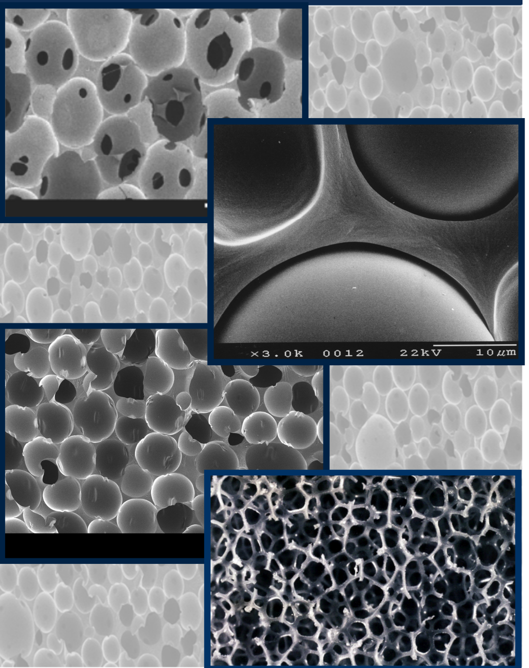
Component Science and Mechanics

SAND2015-9908C



Sandia Fracture Challenge 2 (SFC2) Neilsen, Dion Team Predictions

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Sandia National Laboratories

Sandia National Laboratories

Exceptional service in the national interest

For presentation at the ASME 2015 Intl. Mechanical Engineering Congress and Exposition Symposium on Sandia Fracture Challenge 2, November 13-19, 2015, Houston, TX

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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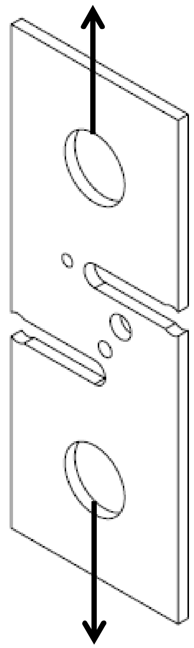
Outline

- Simulation Code
- UCPD Material Model
- Uniaxial Tension
- Butterfly Shear
- Challenge Geometry
- Possible Sources of Error
- Gaps / Recommendations for Future Work

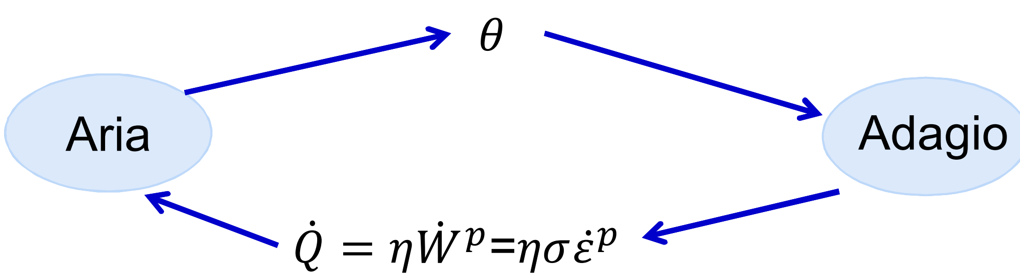


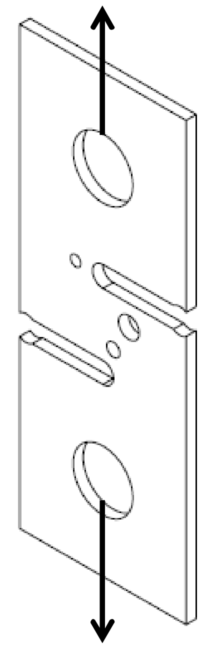
Challenge Geometry:
Ti6Al4V, 3.124 mm thick plate
subjected to uniaxial tension

Simulation Code

- Adagio for Quasi-static Solid Mechanics
- Arpeggio for Coupled Thermal Stress
- Assume that inertia is not important
- Assume 50% of plastic work generates heat (η=0.5)

Arpeggio – Coupled Thermal Stress





2 in x 5 in
0.001 in/sec
1.0 in/sec

SFC2

UCPD Material Model

Stress Rate: $$\dot{\boldsymbol{\sigma}} = \mathbf{E} : \dot{\boldsymbol{\varepsilon}}^{e} = \mathbf{E} : (\dot{\boldsymbol{\varepsilon}} - \dot{\boldsymbol{\varepsilon}}^{in})$$

Inelastic Strain Rate: $$\dot{\boldsymbol{\varepsilon}}^{in} = \frac{3}{2}\dot{\gamma}\,\mathbf{n} = \frac{3}{2} e^{f} \sinh^{p}\left(\frac{\tau}{\alpha D\left(1 - c w^{d}\right)} \right)\mathbf{n}$$

Evolutions Eqns: $$\dot{D} = \frac{A_1 \dot{\gamma}}{(D - D_0)^{A_3}} - A_2 (D - D_0)^2$$ *or* $$D = \hat{D}(\gamma)$$

Flow Direction: $$\mathbf{n} = \frac{\mathbf{s}}{\tau}$$

Effective Stress: $$\tau = \sqrt{\frac{3}{2}\mathbf{s} : \mathbf{s}}$$

Reference: M.K. Neilsen, S.N. Burchett, C.M. Stone, and J.J. Stephens, 'A Viscoplastic Theory for Braze Alloys,' SAND96-0984, Sandia National Laboratories, April 1996

UCPD Material Model

Wilkins et al.'s Damage:

$$w = \int \left(\frac{1}{1 + \frac{p}{\hat{p}}} \right)^{\hat{a}} (2 - A)^{\hat{\beta}} \, d\gamma$$

$$s_1 \geq s_2 \geq s_3 \qquad A = Max\left(\frac{s_2}{s_1}, \frac{s_2}{s_3}\right) \qquad p = \frac{-1}{3} \sigma : i$$

$$J_3 = s_1 s_2 s_3$$

Wellman's Damage:

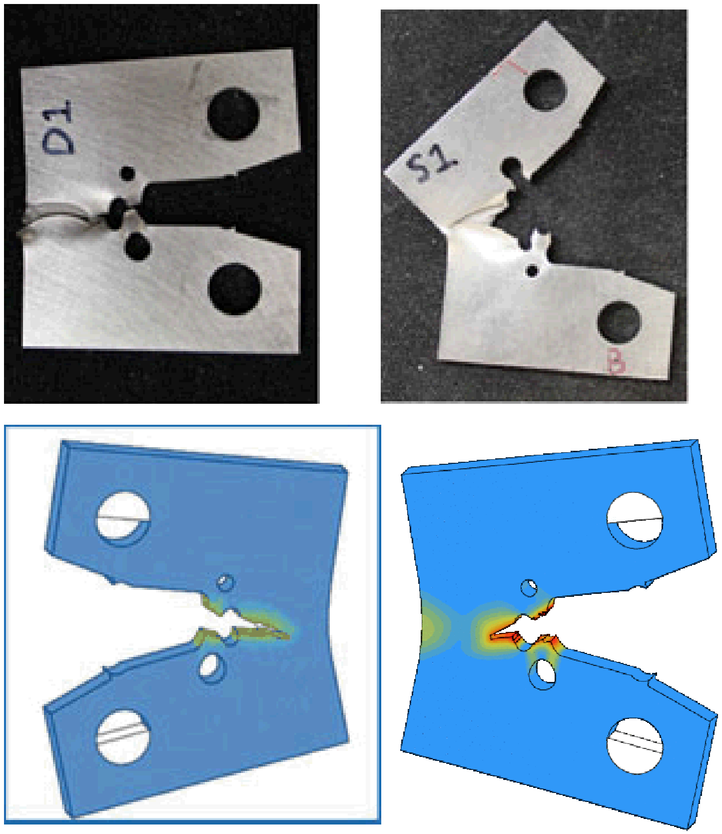
$$w = \int \left| \frac{2\sigma_T}{3(\sigma_T - \sigma_m)} \right|^4 d\gamma \qquad \sigma_m = \frac{1}{3} \sigma : i = -p$$

$$w = \int \left| \frac{\frac{2}{3}}{\left(1 + \frac{p}{\sigma_T}\right)} \right|^4 d\gamma$$

References: M.L. Wilkins, R.D. Streit, and J.E. Reaugh, 'Cumulative-Strain-Damage Model of Ductile Fracture,' UCRL-53058, Lawrence Livermore National Laboratory, October 3, 1980.

G.W. Wellman, 'A Simple Approach to Modeling Ductile Failure,' SAND2012-1343, Sandia National Laboratories, June 2012.

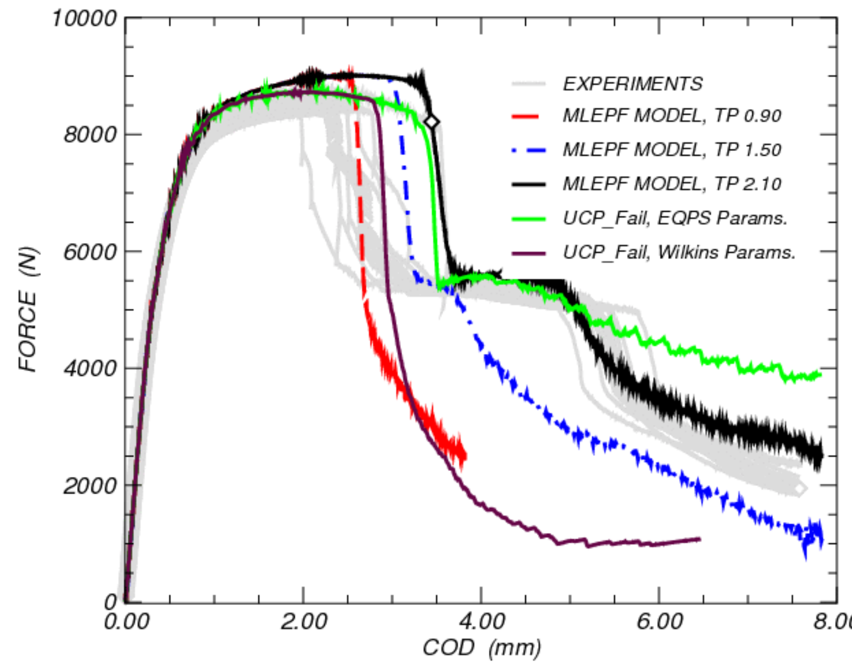
Results/Comparisons: SFC 2012 Predictions



Wellman's Damage (MLEPF)

Wilkins' Damage (UCPD)

PH15-5 H1075 SS

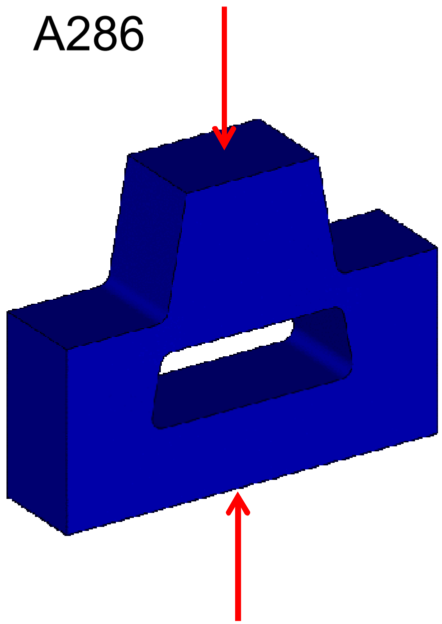


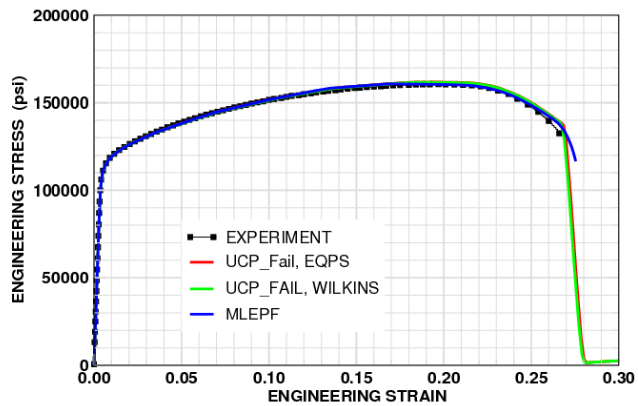
EQPS Params.	Wilkin's Params.
$\hat{a} = 0.0$	$\hat{a} = 1.8$
$\hat{\beta} = 0.0$	$\hat{\beta} = 0.75$

B. L. Boyce et al., 'The Sandia Fracture Challenge: blind round robin predictions of ductile tearing,' *International Journal of Fracture,* **186**, pp. 5-68, 2014.

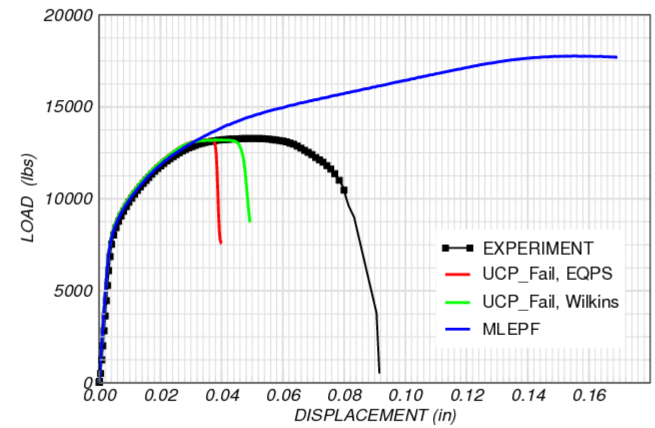
Results/Comparisons: SFC 2013 Predictions

A286

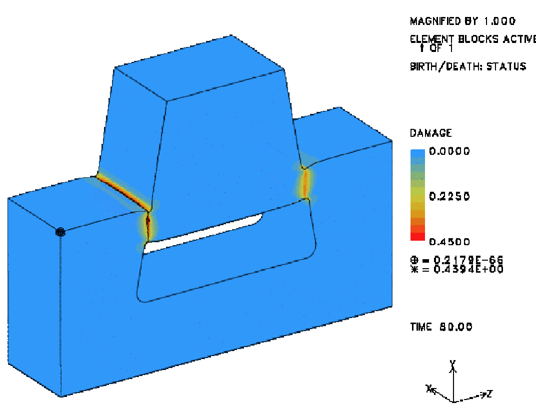




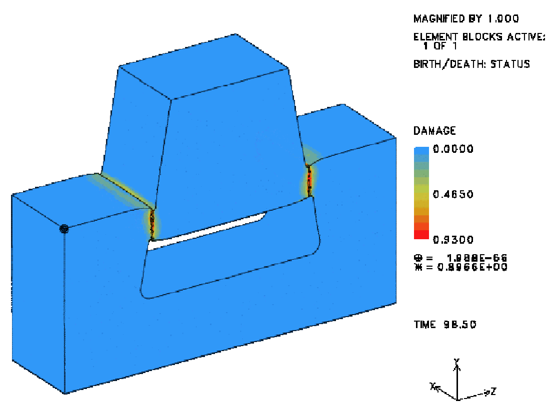
Uniaxial Tension



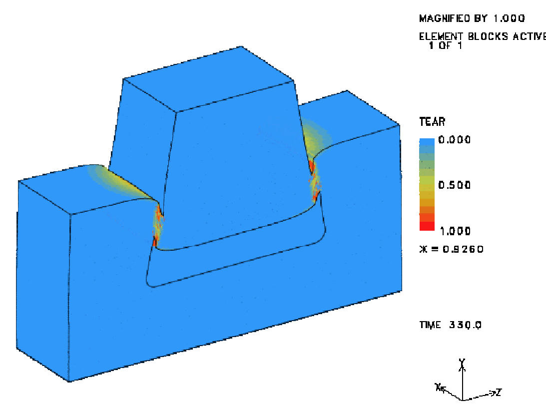
Challenge Shear Test



UCPD, EQPS



UCPD, Wilkins Params

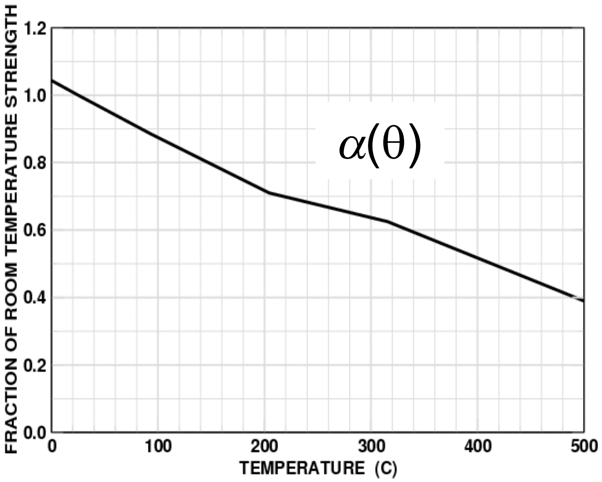


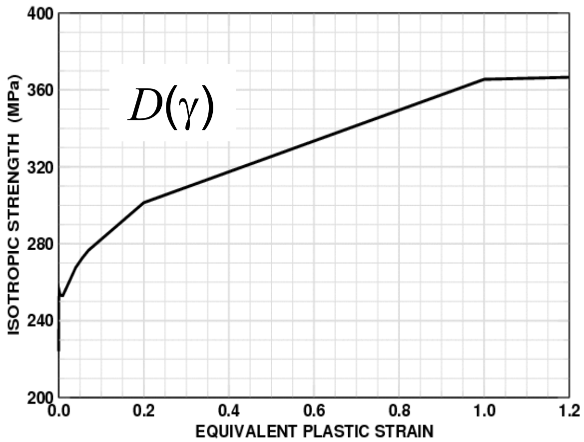
MLEPF – Wellman's Damage

Material Parameters – Ti6Al4V

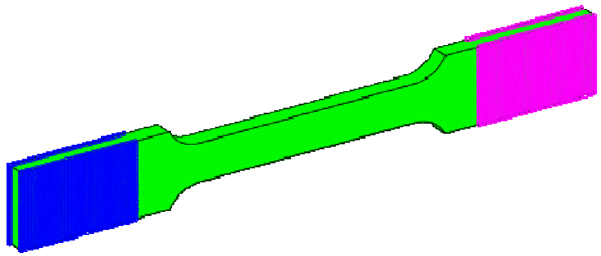
Parameter	Wilkins' Damage	Damage = EQPS
Young's Modulus (MPa)	113,793	113,793
Poisson's Ratio	0.342	0.342
Flow Rate, f	-70.0	-70.0
Sinh Exponent, m	18.0	18.0
Wilkins Alpha, $\hat{a}$	1.8	0.0
Wilkins Beta, $\hat{\beta}$	0.75	0.0
Wilkins Pressure, $\hat{p}$ (MPa)	2,759	2,759
Damage Effect, c	0.25	0.35
Damage Exponent, d	1.0	1.0
Failure Damage	0.72	0.60
Thermal Expansion Coeff. (1/C)	8.6×10^{-6}	8.6×10^{-6}
Density (gm/cm3)	4.43	4.43
Thermal Conductivity (W/m-C)	6.70	6.70
Specific Heat (J/gm-C)	0.5263	0.5263

$$\dot{\boldsymbol{\varepsilon}}^{in} = \frac{3}{2}\dot{\gamma}\,\mathbf{n} = \frac{3}{2}e^{f}\,\sinh^{p}\left(\frac{\tau}{\alpha\,D\left(1-cw^{d}\right)}\right)\mathbf{n}$$

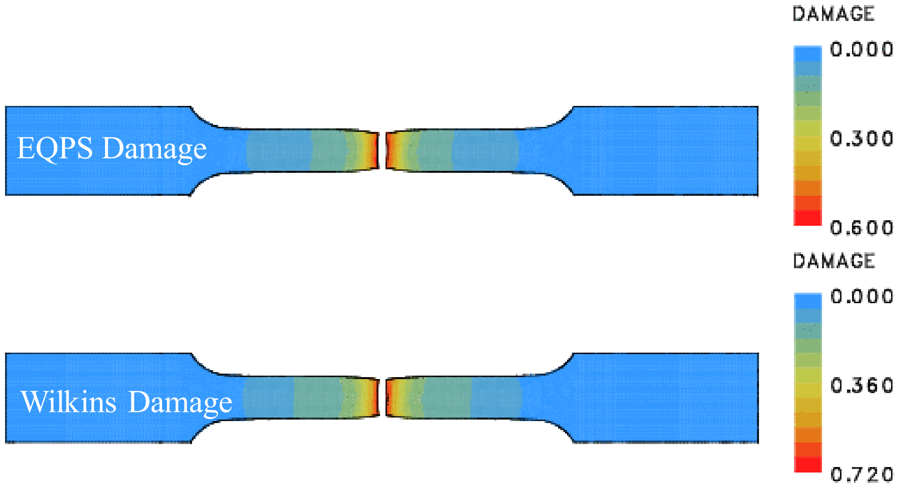




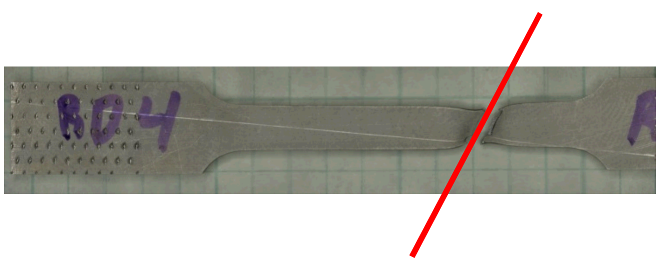
Uniaxial Tension



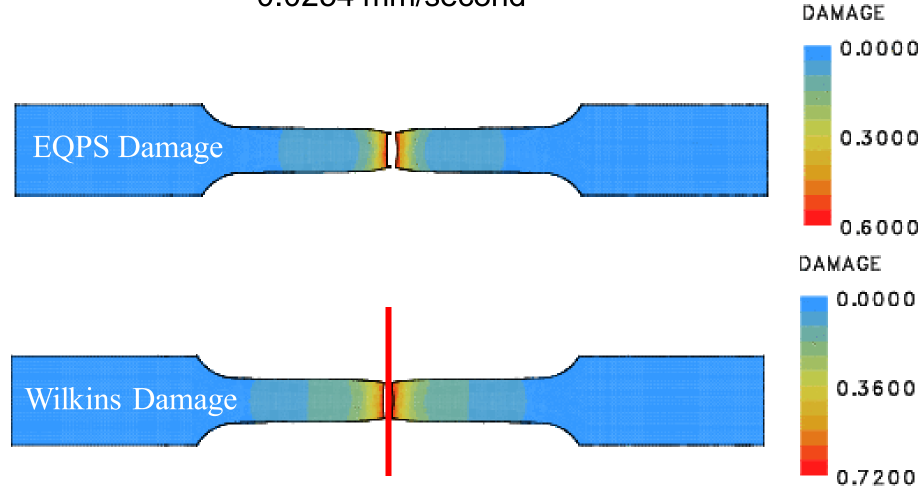
0.0254 mm/second



0.0254 mm/second



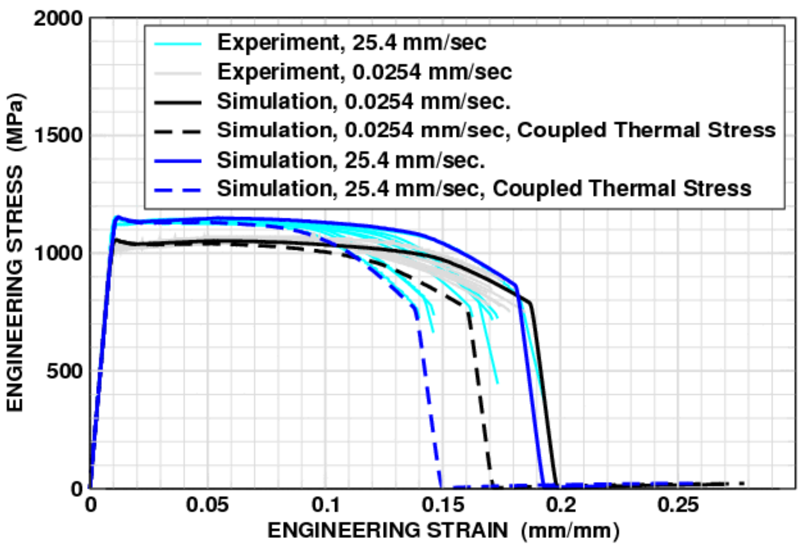
25.4 mm/second



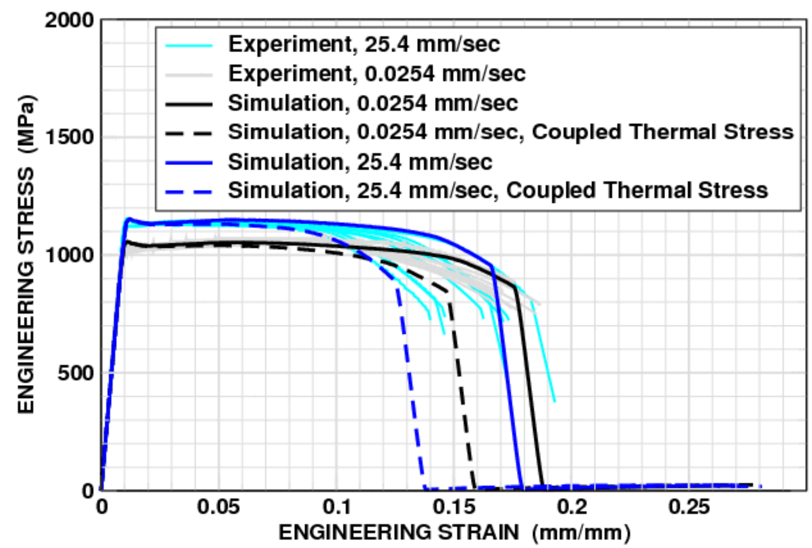
25.4 mm/second

Deformed shape of fractured samples at slow and fast rates compared with isothermal predictions

Uniaxial Tension

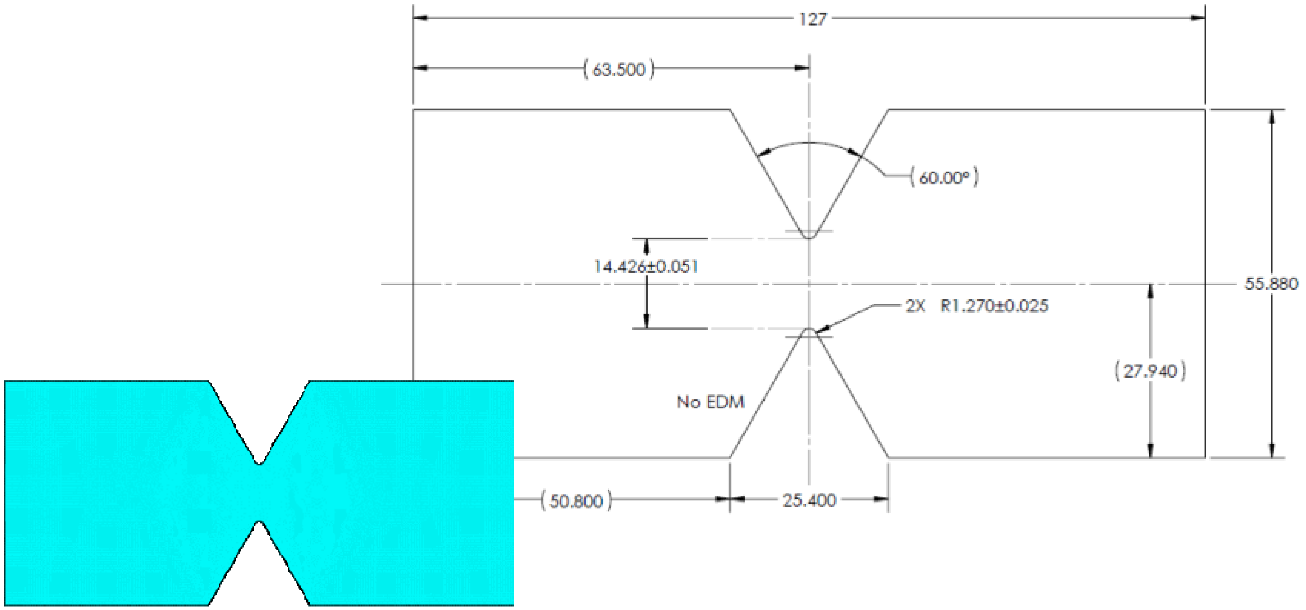


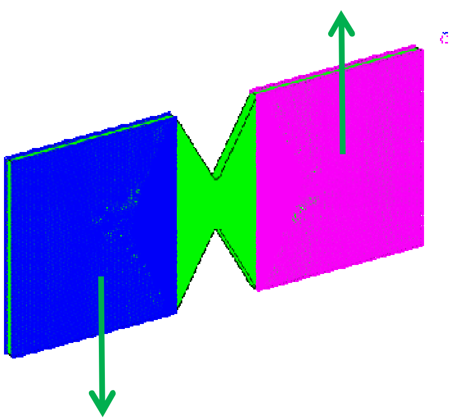
EQPS Damage



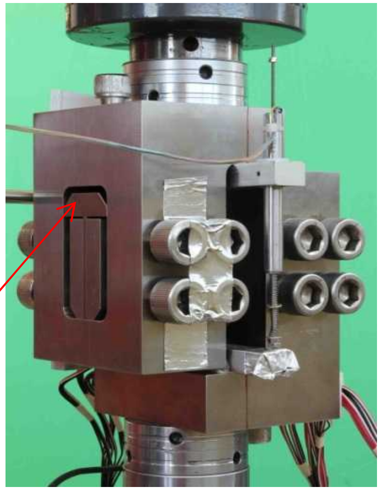
Wilkins' Parameters

Butterfly Shear Test

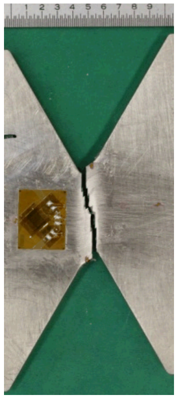




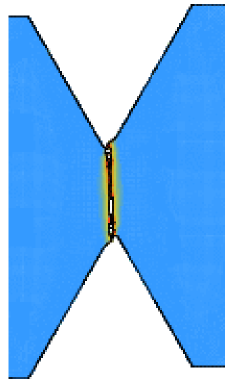
sample is only held by friction between plates until in rotates and hits up against this horizontal clamp that is only hand tightened



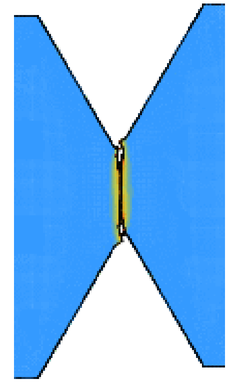
Butterfly Shear Test



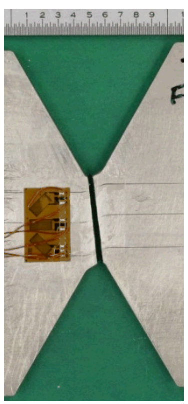
VA1 (slow)



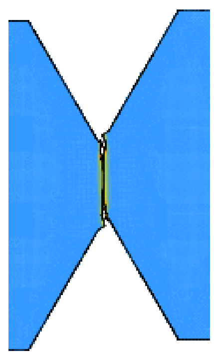
EQPS Damage



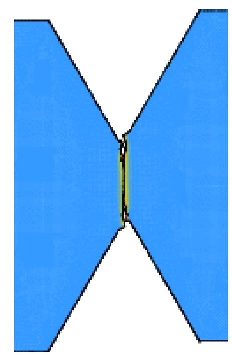
Wilkins' Damage



VA4 (fast)

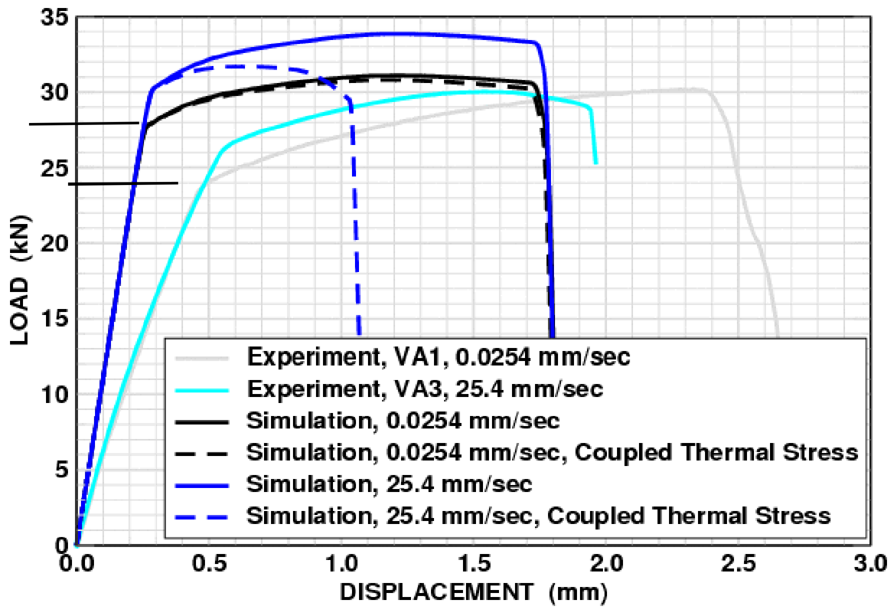


EQPS Damage



Wilkins' Damage

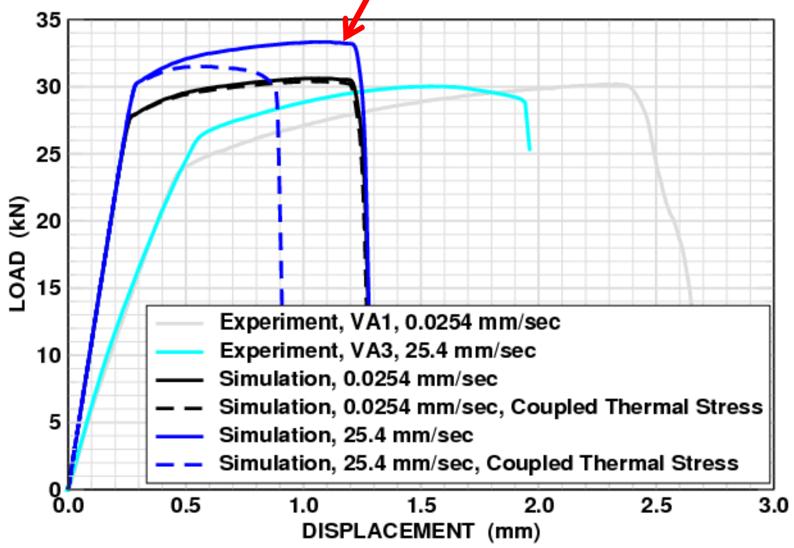
Butterfly Shear Test



EQPS Fail

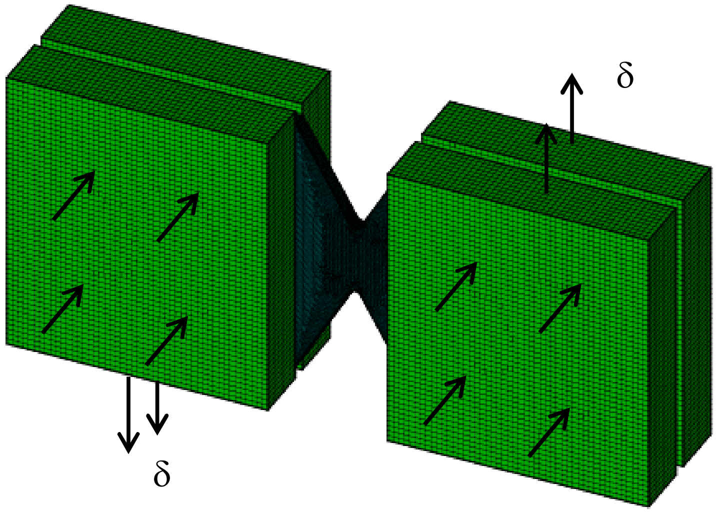
Yield Stress: Experiment/Model ~0.86

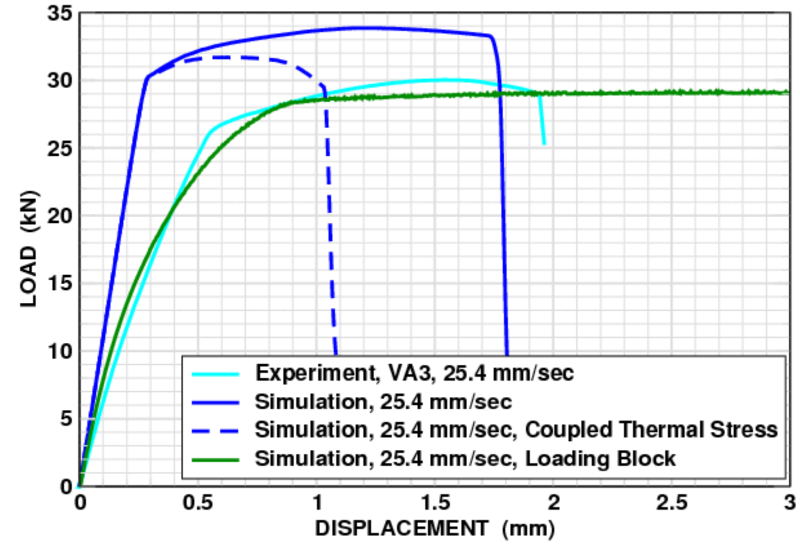
Wilkins' Parameters Reduce Shear Strain to Fail

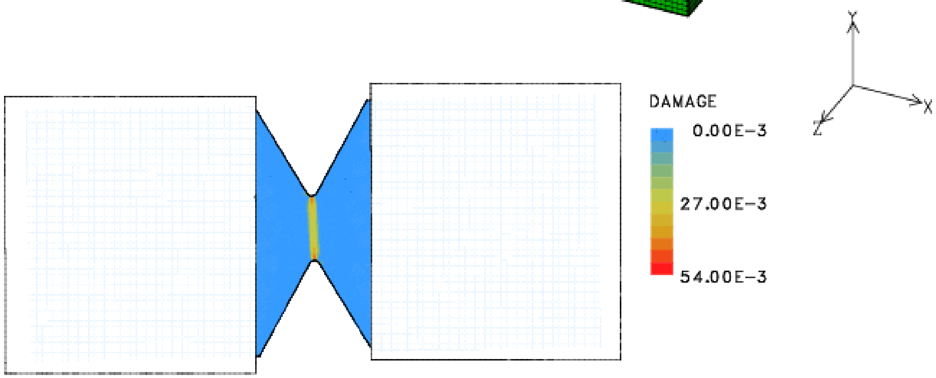


Wilkins' Parameters

Butterfly Shear Test with Loading Blocks





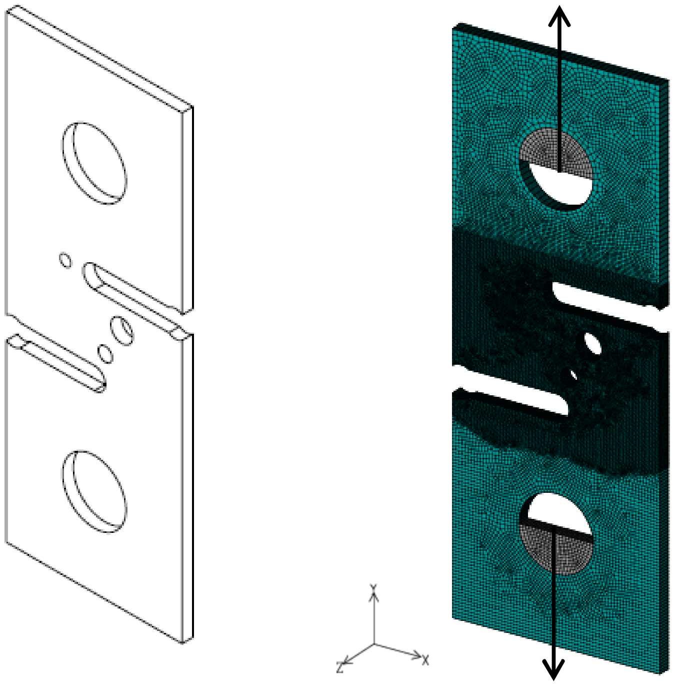


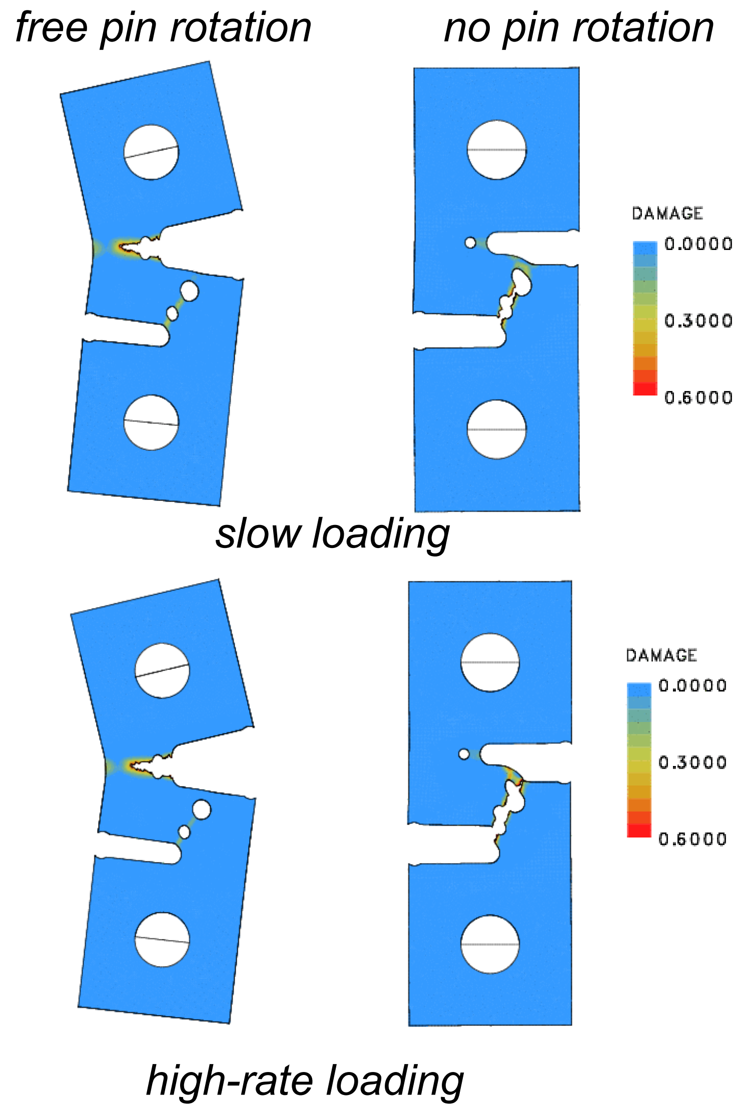
Torque = 0.2(Major Diameter) F_{axial}

67.8 N-m, 0.015875 m diam, 21.35 kN x 4 = 85.4 kN (19,200 lbs)

$\mu = 0.36$

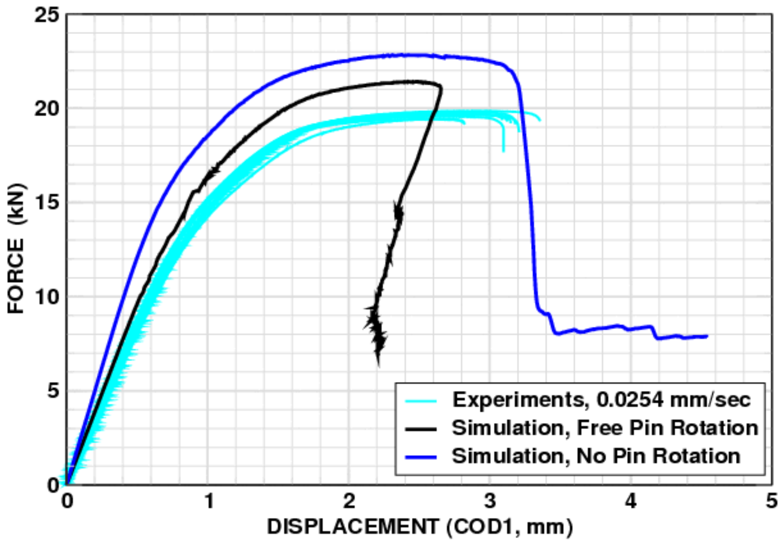
Challenge Geometry



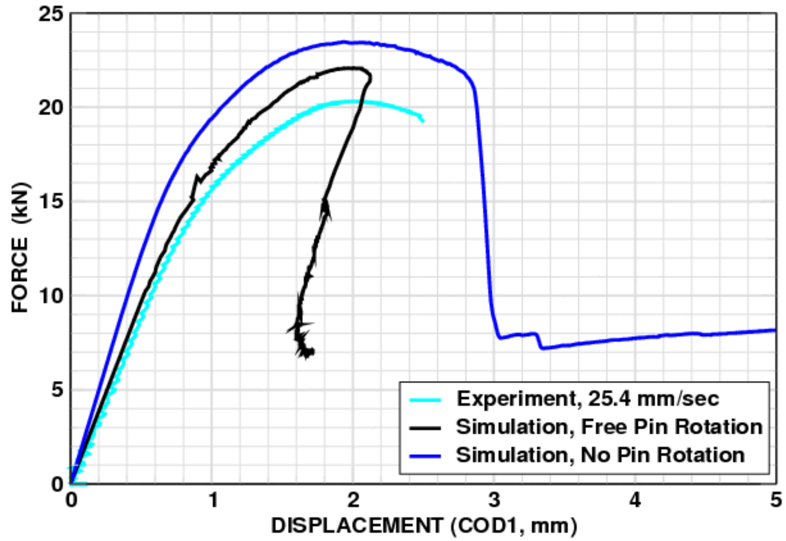


Coupled Thermal Stress
EQPS Damage
3.124 mm, 12 elements Thru Thickness
Free Rotation or No Rotation of Pins

Challenge Geometry



0.0254 mm/sec loading



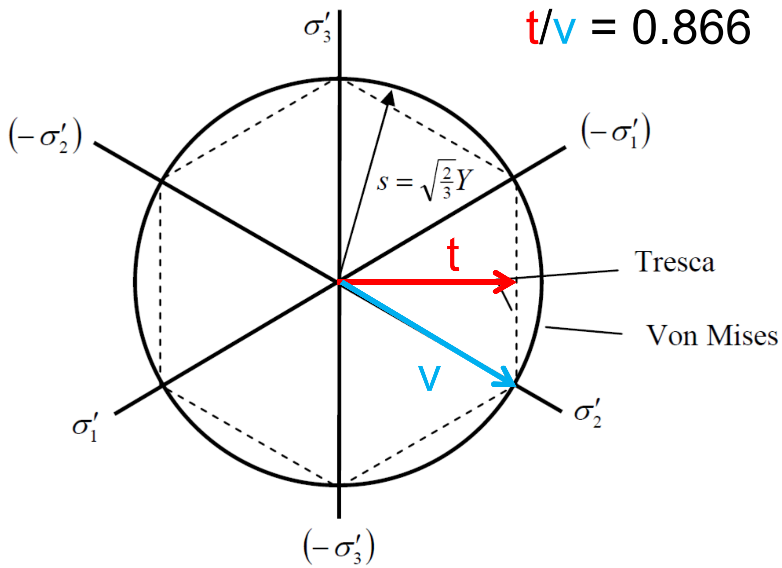
25.4 mm/sec loading

Load vs. COD1 displacement curves blind predictions compared with experimental results

Possible Sources of Error

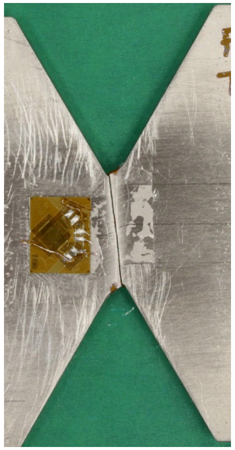
- Challenge crack path depends on pin friction – difficult to model
- For all shear tests: experimental load ~ 0.86 to 0.91 x predicted load.
- Is vonMises potential surface wrong – Hosford or Tresca better for this material
  - Tresca/Mises strength ratio for shear is 0.866 which is close to experiment/prediction

t/v = 0.866



Observation

Accurate predictions of ductile tearing in metals require accurate predictions of bifurcations.



Reference:

B. Boyce and S. Kramer, “The 2nd Sandia Fracture Challenge”, *Imechanica web site* accessed May 30th, 2014. http://imechanica.org/node/16708

Summary

- Failure predictions are sensitive to boundary conditions
- Heating due to plastic work can have dramatic effect especially for materials with little hardening – coupled thermal stress simulations may be needed
- Experimentally measured peak stress for both shear test and challenge geometry was 86 to 91 percent of prediction indicating Hosford/Tresca may be needed in place of vonMises for Ti6Al4V
- Accurate predictions of material behavior and bifurcations are essential for generating subsequent material failure predictions.

Acknowledgements

- Brad Boyce and Sharlotte Kramer, Sandia, for work on SFC2
- Sandia National Laboratories P&EM support of this work.
- Thanks for your kind attention !