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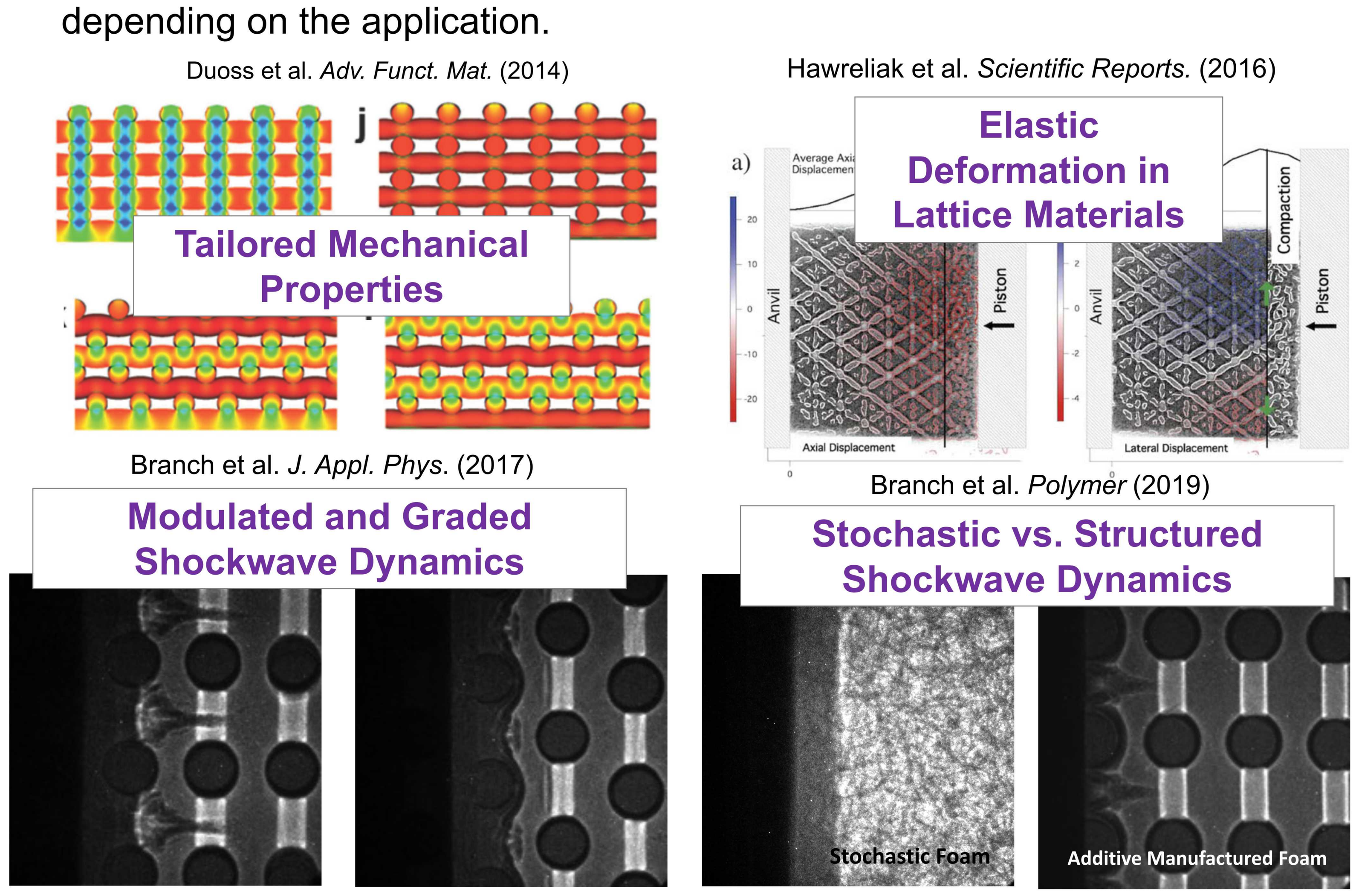
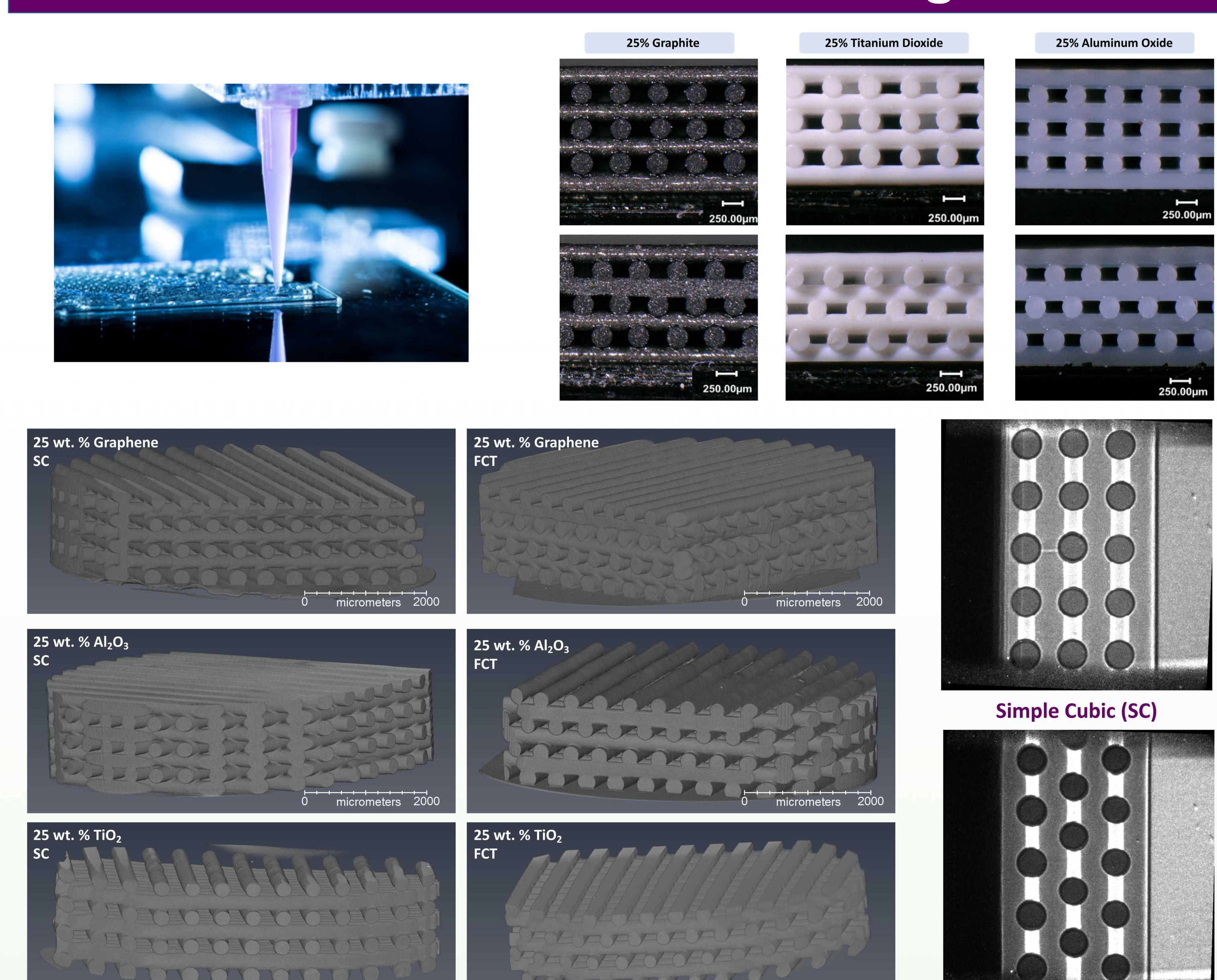
X-ray phase contrast imaging to study the effects of feedstock chemistry on shockwave behavior in AM foams

Motivation

- Additive manufacturing (AM) provides means to assemble hierarchical structures achieving exquisite control of parent structures and interfaces that underpin the mechanical response and further the shock characteristics of polymer materials.
- New paradigm in control of performance afforded through AM methods has lead to the development of novel feedstocks with unique characteristics depending on the application.



Direct Ink Write Printing



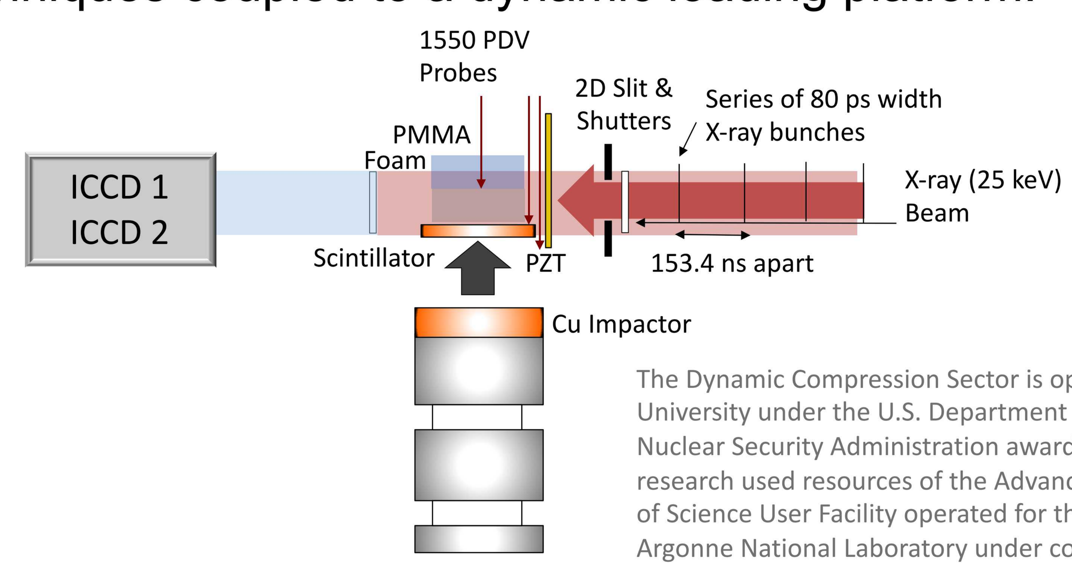
Simple Cubic (SC)

Face – centered Tetragonal (FCT)

Integrity of the micro-lattice structures were characterized using computed tomography. (4X objective, 4 second exposure, 1601 images rotated at 360º, source 80 kV and 7 W, 6.5 µm pixel size)

X-ray Phase Contrast Imaging @ DCS

The interaction of shock waves in 3D printed structures were characterized using spatially resolved ns – resolution x-ray imaging techniques coupled to a dynamic loading platform.

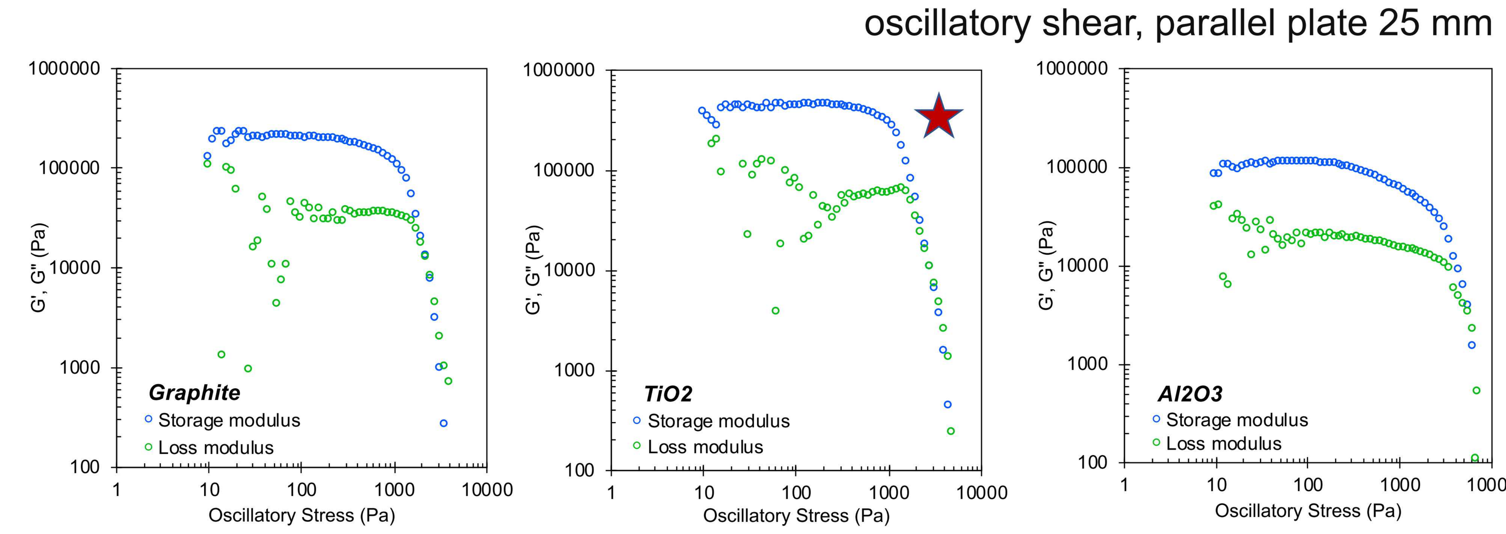


The Dynamic Compression Sector is operated by Washington State University under the U.S. Department of Energy (DOE)/National Nuclear Security Administration award no. DE-NA0002442. This research used resources of the Advanced Photon Source, a DOE Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under contract no. DE-AC02-06CH11357.

Results

Ink Rheology

oscillatory shear, parallel plate 25 mm

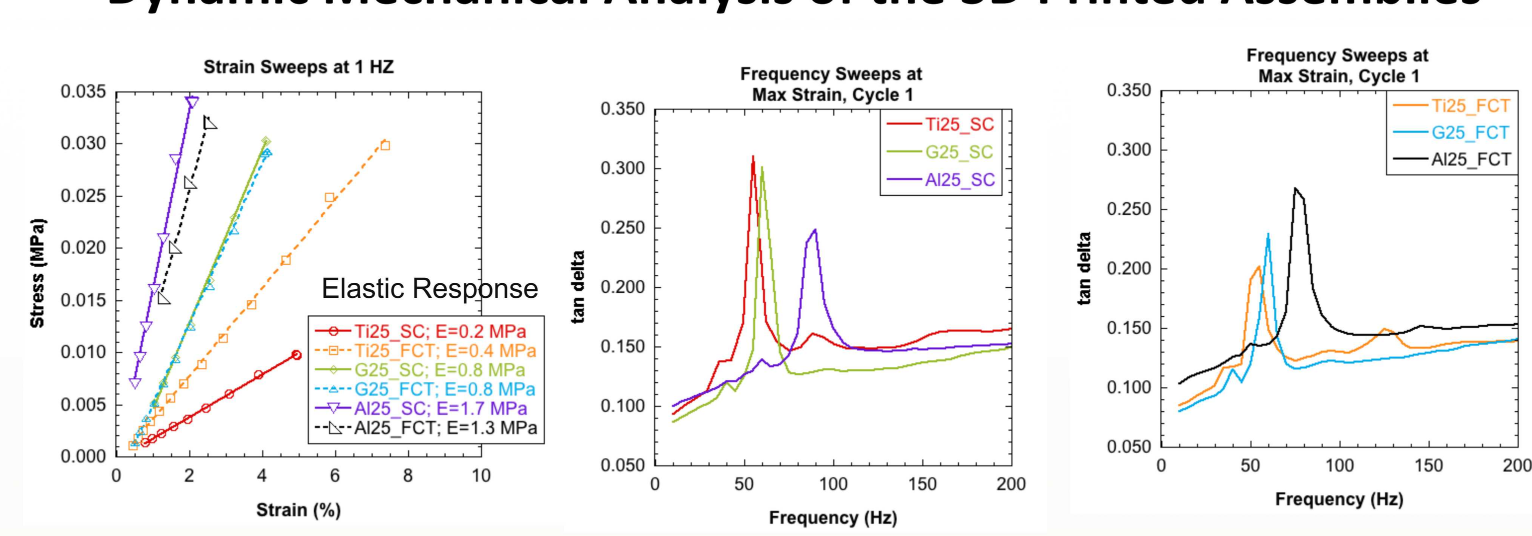


25% Graphite	
A300	**10 wt.%**
OX-50	**0 wt.%**
TiO2	**25 wt.%**
Yield Stress	2240 Pa
Print Pressure	?
Print Speed	?

25% Titanium Dioxide	
A300	**5 wt.%**
OX-50	**5 wt.%**
TiO2	**25 wt.%**
Yield Stress	2825 Pa
Print Pressure	100 psi
Print Speed	2300

25% Aluminum Oxide	
A300	**2 wt.%**
OX-50	**8 wt.%**
Al2O3	**25 wt.%**
Yield Stress	5674 Pa
Print Pressure	100 psi
Print Speed	2500

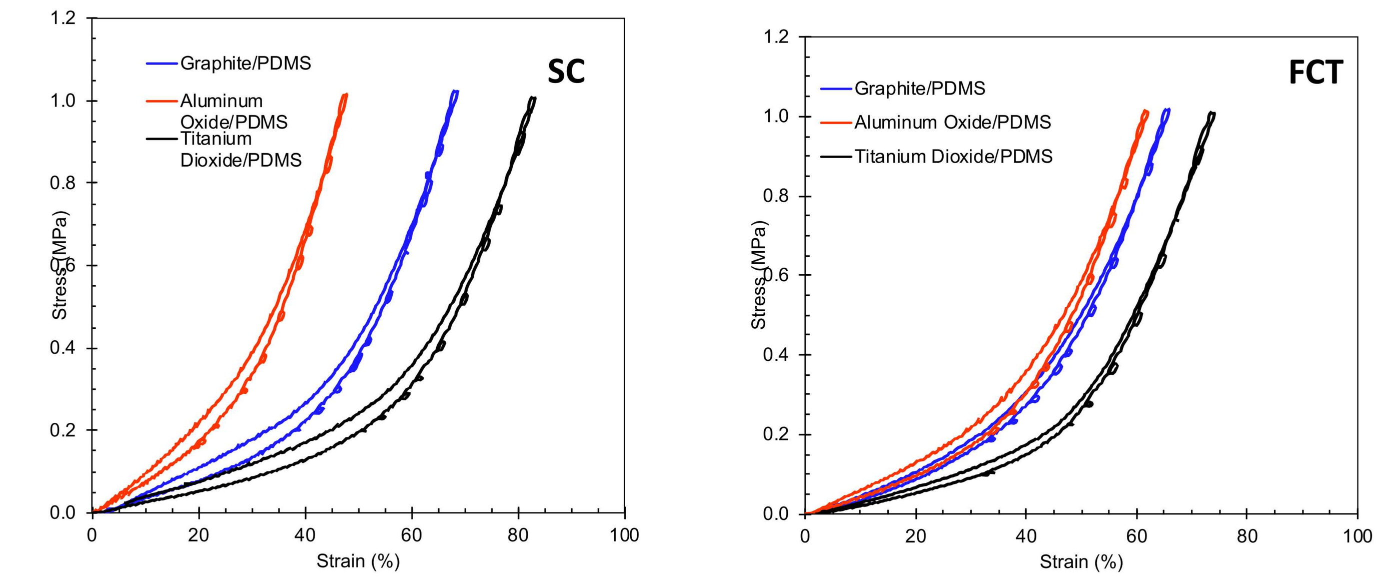
Dynamic Mechanical Analysis of the 3D Printed Assemblies



Sample (25 wt. % Filler)	Peak in Frequency Sweep (Hz)	Young's Modulus from Strain Sweep (MPa)
Al_2O_3-SC	85-90	1.7
Al_2O_3-FCT	75-80	1.3
Graphite-SC	60-65	0.8
Graphite-FCT	55-60	0.8
TiO_2-SC	55	0.2
TiO_2-FCT	50-55	0.4

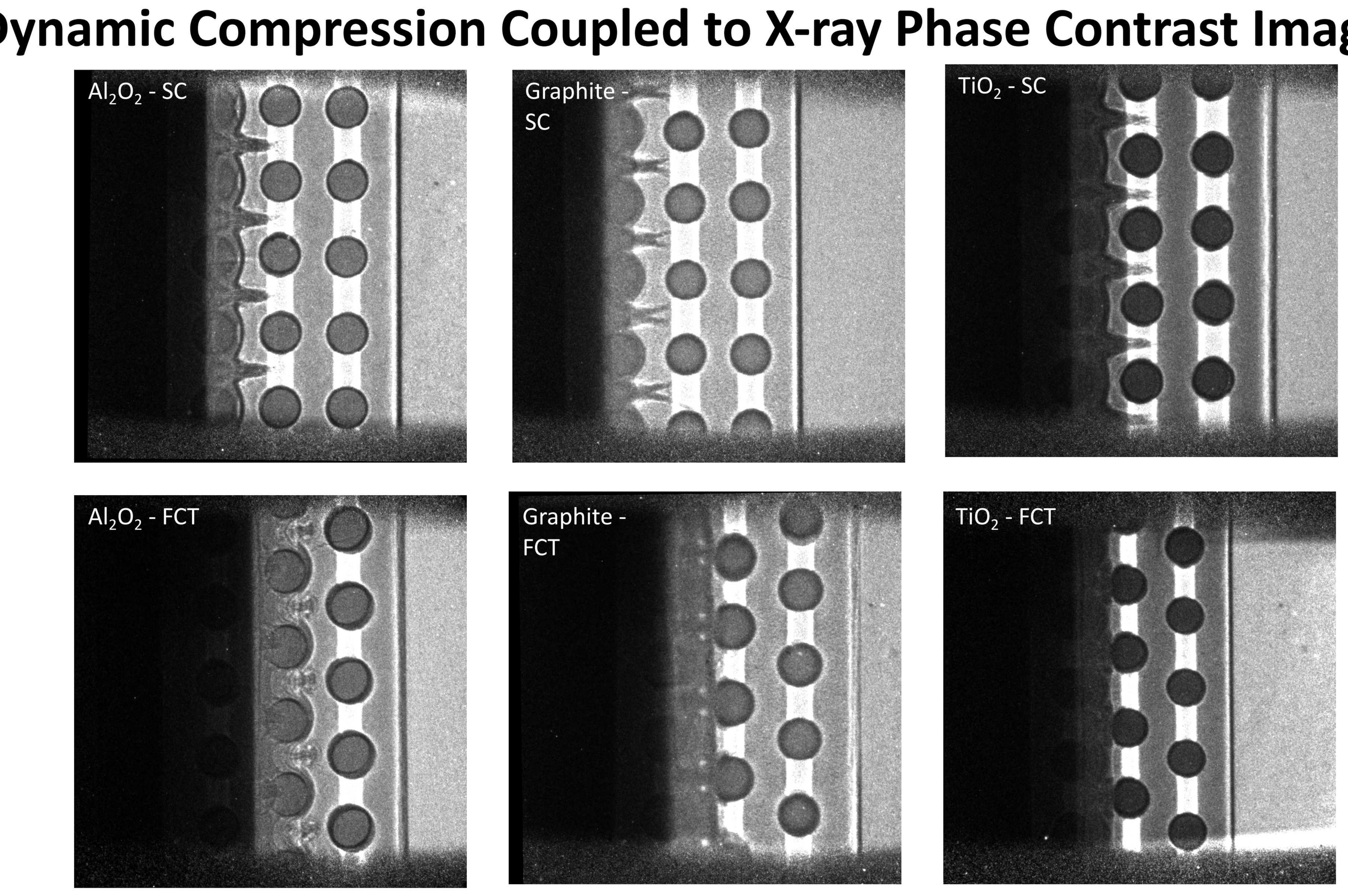
Results

Compressive Mechanical Testing of the 3D Printed Assemblies



- 25 wt. % TiO_2 Filled PDMS SC micro-lattice shows higher compressive strain versus the Al_2O_3 Filled PDMS lattice exhibiting a stiffer polymer matrix.

Dynamic Compression Coupled to X-ray Phase Contrast Imaging



Shot	Filler (25 wt.%)	Lattice Structure	ρ_0 (g/cc)	Sample Thickness (mm)	Projectile Velocity u_0 (mm/µs)	Particle Velocity u_p (mm/µs)	Shock Velocity U_s (mm/µs)	Jet Velocity U_s (mm/µs)
19-2-020	Graphite	SC	0.575±0.001	1.544±0.001	0.699±0.001	0.381±0.047	0.684±0.035	1.892±0.025
19-2-021	Al_2O_3	SC	0.597±0.001	1.541±0.001	0.705±0.001	0.454±0.032	0.782±0.024	1.839±0.005
19-2-022	TiO_2	SC	0.615±0.001	1.632±0.001	0.712±0.001	0.432±0.021	0.697±0.023	2.029±0.011
19-2-023	Al_2O_3	FCT	0.674±0.001	1.547±0.001	0.707±0.001	0.465±0.021	0.803±0.016	-
19-2-024	Graphite	FCT	0.633±0.001	1.553±0.001	0.710±0.001	0.366±0.014	0.704±0.020	-
19-2-025	TiO_2	FCT	0.568±0.003	1.378±0.011	0.705±0.001	0.414±0.020	0.670±0.037	-

Conclusions & Future Directions

- Shock front couples to the SC structure resulting in jet consolidation, the jet velocity is dependent on the filler type and correspond to the mechanical behavior of the ink and the 3D printed assemblies.
- Shockwave propagation is dependent on the filament inclusions. Al_2O_3 wt. % PDMS is less ductile making the polymer matrix more stiff, in turn accelerating the shockwave propagation versus the more ductile materials Graphite and TiO_2 causing a lag in the shockwave.

➢ Future work will combine topological optimization along with high resolution printing to realize a new class of structures tailored for shock dissipation and waveshaping, which will establish a new class of AM materials for dynamic applications.

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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