B[UILD] SMART!

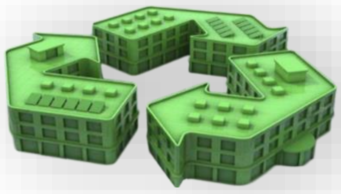
comfort, sicurezza, sostenibilità, innovazione

Gian Marco REVEL

EnDurCrete & ReSHEALience: non-destructive techniques to measure and monitor the durability of concrete

SUSTAINABILITY IN CONSTRUCTION

Decreasing energy expenditure in MATERIALS production



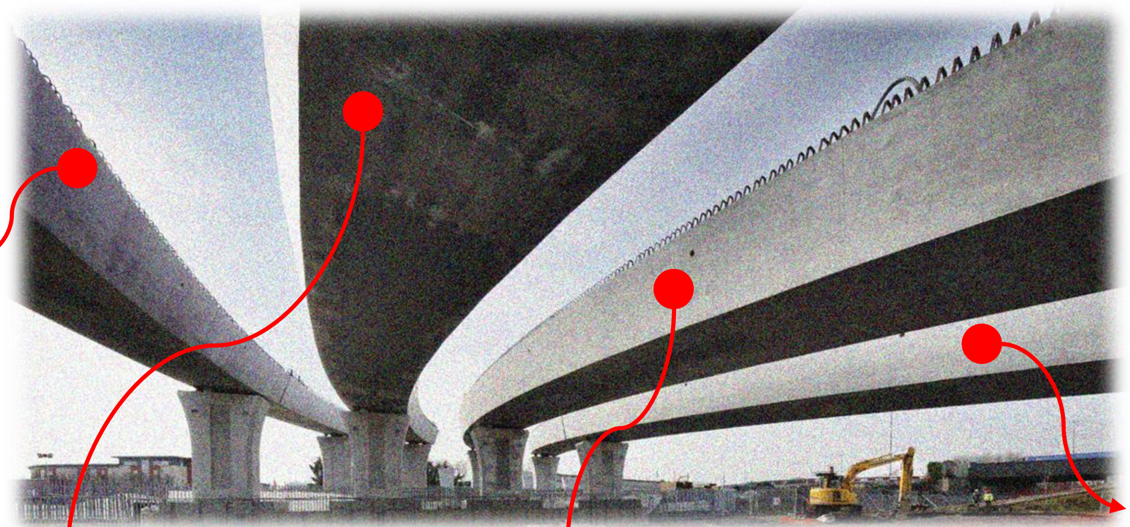
Energetic expenditure reduction in construction

Increasing the ENERGY EFFICIENCY

Increasing the DURABILITY

NDT TO MONITOR CONCRETE DURABILITY: THE FUTURE

Electrical impedance
- Crack detection
- Temperature and humidity
- Chloride ingress
- Carbonation



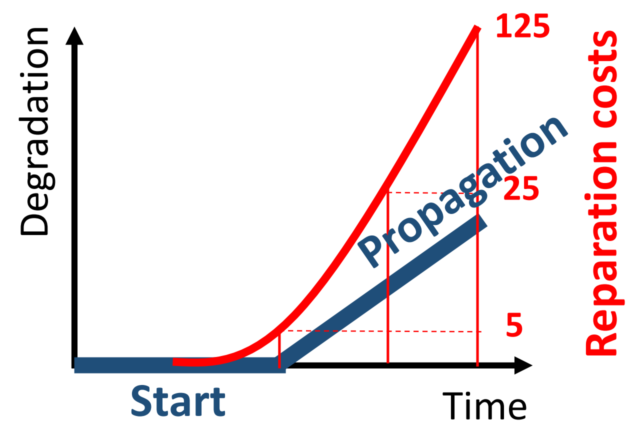
Computer vision
- Crack detection

Thermography
- Humidity

Ultrasound
- Mechanical resistance

- **Electrical impedance**
- **Computer vision**
- **Thermography**
- **GPR**
- **Ultrasound**

→ Data processing →



De Sitter Jr., W.R., Costs for Service Life Optimisation, the Law of Fives, CEB Bulletin d'Information, No. 152, 1984, pp. 131-134, 1983.

NON-DESTRUCTIVE TECHNIQUES

Ultrasound

Computer vision

Electrical impedance

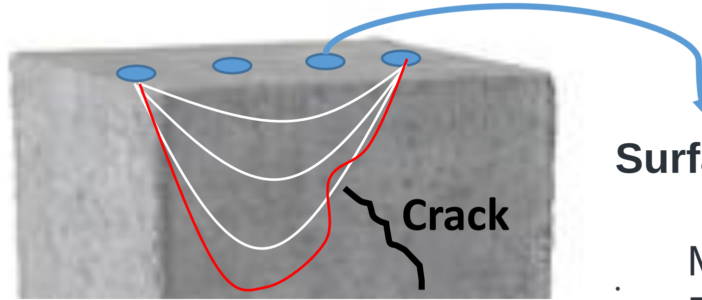
Thermography

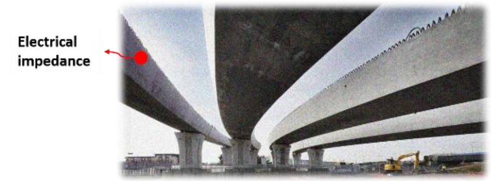
How to assess the concrete durability

It is possible to use a wide selection of non-destructive techniques in order to evaluate the durability of a concrete structure:

- **Electrical impedance measurement**, exploiting the self-sensing properties of concrete
- **Computer vision**, to evaluate the presence of cracks
- **Ultrasound techniques**, to detect possible delamination defects
- **Thermography**, to evaluate the presence of humidity

SELF-SENSING PROPERTIES OF CONCRETE



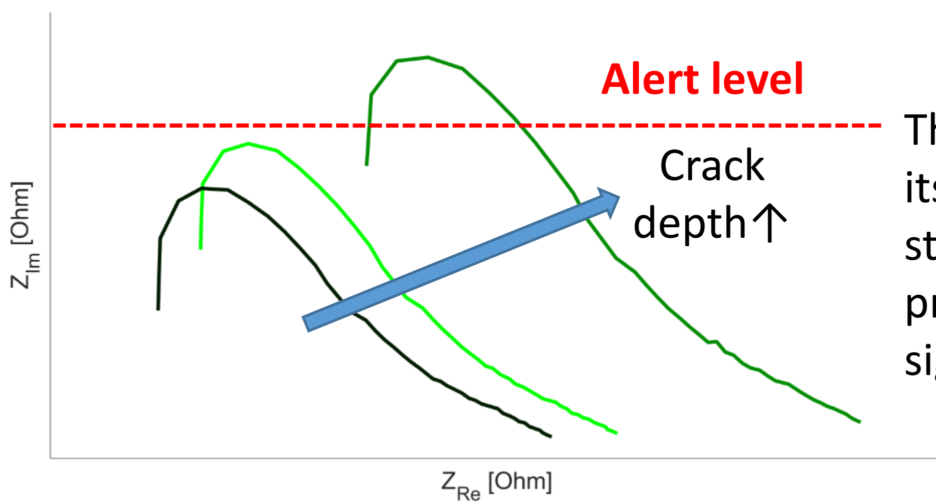


Surface electrodes

- Metallic material (e.g. silver)
- Fixed with conductive epoxy
- Possibility to easily change measurement position
- No necessity to embed electrodes during casting phase

The presence of a **structural defect** alters the electric current lines path

Different measured impedance



The material itself senses its status and provides alert signal.

4-electrode measurement:

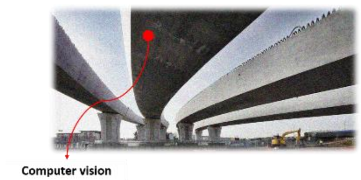
- An electric current is injected between the two external electrodes
- The corresponding electric potential difference is measured between the two internal electrodes

Electrical impedance of concrete: how much information can we obtain from it?

Electrical impedance of concrete depends on many factors:

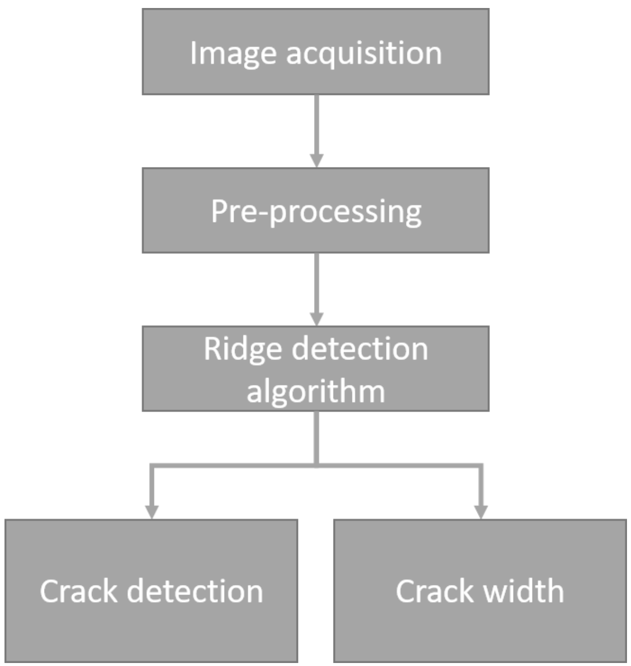
- Cement type and composition
- Water/cement ratio
- Porosity
- Curing type and consolidation degree
- Moisture content
- Environmental factors (i.e. **humidity** and **temperature**)
- Reinforcement corrosion (and so durability)
- Chloride penetration
- Carbonation
- Presence of **cracks**
- Mechanical stresses (**piezoresistive behavior**)

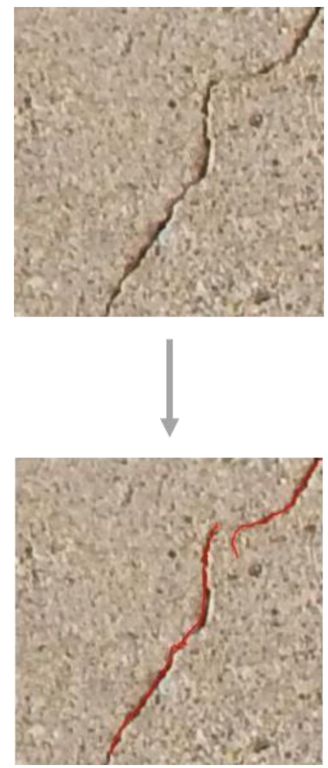
NDT FOR CONCRETE: COMPUTER VISION



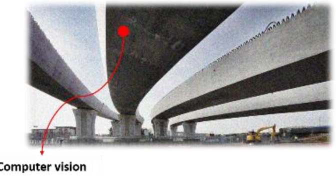
Ridge detection algorithms

In computer vision, **ridge detection algorithms** detect thin lines darker or brighter than their neighborhood.

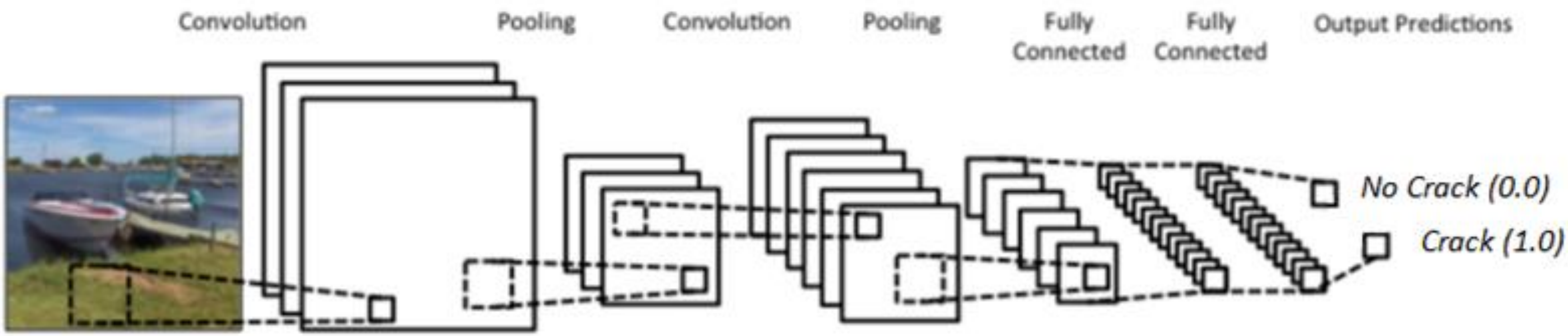




NDT FOR CONCRETE: COMPUTER VISION



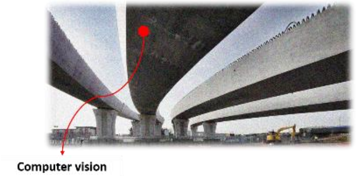
Convolutional Neural Networks (CNN)



- **Convolutional layer:** set of learnable filters sliding over the image spatially, computing the dot products between the entries of the filter and the input image.
- **Pooling layer:** form of non-linear down-sampling; its goal is to progressively reduce the spatial size of the representation (computation reduction, overfitting control).

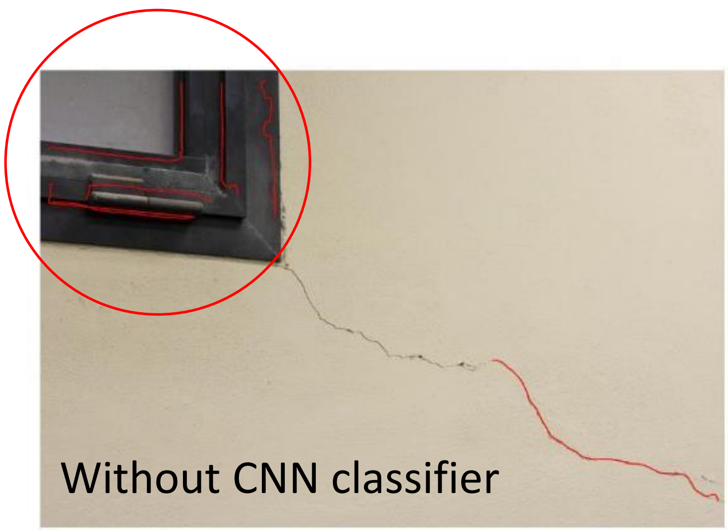
Convolutional Neural Networks (CNNs) are a category of Neural Networks that have proven very effective in areas such as **image classification**.

Crack images database → CNN Training → CNN Classifier

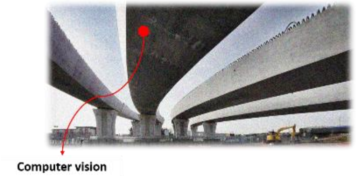


Ridge detection algorithm and CNN

- A **ridge detection algorithm**, as opposed to edge detection algorithms, allows us to detect the central part of a crack, so it is possible to measure the **crack width**.
- These algorithms fail to detect cracks in not-only cracks images, but **Convolutional Neural Networks** can help to solve the problem, by means of small regions progressive selection.



NDT FOR CONCRETE: COMPUTER VISION



An useful fast and easy-to-use instrument for maintenance operators

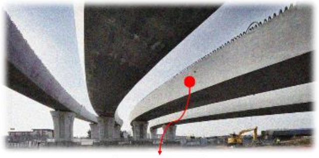
- The use of computer vision techniques allows us to detect submillimeter cracks.
- A crack width of **0.3 mm** is considered <u>possibly dangerous</u>.
- It is possible to think at a colour **code** (i.e. green, yellow and red) for the dangerousness level of a crack.

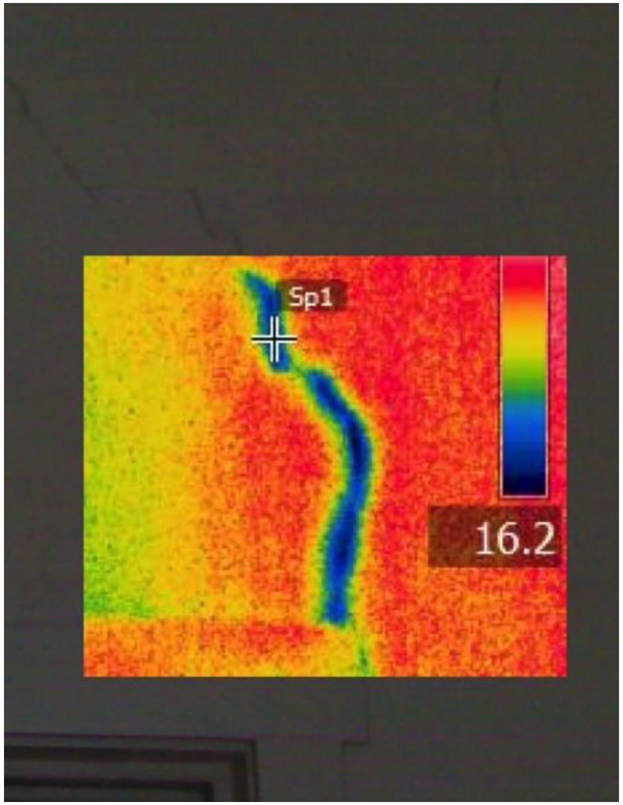
Low risk

Medium risk

High risk

NDT FOR CONCRETE: THERMOGRAPHY

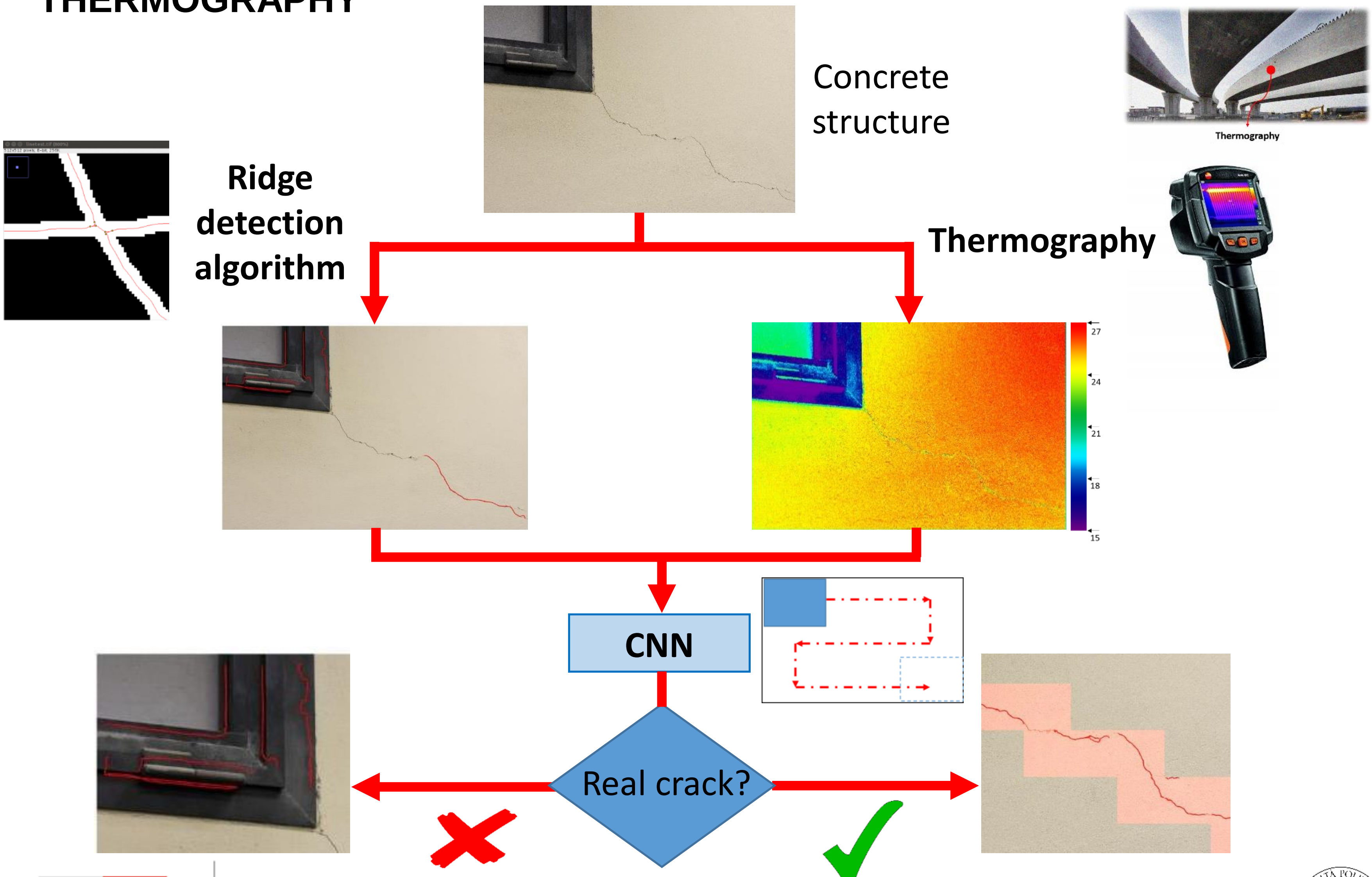




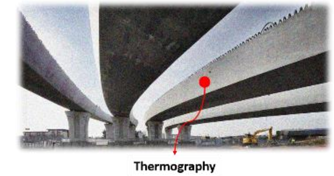
How to distinguish between a real crack and a scratch?

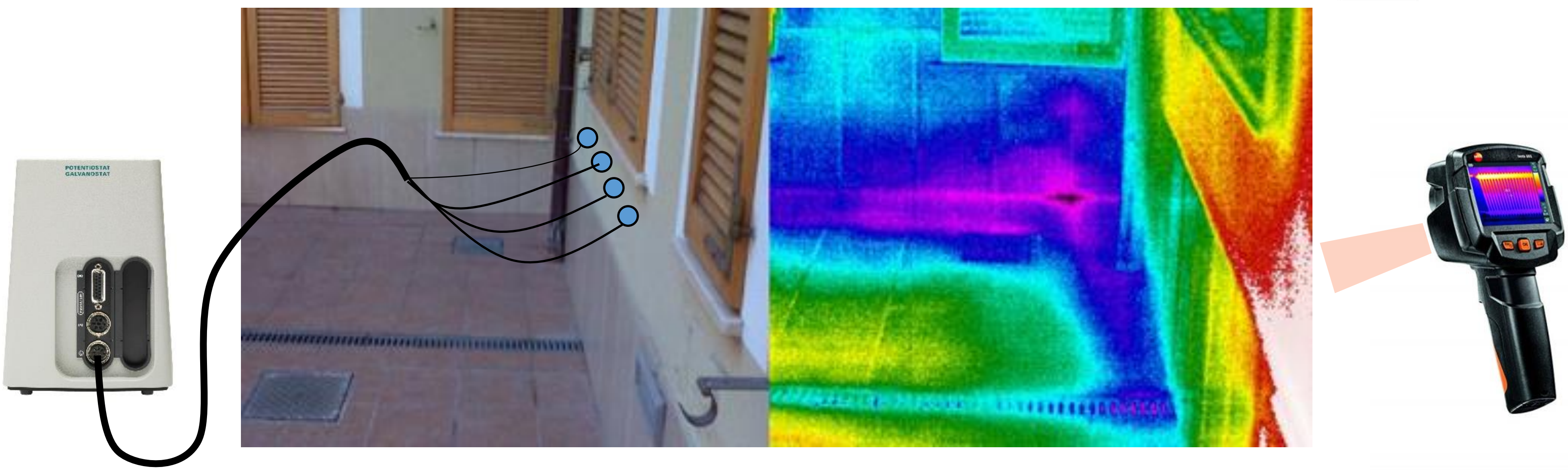
- The combination of computer vision and **thermography** (CVT) can be useful.
- A real crack can be penetrated by **humidity**, which can be detected by thermography.
- In addition, thermography can detect delamination in concrete structures.

NDT FOR CONCRETE: COMPUTER VISION & THERMOGRAPHY



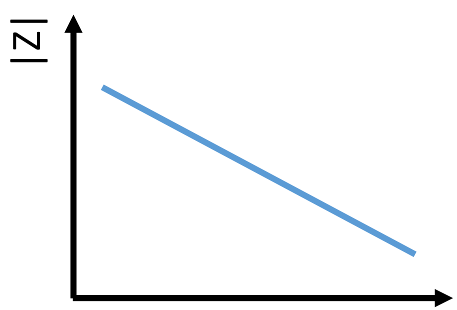
NDT FOR CONCRETE: THERMOGRAPHY & ELECTRICAL IMPEDANCE MEASUREMENT





Humidity↑

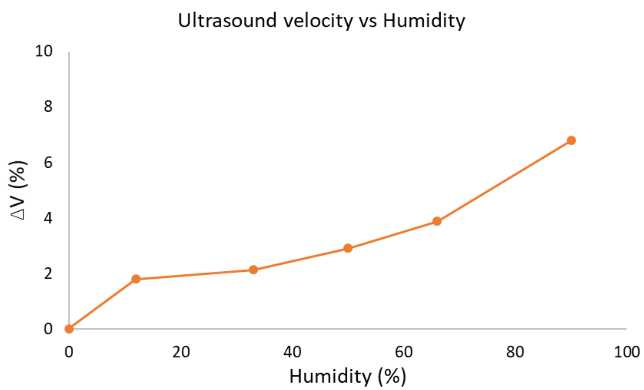
Electrical impedance↓



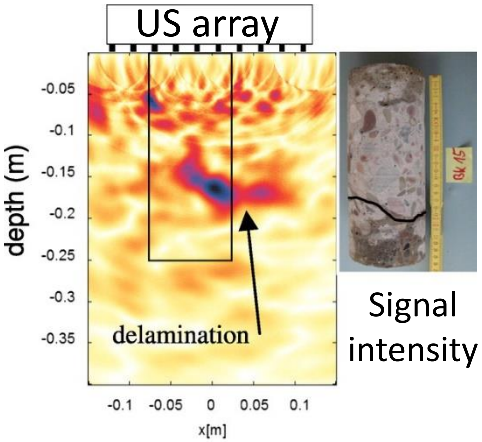
- Electrical impedance is able to detect water content changes.
- The correlation between electrical impedance signal and humidity (e.g. *rising damp*) can be confirmed through thermography imaging.

Ultrasound inspection to detect delamination

- **Ultrasound velocity** measurement is sensitive to humidity content of concrete.
- Possibility to detect delamination in concrete structures.
- Possibility to measure the time variations of concrete modulus of elasticity.



Humidity correlation



Delamination detection (ultrasound tomography)

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comfort, sicurezza, sostenibilità, innovazione

Francesca TITTARELLI

Novel carbon based additions for self sensing concretes

ADDITIONS IN CONCRETE

CONCRETE

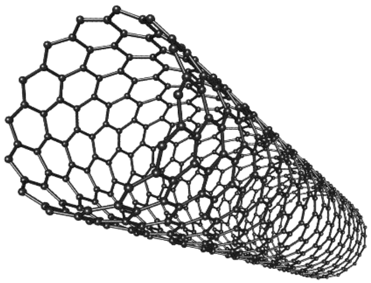
FILLERS/FIBERS

…MECHANICAL PERFORMANCES

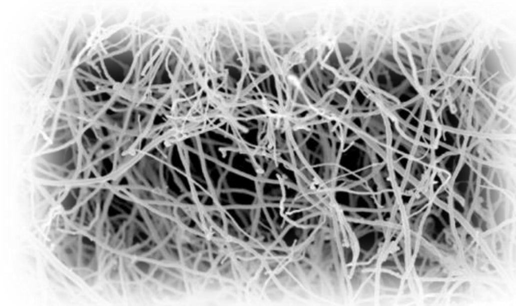
…DURABILITY

CARBON BASED ADDITIONS

Graphene



Carbon Nanotubes



Carbon Nanofibers

Electrical conductivity

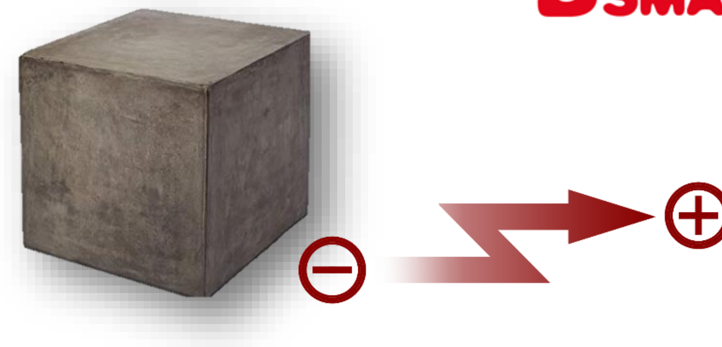
Mechanical Strength

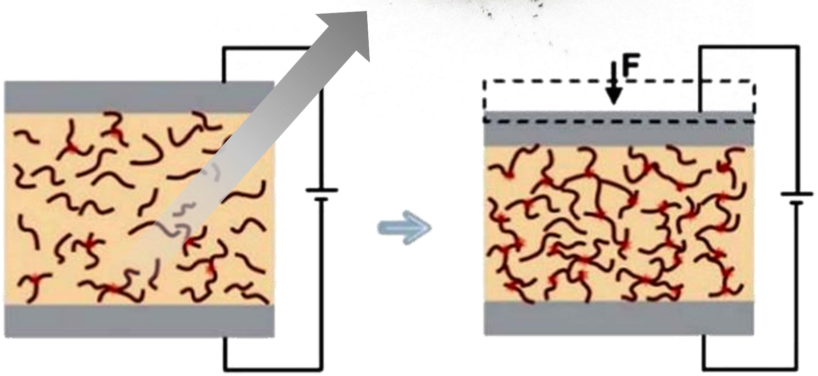
Lightness

Hydrophobicity

SELF-SENSING CONCRETE

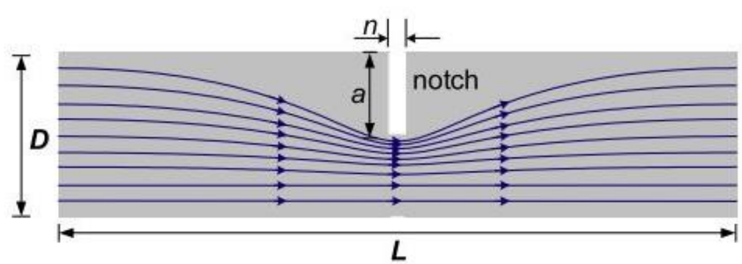
Carbon-based additions





- Strain

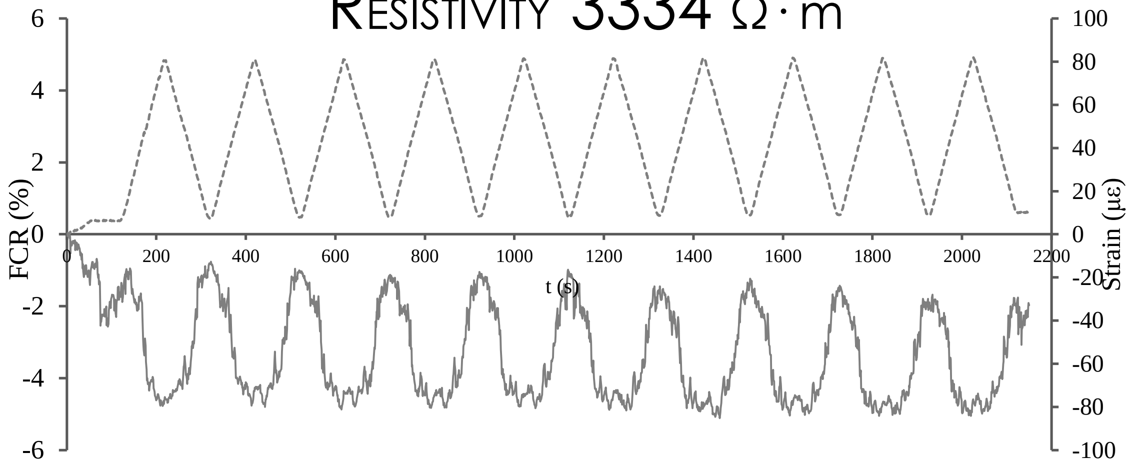
- Water penetration

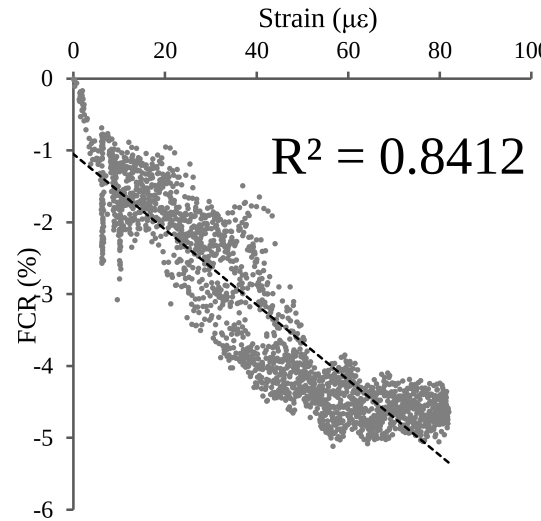


- Cracking

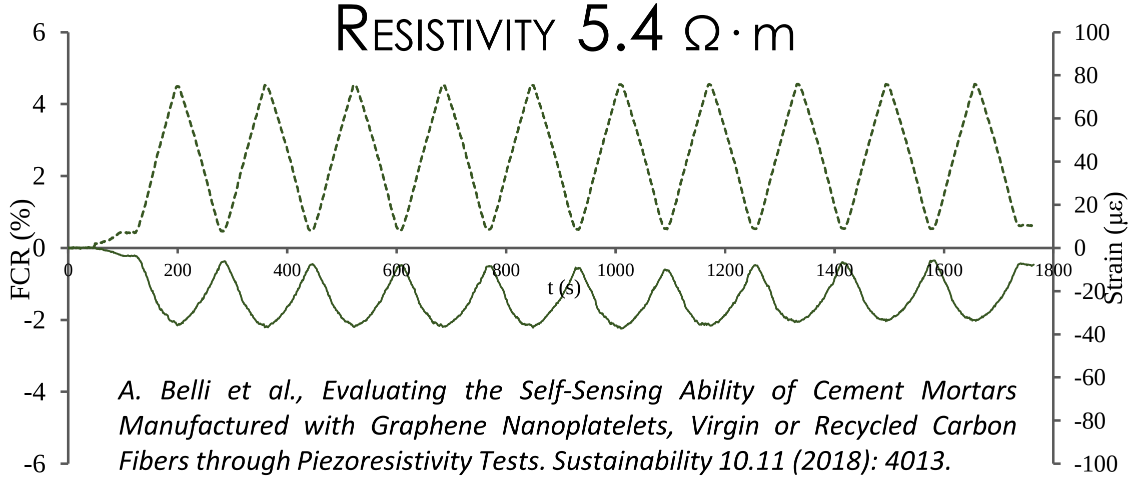
SELF-SENSING CONCRETE

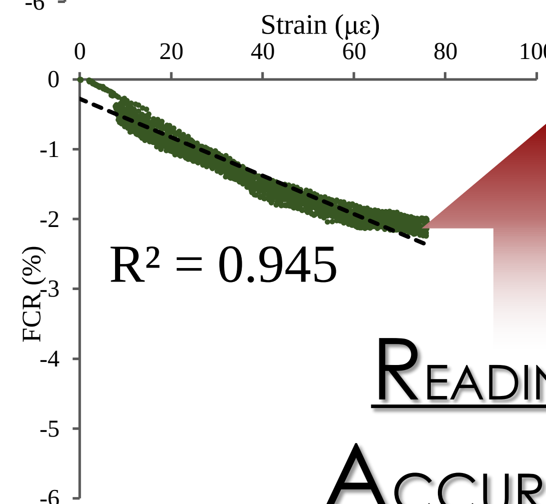
Resistivity 3334 Ω·m





Resistivity 5.4 Ω·m

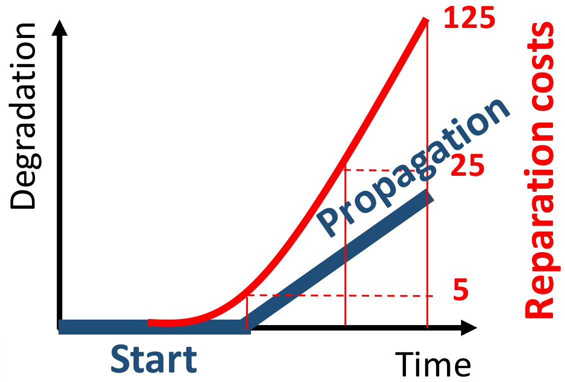




A. Belli et al., Evaluating the Self-Sensing Ability of Cement Mortars Manufactured with Graphene Nanoplatelets, Virgin or Recycled Carbon Fibers through Piezoresistivity Tests. Sustainability 10.11 (2018): 4013.

READING ACCURACY

CONCRETE STRUCTURES MONITORING SYSTEM



De Sitter Jr., W.R., Costs for Service Life Optimisation, the Law of Fives, CEB Bulletin d'Information, No. 152, 1984, pp. 131-134, 1983.

EARTHQUAKE OF VALLE DEL TRONTO
AUGUST 24th, 2016

MORANDI BRIDGE COLLAPSE
AUGUST 14th, 2018

CONCRETE STRUCTURES
IN SERVICE LIFE

NORME TECNICHE COSTRUZIONI (NTC 2018)

Approvate con D.M. del 17 gennaio 2018

CAPITOLO 2.

SICUREZZA E PRESTAZIONI ATTESE

2.2.4. DURABILITA'

Un adeguato livello di durabilità può essere garantito progettando la costruzione, e la specifica manutenzione, in modo tale che il degrado della struttura, che si dovesse verificare durante la sua vita nominale di progetto, non riduca le prestazioni della costruzione al di sotto del livello previsto.

Tale requisito può essere soddisfatto attraverso l'adozione di appropriati provvedimenti stabiliti tenendo conto delle previste condizioni ambientali e di manutenzione ed in base alle peculiarità del singolo progetto, tra cui:

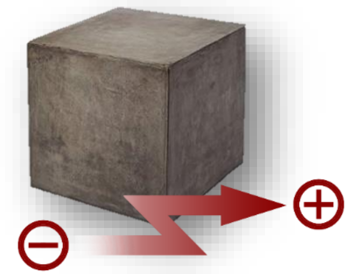
a) scelta opportuna dei materiali;
b) dimensionamento opportuno delle strutture;
c) scelta opportuna dei dettagli costruttivi;
d) adozione di tipologie costruttive e strutturali che consentano, ove possibile, l'ispezionabilità delle parti strutturali;
e) pianificazione di misure di protezione e manutenzione; oppure, quando queste non siano previste o possibili, progettazione rivolta a garantire che il deterioramento della costruzione o dei materiali che la compongono non ne causi il collasso;
f) impiego di prodotti e componenti chiaramente identificati in termini di caratteristiche meccanico-fisico-chimiche, indispensabili alla valutazione della sicurezza, e dotati di idonea qualificazione, così come specificato al Capitolo 11;
g) applicazione di sostanze o ricoprimenti protettivi dei materiali, soprattutto nei punti non più visibili o difficilmente ispezionabili ad opera completata;
h) adozione di sistemi di controllo, passivi o attivi, adatti alle azioni e ai fenomeni ai quali l'opera può essere sottoposta.

Le condizioni ambientali devono essere identificate in fase di progetto in modo da valutarne la rilevanza nei confronti della durabilità.

SELF-SENSING CONCRETE STRUCTURES

TRADITIONAL MONITORING DEVICES

SELF-SENSING CONCRETE

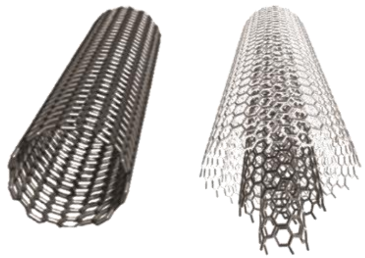


EASE OF APPLICATION

CONTINUITY OF READINGS

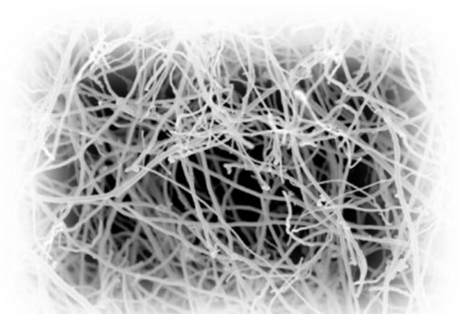
MAINTENANCE

STATE OF THE ART



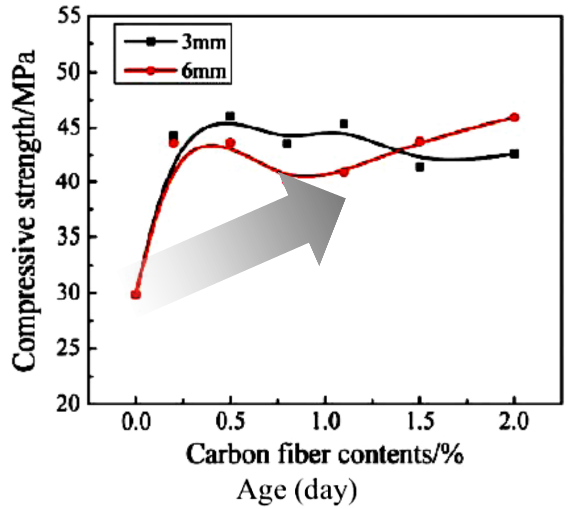
CARBON NANOTUBES

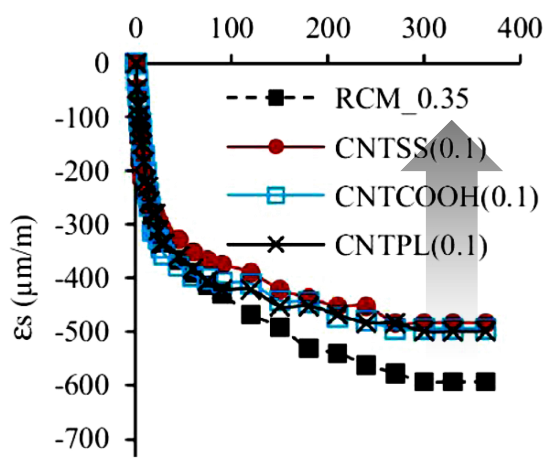
[1] B. Han et al., Reinforcement effect and mechanism of carbon fibers to mechanical and electrically conductive properties of cement-based materials, Constr. Build. Mater. 125 (2016) 479–489.



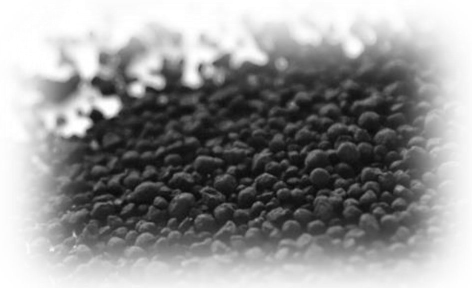
CARBON NANOFIBERS

COMPRESSIVE STRENGTH [1]



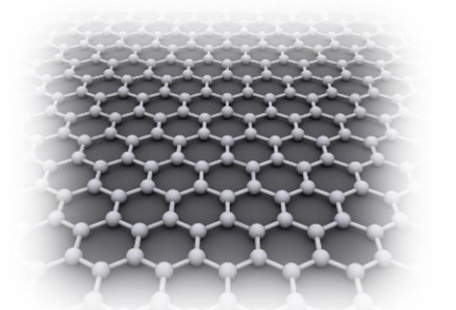


SHRINKAGE STRAIN [2]



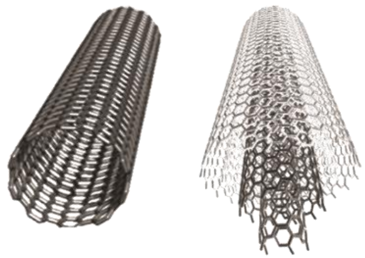
CARBON BLACK

[2] A. Hawreen et al., On the mechanical and shrinkage behavior of cement mortars reinforced with carbon nanotubes, Constr. Build. Mater. 168 (2018) 459–470.



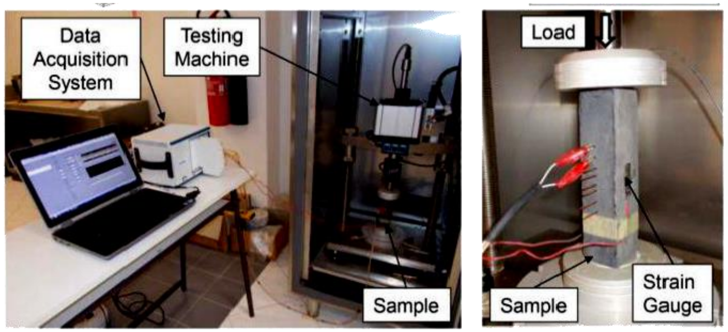
GRAPHENE

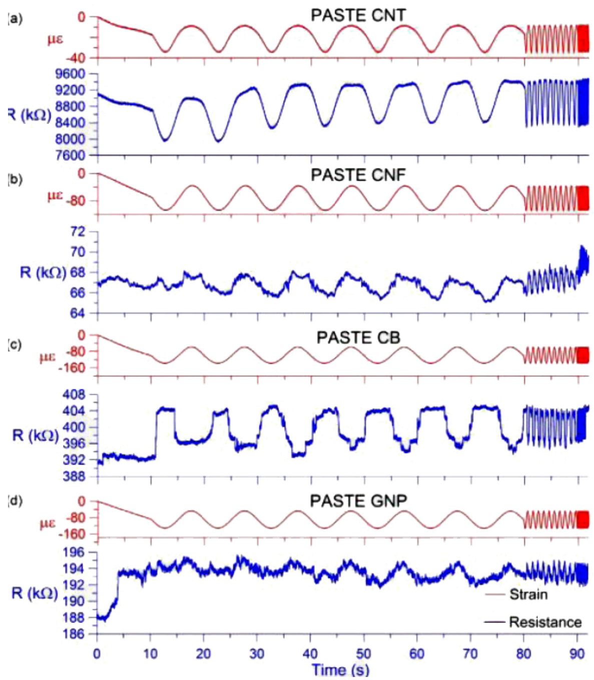
STATE OF THE ART



CARBON NANOTUBES

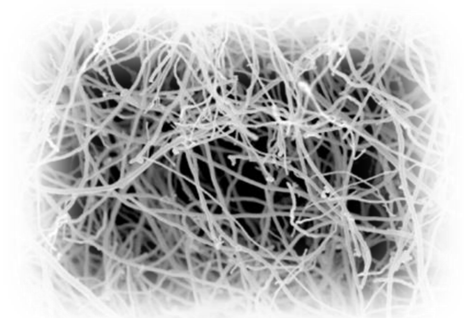
[3] A. D'Alessandro et al., Multipurpose experimental characterization of smart nanocomposite cement-based materials for thermal-energy efficiency and strain-sensing capability, Sol. Energy Mater. Sol. Cells. 161 (2017) 77–88.



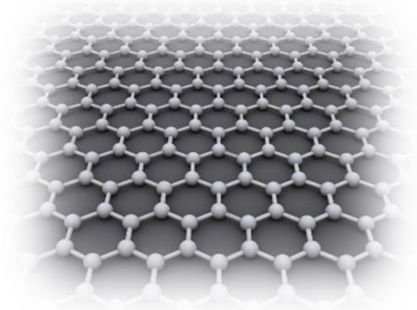


CARBON BLACK

FRACTIONAL CHANGE IN RESISTIVITY [3]

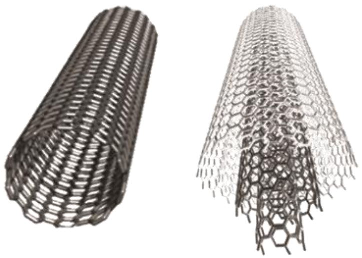


CARBON NANOFIBERS



GRAPHENE

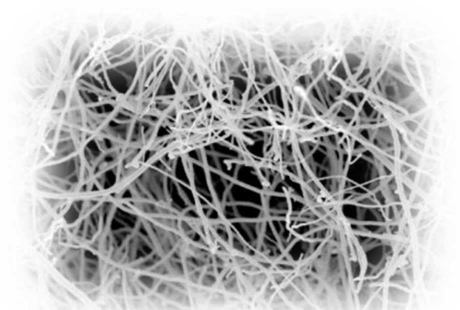
STATE OF THE ART



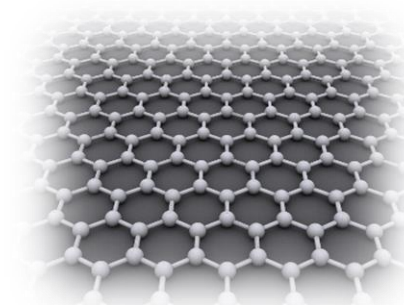
Carbon Nanotubes

Carbon Black

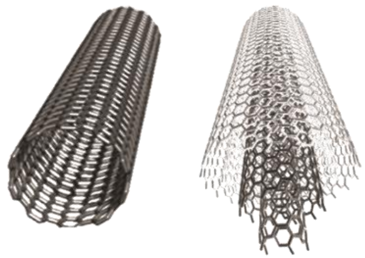
Very high PRICE



Carbon nanofibers



Graphene

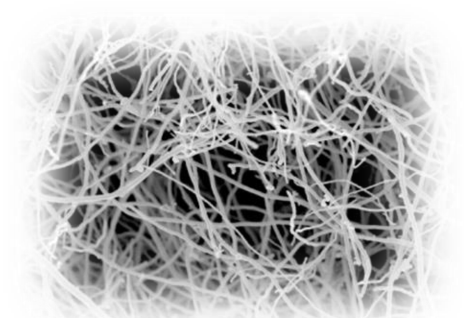


CARBON NANOTUBES

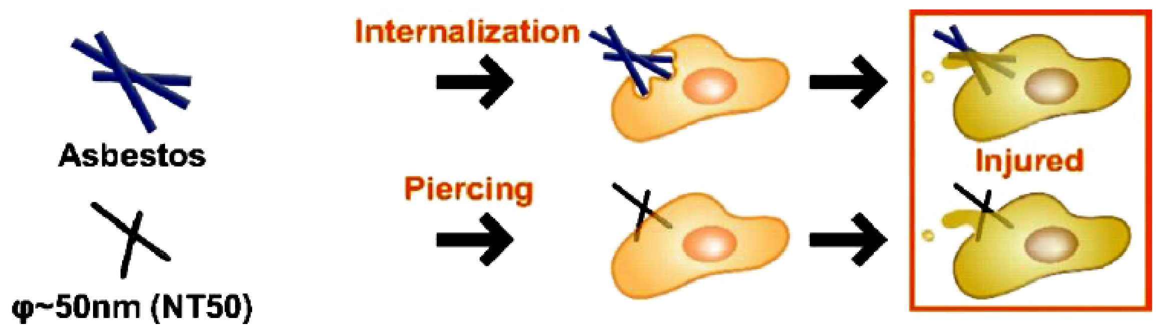
[4] *C. Corredor et al., Distruption of model cell membranes by carbon nanotubes, Carbon N. Y. 60 (2013) 67–75.*

HIGH TOXICITY

CARBON BLACK



CARBON NANOFIBERS



EFFECT OF CARBON NANOTUBES AND ASBESTOS FIBERS ON MESOTHELIAL CELLS [4]

RECYCLED CARBON-BASED ADDITIONS

INDUSTRIAL BY-PRODUCTS…

ECO - FRIENDLY

LOW COSTS

PRELIMINARY TESTS ON PASTES

COMMERCIAL

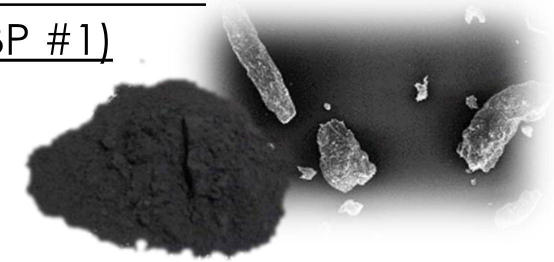
- <u>Graphene Nanoplatelets (GNPs)</u>

Carbon content > 99 %

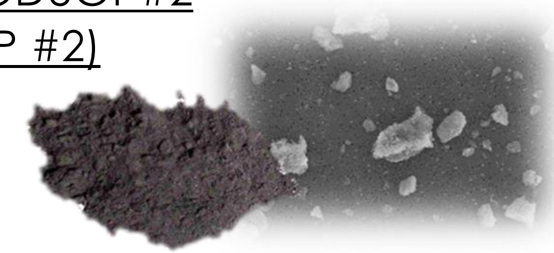
VS.

RECYCLED

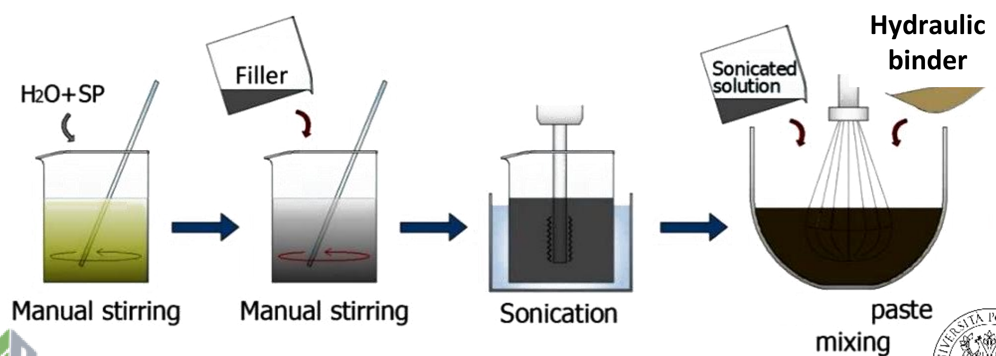
- <u>By-product #1 (BP #1)</u>



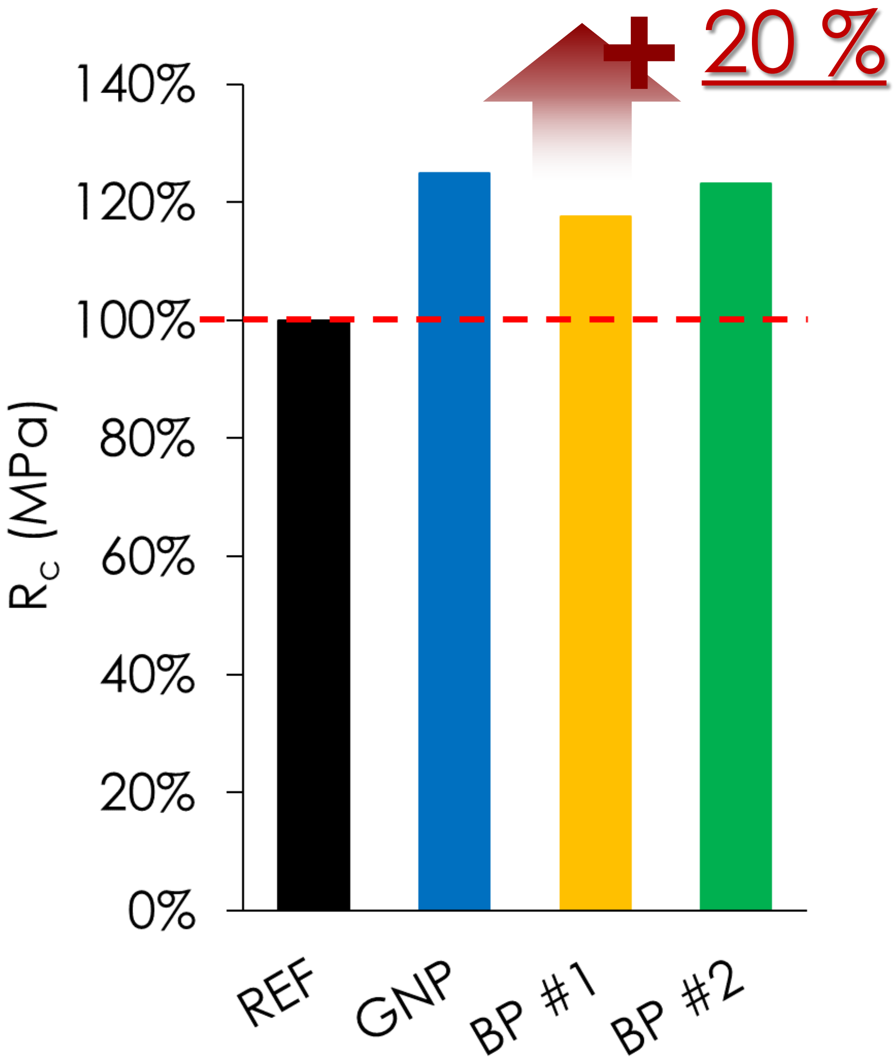
- <u>By-product #2 (BP #2)</u>



Hydraulic Binder



MECHANICAL TESTS



COMPRESSIVE STRENGTH

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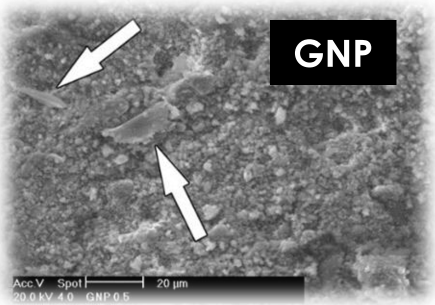
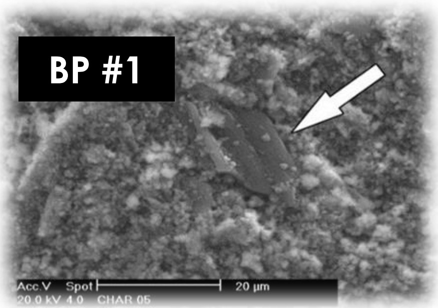
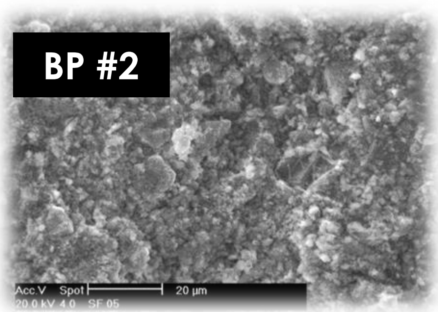
MICROSTRUCTURAL ANALYSES

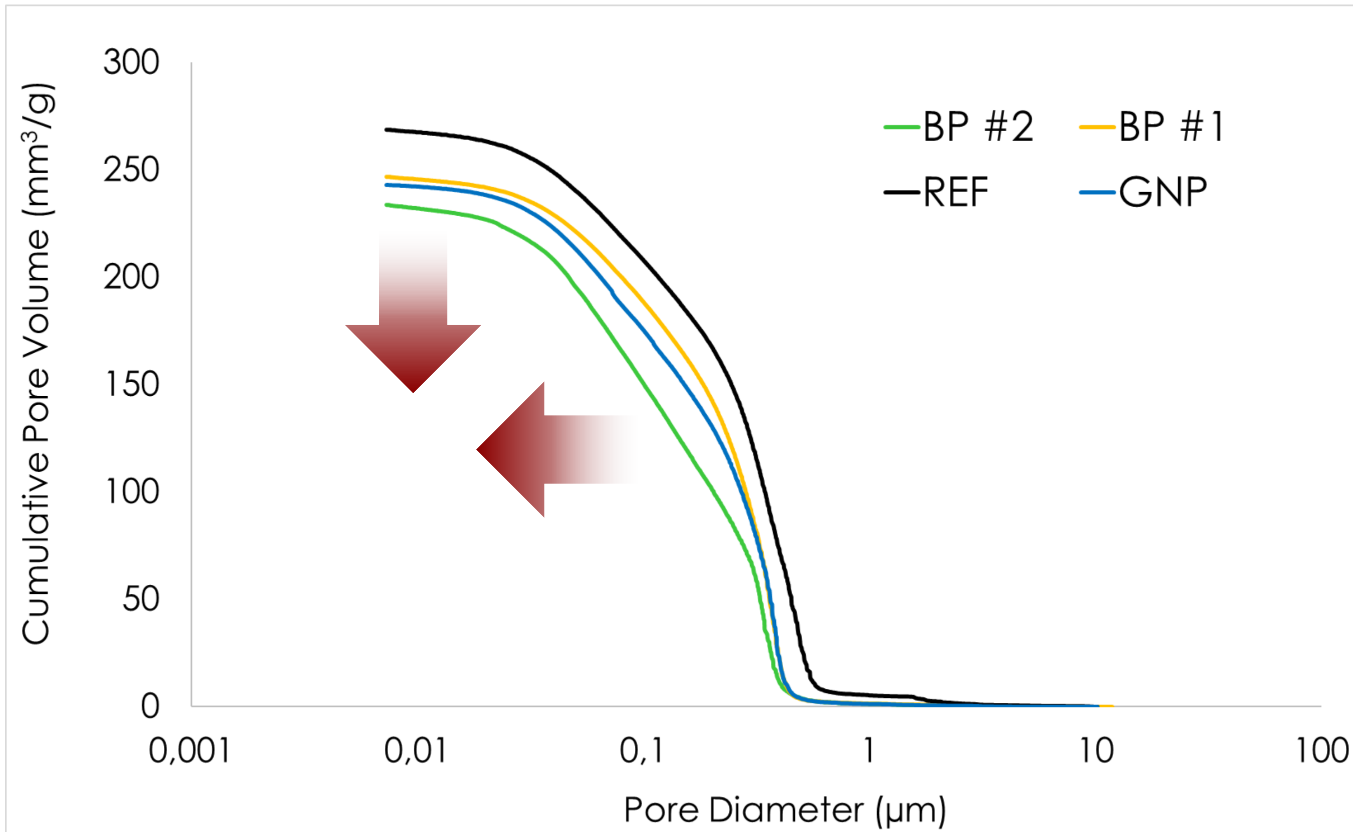
SEM IMAGES



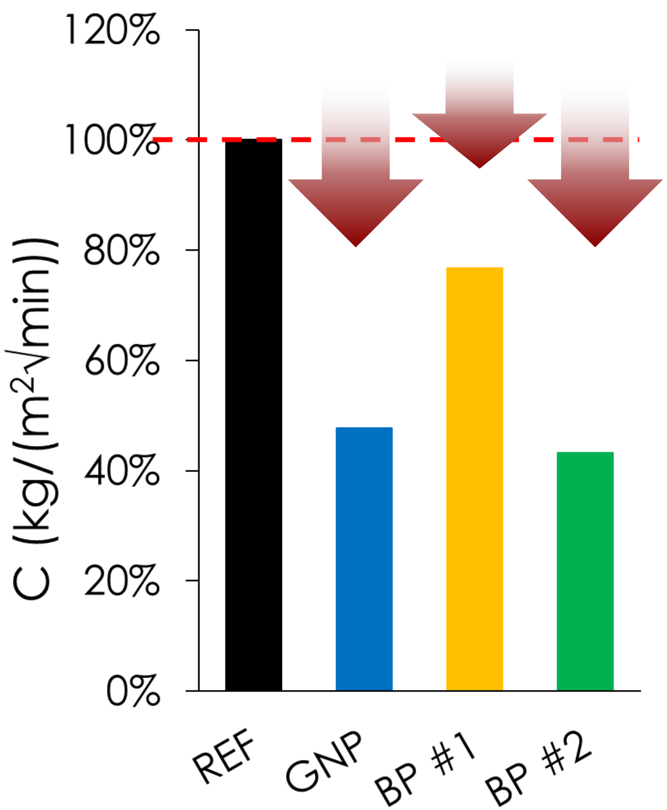


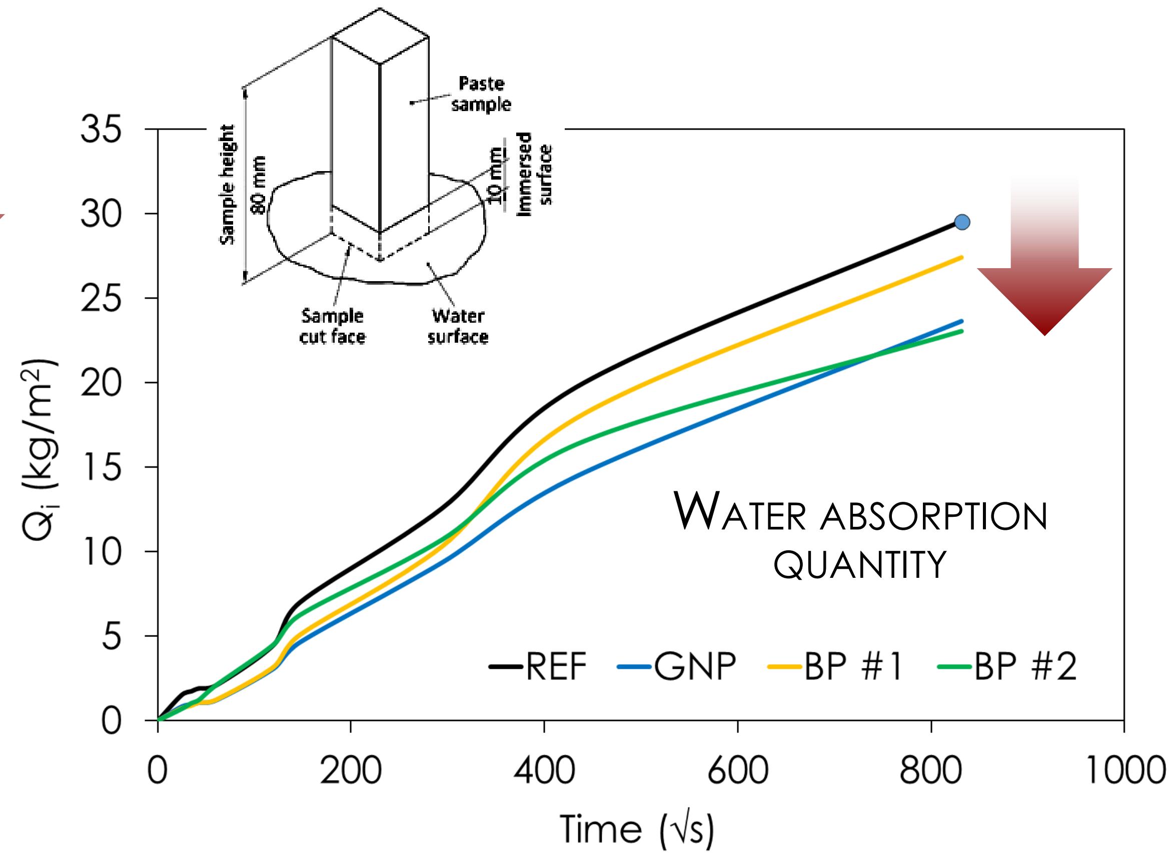


POROSIMETRIC CURVES



WATER ABSORPTION

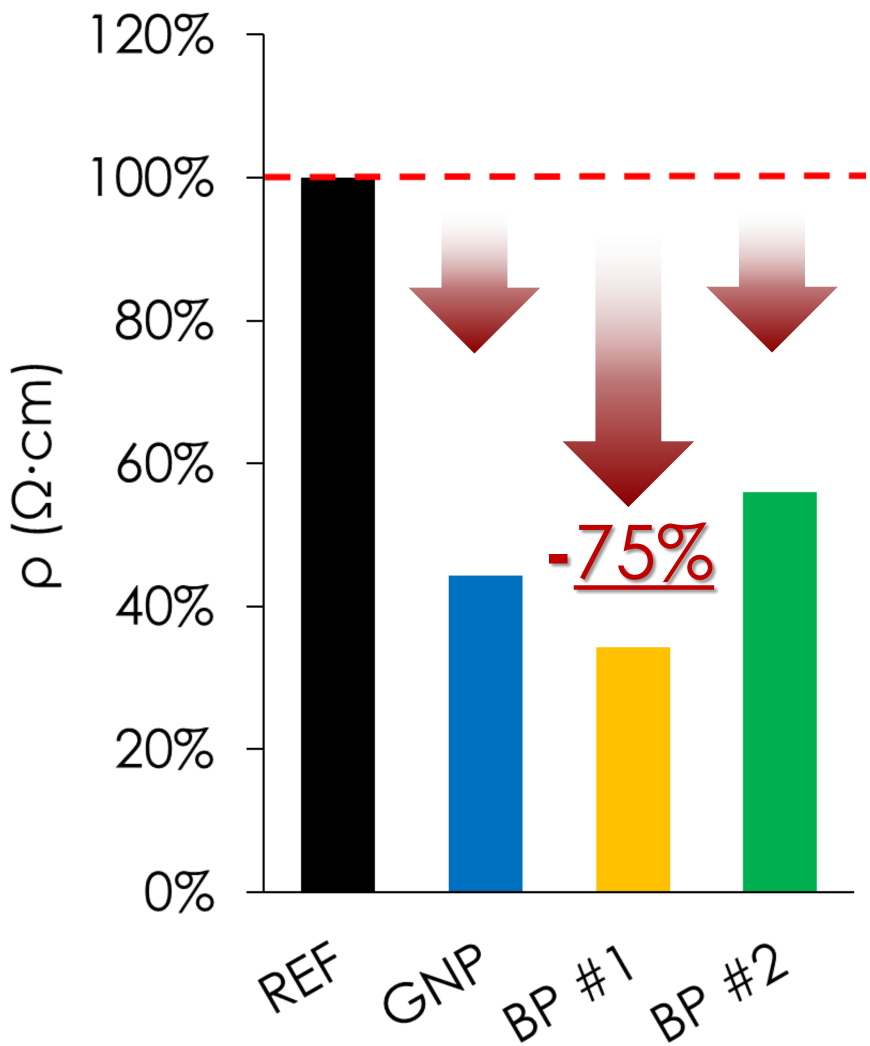


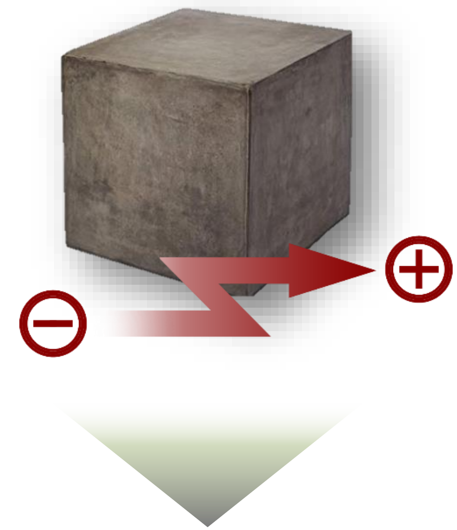


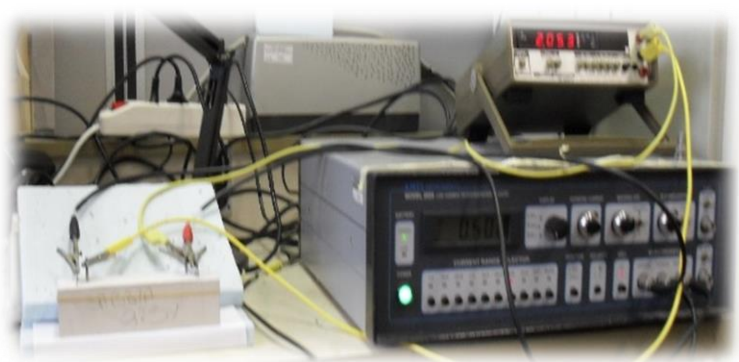
ABSORPTION COEFFICIENT

UNI EN 1015-18:2004

ELECTRICAL RESISTIVITY







ELECTRICAL MEASUREMENTS DEVICES

CARBON FIBERS AND SELF SENSING

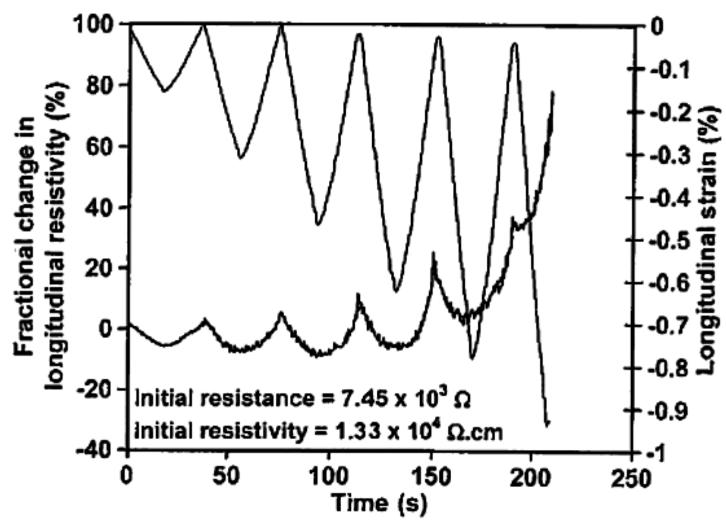
CARBON FIBERS

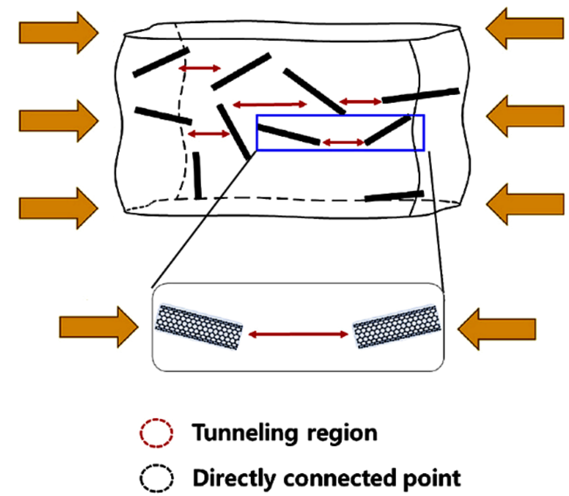
STRUCTURAL HEALTH MONITORING [2]

[2] S. Wen, Effects of Strain and Damage on Strain-Sensing Ability of Carbon Fiber Cement, J. Mater. Civ. Eng. 18 (2006) 355–360.

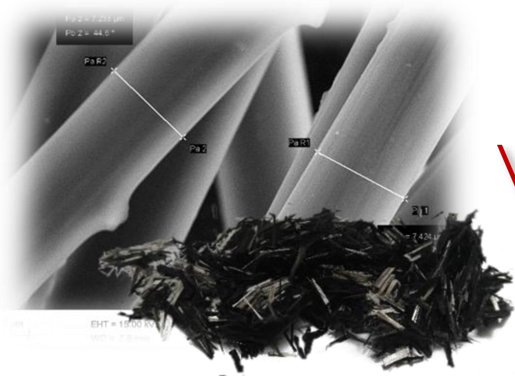
[1] R.N. Howser et al., Self-sensing of carbon nanofiber concrete columns subjected to reversed cyclic loading, Smart Mater. Struct. 20 (2011) 85031.

CONCRETE COLUMN WITH CARBON FIBERS [1]



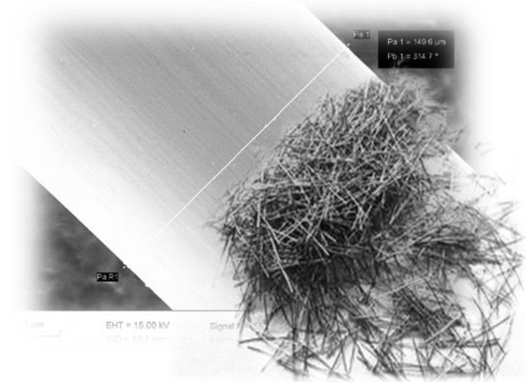


MORTARS WITH CONDUCTIVE FIBERS



VS.

VS.



Virgin Carbon Fibers (VCF)

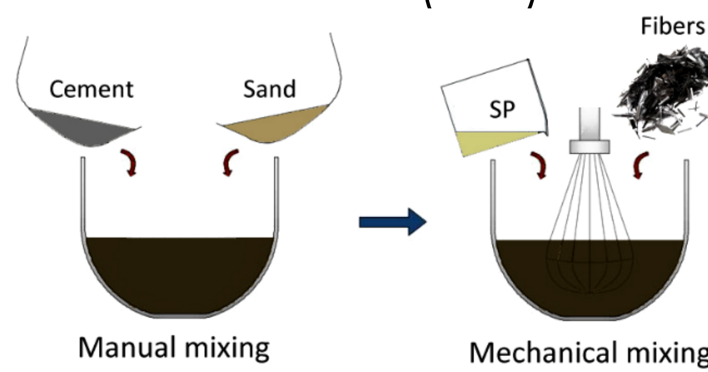
Recycled Carbon Fibers (RCF)

Metallic Fibers (MET)

CEMENT

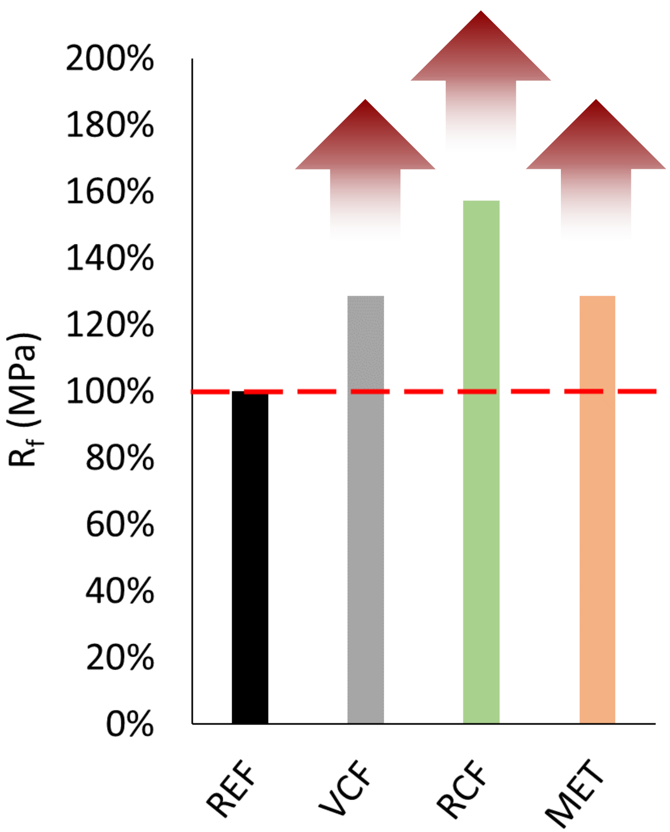
+

SAND

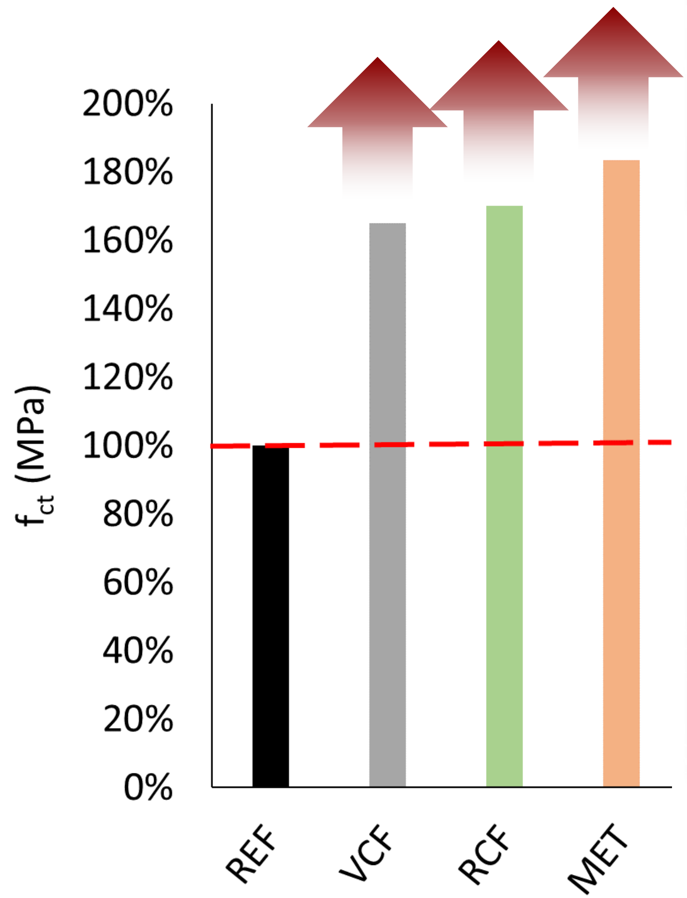


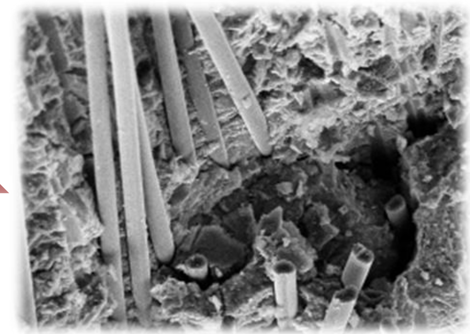
MECHANICAL TESTS

FLEXURAL STRENGTH

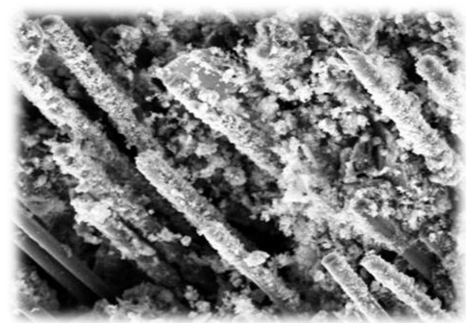


TENSILE SPLITTING STRENGTH



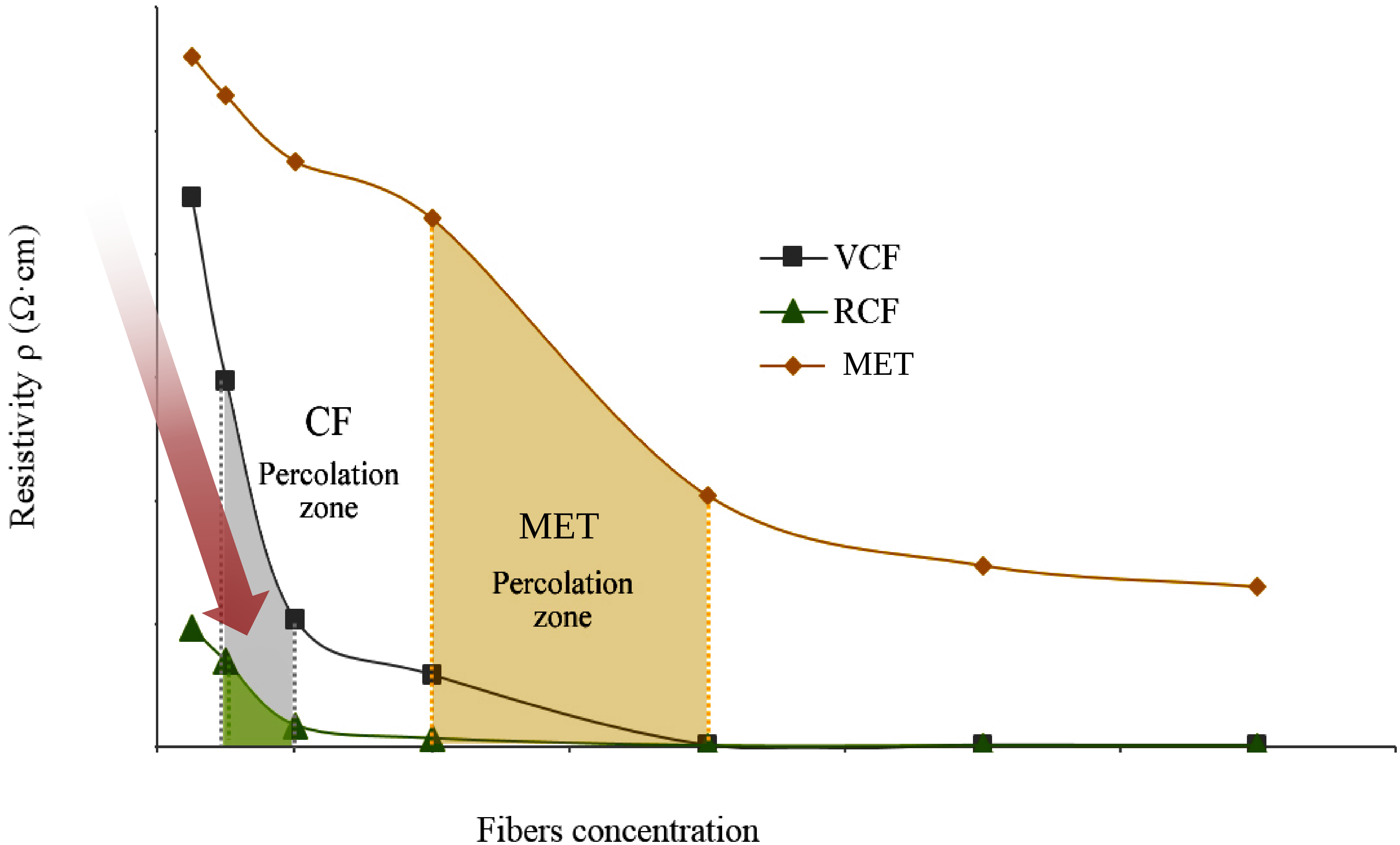


VIRGIN CARBON FIBERS



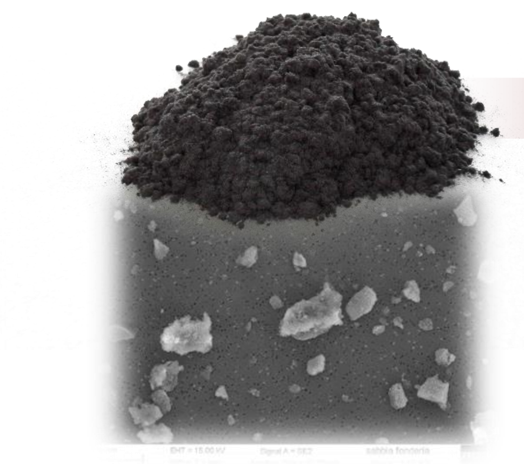
RECYCLED CARBON FIBERS

ELECTRICAL CONDUCTIVITY

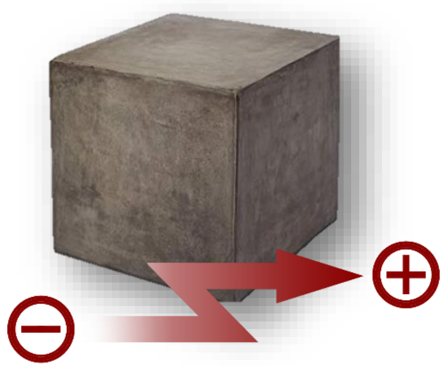


BUILD SMART!

HYBRID FILLERS/FIBERS MORTARS



FILLERS



FIBERS

COMPRESSIVE STRENGTH CLASS

C40/50

MICROSTRUCTURE REFINEMENT

ELECTRICAL CONDUCTIVITY

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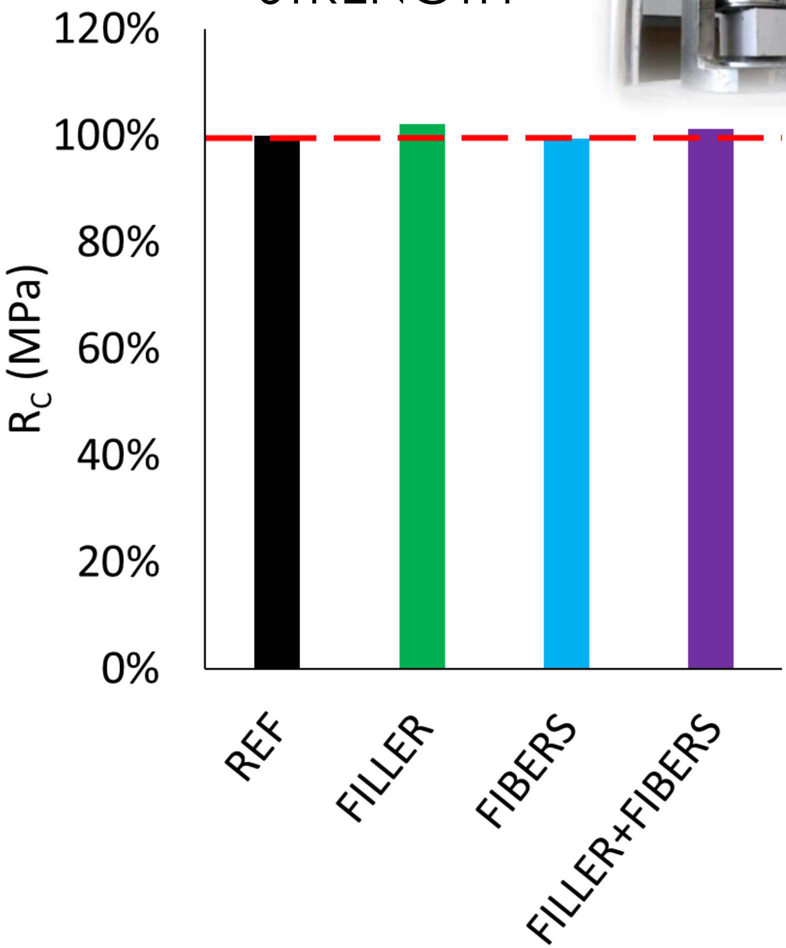
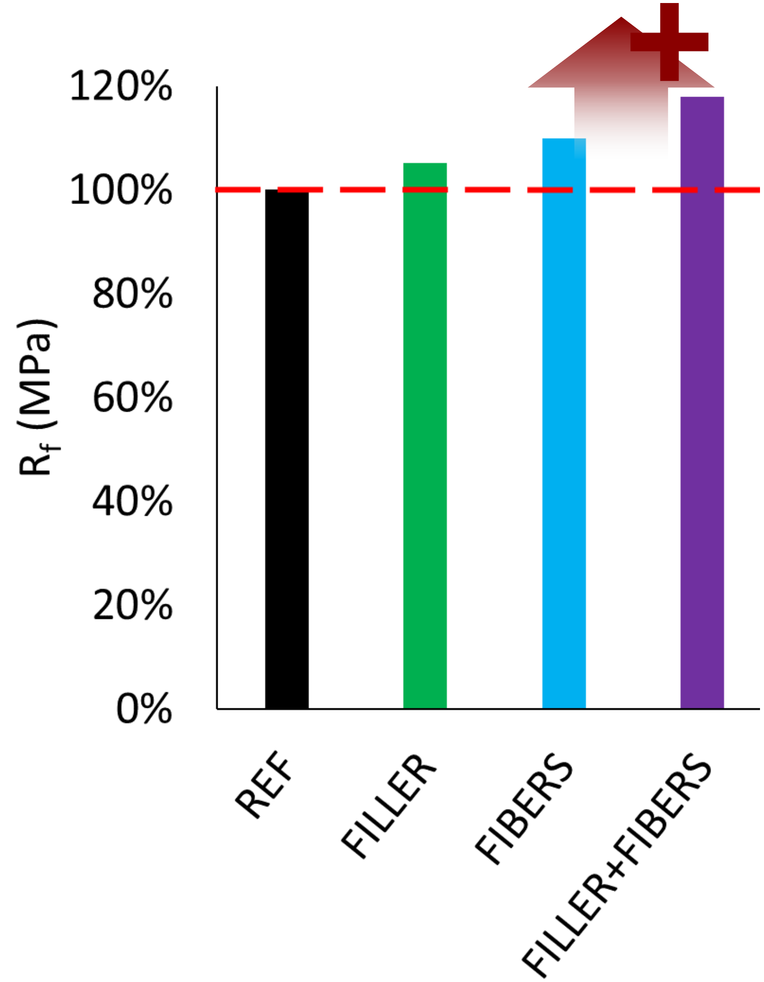
MECHANICAL TESTS

BUILD SMART!

COMPRESSIVE STRENGTH



FLEXURAL STRENGTH



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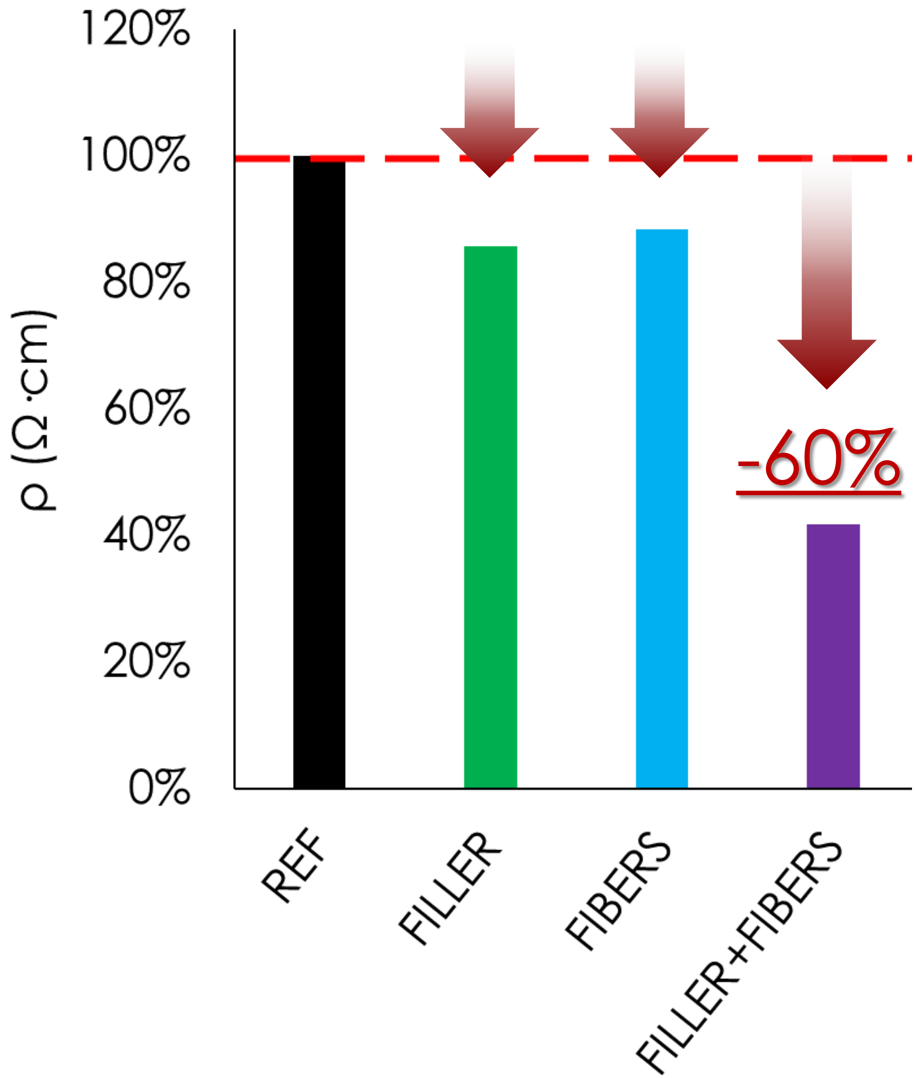
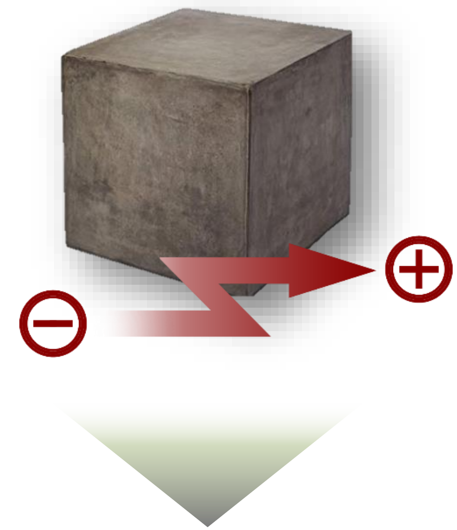
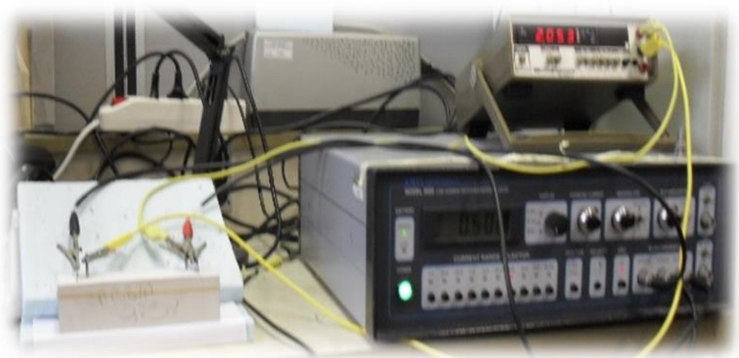
ELECTRICAL RESISTIVITY







ELECTRICAL MEASUREMENTS DEVICES

COMMERCIAL vs. RECYCLED ADDITIONS

PROPERTY	COMMERCIAL	RECYCLED
Enhanced mechanical performances	✓	✓
Enhanced durability	✓	✓
Enhanced electrical conductivity	✓	✓
	High cost ✗	**Low cost** ✓

B[UILD] SMART!

Padiglione 4

B[UILD] SMART! INVOLUCRO

Padiglione 10

B[UILD] SMART! COSTRUZIONI

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