SAND2022-14355C

Intermediate Strain Rate Behavior of a Polymer-Particulate Composite with High Solids Loading

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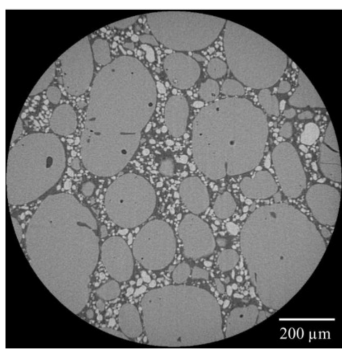
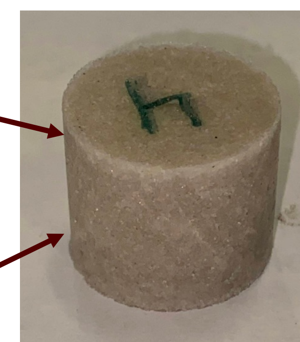
Composite Materials!

Gupta, Nikhil, et al. *Jom* 66.2 (2014): 245-254.



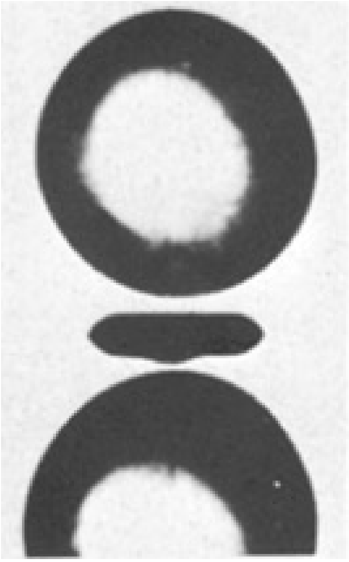
Erikson, William W., et al. No. SAND2018-6612C. Sandia National Lab.(SNL-NM) 2018.



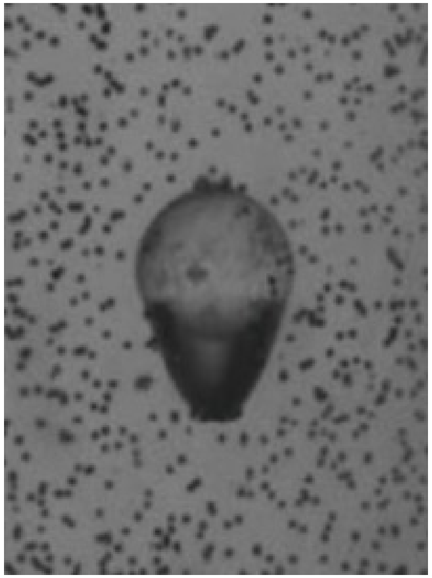
Pictures not referenced are from either Wikipedia or are personal photos

Complex Mechanical Behavior

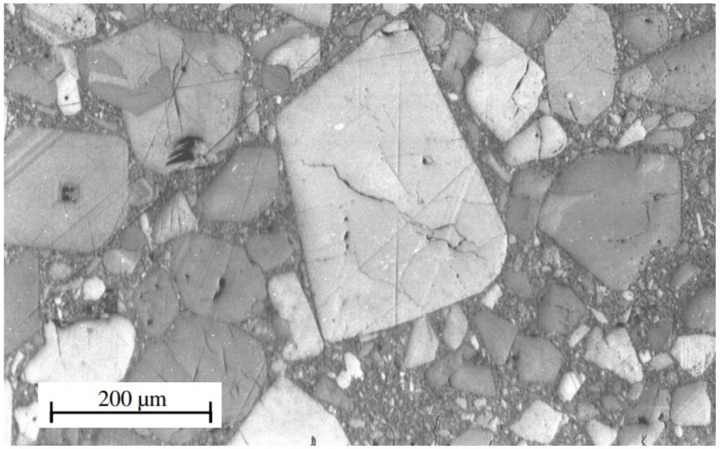
- Strain rate, pressure and temperature dependent
- Damage mechanisms depend on
  - Particle
  - Binder
  - Interaction between the two
- Role of particle morphology and strength on damage accumulation?



Gent, A. N., and Byoungkyeu Park. *Journal of Materials Science* 19.6 (1984): 1947-1956.



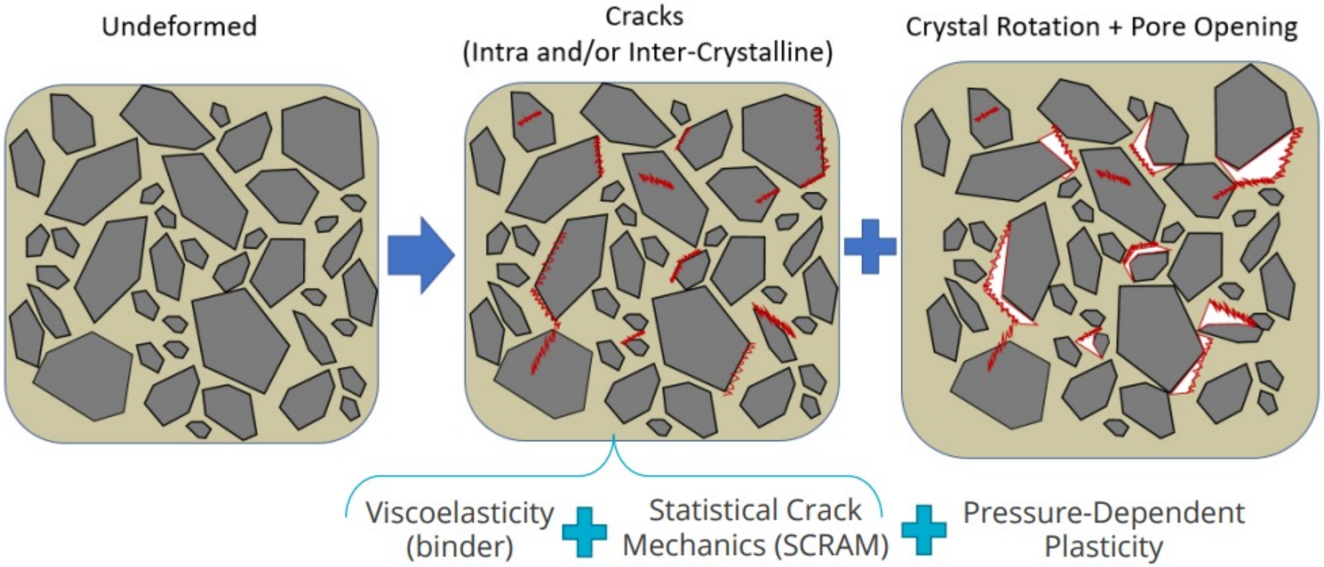
Kosta, Tomislav, and Jesus O. Mares. *Advancement of Optical Methods & Digital Image Correlation in Experimental Mechanics.* 2021. 83-88.

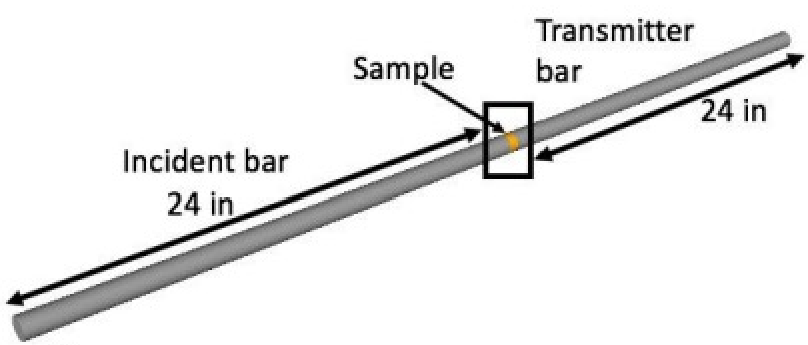


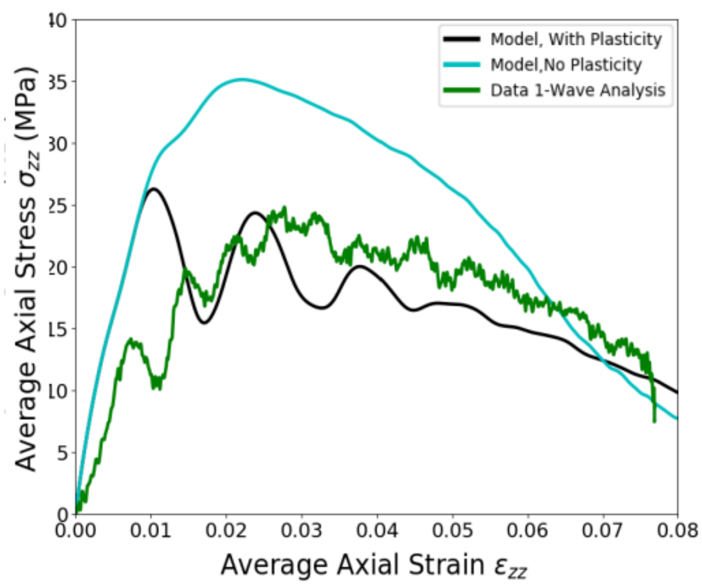
Rae, P. J., et al. Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences 458.2019 (2002): 743-762.

Modeling Efforts

- Collaborators are modeling complex phenomena of these particle polymer composites







All figures on slide from Brown, J., et al. No. SAND 2022-7768C. Sandia National Lab.(SNL-NM) 2022.

Materials

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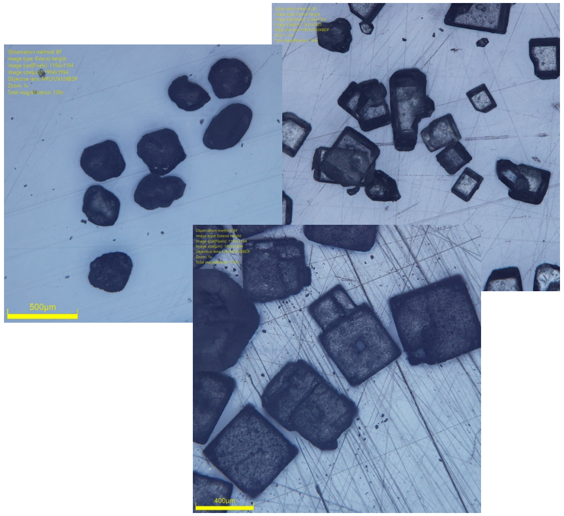
Polymer

- Sylgard 184®
- Two part polydimethylsiloxane (PDMS)
- Well characterized
- Can accept many particle systems
- Easily varied mechanical properties

Particles

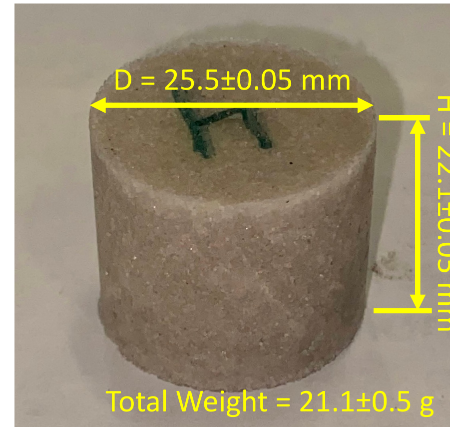


- Inert crystalline particles with a wide variety of morphology
- Silica sand, caster sugar, sodium chloride

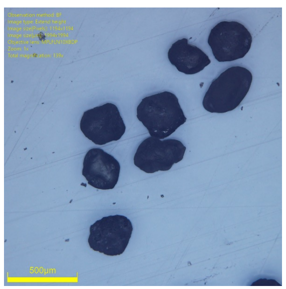
Control of these two materials allows for parametric study of dynamic material behavior

Composite Fabrication

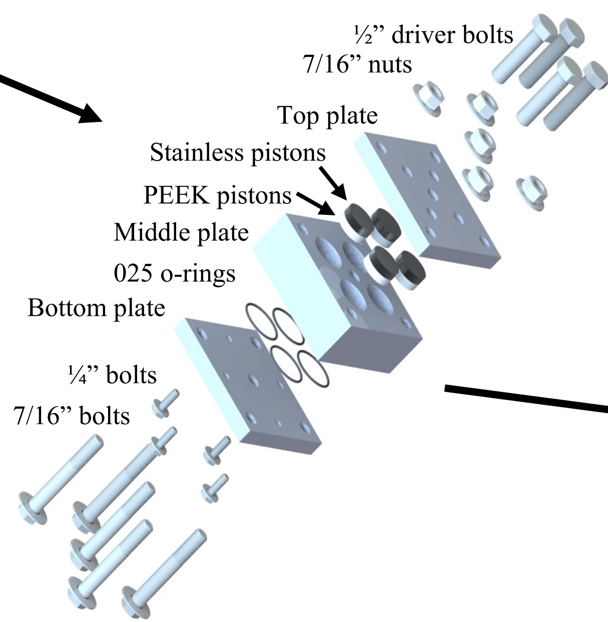
- Manufacturing method to create uniform heterogenous composites
- Involves degassing of constituents and curing in elevated temperature and pressure environment
- Careful control of manufacturing process needed for consistent mechanical response



80% wt particle



- Polymer Cure Parameters
- ASTM D618 (Conditioning for plastics)
- ASTM D695 (Compressive Properties Of Rigid Plastics)



Particle Characterization

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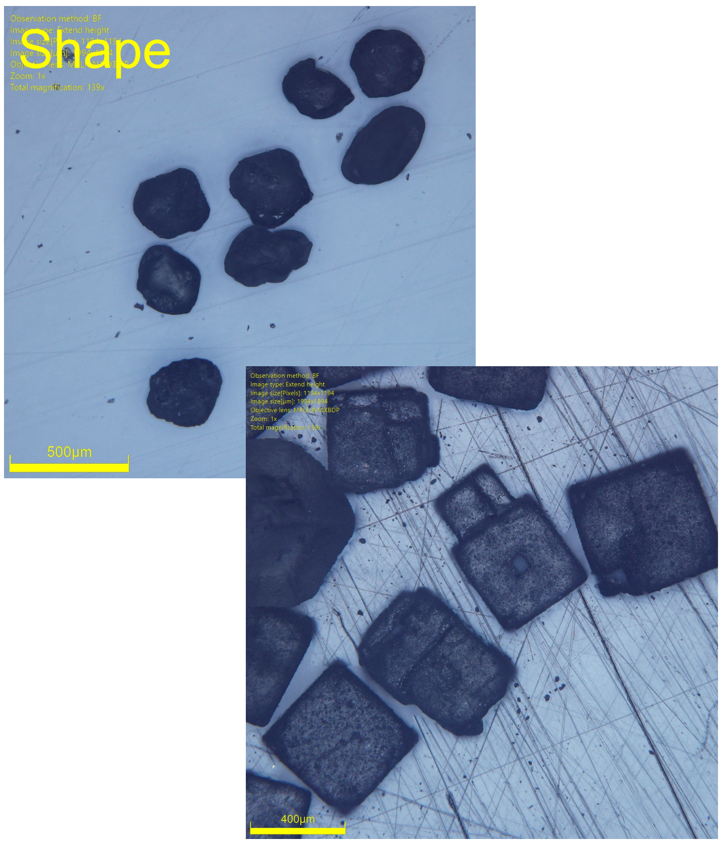
- Influence of particle characteristics on composites

Silica, CAS# 14808-60-7
GFS Chemicals
Silica sand 50-70 mesh

Silica Sand	
	Diameter on cumulative % (µm)
10%	243
50%	324
90%	458

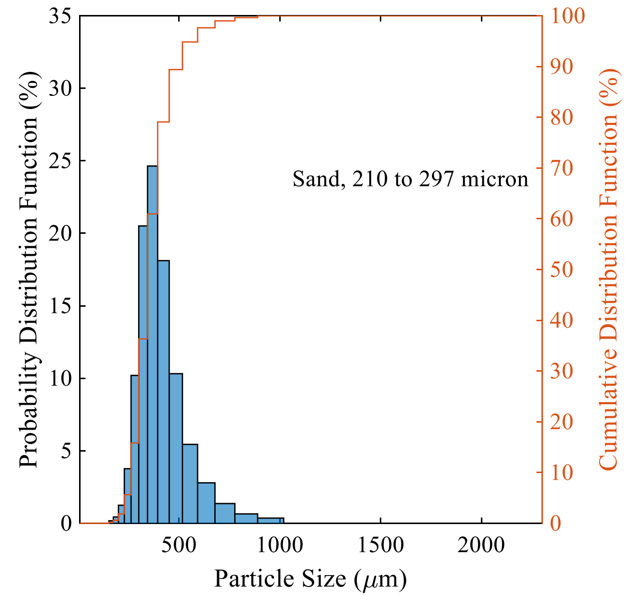


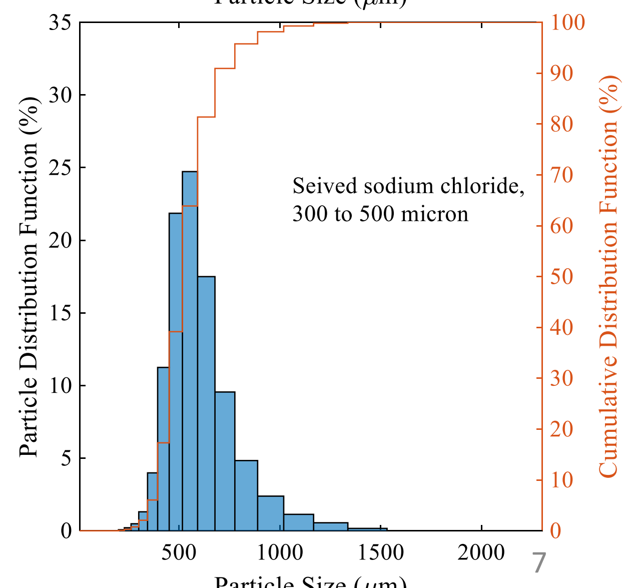
Optical images of particles using Olympus DXS 500 optical microscope

Sodium Chloride, CAS# 7647-14-5

Sieved Sodium Chloride	
	Diameter on cumulative % (µm)
10%	362
50%	479
90%	670

Particle size distribution measured with LA-960V2 Horiba Particle Size Analyzer at the Materials Characterization Facility

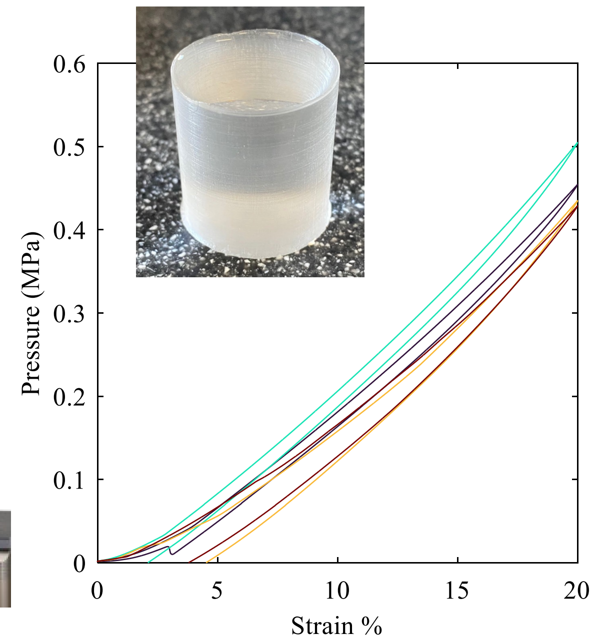




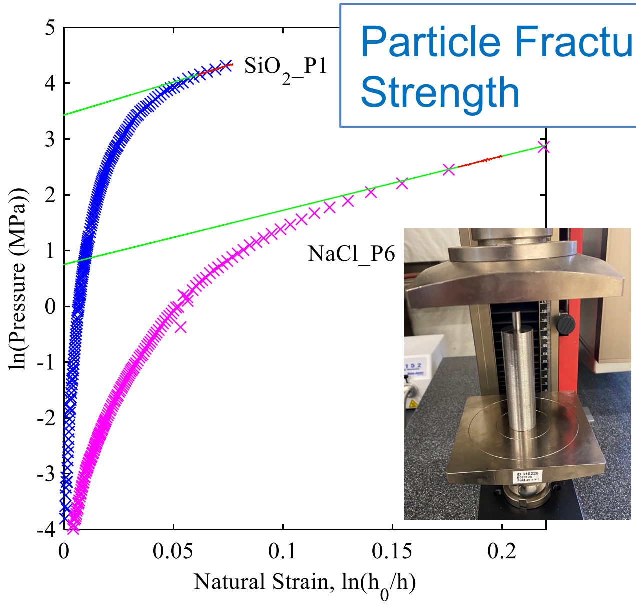
Constituent Strength Characterization

Particle Agglomerate Strength		
Test	Silica Sand Strength (MPa)	Sodium Chloride Strength (MPa)
1	365.5	22.9
2	232.1	26.5
3	309.5	26.8
4	295.9	25.0
5	281.1	24.5
6	363.2	20.6
Average	323.1±69.7	24.4±4.7

- Particle agglomerate strength measured using method detailed in Adams et al. (1994)



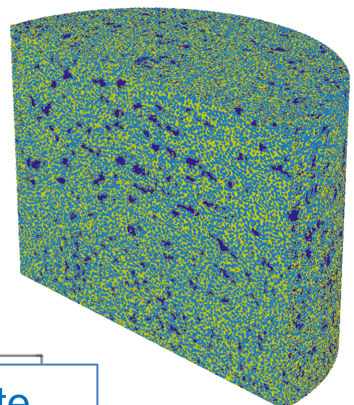
Particle Fracture Strength



Sylgard Stiffness	
Test	Stiffness (MPa)
1	2.27
2	2.52
3	2.17
4	2.14
Average	2.28±0.21

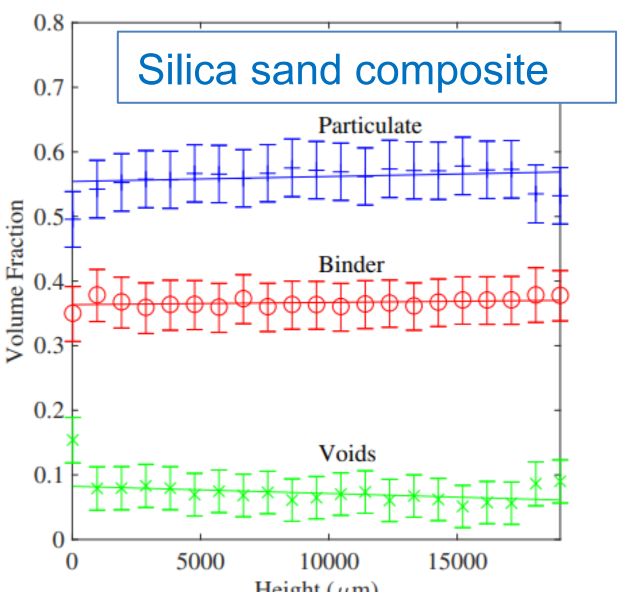
Volumetric Characterization

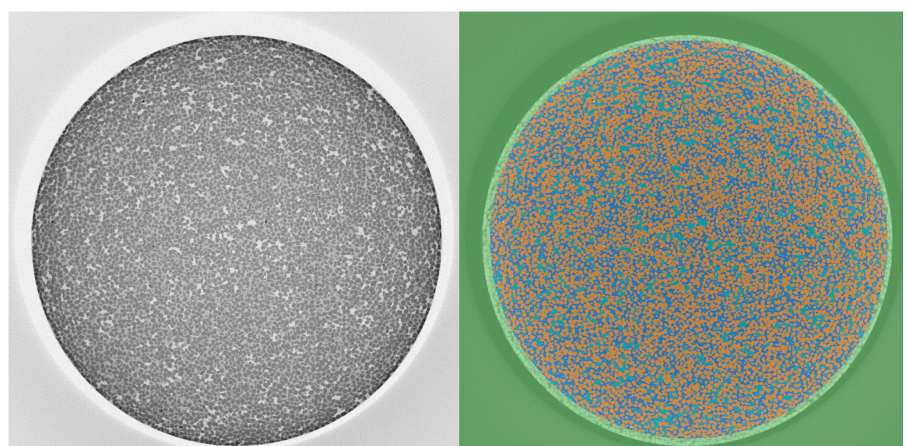
- View heterogeneity of samples through micro-CT visualization
- K-means clustering segmentation to extract information on mass and volume fractions
- North Star Imaging X50 micro-CT machine



Silica Sand Composite			
	Constituent	Lab Measurement	Micro-CT
Volume Fraction	Voids	6.4±0.4%	7.2±3.3%
	Binder	34.4±1.4%	36.7±3.9%
	Particle	59.3±1.7%	56.2±4.4%
Mass Fraction	Binder	18.4±0.3%	20.3±2.4%
	Particle	81.6±0.3%	79.7±5.5%

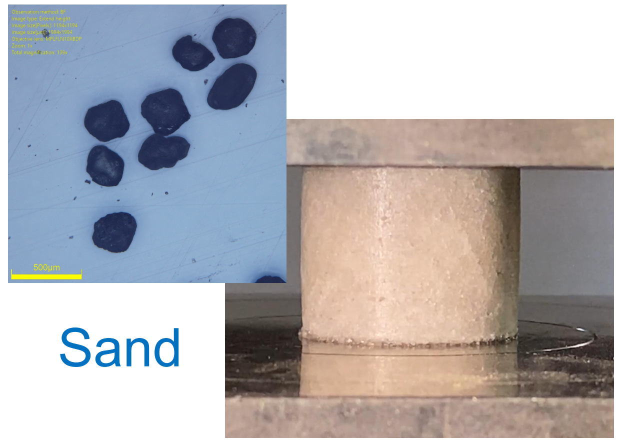
Sodium Chloride Composite			
	Constituent	Lab Measurement	Micro-CT
Volume Fraction	Voids	13.4±0.7%	11.1±1.8%
	Binder	28.9±0.7%	32.4±3.9%
	Particle	60.8±1.4%	56.5±3.9%
Mass Fraction	Binder	18.5±0.02%	18.3±2.8%
	Particle	81.5±0.02%	81.8±4.7%



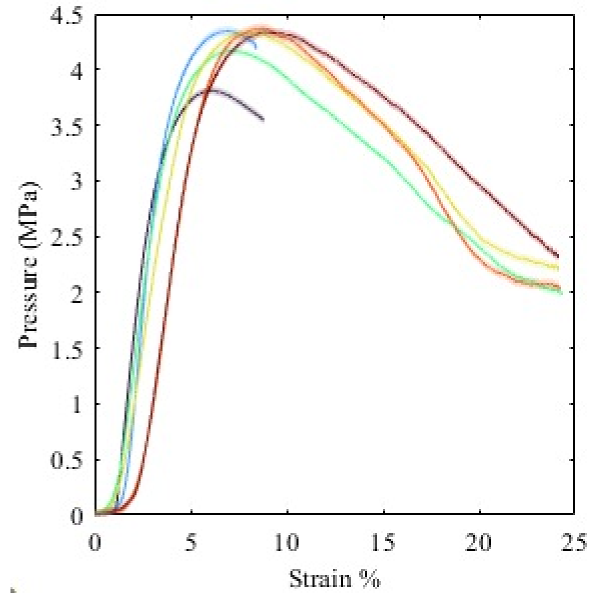


Quasistatic Response

- Composites with varying particle systems uniaxially compressed
- Single compression

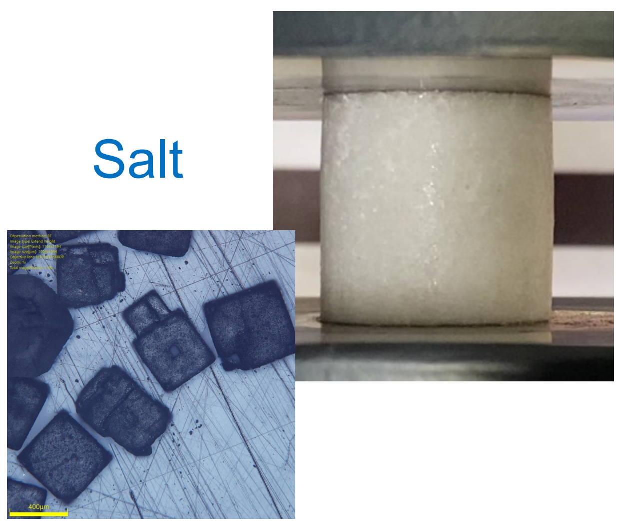


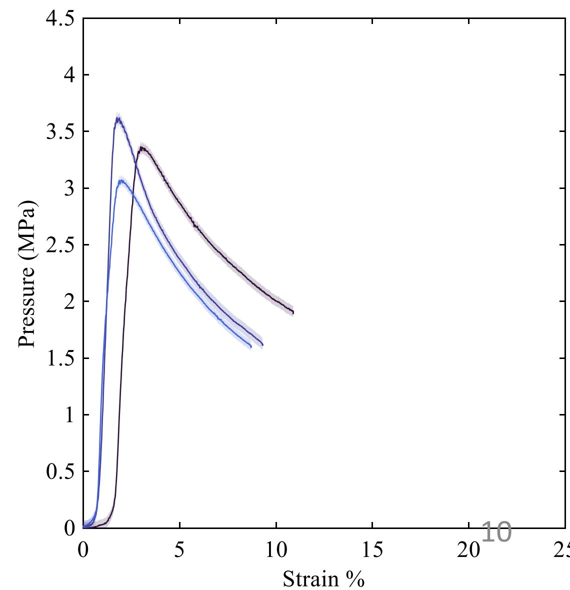
Sand



Q-S Strength

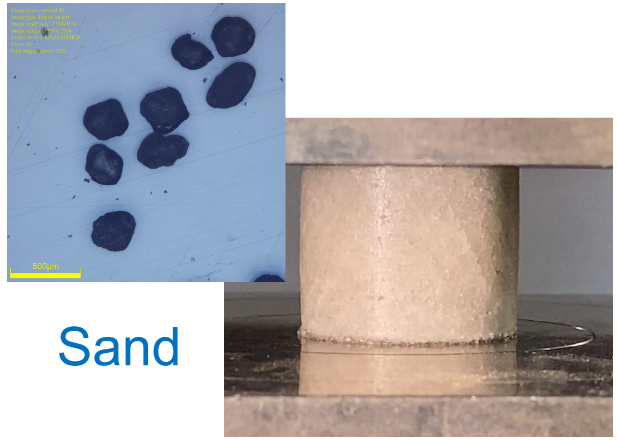
Salt



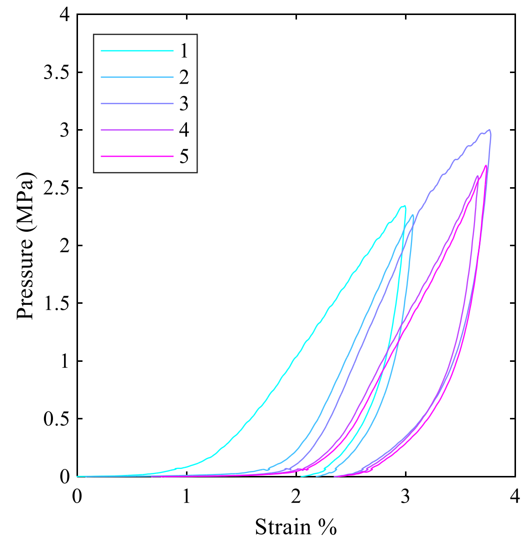


Quasistatic Response

- Composites with varying particle systems uniaxially compressed
- Cyclic discrete compression tests
- Damage observed in both samples

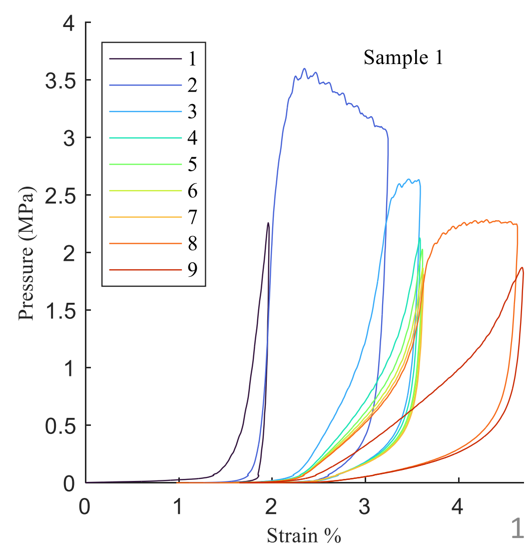


Sand



Q-S Strength

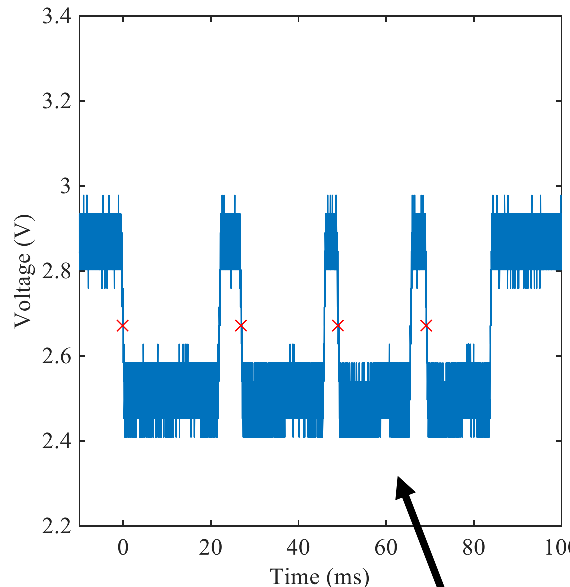
Salt

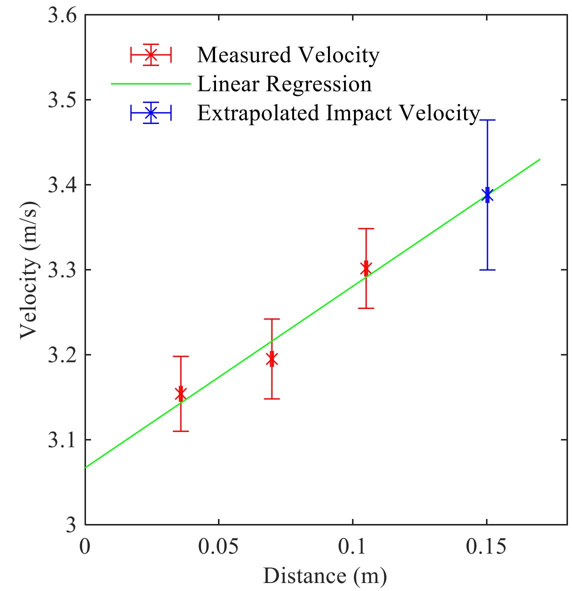


Dynamic Testing – Drop Test

Drop test experiment with aluminum impactor.
Trolley masses: Steel: 4.5 kg,
Maximum drop height: 165 cm

Impactor velocity measurement system

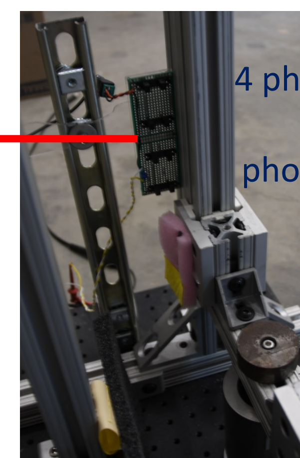




Picoscope 2408B

Delay generator

High speed camera



4 photodiodes and photosensors

Elastic deformation to fragmentation observed

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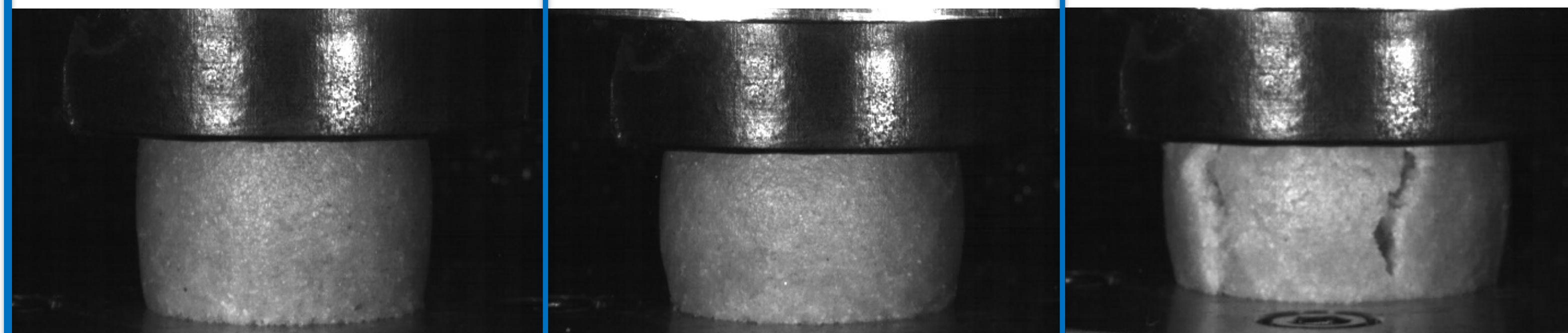
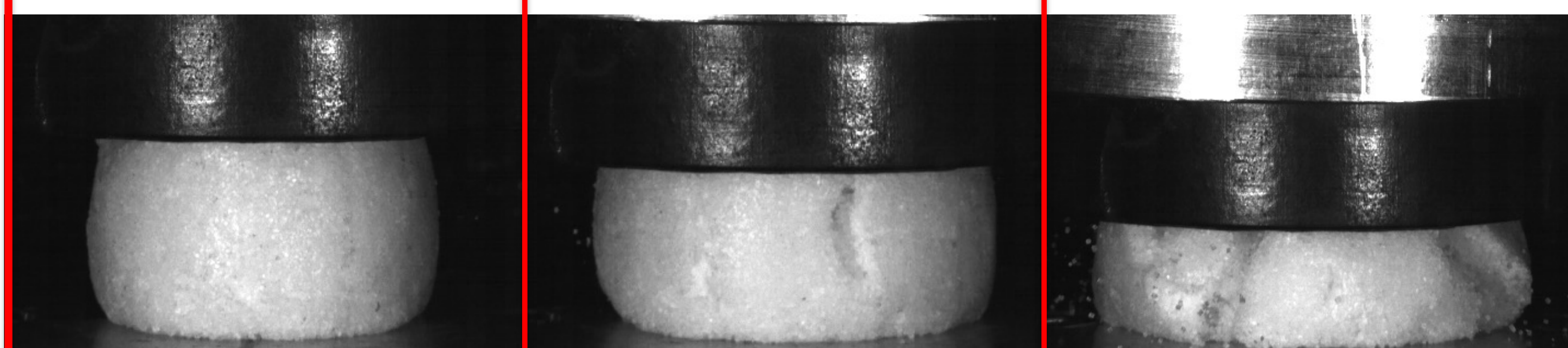
Silica Sand Composite

Impact Velocity *V*: 2.40±0.04 ms^{-1} Initial Strain Rate $\dot{\varepsilon}$: 122±2 s^{-1} Impact Energy *E*: 12.9±0.5 J	*V*: 2.83±0.09 ms^{-1} $\dot{\varepsilon}$: 139±5 s^{-1} *E*: 18.1±1.2 J	*V*: 3.39±0.08 ms^{-1} $\dot{\varepsilon}$: 169±5 s^{-1} *E*: 25.8±1.3 J



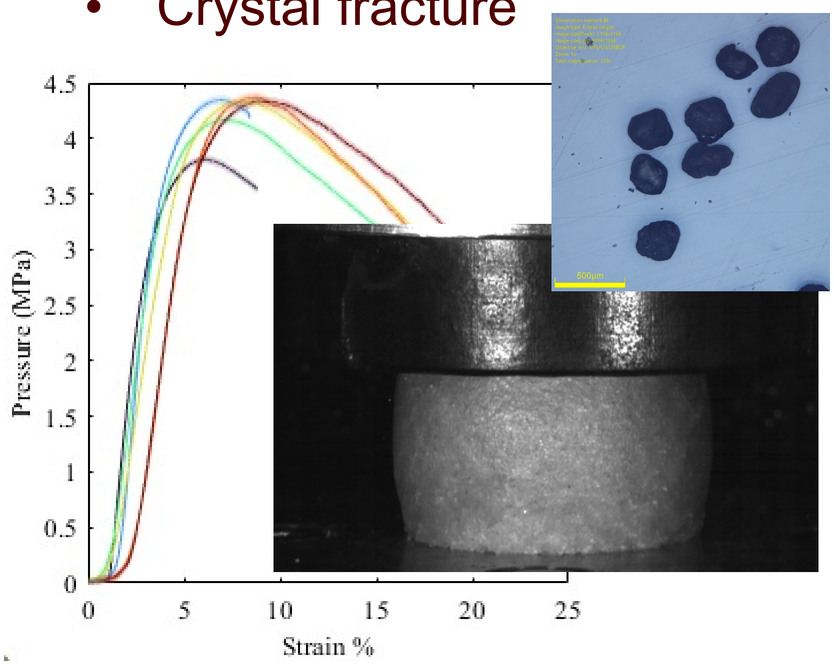
Sodium Chloride Composite

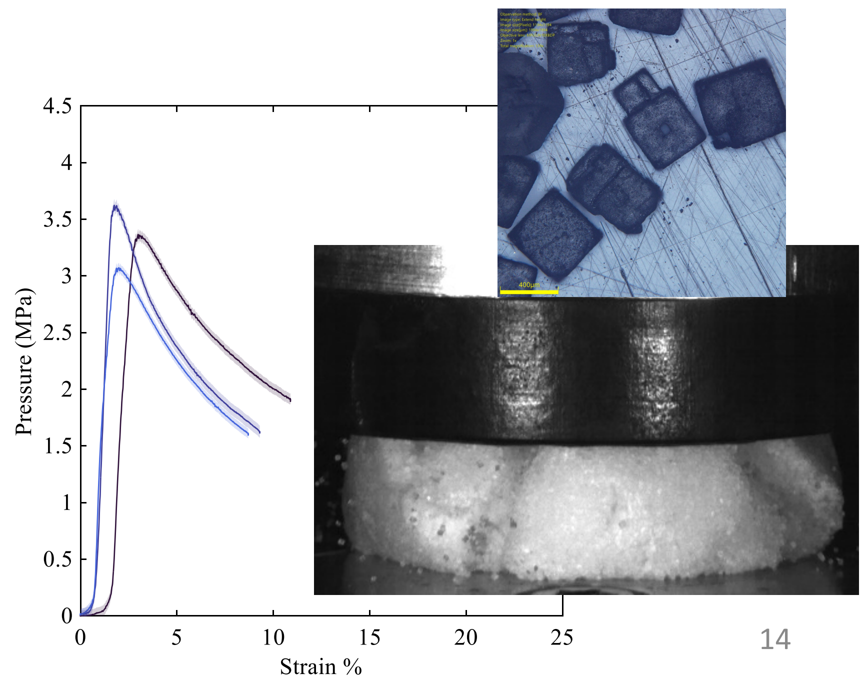
V: 2.01±0.02 ms^{-1} $\dot{\varepsilon}$: 92.1±1.1 s^{-1} *E*: 9.09±0.14 J	*V*: 2.40±0.06 ms^{-1} $\dot{\varepsilon}$: 118±3 s^{-1} *E*: 13.0±0.6 J	*V*: 2.89±0.07 ms^{-1} $\dot{\varepsilon}$: 134±3 s^{-1} *E*: 18.8±0.9 J



Conclusion

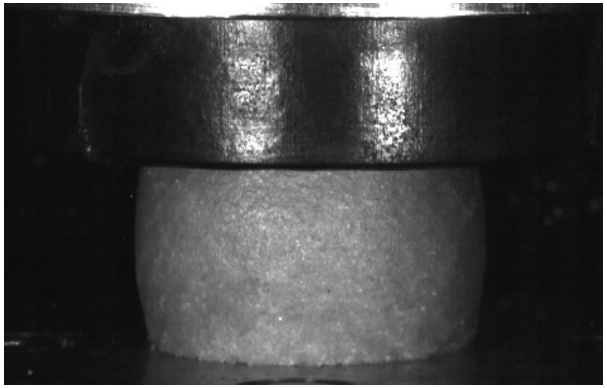
- Higher particle strength filler leads to composite more resistant to damage mechanisms
  - Quasistatic and dynamic
- Influence of each damage mechanism unknown
  - Binder rupture
  - Interfacial debonding
  - Crystal fracture

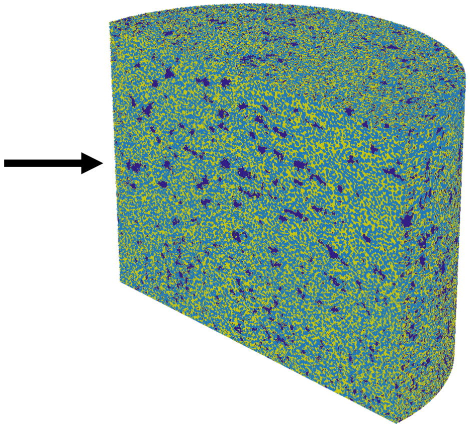




Future work

- Post sample volumetric visualization
  - View failure modes after mechanical stimulus
- Split Hopkinson pressure bar impact testing
  - Span larger strain rate range
  - Extract bulk stress strain data
  - High speed imaging to view material deformation and fracture





Acknowledgements

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- Sandia National Laboratories collaborators Dr. Judith Brown and Dr. Michael Kaneshige
- Texas A and M University Materials Characterization Core Facility (RRID:SCR 022202)
  - Particle diagnostics
- Dr. George Pharr
  - Photron SA-Z camera and lighting
- ZwickRoell, LP and Mr. James Gray
  - Use of 2.5kN Zwicki

Questions?

4 part mold planarity uncertainty

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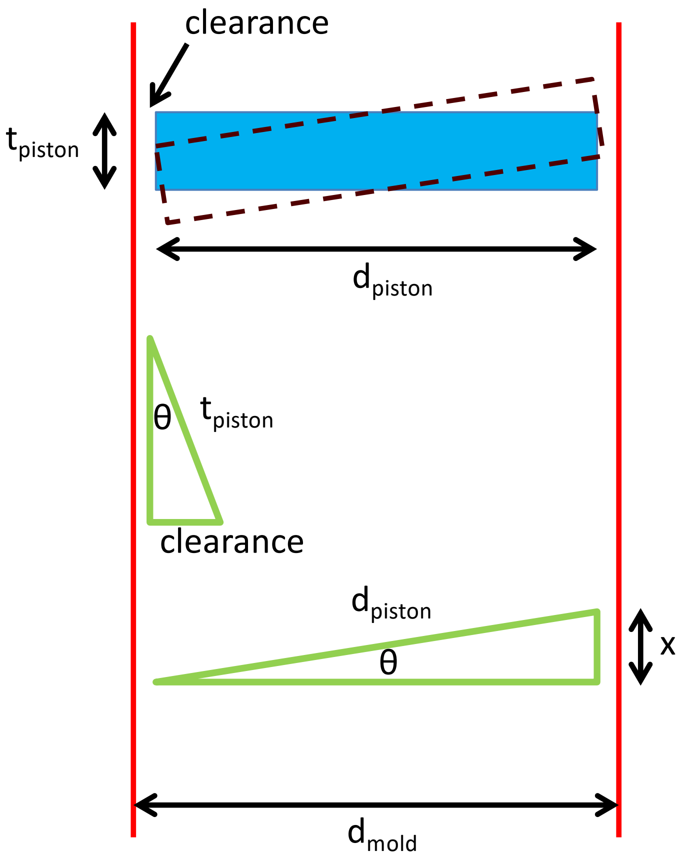
- Quantifying uncertainty in planarity assuming single pistons are free to rotate
- Initial assumptions
  - t_{piston} = 0.197 in, measured from steel pistons
  - d_{piston} = 0.998 in, measured from steel pistons
  - d_{mold} = 1 in, assumed from reamed holes
- x = 0.01 in in this scenario (10 mils, ±5 mils from center)
- For a 1 inch tall sample, this corresponds to ±0.5% strain measured from center
- Conservative assessment as this does not take into account driver bolt flattening the piston

$$\theta = sin^{-1}\left(\frac{clearance}{t_{piston}}\right)$$

$$x = d_{piston} * \sin(\theta)$$



Piston Uncertainty Propagation

- Measured variety of samples using dial indicator on mill machine surface

		Samples											
		Thin PEEK Piston		Stainless and PEEK Pistons							Thick PEEK Piston		
		14	17	27	28	29	30	65	68	74	63	67	71
Measurement relative to average (mils)	AVG	7.7	-0.4	1.3	-3.6	1.4	-0.2	-3.5	-2.2	-0.8	0	-0.2	0.8
	C	-7.7	0.4	-1.3	3.6	-1.4	0.2	3.5	2.2	0.8	0	0.2	-0.8
	1	-9.7	-6.6	0.7	-3.4	2.1	2.2	-7.5	1.2	-2.2	3	-0.8	4.2
	2	-5.7	-1.6	3.7	2.6	2.1	0.2	1.5	2.2	-6.2	-2	-5.8	-3.8
	3	13.3	6.4	-0.3	0.6	-1.4	-1.8	5	-3.8	1.8	-3	3.2	-3.8
	4	9.8	1.4	-2.8	-3.4	-1.4	-0.8	-2.5	-1.8	5.8	2	3.2	4.2
	Tolerance	13.3	6.6	3.7	3.6	2.1	2.2	7.5	3.8	6.2	3	5.8	4.2

- **Worst case samples are ±7.5 mils from average**

5

ViscoPlastic-ViscoSCRAM Model Theory

- Kinematics:

$$\epsilon = e + \frac{1}{3}\epsilon_{\text{vol}}\boldsymbol{I} \qquad \sigma_{\text{m}} = K\epsilon_{\text{vol}}$$

$$e = (e^{ve} + e^{D}) + e^{p}$$

- Viscoelasticity

$$\dot{s} = 2G^{\infty}\dot{e}^{ve} + \sum_{\kappa=1}^{N}\left(2G^{(\kappa)}\dot{e}^{ve} - \frac{s^{(\kappa)}}{\tau^{(\kappa)}}\right)$$

Prony series of shear moduli and relaxation times

- SCRAM Damage

$$e^{D} = \frac{1}{2G_0}\left(\frac{c}{a}\right)^{3} s$$

$$\dot{c} = \begin{cases} v_{res}\left(\frac{K_I}{K_1}\right)^{m} & \text{for } K_I < K' \\ v_{res}\left[1 - \left(\frac{K_{0\mu}}{K_I}\right)^{2}\right] & \text{otherwise} \end{cases}$$

$$\dot{s}^{(\kappa)} = 2G^{(\kappa)}(\dot{e} - \dot{e}^{p}) - \frac{s^{(\kappa)}}{\tau^{(\kappa)}} - \frac{G^{(\kappa)}}{G_0}\left[\frac{3}{a}\left(\frac{c}{a}\right)^{2}\dot{c}s + \left(\frac{c}{a}\right)^{3}\dot{s}\right]$$

$$D = \frac{\left(\frac{c}{a}\right)^{3}}{1 + \left(\frac{c}{a}\right)^{3}}$$

M.A. Buehler, D.J. Luscher, Int. J. Num. Meth. Eng. 2014

- Drucker-Prager Plasticity

$$f(\sigma_{ij}) = \sigma_e + A \cdot \sigma_m - \sigma_y$$

$$g(\sigma_{ij}) = \sigma_e + B \cdot \sigma_m - \sigma_y$$

$$\dot{\epsilon}^{p} = \dot{\lambda}\frac{\partial g}{\partial \sigma}$$

$$\dot{\lambda} = \frac{1}{\tilde{\tau}}\left\langle\frac{f(\sigma_{ij})}{\sigma_0}\right\rangle^{\tilde{m}} \qquad \sigma_e = \sqrt{\frac{3}{2}s_{ij}s_{ij}}$$

LDRD

Slide pulled from Dr. Judy Brown's presentation "The role of pressure-dependent viscoplasticity and volumetric dilatation in energetic materials at intermediate strain rates" July 2022