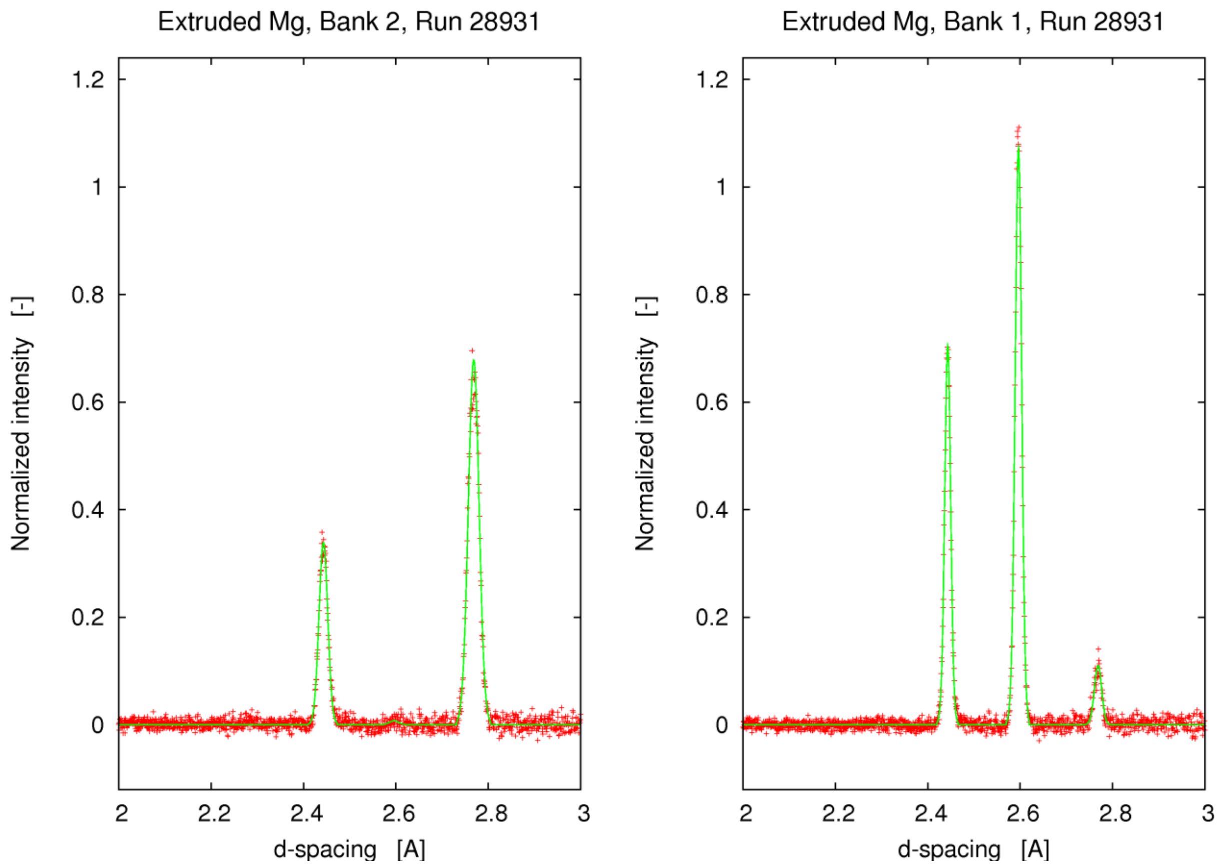
Macro Stress During Neutron Measurements





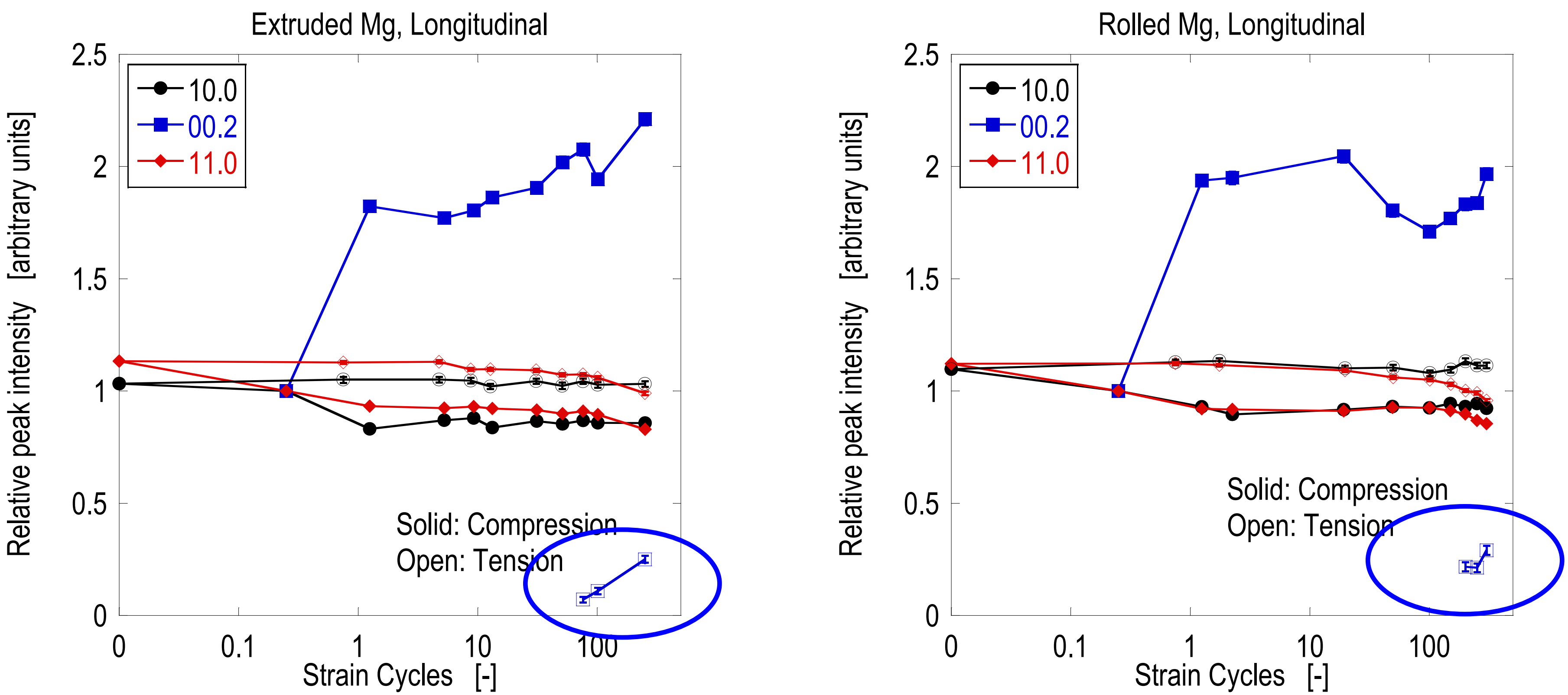
- Development of maximum and minimum stresses
  - Both show evidence of cyclic hardening

Measured Diffraction Data



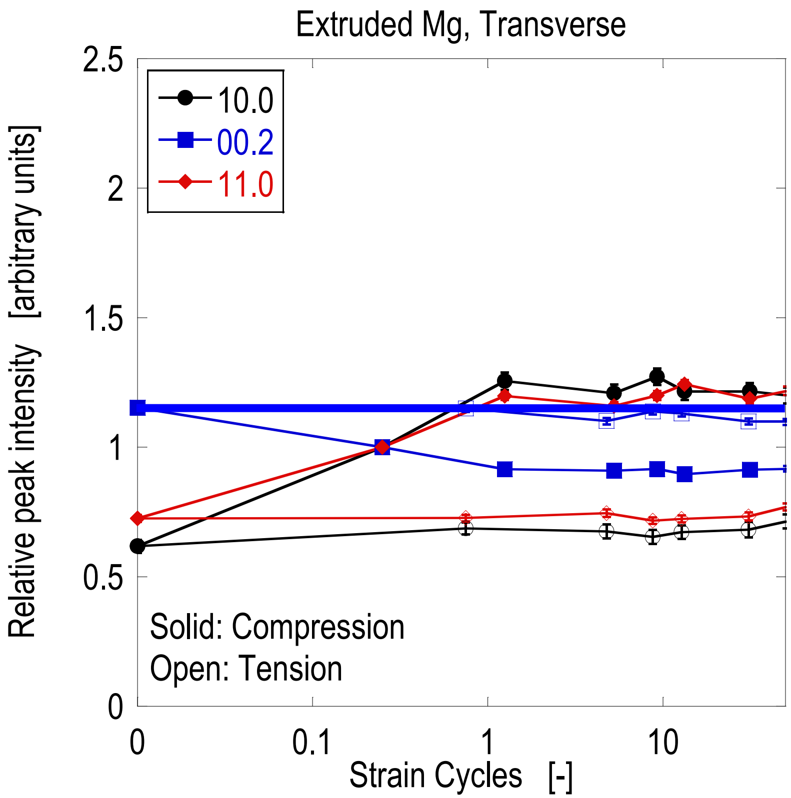
- Initially twins disappears fully upon tensile loading
  - At the end, residual twins are observed in tension

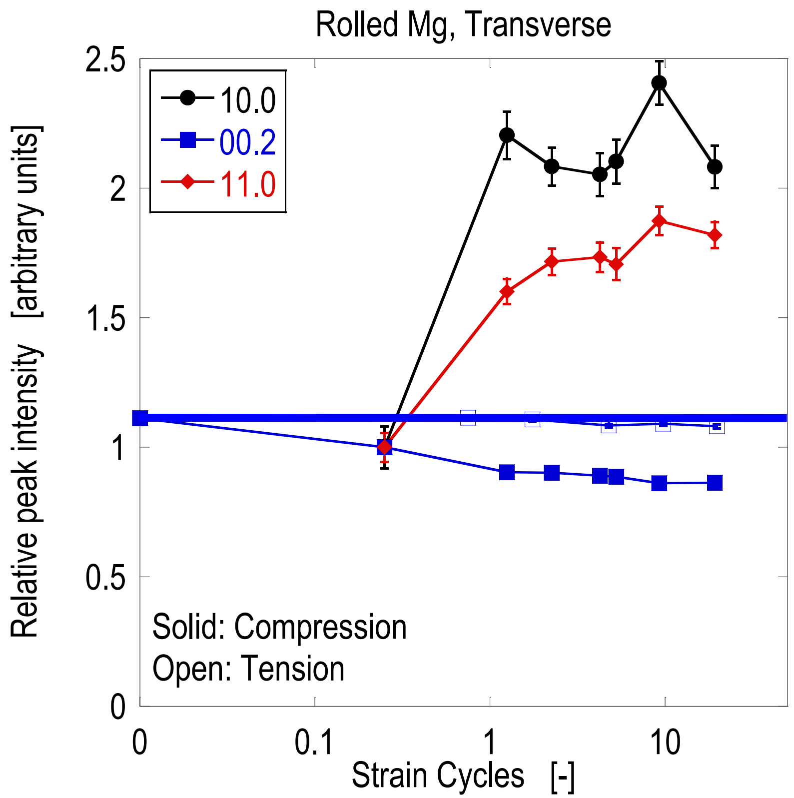
Peak Intensities: Twin Volume Fraction



- Twin volume fraction after 2% compressive load is about 15%
- Residual twins are observed above ~75 and ~150 cycles, respectively

Peak Intensities: De-Twinning or Re-Twinning





- Transverse 00.2 intensity is constant in early cycles
  - Supports De-twinning rather than Re-twinning

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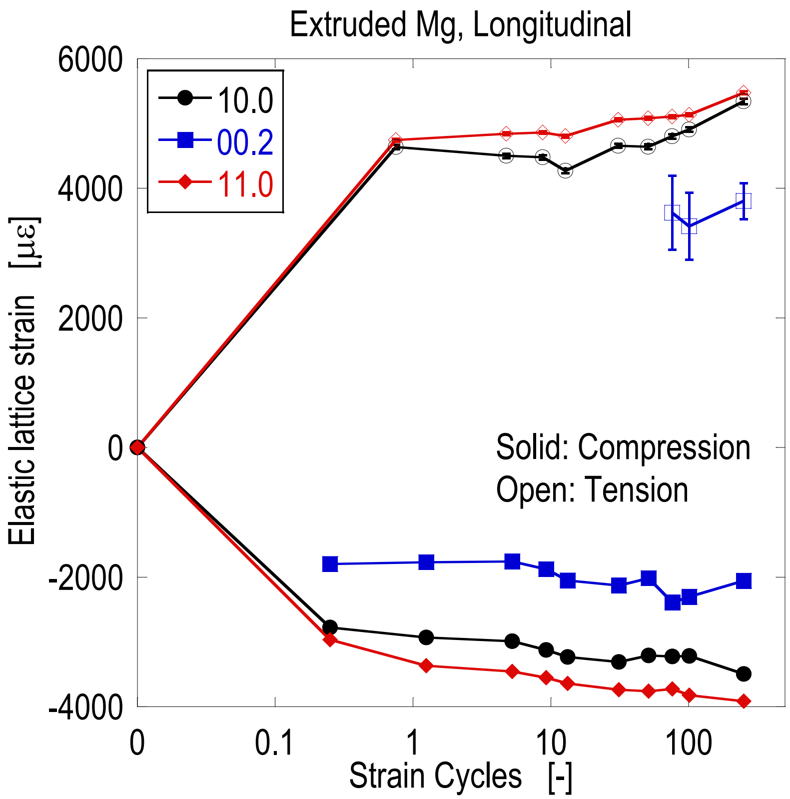
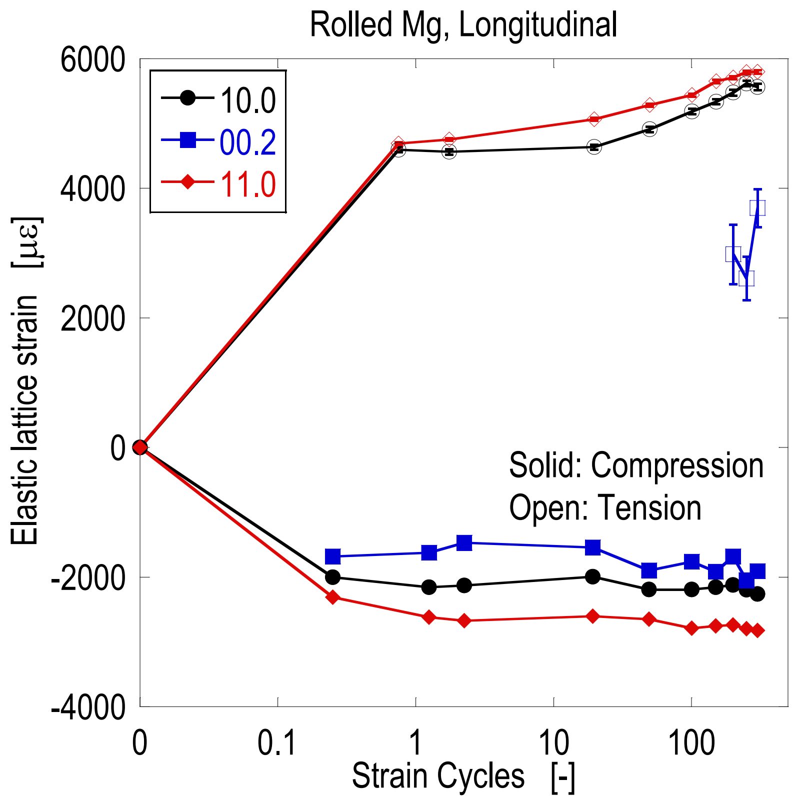
Lattice Strains

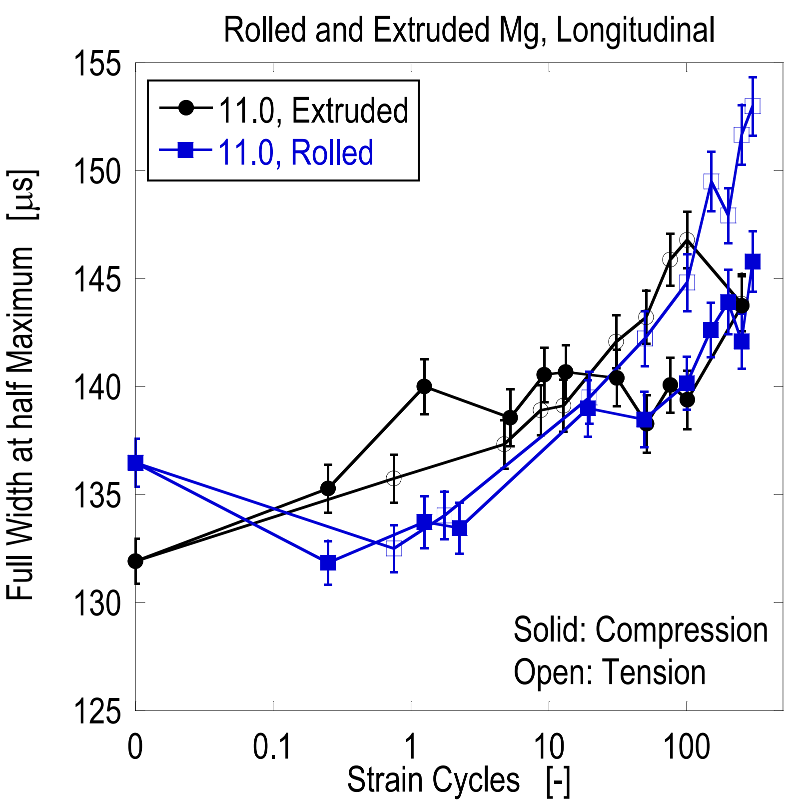




- The lattice strain follow the macro stress
  - Intergranular strains largest for Extruded: 2000 με (~80 MPa)

Peak Width

- Increasing peak width with cycles
  - Slight initial decrease for Rolled
- Twinning/De-twinning process leaves behind ‘debris’
  - Leads to hardening



Conclusions

- Investigated twinning and de-twinning in Extruded and Rolled magnesium AZ31 alloy during low cycle fatigue test
  - Cyclic hardening was observed for both Extruded and Rolled
- In-situ neutron diffraction measurements were made at select cycles
- De-twinning or Re-twinning?
  - Development of peak intensities are consistent with full de-twinning up to ~75 and ~150 cycles for Extruded and Rolled, respectively
  - Longitudinal 00.2 peak intensity fully disappear
  - Transverse 00.2 peak intensity returns to initial level

  $\Rightarrow$ Diffraction based evidence that supports the conclusions of Wagoner et al.

Conclusions

- Higher cycles
  - Residual 00.2 intensity is observed longitudinal at minimum strain
  - Decrease of 11.0 intensity observed longitudinal at minimum and maximum strain
  - Consistent with the lower Schmid factor for tensile twinning of grains with 11.0 along the loading axis compared to grains with 10.0 along the loading axis (0.37 and 0.49, respectively)
- Lattice strains
  - Follows the macro stress behavior
  - Intergranular strains rise to about 2000 $\mu\varepsilon$ (~80 MPa)
- Peak width
  - Monotonic increasing peak width with cycles
  - Increase in defects or 'debris' from the twinning/de-twinning process
  - Leads to hardening as observed