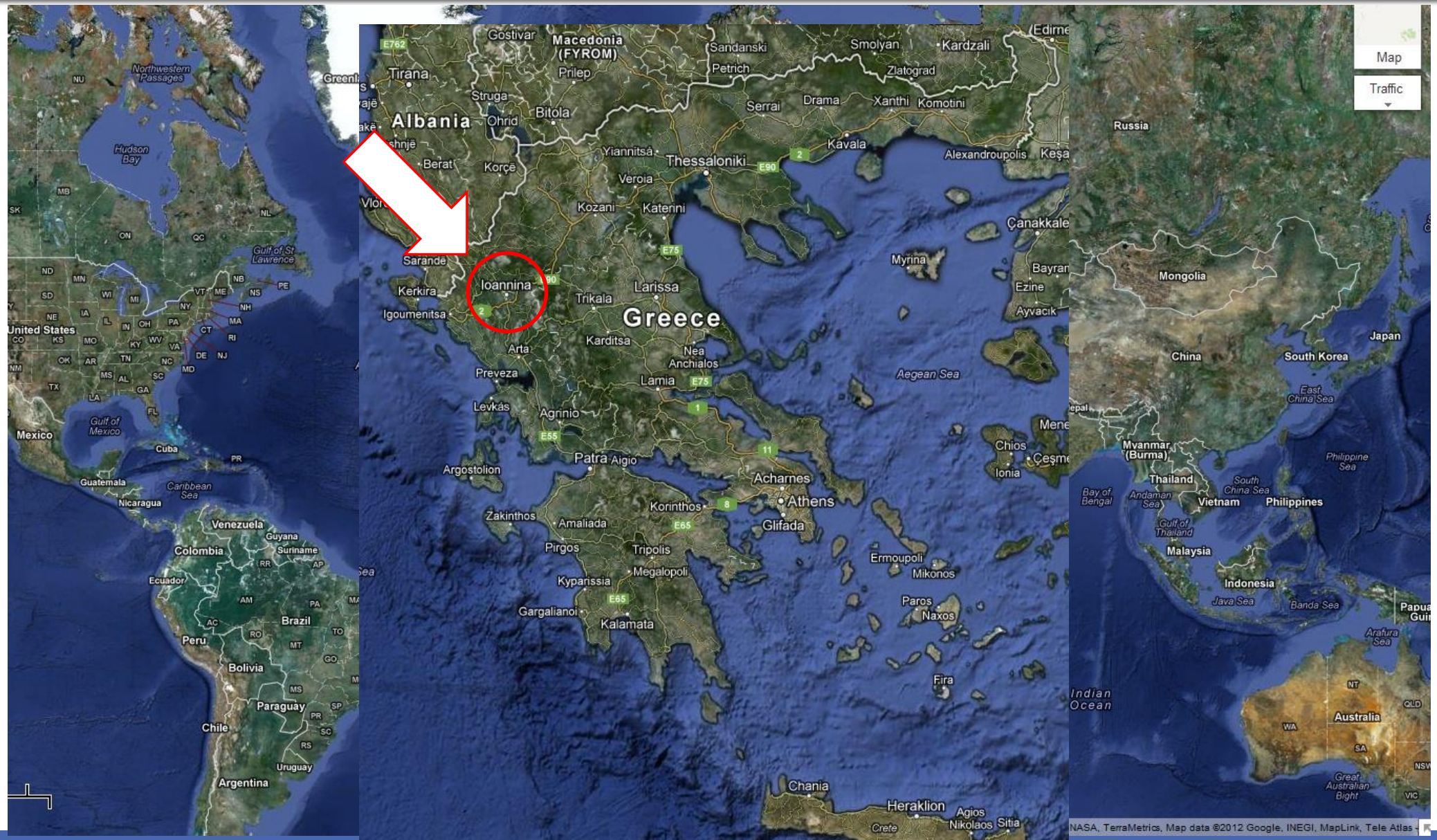
COMPOSITE AND SMART MATERIALS LABORATORY
-CSML-

Department of Materials Science Engineering, University of Ioannina, Greece
http://csmlab.materials.uoi.gr/index.php/en/

Lab director: Prof. A. Paipetis

Greece - Ioannina – University of Ioannina and CSML lab



Research & Development of Advanced Composite and Smart materials

Design for:

- ✓ Performance
- ✓ Durability
- ✓ Functionality
- ✓ Response to Conjugated Load (Mechanical, Thermal, Electrical)
- ✓ Self diagnosis and Self healing
- ✓ Non-destructive testing
- ✓ Structural health monitoring
- ✓ Recycling

Applications:

- ❑ Aerospace
- ❑ Automotive
- ❑ Naval
- ❑ Civil
- ❑ Packaging

Lab facilities ~ 500m^2 (2 Prof. research staff, 1 Lab teaching staff, 2 Post-Docs, 8 PhD, 5 MSc, 10 Thesis)

Faculty members:

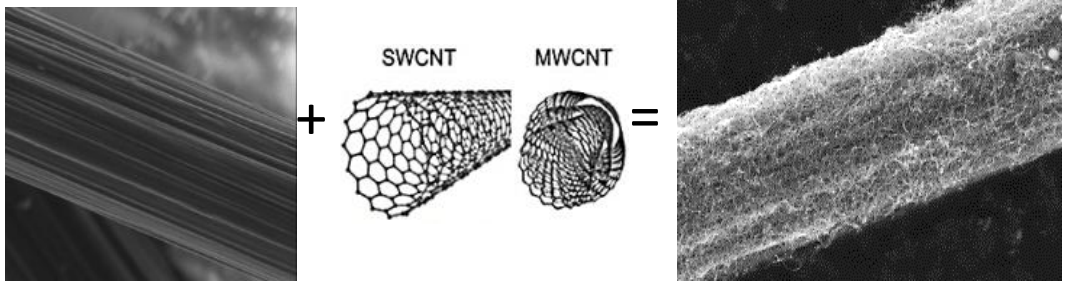
Alkis Paipetis (Prof.)
Nektaria Marianthi Barkoula (Assist. Prof.)

Researchers:

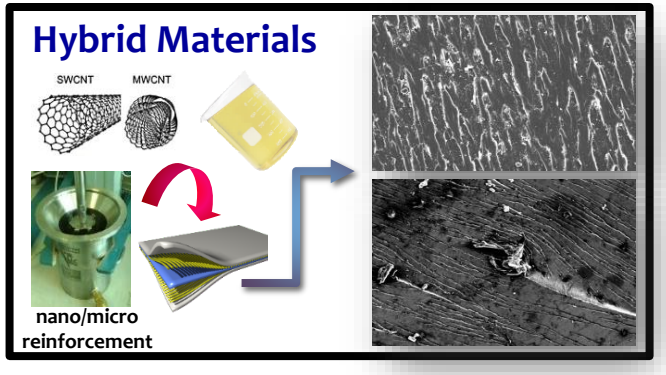
Lazaros Tzounis, Kyriaki Tsirka, George Karalis, Christos Mytafidis, Maria Kosarli, Anastasia Polymerou
Ioanna Vareli, George Fotinidis, Anthi Poulia, Labros Koutsotolis (+6 Master students, +10 Diploma students)

Research Areas – Related Activities

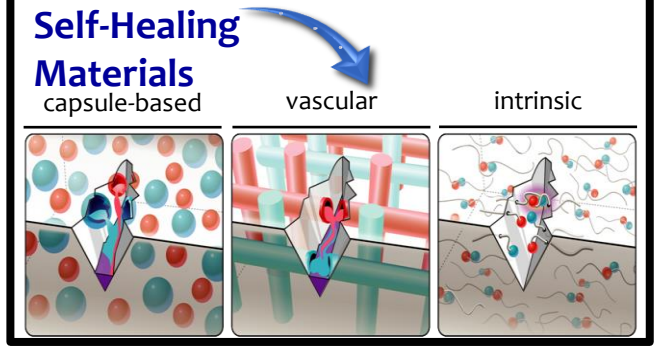
Hierarchical reinforcement Materials



Hybrid Materials

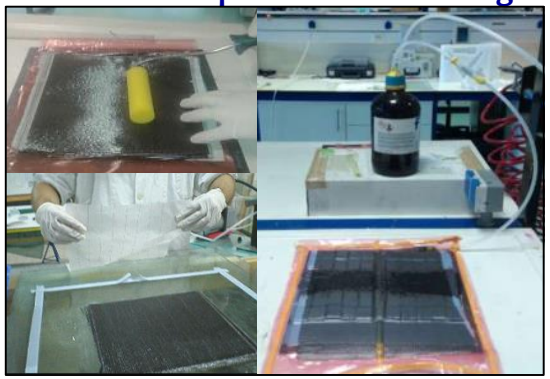


Self-Healing Materials



Prepreger pilot line (creel cabinet / spreading unit)

Laminate Composite manufacturing

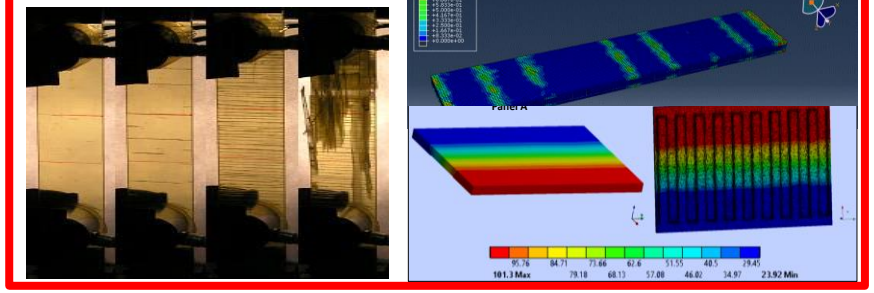


Hot-press assisted lay-up

Roll-to-roll (R2R) pilot line for printed electronics/ processes, device fabrication (TEGs, OPVs, sensors) & packaging (slot-die, bath, etc.)

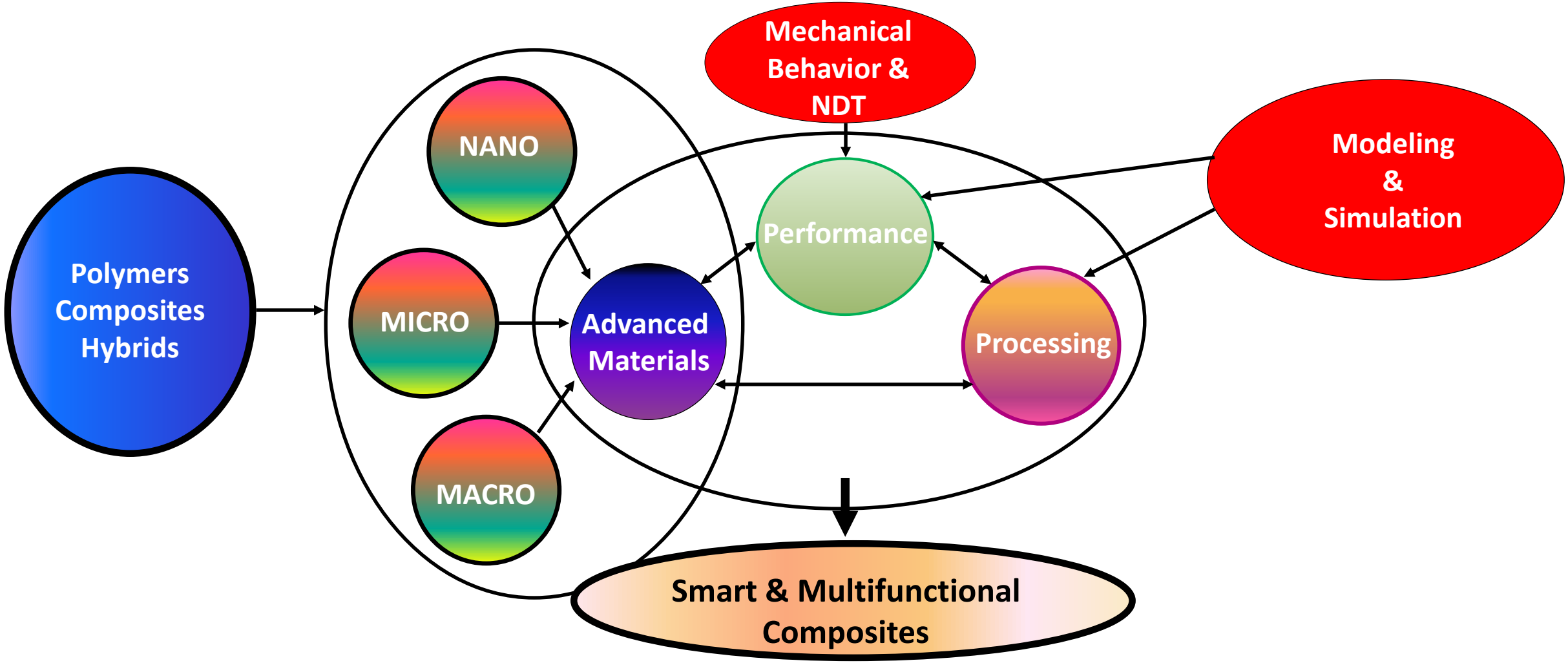
NDT and SHM technologies (C-Scan, Impedance spectroscopy, IR-T with lock-in, AE)

Predictive Modeling & Simulation



Applications

CSML Approach

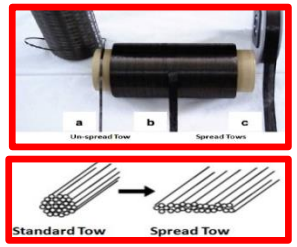


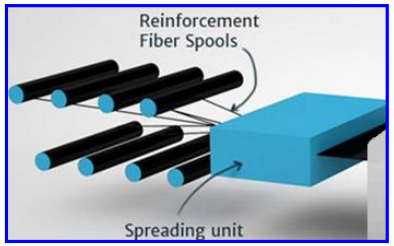
→ >100 scientific publications in high impact factor journals
→ Competitiveness in MG, NMBP, ICT, LC, FOF, FTI, SPIRE, CleanSky, Health H2020 calls

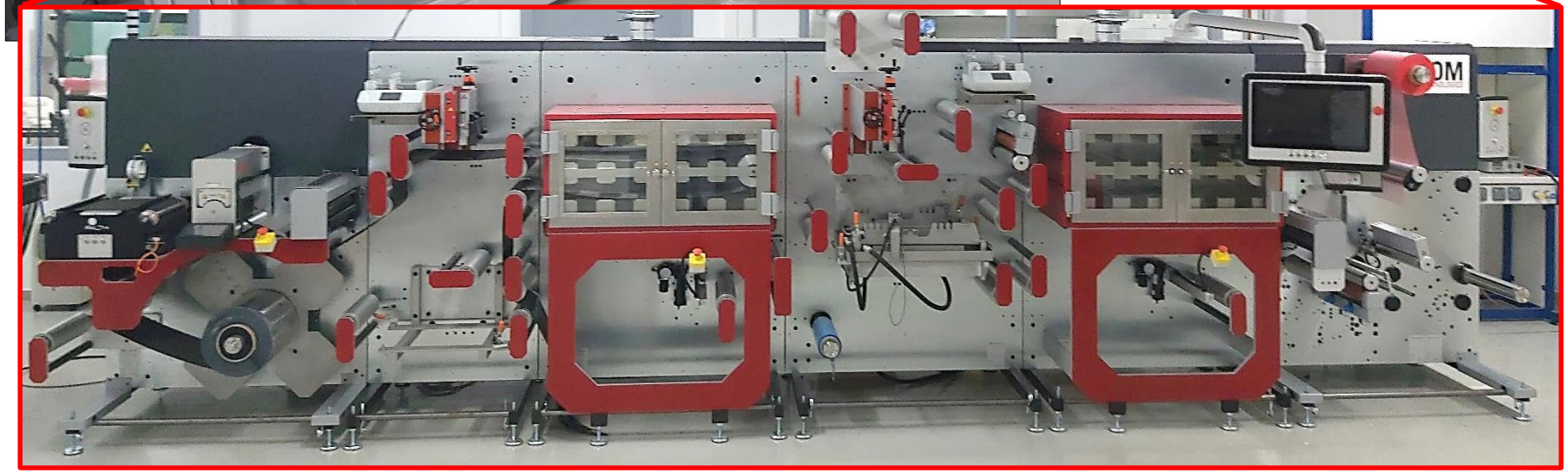
Manufacturing Facilities

Advanced Manufacturing Processes

Pilot roll-to-roll (r2r) line for continuous manufacturing of advanced composites: Coated fibers and Prepregs



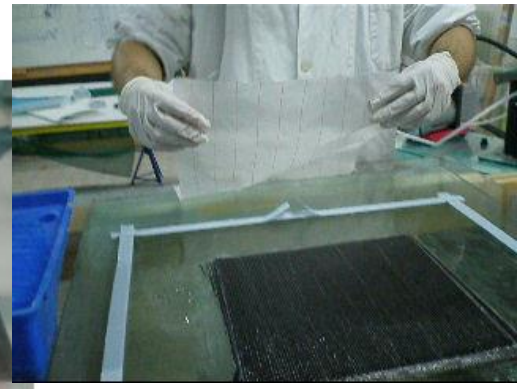


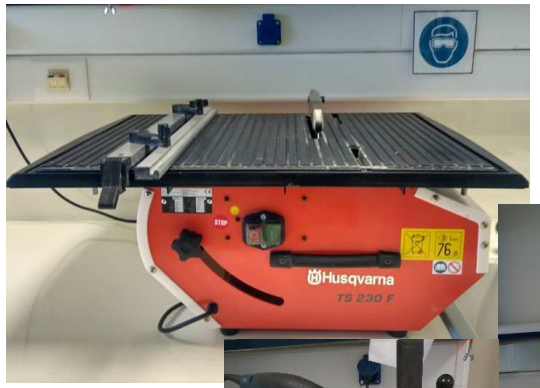


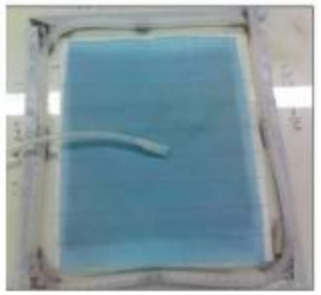
Capabilities

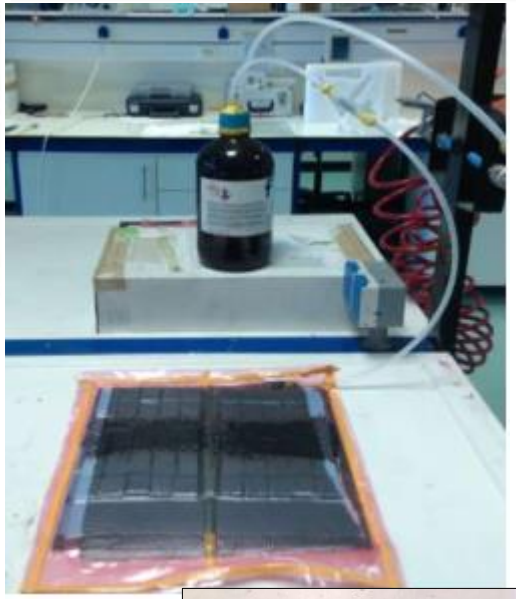
- Spreading unit (for fiber tows)
- Unwinder (for fiber tapes or mats)
- Coating / deposition unit: slot die and bath coating technologies
- Oven for drying
- Resin impregnation unit: slot die and bath coating technologies
- Pressure assisted lamination unit
- Oven for partial curing of prepreg
- Winding unit

Manufacturing Processes









Facilities for

- Hand lamination
- Vacuum and infusion
- Post-manufacturing processes: Cutting, Milling, Polishing, Grinding
- Fiber Spinning

Manufacturing Facilities (indicative)

Facilities for composites manufacturing

- Hydraulic hot press
- Vacuum ovens
- High temperature ovens

Mixing facilities for

- Simple mixing processes,
- High speed shear mixing (bead mill and impeller mode),
- Ultrasonic Mixing
- Ultrasonic bath

Testing & Characterisation Facilities – Equipment – Infrastructure

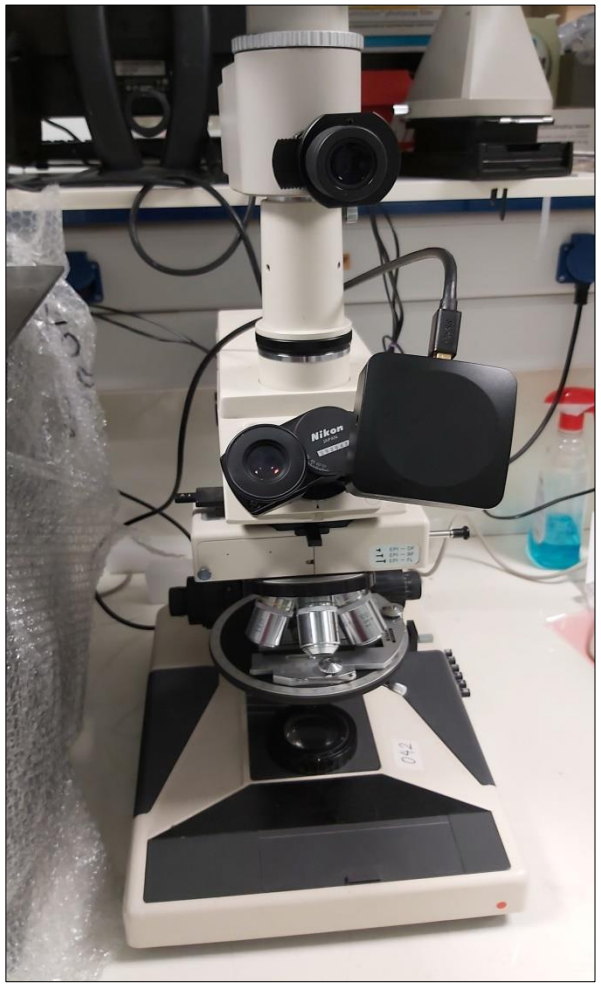
Spectroscopy

- Raman Confocal Microscope (514 / 785nm laser line, Labram HR –Horiba micro-Raman system; coupled with a micro-tensile tester

Agilent 4300 Handheld Portable FTIR

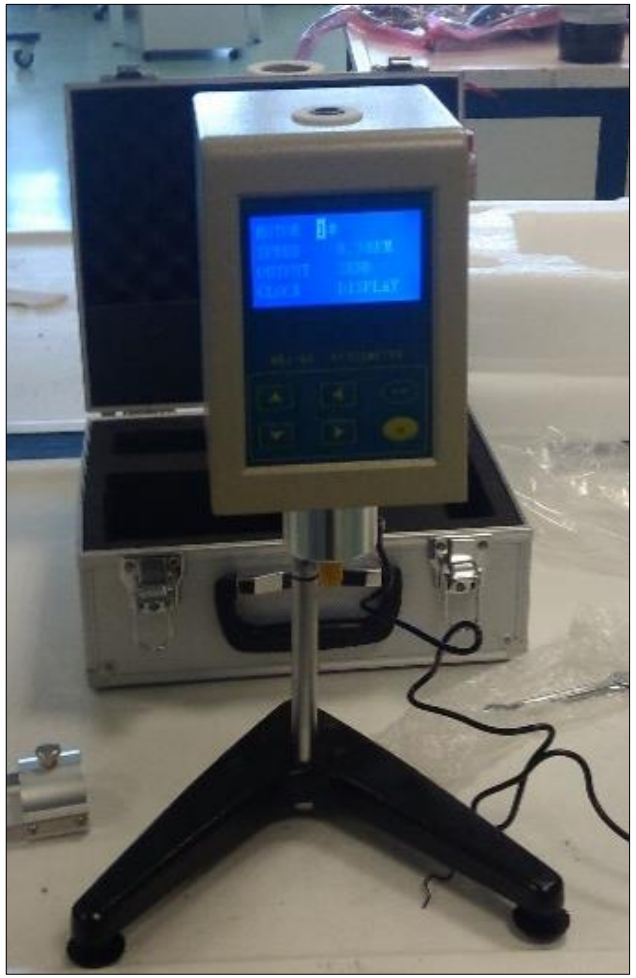
- Ergonomic handheld FTIR spectrometer design for ease of use and optimal data measurement
- DGTS detector for broad spectral coverage for routine analysis
- MicroLab Mobile FTIR software

Optical Microscopy, Rheology



- Optical microscope

(Olympus - 10x to 1000x objectives)



- Viscometer (dynamic viscosity of resins, nanoinks)

Scanning Electron Microscopy

Phenom Pharos Desktop SEM
Desktop SEM with FEG source for high brightness imaging

Light optical magnification	•20–134x
Electron optical magnification range	•200–1,000,000x
Resolution	•2.5 nm (SE), 4 nm (BSE) at 15 kV •10 nm (SE) at 3 kV

Nanomorphology – Nanometrology, Surface Characterization (structure, wetting properties)

- Atomic Force Microscope (AFM, Bruker Innova, contact – tapping mode) for nanomorphology characterisation, Conductive AFM, Surface Potential (SPoM), Scanning Capacitance Microscopy (SCM), MFM, Force Modulation Microscopy, Liquid Imaging

- Contact Angle Goniometer (contact angle, surface tension of liquids and surface energy of solid surfaces determination)

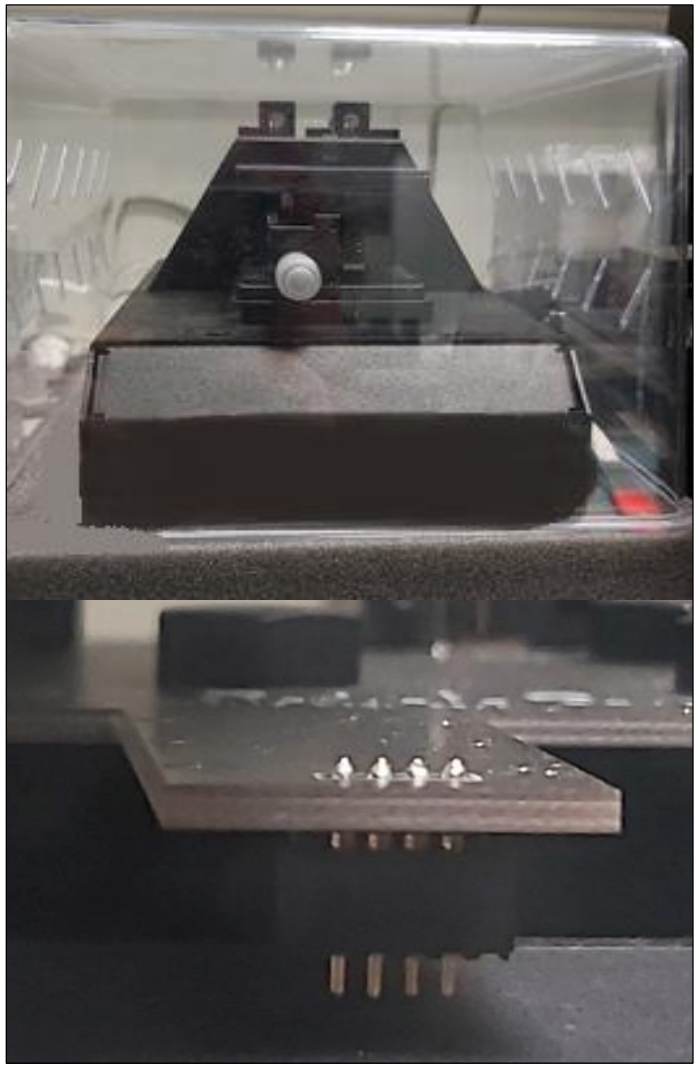
Electrical characterisation of thin films & bulk materials: DC and AC measurements / equipment

- Dielectric Spectroscopy (1KHz-1GHz)

- DC power supply (Manson, 0.1 – 30V)

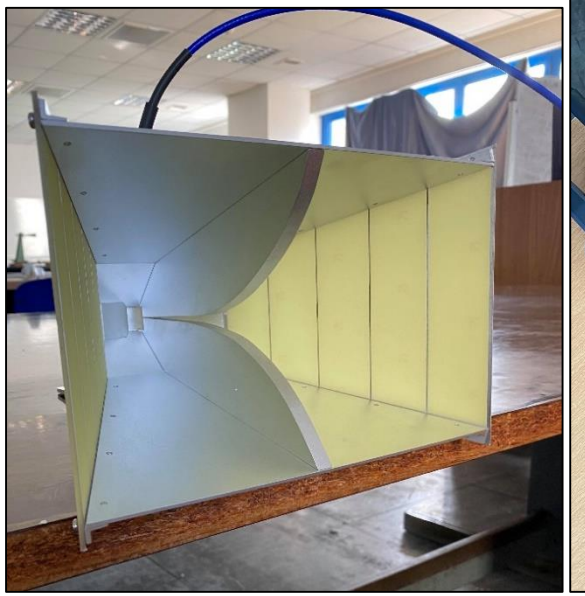
- Textronics AFG3052C dual channel Ultrasonics pulse generator

- Textronics dual-channel Oscilloscope (TDS 2002C)



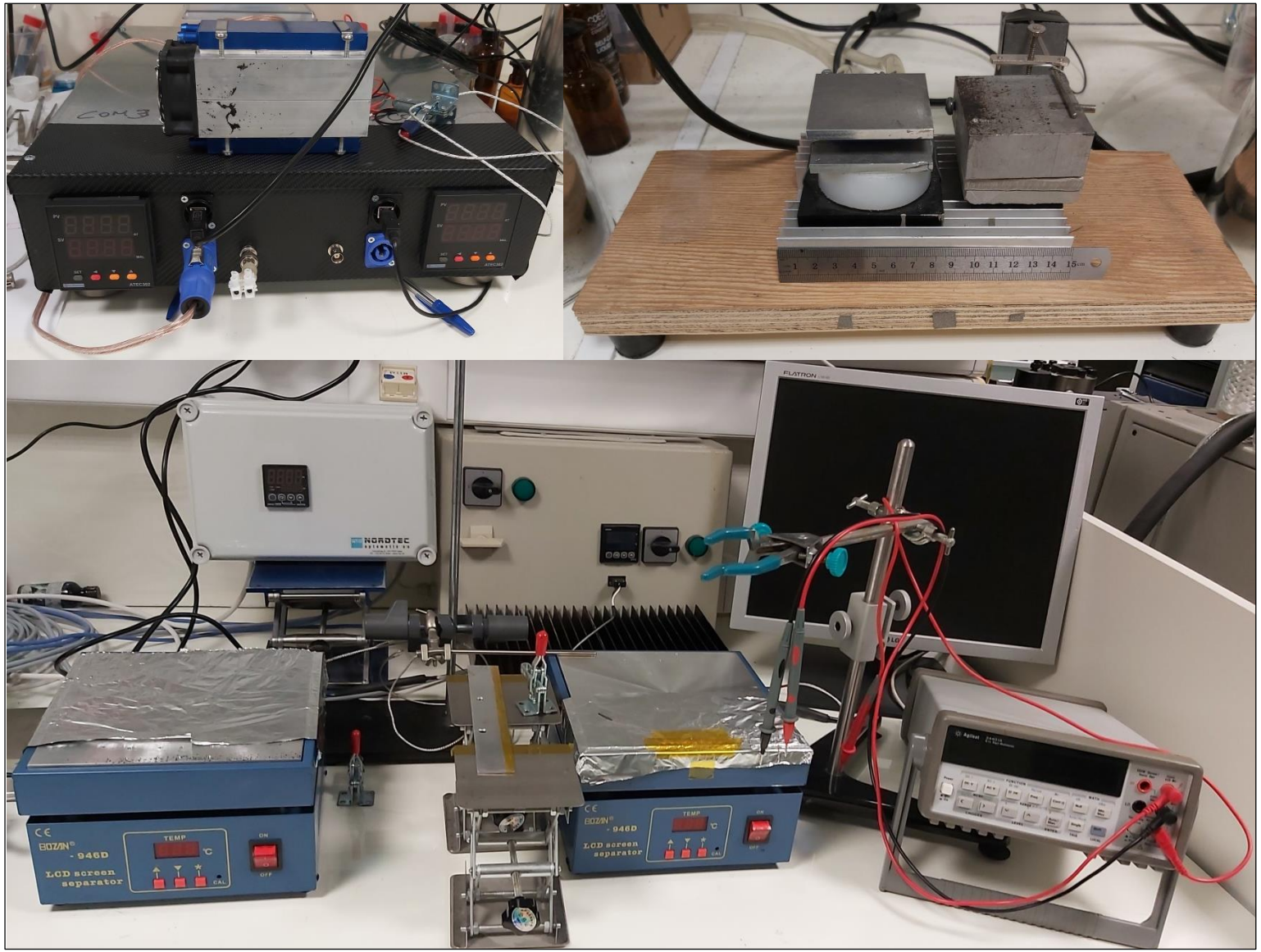
- Four-probe sheet resistance & electrical conductivity meter

EMI Shielding infrastructure – Set-up



- Keysight Vector Network Analyzer (VNA) 300 kHz-9 GHz, two wideband dual-ridged horn antennas (Vector Telecom) 1GHz-18 GHz (electormagnetic interference measurements on wide frequency range)

Thermoelectric materials and thermoelectric generator (TEG) characterisation



- Thermal gradient stage with PLC controlled Peltier for thermoelectric material measurements (-20°C to 200°C)
- Various hot plates and Voltage/ Current multimeters (Agilent 34401A6½) for thermoelectric generator (TEG) characterisation upon applying different load resistances (R_{load}) at different thermal gradients (ΔT)

Mechanical testing: Static, Dynamic, Impact, Micromechanics

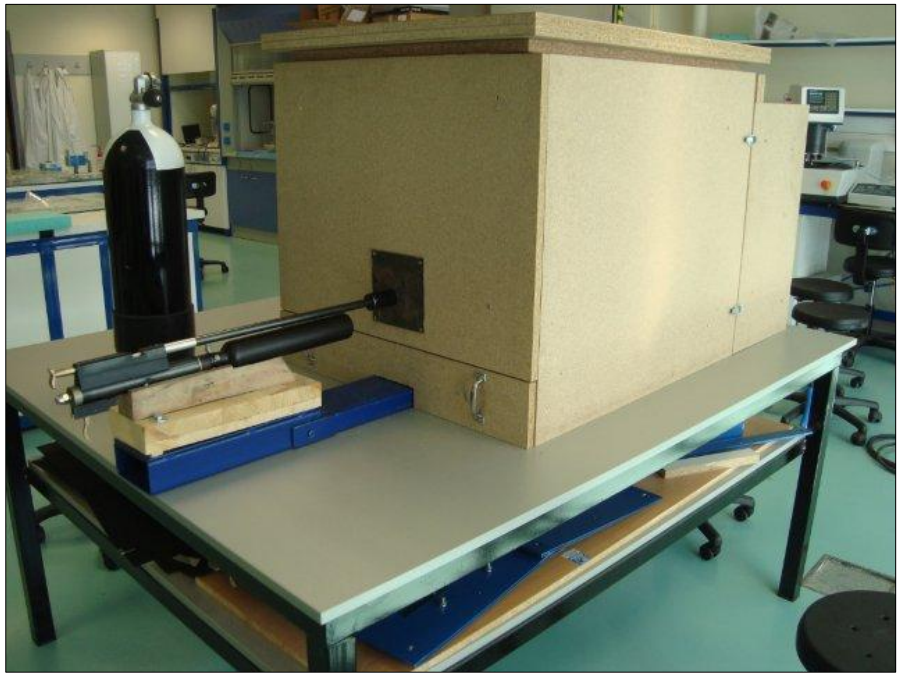
JINAN TESTING EQUIPMENT IE CORPORATION UTS MaxTest software (tensile, compression and bending, 10 kN and 100kN load cell)

- low/high temperature
- -100 ◦C to +350 ◦C
- fatigue graded

- Fatigue Testing Machine (Instron 8801; dynamic-static testing, up to 100 kN, low/high temperature fatigue graded oven)

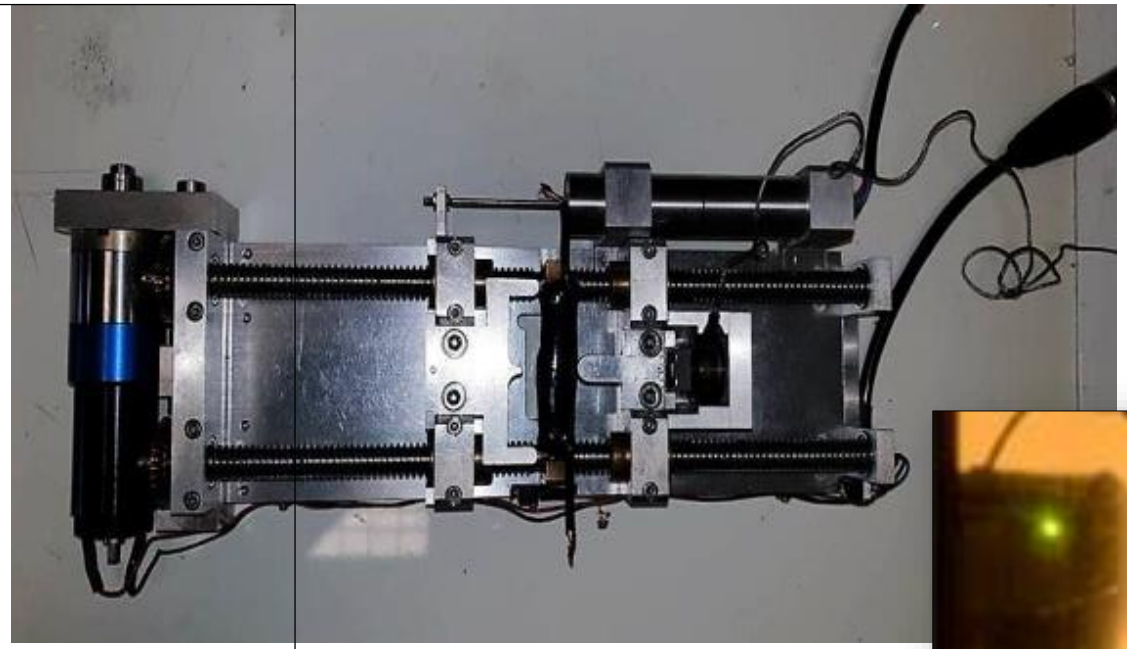
Mechanical testing: Static, Dynamic, Impact, Micromechanics

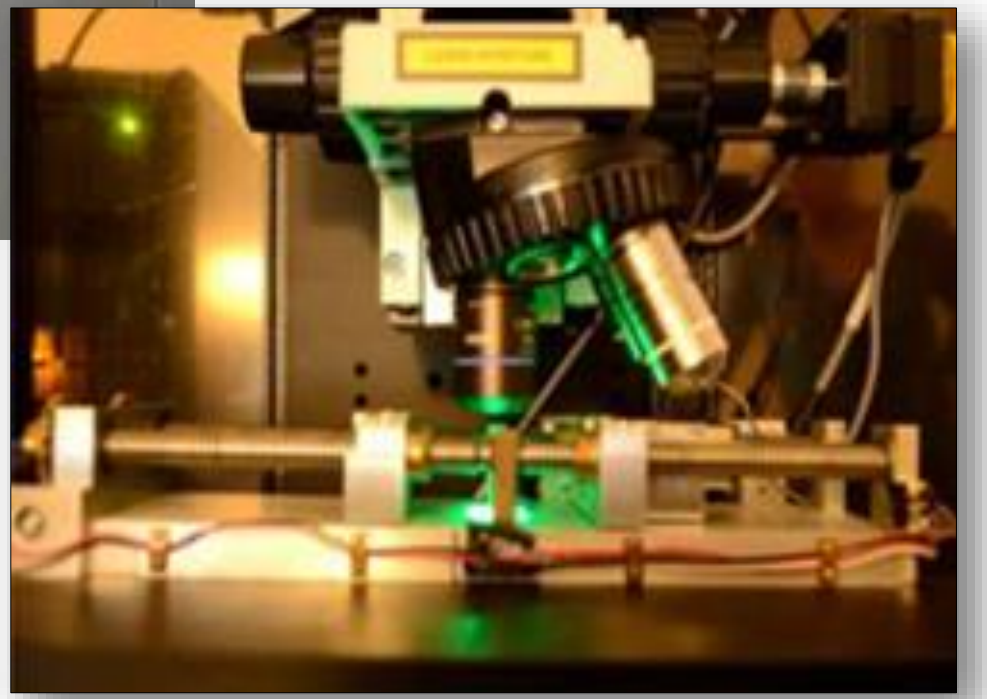
- Fully instruments Impact Testing Machine (Instron)
- Low velocity impact jig for composite plates
- Equipped with anti-bounce mechanism



- Ballistic Impact (high velocity impact)
- In house manufactured
- Optical velocity measurement
- Max 350 m/s

Mechanical testing: Static, Dynamic, Impact, Micromechanics

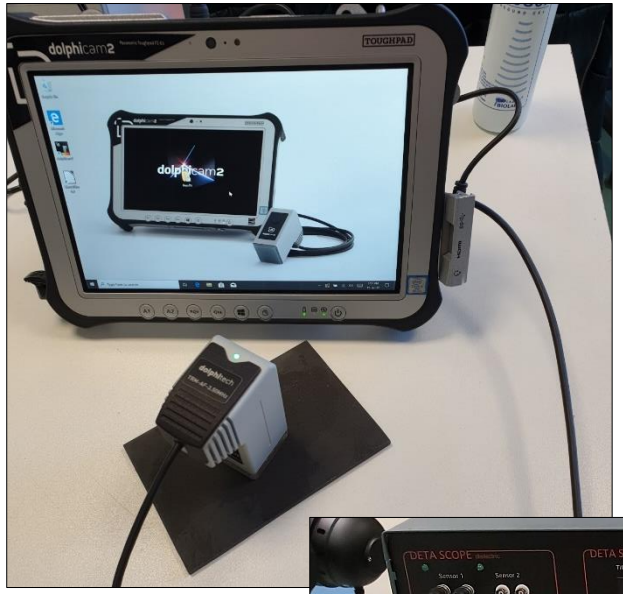




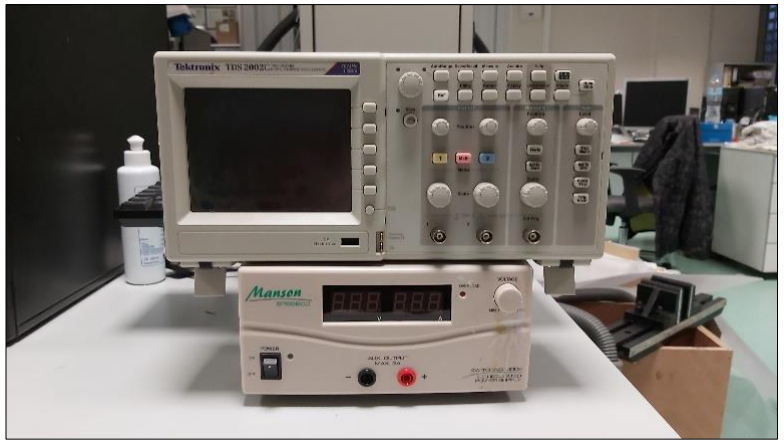
- Mini tensile machine for Microscopic and Raman studies
- Compressive and bending measurements (2N, 45N, 450N, 4.5KN load cells)

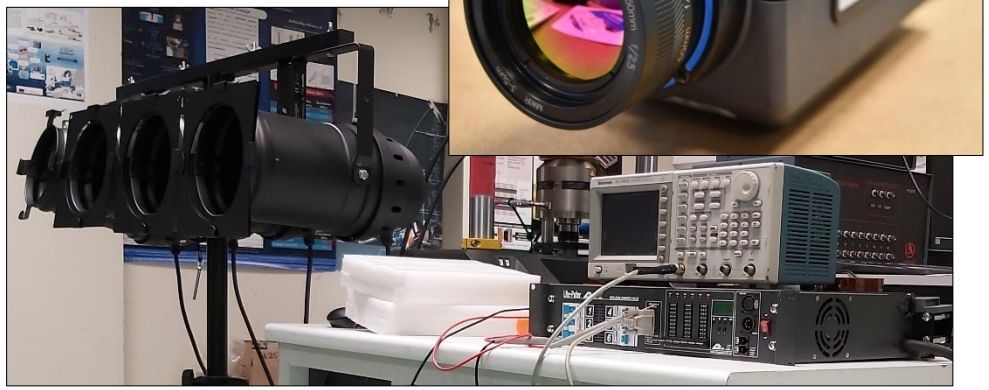
Structural Health Monitoring (SHM) and Non-Destructive Testing Facilities – Equipment -Technologies

Structural Health Monitoring (SHM) and Non-destructive Testing (NDT) equipment



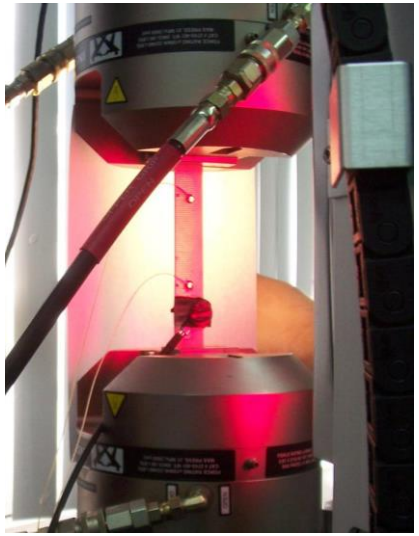
C-Scan
Ultrasound inspection
Impedance Spectroscopy
IR thermography
Acoustic emission
Electrical methods

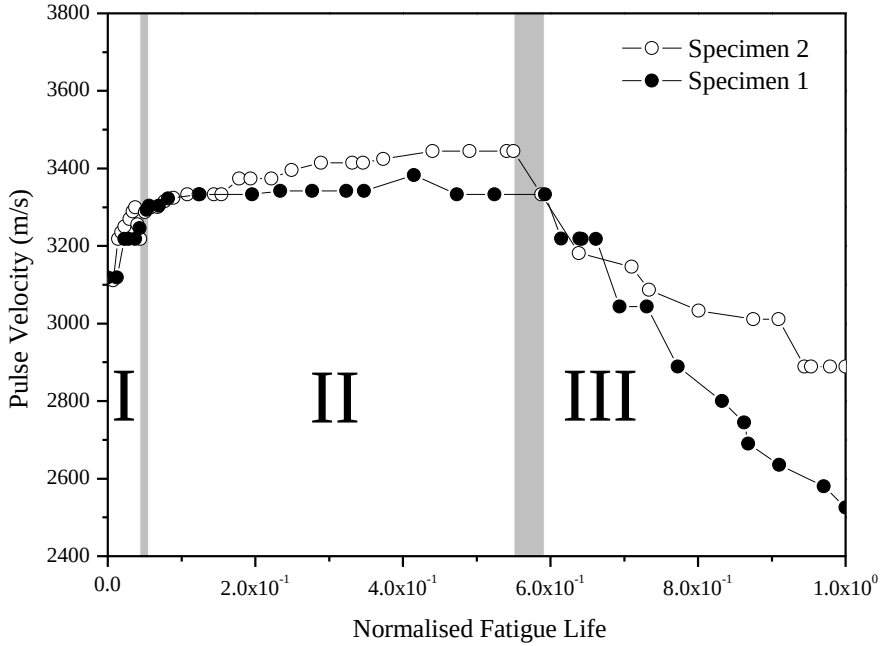




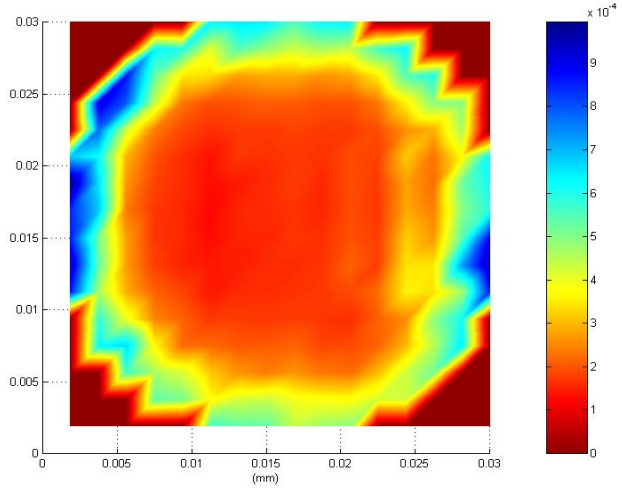
Structural Health Monitoring (SHM) Applications of NDTs

✓FATIGUE LIFE PREDICTION via AE

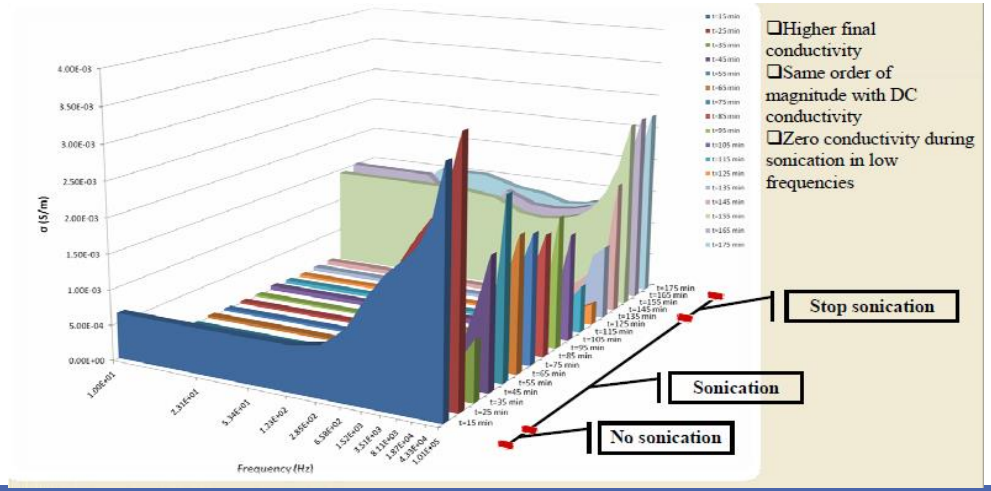




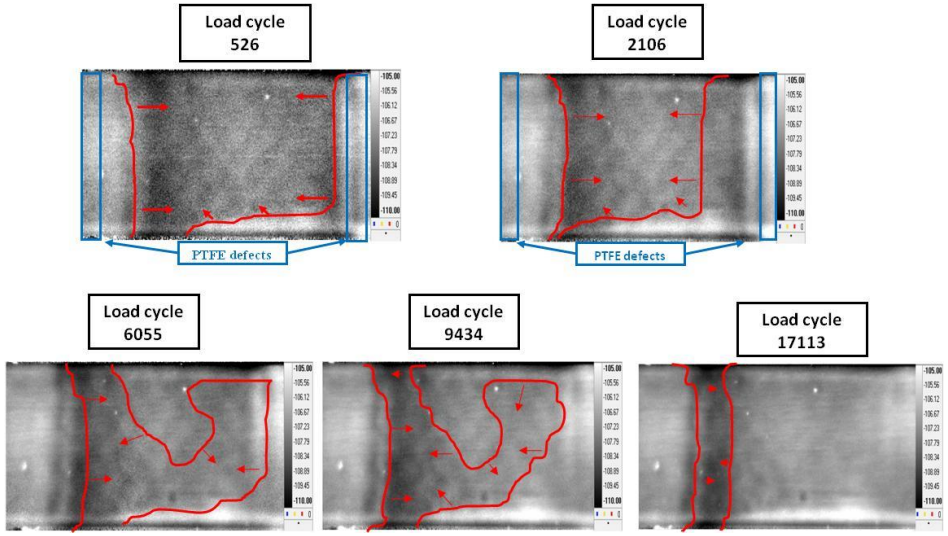
✓ELECTRICAL DAMAGE TOPOGRAPHY



✓DISPERSION MONITORING

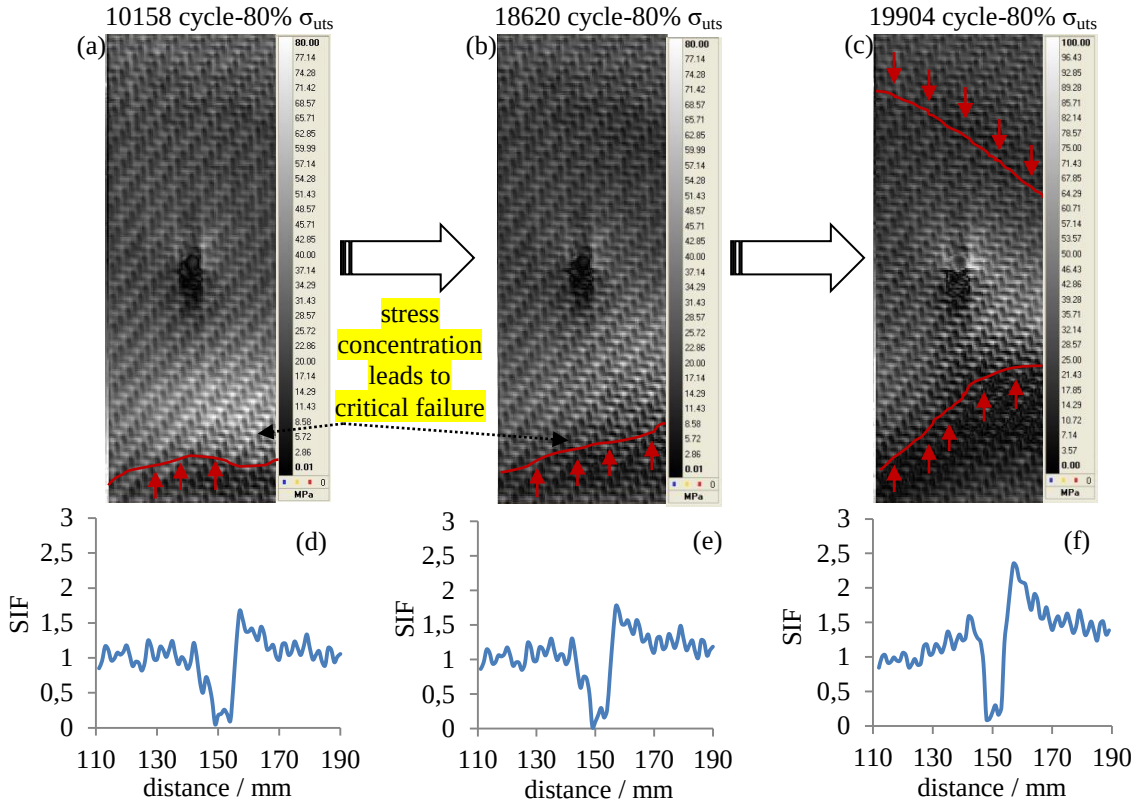


✓REPAIR EFFICIENCY MONITORING

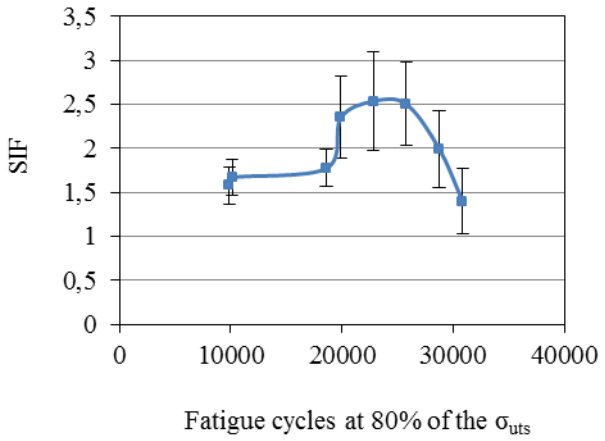


Structural health monitoring

✓Stress concentration in notched composite laminates

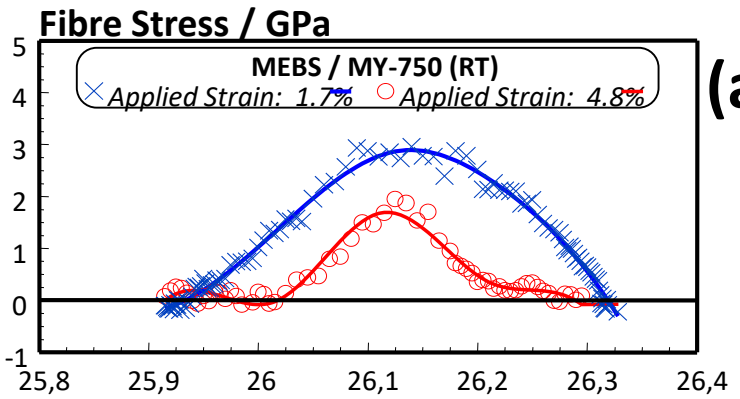


Experimental thermoelastic stress monitoring

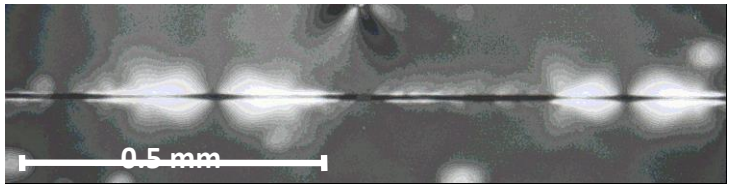


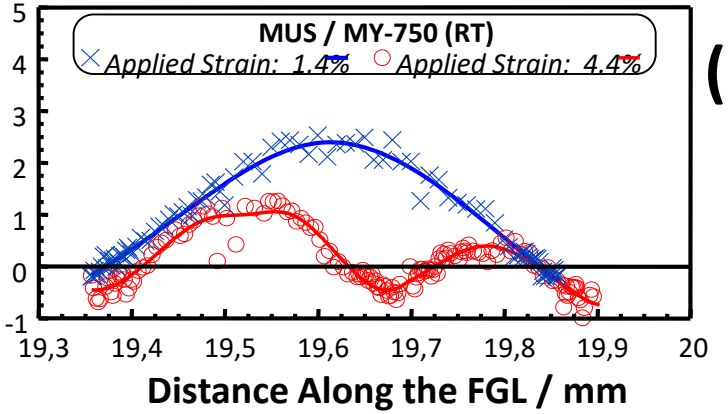
$$\Delta T = -(\mathrm{T}/\rho C_p)(\alpha_L \Delta\sigma_L + \alpha_T \Delta\sigma_T) = \mathrm{K}_{mL} T \Delta\sigma + \mathrm{K}_{mT} T \Delta\sigma$$

Micromechanics: SFFT coupled with Raman

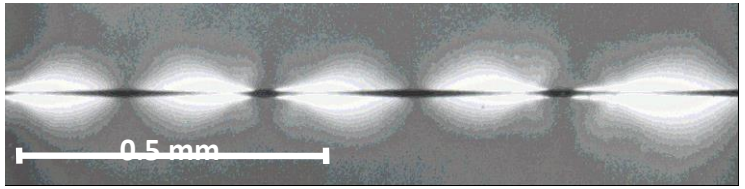


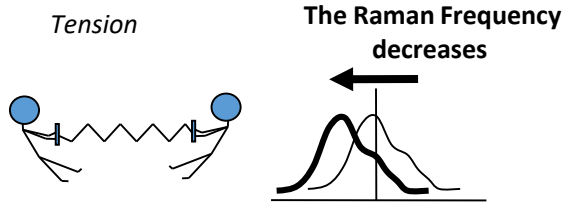
(a) Sized fibre

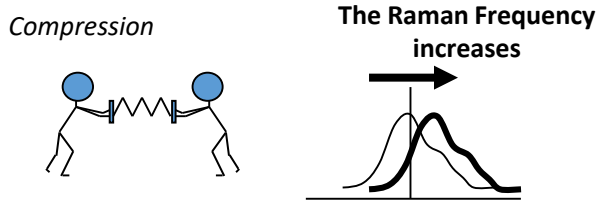




(b) Unsized fibre



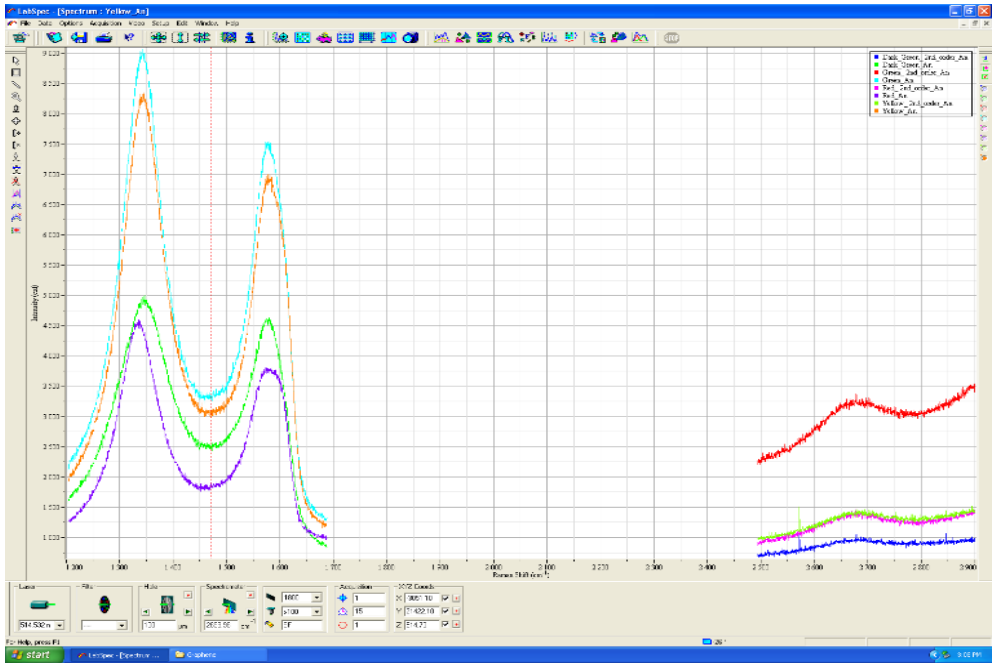


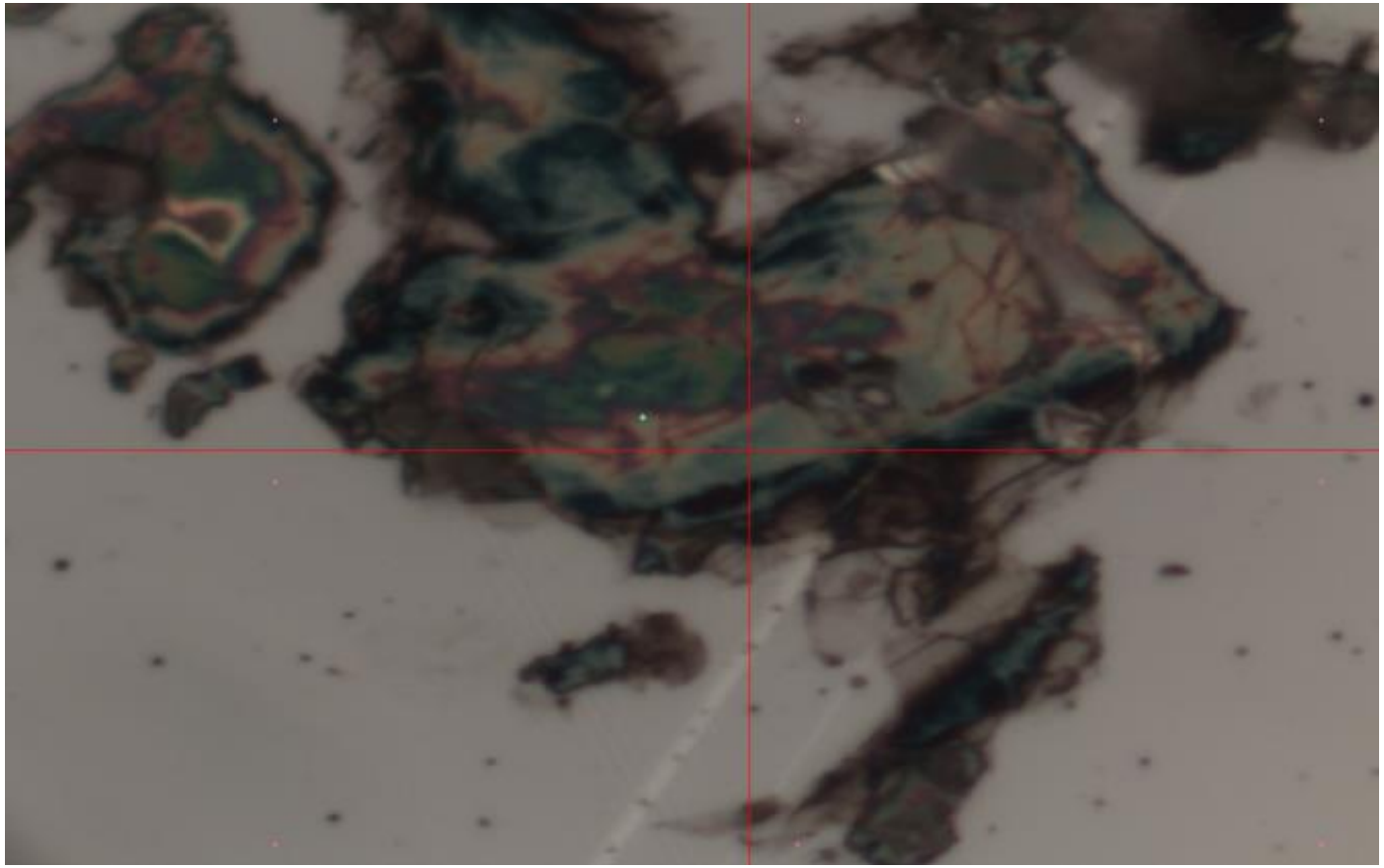


Raman 2-D mapping of graphitic nanostructures

✓2D stress mapping on single layer graphene using Raman Spectroscopy

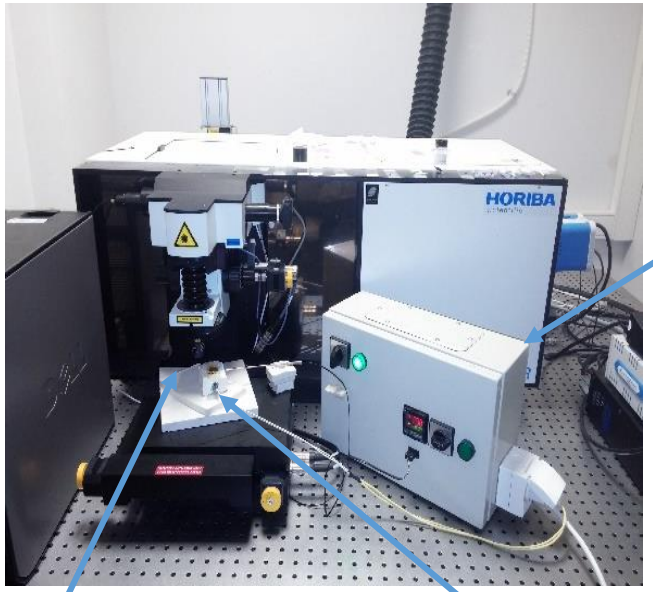
Graphitic nanostructures

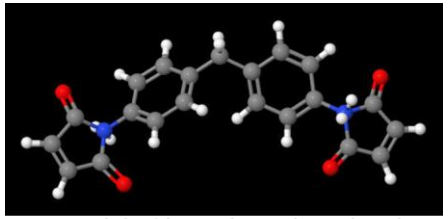




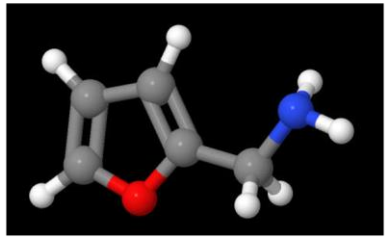
Self-healing composites

✓ Raman monitoring of intrinsic Diels – Alder reactions for successive healing cycles.

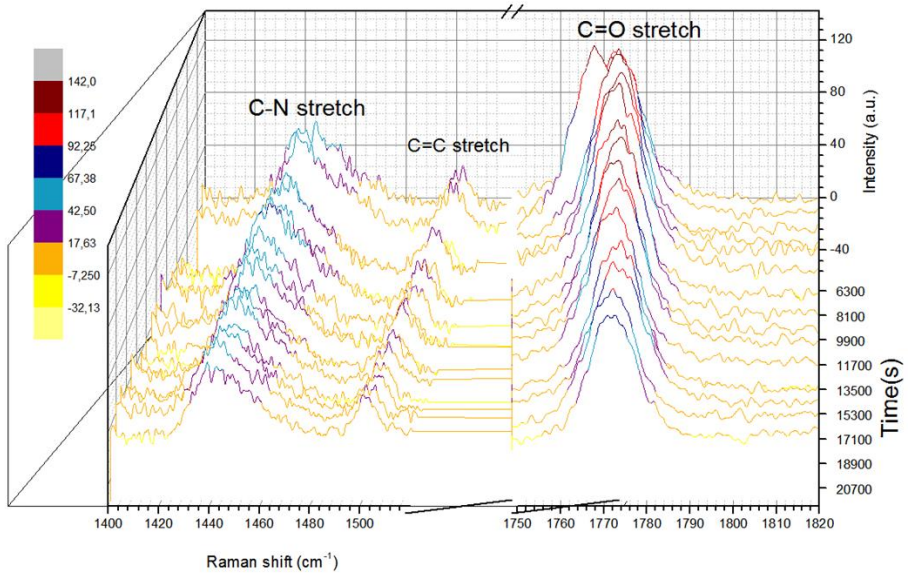


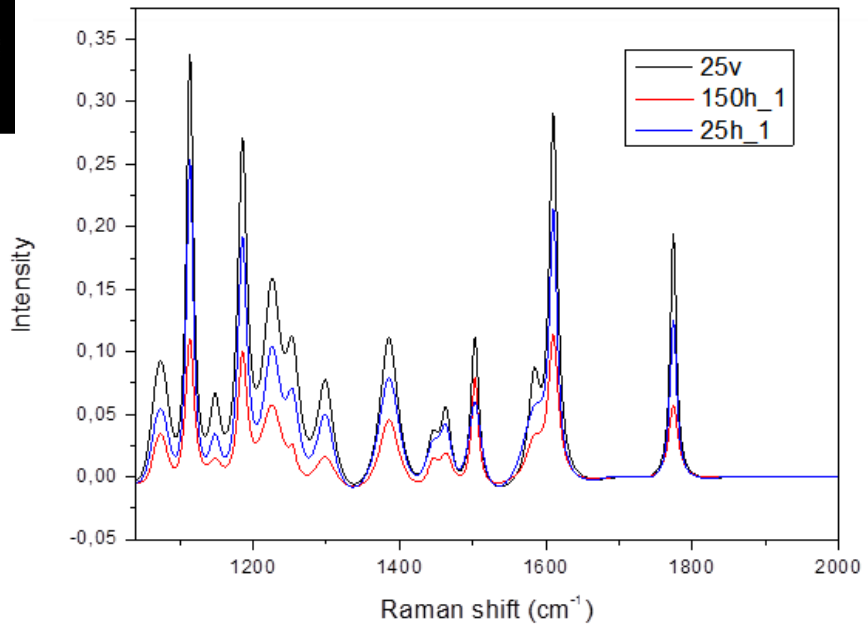


3D model of bismaleimide molecule



3D model of furfuryl amine



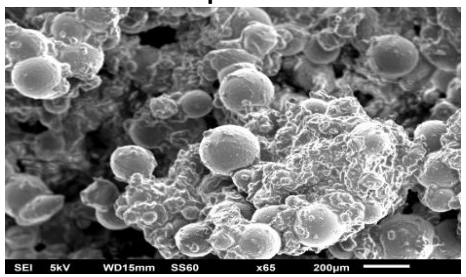


Smart & Multifunctional Structures - Materials - Concepts

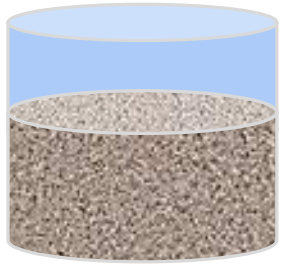
Self-healing technologies (Capsule based – Vascular – Intrinsic)

Capsule-based

Capsules

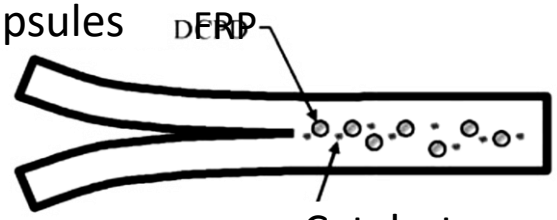


Epoxy + Capsules

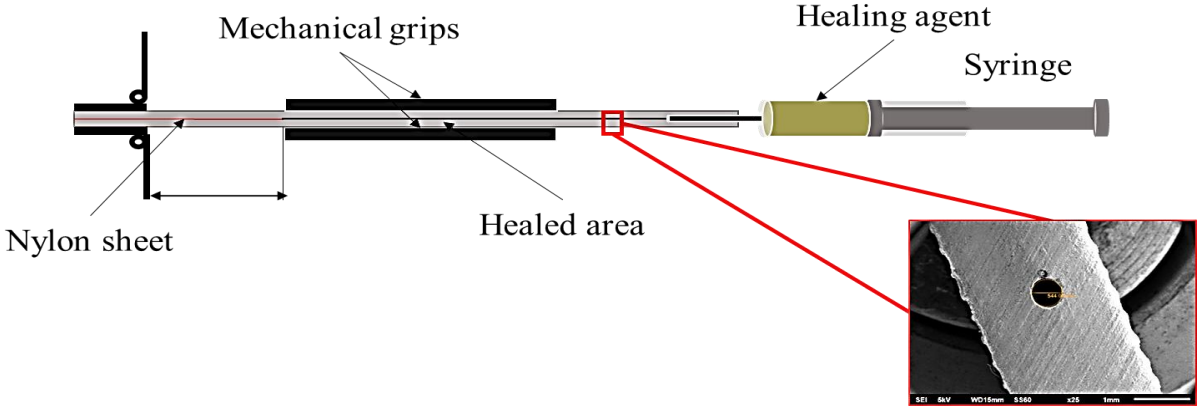


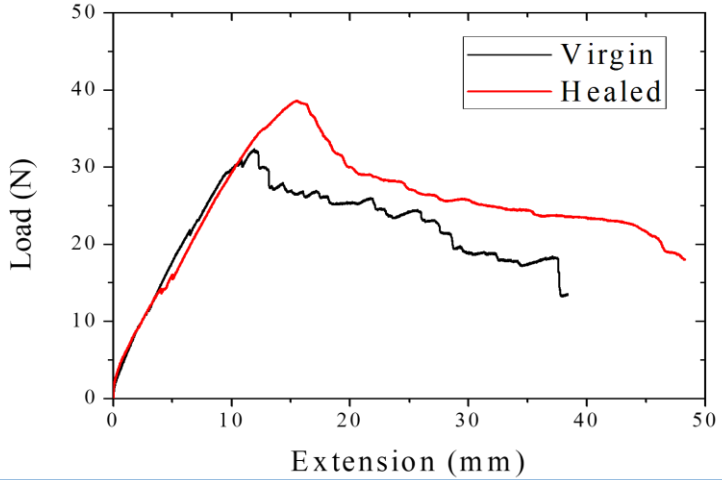
UF-Capsules

Self-healing FRP

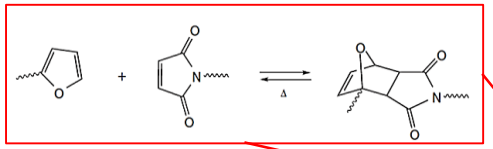


Vascular

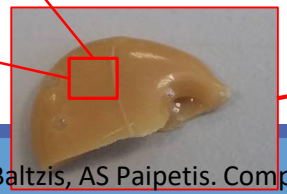




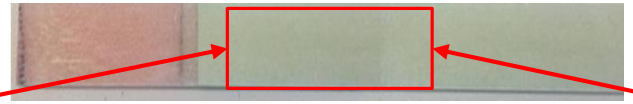
Intrinsic



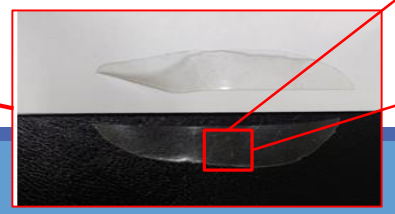
Diels-Alder

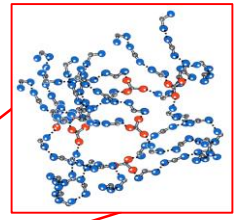


Self-healing FRP



Supramolecular





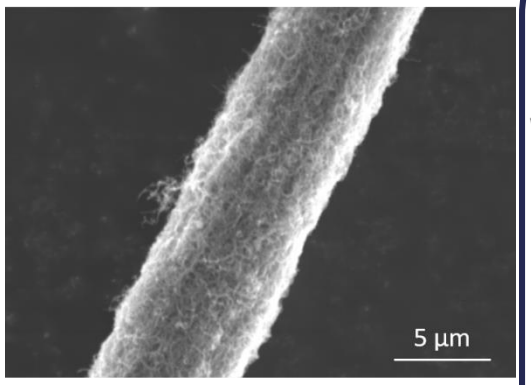
DG Bekas, K Tsirka, D Baltzis, AS Paipetis. Composites Part B: Engineering 87, 92-119, 2016
R Rodriguez, DG Bekas, S Flórez, M Kosarli, AS Paipetis. Polymer 187, 122084, 2020

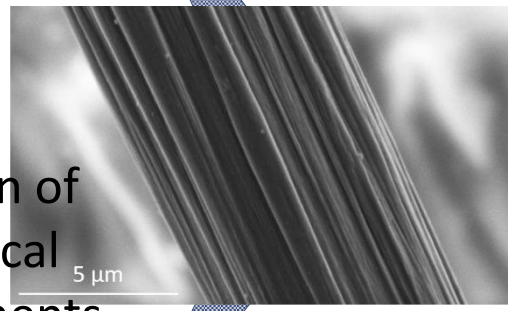
Hierarchical Reinforcements as Raman strain sensors

2. Dispersion of CNTs in aqueous medium

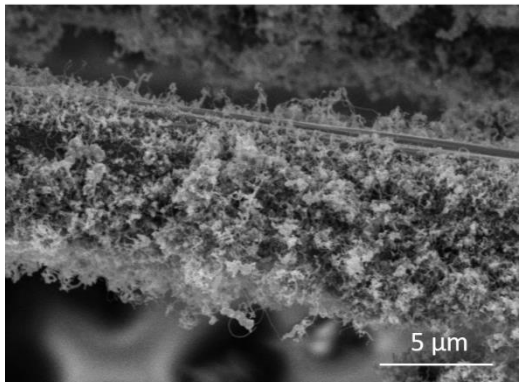
1. Wet chemical oxidation of CFs and CNTs

3. Deposition of CNTs on CFs via immersion



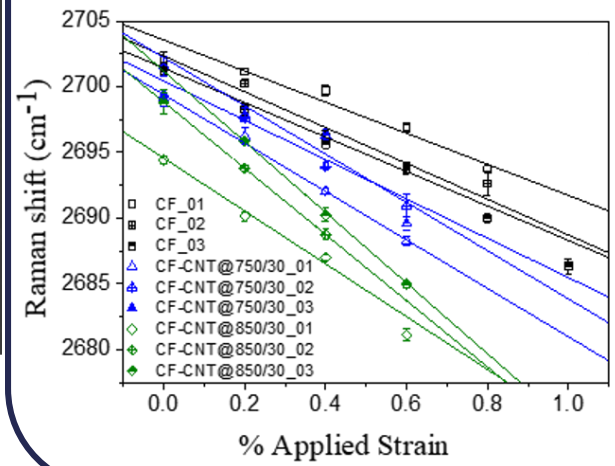


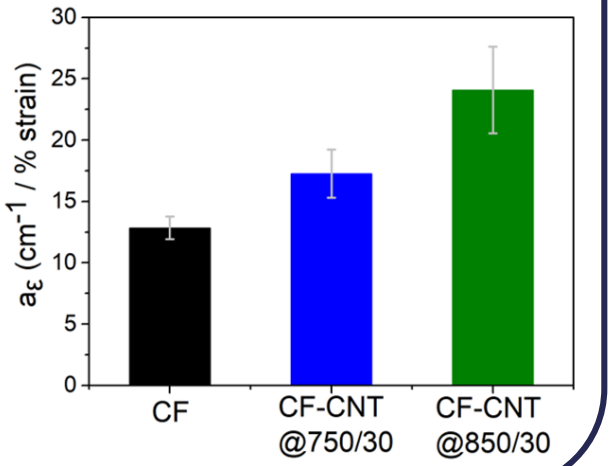
Production of Hierarchical Reinforcements



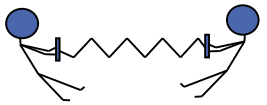
Growth of CNTs onto CFs via Catalytic Chemical Vapor Deposition

Raman strain sensing ability

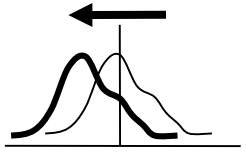




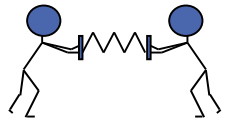
Tension



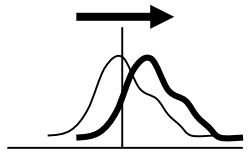
The Raman Frequency decreases



Compression

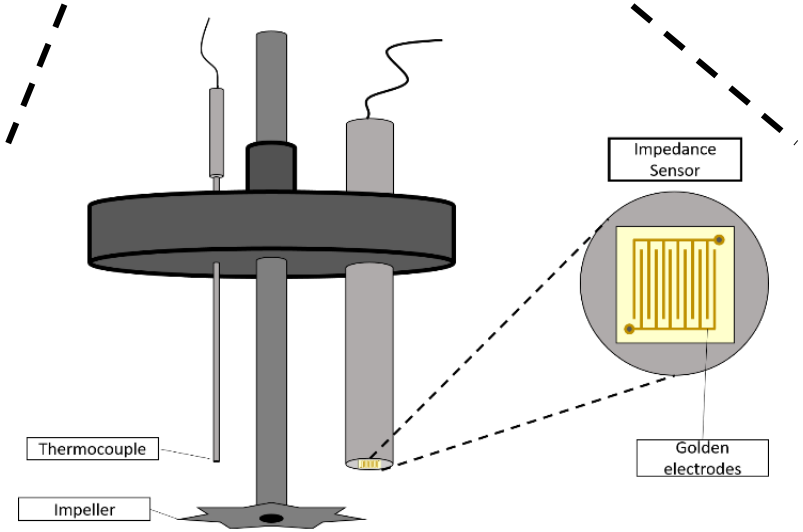


The Raman Frequency increases

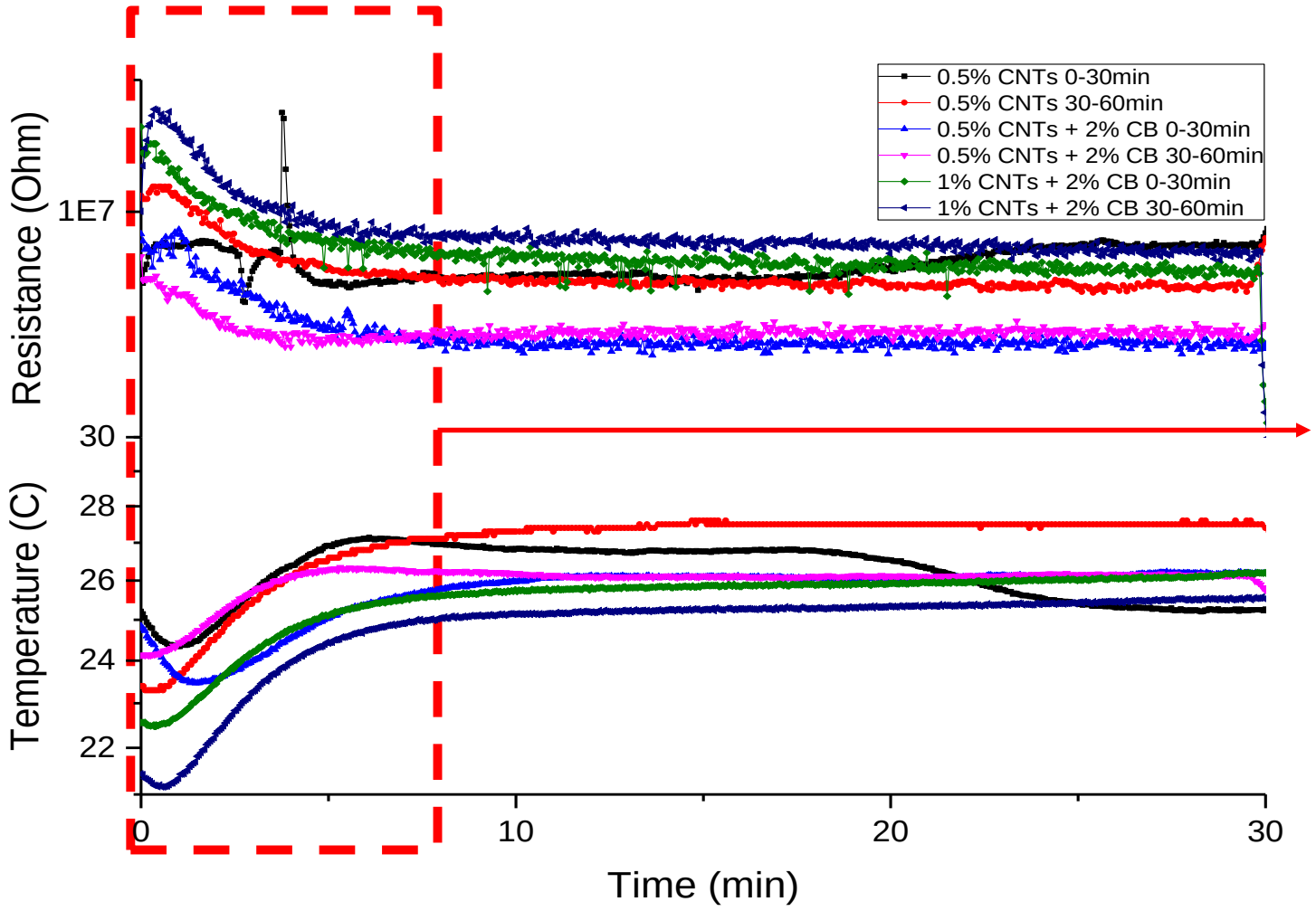


A Paipetis, C Galiotis. Composites Part A: Applied Science and Manufacturing 27 (9), 755-767, 1997.
K Tsirka, G Karalis, AS Paipetis. Journal of Materials Engineering and Performance 27 (10), 5095-5101, 2018.
K Tsirka, L Tzounis, A Avgeropoulos, M Liebscher, V Mechtcherine, A S Paipetis Composites Science and Technology 165, 240-249, 2018

Dispersion process real-time monitoring / Preparation of Hybrid Composites



0-8 min: resistance depend to temperature fluctuations (high temperatures cause viscosity decrease).

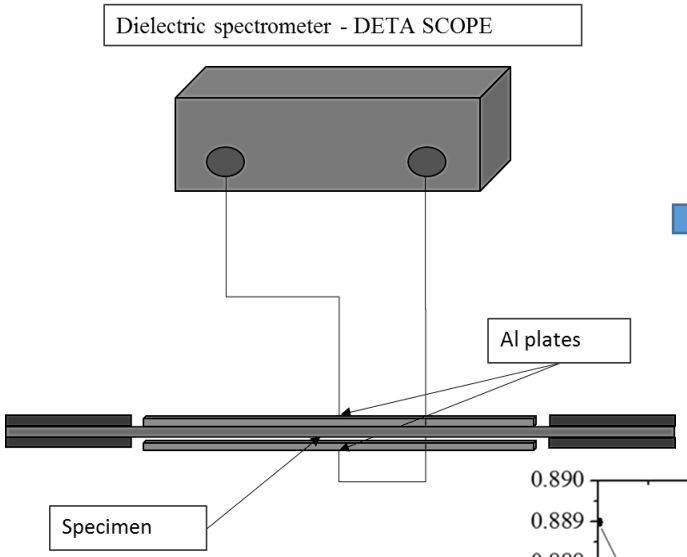


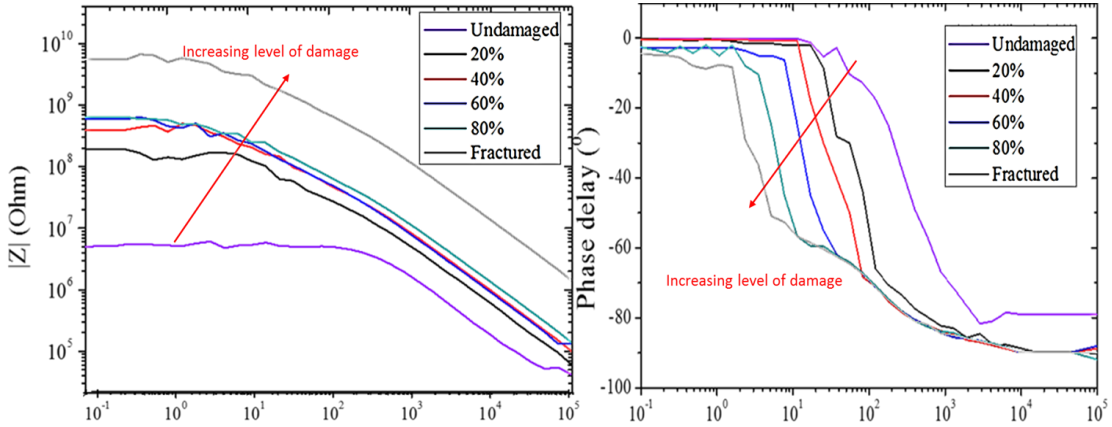
G Foteinidis, K Tsirka, L Tzounis, D Baltzis, AS Paipetis. Applied Sciences 9 (18), 3757, 2019
D Baltzis, DG Bekas, G Tzachristas, A Parlamas, M Karabela, NE Zafeiropoulos, AS Paipetis. Composites Science and Technology 153, 7-17, 2017

Structural health monitoring

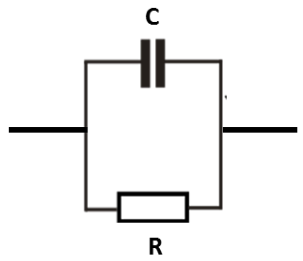
- **Impedance Spectroscopy**

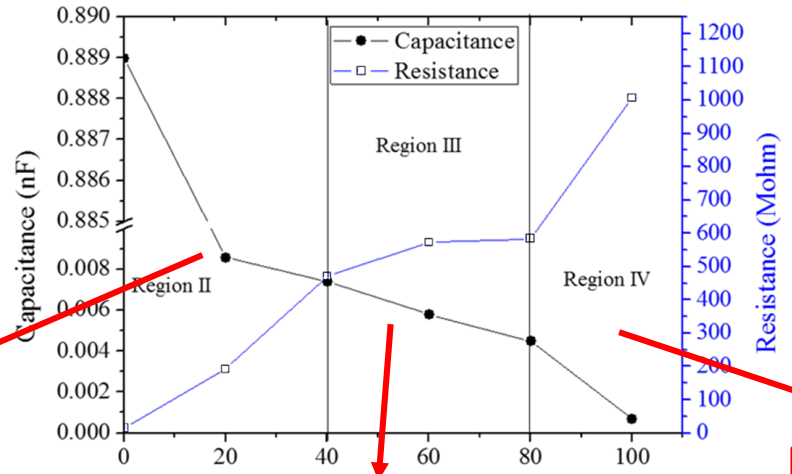
Bode plots

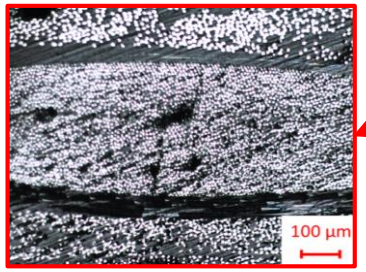


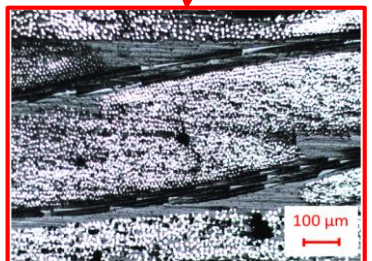


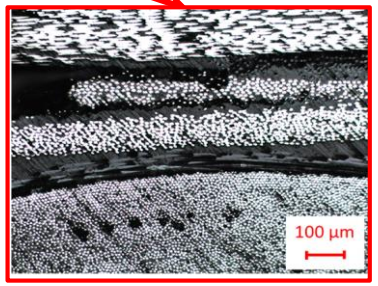
Damage modeling



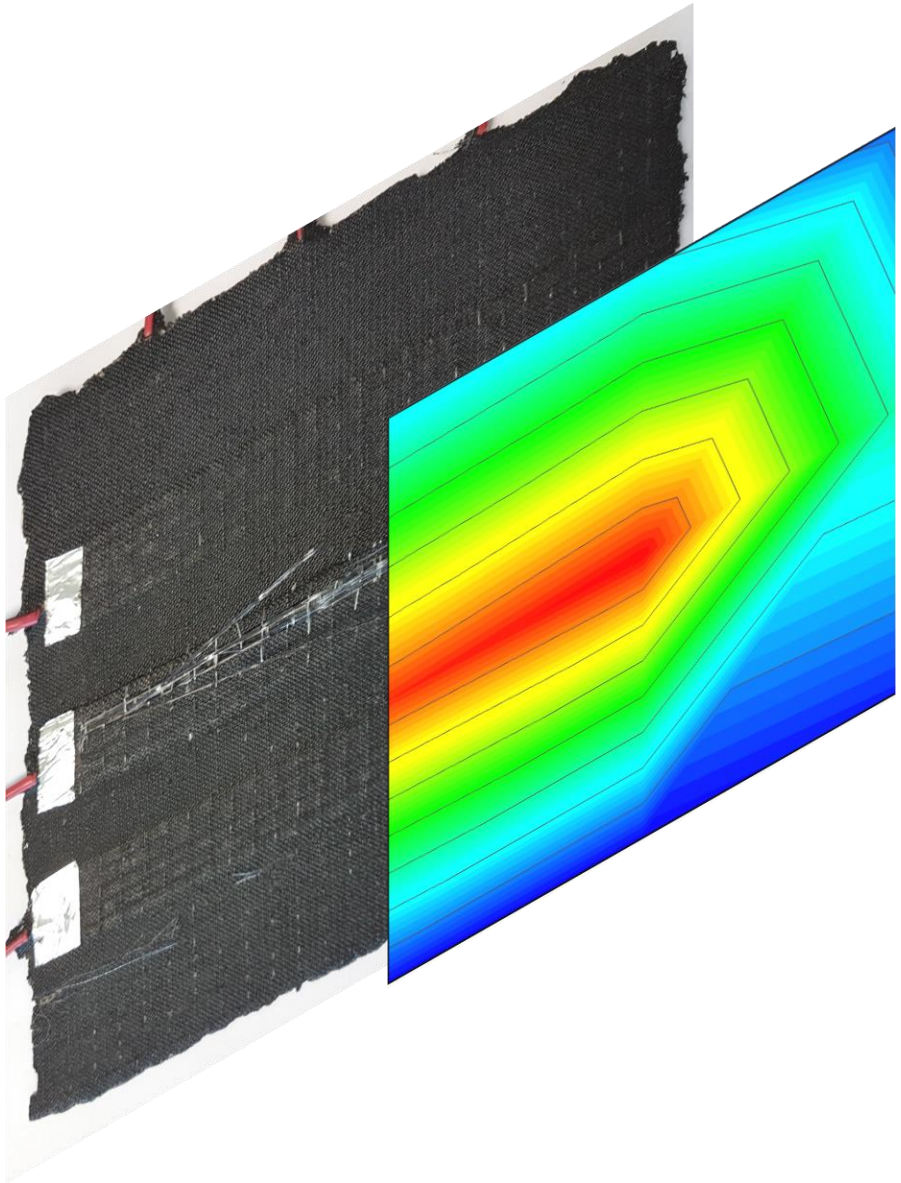


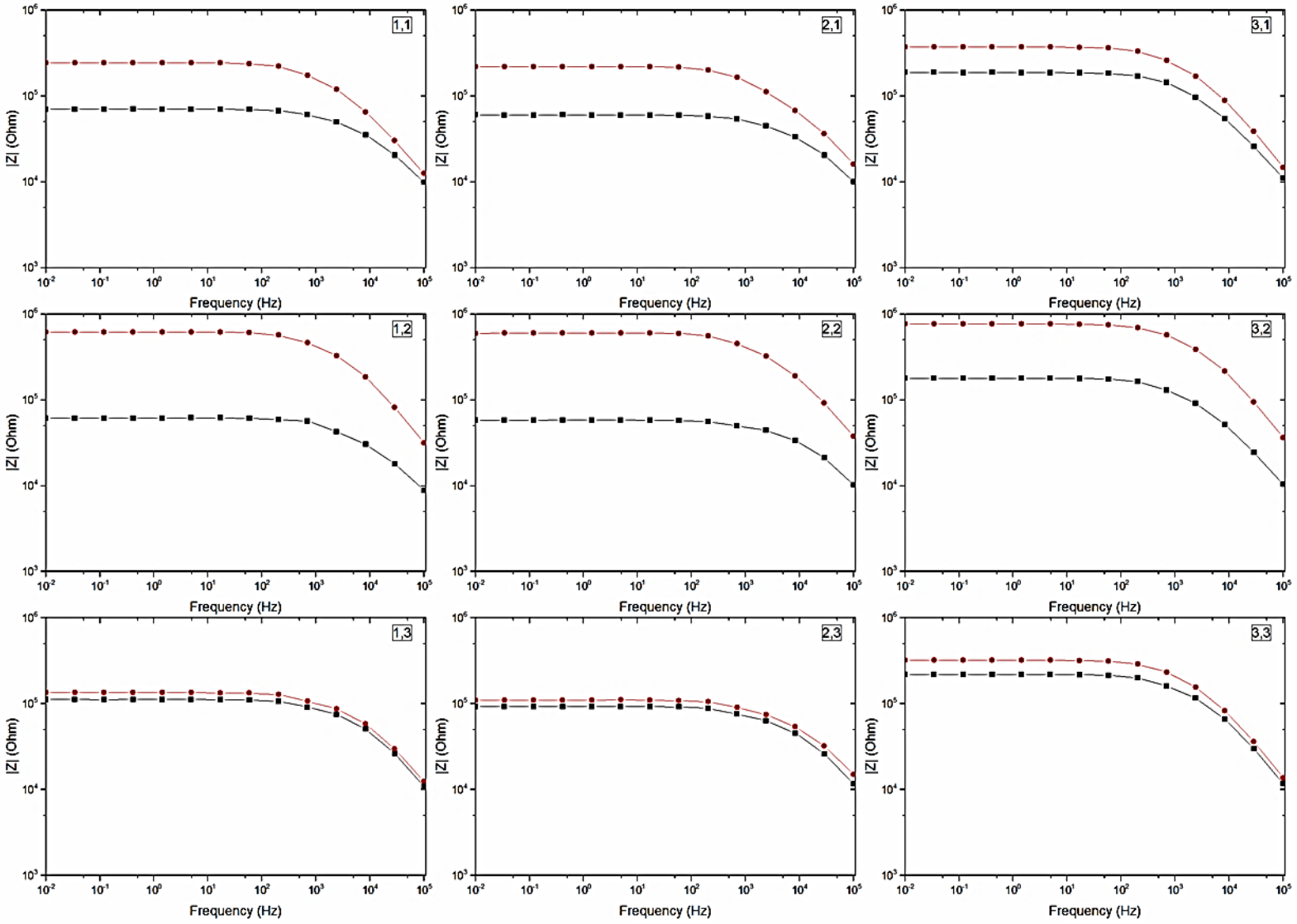






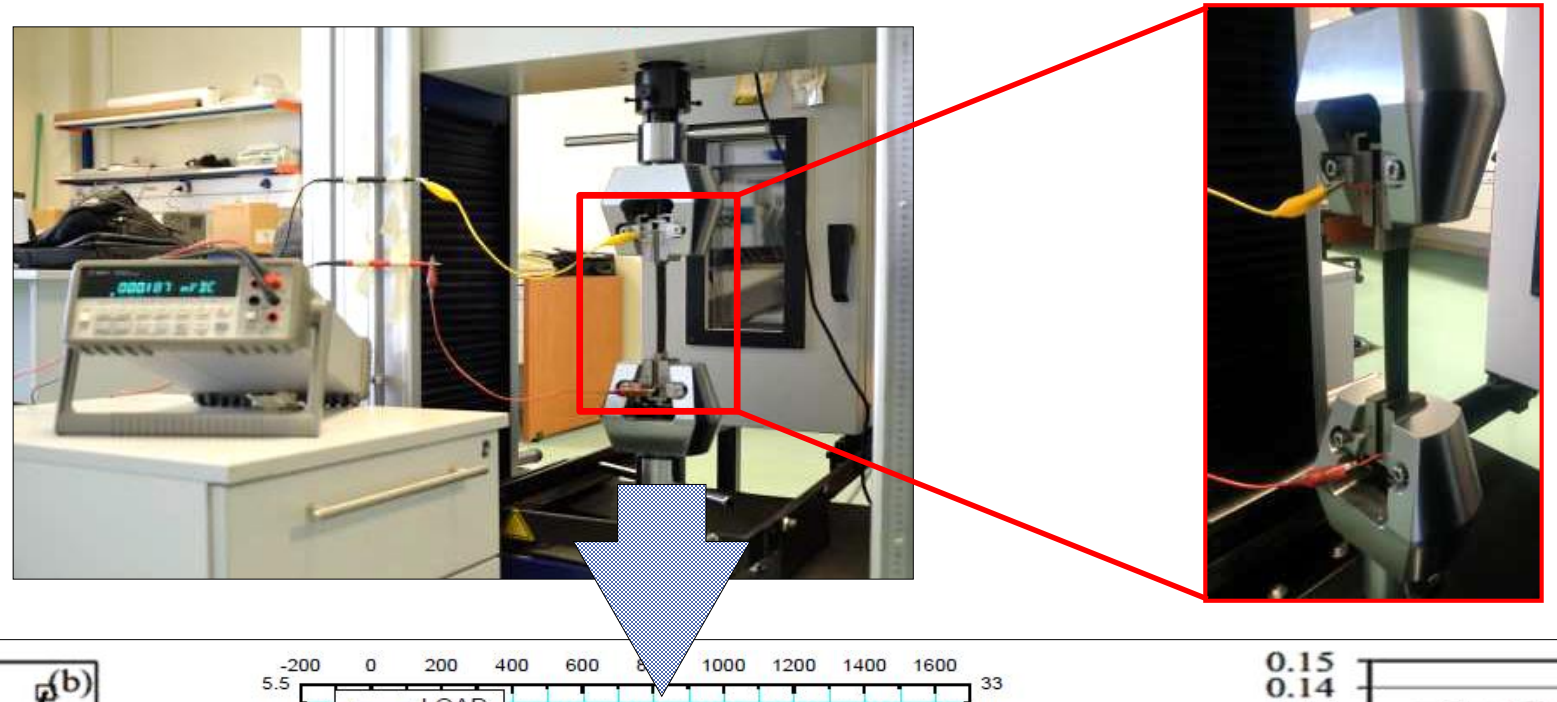
Structural Heath Monitoring – Impedance spectroscopy mapping for defect localization

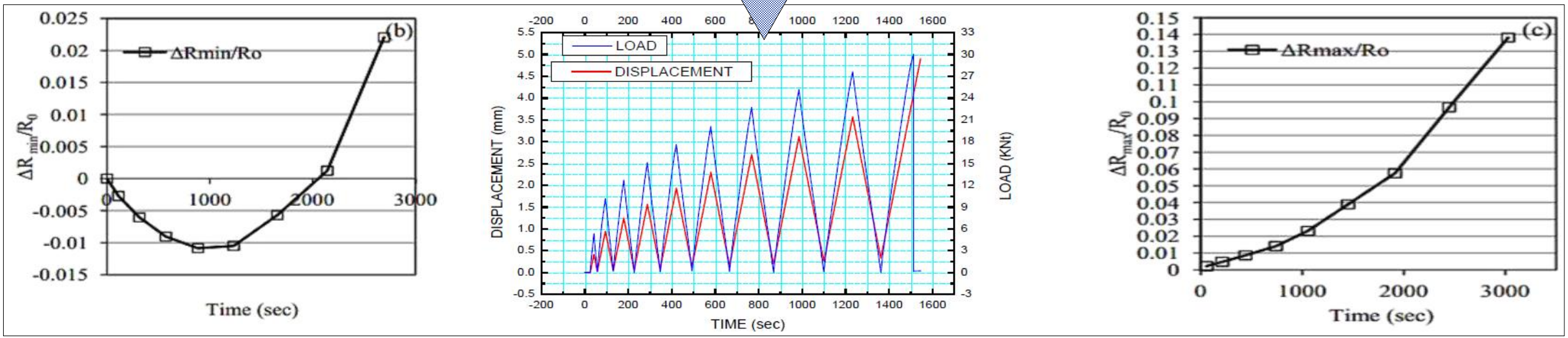




Structural Heath Monitoring – Electrical resistance change method (DC method)

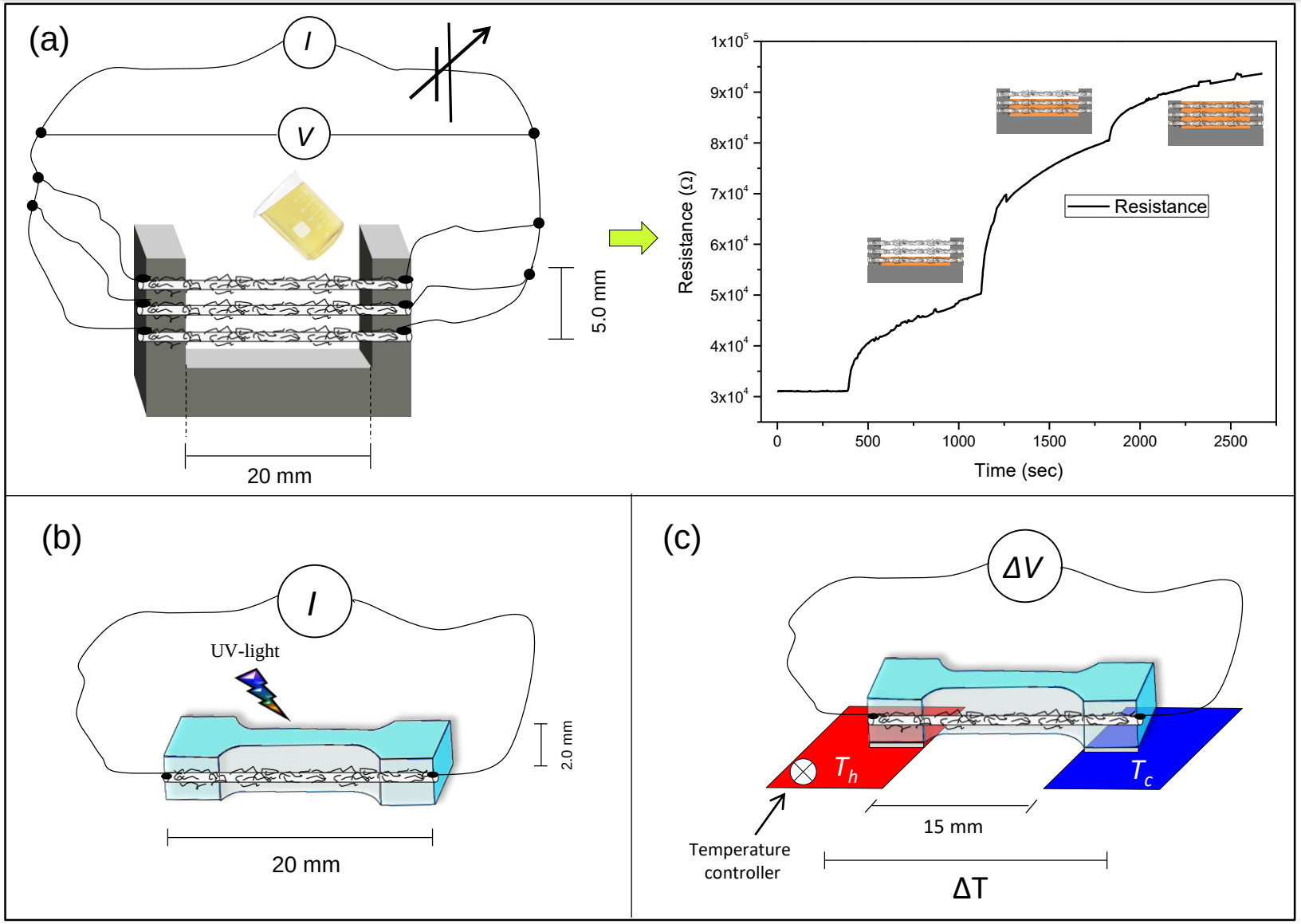
On line DC resistance measurements





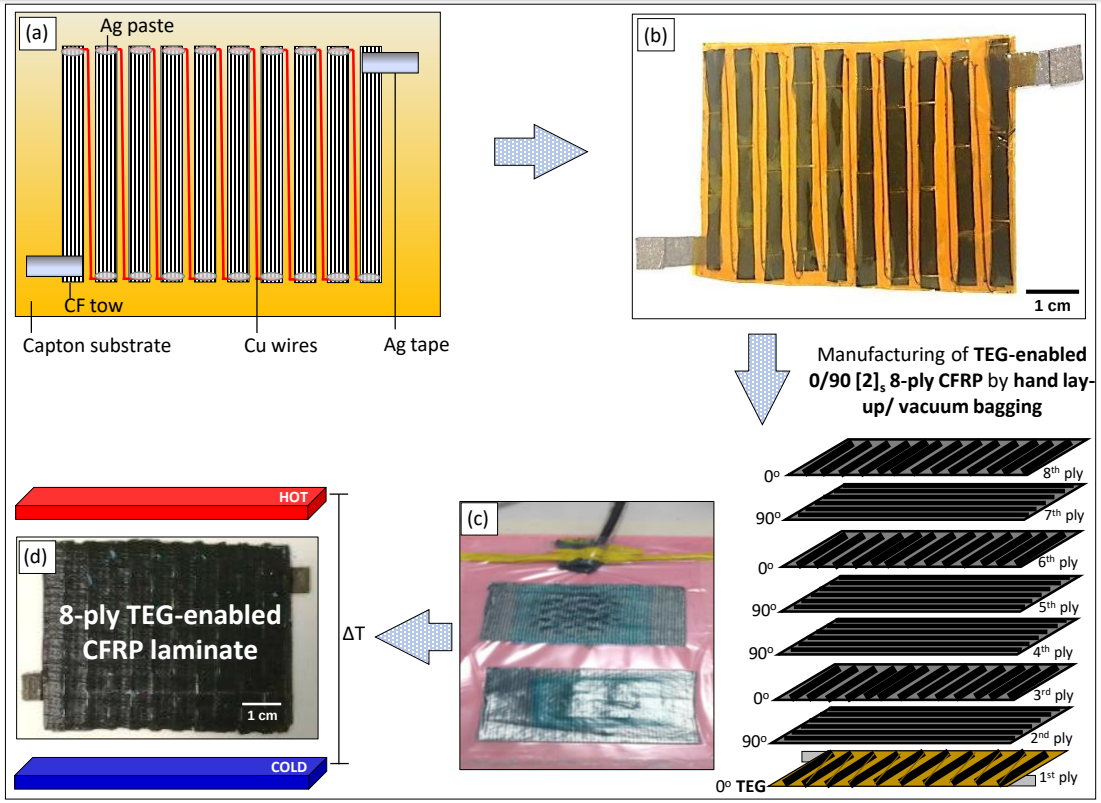
D Bekas, SA Grammatikos, C Kouimtzi, AS Paipetis. IOP Conference Series: Materials Science and Engineering 74 (1), 012002, 2015.
SA Grammatikos, EZ Kordatos, TE Matikas, AS Paipetis. Journal of materials engineering and performance 23 (1), 169-180, 2014.
SA Grammatikos, AS Paipetis. Composites Part B: Engineering 43 (6), 2687-2696, 2012.

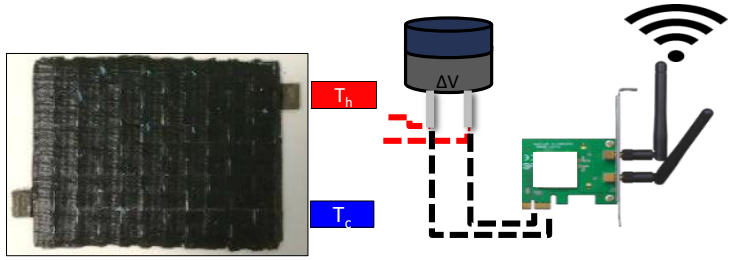
Cure monitoring / UV-sensing / Thermal energy harvesting (TEG) by hierarchical reinforcements



- **Cure detection** and **Cure monitoring** utilizing **Hierarchical reinforcements** by **changes in electrical properties** (resistance, impedance) due to **Enthalpic & Entropic phenomena** taking place during **Epoxy hardening**
- **UV-sensing** due to the **wide band gap of doped CNTs** allowing the excitation by UV-light. **Structural Health Monitoring** of the sensitive polymer matrix to UV-exposure
- **Thermal Energy Harvesting** by the Composite acting as **TEG**

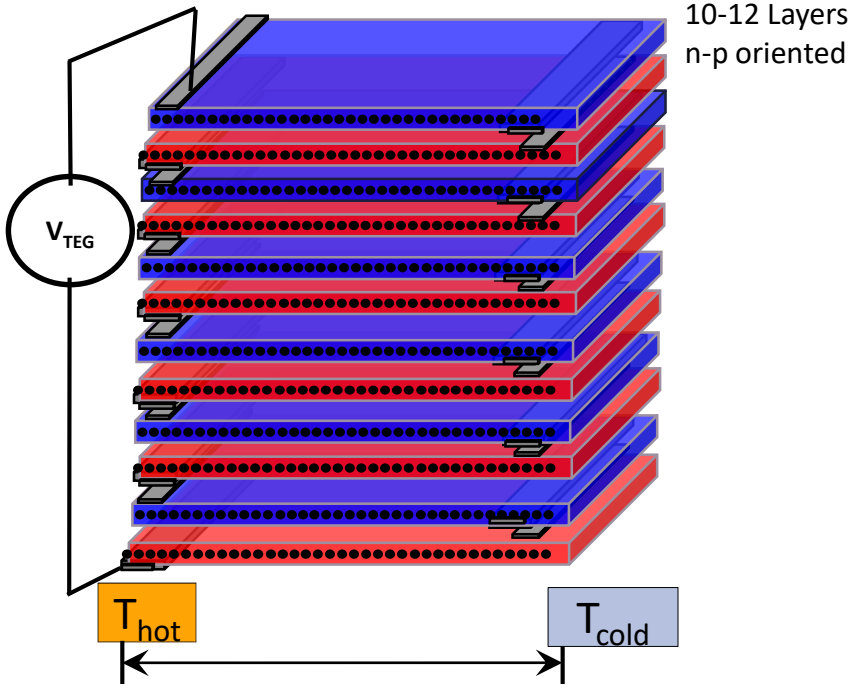
Energy Harvesting Laminates: Carbon fiber based TEG and integration as a lamina towards TEG-enabled laminates



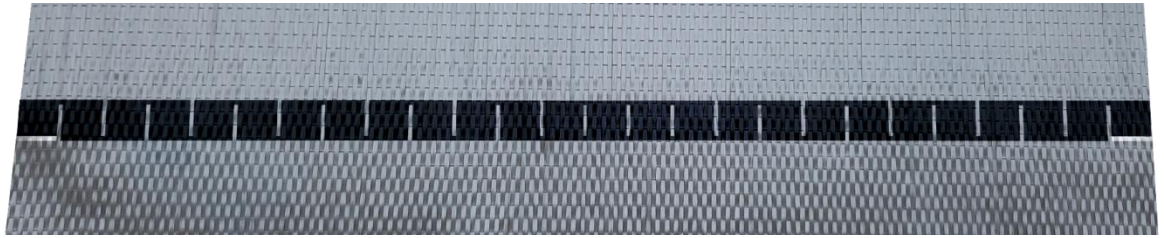


→ **Thermal energy harvesting by structural composites - Green transport.**
→ **TEGs consisting of carbon fiber tows used as reinforcements in advanced composites.**
→ **Potential application as a structural part of the car frame or chassis (bumper – exhaust)**

TEG-enabled laminate composite



Printed TEG onto UD-Glass Fabric and resin impregnation (prepreg) towards TEG-enabled system lamina in laminate composite

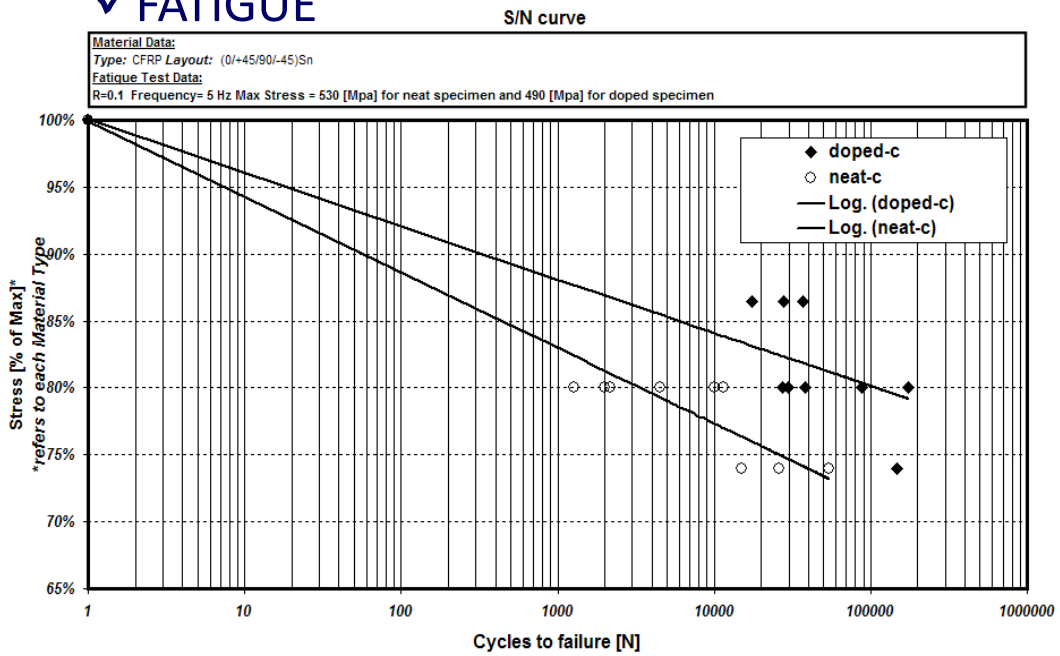


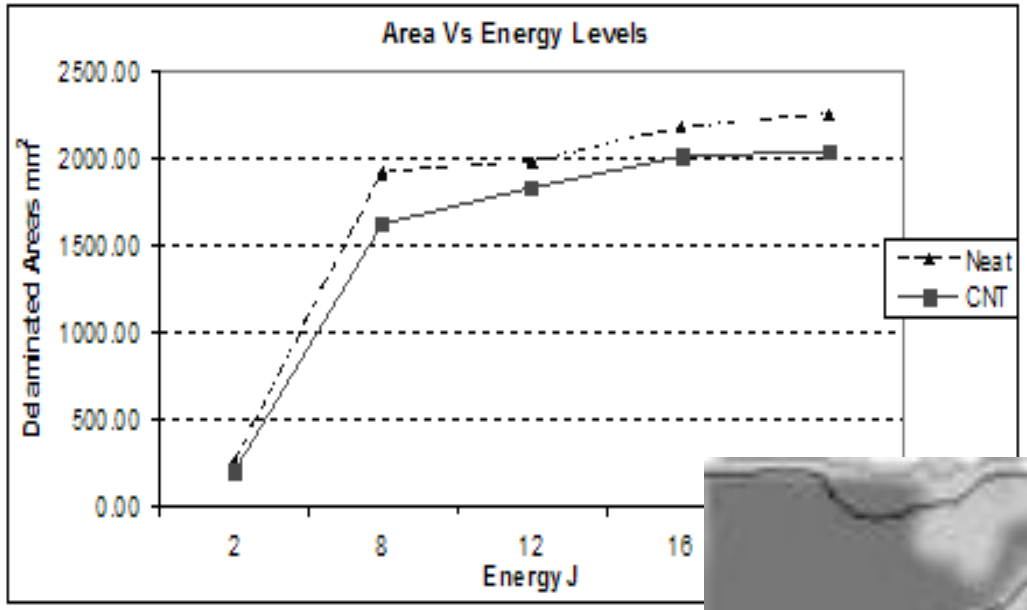
Smart & Multifunctional Structures - Performance

Hybrid and Hierarchical composites: Impact - Fatigue

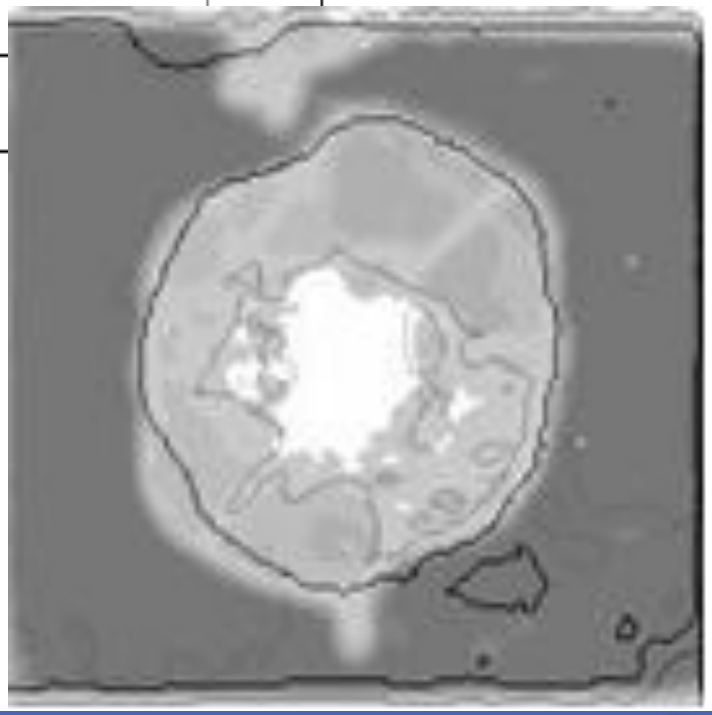
Performance: Hybrid & Hierarchical composites

✓FATIGUE



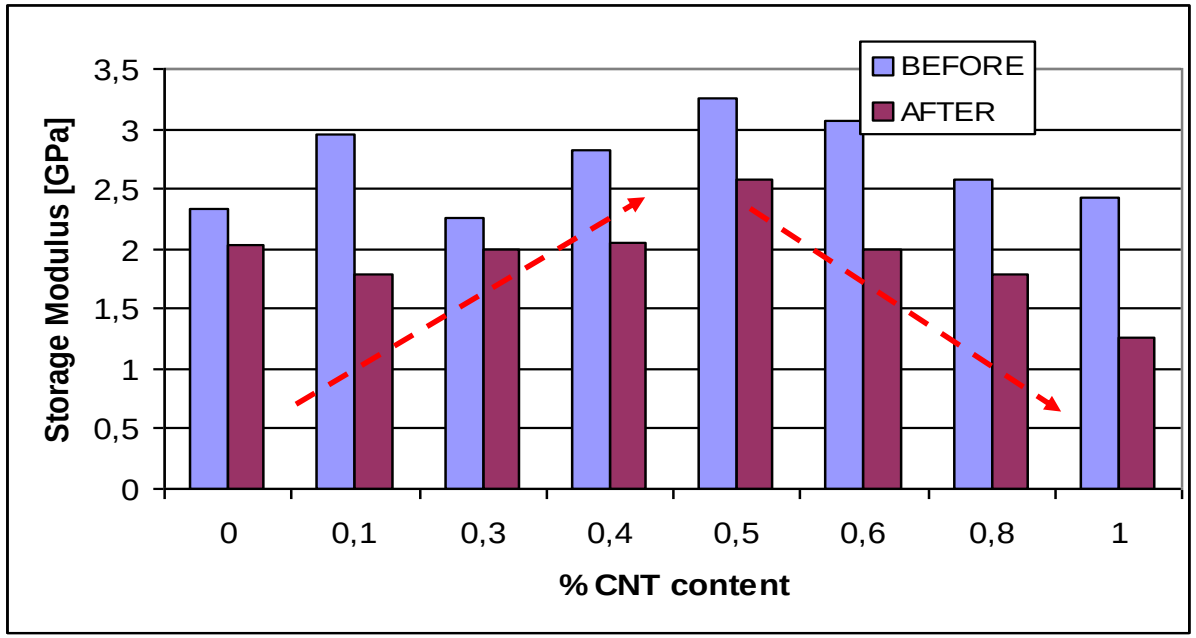


✓IMPACT



Durability

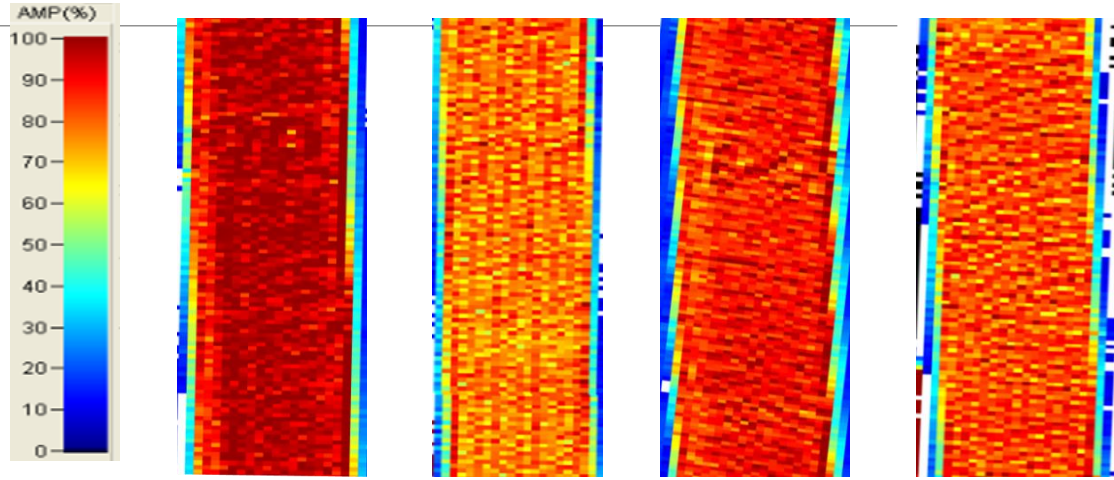
✓DYNAMIC THERMOMECHANICAL ANALYSIS



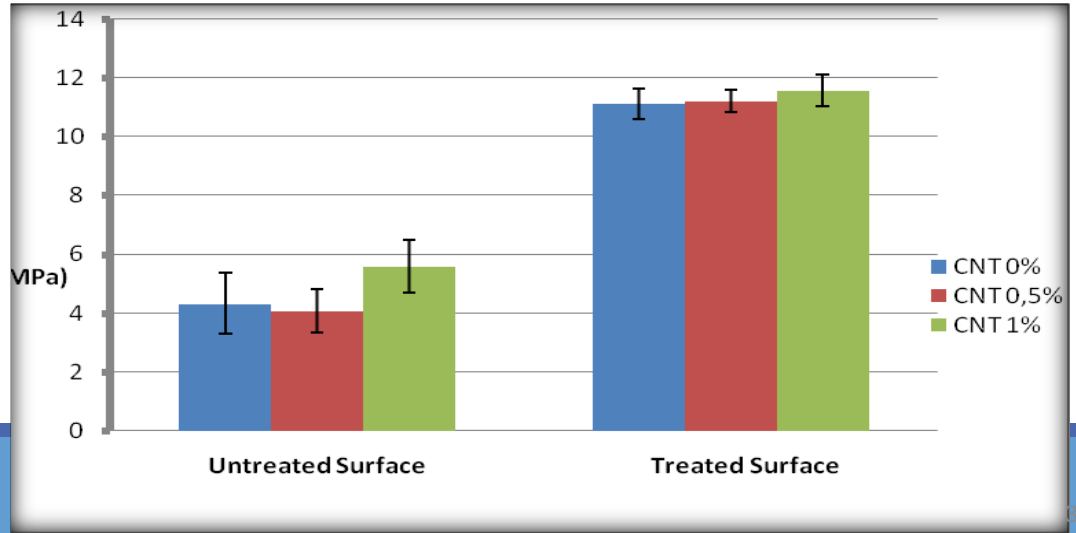
✓HYDROTHERMAL DURABILITY

Neat CFRP | CNT CFRP

Before After | Before After

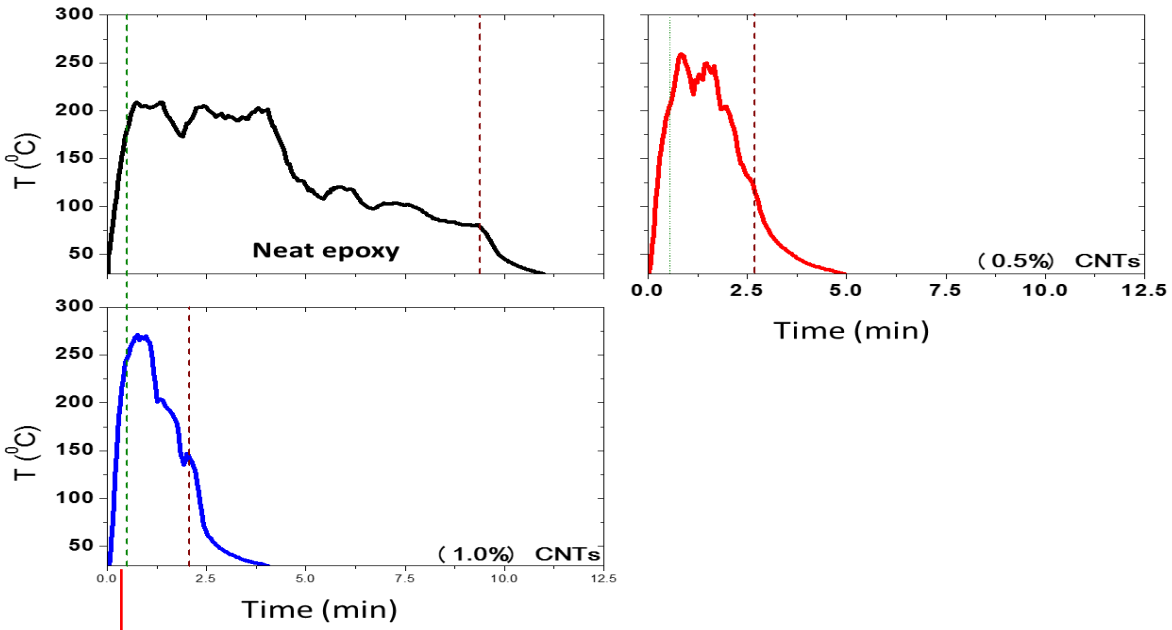


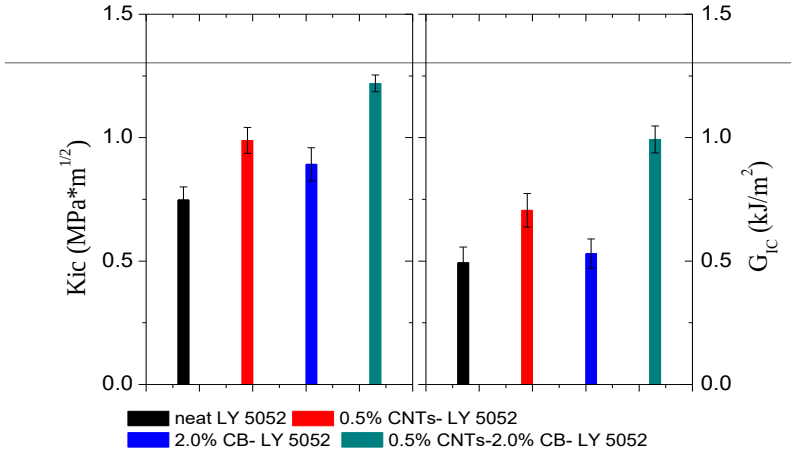
✓BONDING ENHANCEMENT



Fire resistance properties of Epoxy hybrid composites

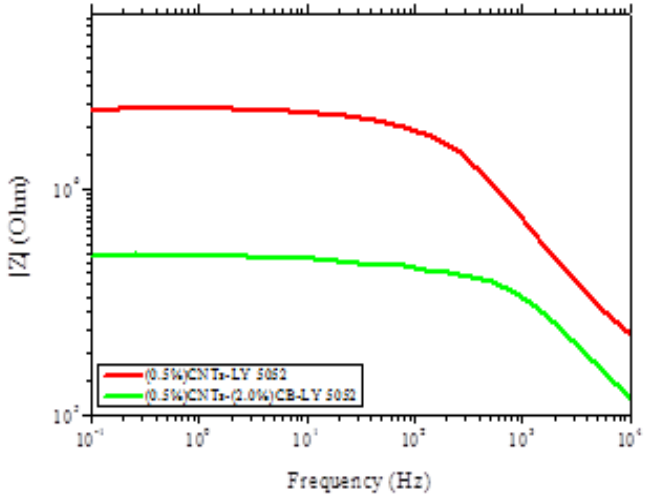
Improved Performance under high temperature and fire conditions





Improved fractured toughness

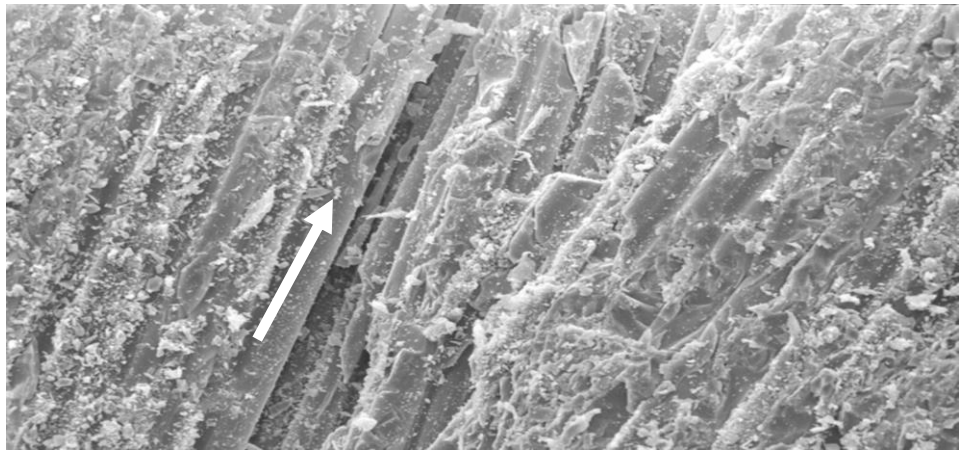
Reduced electrical resistivity



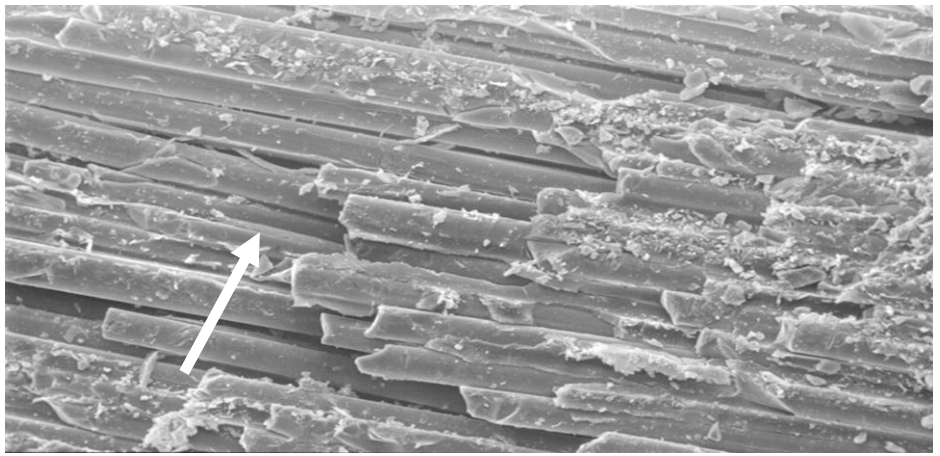
Wear properties of Polymer and Polymer composites

Wear Behaviour

GF/EP-Parallel



GF/EP-Perpendicular

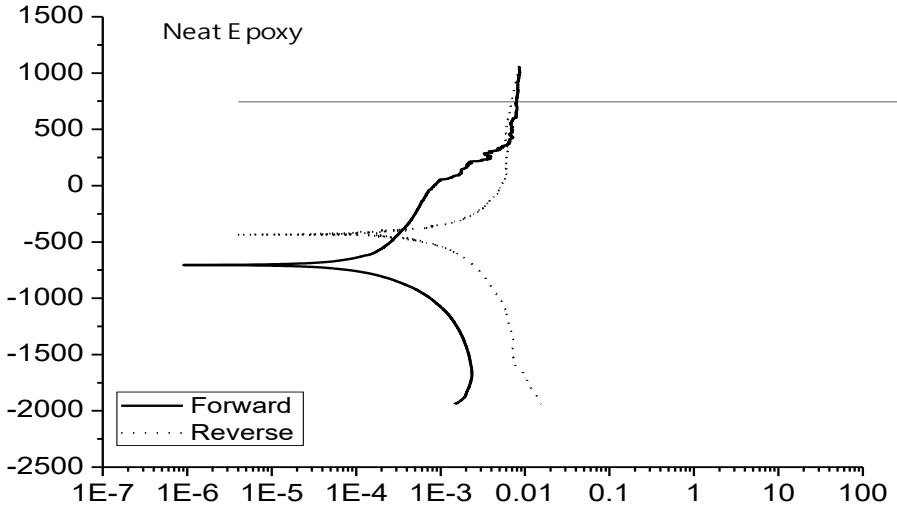


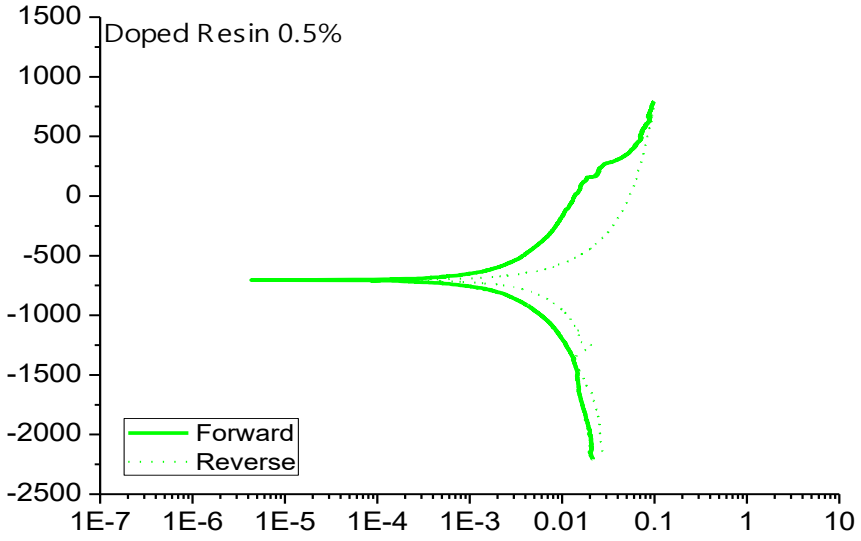
SEM micrographs taken on the eroded surface of composites impacted at 30 angle for 40s.

doi: 10.1177/0731684402021015779Journal of Reinforced Plastics and Composites **October 2002** vol. 21 no. 15 **1377-1388**

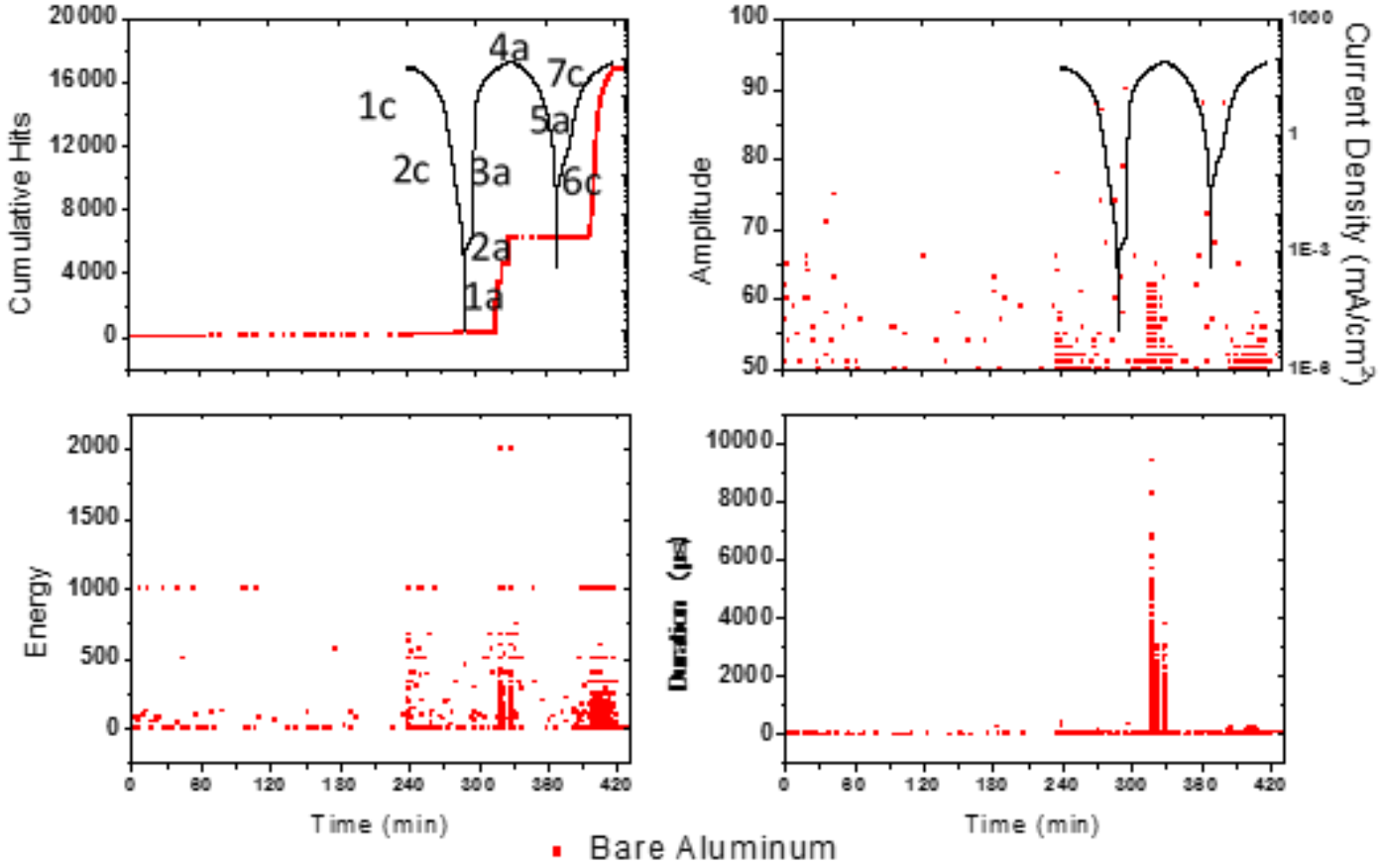
Nanomodified epoxy coatings for corrosion protection

Nano-modified epoxy coatings on Aluminium substrates





Acoustic emission Corrosion monitoring



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Γεώργιος Καραλής
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Νίκος Νικολάου
Γιώργος Τζαχρήστας
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