University of Ioannina
School of Engineering

Department of Materials Science & Engineering

Composite & Smart Materials Lab
(http://csmlab.materials.uoi.gr)

MONITORING THE PROPERTIES OF CEMENTITIOUS COMPOSITE MATERIALS WITH ADVANCED FUNCTIONALITIES

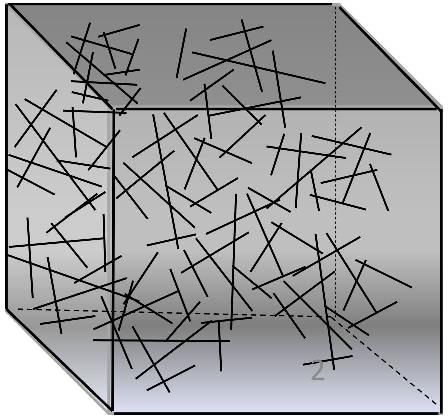
A. Gkaravela, I.Vareli, N.-M.Barkoula and A.S. Paipetis

Motivation of the Study

✓ Green Buildings

✓ Energy Harvesting

✓ Functional Cement

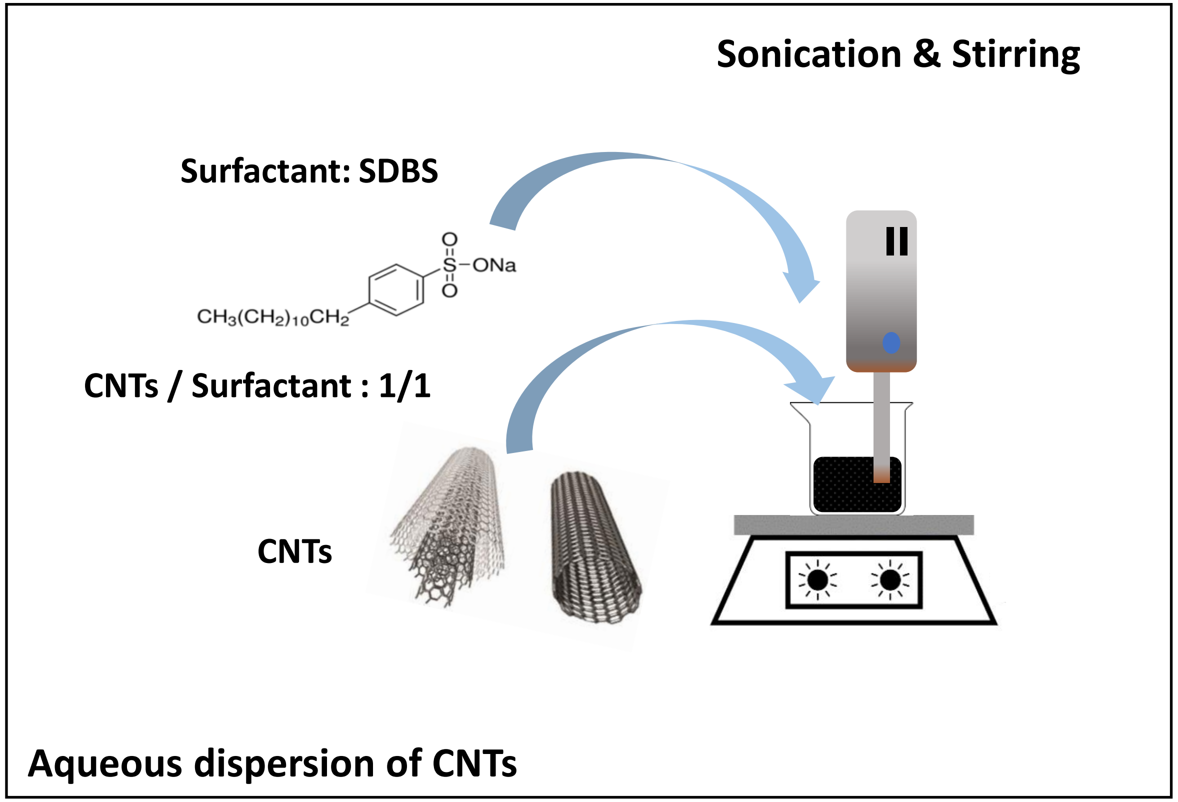


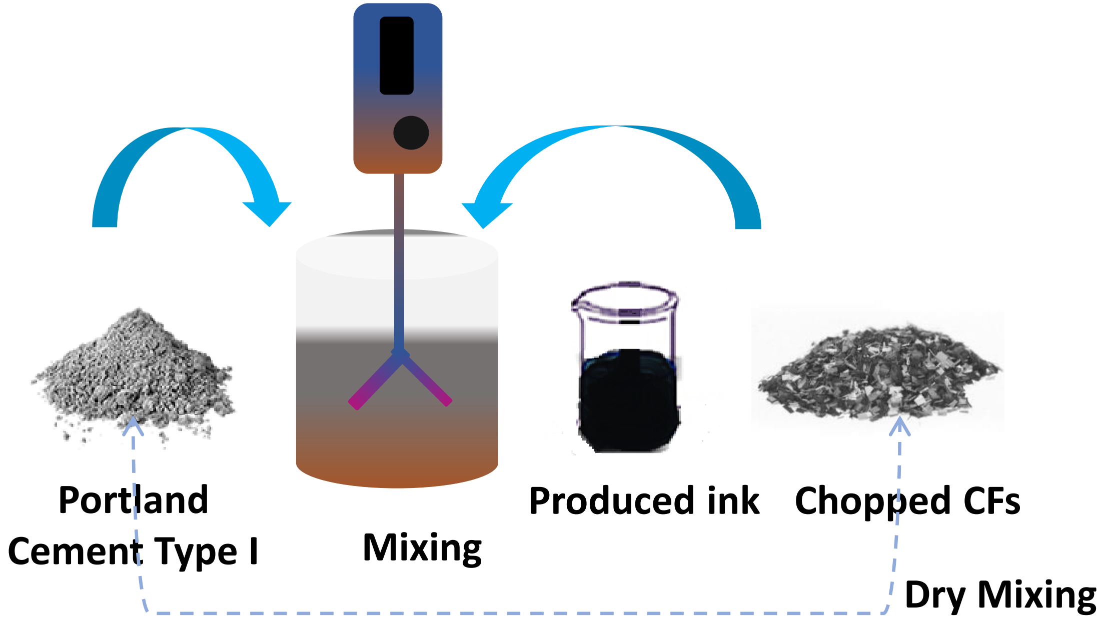
THERMOELECTRIC MICRO- / NANO- CEMENTITIOUS COMPOSITES FOR POTENTIAL THERMAL ENERGY HARVESTING

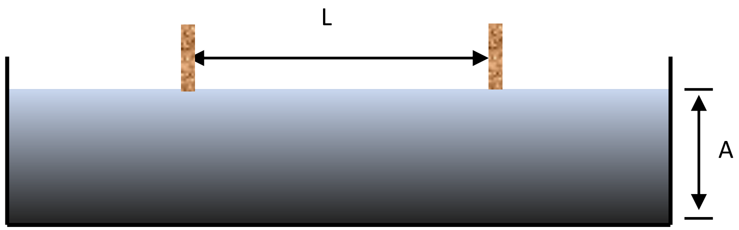
I. Vareli, A. Gkaravela, e. Taouma, N.-M.Barkoula and A.S. Paipetis

Carbon Nanotubes (CNTs) & **Carbon Fibers** (CFs) as fillers are used:

- **to improve mechanical properties**
- **to impart functionalities**
  - **electrical & thermoelectrical properties**







L: distance between the electrodes, A: electrode area inside the cement

Challenges and Goal of this Study

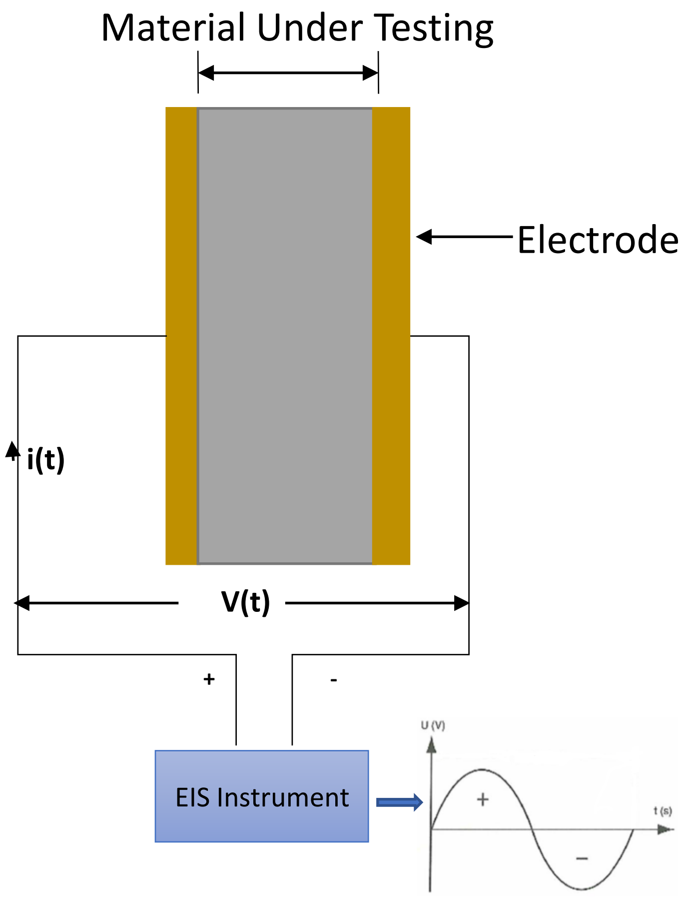
Key Challenges:

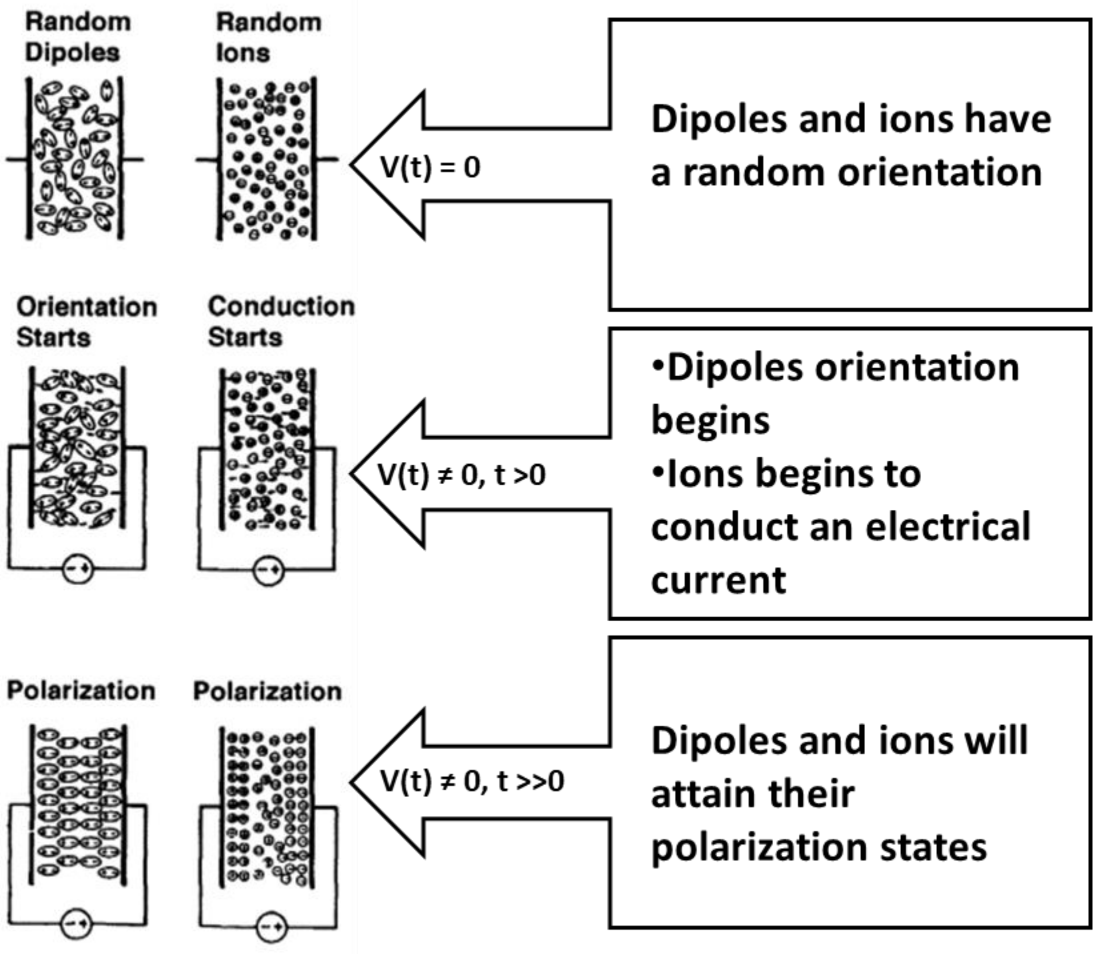
- Avoid agglomeration and achieve homogenous dispersion

Goal:

- Development of a reliable non-destructive methodology to:
  - ✓ Monitor and control the materials’ quality
  - ✓ Detect the changes in the electrical properties during hydration
- Improve the Mechanical Properties
- Develop sensing abilities

An Introduction to Impedance Spectroscopy





$$|Z| (\omega) = Z'(\omega) - iZ'' (\omega)$$

Experimental Protocol – Hydration Process

Cement Composites

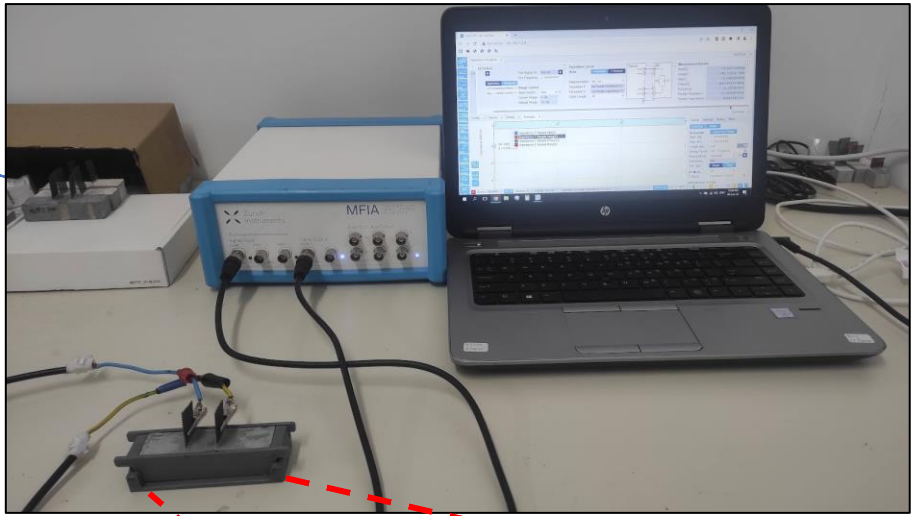
SWCNTs | CFs | Hybrid

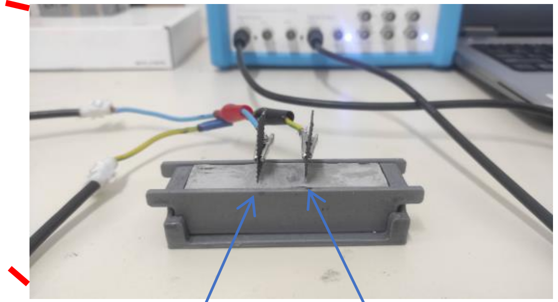
0.1 wt. %* & 0.5 wt. %*

Impedance measurements:
- **After Mixing**
- **1 day of Hydration**
- **28 days of Hydration**

To detect the changes in the electrical properties

MFIA- Impedance Analyzer





Embedded Titanium mesh electrodes

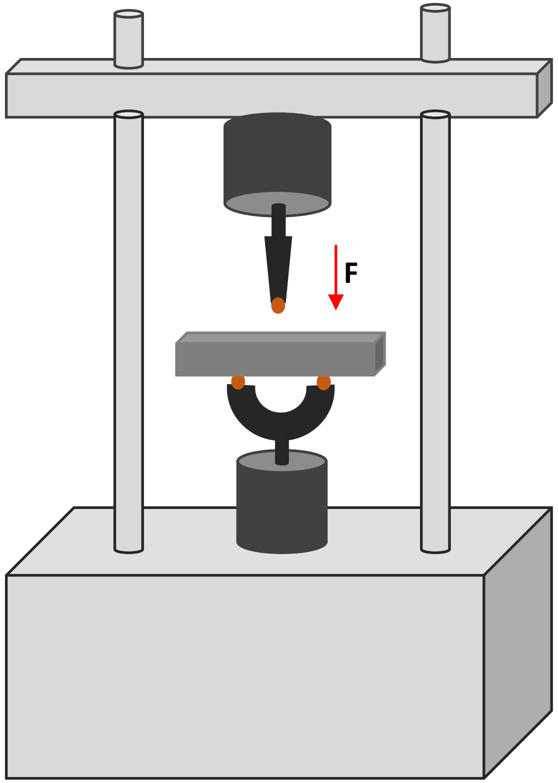
Frequency range (10^{-1}- $5*10^{6}$ Hz)

From the measurements:
- ✓ Impedance, |Z|
- ✓ Real Resistance, Z'
- ✓ Imaginary Reactance, Z''

* By cement weight

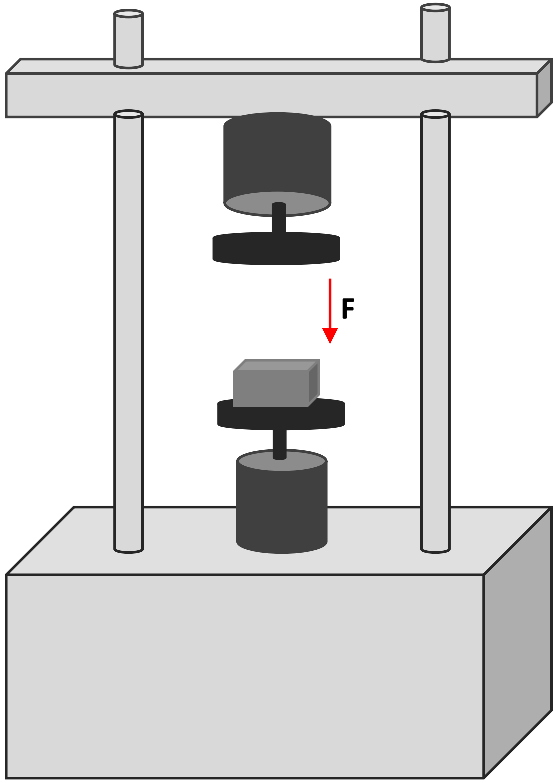
Experimental Protocol – Mechanical Testing/ Sensing

Mechanical Testing



Schematic representation of 3-Point bending test

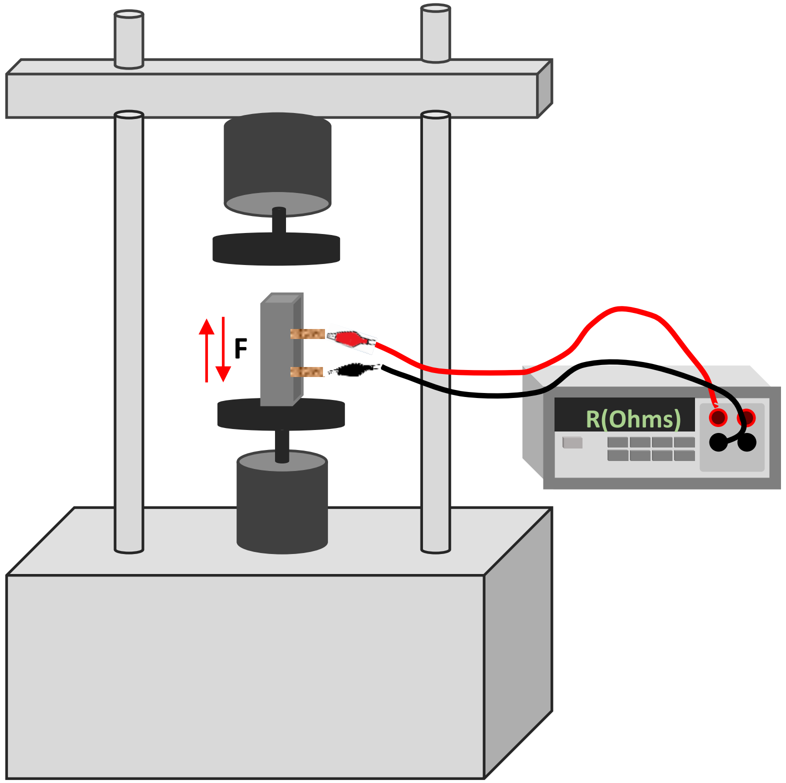
$$\sigma_f = \frac{3FL}{2bd^2}$$



Schematic representation of Compressive test

$$\sigma_c = \frac{F}{A}$$

Piezoresistive sensing

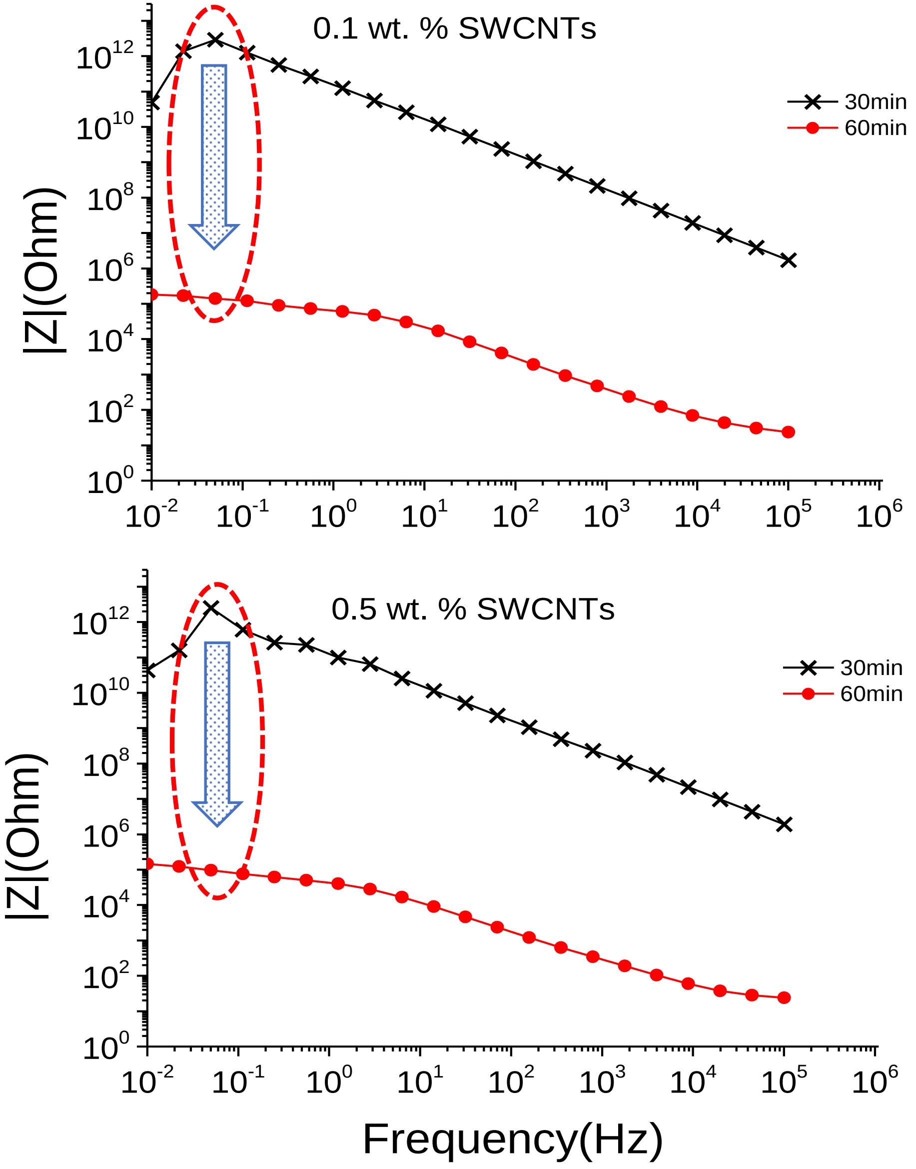


Schematic representation of piezoresistive sensing

F:2→8kN

$\Delta R/R_0\%$

Results - CNTs dispersion

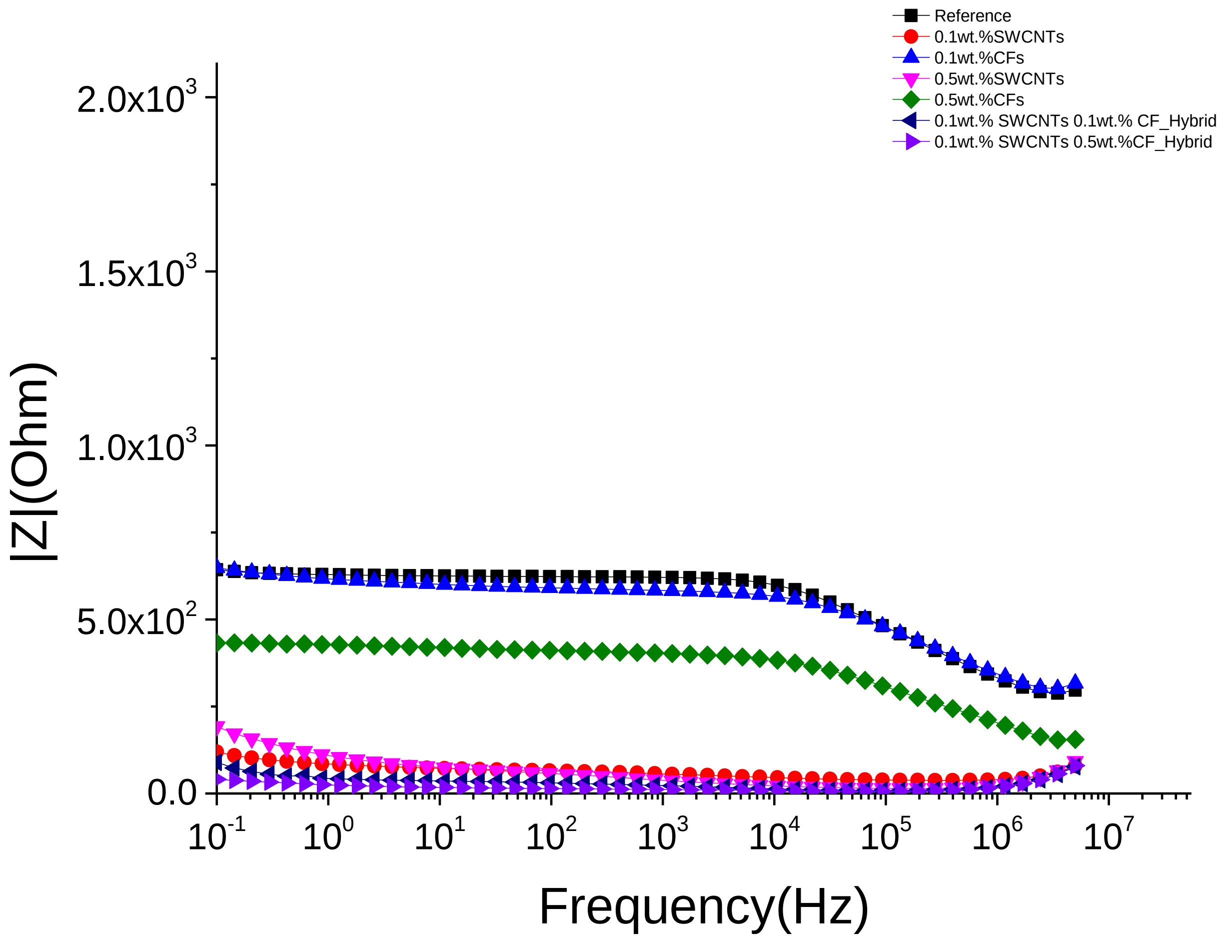


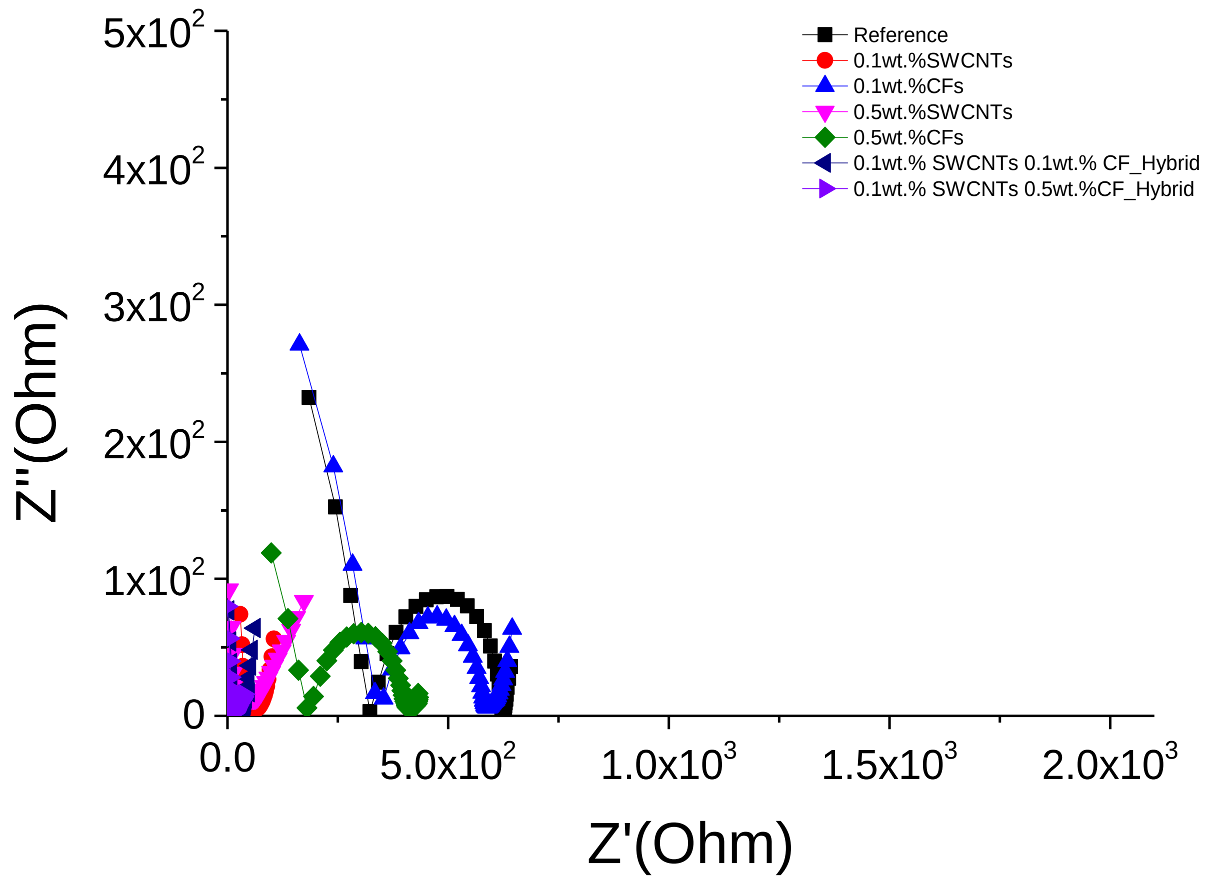
At the frequency of 0.05Hz

Sample	$\lvert Z\rvert(\text{Ohm})_{30min}$	$\lvert Z\rvert(\text{Ohm})_{60min}$
0.1wt.%SWCNTs	$2.94*10^{12}$	$1.41*10^{5}$
0.5wt.%SWCNTs	$1.63*10^{12}$	$5.95*10^{4}$

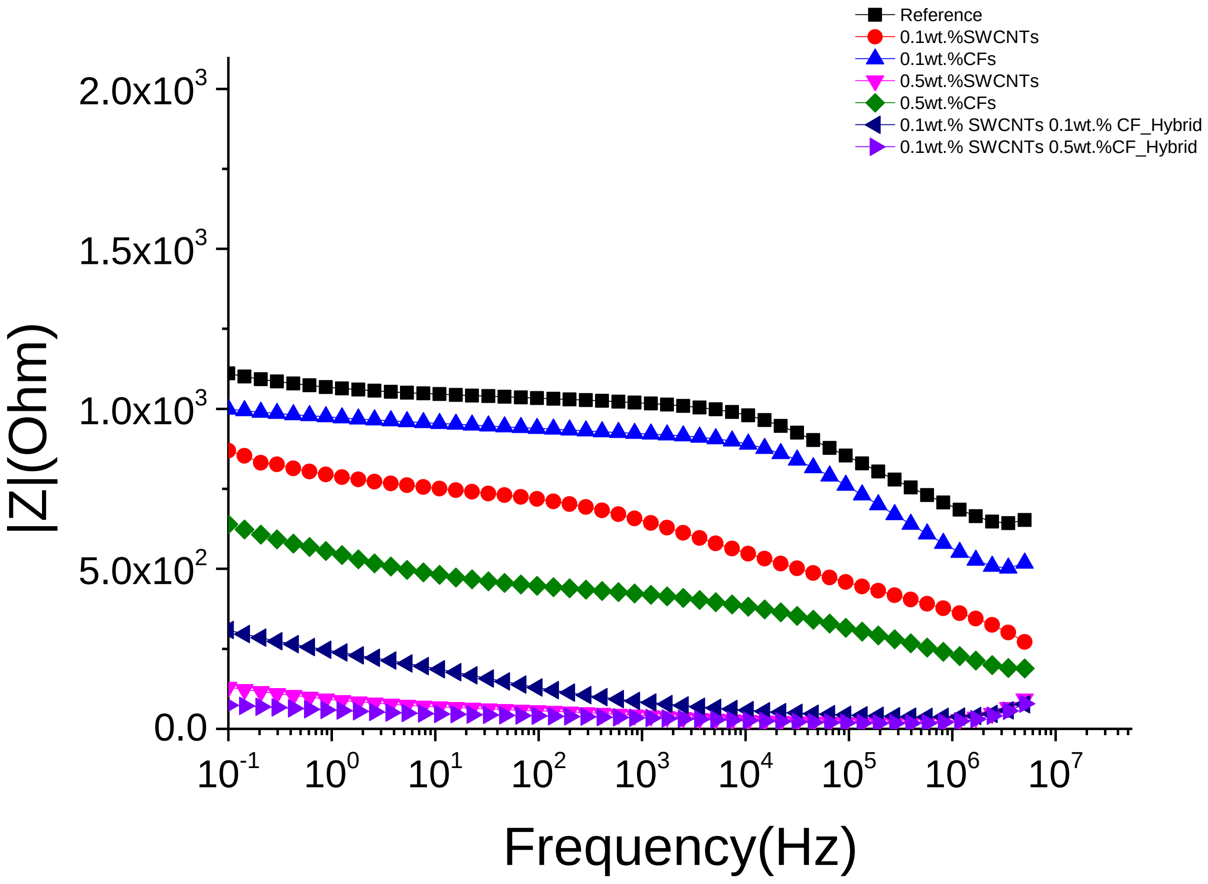
- ✓ **0.1wt.%SWCNTs** A drop of |Z| by seven orders of magnitude, formation of a conductive network
- ✓ **0.5wt.%SWCNTs** A drop of |Z| by eight orders of magnitude, formation of a conductive network
- ✓ **0.5wt.% SWCNTs** Lowest values

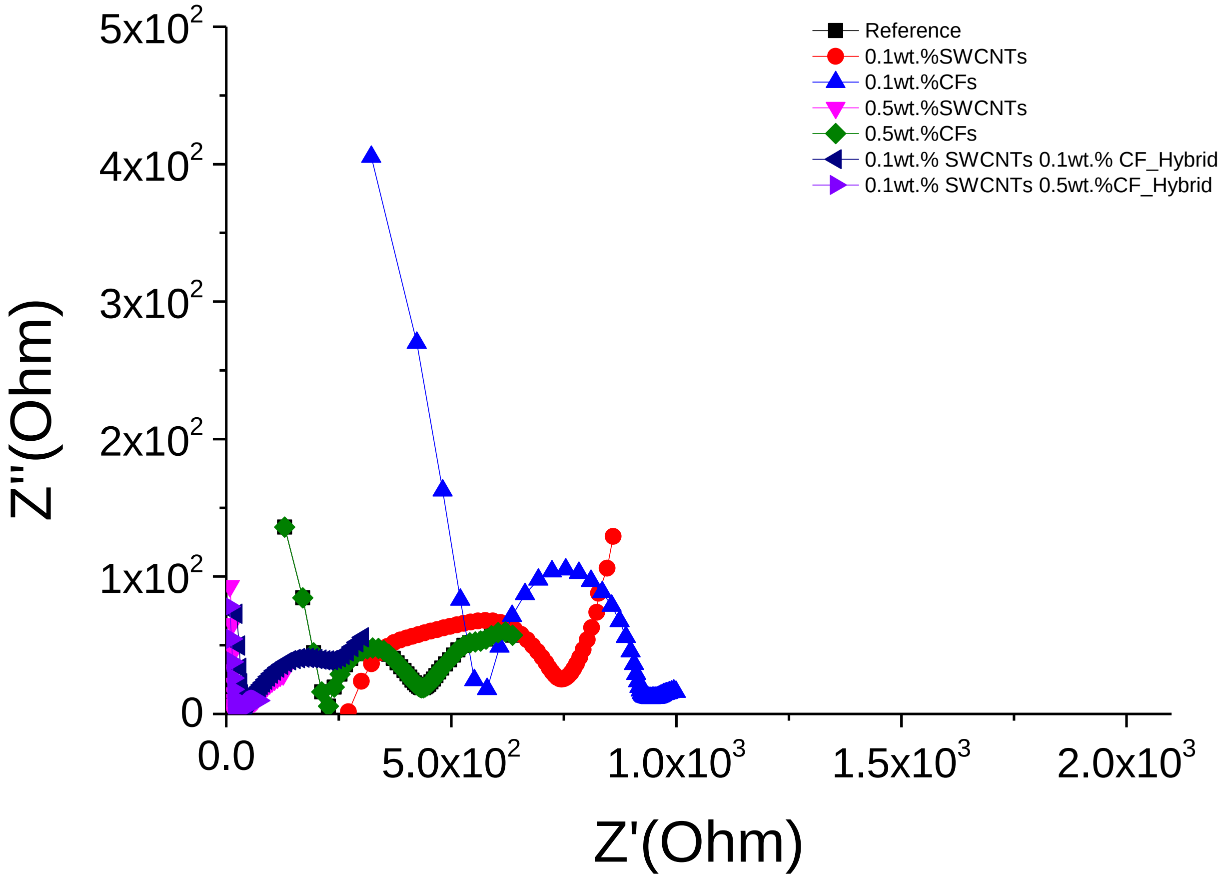
Results – Electrical Properties After Mixing



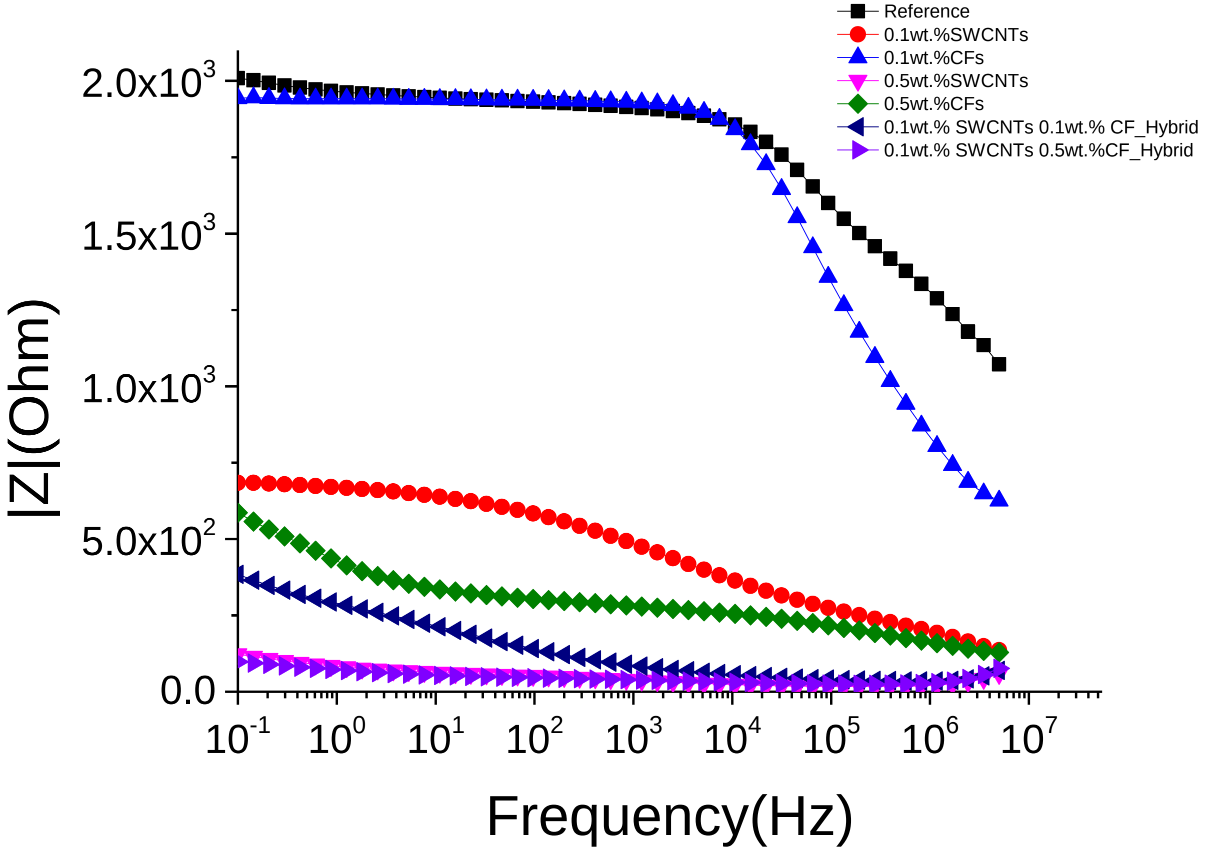


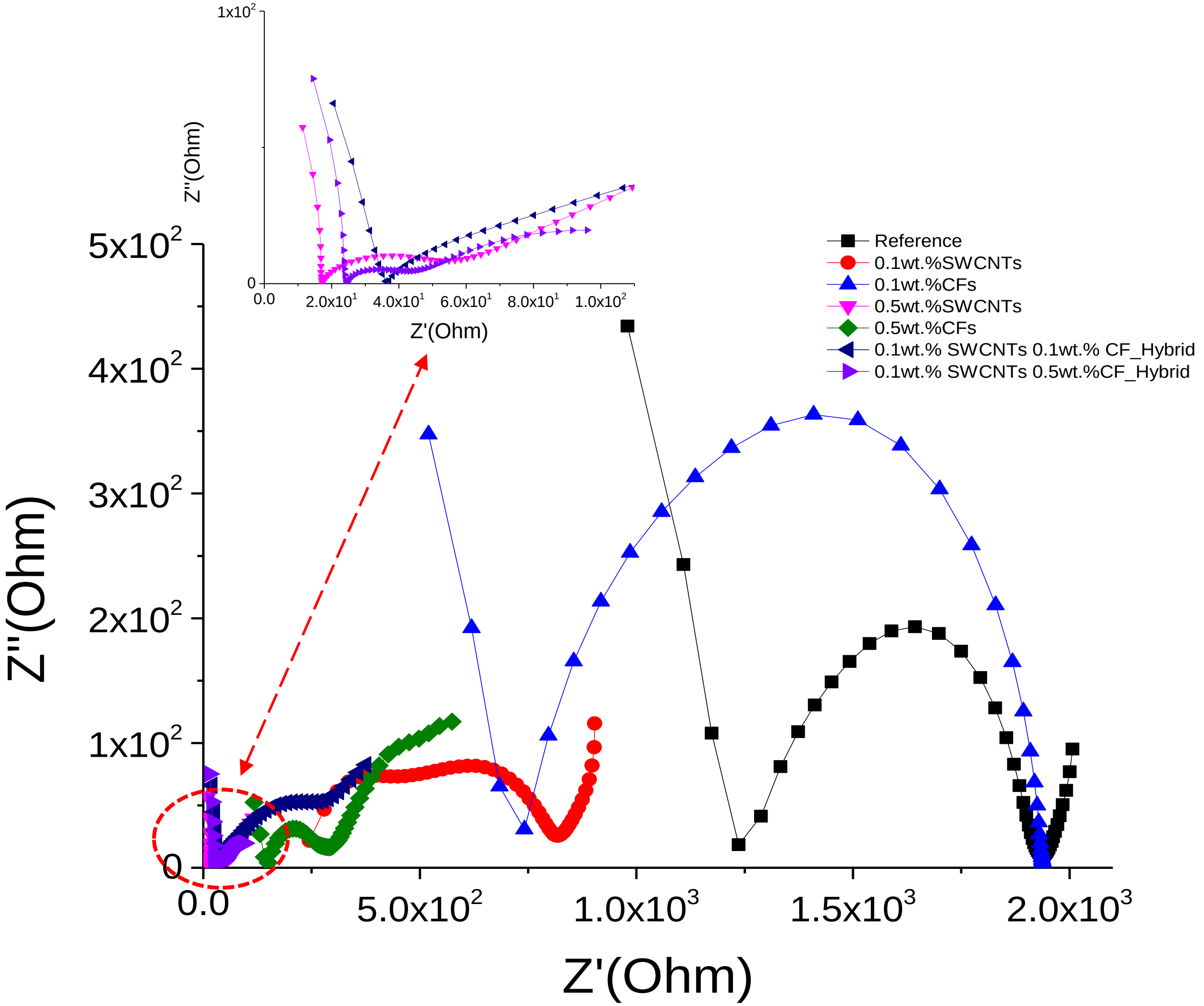
Results – Electrical Properties 1st day of Hydration Process





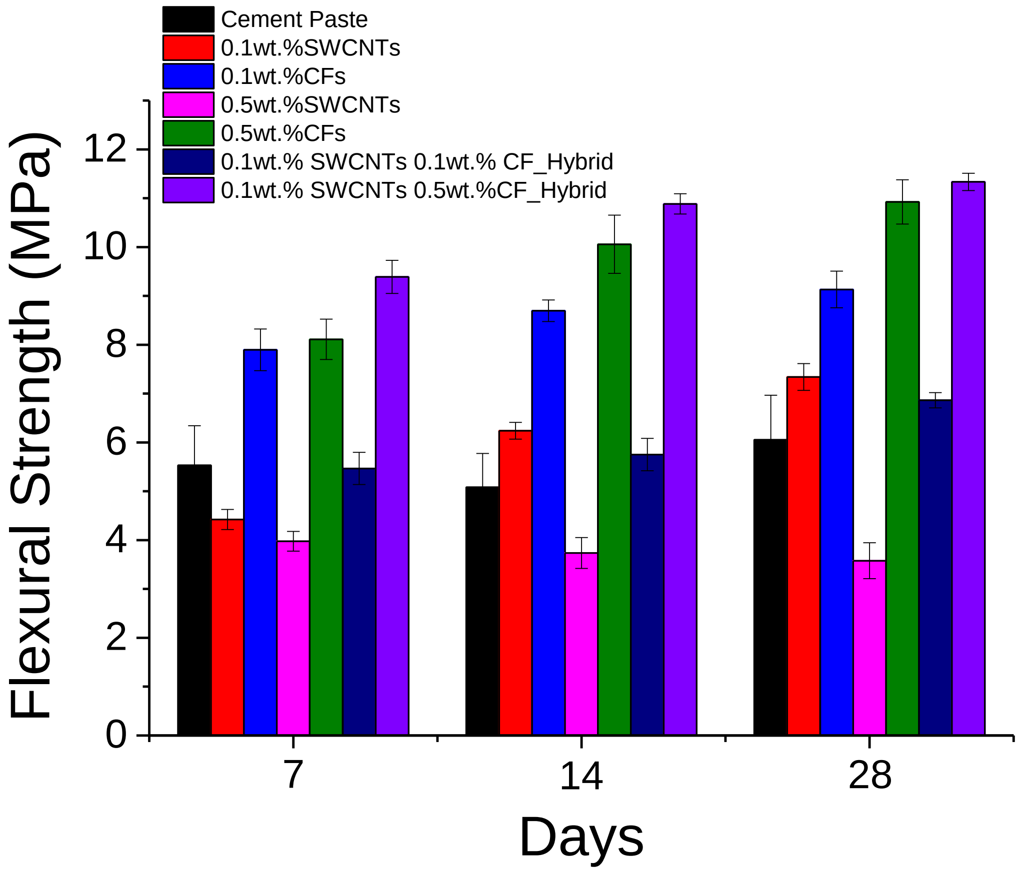
Results – Electrical Properties 28th day of Hydration Process

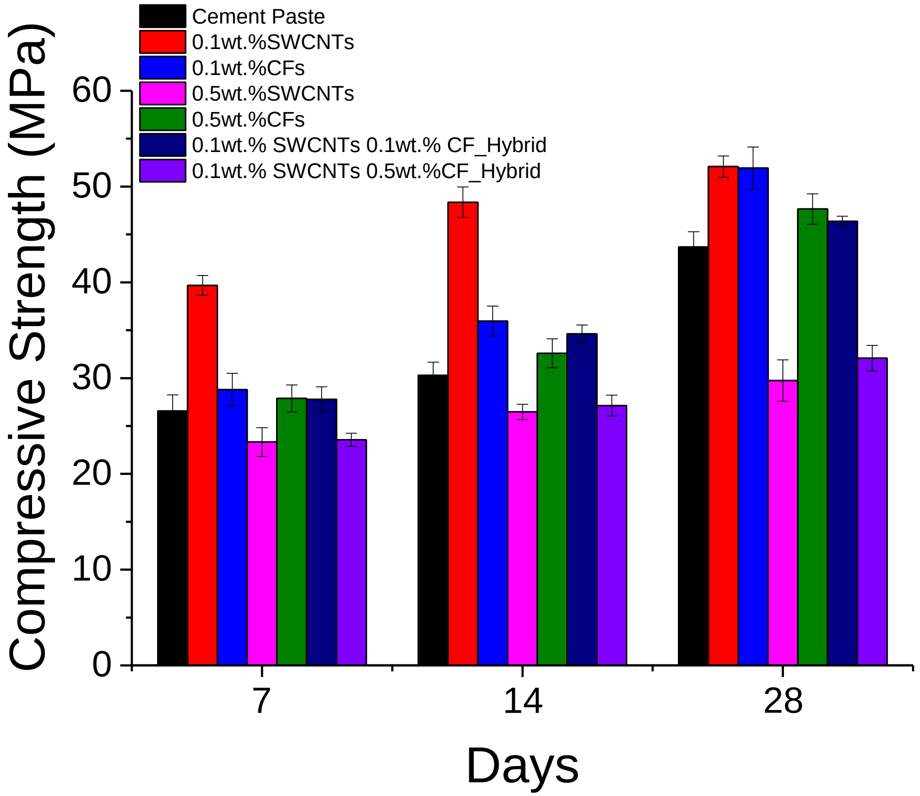




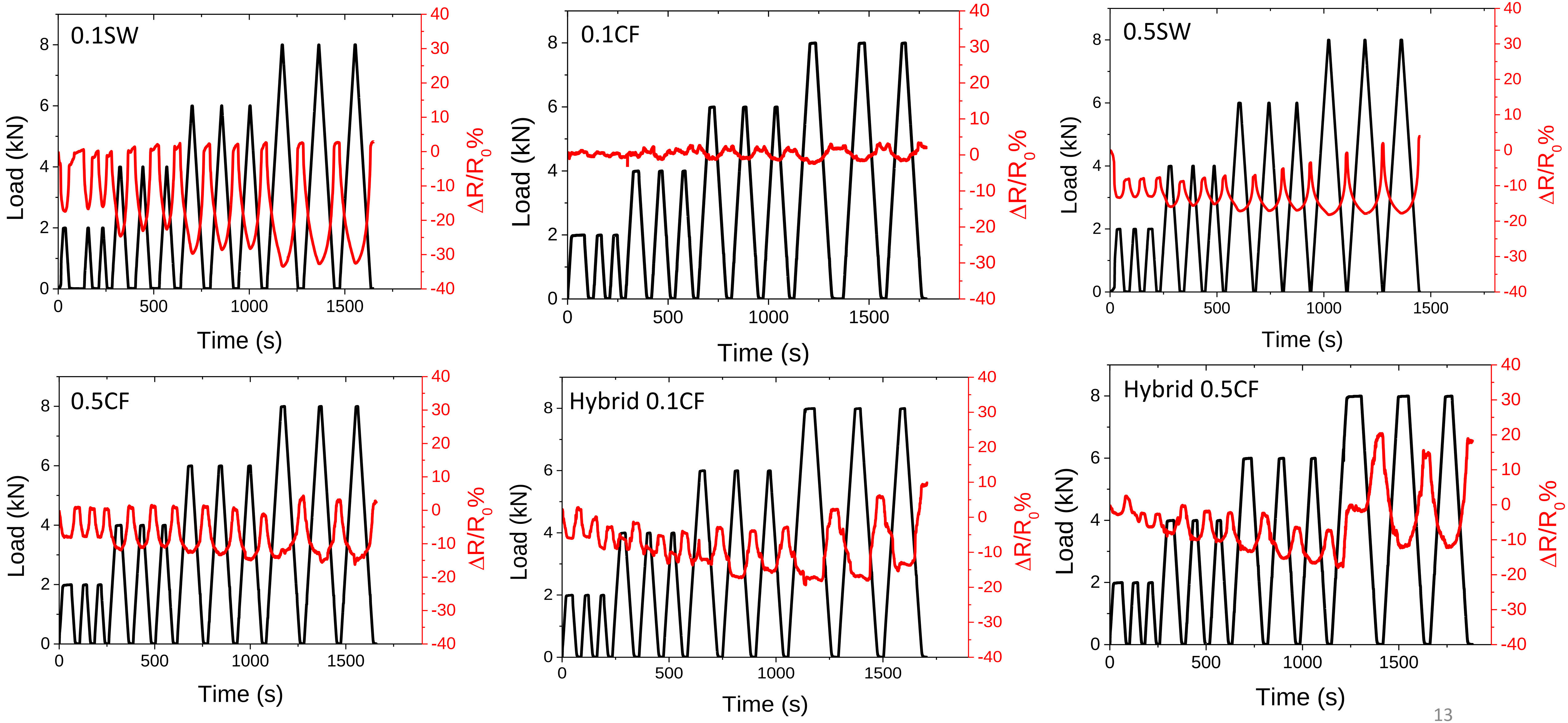
- ↑ values of |Z for 0.1 wt. % CFs as the reference cement, no formation of a conductive network.
- ↓ values of |Z| for 0.1wt. % SWCNTs in relation to reference cement & the 0.1 wt. % CFs, conductive network.
- ↓ values of |Z| for 0.5wt.% SWCNTs 7 hybrid 0.1wt. %SWCNTs &0.5wt.% CFs

Results – Mechanical Properties





Results - Sensing



Conclusions

- Impedance Spectroscopy is a non - destructive technique that can evaluate the CNTs dispersion and the existence of a conductive network .
- 60min of sonication seems to be the optimum sonication time for all cases to avoid agglomeration and achieve homogenous dispersion with electrical properties.
- It is not feasible to form a conductive network for the composites with low concentration of CFs.
- The increase of CNTs/CFs concentration is resulting in lower |Z| values compared to reference cement.
- The type of the reinforcement affects the electrical properties of the composites since the lowest values in the impedance |Z| is presenting by the composite with 0.5wt.% SWCNTs &the hybrid composite with 0.1wt.%SWCNTs &0.5wt.% CFs, following by the composite with 0.5wt.% CFs and the composite with 0.1wt.%SWCNTs.
- The incorporation of the CNTs/CFs into the cement matrix improved the mechanical properties of the cement composites.
- The hybrid composite with 0.1wt.%SWCNTs & 0.5wt.% CFs presents the highest values in flexural strength while the nanocomposite with 0.1wt.%SWCNTs presents the highest values in compressive strength.
- The composites above the percolation threshold exhibit remarkable piezoresistive characteristics.

Acknowledgments

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Thank you!

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Composite and Smart Materials Lab

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- → ***Hybrid*** *composites*
- → ***Simulation*** *& modeling*
- → ***Self-healing*** *polymers & composites*

- → *Non-Destructive Evaluation (**NDE**)*
- → *On-line Structural Health Monitoring (**SHM**)*
- → ***Mechanical / thermomechanical*** *characterization*
- → ***Thermoelectric*** *composites & energy harvesting*