Freeform 3D Printing of Pure Ceramics
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Introduction
Ceramics are favorable for use in extreme environments, as they are lightweight, are resistant to high temperatures and corrosion, and offer comparable mechanical properties to their metal alloy counterparts. Applications include:
- electronic device packaging
- gas turbine components
- heat shields for aerospace structures

Challenges
Current additive manufacturing processes not suitable for ceramics due to:
- extremely high melting point (compared to metals and polymers)
- low laser absorption characteristics
- low production efficiency

Project Goals / Outline
Develop recipe for preceramic polymer solution which can be:
- easily extruded using custom-made 3D printer
- cured to produce strong, dense ceramic parts

Develop recipe for support bath which can:
- be printed into using preceramic polymer solution
- maintain geometry of parts during printing and curing

Determine mechanical properties of printed parts and compare to those cast conventionally

Preceramic Polymer / Ceramic Characterization

Support Bath Characterization

Printing and Curing Process

Print 3D parts into support bath and cure

Fig. 1. Schematic of the freeform printing process

Fig. 2. (A) – (C) CAG image and photos of a 3D printed truss-beam structure after curing and pyrolysis, respectively. (D) The final printed specimen shown over a flame. (E) Several geometries after curing and after pyrolysis. Printing duration for the parts ranged within ~ 8 – 115 seconds.

Fig. 3. (A) Photo of the preceramic polymer solution in vial. Viscosity of the polymer solution is ~800 cP (1 cP = 10⁻³ Pa.s). (B) – (C) Photos of the support yield stress support bath in beakers. Static viscosity of the bath is ~1000 Pa.s. (D) Comparison of the preceramic polymer viscosity to other common liquids. (E) – (G) Rheological properties of the support bath: (E) shear stress vs. shear rate, (F) viscosity vs. shear rate, and (G) storage and loss moduli.

Fig. 4. (A) Thermogravimetric analysis (TGA/DTG) curve and (B) differential scanning calorimetry (DSC) curve for the preceramic polymer. (C) A 3D printed ceramic beam under three-point bending loading for flexural strength measurements. (D) SEM image of the ceramic beam fracture surface. (E) Weibull plot for strength of 3D printed and casted ceramic. N = 33 for 3D printed ceramic and N = 18 for cast ceramic.

Conclusion
- Developed low-cost, efficient, scalable, and novel freeform fabrication method for polymer-derived ceramics
- Created support bath that maintains part geometry during printing and one-step high temperature curing
- Mechanically characterized ceramic beams to confirm high characteristic strength of printed specimens (~257 MPa)

References

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