Hybrid Direct Ink Writing/Embedded Three-Dimensional Printing of Smart Hinge from Shape Memory Polymer

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BACKGROUND

Smart hinges can recover their original shapes after deformation upon exposure to external stimuli, such as temperature, pH levels, and light [1]. Currently, smart hinges are made using shape memory polymers (SMPs) through casting or vat photopolymerization, a three-dimensional (3D) printing method. However, casting cannot fabricate smart hinges with complex geometries, while vat photopolymerization is limited to a single SMP build material that must have a low viscosity and be crosslinkable, severely narrowing the selection of SMPs. Direct ink writing (DIW) and embedded 3D printing (e-3DP) can be simultaneously used to create functional smart hinges with intricate structures and embedded circuits to monitor the performance.

OVERVIEW

A hybrid DIW/e-3DP approach has been proposed and investigated. A photocurable resin, *t*BA/AUD, was selected and mixed with different concentrations of fumed silica (FS) particles to prepare a self-supporting SMP ink. Thus, a complex 3D structure can be printed at uncured state in air via DIW, in which e-3DP can be applied to deposit a conductive ink into different sensors (**Fig. 1**).

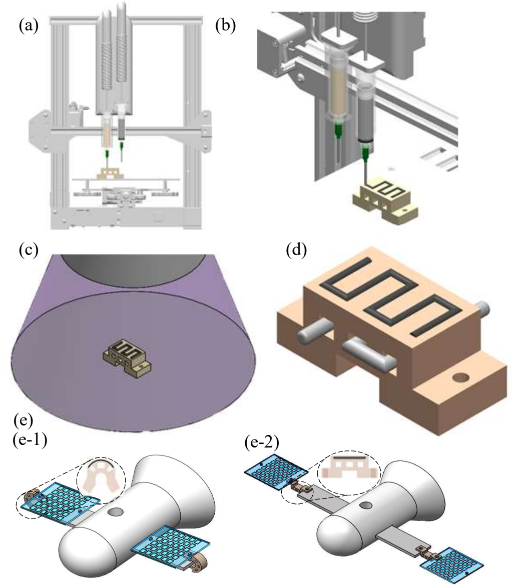

Fig. 1. Schematic of hybrid DIW/e-3DP fabricated smart hinge with embedded circuits. **(a)** DIW of a liquid 3D hinge from a self-supporting SMP ink. **(b)** E-3DP of conductive ink for a strain sensor within the uncured structure. **(c)** UV crosslinking. **(d)** Crosslinked hinge with a resistance wire to induce external stimuli. **(e)** Potential application where **(e-1)** programmed hinges can return to **(e-2)** the original printed shape to deploy mock solar panels.

MATERIALS

1) *tert*-Butyl acrylate (*t*BA): linear chain builder
2) Aliphatic urethane diacrylate (AUD): crosslinker
3) Fumed silica (FS): rheological additive

How will 6, 8, and 10% (w/v) FS affect 50%/50% (w/v) *t*BA/AUD?

RHEOLOGICAL PROPERTY & STABILITY TESTS

Steady shear rate sweeps were performed to determine the yield stress (τ_0) of each SMP ink (**Fig. 2a**). Transient step shear rate sweeps were conducted to assess the thixotropic time (t_c) of each SMP ink (**Fig. 2b**). The mass of the inks with different FS% were recorded to investigate the dry-out phenomenon of the SMP inks (**Fig. 2c**). 50%/50% *t*BA/AUD were used for all tests.

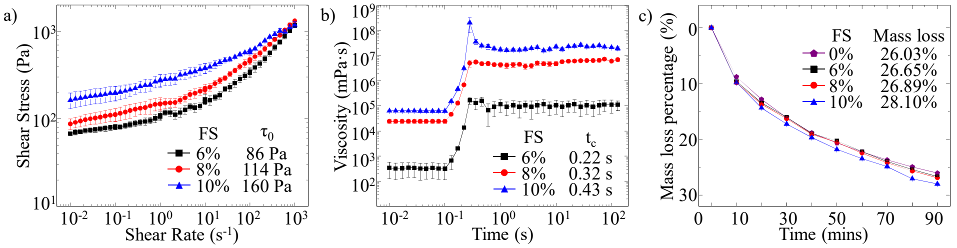

Fig. 2. The **(a)** yield stress, **(b)** thixotropic time, and **(c)** mass loss characterization of SMP inks with different percentages of FS.

FILAMENT PRINTING VIA DIW & E-3DP

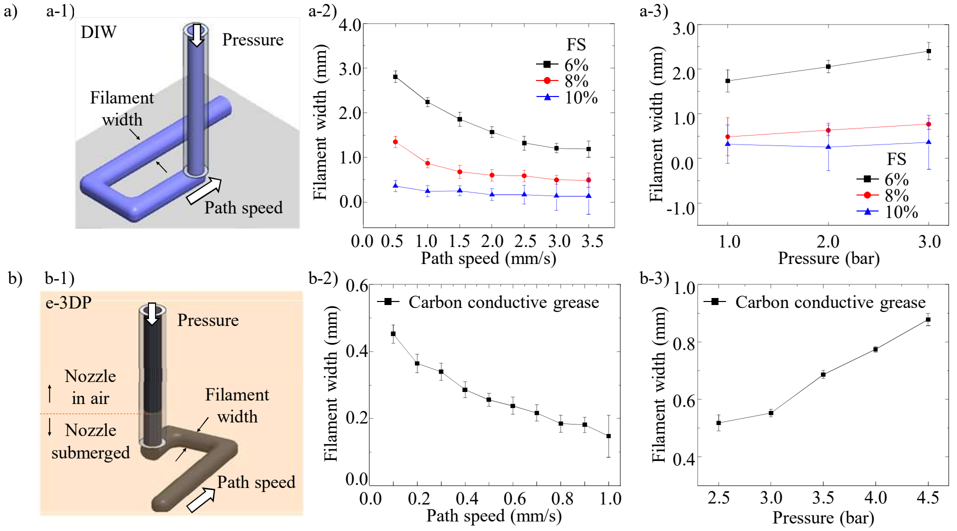

Fig. 3. Printing parameters varied during printing *t*BA/AUD via **(a)** DIW and carbon conductive grease via **(b)** e-3DP. Schematic of **(a-1)** DIW and **(b-1)** e-3DP. Filament width as a function of path speed and pressure in DIW **(a-2, a-3)** and e-3DP **(b-2, b-3)**.

FORMABILITY TESTS

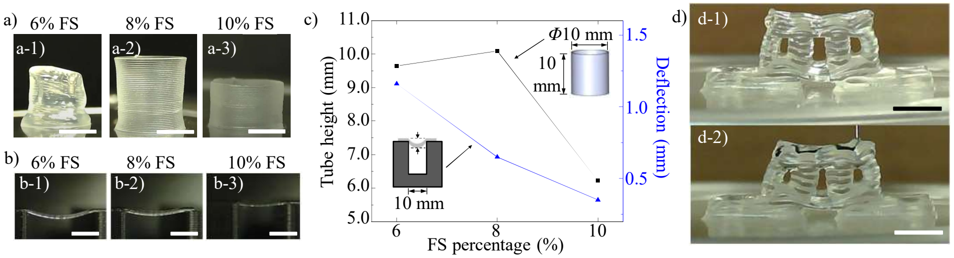

Fig. 4. (a) Vertical tube and **(b)** gap tests. **(c)** Formability test results with schematics of the tube and gap deflection dimensions. **(d)** Hinge after **(d-1)** DIW (2.5 bar and 3.0 mm/s) and during **(d-2)** e-3DP (3.5 bar and 0.3 mm/s). All Scale bars: 5.0 mm.

SMP PROGRAMMING

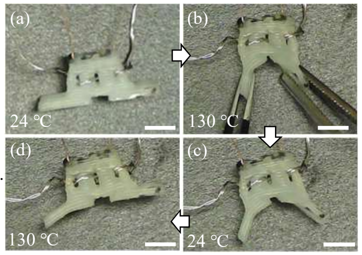

Fig. 5.
(a) Smart hinge in its original, printed shape
(b) Programming
(c) Post-programming
(d) Shape recovery

All scale bars: 5.0 mm.

APPLICATION TESTING

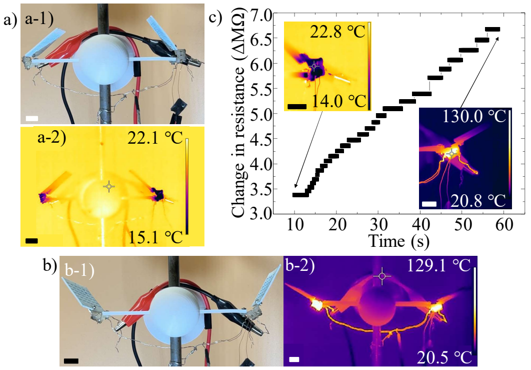

Fig. 6. Application testing. **(a)** Programmed hinges: **(a-1)** front view and **(a-2)** temperature distribution. **(b)** Unfolded hinges: **(b-1)** front view and **(b-2)** temperature distribution. **(c)** Resistance change of hinge during this process and temperature distribution of the hinge (insets). All scale bars: 10.0 mm.

CONCLUSIONS

- FS significantly adjusted the SMP ink's rheological properties.
- 8% (w/v) FS + 50%/50% (w/v) *t*BA/AUD was selected.
- An embedded circuit of carbon conductive grease was successfully printed inside a smart hinge with a complex geometry.
- The change in resistance of the hinge was measured from the e-3DP circuit while the smart hinges deployed mock solar panels on a mock space shuttle.

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- Fellows at UNR 3D Printing Lab

UNR 3D Printing Lab

REFERENCES

[1] Zhang et al., "Mechanically Robust and UV-Curable Shape-Memory Polymers for Digital Light Processing Based 4D Printing," *Advanced Materials*, 2021, 33, p. 2101298.