

INTRODUCTION & OBJECTIVE

What are Liquid Crystal Elastomers (LCEs)?

Liquid Crystal Elastomer

Liquid Crystal (mesogen) + Polymer (Low T_g) + Crosslinks (Fixed point) → Liquid Crystal Elastomer (LCE)

LCE Actuation

LC phase ↔ Isotropic

Stimuli: Heat, Electro-thermal, Photo-thermal, Humidity

ACS AMI 2019, 19514; Small, 2021, 2103700; Macromolecules, 2016, 4023; Small, 2021, 2100910; Molecules, 2022, 4330

Programmable & reversible actuation in response to various stimuli

Why LCE Fibers? (1D vs 2D)

1D Fiber

Design: [Diagram of fiber structure]

Experiment: [Image of fiber]

Adv. Mater. Technol., 2022, 21200934

2D Film

[Image of film]

Angew. Chem. Int. Ed. 2012, 12469

(+) No need for complex alignment process (vs film)

(+) Faster deformation rate due to large surface area (vs film)

Recent Research on LCE Fibers

Cholesteric LCE Fibers

Nat. Mater., 2022, 21, 1441

LCE Nanocomposite Fibers

Nat. Nanotechnol., 2022, 17, 1198

Woven LCE Textiles

35.7°C, 71.2°C, 115.6°C

Adv. Mater., 2023, 202210689

Knitted LCE Textiles

r.t., 120°C

Adv. Mater., 2023, 2302706

Useful for artificial muscles and smart fabrics

Research Objective

Can we develop a method to produce scalable LCE fibers with tunable mechanical properties and adhesion?

RESULTS & DISCUSSION

(1) Synthesis & Production of LCE Fibers

LC Ink

Photoinitiator + Oligomerization → LC Ink

LCE Fiber

UV curing → LCE Fiber

POM

[Polarized Optical Microscopy images]

Optimization of Fiber Production

Winding rate (rpm) vs Temperature (°C)

- Slow Extrusion (X)
- Fast Extrusion (X)
- Unable to hang the fiber (X)
- Steady winding (O)

• A continuous, single strand of LCE fiber can be produced (> 10 m)

• Diameter (20-250 μm) can be tuned by nozzle size, temperature, etc.

• Orientation was verified by polarized optical microscopy (POM).

(2) Characterization

FT-IR

Transmittance (%) vs Wavelength (cm^{-1})

Acrylate peak (810cm^{-1})

• No acrylate peak after curing

WAXS

Before treatment vs After treatment

Intensity (a.u.) vs Angle ($^\circ$)

• No significant disruption in orientation after the LC solution treatment

DSC

Heat flow (Normalized) (W/g) vs Temperature ($^\circ\text{C}$)

LC Ink vs LCE Fiber

$T_g = -8^\circ\text{C}$, $T_g = -13^\circ\text{C}$, $T_{m1} = 107^\circ\text{C}$, $T_{m2} = 103^\circ\text{C}$

Actuation

Normalized Length ($\mu\text{m}/\mu\text{m}$) vs Temperature ($^\circ\text{C}$)

Heating vs Cooling

10 wt%, 20 wt%, 5 wt%, Pristine

• Reversibly actuation (~50%) even after LCN coating

(3) Morphology

OM

Pristine, 10 wt%, 20 wt%

SEM

Pristine, 10 wt%, 20 wt%

LCE core, LCN surface

• Increasing EtOH solution concentration increases the surface roughness

Before treatment, **After treatment**, **After washing**

300 μm

• After washing with EtOH, the fiber surface became smooth again

(4) Mechanical & Adhesive Property

Stress-Strain Curves at 30 $^\circ\text{C}$

Force (N) vs Strain (%)

Pristine, 20 wt%, 10 wt%, 5 wt%

• Considerable increase in mechanical properties after the LCN treatment

Adhesion (180 $^\circ$ peeling test)

Peel Force (N) vs Displacement (mm)

Pristine, 20 wt%, 10 wt%, 5 wt%

Average Force (N)

Pristine: 7.43903, 5 wt%: 1.80246, 10 wt%: 1.72841, 20 wt%: 2.47357

• The peel strength considerably decreases by four times

(5) Weaving LCE Fibers

Woven LCE Fiber (Plain Pattern)

LCE polyester

• Reversible contraction/expansion (RT \leftrightarrow 130 $^\circ\text{C}$, actuation strain ~18%)

CONCLUSION

- The method for mass production of LCE fibers (> 10 m) is developed via 3D printing coupled with a winding apparatus.
- Both mechanical property and adhesion of LCE fiber can be effectively modulated while preserving actuation

ACKNOWLEDGEMENTS

This work was supported by Basic Science Research Program and BK21 Four Program through the NRF