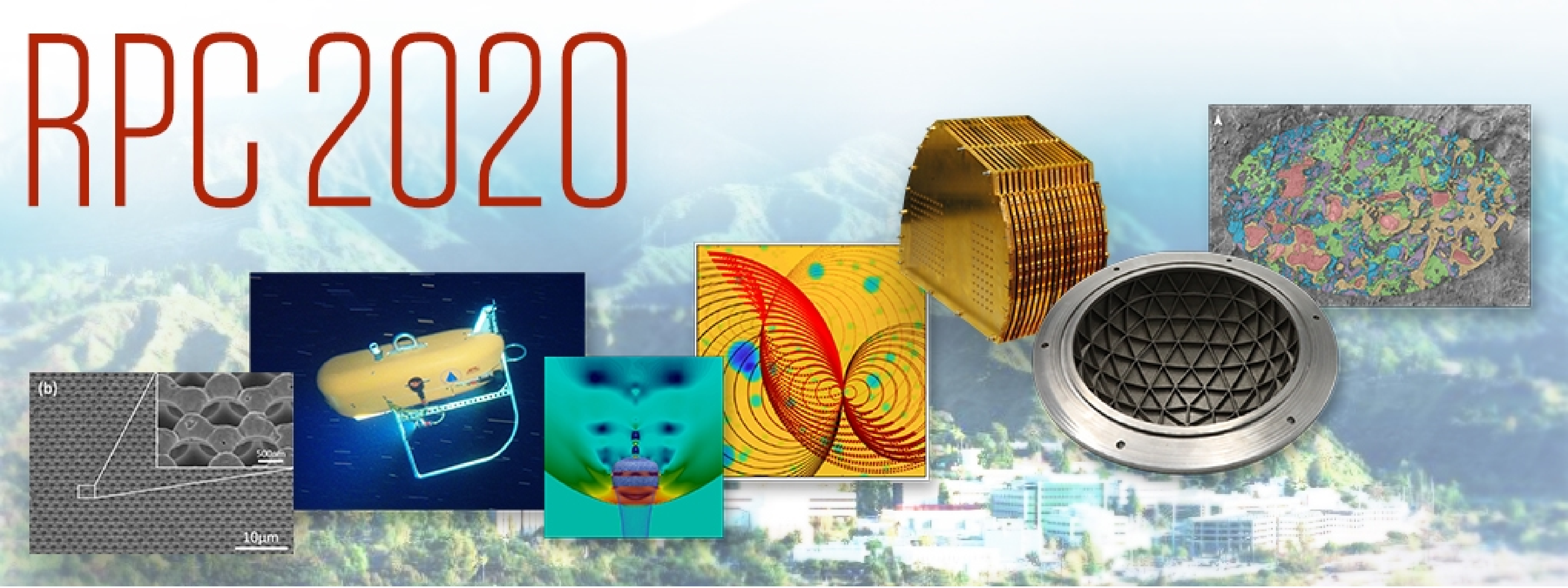

Virtual Research Presentation Conference

3D Printed Ceramic Structures for Magnetometers

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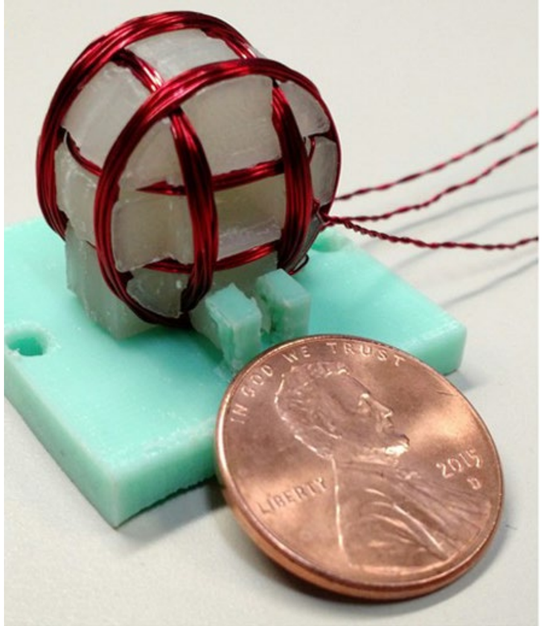
Program: Topic

Assigned Presentation # R20262

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Magnetometer instruments have a long history at JPL and are continuing to be developed for future missions. The next generation of these instruments have increased science capability, requiring a higher degree of sensitivity particularly in the Helmholtz coil structure.



Polymeric Helmholtz coil prototype for next generation Silicon Carbide Magnetometer (SiCMAG)

Cochrane, C. *et al.* Vectorized magnetometer for space applications using electrical readout of atomic scale defects in silicon carbide. *Sci Rep* **6,** 37077 (2016). https://doi.org/10.1038/srep37077

Problem Description

- Historically, polymeric materials (e.g. Lexan) have flown, but exploration of environments with high radiation doses and/or large temperature swings limit the use of polymers

- Zirconia and alumina based oxide ceramics have lower magnetic susceptibility and electrical conductivity than typical metallic materials while maintaining higher strength and resistance to radiation compared to polymers. However, traditional manufacturing of ceramics using subtractive methods pose severe design and geometry limitations, coupled with high cost

- **Here we investigate the feasibility of using ceramic additive manufacturing methods to print magnetometer coil housings**

Methodology

- Survey currently available materials, technologies and vendors for 3D printing of ceramics and down-select based on published material properties, and feature/design limitations (e.g. resolution).
- Design, analyze, and optimize magnetometer housing for 3D printing. Iterate over design to ensure that it is manufacturable and survives defined environment.
- Print and test mechanical and geometry test coupons in sufficient quality to establish preliminary characteristic strength, Weibull modulus, and part to CAD geometry comparison. Additional mechanical test coupons built at varying angles with respect to build direction may be included if budget permits.
- Print and test magnetometer coil housings to compare performance between polymer, metal, and ceramic structures.

Results – Materials and print process selection

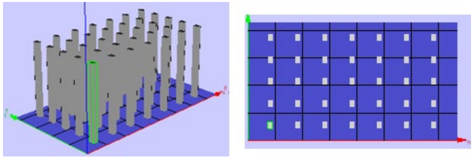
	Density	Magnetic Susceptibility (10^{-6})	Elastic Modulus (Gpa)	Compressive Strength (Gpa)	Fraction Toughness ($Mpa\text{-}m^{1/2}$)	Flexural Strength (Mpa)	Weibull Modulus
Alumina[1,3,4,5]	3.95	-1.433	300	2000-2600	4-5	314	8.21
Zirconia[1,3,5,6]	5.68	-0.636	205	2300	10	1000-1200	13.9
Titanium[2,7]	4.51	14.214	105		66		
ABS[8,9]	1.01-1.21		1.19-2.9		1.19-4.29	70.5	
Ultem[10]	1.27		2.96	151		151.7	

- Zirconia and alumina selected for their, low magnetic susceptibility and high strength
- Evaluated lithography-based ceramic manufacturing (LCM) which produces a green body layer by layer via photo polymerization of a ceramic powder filled polymeric liquid. The green body is then sintered to produce a fully dense ceramic part
    - Printing carried out at Lithoz America LLC.

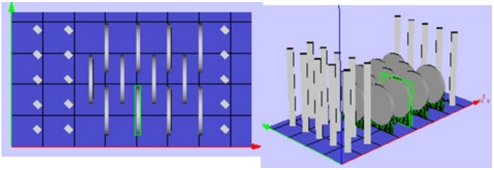
Results- Mechanical properties of AM Ceramics

	Number of test coupons	Average Flexural Strength (Mpa)	Characteristic Strength (Mpa)	Weibull Modulus	Average Flexural Modulus (Gpa)
Alumina Build 1	15	320.0 ± 49.7	339.1	8.8	379.6 ± 80.1
Alumina Build 2	13	363.4 ± 69.8	388.1	7.5	407.4 ± 47.9
Zirconia Z - ortho	30	641.4 ± 132.7	693.8	6.2	215.6 ± 11.6
Zirconia Z 45 degree rotation	15	620.0 ± 95.1	663.0	6.1	212.0 ± 9.3
Zirconia Z-complex	15	527.0 ± 57.1	549.9	12.9	207.8 ± 7.8

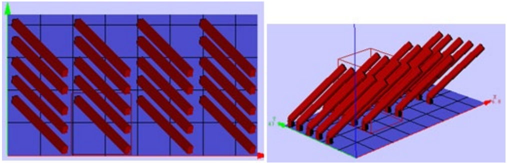
Four point flexural test (ASTM C1161) data for printed alumina and zirconia test specimens



"Z-Ortho" build orientation



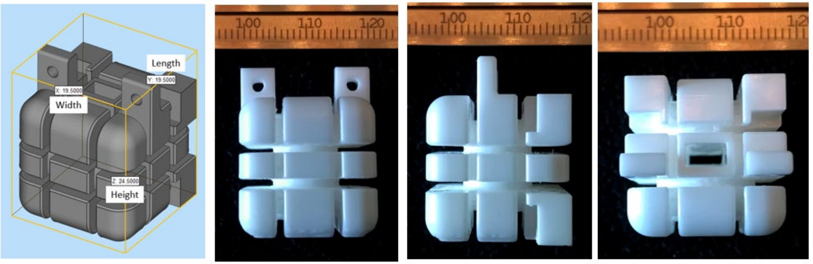
"Z-45" build orientation



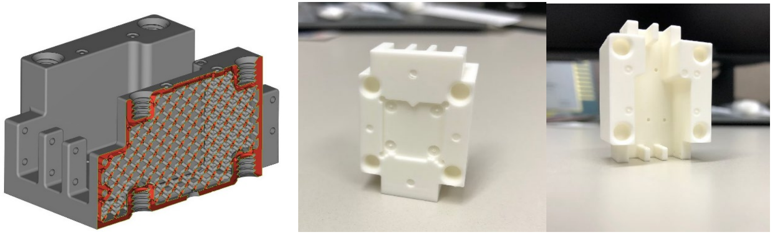
"Z-Complex" build orientation

- Alumina characteristic strength of 340 mpa and 388 mpa for builds 1 and 2, respectively
- Zirconia coupons were built in 3 different orientations to get a preliminary understanding of variability in strength with build orientation (typical in most AM processes) which are illustrated in the above figure
    - Some variability in Weibull modulus is also observed (~6-13) with build orientation. Fractographic analysis may be performed in the future to help elucidate these differences

Results- Printed test coupons and prototypes



CAD model and macro photographs of 3D printed zirconia magnetometer coil housing



CAD model showing internal lattice work and macro photographs 3D printed alumina ceramic manifold for Spacecraft Atmosphere Monitoring (SAM) project

- Printed prototype Helmholtz coil housing in zirconia
- Identified and alternate application and printed prototype ceramic manifold for Spacecraft Atmosphere Monitoring (SAM)
  - The ceramic manifold is a small component for SAM that functions to hold multiple chip based chemical sensors and contains a 0.3mm diameter linear internal channel for directing gas flow.

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