UNIVERSITY OF TORONTO

Highly Flexible and Self-Healable Electronic Skin

Sung Hwa Hong, Harvey HaoTian Shi, Guorui Wang, Tobin Filleter, Hani E. Naguib

Department of Mechanical and Industrial Engineering
Department of Materials Science and Engineering
University of Toronto, Ontario, Canada

TSMART
Toronto Smart Materials & Structures
University of Toronto

The Needs for Next Generation of Flexible Electronics

- **Electronics degrade over time** due to fatigue, environmental conditions, or damages incurred during operation leading to eventual failure of the material.

Flexible circuit

Electronic tattoo

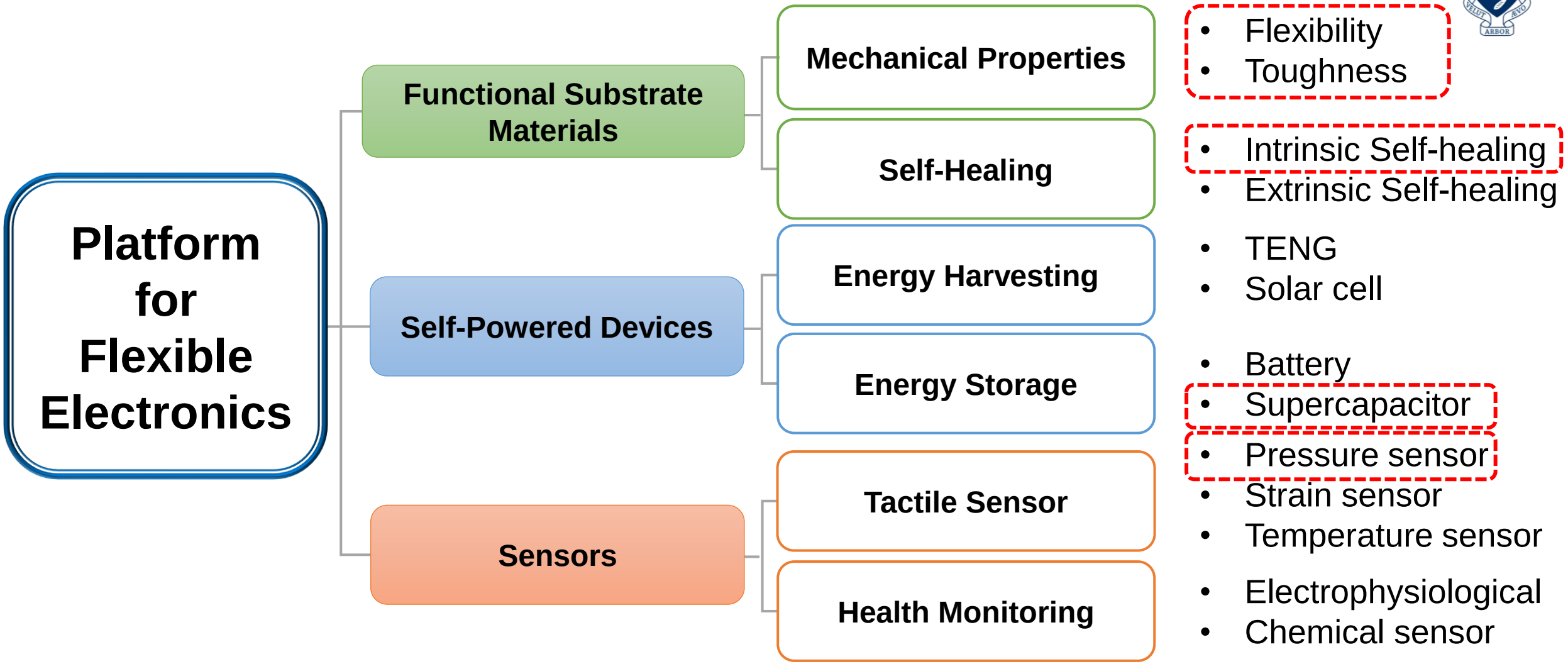
Wearable sensor

Portable Device

Limitation

- **Shortens** lifetime of device
- **Changes/weakens** original integrity
- Causes device **malfunctioning**

Functionalities of Flexible Electronics



Motivation and Objectives

Motivation

- Facile methodology for flexible electronics with high-performing device performance
- Substrate material for **long-term utilization** of devices
  - Material exhibiting the **self-healing properties with high toughness**

Objectives

- Fabricate supercapacitor through **facile methodology**
- Design and synthesize **self-healing polymer** for flexible electronics
- Achieve **high toughness material** that exhibits self-healing behavior

Challenges

Self-Healing ⟷ **Toughness**

Weak interaction

- Chain flexibility / mobility

Strong interaction

- Low chain flexibility / mobility

Reported strategies to enhance toughness for smart skin:

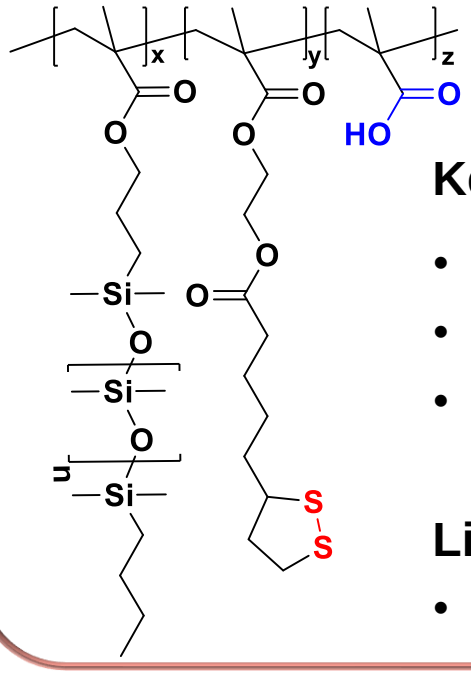
1) Addition of filler

2) Molecular modification of polydimethylsiloxane (PDMS)

3) Molecular modification of polyurethane (PU)

In Situ Fabrication of Fiberous Gel-Elastomer for Exceptionally Tough Material

SP



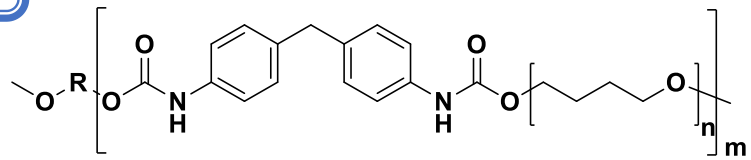
Key Properties

- Low Young's modulus (< 5MPa)
- Rate/efficiency of healing
- Stretchability

Limitation

- Low toughness

PU



Key Properties

- High toughness
- Stretchability

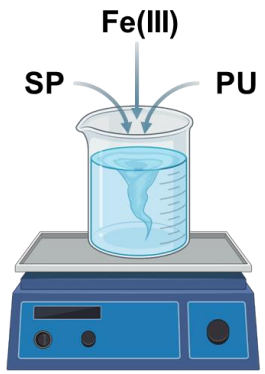
Limitation

- High Young's Modulus
- Limited self-healability

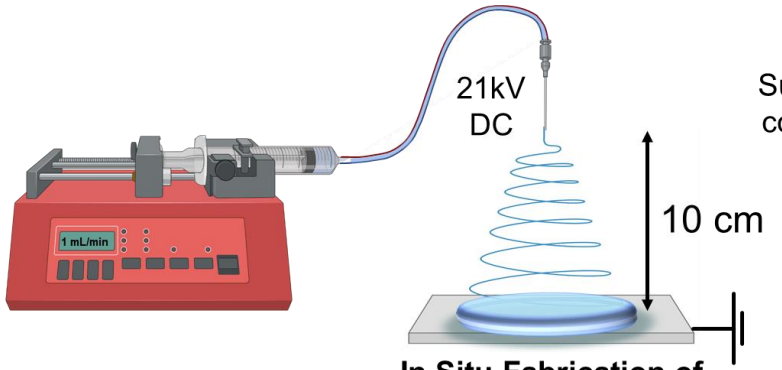
Blend!

SP = self-healing polymer
PU = polyurethane

Fabrication of SPB Gel-Elastomer

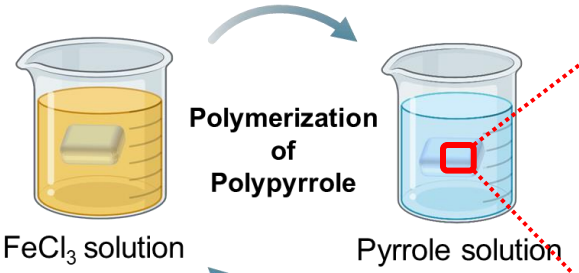


SP/PU weight ratio = 1/1
Fe(III) / COOH molar ratio = 0.5 - 5

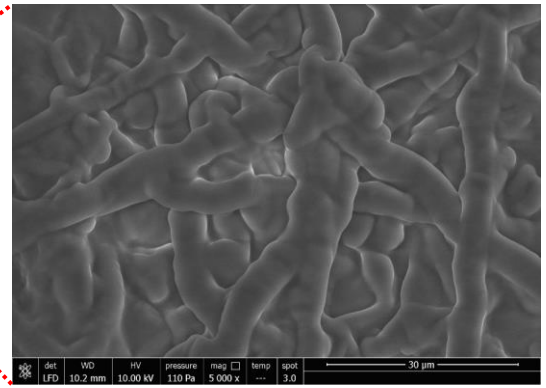


In-Situ Fabrication of Fibrous Gelastomer

Surface coating

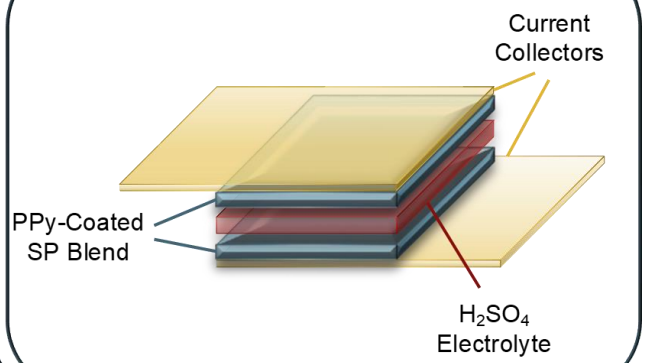


PU+SP

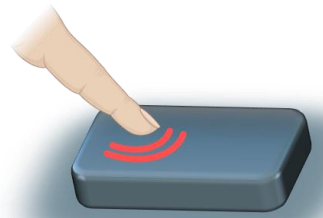


Smart Skin

Supercapacitor



Pressure Sensor



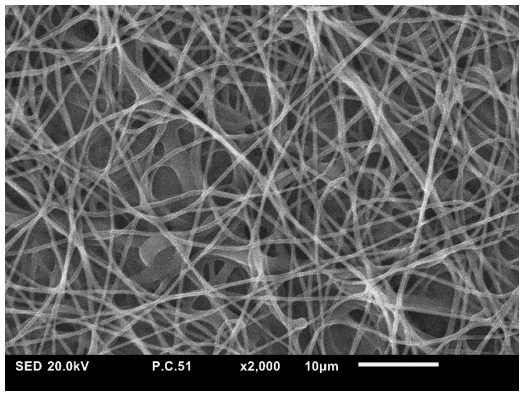
Highly Stretchable

Ultra-tough

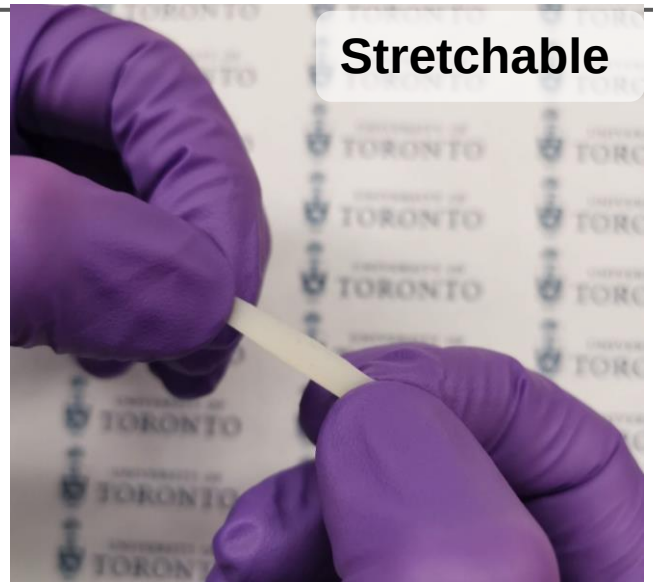
Soft

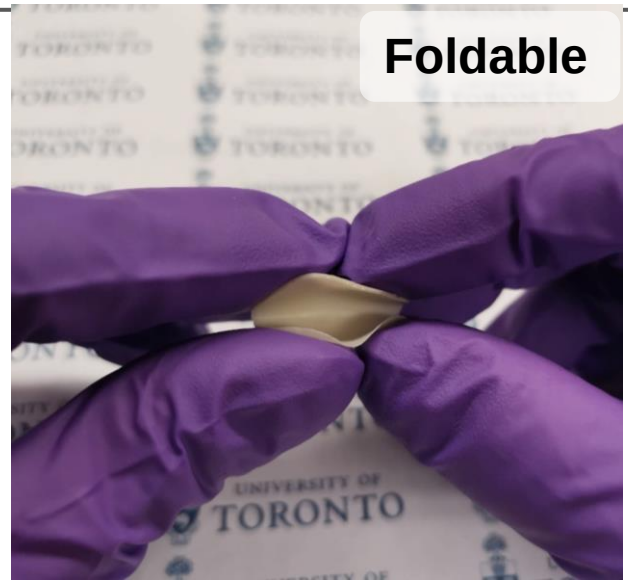
Rapid Self-Healing

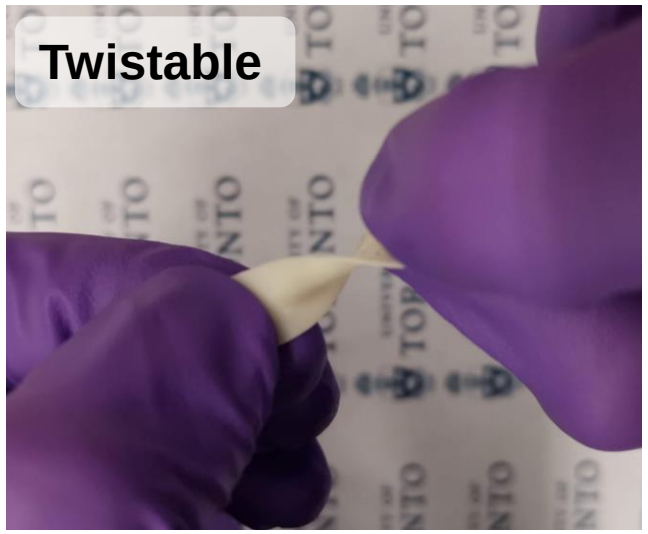
PU Fiber

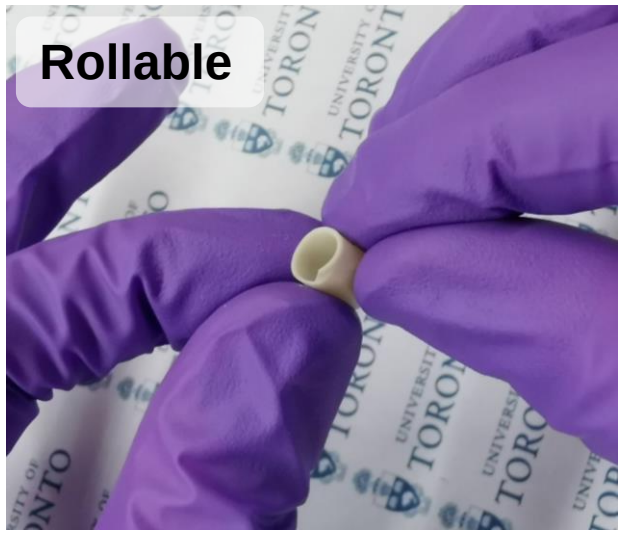


Fabrication of SPB Gelastomer

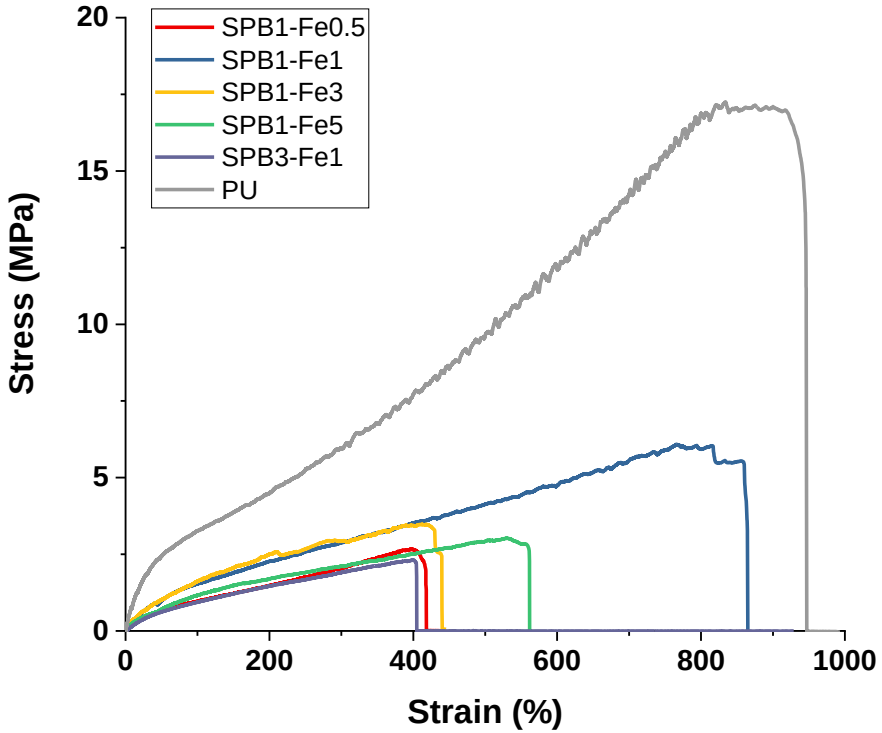








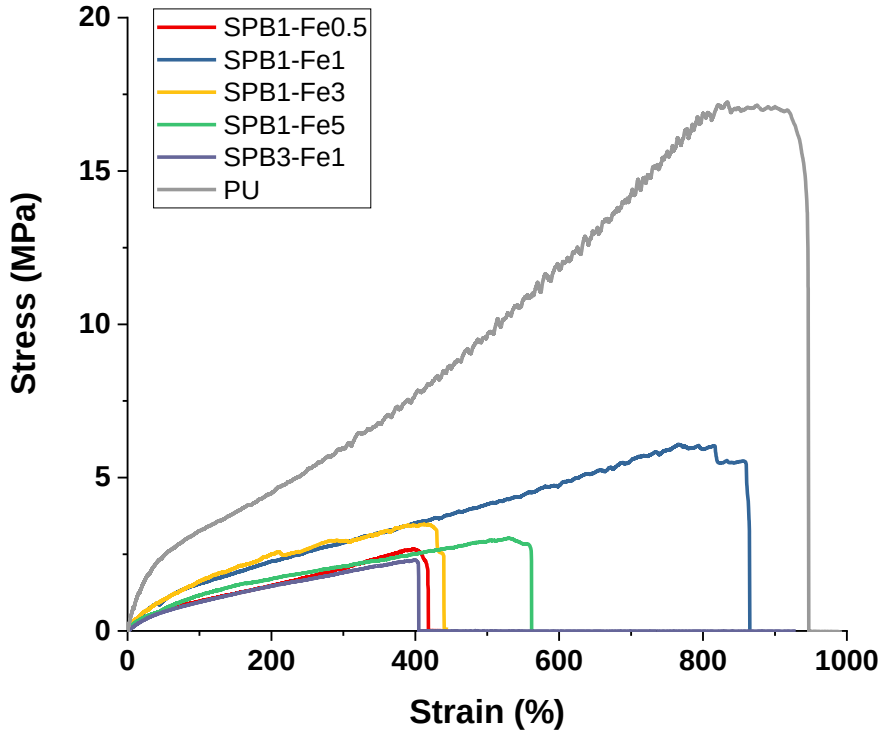
Mechanical Properties of SPBs

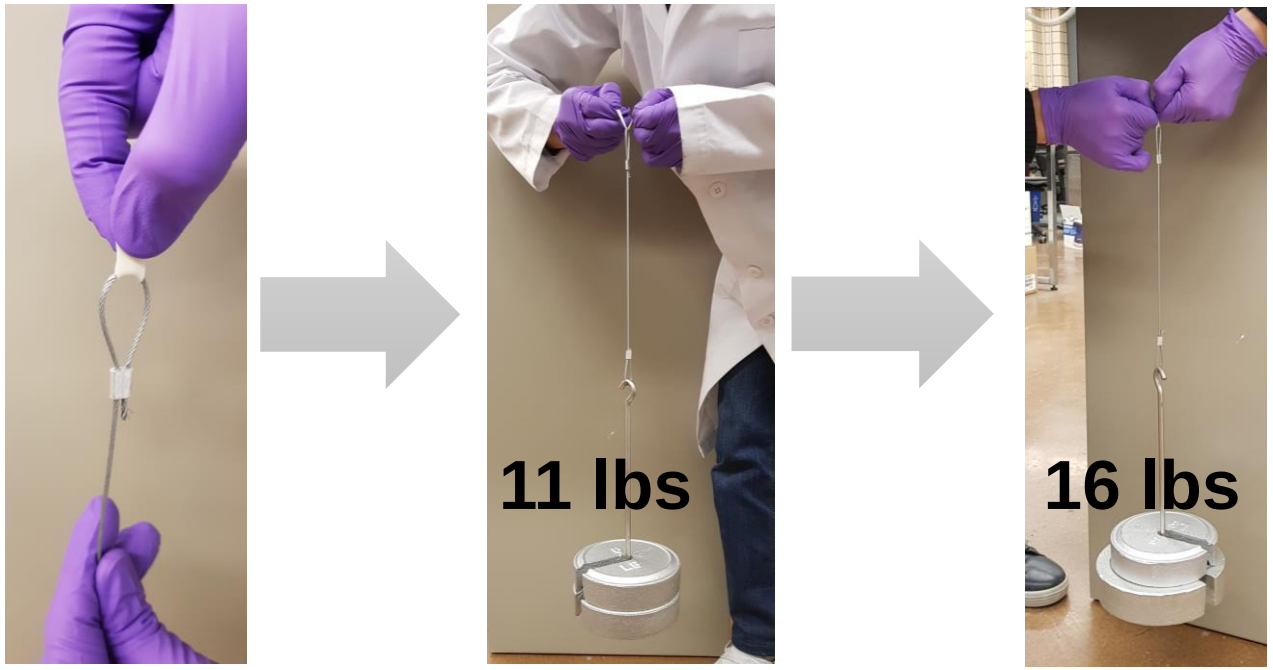


Type of polymer/ crosslinker	Young's modulus (MPa)	Elongation at break (%)	Toughness (MJ/m^3)
SPB1-Fe0.5	2.38 ± 0.71	456 ± 39	7.8 ± 1.0
SPB1-Fe1	3.40 ± 0.62	809 ± 60	31.3 ± 3.5
SPB1-Fe3	3.11 ± 0.40	552 ± 126	15.2 ± 2.9
SPB1-Fe5	2.19 ± 0.24	447 ± 88	7.9 ± 3.0
SPB3-Fe1	1.82 ± 0.13	335 ± 86	3.7 ± 1.7
PU	8.65 ± 0.85	1020 ± 159	100.9 ± 20.0

- **Young's modulus** was **significantly reduced.**
- Relatively **high toughness was achieved.**
- **High fracture strain** due to transient boding that dissipates the stretching energy through association-dissociation

Mechanical Properties of SPB

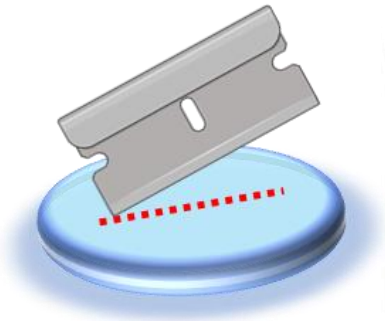




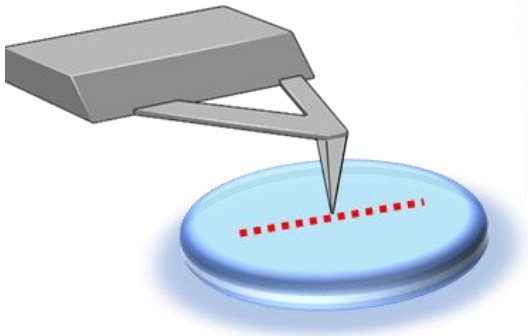
- **Young's modulus was significantly reduced.**
- **Toughness was enhanced.**
- **High fracture strain** due to transient boding that dissipates the stretching energy through association-dissociation

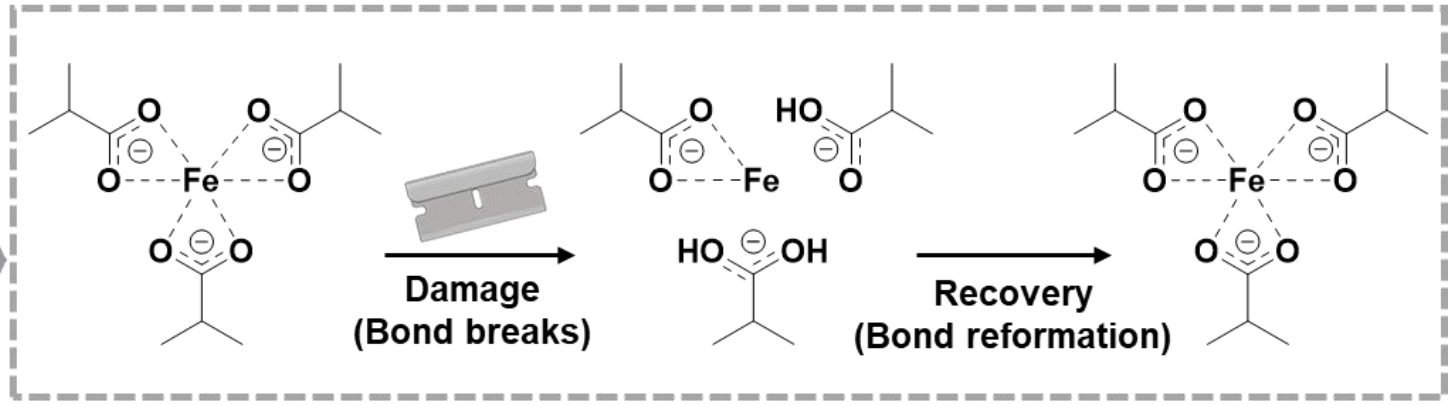
Self-Healing Capability of SPB

Macro-indentation



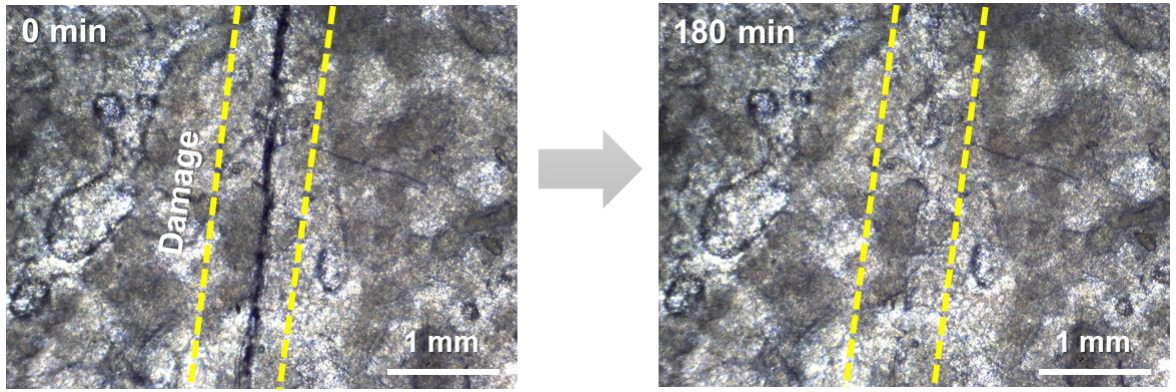
Nanoindentation



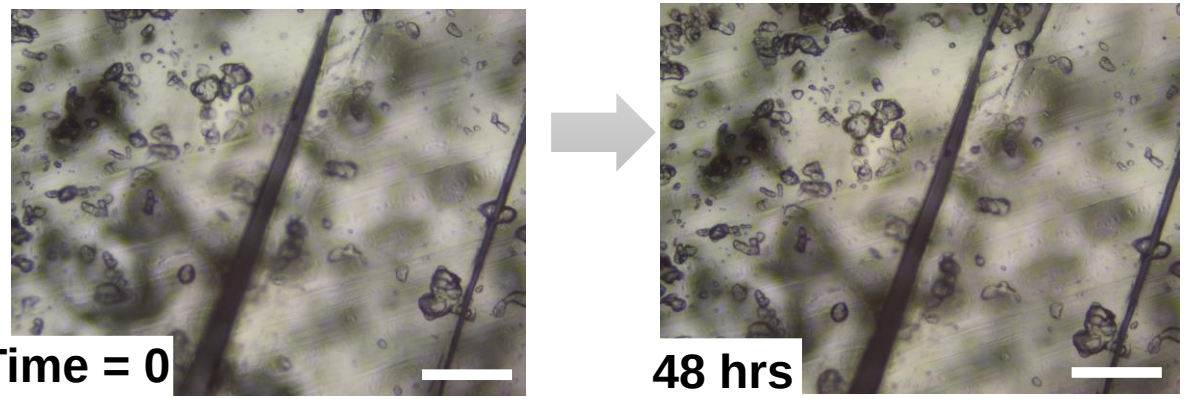


Self-Healing Test at Macroscale

SPB1-Fe1

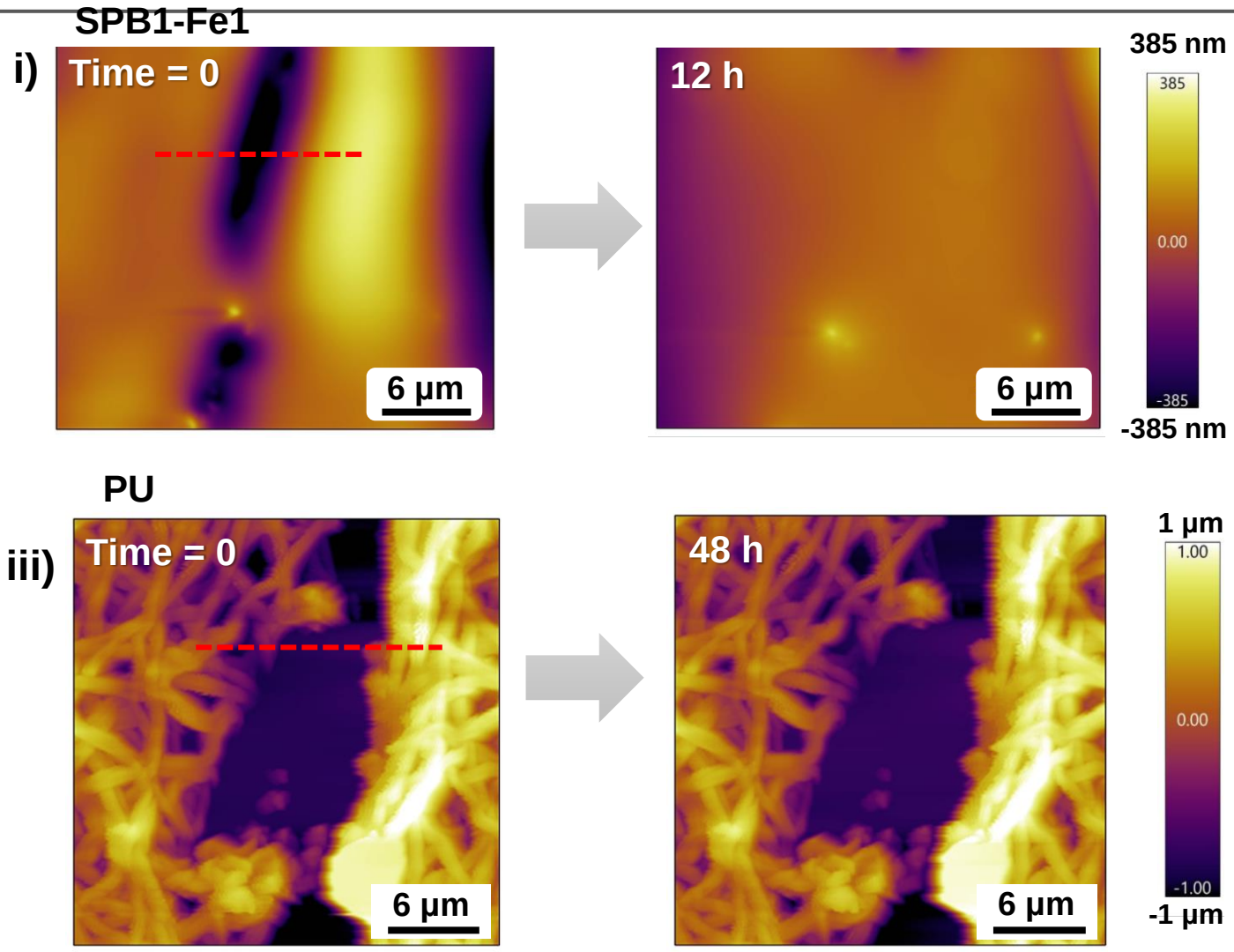


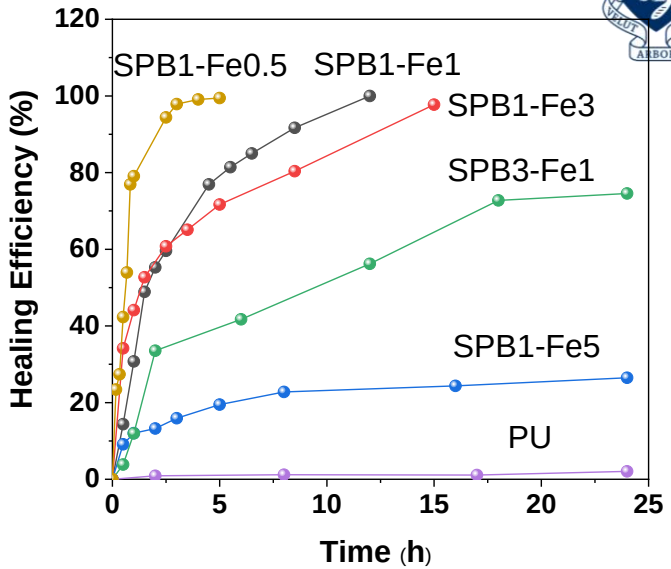
PU

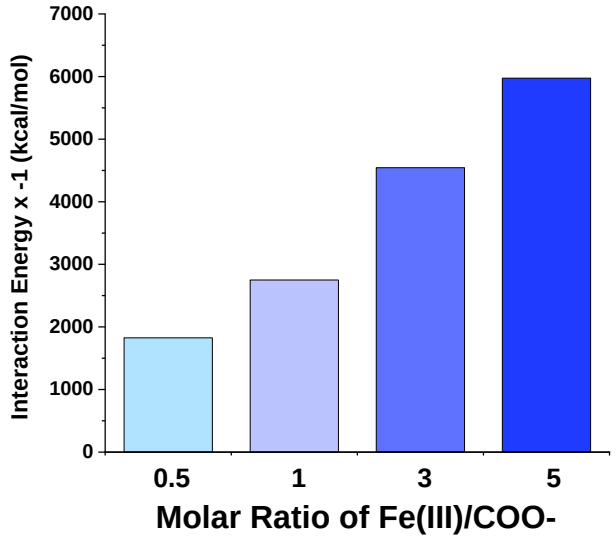


- Macro-indentation experiment is representative of damages from everyday life.
- Optical microscopic images show that the self-healing polymer blend heals at room temperature without any energy input.

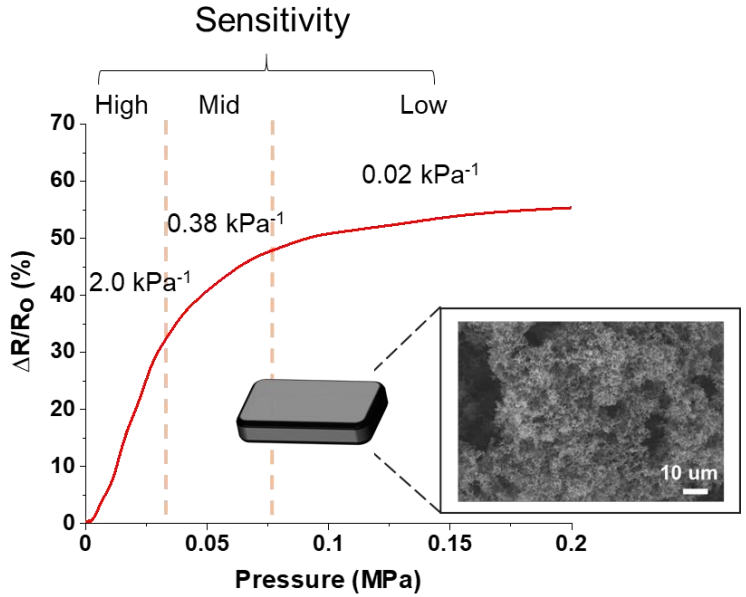
Self-Healing Test at Microscale

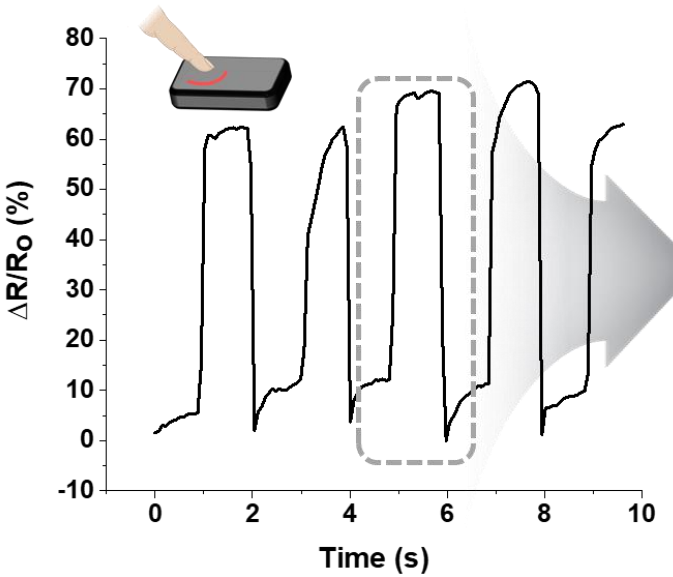


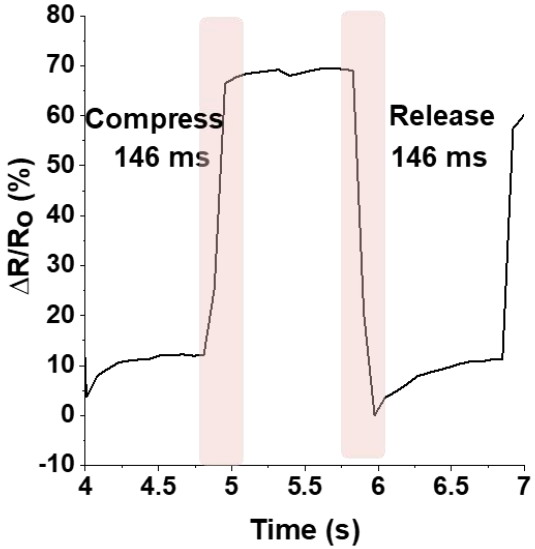


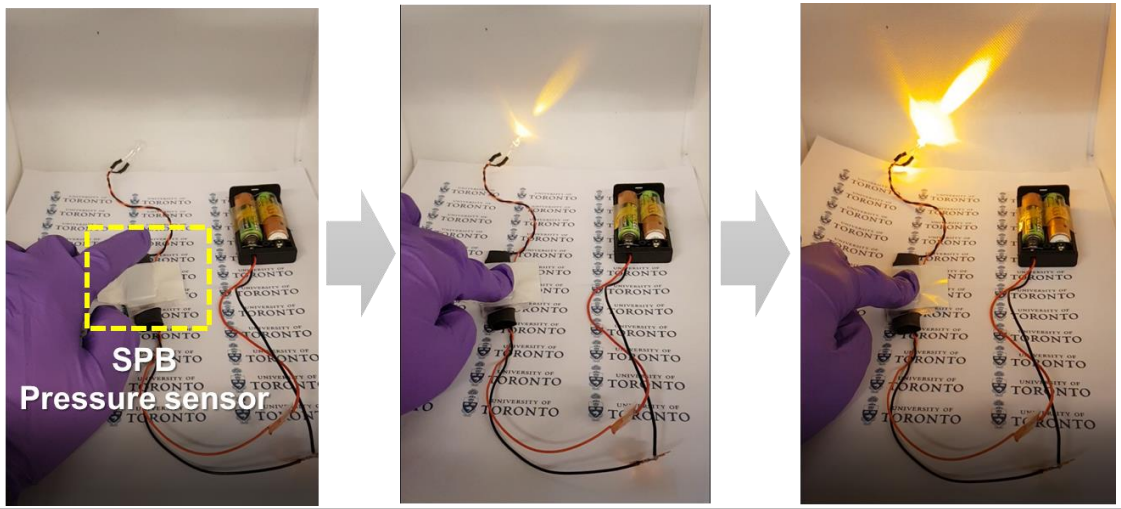


Tactile Sensing Capability of SPB



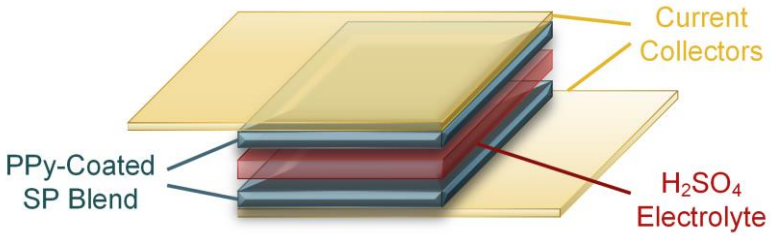


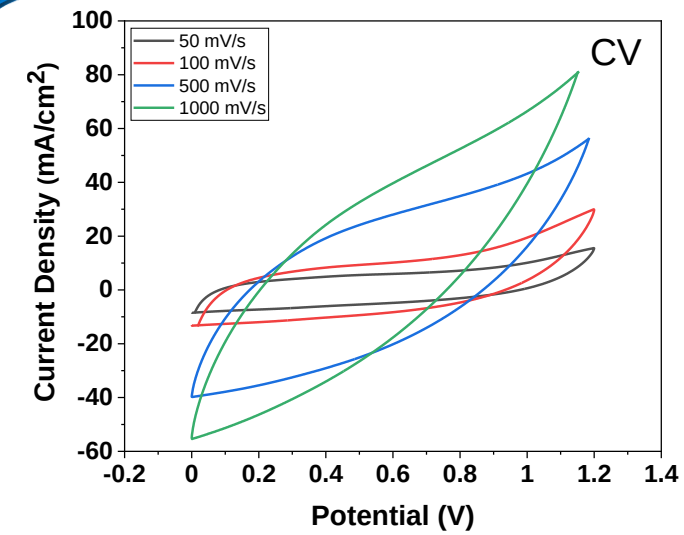


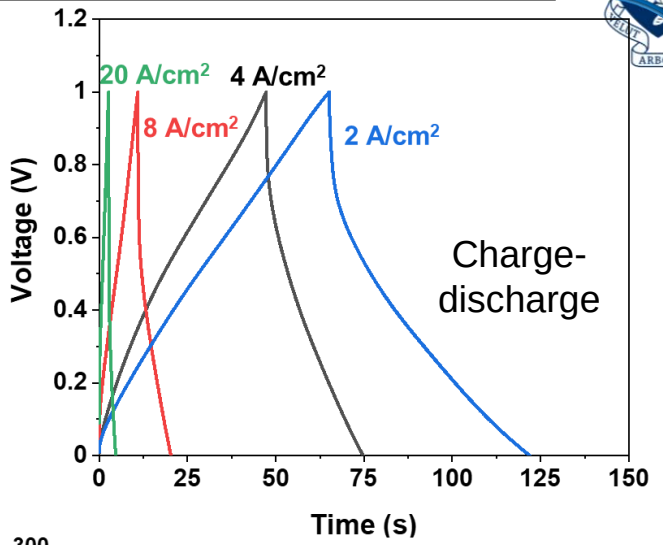


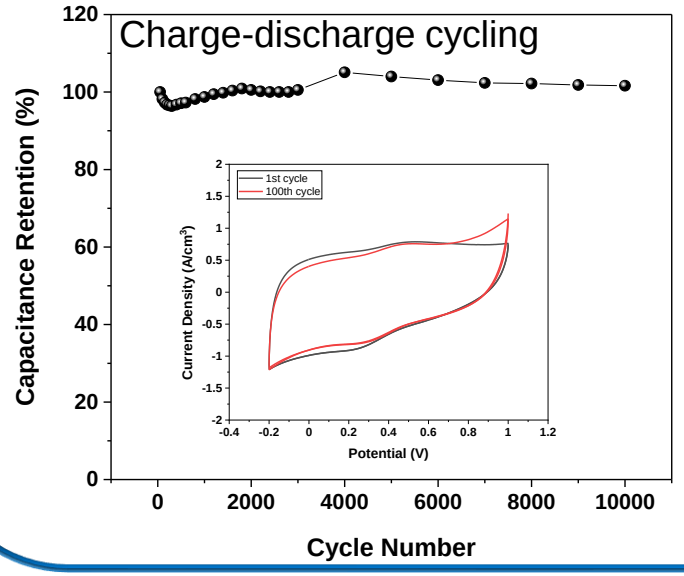
SPB as an Energy Storage Device

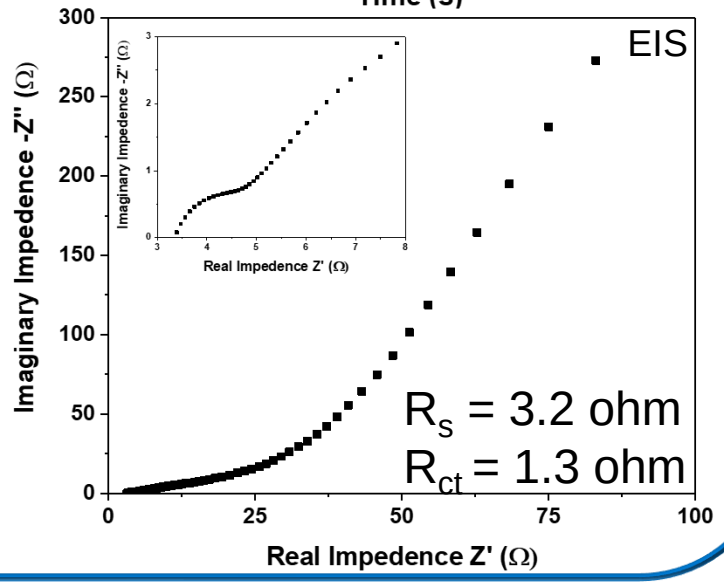
Symmetrical cell using
1 M H_2SO_4 and voltage up to 1.2 V











Conclusion

- **Gel and elastomer polymer blend** has not been studied for highly tough and self-healing material.
- Homogenous and freestanding material was obtained from **electrospinning in-situ**.
- Achieved **a high toughness** below 5 MPa of Young's Modulus.
- Efficient healing at room temperature without any external aid.
- Demonstrated the capability for smart skin as an energy storage device and tactile sensors.

Thank You for Your Attention!