SAND2019-13449C

**SMU**

# On the plastic anisotropy of a HCP cylindrical bar under quasi-static and dynamic uniaxial tensile loading
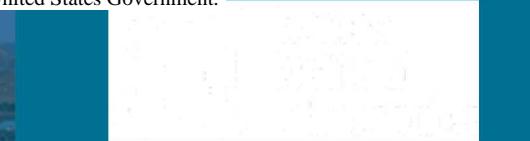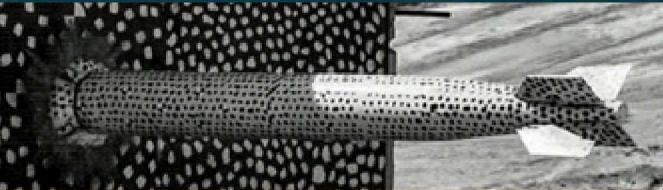
*2019 International Mechanical Engineering Congress & Exposition (IMECE), November 8-14, 2019, Salt Lake City, UT*

PRESENTED BY

Jie Sheng[1], Colin Loeffler[1,2], Xu Nie[1], Wei Tong[1], Brett Sanborn[2], and Bo Song[2]

[1]*Southern Methodist University, Dallas, TX*
[2]*Sandia National Laboratories, Albuquerque, NM*

# Anisotropy: Structures and Properties

**Rusty Gray III, et al. (2010)**

◦ "The development of predictive strength models and thereafter damage-evolution and fracture models, requires a detailed understanding of the correlated effects between microstructure and anisotropy (crystallographic and microstructural) since many engineered materials possess directional mechanical properties."
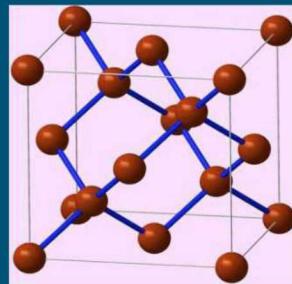

Crystallographic Structure


Microstructure


Material


Component

**Material anisotropy**

**Property anisotropy**
◦ **Stress-strain response**
◦ **Damage evolution**
◦ **Plastic deformation**
◦ **Failure/fracture**

**Strain-rate Effect**

***Material Model with Strain-rate Dependent Anisotropy Feature***

# In-situ Anisotropy Measurement

**Measurements/Observation**

**Tests**

- ➢ **Properties**
  - ➢ **Stress-strain response and failure/fracture**

- ➢ **Morphology**
  - ➢ **In-situ measurement**
  - ➢ **Post-test measurement**

- ➢ **Quasi-static tests**

- ➢ **Dynamic tests**
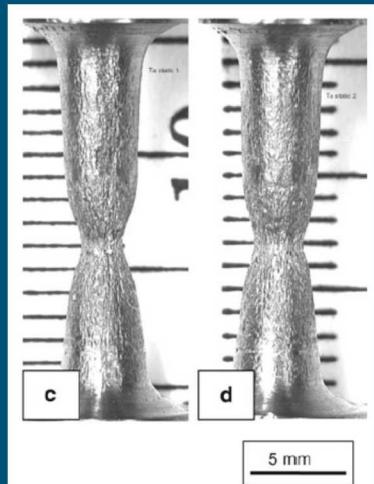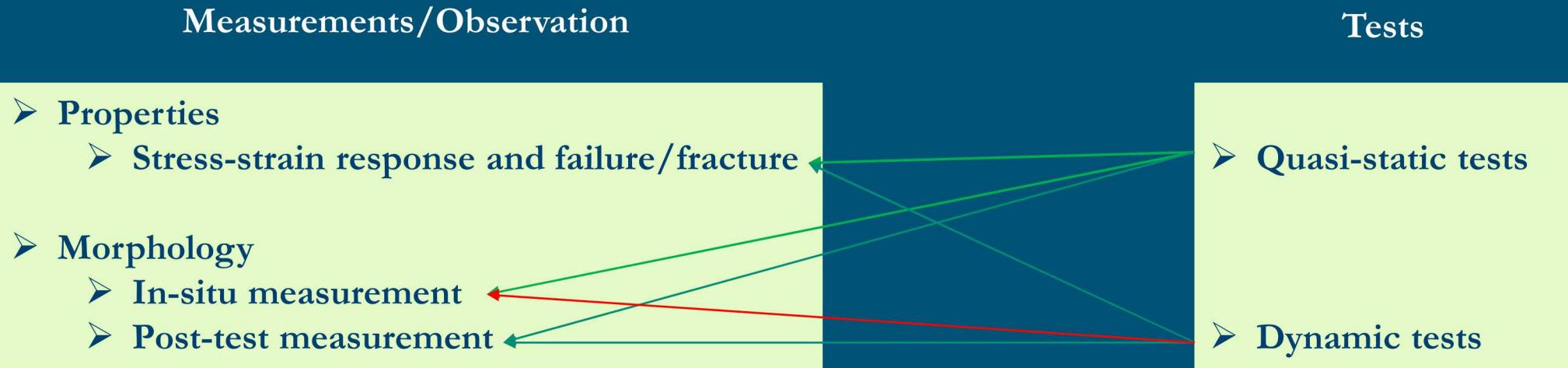
## Why is dynamic in-situ measurement important?

Strain-rate effect

Anisotropy evolution with time/strain

**Strain rate effect of anisotropy evolution**

*Maudlin, P.J., Bingert, J.F., House, J.W., and Chen, S.R. (1999) International Journal of Plasticity, 15:139-166.*
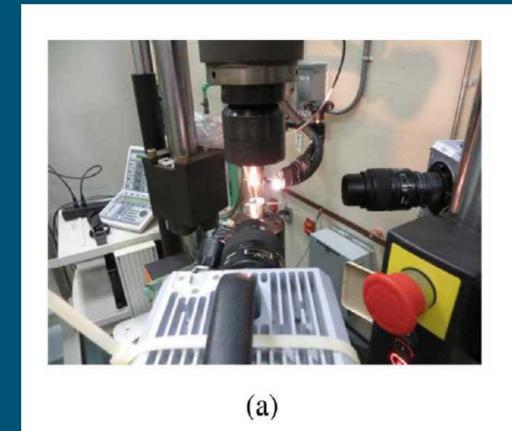
*Kleiser, G.J., Revil-Baudard, B., Cazacu, O., and Pasiliao, C.L., (2015) International Journal of Solids and Structures, 75-76:287-298.*



(a)

# Dynamic In-situ Measurement

The middle image from the direct camera capture
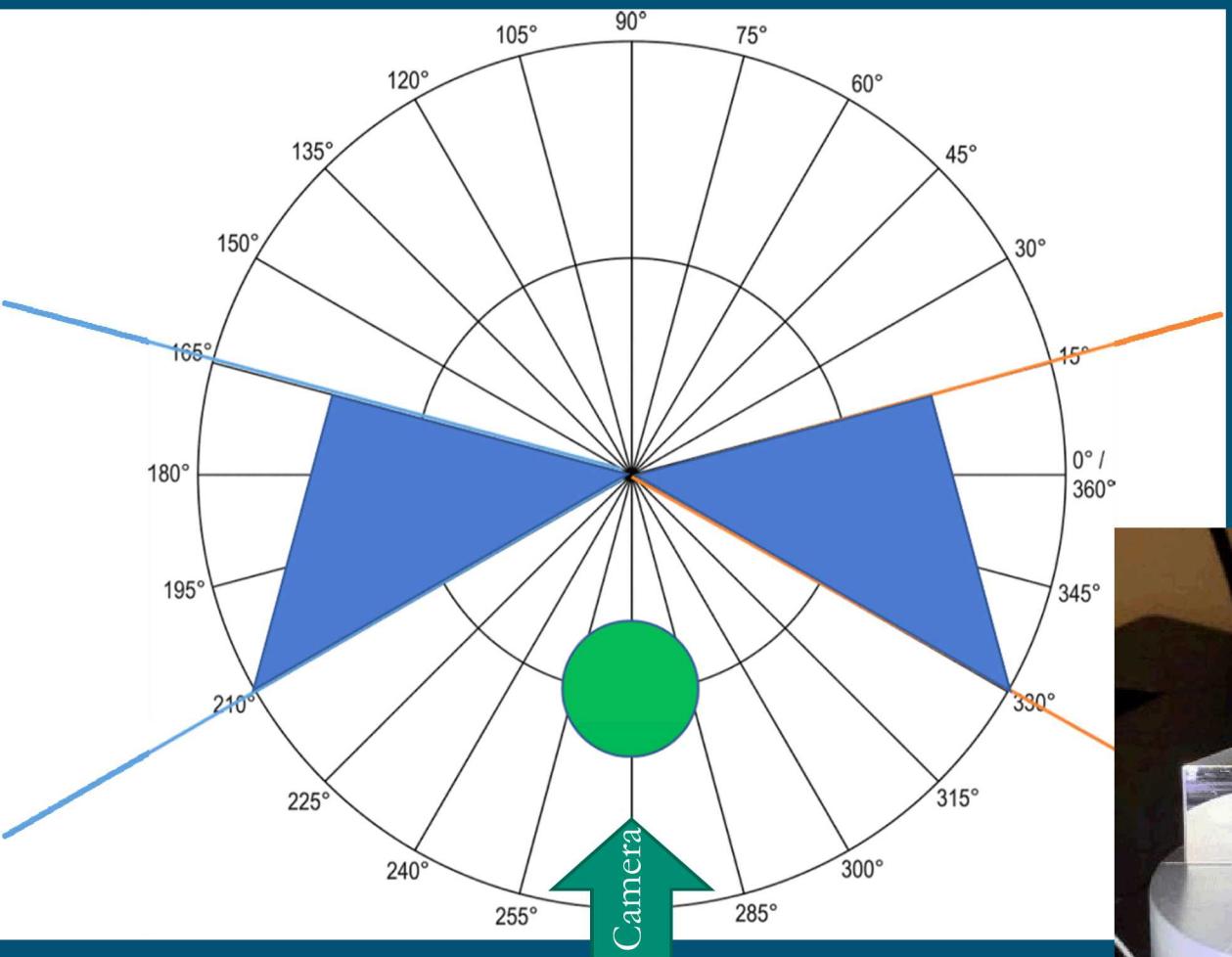


Before Test
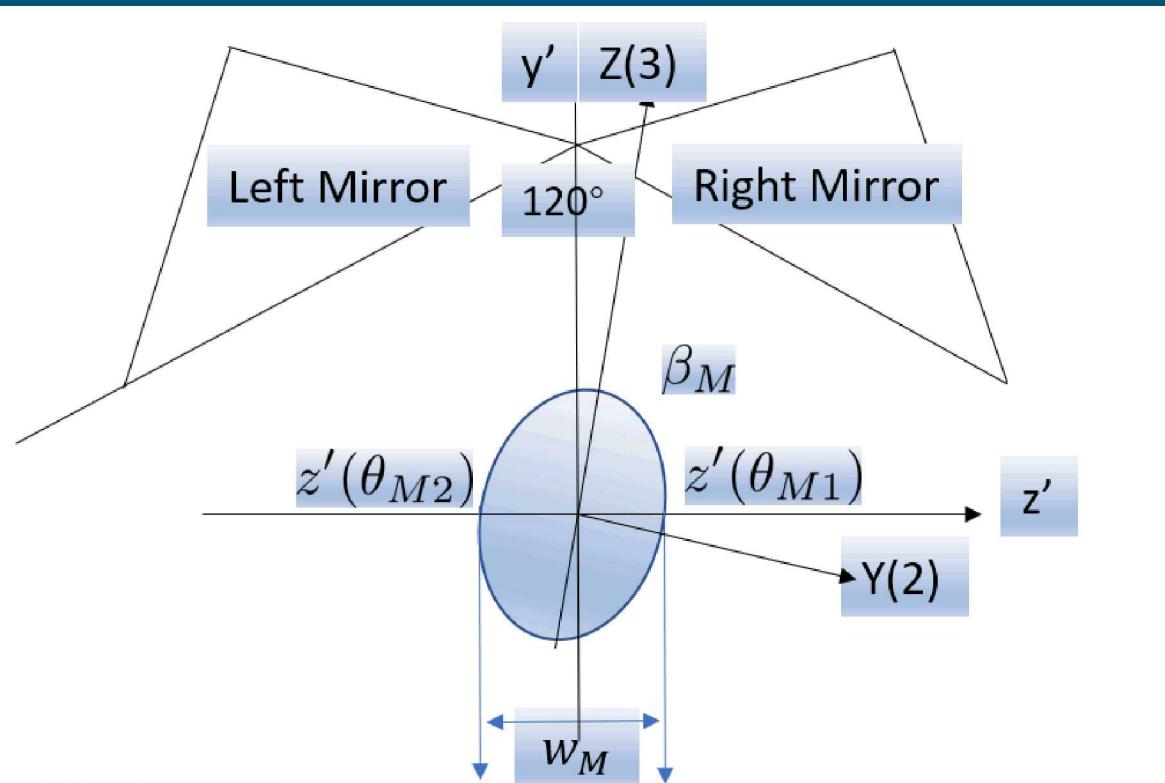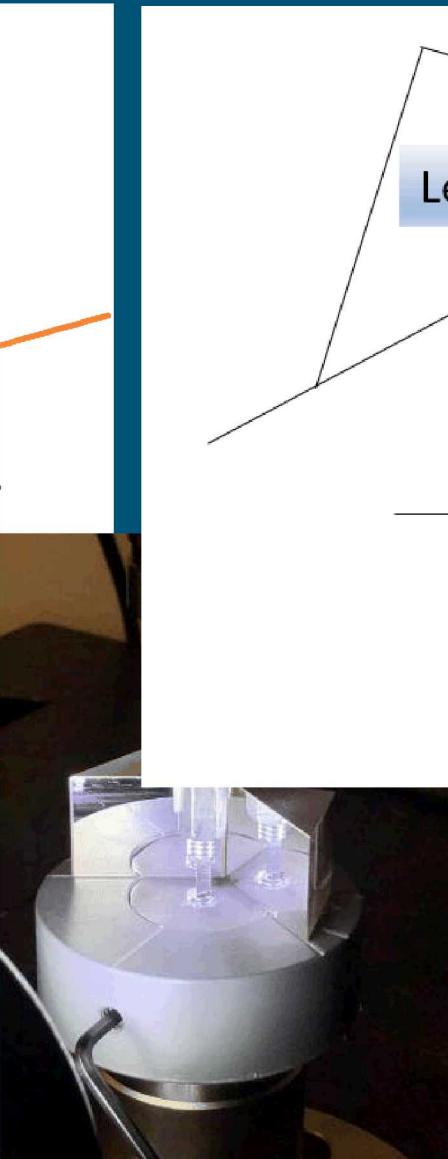


During Test

# Transverse Principal Strain Calculations



In quasi-static case:
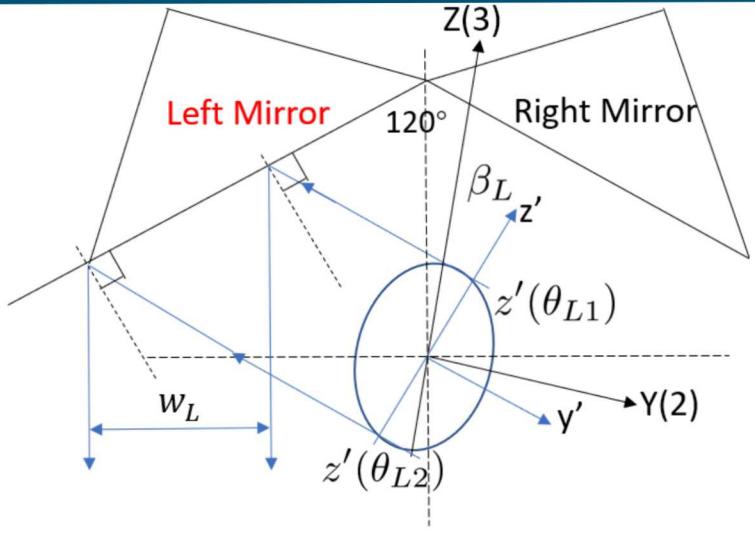
$$D_2^2 = \frac{1}{3}\left(w_L^2 + w_M^2 + w_R^2 - 2\sqrt{w_L^4 - w_L^2 w_M^2 + w_M^4 - w_L^2 w_R^2 - w_M^2 w_R^2 + w_R^4}\right),$$

$$D_3^2 = \frac{1}{3}\left(w_L^2 + w_M^2 + w_R^2 + 2\sqrt{w_L^4 - w_L^2 w_M^2 + w_M^4 - w_L^2 w_R^2 - w_M^2 w_R^2 + w_R^4}\right),$$

$$R = \frac{\varepsilon_2^p}{\varepsilon_3^p} = \frac{\ln\left(D_2/D_0\right)}{\ln\left(D_3/D_0\right)} \qquad \begin{array}{c} R = 1 \\ \downarrow \\ \text{isotropic} \end{array}$$
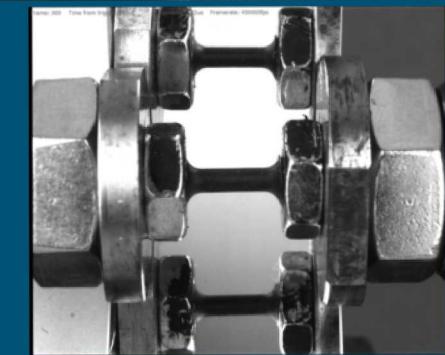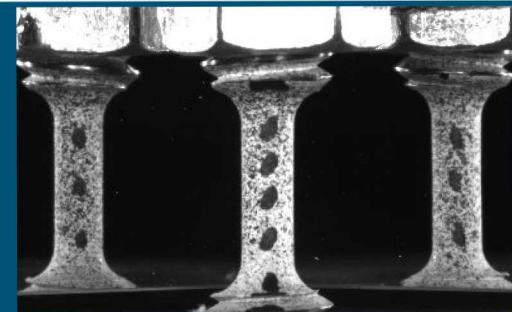
In dynamic case:
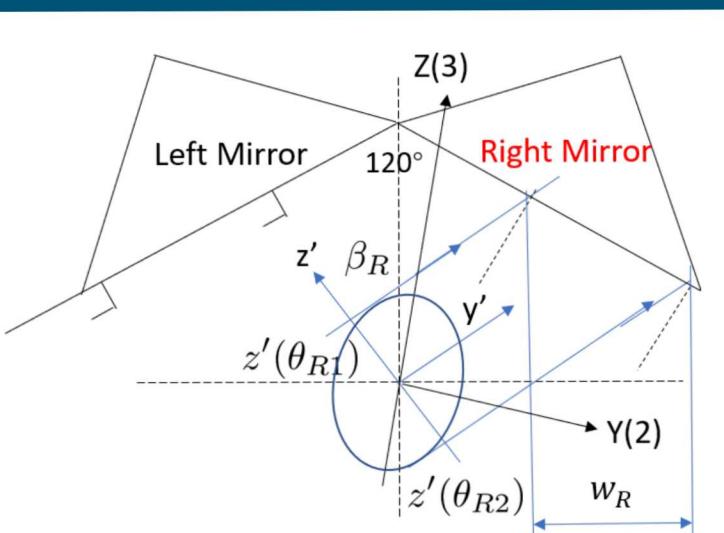
$$D_2^2 = \frac{1}{3}\left(w_B^2 + w_M^2 + w_T^2 - 2\sqrt{w_B^4 - w_B^2 w_M^2 + w_M^4 - w_B^2 w_T^2 - w_M^2 w_T^2 + w_T^4}\right),$$

$$D_3^2 = \frac{1}{3}\left(w_B^2 + w_M^2 + w_T^2 + 2\sqrt{w_B^4 - w_B^2 w_M^2 + w_M^4 - w_B^2 w_T^2 - w_M^2 w_T^2 + w_T^4}\right),$$

# Edge Detection for Diameter Measurements (Profile Measurements)

Verified with quasi-static tests of isotropic tensile specimens
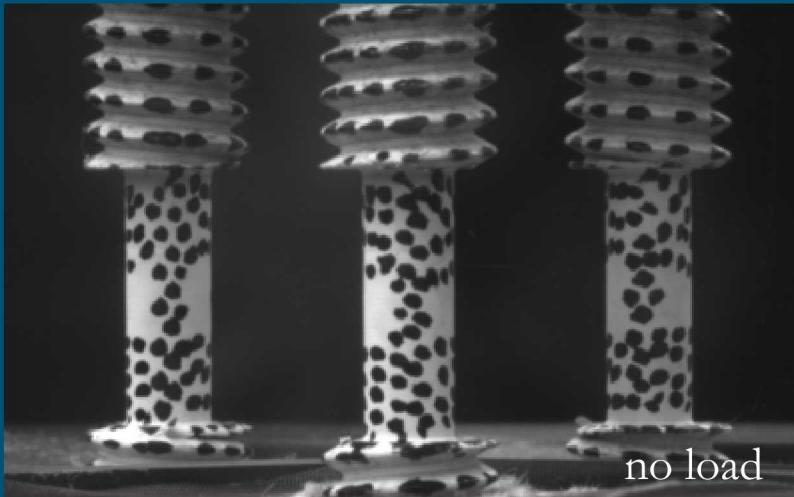


no load
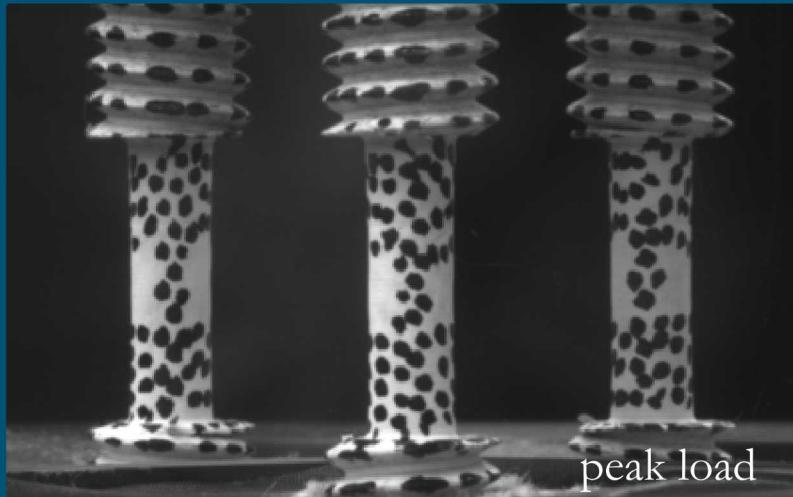
peak load
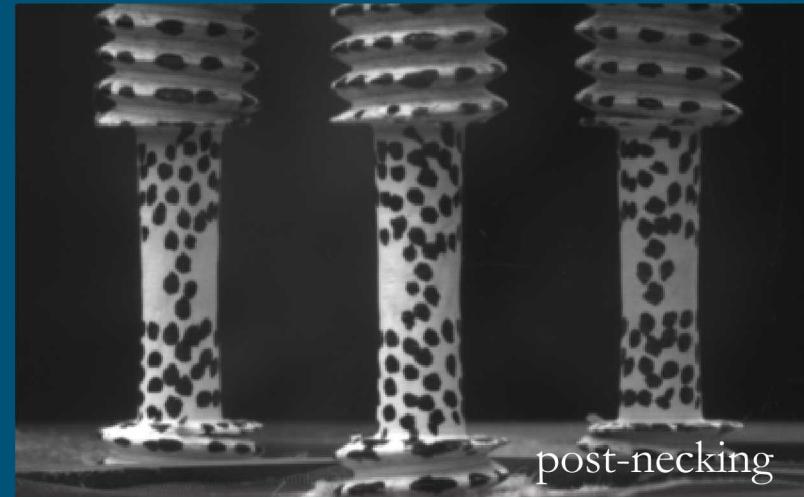
post-necking

AA6061-T6
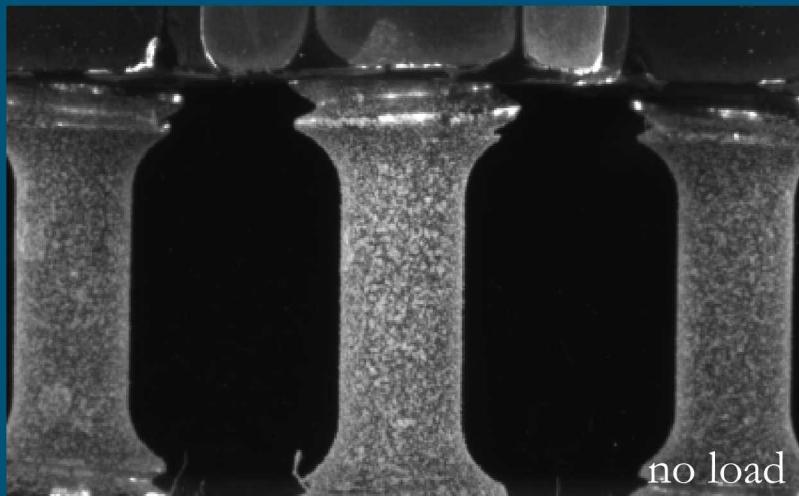


no load
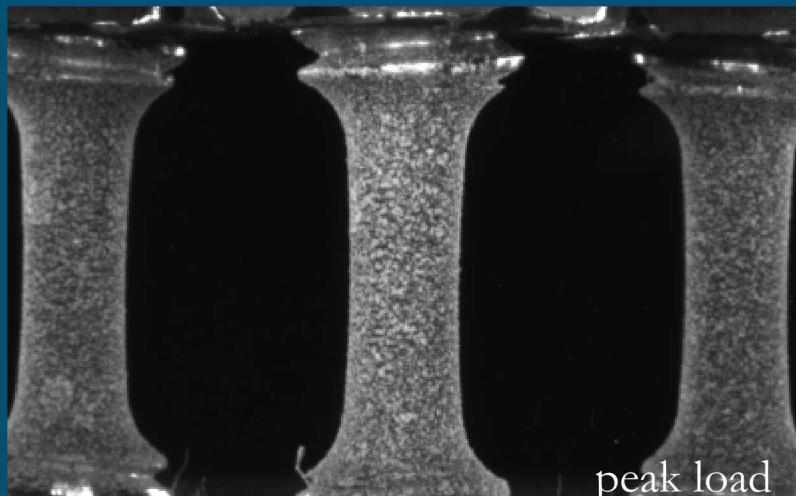
peak load
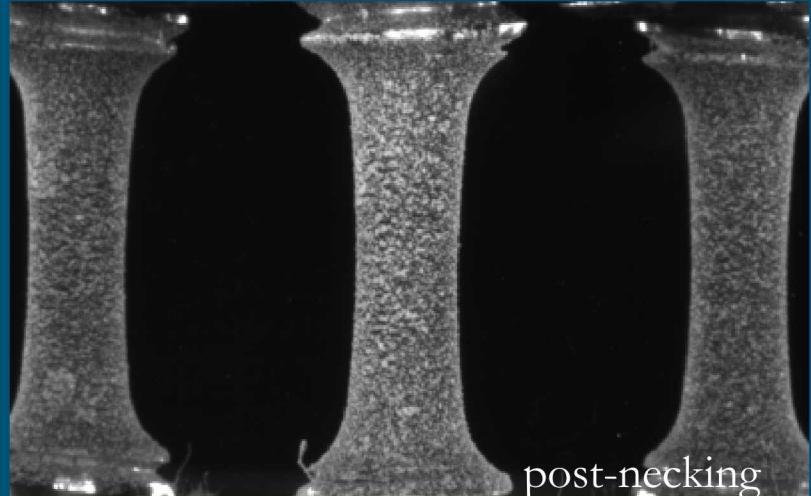
post-necking

SS316

# R-Values from Profile Measurements
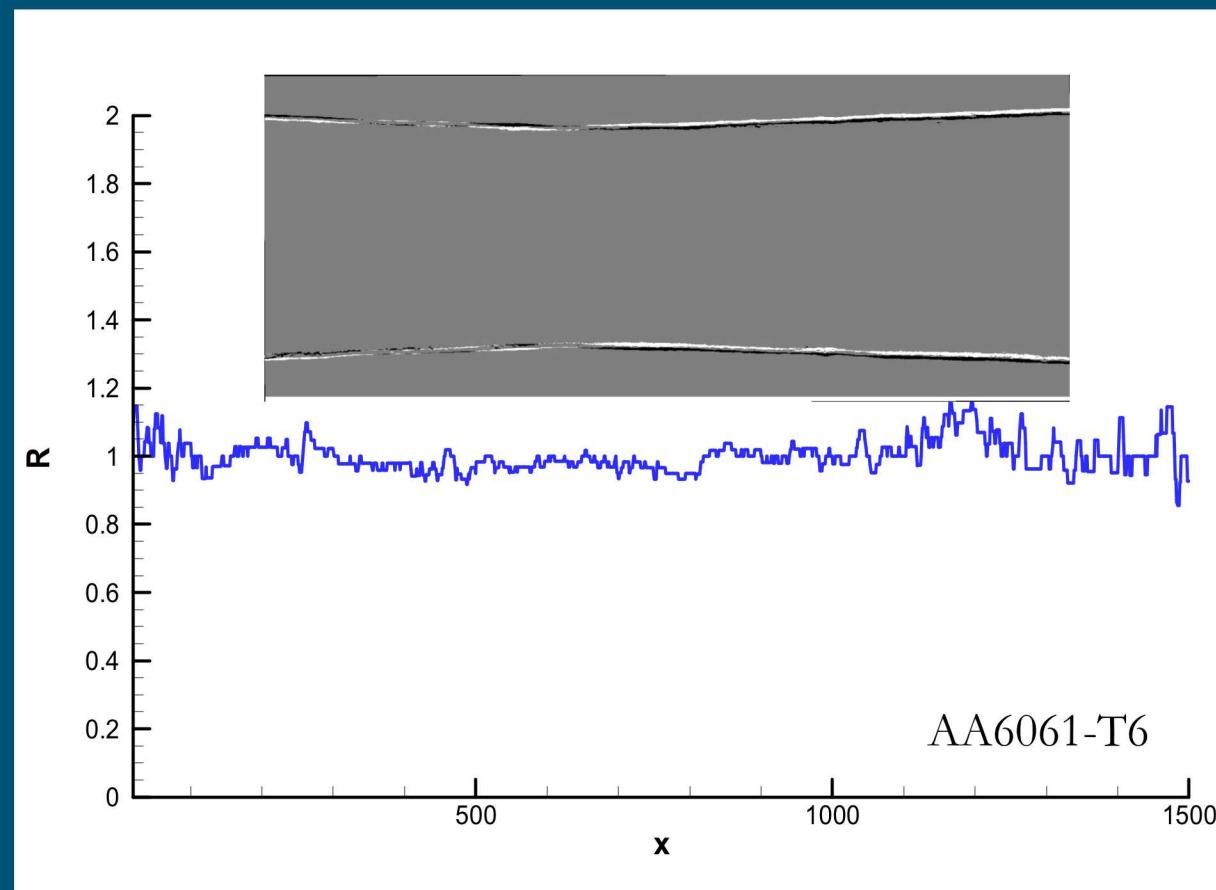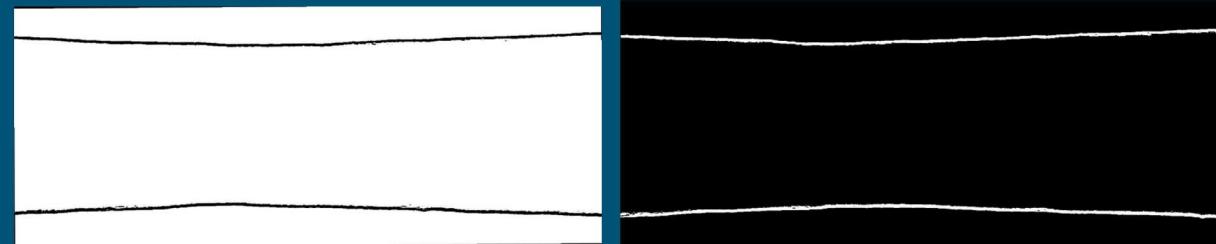


Before Test

After Test

AA6061-T6

SS316
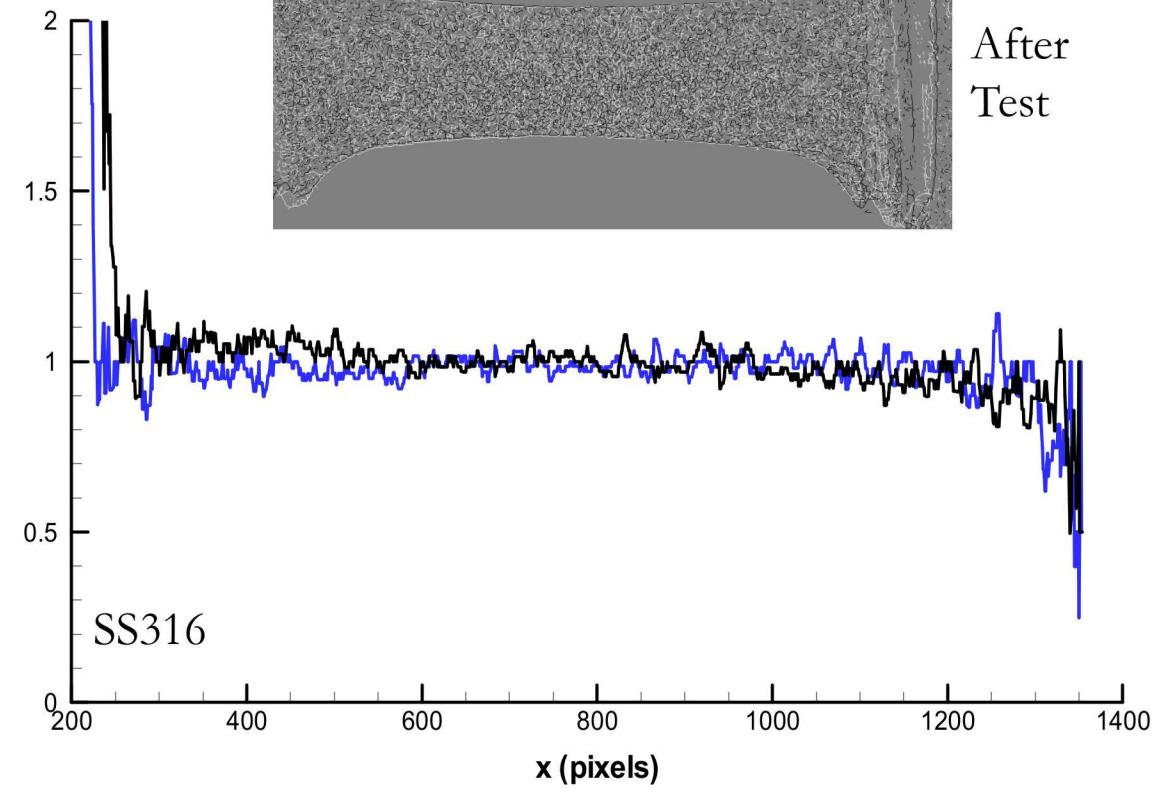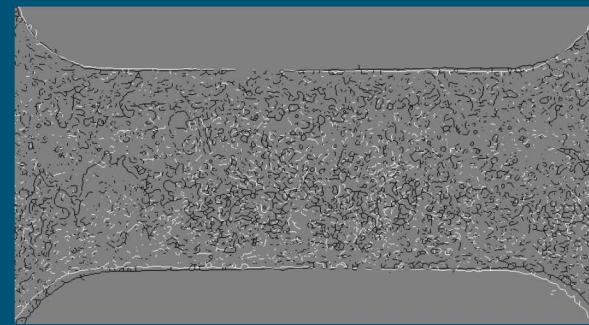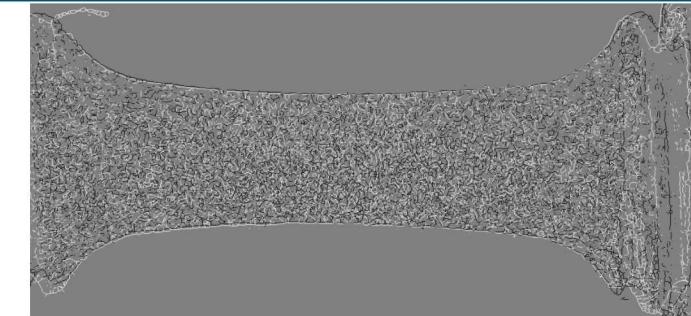
# Quasi-static and Dynamic Tensile Tests of Zirconium

- In-plane Isotropic/Out-of-plane Anisotropic
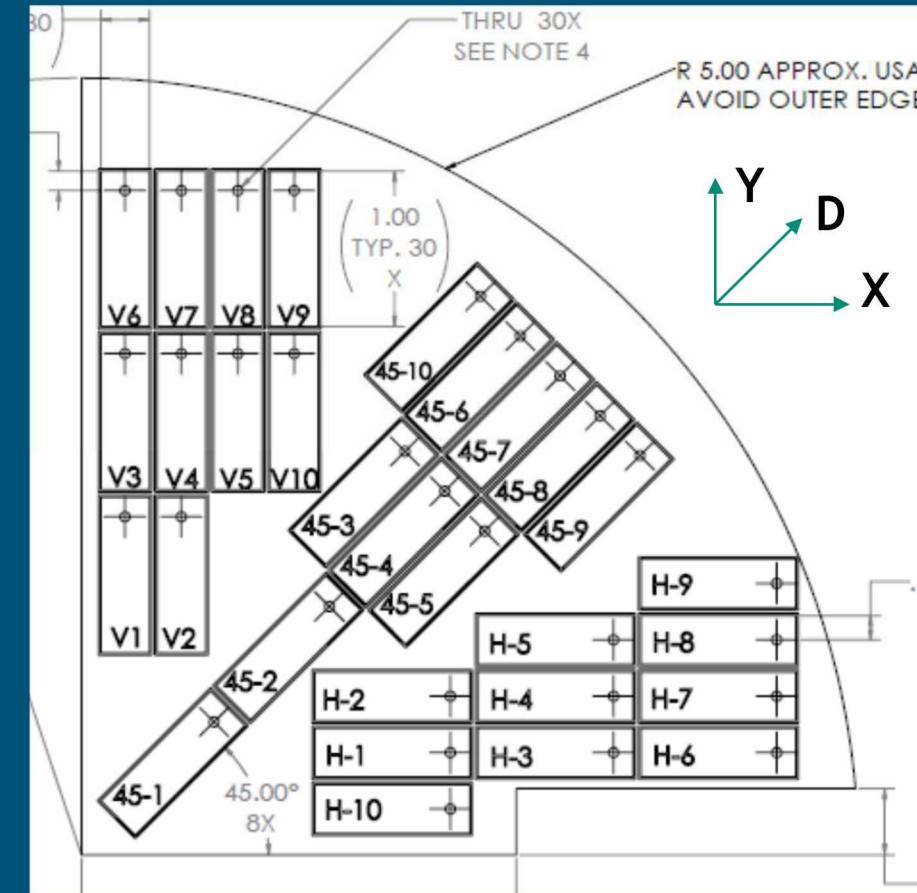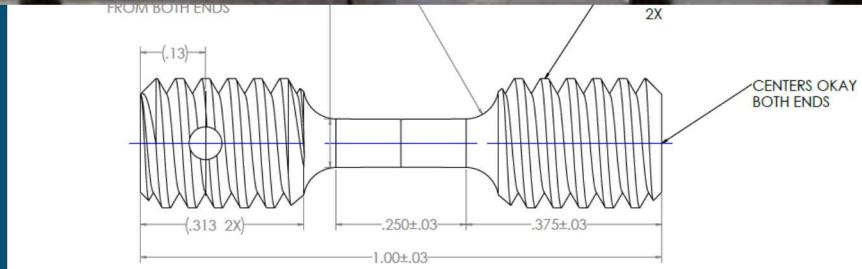


Quasi-static tests:
- ✓ Interrupted tests prior to necking
- ✓ Completed tests to failure

Dynamic tests:
- ✓ Specimens were not failed due to the limited duration of loading

# Quasi-static and Dynamic Tensile Tests of Zirconium
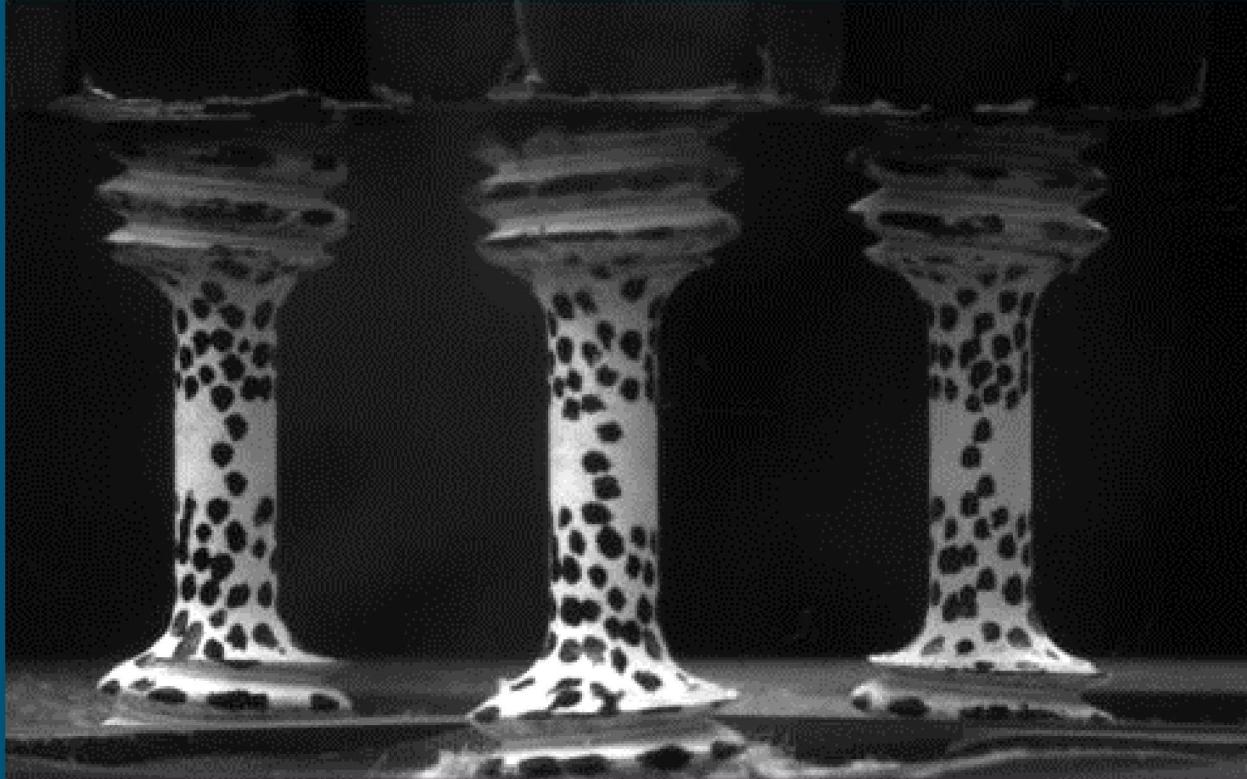


Quasi-static Test
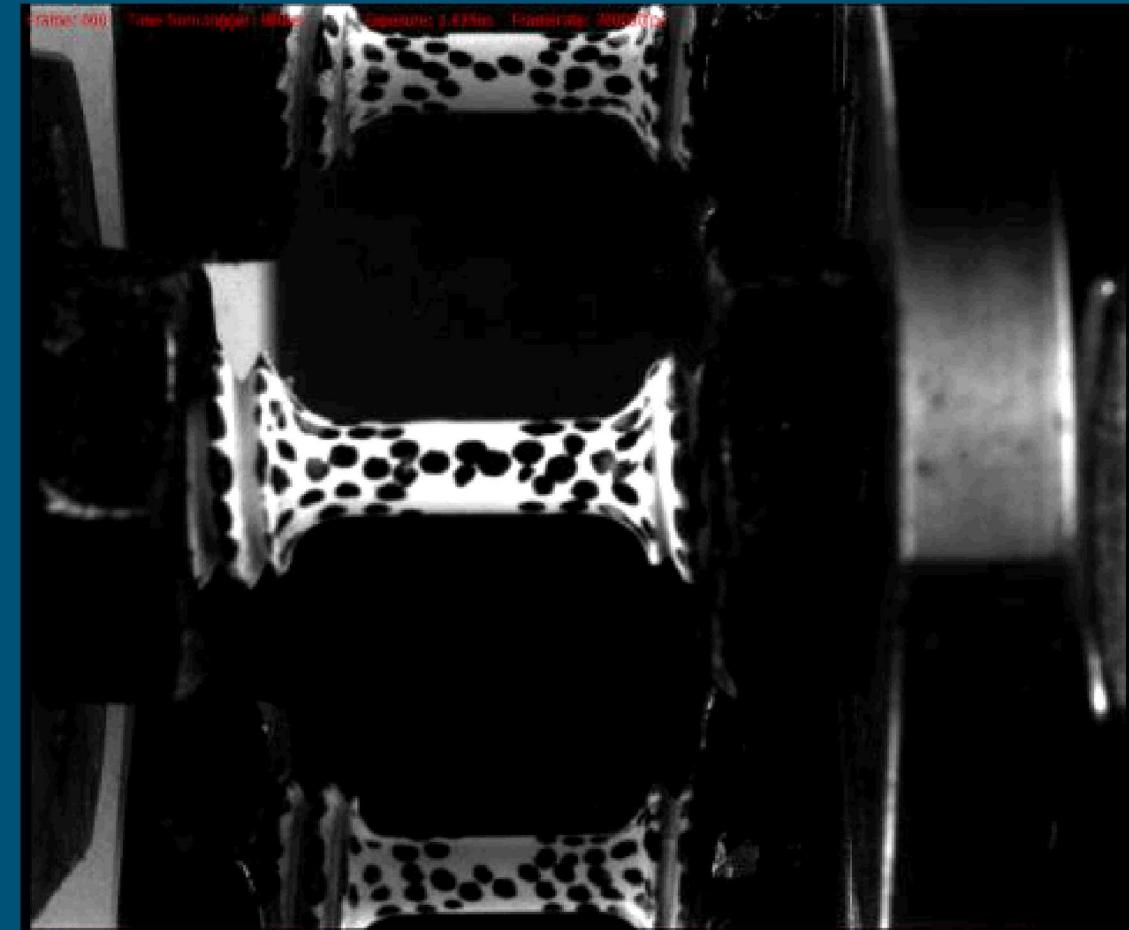


Dynamic Test

Quasi-Static Test  Sample Zr45_4

After Test

2 (Y)

1 (X)

2 (Y)

1 (X)

3 (Z)

After Test

1 (X)

3 (Z)

1 (X)

Before Test

# Quasi-static Interrupted Test (Zr45_4) @ 0.01/s
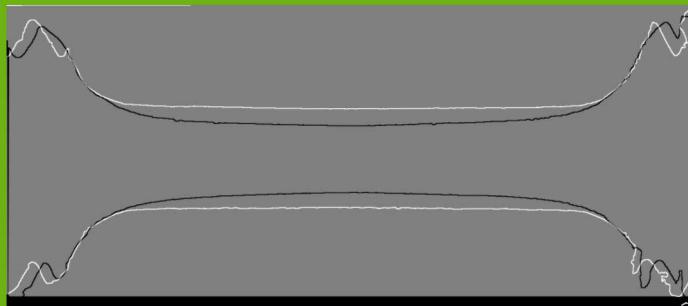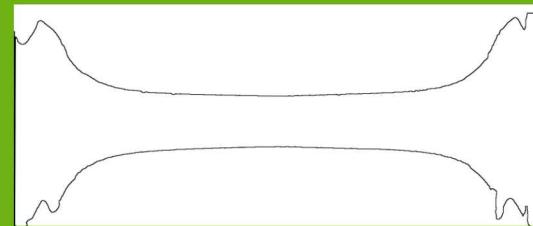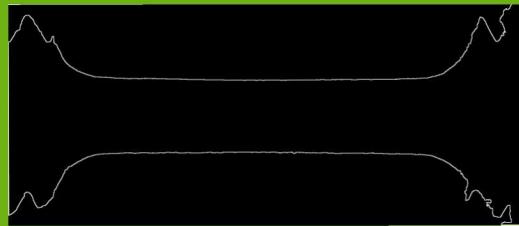


20X
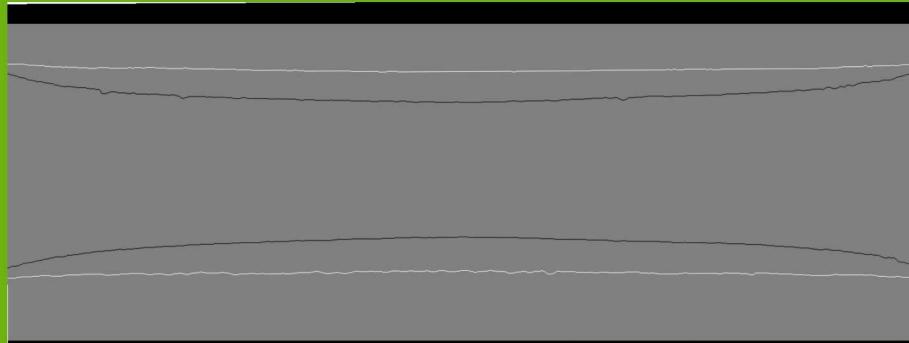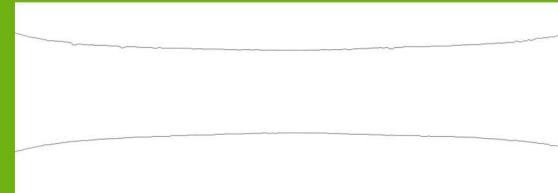
30X
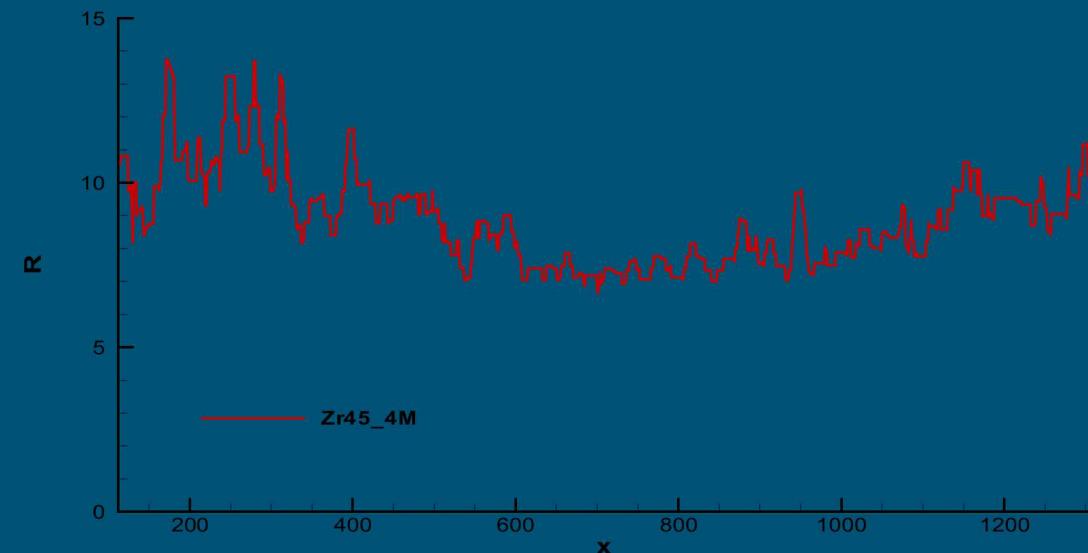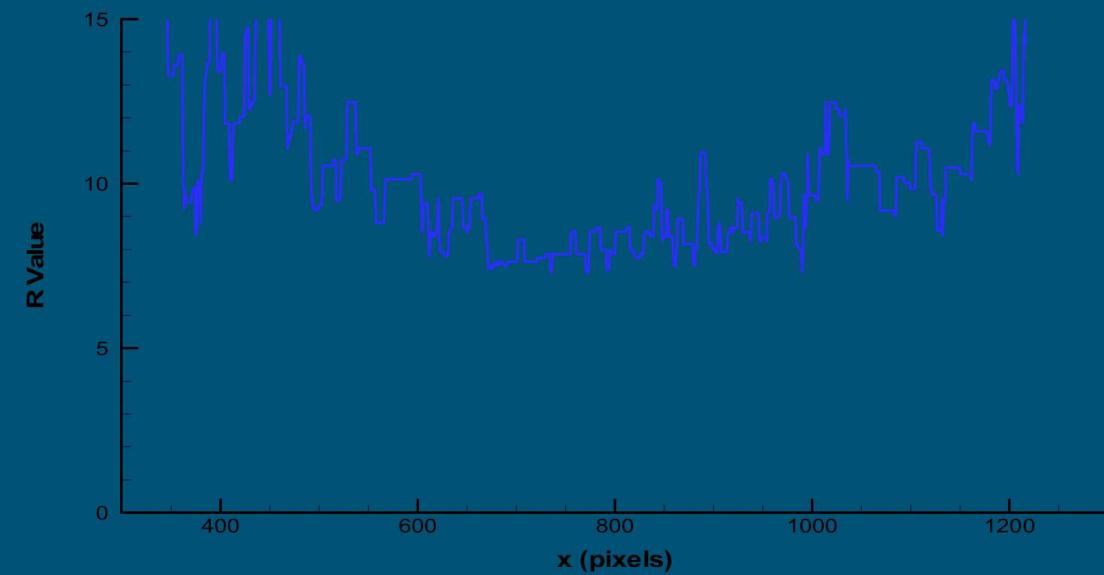
# Quasi-static Interrupted Test (Zr45_7) @ 0.0001/s
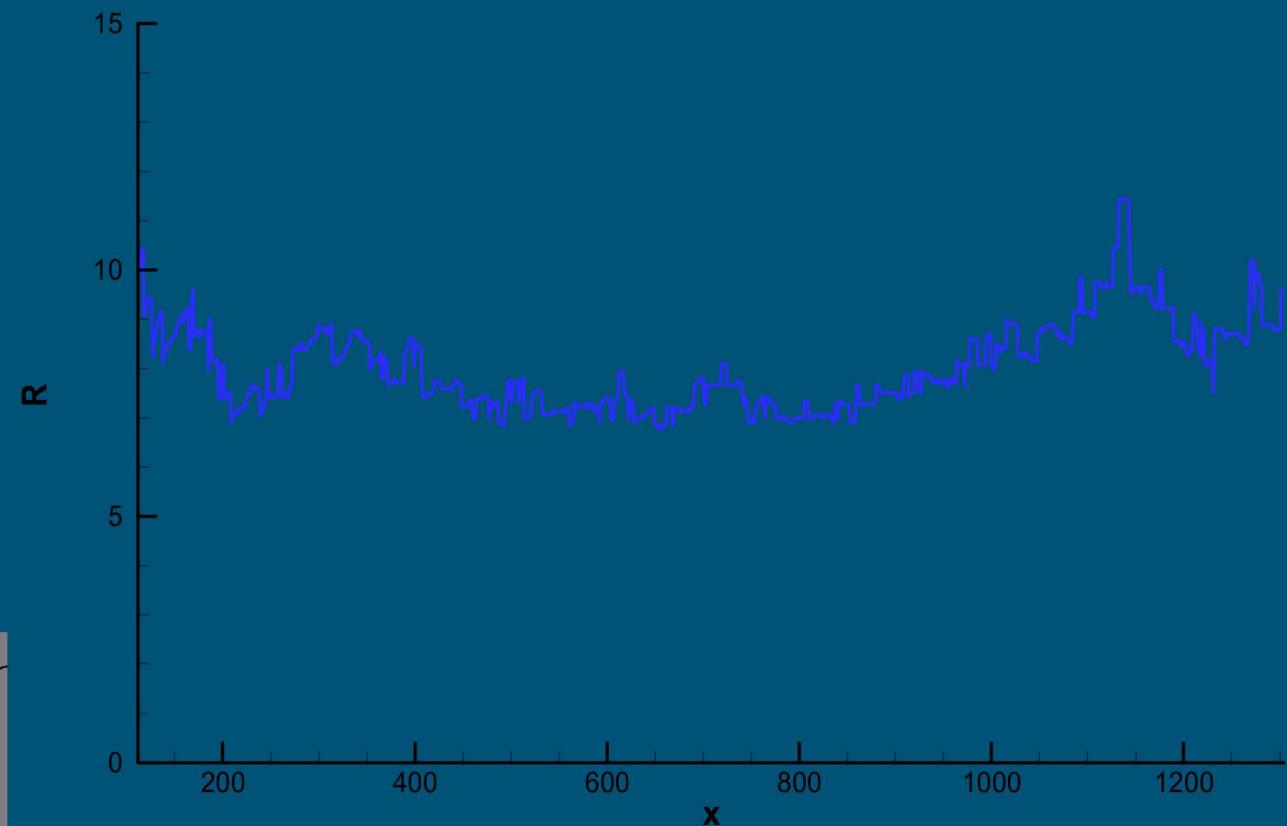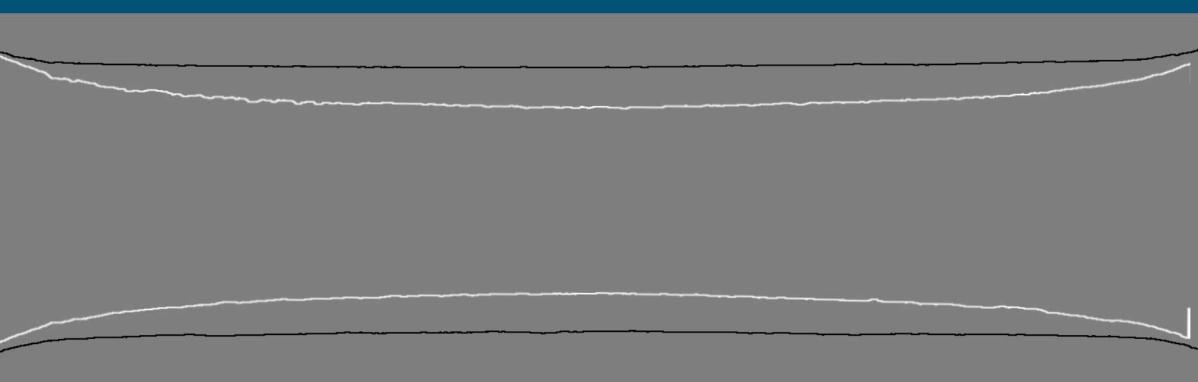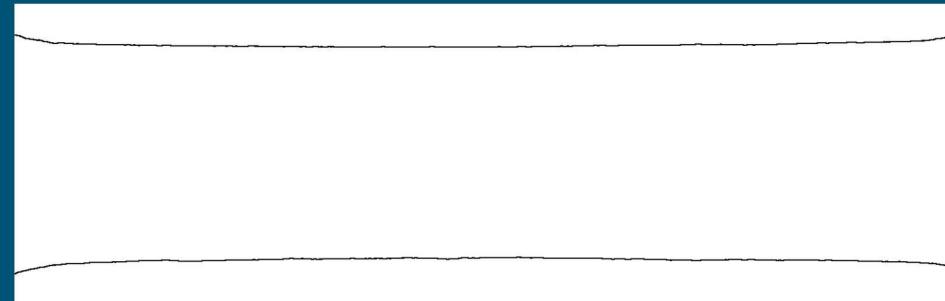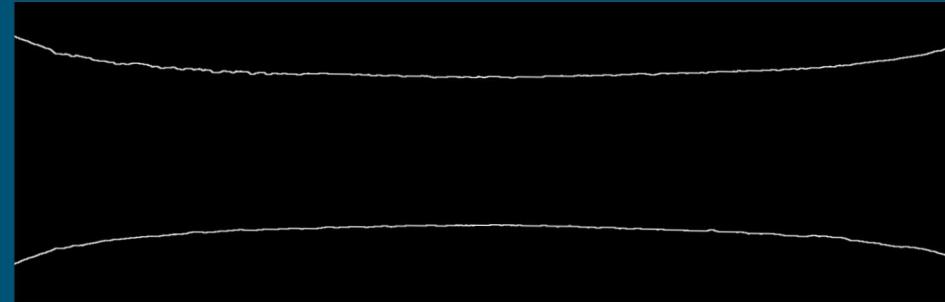
# Comparison of Quasi-static R Values from Interrupted Tests
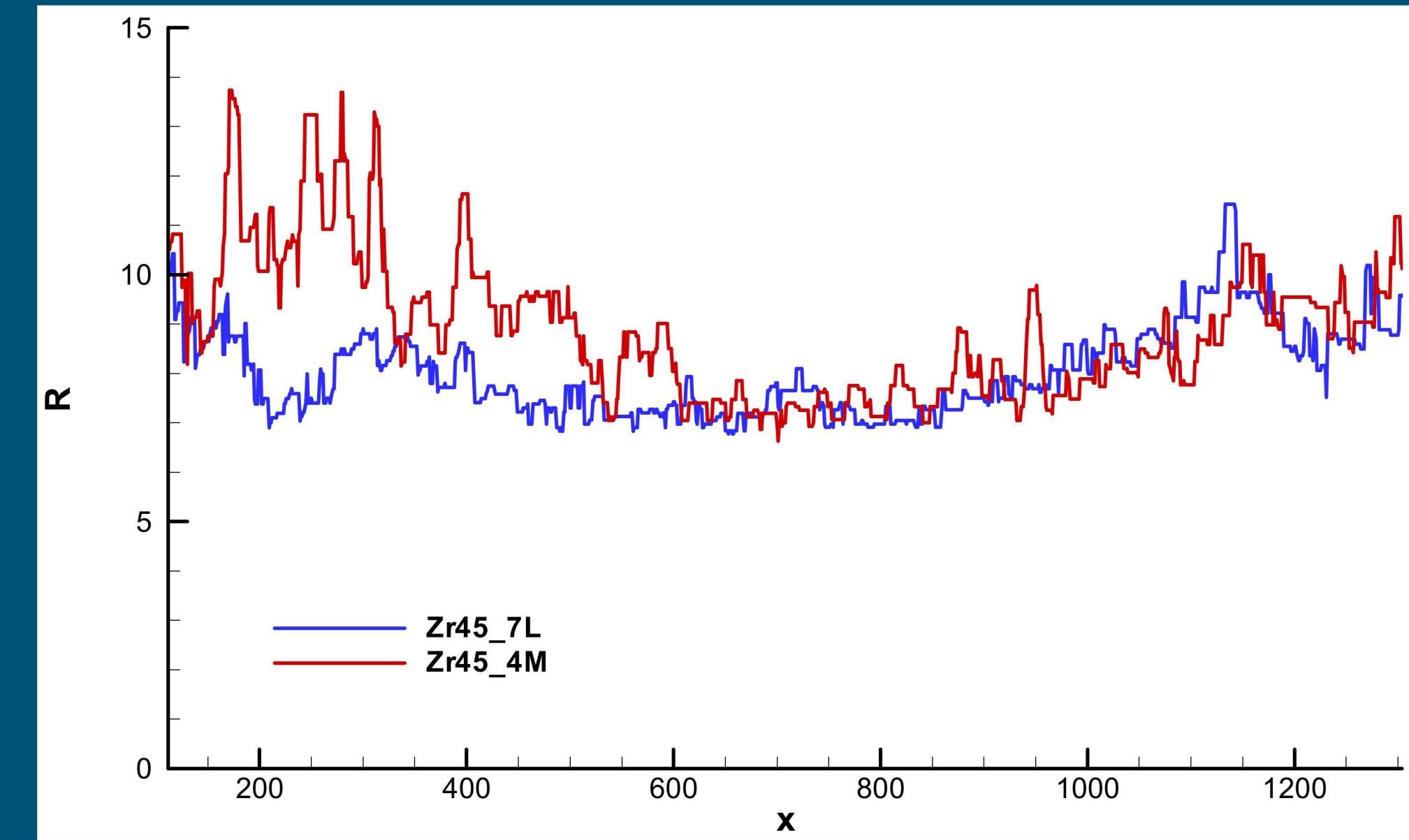
# Quasi-static and Dynamic Tensile Tests of Zirconium



**Left plot:** EngStress(MPa) vs EngStrain

Legend:
- Static_Zr_45_3 0.01 1/s
- Static_Zr_H_7 0.01 1/s
- Static_Zr_V_4 0.01 1/s
- Static_Zr_H_8 0.0001 1/s
- Static_Zr_V_2 0.0001 1/s
- Dynamic_Zr_45_8 792 1/s
- Dynamic_Zr_H_9 716 1/s
- Dynamic_Zr_V_5 723 1/s

Not failure

**Right plot:** TrueStress(MPa) vs TrueStrain

Legend:
- Static_Zr_45_3 0.01 1/s
- Static_Zr_H_7 0.01 1/s
- Static_Zr_V_4 0.01 1/s
- Static_Zr_H_8 0.0001 1/s
- Static_Zr_V_2 0.0001 1/s
- Dynamic_Zr_45_8 792 1/s
- Dynamic_Zr_H_9 716 1/s
- Dynamic_Zr_V_5 723 1/s

Not failure
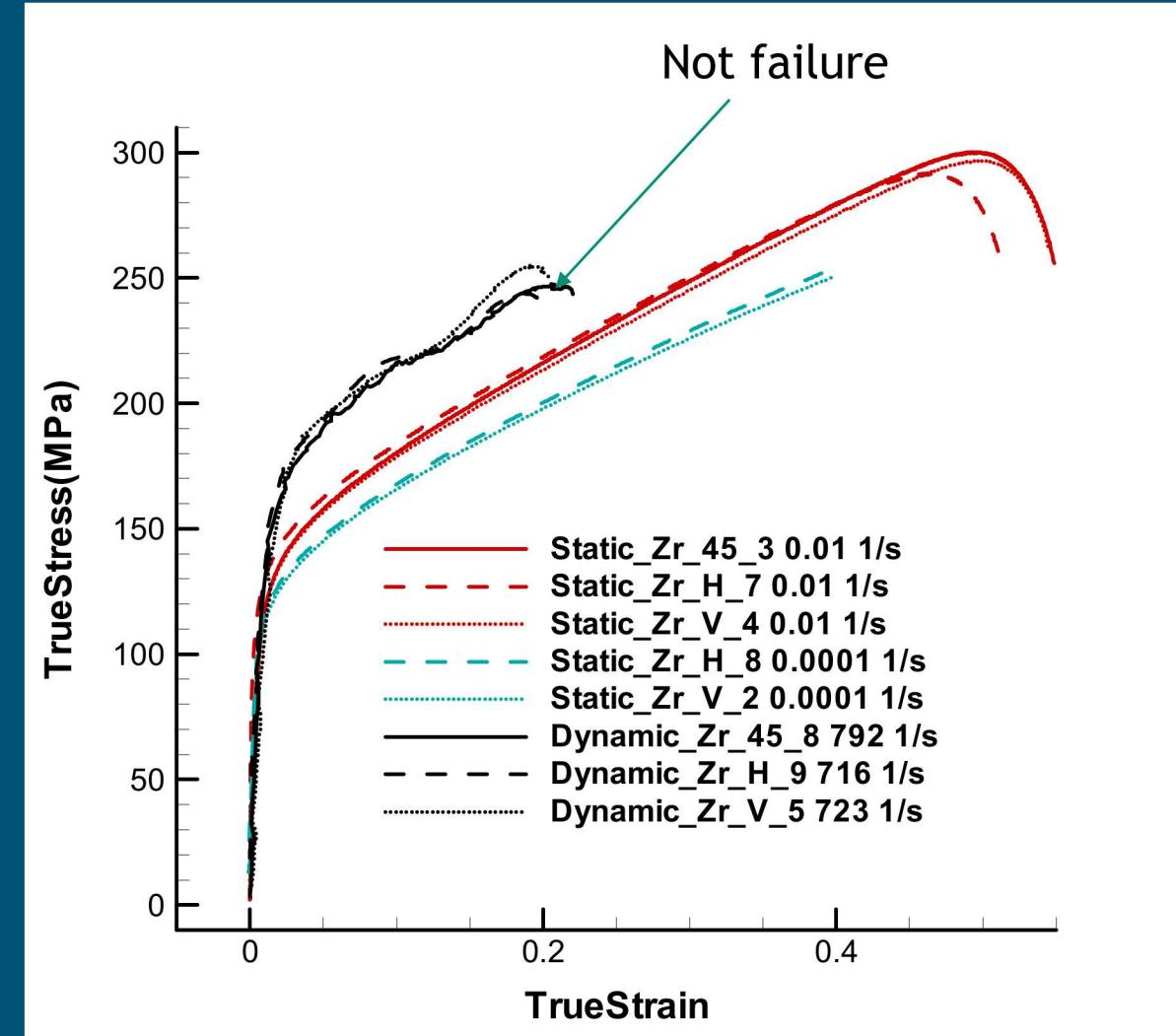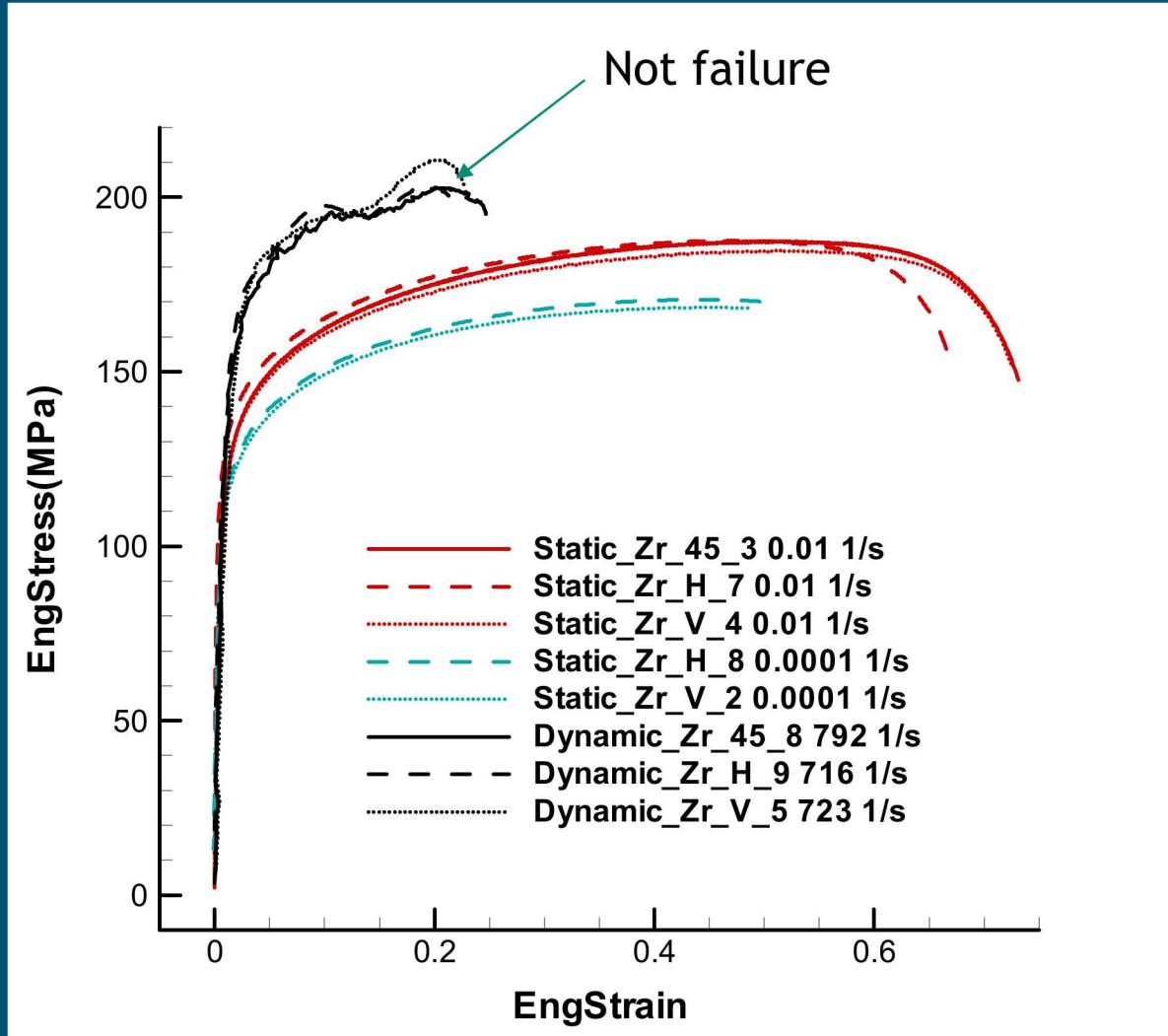
When R~10, ±2 pixels on initial or broad side may generate significant error (20-40%)!
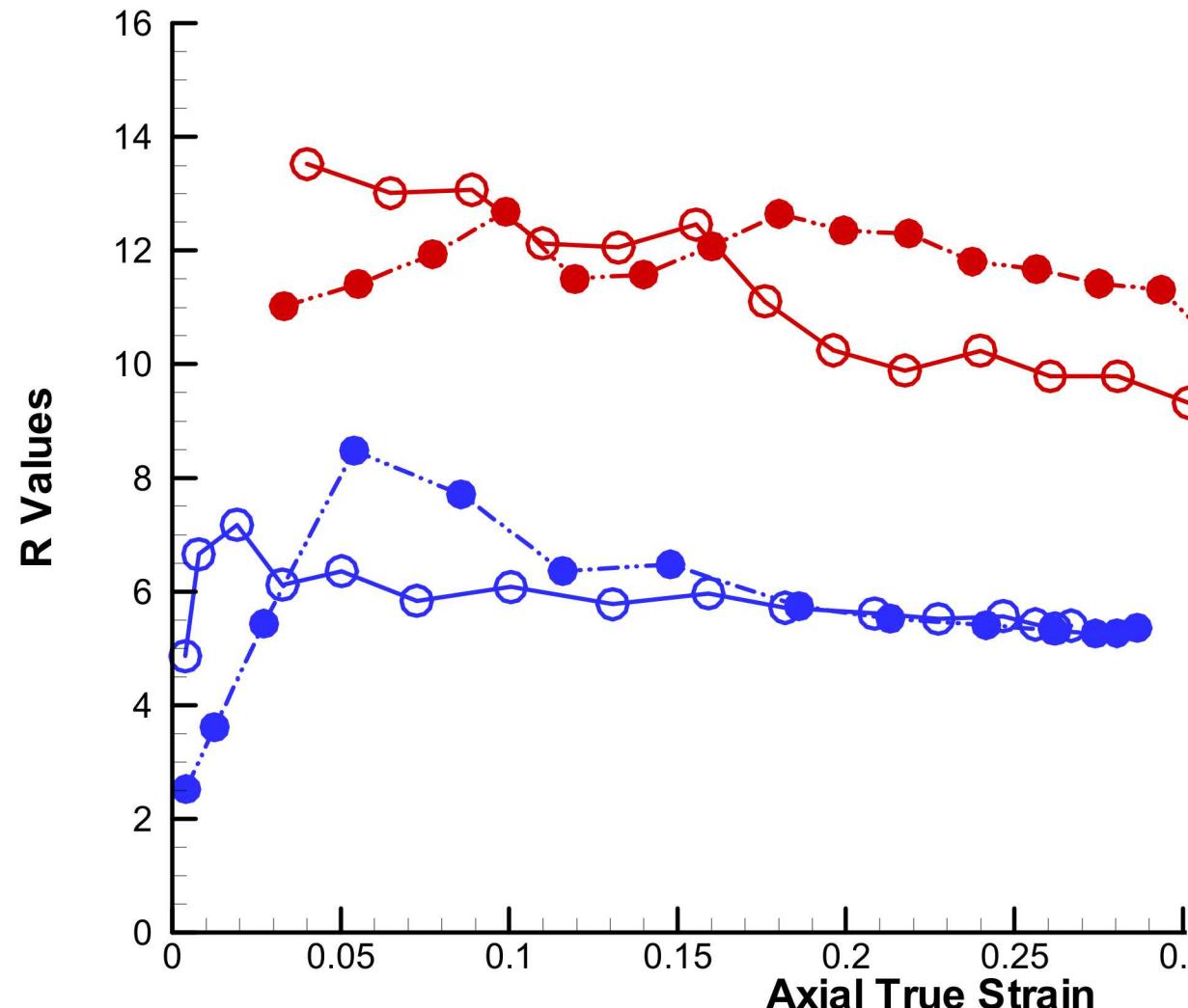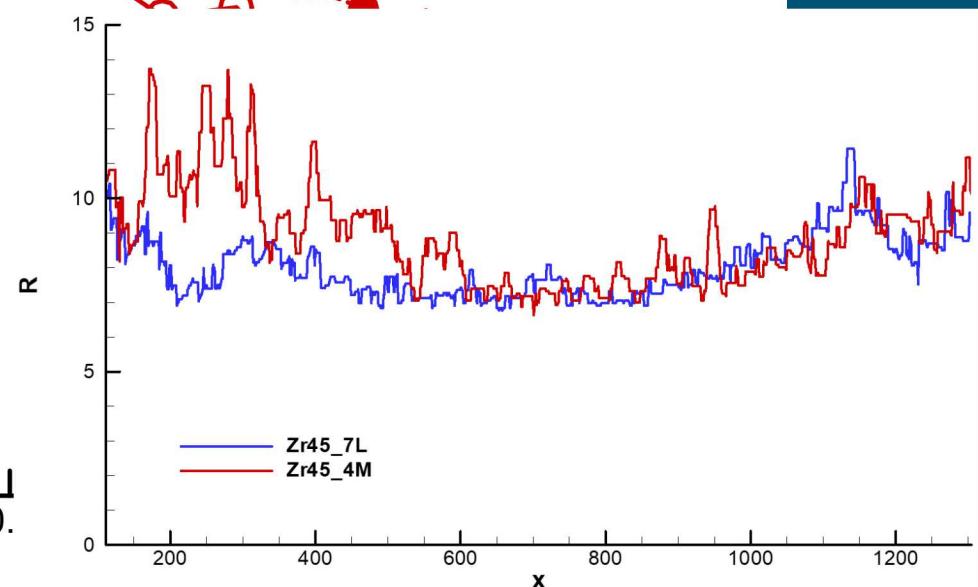
Conclusions and Path Forward

❖ A new experimental diagnostic technique was developed for *in-situ* quantitative measurement of specimen profile during both quasi-static and dynamic loading

❖ Zirconium showed significant out-of-plane anisotropy
  ➤ R value seemed decrease with deformation (increasing true strain)
  ➤ R value significantly depends on strain rate (Dynamic R values were nearly half of quasi-static R value)

❖ **Path Forward**
  ➤ Different Material: 5083 aluminum?
  ➤ Tests:
    ✓ Dynamic tests to failure
    ✓ More tests at different strain rates