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**
- 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

Process Flow

Create preceramic polymer solution

↓

Create support bath

↓

Print 3D parts into support bath and cure

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Characterize support bath (rheological test) and parts (three-point flexural test, differential scanning calorimetry (DSC) / thermal gravimetric analysis (TGA))

Printing and Curing Process

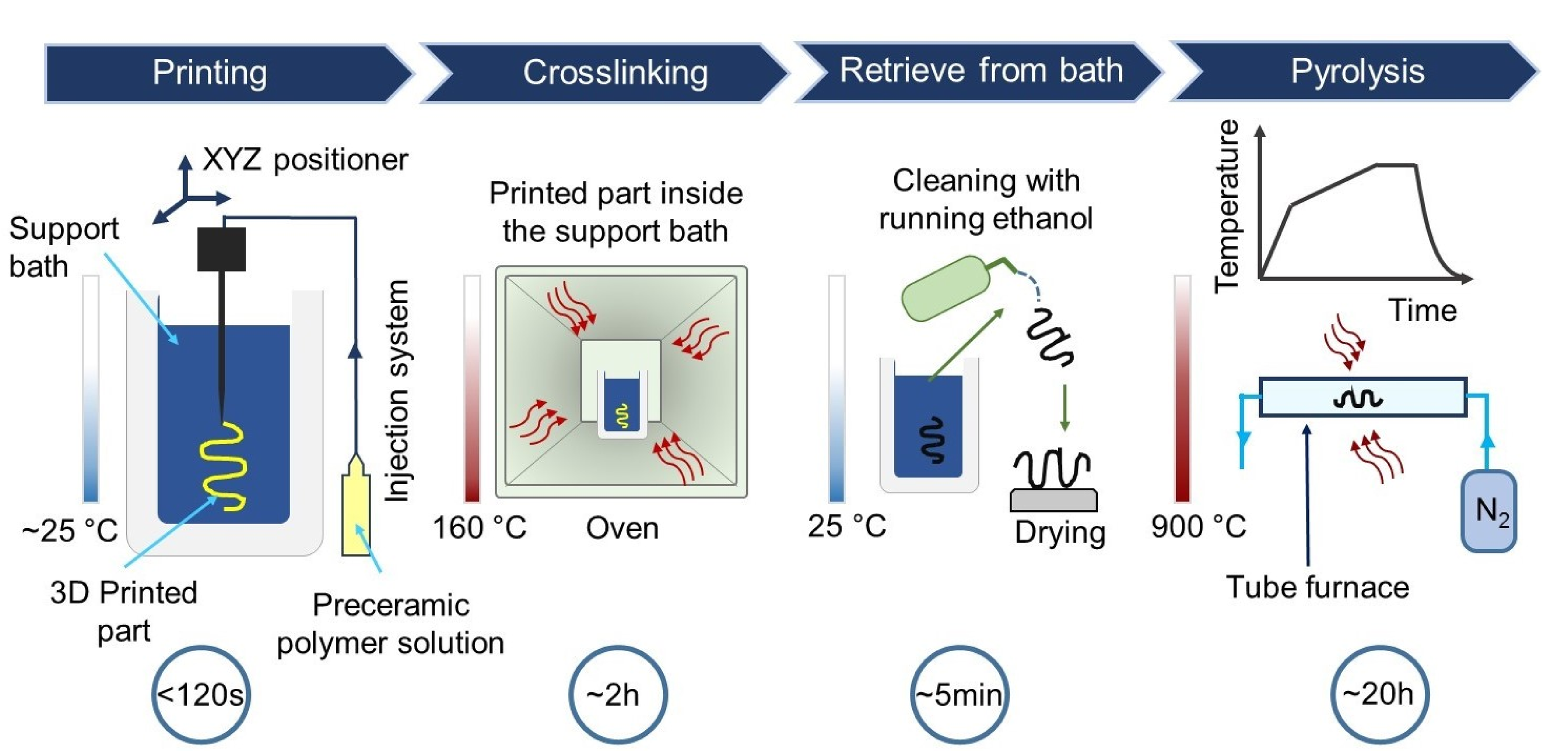

Fig. 1. Schematic of the freeform printing process

Sample Part Geometries

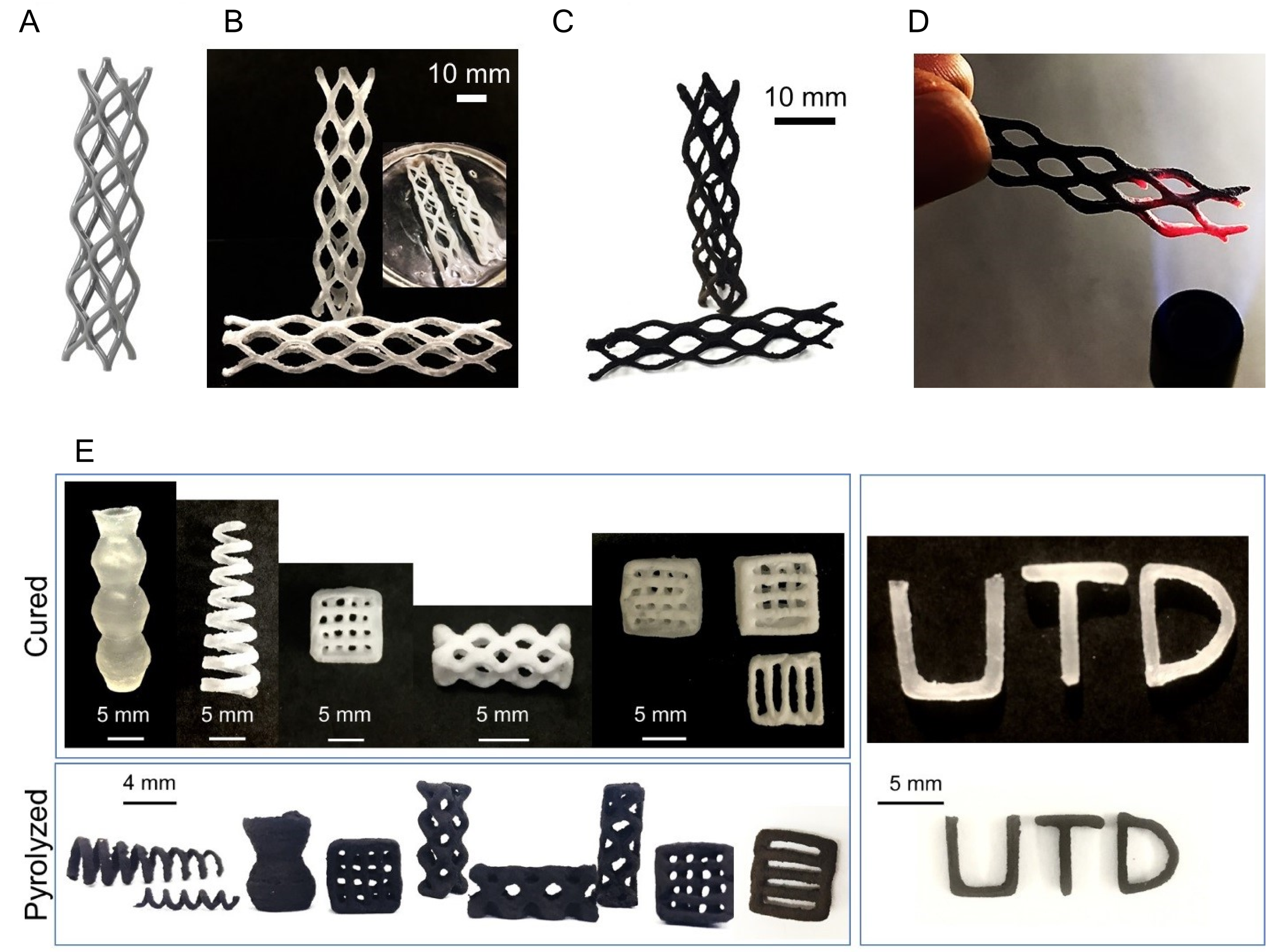

Fig. 2. (A) – (C) CAD image and photos of a 3D printed truss-beam structure after curing and pyrolysis, respectively. **(D)** The final specimen shown over a flame. **(E)** Several geometries after curing and after pyrolysis. Printing duration for the parts ranged within ~ 8 – 115 seconds.

Support Bath Characterization

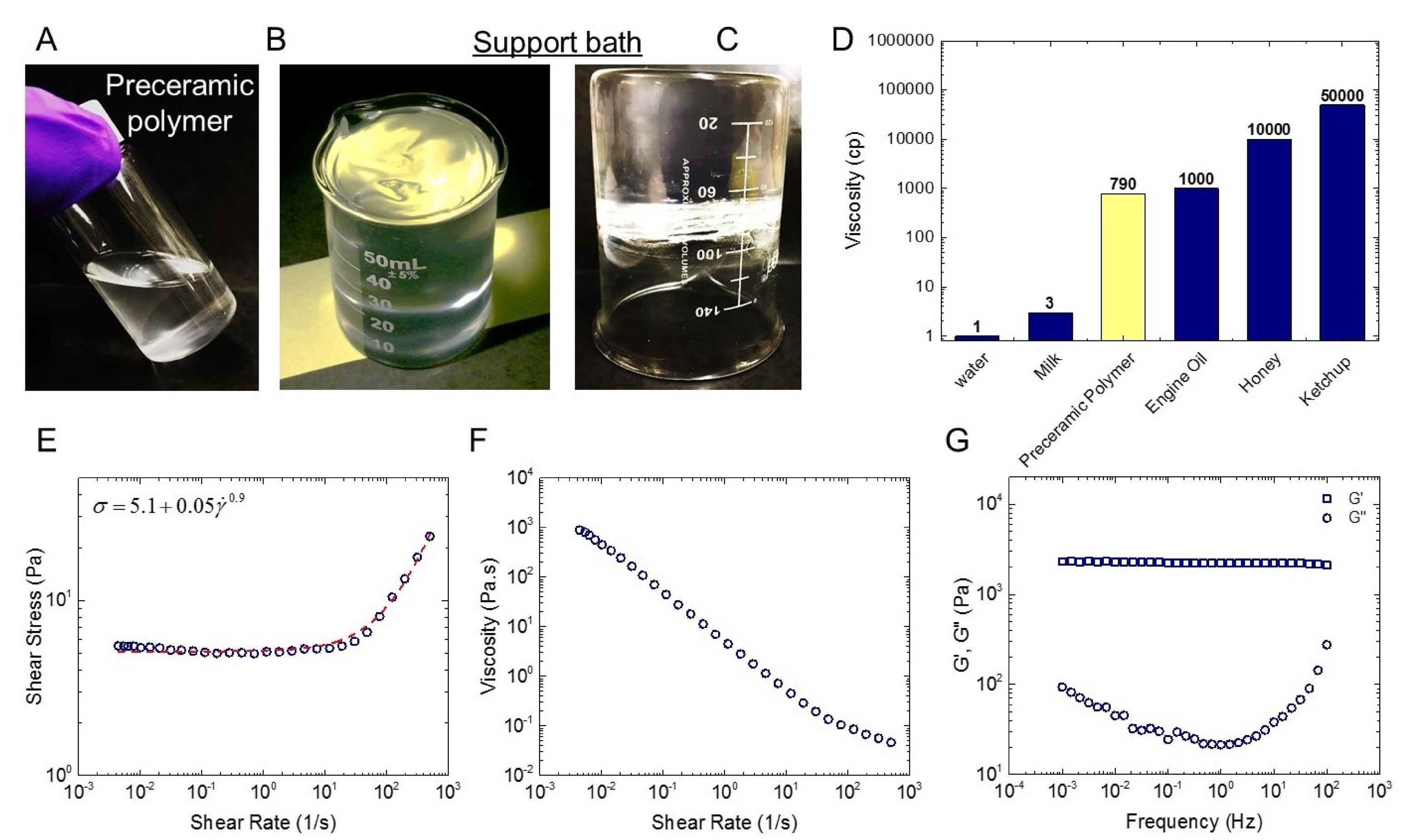

Fig. 3. (A) Photo of the preceramic polymer solution in vial. Viscosity of the polymer solution is ~800 cP (1 cP = 10^{-3} Pa.s). **(B) – (C)** Photos of the support yield stress support bath in beakers. Static viscosity of the bath is ~1000 Pa.s. **(D)** Comparison of the preceramic polymer viscosity 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.

Preceramic Polymer / Ceramic Characterization

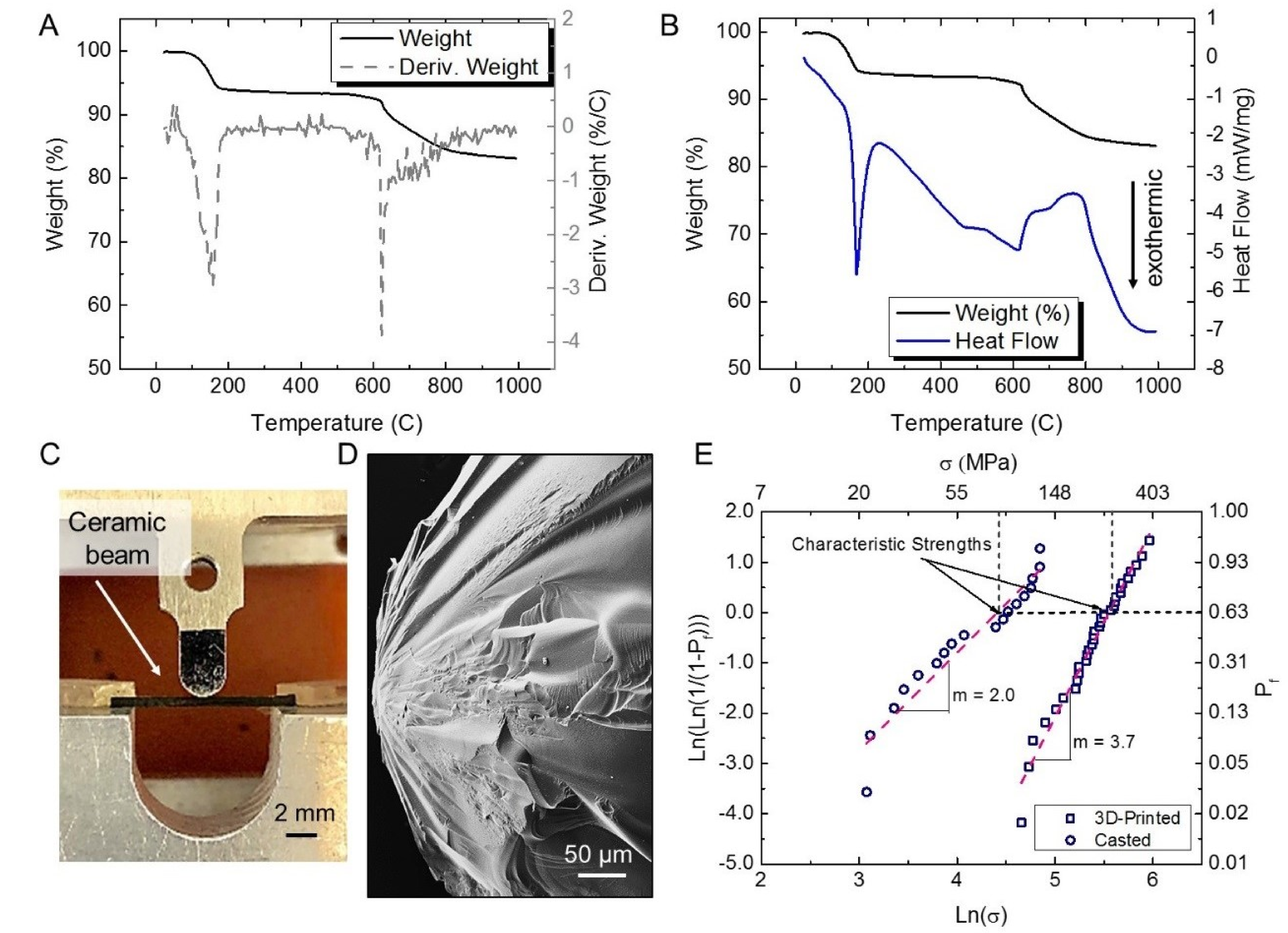

Fig. 4. (A) Thermogravimetric analysis (TGA/DTG) curve and **(B)** differential scanning calorimetry (DCS) curve for the preceramic polymer. **(C)** A 3D-printed ceramic beam under three-point bending loading for flexural strength measurements. **(D)** SEM image of the ceramic beam fracture surface. **(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)

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