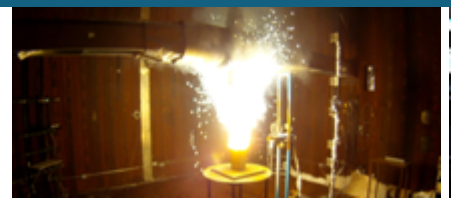
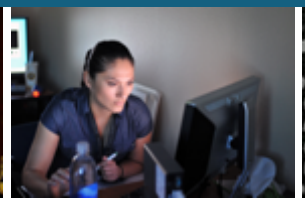
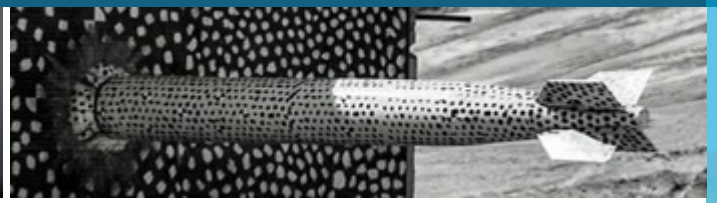
This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2021-5215C

Sandia National Laboratories

DLP Ceramic Printing (Lithoz) at Sandia National Laboratories

LITHOZ®

Dale Cillessen (SNL) & Shawn Allan (Lithoz)

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Presenter Introduction

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.

Shawn Allan

Started Lithoz America in 2017 in New York

BS Ceramic Engineering & Materials Science, Alfred University

MS Materials Science, Georgia Tech

Delivering unmatched Ceramic Additive technologies and materials. Developing sales, training, support, demonstration and development project capabilities for Lithoz in North America.

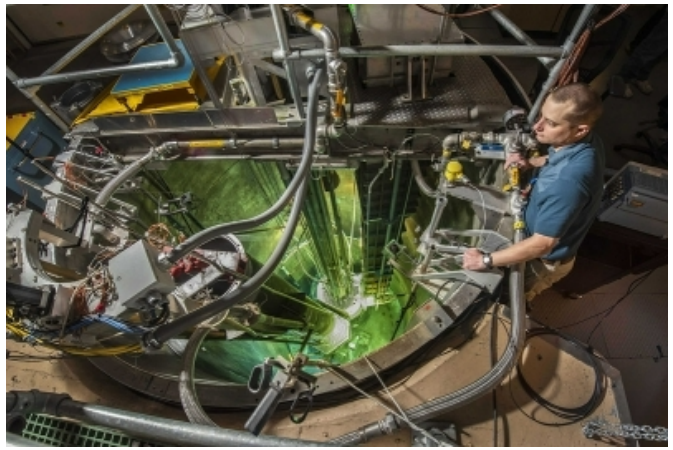
Agenda

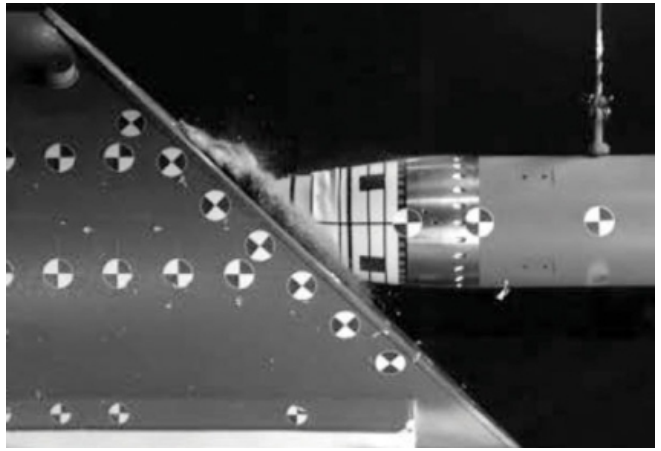
- SNL Introduction
- Lithoz Introduction
- The DLP process
- Exploring and evaluating printed components
- Bringing Lithoz to SNL
- Impact of Ceramic AM at SNL
- Material Development
- Using the CeraFab printer
- Tested Results
- What’s next for Lithoz

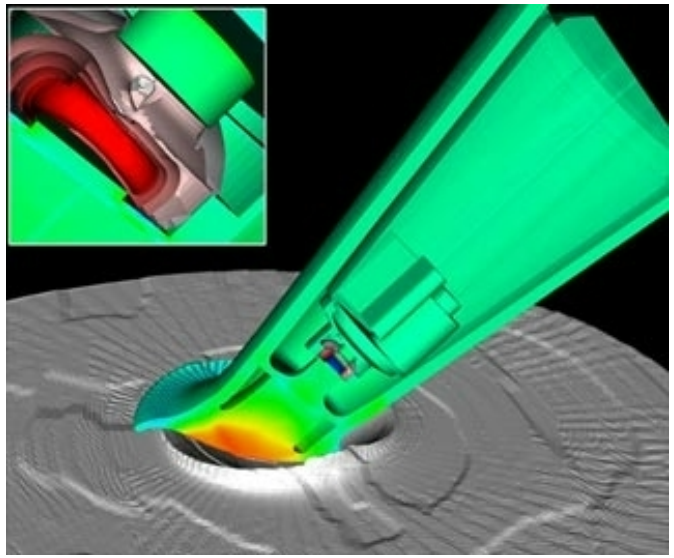
Sandia National Laboratories

Federally Funded Research and Development Center

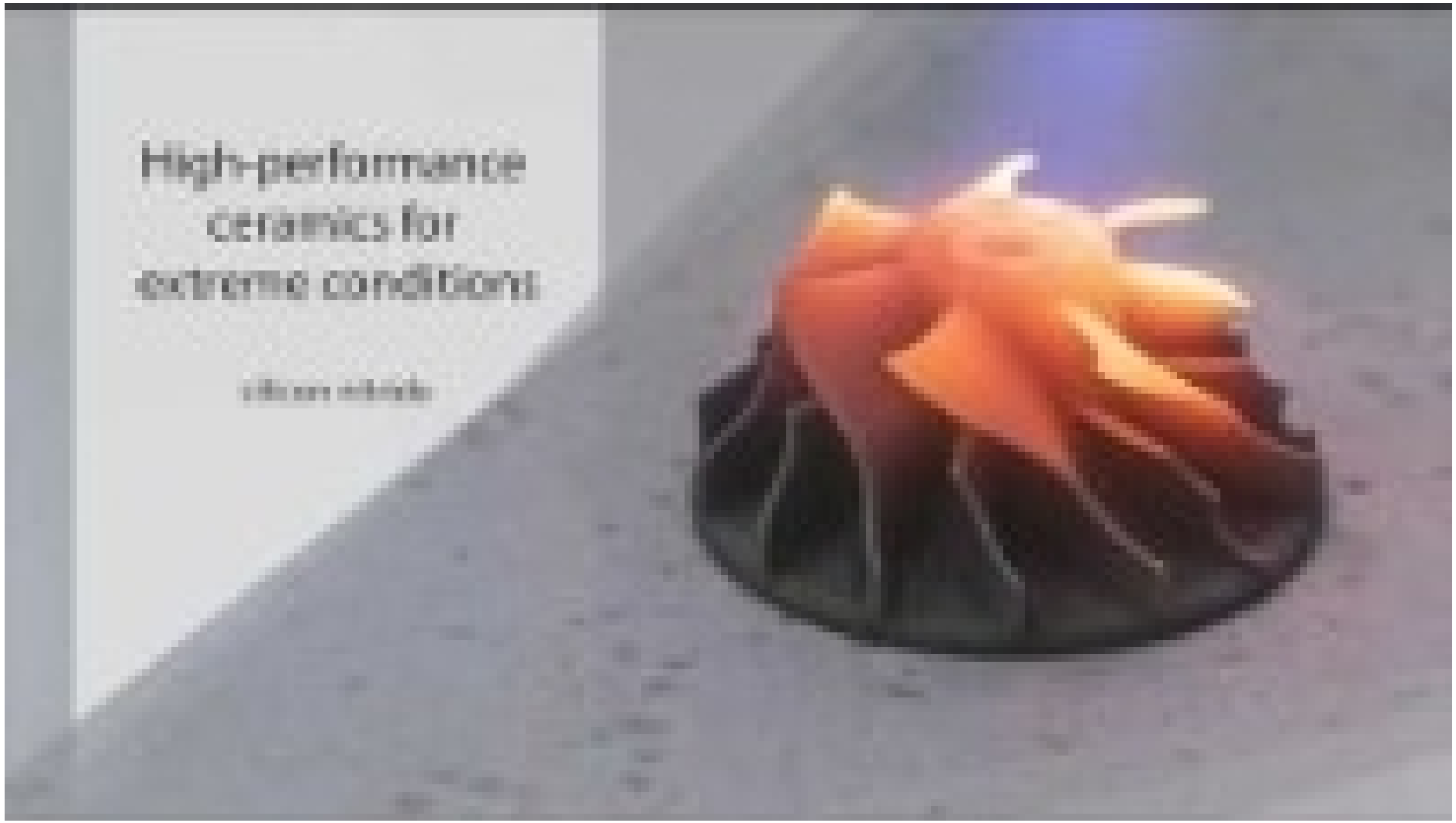
- Nuclear Weapons
- Defense System and Assessments
- Energy and Climate
- International, Homeland, and Nuclear Security







High Performance Ceramics

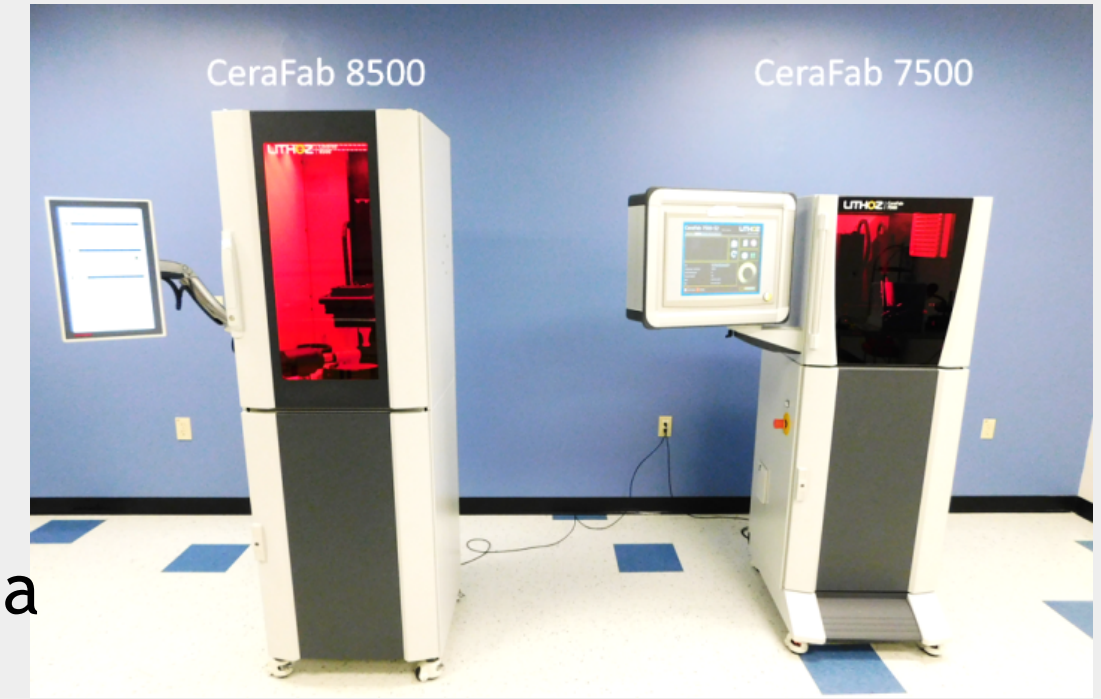


https://www.youtube.com/watch?v=mKJcH65qHKg

Lithoz America Facility

Powder-to-Part Capability

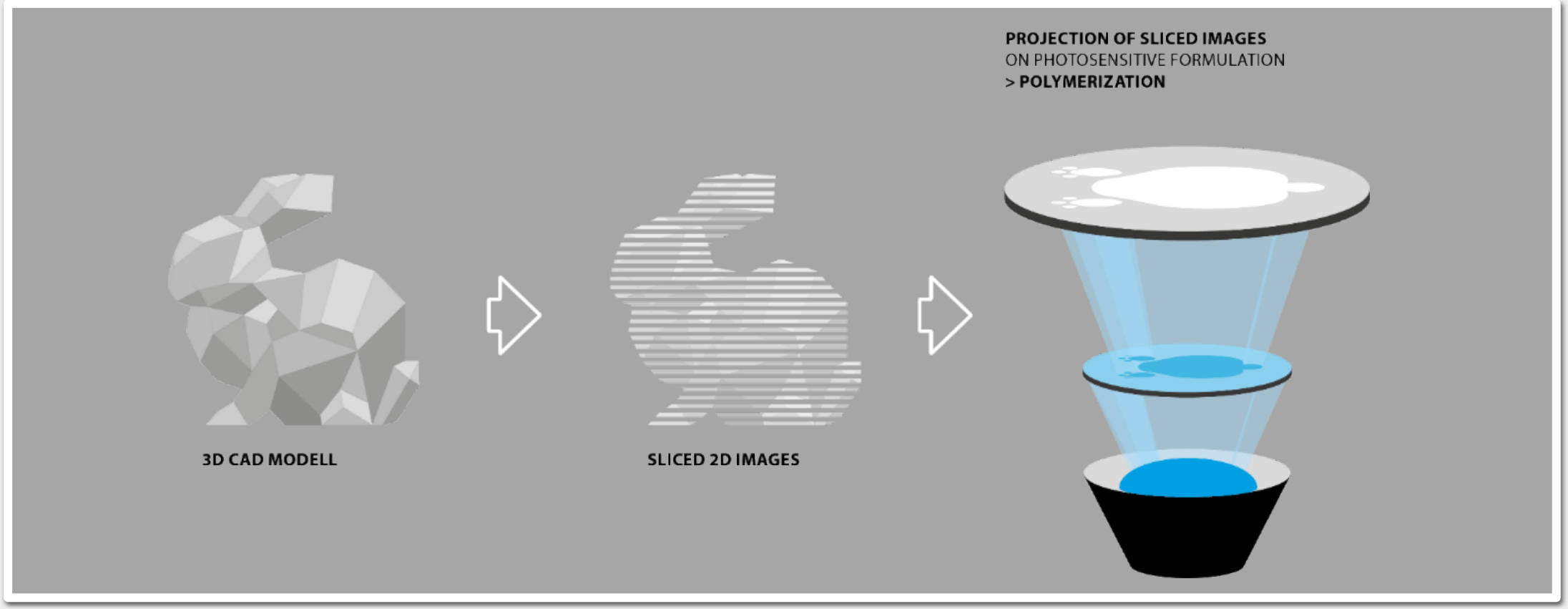
- Printing feasibility studies
- Thermal processing
- Materials development
- Custom slurry production
- Sales, support, service for US & Canada



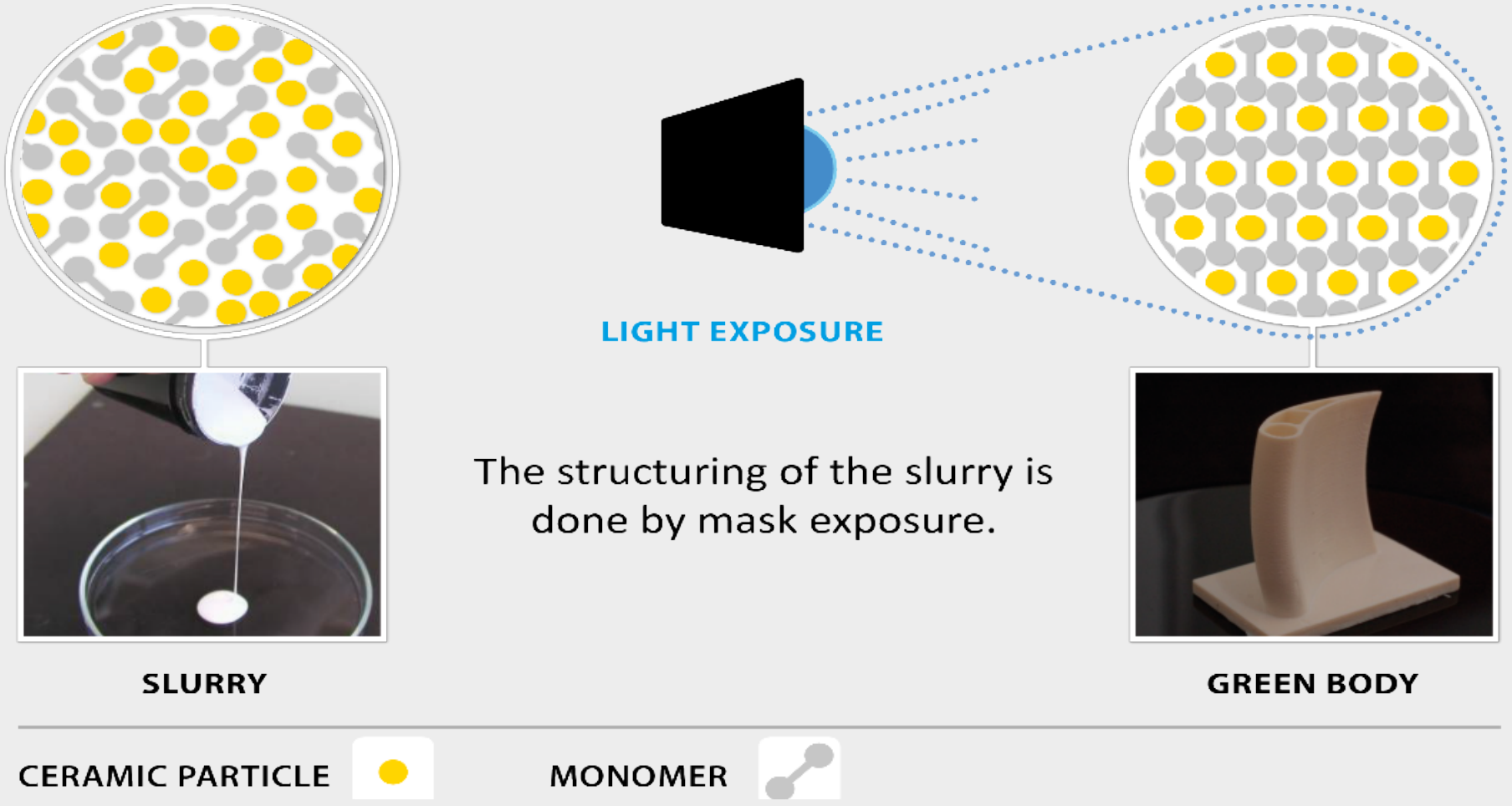
- University partners at Alfred University and Colorado School of Mines (ADAPT member)
- Distinct US-access-only data systems
- AEA Certified by SNL
- Active Culture of IRD – Building targeted collaborations to expand possibilities

DLP process

Layerwise buildup of 3D structures

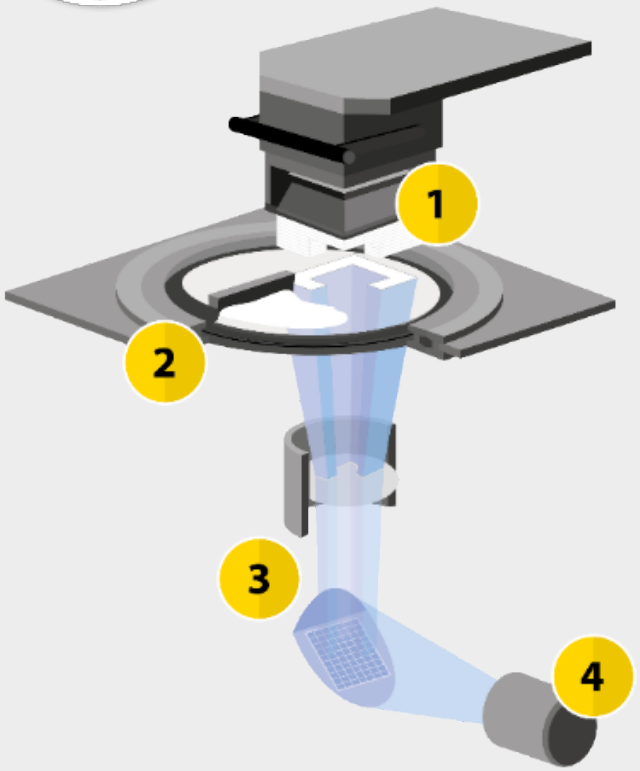


Photopolymerization



LCM-Technology

LCM: Lithography-based Ceramic Manufacturing



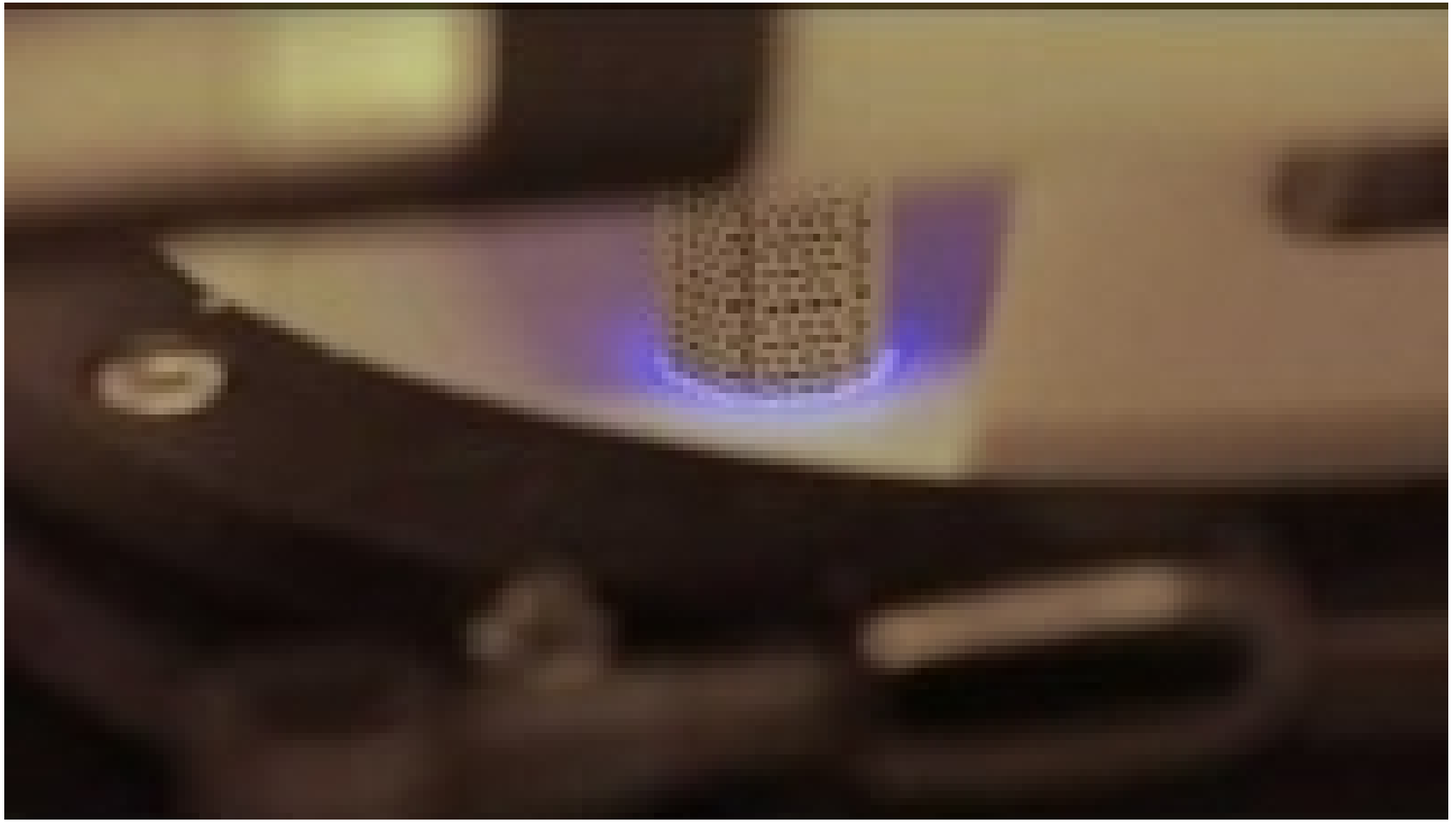
1 BUILDING PLATFORM

2 VAT

3 OPTICAL SYSTEM

4 LED

Lithoz CeraFab in Action

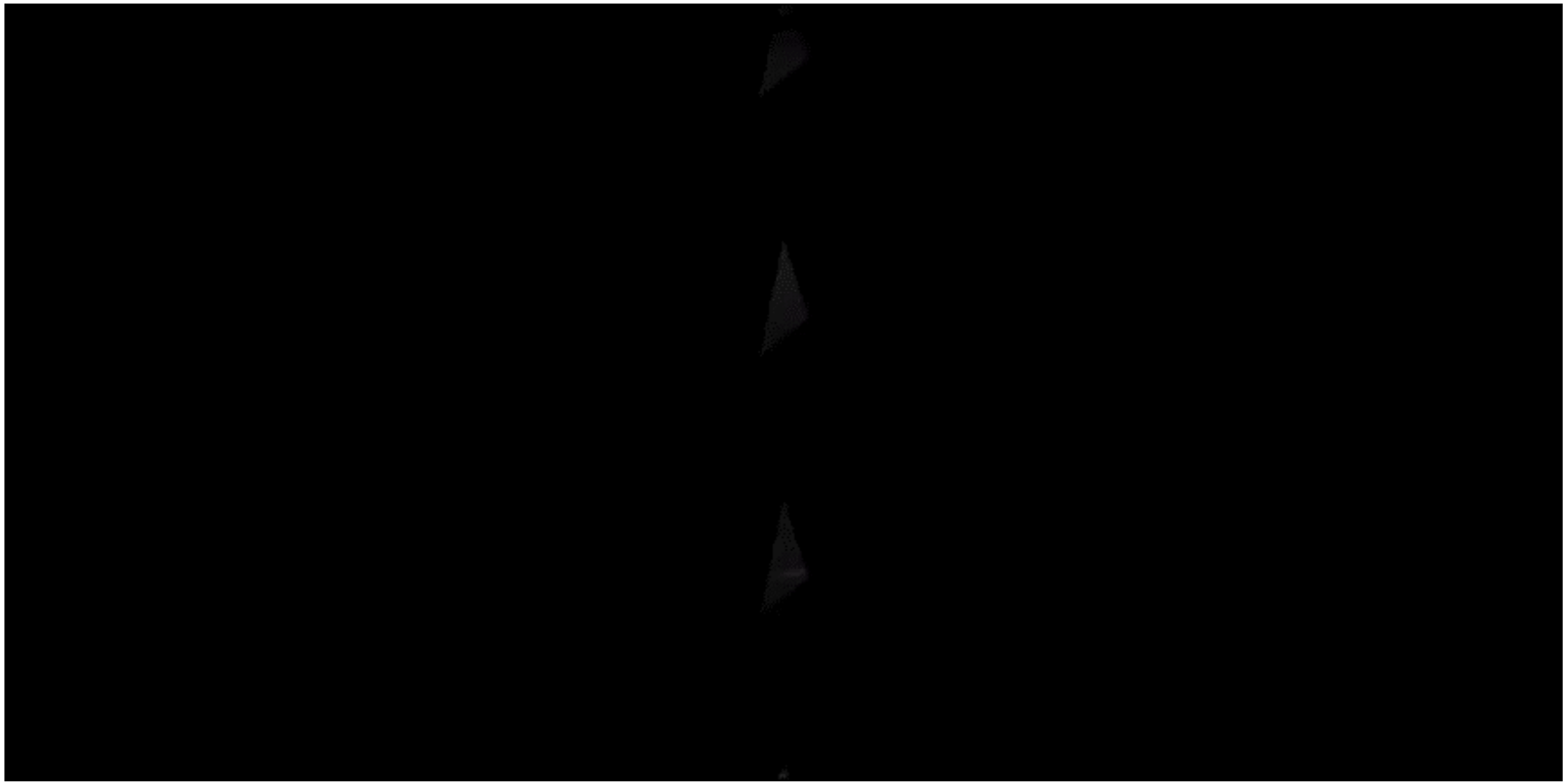


https://www.youtube.com/watch?v=B7cxJCxI9GA

Ceramic Additive as a process

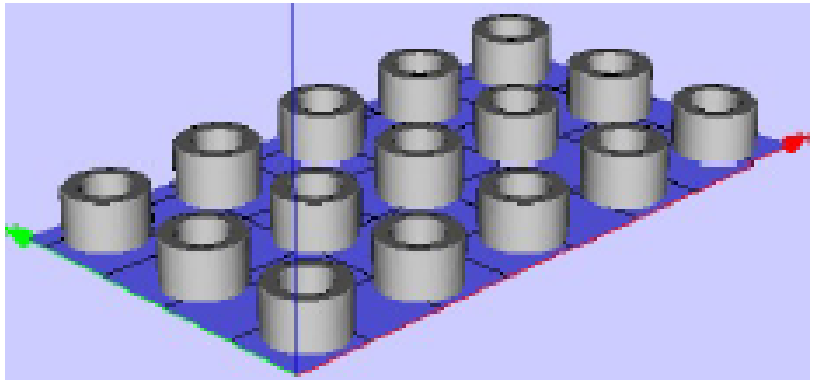
Initial Exploration and the Start of the Validation Process

In 2018 SNL funded the initial request of trail part to Lithoz America. Lithoz manufactured 8 ASTM F19-11 tensile buttons for evaluation. Below is a Computer Tomography (CT) scan through a tensile button.



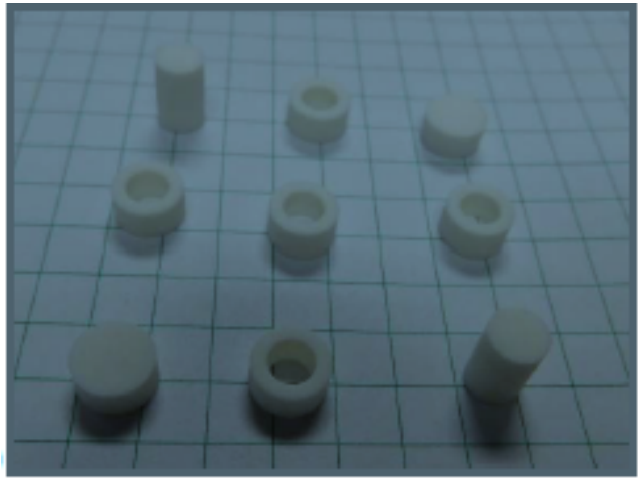
Initial Study Testing Sandia's Custom Ceramic

After success with the tensile buttons and other test geometries, Lithoz America and SNL initiated a custom material development study.



In early 2019 the Sandia ceramic material was printable using the Lithoz printing technology.

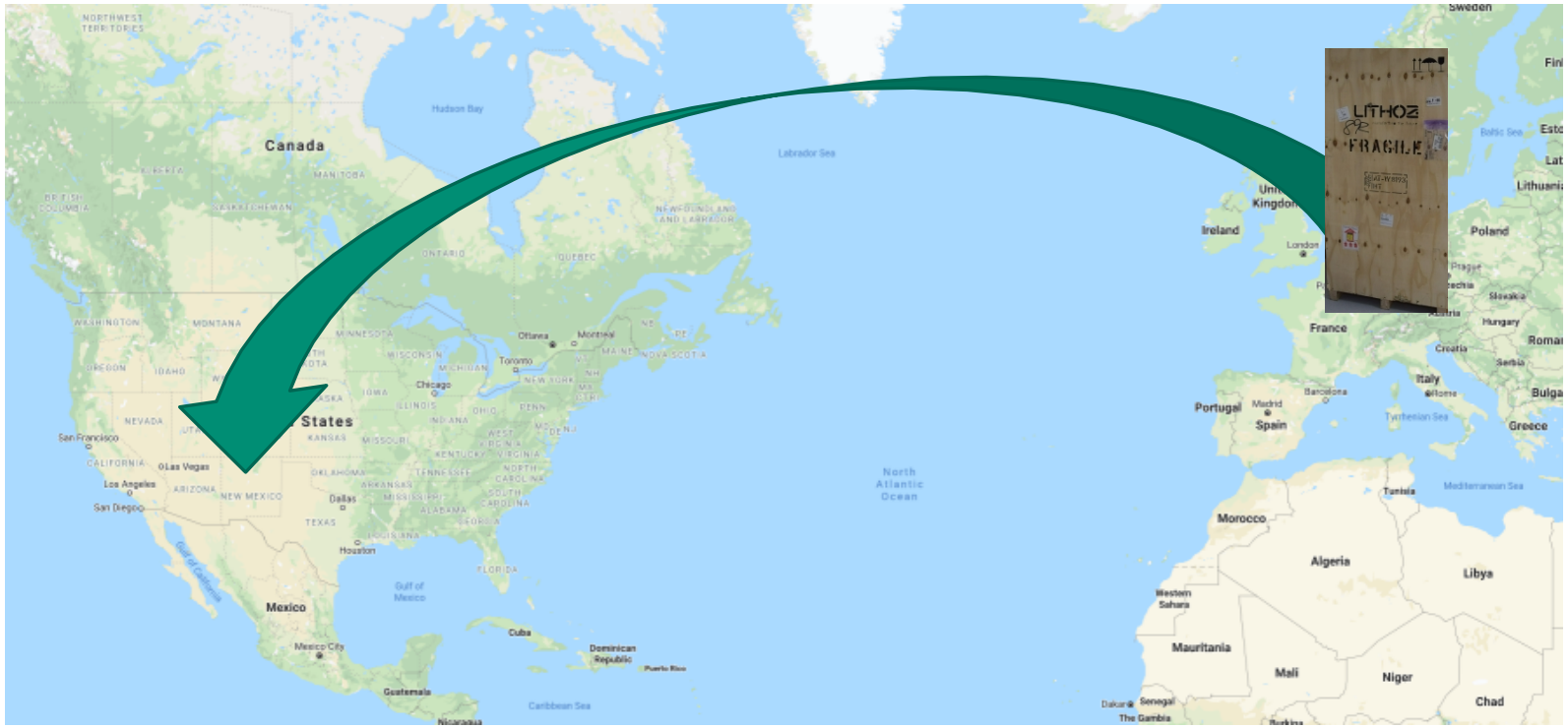
The printed components were further evaluated at Sandia and shown capable of assembly and meeting a hermetic seal requirements.



Bringing Lithoz to Sandia National Laboratories

Initial discussions with Johannas Homa, CEO, Lithoz GmbH on the purchase of the machine was June 2019. With a quick turn-around Lithoz developed a custom version of the CeraFab 8500 printer and was accepted by Sandia in September of 2019.

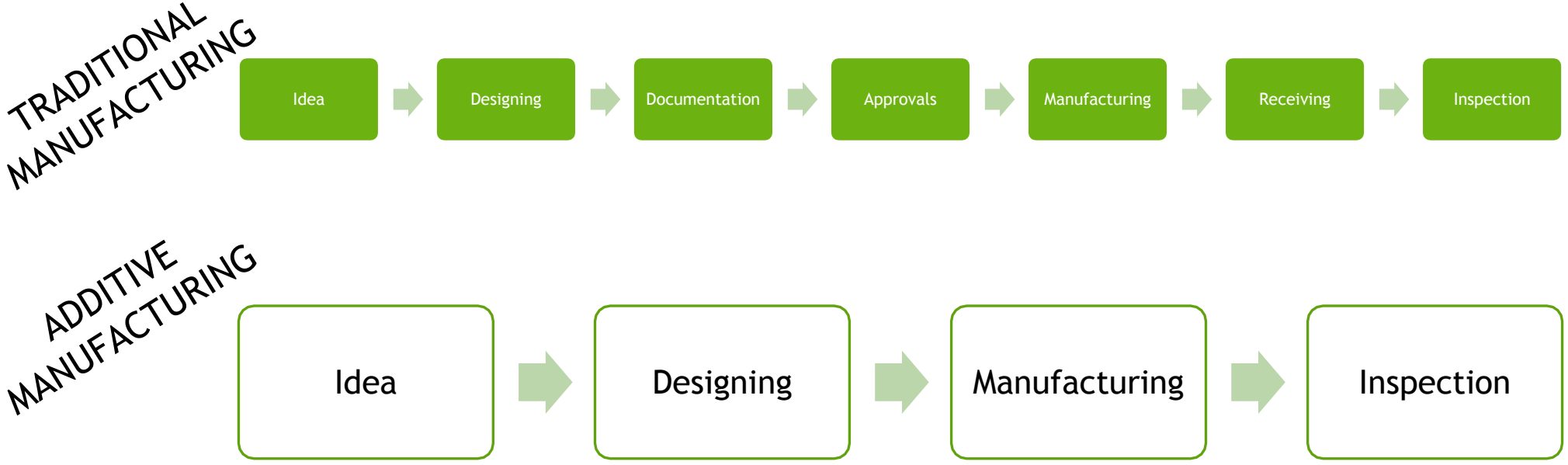
Acceptance of the machine included an inspection comparable to a UL inspection.



Impact of Ceramic AM at SNL

Since initial engagement with Lithoz, SNL has successfully manufactured like-for-like components and characterized properties like hermiticity, strength, and density. Groups at SNL are evaluating the opportunities for insertion of AM ceramics into products.

AM ceramics enabled our designers accelerated development time. Ceramic products that normally take months for manufacturing are realized in weeks.



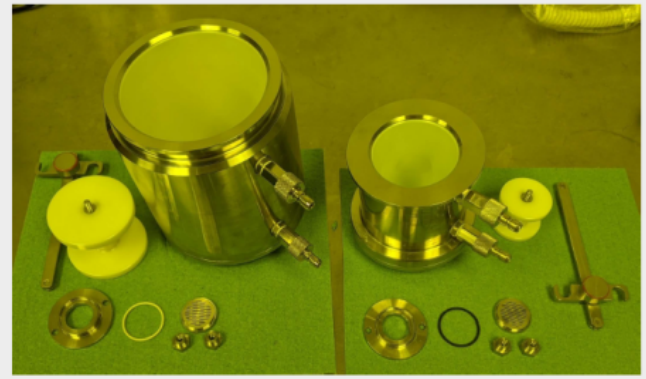
SNL Material Development

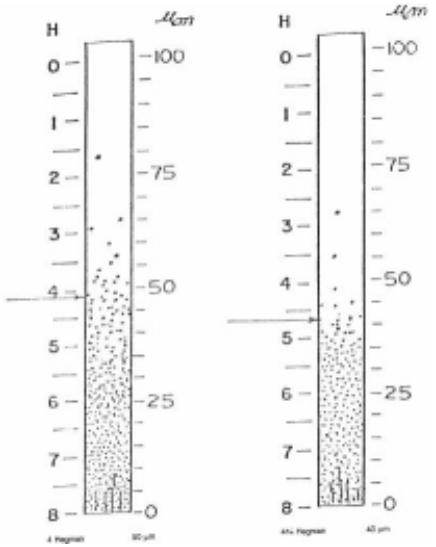
SNL and Lithoz teamed together to develop an SNL powdered ceramic as printable material.

Based on the initial characterization, the SNL ceramic powder was successfully combined with the photocurable resin. Once combined, multiples studies were conduced. Lithoz America is supporting SNL as a material supplier for this product in large batch sizes.

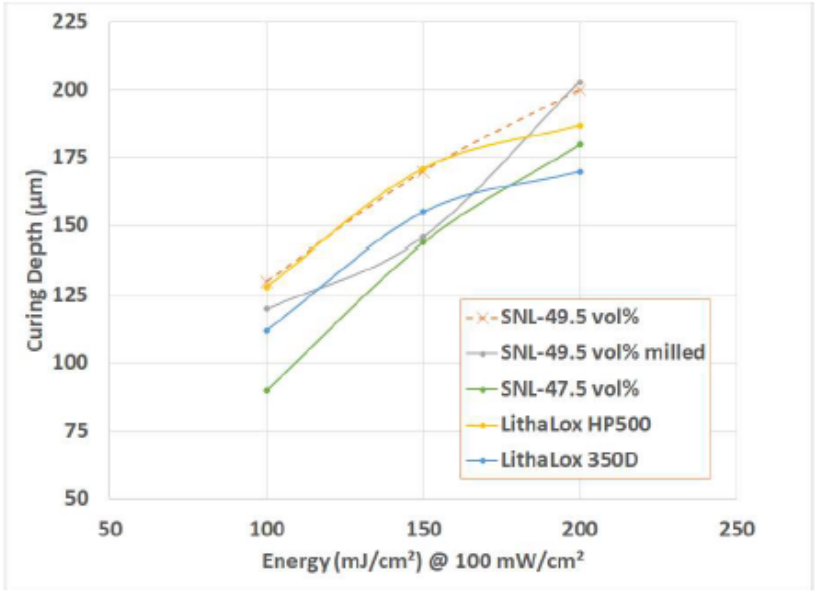
Timeline to develop a new printable material is < 2 weeks.

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





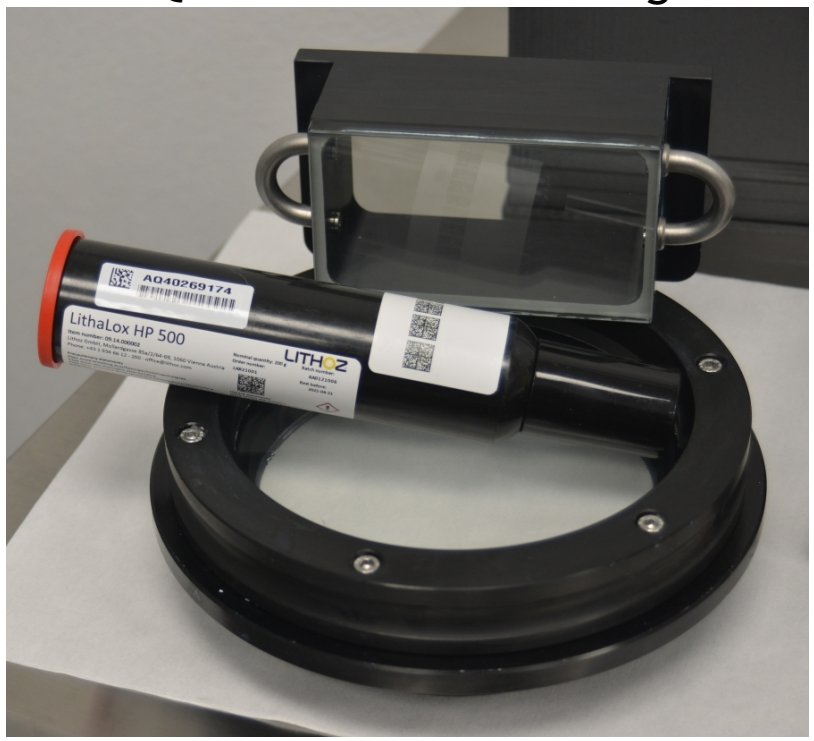
Typical Fineness of Grind gage patterns (from ASTM D 1210-05)



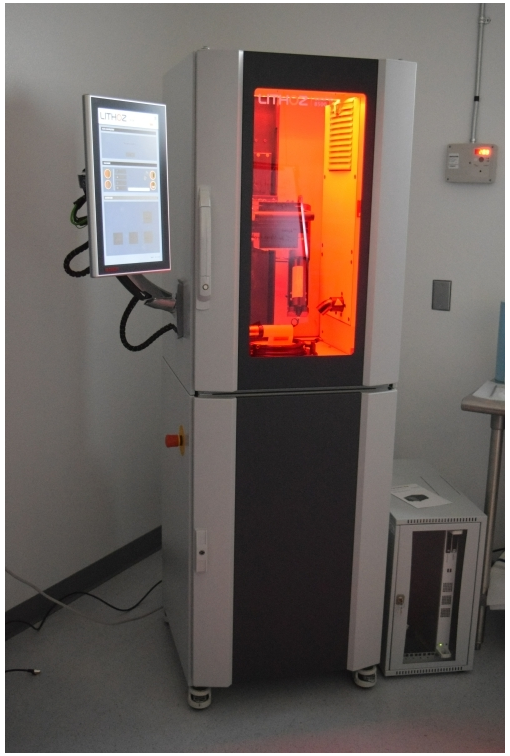
Printer Operations

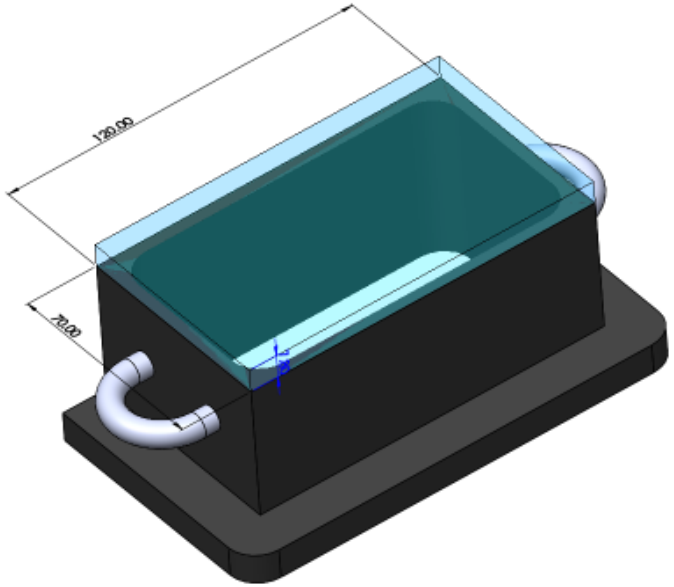
- Simple Touch Screen Interface
- Simple programmable controls from connected PC.
- Standard .STL printing file
- Open system
- Continuous monitoring of build
- Realtime viewing of print status
- Realistic expectations of print duration

Printing Vat, Build Plate, Slurry cartridge
QR for material tracking

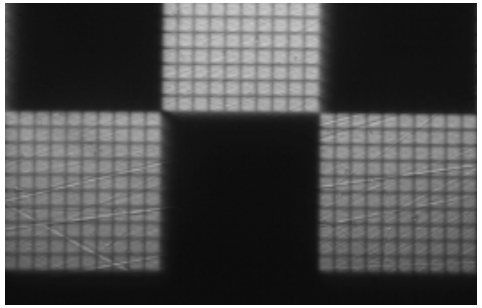


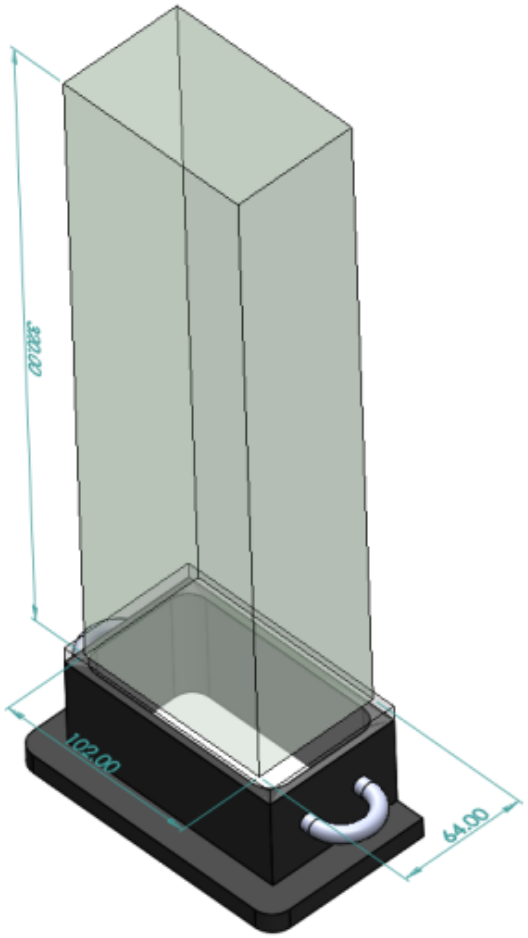
Printer Capability





Build volume (pre-sintering): 102mm X 64mm X 320 mm





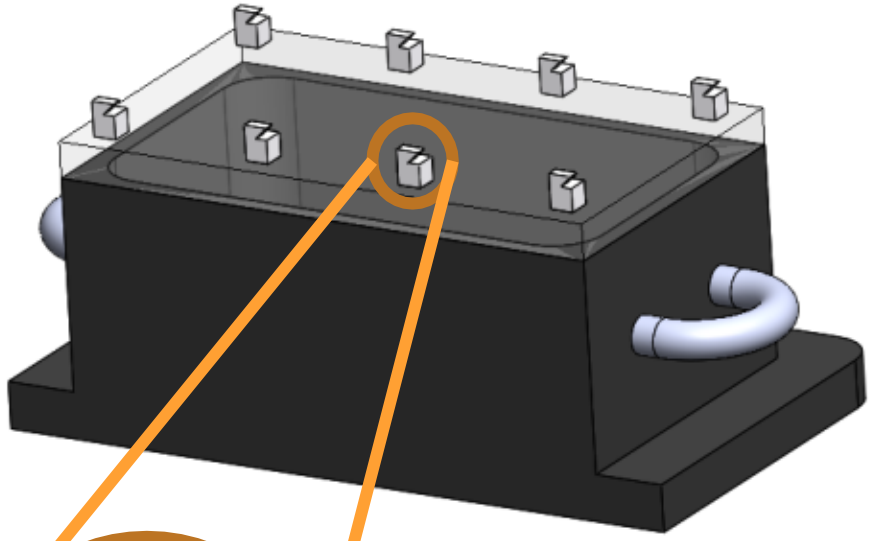
Resolution 40 micrometer X-Y, 10 micrometer (material dependent) Z

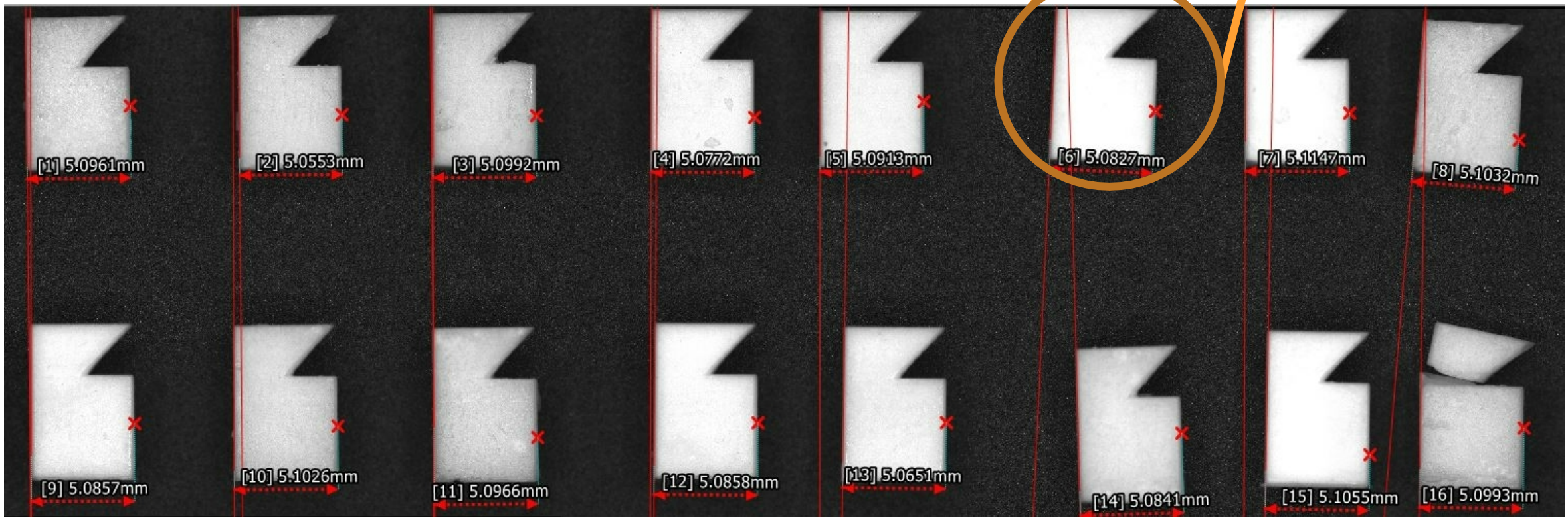
Tolerance Study on Sandia's Lithoz Pri

Study performed to check consistency and accuracy around perimeter of the build plate using Lithoz HP 500 high purity alumina.

No noticeable differences were observed for the accuracy of the printer based on print bed location.

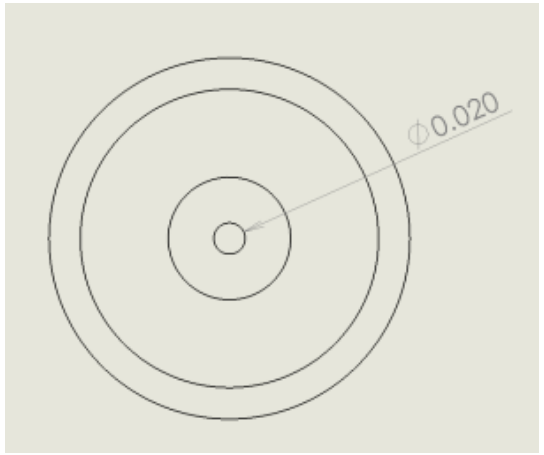
Min Value = 5.0553mm Max Value = 5.1147mm





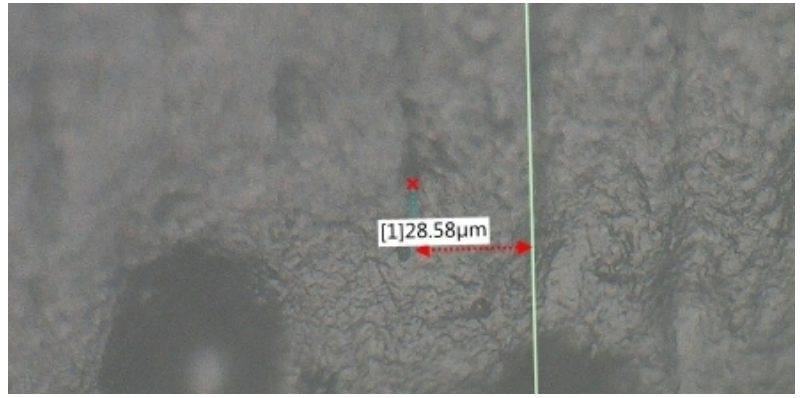
CAD Adjustments to Achieve Desired Outcome

Desired CAD feature



Lithoz HP 500 high purity alumina

Layer thickness 25 micron (0.001 in)



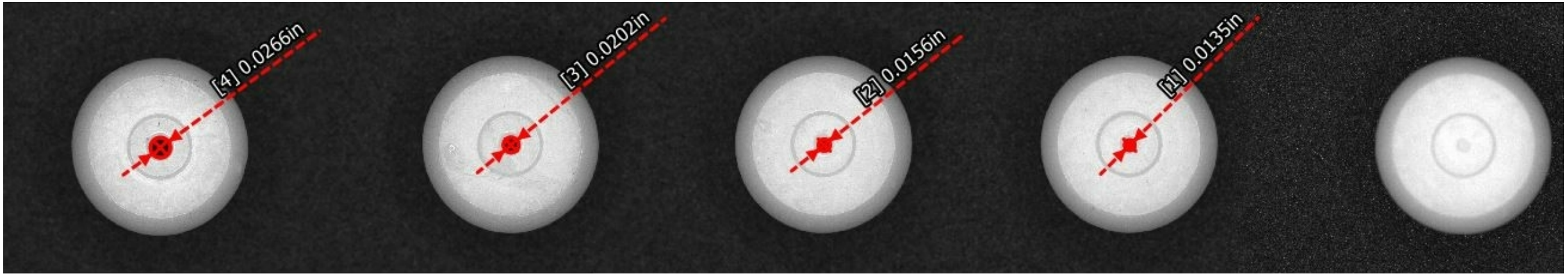
.STL 0.035 Adjustment

.STL 0.035 Adjustment

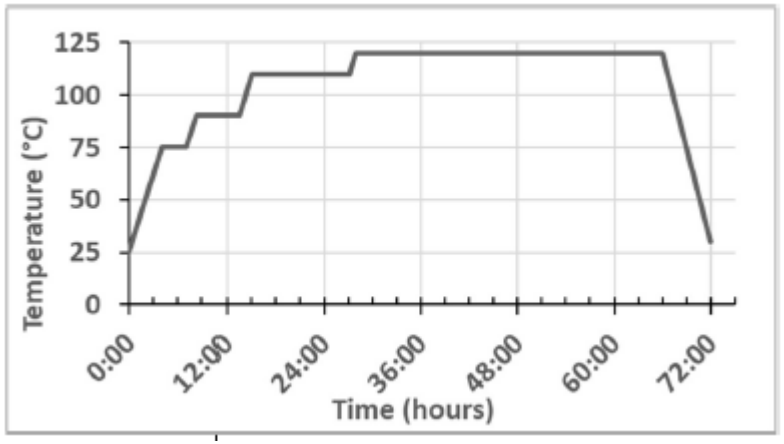
.STL 0.030” Adjustment

.STL 0.025” Adjustment

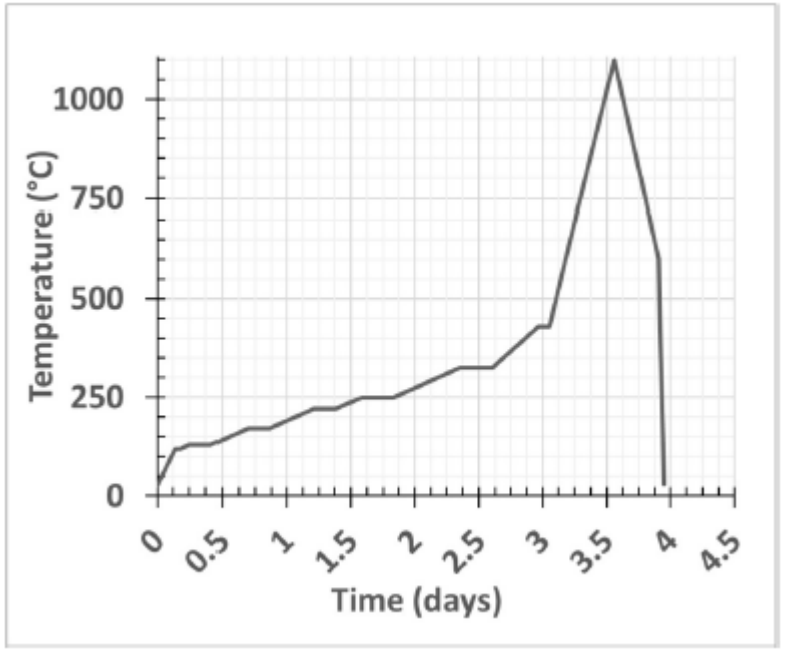
.STL Zero Adjustment



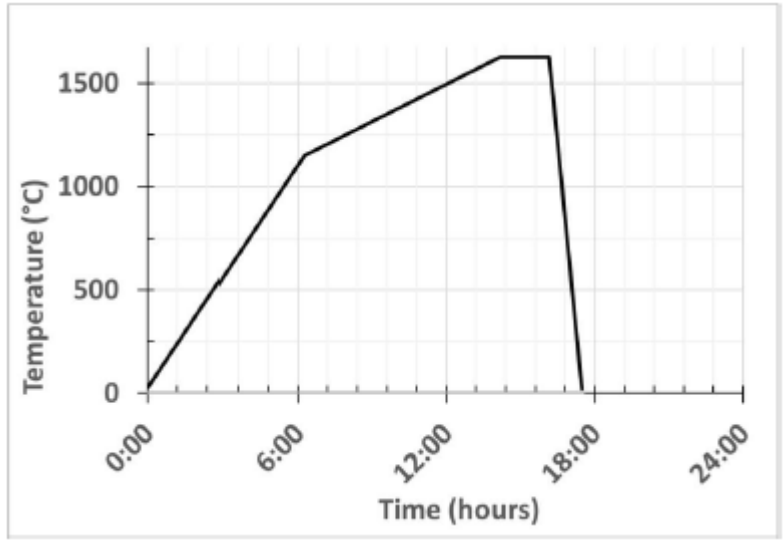
Sintering Characteristics



Preconditioning Temperature Profile



De-binding Temperature Profile



Sintering Temperature Profile

Conservative temperature profile shown

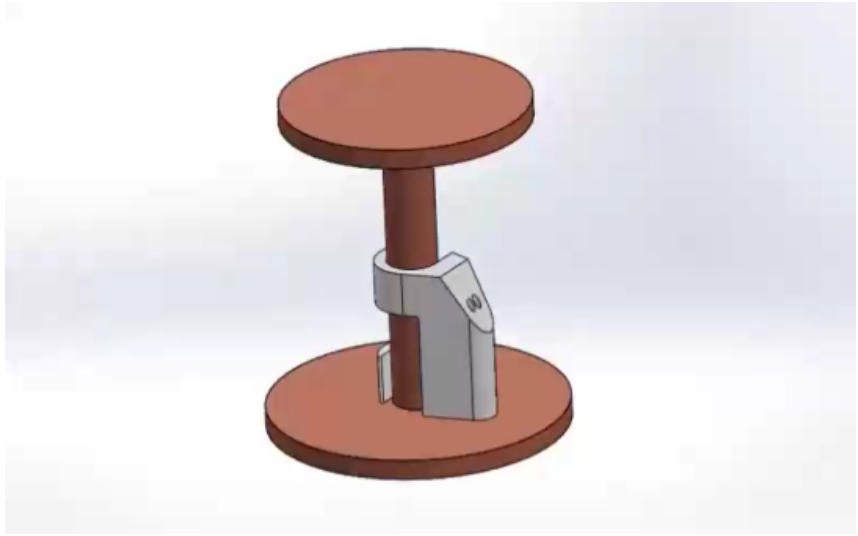
Thin-walled component can be processed in 1-2 days.

Designing for Ceramic AM

As with any manufacturing process, DFAM (Design For Additive Manufacturing) must be considered.

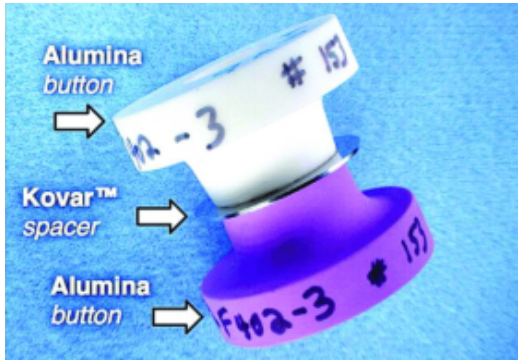
Initial expected tolerance of Lithoz AM Ceramic is +/- 0.002”

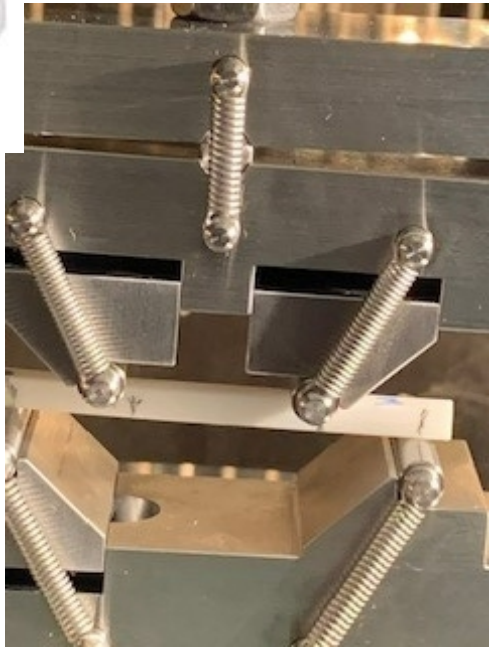
Guidelines are established and available for angles, overhangs, and unsupported features.



Material Characterization Study and Testing Methodology

- Tensile (flexural bend)
- Hermetic Capability
- Density
- Coefficient Thermal Expansion
- Structure via SEM
- Porosity via CT

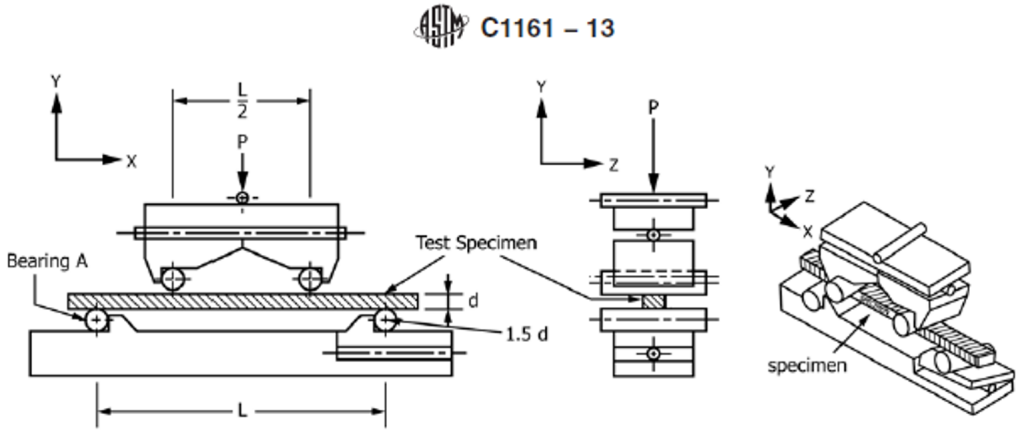


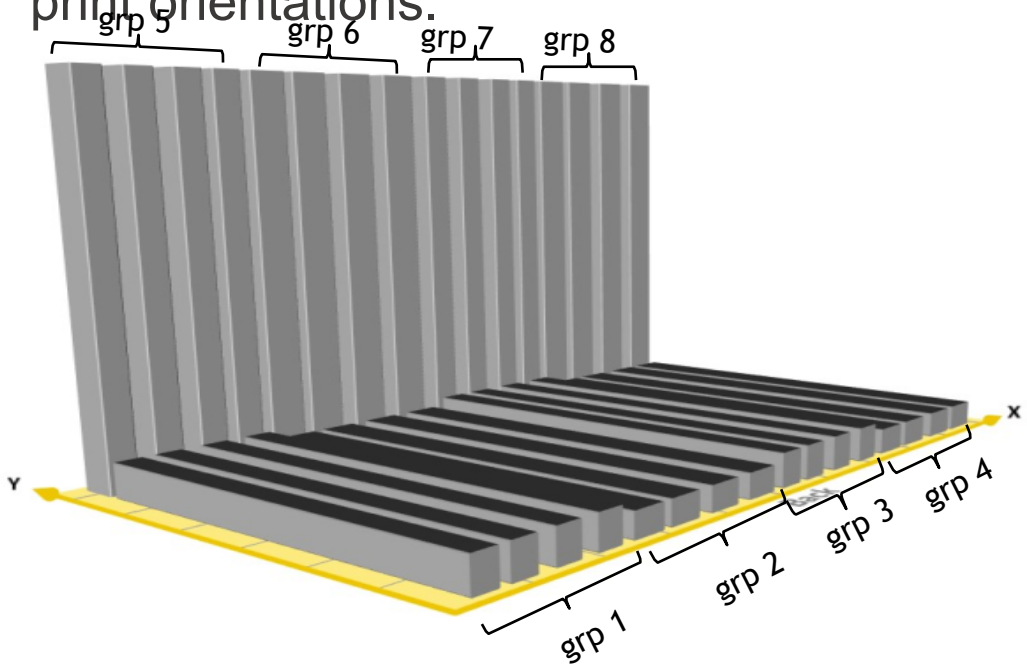


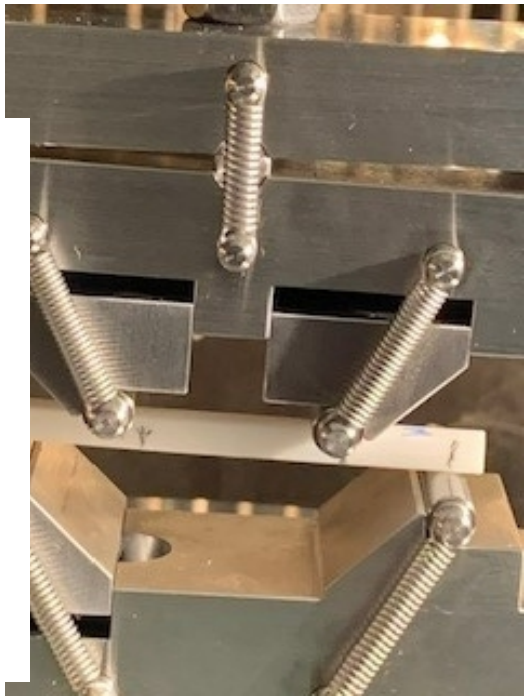
Flexural Bend Testing

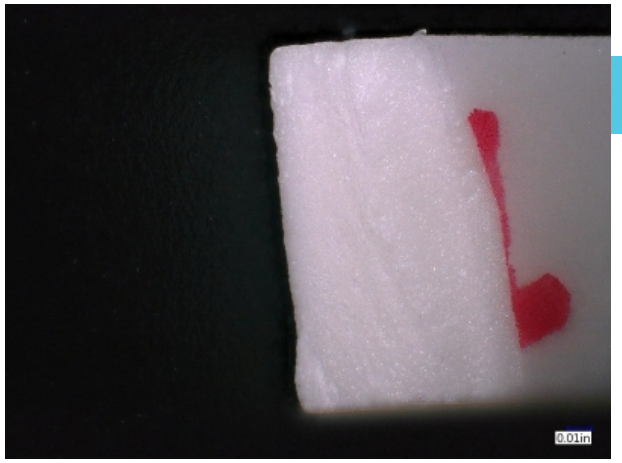
To quantify the strength of ceramics the ASTM C1161-13 four-point bend test was performed.

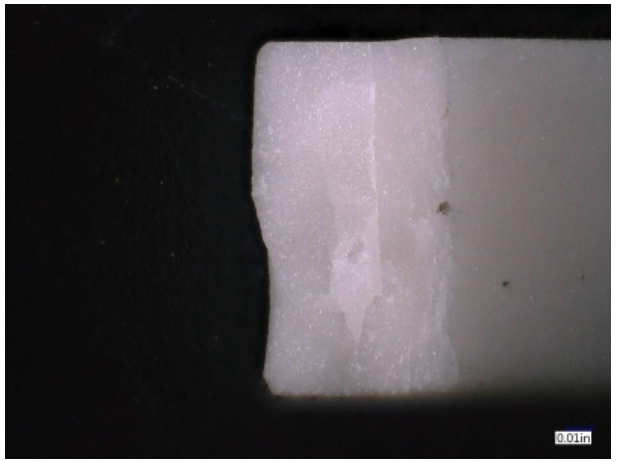
For statistical evaluation 128 samples were evaluated with 4 different print orientations.

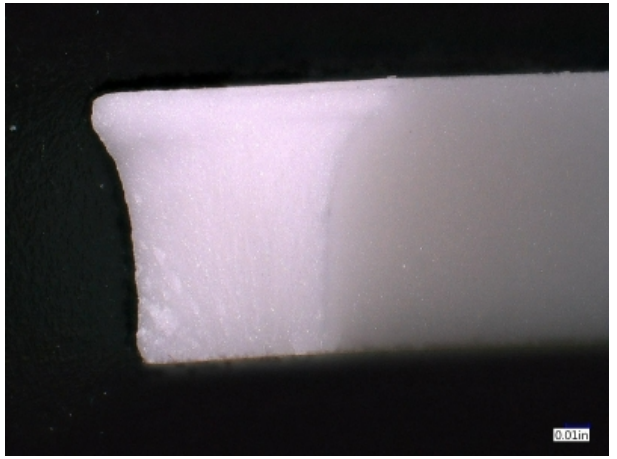






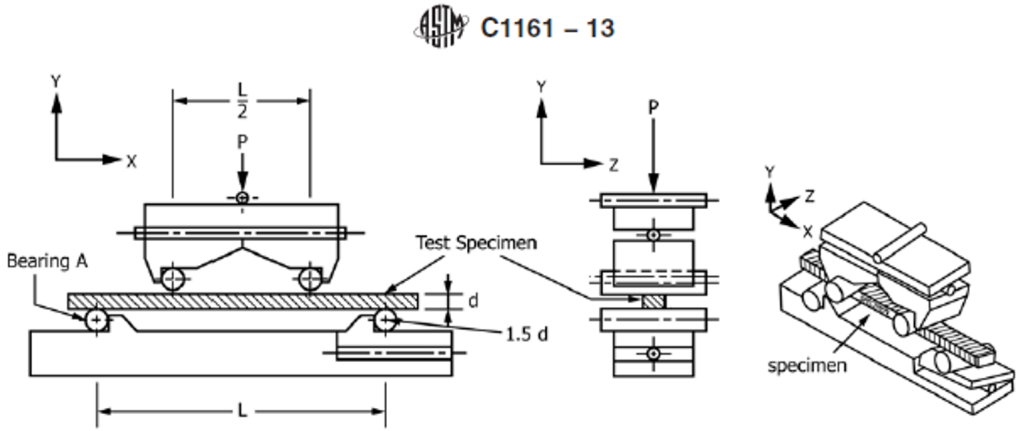


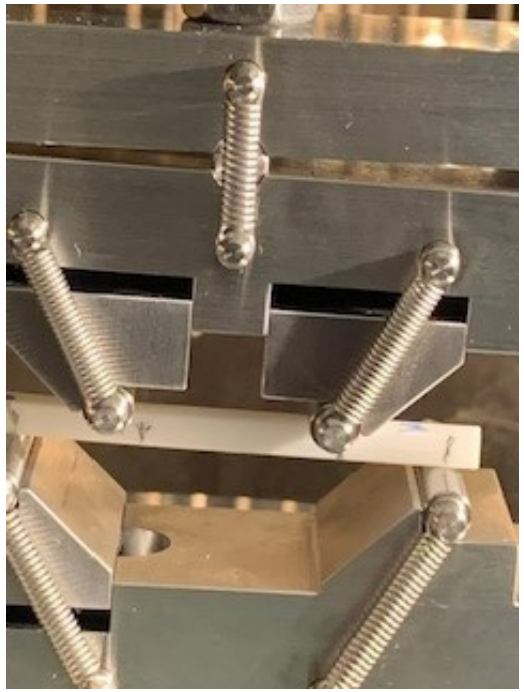


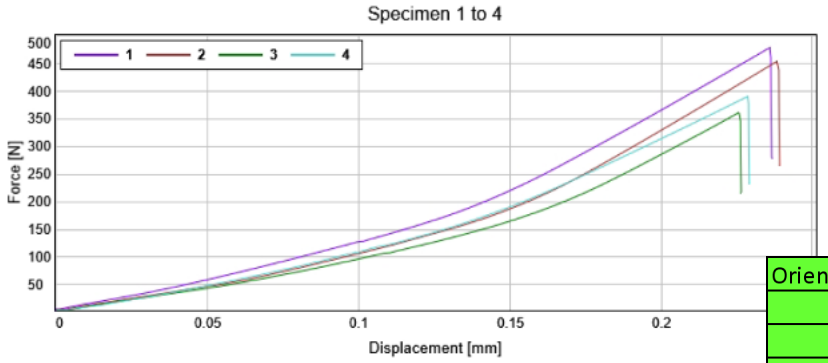


Experimental: Testing

- 5 kN Instron
- 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)

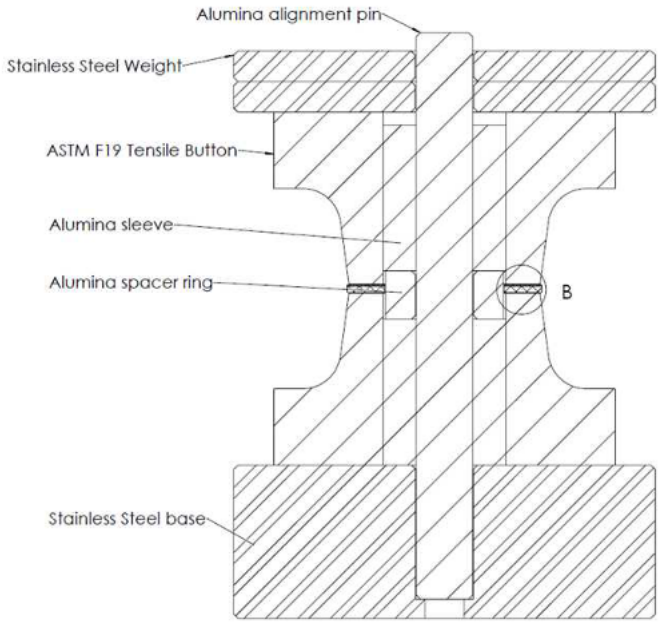


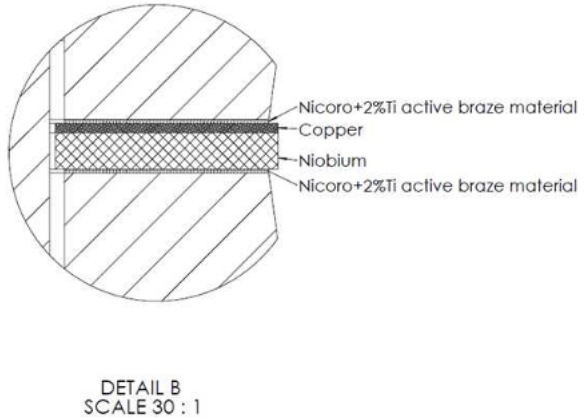


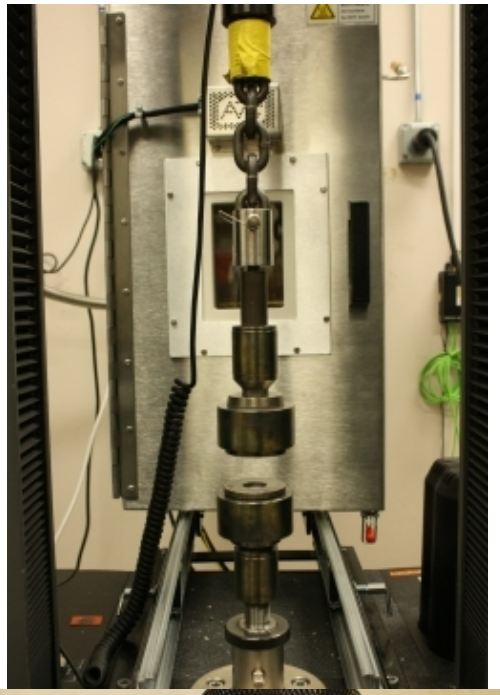


Orientation	number samples	Average failure stress (Mpa)	stdev	width avg (mm)	width std	Thick Avg (mm)	Thick Std	avg humidity (%)	stdev humidity
1	32	314.66	35.16	4.01	0.08	3.04	0.03	48.94	8.00
2	32	320.59	60.71	4.09	0.07	3.02	0.08	50.30	0.52
5	32	328.07	39.10	4.07	0.05	3.04	0.02	50.49	0.45
6	32	313.21	55.74	4.09	0.04	3.05	0.03	50.57	0.43
STC (2021)	30	347.08	19.18	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	-

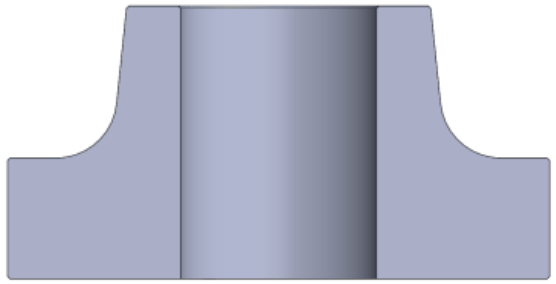
ASTM F19 Tensile Button Braze Testing



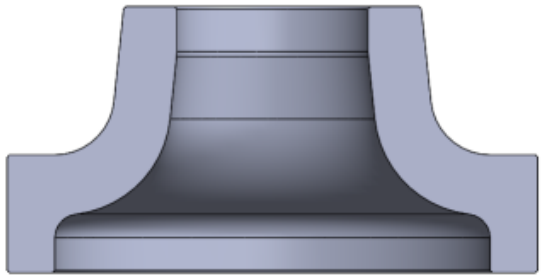




Standard Test Profile
Cross Section



Lithoz Test Profile
Cross Section



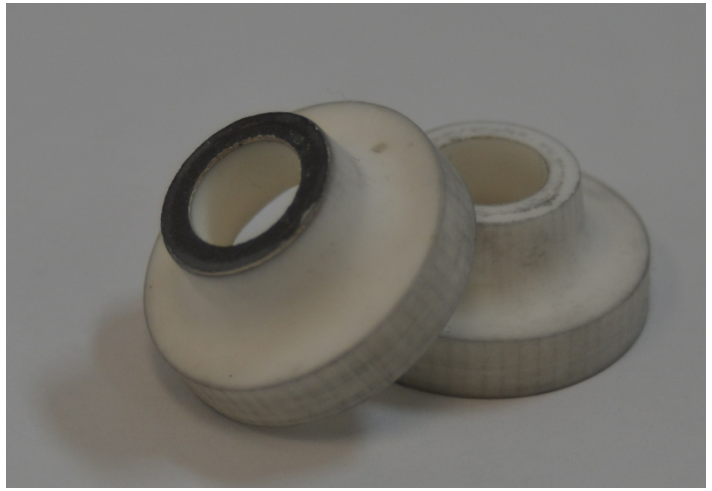
ASTM F19 Tensile Button Testing Results

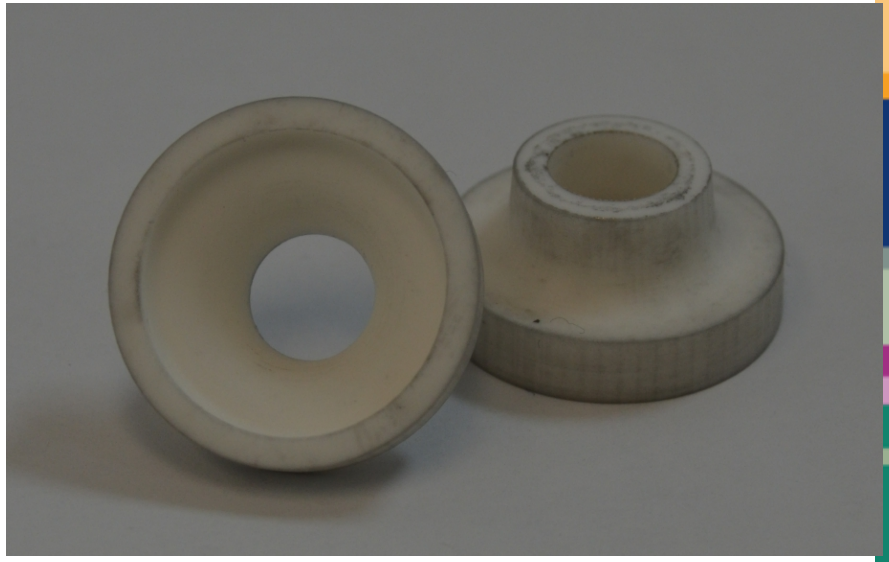
SNL ceramic tensile button manufactured using Lithoz CeraFab 8500.

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.





Density and Coefficient of Thermal Expansion Testing

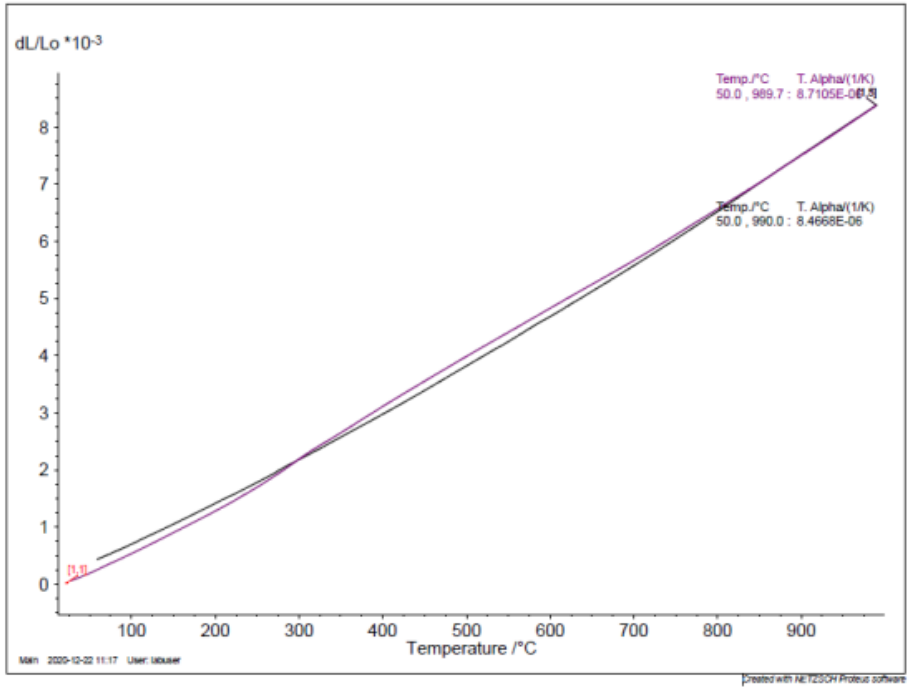
Archimedes Density results ASTM C830

Initial testing shows Additively Manufactured densities are consistent with traditionally manufactured densities.
All measurements were 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	3.72	0.7
T5A2	1.074	0.788	1.077	3.72	1.0
T2A3	1.408	1.033	1.409	3.74	0.3
T3A2	1.192	0.875	1.196	3.71	1.2
T8A2	1.059	0.778	1.06	3.76	0.4

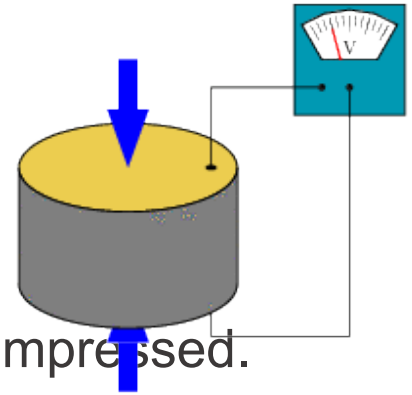
CTE testing ASTM E228-11

Similar to density, the CTE initial test results indicate the printed material performed like traditionally processed Ceramic materials



Future and Current Teaming projects with Lithoz America

Continuing the development of the SNL glass-based alumina ceramic



<u>Material developments underway!</u>

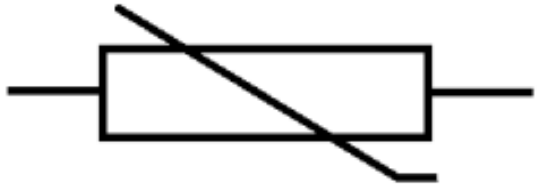
PZT – a piezoelectric ceramic develops a voltage across two faces when compressed.

Al_2O_3 based Cermet – an electrically conductive composite material.

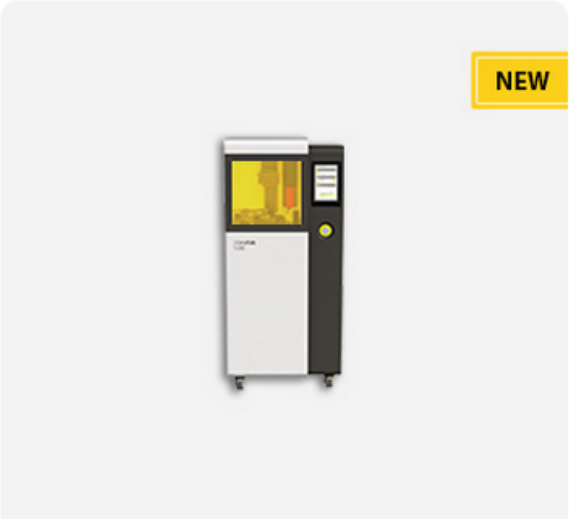
<u>Upcoming developments</u>

Varistor – voltage dependent resistor

Next SNL Glass-based Ceramic



Where Lithoz is Headed!



CeraFab Lab

- **Entry level**
- **Compact and easy-to-use**
- **High-quality components**

CeraFab System

- **Serial production**
- **Easy industrial scale-up**
- **IIoT and Industry 4.0 ready**

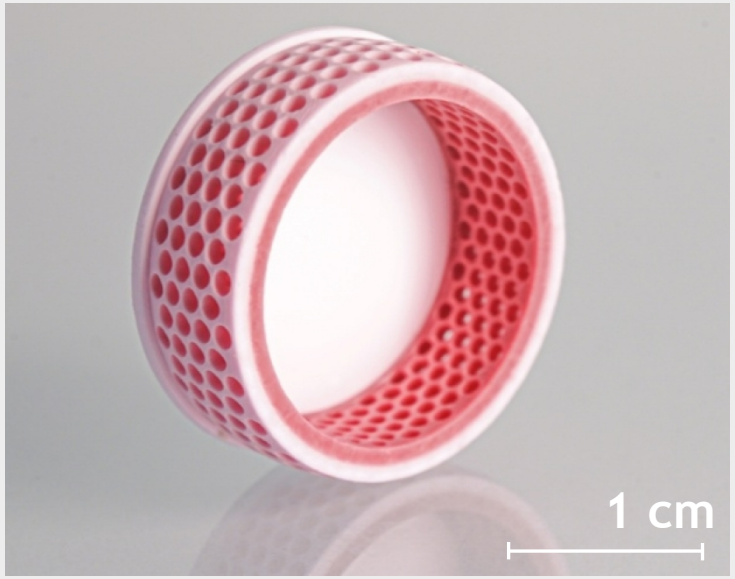
CeraFab Multi

- **Multi-material 3D printing**
- **Combine ceramics, metals, polymers**
- **Integrate own features**

CeraFab System Medical

- **Medical and dental**
- **Widest available range of biomaterials**
- **Automatic documentation and traceability**

Multimaterial Samples



Ring (coloured alumina) „as fired state“

QR Code (coloured alumina) „green parts“

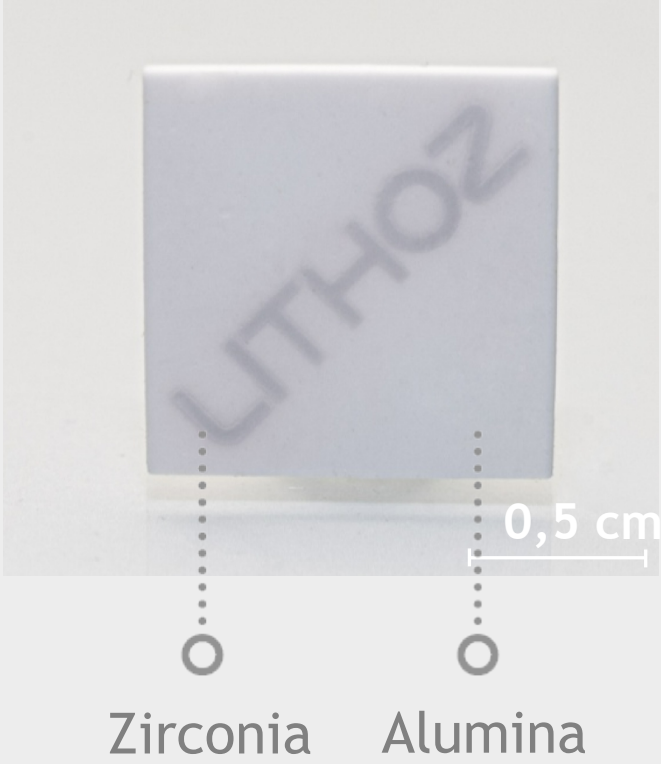


Plate Alumina | Zirconia „as fired state“

THANK YOU!