Additive Manufacturing of Non-Oxide Ceramics for SmallSat Thrusters

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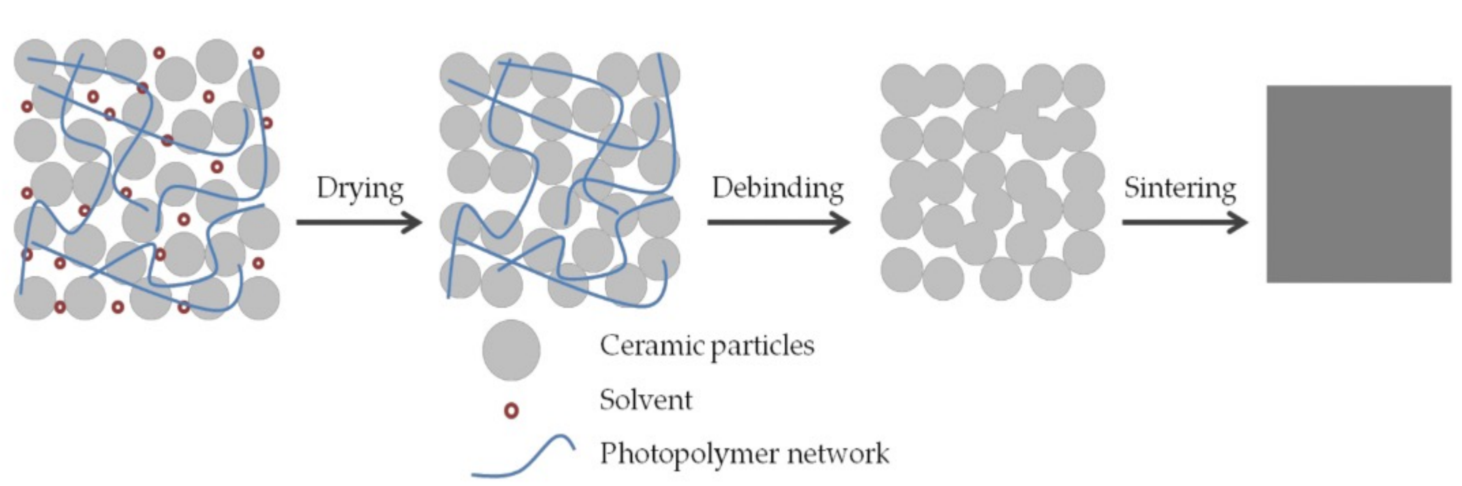
SCAN ME

ABSTRACT

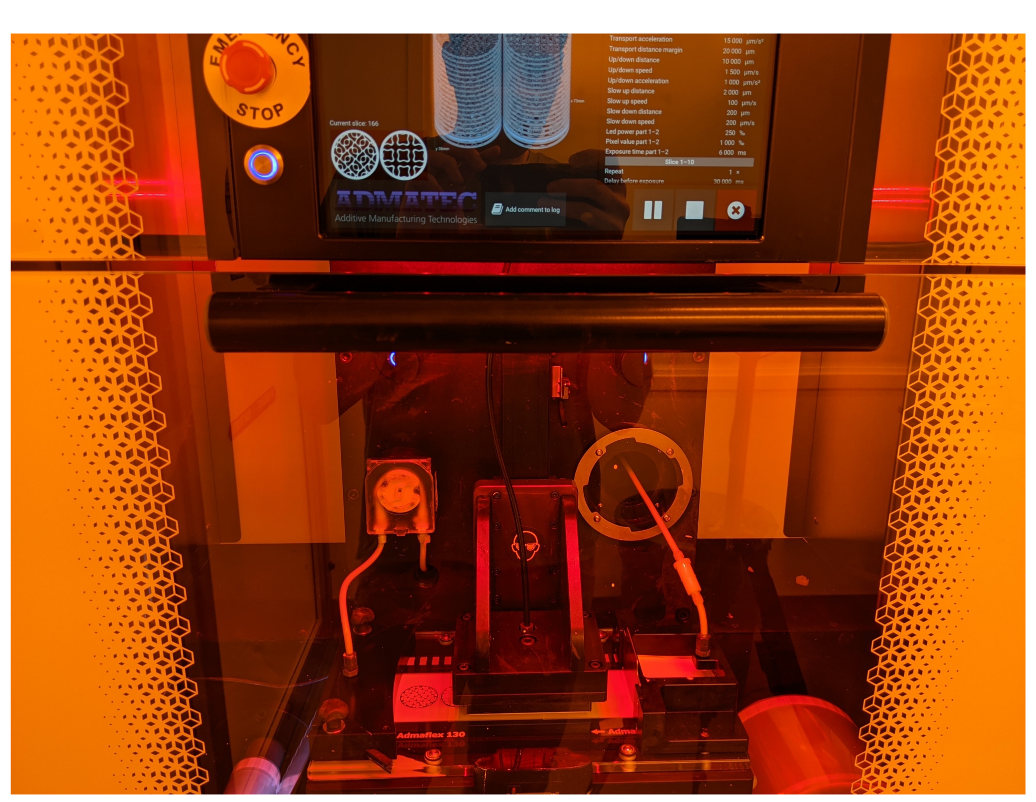
This project is focused on developing a technique to additively manufacture thrusters for smallsat thruster applications. For components like this, the materials must be able to withstand high thermal shocks and pressures, as well as maintain their properties in the presence of highly corrosive propellants like hydrazine. Additive manufacturing of ceramics is a technique that can provide these desired properties, while enabling design flexibility and lowering costs from conventional ceramic manufacturing techniques. By using digital light projection (DLP) to print ceramic parts, we can achieve over 99% dense final parts with feature sizes down to 50 microns, however most research in this method so far focuses on oxide ceramics, as they are much easier to process. This work aims to develop a method for printing non-oxide ceramics, specifically silicon nitride (Si_3N_4), as it has much higher thermal shock resistance, but presents optical challenges for printing with DLP due to its high absorbance and refractive index. The processing is based on already published techniques for printing silicon nitride via DLP, but no published work thus far has focused on using these printed ceramics for the extreme operating conditions they will experience in space. To determine the viability of using printed parts for smallsat applications, the flexural strength of printed test bars will be performed, and thermal shock and pressure testing will be performed on printed scale models of a thruster.

DIGITAL LIGHT PROJECTION (DLP) AM

Suspension of ceramic particles in a photosensitive resin is exposed to light layer-by-layer with ~50 µm feature size. Green parts are then dried, debound in a furnace to burn off polymer resin, and then sintered to achieve final parts with >99% density.



Depiction of the DLP green part post-processing steps[1]



Admatec Admaflex 130 DLP printer

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IMPROVING THERMAL SHOCK RESISTANCE

FLEXURAL BENDING

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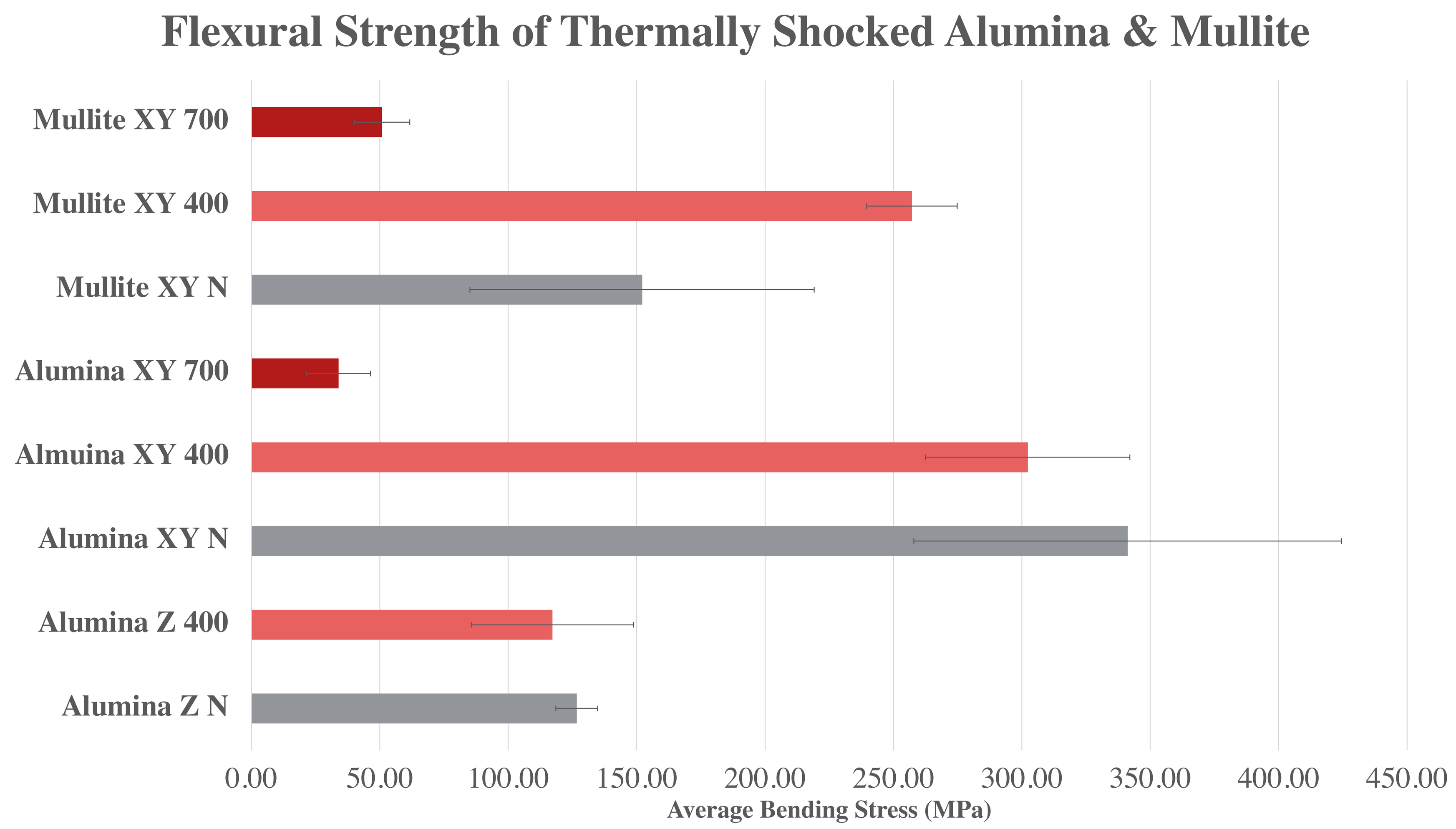
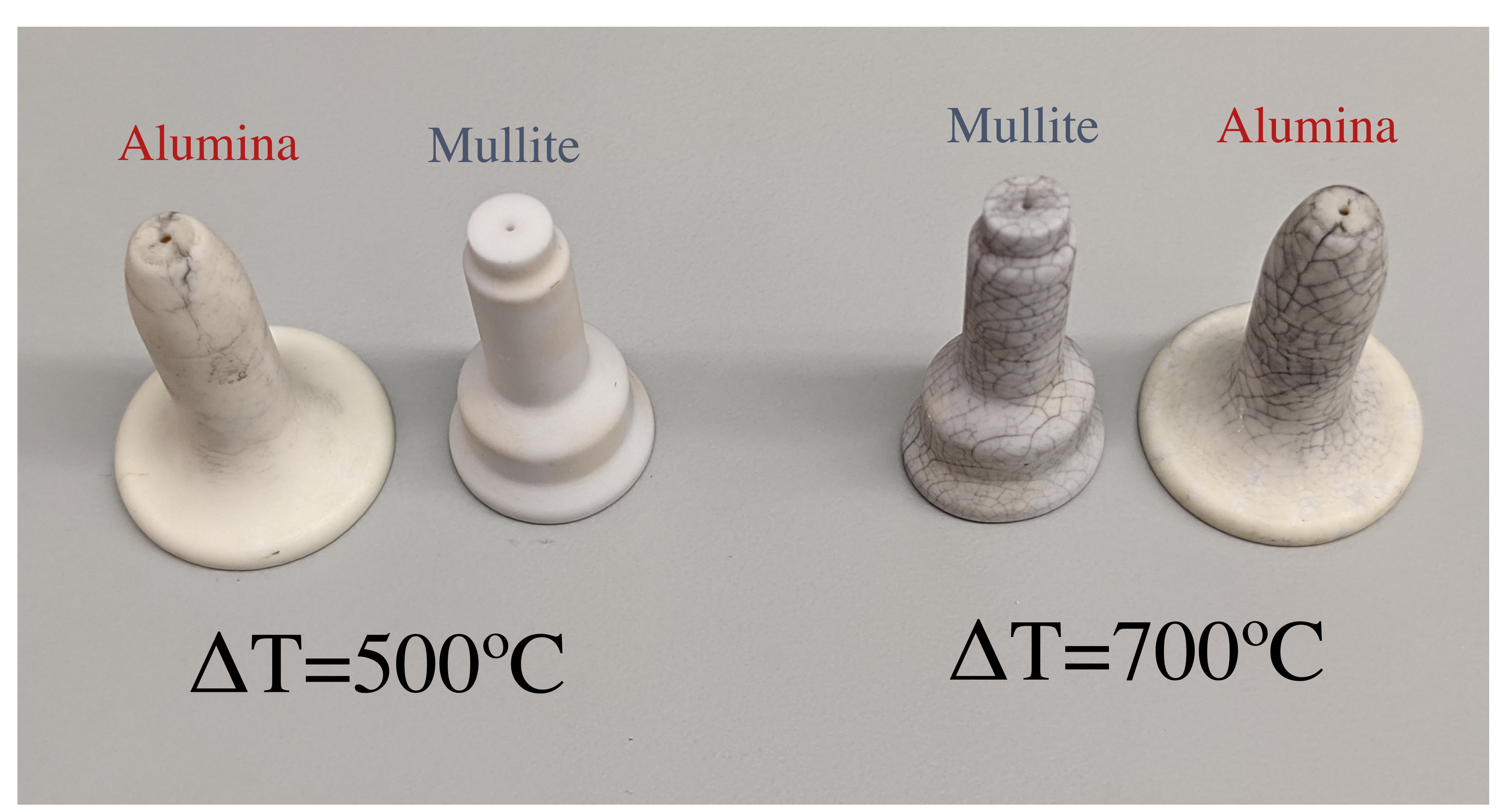


Results of four-point bending tests of alumina and mullite (95% Al_2O_3/5% SiO_2 for unshocked samples and thermal shocks with a ΔT of 400ºC and 700ºC.

NOZZLE THERMAL SHOCK



Conventionally-manufactured alumina nozzles and 3D-printed mullite burners

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DEPTH OF CURE &ADHESION FOR Si_3N_4 SLURRY

Preliminary cure depth testing to determine printing feasibility of printing Si_3N_4 slurry prepared based on prior work[2][3] on our printer, compared to alumina parts. For depth of cure, slurry was exposed over a range of LED powers for a range of exposure times with the goal of achieving a solid thickness of at least 60µm (in alumina, this can be achieved with an exposure time of 3-5s and LED power of 17 mW/cm²). With these preliminary results, it is feasible to print using this method.

	5 s	10 s	15 s
35 mW/cm²	53 μm	66 μm	74 μm
38 mW/cm²	53 μm	65 μm	80 μm
42 mW/cm²	47 μm	73 μm	75 μm
45 mW/cm²	53 μm	71 μm	70 μm

To test success of layer adhesion in printing, slurry was spread on the build platform and exposed in a large square, then more slurry was spread and the process repeated to get a 5-layer piece. Preliminary results are promising for part adhesion during build.

5-layer adhesion test piece successfully removed from build plate. Further work with controlled slurry spreading is needed to more accurately simulate printing conditions.

FUTURE WORK

- Scale up Si_3N_4 slurry development process
- Print test parts in silicon nitride & sinter
- Perform flexural strength & thermal shock testing
- Perform high-pressure testing on printed silicon nitride parts

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