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Evaluation of fracture toughness in graphene-based cementitious nanocomposites via electrical impedance

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Introduction

- **Cementitious materials are widely used in construction**

  Simplicity of production, low-cost, compressive strength, customized shape, etc.

- **Drawback: Low tensile strength and fracture toughness**

Cracking

Introduction

- **Cracking can affect the durability of the construction and costly repair works are required.**

  Leakage, reinforcement corrosion, endanger the structural integrity

- USA: Annual maintenance cost for bridges is estimated at **$ 5.2 billion**.

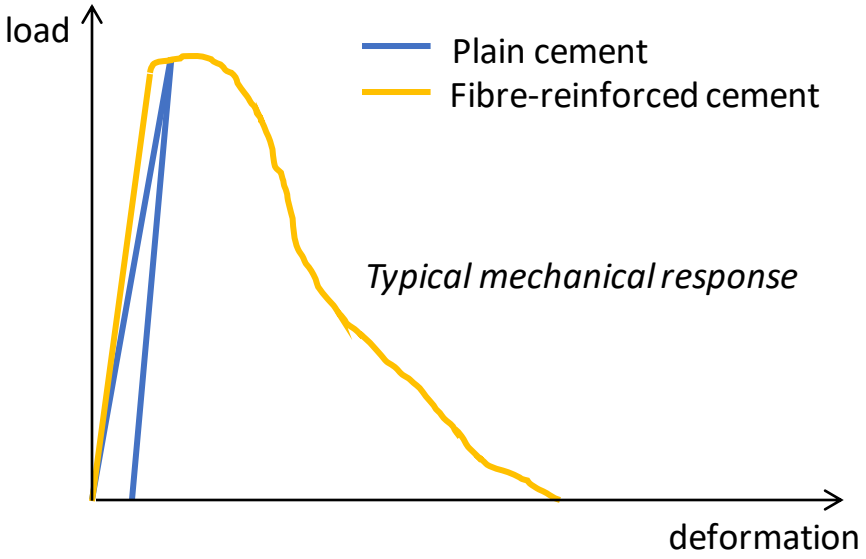
- NL: **33%** of the annual budget for large civil engineering works is spent on inspection, monitoring, maintenance, upgrading and repair.

- UK: repair and maintenance accounts for almost **45%** of the activity in the construction and building industry.

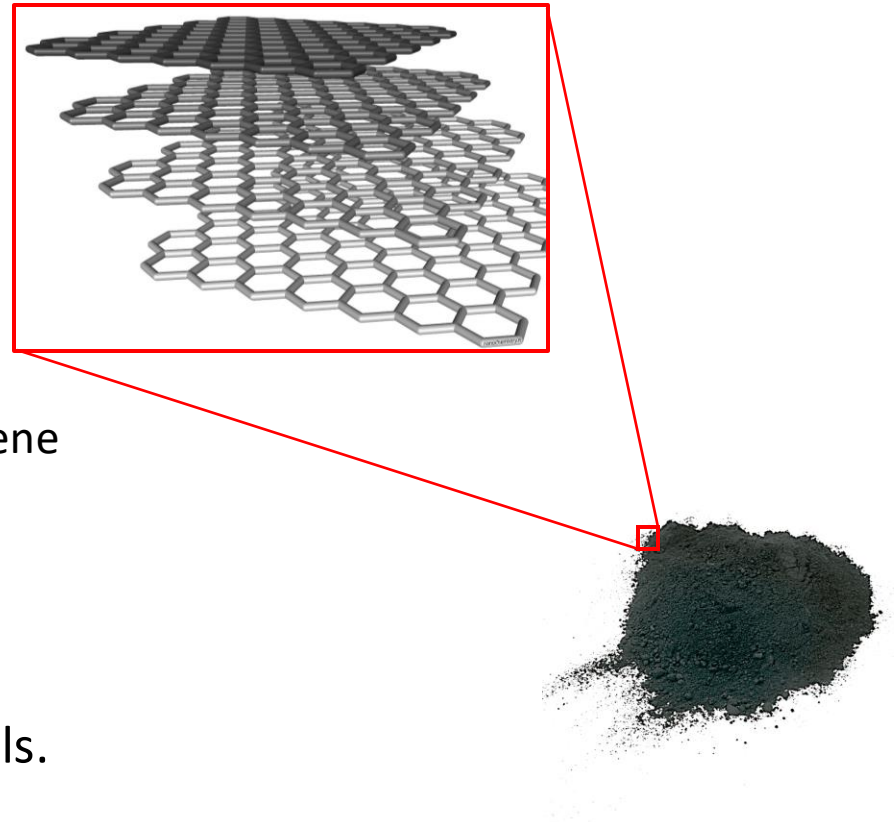
Introduction

- **Additives for mitigation of brittleness in cementitious materials**

  Natural and synthetic fibres, micro- and macro-fibres, textiles (metallic, polymeric, carbon, glass, etc.)



Introduction

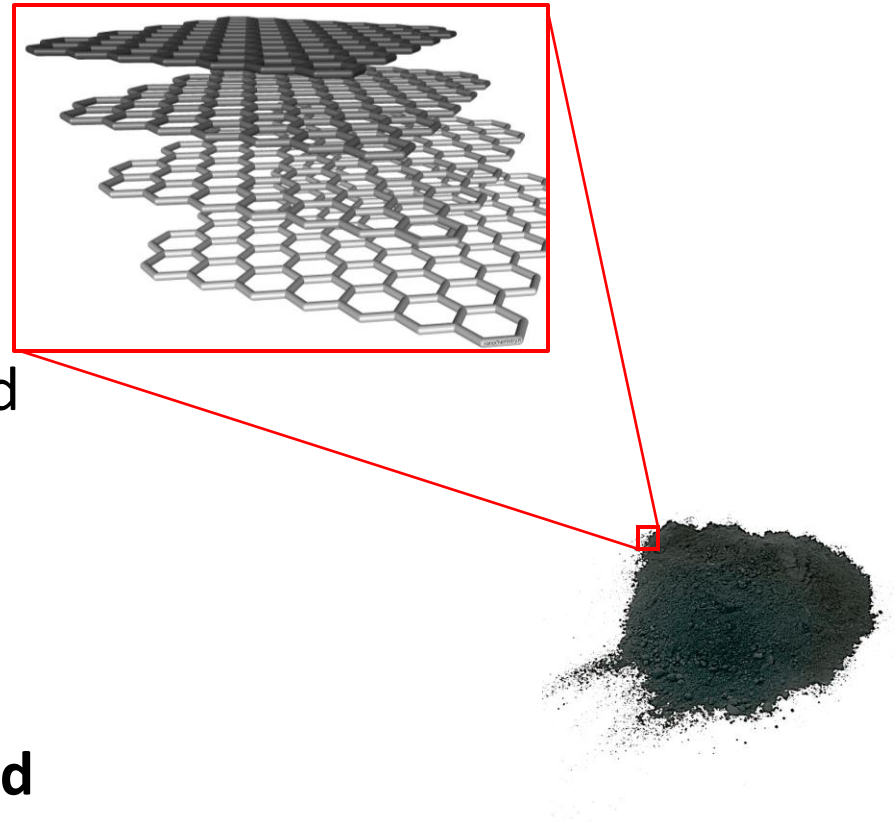


- **Graphene nanoplatelets (GnPs)**

  exfoliated from pristine graphite and consist of several layers of graphene sheets.

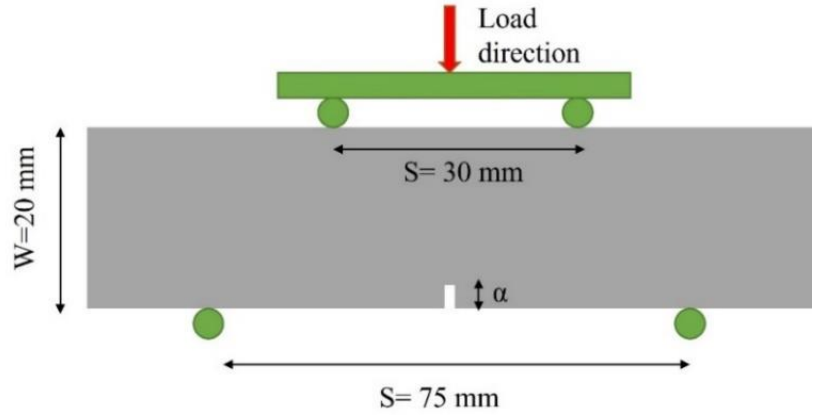
- Promote mechanical, thermal and electrical properties.
- Exhibit low production cost compared to other carbon nanomaterials.
- Can refine the cement microstructure and create a denser matrix.
- Can provide the cement matrix with piezo-resistive properties to give useful information of the stress/strain condition or detect potential damage.

Research objective



- Investigate the effect of GnPs on **fracture toughness** and **electrical resistivity** (AC).
- Explore a **correlation** between the **two parameters**.
- Use electrical measurements as **non-destructive method** to **predict fracture toughness** of cementitious nanocomposites.

Experimental procedure



starting notch, a = 5 mm

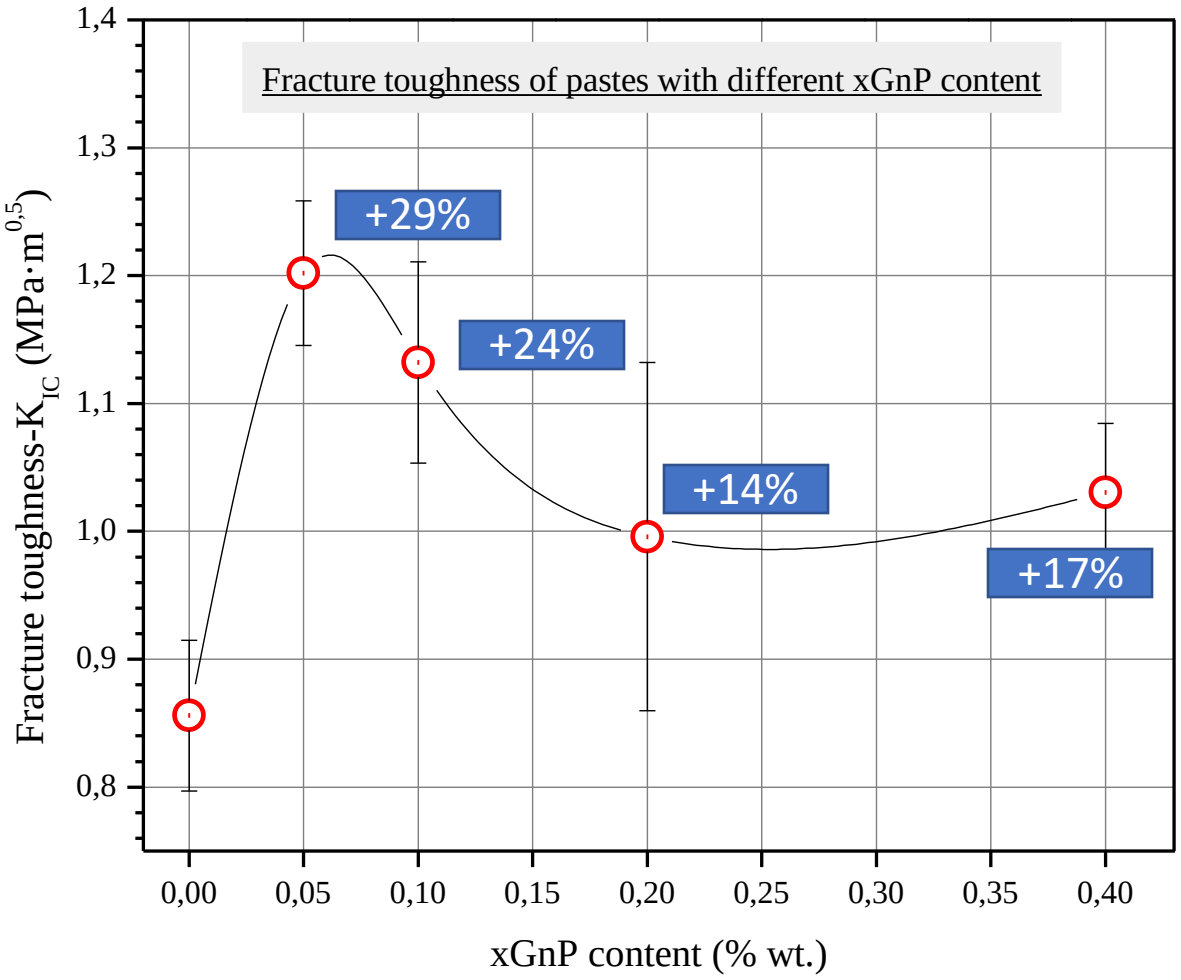
- 5 cement pastes were tested with varying contents of GnPs (0.0%-0.4% per cement weight).
- 3PB was conducted to study fracture toughness (K_{IC}).

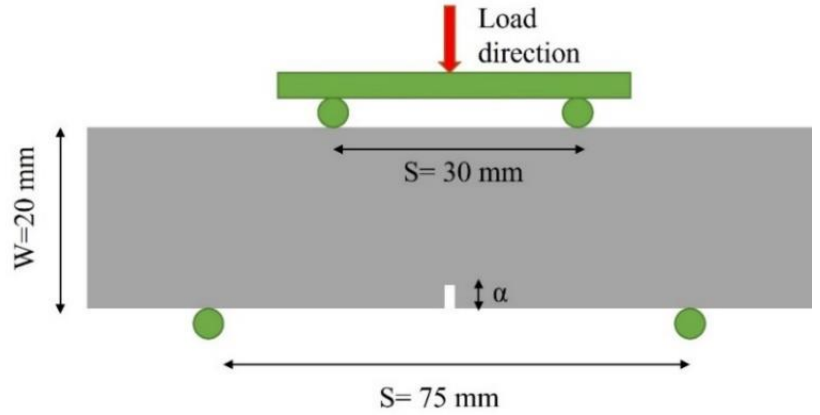
$$K_{IC} = \frac{P_{max} \cdot S}{B \cdot W^{3/2}} \cdot \mathrm{f}\left(\frac{a}{W}\right), \text{ where}$$

$$\mathrm{f}\left(\frac{a}{W}\right) = 3\left(\frac{a}{W}\right)^{1/2} \frac{\left(1.99 - \frac{a}{W}\cdot\left(1-\frac{a}{W}\right)\cdot\left(2.15-3.93\frac{a}{W}+2.7\left(\frac{a}{W}\right)^2\right)\right)}{\left(2+4\cdot\frac{a}{W}\right)\cdot\left(1-\frac{a}{W}\right)^{\frac{3}{2}}}$$

- Evaluation was performed according to ASTM E399
- Electrochemical impedance measurements on SSD prismatic specimens to calculate electrical resistivity (ρ).

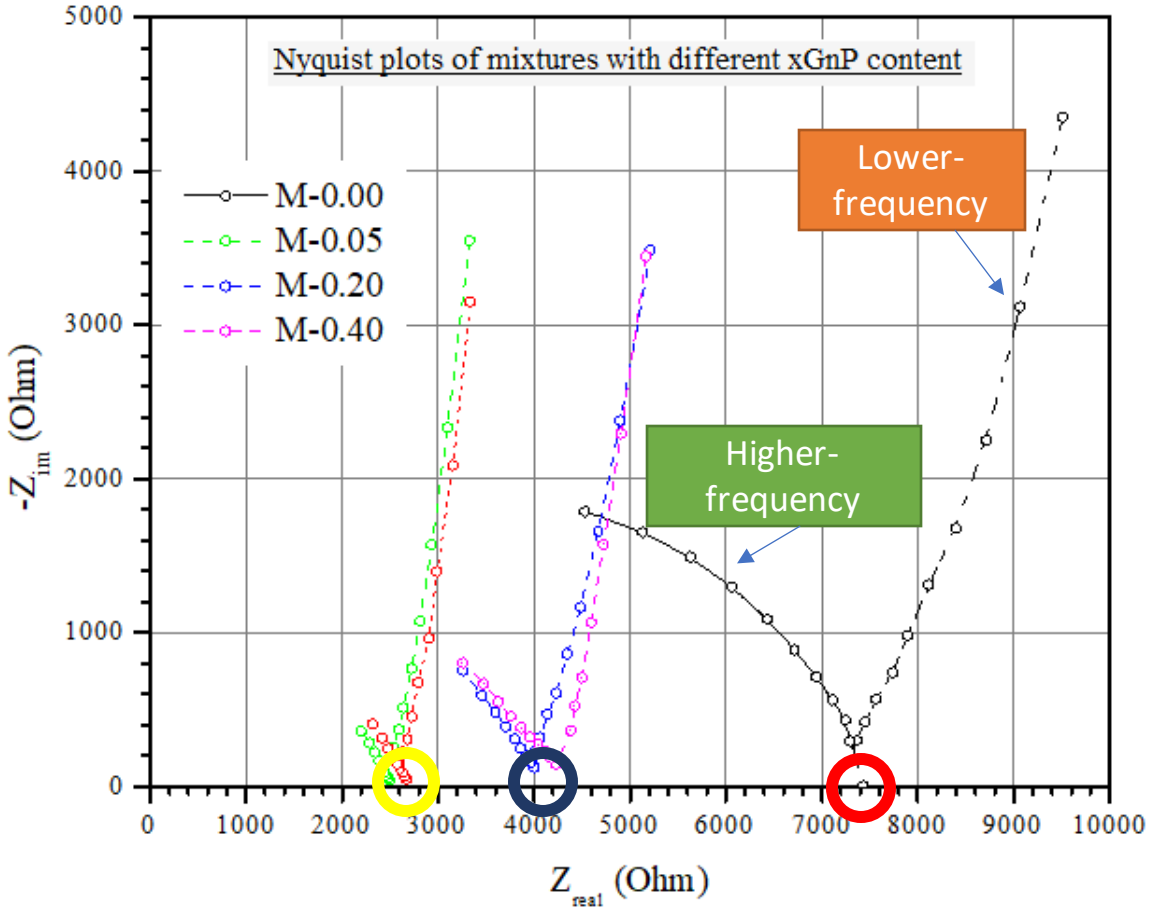
Results- Fracture toughness (K_{IC})





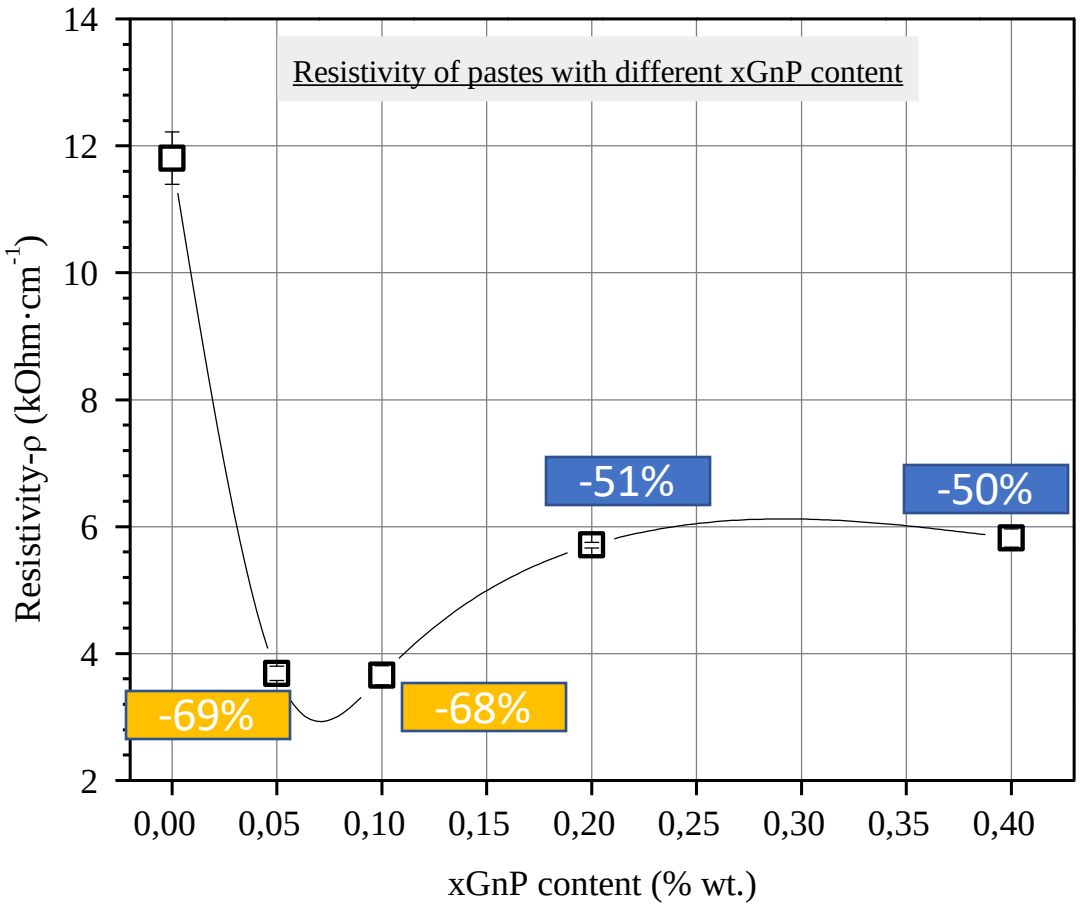
- K_{IC} tends to increase with the addition of GnPs.
- Maximum increase (29%) for 0.05% wt. content of GnPs.
- Then K_{IC} decreases for the mixtures with higher GnPs contents.

Results- Electrochemical impedance (Z)



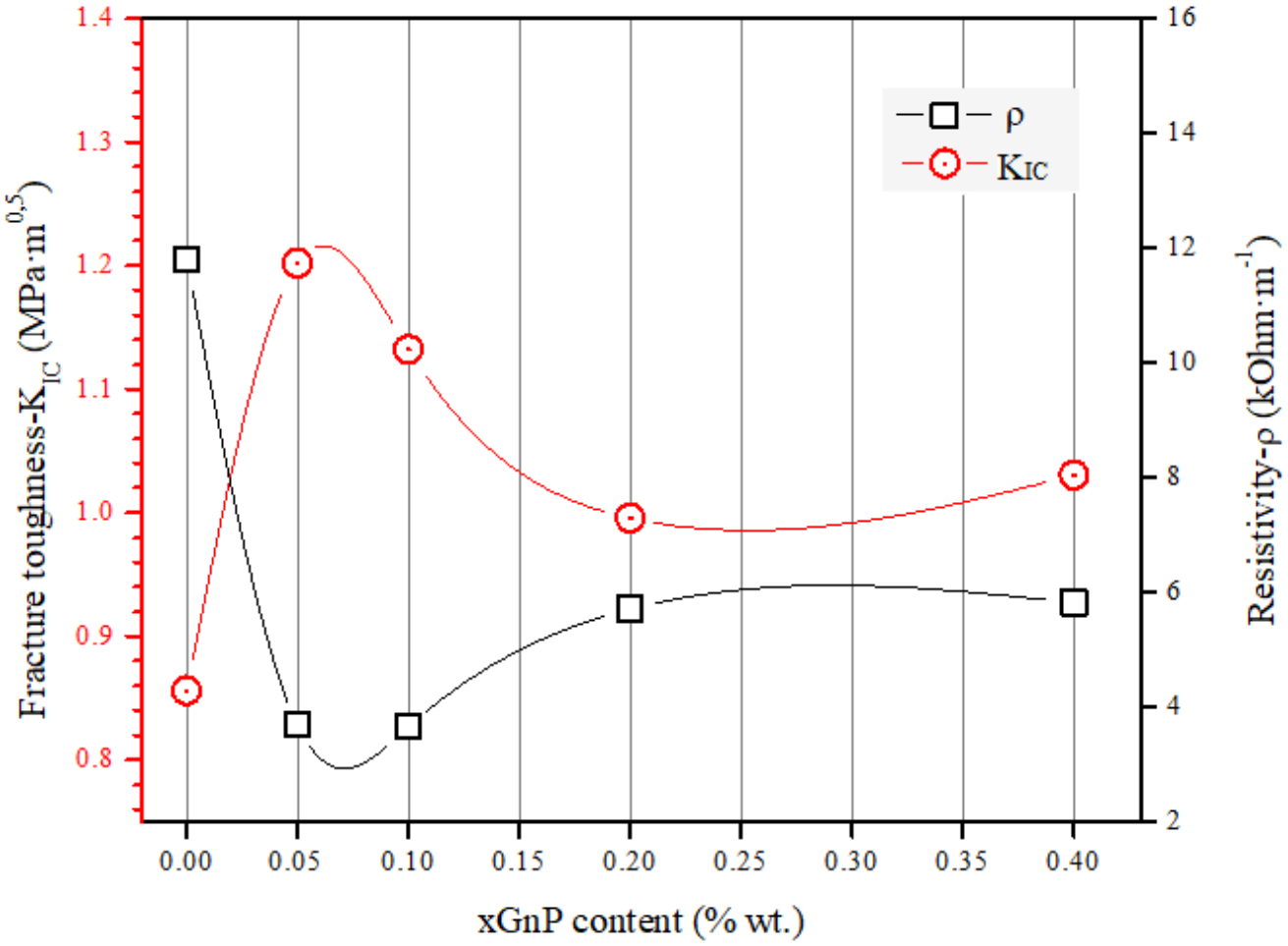
- Nyquists plots (Imaginary-Real impedance).
- Each plot comprises of two arcs; the lower- (electrode response) and the higher-frequency arc (bulk material response).
- "Cusp-point" represents the electrical resistance of the material.
- The electrical resistance of reference paste is located at the right-most part, while the resistance of GnPs-modified pastes is set further left on the graph.
- Electrical resistivity is calculated : $\rho = R \cdot \frac{A}{l}$

Results- Electrical resistivity (ρ)



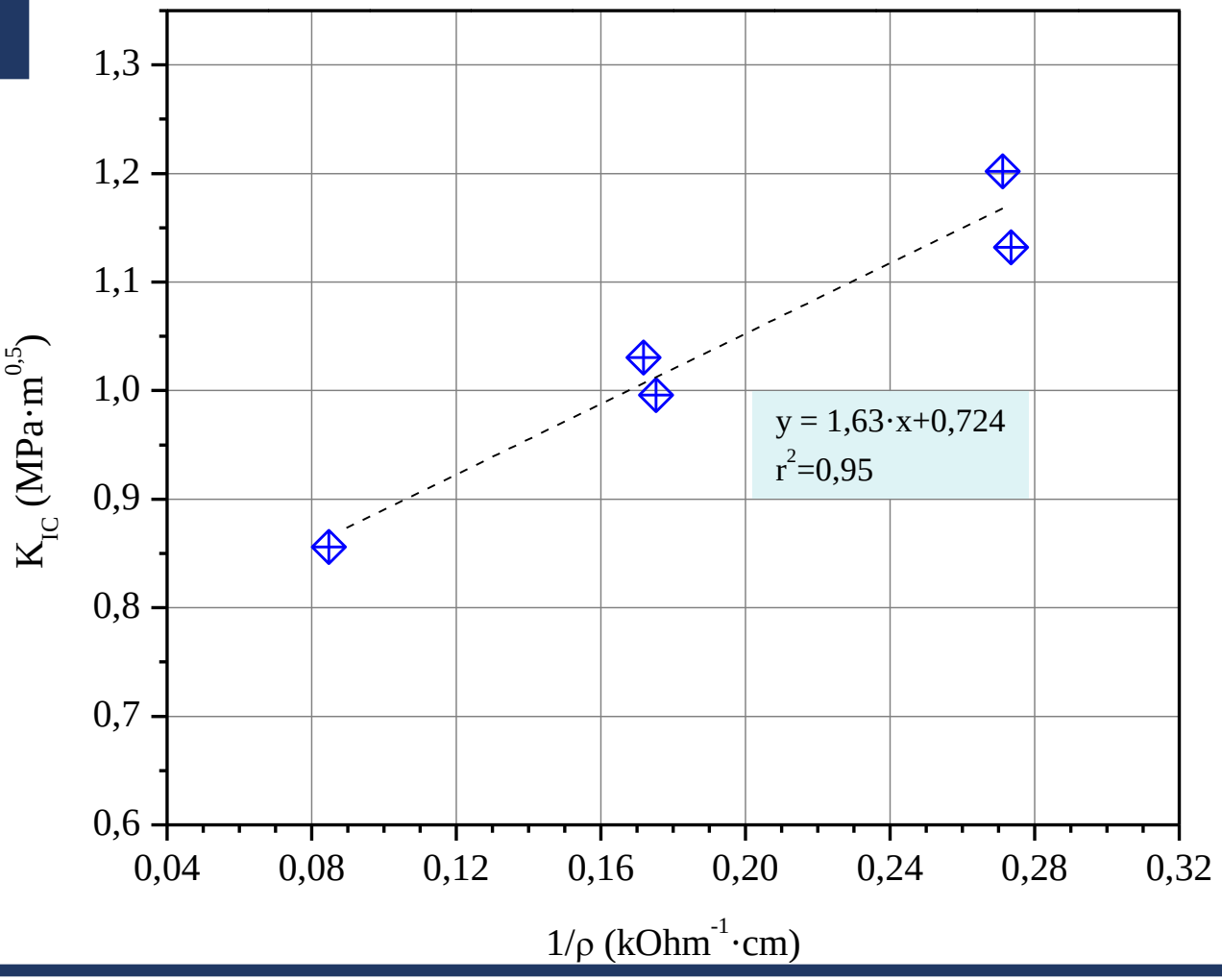
- Electrical resistivity decreases with addition of GnPs in the cement paste.
- ρ drops approximately 3 times for the low-GnPs content pastes and 2 times for the other two pastes.
- The lowest ρ-values of pastes 0.05% and 0.1% indicate that the critical volume fraction (percolation threshold) is found somewhere between those contents.
- When the GnP-content increases the nanoparticles network is probably interrupted by the formation of agglomerates and/or flaws caused by the poorer dispersion of the GnPs.

Results- comparison of K_{IC} and ρ curves



The graphical curves of ρ and K_{IC} as a function of the GnP-content exhibit an almost reverse shape

Results- K_{IC} and 1/ρ graph



- A **nearly linear relation** between the two parameters was revealed by constructing a graph that displays the 1/ ρ and the K_{IC} values.
- The equation expresses specific material and experimental choices.
- It is evident though that the EIS can be used as method to predict/evaluate K_{IC} when ρ has been measured.

Conclusions

- Fracture **toughness** and electrical **resistivity** of **GnPs-reinforced** cement pastes were investigated.

- The addition of **GnPs increased** the **fracture toughness** of the cement pastes. Addition of only 0.05 wt % lead to a 29 % increase of fracture toughness.

- The **electrical resistivity** of the **GnPs-modified pastes dropped** significantly compared to the reference paste.
  The maximum drop (3 times) was found in the pastes with the lower examined GnPs concentrations (0.05 and 0.1 wt %).

Conclusions

- It was proven that there is a **functional relation** between the **fracture toughness** and the **electrical resistivity** obtained by alternate current measurements.

- **Electrochemical impedance** measurements can be used in cementitious (nano)composites as a valid **non-destructive tool to assess their fracture toughness.**

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Thank you for your attention!

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