Hybrid, Multifunctional 3D Printed Nanocomposite **Strain Sensors**

Aaron Soul, Han Zhang, Emiliano Bilotti, Dimitrios Papageorgiou

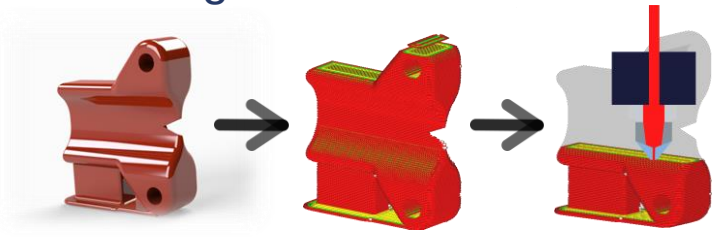
1.1 Introduction

Why 3d printed Strain Sensors?

- Complex Internal Designs
- Tunable Structures

Challenges?

- Material Melt Viscosity
- Feeding Elastic Materials



CAD Design Sliced Model Printing

Hybrid Fillers?

- Network made up for 2+ fillers
- Hybrid fillers can offer:
  - Improved electrical conductivity
  - A range of mechanical properties
  - Cost-effectiveness compared to single
- Combine high conductivity with higher strains at break.
- Optimized processability
- Increased sensing range

Strain Sensor

1.2 Hybrid Composites

Matrix:

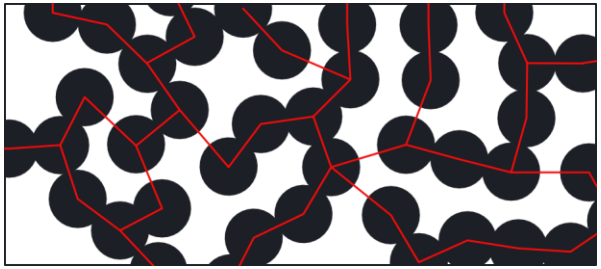
- Thermoplastic Polyurethane / TPU

Fillers:

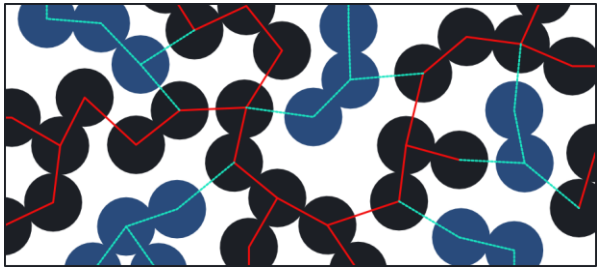
- Carbon Nano Tubes / CNT
- Graphene Nano Platelets / GNP
- Boron Nitride / BN

Exclusion Theory

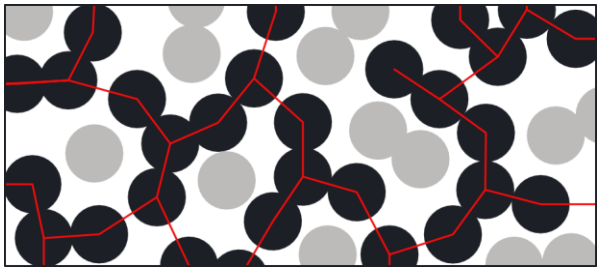
- Occupied space by non or less conductive fillers confines the conductive fillers and densifies the conductive network.



CNT Network



CNT / GNP Network



CNT / BN Network

1.3 Sample Preparation

Base Material:

- TPU_20wt%_CNT Masterbatch Compounded with Twin Screw.

Functional materials:

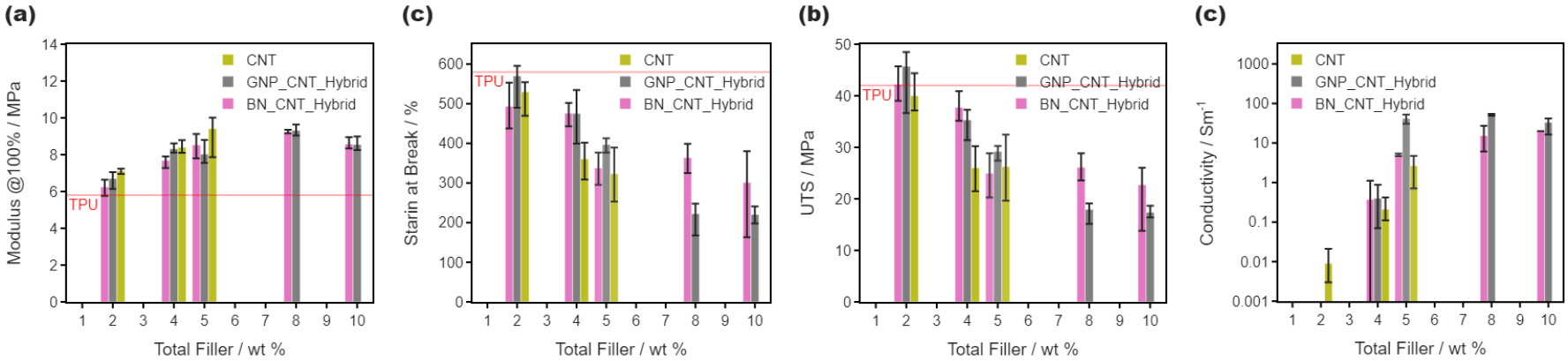
- GNP & BN added using Xplore 15HT Micro Compounder

Table of Materials: **Hybrids are 50:50 wt% Mix**

Total Filler / wt%	2	5	8	10
CNT	CNT_2	CNT_5	-*	-*
GNP_CNT_Hybrid	CNT_1_GNP_1	CNT_2.5_GNP_2.5	CNT_4_GNP_4	CNT_5_GNP_5
BN_CNT_Hybrid	CNT_1_BN_1	CNT_2.5_BN_2.5	CNT_4_BN_4	CNT_5_BN_5

*CNT_8/10 not tested as unable to process 1.75mm filaments, high viscosity/ brittle extrusion

2.1 Mechanical Analysis – Compression Moulded



- Higher filler content improves conductivity but has limited effect on strain at break and modulus.
- Beyond 5wt% total filler, the increase in conductivity is not significant compared to the reduction in strain at break and increase in modulus.
- CNT_BN hybrids have increased strain at break at higher filler loadings, making them more suitable for sensors than CNT_GNP hybrids.

*CNT_8/10 not tested as unable to process 1.75mm filaments, high viscosity/ brittle extrusion

2.2 Filament Production

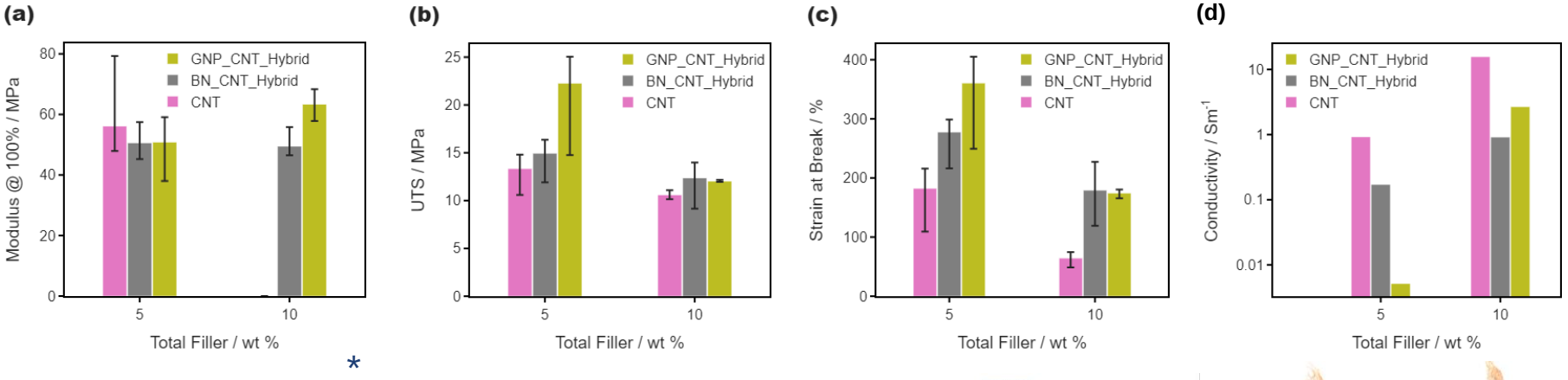
Xplore Micro Compounder

3D printed continuous twin screw feeder

3Devo filament maker

TPU_CNT_2.5_GNP_2.5 Filament

2.3 Printed Properties



*

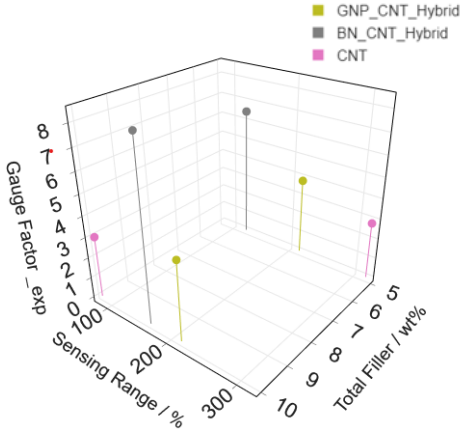
*CNT_10_BN_0_GNP_0:

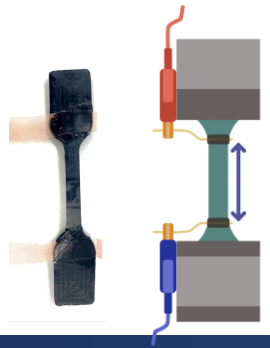
Broke at **64%** strain

FDM Printed with 1.4mm nozzle

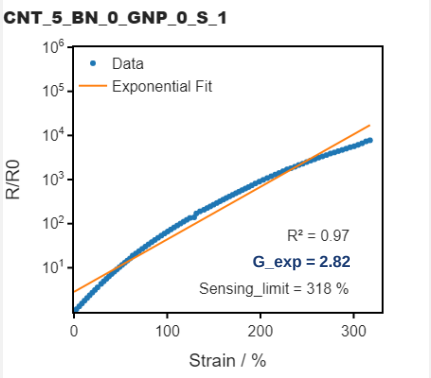
Layer Height 0.35mm

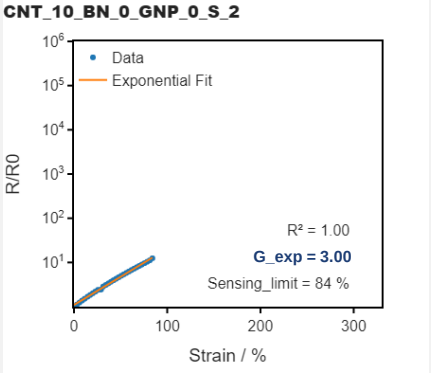
3.1 Sensing



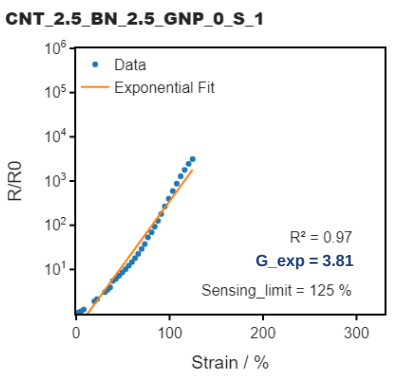


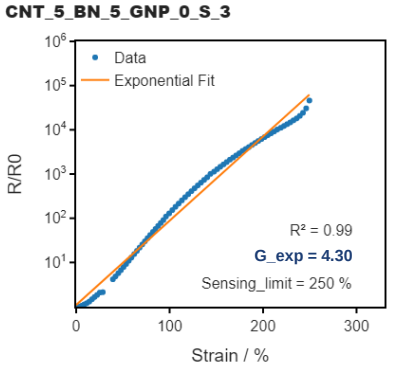
CNT



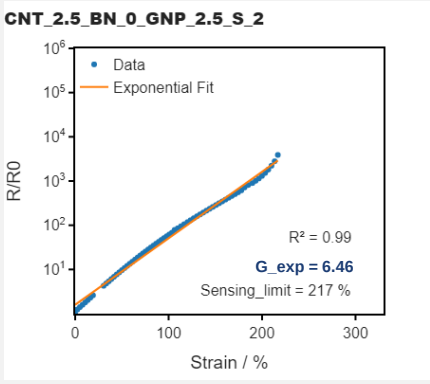


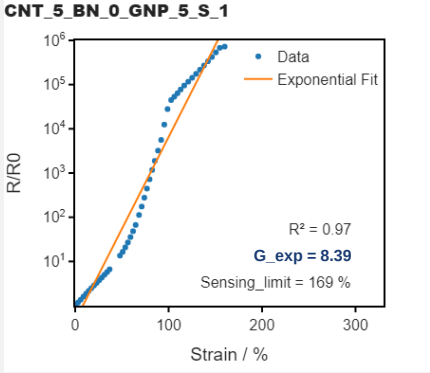
CNT _ BN





CNT _ GNP

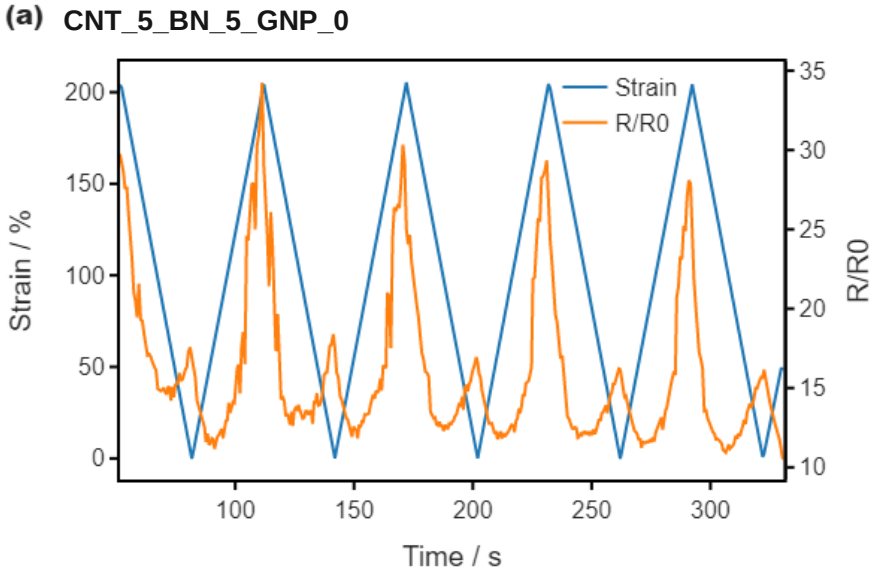




*G_EXP, is the Gauge Factor fitted to a Y logged graph.
Higher Gauge Factor = Greater Amount Sensing

3.2 Strain Sensing, Cyclic

*CNT_5_BN_5_GNP_0: before (left) after (right) testing



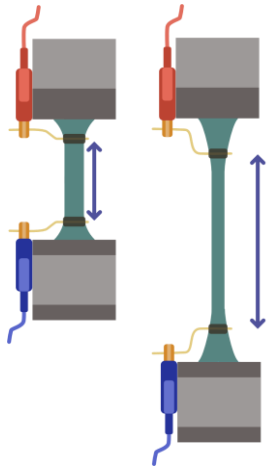
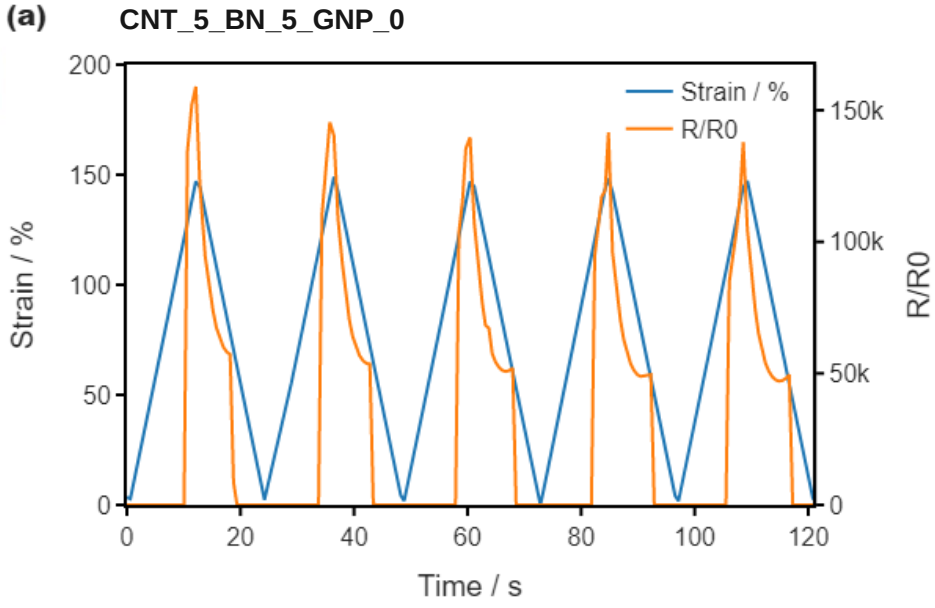


Illustration of strain sensing setup

- CNT BN Hybrids show a clear correlation between strain and resistance when cyclically loaded.
- Large amount of sensing noise present due to breakdown of copper mesh/ sample interface when repeatedly loaded.

3.3 Strain Sensing, Non-regular Cyclic

TPU_5_CNT_5_BN: 3D Printed negative ratio strain sensor



Negative Poisson's Ratio Strain Sensor

- Made form interlocking 6 sided polygons.
- Designed to expand in all directions when strained.
- Graph:
  - Clear spikes as the sensor is stretched
  - Genital relaxation / reduction in resistance as the sensor contracts a slower rate than the strain is removed at.

4.1 Conclusions:

- Conductive fillers in thermoplastic elastomers present a promising avenue for innovative research, but their processability currently hinders their application in 3D printing.
- Utilizing hybrids in the development of printable strain sensors could address the challenge of balancing conductivity and processability.
- TPU_5_CNT_5_BN hybrids demonstrated a well-defined strain resistance trend with a near logarithmic fit, facilitating straightforward sensor calibration.
- These hybrids exhibited a high sensing range of up to 250%, indicating their potential for capturing a wide range of strain values at high accuracy.

Thank You

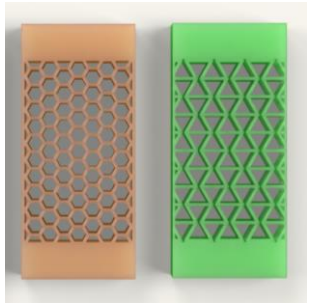
Any Questions?

Queen Mary
University of London

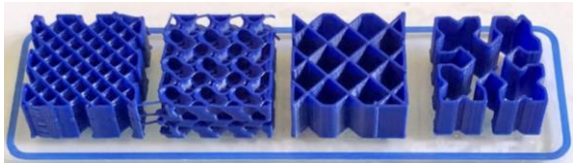
4.1 Next Steps:

- Slicing parameters:
  - Infill
  - Printing type: (Layer by layer/ Continuous)
- Print Orientation:
  - Printing in direction of strain /
    Printing perpendicular to strain direction.
- Use of expanded structures

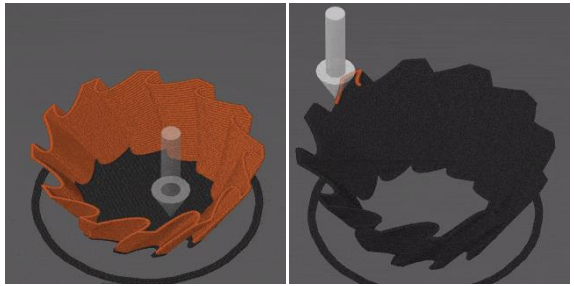
Hex and Negative Poisson's ratio strain sensor designs



Samples at different infill densities



Samples with different infill patterns



Continuous Line Printing *(Vase Mode)*

Conventional Layer by Layer Printing