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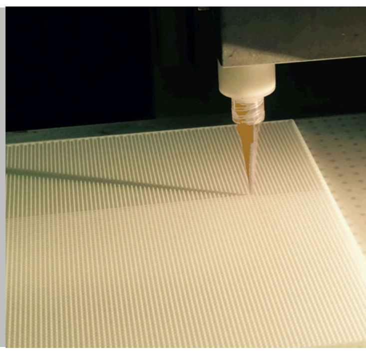

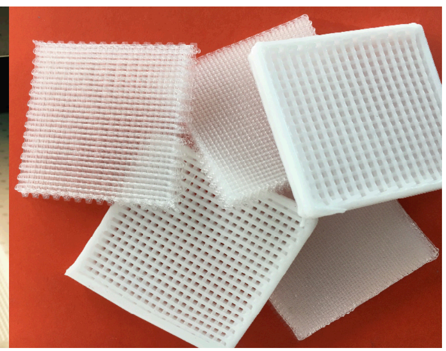

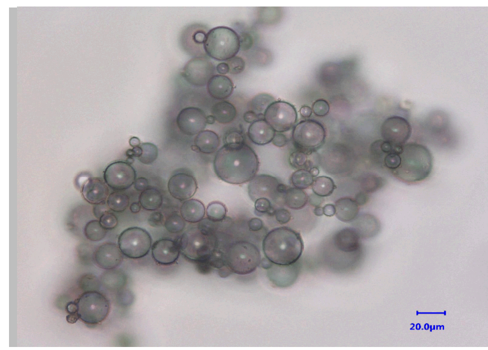

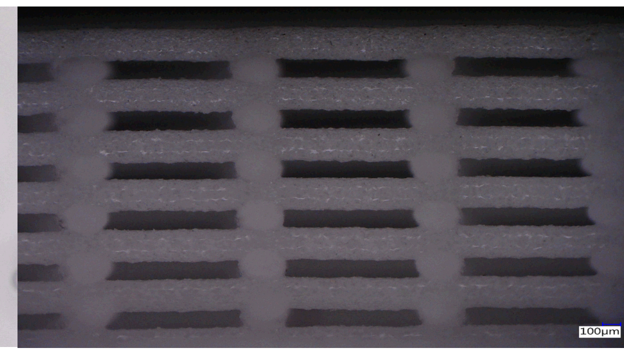

Characterization of 3D Printed Elastomeric Materials

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

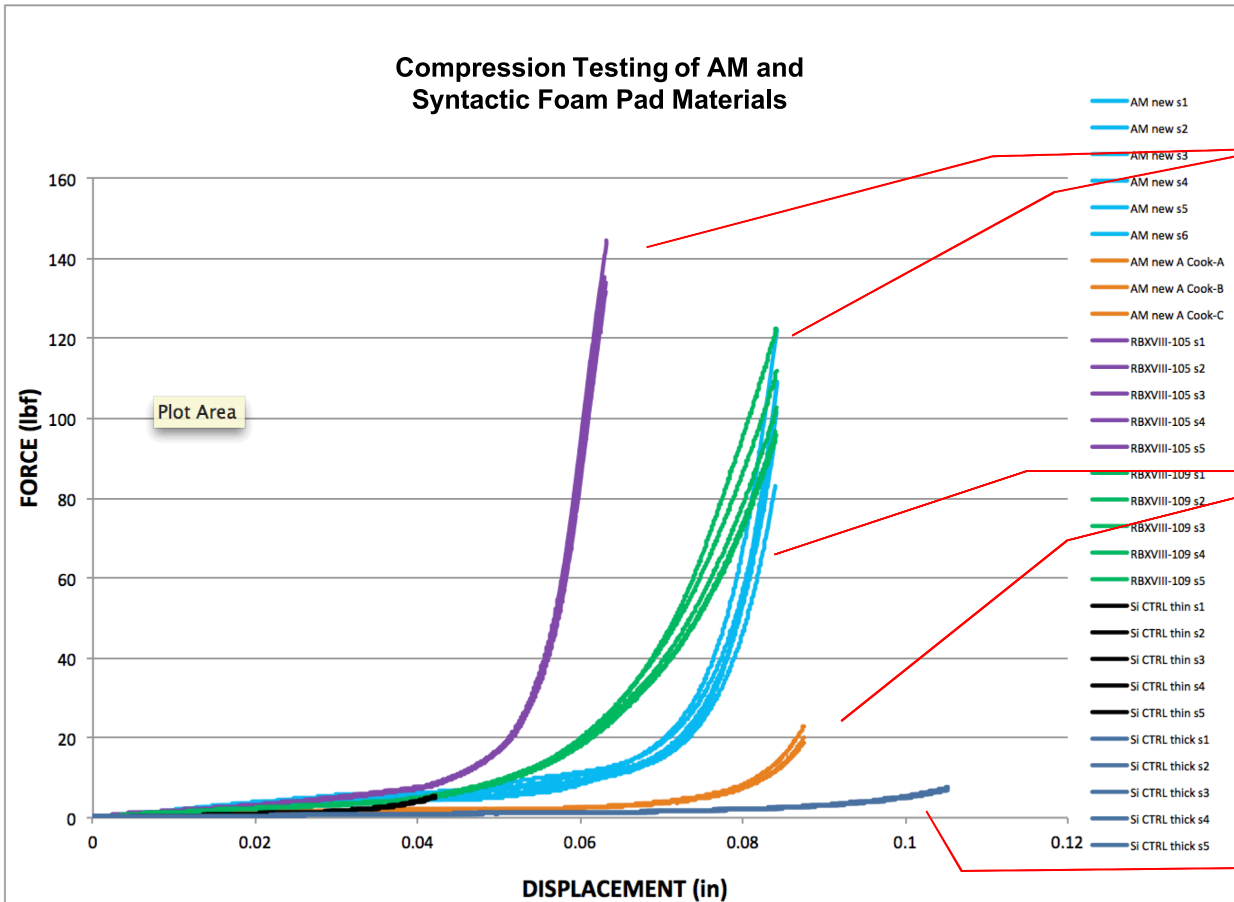
1) Direct Write design and architecture
   A. Processes
   B. Lattice structures
   C. Fillers

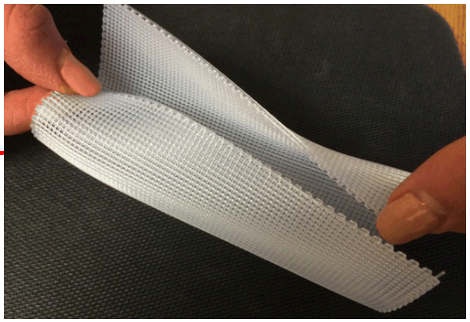
2) Outgassing investigations
   A. Bulk material
   B. GMB outgassing

3) Sub-ambient thermal studies
   A. Thermal transition
   B. CTE observations
   C. Force changes

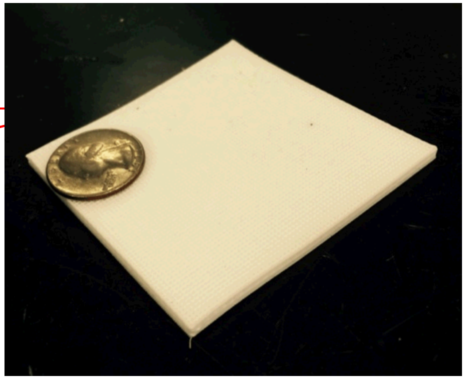
Background

Driven by a desire to replace legacy materials used in systems and a willingness to evaluate manufacturing alternatives, Direct Write processes are being used for the research, development, and fabrication of compression pads and cushions to ultimately replace conventionally manufactured syntactic foams.





3D Printed Silicone (unmodified Gen 1)

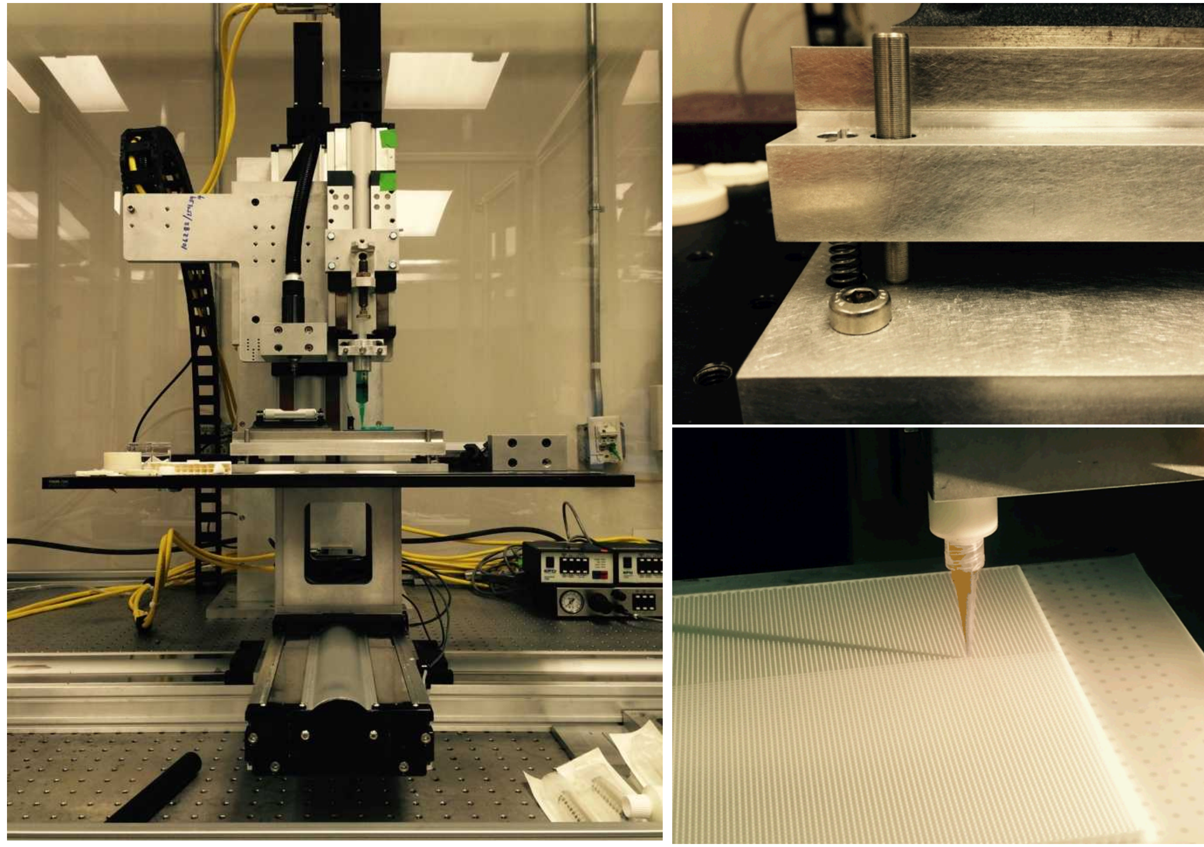


3D Printed Silicone (modified)

LEGACY MATERIAL (syntactic foam)

Direct Write Additive Manufacturing

CAD/CAM interfaces are used to generate solid models and additive manufacturing specific tool-paths for 3D printing of a broad range of materials

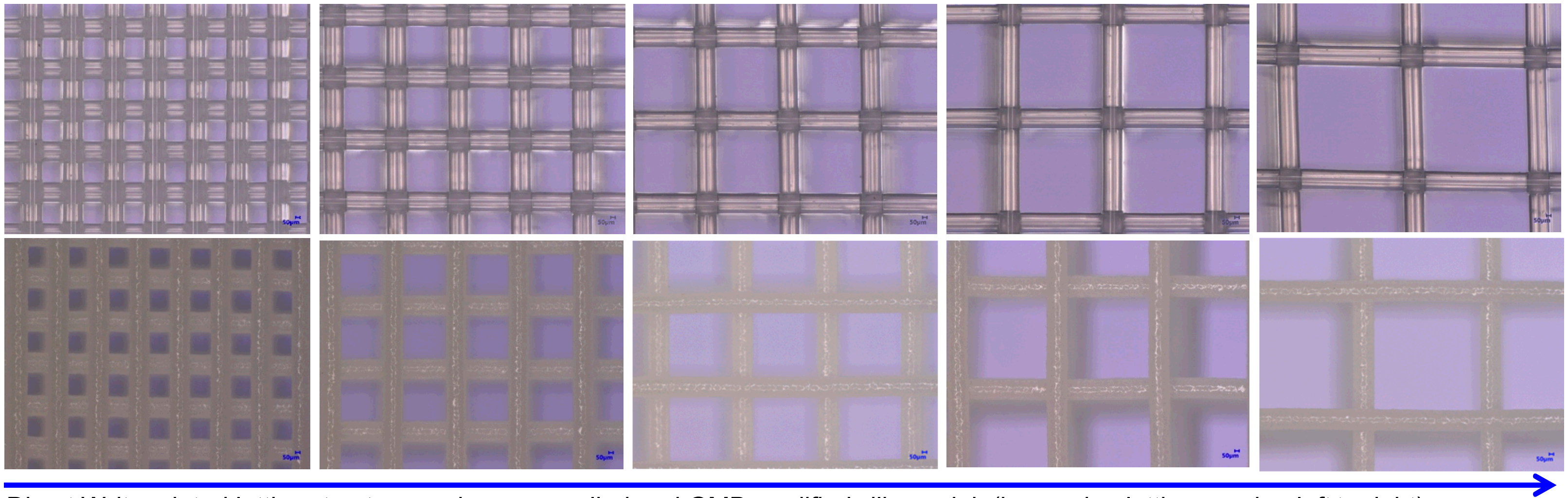


Custom robotic deposition platform for wide area printing of components (max envelope 1 m x .5 m x .5 m)

Surface mapping capability

Precision motion control, positioning hardware, and surface mapping tools enable flawless 3D deposition of consumer grade materials as well as novel research inks

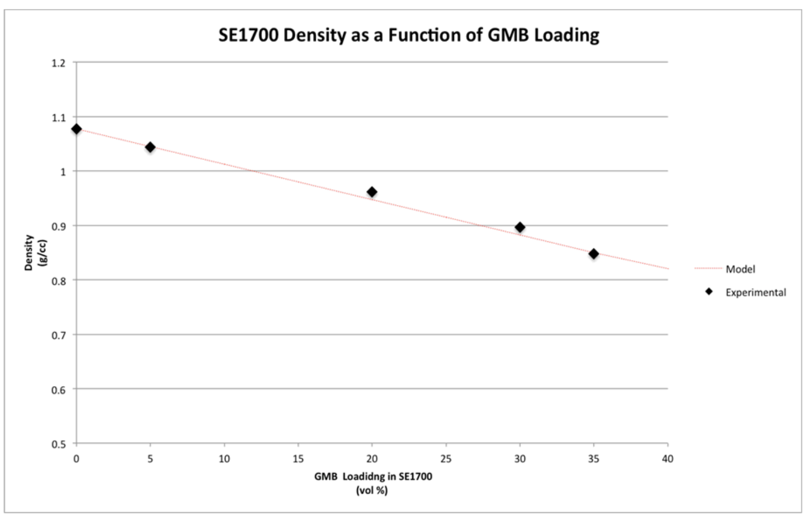
Multiple Routes of Establishing a Tunable Mechanical Response



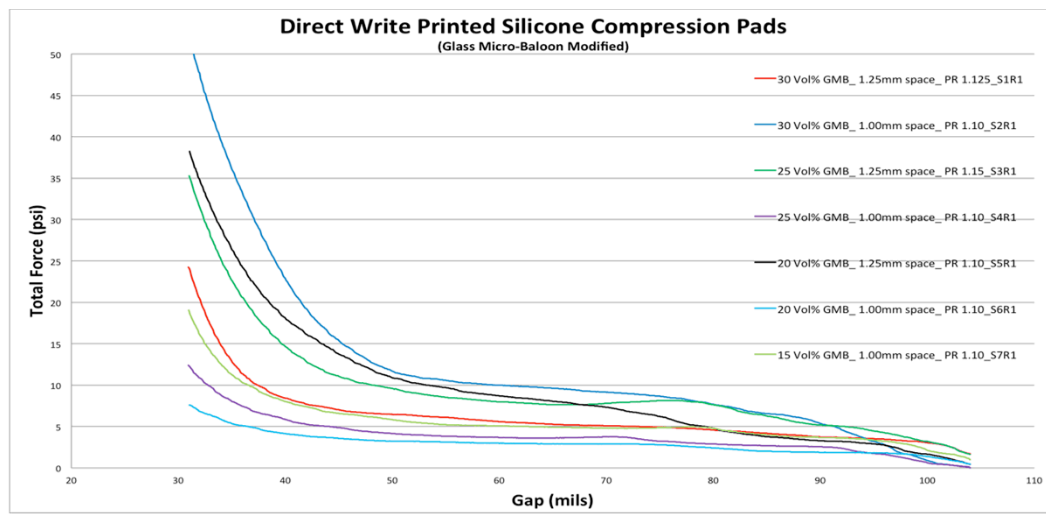
NO GMB

GMB

Direct Write printed lattice structures using as supplied and GMB modified silicone ink (increasing lattice spacing left to right)



SE1700 density as a function of GMB Loading



Printed compression pad mechanical response as a function of lattice parameters

Addressing Material Compatibility Concerns

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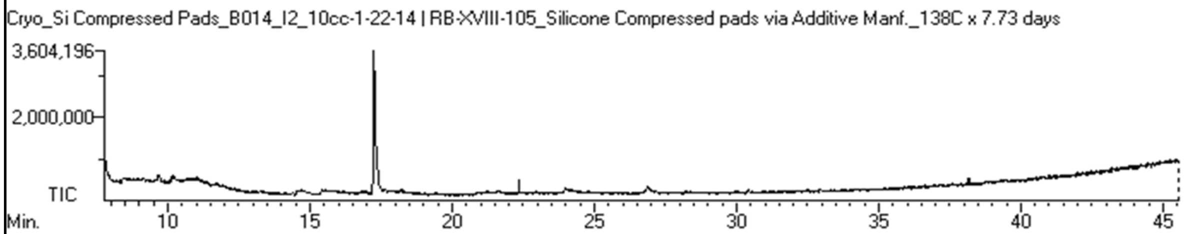
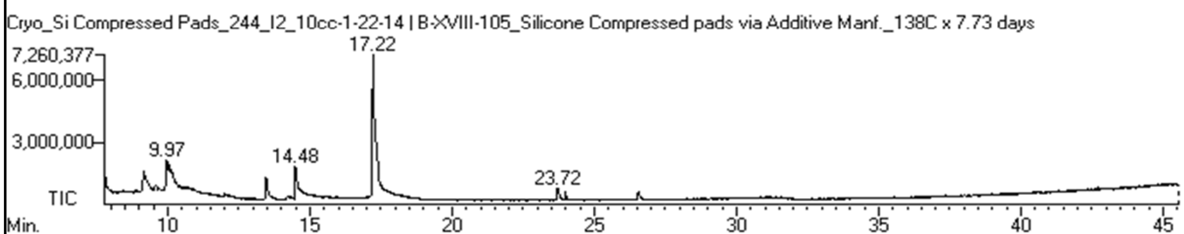
Initial outgassing studies do not reveal the evolution of harmful species form the commercially sourced silicone ink (SE1700) used for 3D printing pads and cushions



RT

17.2: Disiloxane, Hexamethyl

26.7: Trisiloxane, octamethyl-



RT

9.14: Acetaldehyde

9.9: Methanol

13.4: Silane, methoxytrimethyl

17.2: Disiloxane, hexamethyl

14.4: Silanol, trimethyl-

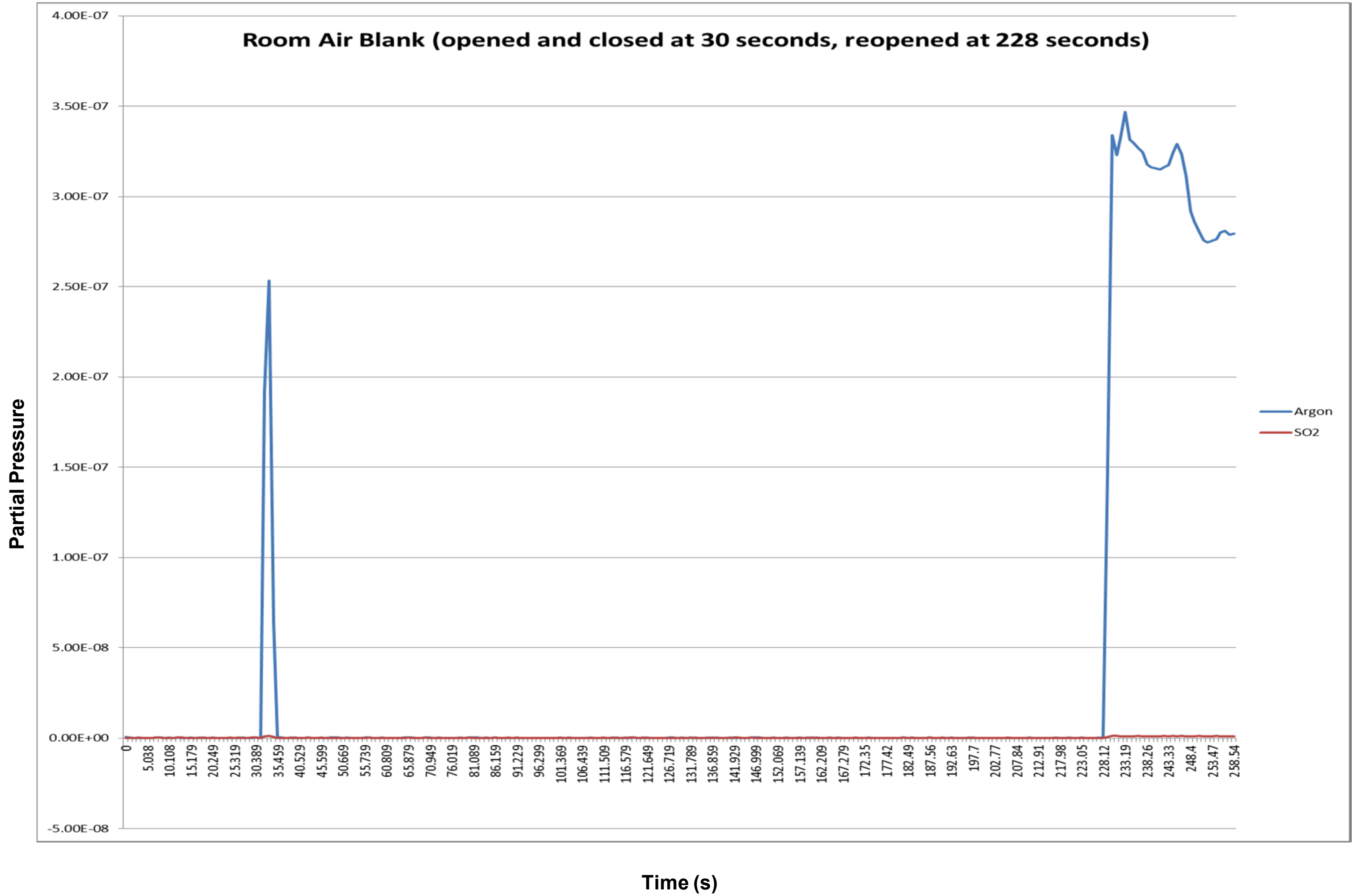
23.6: Cyclotrisiloxane, hexamethyl

26.5: Trisiloxane, octamethyl

Cryo-GCMS used to characterize aged SE1700 to evaluate volatile outgassing species

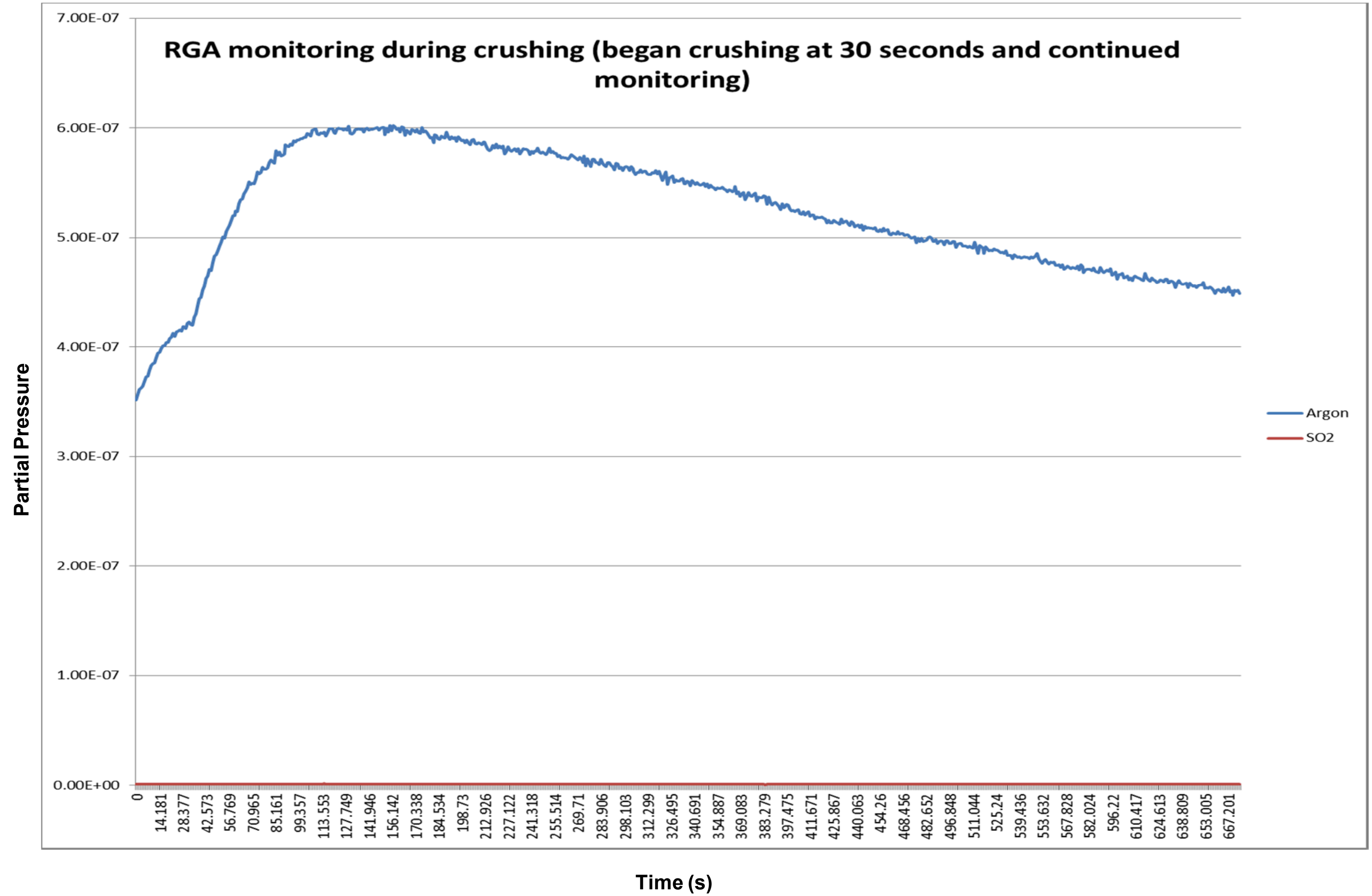
Addressing Material Compatibility Concerns

SO_2 is an expected by-product of GMB fabrication process, RGA is being used to investigate this concern



Addressing Material Compatibility Concerns

Residual Gas Analysis lack of detection of any significant SO_2



Potential Thermal Constraints

"For most uses, silicone elastomers should be **operational over a temperature range of -45 to 200°C (- 49 to 392°F**) for long periods of time. However, at both the low- and high temperature ends of the spectrum, behavior of the materials and performance in particular applications can become more complex and require additional considerations. **For low-temperature performance, thermal cycling to conditions such as -55°C (-67°F) may be possible**, but performance should be verified for your parts or assemblies."

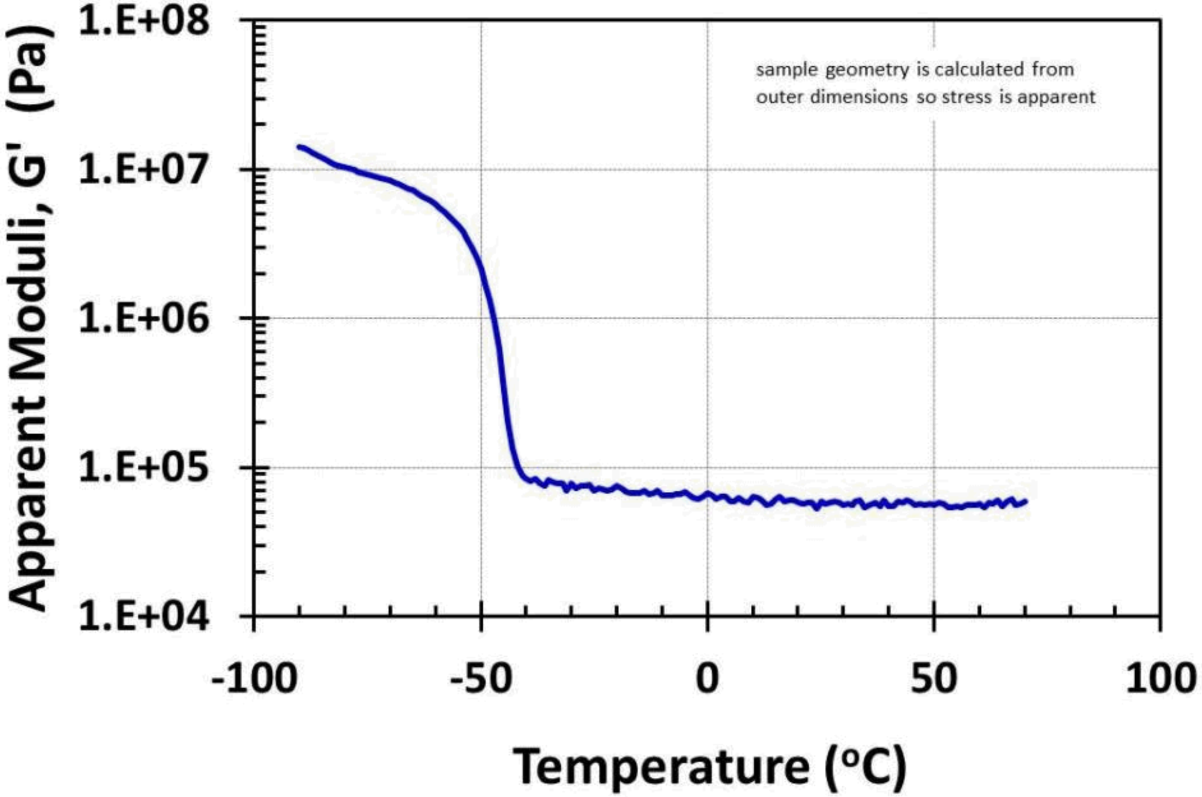
Based on SNL DMA data, there is a low temperature thermal transition ~ -40 °C (vide infra)

It is known that there is a low temperature thermal transition of the SE1700 material.

Question: How does this transition influence the performance of the SE1700 when functioning as a compression pad?

Product Information, Adhesives, SE 1700 Clear & White Adhesive; Corning, D., Ed.; Dow Corning, 2010

Dynamic Mechanical Analysis
(1st Generation AM pad 2014)



Modulus (apparent) vs. temperature. There is large change in modulus at ~-55C.

Dynamic Mechanical Analysis (2014 - 2016 SNL and NSC Pads)

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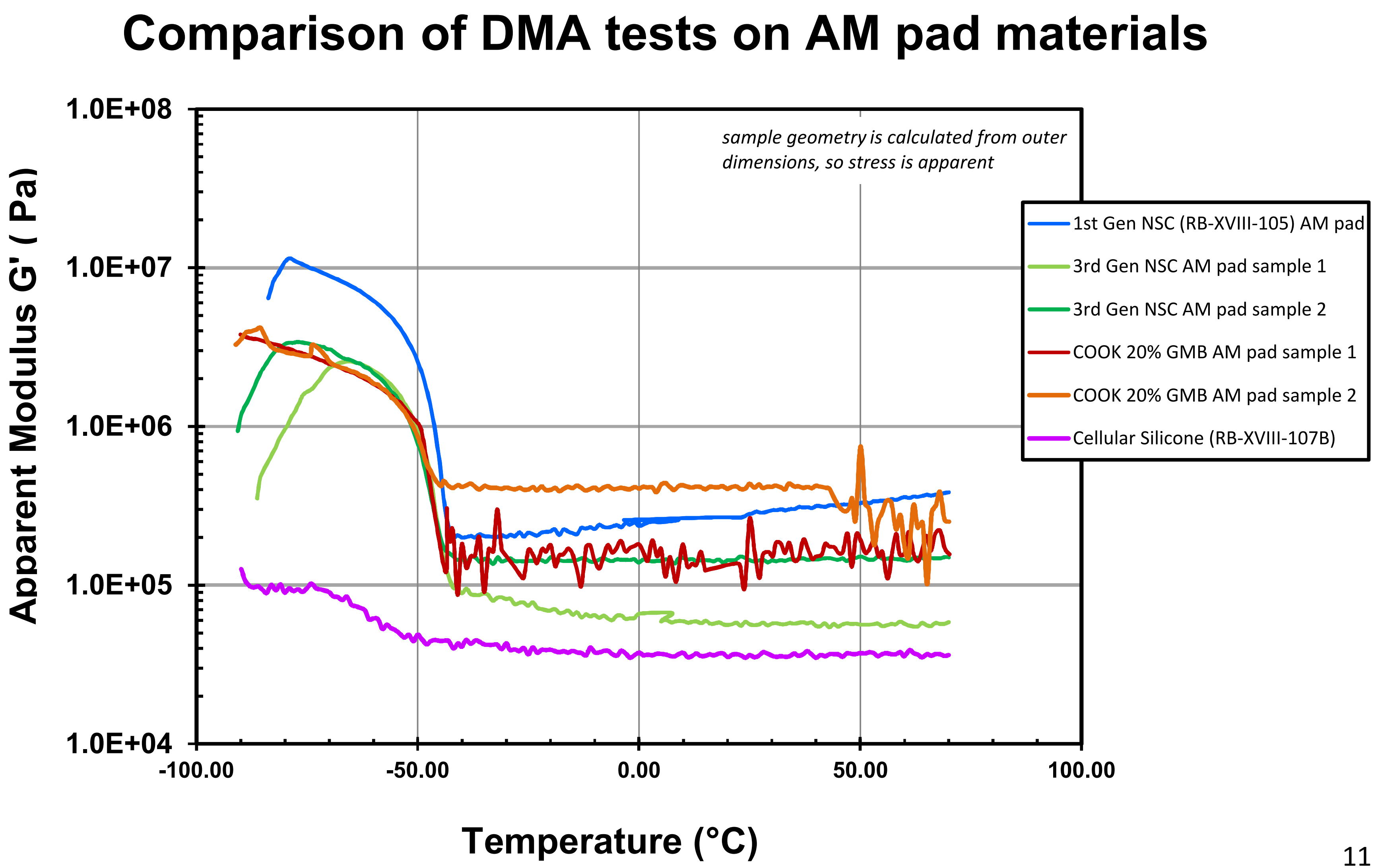
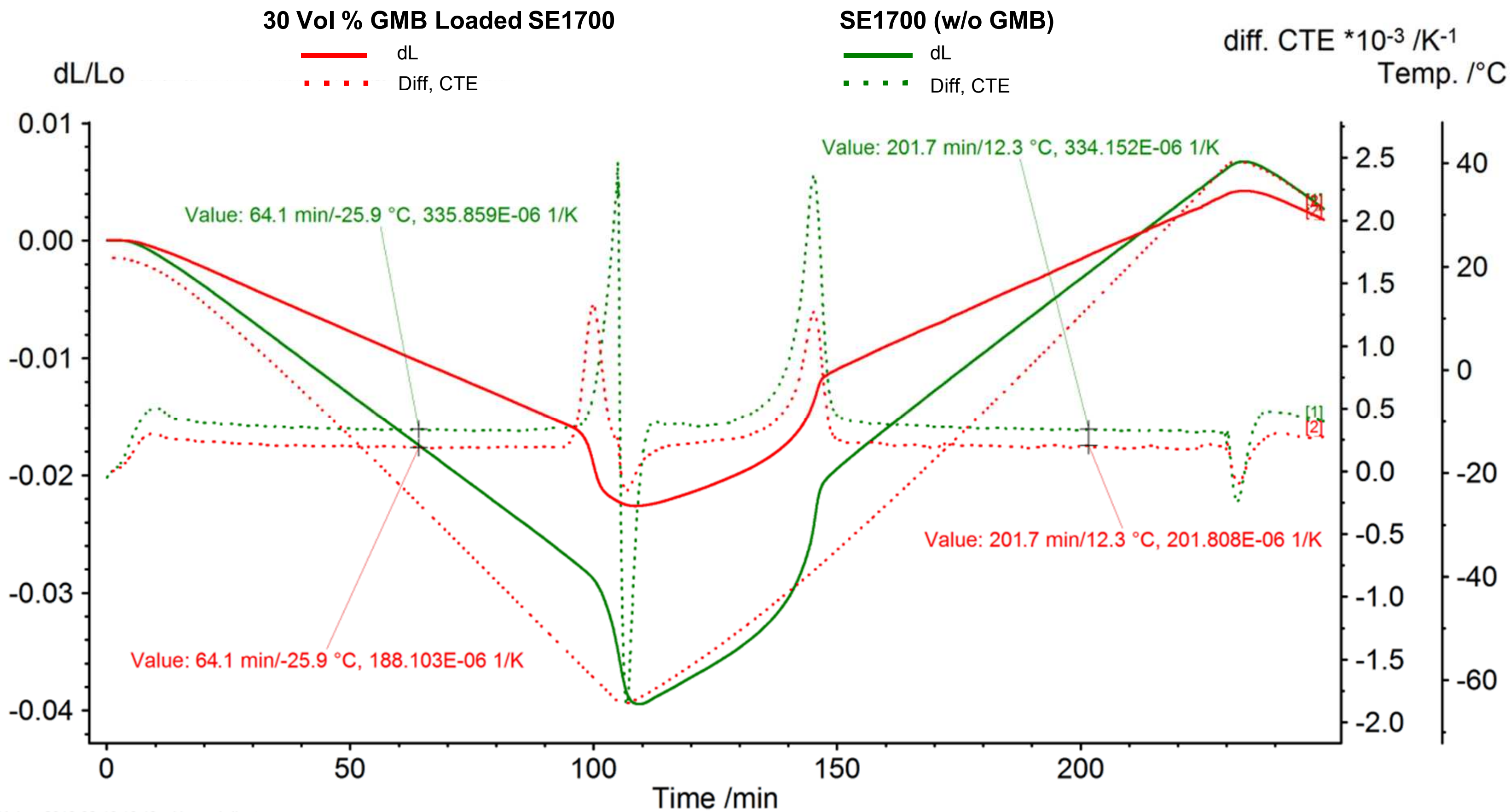


CTE Properties of Printable Silicone Materials

Adding GMBs to SE1700 significantly impacts CTE properties



Project :	Test Runs	**Sample1 :**	Unloaded silicone, 3.736 mm	**Segments :**	3	**Std calib. material :**	Al2O3
Date/time :	2/12/2016 6:47:16 AM	**Sample2 :**	Silicone 30%, 3.548 mm	**Mode/type of meas. :**	Standard Expansion/sample with correction	**M. range(s1) :**	20000 µm
Laboratory :	SNL	**Material1 :**	Silicone	**Sample holder table :**	Fused_si.scl	**M. range(s2) :**	20000 µm
Operator :	TC	**Material2 :**	Silicone	**Sample holder material :**	FUSED SILICA		
Sample1 identity :	Silicone 0%-2	**Atmosphere :**	N2/O2 / N2/O2	**Calibration file :**	AluminaStandard-80C to 45C_1CMinHouseAir-3.ngb-cla		
Sample2 identity :	Silicone 30%-2	**Temp. calib. file :**	TCALZERO.TMX	**Std calib. table :**	Al2o3ne.scl		

[#] Type	Range	Acq.Rate	STC	Co	P2:N2/O2	PG:N2/O2	LN2	GN2	Corr.
[1] 3 x Dynamic	-80°C....45°C/-1.0....1.0K/min	25.00	0	0	50.0	50.0	Off	1.0	dL:080, diff. CTE:8
[2] 3 x Dynamic	-80°C....45°C/-1.0....1.0K/min	25.00	0	0	50.0	50.0	Off	1.0	dL:080, diff. CTE:8

Created with NETZSCH Proteus software

Thermo-Mechanical Characterization of Compression Pads at Sub-ambient Temperatures

Materials Examined

- SNL: 20 Vol% GMB pad (~103 mils)
- NSC: 3rd Gen SE1700 AM Pad (~103 mils)
- Cellular Silicone: (~146 mils) (RB-XVIII-107B)

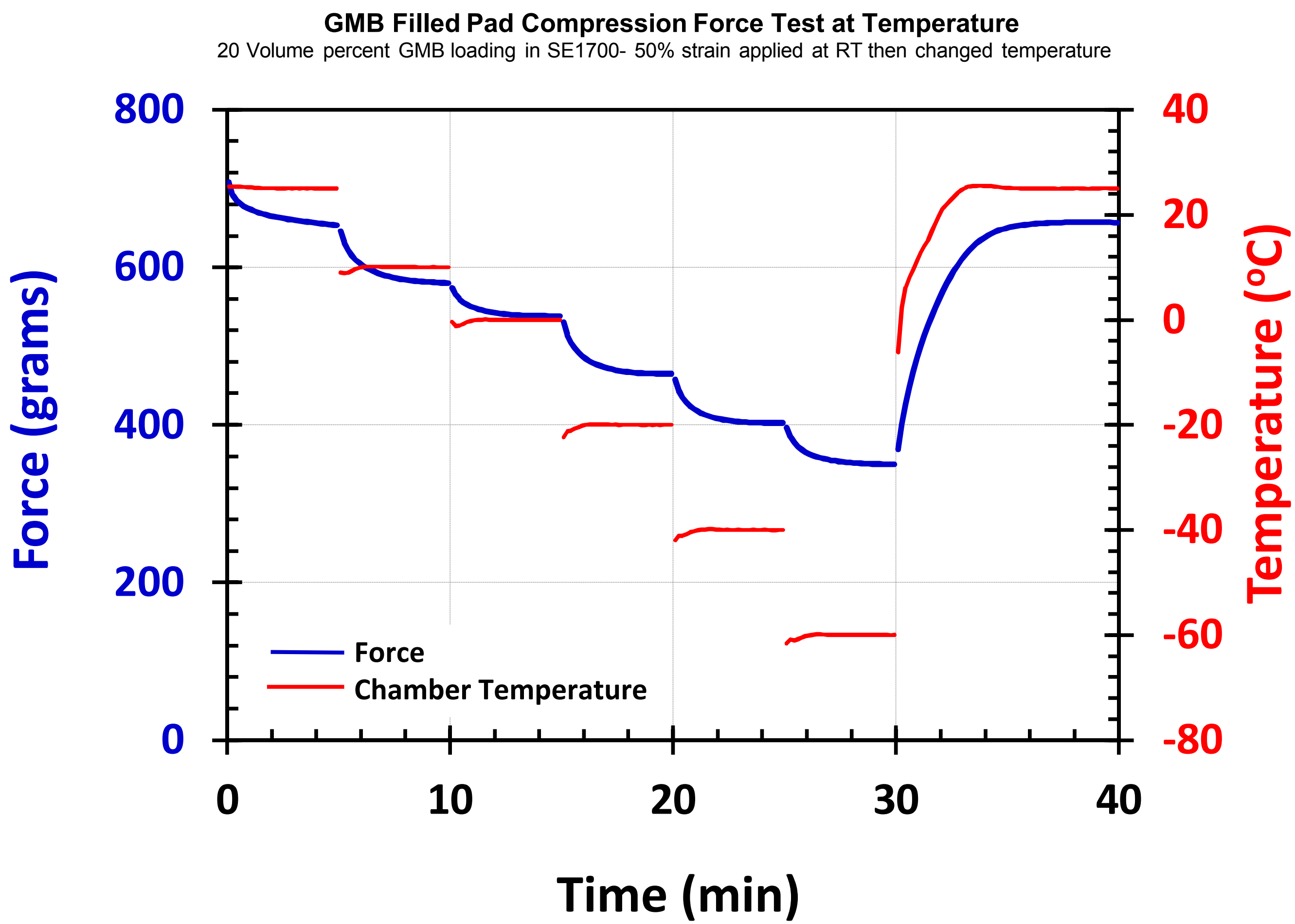
Test Methodology

- Samples compressed to nominally 25% and 50% at room temperature
- Gap size held constant* and force measured as a function of temperature

Experimental Details: TA Instruments DMA RSA-G2, hold times for 300 seconds per temperature, fixed gap size, 0.75 inch diameter samples.

*It did change because of fixturing CTE. This is on the order of 2.6um/C, so only ~260um for -60C in the direction that would decrease the force (make gap larger).

Thermo-Mechanical Characterization of GMB Filled Pads at 50% Compression



Thermo-Mechanical Characterization (dF/dT)

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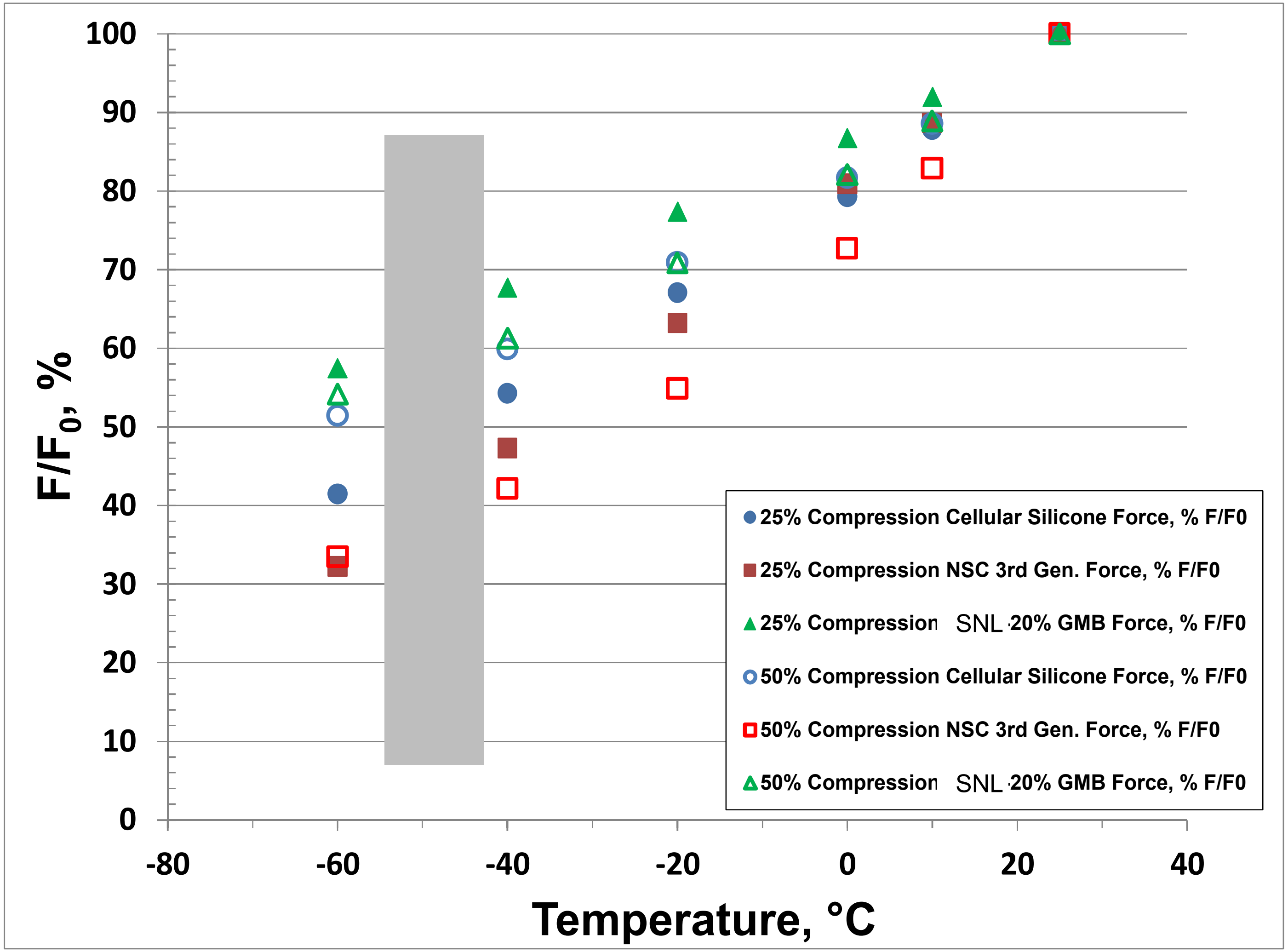
Loading silicone inks with GMBs helps maintain an applied force at sub-ambient temperatures



Conclusions

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- Precision deposition platforms enable 3D printing at high resolution
- Multiple routes to mechanical tunability
- Adding fillers such as GMB to silicone inks improve deposition qualities for AM printing of lattice structures, help manage CTE properties, and result in tailorable force responses
- Initial outgassing and aging studies do not indicate concerns for our application space
- Low temperature thermal transition for SE1700 has little to no influence on static performance
- CTE properties are likely the most influential cause for force change over our design space

Future Work

- Fully characterize lattice parameter space and printable geometries using silicone ink systems
- Develop robust component and process modeling capabilities
- Conduct additional CTE measurements on bulk materials and DW printed structures at elevated (above ambient) temperatures
- Correlate CTE to dynamic force changes
- Understand dynamic sealing
- Collectively expand applications beyond current focus
- Engineer SMART materials (thermal, electrical, mechanical)

Acknowledgements

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