Self-Healing Flexible Sensors for Health Monitoring

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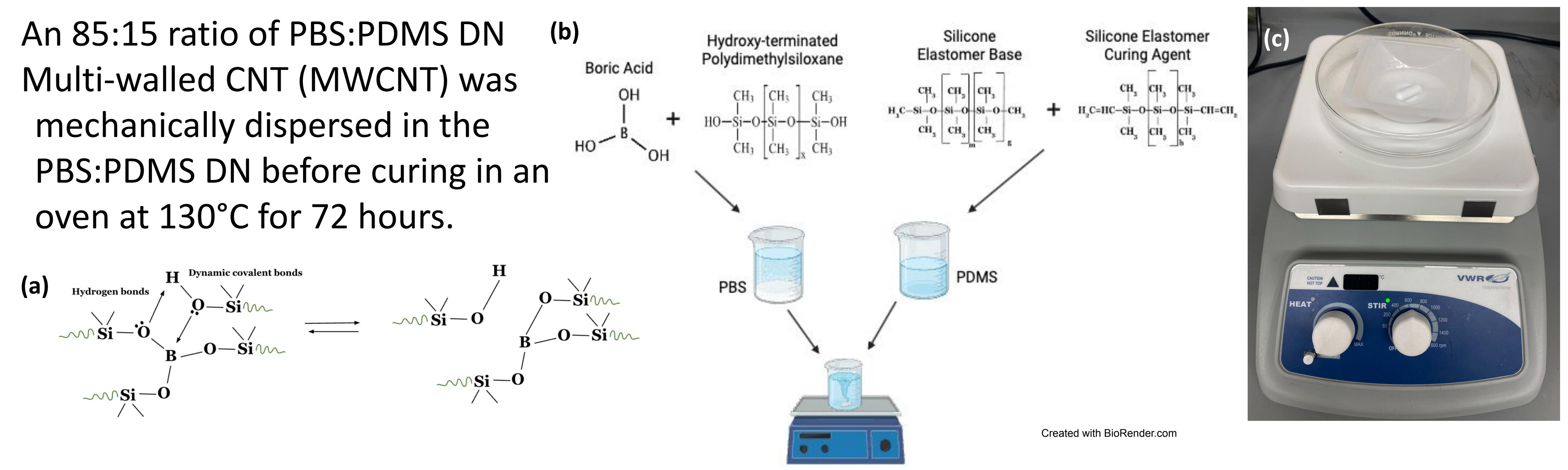
Motivation

- Current wearable health monitoring sensors are made of materials stiffer than skin that remain in a damaged state when fractured.
- Polyborosiloxane (PBS) and Polydimethylsiloxane (PDMS) double network (DN) composite is a polymer that can self-heal.
  - PBS is a soft, rate-dependent polymer that is viscous enough to flow under its own weight. PDMS is a stiffer polymer that provides a structural stability while maintaining the flexible self-healing properties of PBS.
  - Addition of conductive carbon nanotubes (CNT) allows for electrical measurements
- The current study aims to understand and quantify the mechanical and electrical response of this polymer composite.

Figure 1. Shape recovery response of PBS:PDMS DN with CNT to return to original length over time after being stretched to 10% of its length.

Fabrication

- An 85:15 ratio of PBS:PDMS DN
- Multi-walled CNT (MWCNT) was mechanically dispersed in the PBS:PDMS DN before curing in an oven at 130°C for 72 hours.



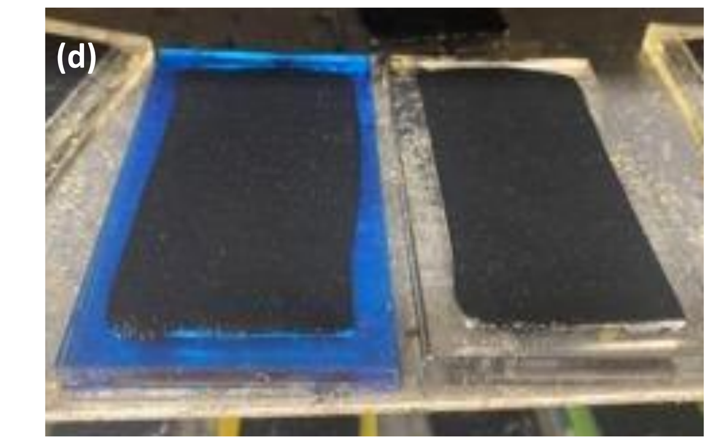


Figure 2. (a) Chemical structure of PBS and PDMS bonding. (b) Chemical fabrication of PBS and PDMS. (c) Mixing of polymer precursors and CNT using stir plate. (d) CNT/PBS/PDMS mixture in acrylic molds for curing in oven.

Objectives and Methods

Objectives

- Understand the macroscopic effect of strain and strain rate on the electrical response of the CNT/PBS/PDMS DN composite.
- Quantification of static resistance evolution in CNT/PBS/PDMS DN samples.

Methods

- Static resistance
  - Measurements were taken every other day in a robust 3D-printed apparatus with spring attachments.
- Dynamic resistance testing
  - Samples were tested under various strain rates (0.001 s^{-1}, 0.01 s^{-1}, 0.1 s^{-1}, 1 s^{-1}) while measuring electrical response and applied stress over increasing strain.

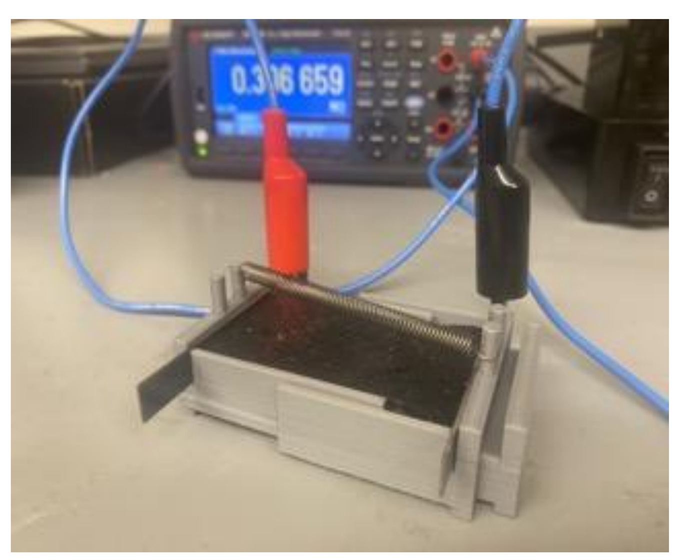


Figure 3. 3D printed static resistance testing apparatus in use while connected to multimeter.

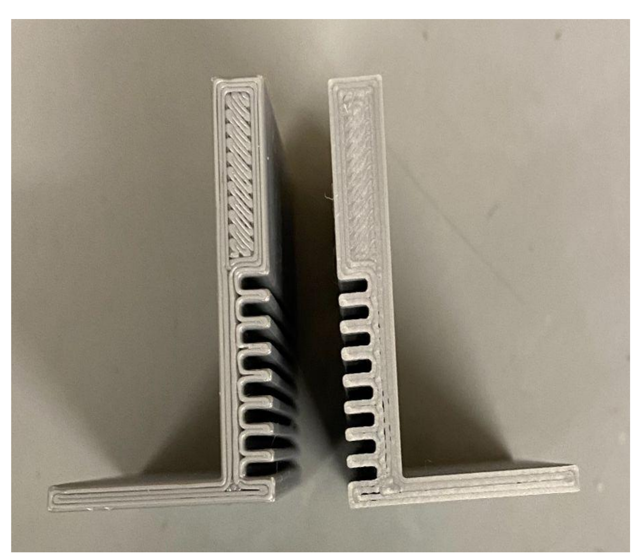


Figure 4. 3D printed dynamic resistance testing fixtures for polymer composite adhesion and resistance measurements.

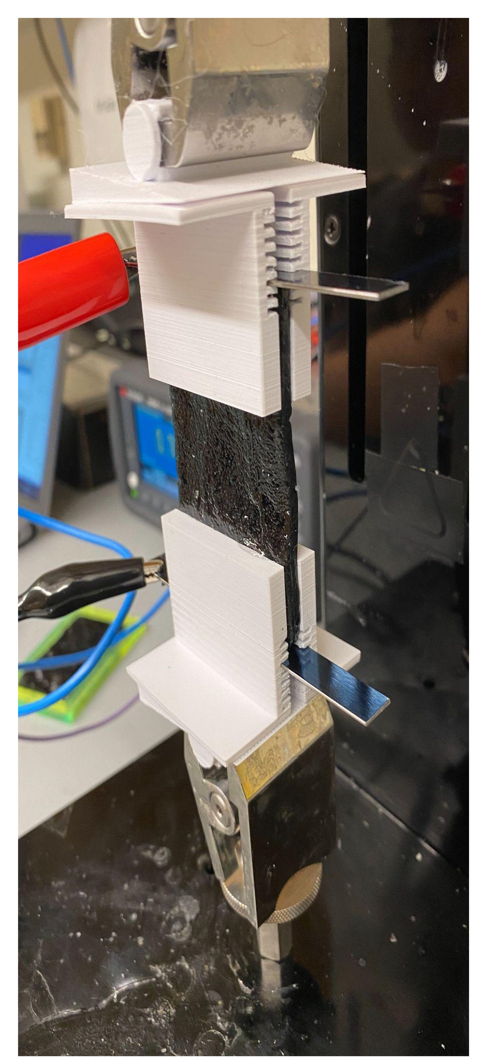


Figure 5. Dynamic resistance testing apparatus in use while connected to mechanical tester under tensile load. Metal strips in place for resistance measurements.

Results

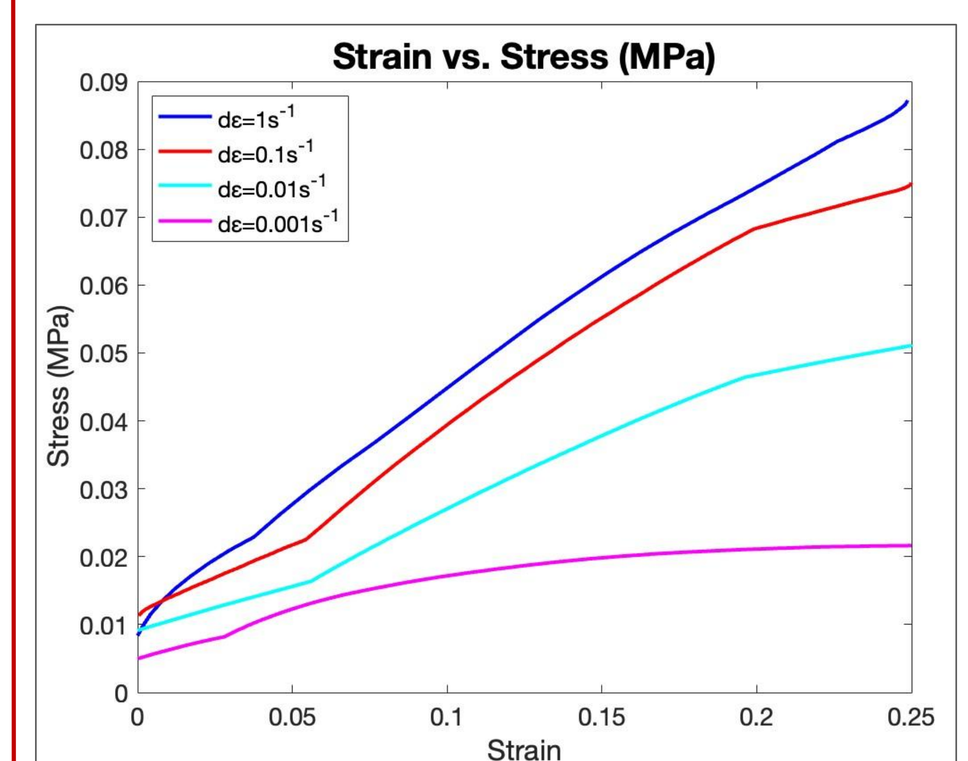


Figure 6. Stress-strain response of the CNT filled DN composite for strain rates of $1s^{-1}$, $0.1s^{-1}$, $0.01s^{-1}$, and $0.001s^{-1}$.

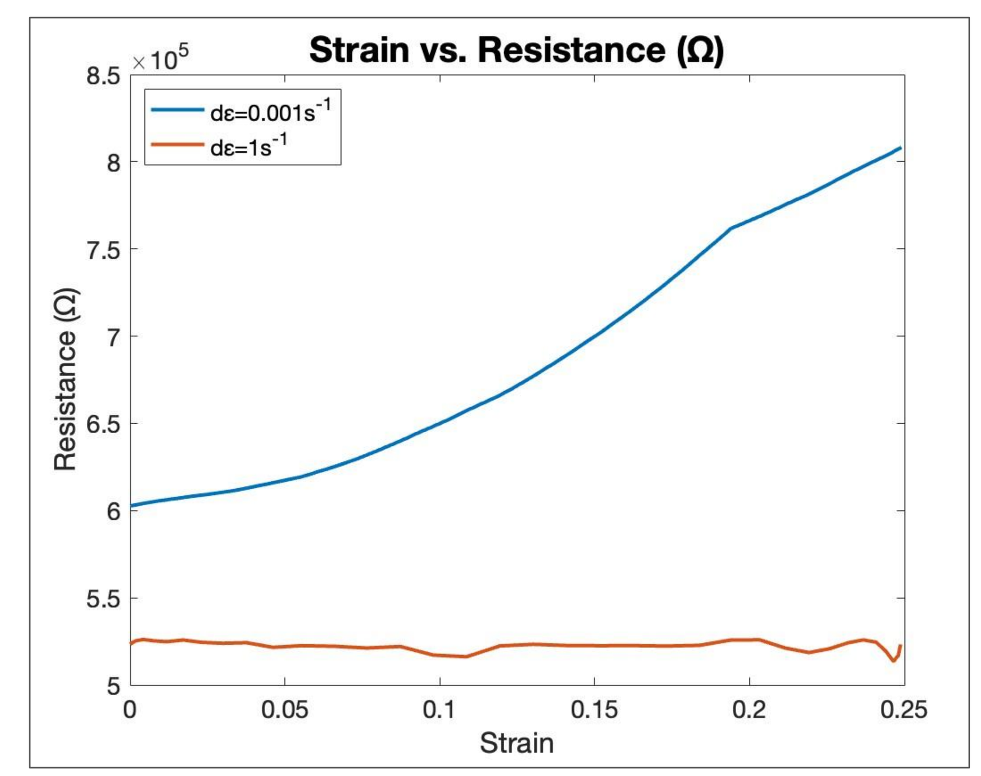


Figure 7. Strain vs. Resistance (Ω) graphs for strain rates of $1s^{-1}$ and $0.001s^{-1}$.

Conclusions

- At a given strain level, the polymer composite exhibits increasing stress magnitudes with increasing strain rates.
- There exists a rate-dependent trend of increasing resistance when the CNT/PBS/PDMS DN sample is subjected to strain for the two strain rate extremes, with lower strain rates yielding higher changes in electrical resistance. However, further testing is required for strain rates of $0.1s^{-1}$ and $0.01s^{-1}$.
- CNT/PBS/PDMS DN is a viable strain sensor material option due to its rate-dependent mechanical and electrical responses and self-healing capabilities.

Ongoing and Future Work

- **Fabrication**: Improving dispersion of MWCNT in PBS:PDMS DN.
- **Modeling**: Developing a mathematical model to predict strain and strain rate through the sensor's electrical properties.
- **Future Work**: Quantifying multidimensional strain and strain rate fields using PBS/PDMS polymer matrix, further testing on strain rates of $0.1s^{-1}$ and $0.01s^{-1}$, characterizing a trend (or lack thereof) for change in electrical resistance across increasing strain rates, and quantifying self-healing properties.

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