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Characterization of a Thermoplastic Polymer at Different Environment

Helena Jin[1], Wei-Yang Lu[1], Kevin Nelson[1],
Pania Newell[2], Terry Hinnerichs[2]

[1]*Mechanics of Materials Department*
Sandia National Laboratories Livermore, CA

[2]*Solid Mechanics*
Sandia National Laboratories Albuquerque, NM

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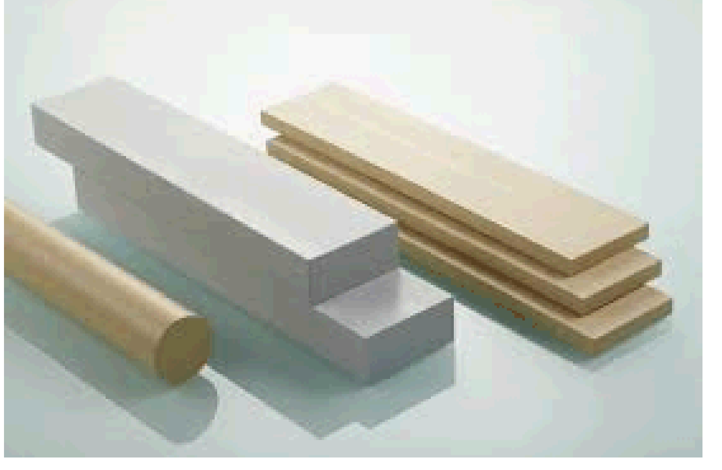
Material: Polyether Ether Ketone (PEEK)

PEEK (Polyether ether ketone) is a thermoplastic polymer with excellent mechanical and chemical resistance properties at a wide range of temperatures.

- Outstanding chemical resistance
- Good mechanical properties at elevated temperatures
- Resistant to hot water and steam
- Glass temperature at 145 ^{o}C
- Melting point at 345 ^{o}C



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Background and Motivation

- PEEK has important application at Sandia.
- The ductile-fracture material model within Sierra Mechanics was adopted for the computational modeling effort.
- The ductile-fracture material model is a plasticity model based on the power-law hardening, which calculates a failure parameter.
- Mechanical data is needed to calibrate a material model for the PEEK material.

Material parameters

$$\bar{\sigma} = \sigma_y + A < \bar{\epsilon}_P - \bar{\epsilon}_L >^n$$

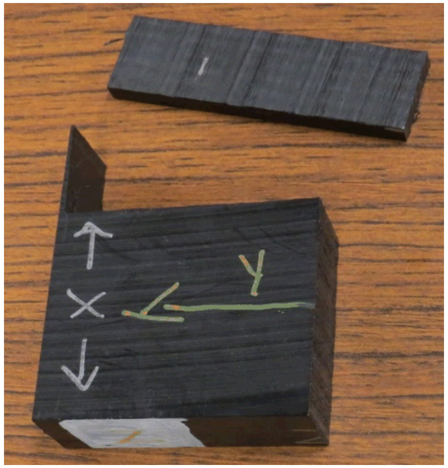
Von Mises stress

Yield stress

Equivalent plastic strain

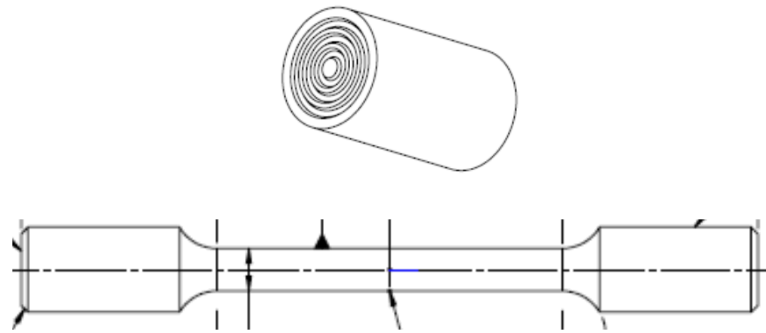
Luders strain

Specimen and Experiment Design



PEEK Material

- A block of material with a couple of inches in-plane dimension;
- 0.5-in of thickness;



Tension and compression test parameters:

- Orientation: x and y directions
- Temperature: room temperature and 0^oC
- Loading rate: 0.002 in/s and 2.0 in/s

Bending testing parameters:

- Orientation: z direction
- Temperature: room temperature and 0^oC
- Loading rate: 0.005 in/s and 2.0 in/s

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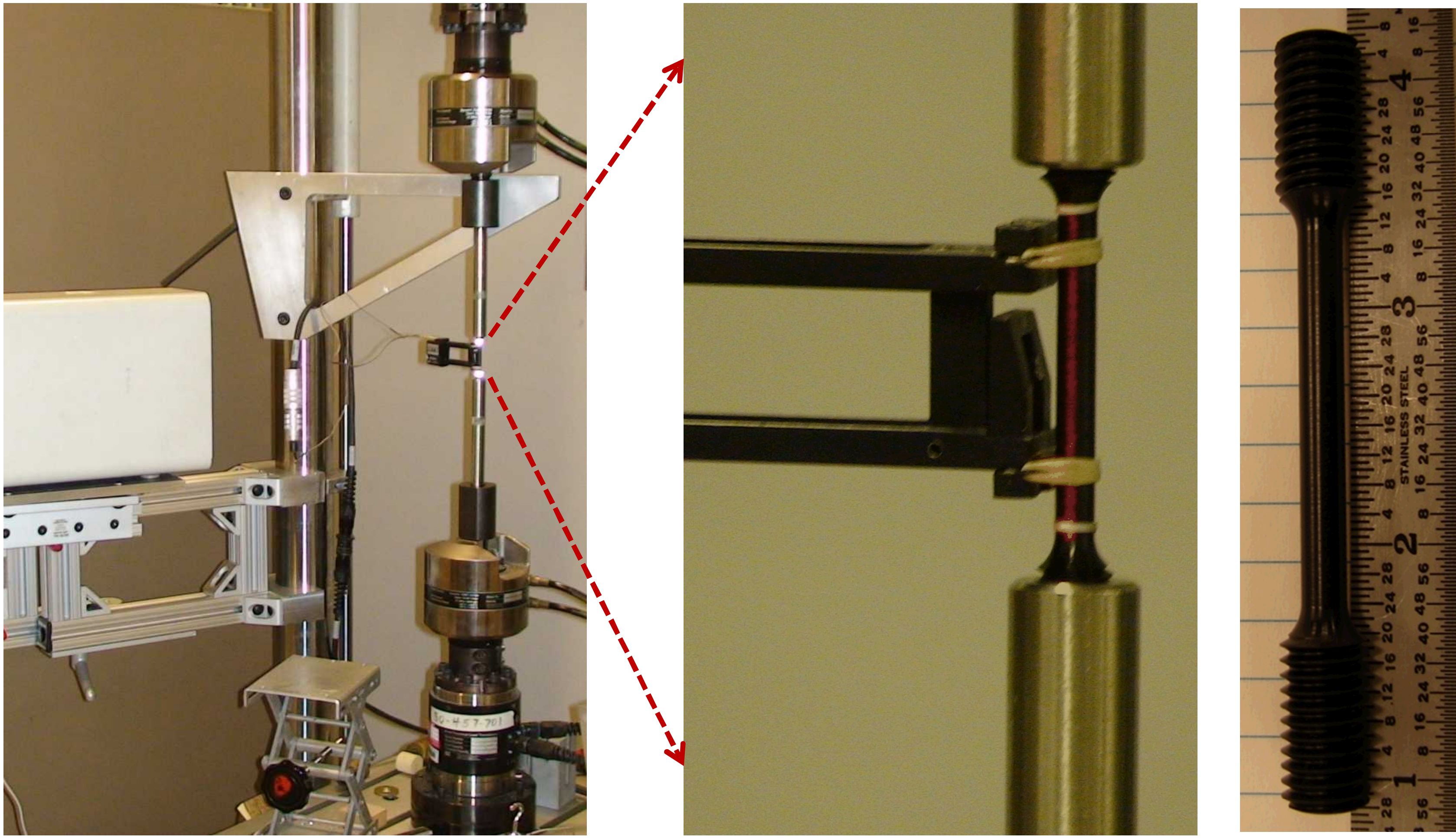
Experimental Setup of Tensile Test at Room Temperature



Tensile testing at room temperature at quasi-static rate

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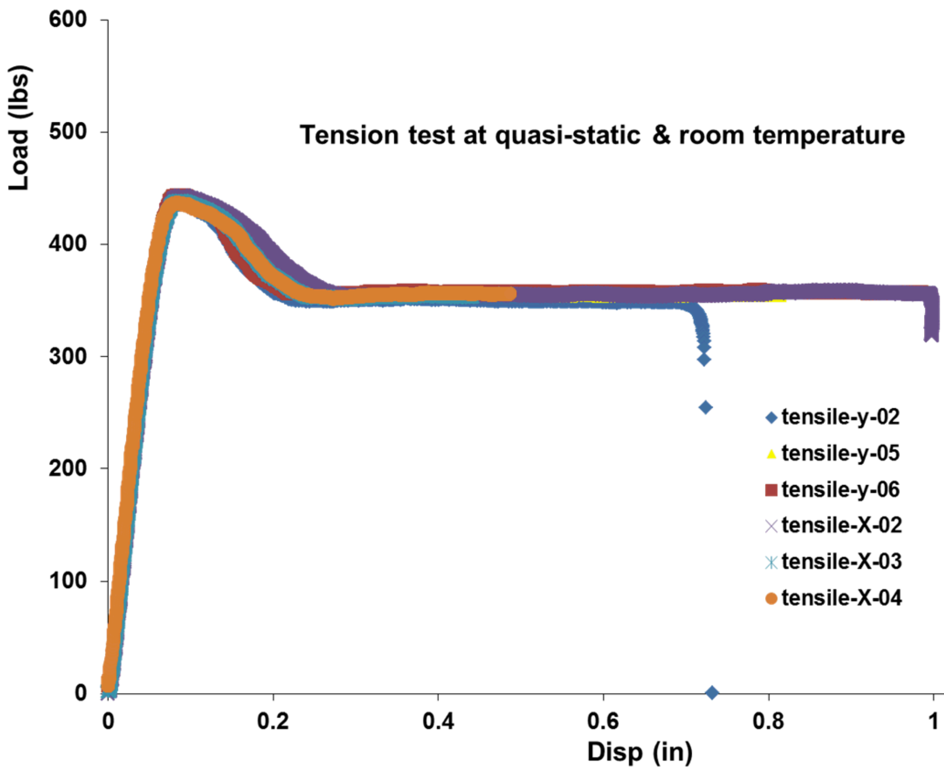
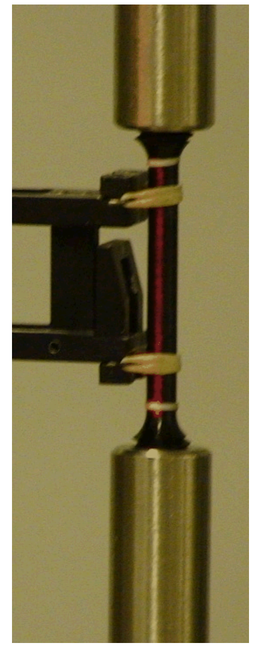
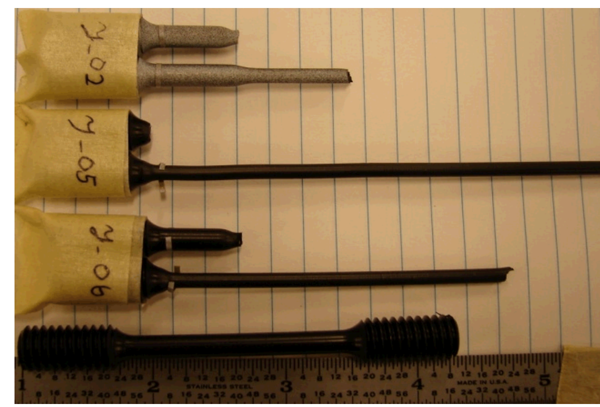
Tension Test at Quasi-static Rate







- The necking propagation might vary in each specimen, which causes the variation of the final elongation of the specimens.
- There is no difference in elastic properties and maximum strength in x and y direction for specimens loaded at quasi-static and room temperature.

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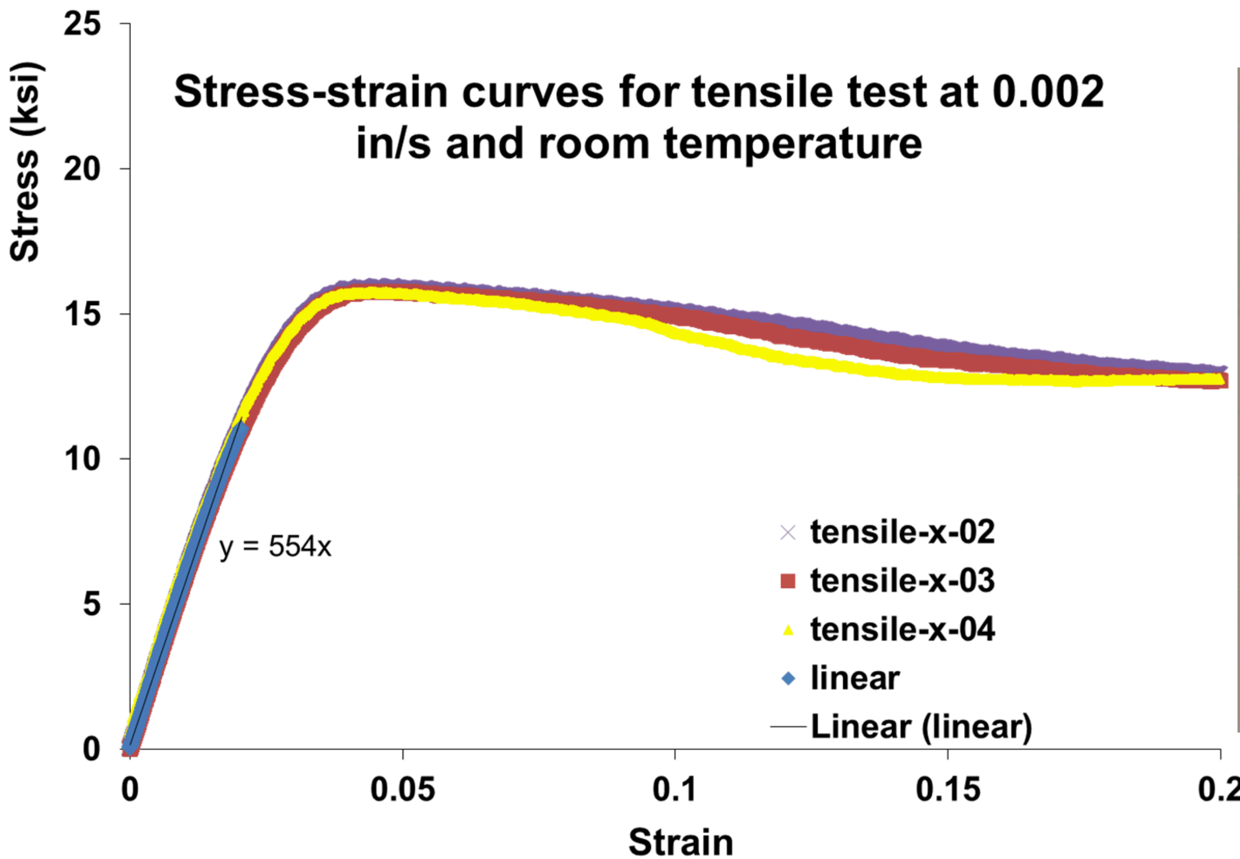
Stress versus strain curves for tension test quasi-static rate



- Maximum stress = 15.9 ksi; Young's modulus = 550 ksi
- 2% off yield stress =15.8 15.8 ksi; Yield strain = 4.9%

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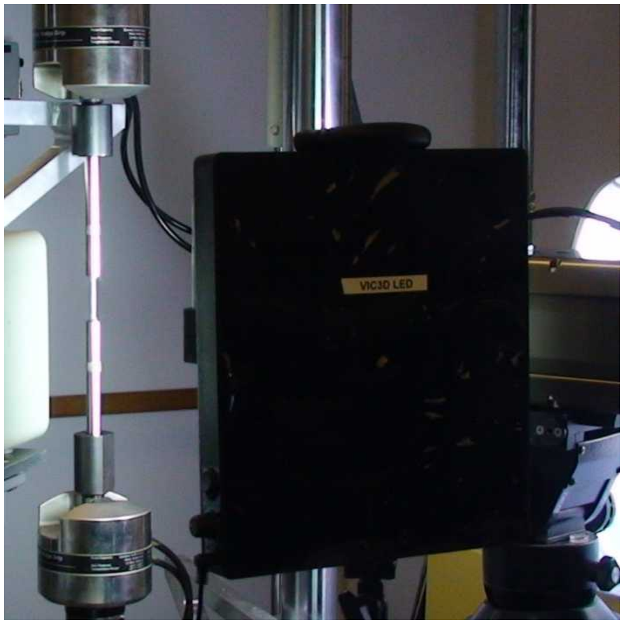
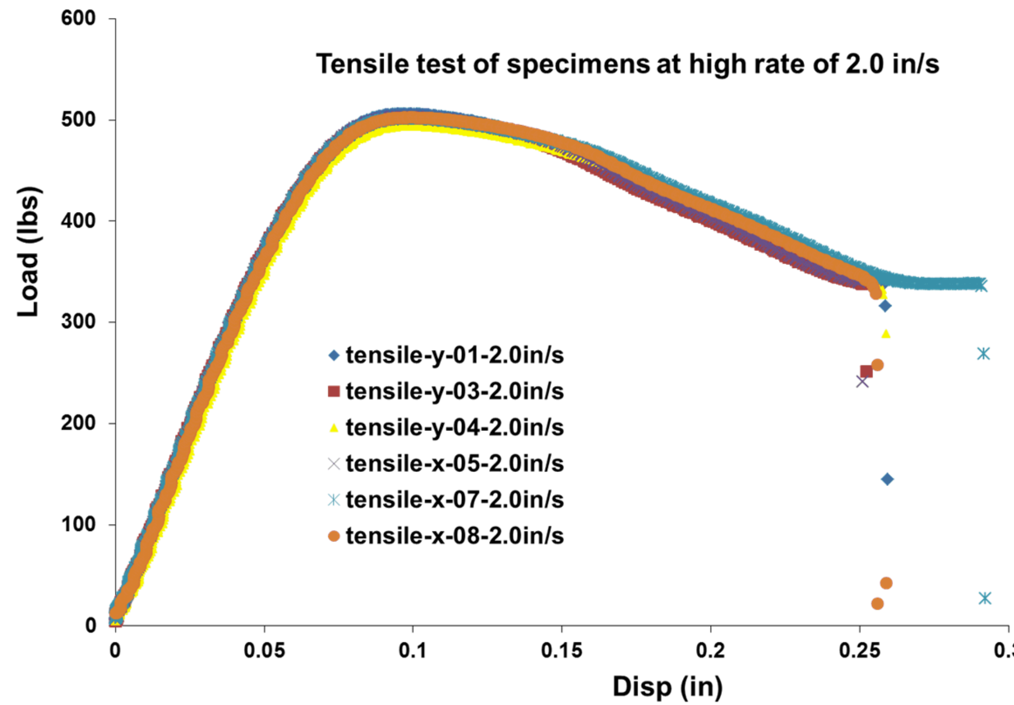
Tension test at higher rate (2.0 in/s)

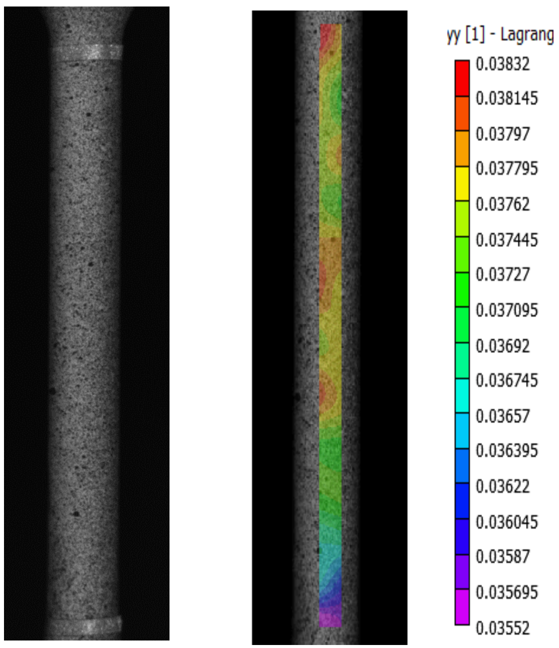




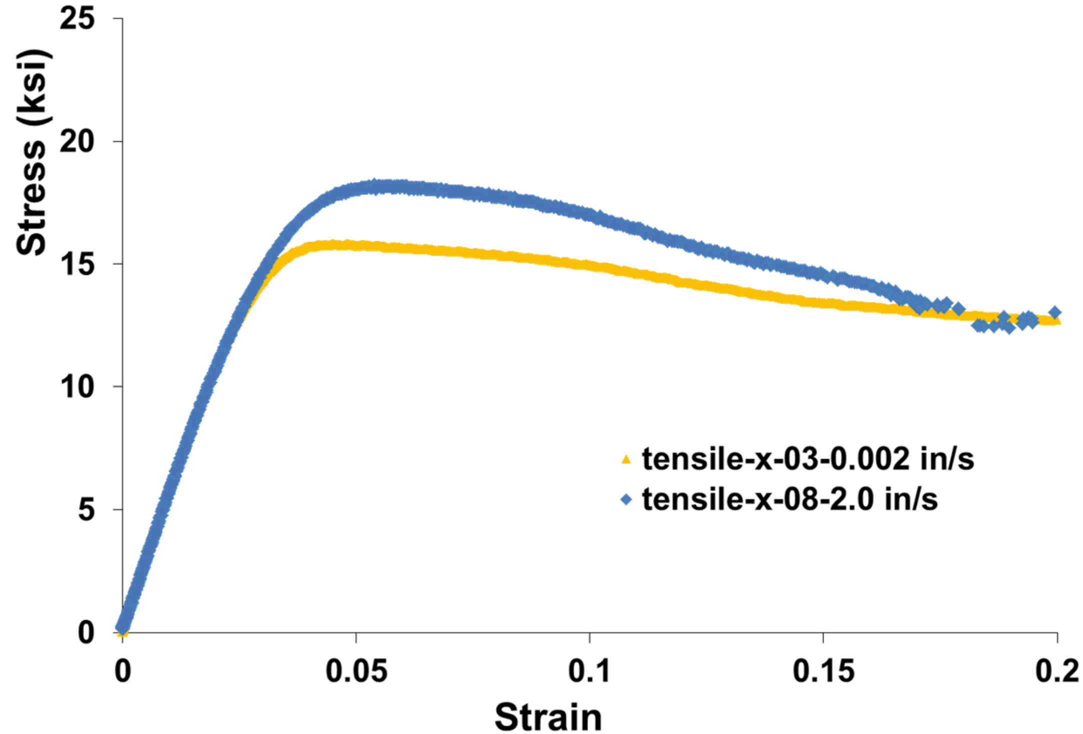
- Laser extensometer is not fast enough to measure the displacement and strain;
- DIC technique is applied to measure the displacement and strain over the gage;

There is no difference in elastic properties and maximum strength in x and y direction for specimens loaded at room temperature and 2.0/s;

Engineering Stress~Strain Curve for Tensile Test at quasi-static and higher rates



#0 #550 @17.2ksi



- Same young's modulus at higher and quasi-static rates;
- Higher yield and maximum stress at 2 in/s than at 0.002 in/s.

- Maximum stress = 18.2 ksi; Young's modulus = 550 ksi
- 2% off yield stress =18.1 ksi; Yield strain = 5.2%

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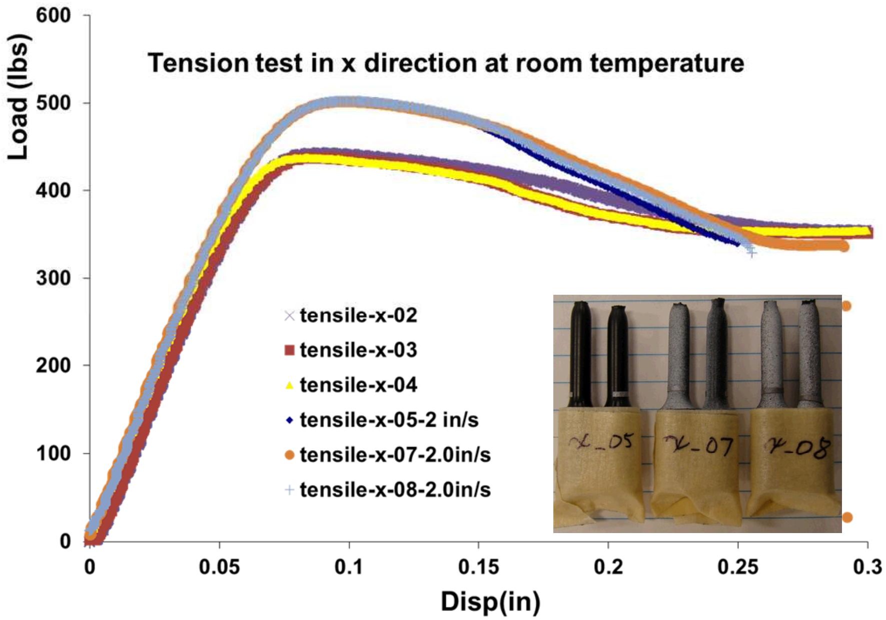
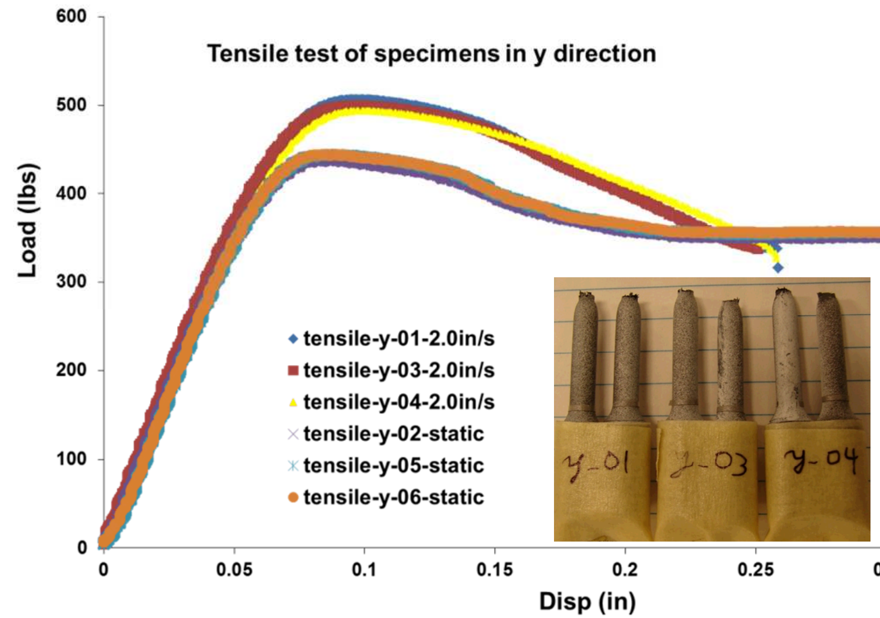
Comparison of tension tests at quasi-static and higher rates





- ❑ No difference in elastic modulus;
- ❑ Higher yield and maximum loads at 2 in/s than at 0.002 in/s;
- ❑ The necking does not propagate over the gage for specimens loaded at 2.0 in/s;

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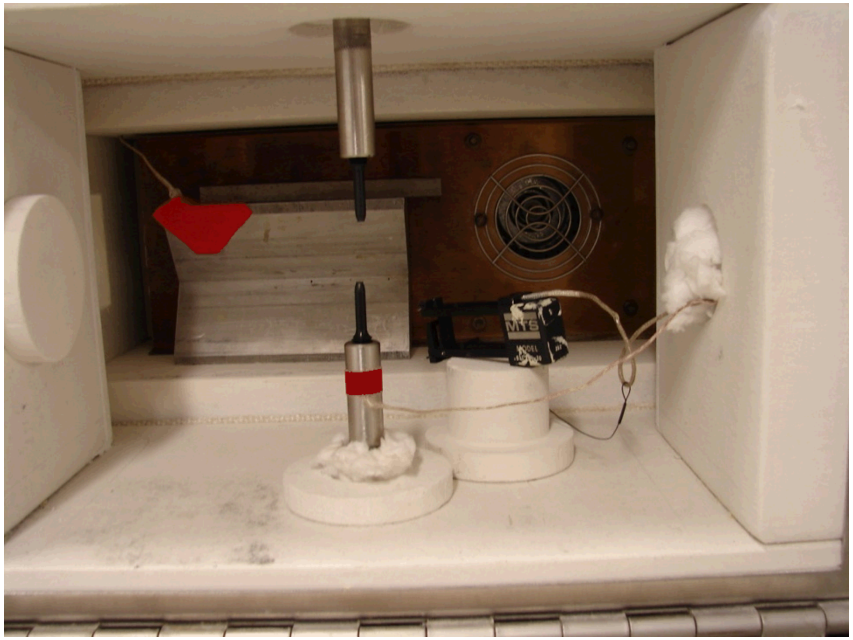
Tension test at low temperature (0^oC)



- Liquid nitrogen and environmental chamber are used to reach 0^oC.
- DIC technique is applied to measure the displacement and strain over the gage at 2.0 in/s;
- Resistant heating strip is attached to the chamber to defrost the glass window in order to take consistent images for DIC.

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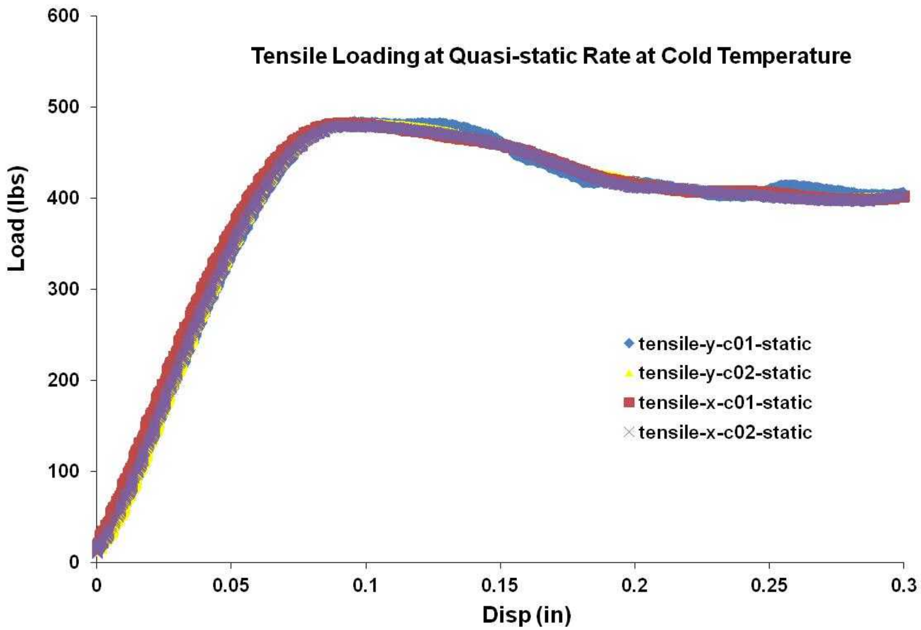
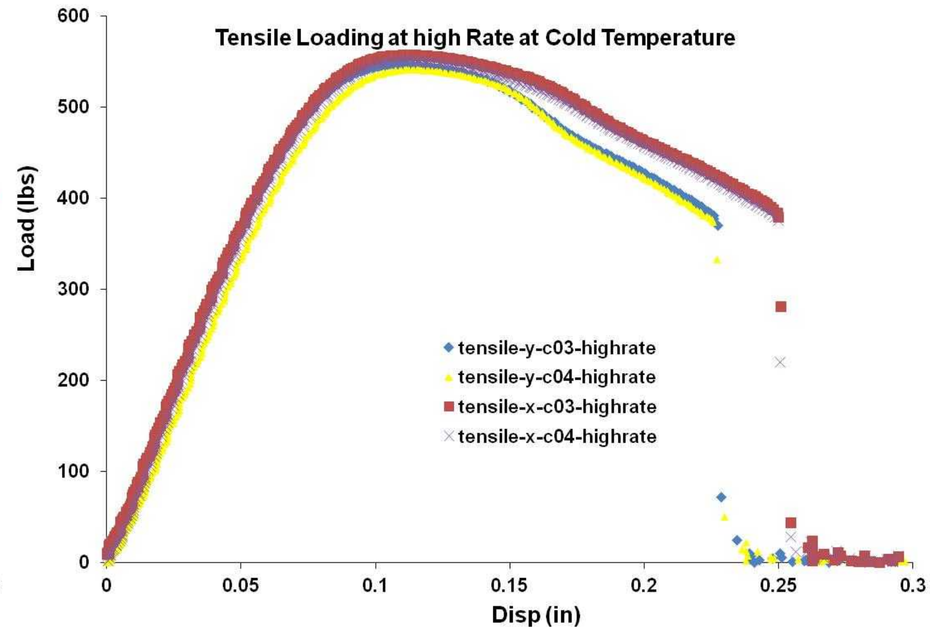
Comparison of tension tests at cold temperature





- The material does not show anisotropy in x and y directions at cold temperature at both static and higher rate loading.
- At cold temperature tests, the material has higher yield and maximum load at higher loading rate.

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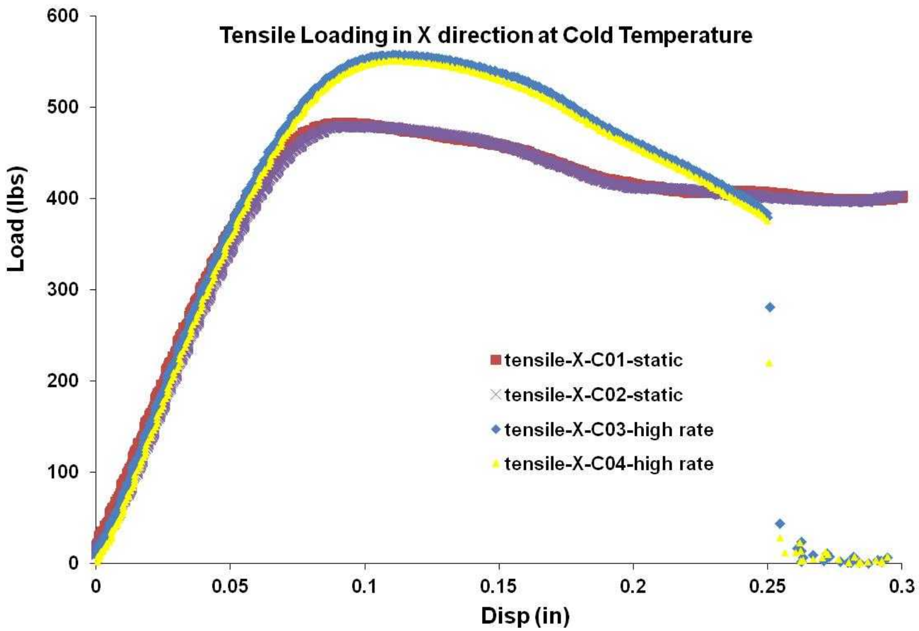
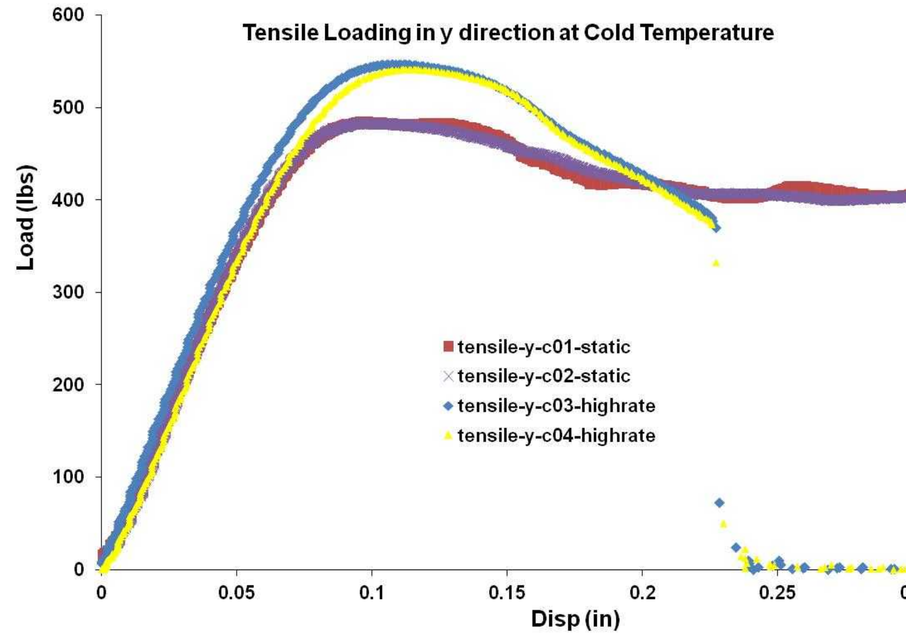
Comparison of tension tests at cold temperature





- ❑ No difference in young's modulus;
- ❑ Higher yield and maximum load at 2 in/s than at 0.002 in/s in both x and y directions;
- ❑ The necking does not propagate over the gage for specimens loaded at 2.0 in/s;

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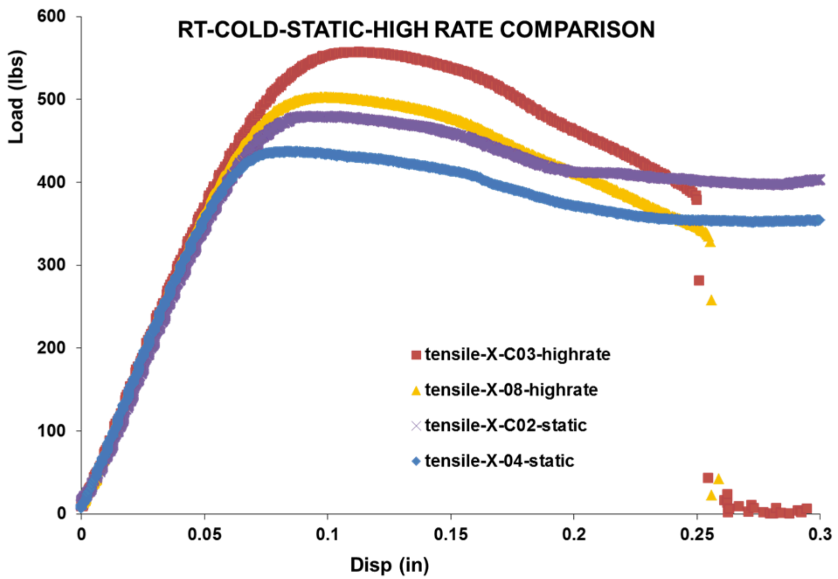
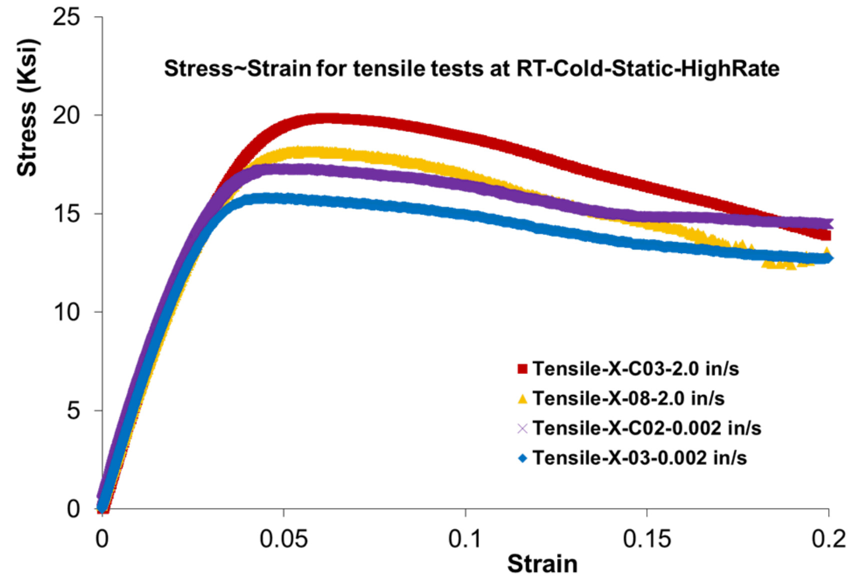
Comparison of tension tests different loading conditions





- ❑ Specimen has higher yield and maximum stresses at higher rate than that of quasi-static, but same young's modulus.
- ❑ Specimen has higher yield and maximum load at cold temperature than that of room temperature.

Conditions	modulus (ksi)	maximum load (lbs)	maximum stress (ksi)	2% off yield stress (ksi)	yield strain (%)
RT-Static	550	440	15.9	15.8	4.9
Cold-Static		480	17.3	17.3	5.1
RT-High Rate		505	18.2	18.2	5.3
Cold-High Rate		557	20.1	20.0	5.5

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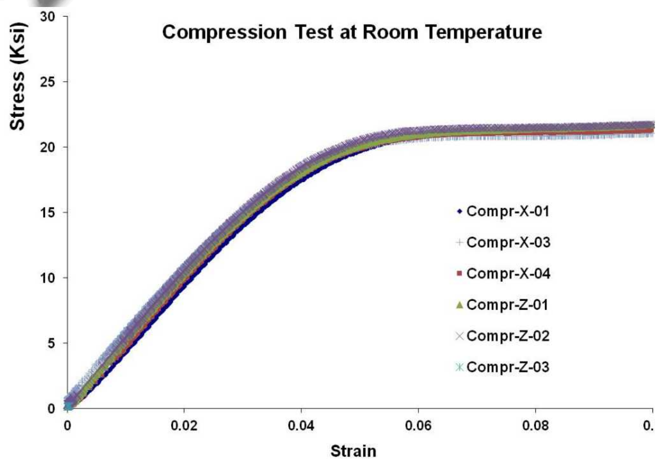
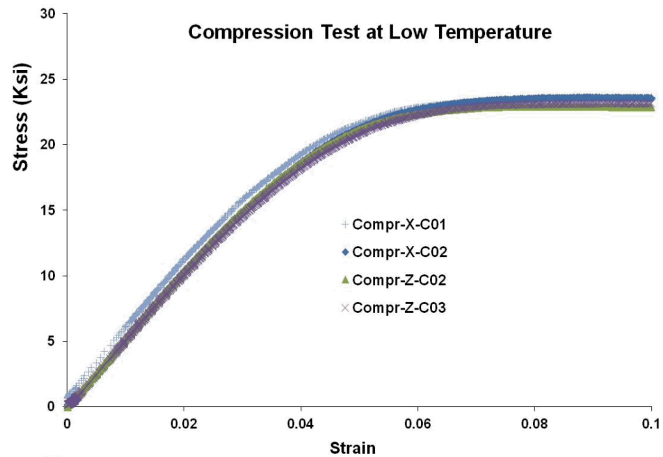
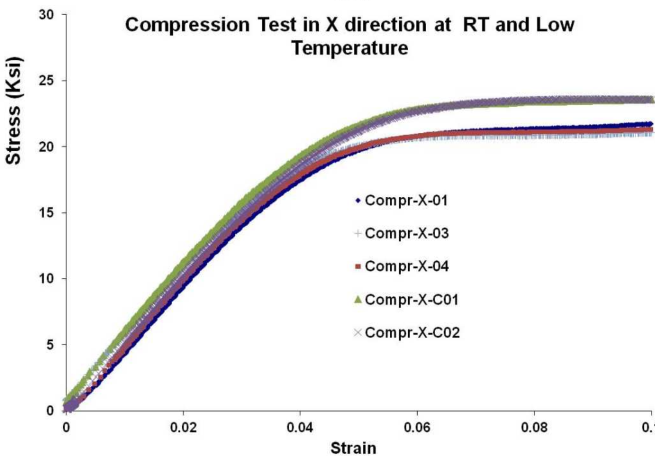
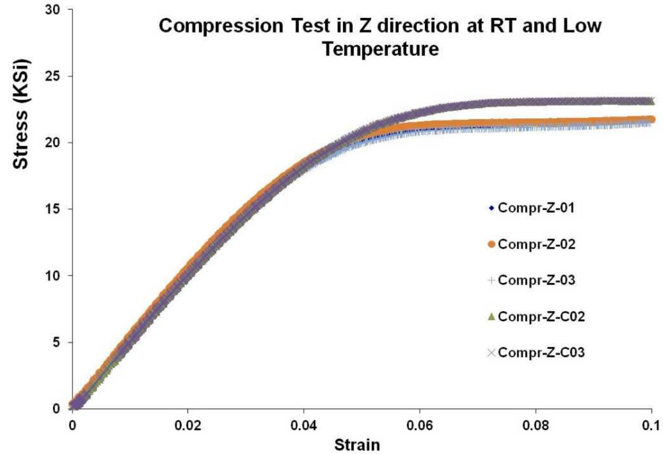
Comparison of compression tests









	Modulus (Ksi)	yield strain	2% offset Yield stress (Ksi)
X-RT	506	0.061	20.80
X-Cold	515	0.065	23.07
Z-RT	516	0.061	21.09
Z-Cold	513	0.064	23.32

- There is no difference in x and z direction.
- Young's modulus is same (~510ksi) for both low and room temperatures, however, the yield stress is higher at low temperature.

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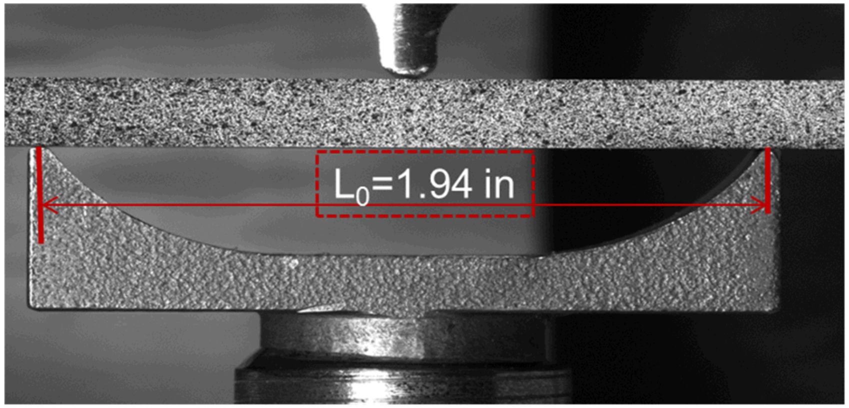
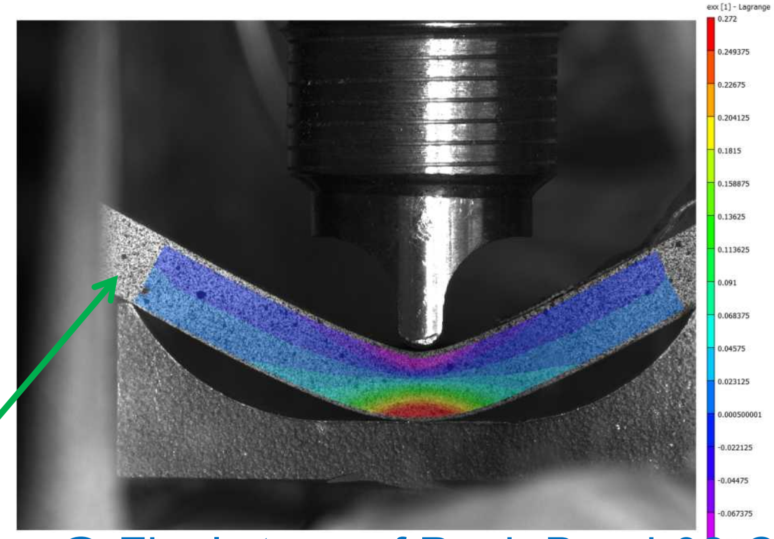
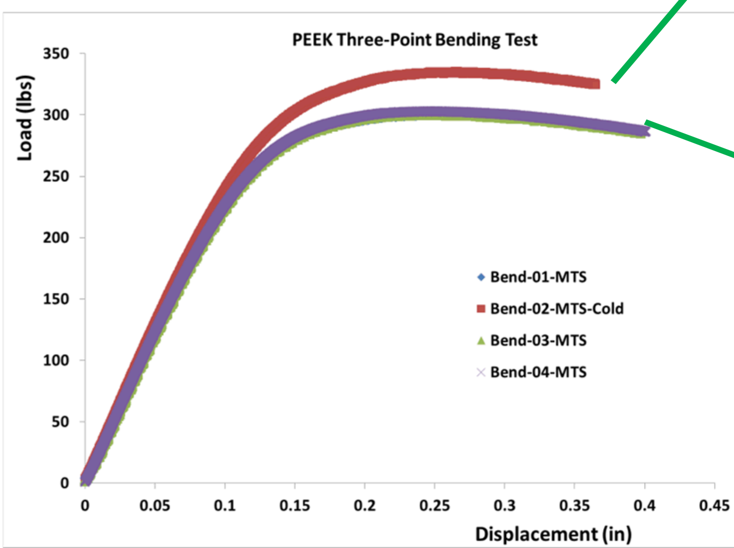
Three Point Bending Test

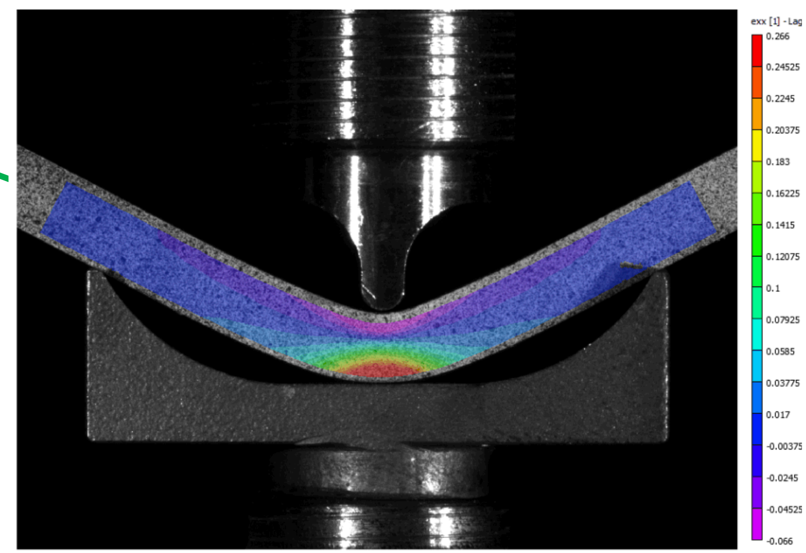


Fixture: L_0=1.94 in, W=0.76 in
Specimen: L=3.45 in, W=0.50 in, B=0.25 in



Exx @ Final stage of Peek-Bend-02-Cold





Exx @Final stage of Peek-Bend-03-RT

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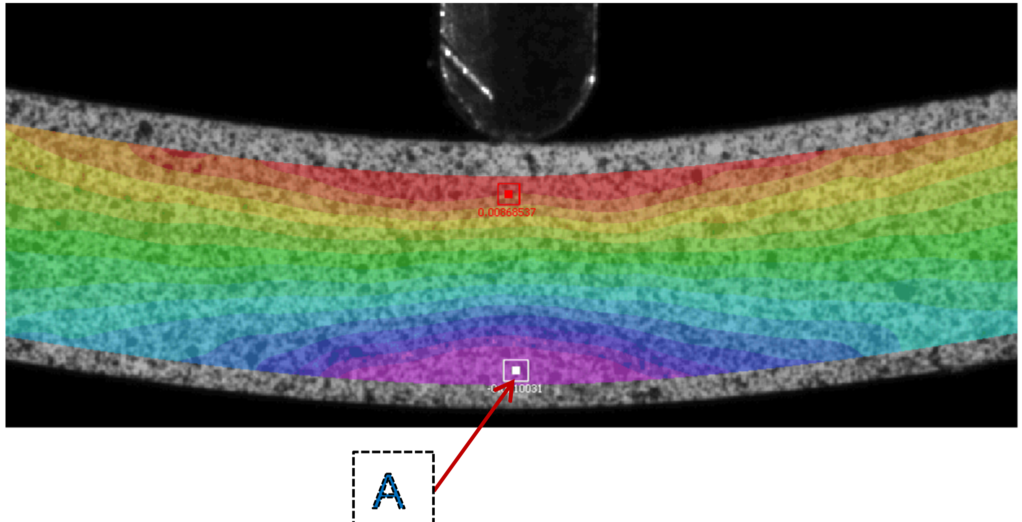
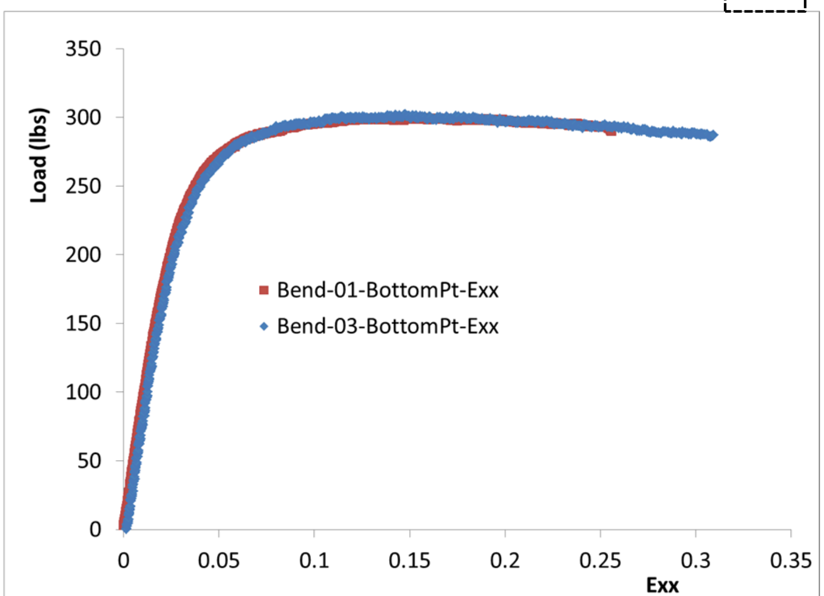
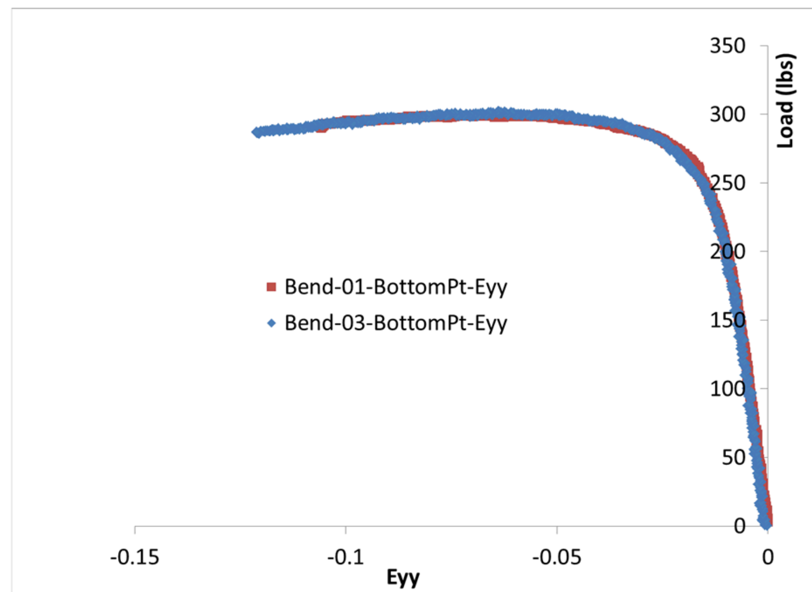
Exx and Eyy History from DIC





Exx @ pt A for Bend-01&03



Eyy @ pt A for Bend-01&03

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Summary

- Mechanical characterization of PEEK materials is conducted at two temperature, two loading rates, three loading directions.
- The PEEK material does not show anisotropy in three directions.
- The different loading conditions do not affect the young's modulus of the material. However, the material shows higher yield and maximum stresses at lower temperature and higher loading rate.
- Compression test of the material also show similar effects of the temperature.
- Three point bending tests were conducted to validate the simulation results.