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SAND2021-10813C

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ADDITIVE MANUFACTURING

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Additively Manufacturing a Glass-Bonded Ceramic at Sandia National Laboratories

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Presenter Biography

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Dale Cillessen, P.E.

A Senior Member of the Technical Staff in the Applied Science Technology Maturation Department at Sandia National Laboratories in Albuquerque, NM. Dale is the engineering operational lead of Sandia's metal and ceramic printing facility. His research focuses on developing accurate, repeatable, structurally sound advanced manufactured components.

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Agenda

- Who is Sandia National Laboratories
- Motivation
- Reducing Manufacturing Time
- SNL’s ceramic material compatibility with Lithoz DLP.
- Developing a Glass-Bonded Alumina Ceramic
- Material Characterization Study and Testing Methodology

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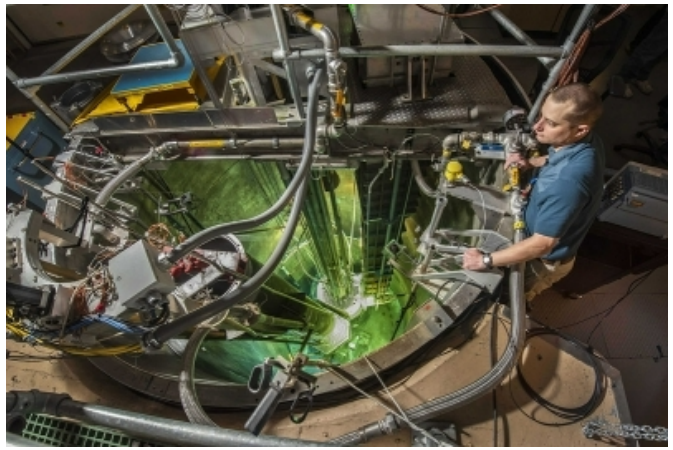
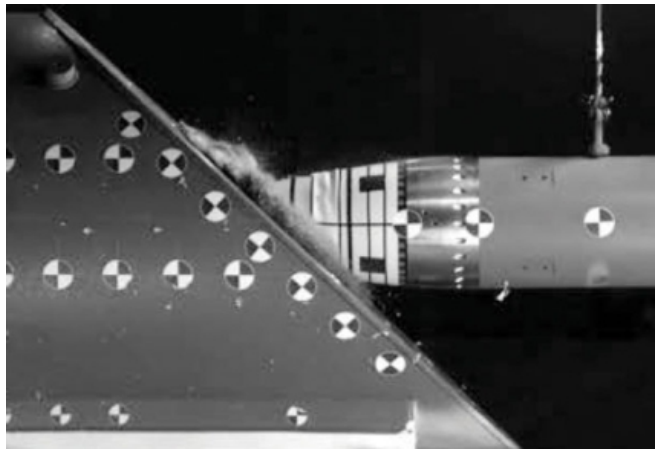
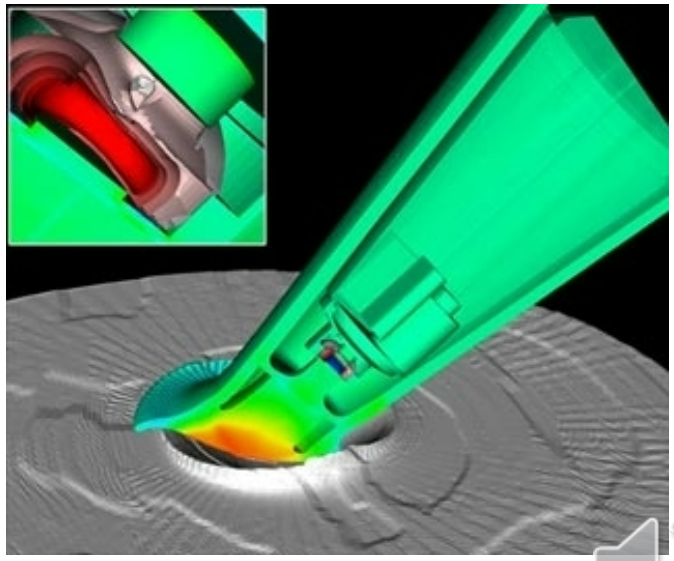
Who is Sandia National Laboratories

Sandia National Laboratories is one of the three National Nuclear Security Administrations research and development laboratories in the United States.

The primary mission is to develop, engineer and test the non-nuclear component of nuclear weapons.







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Motivation

At Sandia National Laboratories Advanced Manufacturing enables rapid product realization.

The pursuit for Advanced Manufacturing capabilities has pushed SNL to investigate internal developmental opportunities.

Ceramic Additive Manufacturing reduces development time, opens design opportunities, and provides rapid exploration of custom materials.

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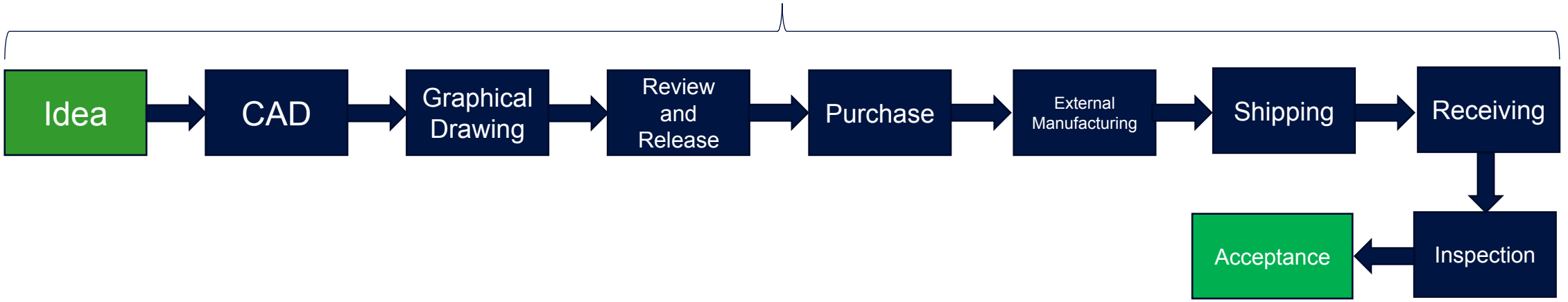
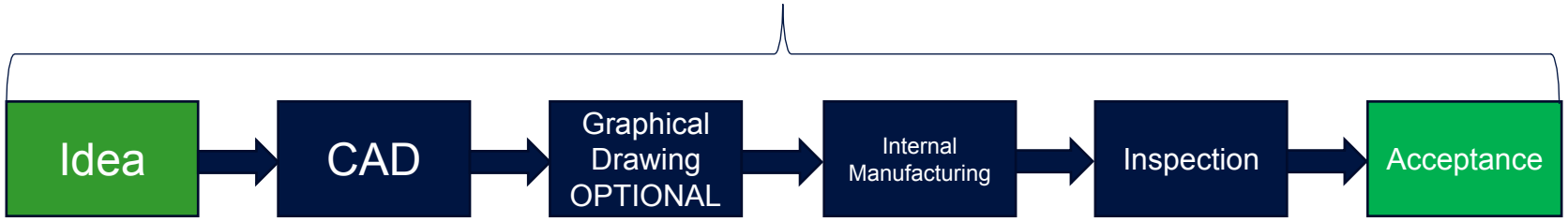
Reducing Requirements and Removing the Procurement Burden

Traditional Manufacturing Process at SNL
Expected duration 4 – 6 months!



Ceramic Additive Manufacturing Process Internal to SNL

Tested duration < 2 weeks!



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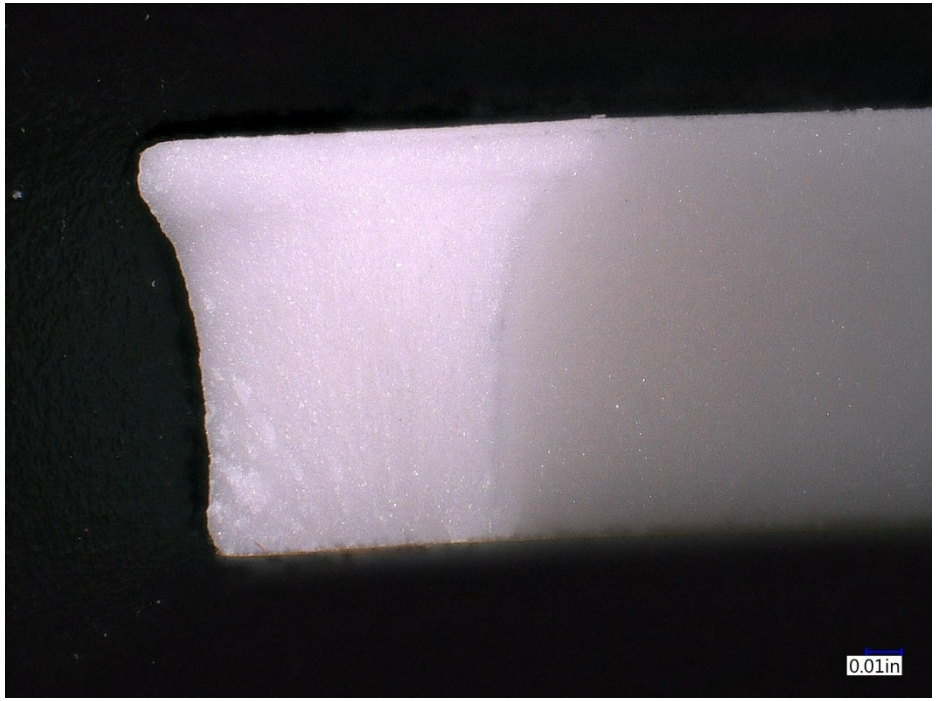
Developing and Characterizing a Glass-Bonded Alumina

In the mid 90's Sandia developed a Glass-Bonded Alumina ceramic. The glass-bonded material is 94% Al_2O_3, 1.5% MgO, 1.2% CaO, and 3% SiO_2 . The addition of Silica allows for processing at lower temperatures compared to pure Al_2O_3.

In 2018, Lithoz America successfully manufactured test components using SNL's base ceramic material combined with Lithoz photosensitive resin.



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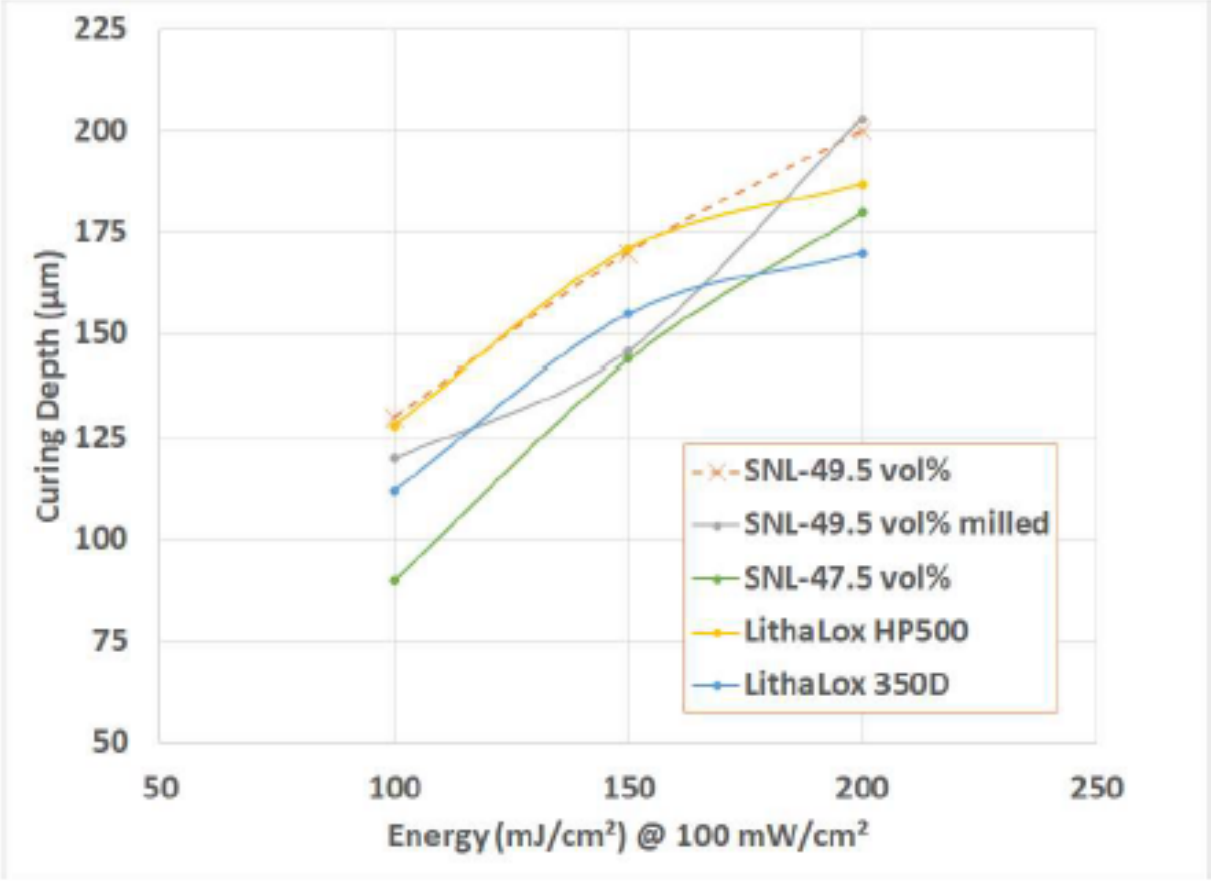
Testing for DLP compatibility

A curing depth study reviled SNL's glass-bonded alumina ceramic with Lithoz light sensitive resin was compatible.

The energy available in the Lithoz CeraFab printer exceeded the required amount for material solidification.



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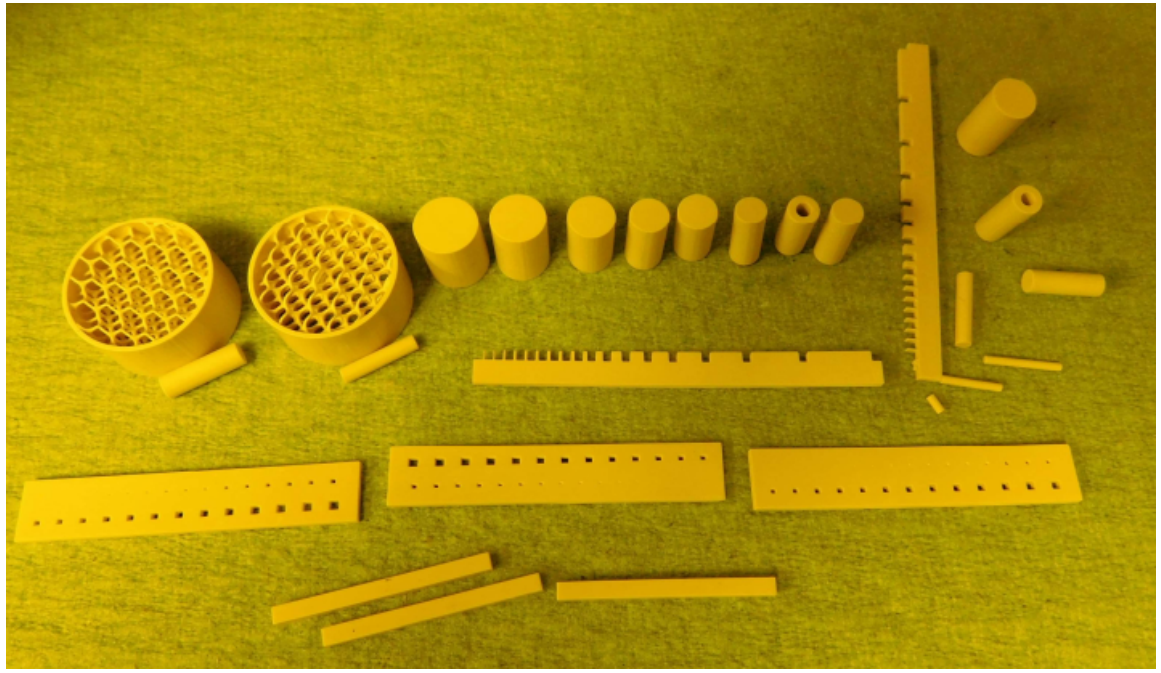
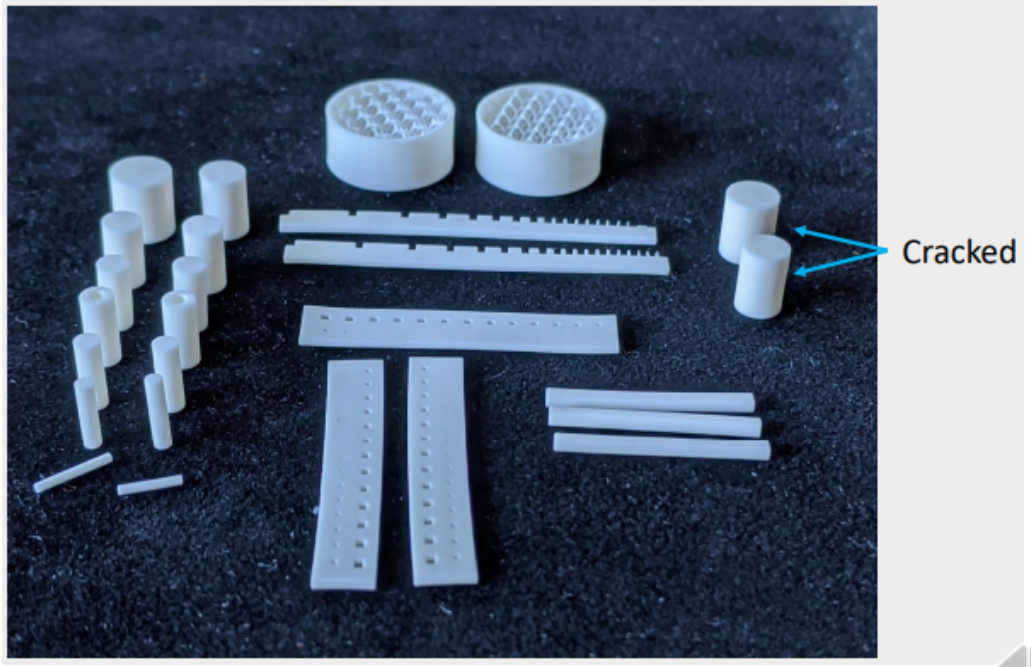
Test Geometries

As part of the material development, Lithoz America manufactured and sintered test samples for SNL evaluation.

Cleaned pre-thermal processing



Sintered



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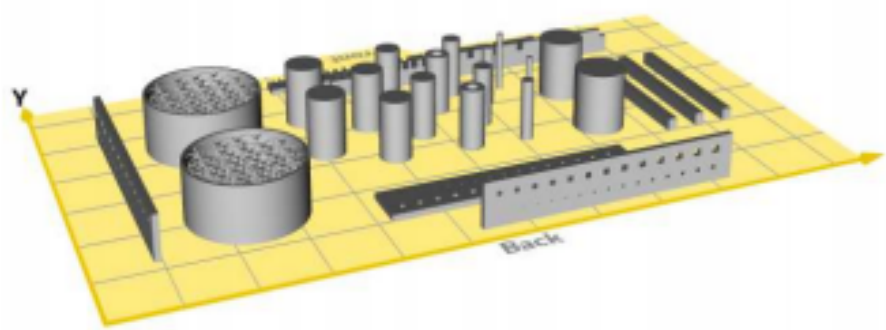
Lithoz America developed material processing recommendations



Parameter	Standard Value
Layer Thickness	25 µm
DLP energy	110 mJ/cm^2
Lateral (XY) Shrinkage	1.203
Vertical (Z) Shrinkage	1.353

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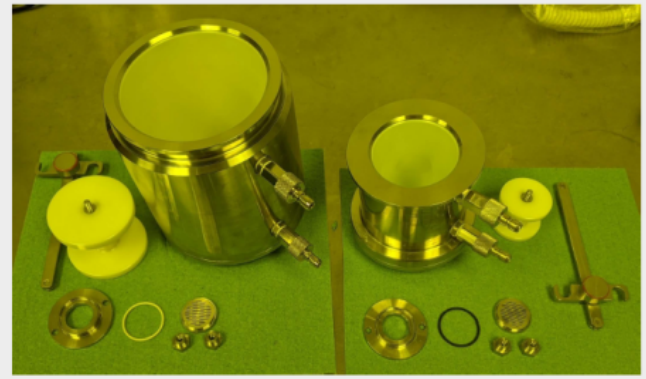
Scaling for Production

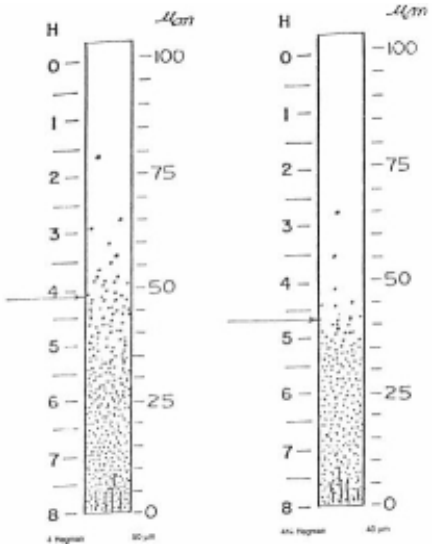
Lithoz America conducted a scaling evaluation.

Resulting in batch sizes of 1kg.

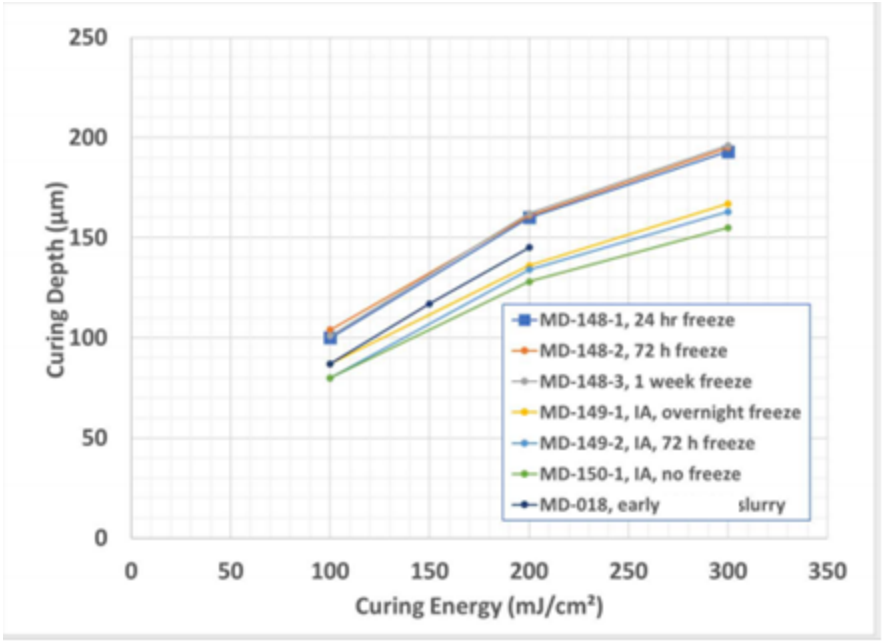
Timeline to develop a 1 kg batch < 2 weeks.

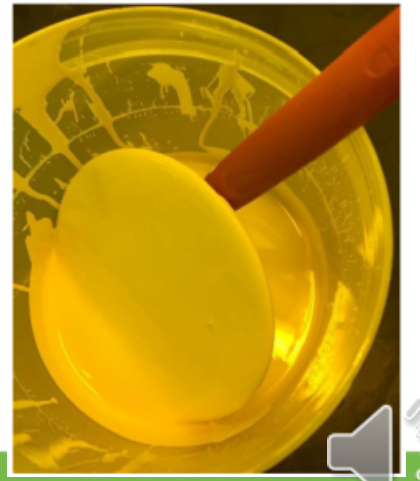
New mixing kit, 1000 mL compared with original 250 mL kit





Typical Fineness of Grind gage patterns (from ASTM D 1210-05)





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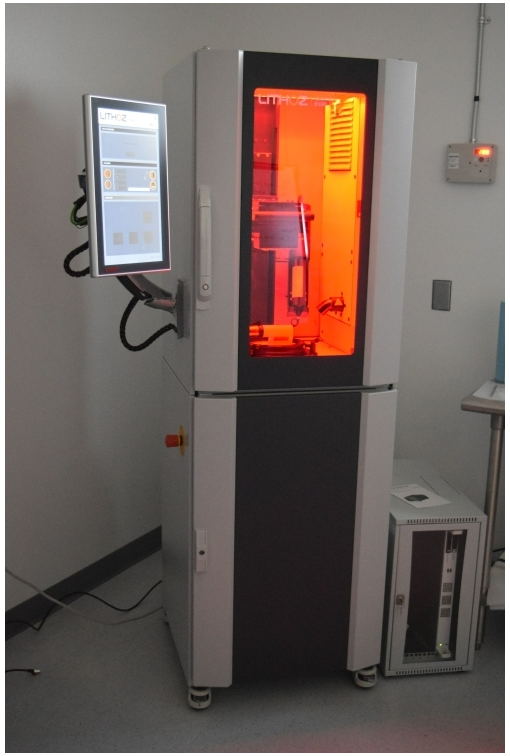
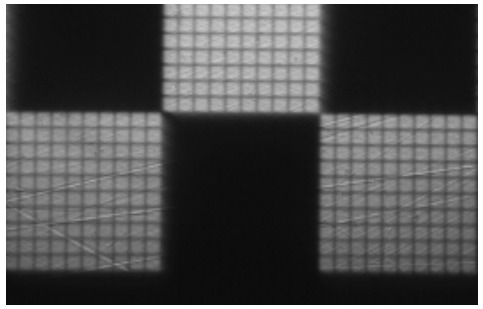
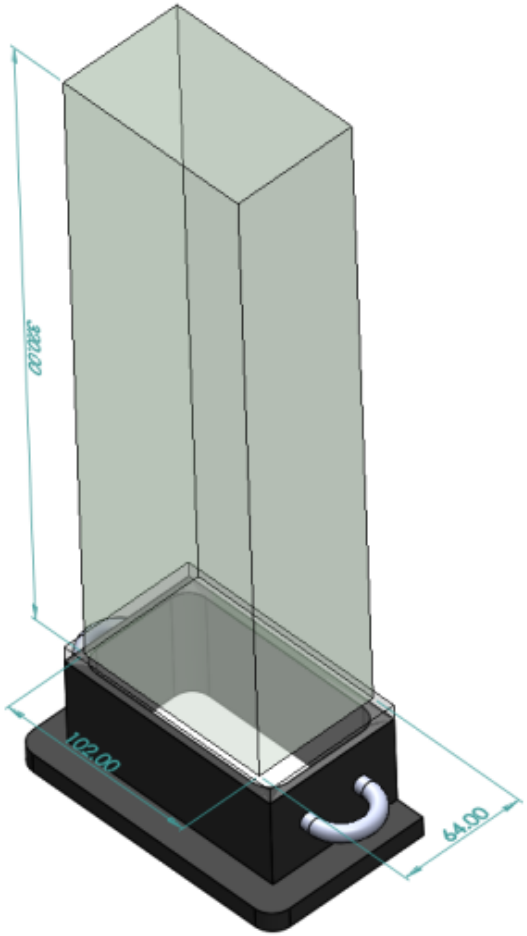
Sandia's CeraFab 8500





Resolution 40 micrometer X-Y, 10 micrometer (material dependent) Z



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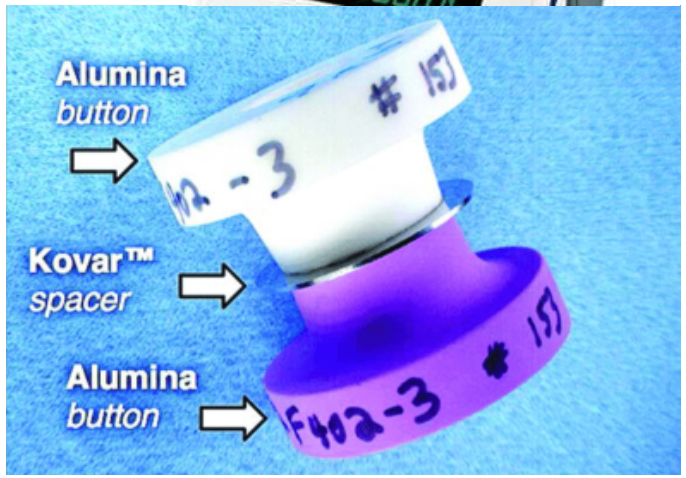
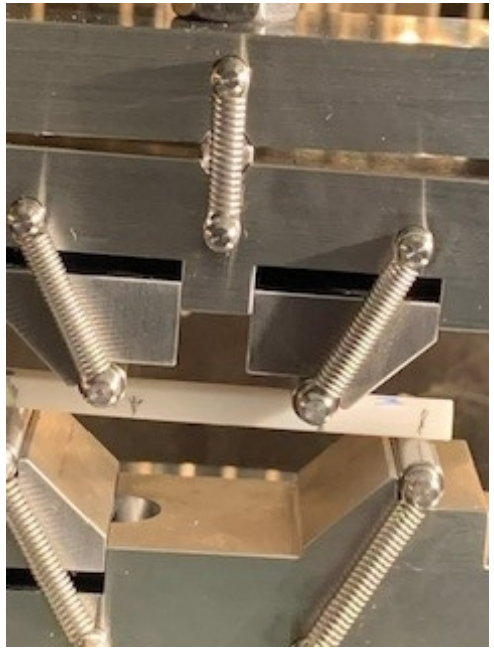
Material Characterization Study and Testing Methodology

- Tensile (flexural bend)
- Density
- Coefficient Thermal Expansion
- Hermetic Capability
- Porosity





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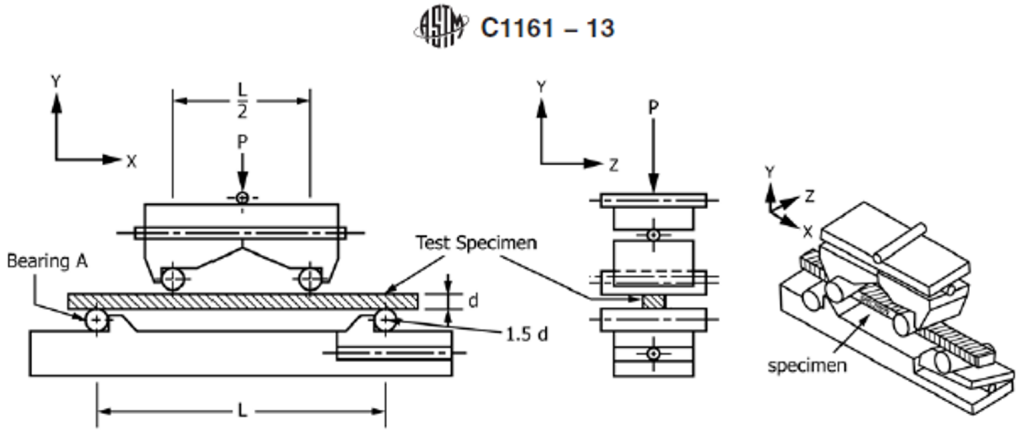
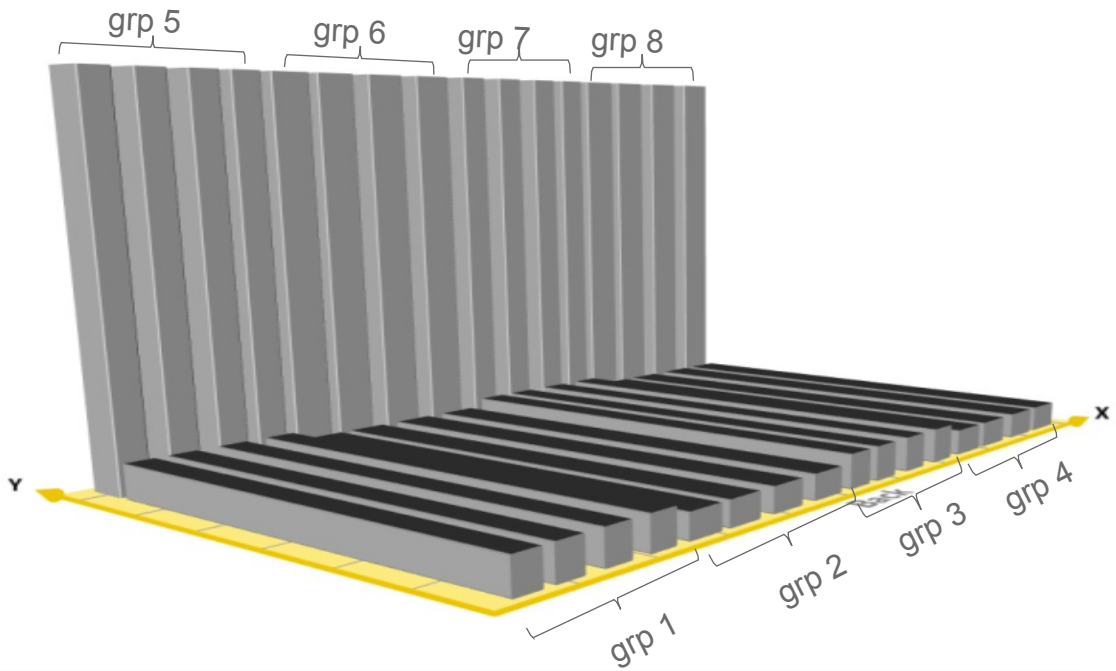
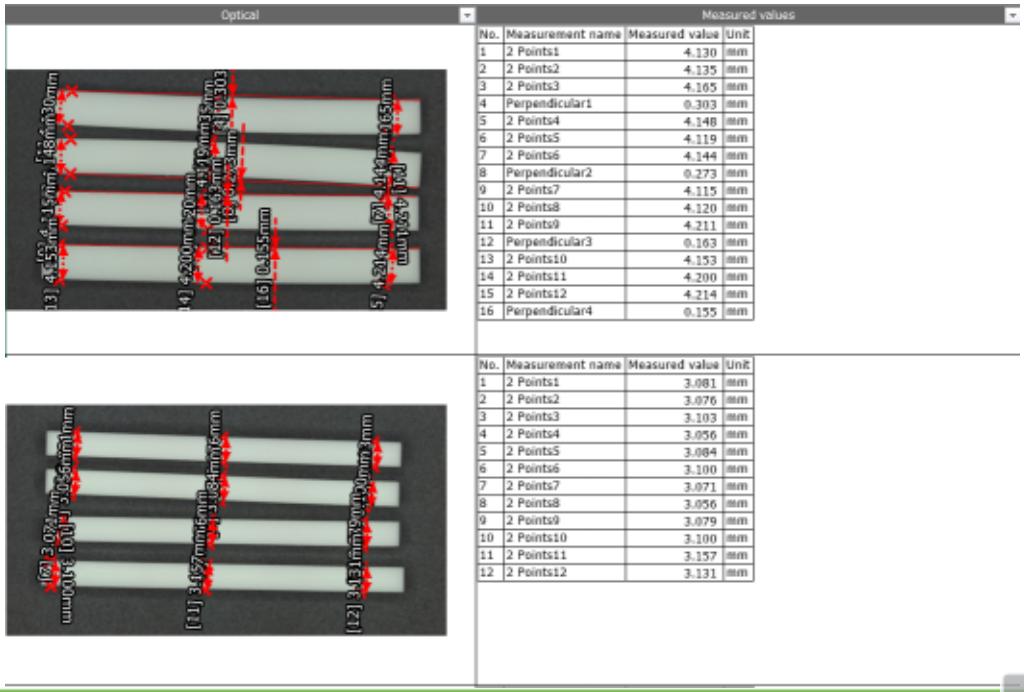
Flexural Bend Testing Methodology

To quantify the strength of ceramics the ASTM C1161-13 four-point bend test was performed.
For statistical evaluation 128 samples were evaluated with 4 different print orientations.







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Flexural Bend Testing

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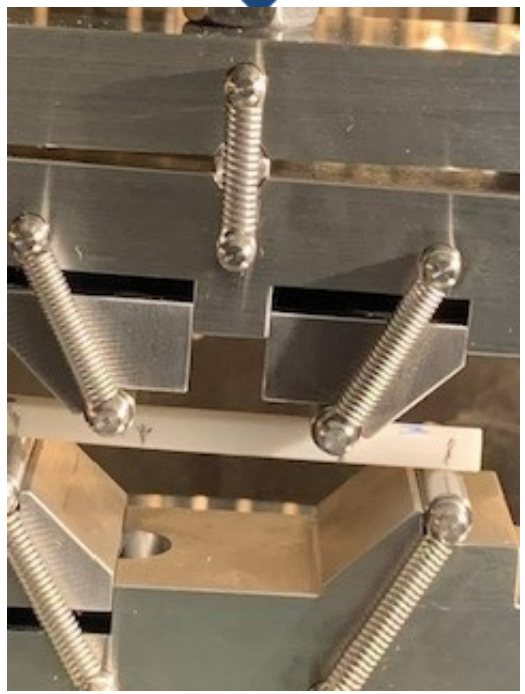
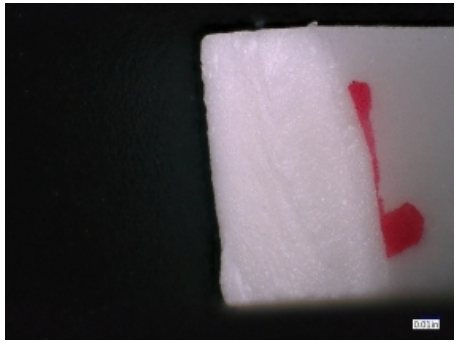
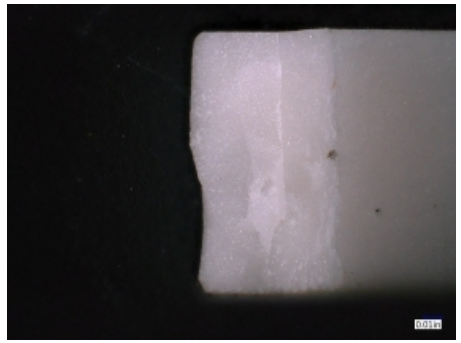
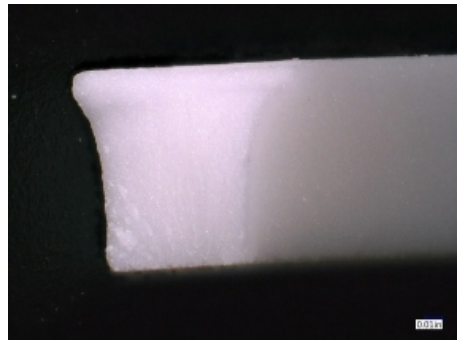
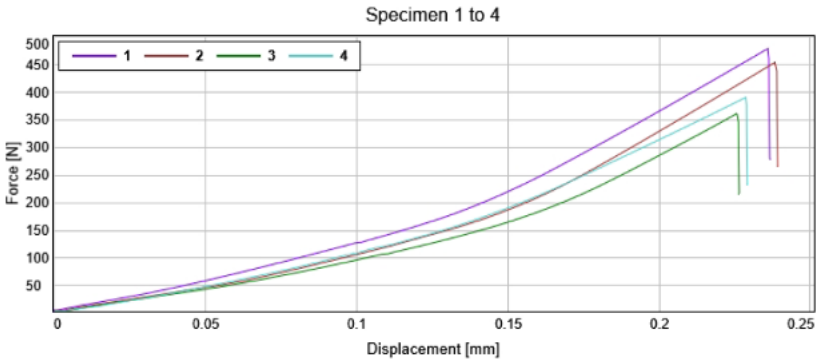
- 5 kN Instron load cell
- ASTM C1161
- $S = \frac{3\,PL}{4\,bd^2}$;
  - S = specimen strength
  - P=break force
  - L = outer support span
  - b = specimen width (4mm)
  - d = specimen thickness (3mm)











Orientation	number samples	Average failure stress (Mpa)	stdev	width avg (mm)	width std	Thick Avg (mm)	Thick Std	avg humidity (%)	stdev humidity
1	32	314.66	35.16	4.01	0.08	3.04	0.03	48.94	8.00
2	32	320.59	60.71	4.09	0.07	3.02	0.08	50.30	0.52
5	32	328.07	39.10	4.07	0.05	3.04	0.02	50.49	0.45
6	32	313.21	55.74	4.09	0.04	3.05	0.03	50.57	0.43
STC (2021)	30	347.08	19.13	4.01	0.01	3.01	0.01	49.94	0.57
STC (2017)	29	357.93	17.58	4.00	0.00	3.01	0.00	50.00	-

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Archimedes Density

Archimedes Density per ASTM C830

Initial testing shows Additively Manufactured densities are consistent with traditionally manufactured densities.

Density measurements conducted on As-printed samples

Sample ID	Dry Weight (g)	Suspended Weight (g)	Saturated Weight (g)	Bulk Density (g/cc)**	Open Porosity (%)
4 - TRADITIONAL	1.06	0.777	1.062	3.719	0.702
T5A2	1.074	0.788	1.077	3.716	1.038
T2A3	1.408	1.033	1.409	3.745	0.266
T3A2	1.192	0.875	1.196	3.713	1.246
T8A2	1.059	0.778	1.06	3.755	0.355

AM Ceramic

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Coefficient of Thermal Expansion

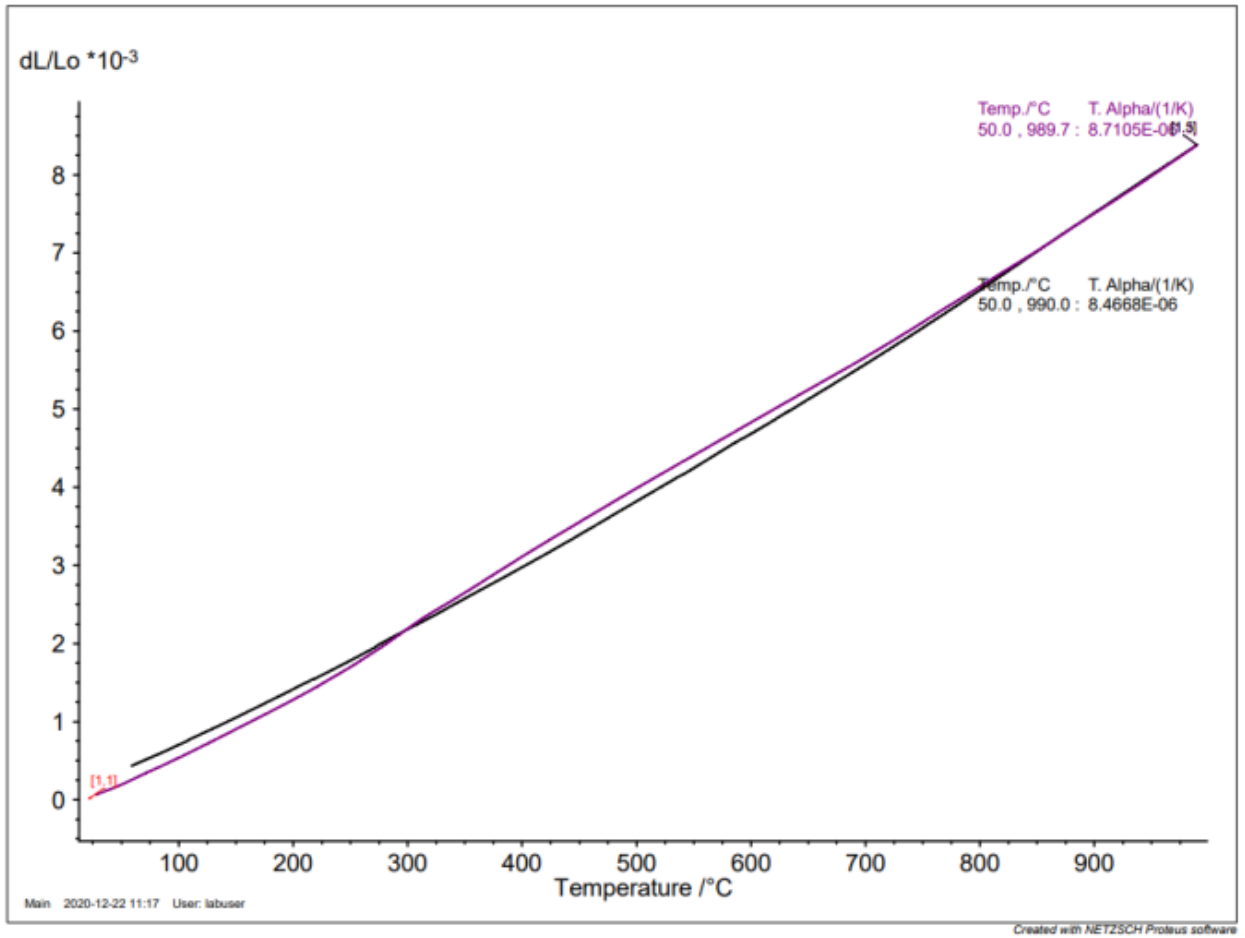
CTE testing ASTM E228-11

Similar to density, the CTE initial test results indicate the printed material performed similar to the traditionally processed ceramic material.

Minor discrepancy noted in the heating curve. From the cooling curve 990 C – 50C the CTE was calculated at 8.47 x10^-6/C.

The elastic constants were measured to be

Yong's Modulus (E) – 317 GPa
Shear Modulus (G) – 127 GPa
Poisson's Ratio – 0.246
Bulk Modulus (K) – 208 GPa



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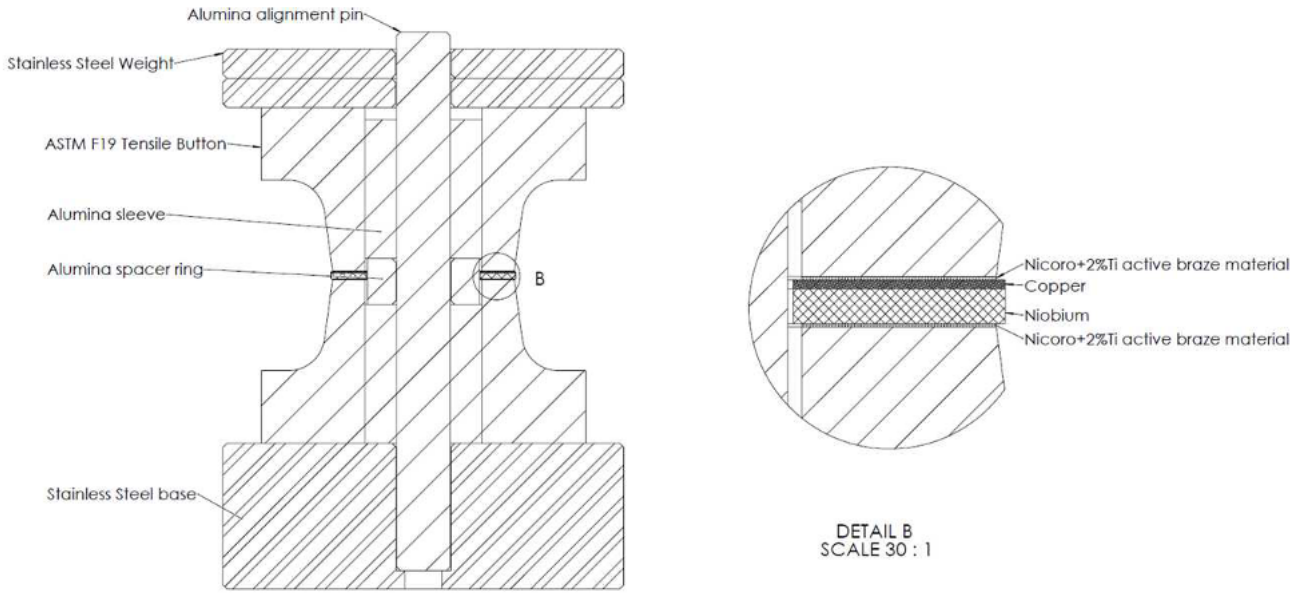
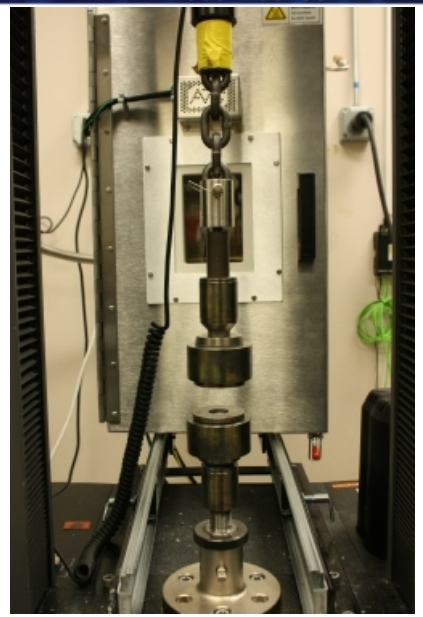
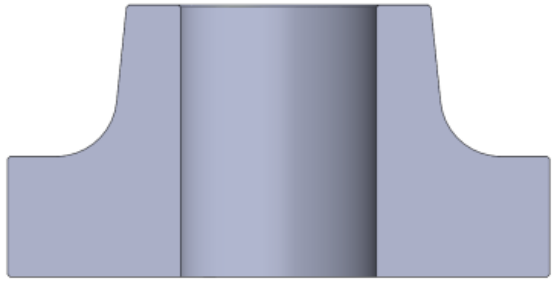
ASTM F19 Tensile Button Braze Testing

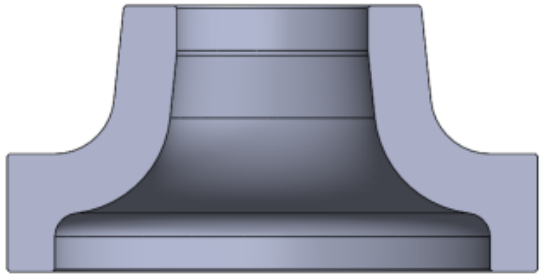




Standard Test Profile Cross Section



Lithoz Test Profile Cross Section



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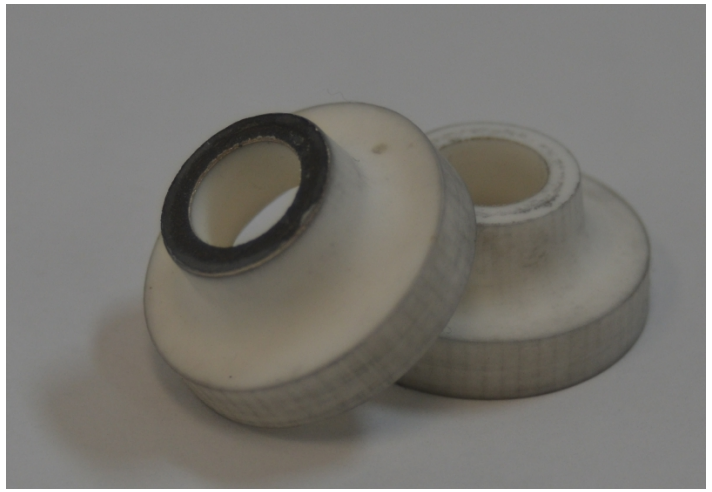
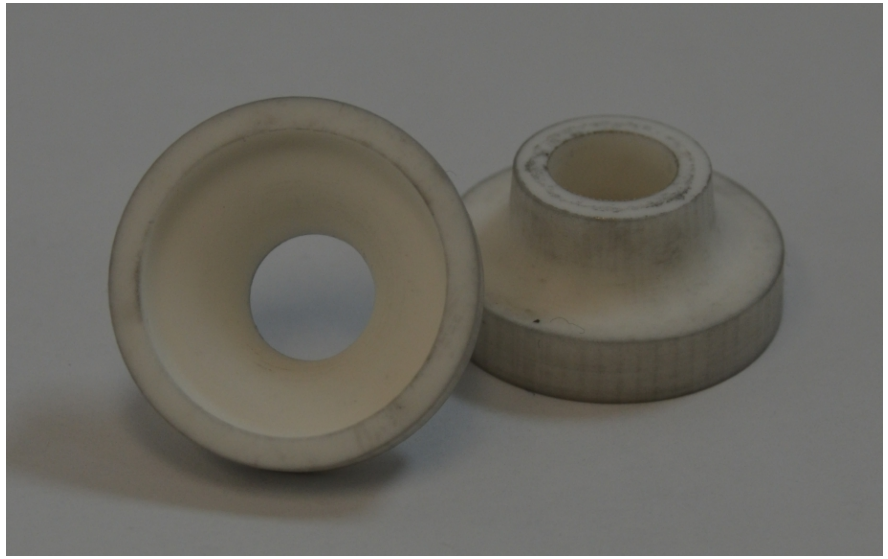
ASTM F19 Tensile Button Testing Results

SNL ceramic tensile button manufactured using Lithoz CeraFab 8500.
Tensile button braze tested for hermeticity.
Test verified AM Tensile Button ceramic was not the failure point.
Study to be continued with different braze materials and larger sample size.





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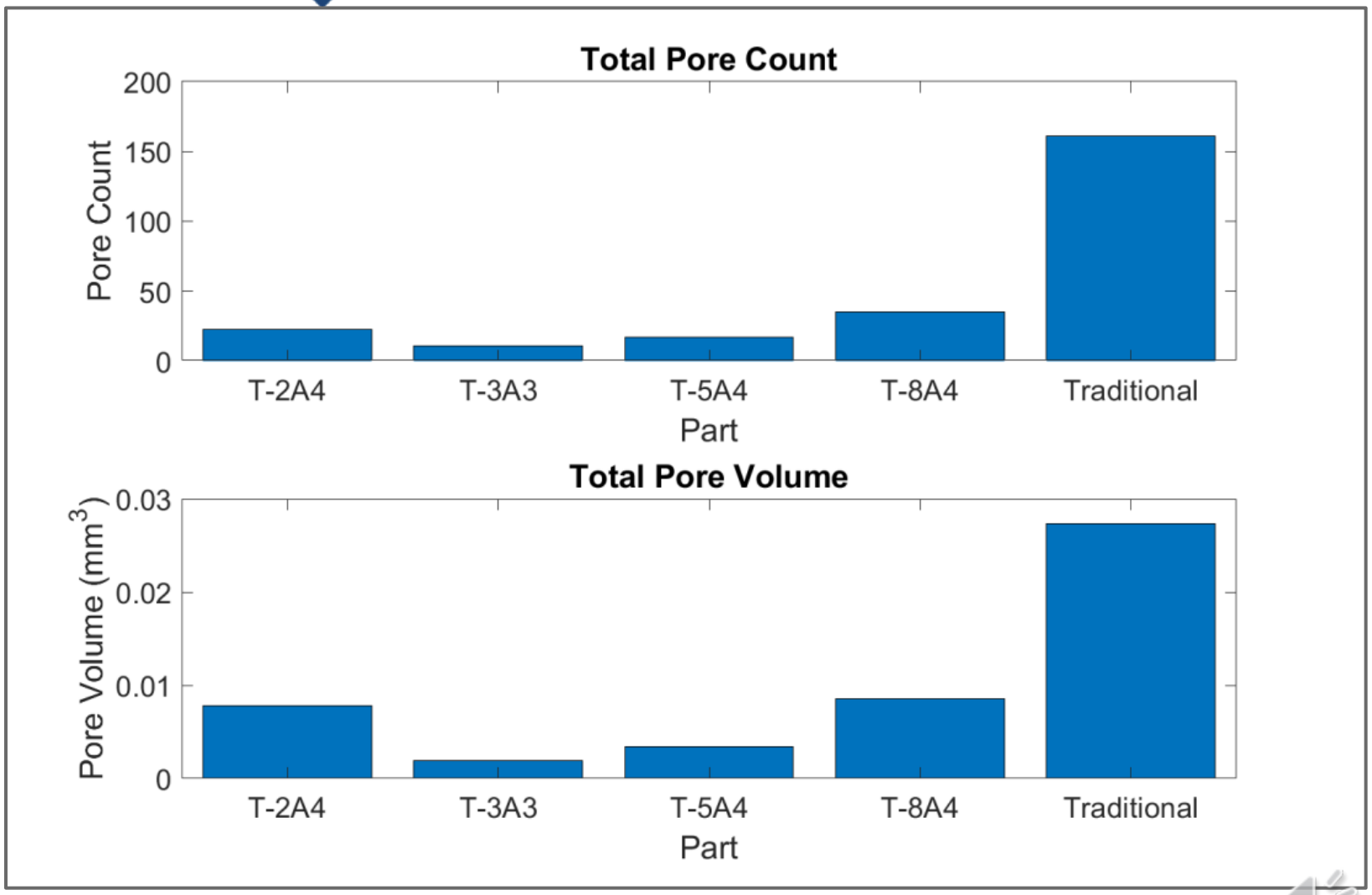
Computer Tomography Porosity Overview

The additively manufactured glass-bonded alumina contained significantly less pores in comparison to the traditionally manufactured samples.

Pore volume followed the trend of pore count.



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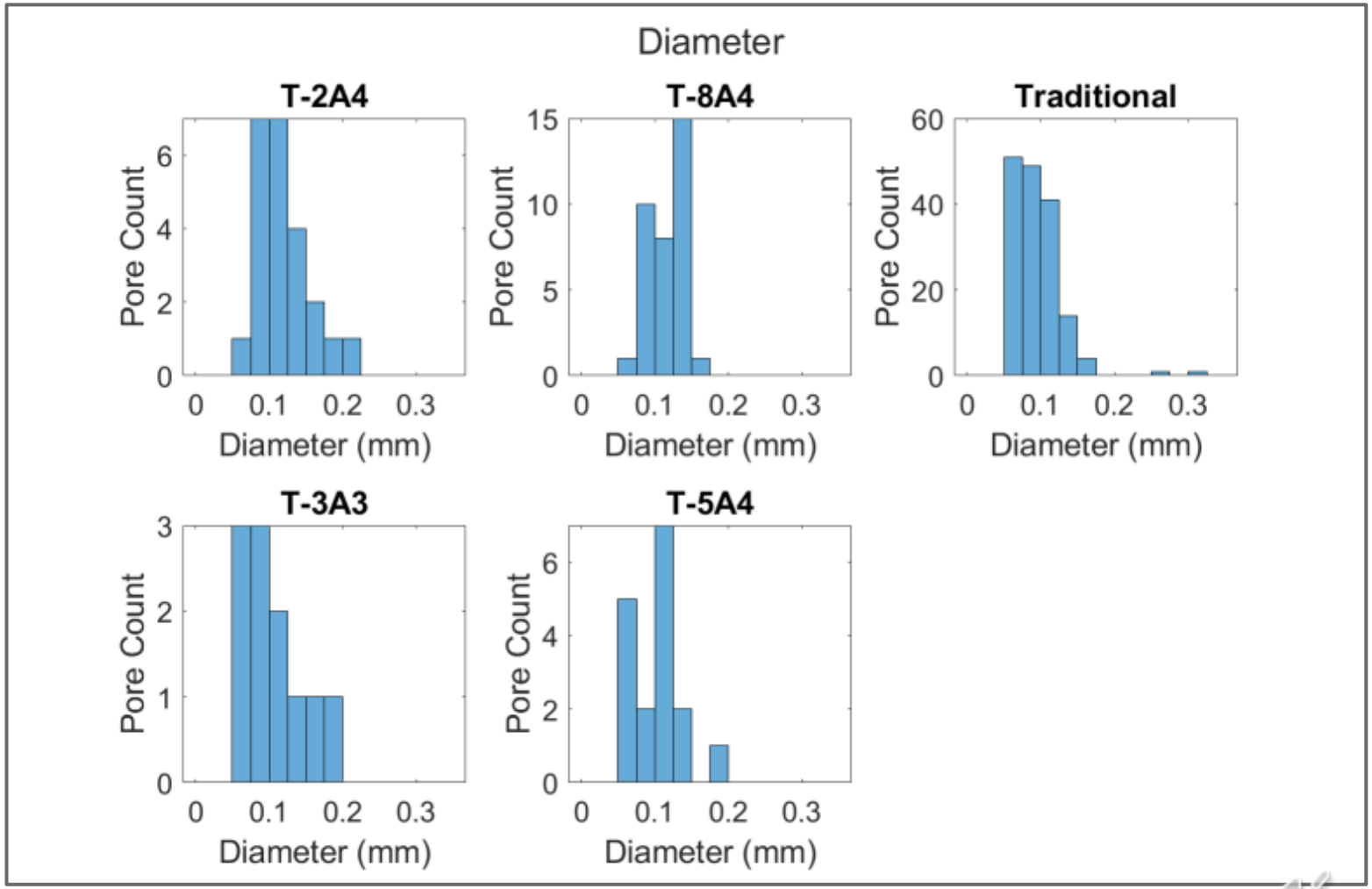
Computer Tomography Porosity Overview continued

Pore diameter was measured for each sample.

The diameter distribution was consistent for all measured samples.



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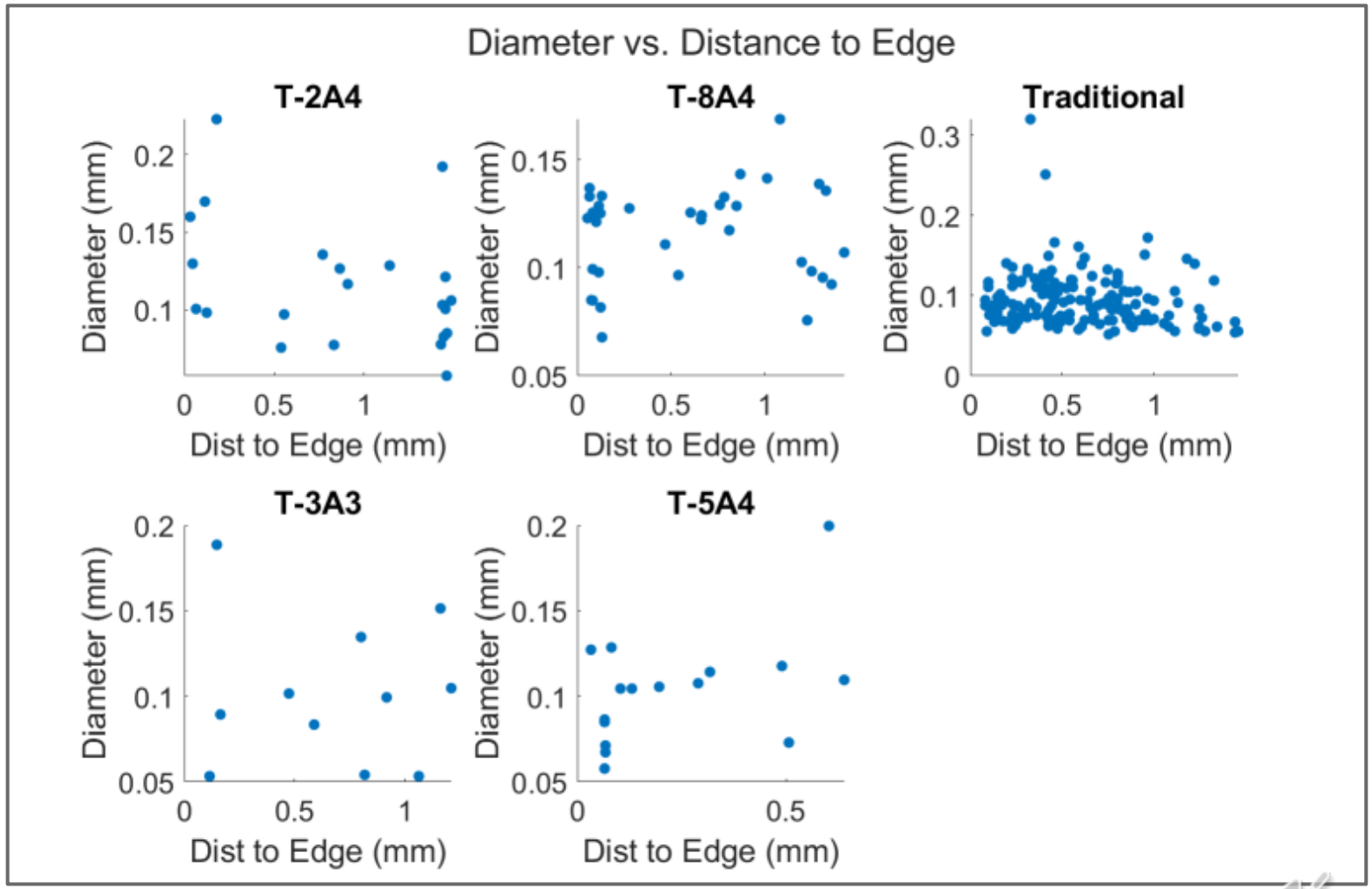
Computer Tomography Porosity Overview continued

No correlation identified between diameter of pores and distance to the edge.

Samples T-8A4 and T-5A4 show a larger concentration of pores closer to the edge of the material.

All samples measured show pores through the thickness.



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Conclusion

Through continued teaming, Lithoz America and Sandia National Laboratories developed production ready glass-bonded alumina ceramics for use in DLP additive technologies.

The Lithoz CeraFab DLP additive manufacturing technology and appropriate thermal processing equipment produces results comparable in performance to conventionally manufactured materials.

The additively manufactured glass-bonded ceramic drastically improved the porosity.

By continued investments from our stakeholders, ceramic additive manufacturing is enabling our designers to push the limits for next generation products.

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Thank you

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